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Hypersonic Research Facilities Study

Volume II Part 1

Phase I Preliminary Studies

Research Requirements and Ground Facility Synthesis

Prepared Under Contract No. NAS2-5458
by
Advanced Engineering
MCDONNELL AIRCRAFT COMPANY
for
OART - ADVANCED CONCEPTS AND MISSIONS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Moffett Field, California 94035

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FOREWORD

This report summarizes the results of Phase I of the Hypersonic Research Facilities Study performed from 1 July 1969 through 19 September 1969 under National Aeronautics and Space Administration Contract NAS2-5458 by McDonnell Aircraft Company (MCAIR), St. Louis, Missouri, a division of McDonnell Douglas Corporation.

The study was sponsored by the Office of Advanced Research and Technology with Mr. Richard H. Petersen as Study Monitor and Mr. Hubert Drake as alternate Study Monitor.

Mr. Charles J. Pirrello was Manager of the HYFAC project and Mr. Paul A. Czysz was Deputy Manager. The study was conducted within MCAIR Advanced Engineering, which is directed by Mr. R. H. Belt, Vice President, Aircraft Engineering. The HYFAC study team was an element of the Advanced Systems Concepts project managed by Mr. Harold D. Altis.

The basic task of Phase I was to establish the desirable research objectives for hypersonic flight, and to evaluate the research return available from various candidate facilities, including the impact of facility cost. The Phase I study has been conducted in accordance with the requirements and instructions of NASA RFP A-15109 (HK-81), McDonnell Technical Proposal Report G970, and OART correspondence received during the Phase I period.

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Volume I	Summary	CR 114322
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	Part 1 - Research Requirements and Ground Facility Synthesis	CR 114323
	Part 2 - Flight Vehicle Synthesis	CR 114324
Volume III	Phase II Parametric Studies	
	Part 1 - Research Requirements and Ground Facility Synthesis	CR 114325
	Part 2 - Flight Vehicle Synthesis	CR 114326
Volume IV	Phase III Final Studies	
	Part 1 - Flight Research Facilities	CR 114327
	Part 2 - Ground Research Facilities	CR 114328
	Part 3 - Research Requirements Analysis and Facility Potential	CR 114329
Volume V	Limited Rights Data	CR 114330
Volume VI	Operational System Characteristics	CR 114331

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This work was performed by an Aircraft Advanced Engineering study team with Charles J. Pirrello as Study Manager.

The following contributed significantly to the contents of this volume:

P. Czysz	Deputy Study Manager
R. Crook	Flow Facility Design Specialist
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J. Klingler	Ground Facility Cost Analyst
C. Hilgarth	Ground Facility Costs Estimator
D. Raines	Facility Systems Analyst
R. Dighton	Systems Analysis
J. Schudel	Research Requirements Evaluation

SUMMARY

Airbreathing hypersonic aircraft employing liquid hydrogen fuel have the potential of satisfying a number of mission requirements in the 1980-2000 time period. However, major advances in the technological state of the art are necessary before such aircraft can be considered either feasible or practical. The objective of Contract NAS 2-5458 was to assess the research and development requirements for hypersonic aircraft and based on these requirements, to provide the NASA with characteristics of a number of desirable hypersonic research facilities. The study is organized in three phases. Phase I is a preliminary analysis of a broad group of concepts. The purpose of Phase I was to compare the characteristics of these facilities considering research capability, versatility, adaptability, system confidence and costs and based on these comparisons select those facilities that appear most attractive for parametric study and further refinement in Phase II. This part of Volume II presents the results of the research requirements analysis and the design and cost synthesis of the ground research facilities. The significant results obtained are:

(1) Research associated with engine development, engine/airframe integration, and reusable thermal protection systems was ranked as most critical to the development of hypersonic aircraft.

(2) There is a distinct gap in desired versus available Reynolds number capability in existing wind tunnels across the entire Mach number range. This gap can be filled by the construction of as few as three new gas dynamic facilities.

(3) It is possible to provide test Reynolds numbers as high as one-fifth the maximum flight values in wind tunnels having long run times and thus high productivity. If full flight Reynolds numbers are required, however, impulse facilities must be used in order to keep acquisition and operating costs within reason.

(4) The minimum wind tunnel size which can be used to produce a given Reynolds number is a function of model and balance strength. This relationship was used to size the various gas dynamic facilities.

(5) Required airbreathing engine test facilities represent a very large increase over existing mass flow capability and will require the largest expenditures of the flow type facilities. Convertible scramjet and scramjet engines will have to be tested and developed on a modular basis because of the large mass flow requirements of the complete engines. No existing heater types are capable of these mass flows, and the cost of compressor and exhauster plants for complete engine testing would be prohibitive.

(6) Two heater concepts are proposed for scramjet testing, both of which employ continuous flow and a programmed test trajectory in order to prevent the thermal shock to the engine refractory materials that blowdown facilities produce. Both concepts also avoid the high concentrations of water vapor in the test medium which are present in existing vitiated air facilities - water vapor having a deleterious effect on the engine materials.

(7) Candidate structural test facilities have been specified having a wide range of simulation levels and maximum test article sizes. Research value analysis shows that smaller facilities, capable of testing a major section of a full scale operational vehicle (or an entire research vehicle) have nearly as much capability as full scale facilities at very much lower acquisition and operating costs.

(8) Materials test facilities have shown a high research value both individually and collectively. Costs are miniscule compared to most of the other facility categories. Investment in a well equipped materials test and fabrication technology laboratory will pay large dividends.

(9) Several facility types, though necessary for hypersonic vehicle development, represent capabilities already existing or small improvements to existing capabilities. These are: rocket engine test facilities, avionics facilities, flight simulators, and radiation facilities. No further definitions or refinements of these facility types are planned for Phase II of the study.

(10) The fire suppression and fluids systems facilities examined could not be justified on an independent basis. These capabilities are best included as additional capabilities of a generalized environmental structural facility.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
ARC	Ames Research Center
A	ampere
A-h	Ampere-hour
AB	all body
A/D	analog to digital conversion
Alt	altitude
AM	amplitude modulation
Aero 50	Aerozine 50, a 50/50 mixture of UDMH and Hydrazine
bp	boiling point
Btu	British thermal unit
°C	degrees Celscius (centigrade)
c.g.	center of gravity
c.p.	center of pressure
cm	centimeters
CSJ	convertible scramjet
db	decibel
D/A	digital to analog conversion
diam	diameter
eng	engine
°F	degrees Fahrenheit
FRC	Flight Research Center
ft	feet
fps	feet per second
GE	General Electric Co.

LIST OF ABBREVIATIONS (Cont)

Abbreviation	Definition
hr	hour
Hz	hertz
HF	high frequency
HTO	horizontal takeoff
HYFAC	Hypersonic Research Facilities
ILS	instrument landing system
in.	inch
inst	installed
IRFNA	inhibited red fuming nitric acid
J	joule
JP	jet propulsion fuel
^{o}K	degrees Kelvin (absolute)
kg	kilogram
L	liquid
lb	pounds, force
LO_2	liquid oxygen
LH_2	liquid hydrogen
lbm	pounds, mass
mi	mile
m	meter
max	maximum
min	minimum
MCAIR	McDonnell Aircraft Company
MDAC (EAST)	McDonnell Douglas Astronautics Company (EAST)

LIST OF ABBREVIATIONS (Cont)

Abbreviation	Definition
nmi	nautical mile
N	newtons
No.	number
OWE	operational weight empty
psi	pounds per square inch
PFRT	Preliminary Flight Rating Test
P&WA	Pratt & Whitney Aircraft
°R	degrees Rankine (absolute)
R&D	research and development
RDT&E	research, development, test, and evaluation
RF	radio frequency
RJ	ramjet
RKT	rocket
RP	rocket propellent
s, sec	seconds
SJ	scramjet
smi	statute mile
TF	turbofan
TIT	turbine inlet temperature
TJ	turbojet
TMC	The Marquard Corporation
TRJ	turboramjet
TOGW	takeoff gross weight
UARL	United Aircraft Research Laboratory

LIST OF ABBREVIATIONS (Cont)

Abbreviation	Definition
UDMH	unsymmetrical dimethyl hydrazine
UHF	ultra high frequency
uninst	uninstalled
VTO	vertical takeoff
V	volt
WB	winged body
W/O	without
wt	weight
W	watt

LIST OF SYMBOLS

Symbol	Definition
a	acceleration
A	area
AR	aspect ratio
α	angle of attack, ratio of wing span to vehicle length
β	ratio of mean aerodynamic chord to vehicle length, side slip
b	wing span
C_D	drag coefficient
C_{D_o}	zero lift drag coefficient
C	cross sectional area of wind tunnel test section
$\bar{c}$	mean aerodynamic chord
C_R	wing root chord
C_T	wing tip chord
C_1	balance normal force load capacity divided by balance diameter squared
C_L	lift coefficient
C_{L_α}	lift curve slope
$C_{L_{\alpha_o}}$	lift curve slope at zero lift
C_m	pitching moment
γ	ratio of specific heats, flight path angle
d	diameter, balance diameter
D	drag
δ	deflection
Δ	increment between two values

LIST OF SYMBOLS (Cont)

Symbol	Definition
Δt	test time
ΔV	equivalent velocity requirement
ΔV_i	velocity increment due to i^{th} cause
ΔC_{D_o}	incremental drag at zero lift
e	span efficiency factor
E_c	compressive modulus of elasticity
ε	nozzle expansion ratio
F_{tu}	ultimate tensile strength
F_{ty}	yield tensile strength
F	propulsive thrust
f/a	fuel to air weight ratio
g	acceleration due to gravity
g_o	acceleration due to gravity, sea level, 45° geographic latitude = 9.80665 m/sec^2
H	geopotential pressure altitude
h	wind tunnel test section height, vehicle fuselage height
H_2	molecular hydrogen
I_{sp}	specific impulse
K	additional drag factor, ratio of model wing area to wind tunnel test section cross sectional area
K_D	inlet process efficiency
ℓ	moment arm, length
L'	induced drag factor
L	lift, length

LIST OF SYMBOLS (Cont)

Symbol	Definition
L/D	lift to drag ratio
m	mass
M	Mach number, bending moment
$\dot{m}$	mass flow
n_z	flight path normal load factor
η_{KE}	inlet kinetic energy efficiency
N.F.	normal force
n	inlet height-to-width ratio
N_2O_4	nitrogen tetroxide
O_2	molecular oxygen
o/f	oxidizer to fuel weight flow ratio
p	pressure
ϕ	fuel equivalence ratio, ratio of actual fuel flow to stoichiometric fuel flow
θ	angle between shock attachment point and cowl lip
q	dynamic pressure
R	specific gas constant
R_E	mean radius of the earth
$\mathscr{R}$	universal gas constant
Re	Reynolds number
ρ	density
σ, F_s	stress
S	area
S/R	dimensionless entropy

LIST OF SYMBOLS (Cont)

Symbol	Definition
t	time
T	temperature
T_r	recovery temperature
T_w	wall temperature
V	velocity
Vol	volume
$\dot{w}$	weight flow
w	weight
ψ	heading angle, yaw angle
Z	geometric altitude

LIST OF SYMBOLS (Cont)

SUBSCRIPTS

Propulsion Station Designations

0	free stream
c	capture, a fixed reference area on vehicle
cowl	cowl lip
2	engine face
3	engine exit
e	nozzle exit
t	nozzle throat

General

aero	attributable to aerodynamic forces
c	chamber conditions, cruise
cent	attributable to centrifugal forces
D	drag
E	empty
e	engine exit
eff	effective
f	final
F	frontal
i	initial
∞	free stream
G	associated with gravity forces, gross
I	ideal
M	maneuvering

LIST OF SYMBOLS (Cont)

Symbol	Definition
max	maximum
min	minimum
N	net
o	isentropic reservoir conditions, evaluated at zero lift
prop	attributible to propulsion system
p	associated with pressure forces, planform
R	wing root
S	structural
s	vehicle, model stagnation
t	total conditions corresponding to isentropic case
TO	takeoff
TJ	attributable to turbojet propulsion system
SJ	attributable to scramjet propulsion system
t	wing tip
test	associated with test time
wet	wetted
vac	associated with vacuum conditions
x	longitudinal direction
y	lateral direction
z	vertical direction

1. INTRODUCTION

This volume of the final report summarizes the results of the first phase of the Hypersonic Research Facilities Study (HYFAC). The primary objective of this study is to assess the research and development requirements for potential future operational hypersonic aircraft and based on these requirements provide NASA with descriptions of a number of attractive hypersonic research facilities consisting of performance, cost, development time schedule, and research capability estimates. The research facilities studied include both flight research aircraft and ground test facilities. To accomplish this overall objective a three phase analysis program followed by a reporting period is in process, as illustrated in Figure 1-1.

Major elements of the Phase I activities were (1) selection and definition of the potential future operational aircraft systems which form the basis for the study, (2) identification and evaluation of research and development needed for the potential operational aircraft, (3) design synthesis of flight research aircraft concepts and determination of their capabilities and costs, (4) design synthesis of ground research facilities and determination of their capabilities and costs, and (5) evaluation of the research value and costs of each facility and selection of the most attractive flight and ground facilities for parametric study in Phase II.

With the participation of a number of research offices within the NASA and the USAF, 102 Research Objectives were identified and evaluated by the study team.

Candidate flight research vehicles were developed combining elements of the various system options illustrated in Figure 1-2. For each concept the flight vehicle performance, weight, cost, and capability to contribute to the accomplishment of the Research Objectives were determined. Finally, each vehicle was evaluated with respect to its research value so as to reduce the candidates to those most attractive vehicles to carry into the Phase II parametric evaluation.

Candidate ground research facilities were developed combining the elements of the various conceptual options illustrated in Figure 1-3. For each concept its general arrangement, size, performance, cost, and capability to accomplish the Research Objectives were determined. Each facility was continuously evaluated during Phase I so that facilities not showing significant capability or research return were deleted from further study. Finally, each facility was evaluated with respect to its research value so as to reduce the candidate facilities to those most attractive to carry into Phase II parametric evaluation.

The results of the design studies, the comparative evaluations and screening, and the recommended facilities for Phase II parametric study are presented in this report.

FIGURE 1-1 PROGRAM MILESTONE SCHEDULE

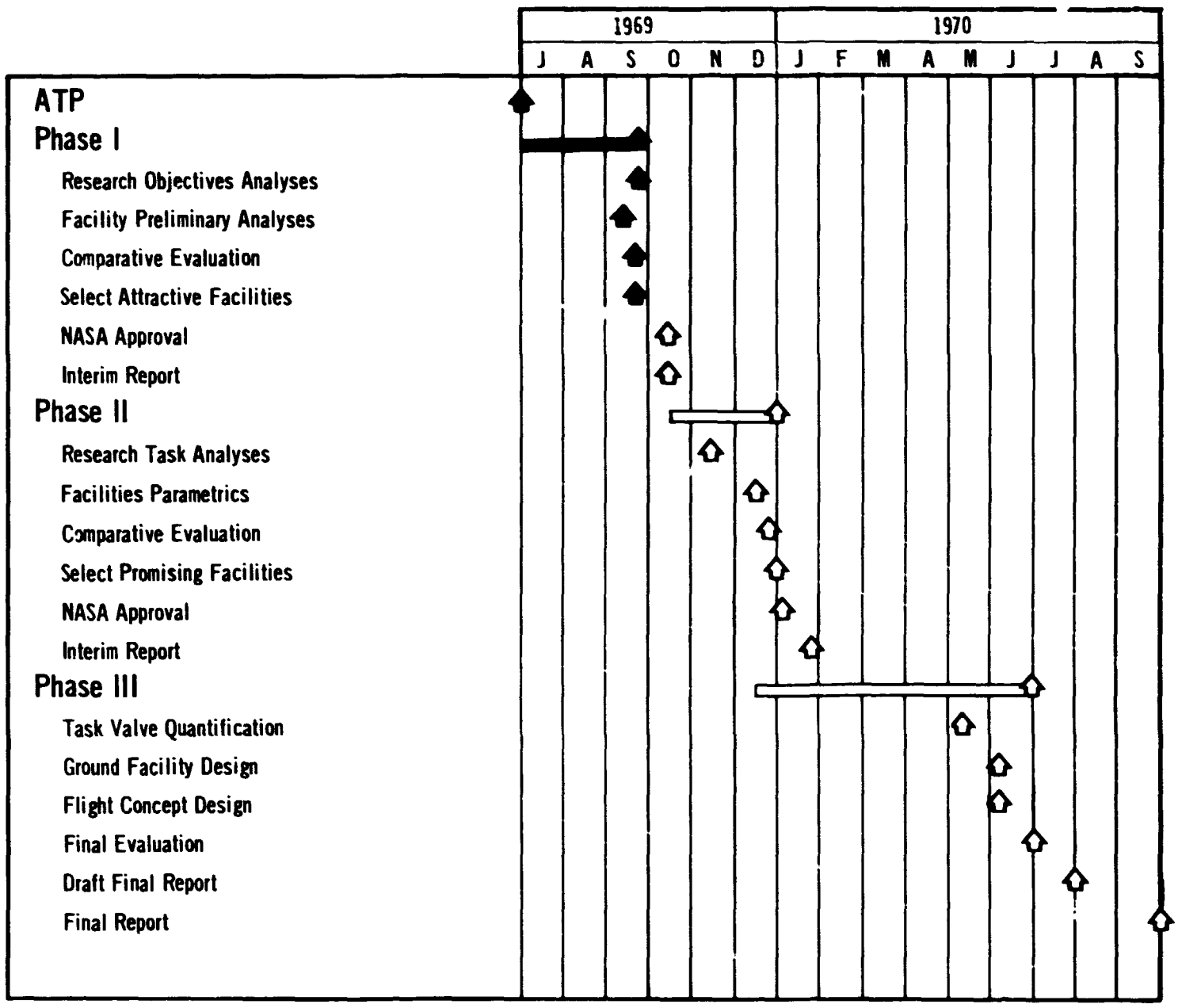


FIGURE 1-2 FLIGHT VEHICLE OPTIONS

DESIGN PARAMETER	OPTIONS STUDIED
Speed	M 0.9, 2, 4.5, 6, 12
Launch Mode	Horizontal Takeoff Vertical Takeoff Air Launched Booster Staged
Control Mode	Manned, Unmanned
Acceleration Propulsion	Turbojet, Turboramjet, Rocket
Hypersonic Propulsion	Turboramjet, Ramjet, Scramjet, Convertible Scramjet, Rocket
Propellants	JP, LH_2, LO_2 LH_2 N_2O_4 Aero 50

FIGURE 1–3 GROUND FACILITY OPTIONS

GASDYNAMIC FACILITIES

DESIGN PARAMETERS	OPTIONS STUDIED
● Mach Number Range	0 M 13
● Maximum Reynolds Number Range	20% full-scale to full-scale.
● Energy Source	Continuous, intermittent heaters, impulse heaters.
● Model Balance Strength	Present capability to projected capability.

ENGINE TEST FACILITIES

DESIGN PARAMETERS	OPTIONS STUDIED
● Engine Size	Current and projected engines.
● Inlet Size	Angles of attack, geometric variations, spill-bleed quantities.
● Temperature/Pressure	Flight duplicated conditions.
● Run Time	PFRT in acceptable time.
● Direct Connect Free Jet	Degree of complete inlet flow field simulation.

STRUCTURAL TEST FACILITIES

DESIGN PARAMETERS	OPTIONS STUDIED
● Test Article Size	Coupon to full scale aircraft.
● Degrees of Simulation	Mechanical – Static/Dynamic Thermal – Static/Dynamic Acoustic Altitude – Static/Dynamic Fuel tankage loaded, with/without fuel flow.

MATERIAL RESEARCH FACILITIES

DESIGN PARAMETERS	OPTIONS STUDIED
● Materials Properties, Test Article Size	Coupon to component.
● Fabrication Technology	Sample to major section, various degrees of fabrication capability from simple operations on single pieces, to fabrication of complete structural sections.

FLIGHT SIMULATORS

DESIGN PARAMETERS	OPTIONS STUDIED
● Acceleration	Up to limits of operational aircraft, 3.5g.
● Motion	Up to 100 feet motion.
● Video Simulation	Color television, 2-dimensional.
● Audio Simulation	Full range stereo.
● Cockpit Instrumentation	Actual crew station.

SUBSYSTEMS TEST FACILITIES

FUEL SYSTEMS TEST FACILITIES

DESIGN PARAMETERS	OPTIONS STUDIED
● Component Size	Full scale.
● Simulation	Local environment, pressure, temperature, loads.

AVIONICS FACILITIES

DESIGN PARAMETERS	OPTIONS STUDIED
● Model Size ● Facility Size	Size consistent with obtaining antenna data for potential operational hypersonic aircraft using recommended frequencies.

RADIATION FACILITIES

Precise parameters describing this facility would be highly classified and have very limited access.
The facility performance was based on articles in open literature describing current facility concepts and capability.

2. PHASE I ANALYSIS - PRELIMINARY STUDIES

The HYFAC study is a 12-month investigation of the facility requirements associated with the research and development of hypersonic aircraft. The study is conducted in three phases, as illustrated in Figure 1-1. Phase I consisted of: a preliminary identification of research requirements, identification of a number of flight and ground research facilities, preliminary assessment of their cost and research capability, and selection of attractive facilities for further study in Phase II.

2.1 OBJECTIVES

The objective of Phase I was to make preliminary estimates of the performance, research capability, and costs of a large number of facility concepts and through comparison reduce these concepts to approximately 20 of the most attractive facilities for Phase II refinement.

Specific areas of emphasis included (1) identification of the necessary research associated with operational hypersonic aircraft, (2) evaluation of methods of accomplishing this research, and (3) analysis of the capability and costs of the conceptual flight and ground research facilities.

2.2 GROUND RULES

General study ground rules applied to all phases of this study are listed below. (Other ground rules which applied to specific segments of the study are presented in the appropriate sections of the report.)

(a) All cost estimates are reported in 1970 dollars.

(b) The assumed state of the art is commensurate with initiation of facility development during the time period from 1970 to 1975. Wherever feasible, proven technology (or technology expected to be proven by the start date) was utilized. Where such design was not feasible, conservative overdesign practices, requiring minimum improvements in the state of the art, were followed.

(c) Close coordination is assumed between the NASA and the contractors who are building facilities or aircraft, thus minimizing the need for extensive documentation and quality assurance programs.

(d) Aircraft construction is assumed to conform to experimental shop procedures.

(e) The development costs for flight research vehicles include all necessary engine and avionics development costs.

(f) It is assumed that engines need not be developed to the reliability normally required for operational (non-research) use.

(g) The primary flight safety criterion is that no single component malfunction shall cause a catastrophic situation.

(h) Reliable rocket or airbreathing engine performance consistent with that required for JP-fueled, single-engine aircraft is required during takeoff and climb to 25,000 ft (7630m).

(i) Where applicable, the vehicle landing characteristics are suitable for unpowered landing by a skilled pilot. Adequate fuel reserves are provided to compensate for uncertainties in engine SFC, for meteorological and operational dispersions in fuel consumption, and for powered emergency operations.

(j) Edwards Air Force Base is considered as the primary operational field for flight research vehicles.

(k) It is assumed that maximum use will be made of existing or planned tracking and communications facilities.

(l) The U.S. Standard Atmosphere - 1962 is used throughout the study.

2.3 APPROACH

The study process used in Phase I is illustrated in Figure 2-1. Identification of required research and development is focused on future operational aircraft systems derived from previous industry and in-house MCAIR studies. These systems were selected with NASA concurrence at the onset of the study, and form the fundamental basis for determination of research and development requirements for hypersonic aircraft. The dynamic nature of future hypersonic aircraft makes selection of any singular group of systems subject to disqualification as new system needs are determined and technology breakthroughs occur. Thus, to provide the broadest possible definition of future research requirements, a number of design options were defined for each potential operational system that could be exercised in propulsion, fuels, structure, thermal protection, and heat shielding. In the selection of these operational systems, MCAIR recognizes that some differences exist in both the analytical methods, assumptions, and criteria used in their initial generation. These differences do not affect the validity of the research requirements and may well serve to give visibility to points that might otherwise be obscured. No additional designs or optimizations of these operational concepts were conducted. Characteristics of these operational systems are presented in Volume VI and a brief summary is given in Figure 2-2.

The study process allows for determination of both research and development requirements for the operational systems; however, the primary interest is in research and this fact has been reflected in the recommended Phase II studies summarized in Sections 5 and 7.

The identification of research requirements for hypersonic aircraft forms the focus for evaluation of hypersonic research facilities as illustrated in Figure 2-1. In Phase I these requirements have been identified in a broad sense and referred to as "Research Objectives". The process by which these "Research Objectives" were obtained and research value determined is presented in Section 3. The placement of value (intrinsic value) on these objectives is an initial step in the facility evaluation process which involves determination of the reserach value for each facility. The identification and evaluation of these research objectives was accomplished with the assistance of the scientific community as discussed in Section 3.

The results of the preliminary studies are presented in Section 3 for the research requirements, Section 4 for the flight research facilities and Section 6 for the ground research facilities. The results of the comparisons and evaluations, along with conclusions and recommended facilities for Phase II parametric study, are presented in Section 5 for the flight research facilities and Section 7 for the ground research facilities.

FIGURE 2-1 STUDY PROCESS

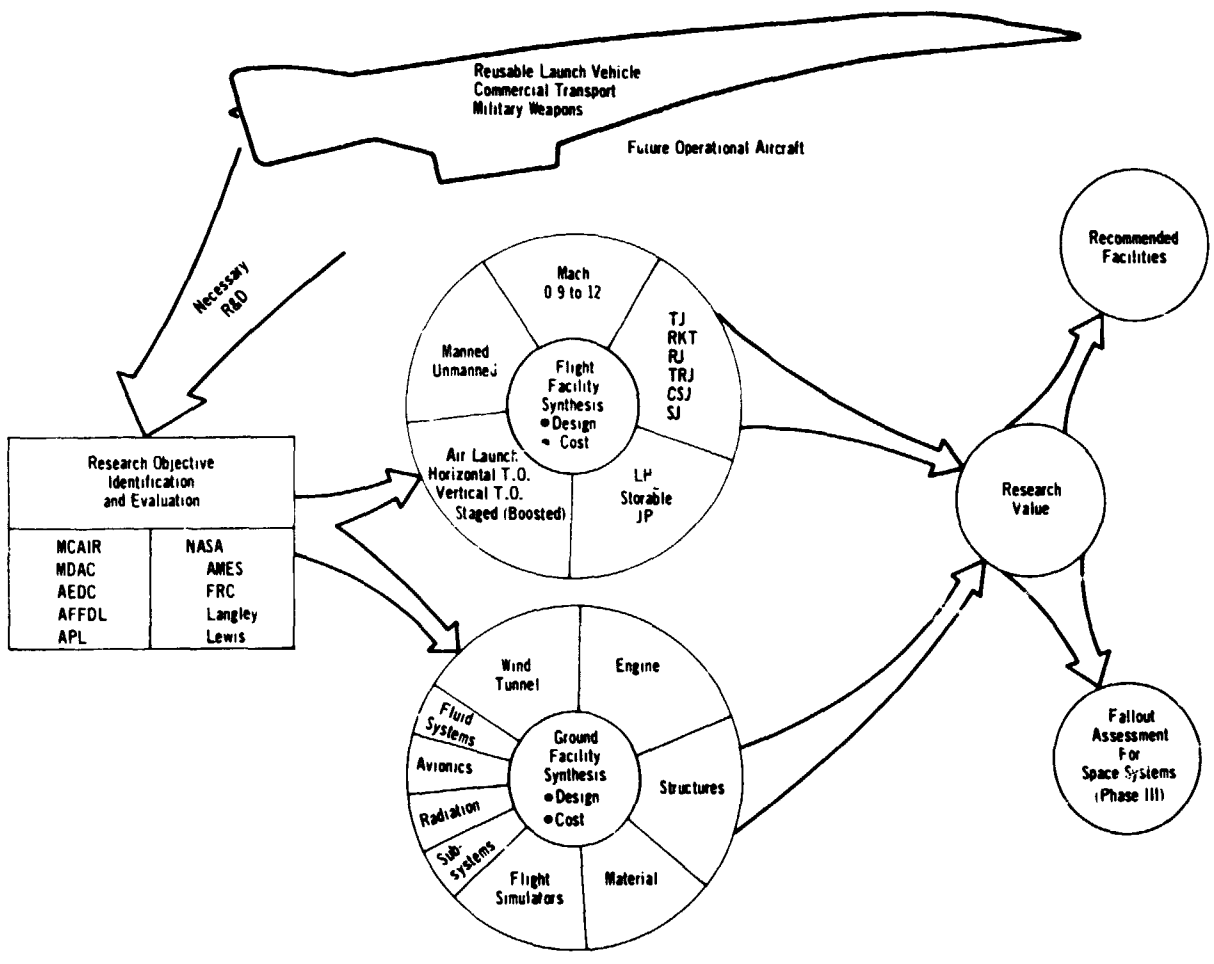


FIGURE 2-2 OPERATIONAL SYSTEMS SUMMARY

CODE	TYPE
	RECOVERABLE 1ST STAGE LAUNCH VEHICLE HORIZONTAL TAKEOFF
L_1	Turbojet plus Ramjet, M = 5 to 7 staging
L_2	Turbojet plus convertible Scramjet, M = 8 to 10 staging
L_3	All rocket, Mach 12, staging
L_4	Rocket plus Scramjet, Mach 10 staging
	HYPERSONIC TRANSPORT
C_1	Mach = 6, Turboramjet
C_2	Mach = 10, Turbojet plus Convertible Scramjet
	MILITARY SYSTEMS
M_1	M = 4.5 Advanced Manned Interceptor, Turboramjet
M_2	M = 12 Strike, Rocket plus Scramjet
M_3	M = 8 to 12 Interceptor, Rocket plus Scramjet

3. HYPERSONIC RESEARCH REQUIREMENTS

Major emphasis has been directed, during Phase I, toward identification of valid Research Objectives and quantification of the research value of each objective. A disciplined approach to identification and evaluation of hypersonic research requirements was pursued, using elements of decision theory. The primary intent of this approach was to utilize the large base of qualitative data existing on the subject of hypersonic research in government and industry.

The techniques utilized in this study have not identified or created new hypersonic research requirements. In fact, almost all of the Research Objectives in this report have been previously discussed in NASA or USAF reports. Rather, Phase I study effort has served to place these Research Objectives in the proper perspective relative to potential operational systems.

The initial step in establishing research requirements involved identification of meaningful Research Objectives. Recognized experts in technology disciplines associated with hypersonic flight participated in the identification of these Research Objectives in order to assure that all interfaces and interactions were properly recognized. Research Objectives were derived using a systematic synthesis process considering the design, development, and test requirements of potential operational aircraft, as well as operational considerations. Elements considered in this identification process are illustrated in Figure 3-1. The Research Objectives identified and evaluated in Phase I are hypersonic aircraft R & D requirements stated in broad terms. These objectives will be divided into Research Tasks during Phase II. These specific tasks, each requiring a number of definitive test programs, must be accomplished to achieve each of the Research Objectives.

All of the Research Objectives identified are not of equal value in assuring the successful development of a given operational system. Decision theory analyses were used to establish a framework in which the relative worth of each Research Objective could be evaluated. The key input to this part of the research requirements analysis was participation of NASA, USAF, and McDonnell Douglas personnel.

Evaluation participation is summarized below in terms of the number of participants from each organization.

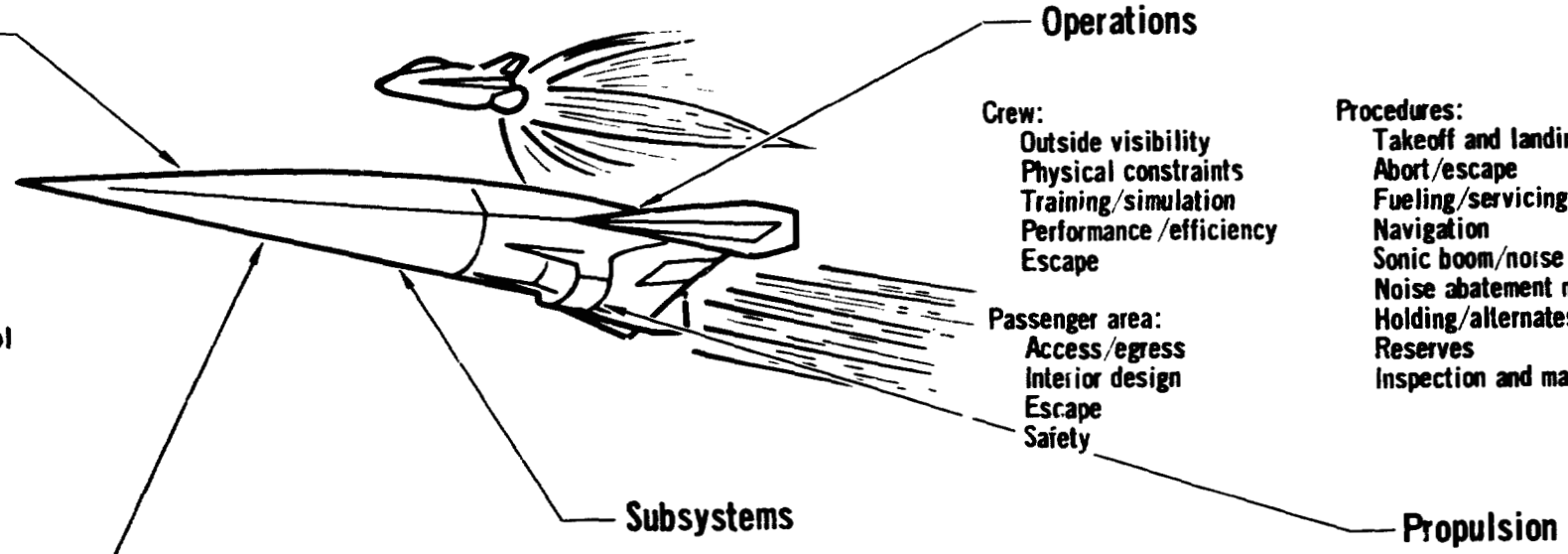
NASA	
Langley Research Center	7
Flight Research Center	11
Lewis Research Center	5
Ames Research Center	12
	35
USAF	6
MCDONNELL AIRCRAFT	19
MCDONNELL DOUGLAS ASTRONAUTICS	6
Total	66

The evaluation of Research Objectives resulted in the assignment of an intrinsic value to each objective. This intrinsic value is meant to measure the inherent worth of each Research Objective as it contributes to the technology base available in the development of an operational system. The mechanics of translating the evaluators' inputs to intrinsic values is described in Section 3.2.

A significant portion of the study effort has been devoted to definition of candidate ground and flight research facilities. Each Research Objective was reviewed by McDonnell Aircraft project specialists to quantitatively determine the portion of the objective which could be fulfilled in existing ground test facilities, or in candidate new ground test or new flight test facilities. Correlation of facility capability with each objective allows the value of the facility to be determined as it relates to a given Research Objective. The mechanics of this correlation is described in Section 3.3.1.

The principal goal of the research requirements analysis is establishment of the research value of each candidate ground test facility and flight research vehicle. This establishment of the research value of these new facilities is determined by multiplying the intrinsic value of each Research Objective by the percentage of the objective which could be satisfied by a particular facility, and summing these values for all applicable Research Objectives which could be accomplished in the particular facility. This technique yields the overall research value of a facility as it applies to a given operational system. The matrix of research values obtained by this procedure is presented in Section 3.3.2. Since the intrinsic value of each Research Objective is different for each operational system, it is desirable to obtain an overall research value for each candidate facility, independent of operational systems. This goal is achieved by averaging the research values across the spectrum of operational systems.

FIGURE 3-1 FUNCTIONAL SYSTEM ELEMENTS



Configuration

Aerodynamics:
- Performance
- Lift augmentation
- Flow interactions
- Buffet
- Sonic boom
- Aeroelasticity
- Stability and control

Thermodynamics:
- Boundary layer
- Lee side flow
- Local heating
- Flow interactions

Control surfaces:
- Effectiveness
- Stability and control
- Local heating
- Actuation systems

Structure

Airframe:
- Thermal stresses
- Fatigue
- Dynamics
- Acoustics
- Quality Assurance
- Reusability
- Hot/cooled
- Integral/non-integral tanks

Materials:
- Compatibility
- Physical properties
- Fabrication
- Sealing
- Protective coatings

Operations

Crew:
- Outside visibility
- Physical constraints
- Training/simulation
- Performance /efficiency
- Escape

Passenger area:
- Access/egress
- Interior design
- Escape
- Safety

Procedures:
- Takeoff and landing
- Abort/escape
- Fueling/servicing
- Navigation
- Sonic boom/noise
- Noise abatement maneuvers
- Holding/alternates
- Reserves
- Inspection and maintainence

Subsystems

Fuel systems:
- Storage /tankage
- Insulation
- Fluid dynamics
- Heat exchanger
- Material compatibility
- Abort procedure
- Safety
- Controls

Avionics:
- Antenna /radome
- Stability augmentation
- Air data
- Countermeasures

Weapons:
- Launch technique
- Launch effects
- Storage

Hydraulic/Electro-Mechanical:
- Control actuators
- Landing gear
- Engine controls
- Inlet actuators

Auxiliary power unit:

Environmental control:
- Cabin/cockpit
- Engine/inlets
- Equipment
- Cargo
- Weapons bay

Propulsion

Inlet:
- Pressure recovery
- Variable capture area
- Real gas effects

Engine:
- Airbreathing
- Rocket
- Fuels
- Controls

Nozzle:
- Propulsive Lift
- Variable geometry
- Real gas effects

Integration:
- Inlet
- Engine
- Cooling
- Nozzle/airframe

3.1 IDENTIFICATION OF RESEARCH OBJECTIVES

A systematic approach to identification of a valid and comprehensive list of Research Objectives was pursued in Phase I. Formulation and review of this list of objectives was accomplished by McDonnell Douglas, NASA, and USAF personnel. The 102 objectives judged to be necessary for each of the potential operational systems are listed in Figure 3-2. Application of each objective to the nine specific potential operational systems considered in this facilities study is also described in Figure 3-2. Principal characteristics of these operational systems are summarized below. Included are optional Mach range and propulsion systems. Design options can be found in Volume II, Part 1.

Code	System Type	Mach No. Range	Propulsion	
			Baseline	Options
L_1	Reusable Launch	5 to 7	TRJ	-
L_2	Reusable Launch	8 to 10	TJ + CSJ	TRJ + SJ
L_3	Reusable Launch	12	RKT	-
L_4	Reusable Launch	10	RKT + SJ	RKT + CSJ
C_1	Hypersonic Transport	6	TRJ	TFRJ
C_2	Hypersonic Transport	10	TJ + CSJ	TRJ + SJ
M_1	Advanced Manned Interceptor	1.5 (Option: M6+)	TRJ	TFRJ, SERJ
M_2	Strategic Strike	12	RKT + SJ	RKT + CSJ
M_3	Interceptor	8 to 12	RKT + SJ	-

Applicability of each Research Objective to potential operational systems is indicated in Figure 3.2 by check marks, or by an "All" if the objective applies across-the-board to the spectrum of operational systems. The original list of 102 objectives was screened to eliminate those objectives involving design options, particularly optional propulsion systems, which overlap or are redundant with other objectives. This screening resulted in a list of objectives identified as the baseline case throughout this report. In this way, an identification of that research fundamentally necessary to acquire a particular operational system was obtained for the baseline case. Research objectives eliminated to obtain the baseline list are identified with an asterisk in Figure 3.2. The research values in this report are based on this baseline case. Ranking based on the entire list of 102 objectives (identified as the baseline + options case in this report) are briefly discussed in Section 3.3.3.

FIGURE 3-2 RESEARCH OBJECTIVES

Description	Applicable Operational Systems								
	L_1	L_2	L_3	L_4	C_1	C_2	M_1	M_2	M_3
AERODYNAMICS									
1. Determine low speed (takeoff and landing) aerodynamic characteristics of hypersonic aircraft.	All								
2. Determine subsonic and transonic aerodynamic characteristics of hypersonic aircraft.	All								
3. Determine supersonic and hypersonic aerodynamic characteristics of hypersonic aircraft.	All								
4. Provide new or update present testing techniques for aerodynamic research facilities so Reynolds number, shock wave, and boundary layer dependent phenomena can be correctly simulated using subscale models.	All								
5. Define the design criteria and systems requirements for optimum and acceptable handling qualities for hypersonic aircraft.	All								
6. Evaluate design techniques for obtaining favorable aerodynamic interference effects through surface or inlet positioning.	All								
7. Evaluate design techniques of using the aircraft body for engine exhaust expansion, thereby providing additional lift, and determine the effect of propulsive gas flow interactions, such as rocket exhaust plumes, on the aerodynamic characteristics of hypersonic aircraft.	✓	✓	✓	✓	✓	✓		✓	✓
8. Evaluate design techniques to improve low speed, takeoff, and landing characteristics for hypersonic aircraft (i.e., use of variable geometry, auxiliary lift devices, or propulsive lift augmentation) and techniques to reduce transonic drag.	All * →								

	Description	Applicable Operational Systems								
		L_1	L_2	L_3	L_4	C_1	C_2	M_1	M_2	M_3
9.	Investigate the effect on hypersonic aircraft stability and control of engine on-off operation, inlet unstarts, variable inlet and nozzle geometry, bypass airflows, propulsion mode changes, boattail forces, and aerothermoelastic effects.	All								
10.	Develop design principles for stage integration which provide reduced drag characteristics and other aerodynamic improvements throughout the speed range for two-stage hypersonic launch vehicles.	✓	✓	✓	✓					
11.	Determine separation techniques for two stage hypersonic vehicles which will provide positive separation and controllability.	✓	✓	✓	✓					
12.	Improve fundamental knowledge of hypersonic boundary layer behavior in the presence of adverse pressure gradients and shock interactions such as are encountered in inlets.	All								
13.	Investigate unsteady control surface hinge moments due to boundary layer and shock wave interaction.	All * →								
14.	Develop correlation techniques for the prediction of buffet onset for low aspect ratio configurations, involving longitudinal (body) bending motions as well as wing bending responses.	All								
15.	Evaluate configuration shaping techniques and flight path variation for alleviating sonic boom intensity, and study near and far field noise levels.	All								
16.	Develop correlation methods for the prediction of heat transfer and drag for turbulent boundary layers with pressure gradients and three-dimensional flows for windward flows.	All								

Description	Applicable Operational Systems								
	L_1	L_2	L_3	L_4	C_1	C_2	M_1	M_2	M_3
17. Determine correlations for the prediction of boundary layer transition.	All * →								
18. Investigate the use of strategically located reaction control jets on hypersonic aircraft to reduce the aerodynamic control surface deflection and surface heating.	✓	✓	✓	✓		✓		✓	✓
19. Determine the effectiveness of various types of control surfaces and their locations for providing sufficient control throughout the entire flight spectrum, and improve methods of predicting aerodynamic heating for deflected control surfaces.	All								
THERMODYNAMICS									
20. Extend the knowledge of predicting hypersonic aerothermodynamic parameters in a three-dimensional flow field.	All								
21. Extend the knowledge of aerothermodynamic prediction techniques at hypersonic velocities providing means of relating either analytical or wind tunnel results accurately to real flight conditions.	All * →								
22. Investigate shaping of aerodynamic surfaces to reduce skin temperatures, and the effects of protuberances and surface irregularities on hypersonic aircraft drag and aerodynamic heating.	All								
23. Determine the effects of transpirative or ablative processes on skin friction and heat transfer.	✓	✓	✓	✓					
24. Determine the effects of embedded shock, vortices, separation, and reattachment on skin friction and heat transfer for leeside flows.	All * →								
25. Determine the aerodynamic heating effects produced by flow through gaps resulting from adjacent aircraft surfaces, and rapid changes in operational altitude.	All								

Description	Applicable Operational Systems								
	L_1	L_2	L_3	L_4	C_1	C_2	M_1	M_2	M_3
26. Determine increased heat transfer and reduced radiation cooling due to flow field/vehicle geometry interactions (view factors and flow interference).	All * →								
27. Develop methods for predicting heat transfer due to radiation and gas impingement from engine exhaust.	All								
STRUCTURES AND MATERIALS									
28. Develop efficient reusable thermal protection systems for cryogenic fuels and oxidizer tankage. System considerations should include insulation, vapor barrier, purge techniques, installation and inspection methods, chemical compatibility, temperature cycling, and life time.	All						●		
29. Develop shell theory for non-circular shells with a view to practical fuselage and tank structures to more precisely predict stress levels associated with combined mechanical-thermal loads and their impact on useful life.	All								
30. Evolve more efficient concepts for fuselage and tank structures for both circular and non-circular applications.	All								
31. Develop heat shield technology for reusable heat shield systems. System considerations should include heat shield flutter, sonic and mechanical fatigue, erosion, and chemical reactions with air stream and attaching structure.	All * →								
32. Develop efficient reusable leading edge concepts and identify most applicable concepts for specific portions of the flight regime.	All								

Description	Applicable Operational Systems								
	L_1	L_2	L_3	L_4	C_1	C_2	M_1	M_2	M_3
33. Develop control surface technology, including thermal protection requirements, methods of attachment, sealing, methods of actuation, and thermal cycling.	All								
34. Develop long-life, regeneratively cooled structural concepts for application in high heat flux areas such as leading edges and propulsion systems.	All								
35. Provide a structure which maintains aerodynamic smoothness under actual operational conditions and use.	All * →								
36. Determine the effects of combined mechanical loading, thermal stress cycling, and temperature variations on the life of the structural components.	All * →								
37. Determine the effects of separation forces on the structural dynamic characteristics of the vehicles.	✓	✓	✓	✓				✓ *	✓ *
38. Determine the effects of fuel slosh on the dynamics and inertia loads of low aspect ratio hypersonic aircraft with large volume fuel tankage.	✓	✓	✓	✓	✓	✓		✓	✓
39. Determine the parameters of correlation for the analysis of the effects of near field noise on minimum gauge structures, composite structures, and non-metallics.	All								
40. Develop non-destructive test and inspection methods for sandwich structure, composite materials, diffusion-bonded materials, and coatings.	All								
41. Develop a capability to accurately estimate component and structural mass fractions for all types of hypersonic aircraft designs.	All								
42. Verify the integrity of the structural and thermal structural systems through full-scale component testing.	All								

Description	Applicable Operational Systems								
	L_1	L_2	L_3	L_4	C_1	C_2	M_1	M_2	M_3
43. Develop reusable thermal protection systems for the primary structure.	All								
44. Define the mechanical and physical properties of advanced materials that have potential application in hypersonic aircraft. Prime candidates are: metal matrix composites, high temperature titaniums, superalloys, and refractories.	All								
45. Improve fabrication techniques for advanced materials and complex structures. These include: welding, diffusion bonding, and brazing of metals; composite forming; fabrication of sandwich structure; and fabrication of non-metallics.	All								
46. Develop high temperature bearings, lubricants, closure seals, tires, windshields, and radomes.	All								
47. Develop protective coatings for metals and non-metals to provide resistance to corrosion, erosion, oxidation, and wear and to enhance emittance and radar absorption, for long term exposures to the hypersonic environment.	All * →								
PROPULSION									
48. Develop inlet configurations of either fixed- or variable-geometry that yield high total pressure recovery, low weight and drag, good stability, and minimum distortion over the range of desired flight conditions and engine operating modes, and enable the engine to achieve the desired specific impulse and thrust, through improved techniques for predicting cowl, spill, additive, bleed, and bypass drag characteristics, and improved inlet off-design performance.	✓	✓		✓	✓	✓	✓	✓	✓

Description	Applicable Operational Systems								
	L_1	L_2	L_3	L_4	C_1	C_2	M_1	M_2	M_3
49. Evaluate effects of inlet installation within the vehicle pressure field on inlet performance and on inlet drag. The effect of boundary layer ingestion on inlet performance must be determined and techniques to control and remove boundary layer must be developed.	✓ *	✓		✓	✓	✓	✓	✓	✓
50. Evaluate variable capture area inlet designs required for operation across the range of desired flight conditions of speed and attitude (angle of attack).	✓ *	✓		✓	✓	✓	✓	✓	✓
51. Evaluate real gas effects on inlet and nozzle performance.	*	✓		✓		✓		✓	✓
52. Develop engine design concepts amenable to cooling by various techniques (regeneration, ablation, radiation, other); consider ascent and descent as well as cruise.	✓ *	✓		✓	✓	✓	✓	✓	✓
53. Develop engine component technology (burners, turbines, heat exchangers, controls) suitable for cryogenic fuels.	✓ *	✓		✓	✓	✓	✓	✓	✓
54. Develop advanced engine components having light weight with perhaps shortened lifetime.	✓ *	✓		✓	✓	✓	✓	✓	✓
55. Investigate methods for reducing engine noise during takeoff and landing.					✓	✓			
56. Study combustion problems of ramjets when operated for thrust augmentation at transonic or low supersonic flight speeds.	✓	✓ *			✓	✓ *	✓		
57. Develop and integrate engine components into complete, large-scale turboramjet systems and demonstrate compatibility and overall performance throughout an extensive flight envelope and operating mode changes.	✓	✓			✓	✓	✓		

	Description	Applicable Operational Systems								
		L_1	L_2	L_3	L_4	C_1	C_2	M_1	M_2	M_3
58.	Perform sufficient cycle analysis, component testing, and mission analysis to select the best multi-mode cycle and size engine for application to a specific hypersonic mission aircraft.	All								
59.	Develop and integrate engine components into complete, large-scale ramjet systems and demonstrate compatibility and overall performance throughout an extensive flight envelope and operating mode changes.	✓ * →				✓		✓		
60.	Develop and integrate engine components into complete, large-scale convertible scramjet systems and demonstrate compatibility and overall performance throughout an extensive flight envelope and operating mode changes.		✓		✓ *		✓ *		✓ *	
61.	Develop and integrate engine components into complete, large-scale scramjet systems and demonstrate compatibility and overall performance throughout an extensive flight envelope and operating mode changes.		✓ *		✓		✓		✓	✓
62.	Demonstrate rocket-powered engine operation in a horizontal takeoff aircraft throughout an extensive flight envelope of speeds, altitude, and attitude.			✓	✓				✓	✓
63.	Develop inlet controls for hypersonic aircraft which are simple, reliable, accurate, and have rapid response.	✓ * →	✓			✓	✓	✓		
64.	Evaluate suitability of auxiliary turbojets for landing of hypersonic vehicles.			✓	✓				✓	✓
65.	Determine nozzle configurations to produce high net thrust while maintaining efficient integration with the airframe.	✓	✓		✓	✓	✓	✓	✓	✓

Description	Applicable Operational Systems								
	L_1	L_2	L_3	L_4	C_1	C_2	M_1	M_2	M_3
66. Evaluate variable nozzle geometry requirements for operation across a wide speed range, and mechanical concepts to produce it.	✓ *	✓		✓	✓	✓	✓	✓	✓
67. Determine inlet/engine compatibility criteria (both steady-state and time-varying) of high-total-pressure-recovery, wide-Mach-range inlets.	✓	✓		✓	✓	✓	✓	✓	✓
SUBSYSTEMS									
68. Develop operational systems and procedures for the thermal conditioning, storage, and safe handling of cryogenic propellants which are compatible with typical airfield requirements; also, consider logistics, production facilities, and cost of fuel delivered to airplanes at various airfield locations around the world.	✓	✓	✓	✓	✓	✓		✓	✓
69. Develop analytical correlation techniques through empirical evaluation to permit the determination of the fluid dynamic and thermodynamic characteristics of cryogenic propellants in large horizontal tankage in a vibrating, sloshing, pressurized environment.	✓	✓	✓	✓	✓	✓		✓	✓
70. Develop regenerative cryogenic heat exchangers, thermodynamic correlations, and control systems for structural and engine cooling which are compatible with representative vehicle heat loads and material temperature limits.	✓	✓	✓	✓	✓	✓		✓	✓
71. Improve fuel performance of new or existing hydrocarbon fuels through increase in (1) thermal stability or utilization of vaporizing and endothermic fuels, (2) fuel density and energy content, and (3) combustion properties.	✓	✓			✓		✓		

	Description	Applicable Operational Systems								
		L_1	L_2	L_3	L_4	C_1	C_2	M_1	M_2	M_3
72.	Determine fuel system design requirements imposed by the use of thermally stable and endothermic fuels in high temperature aircraft environment, including such areas as contamination limits, inert pressurization, and ground support systems.	✓	✓			✓		✓		
73.	Advance the technology of cryogenic fuel system components in the areas of reduced weight and increased reliability. Particular areas requiring advancement include liquid hydrogen static and dynamic sealing and rotating machinery operating in cryogenic environment.	✓	✓	✓	✓	✓	✓		✓	✓
74.	Determine rapid cryogenic servicing techniques necessary to achieve required reaction and turnaround times for military and commercial vehicles.	* →				✓	✓		✓	✓
75.	Develop viable aircraft fuel tankage concepts (integral and non-integral tanks, sub-cooled and saturated fuel), and develop cryogenically fueled integrated aircraft fuel system operation and control techniques to account for propellant utilization, management, and pressurization requirements during both ground and flight environments.	✓	✓	✓	✓	✓	✓		✓	✓
76.	Determine capability of flush recessed antennas required for hypersonic flight to supply patterns compatible with communication, navigation, and electronic warfare functions.	All								
77.	Determine flush or recessed antenna design techniques necessary to allow operation in the elevated hypersonic temperature environment.	All * →								
78.	Investigate stability augmentation systems capable of control in the hypersonic region, and recovery from pilot-induced oscillations.	✓	✓	✓	✓	✓	✓		✓	✓

	Description	Applicable Operational Systems								
		L_1	L_2	L_3	L_4	C_1	C_2	M_1	M_2	M_3
79.	Determine air data measurement techniques applicable to the hypersonic environment such as fixed orifice pressure measurements and laser densitometers.	All								
80.	Develop actuation techniques and hardware to provide control surface motion over the range of environment encountered in the hypersonic flight regime. This includes development of high temperature hydraulic and pneumatic drive systems and components.	All								
81.	Develop high temperature actuator systems for engine inlet and nozzle adjustment.	All * →								
82.	Develop auxiliary power units for rocket-scram and ramjet-powered aircraft, including necessary emergency power equipment in case of primary unit failure.	All								
83.	Develop environmental control system utilizing liquid cryogens as the heat sink, based on allowable internal wall temperatures for crew and passenger comfort and effectiveness.	✓	✓	✓	✓	✓	✓		✓	✓
84.	Develop environmental control systems for Mach 4 to 6 hydrocarbon-fueled vehicles, based on allowable internal wall temperatures for crew and passenger comfort and effectiveness.	✓				✓		✓		
85.	Develop launch techniques for AAM and ASM weapons in hypersonic flights.							✓	✓	✓
86.	Investigate methods of heat shielding missile launchers, doors, and internal structure in hypersonic environment.	* →						✓	✓	✓

Description	Applicable Operational Systems								
OPERATION	L_1	L_2	L_3	L_4	C_1	C_2	M_1	M_2	M_3
87. Evaluate various methods of terminal approach and landing for hypersonic aircraft (including high angle glide slopes) and determine the design penalty associated with operational requirements for loiter, go-around, short runway operation, and all-weather capability, including visibility augmentation.	All								
88. Study hazards inherent in the use of cryogenic fuels, on ground and in flight, during both normal and abnormal operation.	All * →								
89. Investigate man-machine compatibility as related to the control and navigation of a hypersonic vehicle at both high and low Mach numbers.	All								
90. Establish optimum landing techniques for a hypersonic vehicle.	All * →								
91. Develop effective communication techniques for safe flight planning.	All								
92. Investigate various ascent trajectories to assess the tolerable axial and normal "g" loads.	All								
93. Investigate effects of vehicle dynamics and centrifugal effects on crew performance capability, and passenger comfort in hypersonic flight.	All * →								
94. Develop abort, fuel dump, and crew escape systems and procedures for hypersonic aircraft; investigate escape techniques and emergency egress procedures over hot structure escape paths, and in the vicinity of large quantities of LH_2 or GH_2.	All								
95. Determine the effects of bank angle, yaw, angle of attack, flow field benefit, turbulence, and variations in atmospheric conditions on boost, cruise, and descent performance for hypersonic aircraft.	All								

	Description	Applicable Operational Systems								
		L_1	L_2	L_3	L_4	C_1	C_2	M_1	M_2	M_3
96.	Define and demonstrate the capability to stay within specified operational margins to not exceed aircraft placards (i.e., duct pressure, temperature, stability, dynamic pressure, and load factor limits).	All								
97.	Develop leak detection methods for cryogenic propellant tanks.	All								
98.	Investigate concepts for providing an atmosphere of motion and security for passengers in a windowless aircraft.					✓	✓			
99.	Investigate short takeoff techniques using forced rotation, including gimballed rocket and canard techniques.			✓	✓				✓	✓
100.	Develop practical ground hold methods for cryogenic systems leading to quick response times and high operational readiness.	* →							✓	✓
101.	Develop specifications for adequate Air Traffic Control procedures and ground-based navigation systems.	All								
102.	Develop inspection and repair techniques for hypersonic vehicle structures.	All								

3.2 EVALUATION OF RESEARCH OBJECTIVES

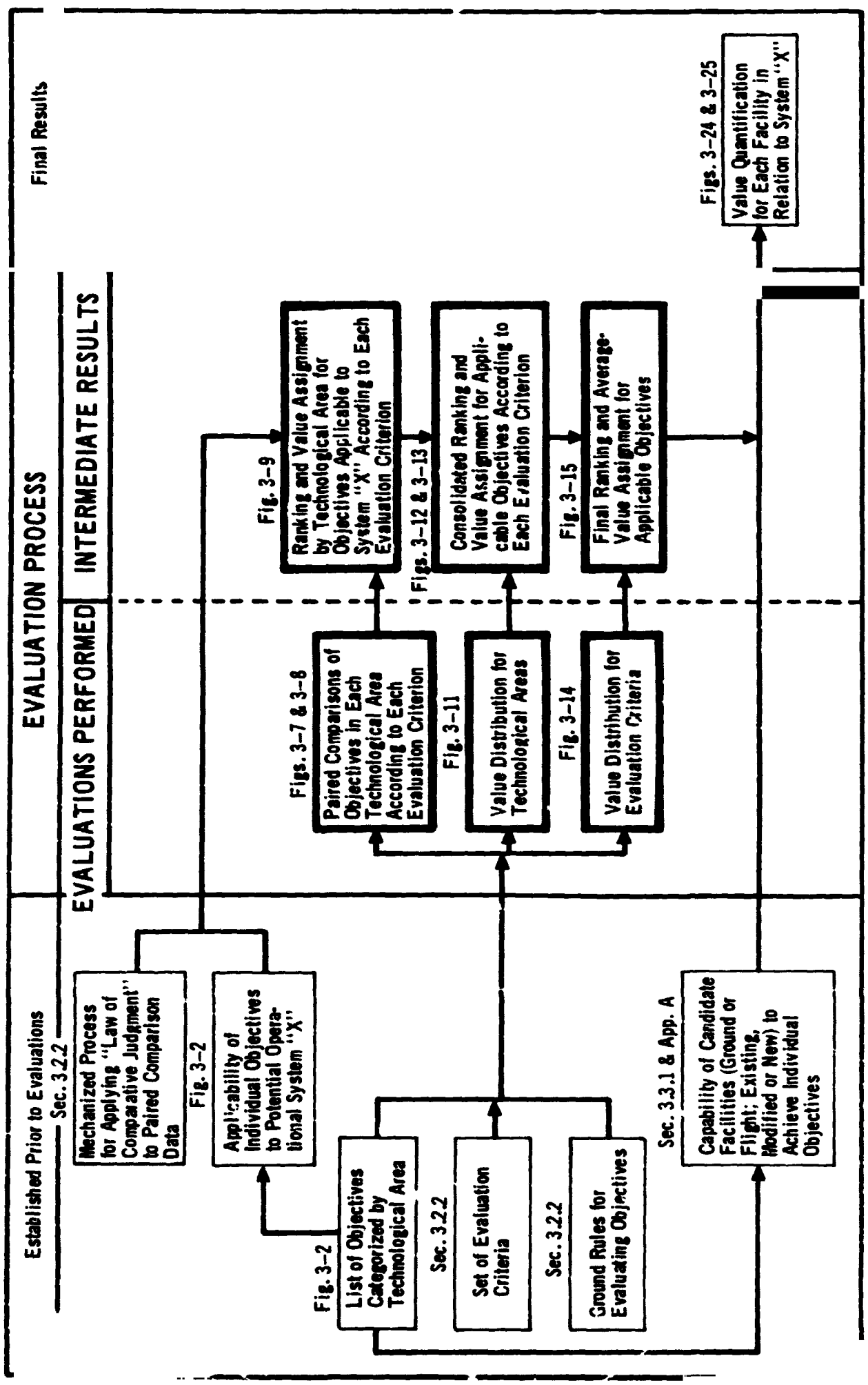
The Research Objectives identified by NASA, USAF, and MCAIR personnel and listed in Figure 3-2 were used as the basis for quantifying the value of each of the candidate flight and ground facilities. This determination is based on two factors: (1) The importance (or value) of the research described by each objective, and (2) the capability of the various facilities to accomplish the individual objectives. This section presents the method used to determine the inherent worth (or value) of each objective relative to all of the other objectives.

The relationship of the various elements involved in this evaluation is depicted in block diagram form in Figure 3-3. The key elements in the evaluation process are designated by the heavily outlined blocks. Also shown is the relationship of these elements to the aspects of the analysis performed prior to the evaluation phase and to the final results. The evaluation process is illustrated for an arbitrary system, designated Potential Operational System "X". Associated figures and sections from the text are noted above each block in the figure.

3.2.1 BASIC ELEMENTS OF THE EVALUATION - Several techniques for determining the value of Research Objectives have been examined. One such method would involve the direct assignment of relative ratings to the various objectives in relation to several criteria. The ratings for each objective would then be averaged over all the evaluations and criteria to obtain final values. Because the number of objectives in this study is so large, however, it is highly unlikely that evaluators could keep them all in mind simultaneously while making relative value assignments, hence this method was not selected. Another variation, related to the so-called "Delphi Method," would provide for several iterations during the evaluation procedure, whereby those points involving considerable disagreement could be more thoroughly examined, and a consensus ultimately could be reached, or at least approached. This process was not considered feasible because of the time it would require and because the participants were scattered throughout the country. Since a large number of participants were available however, and since many items had to be evaluated using a method involving only one iteration, the process selected as most appropriate for this study involves (1) the "Method of Paired Comparisons" for generating the basic value data and (2) the "Law of Comparative Judgment" for processing this basic data and establishing the inherent value of the objectives. These techniques are discussed in this section, along with the other basic elements involved in evaluating the Research Objectives. Elements of this description involve the listing of objectives (categorized by technological area), the criteria by which these objectives are evaluated, and the basic ground rules for comparing the objectives with each other.

(a) Method of Paired Comparisons - If a subject is asked to rank a number of items with respect to a particular evaluation criterion, it is a fairly simple task to arrange them in a list in descending order of importance, provided the number of items in the list is relatively small. However, as the size of the list increases, the need arises for an organized method for ranking the items. Furthermore, if an intrinsic value is to be derived for each of the items by means of the Law of Comparative Judgment, it is required that data be available in a form indicating "the proportion of times a given item is judged greater than any other item." The Method of Paired Comparisons provides both an organized procedure for ranking items by an individual voter and a method for obtaining empirical estimates

FIGURE 3-3 EVALUATION OF RESEARCH OBJECTIVES (POTENTIAL OPERATIONAL SYSTEM "X")

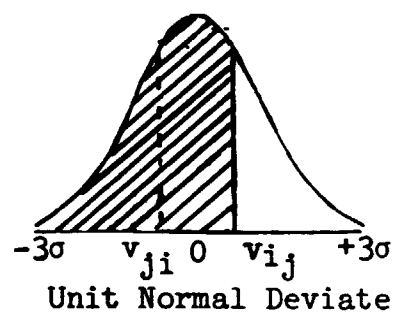


of proportions which can be processed by the Law of Comparative Judgment. Each item is compared in turn with each other item, and for every pairing a preference is indicated for one item or the other. With N items, the number of pairs and hence the number of judgments required is N(N-1)/2.

(b) Law of Comparative Judgment - According to the Law of Comparative Judgment, the differences of opinion of a large number of subjects concerning which of two items ranks higher in importance follows a normal distribution. Accordingly, the likelihood that there will be several persons who disagree concerning the importance of two items is much greater than is the likelihood that all the voting subjects will prefer one of the items in a pairing over the other. Since the probability of universal agreement is so small, in pairings where such agreement does occur, the difference in values assigned to the items in the pairing is far greater than in cases where some disagreement exists. This is the basic rationale for use of the normal distribution in connection with the Law of Comparative Judgment.

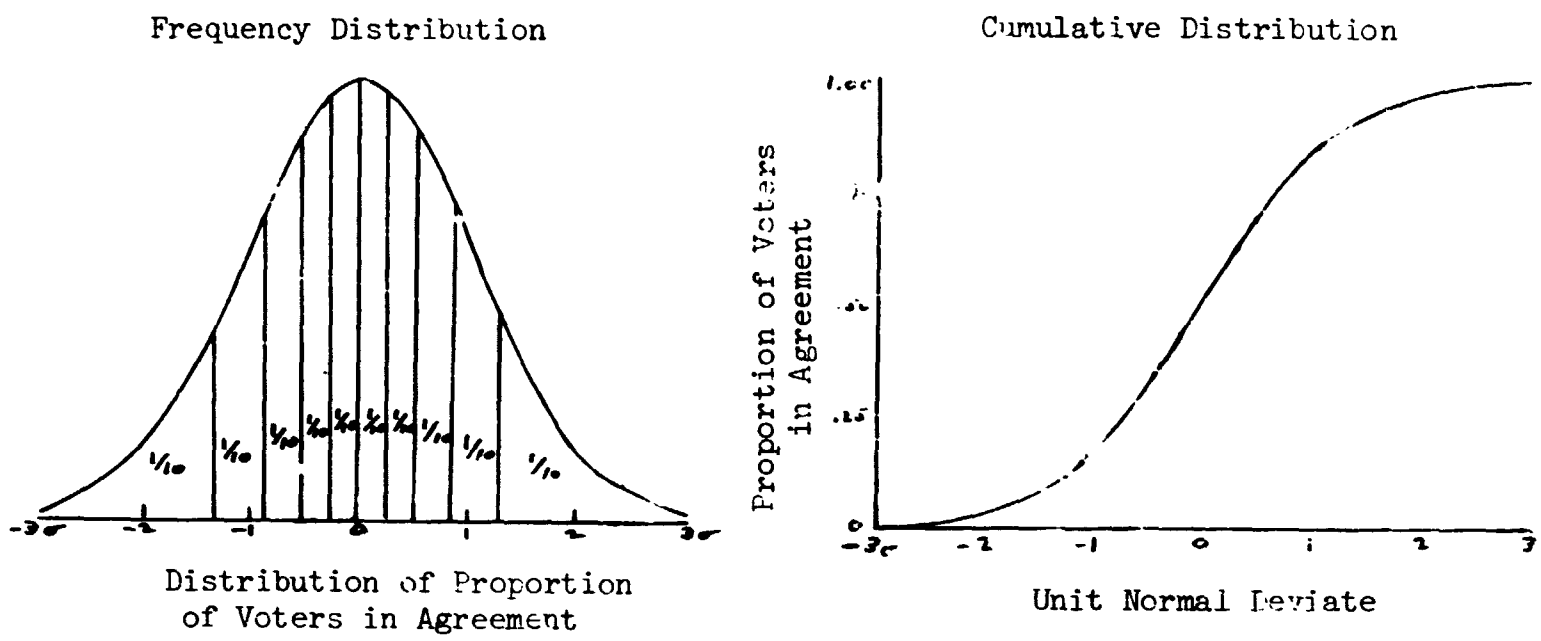
In the evaluation of Hypersonic Research Objectives, the simplifying assumption will be made that the area under the unit normal curve between -3 and +3 standard deviations is unity. With this in mind, the principle involved in use of the normal distribution is illustrated in Figure 3-4. The shaded area represents the proportion of voters who prefer Item "i" to Item "j". The value "v_{ij}" is the unit normal deviate corresponding to this proportion. The value "v_{ji}" corresponds to the proportion who prefer Item "j" and, since the distribution is symmetric about the zero point, $v_{ij} = v_{ji}$ o. If, for example, 10 voters are involved in paired comparisons of a number of items, the area beneath the unit normal curve is divided into 10 segments of equal area, as shown in the left portion of Figure 3-5. The right portion of Figure 3-5 illustrates the associated cumulative distribution function. For a sample size of 10 voters, the relationship in tabular form between the number of voters (P) choosing a given item over another in a particular pairing and the corresponding unit normal deviate value (X_p) is as given in Figure 3-6.

FIGURE 3-4 NORMAL DISTRIBUTION



3.2.2 MECHANICS OF THE RESEARCH OBJECTIVE EVALUATION - Ideally, the evaluation would involve a consideration by each evaluator of every possible pairing from among the 102 Research Objectives, using the Method of Paired Comparisons. However, due to the magnitude of such a task, which would involve thousands of comparisons, the Research Objectives were broken down into six basic technological areas: (a) aerodynamics, (b) thermodynamics, (c) structures and materials, (d) propulsion, (e) subsystems, and (f) operation. Government and industry specialists evaluated the Research Objectives which applied to their areas of technical awareness. The Method of Paired Comparisons was the basic technique used to evaluate

FIGURE 3-5 DISTRIBUTION OF VOTERS



the inherent worth of the objectives within each area. This breakdown was performed strictly for convenience, since many objectives actually span two or more technology areas. In such cases, an objective was placed in the category to which it is most strongly related. Weighting factors determined for each area were then applied to the results from the individual areas, yielding a consolidated ranking of all the objectives involved. The mechanics of the evaluation can probably best be described by presenting an actual example from the Research Objective evaluation.

A copy of an original paired comparison evaluation form, completed by one of the specialists in the aerodynamics category, is shown in Figure 3-7. Each objective is compared in turn with each of the other objectives within this technological area, and for every pairing one objective or the other is chosen as more important. Relative importance is judged on the basis of which of the two objectives the evaluator feels will contribute more toward achievement of the potential operational systems. The comparison process is facilitated by arrangement of the objectives in rows and columns. The evaluator indicates his choice for a particular pairing in the space corresponding to the intersection of the two objectives in the pairing. A "one" indicates that the evaluator considers the row objective more important than the column objective, while a "zero" indicates that the column objective is chosen as more important.

FIGURE 3-6 TABLE OF UNIT NORMAL DEVIATES (10 VOTERS)

P	0	1	2	3	4	5	6	7	8	9	10
X_p	-3.00	-1.28	-.84	-.52	-.25	0	.25	.52	.84	1.28	3.00

FIGURE 3–7 PAIRED COMPARISON EVALUATION FORM

Hypersonic Rese · acilities Study
Contract No. (NAS2-5058)

A. AERODYNAMICS

Instructions:

Make an insertion in each square to the left of the double line.

Indicate which of the two objectives in the pairing you feel involves more important research for the achievement of those potential operational systems to which both objectives apply, according to the following evaluation criterion:

(a) TECHNOLOGY ADVANCEMENT

If you consider the Row objective more important than the Column objective, insert a "1".

If you consider the Column objective more important, insert a "0".

Appl. Oper. Systems: L_1 L_2 L_3 L_4 C_1 C_2 M_1 M_2 M_3

Column (0)

Row (1) Objective	L_1	L_2	L_3	L_4	C_1	C_2	M_1	M_2	M_3	1. Low speed (T/O & landing) aero chars	2. Subsonic & transonic aero chars	3. Supersonic & hypersonic aero chars	4. Test techns for Re No, shk wv & bndy lr phen	5. Optimum & acceptable handling qualities	6. Surface/inlet pos – favor aero interference	7. Eng exst exp for add lift/prop gas flo int eff	8. Des techns for lo speed chars & tran drag red	9. Parameters affecting stability & control	10. Stage integration for aero improvement	11. Separation techns for pos separ & control	12. Hypersonic boundary layer behavior	13. Unsteady control surface hinge moments	14. Predict techns for buffet onset of low AR A/C	15. Techns for alleviating sonic boom intensity	16. Heat trans & drag for turb boundary layers	17. Pred techns for bndy layer transition	18. Effects of reaction control jets	19. Cntl surf effect/heat effects when deflected
1. Low speed (T/O & landing) aerodynamic characteristics	●	●	●	●	●	●	●	●	●		0	1	1	1	1	1	1	1	1		1	1	1	1	1		1	1
2. Subsonic & transonic aerodynamic characteristics	●	●	●	●	●	●	●	●	●				1		1	1		1	1		1	1	1	1	1		1	1
3. Supersonic & hypersonic aerodynamic characteristics	●	●	●	●	●	●	●	●	●					1	1	1	1	1	1	1						1	1	1
4. Testing techns for Re No, shock wave & bndy layer phenomena	●	●	●	●	●	●	●	●	●						1		1	1	1	0	1	1	1	1	1	1	1	1
5. Optimum & acceptable handling qualities	●	●	●	●	●	●	●	●	●							1			1		1	1		1	1	1	1	1
6. Surface or inlet position for favorable aero interference	●	●	●	●	●	●	●	●	●								1	1			1	1	1					
7. Engine exhaust expan for added lift propul gas flo interaction effects	●	●	●	●	●	●		●	●									1			1	1	1	1			1	
8. Design techns for low speed chars & transonic drag reduction	●	●	●	●	●	●	●	●	●										1		1	1	1	1				1
9. Paramaters affecting hypersonic A/C stability & control	●	●	●	●	●	●	●	●	●										1		1	1	1	1	1	1	1	
10. Stage integration providing aerodynamic improvements	●	●	●	●																1	1							
11. Separation techns for positive separation & controllability	●	●	●	●																	1	1	1	1		1		
12. Hypersonic boundary layer behavior	●	●	●	●	●	●	●	●	●													1		1				
13. Unsteady control surface hinge moments	●	●	●	●	●	●	●	●	●														1					
14. Prediction techns for buffet onset of low AR configs	●	●	●	●	●	●	●	●	●															1				
15. Techniques for alleviating sonic boom intensity	●	●	●	●	●	●	●	●	●																1			
16. Heat transfer & drag for turbulent boundary layers	●	●	●	●	●	●	●	●	●																			
17. Prediction techniques for boundary layer transition	●	●	●	●	●	●	●	●	●																		1	
18. Effects of strategically located reaction control jets	●	●	●	●		●		●	●																			1
19. Control surface effectiveness heat effects when deflected	●	●	●	●	●	●	●	●	●																			

This rating process was repeated for two evaluation criteria, Technology Advancement and Cost and Schedule. These criteria are described as follows:

(a) Technology Advancement - This criterion can be considered as the extent to which the Research Objective contributes to the technical knowledge required to achieve an operational hypersonic vehicle. This contribution could involve:

- o Understanding of fundamental physical or physiochemical behavior and interactions.
- o Application of principles to design concepts.
- o Confirmation of adequacy of design or manufacture.
- o Reduction in overdesign penalties.

(b) Cost and Schedule - This criterion indicates the extent to which the research contributes to obtaining a sound cost and schedule basis for initiating an acquisition program for an operational hypersonic vehicle. This contribution might include:

- o Establishment of a sound system costing base.
- o Achievement of major time savings relative to system development.
- o Uncovering of design problems that would be costly and time-consuming to correct during a system procurement cycle.

All of the Research Objectives were evaluated twice, once for each of these evaluation criteria. The example shown in Figures 3-7 through 3-11, however, corresponds only to Criterion (A) (Technology Advancement).

The paired-comparison evaluations generated a large amount of data, necessitating use of a digital computer to process the inputs. A typical output is shown in Figure 3-8 for the aerodynamics example being used to illustrate the Research Objectives evaluation procedure. The entire matrix is shown completed at the top of the page. The evaluators were not asked to fill in the entire evaluation matrix, since the lower-left half of the matrix represents the inverse of the upper-right half. The ranking of the objectives for the particular evaluator is shown at the bottom of the page. The total for each objective is found by summing the elements in the rows of the matrix corresponding to that objective. The diagonal elements, represented by the double asterisks, are ignored, since the objectives were not compared to themselves. These individual results are not used directly in the analysis; however, they can be useful for comparison of an individual's preferences with the composite results based on the preferences of all the participants in the evaluation.

The composite results of the 22 persons evaluating the aerodynamics category are summarized in Figure 3-9. This summary is shown for Operational System L1. Objectives No. 8, 13, and 17 are not included in this case, reducing

FIGURE 3-8 INDIVIDUAL'S RESULTS

EVALUATION CRITERION - A. TECHNOLOGY ADVANCEMENT

A. AERODYNAMICS

NO.	CODE	OBJECTIVE	NO.= 5	10	15	20
1	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	** 0 0 0 0 0 0 0 0 1 0 0 1 1 1 0 0 0 0			
2	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	1** 0 1 0 0 0 1 0 1 0 0 1 1 1 1 0 1 0			
3	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	1 1** 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1			
4	4	TEST TECHNS FOR RE NO, SHOCK WAVE & BNDY LR PHEN	1 0 0** 0 0 0 1 0 0 0 0 1 1 1 0 0 1 0			
5	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	1 1 0 1** 1 1 1 1 1 0 1 1 1 1 1 1 1 0			
6	6	SURFACE/INLET POSITION - FAVOR AERO INTEFERENCE	1 1 0 1 0** 0 1 0 1 0 0 1 0 0 0 0 0 0			
7	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	1 1 0 1 0 1** 1 0 1 0 0 1 1 1 0 1 1 0			
8	8	DES TECHNS FOR LO SPEED CHARS & TRAN DRAG REDUCT	1 0 0 0 0 0 0** 0 1 0 0 1 0 0 0 0 0 0			
9	9	PARAMATERS AFFECTING STABILITY & CONTROL	1 1 0 1 0 1 1 1** 1 0 0 1 1 1 1 1 1 0			
10	10	STAGE INTEGRATION FOR AERO IMPROVEMENTS	0 0 0 1 0 0 0 0 0** 0 0 1 0 0 0 0 0 0			
11	11	SEPARATION TECHNS FOR POSITIVE SEPAR & CONTROL	1 1 0 1 1 1 1 1 1 1** 1 1 1 1 0 1 1 0			
12	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	1 1 0 1 0 1 1 1 1 1 0** 1 1 1 0 1 1 0			
13	13	UNSTEADY CONTROL SURFACE HINGE MOMENTS	0 0 0 0 0 0 0 0 0 0 0 0** 0 0 0 0 0 0			
14	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	0 0 0 0 0 1 0 1 0 1 0 0 1** 0 0 0 1 0			
15	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	0 0 0 0 0 1 0 1 0 1 0 0 1 1** 0 1 0 0			
16	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	1 0 0 1 0 1 1 1 0 1 1 1 1 1 1** 1 1 0			
17	17	PREDICT TECHNS FOR BNDY LAYER TRANSITION	1 1 0 1 0 1 0 1 0 1 0 0 1 1 0 0** 1 0			
18	18	EFFECTS OF REACTION CONTROL JETS	1 0 0 0 0 1 0 1 0 1 0 0 1 0 1 0 0** 0			
19	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1**			

RANK	CODE	OBJECTIVE	TOTAL
1	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	18
2	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	17
3	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	15
4	11	SEPARATION TECHNS FOR POSITIVE SEPAR & CONTROL	15
5	9	PARAMATERS AFFECTING STABILITY & CONTROL	13
6	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	13
7	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	13
8	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	11
9	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	9
10	17	PREDICT TECHNS FOR BNDY LAYER TRANSITION	9
11	4	TEST TECHNS FOR RE NO, SHOCK WAVE & BNDY LR PHEN	6
12	6	SURFACE/INLET POSITION - FAVOR AERO INTEFERENCE	6
13	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	6
14	18	EFFECTS OF REACTION CONTROL JETS	6
15	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	5
16	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	4
17	8	DES TECHNS FOR LO SPEED CHARS & TRAN DRAG REDUCT	3
18	10	STAGE INTEGRATION FOR AERO IMPROVEMENTS	2
19	13	UNSTEADY CONTROL SURFACE HINGE MOMENTS	0

FIGURE 3-9 COMPOSITE RESULTS Operational System No. 1-(L1)

Evaluation Criterion – A. Technology A

A. AERODYNAMICS
(22 EVALUATORS)
(.183)

NO.	CODE	OBJECTIVE	NO.= 5 10 15 20
1	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	**13 4 6101211 812.110171712010
2	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	9** 4 6 81311 7141211191912191 0
3	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	1818**111516141518171721221819 18
4	4	TEST TECHNS FOR RE NO. SHOCK WAVE & BNDY LR PHEN	161611**1515131218141321191521 14
5	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	1214 7 7**1112131510 819161220 9
6	6	SUR ACE/INLET POSITION - FAVOR AERO INTEFERENCE	10 9 6 711**10 81514 81815 91810
7	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	1111 8 910 12**1117141017151220 13
8	9	PARAMATERS AFFECTING STABILITY & CONTROL	1415 7101214 11**1513122019162011
9	10	STAGE INTEGRATION FOR AERO IMPROVEMENTS	10 8 4 4 7 7 5 7**11 41215 714 8
10	11	SEPARATION TECHNS FOR POSITIVE SEPAR & CONTROL	1110 5 812 8 8 911** 81718 717 7
11	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	1211 5 9141412191814**2219162213
12	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	5 3 1 1 3 4 5 210 5 6**14 116 5
13	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	5 3 1 3 6 7 7 3 7 4 3 8** 512 6
14	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	1110 4 7101310 61515 62117**1912
15	18	EFFECTS OF REACTION CONTROL JETS	2 3 3 1 2 4 2 2 8 5 0 610 3** 2
16	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	1212 4 81312 9111415 917161020**

RANK	CODE	OBJECTIVE	INITIAL VALUE	NORMALIZED VALUE	FINAL VALUE
1	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	13.7	65.2	71.6
2	4	TEST TECHNS FOR RE NO. SHOCK WAVE & BNDY LR PHEN	9.3	60.3	66.2
3	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	9.3	60.0	65.9
4	9	PARAMATERS AFFECTING STABILITY & CONTROL	5.9	56.5	62.1
5	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	3.3	53.7	58.9
6	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	2.4	52.7	57.9
7	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	2.2	52.5	57.6
8	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	1.9	52.1	57.2
9	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	1.4	51.6	56.6
10	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	1.1	51.2	56.2
11	6	SURFACE/INLET POSITION - FAVOR AERO INTEFERENCE	0.5	50.6	55.6
12	11	SEPARATION TECHNS FOR POSITIVE SEPAR & CONTROL	-0.9	49.0	53.8
13	10	STAGE INTEGRATION FOR AERO IMPROVEMENTS	-5.2	44.2	48.5
14	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	-12.1	35.9	39.5
15	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	-14.7	33.7	37.1
16	18	EFFECTS OF REACTION CONTROL JETS	-17.4	30.7	33.7

the number of objectives in the aerodynamics section from 19 to 16. Each element of the matrix shown at the top of Figure 3-9 represents the number of evaluators who selected the row objective over the column objective. Symmetric elements sum to the number of evaluators, i.e., $P_{ij} + P_{ji} = 22$, where P_{ij} is the element in the "i'th" row, "j'th" column. As indicated in the first row, second column, 13 evaluators chose Objective 1 over Objective 2. The other nine aerodynamics participants chose Objective 2 over Objective 1, as indicated in the second row, first column. It can be seen from Figures 3-7 and 3-8 that the particular evaluator represented in those figures is one of the nine participants who chose Objective 2 over Objective 1.

Use of the Law of Comparative Judgment to convert the evaluators' inputs to ranking values for each objective is illustrated in the lower half of Figure 3-9. A key part in this conversion is played by the unit normal deviate. The unit normal deviates for 22 evaluators are tabulated in Figure 3-10.

FIGURE 3-10 UNIT NORMAL DEVIATE TABULATION (22 EVALUATORS)

P	0	1	2	3	4	5	6	7	8	9	10	11
X_p	-3.00	-1.69	-1.33	-1.10	-.91	-.75	-.60	-.47	-.35	-.23	-.11	0

P	12	13	14	15	16	17	18	19	20	21	22
X_p	.11	.23	.35	.47	.60	.75	.91	1.10	1.33	1.69	3.00

Figure 3-10 is of the same form as Figure 3-6 but contains more entries, since the range of possible total votes for a given item has been expanded from 0-10 to 0-22.

In the lower portion of Figure 3-9, the ranking and value assignments are shown for the 16 aerodynamics objectives evaluated in relation to Operational System L1. The initial value (v_i) for a particular objective is obtained by summing the unit normal deviate values corresponding to the elements in the appropriate row of the composite matrix. Thus, for Objective "x", the initial value v_{i_x} is determined by the following formula:

$$v_{i_x} = \sum_{\substack{y=1 \\ y \neq x}}^{N} X_{p(x,\,y)}$$

where x = objective being evaluated

y = objective to which Objective "x" is compared

$P_{(x,\,y)}$ = no. of evaluators choosing Objective "x" over Objective "y"

$X_{P_{(x,\,y)}}$ = unit normal deviate for x vs. y

N = no. of Objectives in the evaluation

Applying the unit normal deviates in Figure 3-10 to the first row of the composite matrix of Figure 3-9,

$$v_{i_1} = X_{13} \times X_4 + X_6 + X_{10} + X_{12} + X_{11} + X_8 + X_{12} + X_{11} + X_{10} + X_{17}$$

$$+ X_{17} + X_{11} + X_{20} + X_{10}$$

$$= 0.23 - 0.91 - 0.60 - 0.11 + 0.11 + 0 - 0.35 + 0.1 + 0 - 0.11 + 0.75$$

$$+ 0.75 + 0 + 1.33 - 0.11$$

$$v_{i_1} = 1.1,$$

which is the initial value for Objective 1 shown in Figure 3-9. The same process is applied to each of the other rows in the composite matrix, and the resulting initial values for the 16 aerodynamics objectives are shown in the lower portion of Figure 3-9, arranged in order of decreasing value. This set of values provides a placement of the objectives along a linear scale of positive and negative values which sum to zero.

The technique described for the objectives in the aerodynamics area is also applied to the data submitted by the evaluators in each of the other five technological areas, and an initial value is determined for each of the objectives in these areas as well. It is now necessary to merge the results from the six separate areas into a consolidated ranking and value assignment for all the objectives. Two steps are involved in this consolidation. First, since the various technological areas contain different numbers of objectives, the initial values must be normalized on a common scale. Secondly, since some areas of research are judged to be more important than others, the values of the objectives must be adjusted so that objectives in areas considered above average in importance are raised in value while those in below average areas are lowered. Thus, the first step provides a means for expressing in a consistent manner the relationship between the objectives within each individual area, while the second step uses a logical rationale to merge these normalized results from individual areas into a consolidated set of values which reflects the importance of the particular area of research for each objective. The range of possible initial values is (-3) (N-1) to (+3) (N-1), where N is the number of objectives involved. The initial value for an objective is thus dependent on the number of objectives (N) included in its particular technological area. The following equation is used to normalize all the initial values onto a common scale ranging from 0 to 100.

$$v_n = 50 \left[\frac{v_i}{(3)\ (N-1)} + 1 \right]$$

where v_n = normalized value

v_i = initial value

N = no. of objectives in the area under investigation.

Each normalized value "v_n" then indicates the percentage which the initial value "v_i" has attained of the possible value achievable in its area. If, for example, $v_i = (+3)\ (N-1)$, then $v_n = 100$. If, at the other extreme, $v_i = (-3)\ (N-1)$, then $v_n = 0$. And if v_i has the average value of zero, then $v_n = 50$. In the example shown in Figure 3-9, N = 16. Thus, for Objective "x",

$$v_{n_x} = 50 \left[\frac{v_{i_x}}{45} + 1 \right]$$

or,

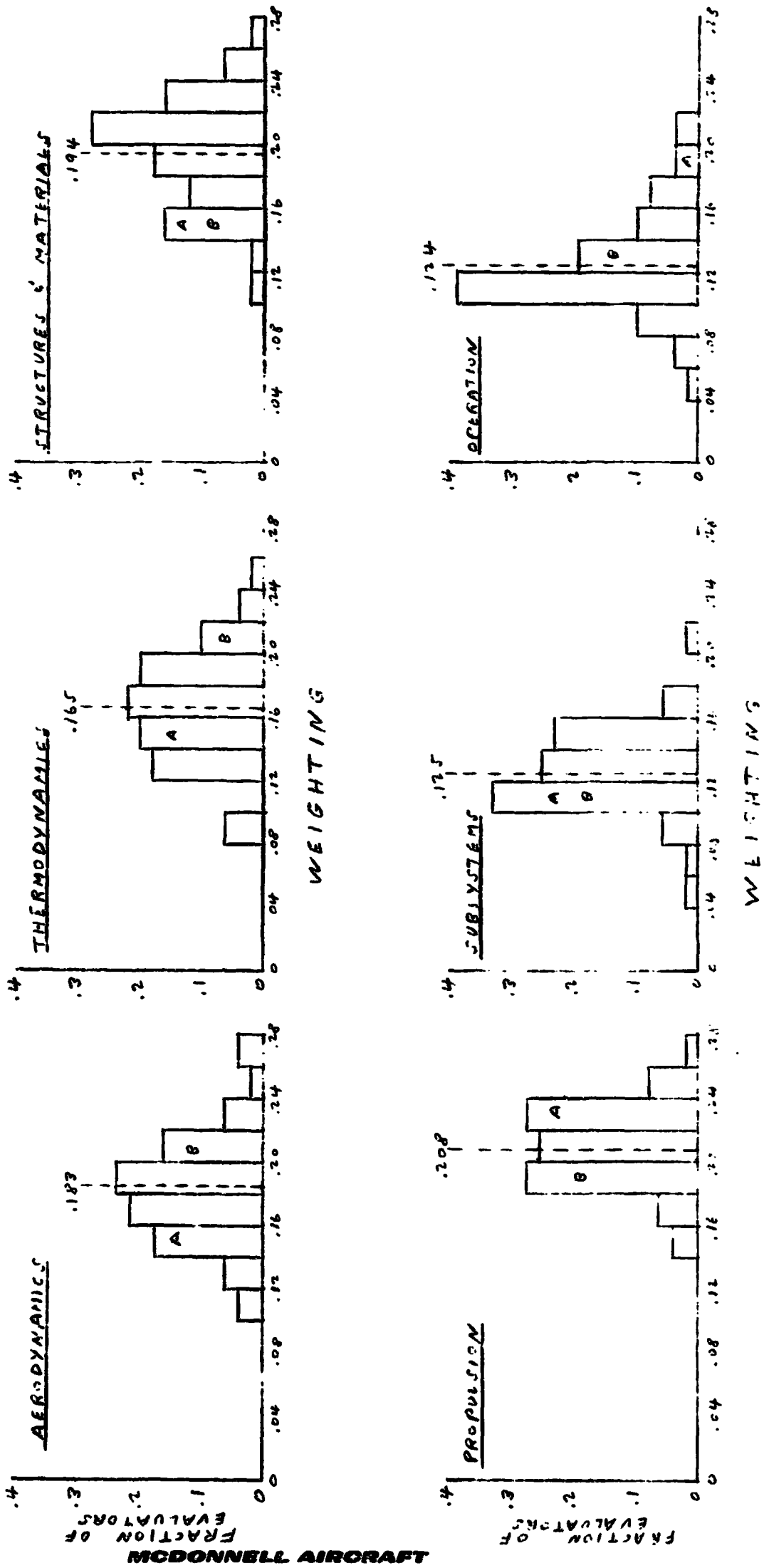
$$v_{n_x} = 1.11\ v_{i_x} + 50$$

As can be seen in the "Normalized Value" column of Figure 3-9, Objective 3 attains 65.2 percent of its maximum possible value, while Objective 18 achieves only 30.7 percent of the maximum value achievable.

The final value of each objective for a given evaluation criterion depends on the relative weighting of the technological area in which the objective is included. Persons rating the technological areas were asked to assign an importance rating ranging from 1 to 10 to each of the areas involved. They were requested in making these assessments to consider collectively the set of all objectives within a given technological area and to make a judgment as to the importance of the set of objectives leading to attainment of the potential operational systems. The number of points assigned by an evaluator to a given area was divided by the total points assigned by him to all areas to obtain his relative weighting for the given area. These relative weightings were then averaged over all the participants to obtain a weighting for each of the six technological areas. The distribution of technological weightings is shown in Figure 3-11. The dashed lines in the figure indicate the resulting average values which were used in the analysis. The weightings computed for two representative evaluators, designated "A" and "B", are also shown. It can be seen that the weightings for the propulsion area are spread over a somewhat smaller range (.14 to .28) than are those in other areas. The highest degree of agreement for a particular increment within a technological area occurs in the operation area, to which nearly 40 percent of the evaluators assigned a weighting between .10 and .12.

To obtain the final value of an objective, its normalized value is multiplied by the ratio of the weighting of its area to the average weighting. Since there are six technological areas, the average weighting is 1/6, or 0.167. So, in the example of Figure 3-9, since the weighting for the aerodynamics area is 0.183, the final values for the objectives in this area are derived by multiplying the normalized values by .183/.167, or 1.096.

FIGURE 3–11 WEIGHTING DISTRIBUTION FOR TECHNOLOGICAL AREAS



Research Objectives are consolidated and ranked according to final value. Figure 3-12 summarizes the results for Criterion A (Technology Advancement). Final values are shown for all 67 objectives which apply to Operational System L1. Included among these 67 objectives are the 16 aerodynamics objectives shown in Figure 3-9. Also illustrated at the top of Figure 3-12 are the relative weightings and the number of evaluators in each technological area.

As mentioned previously, the participants evaluated the objectives in each technological area twice, once in relation to each of the two evaluation criteria. The evaluation process described in the preceeding paragraphs was also applied to the data submitted by the evaluators in relation to Evaluation Criterion B (Cost and Schedule), and the resulting ranking and final value assignments relative to this criterion are illustrated in Figure 3-13 for Operational System L1.

Finally, weightings were obtained for the two evaluation criteria (Technology Advancement and Cost and Schedule) by the same technique which was used to determine the weighting of the technological areas. The distribution of evaluation criterion weightings is shown in Figure 3-14. The tabulation and associated histograms illustrate, for example, that 50 percent of the evaluators consider the relative importance of Technology Advancement to Cost and Schedule to be approximately 6 to 4.

A final weighted average, incorporating the results of the criterion weightings, allowed ranking of the Research Objectives for each potential operational system. This final step in the evaluation of Research Objectives is illustrated in Figure 3-15 for Operational System L1. The weighted average value for an objective is obtained by multiplying its final value for each of the two criteria by the appropriate criterion weighting and then summing the two products. Using Objective 28 as an example, the average value is (76.6) (.604) + (72.3) (.396) = 74.9, where .604 and .396 are the criterion weightings and 76.6 and 72.3 are the final values for Objective 28 for the Technology Advancement and Cost and Schedule criteria, respectively.

The weighted-average values derived from the Research Objective evaluation are defined as the intrinsic values of the objectives. The intrinsic value of each Research Objective varies from one potential operational system to the next because a different combination of objectives corresponds to each system. The Research Objective intrinsic value ratings for the nine potential operational systems are presented in Figures 3-15 through 3-23. An indication of areas of necessary research is seen by examination of the ratings in these figures. It is interesting to note that propulsion and thermo/structural research is valued very highly; however, aerodynamic research is also highly rated, confirming the historical need for understanding of the aerothermal characteristics of an aircraft when one considers the basic research requirements to initiate acquisition of a specific system.

FIGURE 3-12 CONSOLIDATED RANKING AND VALUE ASSIGNMENT EVALUATION CRITERION – A. TECHNOLOGY ADVANCEMENT

Operational System No. 1-(L1)

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS
A. AERODYNAMICS	.183	22
B. THERMODYNAMICS	.165	18
C. STRUCTURES & MATERIAL	.194	21
D. PROPULSION	.208	24
E. SUBSYSTEMS	.125	15
F. OPERATION	.124	19

RANK	CODE	OBJECTIVE	FINAL VALUE
1	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	76.6
2	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	73.4
3	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	72.9
4	57	TURBORAMJET SYSTEMS - DEVELOP & DEMONSTRATE	71.8
5	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	71.6
6	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	68.5
7	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	66.7
8	4	TEST TECHNS FOR RE NO, SHOCK WAVE & BNDY LR PHEN	66.2
9	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	65.9
10	67	INLET/ENGINE COMPATIBILITY CRITERIA	64.7
11	58	BEST MULTIMODE CYCLE & ENGINE SIZE	63.8
12	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	62.9
13	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	62.9
14	33	CONTROL SURFACE TECHNOLOGY	62.1
15	5	PARAMATERS AFFECTING STABILITY & CONTROL	62.1
16	65	NOZZLE CONFIGURATIONS	59.9
17	31	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	59.3
18	32	REUSABLE LEADING EDGE CONCEPTS	59.1
19	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	58.9
20	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	58.7
21	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	57.9
22	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	57.6
23	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	57.4
24	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	57.2
25	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	56.6
26	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	56.2
27	6	SURFACE/INLET POSITION - FAVOR AERO INTERFERENCE	55.6
28	11	SEPARATION TECHNS FOR POSITIVE SEPAR & CONTROL	53.8
29	46	HIGH TEMPERATURE EQUIPMENT	53.8
30	22	SURFACE SHAPING & PROTUR EFFECTS ON DRAG & HEAT	53.2
31	25	HEATING EFFECTS FROM FLOW THRU GAPS	50.3
32	7[illegible]	REGEN CRYO HEAT EXCH'S/THRMO CORLS/COOL CNT STMS	49.2
33	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	49.1
34	10	STAGE INTEGRATION FOR AERO IMPROVEMENTS	48.5
35	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	48.0
36	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	46.3
37	56	COMBUSTION PROBLEMS OF RAMJETS FOR THRST AUGMENT	45.8
38	37	EFF OF SEPARATION FORCES ON DYNAMIC CHARS	45.2
39	80	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	45.2
40	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	44.7
41	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	44.1
42	39	NEAR FIELD NOISE EFFECTS	42.6
43	57	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	42.5
44	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	41.4
45	73	CRYO SYSTEM COMPONENTS - RED WT/INCR RELIABILITY	41.1
46	87	TERMINAL APPROACH & LANDING METHODS	40.8
47	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	40.4
48	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	40.3
49	68	THML COND, STORAGE & SAFE HNDLG OF CRYO FUELS	40.3
50	23	TRANSPIR/ABLAT EFCTS - SKIN FRICT/HEAT TRANSFER	40.2
51	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	39.5
52	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	39.1
53	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	39.1
54	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIO'S	38.7
55	55	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	38.3
56	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	37.9
57	84	ENVIRON CNTL SYSTEM - M4-6 HYDROCARBON VEHICLE	37.6
58	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	37.0
59	92	ASCENT TRAJECTORY INVESTIGATION	34.5
60	18	EFFECTS OF REACTION CONTROL JETS	33.7
61	71	IMPROVEMENT OF HYDROCARBON FUEL PERFORMANCE	33.2
62	72	FUEL SYSTEM DESIGN REQUIREMENTS	33.1
63	82	AUXILIARY POWER UNITS	30.0
64	101	AIR TRAFFIC CNTL PROCDRS & GND-BASED NAV SYSTEMS	29.5
65	79	AIR DATA MEASUREMENT TECHNIQUES	27.7
66	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	24.5
67	91	COMMUNICATION TECHNIQUES	21.6

FIGURE 3-13 CONSOLIDATED RANKING AND VALUE ASSIGNMENT EVALUATION CRITERION – B. COST AND SCHEDULE

Operational System No. 1–(L1)

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS
A. AERODYNAMICS	.183	22
B. THERMODYNAMICS	.165	18
C. STRUCTURES & MATERIAL	.194	21
D. PROPULSION	.208	24
E. SUBSYSTEMS	.125	15
F. OPERATION	.124	19

RANK	CODE	OBJECTIVE	FINAL VALUE
1	57	TURBORAMJET SYSTEMS - DEVELOP & D[illegible]ISTRATE	74.6
2	34	LONG-LIFE REGEN-COOLED STRUCTURAL [illegible]NCEPTS	73.7
3	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	72.3
4	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	69.3
5	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	69.2
6	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	67.7
7	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	67.1
8	4	TEST TECHNS FOR RE NO, SHOCK WAVE & BNDY LR PHEN	65.5
9	4[illegible]	TEST & INSP METHODS FOR ADVANCED STRUCTURES	63.8
10	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	62.8
11	67	INLET/ENGINE COMPATIBILITY CRITERIA	62.3
12	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	62.0
13	33	CONTROL SURFACE TECHNOLOGY	61.6
14	56	BEST MULTIMODE CYCLE & ENGINE SIZE	60.6
15	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	60.6
16	65	NOZZLE CONFIGURATIONS	60.0
17	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	59.9
18	9	PARAMATERS AFFECTING STABILITY & CONTROL	59.8
19	32	REUSABLE LEADING EDGE CONCEPTS	59.2
20	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	59.1
21	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	58.4
22	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	57.4
23	22	SURFACE SHAPING & PROTUB EFFECTS ON DRAG & HEAT	56.9
24	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	56.9
25	3[illegible]	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	56.5
26	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	56.3
27	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	55.9
28	46	HIGH TEMPERATURE EQUIPMENT	55.9
29	6	SURFACE/INLET POSITION - FAVOR AERO INTEFERENCE	55.7
30	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	55.6
31	11	SEPARATION TECHNS FOR POSITIVE SEPAR & CONTROL	55.0
32	1[illegible]	STAGE INTEGRATION FOR AERO IMPROVEMENTS	49.9
33	56	COMBUSTION PROBLEMS OF RAMJETS FOR THRST AUGMENT	49.8
34	70	REGEN CRYO HEAT EXCHRS/THRMO CORLS/COOL CNT STMS	48.7
35	25	HEATING EFFECTS FROM FLOW THRU GAPS	48.2
36	68	THML COND, STORAGE & SAFE HNDLG OF CRYO FUELS	46.2
37	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	45.9
38	37	EFF OF SEPARATION FORCES ON DYNAMIC CHARS	45.5
39	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	45.0
40	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	44.9
41	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	43.7
42	80	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	43.6
43	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	43.4
44	73	CRYO SYSTEM COMPONENTS - RED WT/INCR RELIABILITY	42.1
45	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	42.0
46	39	NEAR FIELD NOISE EFFECTS	41.9
47	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	41.4
48	23	TRANSPIR/ABLAT EFCTS - SKIN FRICT/HEAT TRANSFER	40.9
49	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	40.4
50	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	40.1
51	97	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	40.0
52	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIO'S	39.7
53	87	TERMINAL APPROACH & LANDING METHODS	39.1
54	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	38.4
55	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	38.2
56	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	37.2
57	84	ENVIRON CNTL SYSTEM - M4-6 HYDROCARBON VEHICLE	37.1
58	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	36.7
59	72	FUEL SYSTEM DESIGN REQUIREMENTS	35.6
60	92	ASCENT TRAJECTORY INVESTIGATION	32.8
61	82	AUXILIARY POWER UNITS	32.2
62	18	EFFECTS OF REACTION CONTROL JETS	31.0
63	79	AIR DATA MEASUREMENT TECHNIQUES	29.7
64	71	IMPROVEMENT OF HYDROCARBON FUEL PERFORMANCE	28.1
65	101	AIR TRAFFIC CNTL PROCDRS & GND-BASED NAV SYSTEMS	28.1
66	91	COMMUNICATION TECHNIQUES	25.2
67	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	24.6

FIGURE 3-14 WEIGHTING DISTRIBUTION FOR EVALUATION CRITERIA

PCT. OF EVALUATORS	WEIGHTING INTERVALS TECHNOLOGY ADVANCEMENT	COST AND SCHEDULE
8	.35 to .45	.55 to .65
10	.45 to .55	.45 to .55
50	.55 to .65	.35 to .45
20	.65 to .75	.25 to .35
12	.75 to .85	.15 to .25
100		

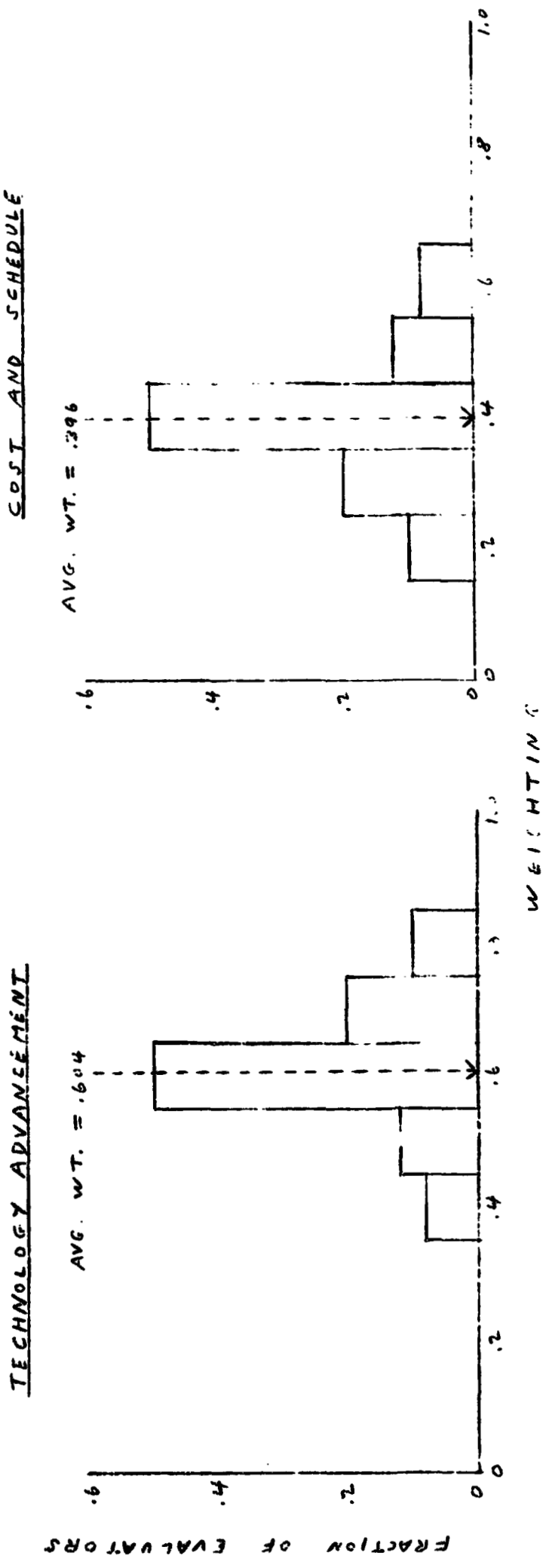


FIGURE 3-15 OPERATIONAL SYSTEM NO. 1 – (L1) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS	EVALUATION CRITERION	REL. WT.
A. AERODYNAMICS	.183	22	A. TECHNOLOGY ADVANCEMENT	.604
B. THERMODYNAMICS	.165	18	B. COST & SCHEDULE	.396
C. STRUCTURES & MATERIAL	.194	21		
D. PROPULSION	.208	24		
E. SUBSYSTEMS	.125	15		
F. OPERATION	.124	19		

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	74.9
2	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	73.5
3	57	TURBORAMJET SYSTEMS - DEVELOP & DEMONSTRATE	72.9
4	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	71.5
5	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.1
6	46	INLET CONFIGURATIONS WITH DESIRABLE CHARS	67.9
7	4	TEST TECHNS FOR RE NO, SHOCK WAVE & BNDY LR PHEN	66.0
8	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	65.4
9	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	64.8
10	67	INLET/ENGINE COMPATIBILITY CRITERIA	63.7
11	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	62.8
12	58	BEST MULTIMODE CYCLE & ENGINE SIZE	62.5
13	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	62.5
14	33	CONTROL SURFACE TECHNOLOGY	61.9
15	9	PARAMATERS AFFECTING STABILITY & CONTROL	61.2
16	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	60.7
17	65	NOZZLE CONFIGURATIONS	59.9
18	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	59.3
19	32	REUSABLE LEADING EDGE CONCEPTS	59.1
20	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	58.2
21	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	58.0
22	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	57.4
23	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	57.3
24	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	57.1
25	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	56.8
26	20	HYPERSONIC AERCTHERMO PARAMS IN 3-DIM FLOW	56.7
27	6	SURFACE/INLET POSITION - FAVOR AERO INTEFERENCE	55.6
28	22	SURFACE SHAPING & PROTUB EFFECTS ON DRAG & HEAT	54.7
29	46	HIGH TEMPERATURE EQUIPMENT	54.6
30	11	SEPARATION TECHNS FOR POSITIVE SEPAR & CONTROL	54.3
31	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	52.4
32	25	HEATING EFFECTS FROM FLOW THRU GAPS	49.5
33	10	STAGE INTEGRATION FOR AERO IMPROVEMENTS	49.1
34	70	REGEN CRYO HEAT EXCHRS/THRMO CORLS/COOL CNT STMS	49.0
35	56	COMBUSTION PROBLEMS OF RAMJETS FOR THRST AUGMENT	47.4
36	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	46.2
37	37	EFF OF SEPARATION FORCES ON DYNAMIC CHARS	45.3
38	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	44.8
39	80	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	44.6
40	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	44.5
41	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	44.3
42	68	THML CCND, STORAGE & SAFE HNDLG OF CRYO FUELS	42.6
43	39	NEAR FIELD NOISE EFFECTS	42.3
44	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	41.6
45	73	CRYO SYSTEM COMPONENTS - RCD WT/INCR RELIABILITY	41.5
46	57	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	41.5
47	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	41.4
48	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	41.0
49	23	TRANSPIR/ABLAT EFCTS - SKIN FRICT/HEAT TRANSFER	40.5
50	87	TERMINAL APPROACH & LANDING METHODS	40.1
51	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	39.5
52	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	39.2
53	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIO'S	39.1
54	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	39.0
55	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	38.9
56	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	38.8
57	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	38.1
58	84	ENVIRON CNTL SYSTEM - M4-6 HYDROCARBON VEHICLE	37.4
59	72	FUEL SYSTEM DESIGN REQUIREMENTS	34.1
60	92	ASCENT TRAJECTORY INVESTIGATION	33.8
61	18	EFFECTS OF REACTION CONTROL JETS	32.6
62	71	IMPROVEMENT OF HYDROCARBON FUEL PERFORMANCE	31.2
63	82	AUXILIARY POWER UNITS	30.9
64	101	AIR TRAFFIC CNTL PROCDRS & GND-BASED NAV SYSTEMS	29.0
65	79	AIR DATA MEASUREMENT TECHNIQUES	28.5
66	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	24.6
67	91	COMMUNICATION TECHNIQUES	23.0

FIGURE 3-16 OPERATIONAL SYSTEM NO. 2 – (L2) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS	EVALUATION CRITERION	REL. WT.
A. AERODYNAMICS	.183	22	A. TECHNOLOGY ADVANCEMENT	.604
B. THERMODYNAMICS	.165	18	B. COST & SCHEDULE	.396
C. STRUCTURES & MATERIAL	.194	21		
D. PROPULSION	.208	24		
E. SUBSYSTEMS	.125	15		
F. OPERATION	.124	19		

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	28	RELS THML PROT STMS - CRYO FUELS/OXIDR TNKG	74.5
2	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	73.5
3	62	CONVERTIBLE SCRAMJET SYSTEMS - DEVELOP & DEMON	72.0
4	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	71.5
5	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.1
6	57	TURBORAMJET SYSTEMS - DEVELOP & DEMONSTRATE	68.4
7	4	TEST TECHNS FOR RE NO, SHOCK WAVE & BNDY LR PHEN	66.0
8	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	65.4
9	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	64.9
10	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	62.6
11	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	62.5
12	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	62.4
13	33	CONTROL SURFACE TECHNOLOGY	61.9
14	9	PARAMETERS AFFECTING STABILITY & CONTROL	61.2
15	46	TEST & INSP METHODS FOR ADVANCED STRUCTURES	60.7
16	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	59.3
17	58	BEST MULTIMODE CYCLE & ENGINE SIZE	59.2
18	32	REUSABLE LEADING EDGE CONCEPTS	59.1
19	67	INLET/ENGINE COMPATIBILITY CRITERIA	58.3
20	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	58.2
21	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	58.0
22	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	57.4
23	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	57.3
24	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	57.1
25	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	56.8
26	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	56.7
27	6	SURFACE/INLET POSITION - FAVOR AERO INTERFERENCE	55.6
28	22	SURFACE SHAPING & PROTUR EFFECTS ON DRAG & HEAT	54.7
29	46	HIGH TEMPERATURE EQUIPMENT	54.6
30	11	SEPARATION TECHNS FOR POSITIVE SEPAR & CONTROL	54.3
31	65	NOZZLE CONFIGURATIONS	54.1
32	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	52.4
33	25	HEATING EFFECTS FROM FLOW THRU GAPS	49.5
34	72	REGEN CRYO HEAT EXCHRS/THRMO CORLS/COOL CNT STMS	49.3
35	10	STAGE INTEGRATION FOR AERO IMPROVEMENTS	49.1
36	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	46.2
37	37	EFF OF SEPARATION FORCES ON DYNAMIC CHARS	45.3
38	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	44.8
39	80	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	44.[illegible]
40	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	44.5
41	85	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	44.5
42	68	THML COND, STORAGE & SAFE HNDLG OF CRYO FUELS	42.8
43	39	NEAR FIELD NOISE EFFECTS	42.3
44	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	41.6
45	73	CRYO SYSTEM COMPONENTS - RED WT/INCR RELIABILITY	41.5
46	97	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	41.5
47	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	41.4
48	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	41.0
49	23	TRANSPIR/ABLAT EFCTS - SKIN FRICT/HEAT TRANSFER	40.5
50	87	TERMINAL APPROACH & LANDING METHODS	40.1
51	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	39.5
52	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIO'S	39.1
53	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	39.0
54	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	38.9
55	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	38.8
56	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	38.7
57	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	38.0
58	72	FUEL SYSTEM DESIGN REQUIREMENTS	34.3
59	92	ASCENT TRAJECTORY INVESTIGATION	33.8
60	18	EFFECTS OF REACTION CONTROL JETS	32.6
61	71	IMPROVEMENT OF HYDROCARBON FUEL PERFORMANCE	31.3
62	82	AUXILIARY POWER UNITS	30.7
63	101	AIR TRAFFIC CNTL PROCDRS & GND-BASED NAV SYSTEMS	29.0
64	79	AIR DATA MEASUREMENT TECHNIQUES	28.1
65	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	24.5
66	91	COMMUNICATION TECHNIQUES	23.0

FIGURE 3-17 OPERATIONAL SYSTEM NO. 3 – (L3) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS	EVALUATION CRITERION	REL. WT.
A. AERODYNAMICS	.183	22	A. TECHNOLOGY ADVANCEMENT	.604
B. THERMODYNAMICS	.165	18	B. COST & SCHEDULE	.396
C. STRUCTURES & MATERIAL	.194	21		
D. PROPULSION	.238	24		
E. SUBSYSTEMS	.125	15		
F. OPERATION	.124	19		

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	58	BEST MULTIMODE CYCLE & E NE SIZE	81.9
2	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	74.9
3	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	73.5
4	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	71.5
5	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.1
6	4	TEST TECHNS FOR RE NO, SHOCK WAVE & BNDY LR PHEN	66.0
7	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	65.4
8	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	64.8
9	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	62.8
10	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	62.5
11	33	CONTROL SURFACE TECHNOLOGY	61.9
12	5	PARAMATERS AFFECTING STABILITY & CONTROL	61.2
13	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	60.7
14	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	59.3
15	32	REUSABLE LEADING EDGE CONCEPTS	59.1
16	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	59.2
17	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	58.0
18	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	57.4
19	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	57.3
20	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	57.1
21	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	56.8
22	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	56.7
23	62	RKT-PWD ENGINE OPERATION IN HORIZ T/O A/C	56.6
24	6	SURFACE/INLET POSITION - FAVOR AERO INTEFERENCE	55.6
25	22	SURFACE SHAPING & PROTUB EFFECTS ON DRAG & HEAT	54.7
26	46	HIGH TEMPERATURE EQUIPMENT	54.6
27	11	SEPARATION TECHNS FOR POSITIVE SEPAR & CONTROL	54.3
28	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	52.4
29	25	HEATING EFFECTS FROM FLOW THRU GAPS	49.5
30	10	STAGE INTEGRATION FOR AERO IMPROVEMENTS	49.1
31	70	REGEN CRYO HEAT EXCHRS/THRMO CORLS/COOL CNT STMS	48.9
32	64	AUXILIARY TURBOJETS FOR LANDING HYPERSONIC VEHS	48.7
33	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	46.2
34	37	EFF OF SEPARATION FORCES ON DYNAMIC CHARS	45.3
35	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	44.8
36	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	44.6
37	80	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	44.2
38	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	43.5
39	39	NEAR FIELD NOISE EFFECTS	42.3
40	97	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	42.0
41	58	THML COND, STORAGE & SAFE HNDLG OF CRYO FUELS	41.8
42	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	41.7
43	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	41.6
44	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	41.3
45	87	TERMINAL APPROACH & LANDING METHODS	40.7
46	73	CRYO SYSTEM COMPONENTS - RED WT/INCR RELIABILITY	40.5
47	23	TRANSPIR/ABLAT EFCTS - SKIN FRICT/HEAT TRANSFER	40.5
48	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	39.7
49	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	39.5
50	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	39.1
51	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	38.9
52	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIO'S	38.6
53	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	37.7
54	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	37.3
55	92	ASCENT TRAJECTORY INVESTIGATION	34.6
56	18	EFFECTS OF REACTION CONTROL JETS	32.6
57	99	SHORT TAKEOFF TECHNIQUES	31.9
58	101	AIR TRAFFIC CNTL PRCDRS & GND-BASED NAV SYSTEMS	29.5
59	82	AUXILIARY POWER UNITS	29.2
60	79	AIR DATA MEASUREMENT TECHNIQUES	27.8
61	91	COMMUNICATION TECHNIQUES	24.1
62	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	22.8

FIGURE 3-18 OPERATIONAL SYSTEM NO. 4 – (L4) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS	EVALUATION CRITERION	REL. WT.
A. AERODYNAMICS	.183	22	A. TECHNOLOGY ADVANCEMENT	.604
B. THERMODYNAMICS	.165	18	B. COST & SCHEDULE	.396
C. STRUCTURES & MATERIAL	.194	21		
D. PROPULSION	.208	24		
E. SUBSYSTEMS	.125	15		
F. OPERATION	.124	19		

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	61	SCRAMJET SYSTEMS - DEVELOP & DEMONSTRATE	77.0
2	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	74.9
3	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	73.5
4	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	72.8
5	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	71.5
6	67	INLET/ENGINE COMPATIBILITY CRITERIA	70.8
7	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.1
8	58	BEST MULTIMODE CYCLE & ENGINE SIZE	67.3
9	65	NOZZLE CONFIGURATIONS	66.8
10	4	TEST TECHNS FOR RE NO. SHOCK WAVE & BNDY LR PHEN	66.0
11	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	65.4
12	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	64.8
13	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	62.8
14	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	62.5
15	33	CONTROL SURFACE TECHNOLOGY	61.9
16	9	PARAMATERS AFFECTING STABILITY & CONTROL	61.2
17	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	60.7
18	7	ENG EXST EXP FOR ADC LIFT/PROP GAS FLO INT EFCTS	59.3
19	32	REUSABLE LEADING EDGE CONCEPTS	59.1
20	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	58.2
21	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	58.0
22	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	57.4
23	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	57.3
24	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	57.1
25	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	56.8
26	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	56.7
27	6	SURFACE/INLET POSITION - FAVOR AERO INTEFERENCE	55.6
28	22	SURFACE SHAPING & CONTOUR EFFECTS ON DRAG & HEAT	54.7
29	46	HIGH TEMPERATURE EQUIPMENT	54.6
30	11	SEPARATION TECHNS FOR POSITIVE SEPAR & CONTROL	54.3
31	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	52.4
32	25	HEATING EFFECTS FROM FLOW THRU GAPS	49.5
33	10	STAGE INTEGRATION FOR AERO IMPROVEMENTS	49.1
34	70	REGEN CRYO HEAT EXCHRS/THRMO CORLS/COOL CNT STMS	48.9
35	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	46.2
36	37	EFF OF SEPARATION FORCES ON DYNAMIC CHARS	45.3
37	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	44.8
38	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	44.6
39	62	RKT-PWD ENGINE OPERATION IN HORIZ T/O A/C	44.5
40	80	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	44.2
41	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	43.5
42	39	NEAR FIELD NOISE EFFECTS	42.3
43	97	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	42.0
44	68	THML COND, STORAGE & SAFE HNDLG OF CRYO FUELS	41.8
45	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	41.7
46	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	41.6
47	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	41.3
48	87	TERMINAL APPROACH & LANDING METHODS	40.7
49	73	CRYO SYSTEM COMPONENTS - RED WT/INCR RELIABILITY	40.5
50	23	TRANSPIR/ABLAT EFCTS - SKIN FRICT/HEAT TRANSFER	40.5
51	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	39.7
52	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	39.5
53	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	39.1
54	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	38.9
55	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIO'S	38.6
56	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	37.7
57	64	AUXILIARY TURBOJETS FOR LANDING HYPERSONIC VEHS	37.5
58	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	37.3
59	92	ASCENT TRAJECTORY INVESTIGATION	34.6
60	18	EFFECTS OF REACTION CONTROL JETS	32.6
61	99	SHORT TAKEOFF TECHNIQUES	31.9
62	101	AIR TRAFFIC CNTL PRCDRS & GND-BASED NAV SYSTEMS	29.5
63	82	AUXILIARY POWER UNITS	29.2
64	79	AIR DATA MEASUREMENT TECHNIQUES	27.8
65	91	COMMUNICATION TECHNIQUES	24.1
66	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	22.8

FIGURE 3-19 OPERATIONAL SYSTEM NO. 5 – (C1) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS	EVALUATION CRITERION	REL. WT.
A. AERODYNAMICS	.183	22	A. TECHNOLOGY ADVANCEMENT	.604
B. THERMODYNAMICS	.165	18	B. COST & SCHEDULE	.396
C. STRUCTURES & MATERIAL	.194	21		
D. PROPULSION	.208	24		
E. SUBSYSTEMS	.125	15		
F. OPERATION	.124	19		

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	57	TURBORAMJET SYSTEMS - DEVELOP & DEMONSTRATE	78.2
2	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	74.4
3	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	72.5
4	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	72.5
5	43	RELSABLE THML PROTECT STMS - PRIMARY STRUCTURE	70.6
6	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	69.7
7	67	INLET/ENGINE COMPATIBILITY CRITERIA	68.0
8	58	BEST MULTIMODE CYCLE & ENGINE SIZE	67.0
9	65	NOZZLE CONFIGURATIONS	66.4
10	4	TEST TECHNS FOR RE NO, SHOCK WAVE & BNDY LR PHEN	64.7
11	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	64.7
12	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	64.5
13	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	61.9
14	33	CONTROL SURFACE TECHNOLOGY	60.5
15	49	TEST & INSP METHODS FOR ADVANCED STRUCTURES	60.1
16	9	PARAMATERS AFFECTING STABILITY & CONTROL	59.9
17	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	59.2
18	32	RELSABLE LEADING EDGE CONCEPTS	57.9
19	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	57.5
20	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	56.8
21	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	55.5
22	20	HYPERSONIC AERLTHERMO PARAMS IN 3-DIM FLOW	55.5
23	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	55.2
24	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	54.9
25	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	54.9
26	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	54.4
27	46	HIGH TEMPERATURE EQUIPMENT	53.7
28	6	SURFACE/INLET POSITION - FAVOR AERO INTEFERENCE	53.2
29	22	SURFACE SHAPING & PROTUB EFFECTS ON DRAG & HEAT	52.6
30	56	COMBUSTION PROBLEMS OF RAMJETS FOR THRST AUGMENT	51.8
31	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	51.6
32	70	REGEN CRYO HEAT EXCHRS/THRMO CORLS/COOL CNT STMS	49.0
33	83	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	47.5
34	25	HEATING EFFECTS FROM FLOW THRU GAPS	45.7
35	80	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	44.6
36	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL T[illegible]	44.3
37	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXT[illegible]	44.3
38	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELL	43.8
39	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	43.7
40	57	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	43.5
41	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	42.6
42	68	THML COND, STORAGE & SAFE HNDLG OF CRYO FUELS	42.6
43	87	TERMINAL APPROACH & LANDING METHODS	42.5
44	73	CRYO SYSTEM COMPONENTS - RED WT/INCR RELIABILITY	41.5
45	39	NEAR FIELD NOISE EFFECTS	41.4
46	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	40.2
47	56	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	40.0
48	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	39.6
49	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	39.2
50	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIO'S	39.1
51	65	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	38.1
52	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	38.0
53	84	ENVIRON CNTL SYSTEM - M4-6 HYDROCARBON VEHICLE	37.4
54	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	35.8
55	92	ASCENT TRAJECTORY INVESTIGATION	35.7
56	72	FUEL SYSTEM DESIGN REQUIREMENTS	34.1
57	55	ENGINE NOISE REDUCTION DURING T/O & LANDING	33.0
58	71	IMPROVEMENT OF HYDROCARBON FUEL PERFORMANCE	31.2
59	101	AIR TRAFFIC CNTL PROCDS & GND-BASED NAV SYSTEMS	30.9
60	82	AUXILIARY POWER UNITS	30.9
61	79	AIR DATA MEASUREMENT TECHNIQUES	28.5
62	91	COMMUNICATION TECHNIQUES	25.2
63	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	24.6
64	68	ATMOS OF MOTION & SECURITY IN WINDOWLESS A/C	17.5

FIGURE 3-20 OPERATIONAL SYSTEM NO. 6 – (C2) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS	EVALUATION CRITERION	REL. WT.
A. AERODYNAMICS	.183	22	A. TECHNOLOGY ADVANCEMENT	.604
B. THERMODYNAMICS	.165	18	B. COST & SCHEDULE	.396
C. STRUCTURES & MATERIAL	.194	21		
D. PROPULSION	.248	24		
E. SUBSYSTEMS	.125	15		
F. OPERATION	.124	19		

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	57	TURBORAMJET SYSTEMS - DEVELOP & DEMONSTRATE	74.7
2	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	74.4
3	61	SCRAMJET SYSTEMS - DEVELOP & DEMONSTRATE	73.0
4	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	72.5
5	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	70.6
6	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.2
7	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	68.8
8	4	TEST TECHNS FOR RE NO. SHOCK WAVE & BNDY LR PHEN	66.6
9	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	64.7
10	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	64.5
11	58	BEST MULTIMODE CYCLE & ENGINE SIZE	64.2
12	67	INLET/ENGINE COMPATIBILITY CRITERIA	64.1
13	65	NOZZLE CONFIGURATIONS	62.2
14	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	62.2
15	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	61.9
16	9	PARAMETERS AFFECTING STABILITY & CONTROL	61.2
17	33	CONTROL SURFACE TECHNOLOGY	60.5
18	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	60.1
19	7	EXC EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	58.7
20	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	58.3
21	32	REUSABLE LEADING EDGE CONCEPTS	57.9
22	36	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	57.5
23	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	57.1
24	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	56.8
25	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	56.8
26	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	56.0
27	20	HYPERSONIC AERO THERMO PARAMS IN 3-DIM FLOW	55.5
28	6	SURFACE/INLET POSITION - FAVOR AERO INTEFERENCE	55.0
29	46	HIGH TEMPERATURE EQUIPMENT	53.7
30	22	SURFACE SHAPING & PROTUB EFFECTS ON DRAG & HEAT	52.6
31	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	51.6
32	70	REGEN CRYO HEAT EXCHRS/THRMO CORLS/COOL CNT STMS	48.9
33	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	47.5
34	25	HEATING EFFECTS FROM FLOW THRU GAPS	45.7
35	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	44.3
36	80	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	44.2
37	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	43.8
38	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	43.7
39	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	43.5
40	57	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	43.5
41	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	42.6
42	87	TERMINAL APPROACH & LANDING METHODS	42.5
43	68	THML COND, STORAGE & SAFE HNDLG OF CRYO FUELS	41.8
44	35	NEAR FIELD NOISE EFFECTS	41.4
45	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	41.1
46	73	CRYO SYSTEM COMPONENTS - RED WT/INCR RELIABILITY	40.5
47	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	40.2
48	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	40.0
49	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM DIG'S	38.6
50	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	38.3
51	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	38.0
52	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	37.7
53	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	37.3
54	52	ASCENT TRAJECTORY INVESTIGATION	35.7
55	18	EFFECTS OF REACTION CONTROL JETS	31.0
56	101	AIR TRAF[illegible] CNTL PRCDRS & GND-BASED NAV SYSTEMS	3[illegible].9
57	55	ENGINE N[illegible]SE REDUCTION DURING T/O & LANDING	29.6
58	82	AUXILIARY POWER UNITS	29.2
59	79	AIR DATA MEASUREMENT [illegible]ES	27.8
60	91	COMMUNICATION TECH	25.2
61	76	FLUSH RECE[illegible]SED [illegible]TIBLE PATTERNS	22.8
62	98	ATMOS OF M[illegible]ION [illegible] WINDOWLESS A/C	17.5

FIGURE 3-21 OPERATIONAL SYSTEM NO. 7 – (M1) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS	EVALUATION CRITERION	REL. WT.
A. AERODYNAMICS	.183	22	A. TECHNOLOGY ADVANCEMENT	.604
B. THERMODYNAMICS	.165	18	B. COST & SCHEDULE	.396
C. STRUCTURES & MATERIAL	.194	21		
D. PROPULSION	.208	24		
E. SUBSYSTEMS	.125	15		
F. OPERATION	.124	19		

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	57	TURBURAMJET SYSTEMS - DEVELOP & DEMONSTRATE	72.9
2	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	71.2
3	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	70.7
4	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.6
5	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	67.9
6	4	TEST TECHNS FOR RE NO. SHOCK WAVE & BNDY LR INTER	65.2
7	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	64.2
8	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	64.2
9	67	INLET/ENGINE COMPATIBILITY CRITERIA	63.7
10	58	BEST MULTIMODE CYCLE & ENGINE SIZE	62.5
11	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	61.6
12	9	PARAMATERS AFFECTING STABILITY & CONTROL	60.4
13	33	CONTROL SURFACE TECHNOLOGY	60.1
14	65	NOZZLE CONFIGURATIONS	59.9
15	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	59.7
16	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	59.3
17	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	58.1
18	32	REUSABLE LEADING EDGE CONCEPTS	57.9
19	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	55.6
20	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	55.5
21	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	55.3
22	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	55.2
23	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	55.1
24	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	54.5
25	46	HIGH TEMPERATURE EQUIPMENT	53.5
26	6	SURFACE/INLET POSITION - FAVOR AERO INTEFERENCE	53.2
27	22	SURFACE SHAPING & PROTUB EFFECTS ON DRAG & HEAT	52.6
28	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	51.7
29	87	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	51.3
30	56	COMBUSTION PROBLEMS OF RAMJETS FOR THRST AUGMENT	47.4
31	25	HEATING EFFECTS FROM FLOW THRU GAPS	45.7
32	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	45.0
33	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	44.3
34	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	43.3
35	85	LAUNCH TECHNS FOR AAM & ASM WEAPONS	42.3
36	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	41.8
37	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	41.7
38	84	ENVIRON CNTL SYSTEM - M4-6 HYDROCARBON VEHICLE	41.1
39	39	NEAR FIELD NOISE EFFECTS	40.3
40	87	TERMINAL APPROACH & LANDING METHODS	40.0
41	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	39.5
42	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	39.4
43	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	39.1
44	72	FUEL SYSTEM DESIGN REQUIREMENTS	36.8
45	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	35.4
46	71	IMPROVEMENT OF HYDROCARBON FUEL PERFORMANCE	34.8
47	62	ASCENT TRAJECTORY INVESTIGATION	33.7
48	82	AUXILIARY POWER UNITS	33.0
49	79	AIR DATA MEASUREMENT TECHNIQUES	31.5
50	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	29.2
51	101	AIR TRAFFIC CNTL PROCDRS & GND-BASED NAV SYSTEMS	29.0
52	51	COMMUNICATION TECHNIQUES	24.6

FIGURE 3-22 OPERATIONAL SYSTEM NO. 8 – (M2) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS	EVALUATION CRITERION	REL. WT.
A. AERODYNAMICS	.183	22	A. TECHNOLOGY ADVANCEMENT	.604
B. THERMODYNAMICS	.165	18	B. COST & SCHEDULE	.396
C. STRUCTURES & MATERIAL	.194	21		
D. PROPULSION	.208	24		
E. SUBSYSTEMS	.125	15		
F. OPERATION	.124	19		

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	61	SCRAMJET SYSTEMS - DEVELOP & DEMONSTRATE	77.0
2	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	74.4
3	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	72.8
4	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	72.5
5	67	INLET/ENGINE COMPATIBILITY CRITERIA	70.8
6	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	70.6
7	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.2
8	58	REST MULTIMODE CYCLE & ENGINE SIZE	67.3
9	65	NOZZLE CONFIGURATIONS	66.8
10	4	TEST TECHNS FOR RE NO. SHOCK WAVE & BNDY LR PHEN	66.0
11	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	64.7
12	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	64.5
13	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	62.2
14	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	61.9
15	9	PARAMATERS AFFECTING STABILITY & CONTROL	61.2
16	33	CONTROL SURFACE TECHNOLOGY	60.5
17	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	60.1
18	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	58.7
19	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	58.3
20	32	REUSABLE LEADING EDGE CONCEPTS	57.9
21	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	57.5
22	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	57.1
23	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	56.8
24	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	56.8
25	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	56.0
26	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	55.5
27	6	SURFACE/INLET POSITION - FAVOR AERO INTERFERENCE	55.0
28	46	HIGH TEMPERATURE EQUIPMENT	53.7
29	22	SURFACE SHAPING & PROTUB EFFECTS ON DRAG & HEAT	52.6
30	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	51.6
31	76	REGEN CRYO HEAT EXCHRS/THRMO COPLS/COOL CNT STMS	48.8
32	25	HEATING EFFECTS FROM FLOW THRU GAPS	45.7
33	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	44.6
34	62	RKT-PWD ENGINE OPERATION IN HORIZ T/O A/C	44.5
35	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	44.3
36	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	43.8
37	80	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	43.7
38	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	43.5
39	57	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	42.0
40	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	41.7
41	39	NEAR FIELD NOISE EFFECTS	41.4
42	68	THML COND, STORAGE & SAFE HNDLG OF CRYO FUELS	41.3
43	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	41.3
44	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	41.1
45	87	TERMINAL APPROACH & LANDING METHODS	40.7
46	73	CRYO SYSTEM COMPONENTS - RCD WT/INCR RELIABILITY	40.2
47	95	EFFECTS OF VAR COADS ON BOOST, CRUISE & DESCENT	39.7
48	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	39.1
49	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIO'S	38.5
50	85	LAUNCH TECHNS FOR AAM & ASM WEAPONS	38.4
51	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	38.3
52	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	38.0
53	64	AUXILIARY TURBOJETS FOR LANDING HYPERSONIC VEHS	37.5
54	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	37.3
55	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	37.2
56	92	ASCENT TRAJECTORY INVESTIGATION	34.6
57	99	SHORT TAKEOFF TECHNIQUES	31.9
58	18	EFFECTS OF REACTION CONTROL JETS	31.0
59	101	AIR TRAFFIC CNTL PROCDRS & GND-BASED NAV SYSTEMS	29.5
60	82	AUXILIARY POWER UNITS	29.5
61	79	AIR DATA MEASUREMENT TECHNIQUES	28.1
62	91	COMMUNICATION TECHNIQUES	24.1
63	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	23.7

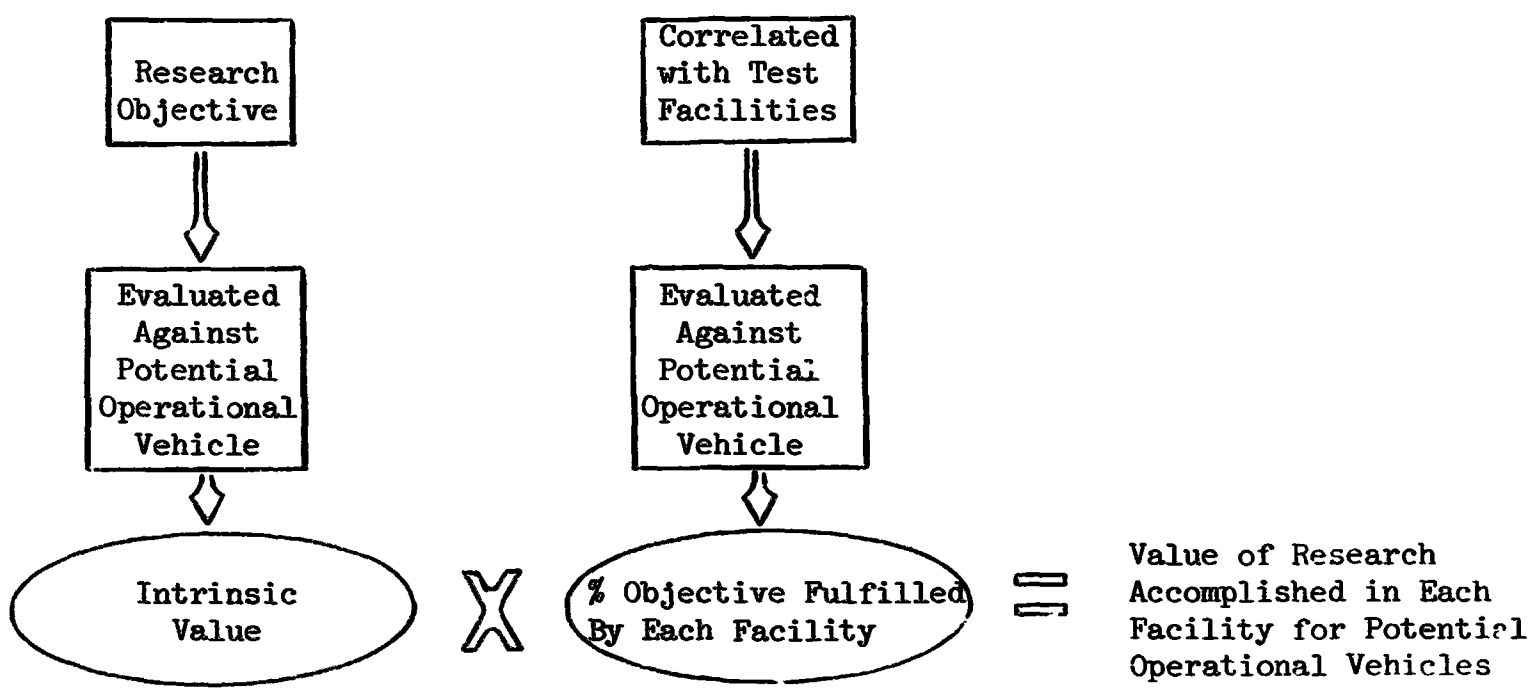
FIGURE 3-23 OPERATIONAL SYSTEM NO. 9 – (M3) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS	EVALUATION CRITERION	REL. WT.
A. AERODYNAMICS	.183	22	A. TECHNOLOGY ADVANCEMENT	.604
B. THERMODYNAMICS	.165	18	B. COST & SCHEDULE	.396
C. STRUCTURES & MATERIAL	.194	21		
D. PROPULSION	.208	24		
E. SUBSYSTEMS	.125	15		
F. OPERATION	.124	19		

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	6	SCRAMJET SYSTEMS - DEVELOP & DEMONSTRATE	77.0
2	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	74.[illegible]
3	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	72.8
4	3	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	72.5
5	67	INLET/ENGINE COMPATIBILITY CRITERIA	70.9
6	43	RELSABLE THML PROTECT STMS - PRIMARY STRUCTURE	70.6
7	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.2
8	51	BEST MULTIMODE CYCLE & ENGINE SIZE	67.3
9	65	NOZZLE CONFIGURATIONS	66.8
10	4	TEST TECHNS FOR RE NO, SHOCK WAVE & BDY LR PHEN	66.0
11	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	64.7
12	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	64.5
13	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	62.2
14	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	61.9
15	5	PARAMATERS AFFECTING STABILITY & CONTROL	61.2
16	33	CONTROL SURFACE TECHNOLOGY	60.5
17	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	60.1
18	7	ENG EXCT EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	58.7
19	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	58.3
20	32	RELSABLE LEADING EDGE CONCEPTS	57.9
21	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	57.5
22	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	57.1
23	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	56.8
24	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	56.8
25	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	56.0
26	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	55.5
27	6	SURFACE/INLET POSITION - FAVOR AERO INTEFERENCE	55.0
28	46	HIGH TEMPERATURE EQUIPMENT	53.7
29	22	SURFACE SHAPING & PROTUR EFFECTS ON DRAG & HEAT	52.6
30	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	51.6
31	70	REGEN CRYO HEAT EXCHRS/THRMO CONTLS/COOL CNT STMS	48.8
32	25	HEATING EFFECTS FROM FLOW THRU GAPS	45.7
33	85	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	44.6
34	62	RKT-PWD ENGINE OPERATION IN HORIZ T/O A/C	44.5
35	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	44.3
36	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	43.8
37	86	ACTUATION TECHNS & MONR FOR CNTL SURFACE MOTION	43.7
38	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	43.5
39	57	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	42.0
40	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	41.7
41	39	NEAR FIELD NOISE EFFECTS	41.4
42	68	THML COND, STORAGE & SAFE HNDLG OF CRYO FUELS	41.3
43	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	41.3
44	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	41.1
45	87	TERMINAL APPROACH & LANDING METHODS	40.7
46	73	CRYO SYSTEM COMPONENTS - RED WT/INCR RELIABILITY	40.2
47	95	EFFECTS OF VAR CONC. ON BOOST, CRUISE & DESCENT	39.7
48	56	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	39.1
49	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIO'S	38.5
50	85	LAUNCH TECHNS FOR AAM & ASM WEAPONS	38.4
51	14	PREDICT TECHNS FOR BUFFET ONSET OF LCN AR A/C	38.3
52	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	38.0
53	64	AUXILIARY TURBOJETS FOR LANDING HYPERSONIC VEHS	37.5
54	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	37.3
55	65	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	37.2
56	92	ASCENT TRAJECTORY INVESTIGATION	34.6
57	99	SHORT TAKEOFF TECHNIQUES	31.9
58	18	EFFECTS OF REACTION CONTROL JETS	31.0
59	101	AIR TRAFFIC CNTL PROCDRS & GND-BASED NAV SYSTEMS	29.5
60	82	AUXILIARY POWER UNITS	29.5
61	79	AIR DATA MEASUREMENT TECHNIQUES	28.1
62	91	COMMUNICATION TECHNIQUES	24.1
63	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	23.7

3.3 RESEARCH VALUE ANALYSIS

3.3.1 RESEARCH OBJECTIVE/RESEARCH FACILITY CORRELATION - Research Objectives were reviewed by MCAIR to quantitatively determine the extent to which each of them could be fulfilled in potential new ground test and candidate new flight facilities. The identified Research Objectives are presented in Section 3.1, with candidate new facilities fully described in Sections 4 and 5 (flight test) and 6 and 7 (ground test). Correlation of each objective with the facility capability enables identification of the value of each facility as it relates to a given Research Objective. When coupled with the intrinsic value of a specific Research Objective (to achieve high-confidence development of an operational vehicle), the objective/facility correlation provides a measure of the value of each facility and quantification of the facility contribution toward achieving the Research Objectives related to a particular operational vehicle. The process is clarified in the flow diagram shown below.



A tabulation of the Research Objective/test facility correlation applicable to the baseline operational vehicles is presented in Appendix A of this volume. This tabulation is categorized by objectives, indicating the applicable potential operational aircraft, candidate test facilities, the portion of the objective fulfilled in each facility, and test facility limitations, where appropriate. For some objectives, a discernible difference may be realized in application of a specific Research Objective/facility correlation to the potential operational vehicles. For these cases, an appropriate grouping of operational vehicles (e.g. Rocket Boost vs Airbreathing) is identified and the test facility capability determined accordingly for each objective.

The Research Objectives are categorized according to major technical disciplines, as described previously in Section 3.1. This categorization facilitates the objective/facility correlation task by identifying the technical

group. For those cases where an objective appears to be repeated in two or more technical disciplines, the correlation within each discipline was based upon the portion of the overall Research Objective applicable to that specific discipline. For example, development of a regenerative hydrogen heat exchanger is a structural objective (Number 34, to develop long-life structural concepts); a propulsion objective (Number 53, to develop engine component technology); and, a subsystem objective (Number 70, to verify fluid correlations and fluid control techniques). As a result, only those facilities are identified for each case which satisfy the specified disciplinary objectives.

The relative capability of each facility to accomplish or contribute to the satisfaction of a Research Objective is based on the general contribution of testing to the scope of the task, and also upon the portion of the objective which the facility is determined capable of satisfying. Each facility capability number so generated includes the capability of existing ground facilities, considered collectively, in conjunction with the new ground or flight facility under consideration.

Potential new ground test facilities considered in this correlation are those identified as attractive candidates in Sections 5 and 6. Each of these was reviewed to determine the contribution of that particular facility in terms of satisfying the Research Objectives. Again, the objective was studied to determine the overall scope and the effective contribution of empirical results before assessing the relative contribution offered by a given facility.

Candidate flight research vehicles, identified in Sections 4 and 5, were assessed in much the same manner. The synthesis of flight vehicles was not as restrictive as for ground facilities; i.e. flight research facilities are, of necessity, interdisciplinary. Hence, they offer the capability to perform a variety of Research Objectives. For the most part, ground facilities are tailored toward satisfaction of Research Objectives peculiar to a given type of research. Correlation of flight research facilities with each Research Objective is included in the tabulation presented in Appendix A.

Key parameters used to assess capability of wind tunnel facilities to meet aerodynamic objectives are Reynolds number, Mach number, and run time, along with physical acceptance of model size. These parameters are supplemented by requirements for flight simulators with 6 degrees of freedom, motion simulation, and audio-visual displays. The high temperature capability available from engine test facilities contributes significantly to achievement of the aerothermal objectives. Potential new flight facilities were generally graded on their Reynolds number and Mach number capability for accomplishing the high speed objectives. During the selection process, unmanned vehicles were downgraded for those objectives requiring vehicle operation flexibility or flying qualities investigations. The variable stability and lower speed all-body configurations were found to offer significant capability for satisfaction of subsonic and transonic flight Research Objectives.

Contribution of the candidate new structural and manufacturing facilities were generally measured in terms of physical size of the accommodated test specimen and overall power capability for simulation of heat load, dynamic test capability, and overall mission environment. The engine test facilities are expected to provide capability for accomplishing high temperature flow simulation to allow testing in a representative dynamic pressure environment. Structural Research Objectives which required experimental data for solution were considered satisfied in their entirety by demonstration on a flight vehicle.

Propulsion objectives were satisfied, in general, by combination of air flow and simulated temperature capability with relative ranking performed in proportion to the Mach number and Reynolds number capabilities. For component and control system development, fluid flow facilities were also found to offer a valuable contribution. Candidate new flight facilities were judged applicable on the basis of the propulsion concept incorporated into that vehicle. For example, the rocket-boosted vehicles offer little or no potential for satisfaction of turboramjet development objectives. The relative contribution of each applicable flight vehicle was measured in terms of Mach number and Reynolds number capability, as compared with the flight environment for the operational vehicle.

The extent to which fluid flow facilities can contribute to satisfaction of the Research Objectives related to development of the cryogenic propellant systems is measured in terms of storage capacity, operating pressure, and mass flow capability. Total power capability impacts development of the heat exchanger and hot gas control hardware, while environmental chamber size provides altitude simulation capability for horizontal tank/pressurization system development. Flight facilities were considered to contribute to a large extent by virtue of concept demonstration. The rationale which accompanies the correlation of facility capability with Research Objectives is briefly summarized for each baseline objective in the listing presented in Appendix A.

The results presented are representative of the first level of definition of the Research Objectives and required development tasks. The results of current evaluations of the Research Objectives will enable a more meaningful definition of tasks and subsequent correlation of facility capabilities (in terms of both absolute value and relative increment) during Phase II.

3.3.2 RESEARCH VALUE RESULTS - Facility research values were determined based on the intrinsic values of the Research Objectives, described in Section 3.2, and on the capability of ground and flight facilities to accomplish the objectives, summarized in Section 3.3.1. The intrinsic value of each Research Objective represents the relative value of the objective in contributing to the necessary research for an operational hypersonic airplane. MCAIR specialists in the technical disciplines and in flight and ground testing evaluated the capability of existing ground facilities and new ground and flight-testing facilities to achieve these objectives.

The research value of each new ground and flight facility with regard to a particular Research Objective was then determined by multiplying the intrinsic value of the objective by the fractional part of the objective which could be satisfied in the facility. Summation of these values for all the objectives yields the overall research value of the facility. This value represents the capability of the facility to satisfy the research requirements generated by each potential operational hypersonic system.

Research values are summarized for the candidate ground test facilities in Figure 3-24 and for the candidate flight research vehicles in Figure 3-25. Values are presented for each of the nine potential operational systems. Also shown in Figures 3-24 and 3-25 are values representing the total research required for achieving each of the operational systems, determined by summing the intrinsic values of all the objectives which apply to that system. These summary values place in perspective the research capability value shown for each of the new ground and flight facilities.

It is desirable to compare the capability of each research facility in a generalized sense as well as for specific potential operational systems. This is accomplished by developing an average value for the spectrum of potential operational systems. This average value is derived by grouping the vehicles into six classes selected as representative of distinct differences in vehicle concepts. These six classes are: (1) L1, (2) L2, L3 & L4, (3) C1, (4) C2, (5) M1, and (6) M2 & M3. Average values are determined within the groups, and then the values for the six groups are averaged to obtain the summary values presented in Figure 3-26.

Research value is used as a figure of merit in evaluating the capability of research facilities. Analysis of facility capability relative to objectives in the six technical areas (Aerodynamics, Thermodynamics, Structures and Materials, Propulsion, Subsystems, and Operation) illustrates the impact of the operational system being considered on the relative attractiveness of candidate flight research vehicles.

An example of the strong correlation between a particular type of research vehicle and a corresponding class of operational systems is shown in Figure 3-27. Two flight facilities are considered in this example: Facility 200 (M 4.5, TRJ) and Facility 250 (M 12, RKT). Each of these facilities is considered in relation to two potentional operational systems: L3 (M 12, RKT) and M1 (AMI: M 4.5, TRJ). As expected, Facility 250 contributes more toward achieving Research Objectives leading to development of L3 than does Facility 200 (1816 to 1153), while Facility 200 shows an advantage (1505 to 1335) in the attainment of objectives required for M1's development. These facility values are shown as the numerator in the upper right portion of each graph, along with the total research required for the operational system (shown as the denominator and found by summing the intrinsic values of all the applicable objectives). Also shown are the corresponding percentages of required research achieved by the facilities. Some clarification of the factors involved in deriving these overall values is provided by the breakdown according to technological area shown in each quadrant of Figure 3-27. It should be recognized that some of the objectives do not lend themselves to clear-cut categorization by technological area (e.g., objectives involving heating problems are included in the structures and

FIGURE 3-24 RESEARCH VALUES FOR GROUND FACILITIES

Facility Code	Potential Operational Systems								
	L1	L2	L3	L4	C1	C2	M1	M2	M3
GD2	114	90	141	110	122	87	108	120	120
GD3	484	446	347	363	660	379	689	371	371
GD4	28	28	30	29	42	28	42	29	29
GD7	302	348	260	369	128	306	110	317	317
GD12	6	6	8	7	7	6	6	7	7
GD13	19	18	25	20	20	19	19	20	20
GD15	283	282	289	285	230	240	194	240	240
GD16	121	121	123	122	125	116	125	117	117
E6	240	125	120	87	289	106	282	75	75
E7	267	178	120	108	319	140	310	97	97
E8	298	315	203	313	269	285	233	279	279
E9	197	315	203	336	159	291	159	302	302
E10	184	276	190	293	159	253	159	262	262
E20	267	178	120	108	319	140	310	97	97
FS1	96	96	99	99	102	102	97	97	97
FS2	73	73	82	82	84	84	73	80	80
FS3	135	135	137	137	153	152	118	136	136
S1	141	141	141	141	139	139	123	139	139
S2	155	155	148	148	154	153	133	146	146
S3	186	186	185	185	183	183	186	182	182
S4	89	88	81	81	88	88	86	80	80
S5	235	234	227	227	232	231	195	224	224
S6	107	107	107	107	106	106	45	106	106
S7	4	4	4	4	4	4	4	4	4
S9	7	7	0	0	8	7	0	0	0
M2	188	188	188	188	186	186	150	186	186
M3	159	159	159	159	158	158	121	157	157
M4	178	178	178	178	177	177	168	176	176
F1	77	39	38	38	77	38	41	37	37
F2	74	74	39	39	74	39	38	39	39
F3	216	185	173	173	216	181	66	172	172
F4	249	211	206	206	249	206	74	205	205
F5	76	76	75	75	77	77	0	75	75
SS1	100	101	67	67	104	70	69	67	67
SS2	12	12	12	12	12	12	12	12	12
R1	0	0	0	0	0	0	0	0	0
A1	25	24	23	23	25	23	29	24	24
A2	0	0	0	0	0	0	0	0	0
Total Required	3329	3291	3068	3236	3156	3098	2623	3136	3136

FIGURE 3-25 RESEARCH VALUES FOR FLIGHT VEHICLES

Vehicle Code	Potential Operational Systems								
	L1	L2	L3	L4	C1	C2	M1	M2	M3
200	1300	1144	1153	1149	1504	1076	1505	1065	1065
204	1427	1223	1221	1221	1637	1226	1253	1163	1163
205	1762	1558	1492	1492	1891	1468	1462	1391	1391
207	1687	1544	1626	1573	1769	1419	1385	1513	1513
210	1827	1622	1567	1559	1960	1534	1535	1458	1458
213	1782	1607	1701	1640	1870	1484	1439	1581	1581
214	1532	1516	1598	1544	1607	1392	1321	1486	1486
220	1322	1153	1148	1148	1443	1066	1052	1072	1072
221	1322	1153	1148	1148	1443	1066	1052	1072	1072
232	1930	2154	2012	2228	1776	2033	1504	2153	2153
233	1705	1723	1786	1754	1556	1580	1309	1683	1683
234	1705	1723	1786	1754	1556	1580	1309	1683	1683
250	1735	1753	1816	1784	1582	1609	1335	1713	1713
250 J2S	1735	1753	1816	1784	1582	1609	1335	1713	1713
251	1735	1753	1816	1784	1582	1609	1335	1713	1713
252	1735	1753	1816	1784	1582	1609	1335	1713	1713
253	1555	1573	1639	1607	1402	1433	1335	1537	1537
254	1956	2178	2054	2258	1804	2061	1583	2184	2184
255	1956	2178	2054	2258	1804	2061	1583	2184	2184
256	1643	1661	1727	1695	1484	1519	1416	1623	1623
257	1980	2192	1973	2231	1860	2093	1599	2115	2115
270	1726	1744	1723	1745	1579	1601	1332	1632	1632
271	2004	2226	2018	2276	1856	2108	1580	2159	2159
280	1559	1780	1554	1820	1491	1697	1262	1723	1723
281	1314	1366	1343	1364	1252	1262	1076	1271	1271
282	1169	1222	1201	1222	1107	1120	1076	1130	1130
284	1402	1420	1396	1418	1332	1314	1088	1323	1323
285	1410	1428	1488	1456	1340	1323	1095	1404	1404
290	260	259	262	260	170	156	187	168	168
291	226	226	228	227	227	227	225	226	226
292	404	404	406	405	321	301	341	311	311
Total Required	3329	3291	3068	3236	3156	3098	2623	3136	3136

FIGURE 3-26 FACILITY RESEARCH VALUE SUMMARY

(Values Averaged Over All Nine Operational Systems)

Ground Facility	Average Value	Flight Facility	Average Value
GD2	111	200	1270
GD3	495	204	1321
GD4	33	205	1581
GD7	248	207	1559
GD12	6	210	1649
GD13	20	213	1634
GD15	245	214	1482
GD16	121	220	1184
E6	184	221	1184
E7	211	232	1921
E8	274	233	1598
E9	232	234	1598
E10	212	250	1626
E20	211	250 J2S	1626
FS1	99	251	1626
FS2	79	252	1626
FS3	138	253	1478
S1	137	254	1958
S2	149	255	1958
S3	184	256	1563
S4	86	257	1963
S5	224	270	1601
S6	96	271	1980
S7	4	280	1575
S9	4	281	1256
M2	181	282	1136
M3	152	284	1312
M4	176	285	1338
F1	51	290	200
F2	52	291	226
F3	171	292	347
F4	198		
F5	63		
SS1	81		
SS2	12		
R1	0		
A1	25		
A2	0		

materials area if in the development stage, but are listed as thermodynamics objectives if still in the research stage). Nevertheless, practical aspects of the evaluation process dictated a grouping of the objectives, and the results support the validity of the selected breakdown by technological area. The shaded portion for each technological area in the bar charts of Figure 3-27 indicates the research achievable by the facility with regard to the objectives included in the technological area. The total bar (shaded plus unshaded) represents the total value of research required in the technological area. This value is calculated by summing the intrinsic values of all the objectives in the area. Alternately, the same value can be derived by multiplying the average value in the area by the number of objectives in the area. The average value in each area is 50 before the weighting influence of the area is applied. Hence,

$$V_{AVG} = (50)(W_T/W_{AVG})$$

where: V_{AVG} = average value in technological area
W_T = relative weighting of technological area
W_{AVG} = average technological area weighting

Since in this study six technological areas are involved, $W_{AVG} = 1/6$, and

$$V_{AVG} = 300\ W_T$$

The total value of research required in a technological area (equivalent to the sum of the intrinsic values in the area) can then be expressed by the formula:

$$V_T = (300)(W_T)(N),$$

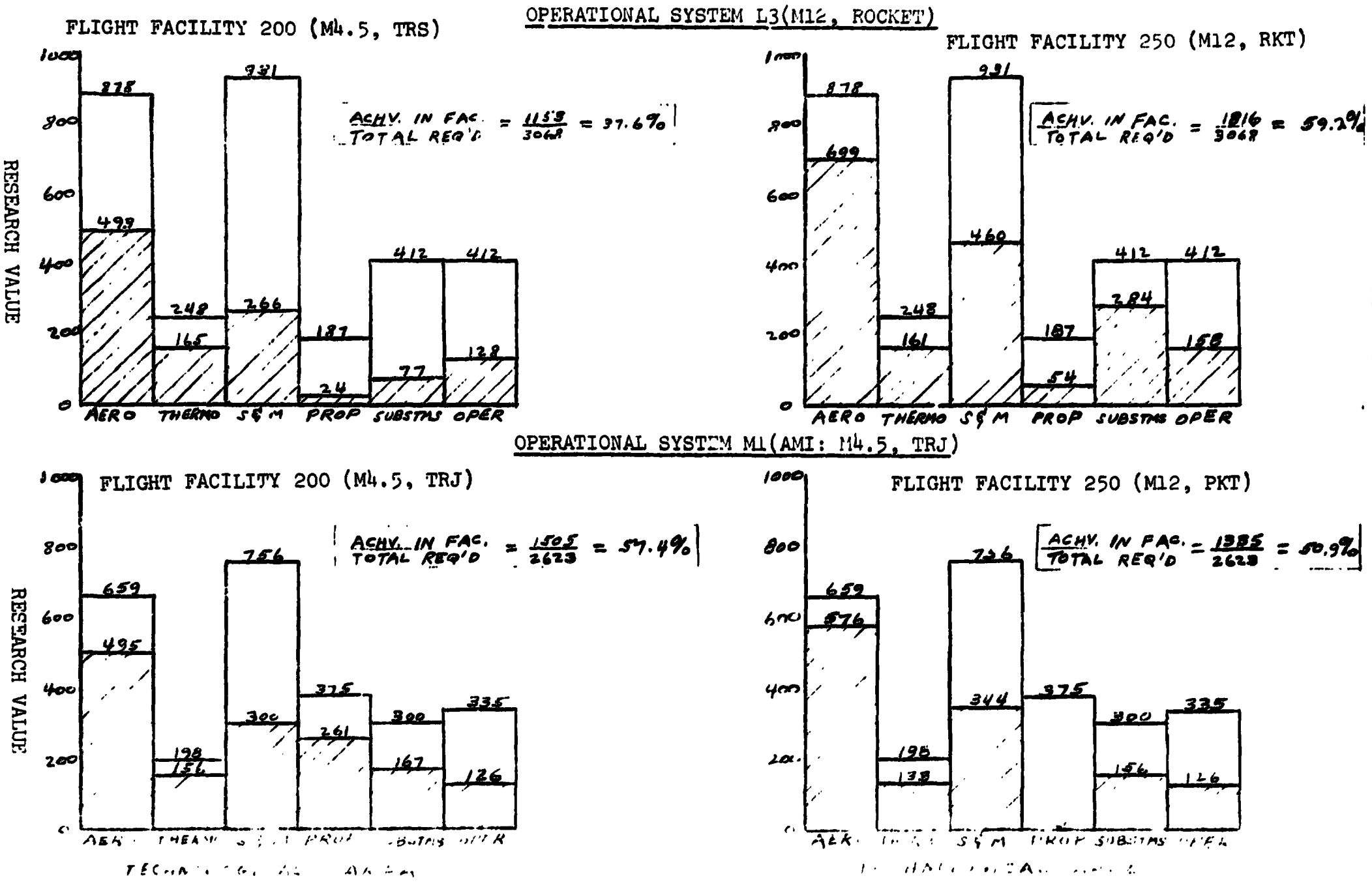
where: V_T = total research value in technological area
W_T = relative weighting of technological area
N = number of objectives in technological area

For example, since the number of objectives in the aerodynamics area applicable to Operational System L3 is 16 and the relative weighting for this area is .183, the total value of aerodynamics research relative to L3 according to the above equation is:

$$V_T = (300)(.183)(16)$$
$$V_T = 878,$$

as shown in Figure 3-27. Thus, the height of each total block in this figure depends on two factors: (1) the relative importance (W_T) of the area and, (2) the number of objectives (N) in the area. In each of the four graphs of the figure, the sum of the values represented by the six total blocks (shaded plus unshaded) is shown in the upper right portion of the graph as the total research required, while the sum of the shaded portions only is shown as the research achievable in the facility.

FIGURE 3-27 FLIGHT FACILITY/OPERATIONAL SYSTEM CORRELATION ILLUSTRATIVE EXAMPLE



As illustrated by the data of Figure 3-27, the overall advantage of 1816 to 1153 for Facility 250 over Facility 200 in relation to Operational System L3 is due primarily to the difference in research achievable by these two facilities in the areas of aerodynamics (699 to 493), structures and materials (460 to 266), and subsystems (284 to 77). Little is provided in the propulsion area by either facility. For reference, Objective 58, "Selection of Best Multi-mode Cycle and Engine Size," is the only propulsion objective for which Facility 200 has capability in relation to L3, and Objective 62, "Rocket-Powered Engine Operation in Horizontal Takeoff Aircraft," is the only propulsion objective which Facility 250 can even partially satisfy for L3. Hence, since Facility 200 is judged to be capable of accomplishing 30% of Objective 58, which has an intrinsic value of 81, Facility 200 has a propulsion value of 81 X .30 = 24; and since Facility 250 is rated capable of satisfying 95% of Objective 62, which has an intrinsic value of 57, Facility 250 has a propulsion value of 57 X .95 = 54. For Operational System M1, on the other hand, the advantage attained by Facility 200 can be attributed mainly to its large advantage in the propulsion area. Facility 200 is judged capable of achieving a portion of five of the six objectives included in this area relative to M1, accumulating a propulsion value of 261. By comparison, Facility 250 (employing rockets only), has no capability for achieving any of the six objectives involved, resulting in a propulsion value of zero relative to M1. This type of breakdown by technological area, or even by individual objective, is available from the research value analysis performed during Phase I.

A figure of merit which may be used for flight research vehicles is the percent of total research requirements which can be fulfilled by each test vehicle. Four representative flight research vehicles are compared on this basis in Figure 3-28. This comparison illustrates the consistent match between candidate flight vehicles and operational systems with similar performance and configuration characteristics. The bars for each facility represent the range of values for each research vehicle considering the complete spectrum of potential operational systems. The percentage of research accomplished is derived from the data presented in Figure 3-25 by dividing the research value for the particular research vehicle by the total research requirements for each operational system. Average research values and total system costs are also identified in Figure 3-28 for the four representative test aircraft. The costs shown are developed in detail in Section 4, based on the complete vehicle descriptions presented in that section, and are included here only for positioning the vehicles along the abscissa.

3.3.3 RESEARCH VALUE FOR BASELINE + OPTIONS CASE - As noted previously, the primary analysis of Research Objectives involves only those objectives essential to the development of potential operational systems. Those of the original list of 102 objectives which are concerned with optional propulsion systems, or which involve overlap or redundancy with other objectives, are not considered in the baseline case. However, the entire list of 102 objectives related to each operational system, including options and redundant objectives, has been examined, and the results are presented in Figures 3-29 through 3-37. The optional and the redundant objectives are designated in these figures by asterisks. The effect of the inclusion of these additional objectives can be seen by comparing these results with those shown in Figure 3-15 through 3-23 for the baseline case. The ranking and intrinsic value (weighted average) assignments for the 62 objectives relative to System C2 (M10, TRJ/CSJ, Commercial HST), for

FIGURE 3-28 FLIGHT FACILITY/OPERATIONAL SYSTEM MATCHING

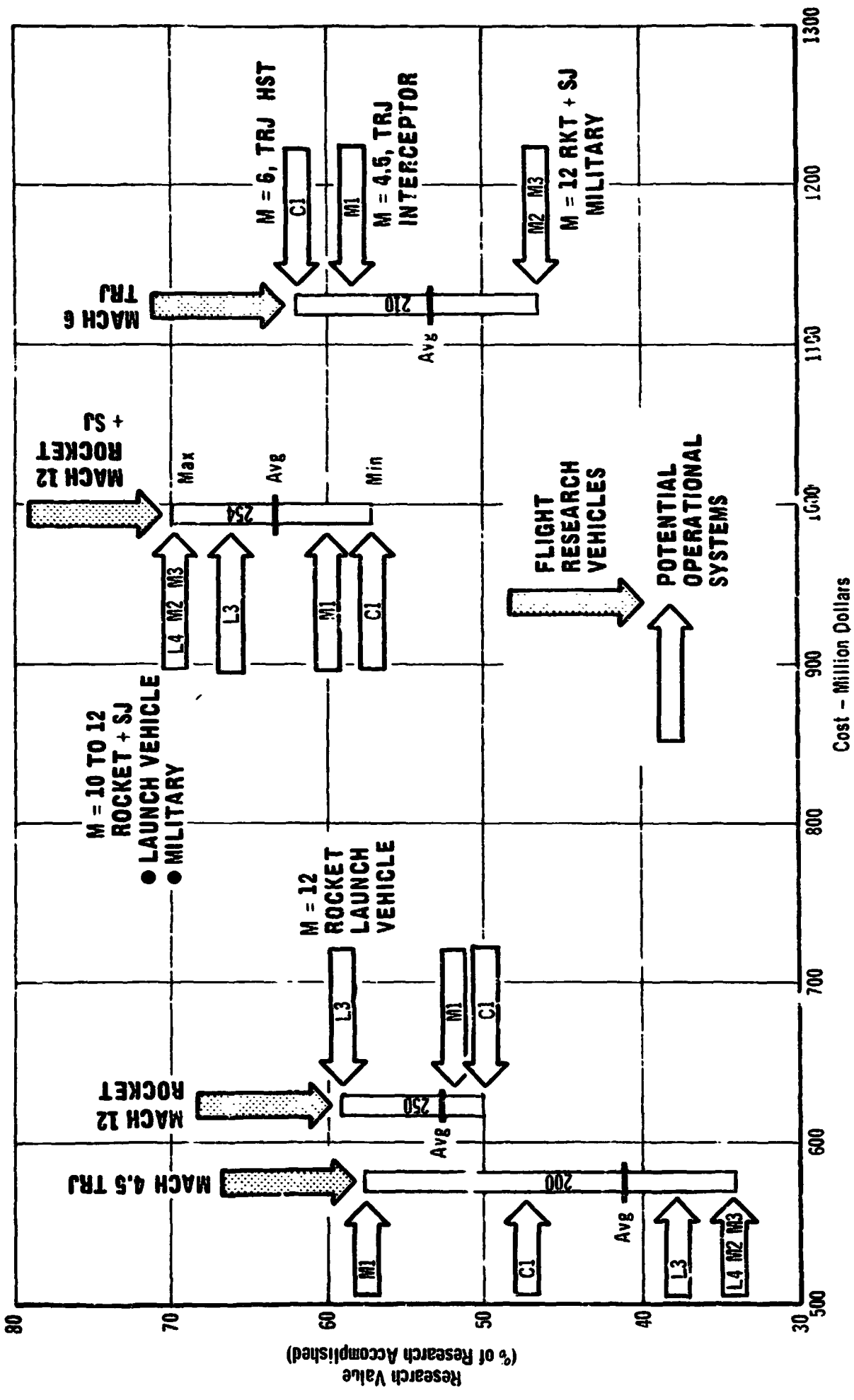


FIGURE 3-29 OPERATIONAL SYSTEM NO. 1 – (L1) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS
A. AERODYNAMICS	.183	22
B. THERMODYNAMICS	.165	18
C. STRUCTURES & MATERIAL	.194	21
D. PROPULSION	.208	24
E. SUBSYSTEMS	.125	15
F. OPERATION	.124	19

EVALUATION CRITERION	REL. WT.
A. TECHNOLOGY ADVANCEMENT	.604
B. COST & SCHEDULE	.396

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	75.5
2	57	TURBORAMJET SYSTEMS - DEVELOP & DEMONSTRATE	74.8
3	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	73.4
4	59*	RAMJET SYSTEMS - DEVELOP & DEMONSTRATE	73.1
5	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	72.7
6	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	72.7
7	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.2
8	31*	REUSABLE HEAT SHIELD SYSTEMS	67.6
9	67	INLET/ENGINE COMPATIBILITY CRITERIA	67.4
10	4	TEST TECHNS FOR RE NO, SHOCK WAVE & BNDY LR PHEN	65.9
11	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	65.7
12	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	65.6
13	58	BEST MULTIMODE CYCLE & ENGINE SIZE	64.9
14	52*	ENGINE DESIGN CNCPTS FOR VARIOUS COOLING TECHNS	64.0
15	65	NOZZLE CONFIGURATIONS	63.9
16	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	63.9
17	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	63.4
18	33	CONTROL SURFACE TECHNOLOGY	62.8
19	36*	EFF OF COMB MECH LONG, THML STRS CYC, TEMP VAR	62.0
20	50*	VARIABLE CAPTURE AREA INLET DESIGNS	61.9
21	9	PARAMETERS AFFECTING STABILITY & CONTROL	61.8
22	49*	EFFECTS ON PERF/DRAG OF INLET IN PRESSURE FIELD	61.7
23	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	61.2
24	32	REUSABLE LEADING EDGE CONCEPTS	60.0
25	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	59.6
26	21*	HYPER AERCTHERMO PREDICT TECHNS - ACT SIMULS	58.9
27	8*	DES TECHNS FOR LO SPEED CHARS & TRAN DRAG REDUCT	58.6
28	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	58.5
29	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	58.5
30	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	58.4
31	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	58.2
32	66*	VARIABLE NOZZLE GEOM REQS & MECHANICAL CONCEPTS	57.9
33	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	57.8
34	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	57.8
35	53*	ENGINE COMPONENT TECHNOLOGY - CRYO FUELS	57.5
36	63*	EFFECTIVE INLET CONTROLS	56.5
37	47*	PROTECTIVE COATINGS FOR METALS & NON-METALS	56.2
38	6	SURFACE/INLET POSITION - FAVOR AERO INTERFERENCE	55.8
39	46	HIGH TEMPERATURE EQUIPMENT	55.3
40	11	SEPARATION TECHNS FOR POSITIVE SEPAR & CONTROL	54.9
41	17*	PREDICT TECHNS FOR BNDY LAYER TRANSITION	54.8
42	26*	HEAT EFFECTS - FLOW FIELD/VEH GEOM INTERACTIONS	54.0
43	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	53.7
44	24*	EMBEDDED SHOCK, VORTEX, SEPAR & REATCH EFFECTS	53.4
45	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	52.8
46	56	COMBUSTION PROBLEMS OF RAMJETS FOR THRST AUGMENT	50.8
47	22	SURFACE SHAPING & PROTUB EFFECTS ON DRAG & HEAT	50.7
48	10	STAGE INTEGRATION FOR AERO IMPROVEMENTS	49.5
49	70	REGEN CRYO HEAT EXCHRS/THRMO CORLS/COOL CNT STMS	49.1
50	54*	ADVANCED ENGINE COMPONENTS - LIGHT WT/SHORT LIFE	45.9
51	37	EFF OF SEPARATION FORCES ON DYNAMIC CHARS	45.8
52	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	45.7
53	25	HEATING EFFECTS FROM FLOW THRU GAPS	45.3
54	81*	HI TEMP ACTUATOR SYSTEMS - INLET & NOZZLE ADJS	44.4
55	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	44.4
56	80	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	44.3
57	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	44.2
58	68	THML COND, STORAGE & SAFE HNDLG OF CRYO FUELS	42.6
59	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	42.1
60	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	42.0
61	73	CRYO SYSTEM COMPONENTS - RED WT/INCR RELIABILITY	42.0
62	39	NEAR FIELD NOISE EFFECTS	41.8
63	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	41.8
64	87	TERMINAL APPROACH & LANDING METHODS	41.6
65	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	41.0
66	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	40.5
67	13*	UNSTEADY CONTROL SURFACE HINGE MOMENTS	40.4
68	97	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	40.3
69	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIO'S	39.6
70	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	39.5
71	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	39.5
72	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	39.4
73	88*	HAZARDS INHERENT IN USE OF CRYO FUELS	39.4
74	23	TRANSPIR/ABLAT EFCTS - SKIN FRICT/HEAT TRANSFER	39.2
75	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	38.9
76	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	38.4
77	35*	STRUCTURE MAINTAINING AERODYNAMIC SMOOTHNESS	38.4
78	94	ENVIRON CNTL SYSTEM - M4-6 HYDROCARBON VEHICLE	37.8
79	90*	OPTIMUM LANDING TECHNS FOR HYPERSONIC VEHICLE	37.4
80	72	FUEL SYSTEM DESIGN REQUIREMENTS	34.3
81	92	ASCENT TRAJECTORY INVESTIGATION	34.3
82	18	EFFECTS OF REACTION CONTROL JETS	33.5
83	82	AUXILIARY POWER UNITS	31.4
84	71	IMPROVEMENT OF HYDROCARBON FUEL PERFORMANCE	31.3
85	93*	EFCTS OF VEH DYN/CENTRIF EFCTS ON CREW/PSSNGRS	31.1
86	101	AIR TRAFFIC CNTL PRCDRS & GND-BASED NAV SYSTEMS	29.7
87	79	AIR DATA MEASUREMENT TECHNIQUES	28.5
88	77*	FLUSH OR RECESSED ANTENNA DESIGN TECHNIQUES	28.3
89	91	COMMUNICATION TECHNIQUES	24.5
90	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	24.1

FIGURE 3-30 OPERATIONAL SYSTEM NO. 2 – (L2) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS
A. AERODYNAMICS	.183	22
B. THERMODYNAMICS	.165	16
C. STRUCTURES & MATERIAL	.194	21
D. PROPULSION	.208	24
E. SUBSYSTEMS	.125	15
F. OPERATION	.124	19

EVALUATION CRITERION	REL. WT.
A. TECHNOLOGY ADVANCEMENT	.604
B. COST & SCHEDULE	.396

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	60	CONVERTIBLE SCRAMJET SYSTEMS - DEVELOP & DEMON	78.6
2	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	75.5
3	57	TURBORAMJET SYSTEMS - DEVELOP & DEMONSTRATE	74.3
4	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	72.8
5	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	72.7
6	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	72.7
7	61*	SCRAMJET SYSTEMS - DEVELOP & DEMONSTRATE	72.3
8	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.2
9	31*	REUSABLE HEAT SHIELD SYSTEMS	67.6
10	67	INLET/ENGINE COMPATIBILITY CRITERIA	67.2
11	4	TEST TECHNS FOR RE NO. SHOCK WAVE & BNDY LR PHEN.	65.9
12	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	65.7
13	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	65.6
14	58	BEST MULTIMODE CYCLE & ENGINE SIZE	65.5
15	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	63.9
16	52*	ENGINE DESIGN CNCPTS FOR VARIOUS COOLING TECHNS	63.4
17	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	63.4
18	65	NOZZLE CONFIGURATIONS	63.0
19	33	CONTROL SURFACE TECHNOLOGY	62.8
20	49*	EFFECTS ON PERF/DRAG OF INLET IN PRESSURE FIELD	62.1
21	36*	EFF OF COMB MECH LONG. THML STRS CYC. TEMP VAR	62.0
22	9	PARAMETERS AFFECTING STABILITY & CONTROL	61.8
23	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	61.2
24	50*	VARIABLE CAPTURE AREA INLET DESIGNS	61.2
25	32	RELSABLE LEADING EDGE CONCEPTS	60.0
26	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	59.6
27	21*	HYPER AERCTHERMO PREDICT TECHNS - ACT SIMULS	58.9
28	8*	DES TECHNS FOR LO SPEED CHARS & TRAN DRAG REDUCT	58.6
29	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	58.5
30	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	58.5
31	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	58.4
32	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	58.2
33	66*	VARIABLE NOZZLE GEOM REQS & MECHANICAL CONCEPTS	57.9
34	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	57.8
35	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	57.8
36	53*	ENGINE COMPONENT TECHNOLOGY - CRYO FUELS	56.8
37	63*	EFFECTIVE INLET CONTROLS	56.7
38	47*	PROTECTIVE COATINGS FOR METALS & NON-METALS	56.2
39	6	SURFACE/INLET POSITION - FAVOR AERO INTERFERENCE	55.8
40	46	HIGH TEMPERATURE EQUIPMENT	55.3
41	11	SEPARATION TECHNS FOR POSITIVE SEPAR & CONTROL	54.9
42	17*	PREDICT TECHNS FOR BNDY LAYER TRANSITION	54.8
43	26*	HEAT EFFECTS - FLOW FIELD/VEH GEOM INTERACTIONS	54.0
44	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	53.7
45	24*	EMBEDDED SHOCK, VORTEX, SEPAR & REATCH EFFECTS	53.4
46	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	52.8
47	56*	COMBUSTION PROBLEMS OF RAMJETS FOR THRST AUGMENT	50.7
48	22	SURFACE SHAPING & PROTUB EFFECTS ON DRAG & HEAT	50.7
49	51*	REAL GAS EFFECTS ON INLET & NOZZLE PERFORMANCE	50.2
50	10	STAGE INTEGRATION FOR AERO IMPROVEMENTS	49.5
51	70	REGEN CRYO HEAT EXCHRS/THRMO CORLS/COOL CNT STMS	49.5
52	37	EFF OF SEPARATION FORCES ON DYNAMIC CHARS	45.8
53	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHE S	45.7
54	54*	ADVANCED ENGINE COMPONENTS - LIGHT WT/SHORT LIFE	45.6
55	25	HEATING EFFECTS FROM FLOW THRU GAPS	45.1
56	81*	HI TEMP ACTUATOR SYSTEMS - INLET & NOZZLE ADJS	44.7
57	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	44.5
58	80	ACTUATION TECHNS & HOWR FOR CNTL SURFACE MOTION	44.3
59	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	44.2
60	68	THML COND, STORAGE & SAFE HNDLG OF CRYO FUELS	42.8
61	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	42.1
62	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	42.0
63	73	CRYO SYSTEM COMPONENTS - RED WT/INCR RELIABILITY	42.0
64	39	NEAR FIELD NOISE EFFECTS	41.8
65	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	41.8
66	87	TERMINAL APPROACH & LANDING METHODS	41.6
67	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	41.0
68	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	40.5
69	13*	UNSTEADY CONTROL SURFACE HINGE MOMENTS	40.4
70	97	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	40.3
71	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIO'S	39.7
72	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	39.5
73	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	39.5
74	88*	HAZARDS INHERENT IN USE OF CRYO FUELS	39.4
75	23	TRANSPIR/ABLAT EFCTS - SKIN FRICT/HEAT TRANSFER	39.2
76	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	39.1
77	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	38.9
78	35*	STRUCTURE MAINTAINING AERODYNAMIC SMOOTHNESS	38.4
79	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	38.3
80	90*	OPTIMUM LANDING TECHNS FOR HYPERSONIC VEHICLE	37.4
81	72	FUEL SYSTEM DESIGN REQUIREMENTS	34.5
82	92	ASCENT TRAJECTORY INVESTIGATION	34.3
83	18	EFFECTS OF REACTION CONTROL JETS	33.5
84	71	IMPROVEMENT OF HYDROCARBON FUEL PERFORMANCE	31.4
85	82	AUXILIARY POWER UNITS	31.3
86	93*	EFCTS OF VEH DYN/CENTRIF EFCTS ON CREW/PSSNGRS	31.1
87	101	AIR TRAFFIC CNTL PRCDRS & GND-BASED NAV SYSTEMS	29.7
88	77*	FLUSH OR RECESSED ANTENNA DESIGN TECHNIQUES	28.3
89	79	AIR DATA MEASUREMENT TECHNIQUES	28.2
90	91	COMMUNICATION TECHNIQUES	24.5
91	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	24.0

FIGURE 3-31 OPERATIONAL SYSTEM NO. 3 – (L3) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS
A. AERODYNAMICS	.183	22
B. THERMODYNAMICS	.165	18
C. STRUCTURES & MATERIAL	.194	21
D. PROPULSION	.208	24
E. SUBSYSTEMS	.125	15
F. OPERATION	.124	19

EVALUATION CRITERION	REL. WT.
A. TECHNOLOGY ADVANCEMENT	.604
B. COST & SCHEDULE	.396

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	58	BEST MULTIMODE CYCLE & ENGINE SIZE	81.9
2	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	75.5
3	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	72.7
4	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	72.7
5	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.2
6	31*	REUSABLE HEAT SHIELD SYSTEMS	67.6
7	4	TEST TECHNS FOR RE NO. SHOCK WAVE & BNDY LR PHEN	65.9
8	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	65.7
9	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	65.6
10	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	63.9
11	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	63.4
12	33	CONTROL SURFACE TECHNOLOGY	62.8
13	36*	EFF OF COMB MECH LONG. THML STRS CYC. TEMP VAR	62.0
14	9	PARAMETERS AFFECTING STABILITY & CONTROL	61.8
15	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	61.2
16	32	REUSABLE LEADING EDGE CONCEPTS	60.0
17	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	59.6
18	21*	HYPER AEROTHERMO PREDICT TECHNS - ACT STIMULS	58.9
19	8*	DES TECHNS FOR LO SPEED CHARS & TRAN DRAG REDUCT	58.6
20	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	58.5
21	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	58.5
22	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	58.4
23	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	58.2
24	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	57.8
25	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	57.8
26	62	RKT-PWD ENGINE OPERATION IN HORIZ T/O A/C	56.6
27	47*	PROTECTIVE COATINGS FOR METALS & NON-METALS	56.2
28	6	SURFACE/INLET POSITION - FAVOR AERO INTEFERENCE	55.8
29	46	HIGH TEMPERATURE EQUIPMENT	55.3
30	11	SEPARATION TECHNS FOR POSITIVE SEPAR & CONTROL	54.9
31	17*	PREDICT TECHNS FOR BNDY LAYER TRANSITION	54.8
32	26*	HEAT EFFECTS - FLOW FIELD/VEH GEOM INTERACTIONS	54.0
33	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	53.7
34	24*	EMBEDDED SHOCK, VORTEX, SEPAR & REATCH EFFECTS	53.4
35	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	52.8
36	22	SURFACE SHAPING & PROTUB EFFECTS ON DRAG & HEAT	50.7
37	10	STAGE INTEGRATION FOR AERO IMPROVEMENTS	49.5
38	70	REGEN CRYO HEAT EXCHRS/THRMO CORLS/COOL CNT STMS	49.1
39	64	AUXILIARY TURBOJETS FOR LANDING HYPERSONIC VEHS	48.7
40	37	EFF OF SEPARATION FORCES ON DYNAMIC CHARS	45.8
41	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	45.7
42	25	HEATING EFFECTS FROM FLOW THRU GAPS	45.3
43	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	44.3
44	81*	HI TEMP ACTUATOR SYSTEMS - INLET & NOZZLE ADJS	44.3
45	80	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	43.9
46	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	43.8
47	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	42.2
48	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	42.1
49	87	TERMINAL APPROACH & LANDING METHODS	42.0
50	68	THML COND, STORAGE & SAFE HNDLG OF CRYO FUELS	41.9
51	39	NEAR FIELD NOISE EFFECTS	41.8
52	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	41.8
53	73	CRYO SYSTEM COMPONENTS - RED WT/INCR RELIABILITY	41.3
54	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	41.0
55	97	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	40.9
56	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	40.8
57	13*	UNSTEADY CONTROL SURFACE HINGE MOMENTS	40.4
58	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	40.0
59	88*	HAZARDS INHERENT IN USE OF CRYO FUELS	39.7
60	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	39.5
61	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIO'S	39.3
62	23	TRANSPIR/ABLAT EFCTS - SKIN FRICT/HEAT TRANSFER	39.2
63	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	39.1
64	35*	STRUCTURE MAINTAINING AERODYNAMIC SMOOTHNESS	38.4
65	83	ENVIRCN CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	38.3
66	90*	OPTIMUM LANDING TECHNS FOR HYPERSONIC VEHICLE	38.0
67	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	37.8
68	92	ASCENT TRAJECTORY INVESTIGATION	34.9
69	18	EFFECTS OF REACTION CONTROL JETS	33.5
70	99	SHORT TAKEOFF TECHNIQUES	32.0
71	93*	EFCTS OF VEH DYN/CENTRIF EFCTS ON CREW/PSSNGRS	31.6
72	82	AUXILIARY POWER UNITS	30.2
73	101	AIR TRAFFIC CNTL PRCDRS & GND-BASED NAV SYSTEMS	30.1
74	79	AIR DATA MEASUREMENT TECHNIQUES	27.9
75	77*	FLUSH OR RECESSED ANTENNA DESIGN TECHNIQUES	27.2
76	91	COMMUNICATION TECHNIQUES	25.3
77	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	22.5

FIGURE 3-32 OPERATIONAL SYSTEM NO. 4 – (L4) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS
A. AERODYNAMICS	.183	22
B. THERMODYNAMICS	.165	18
C. STRUCTURES & MATERIAL	.194	21
D. PROPULSION	.208	24
E. SUBSYSTEMS	.125	15
F. OPERATION	.124	19

EVALUATION CRITERION	REL. WT.
A. TECHNOLOGY ADVANCEMENT	.604
B. COST & SCHEDULE	.396

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	60●	CONVERTIBLE SCRAMJET SYSTEMS - DEVELOP & DEMON	85.0
2	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	75.5
3	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	75.1
4	61	SCRAMJET SYSTEMS - DEVELOP & DEMONSTRATE	74.8
5	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	72.7
6	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	72.7
7	67	INLET/ENGINE COMPATIBILITY CRITERIA	70.5
8	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.2
9	52●	ENGINE DESIGN CNCPTS FOR VARIOUS COOLING TECHNS	68.3
10	58	BEST MULTIMODE CYCLE & ENGINE SIZE	67.9
11	31●	REUSABLE HEAT SHIELD SYSTEMS	67.6
12	65	NOZZLE CONFIGURATIONS	66.5
13	4	TEST TECHNS FOR RE NO. SHOCK WAVE & BNDY LR PHEN	65.9
14	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	65.7
15	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	65.6
16	49●	EFFECTS ON PERF/DRAG OF INLET IN PRESSURE FIELD	65.3
17	50●	VARIABLE CAPTURE AREA INLET DESIGNS	64.1
18	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	63.9
19	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	63.4
20	33	CONTROL SURFACE TECHNOLOGY	62.8
21	36●	EFF OF COMB MECH LONG, THML STRS CYC, TEMP VAR	62.0
22	9	PARAMATERS AFFECTING STABILITY & CONTROL	61.8
23	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	61.2
24	53●	ENGINE COMPONENT TECHNOLOGY - CRYO FUELS	60.5
25	66●	VARIABLE NOZZLE GEOM REQS & MECHANICAL CONCEPTS	60.3
26	32	REUSABLE LEADING EDGE CONCEPTS	60.0
27	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	59.6
28	21●	HYPER AERCTHERMO PREDICT TECHNS - ACT SIMULS	58.9
29	8●	DES TECHNS FOR LO SPEED CHARS & TRAN DRAG REDUCT	58.6
30	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	58.5
31	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	58.5
32	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	58.4
33	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	58.2
34	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	57.8
35	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	57.8
36	47●	PROTECTIVE COATINGS FOR METALS & NON-METALS	56.2
37	6	SURFACE/INLET POSITION - FAVOR AERO INTEFERENCE	55.8
38	46	HIGH TEMPERATURE EQUIPMENT	55.3
39	11	SEPARATION TECHNS FOR POSITIVE SEPAR & CONTROL	54.9
40	17●	PREDICT TECHNS FOR BNDY LAYER TRANSITION	54.8
41	26●	HEAT EFFECTS - FLOW FIELD/VEH GEOM INTERACTIONS	54.0
42	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	53.7
43	24●	EMBEDDED SHOCK, VORTEX, SEPAR & REATCH EFFECTS	53.4
44	51●	REAL GAS EFFECTS ON INLET & NOZZLE PERFORMANCE	52.9
45	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	52.8
46	22	SURFACE SHAPING & PROTUB EFFECTS ON DRAG & HEAT	50.7
47	10	STAGE INTEGRATION FOR AERO IMPROVEMENTS	49.5
48	70	REGEN CRYO HEAT EXCHRS/THRMO CORLS/COOL CNT STMS	49.1
49	54●	ADVANCED ENGINE COMPONENTS - LIGHT WT/SHORT LIFE	49.1
50	37	EFF OF SEPARATION FORCES ON DYNAMIC CHARS	45.8
51	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	45.7
52	25	HEATING EFFECTS FROM FLOW THRU GAPS	45.3
53	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	44.3
54	81●	HI TEMP ACTUATOR SYSTEMS - INLET & NOZZLE ADJS	44.3
55	80	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	43.9
56	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	43.8
57	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	42.2
58	15	TECHNS FOR ALLEVIAT NG SONIC BOOM INTENSITY	42.1
59	87	TERMINAL APPROACH & LANDING METHODS	42.0
60	68	THML CCND, STORAGE & SAFE HNDLG OF CRYO FUELS	41.9
61	39	NEAR FIELD NOISE EFFECTS	41.8
62	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	41.8
63	73	CRYO SYSTEM COMPONENTS - RCD WT/INCR RELIABILITY	41.3
64	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	41.0
65	97	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	40.8
66	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	40.8
67	62	RKT-PWD ENGINE OPERATION IN HORIZ T/O A/C	40.5
68	13●	UNSTEADY CONTROL SURFACE HINGE MOMENTS	40.4
69	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	40.0
70	88●	HAZARDS INHERENT IN USE OF CRYO FUELS	39.7
71	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	39.5
72	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIO'S	39.3
73	23	TRANSPIR/ABLAT EFCTS - SKIN FRICT/HEAT TRANSFER	39.2
74	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	39.1
75	35●	STRUCTURE MAINTAINING AERODYNAMIC SMOOTHNESS	38.4
76	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	38.3
77	90●	OPTIMUM LANDING TECHNS FOR HYPERSONIC VEHICLE	38.0
78	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	37.8
79	64	AUXILIARY TURBOJETS FOR LANDING HYPERSONIC VEHS	35.1
80	92	ASCENT TRAJECTORY INVESTIGATION	34.9
81	18	EFFECTS OF REACTION CONTROL JETS	33.5
82	99	SHORT TAKEOFF TECHNIQUES	32.0
83	93●	EFCTS OF VEH DYN/CENTRIF EFCTS ON CREW/PSSNGRS	31.6
84	82	AUXILIARY POWER UNITS	30.2
85	101	AIR TRAFFIC CNTL PRCDRS & GND-BASED NAV SYSTEMS	30.1
86	79	AIR DATA MEASUREMENT TECHNIQUES	27.9
87	77●	FLUSH OR RECESSED ANTENNA DESIGN TECHNIQUES	27.2
88	91	COMMUNICATION TECHNIQUES	25.3
89	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	22.5

FIGURE 3-33 OPERATIONAL SYSTEM NO. 5 – (C1) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS
A. AERODYNAMICS	.183	22
B. THERMODYNAMICS	.165	18
C. STRUCTURES & MATERIAL	.194	21
D. PROPULSION	.208	24
E. SUBSYSTEMS	.125	15
F. OPERATION	.124	19

EVALUATION CRITERION	REL. WT.
A. TECHNOLOGY ADVANCEMENT	.604
B. COST & SCHEDULE	.396

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	57	TURBORAMJET SYSTEMS - DEVELOP & DEMONSTRATE	76.9
2	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	75.1
3	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	74.9
4	59*	RAMJET SYSTEMS - DEVELOP & DEMONSTRATE	74.4
5	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	72.1
6	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	71.9
7	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	69.9
8	67	INLET/ENGINE COMPATIBILITY CRITERIA	69.0
9	31*	REUSABLE HEAT SHIELD SYSTEMS	67.2
10	58	BEST MULTIMODE CYCLE & ENGINE SIZE	66.6
11	65	NOZZLE CONFIGURATIONS	66.4
12	52*	ENGINE DESIGN CNCPTS FOR VARIOUS COOLING TECHNS	65.5
13	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	65.5
14	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	65.0
15	4	TEST TECHNS FOR RE NO, SHOCK WAVE & BNDY LR PHEN	64.8
16	50*	VARIABLE CAPTURE AREA INLET DESIGNS	63.7
17	49*	EFFECTS ON PERF/DRAG OF INLET IN PRESSURE FIELD	63.6
18	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	62.7
19	33	CONTROL SURFACE TECHNOLOGY	61.7
20	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	61.5
21	38*	EFF OF COMB MECH LONG, THML STRS CYC, TEMP VAR	61.0
22	9	PARAMETERS AFFECTING STABILITY & CONTROL	60.9
23	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	60.8
24	66*	VARIABLE NOZZLE GEOM REQS & MECHANICAL CONCEPTS	.3
25	53*	ENGINE COMPONENT TECHNOLOGY - CRYO FUELS	.2
26	32	REUSABLE LEADING EDGE CONCEPTS	59.1
27	63*	EFFECTIVE INLET CONTROLS	59.0
28	21*	HYPER AERCTHERMO PREDICT TECHNS - ACT SIMULS	58.4
29	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	57.7
30	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	57.6
31	8*	DES TECHNS FOR LO SPEED CHARS & TRAN DRAG REDUCT	57.3
32	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	56.8
33	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	56.8
34	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	56.5
35	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	56.2
36	2	SU SONIC & TRANSONIC AERO CHARACTERISTICS	56.2
37	47*	PROTECTIVE COATINGS FOR METALS & NON-METALS	55.6
38	46	HIGH TEMPERATURE EQUIPMENT	54.7
39	6	SURFACE/INLET POSITION - FAVOR AERO INTERFERENCE	53.8
40	26*	HEAT EFFECTS - FLOW FIELD/VEH GEOM INTERACTIONS	53.3
41	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	53.1
42	17*	PREDICT TECHNS FOR BNDY LAYER TRANSITION	52.5
43	56	COMBUSTION PROBLEMS OF RAMJETS FOR THRST AUGMENT	52.4
44	24*	EMBEDDED SHOCK, VORTEX, SEPAR & REATCH EFFECTS	51.6
45	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	51.5
46	70	REGEN CRYO HEAT EXCHRS/THRMO CORLS/COOL CNT STMS	49.4
47	22	SURFACE SHAPING & PROTUB EFFECTS ON DRAG & HEAT	49.0
48	54*	ADVANCED ENGINE COMPONENTS - LIGHT WT/SHORT LIFE	47.6
49	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	46.5
50	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	45.1
51	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	44.8
52	81*	HI TEMP ACTUATOR SYSTEMS - INLET & NOZZLE ADJS	44.6
53	90	ACTUATION TECHNS & HOWR FOR CNTL SURFACE MOTION	44.5
54	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	43.7
55	87	TERMINAL APPROACH & LANDING METHODS	43.4
56	68	THML COND, STORAGE & SAFE HNDLG OF CRYO FUELS	43.0
57	25	HEATING EFFECTS FROM FLOW THRU GAPS	42.7
58	73	CRYO SYSTEM COMPONENTS - RED WT/INCR RELIABILITY	42.4
59	97	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	41.9
60	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	41.8
61	39	NEAR FIELD NOISE EFFECTS	41.0
62	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	.6
63	88*	HAZARDS INHERENT IN USE OF CRYO FUELS	.6
64	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	40.4
65	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	40.1
66	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIO'S	39.9
67	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	39.8
68	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	39.7
69	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	38.8
70	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	38.7
71	90*	OPTIMUM LANDING TECHNS FOR HYPERSONIC VEHICLE	38.7
72	13*	UNSTEADY CONTROL SURFACE HINGE MOMENTS	38.6
73	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	38.3
74	84	ENVIRON CNTL SYSTEM - M4-6 HYDROCARBON VEHICLE	38.1
75	35*	STRUCTURE MAINTAINING AERODYNAMIC SMOOTHNESS	37.7
76	55	ENGINE NOISE REDUCTION DURING T/O & LANDING	36.4
77	92	ASCENT TRAJECTORY INVESTIGATION	35.7
78	72	FUEL SYSTEM DESIGN REQUIREMENTS	34.8
79	93*	EFCTS OF VEH DYN/CENTRIF EFCTS ON CREW/PSSNGRS	33.7
80	82	AUXILIARY POWER UNITS	31.9
81	71	IMPROVEMENT OF HYDROCARBON FUEL PERFORMANCE	31.6
82	74*	RAPID CRYOGENIC SERVICING TECHNIQUES	31.6
83	101	AIR TRAFFIC CNTL PRCDRS & GND-BASED NAV SYSTEMS	31.2
84	79	AIR DATA MEASUREMENT TECHNIQUES	28.0
85	77*	FLUSH OR RECESSED ANTENNA DESIGN TECHNIQUES	28.7
86	91	COMMUNICATION TECHNIQUES	26.1
87	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	24.8
88	98	ATMOS OF MOTION & SECURITY IN WINDOWLESS A/C	17.3

FIGURE 3-34 OPERATIONAL SYSTEM NO. 6 – (C2) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS
A. AERODYNAMICS	.183	22
B. THERMODYNAMICS	.165	18
C. STRUCTURES & MATERIAL	.194	21
D. PROPULSION	.208	24
E. SUBSYSTEMS	.125	15
F. OPERATION	.124	19

EVALUATION CRITERION	REL. WT.
A. TECHNOLOGY ADVANCEMENT	.604
B. COST & SCHEDULE	.396

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	60*	CONVERTIBLE SCRAMJET SYSTEMS - DEVELOP & DEMON	80.5
2	57	TURBORAMJET SYSTEMS - DEVELOP & DEMONSTRATE	76.2
3	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	75.1
4	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	74.2
5	61	SCRAMJET SYSTEMS - DEVELOP & DEMONSTRATE	73.7
6	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	72.1
7	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	71.9
8	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.3
9	67	INLET/ENGINE COMPATIBILITY CRITERIA	68.6
10	31*	REUSABLE HEAT SHIELD SYSTEMS	67.2
11	58	BEST MULTIMODE CYCLE & ENGINE SIZE	67.0
12	4	TEST TECHNS FOR RE NO, SHOCK WAVE & BNDY LR PHEN	65.9
13	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	65.5
14	65	NOZZLE CONFIGURATIONS	65.2
15	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	65.0
16	52*	ENGINE DESIGN CNCPTS FOR VARIOUS COOLING TECHNS	64.8
17	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	63.8
18	49*	EFFECTS ON PERF/DRAG OF INLET IN PRESSURE FIELD	63.7
19	50*	VARIABLE CAPTURE AREA INLET DESIGNS	62.8
20	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	62.7
21	9	PARAMATERS AFFECTING STABILITY & CONTROL	62.0
22	33	CONTROL SURFACE TECHNOLOGY	61.7
23	36*	EFF OF COMB MECH LONG, THML STRS CYC, TEMP VAR	61.0
24	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	60.8
25	66*	VARIABLE NOZZLE GEOM REQS & MECHANICAL CONCEPTS	60.0
26	32	REUSABLE LEADING EDGE CONCEPTS	59.1
27	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLO INT EFCTS	59.1
28	63*	EFFECTIVE INLET CONTROLS	58.9
29	8*	DES TECHNS FOR LO SPEED CHARS & TRAN DRAG REDUCT	58.7
30	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	58.7
31	21*	HYPER AEROTHERMO PREDICT TECHNS - ACT SIMULS	58.4
32	53*	ENGINE COMPONENT TECHNOLOGY - CRYO FUELS	58.3
33	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	58.2
34	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	57.9
35	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	57.7
36	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	57.7
37	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	57.6
38	47*	PROTECTIVE COATINGS FOR METALS & NON-METALS	55.6
39	6	SURFACE/INLET POSITION - FAVOR AERO INTERFERENCE	55.3
40	46	HIGH TEMPERATURE EQUIPMENT	54.7
41	17*	PREDICT TECHNS FOR BNDY LAYER TRANSITION	53.9
42	26*	HEAT EFFECTS - FLOW FIELD/VEH GEOM INTERACTIONS	53.3
43	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	53.1
44	56*	COMBUSTION PROBLEMS OF RAMJETS FOR THRST AUGMENT	52.2
45	51*	REAL GAS EFFECTS ON INLET & NOZZLE PERFORMANCE	52.0
46	24*	EMBEDDED SHOCK, VORTEX, SEPAR & REATCH EFFECTS	51.6
47	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	51.5
48	70	REGEN CRYO HEAT EXCHRS/THRMO COPLS/COOL CNT STMS	49.4
49	22	SURFACE SHAPING & PROTUR EFFECTS ON DRAG & HEAT	49.0
50	54*	ADVANCED ENGINE COMPONENTS - LIGHT WT/SHORT LIFE	47.2
51	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	46.5
52	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	45.1
53	81*	HI TEMP ACTUATOR SYSTEMS - INLET & NOZZLE ADJS	44.5
54	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	44.4
55	80	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	44.2
56	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	43.7
57	87	TERMINAL APPROACH & LANDING METHODS	43.4
58	25	HEATING EFFECTS FROM FLOW THRU GAPS	42.7
59	68	THML COND, STORAGE & SAFE HNDLG OF CRYO FUELS	42.5
60	73	CRYO SYSTEM COMPONENTS - RED WT/INCR RELIABILITY	41.9
61	97	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	41.9
62	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	41.8
63	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	41.8
64	39	NEAR FIELD NOISE EFFECTS	41.0
65	88*	HAZARDS INHERENT IN USE OF CRYO FUELS	40.6
66	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	40.4
67	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	40.2
68	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	40.1
69	13*	UNSTEADY CONTROL SURFACE HINGE MOMENTS	40.0
70	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	39.8
71	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIO'S	39.7
72	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	38.8
73	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	38.8
74	90*	OPTIMUM LANDING TECHNS FOR HYPERSONIC VEHICLE	38.7
75	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	38.2
76	35*	STRUCTURE MAINTAINING AERODYNAMIC SMOOTHNESS	37.7
77	92	ASCENT TRAJECTORY INVESTIGATION	35.7
78	55	ENGINE NOISE REDUCTION DURING T/O & LANDING	35.4
79	93*	EFCTS OF VEH DYN/CENTRIF EFCTS ON CREW/PSSNGRS	33.7
80	18	EFFECTS OF REACTION CONTROL JETS	32.3
81	101	AIR TRAFFIC CNTL PRCDRS & GND-BASED NAV SYSTEMS	31.2
82	82	AUXILIARY POWER UNITS	30.9
83	74*	RAPID CRYOGENIC SERVICING TECHNIQUES	30.8
84	79	AIR DATA MEASUREMENT TECHNIQUES	28.4
85	77*	FLUSH OR RECESSED ANTENNA DESIGN TECHNIQUES	27.8
86	91	COMMUNICATION TECHNIQUES	26.1
87	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	23.5
88	98	ATMOS OF MOTION & SECURITY IN WINDOWLESS A/C	17.3

FIGURE 3-35 OPERATIONAL SYSTEM NO. 7 – (M1) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS
A. AERODYNAMICS	.183	22
B. THERMODYNAMICS	.165	18
C. STRUCTURES & MATERIAL	.194	21
D. PROPULSION	.208	24
E. SUBSYSTEMS	.125	15
F. OPERATION	.124	19

EVALUATION CRITERION	REL. WT.
A. TECHNOLOGY ADVANCEMENT	.604
B. COST & SCHEDULE	.396

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	57	TURBORAMJET SYSTEMS - DEVELOP & DEMONSTRATE	74.8
2	28*	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	74.5
3	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	73.4
4	59*	RAMJET SYSTEMS - DEVELOP & DEMONSTRATE	73.1
5	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	71.4
6	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.6
7	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	70.0
8	47	INLET/ENGINE COMPATIBILITY CRITERIA	67.4
9	31*	REUSABLE HEAT SHIELD SYSTEMS	66.3
10	4	TEST TECHNS FOR RE NO, SHOCK WAVE & BNDY LR PHEN	65.3
11	58	BEST MULTIMODE CYCLE & ENGINE SIZE	64.9
12	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	64.5
13	52*	ENGINE DESIGN CNCPTS FOR VARIOUS COOLING TECHNS	64.0
14	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	64.0
15	65	NOZZLE CONFIGURATIONS	63.9
16	50*	VARIABLE CAPTURE AREA INLET DESIGNS	61.9
17	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	61.8
18	49*	EFFECTS ON PERF/DRAG OF INLET IN PRESSURE FIELD	61.7
19	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	61.6
20	9	PARAMETERS AFFECTING STABILITY & CONTROL	61.4
21	33	CONTROL SURFACE TECHNOLOGY	60.5
22	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	59.7
23	36*	EFF OF COMB MECH LONG, THML STRS CYC, TEMP VAR	59.5
24	21*	HYPER AEROTHERMO PREDICT TECHNS - ACT SIMULS	58.4
25	66*	VARIABLE NOZZLE GEOM REQS & MECHANICAL CONCEPTS	57.9
26	32	REUSABLE LEADING EDGE CONCEPTS	57.9
27	53*	ENGINE COMPONENT TECHNOLOGY - CRYO FUELS	57.5
28	8*	DES TECHNS FOR LO SPEED CHARS & TRAN DRAG REDUCT	57.5
29	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	57.1
30	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	57.1
31	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	57.0
32	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	56.6
33	63*	EFFECTIVE INLET CONTROLS	56.5
34	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	56.4
35	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	56.3
36	47*	PROTECTIVE COATINGS FOR METALS & NON-METALS	54.5
37	6	SURFACE/INLET POSITION - FAVOR AERO INTERFERENCE	53.9
38	46	HIGH TEMPERATURE EQUIPMENT	53.7
39	26*	HEAT EFFECTS - FLOW FIELD/VEH GEOM INTERACTIONS	53.3
40	17*	PREDICT TECHNS FOR BNDY LAYER TRANSITION	52.3
41	41	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	52.2
42	24*	EMBEDDED SHOCK, VORTEX, SEPAR & REATCH EFFECTS	51.6
43	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	51.5
44	56	COMBUSTION PROBLEMS OF RAMJETS FOR THRST AUGMENT	50.8
45	22	SURFACE SHAPING & PROTUR EFFECTS ON DRAG & HEAT	49.0
46	81*	HI TEMP ACTUATOR SYSTEMS - INLET & NOZZLE ADJS	48.3
47	80	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	48.2
48	54*	ADVANCED ENGINE COMPONENTS - LIGHT WT/SHORT LIFE	45.9
49	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	44.2
50	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	43.9
51	25	HEATING EFFECTS FROM FLOW THRU GAPS	42.7
52	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	42.0
53	87	TERMINAL APPROACH & LANDING METHODS	41.6
54	85	LAUNCH TECHNS FOR AAM & ASM WEAPONS	41.5
55	84	ENVIRON CNTL SYSTEM - M4-6 HYDROCARBON VEHICLE	40.7
56	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	40.5
57	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	40.3
58	97*	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	40.3
59	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	40.1
60	39	NEAR FIELD NOISE EFFECTS	39.7
61	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	39.5
62	88*	HAZARDS INHERENT IN USE OF CRYO FUELS	39.4
63	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	38.9
64	13*	UNSTEADY CONTROL SURFACE HINGE MOMENTS	38.8
65	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	38.2
66	86*	HEAT SHLDNG MISSILE LNCHRS, DRS & INT STRUCTS	37.5
67	90*	OPTIMUM LANDING TECHNS FOR HYPERSONIC VEHICLE	37.4
68	72	FUEL SYSTEM DESIGN REQUIREMENTS	36.7
69	35*	STRUCTURE MAINTAINING AERODYNAMIC SMOOTHNESS	36.6
70	92	ASCENT TRAJECTORY INVESTIGATION	34.3
71	71	IMPROVEMENT OF HYDROCARBON FUEL PERFORMANCE	34.0
72	82	AUXILIARY POWER UNITS	33.6
73	77*	FLUSH OR RECESSED ANTENNA DESIGN TECHNIQUES	32.3
74	79	AIR DATA MEASUREMENT TECHNIQUES	31.6
75	93*	EFCTS OF VEH DYN/CENTRIF EFCTS ON CREW/PSSNGRS	31.1
76	101	AIR TRAFFIC CNTL PRCDRS & GND-BASED NAV SYSTEMS	29
77	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	27.8
78	91	COMMUNICATION TECHNIQUES	24.5

FIGURE 3-36 OPERATIONAL SYSTEM NO. 8 – (M2) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS
A. AERODYNAMICS	.183	22
B. THERMODYNAMICS	.165	18
C. STRUCTURES & MATERIAL	.194	21
D. PROPULSION	.208	24
E. SUBSYSTEMS	.125	15
F. OPERATION	.124	19

EVALUATION CRITERION	REL. WT.
A. TECHNOLOGY ADVANCEMENT	.604
B. COST & SCHEDULE	.396

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	60*	CONVERTIBLE SCRAMJET SYSTEMS - DEVELOP & DEMON	85.0
2	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	75.5
3	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	75.1
4	61	SCRAMJET SYSTEMS - DEVELOP & DEMONSTRATE	74.8
5	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	72.
6	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	72.7
7	67	INLET/ENGINE COMPATIBILITY CRITERIA	70.5
8	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.3
9	52*	ENGINE DESIGN CNCPTS FOR VARIOUS COOLING TECHNS	68.3
10	58	BEST MULTIMODE CYCLE & ENGINE SIZE	67.9
11	31*	REUSABLE HEAT SHIELD SYSTEMS	67.6
12	65	NOZZLE CONFIGURATIONS	66.5
.	4	TEST TECHNS FOR RE NO, SHOCK WAVE & BNDY LR PHEN	65.9
14	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	65.7
15	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	65.6
16	49*	EFFECTS ON PERF/DRAG OF INLET IN PRESSURE FIELD	65.3
17	50*	VARIABLE CAPTURE AREA INLET DESIGNS	64.1
18	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	63.8
19	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	63.4
20	33	CONTROL SURFACE TECHNOLOGY	62.8
21	36*	EFF OF COMB MECH LONG, THML STRS CYC, TEMP VAR	62.0
22	9	PARAMETERS AFFECTING STABILITY & CONTROL	62.0
23	40	TEST & INSP METHODS FOR ADVANCED STRUCTURES	61.2
24	53*	ENGINE COMPONENT TECHNOLOGY - CRYO FUELS	60.5
25	66*	VARIABLE NOZZLE GEOM REQS & MECHANICAL CONCEPTS	60.3
26	32	REUSABLE LEADING EDGE CONCEPTS	60.0
27	7	ENG EXST EXP FOR ADD LIFT/PROP GAS FLD INT EFCTS	59.1
28	8*	DES TECHNS FOR LO SPEED CHARS & TRAN DRAG REDUCT	58.7
29	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	58.7
30	21*	HYPER AEROTHERMO PREDICT TECHNS - ACT SIMULS	58.4
31	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	58.2
32	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	58.2
33	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	57.9
34	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	57.7
35	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	57.6
36	47*	PROTECTIVE COATINGS FOR METALS & NON-METALS	56.2
37	46	HIGH TEMPERATURE EQUIPMENT	55.3
38	6	SURFACE/INLET POSITION - FAVOR AERO INTEFERENCE	55.3
39	17*	PREDICT TECHNS FOR BNDY LAYER TRANSITION	53.9
40	4.	ESTIM OF COMPONENT/STRUCTURAL MASS FRACTIONS	53.7
41	20*	HEAT EFFECTS - FLOW FIELD/VEH GEOM INTERACTIONS	53.3
42	51*	REAL GAS EFFECTS ON INLET & NOZZLE PERFORMANCE	52.9
43	24*	EMBEDDED SHOCK, VORTEX, SEPAR & REATCH EFFECTS	51.6
44	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	51.5
45	70	REGEN CRYO HEAT EXCHRS/THRMO CORLS/COOL CNT STMS	49.2
46	54*	ADVANCED ENGINE COMPONENTS - LIGHT WT/SHORT LIFE	49.1
47	22	SURFACE SHAPING & PROTUR EFFECTS ON DRAG & HEAT	49.0
48	37*	EFF OF SEPARATION FORCES ON DYNAMIC CHARS	45.8
49	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	45.7
50	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	44.6
51	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	44.2
52	81*	HI TEMP ACTUATOR SYSTEMS - INLET & NOZZLE ADJS	44.2
53	80	ACTUATION TECHNS & HDWR FOR CNTL SURFACE MOTION	43.4
54	25	HEATING EFFECTS FROM FLOW THRU GAPS	42.7
55	94	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	42.5
56	87	TERMINAL APPROACH & LANDING METHODS	42.2
57	68	THML CCND, STORAGE & SAFE HNDLG OF CRYO FUELS	42.0
58	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	41.8
59	39	NEAR FIELD NOISE EFFECTS	41.8
60	73	CRYO SYSTEM COMPONENTS - RCD WT/INCR RELIABILITY	41.4
61	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	41.0
62	97	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	40.9
63	62	RKT-PWD ENGINE OPERATION IN HORIZ T/O A/C	40.5
64	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	40.2
65	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	40.1
66	13*	UNSTEADY CONTROL SURFACE HINGE MOMENTS	40.0
67	88*	HAZARDS INHERENT IN USE OF CRYO FUELS	39.9
68	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	39.8
69	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM DIP'S	39.8
70	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	39.5
71	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	39.2
72	85	LAUNCH TECHNS FOR AAM & ASM WEAPONS	39.1
73	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	38.5
74	35*	STRUCTURE MAINTAINING AERODYNAMIC SMOOTHNESS	38.4
75	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	38.1
76	90*	OPTIMUM LANDING TECHNS FOR HYPERSONIC VEHICLE	38.1
77	86*	HEAT SHLDNG MISSILE LNCHRS, DRS & INT STRUCTS	35.2
78	100*	PRACTICAL GROUND HOLD METHODS FOR CRYO SYSTEMS	35.2
79	64	AUXILIARY TURBOJETS FOR LANDING HYPERSONIC VEHS	35.1
80	92	ASCENT TRAJECTORY INVESTIGATION	34.9
81	99	SHORT TAKEOFF TECHNIQUES	32.4
82	18	EFFECTS OF REACTION CONTROL JETS	32.3
83	93*	EFCTS OF VEH DYN/CENTRIF EFCTS ON CREW/PSSNGRS	31.7
84	82	AUXILIARY POWER UNITS	31.3
85	74*	RAPID CRYOGENIC SERVICING TECHNIQUES	31.0
86	101	AIR TRAFFIC CNTL PRCDRS & GND-BASED NAV SYSTEMS	30.1
87	79	AIR DATA MEASUREMENT TECHNIQUES	29.3
88	77*	FLUSH OR RECESSED ANTENNA DESIGN TECHNIQUES	28.6
89	91	COMMUNICATION TECHNIQUES	25.6
90	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	24.7

FIGURE 3-37 OPERATIONAL SYSTEM NO. 9 – (M3) WEIGHTED AVERAGE FOR ALL EVALUATION CRITERIA

TECHNOLOGICAL AREA	REL. WT.	NO. EVALUATORS
A. AERODYNAMICS	.183	22
B. THERMODYNAMICS	.165	18
C. STRUCTURES & MATERIAL	.194	[illegible]
D. PROPULSION	.218	24
E. SUBSYSTEMS	.125	15
F. OPERATION	.124	19

EVALUATION CRITERION	REL. WT.
A. TECHNOLOGY ADVANCEMENT	.604
B. COST & SCHEDULE	.396

RANK	CODE	OBJECTIVE	WEIGHTED AVERAGE
1	11	SCRAMJET SYSTEMS - DEVELOP & DEMONSTRATE	77.2
2	48	INLET CONFIGURATIONS WITH DESIRABLE CHARS	76.8
3	28	REUS THML PROT STMS - CRYO FUELS/OXIDR TNKG	75.5
4	34	LONG-LIFE REGEN-COOLED STRUCTURAL CONCEPTS	72.7
5	43	REUSABLE THML PROTECT STMS - PRIMARY STRUCTURE	72.7
6	47	INLET/ENGINE COMPATIBILITY CRITERIA	71.9
7	3	SUPERSONIC & HYPERSONIC AERO CHARACTERISTICS	70.3
8	53*	ENGINE DESIGN CNCPTS FOR VARIOUS COOLING TECHNS	69.9
9	58	BEST MULTIMODE CYCLE & ENGINE SIZE	68.8
10	65	NOZZLE CONFIGURATIONS	68.2
11	31*	REUSABLE HEAT SHIELD SYSTEMS	67.6
12	49*	EFFECTS ON PERF/DRAG OF INLET IN PRESSURE FIELD	66.5
13	4	TEST TECHNS FOR RE NO, SHOCK WAVE & BNDY LR PHEN	65.9
14	44	MECH/PHYS PROPERTIES OF ADVANCED MATERIALS	65.7
15	45	FAB TECHNS - ADV MATERIALS/COMPLEX STRUCTURES	65.6
16	50*	VARIABLE CAPTURE AREA INLET DESIGNS	65.5
17	12	HYPERSONIC BOUNDARY LAYER BEHAVIOR	63.8
18	42	FULL SCALE COMP TEST OF STRCT/THMSTRCT SYSTEMS	63.4
19	33	CONTROL SURFACE TECHNOLOGY	62.8
20	53*	ENGINE COMPONENT TECHNOLOGY - CRYO FUELS	62.1
21	36*	EFF OF COMB MECH LONG, THML STRS CYC, TEMP VAR	62.0
22	9	PARAMETERS AFFECTING STABILITY & CONTROL	62.0
23	66*	VARIABLE NOZZLE GEOM REQS & MECHANICAL CONCEPTS	61.6
24	47	TEST & INSP METHODS FOR ADVANCED STRUCTURES	61.2
25	32	REUSABLE LEADING EDGE CONCEPTS	60.0
26	7	ENG CNST EXP FOR ADD LIFT/PROP GAS FLD INT EFCTS	59.1
27	8*	DES TECHNS FOR LO SPEED CHARS & TRAN DRAG REDUCT	58.7
28	1	LOW SPEED (T/O & LANDING) AERO CHARACTERISTICS	58.7
29	21*	HYPER AEROTHERMO PREDICT TECHNS - ACT SIMULS	58.4
30	30	FUSELAGE/TANK STRUCTS - MORE EFFICIENT CONCEPTS	58.2
31	19	CNTL SURFACE EFFECT/HEAT EFFECTS WHEN DEFLECTED	58.2
32	16	HEAT TRANS & DRAG FOR TURBULENT BOUNDARY LAYERS	57.9
33	5	OPTIMUM & ACCEPTABLE HANDLING QUALITIES	57.7
34	2	SUBSONIC & TRANSONIC AERO CHARACTERISTICS	57.6
35	47*	PROTECTIVE COATINGS FOR METALS & NON-METALS	56.2
36	46	HIGH TEMPERATURE EQUIPMENT	55.3
37	6	SURFACE/INLET POSITION - FAVOR AERO INTERFERENCE	55.3
38	17*	PREDICT TECHNS FOR BNDY LAYER TRANSITION	53.9
39	51*	REAL GAS EFFECTS ON INLET & NOZZLE PERFORMANCE	53.8
40	41	ESTIM OF COMPONENT/STRUCTURAL MASS EFFECTS	53.7
41	26*	HEAT EFFECTS - FLOW FIELD/VEH GEOM INTERACTNS	53.7
42	24*	EMBEDDED SHOCK, VORTEX, SEPAR & REATCH EFFECTS	51.6
43	20	HYPERSONIC AEROTHERMO PARAMS IN 3-DIM FLOW	51.5
44	54*	ADVANCED ENGINE COMPONENTS - LIGHT WT/SHORT LIFE	50.0
45	70	REGEN CRYO HEAT EXCHRS/THRMO CORLS/COOL CNT STMS	49.2
46	22	SURFACE SHAPING & PROTUB EFFECTS ON DRAG & HEAT	49.0
47	37*	EFF OF SEPARATION FORCES ON DYNAMIC CHARS	45.8
48	29	SHELL THEORY DEVELOPMENT - NON-CIRCULAR SHELLS	45.7
49	89	MAN-MACHINE COMPATIBILITY - CONTROL/NAVIGATION	44.6
50	75	FUEL TANK CONCEPTS/FUEL SYS OPER & CNTL TECHNS	44.2
51	81*	HI TEMP ACTUATOR SYSTEMS - INLET & NOZZLE ADJS	44.2
52	62	RKT-PWD ENGINE OPERATION IN HORIZ T/O A/C	43.6
53	10	ACTUATION TECHNS & POWR FOR CNTL SURFACE MOTION	43.4
54	25	HEATING EFFECTS FROM FLOW THRU GAPS	42.7
55	96	ABORT, FUEL DUMP, ESCAPE & EMERG EGRESS TECHNS	42.5
56	87	TERMINAL APPROACH & LANDING METHODS	42.2
57	68	THML COND, STORAGE & SAFE HNDLG OF CRYO FUELS	42.0
58	15	TECHNS FOR ALLEVIATING SONIC BOOM INTENSITY	41.8
59	39	NEAR FIELD NOISE EFFECTS	41.8
60	73	CRYO SYSTEM COMPONENTS - RED WT/INCR RELIABILITY	41.4
61	102	INSPECTION & REPAIR TECHNS FOR HYPER VEH STRCTS	41.0
62	97	LEAK DETECTION METHODS FOR CRYO FUEL TANKS	40.9
63	14	PREDICT TECHNS FOR BUFFET ONSET OF LOW AR A/C	40.2
64	27	PREDICT TECHNS FOR HEAT TRANSFER - ENG EXHAUST	40.1
65	13*	UNSTEADY CONTROL SURFACE HINGE MOMENTS	40.0
66	88*	HAZARDS INHERENT IN USE OF CRYO FUELS	39.9
67	95	EFFECTS OF VAR CONDS ON BOOST, CRUISE & DESCENT	39.9
68	78	STABILITY AUGMENT SYSTEMS/RECOVERY FROM PIOS	39.8
69	38	FUEL SLOSH EFFECTS ON DYNAMICS/INERTIA LOADS	39.5
70	96	CAPABILITY TO STAY WITHIN SPECIF OPER MARGINS	39.2
71	85	LAUNCH TECHNS FOR AAM & ASM WEAPONS	39.1
72	83	ENVIRON CNTL SYSTEM - LIQUID CRYO AS HEAT SINK	38.5
73	35*	STRUCTURE MAINTAINING AERODYNAMIC SMOOTHNESS	38.4
74	69	FLUID DYN/THERMODYN CHARS OF CRYO FUELS	38.1
75	97*	OPTIMUM LANDING TECHNS FOR HYPERSONIC VEHICLE	38.1
76	64	AUXILIARY TURBOJETS FOR LANDING HYPERSONIC VEH	37.8
77	86*	HEAT SHLDNG MISSILE LNCHRS, DRS & INT STRUCTS	35.2
78	100*	PRACTICAL GROUND HOLD METHODS FOR CRYO SYSTEMS	35.2
79	92	ASCENT TRAJECTORY INVESTIGATION	34.9
80	99	SHORT TAKEOFF TECHNIQUES	32.6
81	18	EFFECTS ON REACTION CONTROL JETS	32.3
82	93*	EFFCTS OF VEH DYN/CENTRIF EFFCTS ON CREW/PSSNGRS	31.7
83	82	AUXILIARY POWER UNITS	31.3
84	74*	RAPID CRYOGENIC SERVICING TECHNIQUES	31.0
85	101	AIR TRAFFIC CNTL PROCDS & GND-BASED NAV SYSTEMS	30.1
86	79	AIR DATA MEASUREMENT TECHNIQUES	29.3
87	77*	FLUSH OR RECESSED ANTENNA DESIGN TECHNIQUES	28.6
88	91	COMMUNICATION TECHNIQUES	25.6
89	76	FLUSH RECESSED ANTENNAS - COMPATIBLE PATTERNS	24.7

example, are shown in Figure 3-20 for the baseline case. For comparison, the results when the 26 additional objectives pertaining to the possible options or redundancies are included are shown in Figure 3-34. Inclusion of these additional objectives results in a slight reordering of the baseline objectives (those without asterisks), relative to the rankings shown in Figure 3-20. This reordering occurs because the 26 new objectives are not simply inserted in the ranking matrix. Rather, the evaluation process is represented in its entirety, resulting in a slight variation in the intrinsic values of all of the Research Objectives.

In another indication of trends, the areas of the most highly desirable research are seen by examination of Figure 3-38. The order presented is based on averaging the rank (not intrinsic value) determined for the objectives for each operational system. For example, Objective No. 60, "Develop and Demonstrate Convertible Scramjet Systems", was ranked first for each of the four operational systems to which it applied, thus obtaining an average rank of 1.0, while Objective No. 57, "Develop and Demonstrate Turboramjet Systems" was ranked first twice, second twice, and third once for the five operational systems to which it applied, thus obtaining an average rank of 1.8. Only the first 10 of the 102 Research Objectives are shown in the illustration. The dominating Research Objectives again are those involving propulsion systems and reusable thermal protection systems.

FIGURE 3-38 AVERAGE RANKINGS

Vehicle Design Options Included - 10 of 102 Objectives Shown

NO.	OBJECTIVE	RANK BY OPERATIONAL SYSTEM								
		L_1	L_2	L_3	L_4	C_1	C_2	M_1	M_2	M_3
60	Convertible Scramjet Development	--	1	--	1	--	1	--	1	--
57	Turboramjet Development	2	3	--	--	1	2	1	--	--
28	Reusable Thermal Protection Systems - Cryogenic Tankage	1	2	2	3	3	3	2	3	3
48	Inlet Configurations	3	4	--	2	2	4	3	2	1
59	Ramjet Development	4	--	--	--	4	--	4	--	--
61	Scramjet Development	--	7	--	4	--	5	--	4	2
34	Regeneratively Cooled Structures	5	5	3	5	6	7	7	5	4
43	Reusable Thermal Protection Systems - Primary Structures	6	6	4	6	5	6	5	6	5
3	Supersonic and Hypersonic Aerodynamic Characteristics	7	8	5	8	7	8	6	8	7
67	Inlet/Engine Compatibility Criteria	9	10	--	7	8	9	8	7	6

NOTE: The dashes indicate that the research objective does not apply to the particular system.

6. GROUND FACILITY SYNTHESIS

Examination of the Research Objectives listed in Figure 3-2 indicates areas where ground research facilities can make a significant contribution to potential new aircraft concepts. The various facility functions and data requirements necessary to achieve the pertinent research were determined, and from this information the facility concepts were formulated. The results of this formulation are summarized as fifty-four individual facility descriptions in Figure 6-1.

6.1 APPROACH

The research needed to design and develop an operational vehicle requires a complex array of test facilities. Because of the diversity of facility types and the unique specialization associated with each facility, very few facilities actually duplicate each other in performance or purpose. In order to determine what type facilities were necessary to meet the experimental requirements, the following formulation criteria were devised: How much research can the facility accomplish; what increment does it offer over existing facilities for the costs involved, and what is its contribution to the confidence level leading to the development of an operational vehicle?

Two categories of ground facilities were analyzed as part of the facility synthesis. First, those which have capability to conduct research necessary to obtain the confidence required to initiate development of a configuration; second, those which provide the experimental capability to develop and qualify a configuration. The categories of ground research facilities considered in this synthesis are:

- Gasdynamic
- Engine
- Structures
- Materials
- Flight Simulation
- Fluid Systems
- Subsystem Test
- Avionics
- Nuclear Radiation.

The sizing criteria for the research oriented facilities require a more in-depth development than those for facilities primarily intended to test full scale hardware. The Phase I facility syntesis is based on current construction and hardware technology to provide a realistic basis for the facility cost estimates. Some of the facilities presented represent only the size and performance of the facility required to accomplish research objectives. Exact determinations of the techniques with which this performance will be obtained will result from the more detailed analyses in Phase II.

6.2 CANDIDATE GROUND FACILITIES

Figure 6-1 provides a brief general description of the candidate facilities, with more detailed descriptions and cost comparisons contained in Figure 6-103. These candidate facilities were selected on the basis of their potential to accomplish the research objectives presented in Section 3. In developing the matrix of candidate facilities, the following factors were considered:

(a) Performance and size increment necessary over existing facilities

(b) Extent of necessary simulation required for a facility concept

(c) Facility operational times consistent with tasks to be accomplished and providing necessary data on timely basis

(d) Variations in the potential vehicle's size, operational envelope, fuel, materials, and propulsion system.

The performance requirements selected for each candidate ground facility baseline design were based on a judgement as to what was required to accomplish the identified research objectives. The ground rules used for establishing this baseline for the nine categories of facilities are given in the following:

The gasdynamic research facilities were sized on the assumption that a capability of achieving 20% maximum full scale Reynolds number was required. This is compared to the approximately 7% maximum full scale Reynolds number capability of existing facilities, when considering the largest potential operational hypersonic aircraft. All of the gasdynamic facilities listed in Figure 6-1 are probably within the current state-of-the-art in terms of fabrication technology, but represent a size and dollar investment not currently undertaken.

The design of the engine research facilities was based on the premise that duplicated flight conditions would be necessary to develop and qualify actual advanced engines for the manned research aircraft, as well as the potential operational aircraft. This premise resulted from the assumption that the engine operating temperatures should be as close to actual values as possible for advanced technology engines operating at near stoichiometric fuel/air ratios.

The structural research facilities were initially sized on the assumption that a large airframe section of a full scale potential operational aircraft is desirable to obtain meaningful structural data. The degree of environmental simulation necessary would result from the Phase I analysis.

The materials research facilities were formulated as low cost, highly productive facilities which could translate data from less expensive, small scale experiments into design criteria for potential operational aircraft which could be verified in the structural research facilities.

The flight simulator facilities were formulated to provide a complete research capability at one location. The candidate facilities are not beyond the current state-of-the art in computer speed and capacity; however, the accelerations and displacements represent a step beyond any current plans.

The fluid test, subsystem, and avionics research facilities were sized on the simple premise that full scale hardware research was necessary to develop and qualify equipment for potential operation aircraft. The avionics facilities are extensions of current capability. For flight conditions less than Mach 12, telemetry can be accomplished at S band frequencies (2-3 GHz), and communications can be accomplished at X band frequencies (10 GHz).

The radiation research facility was envisioned as providing data pertaining to structure, material, hardware, and human damage incurred in a military situation where offensive weapons attack is a probability.

FIGURE 6-1 GROUND TEST FACILITY SUMMARY

Type	Facility Code-Name	English Units		S.I. Units		Run Time
		Size	Simulation	Size	Simulation	
Gasdynamic	GD1 High Reynolds Number Subsonic Wind Tunnel	17 x 24 ft	$0 \leq M \leq 0.6$ $(Re/ft)_{MAX} = 10.5 \times 10^6$	5.18 x 7.32 m	$0 \leq M \leq 0.6$ $(Re/m)_{MAX} = 34.4 \times 10^6$	Continuous
	GD2 High Reynolds Number Near Sonic Tunnel	17 x 24 ft	$0 \leq M \leq 1.0$ $(Re/ft)_{MAX} = 22.0 \times 10^6$	5.18 x 7.32 m	$0 \leq M \leq 1.0$ $(Re/m)_{MAX} = 72.1 \times 10^6$	Continuous
	GD3 High Reynolds Number Trisonic Blowdown Wind Tunnel	16 x 16 ft	$0.5 \leq M \leq 5.0$ $(Re/ft)_{MAX} = 39 \times 10^6$	4.9 x 4.9 m	$0.5 \leq M \leq 5.0$ $(Re/m)_{MAX} = 128 \times 10^6$	30 Seconds
	GD4 Ludwieg Tube, High Reynolds Number Trisonic Wind Tunnel	9 x 12 ft	$0.5 \leq M \leq 3.0$ $(Re/ft)_{MAX} = 150 \times 10^6$	2.7 x 3.7 m	$0.5 \leq M \leq 3.0$ $(Re/m)_{MAX} = 492 \times 10^6$	0.8 to 1.5 Seconds
	GD5 High Reynolds Number Hotshot Type Hypersonic Wind Tunnel	10 ft Dia	$8 \leq M \leq 13$ $(Re/ft)_{MAX} = 12 \times 10^6$	3.05 m Dia	$8 \leq M \leq 13$ $(Re/m)_{MAX} = 39 \times 10^6$	200 Milliseconds
	GD6 High Reynolds Number Shock Tube Driven Hypersonic Wind Tunnel	10 ft Dia	$8 \leq M \leq 13$ $(Re/ft)_{MAX} = 20 \times 10^6$	3.05 m Dia	$8 \leq M \leq 13$ $(Re/m)_{MAX} = 66 \times 10^6$	to 3 Milliseconds
	GD7 High Reynolds Number Gas Piston Driven Hypersonic Wind Tunnel	10 ft Dia	$8 \leq M \leq 13$ $(Re/ft)_{MAX} = 17 \times 10^6$	3.05 m Dia	$8 \leq M \leq 13$ $(Re/m)_{MAX} = 55 \times 10^6$	1 to 4 Seconds
	GD8 High Pressure Alumina Storage Heater Tunnel	12 ft Dia	$5 \leq M \leq 10$ $(Re/ft)_{MAX} = 5 \times 10^6$	3.7 m Dia	$5 \leq M \leq 10$ $(Re/m)_{MAX} = 16.4 \times 10^6$	30 Seconds
	GD9 High Pressure Zirconia Storage Heater Tunnel	5 ft Dia	$8 \leq M \leq 13$ $(Re/ft)_{MAX} = 8 \times 10^6$	1.5 m Dia	$8 \leq M \leq 13$ $(Re/m)_{MAX} = 26.2 \times 10^6$	30 Seconds

FIGURE 6-1 GROUND TEST FACILITY SUMMARY (CONTINUED)

Type	Facility Code-Name	English Units		S.I. Units		Run Time
		Size	Simulation	Size	Simulation	
Gasdynamic	GD10 Multirecompression Heater Wind Tunnel	5 ft Dia	$5 \leq M \leq 13$ $(Re/ft)_{MAX} = 2.1 \times 10^6$	1.5 m Dia	$5 \leq M \leq 13$ $(Re/m)_{MAX} = 6.9 \times 10^6$	1 Minute
	GD11 High Pressure Electric Arc Heated Wind Tunnel	6 ft Dia	$5 \leq M \leq 13$ $(Re/ft)_{MAX} = 0.45 \times 10^6$	1.8 m Dia	$5 \leq M \leq 13$ $(Re/m)_{MAX} = 1.47 \times 10^6$	to 30 Minutes
	GD12 Large Bore Gun Launch Range	10 ft Dia x 1000 ft Long	$M \leq 10$ $(Re/ft)_{MAX} = 385 \times 10^6$	3.05 m Dia x 305 m Long	$M \leq 10$ $(Re/m)_{MAX} = 1260 \times 10^6$	8 Milliseconds
	GD13 Holloman Test Track with Extended Track Modification	13.4 Miles Long	$M \leq 7.0$ $(Re/ft)_{MAX} = 50 \times 10^6$	21.6 km Long	$M \leq 7.0$ $(Re/m)_{MAX} = 164 \times 10^6$	
	GD14 Rocket Launched Scale Models		$10 \leq M \leq 15$ @ 50,000 ft 11.9×10^6 $(Re/ft)_{MAX}$ 17.8×10^6		$10 \leq M \leq 15$ @ 15,000 m 11.9×10^6 $(Re/m)_{MAX}$ 38.4×10^6	
	GD15 Electric Heated Hypersonic Blowdown Tunnel	8.86 x 8.86 ft	$3 \leq M \leq 8.5$ $(Re/ft)_{MAX} = 34 \times 10^6$	2.7 x 2.7 m	$3 \leq M \leq 8.5$ $(Re/m)_{MAX} = 111 \times 10^6$	20 Seconds
	GD16 Ludwieg Tube Hypersonic Tunnel	8.86 x 8.86 ft	$3 \leq M \leq 8.5$ $(Re/ft)_{MAX} = 50 \times 10^6$	2.7 x 2.7 m	$3 \leq M \leq 8.5$ $(Re/m)_{MAX} = 164 \times 10^6$	1 Second
	GD17 High Reynolds Number Trisonic Continuous Wind Tunnel	16 x 16 ft	$0.5 \leq M \leq 5.0$ $(Re/ft)_{MAX} = 39 \times 10^6$	4.9 x 4.9 m	$0.5 \leq M \leq 5.0$ $(Re/m)_{MAX} = 128 \times 10^6$	Continuous

FIGURE 6-1 GROUND TEST FACILITY SUMMARY (CONTINUED)

Type	Facility Code-Name	English Units		S.I. Units		Run Time
		Size	Simulation	Size	Simulation	
Engine Test	E1 Large Rocket Test Cell					
	a) AEDC LRF Test Cell J4	48 ft Dia x 81.5 ft Long	106 to 140 kft 0.5×10^6 to 1.5×10^6 lb Thrust	14.6 m Dia x 25 m Long	32 to 43 km 2.2×10^6 to 6.7×10^6 N Thrust	
	b) AEDC RTF Test Cell J3	18 ft Dia x 40 ft Long	50 to 150 kft 0.2×10^6 lb Thrust	5.5 m Dia x 12.2 m Long	15 to 46 km 0.9×10^6 N Thrust	
	E2 Wind Tunnels Designed to Test Air-Breathing Engines GD1, 2, 3 GD5, 6, 7, 8, 9, 10, 11		Full Scale Tests Sub Scale Tests		Full Scale Tests Sub Scale Tests	
	E3 Turbomachinery Test Facility	16 ft Dia x 72 ft Long	Altitude 10-60 kft Mass Flow Rate - 1300 lb/sec	4.9 m Dia x 22 m Long	Altitude 3-18 km Mass Flow Rate - 590 kg/sec	
	E4 Exhaust Nozzle Test Facility		$5 \leq M \leq 13$ Altitude $\leq$ 150 kft		$5 \leq M \leq 13$ Altitude $\leq$ 46 km	
	E5 Engine Dynamic Simulator		Can accommodate full scale or scaled inlet/ engine sections		Can accommodate full scale or scaled inlet/ engine sections	Continuous
	E6 Direct Connect Turbomachinery Test Cell	Inlet Capture Area 44 ft^2	$0 \leq M \leq 5$ $0 \leq Z \leq 85$ kft	Inlet Capture Area 4.1 m^2	$0 \leq M \leq 5$ $0 \leq Z \leq 26$ km	Continuous
	E7 Free Jet Turbomachinery Engine Facility	Inlet Capture Area 44 ft^2	$0 \leq M \leq 5$ $0 \leq Z \leq 85$ kft	Inlet Capture Area 4.1 m^2	$0 \leq M \leq 5$ $0 \leq Z \leq 26$ km	Continuous

FIGURE 6-1 GROUND TEST FACILITY SUMMARY (CONTINUED)

Type	Facility Code-Name		English Units		S.I. Units		Run Time
			Size	Simulation	Size	Simulation	
Engine Test	E8	Multirecompression Heater Ram/Scramjet Engine Facility	Inlet Capture Area 10 ft^2	$3 \leq M \leq 12$ (Simulated) $75 \leq Z \leq 160$ kft	Inlet Capture Area 0.93 m^2	$3 \leq M \leq 12$ (Simulated) $23 \leq Z \leq 49$ km	Continuous
	E9	Hybrid Heater Scramjet Engine Facility	Inlet Capture Area 10 ft^2	$3 \leq M \leq 8.5$ $75 \leq Z \leq 160$ kft	Inlet Capture Area 0.93 m^2	$3 \leq M \leq 8.5$ $23 \leq Z \leq 49$ km	Comb. Prod. - Cont. Air 30 Sec
	E10	600 Megawatt Arc Heater	Inlet Capture Area 10 ft^2	$6 \leq M \leq 12$ $75 \leq Z \leq 160$ kft	Inlet Capture Area 0.93 m^2	$6 \leq M \leq 12$ $23 \leq Z \leq 49$ km	30 Minutes
	E20	Integrated Turbo-machinery Engine Facilities (E6 and E7 operated as Integrated Facility)					
Flight Simulation	FS1	Flight Simulator Crew Trainer Facility		6 Degrees of Freedom		6 Degrees of Freedom	
	FS2	Takeoff and Landing Simulator		6 Degrees of Freedom Dynamic Takeoff and Landing Simulation		6 Degrees of Freedom Dynamic Takeoff and Landing Simulation	
	FS3	Launch Cruise Simulator		6 Degrees of Freedom Acceleration Simulation, Sensible Acoustic Simulation, Centrifuge		6 Degrees of Freedom Acceleration Simulation, Sensible Acoustic Simulation, Centrifuge	

FIGURE 6-1 GROUND TEST FACILITY SUMMARY (CONTINUED)

Type	Facility Code-Name	English Units		S.I. Units		Run Time
		Size	Simulation	Size	Simulation	
Structures Test	S1 Airframe Static Test Facility	Floor 150 x 350 ft Ceiling 100 ft High	Thermal and Mechanical Load Simulation	Floor 46 x 107 m Ceiling 30.5 m High	Thermal and Mechanical Load Simulation	
	S2A Airframe Dynamic Structural Evaluation Facility	Environment Chamber 150x350x 100 ft high Ceiling and Floor 350 x 150 ft	Static Dynamic, and Thermal Load Simulation to 150 kft	Environment Chamber 46x107x 30.5m high Ceiling and Floor 107 x 46 m	Static Dynamic, and Thermal Load Simulation to 46 km	
	S2B Major Component Dynamic Structural Evaluation Facility	Chamber 100 x100x50 ft Ceiling and Floor 100 x 100 ft	Dynamic and Thermal Load Simulation to 150 kft	Chamber 30.5 x30.3x15 m Ceiling and Floor 30.5 x 30.5 m	Dynamic and Thermal Load Simulation to 46 km	
	S3 Thermal-Mechanical Fatigue Component Test Facility		Thermal and Mechanical Load Simulation		Thermal and Mechanical Load Simulation	
	S4 Airframe Acoustic Test Facility	Acoustic Shroud Enclosure 350 x 150 x 100 ft	170 dB-150 KHz	Acoustic Shroud Enclosure 107 x 46 x 30.5 m	170 dB-150 KHz	
	S5 Component Thermal Acoustic Test	50x50x50 ft	170 dB - 0-5 KHz Thermal Load Simulation	15x15x15 m	170dB - 0-5 KHz Thermal Load Simulation	

FIGURE 6-1 GROUND TEST FACILITY SUMMARY (Continued)

Type	Facility Code-Name		English Units		S.I. Units		Run Time
			Size	Simulation	Size	Simulation	
Structures Test	S6	Tankage Thermal Structural Dynamic Test Facility	Floor 250 x 100 ft	Thermal - 0-25 Btu/ft^2 sec Dynamic - 500,000 lb (2,220,000 N)	Floor 76 x 30.5 m	Thermal - 0-284 kW/m^2 Dynamic - 2,220,000 N	
	S7	Cabin Pressurization Facility	350x150x 100 ft	200 gpm @ 15 psig	107x46x x 30 m	.75 m^3/min @ 10.3 N/cm^2	
	S8	Transparency Test Facility	500 ft^2	65°F to 2500°F	46.5 m^2	18.3^{o}C to 1372°C	
	S9	Cruise-Descent Thermal Vacuum Test Facility	350x150x 100 ft	Altitude Simulation to 150 kft. Thermal Load Simulation .	107x46x30 m	Altitude Simulation to 46 km. Thermal Load Simulation.	
Materials Research	M1	Local Flow Simulation Facility		Local Pressure, gas velocity, and temperature.		Local Pressure, gas velocity, and temperature.	
	M2	Thermal/Mechanical Fatigue Facility		450 to 4500°F over 6 ft^2 - Thermal $\pm$ 1,000,000 lb Mechanical (4,440,000 N)		232 to 2500°C over 0.56 m^2 - Thermal $\pm$ 4,440,000 N Mechanical	
	M4	Fabrication Technology Facility	Vacuum Furnaces 10x10x10 ft Hydrocave 20 x 10 ft Autoclave 80x40x20 ft	3000°F 10,000 psi, 2000°F +500 psid, 1200°F	Vacuum Furnaces 3.05 x 3.05 x 3.05 m Hydrocave 6.1 x 3.05 m Autoclave 24.4x12.2x 6.1 m	1650°C 6,900 N/cm^2, 1095°C 345 N/cm^2, 650°C	
Fluid Systems	F1	Environmental Control Systems Test	50 x 100 ft	Thermal - 1-10 Btu/ft^2 sec Altitude - to 150 kft	15.2x70.5 m	Thermal - 11.4-114 kW/m^2 Altitude - to 46 km	

FIGURE 6-1 GROUND TEST FACILITY SUMMARY (Continued)

Type	Facility Code-Name		English Units		S.I. Units		Run Time
			Size	Simulation	Size	Simulation	
Fluid Systems	F4	Fuel System Dynamic Facility	30 ft Dia x 100 ft Long	Altitude to 150 kft Heating 25 Btu/ft^2 sec over 5000 ft^2 Mechanical - 2000 lb	9.1 m Dia x 30 m Long	Altitude to 46 km Heating 284 kW/m^2 sec over 465 m^2 Mechanical - 8900 N	
	F5	Fuel Handling Technology Test Facility	10 x 20 ft	Altitude to 150 kft	3 x 6 m	Altitude to 46 km	
Subsystem Test	SS1	Fire Suppression System Test Facility	350x150x 100 ft	Altitude to 150 kft Thermal to 3500°F	107x46x30 m	Altitude to 46 km Thermal to 1930°C	
	SS2	Landing Gear Test Facility	Droptower 75 ft Sled Track 30 kft Long	750,000 lb Load (3,320,000 N) 350 Knots, 750,000 lb (3,320,000 N)	Droptower 23 m Sled Track 9.2 km	3,320,000 N Load 190 m/sec (3,320,000 N)	
Nuclear Test	R1	Nuclear Blast		Thermal - 1500 Btu/ft^2 sec over 0.5 ft^2 for 0.5 sec Nuclear - -5 Rad/Sec x -3×10^{13} Rad/Sec 10^{14} Neutrons, cm^2 sec		Thermal - 17,000 kW/m^2 over 465 cm^2 for 0.5 sec Nuclear - -10^5 Rad/Sec x -3×10^{13} Rad/Sec 10^{14} Neutrons/cm^2 sec	
Avionics	A1	Anechoic Chamber	300x100x 100 ft	-30 dB @ 1000 MHz reflectively	92x30x30 m	-30 dB @ 1000 MHz reflectively	
	A2	Microwave Range	1 x 1 Mile		1.6 x 1.6 km		

6.3 FACILITY DESIGN REQUIREMENTS

In discussing the facility design requirements, the governing criteria are grouped into a) a general category related to all types of ground facilities and b) individual requirements related to a more specific description of a particular facility. General criteria are discussed here, while individual requirements are discussed in the sections devoted to the different facility types.

The general criteria consist of defining the boundaries within which the proposed aircraft will fly and specific limitations which apply within these boundaries. These areas are those required to be experimentally simulated; and which will dictate test facility requirements.

Flight paths representative of the potential operational hypersonic vehicles are presented in Figure 6-2. For the purpose of determining general facility operating envelopes, a flight corridor bounded by a dynamic pressure of 2000 psf (95,700 N/m^2) as a maximum, and 200 psf (9570 N/m^2) as a minimum appears to provide a realistic expression of the range of Mach numbers and altitudes for the HYFAC aircraft.

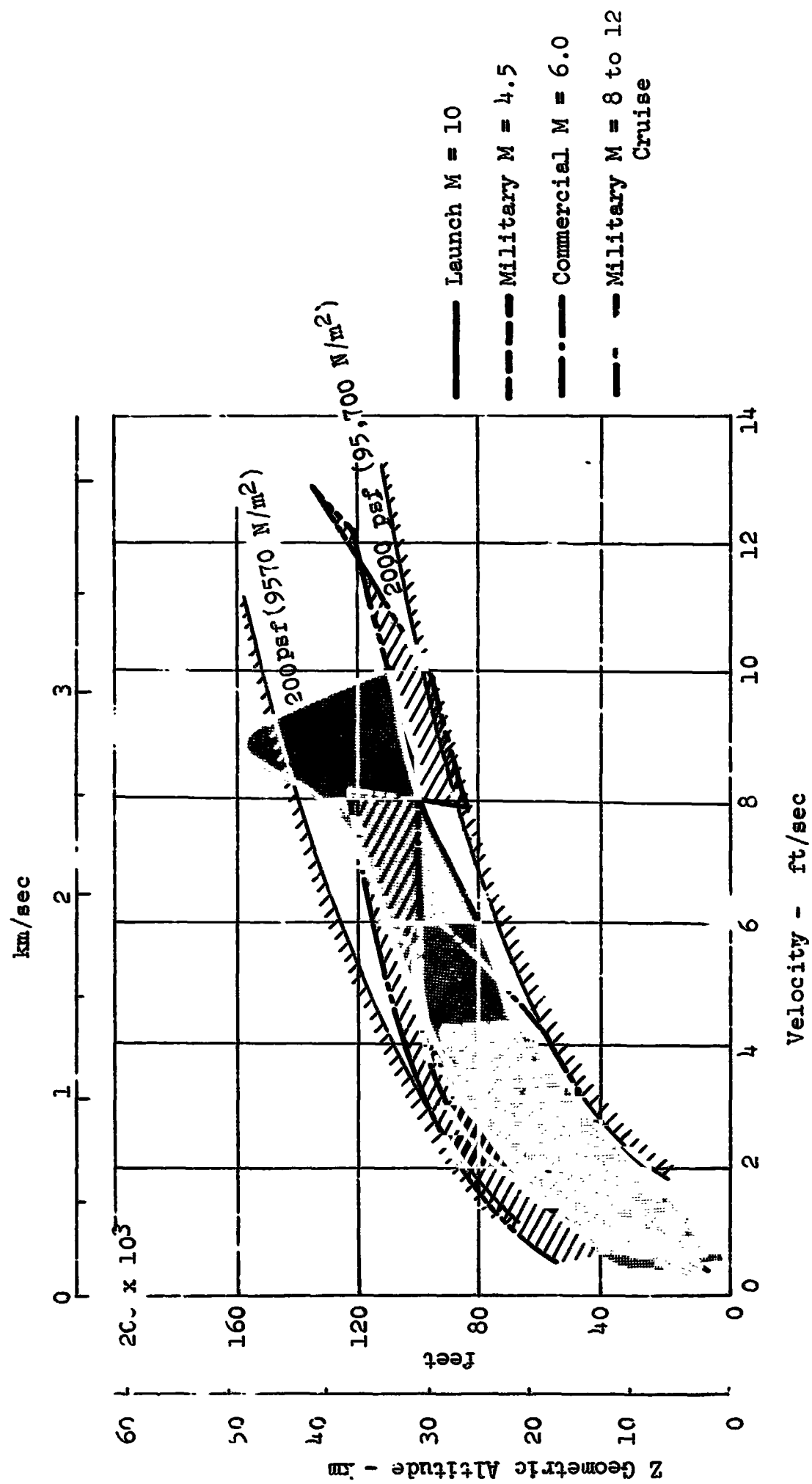
Within this flight corridor differing aerodynamic and thermodynamic flow regimes could be encountered in the local flow fields around the aircraft. Figure 6-3 is an attempt to clarify which flow regimes are pertinent to the class of aircraft represented in Volume VI, and their influence on the facilities which must provide the necessary simulation.

The aerodynamic flow regimes could range from free molecular flows (essentially no intermolecular collisions except in region of physical body) to continuum flows (intermolecular collisions predominate the state description). These different flow regimes could require significantly different experimental methods and flow diagnostic techniques. Their definition with respect to the nine potential operational vehicles is important. From Figure 6-3 it is seen that the majority of the flight envelope falls within the continuum flow regime, and at worst, encounters some transition into the slip flow, for distances of one foot (.305 m) or less. Therefore, non-continuum flow will be restricted to small regions near leading edges, and the overall aerodynamics will be governed by continuum aerodynamics.

The thermodynamic regimes are important to many aspects of experimental research. Depending on the degree of chemical equilibrium and the chemical composition of the gas adjacent to the wall, both the heat transfer rate and the useful life of the surface material could be affected through local chemical reactions between the wall and adjacent boundary layer flow.

From the plot of thermodynamic flow regimes it is possible to indicate the areas in the flight corridor where chemical kinetics can become important, and the extent that chemical nonequilibrium effects are present. The majority of the HYFAC flight corridor lies in the region where chemical effects are negligible. However, at altitudes and velocities greater than those governing this study, nonequilibrium chemistry effects could be an important factor, with 40 to 50 percent of the flow energy frozen in disassociated molecular species. However for the HYFAC aircraft, the nonequilibrum chemistry effects are restricted to areas adjacent to the leading edges of the craft. The gas flow encountered

FIGURE 6-2 FLIGHT PATHS OF SELECTED POSSIBLE OPERATIONAL HYPERSONIC AIRCRAFT

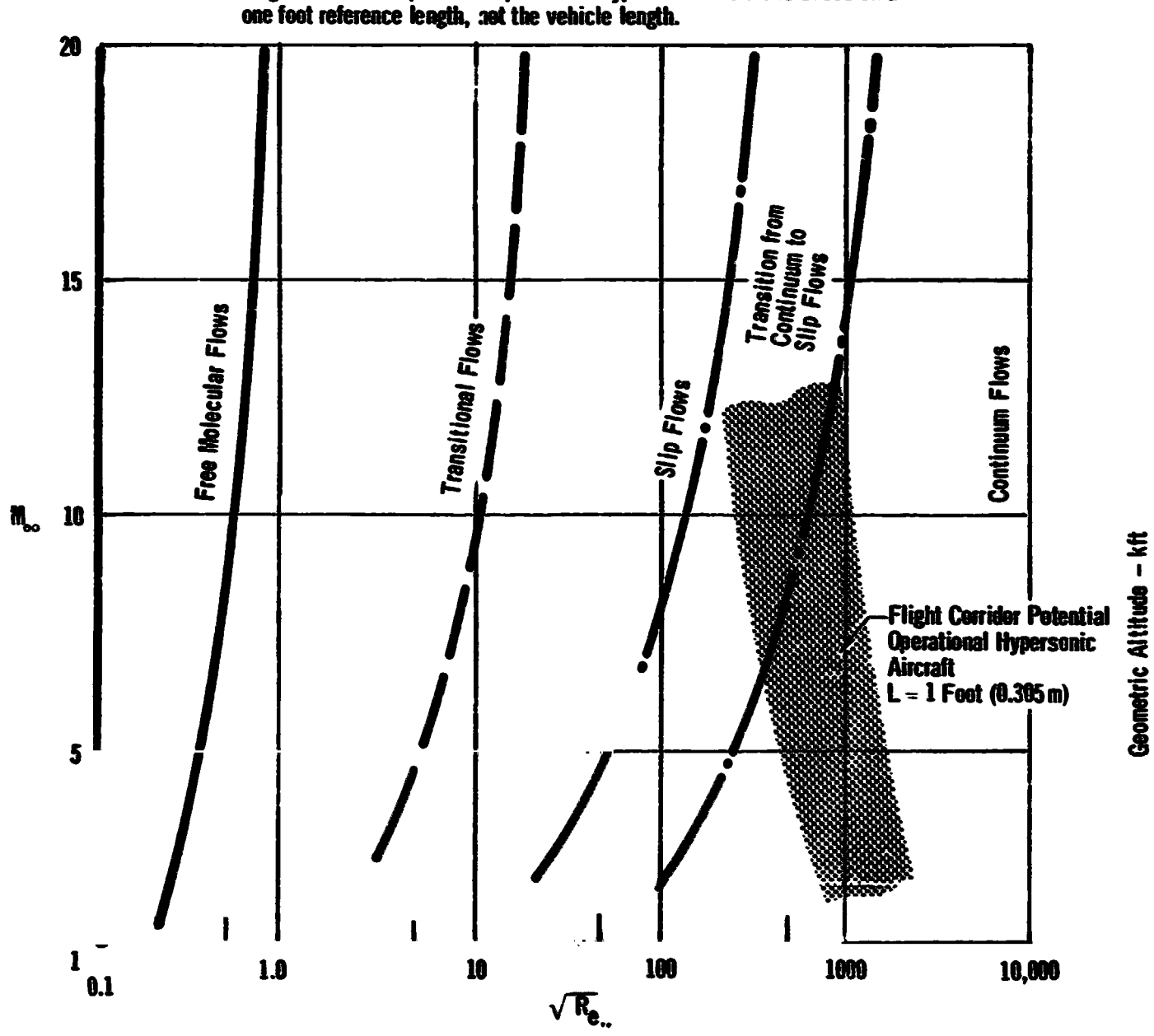


FOLDOUT FRAME 1

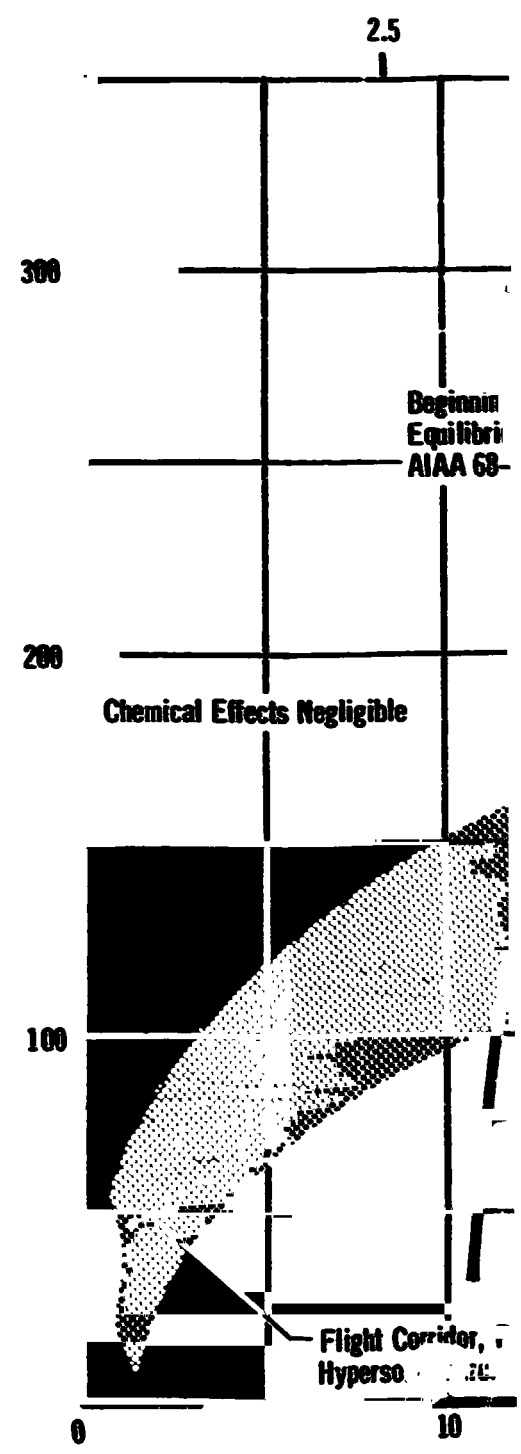
FIGURE 6–3 SUMMARY OF HYFAC VEHICLE FLOW REGIMES

Aerodynamic Flow Regimes

Flight corridor for potential operational hypersonic aircraft is based on a one foot reference length, not the vehicle length.



Thermo



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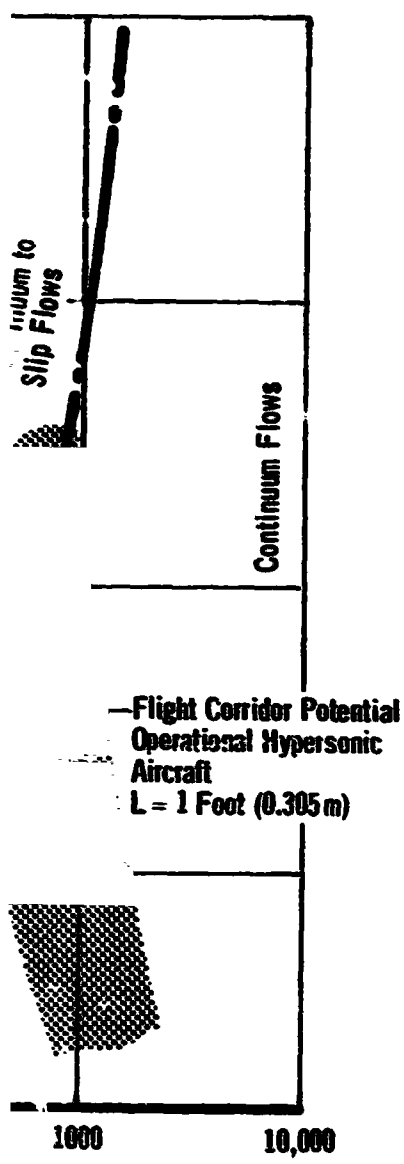
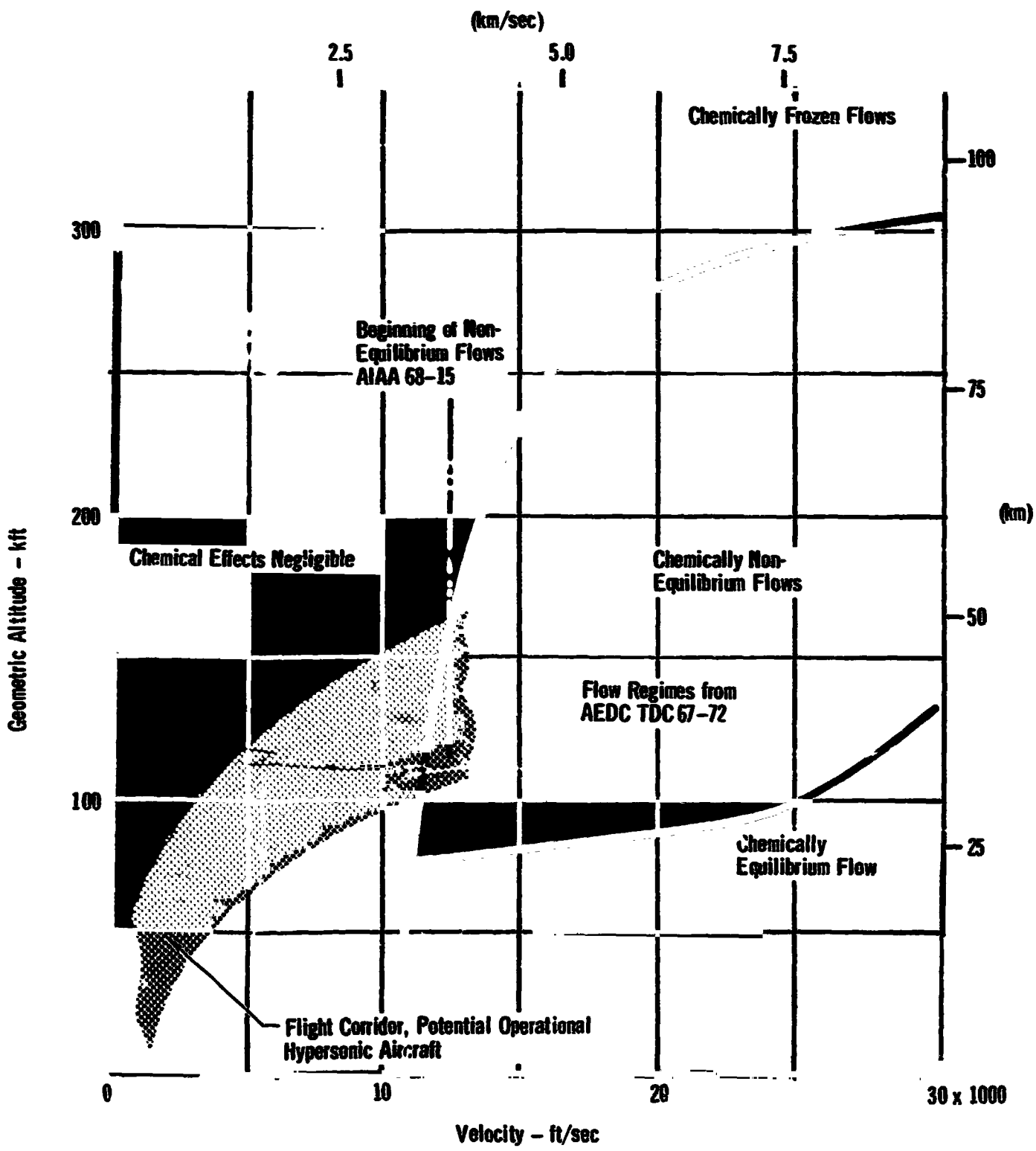
FOLDOUT FRAME 2

EHICLE FLOW REGIMES

based on a



Thermodynamic Flow Regimes



by the aircraft may then be treated as continuum flows with negligible nonequilibrium chemistry effects. For the purpose of simulation, the flows will be considered as a perfect gas with variable specific heats.

The generalized corridor does not provide all the information necessary to judge the simulation requirements because it does not present any limitations on the flight envelope imposed by structural limits, and elevated temperature properties of the materials used to fabricate the vehicle.

Figure 6-4 represents a modification to the general flight corridor to reflect different limitations and operating regions for the potential operational aircraft. The noise and sonic boom limits are applicable to transport systems or any system which must operate over populated areas with the consent of local government. The duct pressure limits apply to ramjets and other engines enclosed in ducts where subsonic duct flow exists. The scramjet with its supersonic combustion and lower static pressures could fly near the maximum dynamic pressure limit.

To assess the limitation associated with elevated surface temperatures, it is necessary to relate material temperature limits to angle of attack, load factor, Mach number and altitude. A relation for constant surface temperature as a function of angle of attack, Mach number, and altitude is presented in Figure 6-5. Using a MCAIR boundary layer heating analysis, the Mach number and altitude combination which produce a given surface radiation equilibrium temperature for a selected angle of attack can be determined. These surface temperatures are based on a surface emissivity of 0.8 and a distance from 5 to 10 feet (1.5 to 3.0 m) aft of the leading edge. The surface temperature given are for reusable structures, which reduces its maximum useful temperature in order to achieve longer service life. Except in the case of aluminum and titanium, this limitation is not a structural limitation, but rather an estimate of the life of the emissivity and oxidation resistant coating as a function of temperature. For limited life structures the maximum useful temperature could be increased about 200°F (100°C).

A second surface temperature limitation can be presented by the material system used on the upper structure of the vehicle. These areas of the aircraft on the leeward side usually experience lower heating rates than those on the windward side, therefore the material system is not always the same. Increased surface temperatures encountered at reduced or negative angles of attack may restrict the maneuvering capability if the material system on the upper surface was selected assuming a higher angle of attack operation.

Using a constant angle of attack to represent a temperature boundary is probably inconsistent with the operation of an airplane, since they generally fly at a constant load factor. The load factor can be expressed as:

$$\eta_z = \frac{C_L S_W q_\infty}{W_c} = \frac{\gamma C_L P_\infty M_\infty^2}{2(W/S_W)}$$

where:

$$\frac{L}{S_W} = \eta_z \left(\frac{W}{S_W}\right)$$

FIGURE 6-4 FLIGHT CORRIDOR BASED ON POSSIBLE OPERATIONAL HYPERSONIC AIRCRAFT

a. English Units

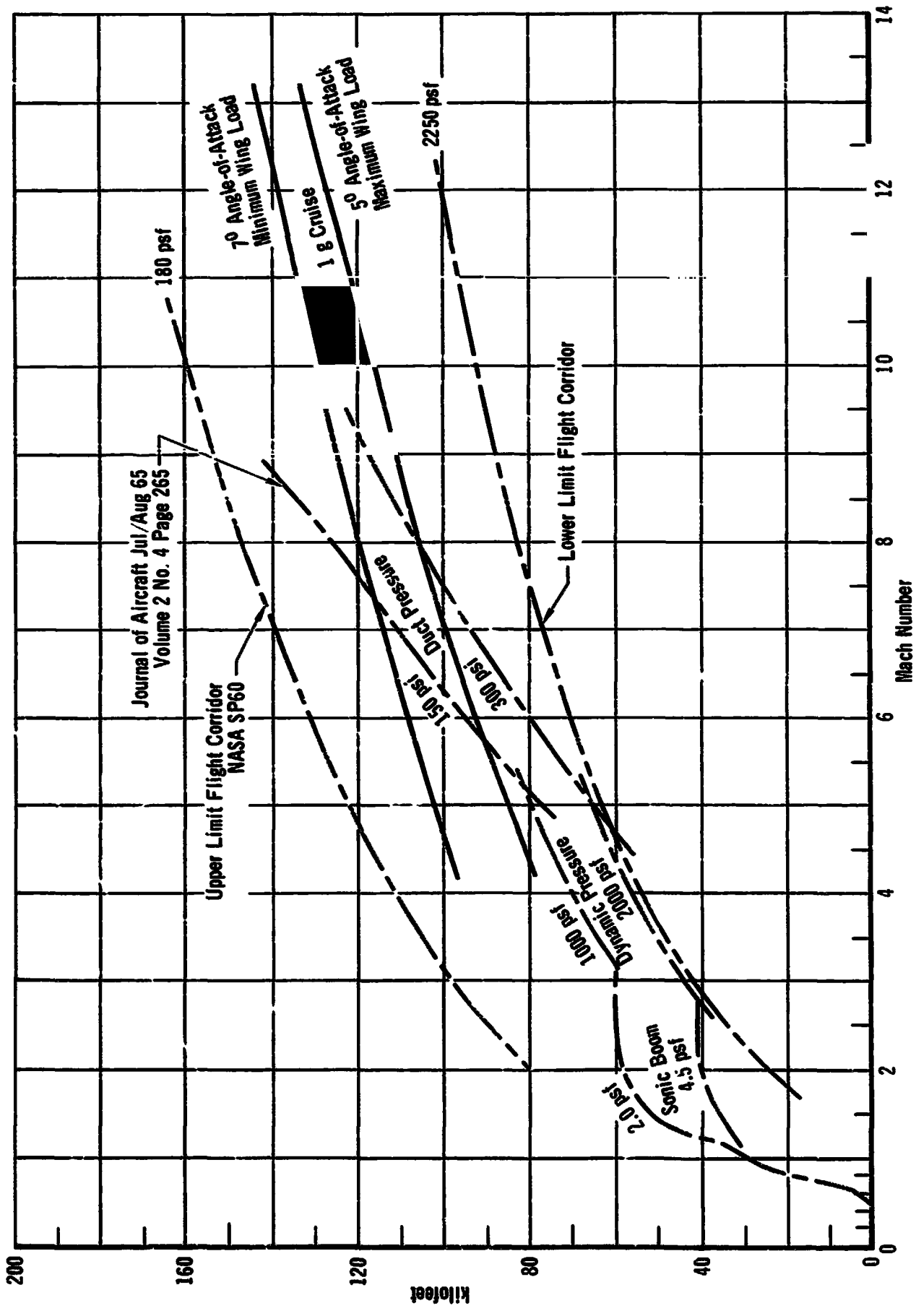


FIGURE 6-4 FLIGHT CORRIDOR BASED ON POSSIBLE OPERATIONAL HYPERSONIC AIRCRAFT (CONTINUED)

b. Standard International Units

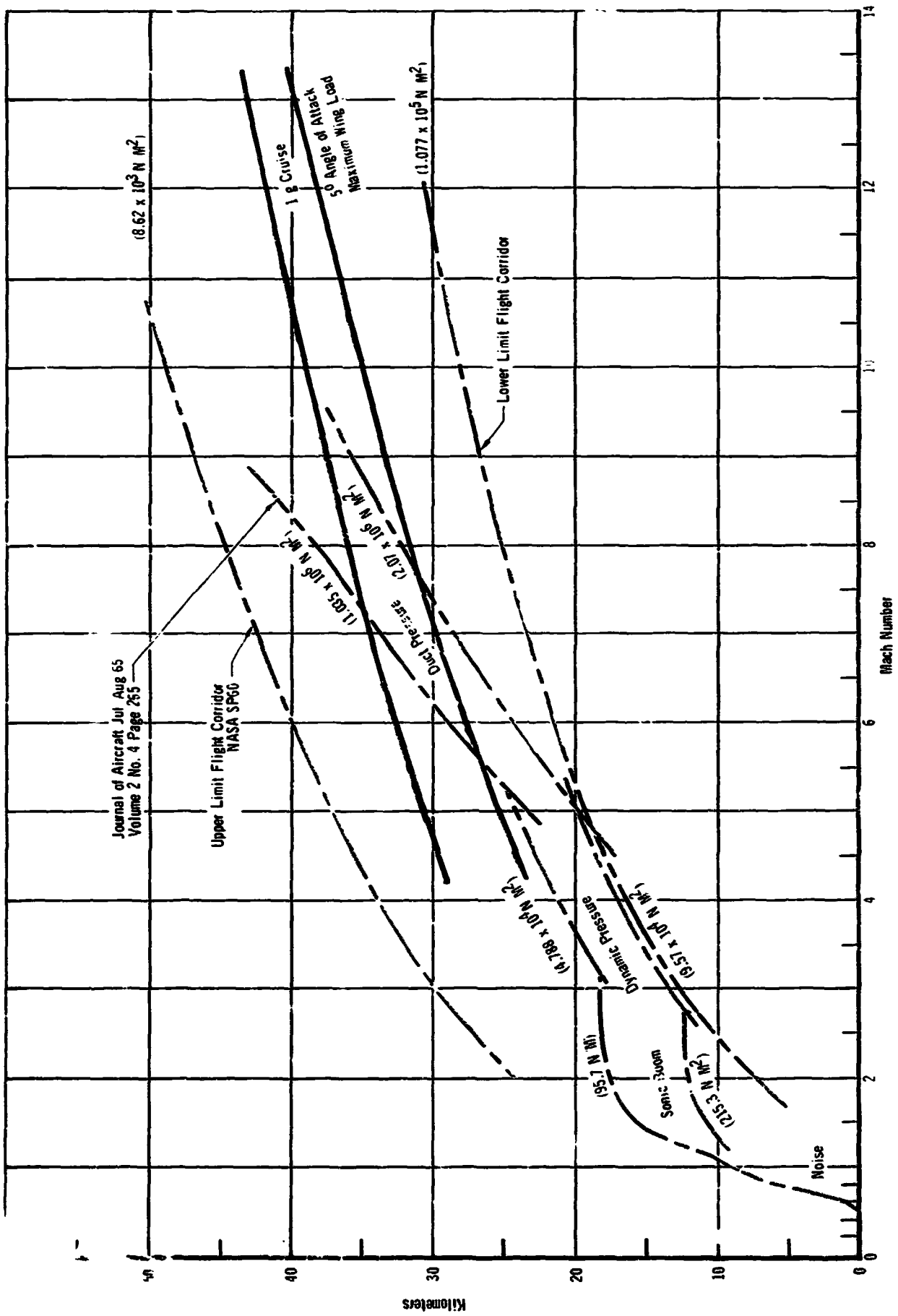


FIGURE 6–5 SURFACE TEMPERATURE LIMIT AS A FUNCTION OF ANGLE-OF-ATTACK, ALTITUDE, AND MACH NUMBER

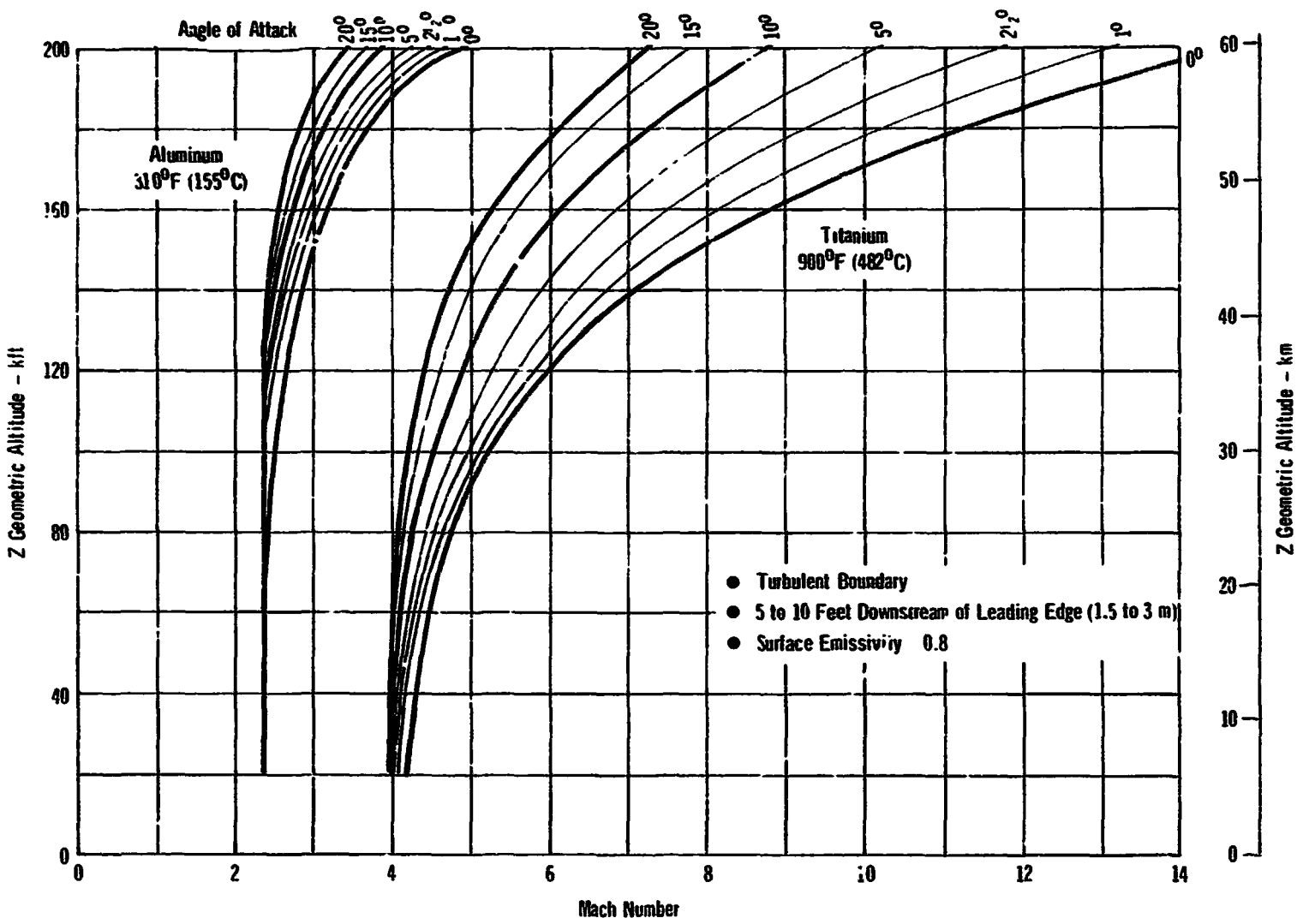


FIGURE 6-5 SURFACE TEMPERATURE LIMIT AS A FUNCTION OF ANGLE-OF-ATTACK, ALTITUDE, AND MACH NUMBER (CONTINUED)

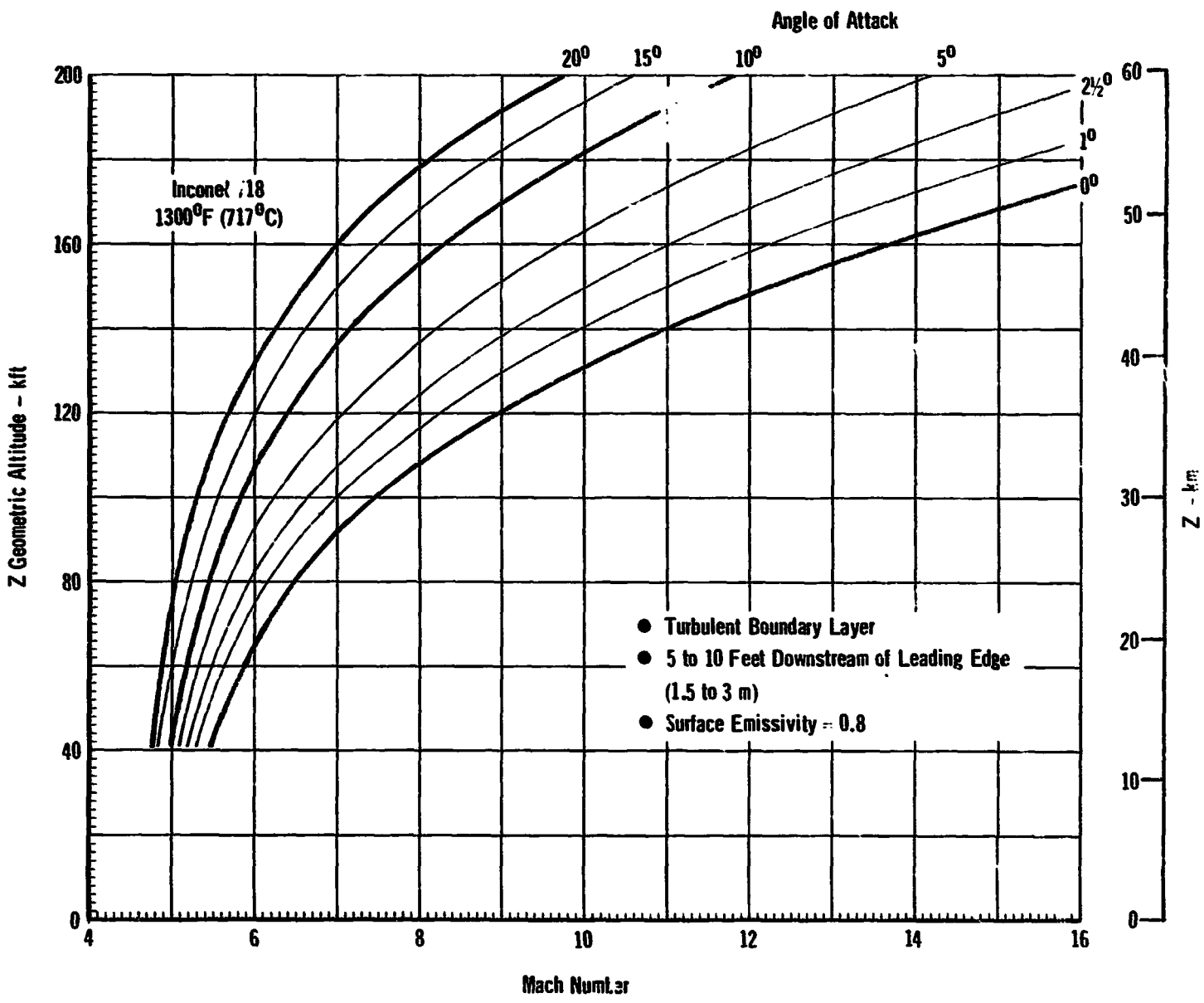


FIGURE 6-5 SURFACE TEMPERATURE LIMIT AS A FUNCTION OF ANGLE-OF-ATTACK, ALTITUDE, AND MACH NUMBER (CONTINUED)

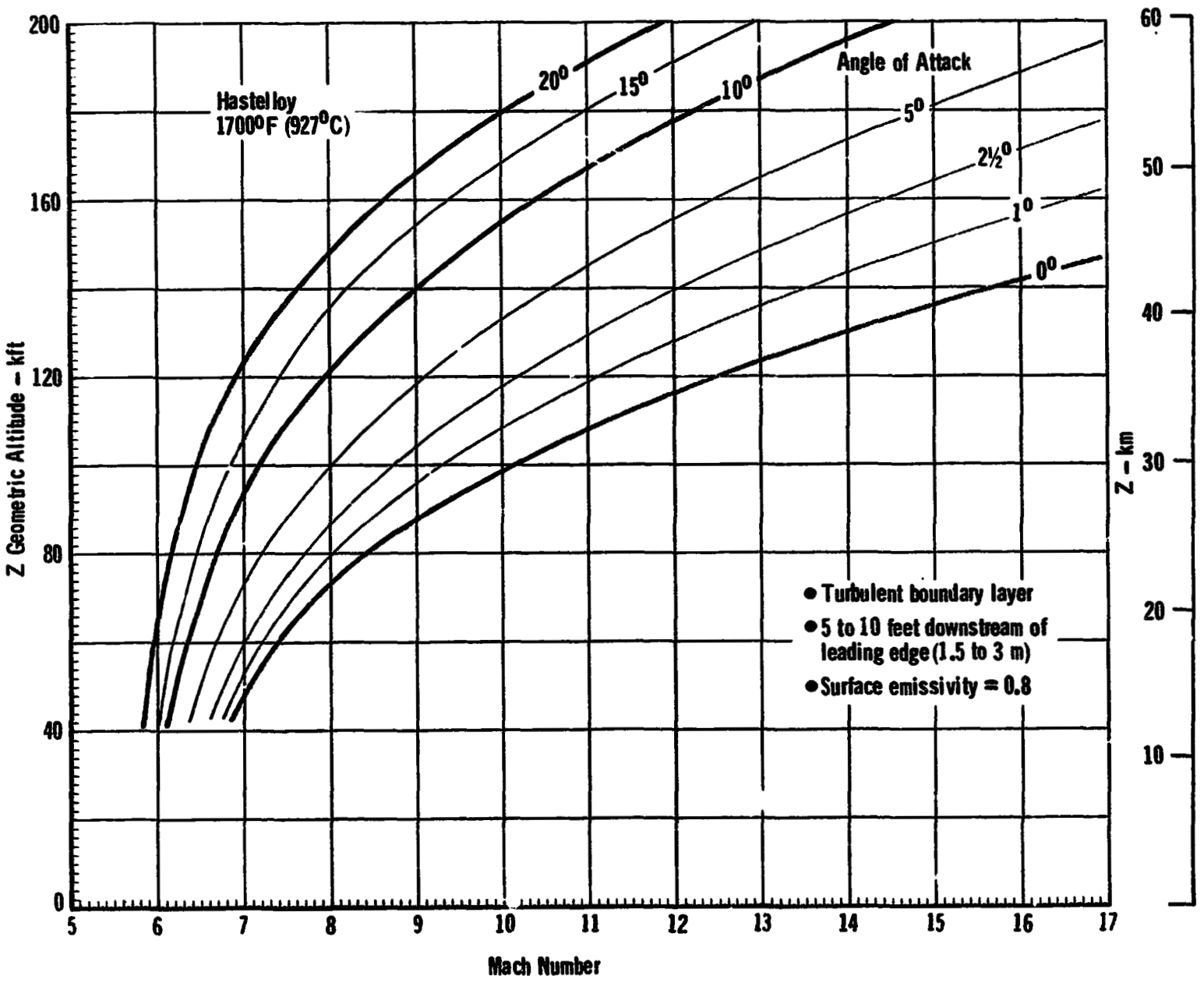
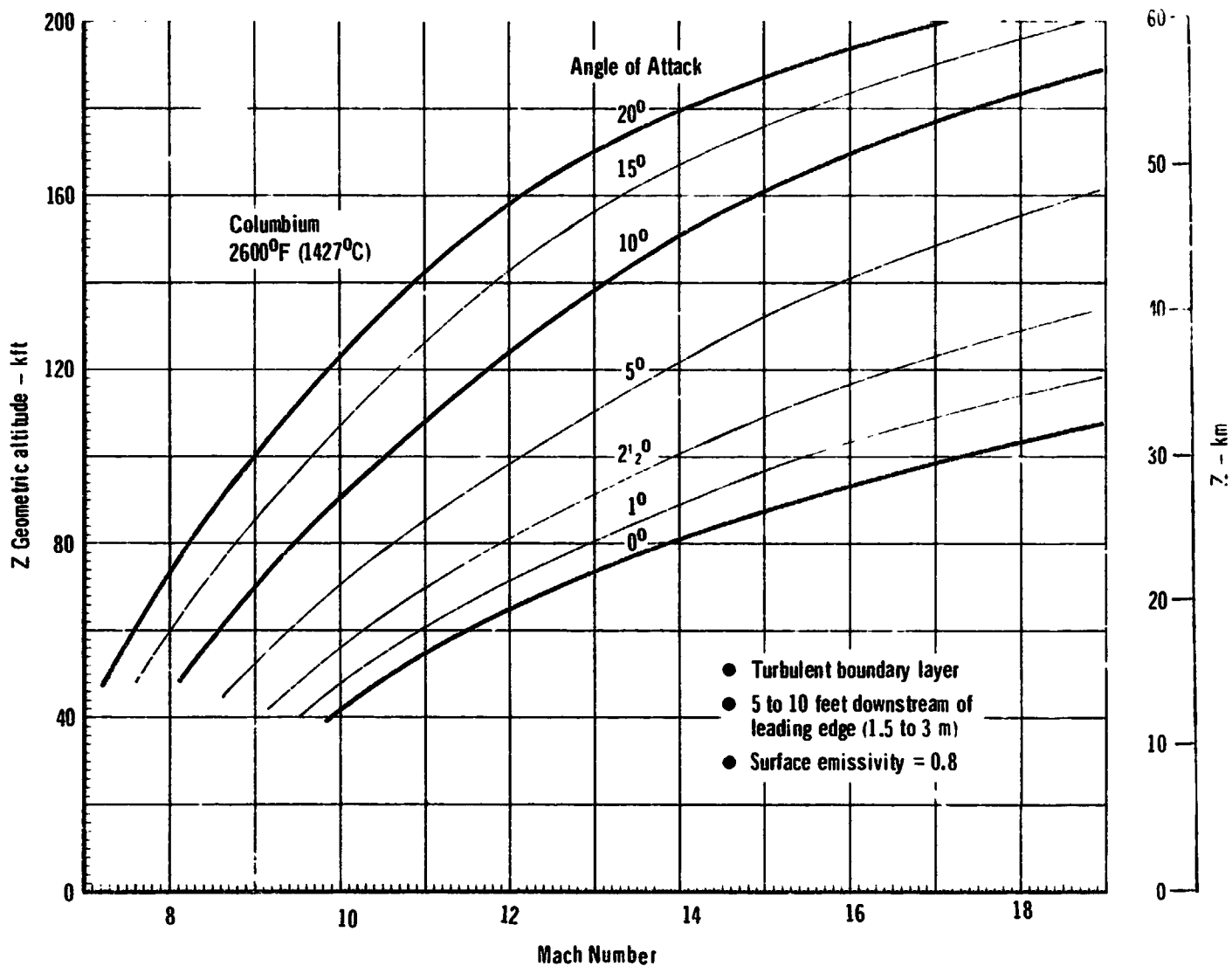


FIGURE 6-5 SURFACE TEMPERATURE LIMIT AS A FUNCTION OF ANGLE-OF-ATTACK, ALTITUDE, AND MACH NUMBER (CONTINUED)



For English units this can be expressed as:

$$\frac{P_\infty}{P_{S.L.}} = \frac{\eta_z \quad (W/S_W)}{1481 \quad C_L \; M_\infty^{\;2}}$$

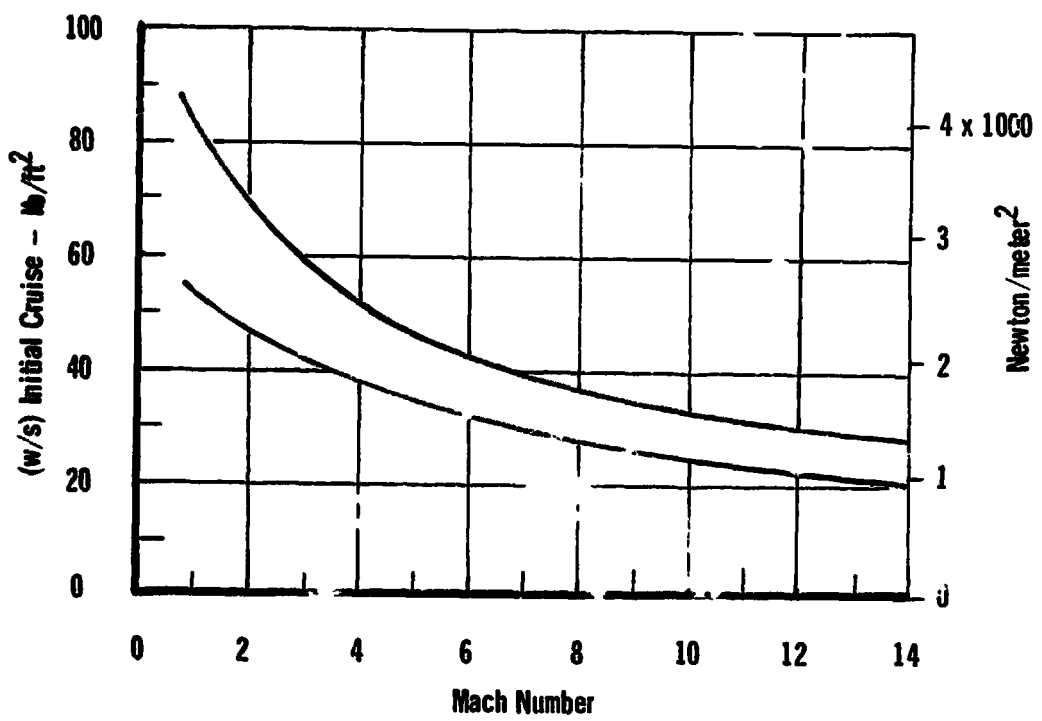
where W/S is in lb/ft^2. For N/m^2 the constant is 70,900. This equation relates the load factor to Mach number, altitude and angle of attack.

The relationship for a constant load factor as a function of Mach number, altitude and attitude can be solved simultaneously with the relationship for surface temperature as a function of Mach number, altitude and attitude to yield the areas where the aircraft can function at both a constant load factor and a constant surface temperature. For the potential operational hypersonic aircraft, representative lift coefficients and ranges of wing loading are given in Figures 6-6 and 6-7. These figures pertain to a vehicle with a 70 to 80 degree swept wing, at the start of hypersonic cruise flight.

For the data presented in Figures 6-6 and 6-7, simultaneous solutions were performed, resulting in the operational envelopes presented in Figure 6-8, defining the flight boundaries as a function of wing loading, load factor, material limits, and angle of attack. A general observation is that as usable material temperature increases, the Mach number range represented by the difference between the maximum and minimum load factor expands markedly, so that a small increase in wing loading or load factor could substantially reduce the maximum operational Mach number for a high temperature material system.

Several factors pertinent to the design of the ground facilities can be gleaned from this series of figures. The angle of attack range of interest for gasdynamic and engine inlet research indicated by the flight corridor limits and the surface temperature maps for cruise and up to about 3.5 g maneuvers is from zero to about a 30 degree maximum. For structural research the maps indicate combinations of flight parameters and attitude which yield a constant surface temperature to provide indications of the range of test conditions of interest in an experimental program. The zero degree angle of attack upper surface temperature limit is indicative of the restrictions which prevent rapid decrease in altitude by reducing the angle of attack. The maps indicate potential areas in the high load factor portion of the curves where operation is possible at dynamic pressures in excess of 2250 psf (108,200 N/m^2), where neither the structural strength or thermal limits are exceeded.

FIGURE 6-6 RANGE OF WING LOADING FOR POTENTIAL OPERATIONAL VEHICLES AT INITIAL CRUISE POINT, AFTER CLIMB AND ACCELERATION TO CRUISE MACH NUMBER



The influence of normal load factors on the operational Mach number increases significantly as the surface temperature is increased. For columbium, a lightly loaded aircraft with a wing loading of 19 psf (910 N/m^2) and a 2 "g" normal load factor limit can operate at Mach numbers up to about 16 during cruise without too many restrictions on its maneuvering capability. Increase this to about 3 1/2 g's and the maximum Mach number reduces to about 12.5. A vehicle which has very little maneuvering capability can increase this maximum Mach number to about 20. Thus, the operational safety, mission, and maneuverability can significantly influence the range of experimental conditions required to simulate the local environment for research on a columbium structures. Specifying the material itself does little more than denote the maximum surface temperature.

This analysis pertains to aircraft flying at moderate angles of attack (less than 30°) and at moderately high dynamic pressures. Had this analysis been done for vehicles flying at high angles of attack (40 to 60°) at lower dynamic pressures the results could have been rather different. The individual temperature maps given in Figure 6-8 are summarized in Figure 6-9. The overlap of various material systems depending on load factor can be seen, as well as the operational areas below the 2000 psf (95,700 N/m^2) dynamic pressure limit where neither the mechanical or thermal limitations of the structure are exceeded.

FIGURE 6-7 LIFT CURVES FOR GENERALIZED HYFAC OPERATIONAL VEHICLES

70° to 80° Wing Sweep Planforms

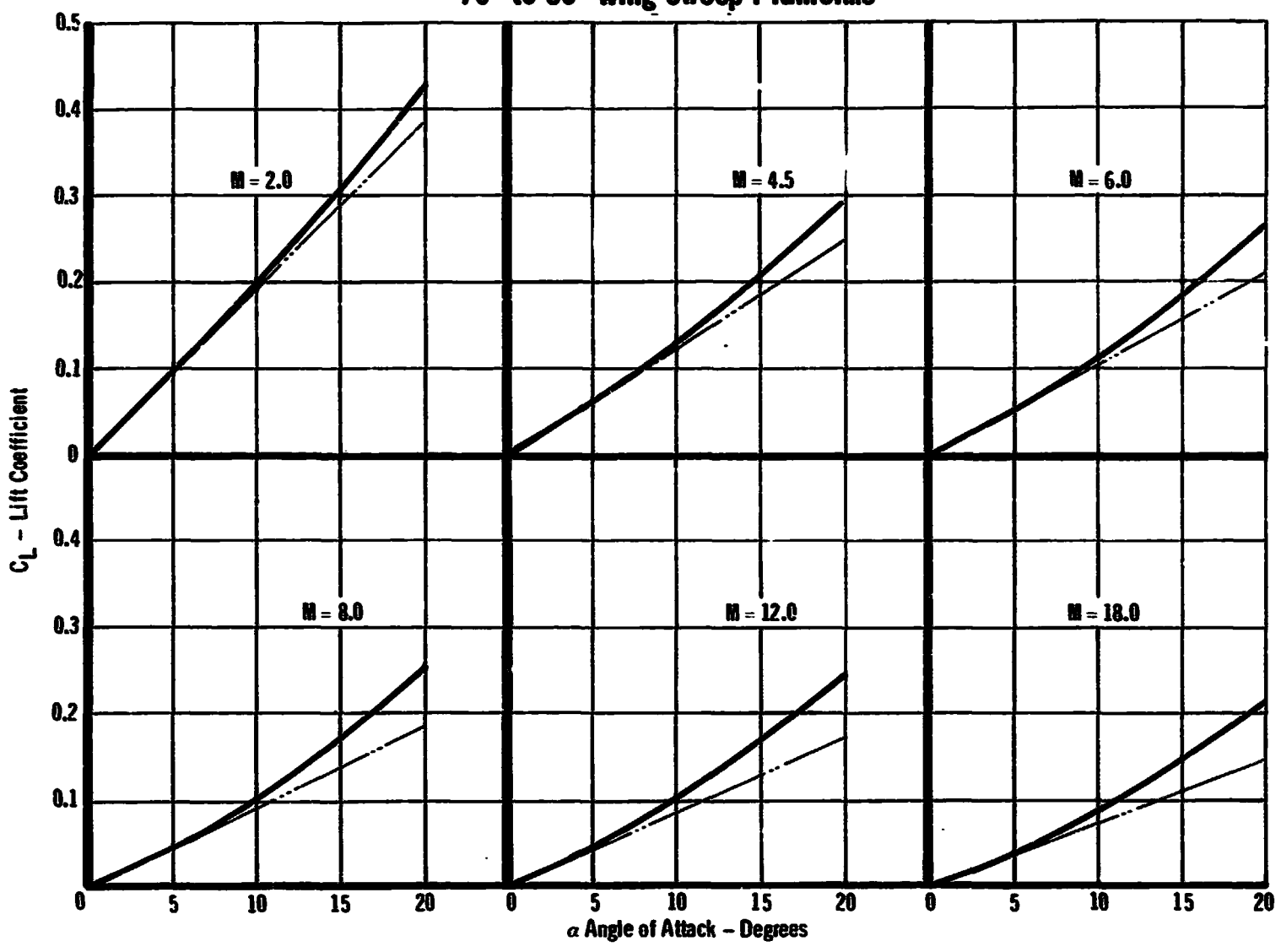


FIGURE 6-8 FLIGHT BOUNDARIES BASED ON WING LOADING, LOAD FACTOR AND MATERIAL LIMITS

$$\frac{L}{S_W} = n_z\left(\frac{W}{S_W}\right)$$

CONVERSIONS	
psf	N/m^2
19	910
36	1730
84	4020
250	12000

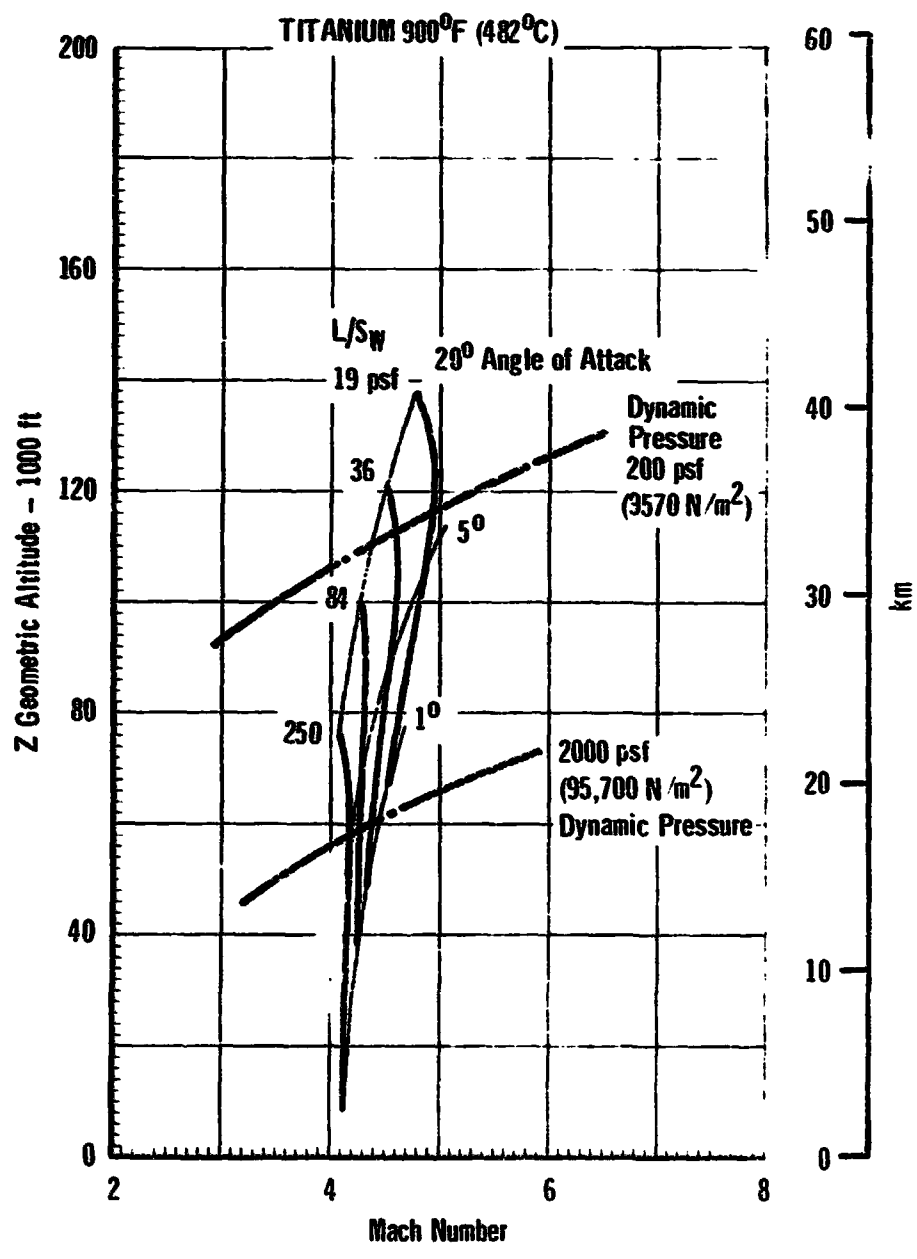
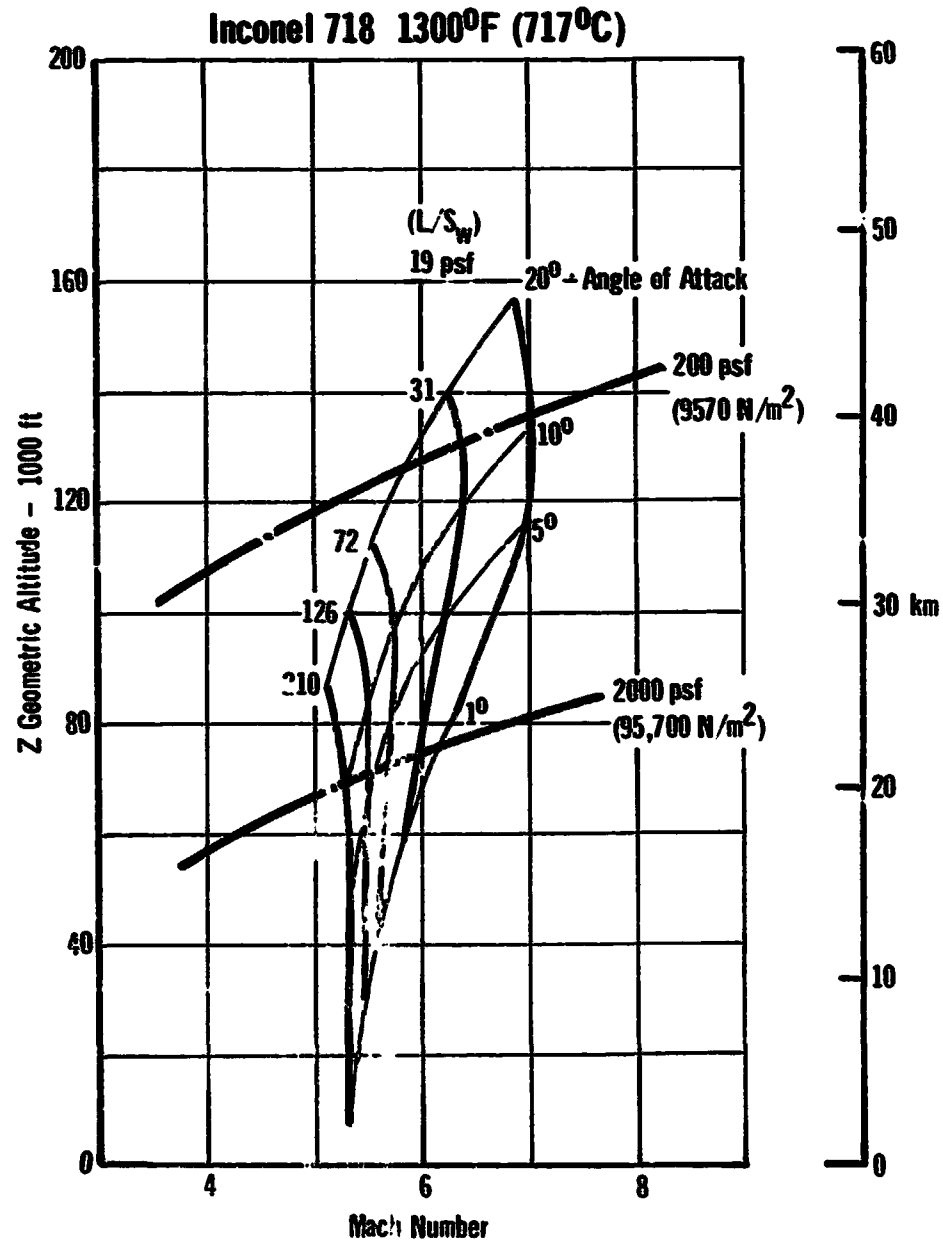


FIGURE 6–8 FLIGHT BOUNDARIES BASED ON WING LOADING, LOAD FACTOR AND MATERIAL LIMITS (CONTINUED)

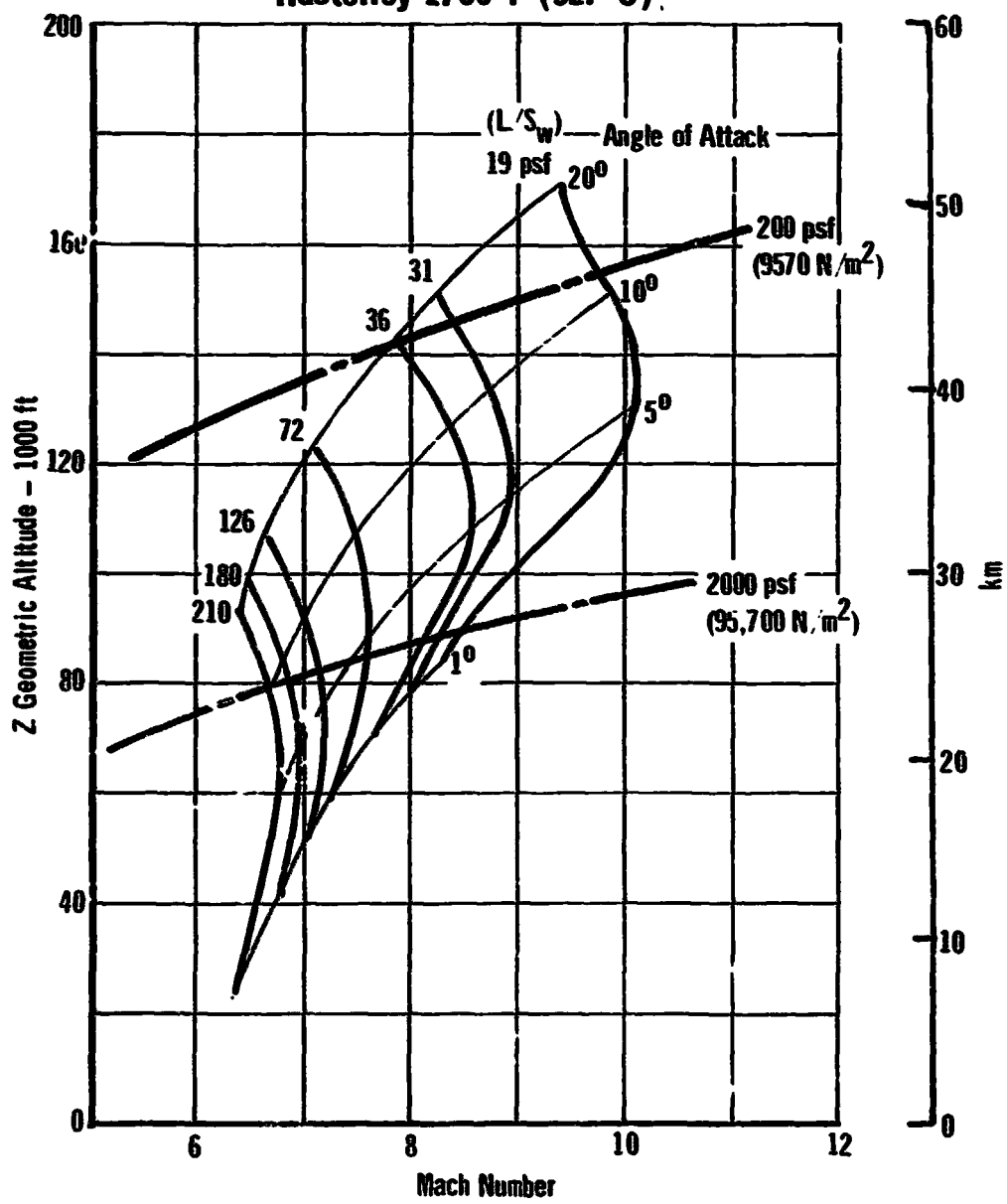


CONVERSIONS

psf	N/m²
19	910
31	1480
72	3450
126	6040
210	10040

FIGURE 6–8 FLIGHT BOUNDARIES BASED ON WING LOADING, LOAD FACTOR AND MATERIAL LIMITS (CONTINUED)

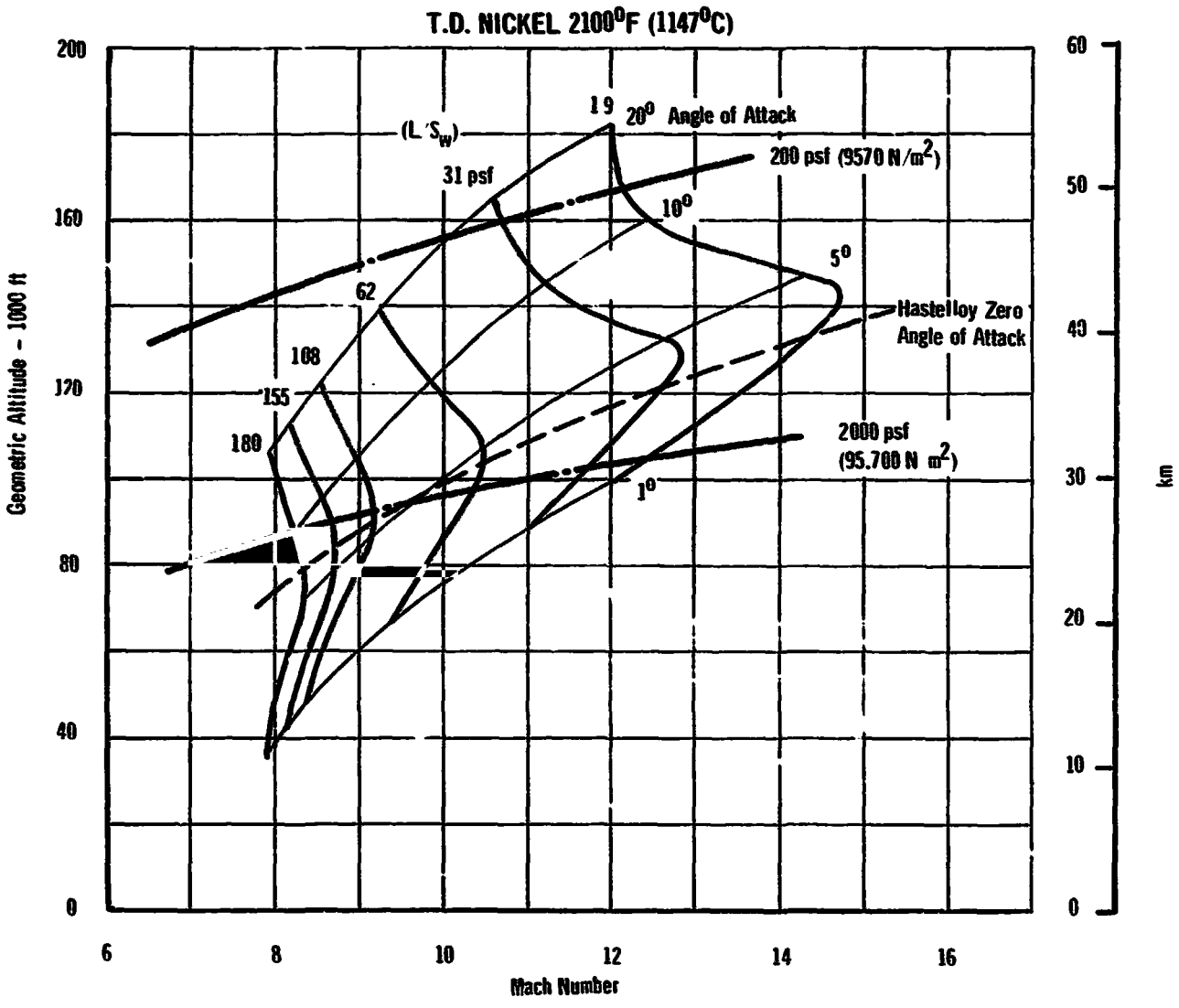
Hastelloy 1700°F (927°C)



CONVERSIONS

psf	N/m²
19	910
31	1480
36	1730
72	3450
126	6040
180	8610
210	10040

FIGURE 6–8 FLIGHT BOUNDARIES BASED ON WING LOADING, LOAD FACTOR AND MATERIAL LIMITS (CONTINUED)



CONVERSIONS	
psf	N/m²
19	910
31	1480
62	2960
108	5150
155	7190
180	8610

FIGURE 6–8 FLIGHT BOUNDARIES BASED ON WING LOADING, LOAD FACTOR AND MATERIAL LIMITS (CONCLUDED)

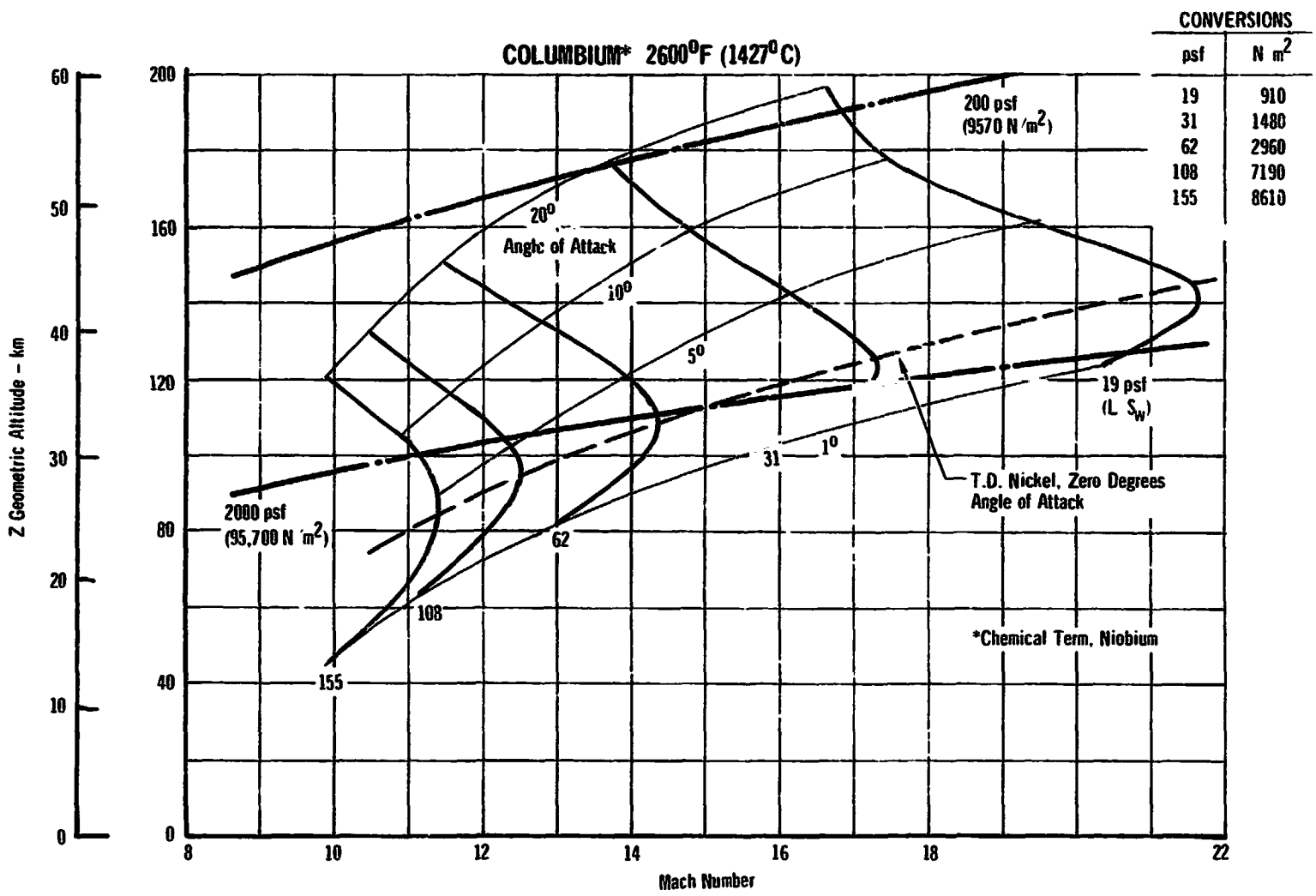
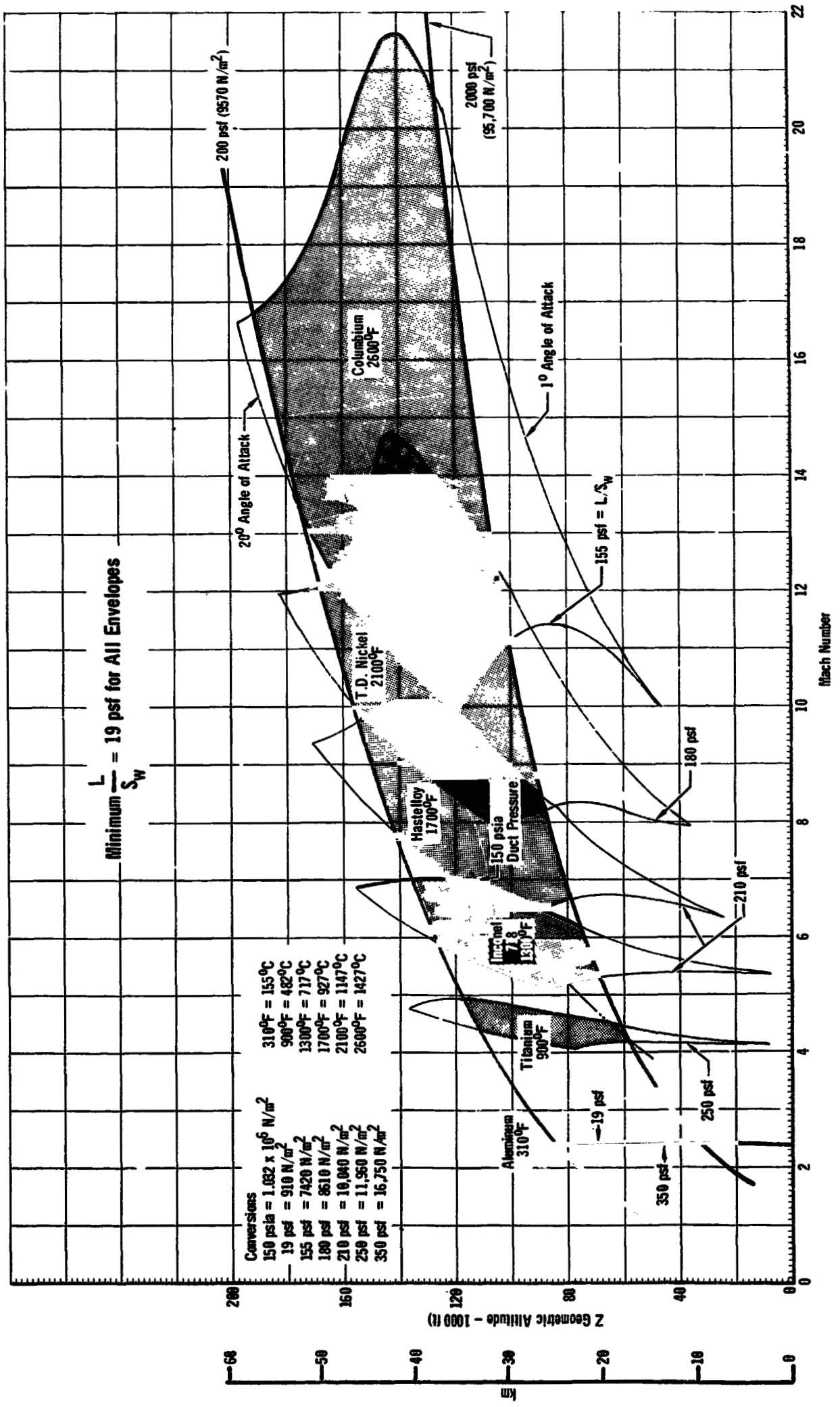


FIGURE 6-9 SUMMARY OF FLIGHT BOUNDARIES BASED ON WING LOADING, LOAD FACTOR, AND MATERIAL TEMPERATURE LIMITS



Lift loading has been used in the previous operational area maps to facilitate their use in determining load factors for both longitudinal and lateral maneuvers. Using the U.S. Standard Atmosphere, 1962 as reference, the following equation was derived to reflect gravitational acceleration changes with altitude and velocity.

$$\left(\frac{W}{S_W}\right)_{V,Z\neq 0} = \left(\frac{W}{S_W}\right)_{V,Z=0} \left[1 - .00008988\ Z - \frac{30.9770\ V_\infty^2}{20{,}902.7 + Z}\right]$$

where:

$\frac{W}{S_W}$ = wing loading, weight per unit area.

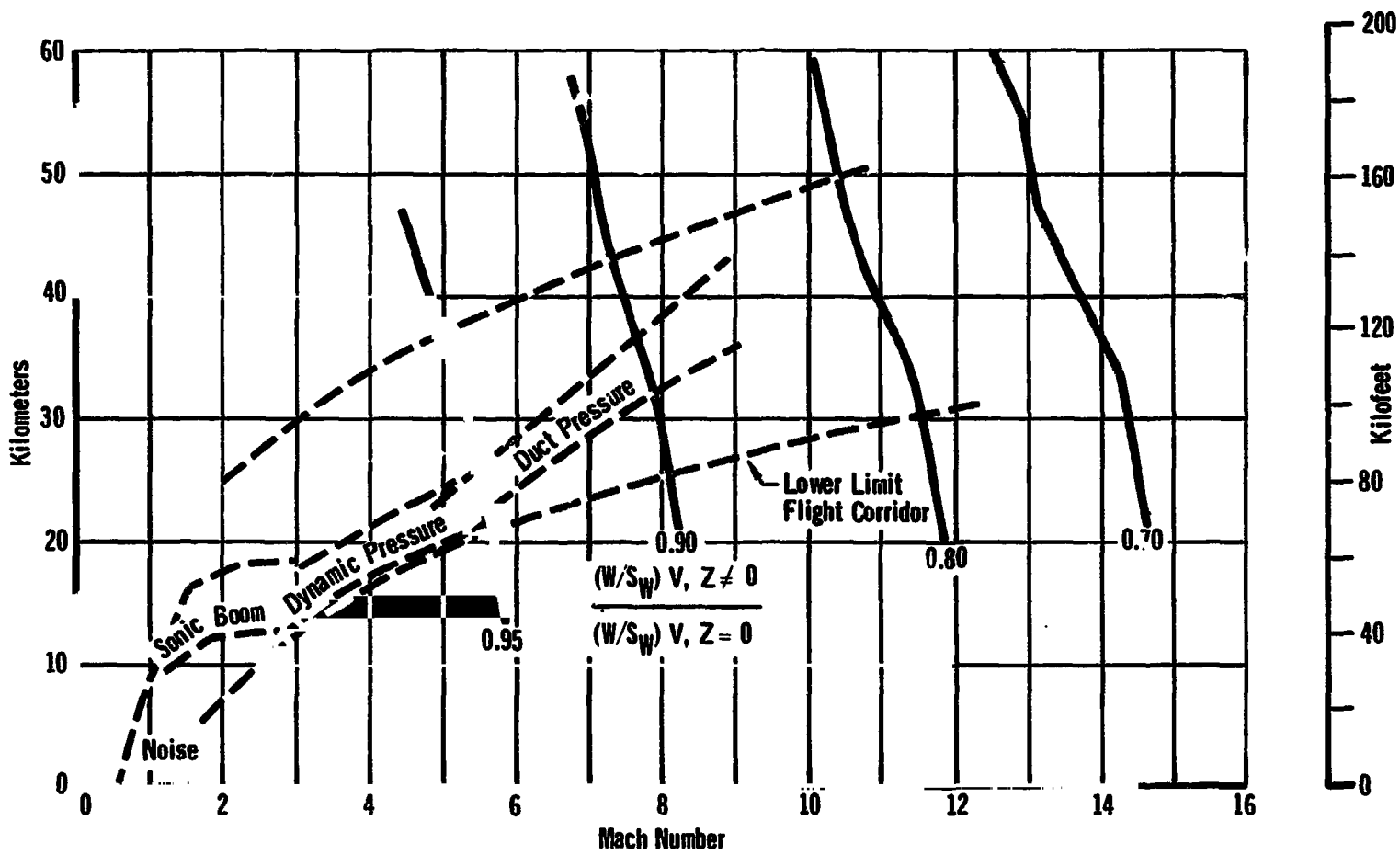
Z = Geometric altitude, kilofeet.

V_∞ = vehicle velocity, kilofeet per second.

mean Radius of the earth 20,902.7 kilofeet (6370 km)

This equation is evaluated in Figure 6-10, indicating a Mach 12 aircraft has over 20% reduction in weight due to speed and altitude. This reduction in weight alters the constant temperature/load factor map because the aircraft angle of attack can be reduced as centrifugal acceleration reduces gravitational acceleration, as shown in Figure 6-11. To ease the estimation of load factor the lift corresponds to that required for the sea level rest weight, not that required for equilibrium flight at local apparent weight.

FIGURE 6-10 REDUCTION OF LOCAL GRAVITATIONAL ACCELERATION DUE TO ALTITUDE AND VELOCITY

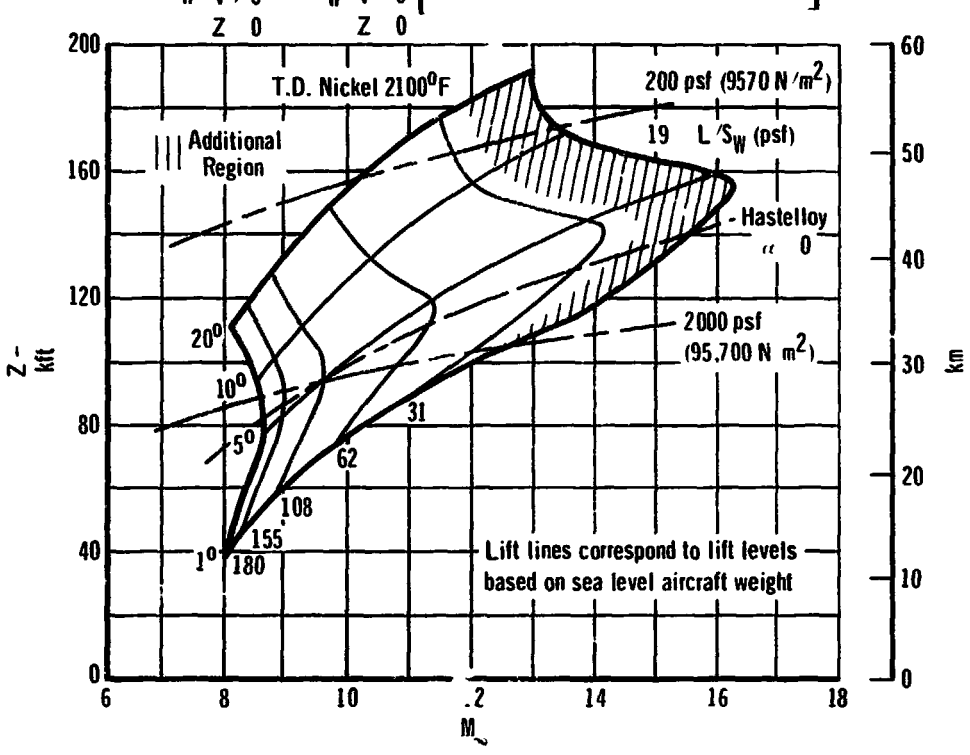


For details of flight path, refer to Figure 6-4.

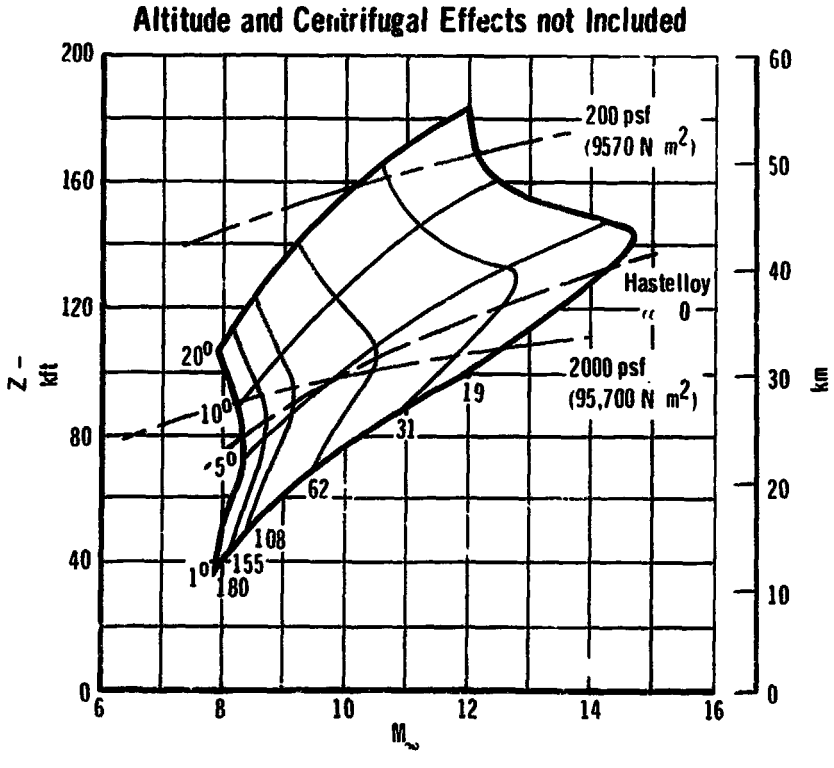
FIGURE 6-11 COMPARISON OF FLIGHT ENVELOPE FOR T.D. NICKEL WITH AND WITHOUT GRAVITATIONAL EFFECTS

Flight Boundaries, Longitudinal Maneuver, $\phi \approx 0^0$
Wing Loading with Altitude and Centrifugal Effects Included

$$\left(\frac{W}{S_W}\right)_{V/Z=0} \quad \left(\frac{W}{S_W}\right)_{V/Z=0}\left[1 - .00008988\ \text{kft} - \left(\frac{30.9770\ \text{kft/sec}}{20,902.7 \times Z}\right)\right]$$



Flight Boundaries, Lateral Maneuver $70^0 \leq \phi \leq 90^0$
Altitude and Centrifugal Effects not Included



6.4 GASDYNAMICS

The role assumed for the gasdynamics research facilities is primarily one of Reynolds number-Mach number simulation, as related to the scaling of viscous aerodynamic phenomena. The static pressure, temperature, and gas velocity in the test section do not correspond to equivalent flight conditions at the same Mach number and Reynolds numbers as only sufficient temperature is provided to avoid gas condensation in the test section. This temperature is normally sufficient for cold wall heat transfer measurements, but not sufficient to attain flight wall temperatures. For the gasdynamic facilities actual flight hardware is generally not used, except in wind tunnels specifically designed as full scale tunnels, such as the Ames 40 x 80 or the Langley 30 x 60. The use of sub-scale models implies that to achieve the same Reynolds number in the tunnel as flight, the unit Reynolds number must be increased correspondingly as the model size is decreased. The dynamic pressures encountered in the wind tunnel can therefore exceed those encountered in flight. Reynolds number is important in scaling boundary layer transition data and model surface finish requirements, dynamic pressure is important in the scaling of dynamically similar structural and aeroelastic models. The development of the wind tunnel sizing criteria will show that the final wind tunnel size is essentially a function of two factors:

(a) the maximum dynamic pressure a model/balance combination will sustain

(b) the magnitude of the Reynolds number necessary to achieve the program goals.

6.4.1 CRITERIA - To specify the gasdynamic facilities required to simulate the flight conditions of the potential operational aircraft, it is necessary to determine the magnitude of parameters to be simulated, permissible model sizes that may be tested and, finally, the required tunnel sizes that will yield the desired level of simulation.

The first step is to estimate the permissible [illegible] of model size relative to the test section size, and two approaches were used to provide 5 criterion on which to base model size. The first approach is based on the technique presented in the 30th Wright Brothers lecture by P. H. Poisson-Quinton as reported in the AIAA Journal of Aircraft, Volume V, No. 3, 1968.

The second approach was to estimate the permissible model size based on model blockage using ASD-TDR-63-230, "Correlation of Wind Tunnel Blockage Data", Feb. 1963. The data was presented in terms of the projected model cross-sectional area normal to the flow referenced to the potential core flow area and as a function of total drag coefficient and Mach number.

On the basis of these two approaches the following five criteria were established:

(a) The maximum model angle of attack is 30°.

(b) The projected model height should not exceed 1/2 the tunnel height.

(c) The model wing area must be less than a specified percentage of the tunnel test section cross-sectional area, to maintain subsonic wall correction magnitude.

(d) The model wing span should not exceed a specific percentage of the test section width.

(e) The model area projected normal to the tunnel centerline must be less than a certain percentage of the potential core area.

Criterion (b) is derived primarily from empirical data and is used as an order of magnitude estimate of model size in hypersonic and high temperature wind tunnels where the boundary layer can be very thick.

Criterion (c) is a subsonic sizing criteria selected to keep the wall boundary corrections to acceptable levels. Both downwash and lift corrections are considered.

Criterion (d) is a subsonic sizing criteria selected to minimize wall boundary influences on the circulation system around the wing to provide a uniform spanwise upwash correction for the wing.

Criterion (e) is based on supersonic wind tunnel blockage data presented in terms of the projected model cross sectional area normal to the flow referenced to the potential flow core area. Blockage limits are presented in terms of total drag coefficient and Mach number. Using the airplane characteristics presented in Volume VI, the maximum sized model which could be accommodated as a function of Mach number was estimated for highly swept planforms.

Each of these criteria can be used to define a characteristic model length referenced to the square root of the tunnel test section cross sectional area.

Defining:

b	=	wing span	w	=	test section width
L	=	aircraft length	h	=	test section height
$\bar{c}$	=	mean aerodynamic chord	C	=	test section area
S_W	=	wing planform area	α	=	angle of attack
AR	=	aspect ratio	Λ	=	sweep back angle

$$K_1 = \frac{b}{L} \qquad K_3 = \frac{S_W}{C}$$

$$K_2 = \frac{\bar{c}}{L} = \frac{K_1}{AR} \qquad K_4 = \frac{b}{w}$$

$$K_5 = \frac{w}{h} \text{ rectangular test section}$$

$$= 4/\pi \text{ circular test sections}$$

Then the model length limits for each criteria are

criterion (b) $\frac{L}{\sqrt{C}} = \frac{K_5}{2 \sin \alpha}$

for $\alpha = 30°$ $\frac{L}{\sqrt{C}} =$

criterion (c)

$$\frac{L}{\sqrt{C}} = \frac{K_3 AR}{K_1}$$

criterion (d)

$$\frac{L}{\sqrt{C}} = \frac{0.7}{K_1 \; K_5}$$

criterion (e)

$$\frac{L}{\sqrt{C}} = \frac{\Delta A/C}{\sin \alpha \cos \Lambda}$$

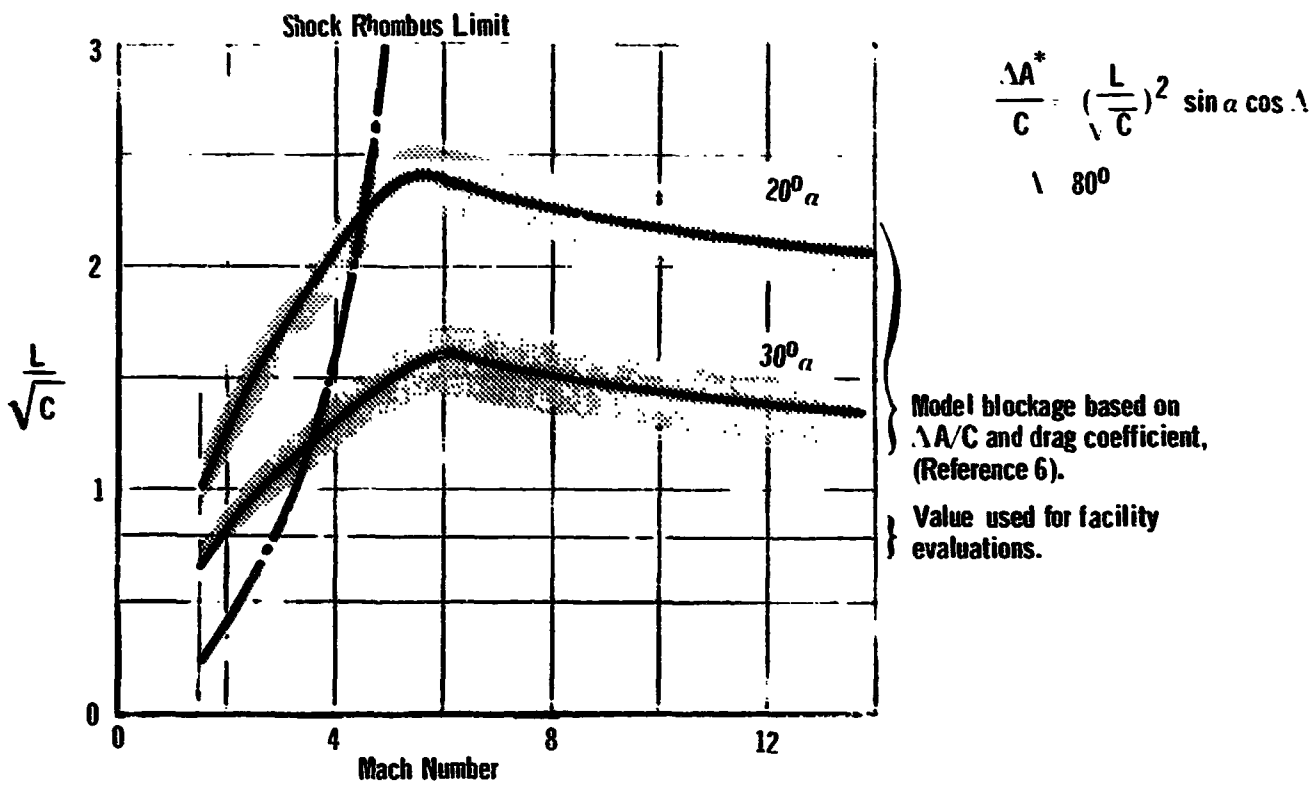
$\frac{\Delta A}{C}$ is obtained from ASD-TDR-63-230, "Correlation of Wind Tunnel Blockage Data, February 1963.

The evaluation of these five criterion is presented in Figure 6-12. For reference the value of $L/\sqrt{C}$ designated by the Mach rhombus is shown for low supersonic Mach numbers assuming a model length equal to 75% of the rhombus length. This characteristic length is indicative of where the reflected shock can impinge on the model, adversely affecting the data. It is also indicative of the Mach numbers where porous wall test section configurations are necessary to minimize shock reflection through wall suction.

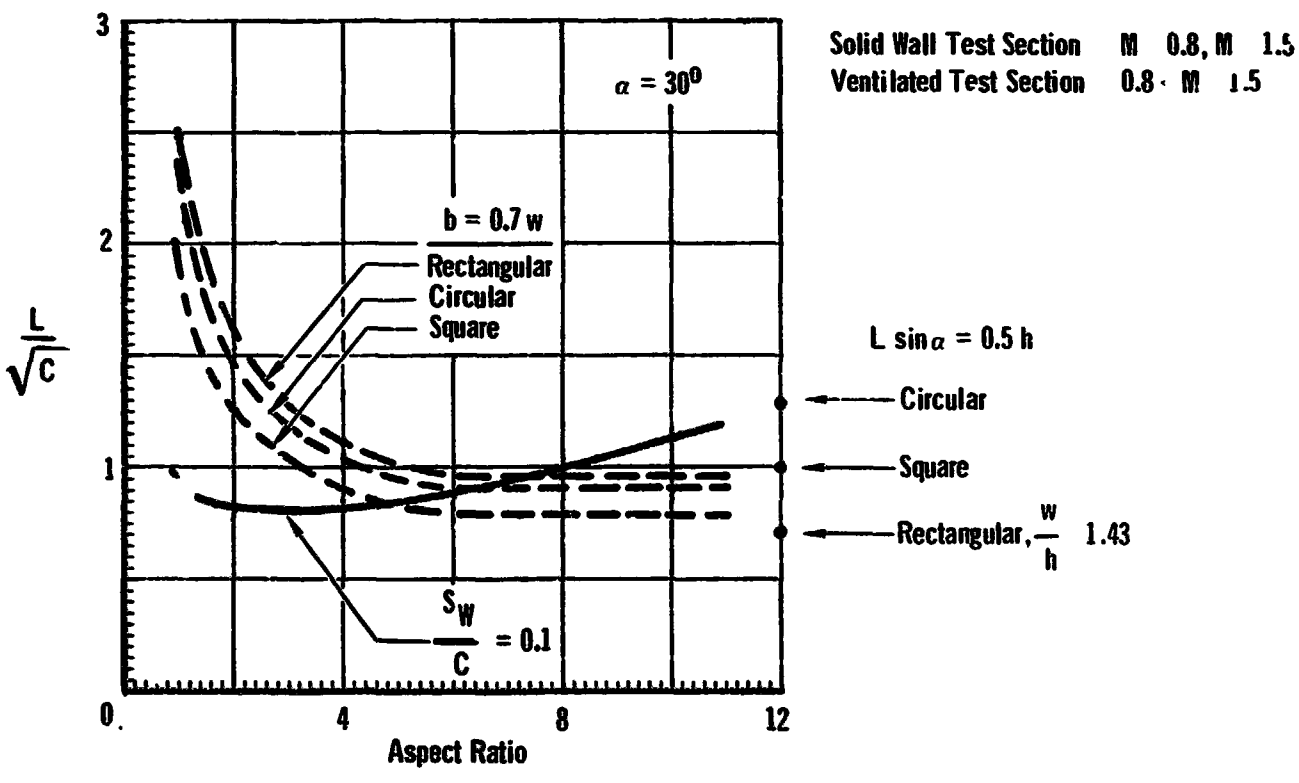
NON-VENTILATED WALLS VENTILATED WALLS

Figure 6-12 illustrates that for the two subsonic criteria, wing area size dominates model selection for aspect ratios less than 5, and model wing span dominates size considerations above 5.

FIGURE 6-12 MODEL SIZING CRITERIA
Supersonic Model Blockage Factors



General Model Blockage Factors



*For higher Mach numbers C should be based on the nozzle geometric dimensions minus the boundary layer displacement thickness.

From low angle of attack blockage considerations, model lengths exceeding twice the test section size are theoretically possible. In practice however, maintaining uniform Mach number distributions over distances greater than two test section diameters is seldom achieved. Model lengths of twice the test section size should probably be considered an upper limit.

The model criterion selected to base the relative size of the facility with respect to the model was

$$L = \frac{\sqrt{C}}{1.3}$$

Although this criterion may appear unduly conservative, (not making use of the maximum capability at all Mach number ranges), in Section 6.4.2 the model cost savings and additional model sizing flexibility provided by this criterion is demonstrated.

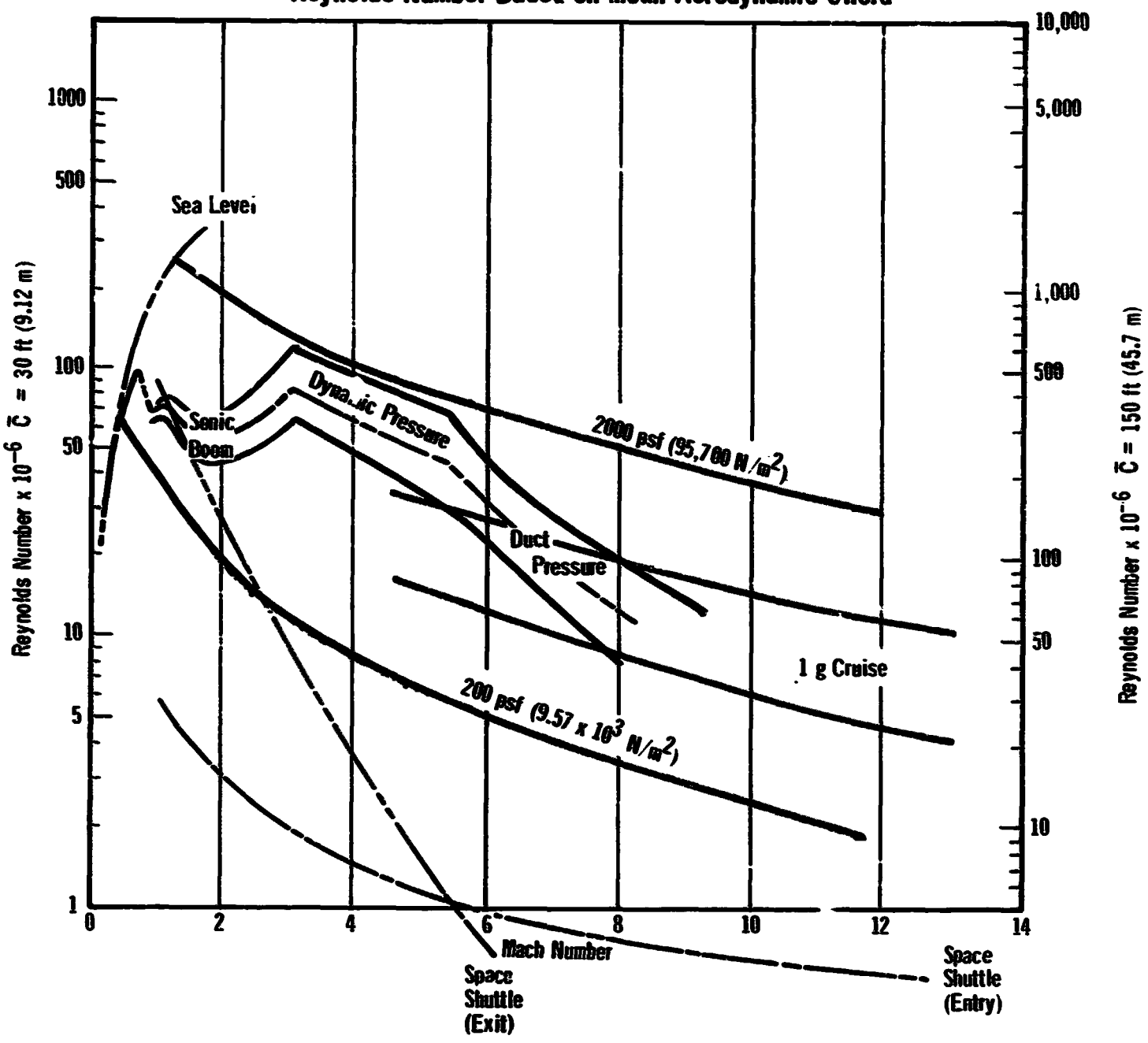
In wind tunnel testing, the parameters generally simulated for flow similarity are the Mach and Reynold number. Based on the aircraft size defined in Volume VI, and flight corridor defined in Figure 6-4 for the potential operational hypersonic aircraft, a Reynolds number, Mach number corridor can be established, as presented in Figure 6-13. The Reynolds number is based on a maximum mean aerodynamic chord of 150 feet (45.7 m) and a minimum mean aerodynamic chord of 30 feet (9.12 m). This figure defines the general Reynolds number envelope which is necessary to be simulated in the wind tunnel. For reference, a representative trajectory for the Space Transportation System (Shuttle) is shown to indicate the contrast in the Reynolds number requirements between a high angle of attack gliding vehicle and a continuous cruise airbreathing aircraft.

Considering a representative flight path for each of the categories of potential operational aircraft, plus existing subsonic transports for comparison, the flight path parameters can be defined for each category as:

(a)	SUBSONIC TRANSPORT	M = .8 at 10 kft (3.05 km)		
		M = .9 at 20 to 40 kft (6.1 to 12.2 km)		
(b)	HYPERSONIC TRANSPORT	M = .7 at 10 kft		(3.0 km)
		M = .8 at 20 kft		(6.1 km)
		M = .9 at 27 kft	NOISE LIMIT	(8.2 km)
		M =1.0 at 30 kft		(9.1 km)
		M =1.3 at 30 kft		(9.8 km)
		M =1.8 at 40 kft	SONIC BOOM	(12.2 km)
		M =2.75 at 42 kft	3 psf	(12.8 km)
		q =2000 psf from $2.75 < M \leq M$ CRUISE (9.57×10^4 N/m^2)		
(c)	LAUNCH VEHICLES	M = .7 at 10 kft		(3.0 km)
		M = .8 at 20 kft		(6.1 km)
		Z = 20 kft from $.8 < M \leq 1.7$		
		q = 2000 psf from $1.7 < M < M$ CRUISE (9.57×10^4 N/m^2)		
(d)	MILITARY VEHICLES	Z = SEA LEVEL from $0 < M \leq 1.17$		
		q = 2000 psf from $1.17 < M < M$ CRUISE (9.57×10^4 N/m^2)		

FIGURE 6-13 REYNOLDS NUMBER CORRIDOR POTENTIAL OPERATIONAL HYPERSONIC AIRCRAFT

Reynolds Number Based on Mean Aerodynamic Chord



These flight paths represent maximum performance conditions for each category based on the information presented in Figure 6-4. These flight paths determine unit Reynolds number as a function of Mach number as shown in Figure 6-14. In terms of maximum unit Reynolds numbers, the military and launch systems present the most demanding requirements. In the center of Figure 6-14, a table lists the physical descriptions of seven different aircraft, which are based on the nine potential operational hypersonic aircraft presented in Volume VI. Using these characteristics, the absolute value of the maximum full scale Reynolds numbers for these seven examples is shown in the bottom graph in Figure 6-14.

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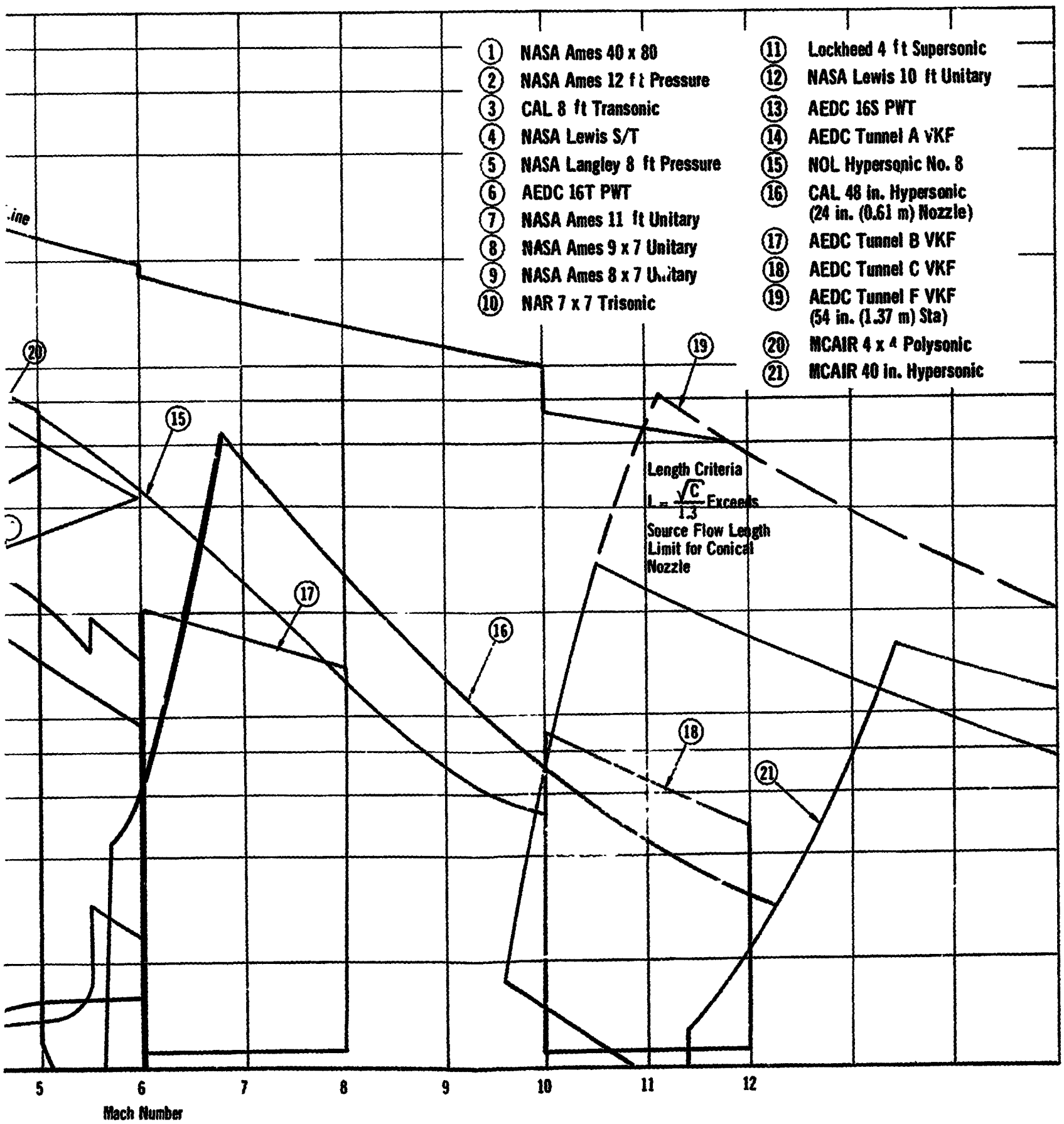
ITIES COMPARED TO REQUIREMENTS



Except for the smaller military aircraft, the maximum Reynolds number requirements for the different aircraft systems is remarkably similar. Notice also that the Reynolds number requirements for the subsonic transport class of aircraft are essentially identical to those of the hypersonic aircraft. Therefore, any facility sized to provide research for the nine potential operational hypersonic aircraft can also accomplish a significant portion of aerodynamic research associated with large transonic aircraft.

Based on the results of subscale tests on low aspect ratio, highly swept configurations at hypersonic speeds, if at least 20% of the full scale Reynolds number can be simulated then extrapolation of drag data to full scale values using present skin friction techniques could probably be achieved with a minimum of uncertainty. Using as a guideline, a 1/5 of maximum full scale Reynolds number limit was adopted as the basis for the candidate gasdynamic facilities performance, thus providing a Reynolds number simulation level greater than this minimum for all other portions of the flight envelope. One reason for selecting the maximum dynamic pressure level, instead of a level consistant with cruise conditions, was the importance of the higher dynamic pressure flight path to the acceleration capability of large, airbreathing hypersonic aircraft. It was judged that correct aerodynamic in this flight regime should be the least compromised by data uncertainties due to the quantity of fuel used during acceleration, and its affect on cruise range.

In analyzing the 1/5 maximum Reynolds number simulation requirement, a gap is identified between this Reynolds number requirement and that which is available in existing wind tunnels, as shown in Figure 6-15. The Reynolds number capability of each of the major aerodynamic test facilities in the U.S. is plotted against its Mach number range. Reynolds number is based on the square root of the test section cross sectional area, which has been shown to be proportional to the length of the maximum permissible model that the facility will accommodate.

Throughout the entire Mach number range there is a considerable deficit between the maximum Reynolds number desired and the maximum Reynolds number available. This is true regardless of the facility type. For the large, continuous facilities, Reynolds numbers are insufficient despite the large model sizes which can be used, because all of these facilities operate with atmospheric or subatmospheric stagnation pressures, required to conserve on installed horsepower or tunnel shell construction costs. Also limiting the Reynolds number capability of existing facilities is the fact that several large tunnels are designed as propulsion wind tunnels and thus produce flight duplicated pressures and temperatures throughout their operating ranges rather than conditions to maximize model Reynolds number.

The smaller blowdown to atmosphere wind tunnels are capable of very high unit Reynolds numbers by virtue of the high stagnation pressures used. The blowdown cycle permits very low power consumption and is amenable to the type of aerodynamic testing normally done by industry, which is primarily configuration development. This type of testing requires many runs at a few selected Mach numbers but multitudes of configuration changes. Much of the data required is drag, stability, or lift differences between competing configuration details. Since many model parts must be manufactured for such studies, economical operation dictates the use of small models. These two factors, in combination with the fact that the airplanes being tested have been much smaller than the HYFAC operational

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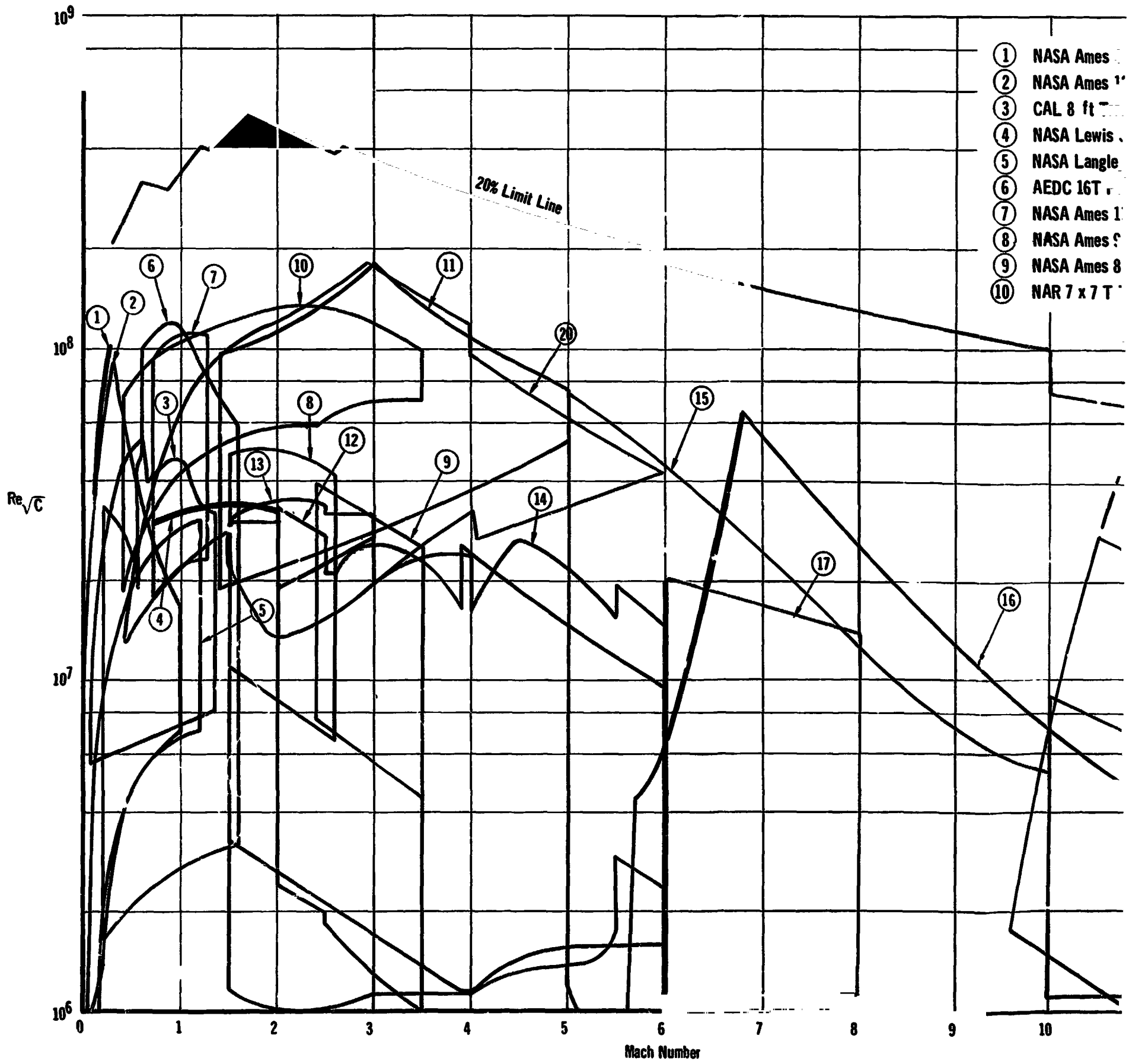
FIGURE 6–15
REYNOLDS NUMBER CAPABILITIES OF EXISTING FACILITIES COMPARED TO REQUIREMENTS



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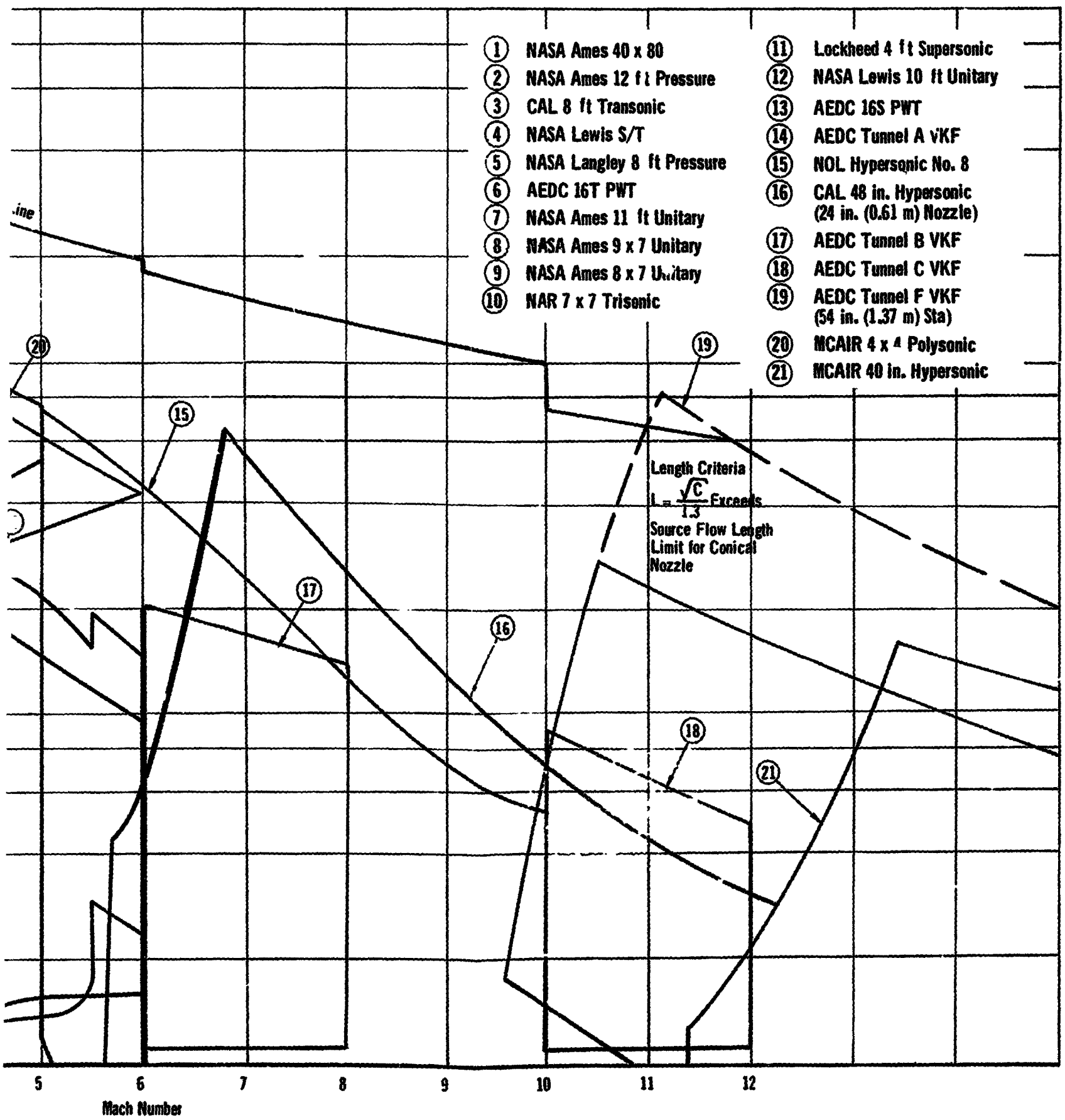


vehicles, led to the design of facilities smaller than required for this study. These blowdown facilities do operate at stagnation pressures around 300-500 psia (207-345 N/cm^2) and thus provide the highest Reynolds number capability available in the Mach 2 to 5 range.

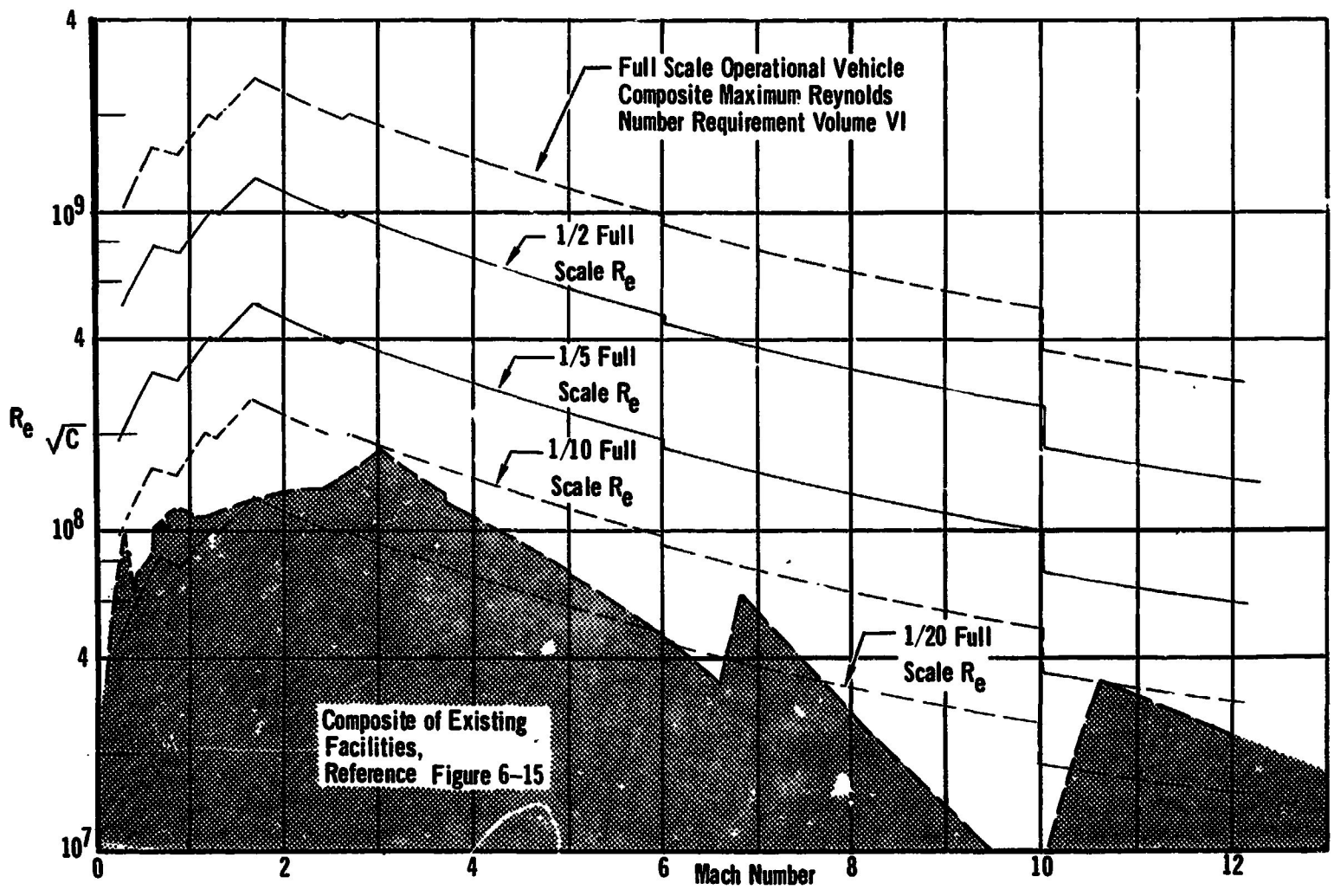
At the high end of the Mach number scale, the most capabile facilities with respect to Reynolds number are impulse types. These types are used primarily because of power considerations. For example, the MCAIR Hypervelocity Impulse Tunnel, a modestly sized (40" dia(100 cm)) facility, has a rate of energy release into the test gas of 6,000 megawatts, which is 2% of the entire U.S. installed generation capacity. The high power is obtained by storing electrical energy in a capacitor bank over a relatively long time at a low power delivery, and releasing this energy in about one millisecond. Continuous facilities of any useful size in the hypersonic range are probably not economically feasible on power consideration alone. Materials problems and extensive water cooling required for protection of facility and model have also prohibited the development of very large, high power continous, hypersonic facilities. The impulse facilities which do exist are smaller than required for the HYFAC study because up until now, most hypersonic testing has been of the pure research variety, with little emphasis on sophisticated refinement of configurations. In the hypersonic range, all of the facilities shown, though perhaps the largest examples of a given type, are still being developed and refined.

It is important to note that the major existing wind tunnel test facilities in the U.S. represent an investment of 1 to 2 billion dollars and are very capable of performing the majority of aerodynamic tests on vehicles which have been built or proposed. The reason for needing any improvement in Reynolds number test capability is keyed only to the large size of the operational vehicles and to the minimum altitude flight profile, which is generally lower at any given Mach number than the flight profiles of existing aircraft. Relaxing either of these requirements would narrow the gap in Reynolds number capability, and would result in changed requirements for new facilities, as is further discussed in the Analysis Section 6.4.2.

Figure 6-16 is presented to give some perspective to the degree of maximum Reynolds number simulation required for gasdynamic research on the HYFAC potential operational aircraft. The shaded area represents the composite capability of all major wind tunnels and the top line represents a composite of the actual maximum Reynolds numbers attained by the HYFAC operational aircraft as a group. Lines of 1/2, 1/5, 1/10, and 1/20 of the maximum full scale values are shown for comparison.

Existing capacity ranges from 1/20 to 1/10 of the maximum full flight values. The criteria on which the facility design specifications were formulated considered that attainment of 1/5 of the maximum flight Reynolds numbers is necessary to permit successful extrapolation of ground test data to flight conditions for very large, airbreathing hypersonic aircraft. A new facility or facilities constructed to attain this level would of course be able to produce nearly full duplication of flight Renolds number for vehicles flying their upper altitude boundary or for smaller aircraft.

FIGURE 6-16 DEGREE OF REYNOLDS NUMBER SIMULATION FOR OPERATIONAL HYPERSONIC AIRCRAFT COMPARED TO EXISTING GAS DYNAMIC FACILITY CAPABILITY



Selection of the 1/5 full scale Reynolds number line for new facility specifications represents about a factor of two increase over existing capability and appears to be a reasonable design goal.

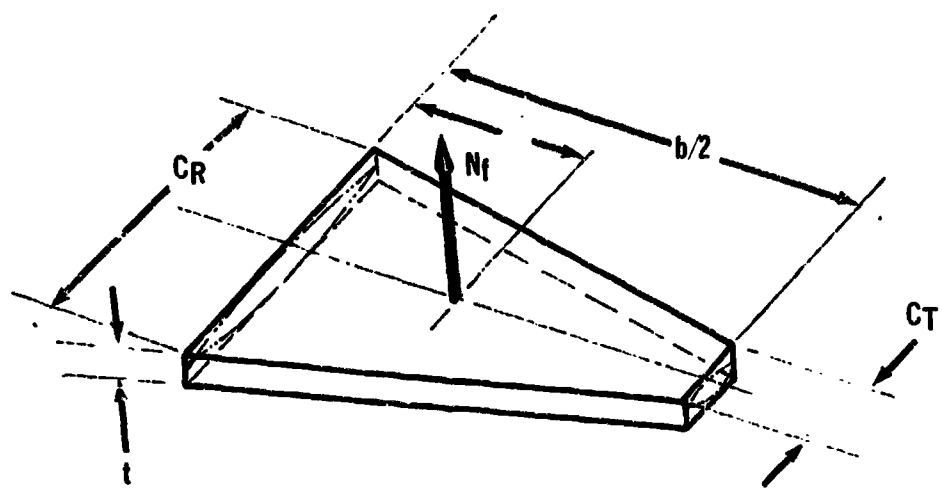
The previous discussion has presented arguments establishing the Reynolds number capability required, and the relative size of the model with respect to the test section. It remains to define a rationale which can describe the model size possible in terms of the maximum Reynolds number that can be achieved dependent on the strength of the model/balance combination. This rationale can generally be developed by considering the strength of the model and balance combination relative to the dynamic pressure encountered in the test section. For the purposes of estimating the minimum model size to achieve a given Reynolds number, three factors are considered.

(a) Spanwise wing bending,

(b) Chordwise wing bending as encountered by low aspect ratio shapes,

(c) Balance strength in terms of normal force capability.

For a generalized wing of arbitrary sweep angle, aspect ratio, and thickness ratio, depicted below:



The following equations can be utilized to develop the root chord bending stress as a function of descriptive geometric parameters and the dynamic pressure.

(1) $S_w = b/2\ \bar{c}\ (1 + \lambda)$

(2) $\lambda = C_T/C_R$

(3) $AR = 2b/\bar{c}\ (1 + \lambda)$

(4) $\ell = b/6\ \left(\frac{1 + 2\lambda}{1 + \lambda}\right)$

(5) $M_{ROOT} = 6\ C_L\ q_\infty\ \frac{S_w}{2}\ \ell$

(6) $\sigma = (36\ C_L\ q_\infty\ S_w\ \ell\ t)/II$

(7) $I = 800\ C_R t^3$

(8) $\bar{c} = 1/2\ (C_T + C_R)$

(Equation 7 represents an average section inertia for an airfoil shape)

where:

AR = aspect ratio

b = wing span (in.)

$\bar{c}$ = mean aerodynamic chord (ft.)

C_L = lift coefficient

C_R = root chord (ft.)

C_T = tip chord (ft.)

I = wing cross-section inertia (in.^{4})

ℓ = distance from root to CG (ft.)

M_{ROOT} = root bending moment (in. lbs)

q_∞ = freestream dynamic pressure (PSF)

S_w = wing area (ft^2)

t = wing thickness (in.)

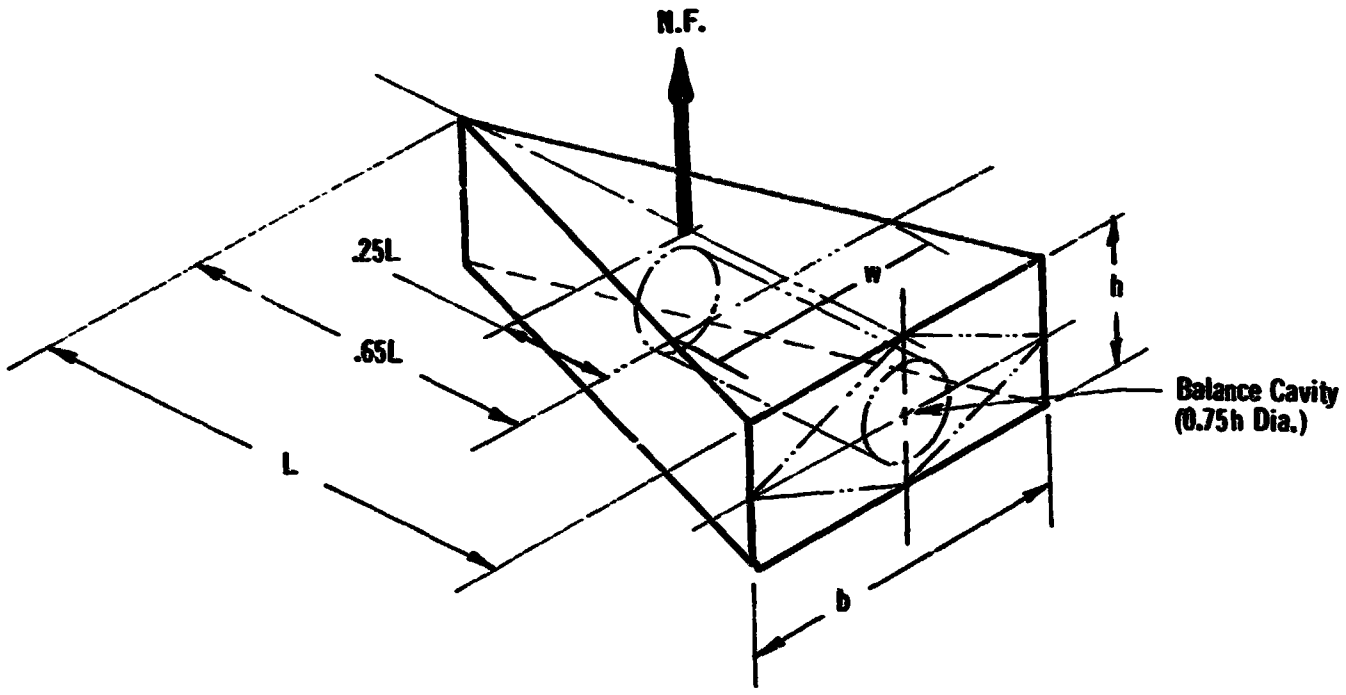
λ = taper ratio C_T/C_R

σ = root bending stress (psi)

Equations (1), (3), (4), (7), and (8) can be substituted into equation (6) to yield the following equations for maximum permissible dynamic pressure.

$$q_\infty = \frac{\dfrac{850\sigma}{C_L} \quad \dfrac{(t/c)^2}{(AR)^2}}{(1 + 2\lambda)\ (1 + \lambda)^2}$$

The above equation assumes that 80 percent of the wing cross-section is effective in carrying the load. This assumption makes allowances for removable leading edge slats, and trailing edge flaps. An interesting observation is that the maximum dynamic pressure is completely determined by nondimensional parameters and is independent of model size. A plot of the above equation is given in Figure 6-17a for various wing taper ratios. A similar development for the chordwise bending strength can be developed using the following diagram:



For highly swept bodies which are subjected to significant chordwise bending stresses, the permissible dynamic pressure is:

$$q_\infty = \frac{120\sigma(h/L)^2}{AR\ (L/b)\ C_L} \quad [\ 1-0.545\ (h/b)]$$

A plot of this equation, which includes the reduction in chordwise bending strength due to the presence of a .75h cavity for the balance, is presented in Figure 6-17b.

The balance used to measure forces and moments in the wind tunnel must have a load carrying capacity consistent with the model size and dynamic pressure. Assuming the balance capacity is a function of balance diameter squared and the balance diameter is 0.7 of the model height, then the dynamic pressure limit the balance can withstand, in terms of normal force capability, can be expressed as:

FIGURE 6–17a MAXIMUM DYNAMIC PRESSURE LIMITS BASED ON MODEL STRENGTH AND BALANCE CAPACITY LIMITATIONS

(Wing Bending Strength in Spanwise Direction)

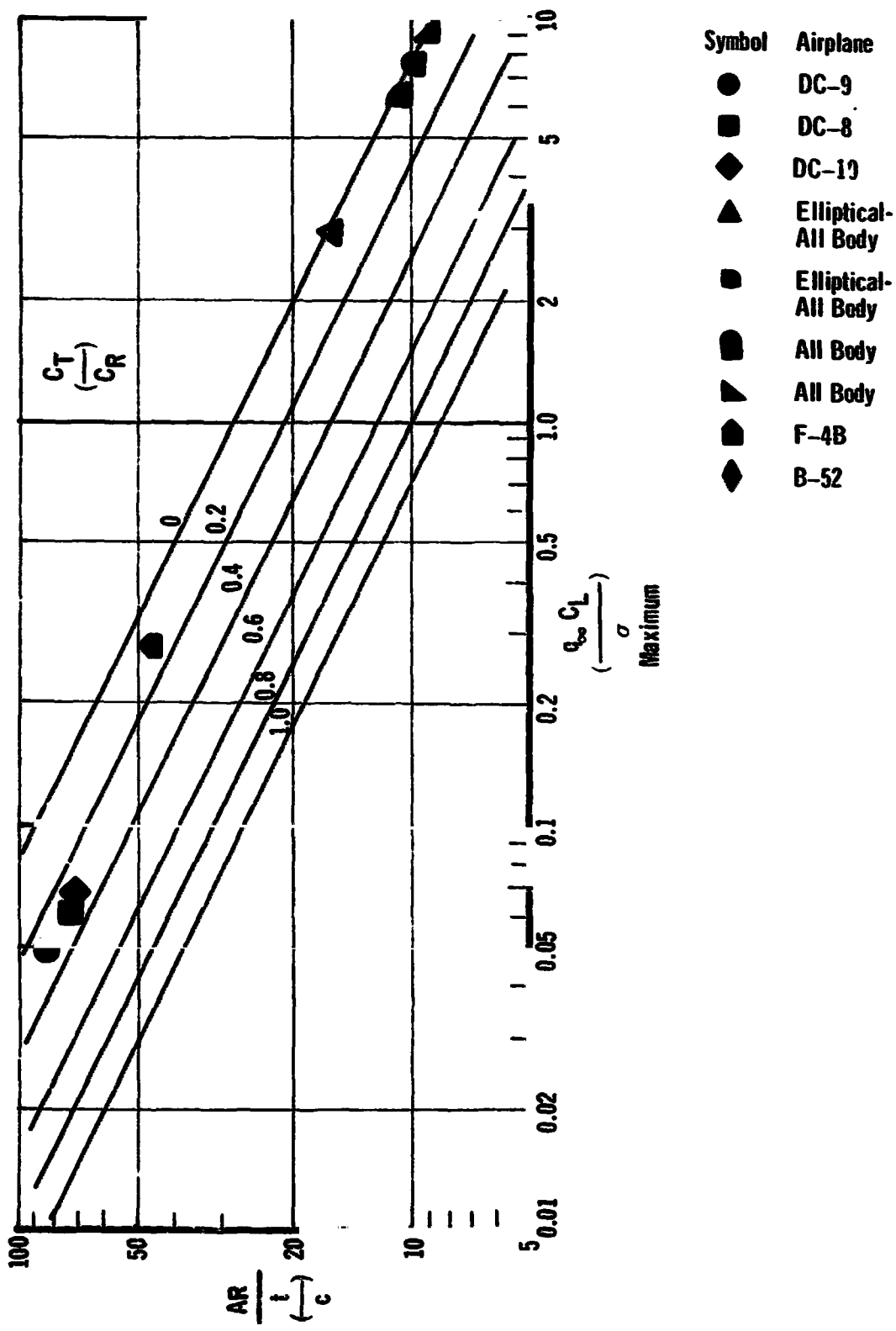


FIGURE 6–17b MAXIMUM DYNAMIC PRESSURE LIMITS BASED ON MODEL STRENGTH AND BALANCE CAPACITY LIMITATIONS (Wing Bending Strength, Chordwise Direction)

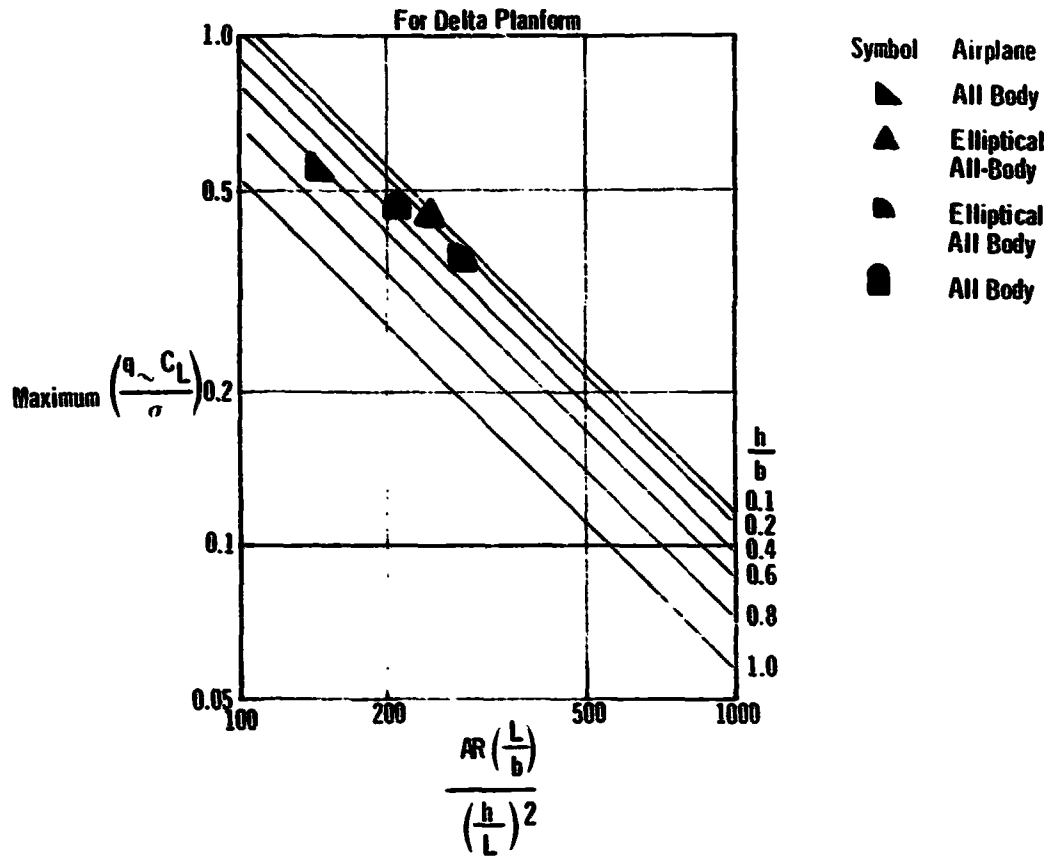
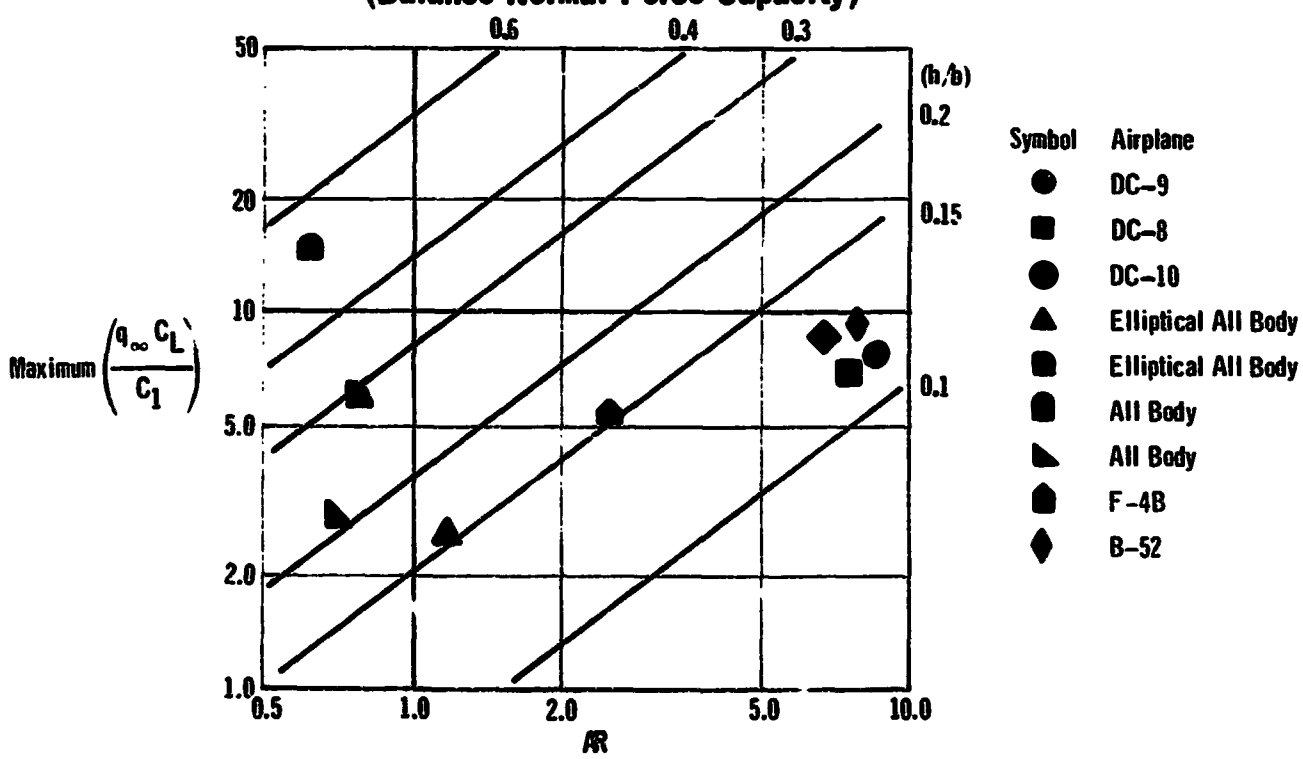


FIGURE 6–17c MAXIMUM DYNAMIC PRESSURE LIMITS BASED ON MODEL STRENGTH AND BALANCE CAPACITY LIMITATIONS (Balance Normal Force Capacity)



$$q_\infty = \frac{66\ C_1\ (h/b)}{C_L}$$

where $C_1 = \frac{\text{normal force capacity}}{d^2}$

d = Balance diameter (in.)

h = vehicle height (in.)

b = model wing span (ft)

q_∞ = freestream dynamic pressure (psf)

C_L = lift coefficient

AR = model aspect ratio.

This equation is plotted in Figure 6-17c.

In order to evaluate these equations, working values of model stress levels and balance load carrying capability are required. Model working stress levels are values determined from a review of published wind tunnel design requirements as well as from MCAIR wind tunnel design procedures. The balance load carrying capability is taken from Figure 6-18 which represents the current balance capacities taken from published data from NASA, AEDC, and current McDonnell Aircraft Company balances. The projections of future balance capacity were obtained from the Task Corporation, Anaheim, California, and are based on a new series of high strength steel balances. The data presented in Figure 6-18 represent the higher strength balances. Many balances available have less capability.

The working stress levels for wind tunnel models and balance load carrying capabilities are summarized in the following table:

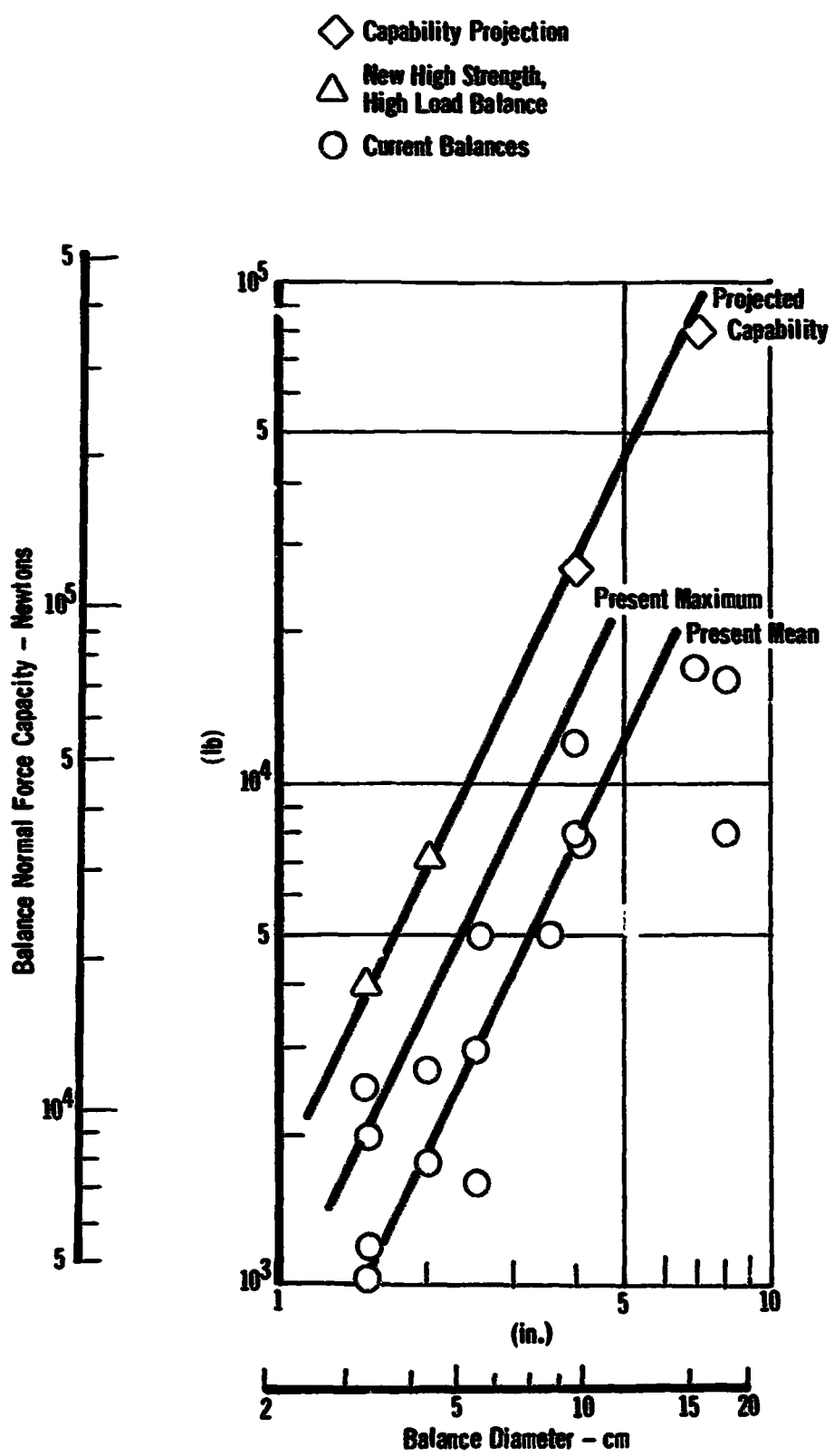
Material Working Stress Limits for Wind Tunnel Models

Material	(σ) Stress Level
Present Steels	35,000 psi (24,000 N/cm^2)
17-4PH	55,000 psi (38,000 N/cm^2)
300 CVM	83,000 psi (57,000 N/cm^2)
Future (1975-1980)	125,000 psi (85,000 N/cm^2)

Balance Load Carrying Capability, Normal Force/Diameter^2

Time Period	Load Capacity (C_1)
Present Mean	500 psi ± 10% (340 N/cm^2)
Present Maximum	900 psi ± 10% (610 N/cm^2)
Projected Future Capability (1971-1975)	1690 psi ± 5% (1150 N/cm^2)

FIGURE 6-18 BALANCE NORMAL FORCE CAPACITY VS DIAMETER



The dynamic pressure limits based on material strength and balance load carrying capability are all functions of non-dimensional geometric parameters, and do not define the model size. This is accomplished by introducing the maximum Reynolds number required as related to dynamic pressure, model size, and Mach number.

Relating tunnel size to the Reynolds number to be simulated and maximum dynamic pressure the model will sustain, the expression for the minimum size tunnel in which the desired level of simulation may be achieved without failing the model is,

$$\sqrt{C} = \frac{R_{e_L} \times 10^{-6}\ T_\infty M_\infty C_L}{1.37\ (q_\infty C_L)\ (1 + \frac{202}{T_\infty})}$$

using the following expression for Reynolds number,

$$R_e = \frac{1.78 \times 10^6\ q_\infty\ (1 + \frac{202}{T_\infty})L}{T_\infty M_\infty}$$

where, $q_\infty\ C_L$ is determined from Figures 6-17a, b, and c. This size then represents the smallest sized facility which will achieve the desired Reynolds numbers without failing either the balance or the model. For the several representative aircraft employed in Figure 6-17, the limiting values of $q_\infty\ C_L$ are presented in Figure 6-19. As indicated by the shaded areas, the achievable dynamic pressures are limited by the balance strength more often than by model strength. This indicates an area where further research could decrease the size of the wind tunnel required to achieve a given Reynolds number. Of course as model size is decreased, the unit Reynolds number is correspondingly increased, therefore some care is necessary because of unit Reynolds number effects on the boundary layer transition Reynolds number, and because of the surface finish necessary to simulate full scale surface finishes with very thin model boundary layers. There is however, probably some lower practical limit to just how much the tunnel size can be decreased, and unit Reynolds numbers increased until considerations other than model and balance strength become important.

Using the Mach and Reynolds number requirements for 1/5 maximum full scale Reynolds number simulation developed in Figure 6-15 and $q_\infty\ C_L$ based on a future material working stress level of 125,000 psi (86,000 N/cm^2) the preceding equation is plotted and presented in Figure 6-20. This figure gives the tunnel size required to achieve 1/5 full scale Reynolds number simulation for various fuselage cross sectional shapes. A high value of b/h would correspond to a slender highly swept lifting body and a low b/h would correspond to the fuselage shape of a subsonic transport.

FIGURE 6-19 MAXIMUM DYNAMIC PRESSURE LIMITS BASED ON MODEL STRENGTH AND BALANCE CAPACITY LIMITATIONS

(SUMMARY)

Aircraft	$(q_\infty C_L)_{Max}$ (psf) Spanwise Bending		$(q_\infty C_L)_{Max}$ (psf) Chordwise Bending		$(q_\infty C_L)_{Max}$ (psf) Balance Limit	
	300 CVM	17-4PH	17-4PH	300 CVM	Present Mean	Present Maximum
F-4B	32,400 (1,550)	21,400 (1,020)			2,650 (126)	4,670 (224)
DC 10	8,420 (400)	5,500 (263)			4,400 (211)	7,750 (371)
DC 8	7,920	5,250			3,000 (143)	5,400 (257)
DC 9	6,310 (302)	4,150 (200)			3,490 (167)	6,260 (300)
Elliptical All Body	490,000 (23,400)	325,000 (15,500)	24,700 (1,180)	37,100 (1,770)	1,880 (90)	1,860 (89)
			20,200 (961)	30,700 (1,460)	1,440 (69)	2,600 (125)
All Body			25,800 (1,230)	38,900 (1,850)	3,130 (150)	5,640 (270)
			30,500 (1,450)	45,900 (2,180)	7,650 (367)	13,800 (660)

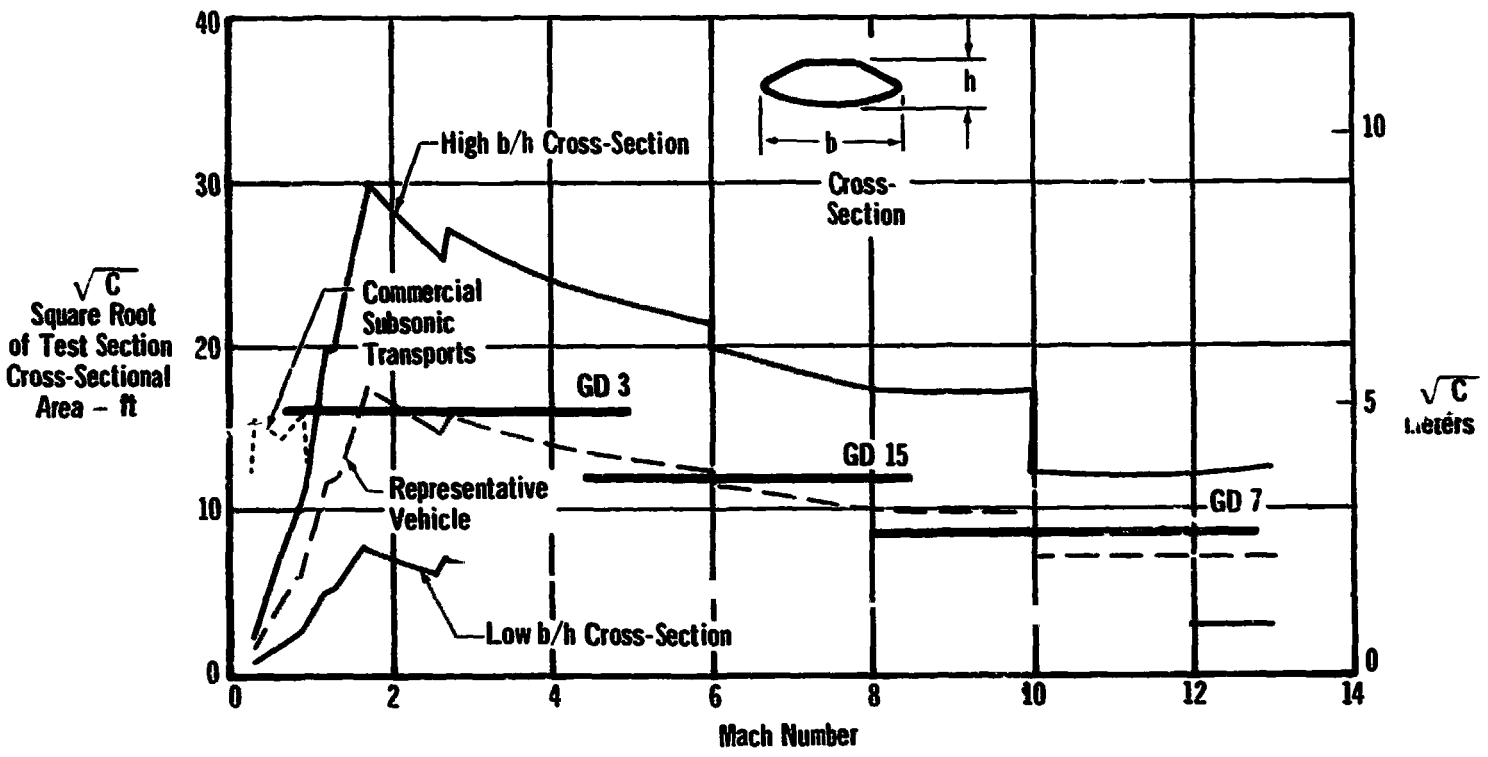
Shaded values indicate minimum values of dynamic pressure values.
Values for N/cm^2 in parentheses.

6.4.2 ANALYSIS - The existing gasdynamic research capability within the United States is capable of providing a very meaningful contribution to any aircraft system in development now or in the future, for example the development of the B-70, C5A, DC10, L-1011, 747, and that of the SST now in progress. Any candidate facility must genuinely satisfy goals which are unattainable in existing facilities to warrant further consideration in this study. The following discussion is intended to point out the dominating role the potential operational aircraft have in arriving at that decision.

The composite existing wind tunnel capability from Figure 6-15 is compared to some of the candidate gasdynamic facilities in Figure 6-21. Only those facilities remaining after the initial facility screening process (section 7) are shown. GD 4 represents a Ludwieg tube tunnel concept to provide flight duplicated Reynolds numbers at near-sonic conditions, and is primarily related to shock/boundary layer interaction scaling in that flight regime. Depending on the thrust minus drag values for large hypersonic aircraft, this facility could be an essential tool for providing accurate transonic acceleration predictions.

FIGURE 6-20 GASDYNAMIC FACILITY SIZE REQUIREMENTS

Wind Tunnel Size 1/5 Full Scale Reynolds Number
Future Materials, 125,000 psi (86,000 N/cm^2) Working Stress
Balances, 1850 lb (1270 N/cm^2) Capacity Per Inch Diameter Squared



The comparison with maximum Reynolds number capability somewhat restricts the overall view of the total facility capability. A facility that can achieve 1/5 the maximum Reynolds number for a very large aircraft flying at maximum dynamic pressure can do much better than maximum for vehicles shorter in length. Also the air-breathing aircraft flight paths require a significantly higher level of Reynolds number simulation than do high angle of attack, gliding entry vehicles, and evaluation of these differences indicate the dominance of vehicle class on the judgements made concerning Reynolds number requirements.

Figure 6-22 compares the Reynolds number corridor from Figure 6-13 for air-breathing airplanes with those of the proposed Space Transportation System (Space Shuttle) gliding entry vehicle for the same length vehicle, 310 feet (95 meters). The contrasting judgements which could be made concerning the adequacy of existing facilities are clearly indicated.

Examining the HYFAC corridor, it is seen that the existing facilities are limited in providing full scale simulation of the flight corridor Reynolds numbers for the proposed operational aircraft. By contrast, it is seen from the space shuttle trajectory that the demands for simulation are met generally by the existing facilities, except for a small portion along the exit trajectory.

Reviewing the aircraft characteristics presented in Volume VI, three representative lengths were selected as characteristic of the nine potential operational hypersonic aircraft. These characteristic lengths were judged to be 310 feet, 190 feet, and 90 feet (95 m, 58 m, and 27 m).

Figures 6-23, 24 and 25 represent a comparison between the Reynolds number simulation capability of existing and study facilities for these three aircraft sizes. For these comparisons the maximum dynamic pressure flight path, 2000 psf (95,700 N/m^2) was matched to the maximum capability for the HYFAC study. For all three aircraft sizes, some general observations can be made. 1) If the HYFAC study facilities can provide a certain degree of Reynolds number simulation, based on maximum dynamic pressure, then existing facilities can provide almost the same level of simulation in the hypersonic cruise corridor. 2) The most serious deficiencies exist in the Mach number regions less than Mach number 7, especially the subsonic to supersonic regime. 3) Existing facilities provide acceptable levels of Reynolds number simulation for the lower end of the dynamic pressure flight regime (200 psf, 9570 N/m^2). The Reynolds number simulation levels which the existing, and study facilities are capable of, for different trajectory conditions, are summarized in the following.

DEGREE OF FULL SCALE REYNOLDS NUMBER SIMULATION

CONDITION	310 ft (95 m) existing	310 ft (95 m) HYFAC	190 ft (58 m) existing	190 ft (58 m) HYFAC	90 ft (27 m) existing	90 ft (27 m) HYFAC
2000 psf (95,700 N/m^2)	1/15	1/5	1/8	1/3	1/5	1
HYPERSONIC CRUISE	1/5	3/4	1/3	1	1	>1
200 psf (9,570 N/m^2)	1	>1	>1	>1	>1	>1
TRANSONIC/SUPERSONIC	1/25	1/5	1/5	1/14	1/8	1

Thus the need for very high Reynolds number facilities is contingent upon the need for large hypersonic aircraft whose operation is dependent on high dynamic pressure acceleration flight paths. It is possible for smaller high performance, high maneuverability aircraft which operate at low altitudes at supersonic Mach numbers to also influence the need for new facilities.

Summarizing, the candidate facilities would be required to provide the desired simulation for the longer vehicles whereas simulation obtained in the existing facilities would suffice for the shorter vehicles.

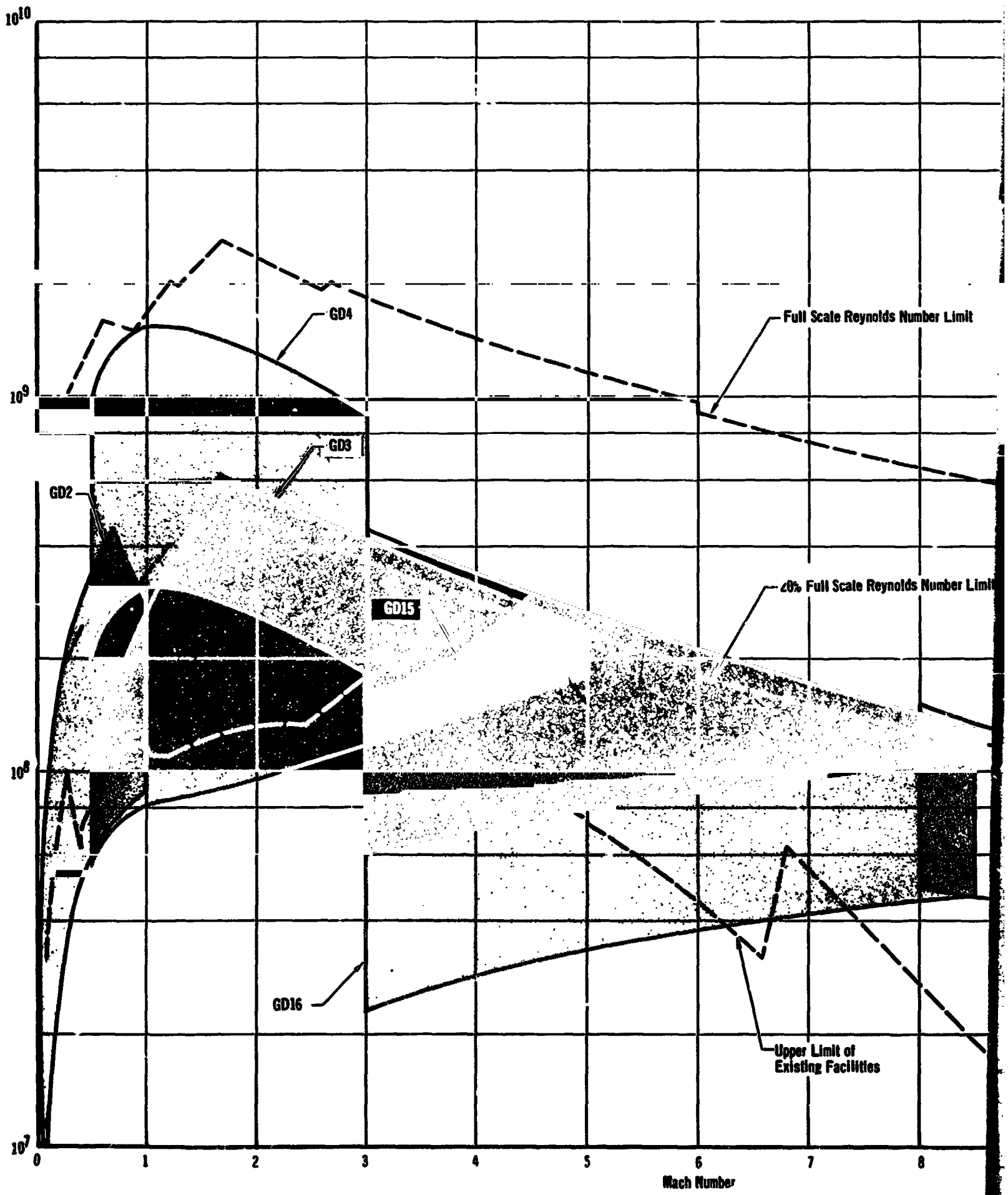
The three facility sizes determined from Figure 6-20 to cover the Mach 12 flight corridor imply that three sizes of models would be necessary to accomplish the research in this Mach number regime, based on a maximum model length of:

$$L = \frac{\sqrt{C}}{1.3}$$

In view of the costs associated with the designing and building of wind tunnel models of the size required for the candidate facilities, 12 feet to 18 feet long, (3.7 to 5.5 m), it is advantageous to create the flexibility of a standard model that is, a single model which can be tested throughout the Mach number range of the proposed hypersonic aircraft. Although the value of

FOLDOUT FRAME 1

FIGURE 6-21 PERFORMANCE OF CANDIDATE FACILITIES



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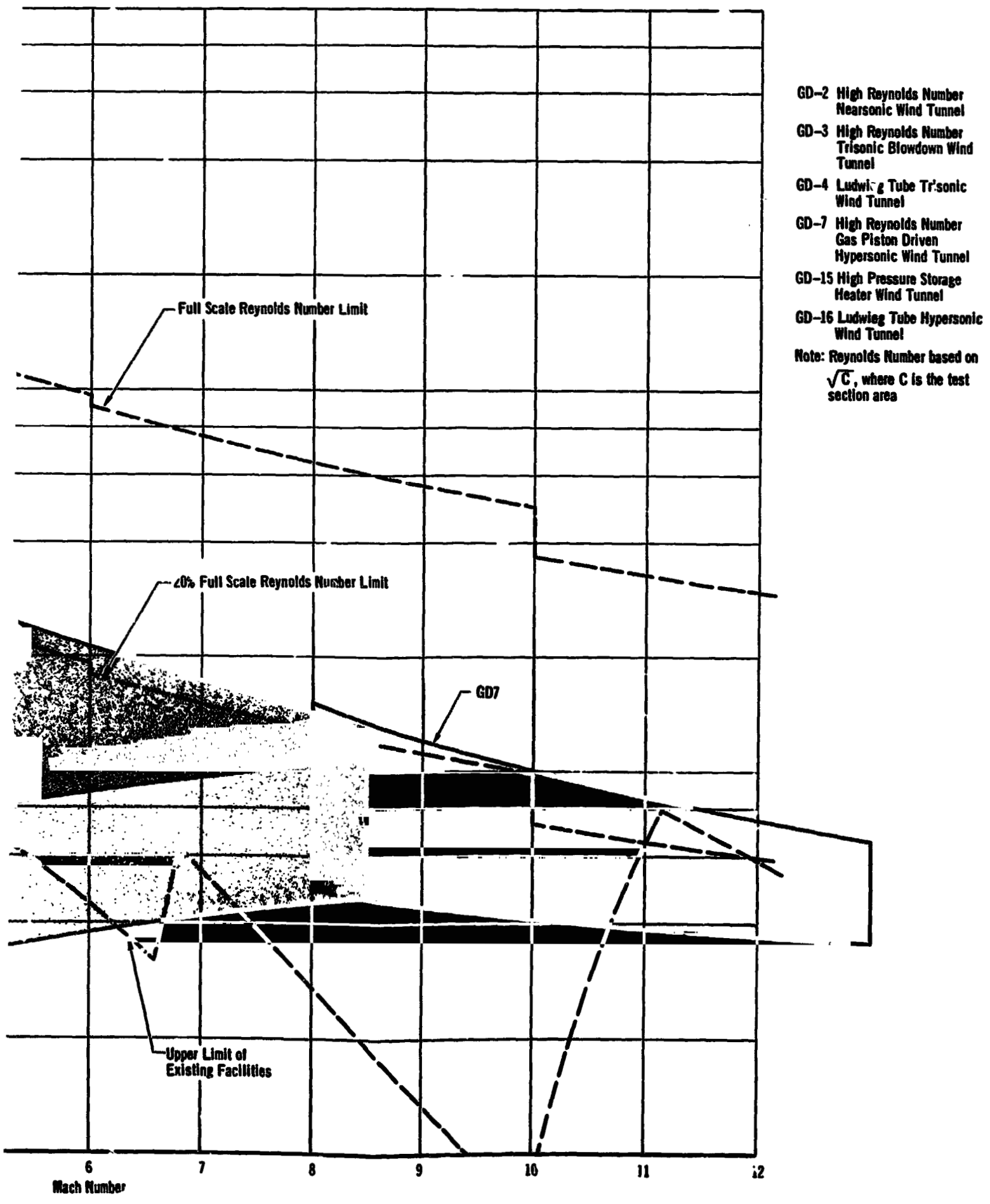
ACILITIES



GD-2 High Reynolds Number Nearsonic Wind Tunnel

GD-3 High Reynolds Number Trisonic Blowdown Wind Tunnel

GD-4 Ludwieg Tube Trisonic Wind Tunnel

GD-7 High Reynolds Number Gas Piston Driven Hypersonic Wind Tunnel

GD-15 High Pressure Storage Heater Wind Tunnel

GD-16 Ludwieg Tube Hypersonic Wind Tunnel

Note: Reynolds Number based on $\sqrt{C}$, where C is the test section area

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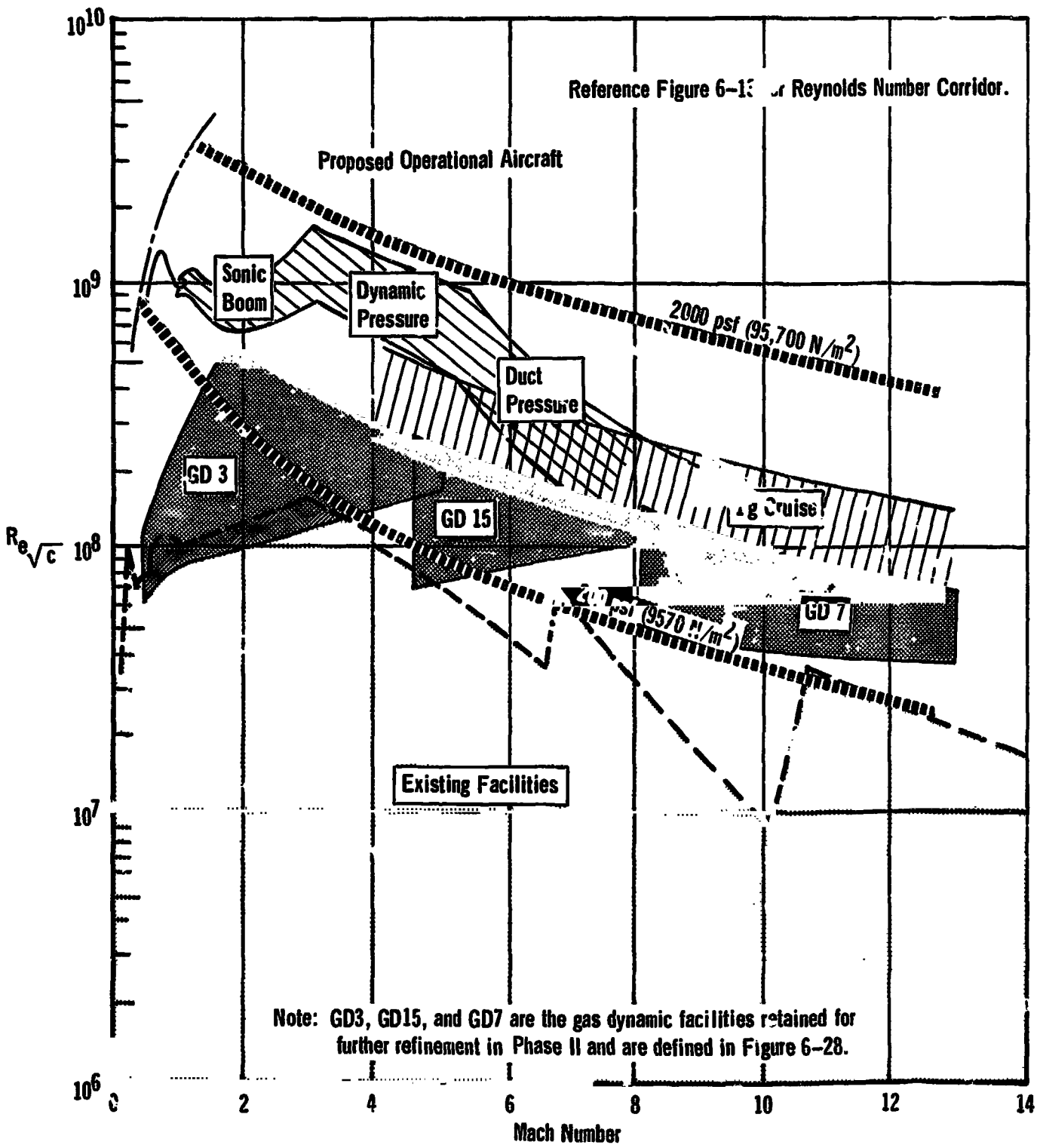
SHUTT

Reynolds Number Corridor Evaluated for a 310 Foot (95 m) Long Vehicle, and Full Scale Reynolds Number Duplication



Note: GD3, GD15, and GD7 are the gas dynamic facilities retained for further refinement in Phase II and are defined in Figure 6–28.

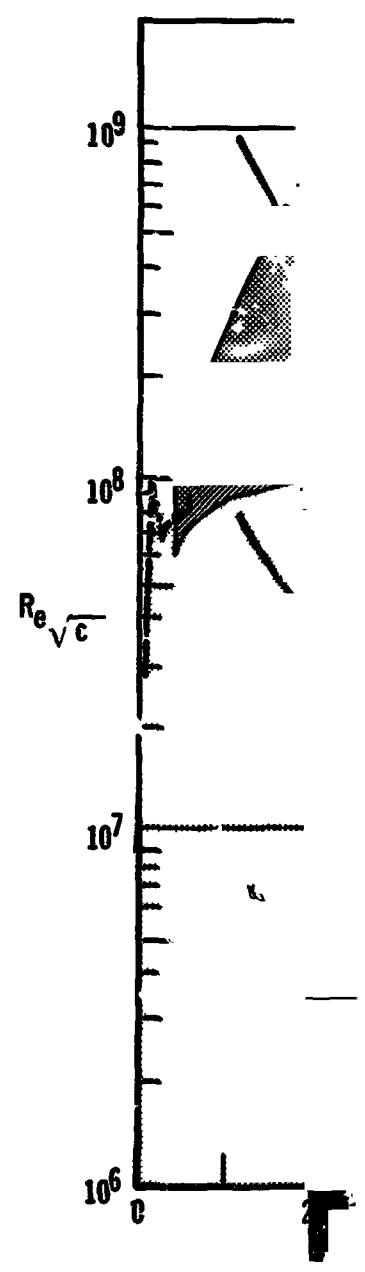
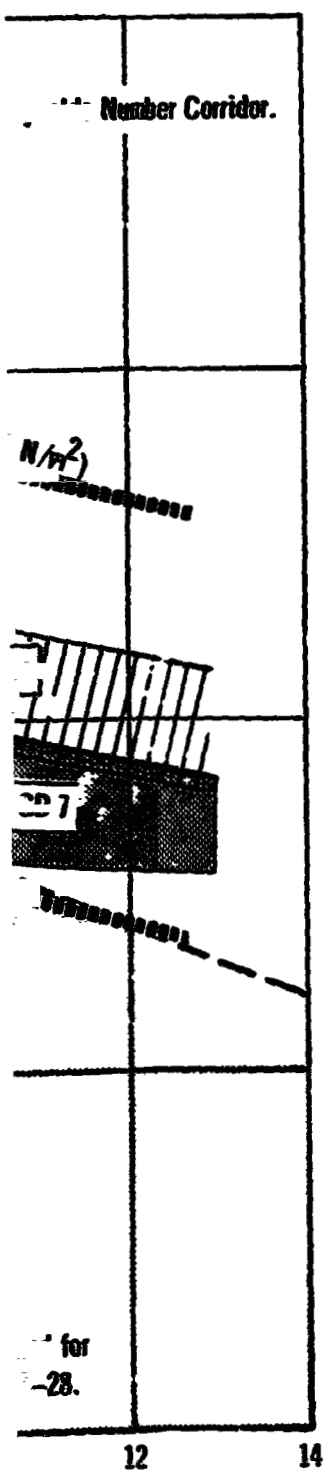


FIGURE 6–22
COMPARISON OF HYFAC VEHICLE REQUIREMENTS AND SPACE SHUTTLE VEHICLE WITH EXISTING CAPABILITY

FOLDOUT FRAME 2



REYNOLDS NUMBER CORRIDOR EVALUATED FOR A 310 FOOT (95 m) LONG VEHICLE AND FULL SCALE REYNOLDS NUMBER DUPLICATION

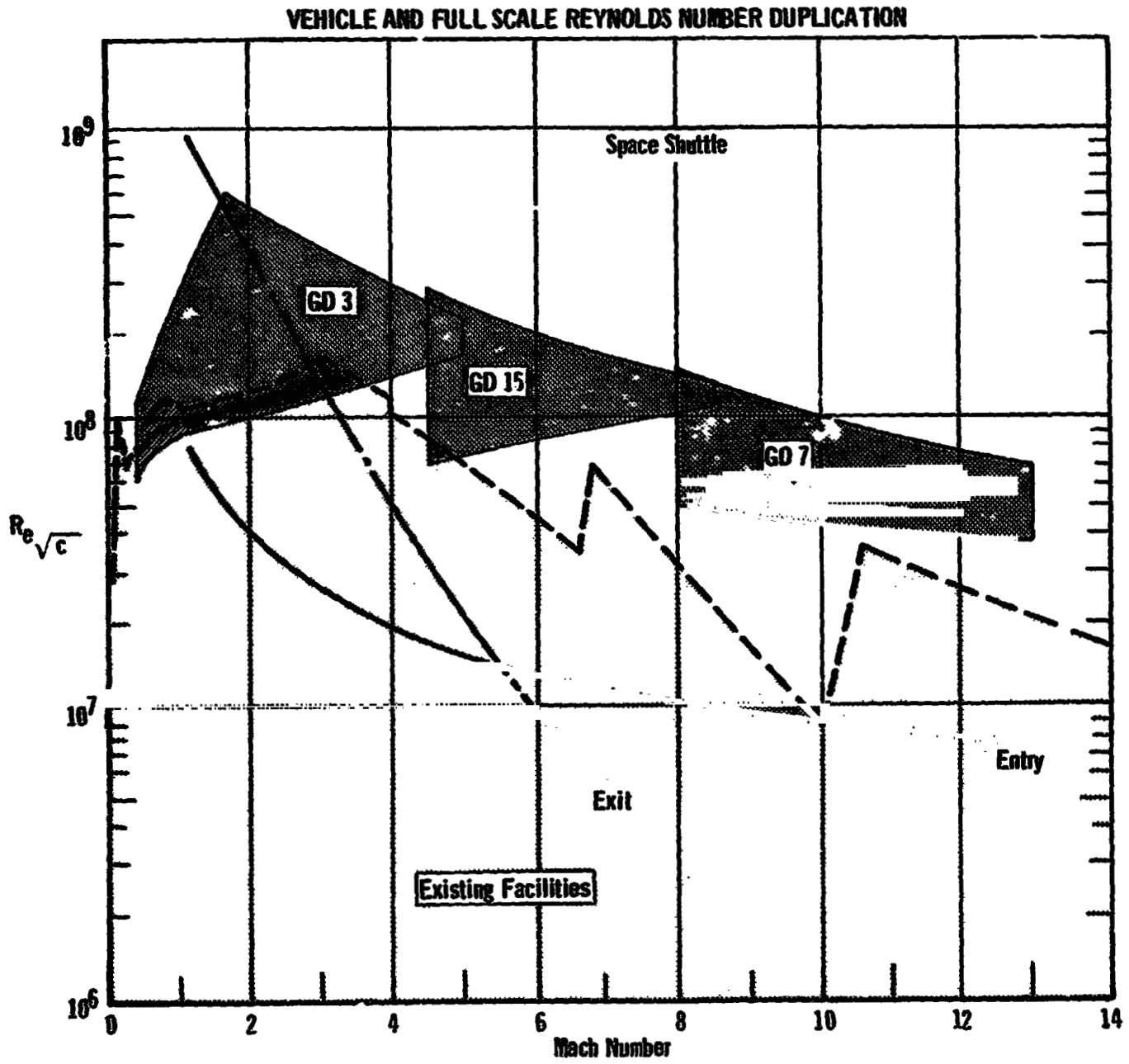


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FIGURE 6–23 COMPARISON OF REQUIREMENTS WITH CAPABILITY, MAXIMUM LENGTH VEHICLE

Reynolds Number Corridor Evaluated for a 310 Foot (95 m) Long Vehicle, and a 1/5 Maximum Full Scale Reynolds Number Simulation Level

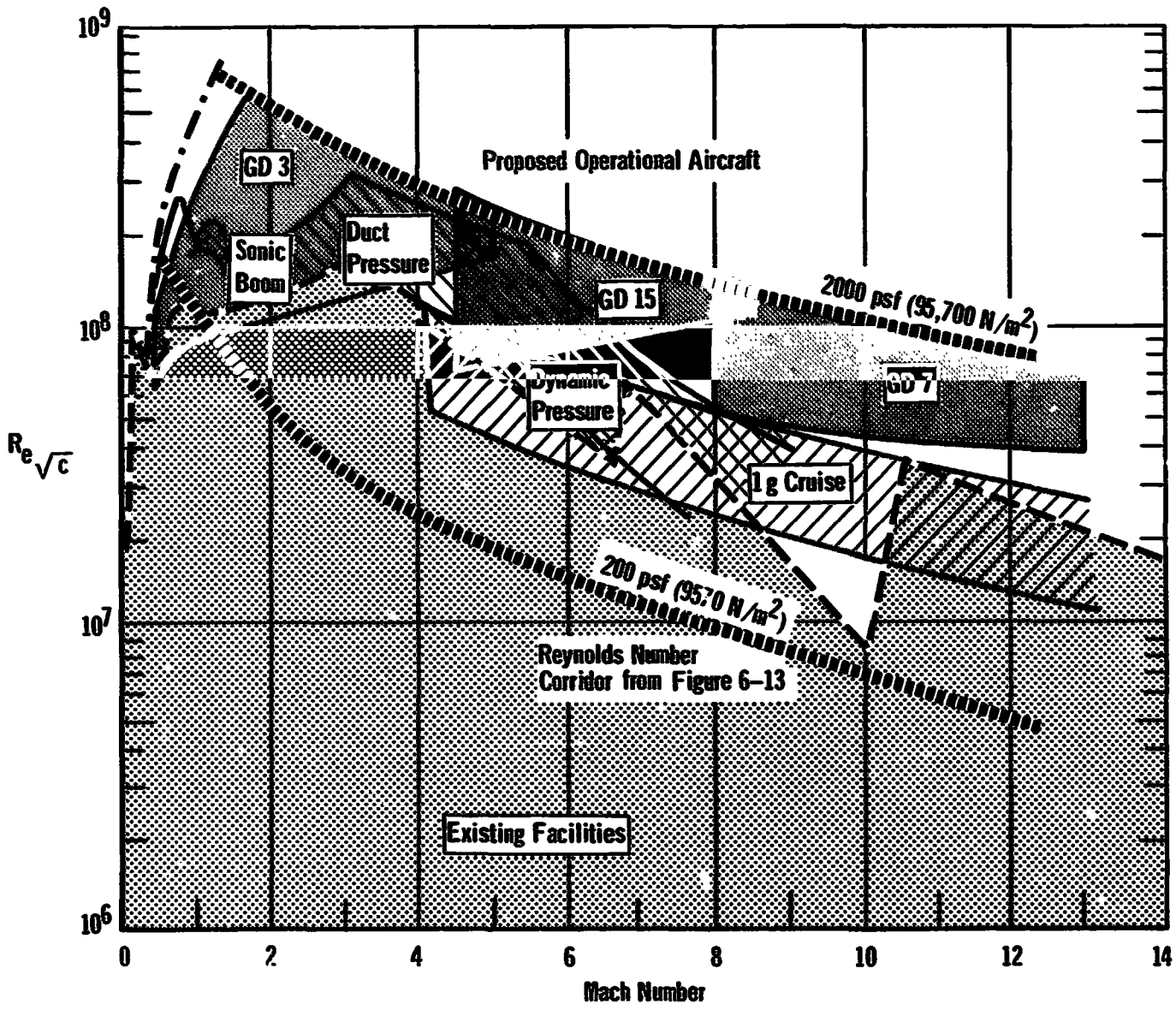


FIGURE 6–24 COMPARISON OF REQUIREMENTS WITH CAPABILITY INTERMEDIATE LENGTH VEHICLE

Reynolds Number Corridor Evaluated for a 190 Foot (58 m) Long Vehicle, and a 1/3 Maximum Full Scale Reynolds Number Simulation Level

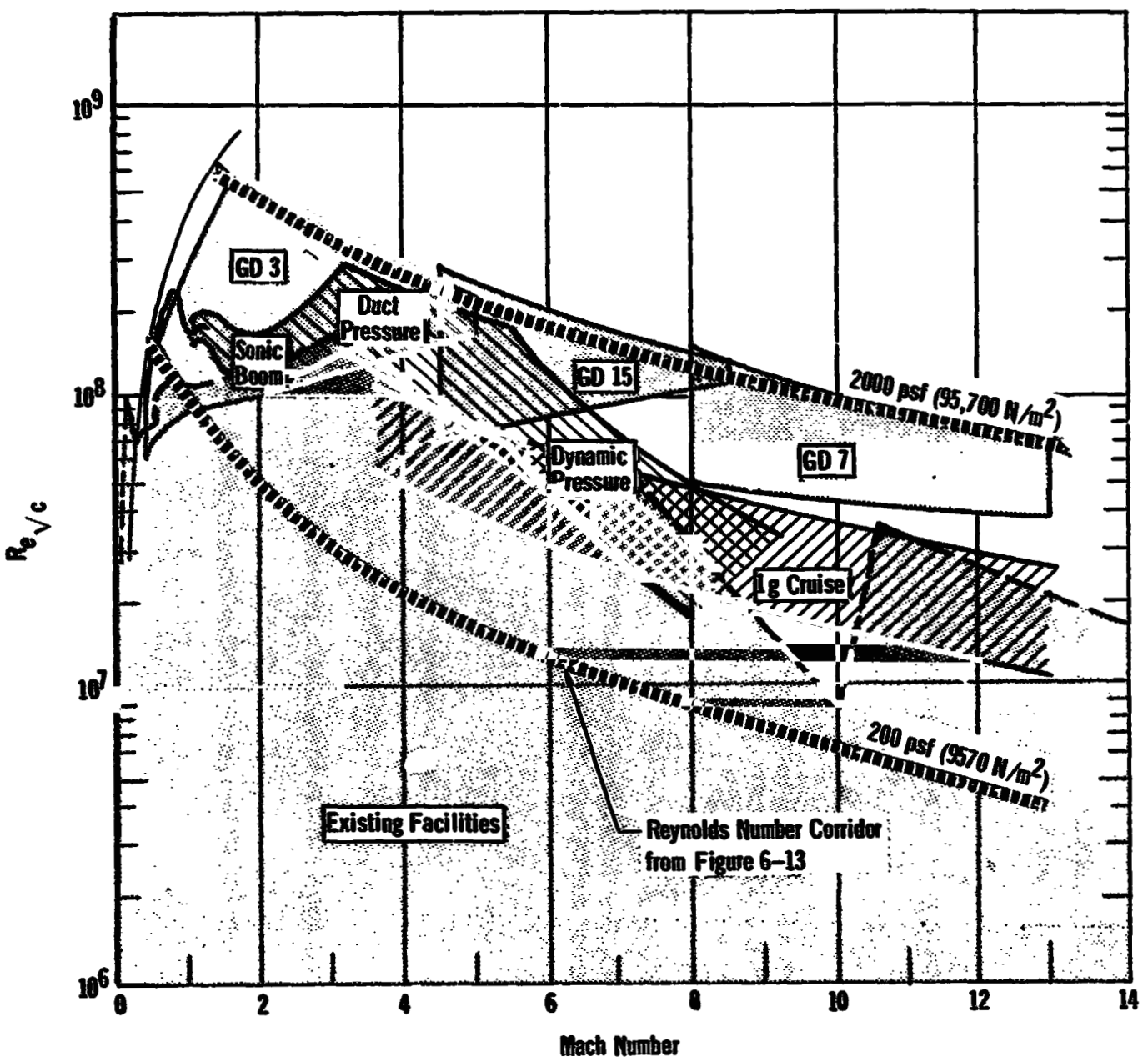
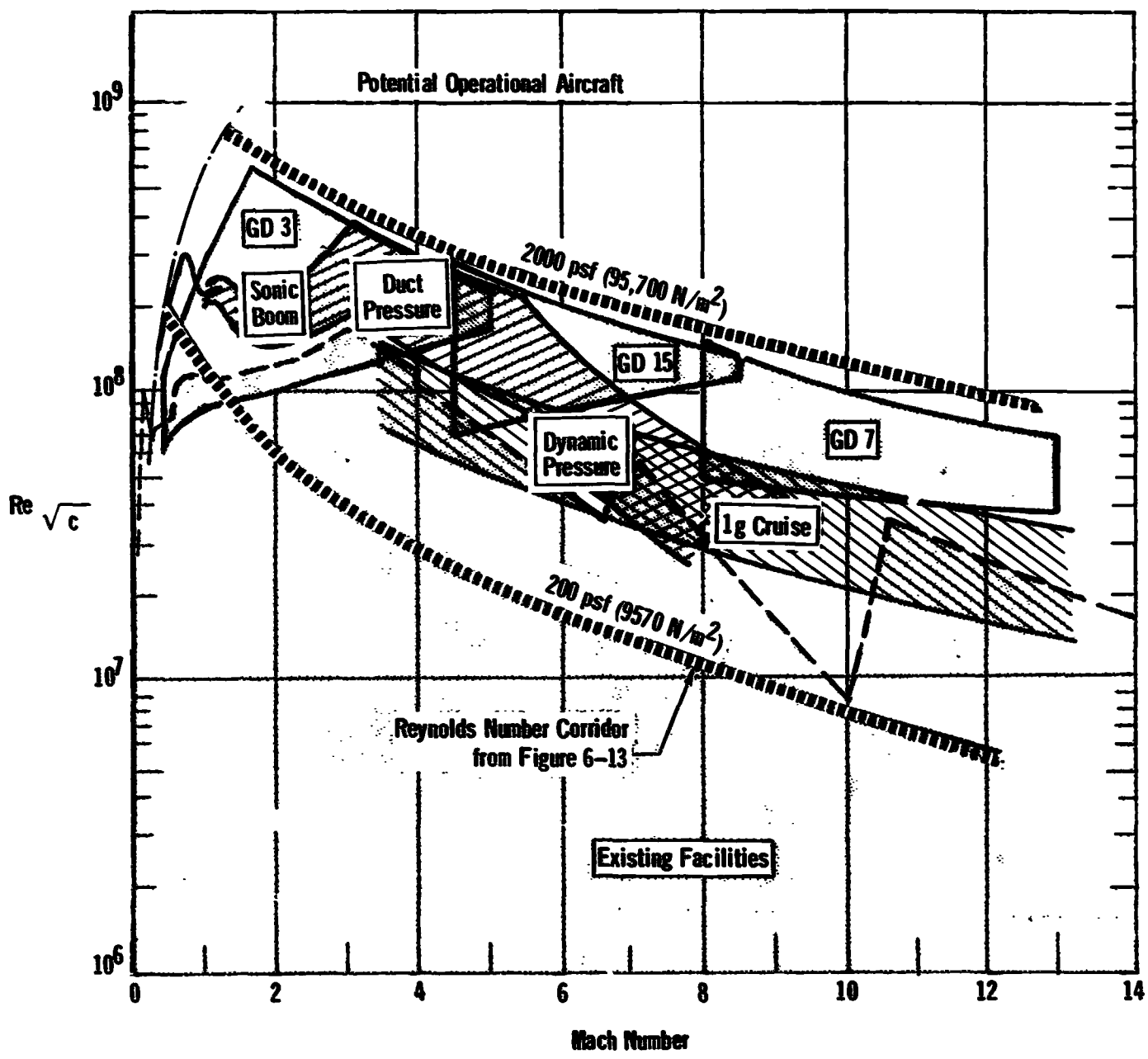


FIGURE 6–25
COMPARISON OF REQUIREMENTS AND CAPABILITY FOR A MINIMUM LENGTH VEHICLE

Reynolds Number Corridor Evaluated for an 85 Foot (26 m) Long Vehicle and a Maximum Full Scale Reynolds Number Duplication



$L = .77\sqrt{C}$ used for the candidate facility evaluation may have seemed too conservative, it can provide model sizing flexibility which can be used to advantage.

Figure 6-26 presents a comparison of the existing facilities' operating range to that of the candidate gasdynamic facilities for a model sized to each test section size based on the above criteria compared to that for one model size, that for GD 3, used in each facility. Figure 6-27 illustrates that this larger model can be accommodated in the smaller, higher Mach number facilities without violating the model blockage guidelines. Thus, the alternative of single models is available, without imposing any limitations on the magnitude of the maximum Reynolds number that can be attained, and in fact increasing it by some 60% at Mach numbers above 8.

FIGURE 6-26a COMPARISON OF GAS DYNAMIC FACILITIES WITH WITH EXISTING FACILITIES
Model Size Based on Tunnel Size
$\sqrt{C} = 1.3L$

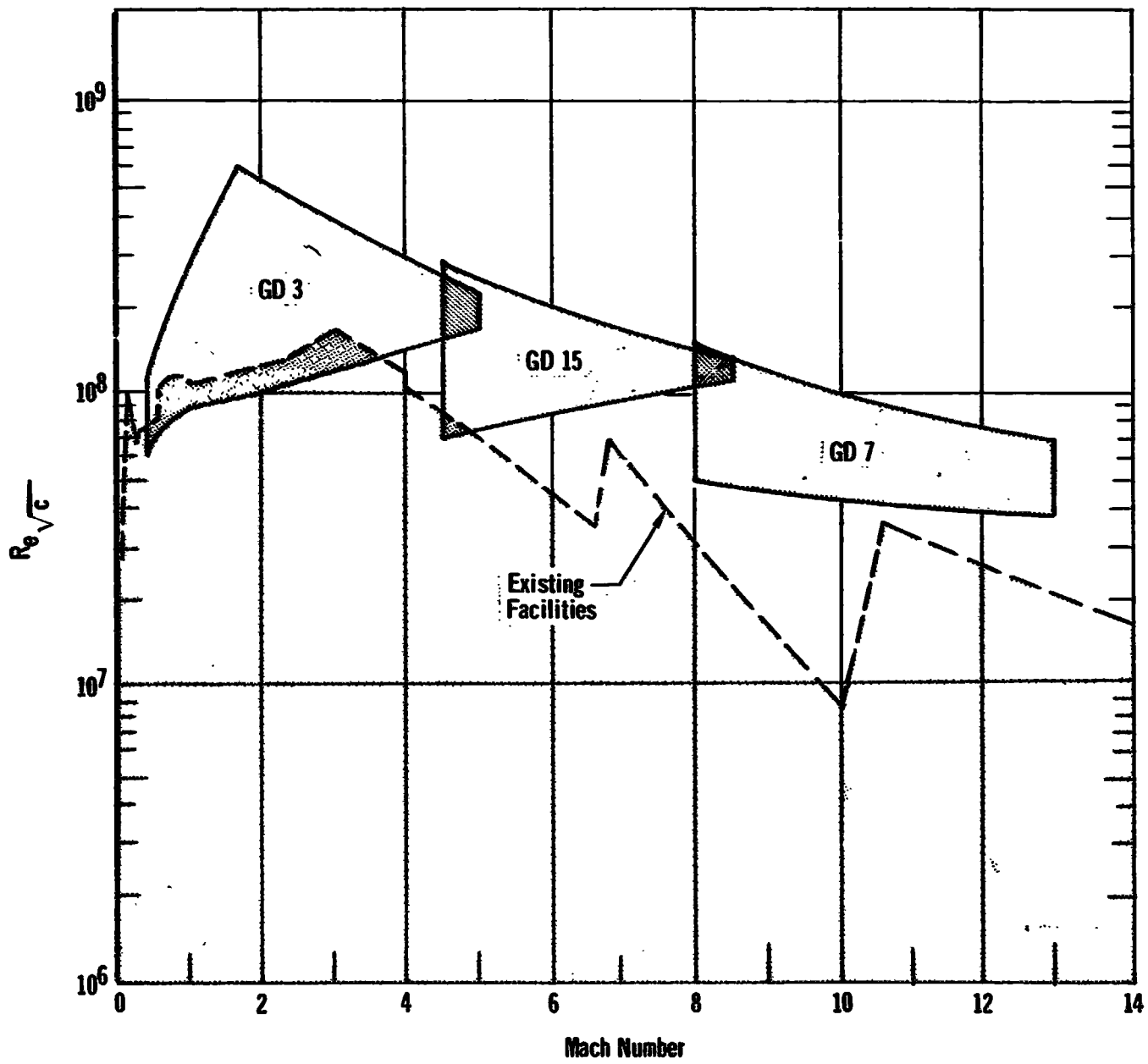
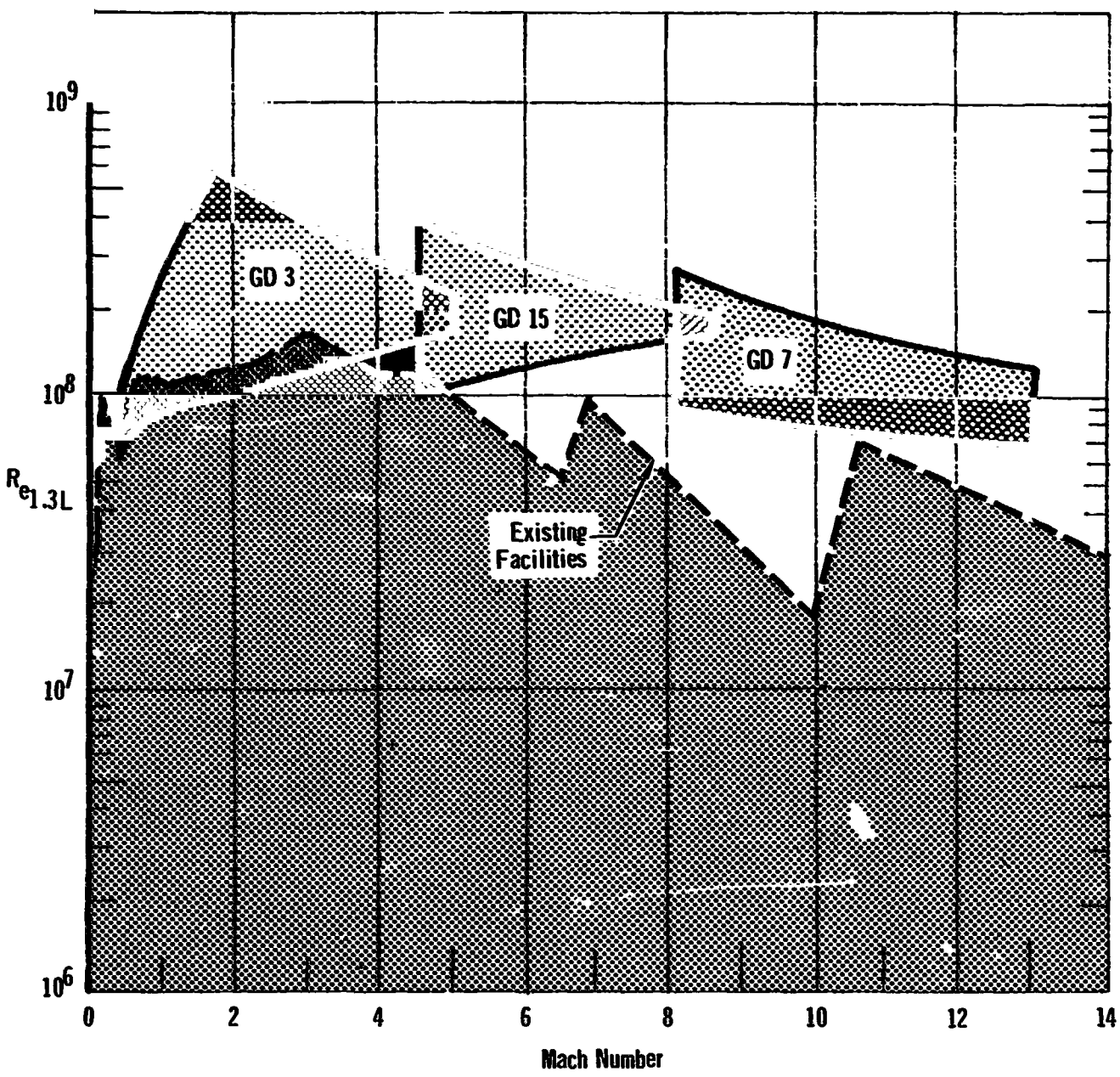


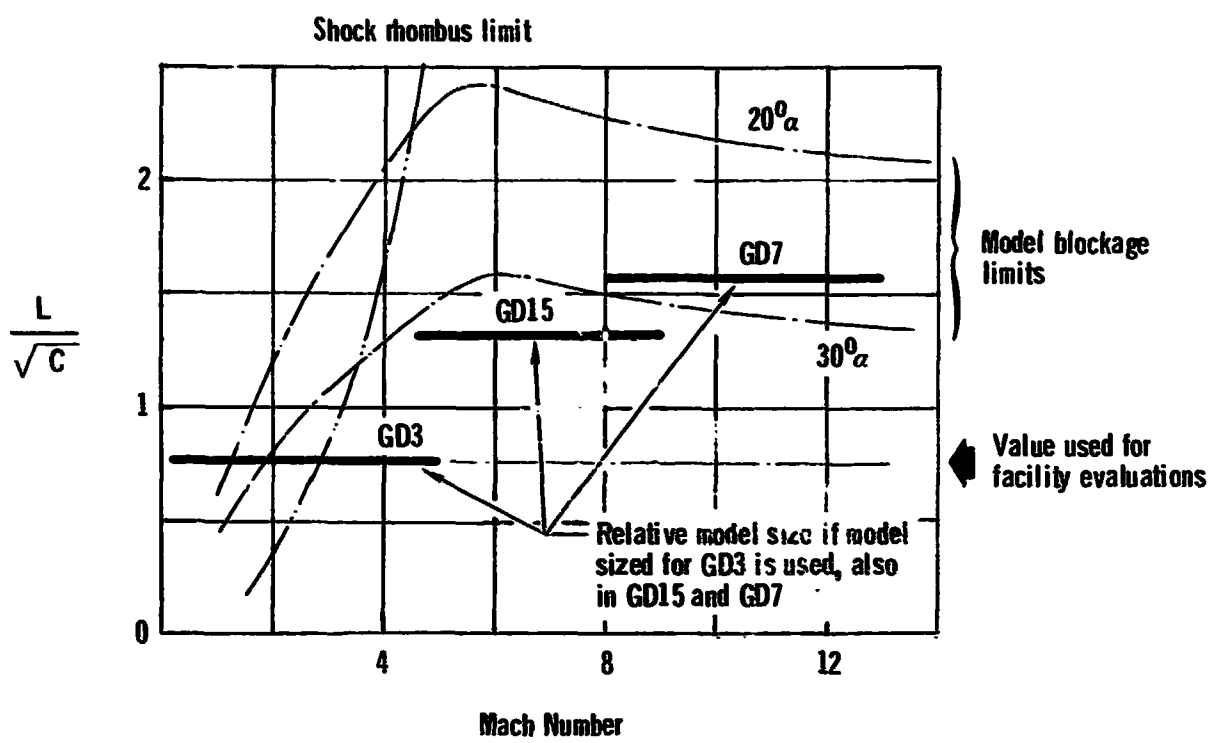
FIGURE 6–26b COMPARISON OF GAS DYNAMIC FACILITIES WITH EXISTING FACILITIES

(Model Size as Required for GD3, Utilized in GD15 and GD7)
Reynolds Number Based on 1.3 Times the Model Length



Reference – Figures 6–16 and 6–20

FIGURE 6-27 MODEL SIZING CRITERIA PROVIDES OPERATIONAL FLEXIBILITY



6.4.3 FACILITY DESIGN CHARACTERISTICS - The description, performance statement, and physical characteristics are presented for those facilities which survived the initial screening processes (Section 7), and represented both a significant contribution to the research required for the potential hypersonic aircraft and a significant increase in existing facility capability. Figure 6-28 is provided to give a perspective into the disposition of the 17 gasdynamic study facilities and why only 6 were carried through for final definition. A more detailed rationale for these dispositions is given in Figure 7-2. Figure 6-103 provides a synopsis of each candidate facility's required performance, size, and costs, where estimated.

FIGURE 6–28 SUMMARY OF CANDIDATE GAS DYNAMIC FACILITIES AND THEIR DISPOSITION IN PHASE I

	Code	Facility Name	Capability	Disposition Code*
Gasdynamic Facilities	GD1	Subsonic Wind Tunnel (Continuous)	High Reynolds Number** Aerodynamic Research, Low Speed, Takeoff and Landing. Maneuvering Conditions. M < 0.5	GD2
	GD2	Nearsonic Wind Tunnel (Continuous)	High Reynolds Number Aerodynamic Research, Subsonic Transonic, Cruise and Maneuvering Conditions. M < 1.0.	R
	GD3	Trisonic Wind Tunnel (Intermittent)	High Reynolds Number Aerothermodynamic Research, Subsonic Transonic Supersonic Flight Conditions. 0.3 < M < 5.0.	II
	GD4	Ludwieg Tube Transonic Tunnel (Impulse)	Flight Duplicated Reynolds Numbers, Transonic Research in Viscous Flows with Shock Interactions. 0.3 < M < 3.0.	R
	GD5	Hypersonic Impulse Tunnel (Hotshot)	High Reynolds Number Aerothermodynamic Research. Lacked Run Time, Greater Operational Risks than GD7.	D
	GD6	Hypersonic Impulse Tunnel (Shock Tube)	High Reynolds Number Aerothermodynamic Research. About One-Thousandth of Run Time of GD7 at Same Conditions.	D
	GD7	Hypersonic Impulse Tunnel (Gas Piston)	High Reynolds Number Aerothermodynamic Research, Intermediate Flight Mach Numbers. 8 < M < 13	II
	GD8	Alumina Storage Heater Facility (Intermittent)	Flight Duplicated Conditions to Mach Number 6. Provided as Part of Engine Research Facility E9.	E9
	GD9	Zirconia Storage Heater Facility (Intermittent)	Flight Duplicated Conditions to Mach Number 8.	E9
	GD10	Multirecompression Heater Facility (Continuous)	Flight Duplicated Conditions to Mach Number 14 (Continuous) or Mach Number 18 (Impulse). Redefined as Engine Facility E8.	E8
	GD11	High Pressure Arc Heater Facility (Continuous)	Flight Duplicated Conditions to Mach Number 12 (Continuous). Redefined as Engine Facility E10.	E10
	GD12	Large Bore Aeroballistics Range	High Reynolds Number Flight Dynamics – Modification to NOL Aeroballistic Range.	R
	GD13	Sled Test Track	Flight Duplicated Reynolds Number – Modification to Hollomann Sled Track.	R
	GD14	Rocket Launched Models	Athena, Scout Boosted Scale Model – Capability Inconsistent with Cost Considering GD2, GD3, GD7, GD15 Capability.	D
	GD15	Hypersonic Blowdown Tunnel (Intermittent)	High Reynolds Number Aerothermodynamic Research, Low Hypersonic Mach Numbers 4.5 < M < 8.5.	D
	GD16	Hypersonic Impulse Tunnel (Ludwieg Tube)	High Reynolds Number Aerothermodynamic Research, Low Hypersonic Mach Number. 4.5 < M < 8.5.	II
	GD17	Trisonic Wind Tunnel (Continuous)	High Reynolds Number Aerodynamic Research, Continuous Version of GD3.	D

* (Facility Code) integrated into indicated facility for Phase II refinement.

** High Reynolds number for the HYFAC study is defined as providing 1/5 of the Reynolds number for a 310 ft (0.95m) long aircraft flying at a dynamic pressure of 2000 psf (95,700 N/m^2).

(R) Does not have high research value as applicable to HYFAC but does to other aircraft systems – recommended for further later study.

(II) Entered into Phase II for further refinement.

(D) Deleted from further refinement.

GD2 HIGH REYNOLDS NUMBER, CONTINUOUS, NEARSONIC WIND TUNNEL

Description:

This facility, Figure 6-29, is a large, high pressure, continuous wind tunnel, one in which the working fluid is continuously processed and recycled through the test section. The intent of the facility is to increase the subsonic testing Reynolds number capability, as represented by the NASA 12' Pressure Tunnel. It is not expected that modifications can be added to existing wind tunnels to provide this capability.

Specifications:

Mach Range: .02 to 1.0
Stagnation Pressure: 14.7 to 90 psia (10.1 to 62 N/cm^2)
Test Section: 17 x 24' (5.18 x 7.31 m)

Design Points:

A) $M = .9$; $Re_{\sqrt{c}} = 3.3 \times 10^8$; $P_o = 52$ psia (36.8 N/cm^2)

B) $M = .7$; $Re_{\sqrt{c}} = 4.5 \times 10^8$; $P_o = 90$ psia (62 N/cm^2)

Power = 274,000 hp (assumed power factor = .15)
(204,000 kW)

Features:

1. Test section isolation gates and pressure relief system for model changes without depressurization of entire circuit.

2. Removable test section carts for efficient test installation. Special building and trackage for carts.

3. Low turbulence provided by large contraction in conjunction with screens and honey comb.

4. Sunshade over entire circuit to minimize thermal gradients.

5. A possible additional capability is a larger V/STOL test section ahead of the high speed test section.

Major Systems:

1. Fan drive, speed control (≃ 274,000 hp) (204,000 kW)

2. Circuit pumping system. P_{max} = 90 psia (62 N/cm^2) Volume = 1.36×10^6 ft^3
Pumping time = 1 hour (3.84×10^4 m^3)

3. Cooling System: Heat exchanger, cooling tower, pumps.

4. Model support sector.

Instrumentation:

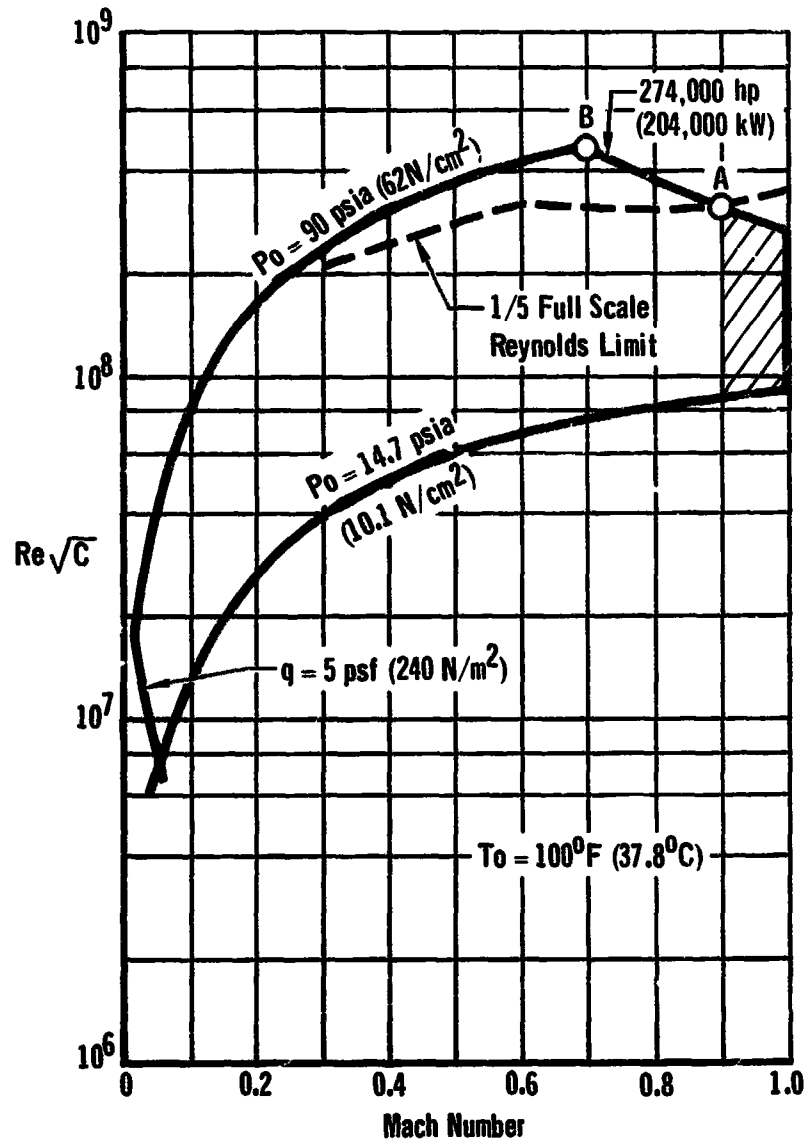
1. External Balance

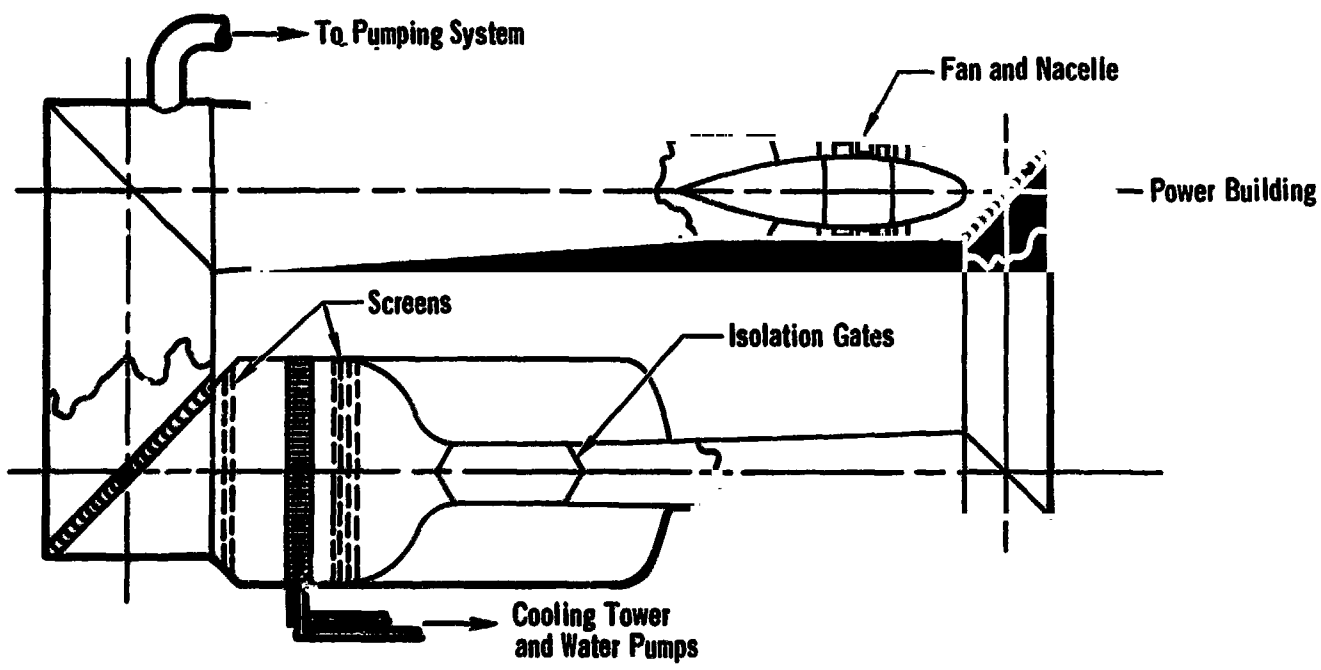
2. Internal Balance

3. Pressure system (transducers, signal conditioning, reference and calibration system, 200 channels)

4. Analog/digital converter and recording system (300 channels).

FIGURE 6-29 GAS DYNAMIC FACILITY GD2, SCHEMATIC DRAWING AND PERFORMANCE





GD3 HIGH REYNOLDS NUMBER TRISONIC BLOWDOWN WIND TUNNEL

Description:

This facility, Figure 6-30, is a large, high pressure, blowdown wind tunnel operating in the range $.5 \leq M \leq 5.0$. It is similar to trisonic type tunnels operated by several companies but has a test section more than 5 times larger in area than the largest such tunnel, the NAR 7' x 7' trisonic wind tunnel. A blowdown facility, one in which air is stored in a tank at high pressure and allowed to exhaust to an evacuated receiver or the atmosphere, was chosen because of the very substantial reduction in price over a continuous type (see description of GD17 which is continuous version of GD3) such as the AEDC 16T and 16S tunnels. Some increase in Reynolds number capability of these tunnels might be possible by increasing the maximum operating pressure and installed horsepower but this is not considered practical to achieve levels appropriate with GD3 as indicated by GD17 in Figure 6-1.

Specifications:

Test Section: 16' x 16' x 40' (4.87 x 4.87 x 12.2 m)
Mach Range: .5 to 5.0
P_o Range: 17.3 to 300 psia (11.9 to 207 N/cm^2)
T_o Range: 100° to 250°F (37.8 to 121°C)
Minimum Run Time = 20 sec.
Pump-up Time = 30 min.

Design Points:

A) $M = 1.67$; $Re\sqrt{c} = 6.2 \times 10^8$; $P_o = 140$ psia (97 N/cm^2); $T_o = 100°F$ (37.8°C)
$\dot{w} = 88{,}400$ lbm/sec (40,000 kg/sec) (Maximum $\dot{w}$)

B) $M = 5.0$; $Re\sqrt{c} = 2.4 \times 10^8$; $P_o = 294$ psi (203 N/cm^2); $T_o = 150°F$ (65.5°C)
$\dot{w} = 9450$ lbm/sec (4280 kg/sec) (Maximum P_o)

C) $M = 5.0$ $Re\sqrt{c} = 1.79 \times 10^8$; $P_o = 280$ psia (193 N/cm^2); $T_o = 250°F$ (121°C)
$\dot{w} = 8300$ lbm/sec (3770 kg/sec) (Maximum T_o)

D) $M = 2.0$ $Re\sqrt{c} = 9.47 \times 10^7$; $P_o = 24$ psia (16.6 N/cm^2); $T_o = 100°F$ (37.8°C)
$\dot{w} = 11{,}450$ lbm/sec (5200 kg/sec)

E) $M = .5$ $Re\sqrt{c} = 1.12 \times 10^8$; $P_o = 35.6$ psia (24.6 N/cm^2); $T_o = 100°F$ (37.8°C)
$\dot{w} = 21{,}950$ lbm/sec (9960 kg/sec) (Minimum Mach)

Features:

1. Compressor plant and storage tanks.

2. Heat exchanger and thermal mass in tanks (for $T_o \leq 150°F$ (65.5°C)).

Features: (Continued)

3. Gas fired heater for $150°F \leq T_o \leq 250°$ ($65.5 \leq T_o \leq 121°C$) (Heat addition during pump-up).

4. Control valve, automatically controlled.

5. Flexible plate nozzle, jacks, control system.

6. Perforated wall transonic carts (2) with model supports.

7. Solid wall supersonic carts with model supports [Carts identical to AEDC 16T, 16S PWT carts].

8. Bypass valves (2) with automatic control system.

9. Variable throat diffuser with hydraulic actuators and automatic control system. Used also as subsonic choke.

10. Building for control room, instrumentation area, photo lab.

11. Model assembly building and trackage for carts. (At least 3 bays for carts.)

Instrumentation:

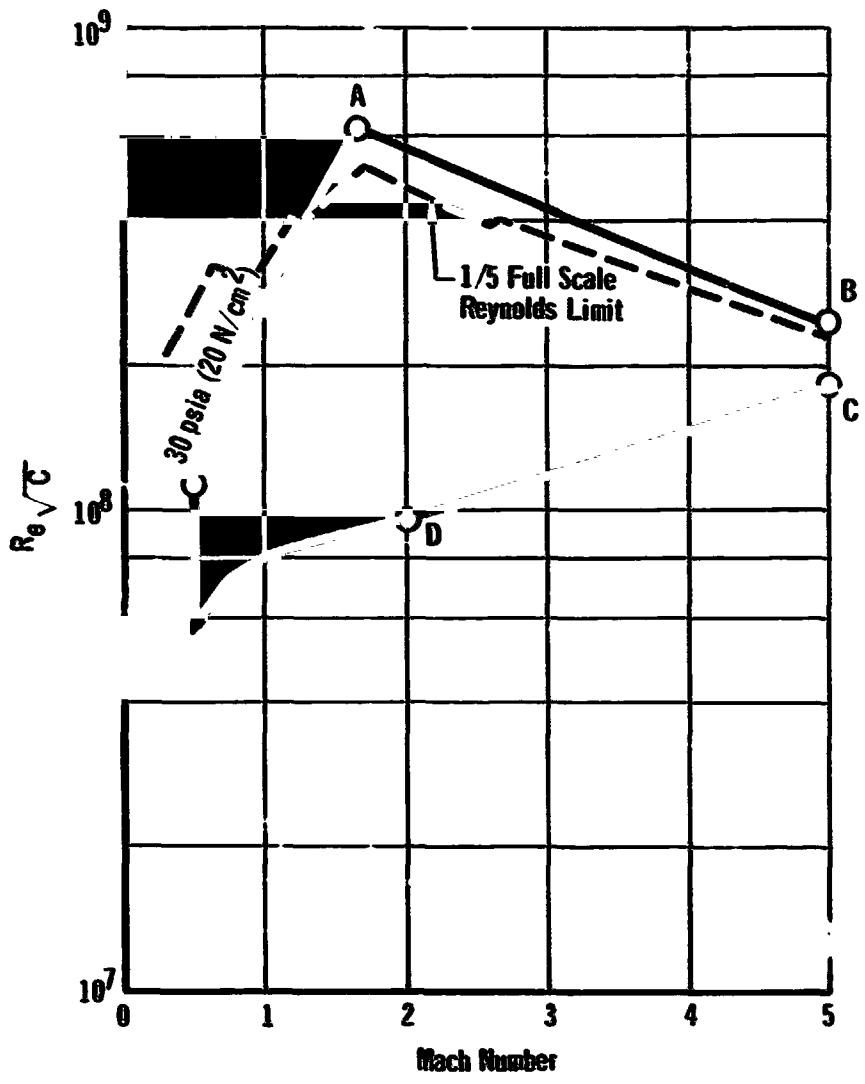
1. Internal balances

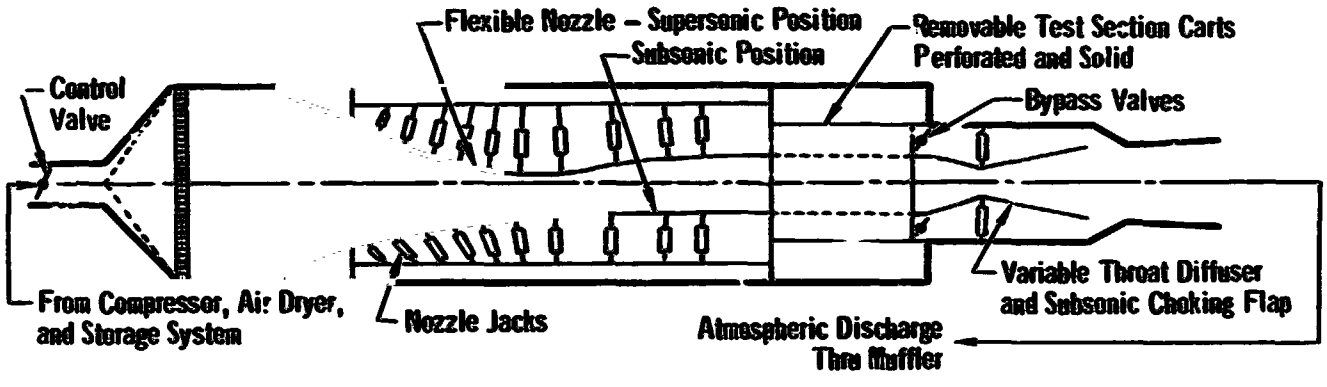
2. Pressure system (reference and calibration system, transducers, signal conditioning, 200 channels)

3. Analog/digital converter and recording system (300 ch

4. Schlieren system.

FIGURE 6–30 GASDYNAMIC FACILITY GD3, SCHEMATIC DRAWING AND PERFORMANCE





GD4 LUDWIEG TUBE, HIGH REYNOLDS NUMBER TRISONIC WIND TUNNEL

Description:

This facility is an impulse type trisonic wind tunnel which nearly duplicates flight Reynolds numbers in the range $0.5 \leq M \leq 3.0$. It is a very large version of the NASA Huntsville prototype tube tunnel and represents a significant extension in transonic testing state-of-the-art at relatively low technological risk, but could present some hardware and operational development effort.

A diagram of the tunnel is presented in Figure 6-31. The test section and charge tube are isolated from the downstream dump tank by a control valve. The portion of the tunnel upstream of the valve is then charged to some predetermined pressure while the dump tank is evacuated. When the valve is opened (about 10 msec) flow is initiated and an expansion wave propagates upstream into the high pressure gas. Usable run time is terminated when the expansion wave is reflected from the end of the charge tube and travels back through the test section. The run time is a function of the length of the charge tube.

In this facility, very high Reynolds numbers are obtained at the cost of run time, which will be about 1 sec. This factor, plus a relatively long turnaround time between shots, will limit the usefulness of this tunnel as a development tool. However, its use will permit the development of reliable methods of extrapolation of data to flight Reynolds numbers. Thus, the major portions of vehicle development programs can be run in more productive tunnels, such as 16T, 16S, or GD3, with confident extrapolation of results to flight Reynolds numbers, based on data obtained on baseline configurations in GD4. There is very little chance of obtaining this test capability by the modification of any existing facility.

Specifications:

[This tunnel is similar to the proposed HIRT facility at AEDC whose estimated cost is $14-18 million.]

Test Section: 9' x 12' (2.74 x 3.68 m)
Mach Range: .5 to 3.0
P_o Range: 100 to 500 psia (69 to 345 N/cm^2)
T_o Range: 100°F (37.8°C)
Run Time: 0.8 to 1.5 sec
Time Between Shots: 2 hours

Design Points:

A) $M = .5$; $Re_{\sqrt{c}} = 1.01 \times 10^9$; $P_o = 500$ psia (345 N/cm^2); $T_o = 100°F$ (37.8°C)

B) $M = 1.0$; $Re_{\sqrt{c}} = 1.53 \times 10^9$; $P_o = 500$ psia (345 N/cm^2); $T_o = 100°F$ (37.8°C)

C) $M = 3.0$; $Re_{\sqrt{c}} = 8.95 \times 10^8$; $P_o = 500$ psia (345 N/cm^2); $T_o = 100°F$ (37.8°C)

Features:

1. Expansion tube, 15' dia. x 1120' long (4.57 m dia. x 342 m long)
   P_{max} = 750 psia (517 N/cm^2)

2. Nozzle type undecided

3. Porous wall transonic test section, and alternate solid wall supersonic test section

4. Tube charging compressor system, t_{ch} = 2 hr (max)

5. Model support, fixed α

6. Non-destructible starting valve and subsonic choking flaps

7. Diffuser and muffler - atmospheric exhaust. Alternate possibility is exhaust to a sealed dump tank

8. Building for control room, office area, instrumentation/calibration area, test set-up area, photo lab

Instrumentation:

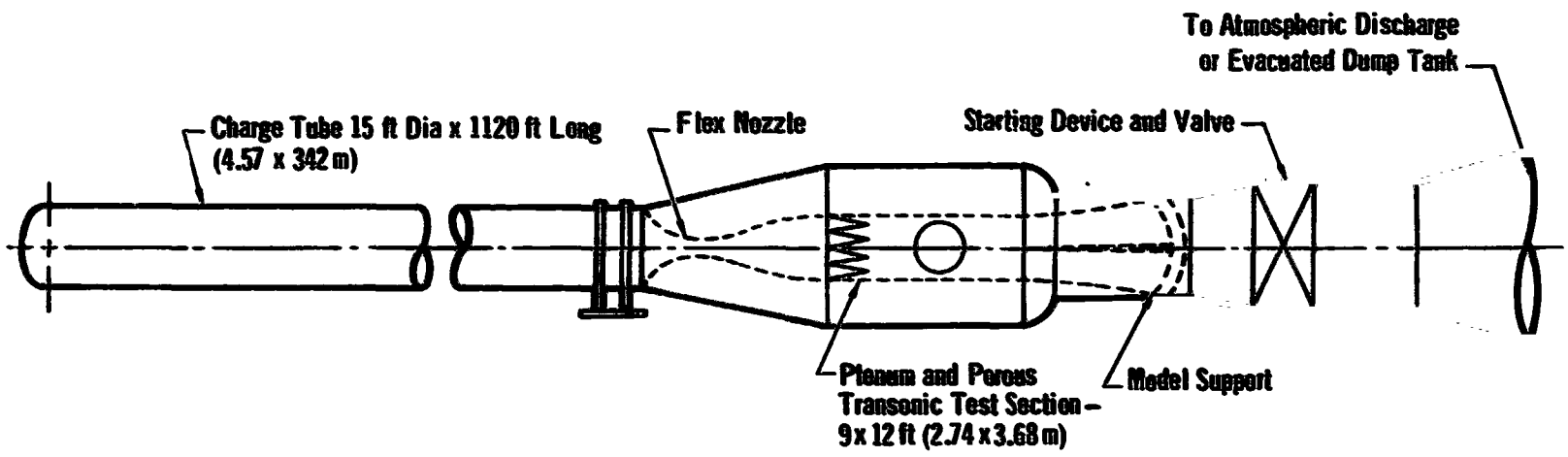
1. Internal balances

2. Pressure system (reference and calibration system, transducers, signal conditioning - 200 channels)

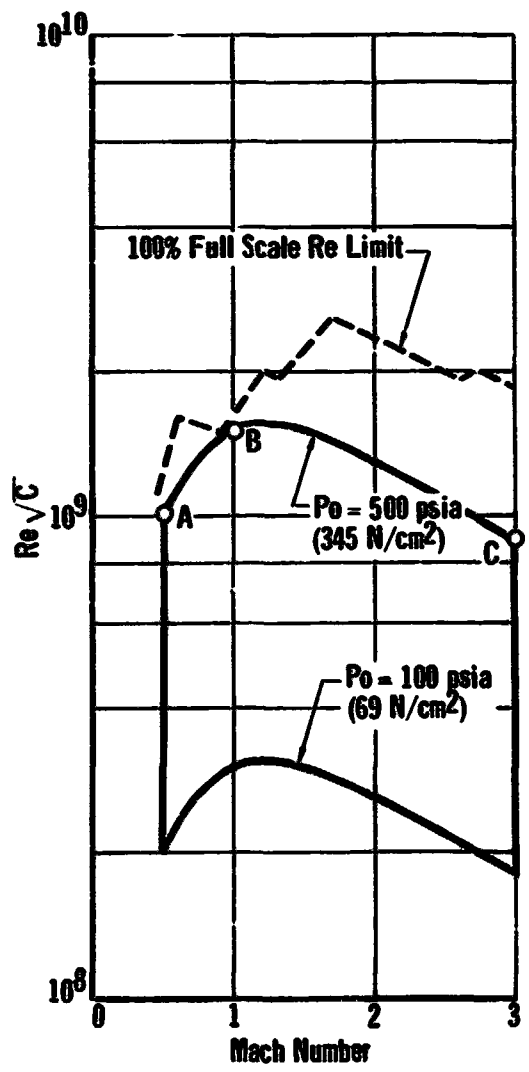
3. High speed loop tape recorder - 500 channels

4. Schlieren system

FIGURE 6–31 GASDYNAMIC FACILITY GD4, SCHEMATIC DRAWING AND PERFORMANCE



REYNOLDS NUMBER-MACH NUMBER PERFORMANCE



GD7 HIGH REYNOLDS NUMBER GAS PISTON DRIVEN HYPERSONIC WIND TUNNEL

Description:

This is a facility operating in the range $8 \leq M \leq 13$, based on the Naval Ordnance Laboratory (NOL) gas piston driver concept. This concept was initially translated into operational hardware by Dr. Victor Zakkay of New York University, and further refined by NOL. A diagram of the tunnel is presented in Figure 6-32. The test section and nozzle are isolated from the stagnation chamber by a series of diaphrams. The driver gas vessel is isolated from the stagnation chamber by a control valve. The driver gas vessel is charged with gas to some pressure level greater than the desired stagnation pressure ($P_{ch} > P_o$). The stagnation chamber is charged with gas to some pressure below P_o. While the working gas in the stagnation chamber is being heated to P_o and T_o, the tunnel downstream of the diaphram is evacuated. The diaphram is then ruptured and the control valve opened. The working gas expands down the nozzle and the driver gas flows into the stagnation chamber at a rate such that a constant P_o is maintained. Run time is essentially limited by the length of the heated section. This driver has the advantage of providing relatively long run times on the order of 1 to 4 sec. The facility does not require water cooling, thus saving cost and complexity. Provision of a high pitch rate model support system can greatly increase the facility productivity although this is not currently included.

Specifications:

Test Section: 10' dia. (3.05 m) contoured nozzle
Mach Range: 8 to 13
P_o Range: 1000 to 18,800 psia (690 to 13,000 N/cm^2)
T_o Range: 1200° to 2500°R (700 to 1390°K)
Run Time: 1 - 4 sec.
Tunnel Recycling Time: 2 hours

Design Points:

A) $M = 8$; $Re_{\sqrt{c}} = 1.5 \times 10^8$; $P_o = 3210$ psia (2215 N/cm^2) $T_o = 1200°R$ (700°K)
$W = 2840$ lbm/sec (1290 kg/sec)

B) $M = 13$; $Re_{\sqrt{c}} = 6.55 \times 10^7$; $P_o = 18,800$ psia (13,00 N/cm^2)
$T_o = 2500°R$ (1390°K) $W = 1028$ lbm/sec (466 kg/sec)

C) $M = 8$; $Re_{\sqrt{c}} = 4.87 \times 10^7$; $P_o = 18,800$ psia (690 N/cm^2);
$T_o = 1260°R$ (700°K) $W = 910$ lbm/sec (413 kg/sec)

D) $M = 13$; $Re_{\sqrt{c}} = 3.54 \times 10^7$; $P_o = 10,000$ psia (6900 N/cm^2);
$T_o = 2500°R$ (1390°K) $W = 545$ lbm/sec (247 kg/sec)

Feature .

[illegible] (3.05 m) axisymmetric nozzles. Closed jet test cabin and [illegible] t.

Features: (Continued)

2. Nitrogen gas pumping and storage system = 1500 psi (1035 N/cm^2)

3. Booster pump system, 1500 psi to 10,000 psi (1035 to 6900 N/cm^2)

4. Electrically heated high pressure gas driver vessels P_o = 30,000 psi (20,700 N/cm^2)

5. Pressure control valves to maintain constant P_o

6. Fixed volume, electrically heated stagnation chamber.

7. Diffuser and dump tank with vacuum system

8. Power supply and control system

9. Building for control room, office area, instrumentation/calibration area, test set-up area, photo lab.

Instrumentation:

1. Internal balances

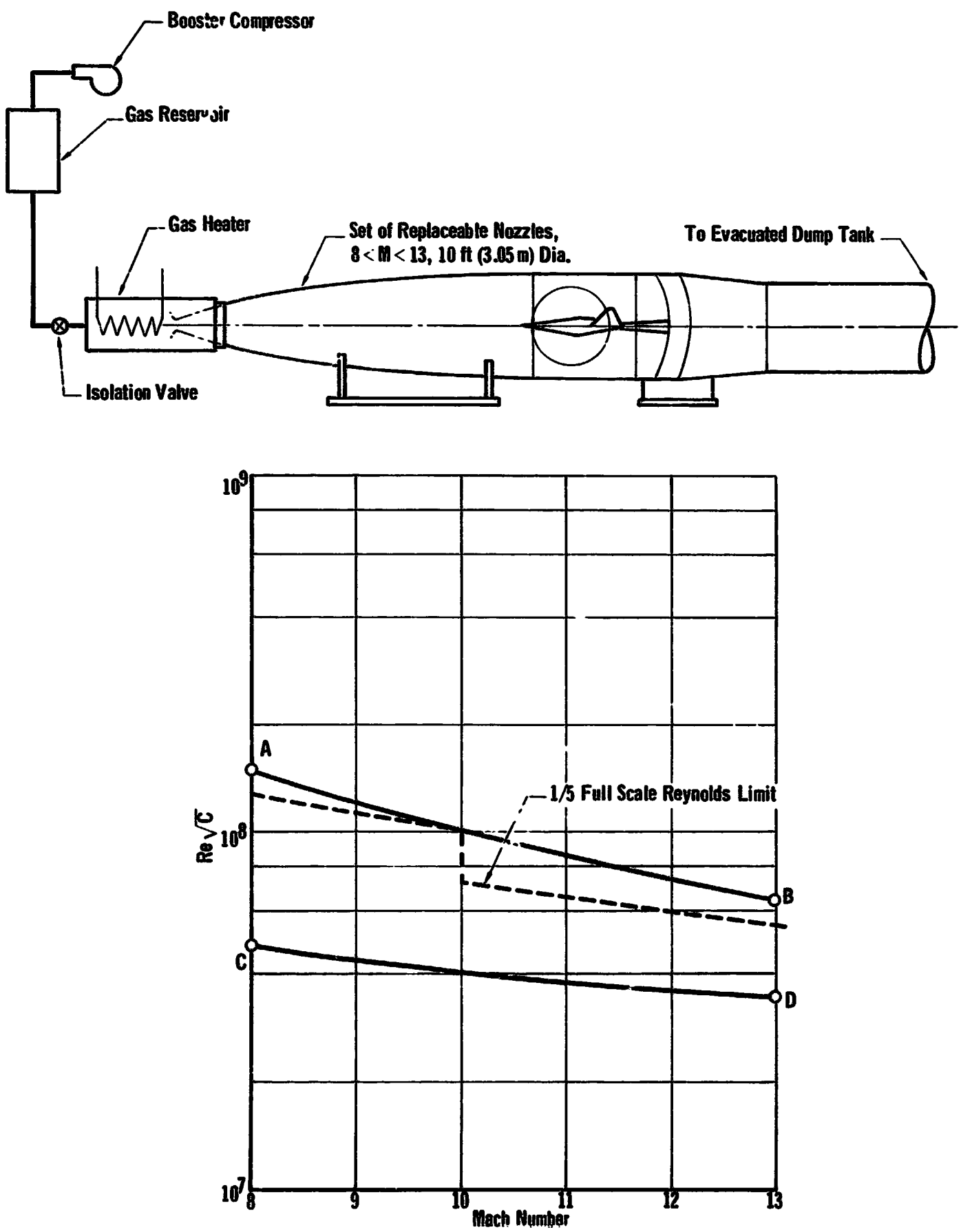
2. Pressure system (Reference and calibration system, transducers, signal conditioning - 200 channels)

3. Temperature system (Reference and calibration system, thermocouples, heat transfer gages, signal conditioning 200 channels)

4. High speed loop tape recorder (500 channels)

5. Schlieren system.

FIGURE 6–32 GASDYNAMIC FACILITY GD7, SCHEMATIC DRAWING AND PERFORMANCE



GD15 ELECTRIC HEATED HYPERSONIC BLOWDOWN TUNNEL

Description:

This facility, Figure 6-33, operates on a blowdown cycle, similar to GD3, in the range $3 \leq M \leq 8.5$, with run times of 20 sec. An induction heated steel matrix storage heater is used.

Specifications:

Test Section: 8.86' x 8.86' (2.7 x 2.7 m)
Mach Range: 3 to 8.5
P_o Range: 53 to 3200 psia (36.6 to 2210 N/cm^2)
T_o Range: 150 to 800 °F (65.5 to 427°C)
Minimum Run Time: 20 sec
Pump Up Time: 60 min

Design Points:

A) $M = 4.5$; $Re_{\sqrt{c}} = 3 \times 10^8$; $P_o = 538$ psia (371 N/cm^2); $T_o = 150°F$ (65.5°C)
$\dot{w} = 8150$ lbm/sec (3700 kg/sec) (Max w)

B) $M = 3.0$; $Re_{\sqrt{c}} = 1.61 \times 10^8$; $P_o = 140$ psia (96.6 N/cm^2); $T_o = 150°F$ (65.5°C)
$\dot{w} = 8150$ lbm/sec (3700 kg/sec)

C) $M = 8.5$; $Re_{\sqrt{c}} = 1.3 \times 10^8$; $P_o = 3200$ psia (2210 N/cm^2); $T_o = 800°F$ (427°C)
$\dot{w} = 2142$ lbm/sec (970 kg/sec) (Max P_o)

D) $M = 3.0$; $Re_{\sqrt{c}} = 6 \times 10^7$; $P_o = 53$ psia (36.6 N/cm^2); $T_o = 150°F$ (65.5°C)
$\dot{w} = 3070$ lbm/sec (1390 kg/sec)

E) $M = 5.0$; $Re_{\sqrt{c}} = 8 \times 10^7$; $P_o = 280$ psia (193 N/cm^2); $T_o - 320°F$ (160°C)
$\dot{w} = 2410$ lbm/sec (1093 kg/sec)

F) $M = 8.5$; $Re_{\sqrt{c}} = 1.07 \times 10^8$; $P_o = 2680$ psia (1850 N/cm^2); $T_o = 800°F$ (427°C)
$\dot{w} = 1830$ lbm/sec (830 kg/sec)

Features:

1. Flexible plate nozzle, jacks, control system. (For less expensive alternate, a 10' dia. (3.05 m) axisymmetric nozzle with a set of replaceable throats may be specified.)

2. Induction heated steel matrix storage heater, steel core 7.5' dia. x 15' deep (2.29 x 4.57m). Shell 11' dia. (3.35m).

3. Heater power supply and control ~ 2.5 megawatt (assuming one hour reheat).

4. Model support, actuation and control system.

Features: (Continued)

5. P_o and T_o control system, consisting of an automatically controlled throttling valve for total weight flow, heater bypass loop with control valve for bypass air, air mixing chamber downstream of heater.

6. Building for control room, office area, instrumentation/calibration area, test setup area, photo lab.

7. Later capability extension provided by steam ejector system for boosting exhaust pressure from 1/2 to 1 atmosphere.

Instrumentation:

1. Internal balances.

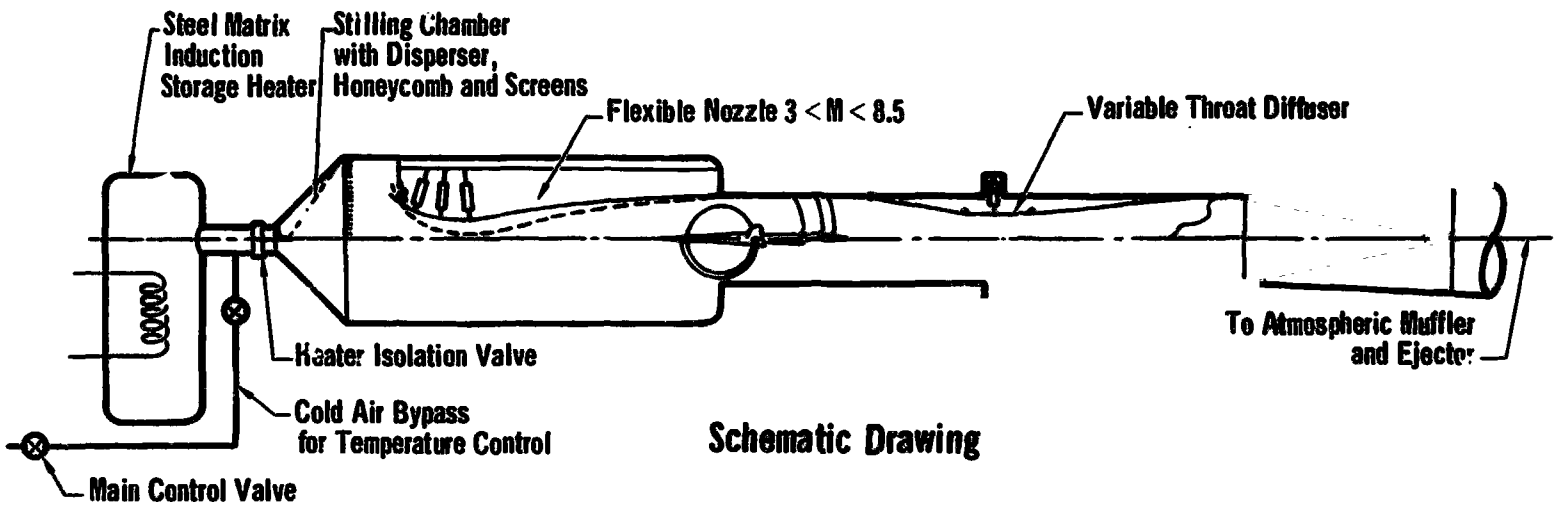
2. Pressure system (reference and calibration system, transducers, signal conditioning, 200 channels).

3. Temperature system (Reference and calibration system, thermocouples, heat transfer gages, signal conditioning, 200 channels).

4. Analog/digital converter and recording system - 500 channels.

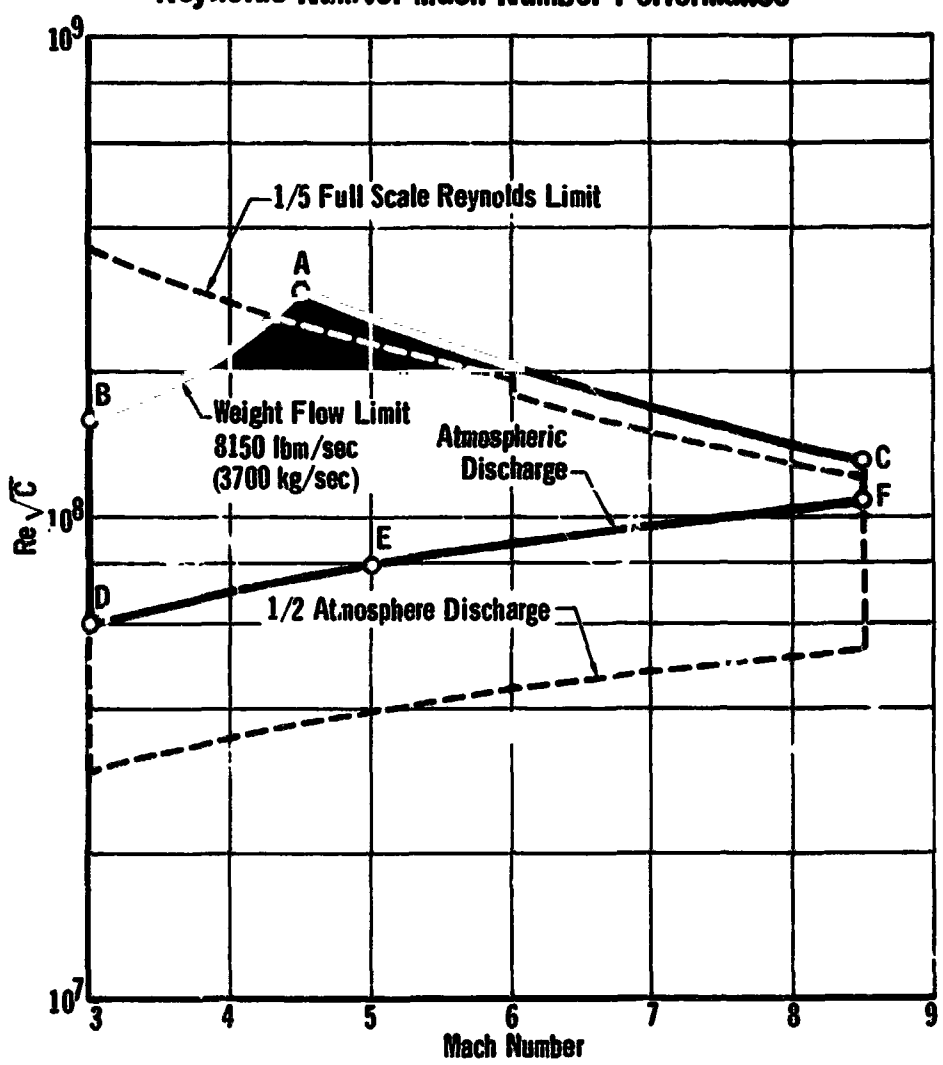
5. Schileren System.

FIGURE 6-33 GASDYNAMIC FACILITY GD15, SCHEMATIC AND PERFORMANCE



Schematic Drawing

Reynolds Number-Mach Number Performance



GD16 LUDWIEG TUBE HYPERSONIC WIND TUNNEL

Description:

This is a Ludwieg Tube Type Impulse Wind Tunnel, Figure 6-34, operating in the range $3 \leq M \leq 8.5$. Its performance is specified to be identical to GD15. This facility is expected to be cheaper than GD15 to build, but less productive and more expensive per data point than GD15. The starting loads at these Mach numbers could severely restrict this type of tunnel if present blowdown facility data is applicable. The technical risk is primarily associated with achieving the desired dynamic pressures if the starting loads are excessive.

Specifications:

Test Section: 8.86' x 8.86' (2.7 x 2.7 m)
Mach Range: 3 to 8.5
P_o Range: 20.8 to 3200 psia (14.3 to 2200 N/cm^2)
T_o Range: 150 to 800°F (65.5 to 427°C)
Minimum Run Time: 1 sec
Time Between Shots: 4 hr

Design Points:

A) $M = 3.0$; $Re_{\sqrt{c}} = 4.43 \times 10^8$; $P_o = 385$ psia (265 N/cm^2); $T_o = 150°F$ (65.5°C)

B) $M = 4.5$; $Re_{\sqrt{c}} = 3.0 \times 10^8$; $P_o = 538$ psia (371 N/cm^2); $T_o = 150°F$ (65.5°C)

C) $M = 8.5$; $Re_{\sqrt{c}} = 1.3 \times 10^8$; $P_o = 3200$ psia (2200 N/cm^2); $T_o = 800°F$ (427°C)

D) $M = 3.0$; $Re_{\sqrt{c}} = 2.3 \times 10^7$; $P_o = 20.8$ psia (14.3 N/cm^2); $T_o = 150°F$ (65.5°C)

E) $M = 5.0$; $Re_{\sqrt{c}} = 3.36 \times 10^7$; $P_o = 110$ psia (75.8 N/cm^2); $T_o = 320°F$ (160°C)

F) $M = 8.5$; $Re_{\sqrt{c}} = 4.7 \times 10^7$; $P_o = 1140$ psia (785 N/cm^2); $T_o = 800°F$ (427°C)

Features:

1. Flexible plate nozzle, jacks, control system. (Alternate method may use 3 or 4 axisymmetric 10' dia. (3.05 m) nozzles.)

2. Expansion tube, 6' dia. x 610' long (1.83 m dia. x 186 m long) [$P_{charge\ max}$ = 4750 psia] (3275 N/cm^2)

3. Fast response tunnel isolation valve

4. Tube charging compressor system - t_{ch} = 3 to 4 hr

5. Heating System - T_{max} = 800°F (427°C) (for heating prior to shot)

6. Model support - Fixed α

Features: (Continued)

7. Diffuser and dump tank

8. Vacuum pumping system

9. Building for control room, office area, instrumentation/calibration area, test set-up area, photo lab

Instrumentation:

1. Internal balances

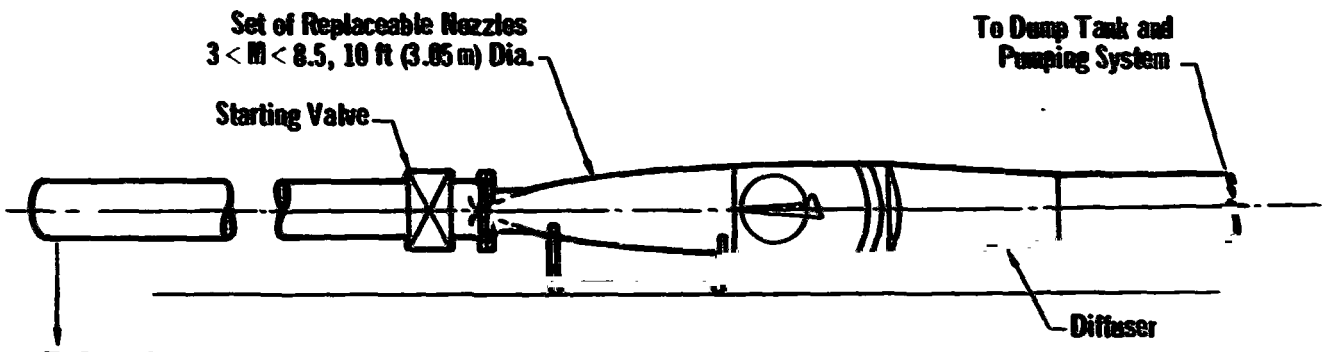
2. Pressure system (reference and calib. system, transducers, signal conditioning, 200 channels)

3. Temperature system (reference and calib. system, thermocouples, heat transfer gages, signal conditioning, 200 channels)

4. High speed loop tape recorder - 500 channels

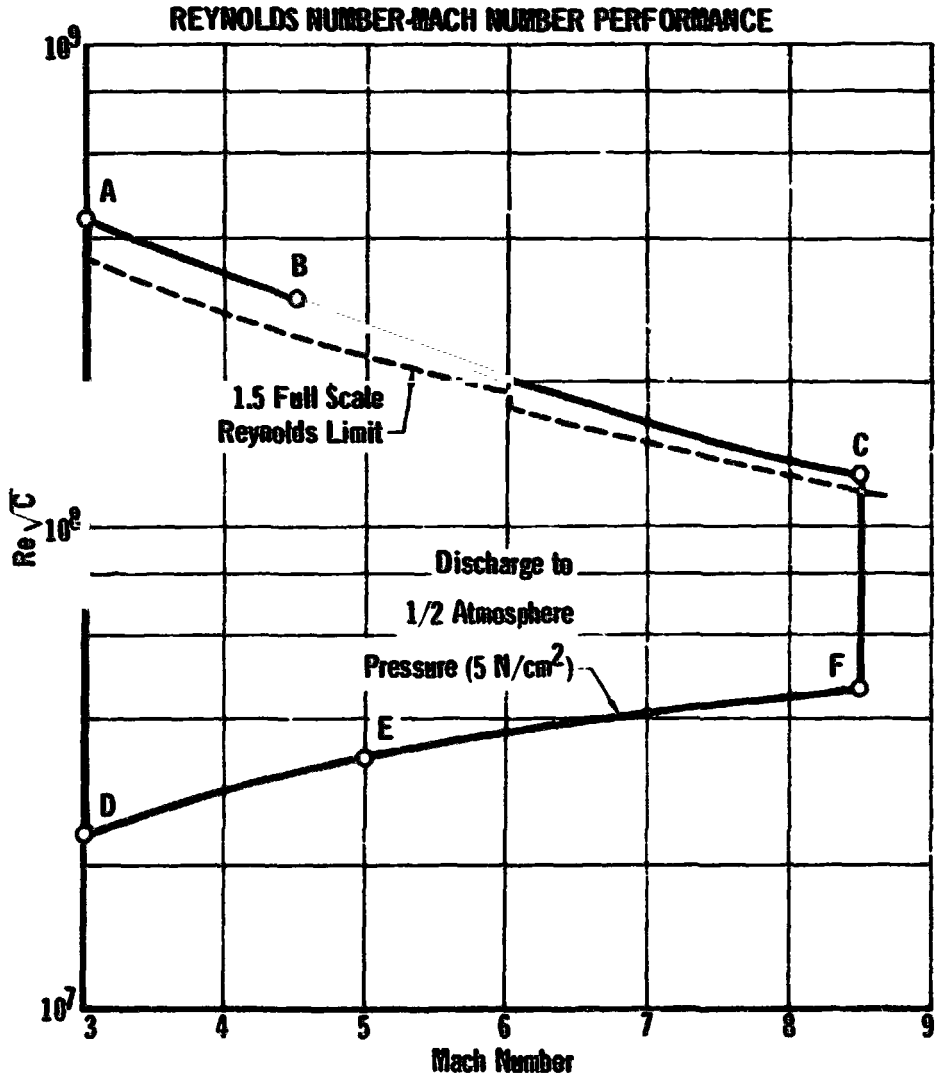
5. Schlieren system

FIGURE 6–34 GASDYNAMIC FACILITY GD16, SCHEMATIC DRAWING AND PERFORMANCE



SCHEMATIC DRAWING

REYNOLDS NUMBER-MACH NUMBER PERFORMANCE



6.4.4 GAS DYNAMIC FACILITY COSTS

Estimated initial investment costs and operating costs of the candidate ground test facilities are shown in tabular form in Figure 6-35. These figures give cost breakdowns as well as totals.

The ground rules and methodology used in developing these cost estimates are discussed in detail in Section 6.11.

FIGURE 6–35 COST SUMMARY, GAS DYNAMIC FACILITIES

Facility Component	Acquisition Cost - 1000 Dollars					
	GD2	GD3	GD4	GD7	GD15	GD16
Tunnel Complex and Services	42,000	46,000	16,000	30,000	26,000	12,610
Major Equipment						
Internal Balance	120	120	120	120	120	120
External Balance	200					
Fluct. Pressure System	400	400	400	400	400	400
Schlieren			300	300	300	300
Temperature System			500	500	500	500
Total Major Equipment	720	520	1,320	1,320	1,320	1,320
Data Acquisition System	1,800	1,800	1,800	1,800	1,800	1,800
A/D Conv. and Recording	500	500			500	
Tape Recorders			500			500
Total Data Acq. and Inst.	2,300	22,300	2,300	1,800	2,300	2,300
Grand Total	45,020	48,820	19,620	33,120	29,620	16,230
	Operating Costs					
$/Hour of Occupancy	6,000	3,400	1,640*	2,630*	1,190	3,400*

*Dollars per Run

6.5 ENGINE RESEARCH FACILITIES

To satisfy future system requirements, engine research facilities will probably be required to accommodate full scale engines and components. Testing the survivability of many of the engine components depends on the achievement of temperatures equivalent to flight values, thus achievement of flight duplicated conditions is very important. A wide range of equivalence ratios, including stoichiometric, is possible over the spectrum of flight regimes and engine concepts. It is not always possible to compensate for a lack of flight duplicated stagnation temperatures in a test facility by increasing equivalence ratio, as is currently done. The approach taken in developing the engine facility concepts was to provide for full temperature duplication over the entire Mach number range, within the limitations of current technology. The facilities were sized to initially accommodate engines currently in design, operation or conceptual development, with further refinements in Phase II to include adaptions to future requirements. In addition to providing flight duplicated conditions, the engine facility concepts will incorporate aerodynamic nozzles for aerothermodynamic/structural research capability at duplicated velocity, Mach number and altitude.

6.5.1 CRITERIA - Two principal criteria dominate the design requirements for the engine test facilities:

- The facility must have the capability to provide duplication of the flight velocity, Mach number and altitude.
- The facility must be capable of accommodating a full scale engine.

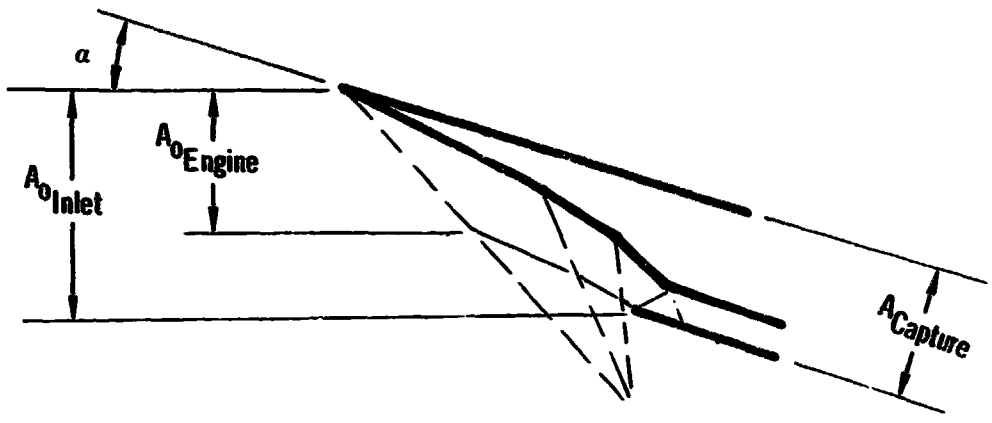
To fully satisfy these two criteria it is necessary to consider the method of simulating the inlet flow, and the effect of inlet geometry and angle of attack on overall test section size.

Several definitions of capture area are possible in the description of inlet characteristics. These are shown graphically in Figure 6-36. $A_{CAPTURE}$ is the geometric frontal area of the inlet when the inlet is at zero degrees angle of attack. $A_{O_{INLET}}$ is the projected geometric frontal area of the inlet when the inlet is at angle of attack. $A_{O_{ENGINE}}$ corresponds to the stream tube area which will enter the engine. $A_{O_{ENGINE}}$ and $A_{CAPTURE}$ are used in computing the engine mass flow while $A_{O_{INLET}}$ is used in sizing the free jet facilities.

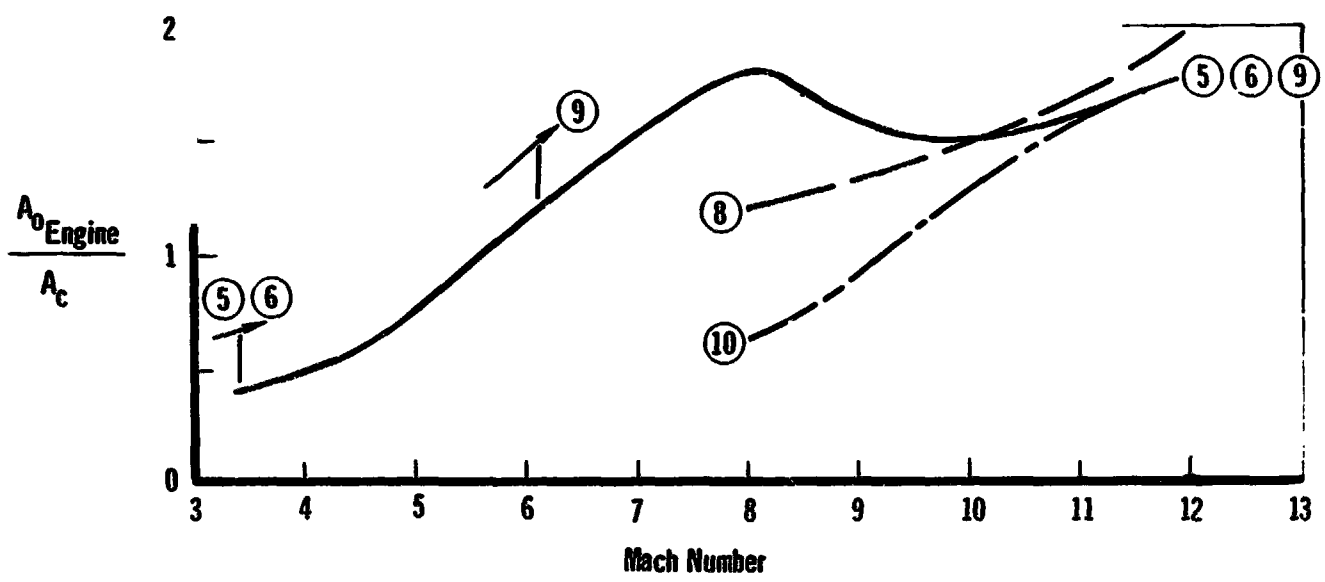
As depicted in Figure 6-36, the magnitude of the stream tube area entering the engine $A_{O_{ENGINE}}$ can be twice the magnitude of the zero angle of attack, geometric capture area (A_c).

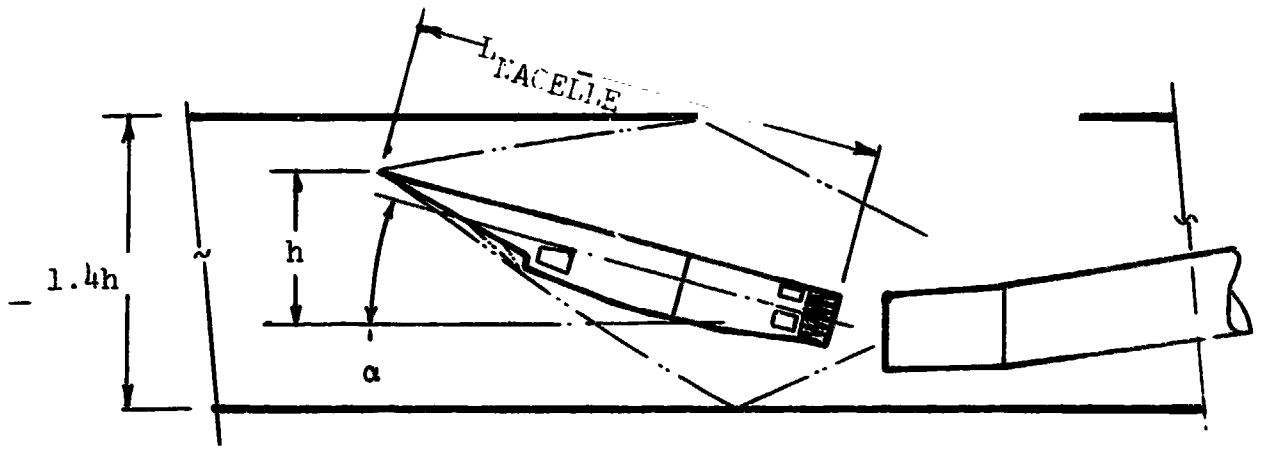
The size of the nozzle required to accommodate an entire engine/inlet combination is primarily dependent on the length of the system and the desired angle of attack, as shown on the following page.

FIGURE 6-36 INLET GEOMETRY DEFINITIONS FOR DETERMINING TEST FACILITY MASS FLOW



(5) CSJ Module 10 Sq Ft (0.93 m²) Total Engine 80 Sq Ft (8.3 m²)
(6) CSJ Module 60 Sq Ft (5.6 m²) Total Engine 480 Sq Ft (44.5 m²)
(7) MA145XCA 20.2 Sq Ft (RJ) (1.87 m²)
(8) Acceleration SJ 45 Sq Ft (4.2 m²) Total Engine 270 Sq Ft (25 m²)
(9) M = 8 Point Design SJ 35 Sq Ft (2.35 m²) Total Engine 140 Sq Ft (13 m²)
(10) M = 12 Point Design SJ 35 Sq Ft (3.35 m²) Total Engine 140 Sq Ft (13 m²)





where:

the test section height > L tan α
≃ 1.4 L tan α

is necessary to provide for proper flow over the inlet lip, and the collection of the engine exhaust gases. For angles of attack approaching 25°, and large advanced aircraft engines, with total lengths exceeding 60 feet (18 m), very high test sections, approaching 40 feet (12 m) in height are necessary. This is about three times the current maximum facility height for propulsion wind tunnels. The attainment of such a facility size in practice would be seriously questioned, from a cost and feasibility standpoint, as about 17 to 18 times the individual engine mass flow is required. It should be noted that for scramjet engines the entire vehicle represents the inlet/combustor/exhaust nozzle system and although the angle of attack range is less, the requirement to place an entire planform into the test section could require an even larger nozzle. For example, a 90 foot (27 m) long aircraft shape with an integrated engine concept would require a nozzle about 43 feet (13 m) in diameter at Mach number 9 flight duplicated conditions.

One alternative is to provide airflow only locally around the inlet as approximated by the area $A_{O_{INLET}}$. Since the inlet length is considerably shorter than the inlet-engine combination, the size of the nozzle could be reduced significantly. Analysis of this approach is presented in Figure 6-37.

Ac_1 is the geometric capture area associated with the relatively highest inlet system under consideration, and Ac_2 is the geometric capture area associated with the relatively widest inlet system under consideration. The minimum size for the test section is then:

$$h'_{MAX} \geq \left[\frac{\sin(\theta + \alpha)}{\sin\theta}\right] \sqrt{n_{MAX}\, Ac_1} \qquad w_{MAX} \geq \sqrt{\frac{Ac_2}{n_{MIN}}}$$

For the purpose of sizing the test facilities, the following limitations were assumed:

(a) A 20 ft^2 (1.86 m^2) capture area engine with a free stream inlet and an n_{MAX}= 6 and a maximum angle of attack of 20 degrees.

(b) A 35 ft^2 (3.25 m^2) capture area engine with a vehicle flow field inlet and an n_{MIN} equal to 0.8 and a maximum angle of attack of 10 degrees.

Using the values of n_{MAX} and n_{MIN} set by the limitations, the value of

$$\frac{\sin(\theta + \alpha)}{\sin\theta} \sqrt{\frac{n_{MAX}}{n_{MIN}}} \approx 3.$$

FIGURE 6–37 INLET GEOMETRY CONSIDERATIONS FOR SIZING FREE JET FACILITIES

$$n = \frac{h}{w}$$

$$h_{Max} = \sqrt{n_{Max} A_{c_1}}$$

$$w_{Max} = \sqrt{\frac{A_{c_2}}{n_{Min}}}$$

$$h' = h \frac{\sin(\theta + \alpha)}{\sin\theta}$$

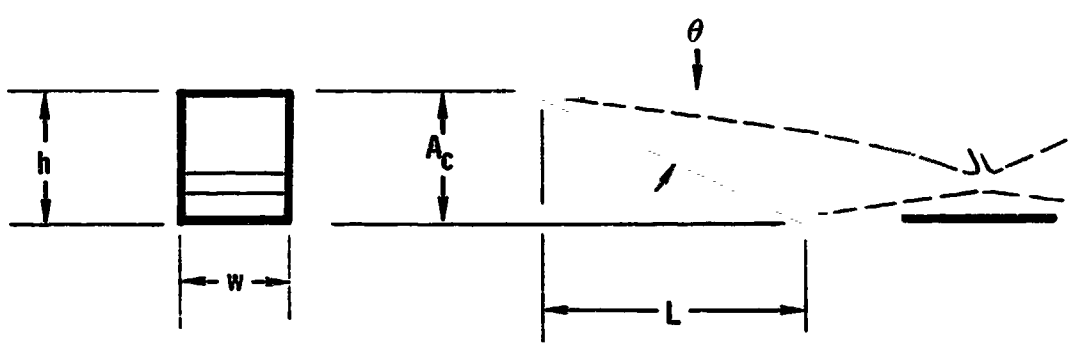
Tunnel Size

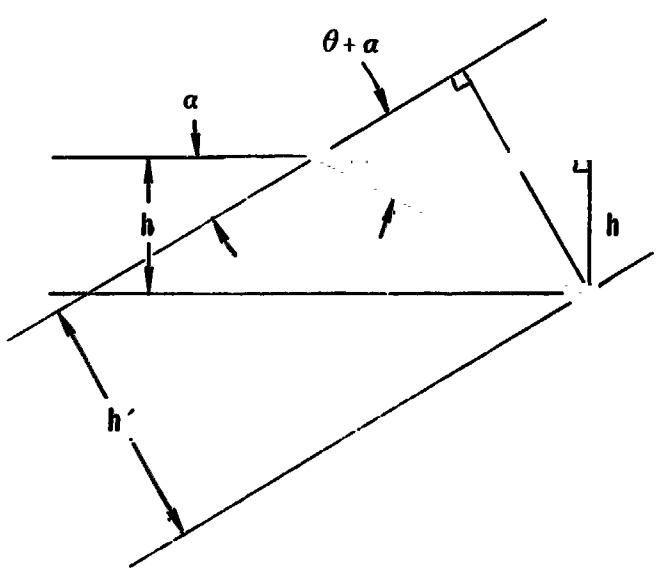
$$C = h'_{Max} w_{Max} = \frac{\sin(\theta+\alpha)}{\sin\theta} \sqrt{\frac{n_{Max}}{n_{Min}}} \overline{A_c}$$

$$A_c = [A_{c_1} A_{c_2}]^{1/2}$$

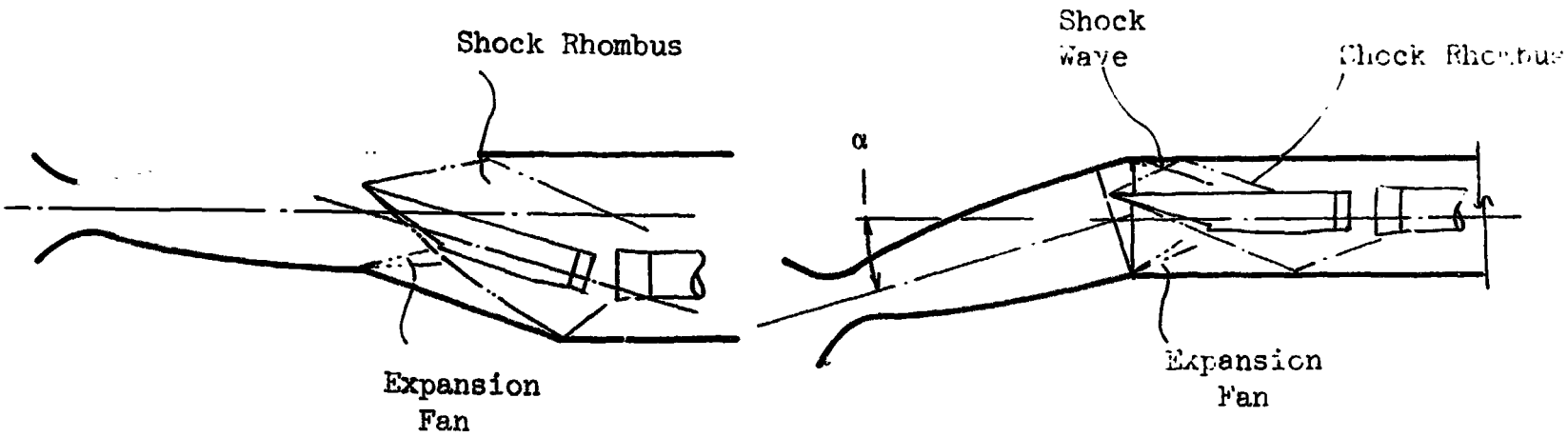
A_{c_1} & A_{c_2} are the geometric capture areas associated with the engines used to size the nozzle height and width respectively.

θ	20^0	20^0	25^0	30^0	40^0
α	20^0	15^0	20^0	20^0	20^0
$\frac{\sin(\theta+\alpha)}{\sin\theta}$	1.87	1.68	1.66	1.53	1.29





Thus, a free jet facility accommodating the inlet requires at least three times the mass flow of the largest individual engine. This type of facility has an undesirable feature associated with the technique employed to pitch the test article, and the non-similarity of the flow field around the remainder of the engine, as depicted below:



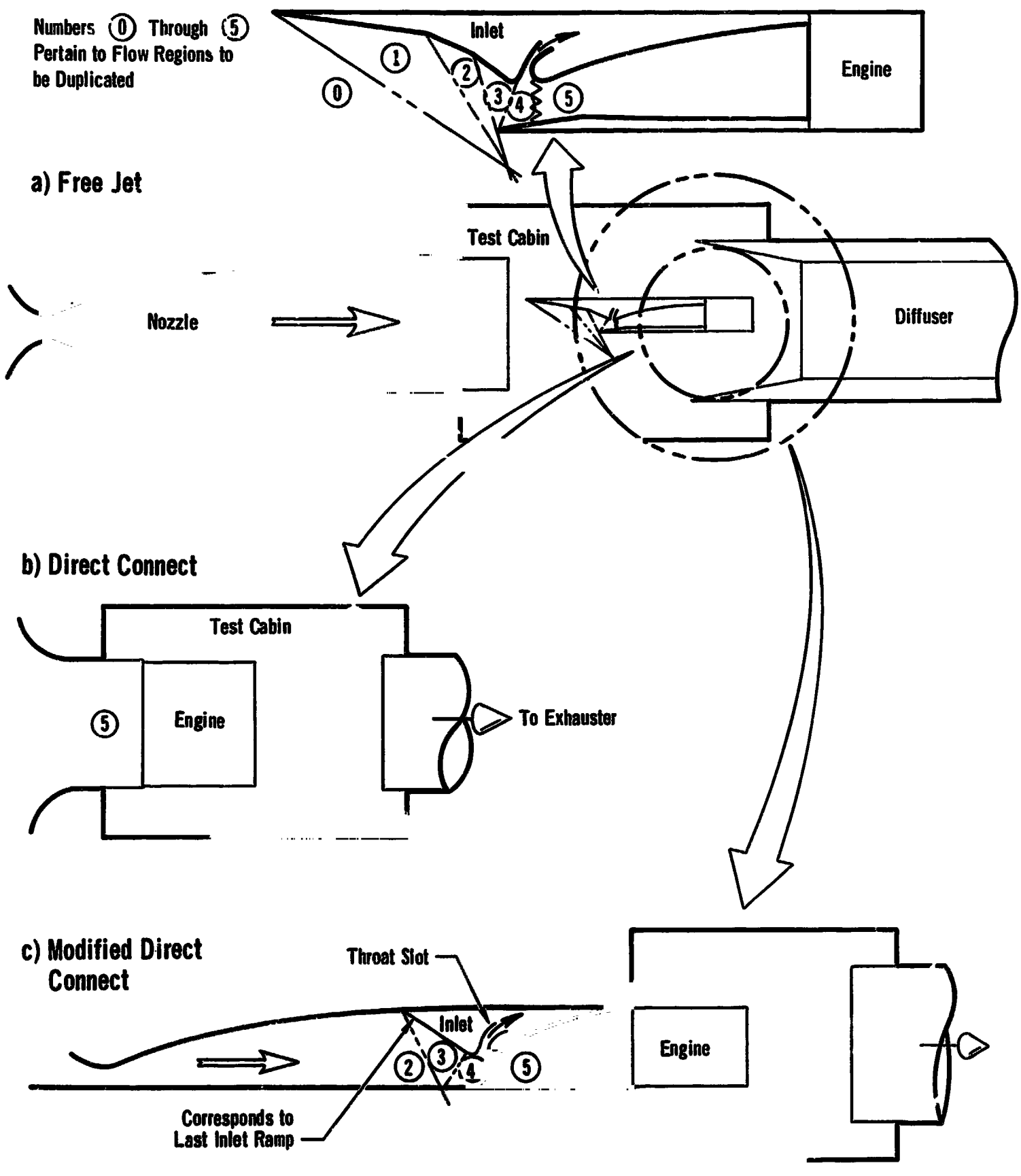
However, this concept may provide the only economic alternative to immersing the entire engine in the flow stream. These aspects will be further refined in Phase II when a sufficient detail will be available to provide a realistic mechanical design/research capability/cost evaluation.

The facility size, complexity, and costs involved with free jet testing of large inlet engine systems in propulsion wind tunnels have historically been significant. In many cases the fidelity of the conditions provided in the test section compared to actual flight conditions have been compromised in order to obtain a viable operational facility. Much of the engine research does not necessarily require complete duplication of the inlet system in order to accomplish meaningful research, and therefore there are three fundamental experimental techniques used for engine research. As depicted in Figure 6-38, these are:

- o free jet, propulsion wind tunnel
- o direct connect
- o modified direct connect.

The advantages of the direct connect technique are a) only the engine mass flow need be provided, which is considerably less than that required for free jet testing, b) the nozzle supplying the airflow to the engine operates at the nominal duct Mach number rather than the free stream Mach number, significantly reducing the nozzle pressure ratio.

FIGURE 6-38 ENGINE TEST METHODS



The other method which provides some flow simulation through the inlet throat and diffuser, and yet provides a measure of reduced stagnation pressure requirements is the modified direct connect technique. As depicted in Figure 6-38, two of the inlet shocks and the throat flow are simulated. This reduces pressure requirements for the facility. Instead of pitching the inlet to achieve greater compression, the reservoir pressure is increased; and the nozzle Mach number and ramp angle are adjusted to represent the effects of the inlet changing angle of attack. Thus, the geometric flow area remains fixed by the nozzle dimensions.

The direct connect method and free jet method will be employed for the turbo machinery facilities as the primary basis for the facility concepts. The modified direct connect technique will also be considered as an alternate arrangement to provide a source of time variant engine/inlet compatibility data without necessarily having to provide a free jet capability. Because of combined mass flow, pressure, and temperature requirements for the scramjet facilities, the modified direct connect method will be a primary criterion for establishing their design.

The most challenging requirements, in terms of reservoir pressure and mass flow are presented by free jet simulation methods. The gas must be isentropically expanded to flight velocity, Mach number, static pressure, and static temperature by an aerodynamic nozzle, with rapidly increasing pressure ratios as Mach number is increased. These simulation requirements are summarized in Figure 6-39a for the flight corridor established in Figure 6-4. The combination of stagnation pressure and temperature cannot be increased without limitation. For facilities which must operate for significant run durations the facility components must be cooled by some technique. The critical component is generally the nozzle throat which experiences the highest heat transfer rates. Data obtained at AEDC, MCAIR, and FDL can generally be correlated into a maximum heat transfer rate which can be accommodated by back side, thin film water cooling techniques, by the expression:

$$\sqrt{P_o}\ H_o = 39{,}000\ \frac{\text{Btu}}{\text{lb}}\ \sqrt{\text{atm}}$$

$$= 2.78 \times 10^7\ \frac{\text{J}}{\text{kg}}\ \sqrt{\frac{\text{N}}{\text{cm}^2}}$$

where P_o is the reservoir pressure and H_o is the reservoir enthalpy.

The shaded area in Figure 6-39a represents the area not available to long run duration facilities because of this cooling limitation. In this area, impulse wind tunnel techniques are necessary to achieve the desired conditions. Figure 6-39b contains the International System unit conversions for the callouts in Figure 6-39a.

In order to define the direct connect and modified direct simulation requirements, the stagnation pressure recovered within the inlet is required. An estimate of this recovery is shown in Figure 6-40a for specific inlets and flight paths, for different regions of the inlet. The recovery represented for a subsonic duct, 5 , is slightly greater than that specified in Mil Spec, MIL-E-5008C, and is based on MCAIR data. The variations in the recovery for the supersonic combustion case generally reflect variations in angle of attack as the aircraft is accelerated to its design speed of Mach 12. A generalized pressure recovery region, representing many duct configurations and data sources is given in Figure 6-40b. Using these pressure recovery values for subsonic combustion, the subsonic direct connect duplication requirements can be represented in Figure 6-41. The shaded area indicates the limits used in this study, of 150 psia maximum duct pressure (103 N/cm^2), and Mach number 6. This Mach number cut-off point could be as high as Mach number 7 or 8, but, the value of equivalence ratio could exceed one by a significant margin, rendering such operation inefficient, though technically possible.

The simulation requirements for modified direct connect methods are given in Figure 6-42. The boundary to the left of the shaded area is representative of the maximum conditions obtainable using vitiated air techniques (mixtures or combustions products, air, and oxygen, which maintain a 20% unburned oxygen content). The limit of the shaded area represents the throat cooling limit given for the free jet simulation requirements in Figure 6-39. Because of the reduced stagnation pressure requirements, duplicated conditions can be achieved at higher Mach numbers than are shown in Figure 6-39a for the isentropic free jet case. Again, transition from subsonic to supersonic combustion is represented at Mach number 6, although this is not necessarily the only transition Mach number. For the modified direct mode, the local Mach number requirements are estimated in Figure 6-43. This local Mach number is substantially less than the free stream Mach number, providing reduced reservoir pressure requirements. For the scramjet engine test section employing modified direct connect techniques, the flow conditions provided by the nozzle correspond to region 3 .

The reservoir pressure and temperature requirements for the different simulation techniques are summarized in Figure 6-44a. This illustrates the rapidly increasing pressure levels as the temperature (velocity) is increased. The limit of current water cooling capabilities is indicated. The pressures which must be provided for a supersonic combustion facility must span two orders of magnitude, indicating that the mechanical compressors and valving associated with such facility could be rather complex and present a significant problem in systems control. Figure 6-44b summarizes the mass flow for turbomachinery, ramjet, and scramjet engines. Details of specific engine requirements comprosing this composite presentation are give[illegible] Volume V. The combination of mass flows, pressures and temperatur[illegible] in Figure 6-44 represent a significant step over existing ca[illegible] ether they can be provided

FIGURE 6-39a RESERVOIR CONDITIONS AND MASS FLOW REQUIRED FOR TEST SECTION DUPLICATION OF FLIGHT CONDITIONS, FREE JET ENGINE TEST, OR WIND TUNNEL

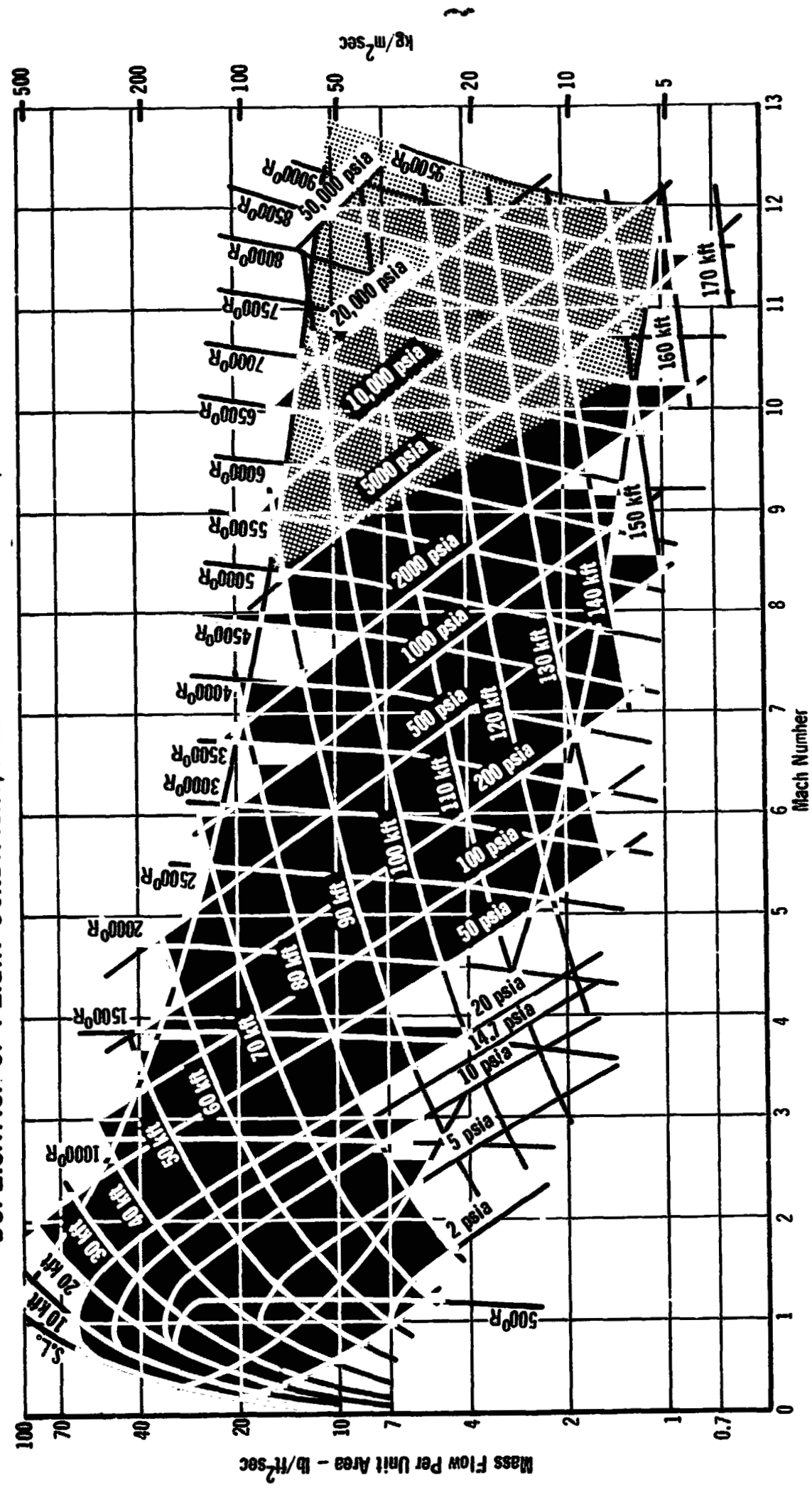
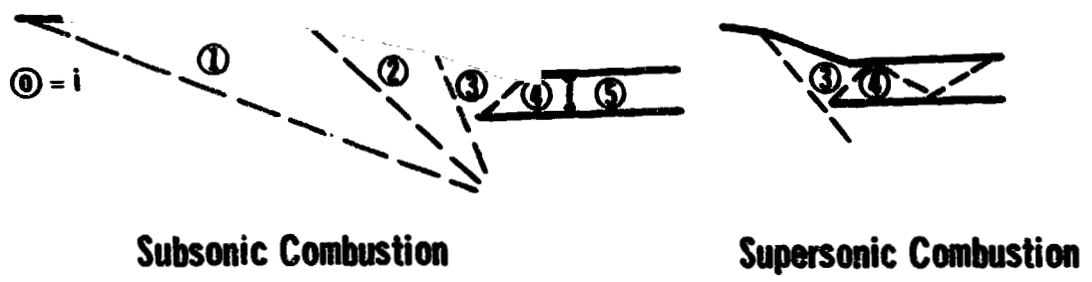


FIGURE 6–39b RESERVOIR CONDITIONS AND MASS FLOW REQUIRED FOR TEST SECTION DUPLICATION OF FLIGHT CONDITIONS

Pressure		Temperature		Geometric Altitude	
psia	N/cm^2	^oR	^oK	kilofeet	kilometers
5.8	4	450	250	0	0
10.1	7	900	500	16.4	5
14.5	10	1350	750	32.8	10
29.0	20	1800	1000	49.2	15
58	40	2250	1250	65.6	20
101	70	2700	1500	82.0	25
145	100	3250	1750	98.4	30
290	200	3590	2000	114.0	35
580	400	4060	2250	131.0	40
1,015	700	4500	2500	147.0	45
1,450	1,000	4950	2750	164.0	50
2,900	2,000	5400	3000	180.0	55
5,800	4,000	5850	3250	197.0	60
10,150	7,000	6300	3500	213.0	65
14,500	10,000	6750	3750	229.0	70
21,700	15,000	7200	4000	246.0	75
29,000	20,000	7640	4250		
58,000	40,000	8100	4500		
		9000	5000		

FIGURE 6–40a DEFINITION OF PRESSURE RECOVERY FOR ENGINE TEST FACILITIES



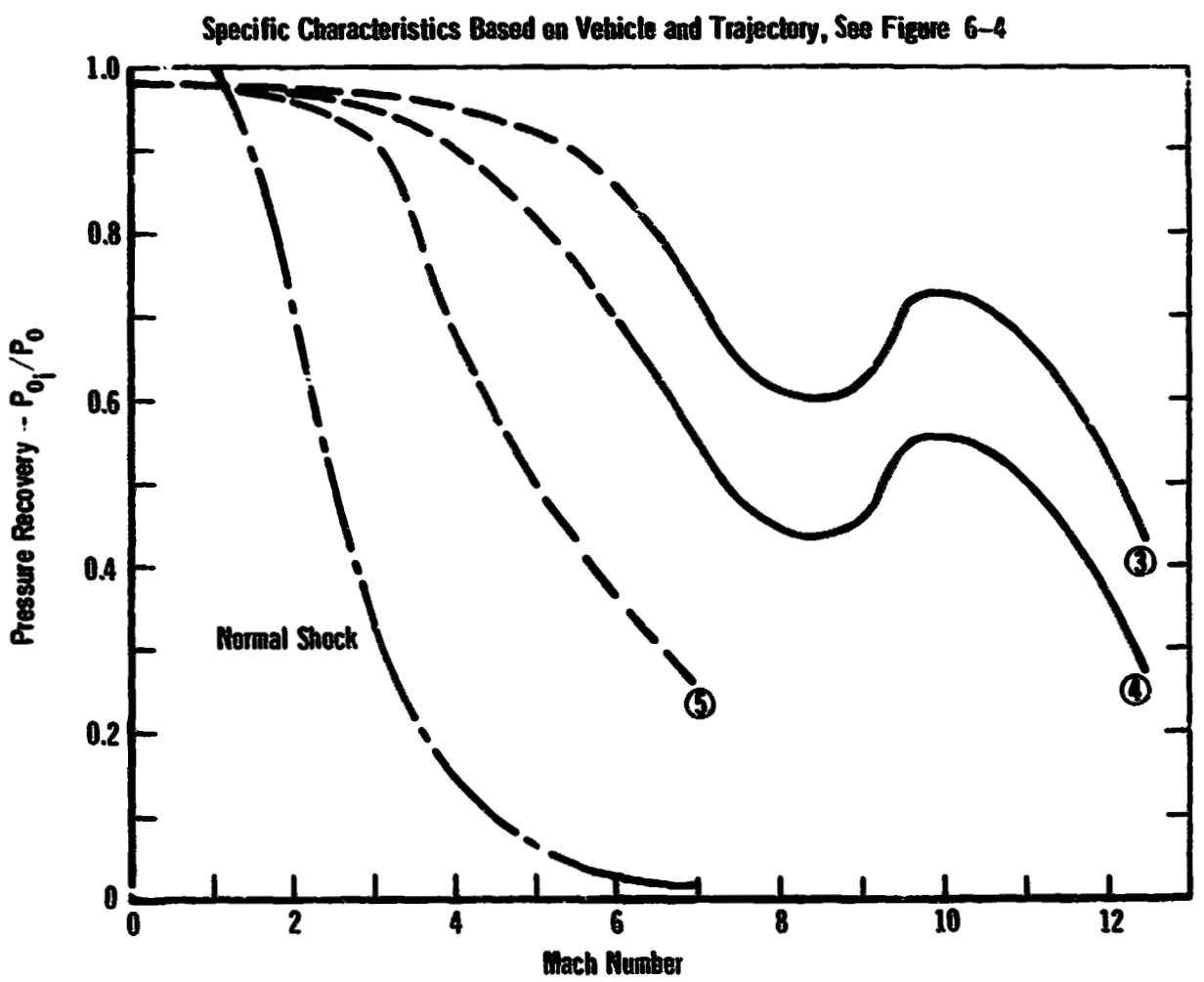
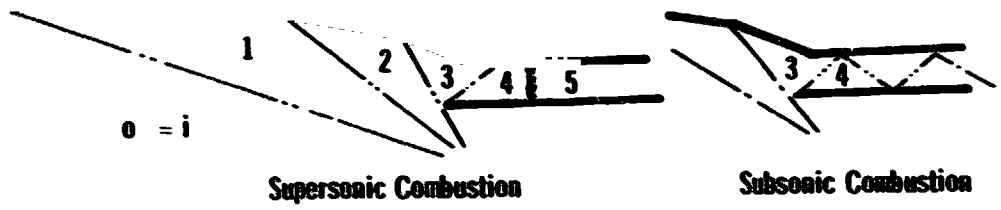


FIGURE 6–40b DEFINITION OF PRESSURE RECOVERY FOR ENGINE TEST FACILITIES



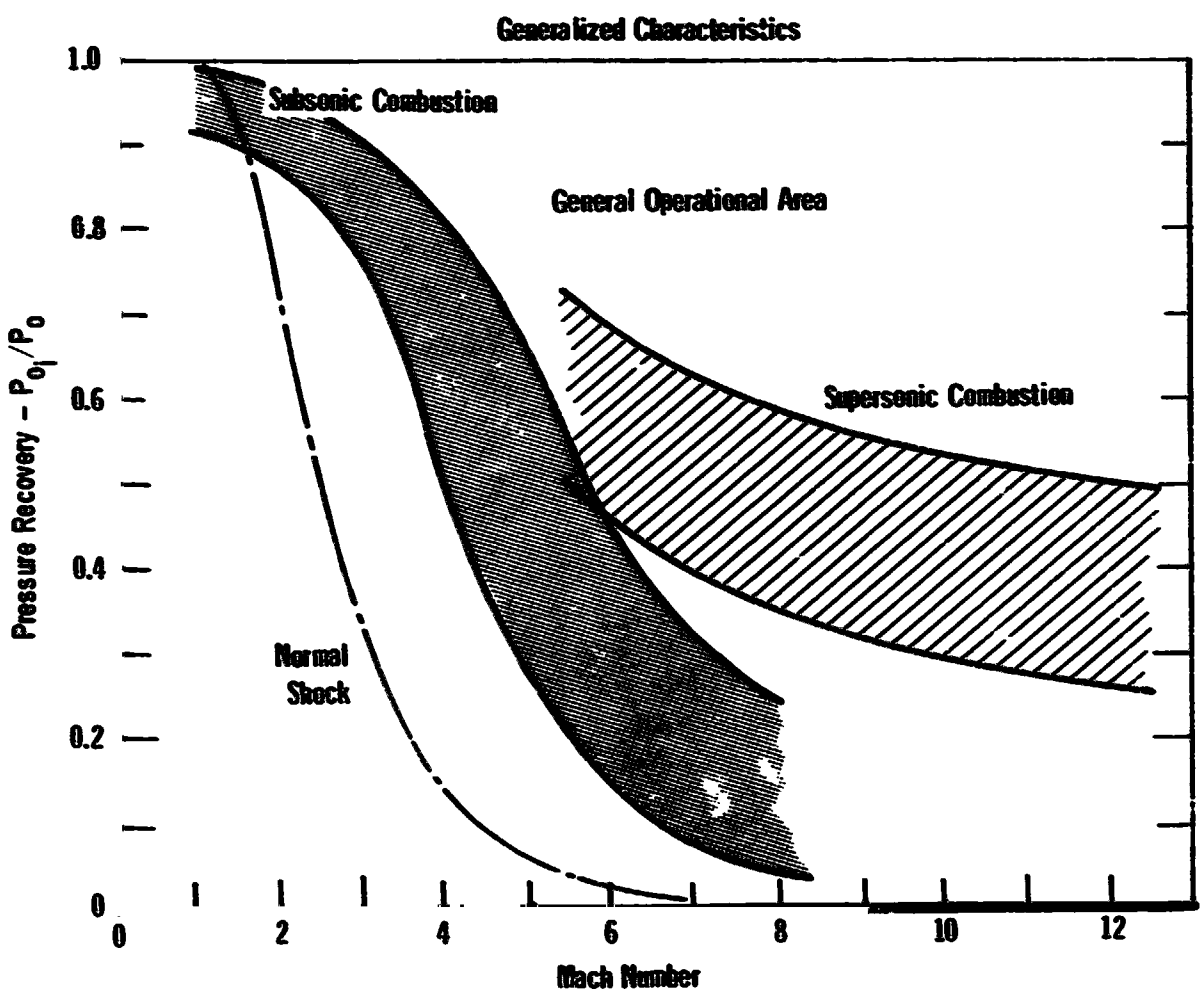


FIGURE 6–41 RESERVOIR CONDITIONS AND MASS FLOW REQUIRED FOR TEST SECTION DUPLICATION OF FLIGHT CONDITIONS, ENGINE TEST FACILITIES, DIRECT CONNECT, TURBOMACHINERY, RAMJET

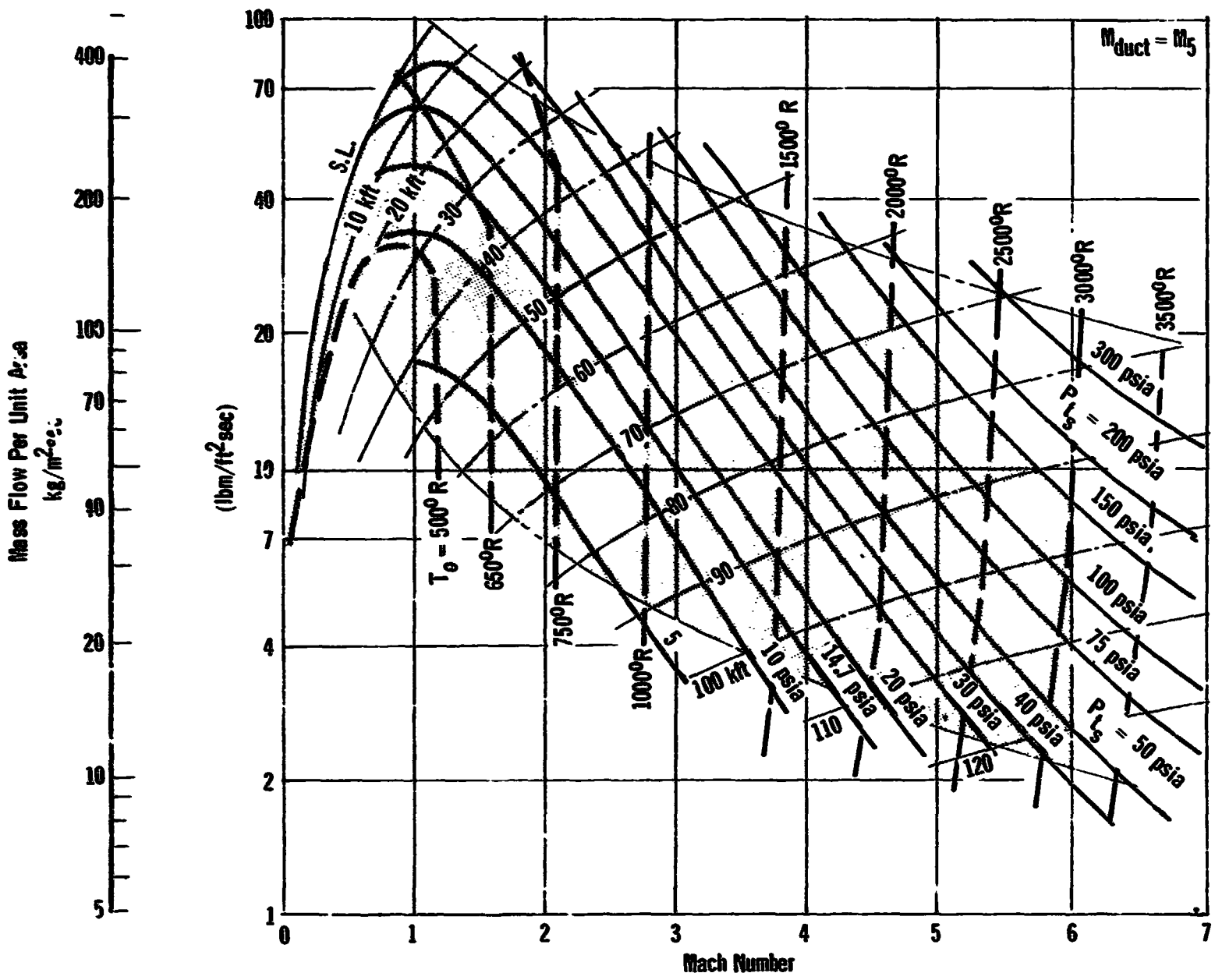


FIGURE 6–42 CONDITIONS AND MASS FLOW REQUIRED FOR TEST SECTION DUPLICATION OF FLIGHT CONDITIONS, ENGINE TEST FACILITIES, MODIFIED DIRECT CONNECT, SCRAMJET, CONVERTIBLE SCRAMJET

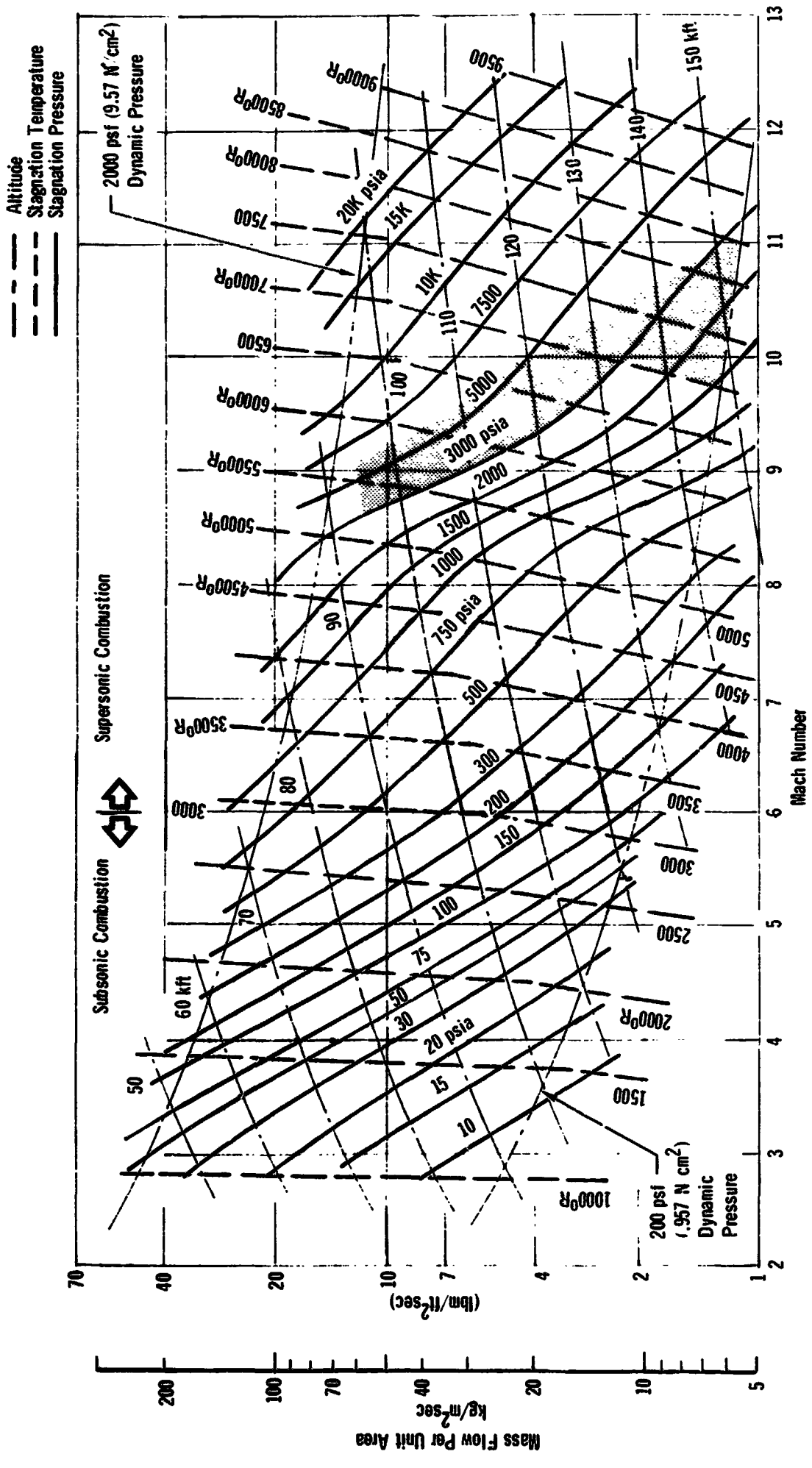


FIGURE 6–43 MACH NUMBER REQUIRED FOR MODIFIED DIRECT CONNECT ENGINE TESTS

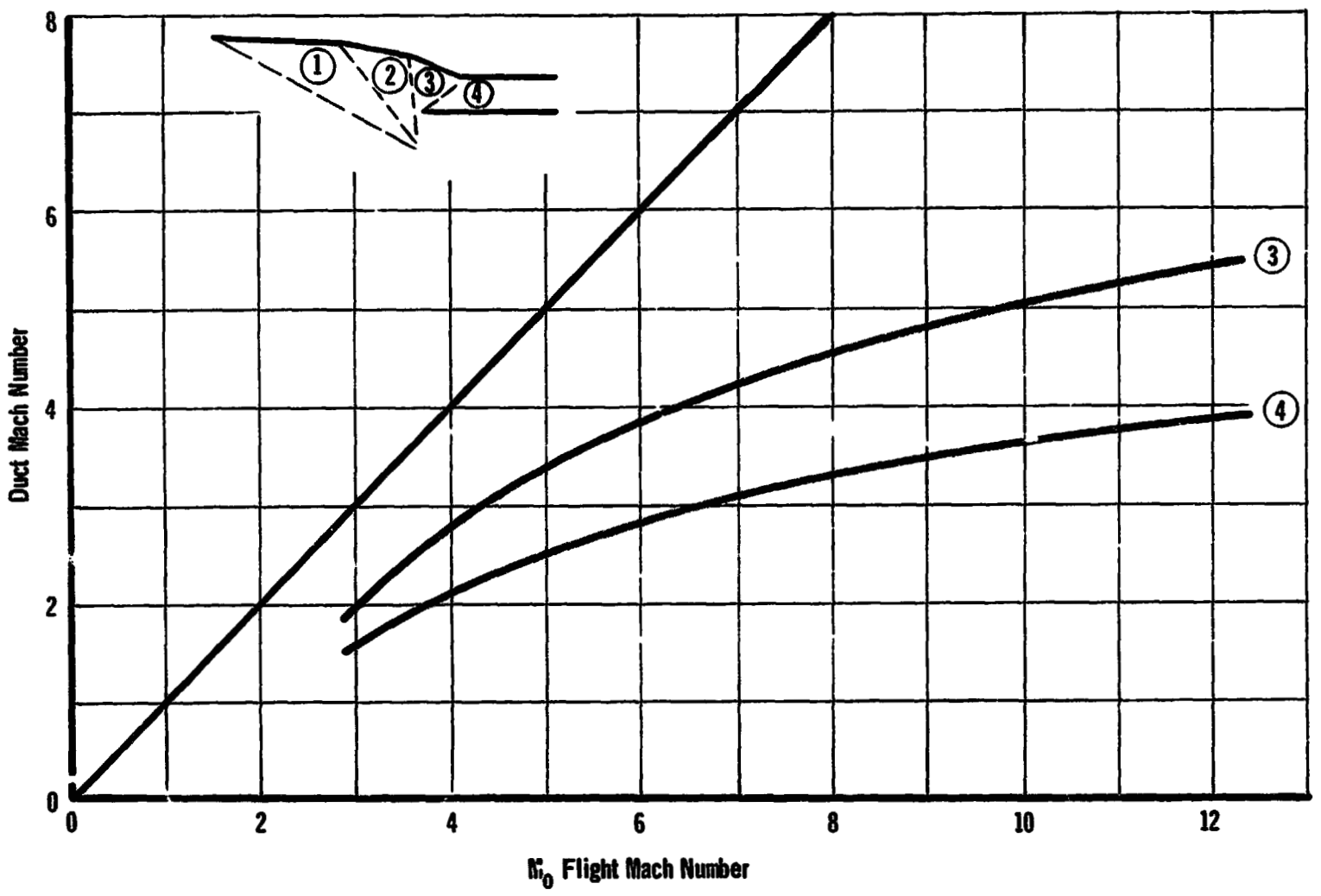


FIGURE 6–44a SUMMARY OF RESERVOIR CONDITIONS FOR DIFFERENT DEGREES OF FLIGHT SIMULATION REQUIRED FOR ENGINE DEVELOPMENT

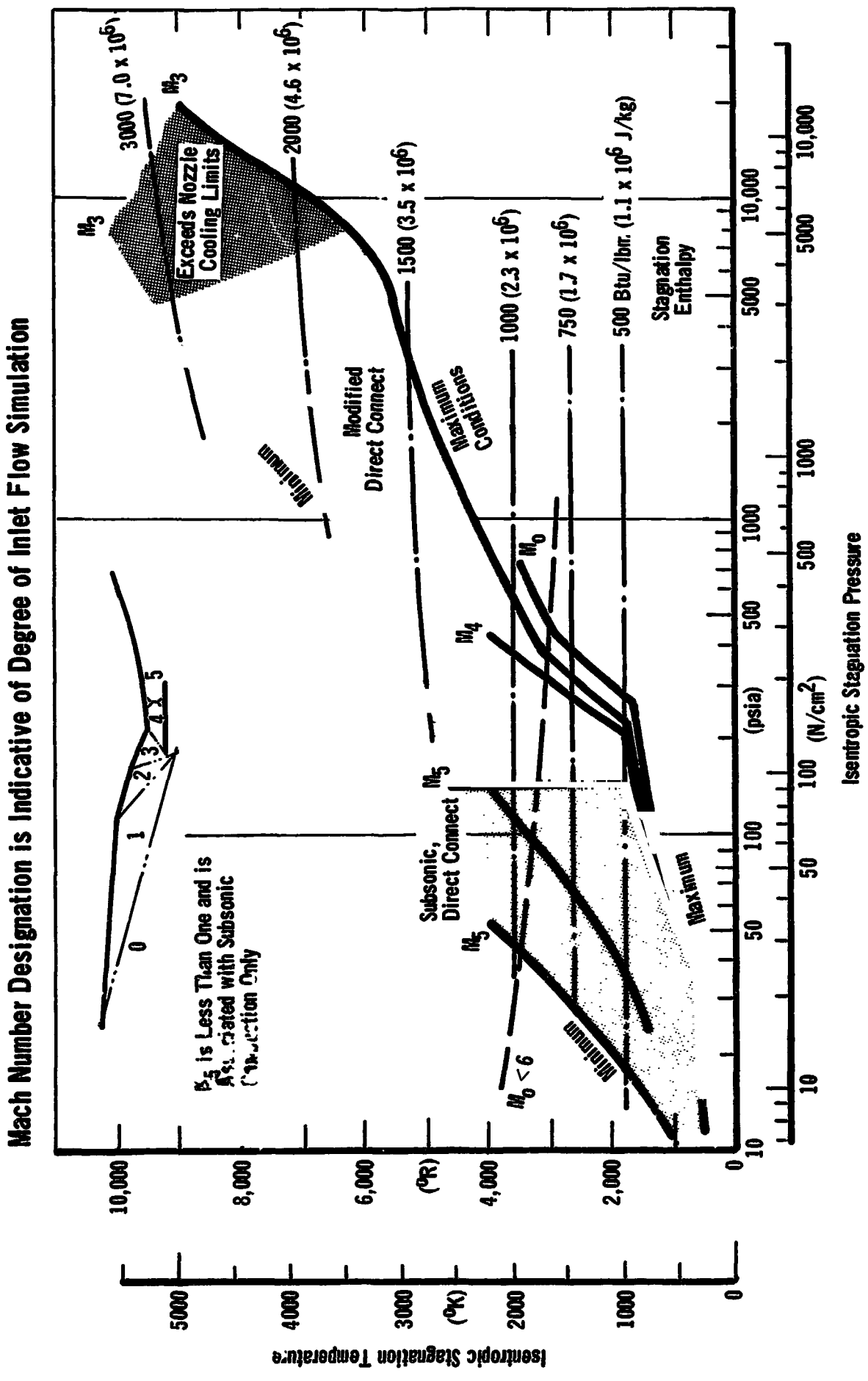
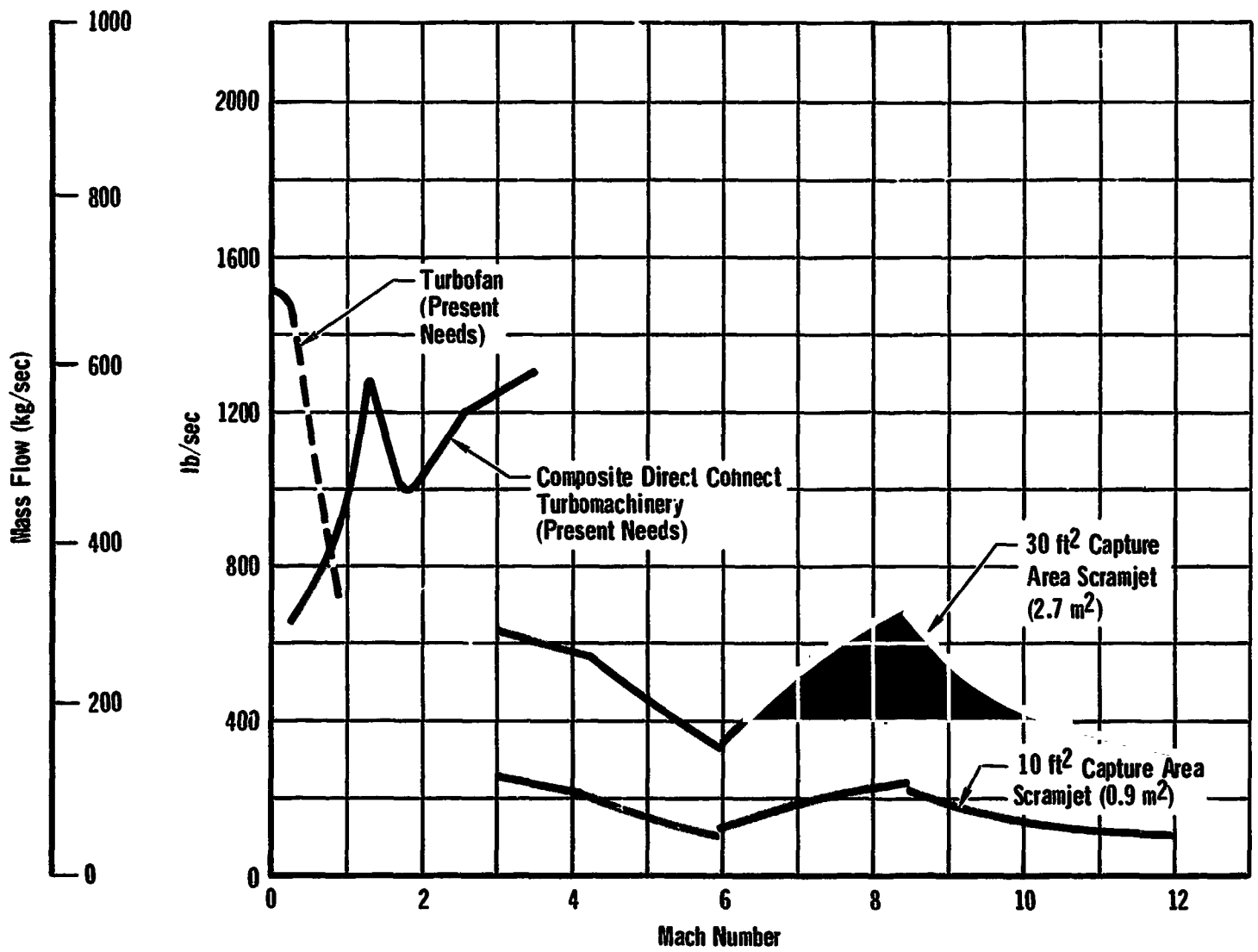


FIGURE 6-44b SUMMARY OF MASS FLOW REQUIREMENTS FOR ENGINE RESEARCH FACILITIES



depends on detailed analyses of the present technology to define hardware feasibility and established realistic costs consistent with the Phase II or Phase III level of detail.

6.5.2 ANALYSIS - There are numerous enthalpy source concepts (reference 1) which provide combinations of pressure and temperature suitable for duplications of various regimes of the flight corridor. A few of these are represented in Figure 6-45. The flight corridor shown is that from Figure 6-4. The four reservoir heated isentropic facilities can provide a complete duplication of the conditions encountered in flight for the potential operational hypersonic aircraft below Mach numbers of 12. The electric heated and combustor heated (vitiated air) facility concepts are capable of continuous operation. The arc facility is capable of operations as long as 30 minutes for some conditions while the impulse facilities are limited to run times less than one-fourth second. For reference the nozzle cooling limit for continuous and transient throat cooling requirements is shown as the performance limit for continuous and intermittent facilities. Previously it was thought that magnetohydrodynamic (MHD) accelerators could provide most of the test conditions beyond the capability of reservoir heated isentropic expansion wind tunnels. However, work by Dr. Leon Ring at AEDC has shown that the entropy level consistent with the operation of MHD accelerators is not consistent with that required to provide the necessary test conditions. The use of the entropy level in defining limits of equilibrium expansion of air through nozzles was first suggested by J. G. Hall and co-workers at the Cornell Aeronautical Laboratory. The basis of this correlation was suggested by observing the similarity between Lighthill's classical equation for entropy (reference 2 and 3) and the equation expressing the rate of change of the atomic species concentration along the nozzle. A correlation parameter (Σ) was developed which provides correlation with respect to nozzle size as well as geometric shape.

$$\Sigma = So/R + a \ln \frac{\tan \theta}{r^*/r_o} + c\, So \ln \frac{\tan \theta}{r^*/r_o}$$

where: r^* = throat radius

r_o = reference throat radius = 1 inch (2.54 cm)

θ = Nozzle Half Angle

The effectiveness of this parameter is demonstrated in Figure 6-46 where the atomic mole fraction is plotted against So/R and the correlation parameter Σ.

This approach greatly simplified the estimation of the degree of chemical equilibrium maintained during the nozzle expansion, by relating directly to the reservoir pressure and temperature.

Examination of Figure 6-46 will indicate that entropy levels represented by values of Σ which exceed 32 cannot be considered to be in chemical equilibrium. This level of reservoir entropy is indicated in Figure 6-45. Normally, the wind tunnel performance for flight duplication is represented in terms of altitude and velocity, however, this presentation is equivalent to an enthalpy/entropy

FIGURE 6-45
APPROXIMATE FLIGHT DUPLICATION CAPABILITY OF VARIOUS TYPES OF ENTHALPY SOURCES

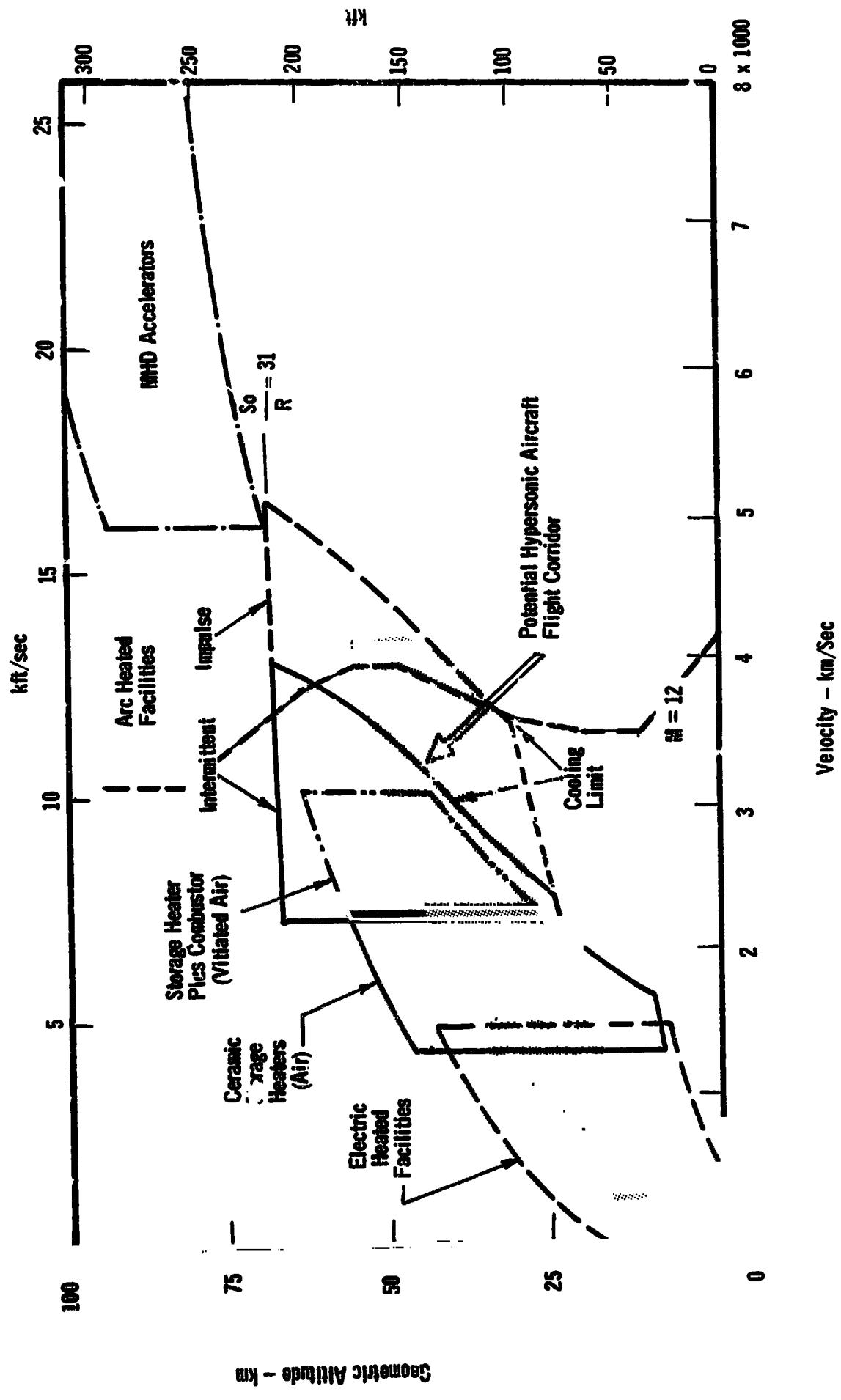
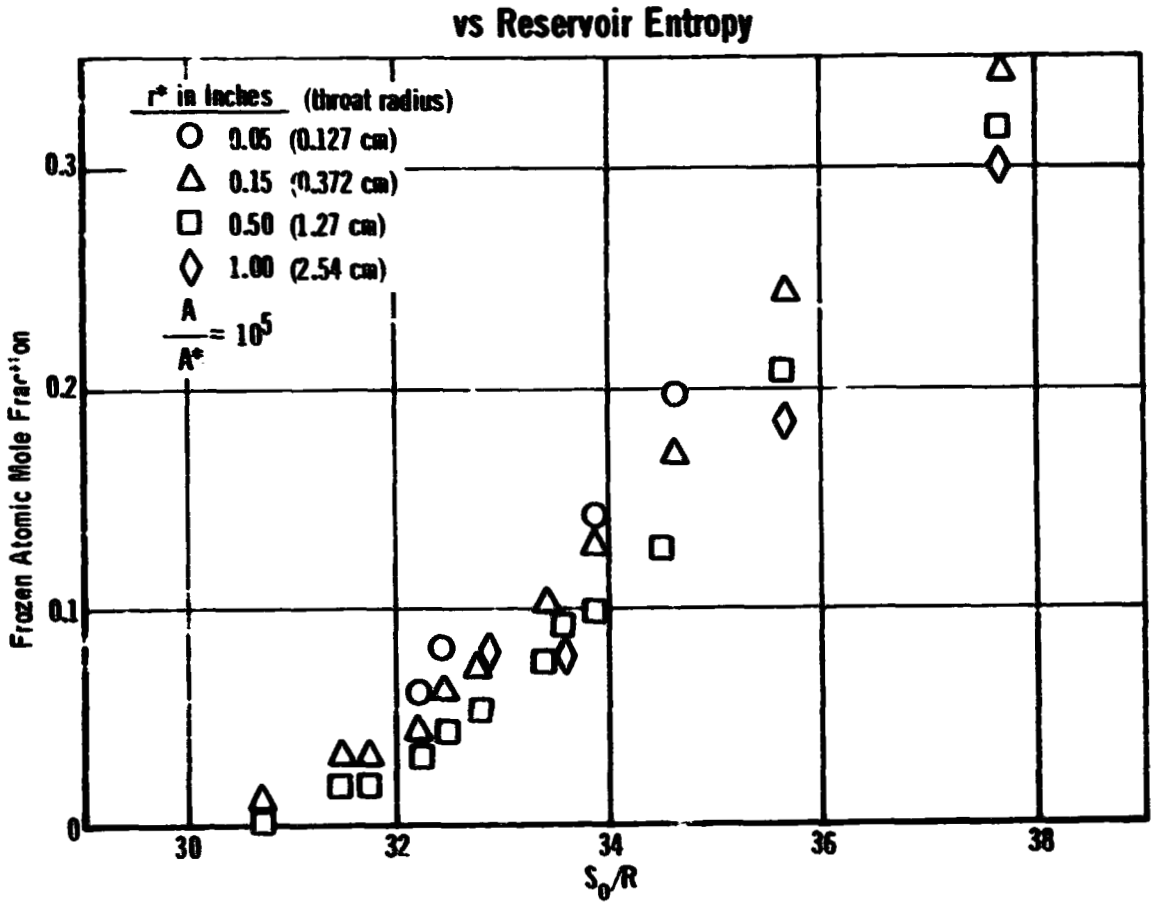
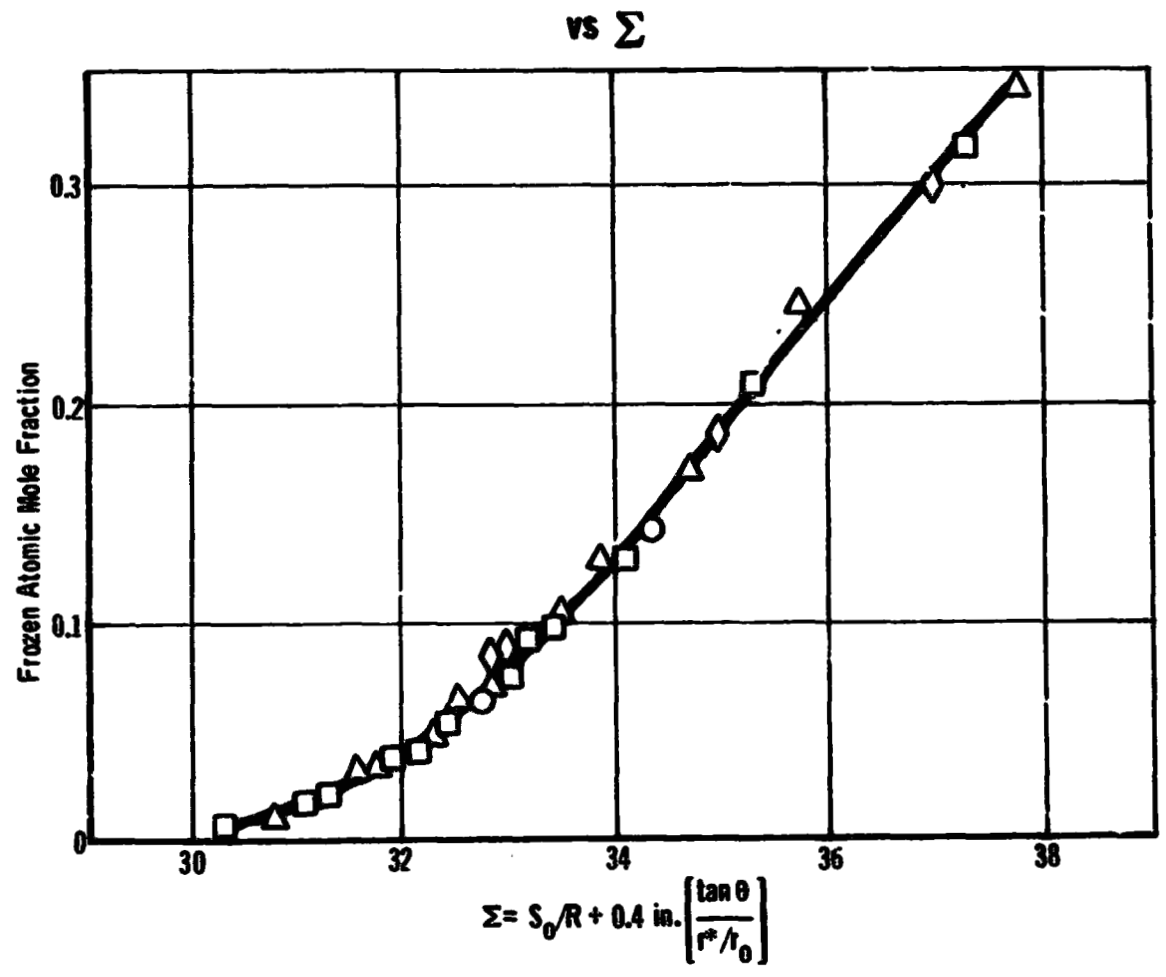


FIGURE 6–46 FROZEN ATOMIC MOLE FRACTION vs RESERVOIR ENTROPY





representation. An isentropic process is one that occurs at constant entropy therefore the entropy in the test section equals the entropy in the reservoir. The magnitude of the entropy in the test section is proportional to the static temperature and pressure, and therefore altitude, thusly:

$$\frac{S}{R} \alpha \frac{\gamma}{\gamma-1} \ln T_\infty - \ln p_\infty .$$

The velocity is related to the enthalpy by the expression:

$$V_\infty \simeq 223.8 \quad H_O$$

where:

V_∞ = flight velocity (ft/sec)
H_O = stagnation enthalpy (Btu/lb)

Dr. Ring has shown that with alkali metal salt seeding, a MHD accelerator can function when the input is provided by a reservoir heated, isentropic expansion device operating at an So/R of 32. However, this is about a minimum level which will assure operation of the accelerator device. The accelerator in accelerating the gas increases the entropy level of the gas. Thus, the condition represented by the exit conditions of the accelerator correspond to a higher altitude than those at the entrance of the accelerator. In Figure 6-45 there is a region between the operation of the MHD accelerator and the isentropic expansion facilities which is apparently beyond the present technology in terms of providing flight duplicated conditions. This could represent a valid ground facility research area if the region corresponding to altitudes less than 200,000 ft (60 km) and velocities greater than 16,000 ft/sec (5 km/sec) must be duplicated to accomplish necessary research. In terms of the requirements for the nine potential operational hypersonic aircraft presented in Volume V, this does not appear necessary unless the Mach number is increased significantly beyond 12. The facility enthalpy source concepts utilized in this study for the engine research facilities appear to provide the necessary conditions up to Mach numbers of 12.

6.5.3 DESIGN CHARACTERISTICS - A brief description of the facility performance, physical characteristics, and facility concept is presented for each of facilities retained after the initial screening process. These facilities represent a significant increment over existing facilities and are needed to provide the defined research.

In order to put the entire ten engine facilities into perspective, Figure 6-47 shows all of the facilities considered in Phase I, and their disposition. Five of these facilities were fully refined in Phase I. A more complete rationale for the disposition of these facilities is given in Section 7. A reasonably complete description of each facility is summarized in Figure 6-103 showing performance and cost estimates where available.

The basic assumption underlying the choice of each candidate engine test facility is that full scale duplication of all flight parameters must be achieved throughout its Mach range. Overall facility size was then keyed to the size of the desired test engine.

Figure 6-50 depicts an alternate arrangement for facilities E8, E9, and E10 to provide aerodynamic, thermodynamic and structural testing capability. The proposed alternate method would allow the scramjet engine test section to be removed and replaced with various nozzles that would form an enclosed free jet test section. Representative nozzle and test article sizes are shown.

FIGURE 6–47 SUMMARY OF ENGINE FACILITIES AND THEIR DISPOSITION IN PHASE I

	Code	Facility Name	Capability	Disposition Code*
Engine Facilities	E1	Large Rocket Engine Facility (Full Scale Engines)	Capability Represented by Existing AEDC and NASA Facilities.	D
	E2	Wind Tunnel Accommodating Engines (Subscale to Full Scale Engines)	Intended to Represent GD8, GD9, GD10, GD11 as Applicable to Engine Research, Flight Duplicated Condition, Inherent in Concept.	D
	E3	Turbomachinery Engine Facility (Full Scale Engines)	Facility Analogous to AEDC 16S, 16T with Mach 5.5 Flight Duplicated Capability, Redefined as E6, E7.	E6
	E4	Exhaust Nozzle Test Facility (Full Scale Engines)	Engine Nozzle Airframe Integration Research, Incorporated into E6, E7.	E7
	E5	Engine Dynamic Simulator	Simulation of Engine Airframe Dynamic Interactions. Represented as Existing Hybrid Computer Facilities, and in E6, E7.	E7
	E6	Direct Connect Turbomachinery Facility (Full Scale Engines)	Flight Duplicated Engine Research to Mach 9, Turbomachinery, Ramjets, and Composite Cycle Engines.	II
	E7	Free Jet Turbomachinery Facility (Full Scale Engines)		II
	E8	Multirecompression Heater Facility (Subscale Engine Module)	Flight Duplicated Condition to Mach 12, Ramjets, Scramjets, Continuous Operation.	II
	E9	Hybrid Heater Facility (Subscale Engine Module)	Flight Duplicated Conditions to Mach 10, Ramjets, Scramjets, Continuous Operation Vitiated Air, Intermittent Clean Air to Mach 8.	II
	E10	High Pressure Arc Heater Facility (Subscale	Flight Duplicated Conditions to Mach 12, Ramjets, Scramjets, Continuous Operation (30 Minutes)	D

* (Facility Code) integrated into indicated facility for Phase II refinement.
(R) Does not have high research value as applicable to HYFAC but does to other aircraft systems – recommended for further later study.
(II) Entered into Phase II for further refinement.
(D) Deleted from further refinement.

E6 DIRECT CONNECT TURBOMACHINERY ENGINE FACILITY

Description:

An altitude simulation test cell for performance and qualification tests of turbojet and turboramjet engines. Will have an air supply and heating plant capable of continuous operation in the direct connect mode from M_∞ = .1 to 5.5. Steam ejectors will provide altitude simulation to 85,000 ft (26 km) for accurate simulation of engine nozzle characteristics. Engine diameter to 90" (2.29m) can be accommodated.

Specifications:

Test Section: 90" dia (2.29 m)
Mach Range: .1 to 5.5 (simulated, direct connect mode)
Altitude Range: 0 to 85 kft (0 to 26 km)
Stagnation Pressure: 14.7 to 226 psia (10.1 to 156 N/cm^2)
Stagnation Temperature: 532 to 2200°R (296 to 1220°K)
Mass Flow Range: 633 to 1650 lbm/sec (287 to 748 kg/sec)
Thrust Stand: 100,000 lb (444,800 N)
Run Time: Continuous

Features:

1. Compressor plant capable of continuous operation.
2. Steam ejector plant for complete altitude duplication.
3. Electric heater.
4. Nozzles for direct connect or modified direct connect testing.
5. Test cell, with thrust stand.
6. Water cooling system.
7. Conventional and cryogenic fuel storage, distribution, and control system.

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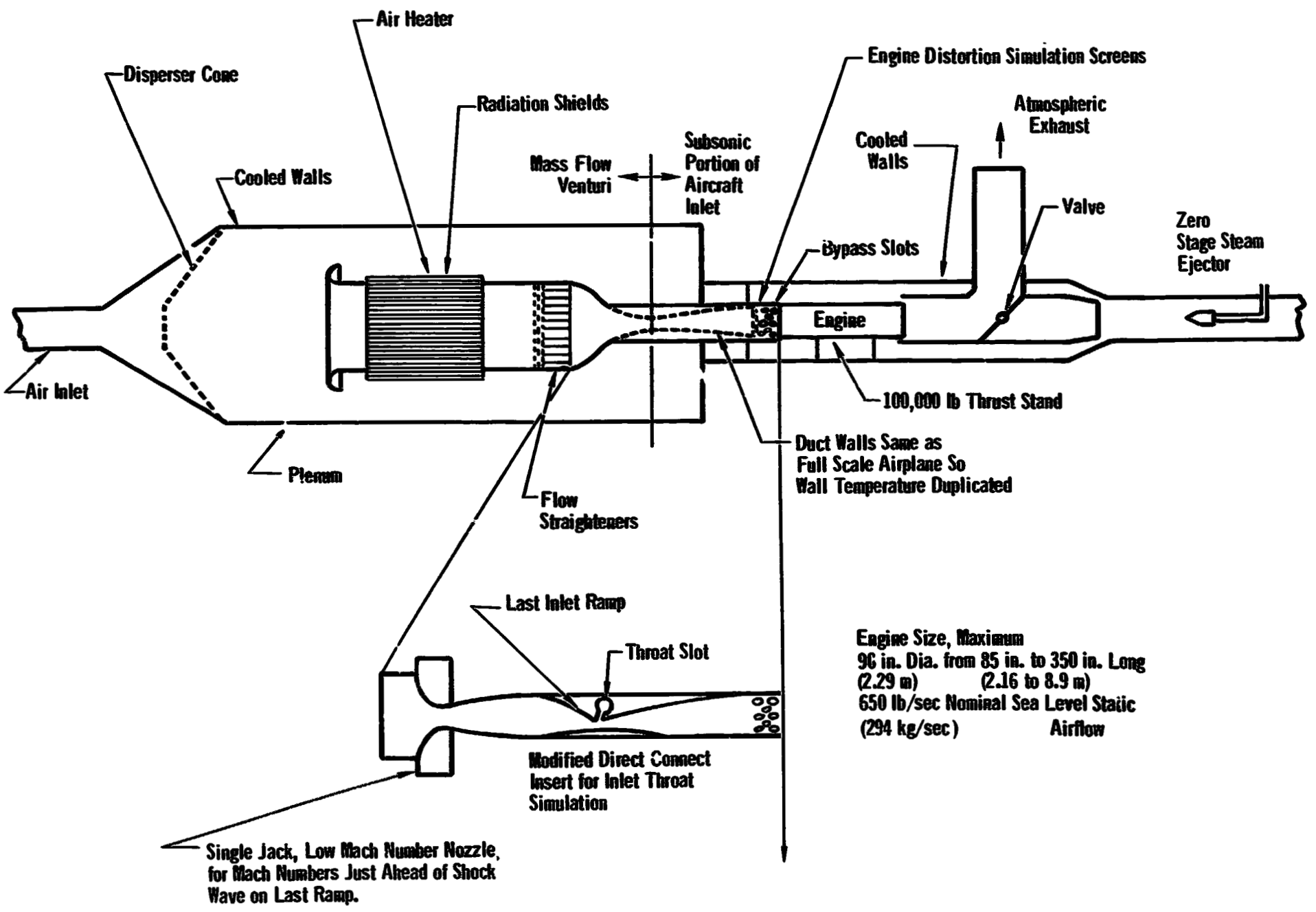
FOLDOUT FRAME 1

FIGURE 6-48 ENGINE FACILITY E6 SCHEMATIC DRAWING AND PERFORMANCE



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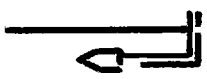
FOLDOUT FRAME 2

Zero Stage Steam Ejector



Flight M_∞	Direct Connect: Stagnation Temperature (^{0}R)	Direct Connect: Stagnation Pressure (psia)	Direct Connect: Mass Flow (lb/sec)	Modified Direct Connect: Stagnation Pressure (psia)	Modified Direct Connect: Mass Flow (lb/sec)
0.1	532 (296)	14.5 (10.0)	633 (287)	14.5 (10.0)	700 (318)
0.5	556 (309)	17.0 (11.7)	710 (322)	17.0 (11.7)	780 (354)
1.0	637 (354)	27.0 (18.6)	930 (421)	27.3 (18.8)	1010 (456)
1.2	682 (379)	34.5 (23.8)	1180 (535)	35.0 (24.1)	1298 (589)
1.7	707 (390)	34.2 (23.6)	1050 (476)	35.0 (24.1)	1155 (524)
2.0	758 (421)	38.3 (26.4)	1090 (495)	39.8 (27.4)	1199 (544)
2.5	880 (489)	52.0 (35.8)	1200 (545)	55.0 (37.9)	1320 (600)
3.0	1090 (606)	76.0 (52.4)	1350 (612)	82.0 (56.5)	1480 (672)
3.5	1350 (750)	105.0 (72.4)	1500 (680)	121.0 (83.4)	1650 (749)
4.0	1630 (906)	129.0 (89.0)	940 (426)	179.0 (123.0)	1030 (468)
4.5	1900 (1060)	150.0 (104.0)	770 (349)	226.0 (156.0)	840 (382)
5.0	2200 (1220)	150.0 (104.0)	630 (286)		690 (313)
	(^{0}K)	(N/cm^2)	(kg/sec)	(N/cm^2)	(kg/sec)

Maximum Matrix Temperature in Heater 2650^{0}R (1480^{0}K).

Maximum Heater Power 530 Megawatts Input with 70% Efficient Heater Equivalent to the Heat Input from 27 lb/sec (12.2 kg/sec) of Gasoline and 380 lb/sec (172 kg/sec) of Air.

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E7 FREE JET TURBOMACHINERY ENGINE FACILITY

Description:

Similar to E6 in air supply, heater and exhauster characteristics. This facility performs continuous tests on turbojet and turboramjet engines (90 in. dia.) (2.28 m) in the free jet mode from M_∞ = 1. to 5.0. A two-dimensional adjustable nozzle capable of α variation of -5° to +20° is provided so that fully programmed flight trajectories (Z, M_∞, α) may be run on a real time schedule.

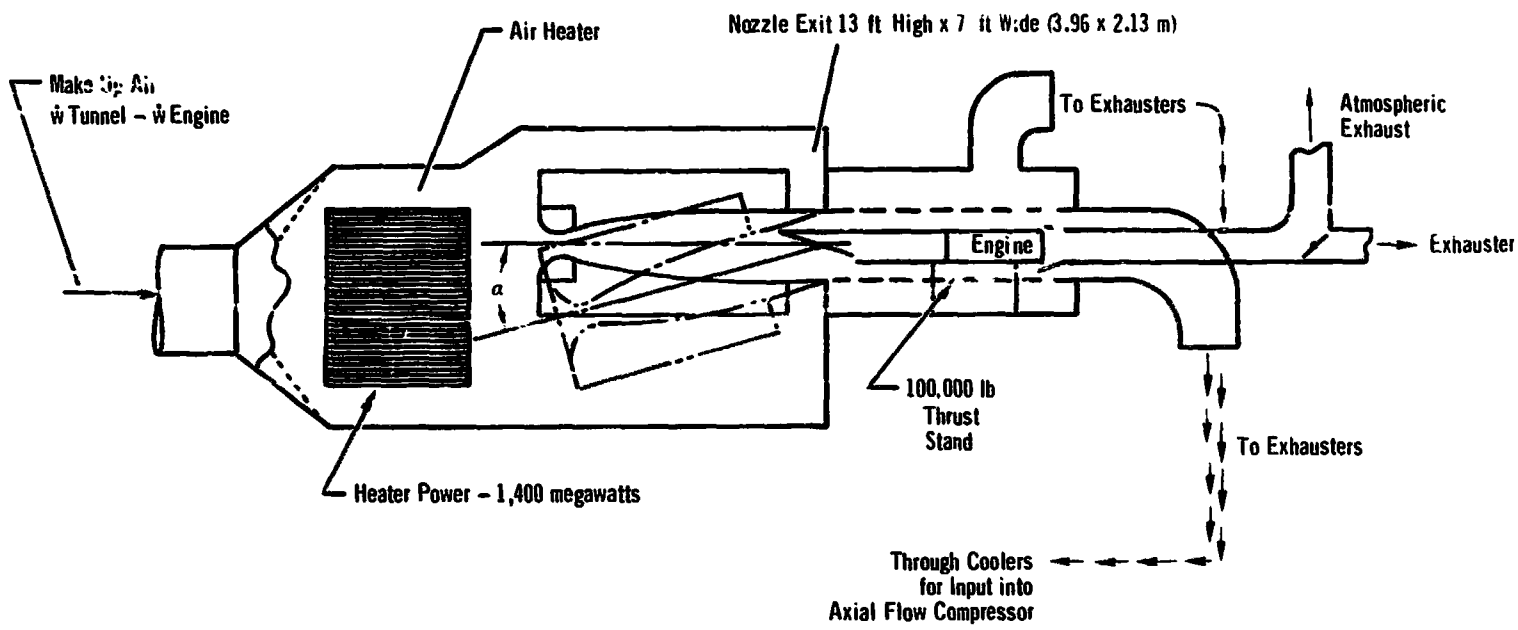
Specifications:

Test Section: 7' x 13' (2.13 x 3.96 m)
Mach Range: .1 to 5.0
Altitude Range: 0 to 85 kft (0 to 26 km)
Stagnation Pressure: 3 to 198 psia (2.07 to 136.5 N/cm^2)
Stagnation Temperature: 532 to 1630 °R (296 to 905 °K)
Mass Flow Range: 910 to 9100 lbm/sec (412 to 4120 kg/sec)
Thrust Stand: 100,000 lb (444,800 N)
Run Time: Continuous

Features:

1. Compressor plant capable of continuous operation.
2. Steam ejector plant for complete altitude duplication.
3. Electric heater.
4. Two-dimensional adjustable nozzle capable of pitching.
5. Test cell with thrust stand.
6. Water cooling.
7. Conventional and cryogenic fuel storage, distribution, and control system.
8. Thermo/structural research can be accomplished in free jet test section.

FIGURE 6-49a ENGINE FACILITY E7, SCHEMATIC DRAWING AND PERFORMANCE

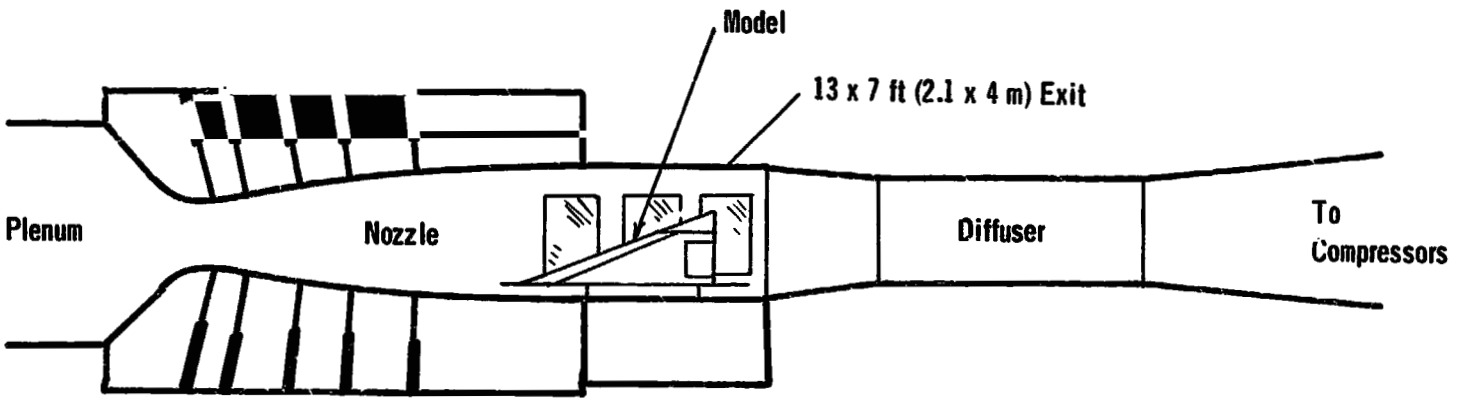


Flight Mach No.	Maximum Plenum Pressure (psia)	Stagnation Temperature (^{0}R)	Engine Mass Flow (Max.) (lbm/sec)	Facility Mass Flow (Max.) (lbm/sec)
0.1	14.8 (10.2)	532 (296)	1500 (680)	2910 (411)
0.5	17.4 (12.0)	556 (309)	1720 (780)	3700 (1600)
1.0	27.7 (19.1)	637 (354)	2240 (1020)	7800 (3540)
1.2	35.2 (24.2)	682 (379)	2630 (1190)	9100 (4100)
1.7	35.6 (24.6)	707 (390)	2080 (942)	6550 (2970)
2.0	40.8 (28.1)	759 (421)	1820 (826)	5720 (2590)
2.5	57.0 (39.3)	880 (489)	1480 (670)	4700 (2130)
3.0	86.0 (59.4)	1090 (606)	1390 (630)	3800 (1720)
3.5	130 (89.0)	1350 (750)	1230 (559)	3450 (1560)
4.0	198 (137.0)	1630 (906)	1080 (490)	3000 (1360)
	(N/cm^2)	(^{0}K)	(kg/sec)	(kg/sec)

Assumes Matrix Heater Temperature – 2650^{0}R (1480^{0}K)

FIGURE 6-49b ENGINE FACILITY E7, SCHEMATIC DRAWING & PERFORMANCE (CONTINUED)

Adjustable Nozzle, M : 5



E8 MULTIRECOMPRESSION HEATER SCRAMJET ENGINE FACILITY

Description:

This facility is designed for modified direct connect continuous testing of convertible scramjet and scramjet engine modules of 10 ft^2 (.929 m^2) capture area from M_∞ = 6 to 12. Complete duplication of flight conditions from Z = 75,000 ft (22.9 km) to 160,000 ft (48.8 km) will be provided by the air supply plant and exhauster system. A two-dimensional adjustable nozzle provides the ability to test a programmed flight trajectory, including transition from subsonic to supersonic combustion for CSJ.

Specifications:

Test Section: 1 ft^2 (.0929 m^2)
Mach Range: 3 to 12 (simulated)
Altitude Range: 45 to 169 kft (13.7 to 48.8 km)
Stagnation Pressure: 850 to 7000 psia (585 to 4820 N/cm^2)
Stagnation Temperature: 3000 to 9500°R (1667 to 5280°K)
Mass Flow Range: 41 to 516 lbm/sec (18.6 to 234 kg/sec)
Run Time: Continuous

Features:

1. Compressor plant capable of supplying cold air at desired $\dot{m}$, and P_o on a continuous basis.
2. Steam ejector plant for complete altitude duplication.
3. Multirecompression heater. *
4. 2 heater drive motors, synchronized by timing gears.
5. Watercooled, flexible, two-dimensional nozzle.
6. Test cell, with inserts for duplication of engine or vehicle contours.
7. Water cooling system.
8. Cryogenic fuel storage, distribution, and control system.

* The multirecompression heater is a mechanical device which uses geared rotors to successively compress the gas to produce extremely high temperatures. It is a concept under development by Roger Weatherston at the Cornell Aeronautical Laboratory.

FIGURE 6–50 ALTERNATE ARRANGEMENT FOR FACILITIES E8, E9, AND E10 FOR AERODYNAMIC, THERMODYNAMIC, AND STRUCTURAL TESTS AT FLIGHT DUPLICATED CONDITIONS

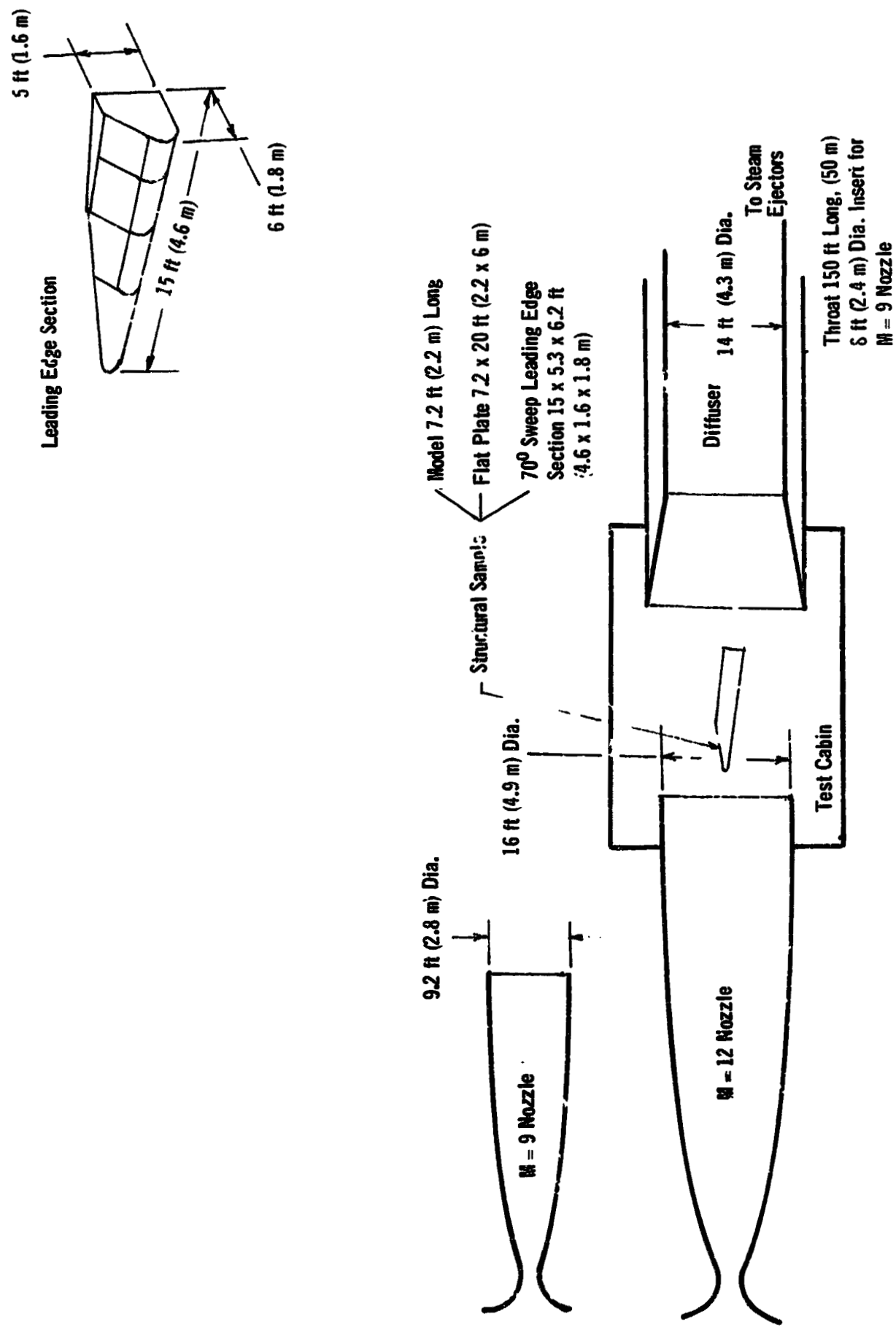


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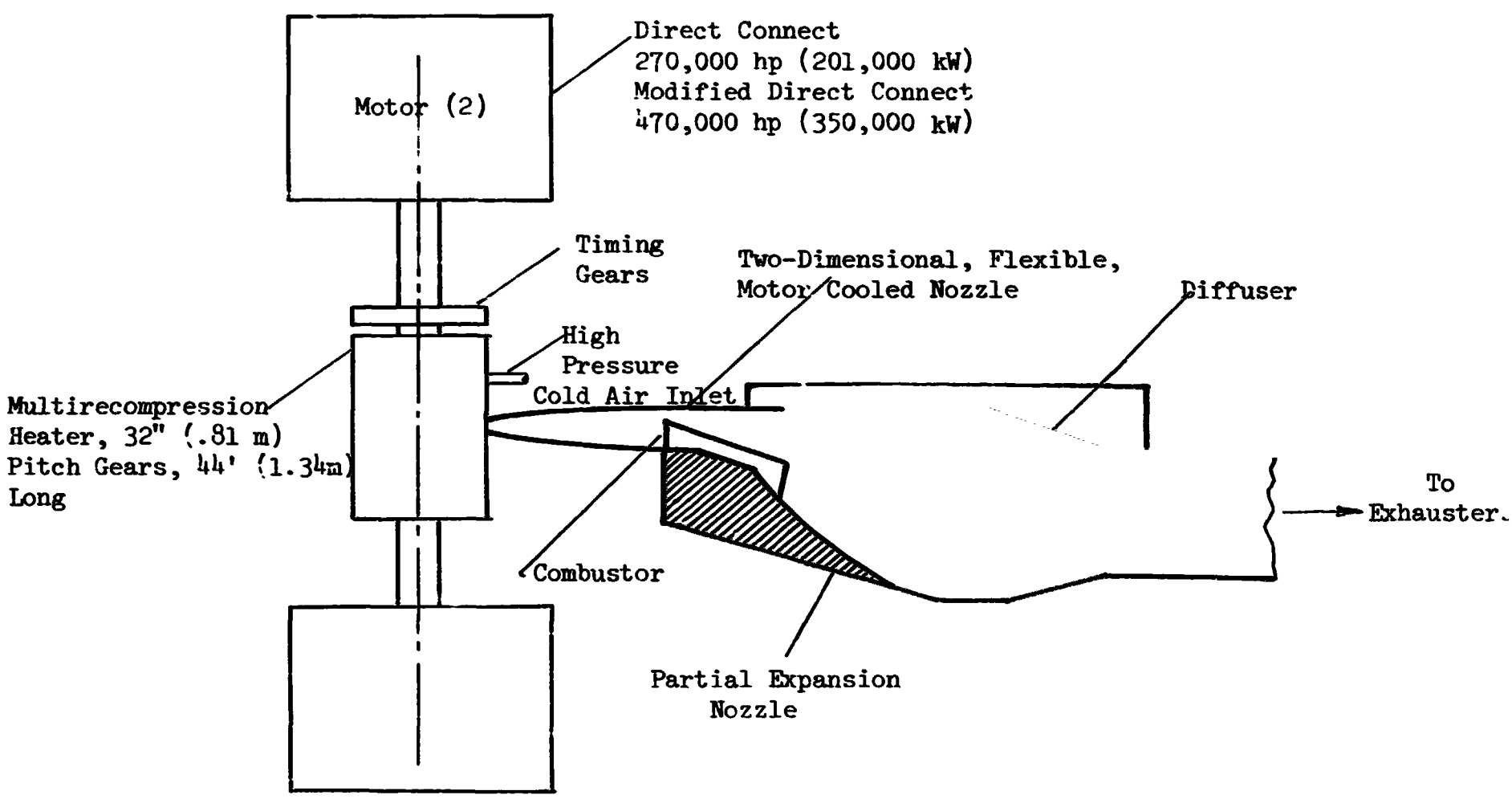
FIGURE 6-51 ENGINE FACILITY E8, SCHEMATIC DRAWING AND PERFORMANCE



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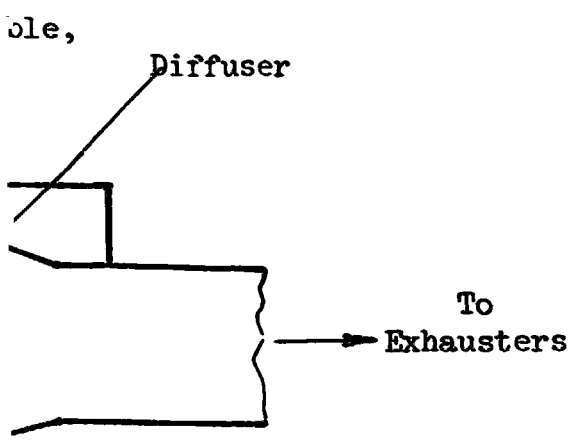

M_∞	Stagnation Pressure (psia)	Stagnation Temperature (°R)	Facility Mass Flow (lbm/sec)	Power (kW)
3.0	84 (58)	1090 (605)	180 (81.6)	57,000
3.5	126 (87)	1350 (750)	180 (81.6)	65,000
4.0	191 (132)	1630 (906)	180 (81.6)	84,000)
4.5	247 (170)	1900 (1060)	160 (72.6)	87,000
5.0	280 (193)	2200 (1220)	140 (63.5)	87,000
5.5	318 (220)	2600 (1440)	120 (54.5)	90,000
6.0	850 (585)	3000 (1670)	233 (106.0)	200,000
7.0	1500 (1030)	3700 (2050)	409 (185.0)	460,000
8.0	2000 (1380)	4600 (2560)	516 (233.0)	713,000
9.0	5000 (3440)	5600 (3110)	387 (171.0)	615,000
9.4	7000 (4820)	6000 (3300)	342 (155.0)	592,000
10.2	6300 (4440)	7000 (3900)	167 (75.6)	361,000
10.9	5600 (3860)	8000 (4440)	102 (46.0)	246,000
11.6	5000 (3440)	3000 (5000)	60.2 (27.0)	184,000
12.0	4700 (3230)	9500 (5280)	41.4 (19.0)	133,000
	(N/cm^2)	(°K)	(kg/sec)	

Facility Mass Flow = Engine Mass Flow Plus Leakage Mass Flow

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E9 HYBRID HEATER SCRAMJET ENGINE FACILITY

Description:

Capable of modified direct connect testing of CSJ and SJ engines. Continuous flow is provided to a heater which operates by the combustion of oxygen enriched air and carbon. This system will be used for long time engine structural and operational qualification. For engine performance testing on a short time basis using pure air, the combustion heater is vented and flow is run through a zirconia storage heater, with no pause in the testing. The combustion heater is brought back onto line when the storage bed temperature drops below the required level. An alternate to the combustion heater will be a continuously operating electrical graphite heater. This heater operates on nitrogen. A mixing chamber is provided downstream of the heater for addition of oxygen and/or N_2O for additional heat. The facility test capability in terms of air plant and exhauster capability, nozzle and engine module size is similar to that of E8.

Specifications:

Test Section: .84 ft^2 (.077 m^2)
Mach Range: 3 to 8.5 (simulated)
Altitude Range: 45 to 140 kft (13.7 to 43 km)
Stagnation Pressure: 84 to 3110 psia (58 to 2150 N/cm^2)
Stagnation Temperature: 1090 to 5100°R (610 to 2840°K)
Mass Flow Range: 120 to 210 lbm/sec (54.3 to 95.3 kg/sec)
Run Time: Continuous

Features:

1. Carbon/air/O_2 combustion chamber.
2. Zirconia storage heater.
3. High pressure air, O_2 compressor plant.
4. Steam ejector plant for complete altitude duplication.
5. Possible alternate heater - Graphite induction type.
6. Water cooled, flexible, two-dimensional nozzle.
7. Test cell, with inserts for duplication of engine or vehicle contours.
8. Water cooling system.
9. Cryogenic fuel storage, distribution, and control system.

The carbon combustion concept represents a unique approach to provide high temperature gas for scramjet engine research. The selection of carbon instead of a hydrocarbon or other fuel to provide a vitiated test gas is based primarily on the relative chemical reaction rates between different structural materials and coatings and various gases. This concept has been proposed earlier as a possible structural testing flow facility for MCAIR (reference 4).

Preliminary review of the chemical composition of the combustion products for an oxygen rich combustion of carbon indicates negligible concentration of CO and free C. The data presented in Figure 6-52 is a compilation of data from many sources indicating the temperature at which significant chemical reactions have been observed between various materials and gases. Most of the information found in this figure is summarized in reference 5. For basic metal and ceramic

FIGURE 6-52 MATERIAL REACTIONS WITH DIFFERENT GASES

Temperatures Indicate When Significant Chemical Reactions Begin - °F (°C)

METALS	OXYGEN	NITROGEN	WATER VAPOR	HYDROGEN	HELIUM	OTHERS
GRAPHITE	840 (449)	5400 (2980)	Considerable at 1500 (815)	1800-6300 (982-3480)	5000 (2760)	Considerable With CO_2 1500 (815)
W	1100 (593)	Forms Nitrides Above 2700 (1482)	1290 (700)	4500 (2480)	5100-5500 (2820-3040)	CO 2600 (1426) CO_2 2200 (1205)
Re	660 (349)	No Effect	Promotes Oxidation		5000 (2760)	
Ta	930 (499)	3800 (2090)	930 (500)	Forms Hydride	5100 (2820)	
Mo	930 (499)	2700 (1482)	1300 (705)	2500-3000 (1370-1650)	4000 (2205)	CO 2600 (1426) CO_2 2200 (1205)
Ir	2100 (1149)	No Effect			4200 (2315)	
Rh Rh	2000 (1092)	Very Slight at 1800 (982)			3500 (1920)	
Nb	1100 (593)	No Effect	930 (500)	Forms Hydride		
OXIDES						
ThO_2	2600 (1428)	Good Resistance	Forms Hydrates		Volatile at 4200 (2315)	Reduced by C
MgO	4350 (2400)	3600 (1982)	Hydrates		Volatile at 3300 (1818)	Poor Resistance to CO
ZrO_2	4350 (2400)	3400-4000 (1870-2200)	4100 (2260)	Hydrides at High Temp	Volatile at 4200 (2315)	Reduced by C
BeO	4300 (2370)	Excellent Resistance	Hydrates	Not Attacked	Volatile at 3800 (2080)	Poor Resistance to CO
Al_2O_3	3500 (1927)	Good Resistance	Very Small at 2700 (1482)	3100 (1702)	3600 (1980)	Resistance to All Gases But F_2
SiO_2	3100 (1702)		Volatile at 2650 (1452)		Volatile at 2400 (1315)	
SILICIDES						
W_3Si_2	2600-3100 (1426-1702)	Probably Stable	2600-3100 (1426-1702)			Most Silicides Probably React With Carbon
WSi_2	3500 (1928)		3500 (1928)			
Mo_3Si_2		Probably Stable	Poor Resistance		Stable to Melting Point	
$MoSi_2$	2100-2600 (1149-1426)		Poor Resistance			
Mo_4Si_3C	3500 (1927)					
NbSi	Stable to Red Heat	Forms				
$NbSi_2$	1500-2000 (815-1092)	Nitrides				
$TaSi_2$	2000-2500 (1092-1370)	Unstable				
$TaSi_2$	2700 (1482)	Above 2500 (1370)				
NITRIDES						
BN	3000 (1650)		1800 (982)			React With C

Nb is niobium (chemical name for columbium)

materials, as well as those appearing as coating systems (Silicides and Nitrides), the presence of water vapor significantly degrades the temperature limit at which significant chemical reactions are observed. For a CO_2 and oxygen mixture however, the presence of oxygen would appear to dominate the oxidation process. Thus, using a hydrocarbon or hydrogen as a fuel, the predominance of water vapor could drastically shorten the apparent useful life of a metal or coated refractory metal structure, while having only a negligible effect on zirconia or alumina materials.

In addition, the presence of large quantities of water vapor prevents expansion of flow conditions to Mach numbers greater than 7 because of water condensation effects. The molecular weight of water vapor (18) can reduce the molecular weight of the test gas as well as alter the chemistry. Based on the rankings shown in Figure 6-53, it was decided that the carbon combustor system offered the best combination of factors which would permit realistic evaluation of engines and structures under duplicated flow conditions. Although the molecular weight is somewhat higher for the carbon system than for some of the other hydrocarbon systems, its high energy release in terms of energy per unit volume means that, at temperatures of about 5000°R and less, such small amounts of combustion products need be mixed with the air that the molecular weight is close to pure air.

The Cabot Corporation of Boston, Massachusetts will be contacted in Phase II to determine to what extent they can add their expertise to this concept to arrive at a viable concept, as well as provide better definitions of actual performance capability.

FIGURE 6-53 IDEAL PRODUCTS OF COMBUSTION FOR VARIOUS FUEL-OXIDIZER COMBINATIONS

		Fuel	Product Molecular Weight
1.	$.88\ N_2 + N_2O + .01\ Ar \rightarrow .78\ N_2 + .21\ O_2 + .01\ Ar$	Nitric Oxide	(28.9)
2.	$N_2H_4 + 1.82\ O_2 \rightarrow N_2 + 2\ H_2O + 0.82\ O_2$	Hydrazine	(23.6)
3.	$C_3H_8 + 6.87\ O_2 \rightarrow 3CO_2 + 4\ H_2O + 1.87\ O_2$	Propane	(26.0)
4.	$2\ NH_3 + 2.58\ O_2 \rightarrow N_2 + 3\ H_2O + 1.08\ O_2$	Ammonia	(23.0)
5.	$H_2 + .765\ O_2 \rightarrow H_2O + .265\ O_2$	Hydrogen	(20.9)
6.	$C_{3.05}H_{5.4} + 4.93\ O_2 \rightarrow 3.05\ CO_2 + 2.7\ H_2O + 1.53\ O_2$	MAPP	(31.8)
7.	$C_2H_2 + 3.290\ O_2 \rightarrow 2\ CO_2 + H_2O + .798\ O_2$	Acetylene	(34.6)
8.	$C + 1.266\ O_2 \rightarrow CO_2 + .266\ O_2$	Carbon	(41.5)

MASS COMPOSITION IN PERCENT

Fuel	O_2	CO_2	H_2O	N_2	*Rank	Maximum Temp.
N_2O	21	-	-	79	1	4800°R (2670°K)
N_2H_4	21	-	52	26	5	5800 (3210)
C_3H_8	21	34	45	-	4	5300 (2950)
NH_3	21	-	59	20	6	5300 (2950)
H_2	21	-	79	-	7	4800 (2670)
$C_{3.05}H_{5.4}$	21	42	37	-	3	5500 (3050)
C_2H_2	21	53	26	-	2	5900 (3280)
C	21	79	-	-	1	6000 (3340)

*In terms of water vapor content

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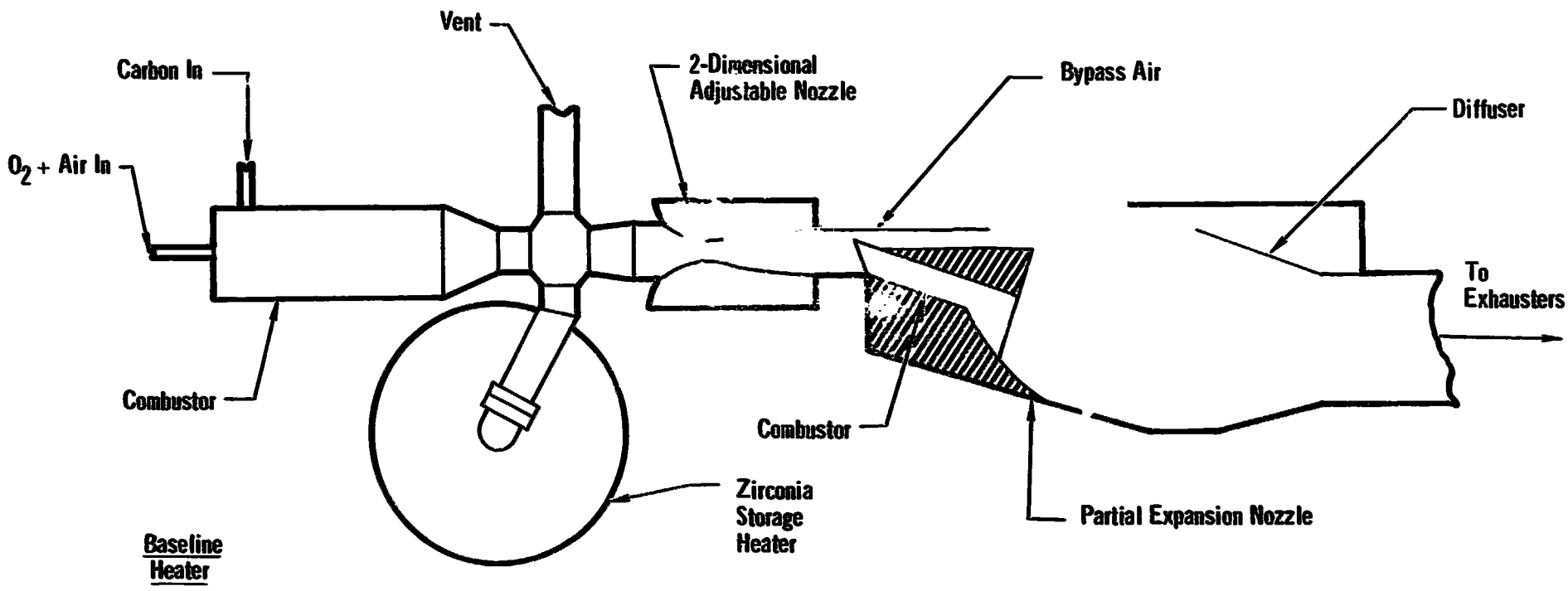
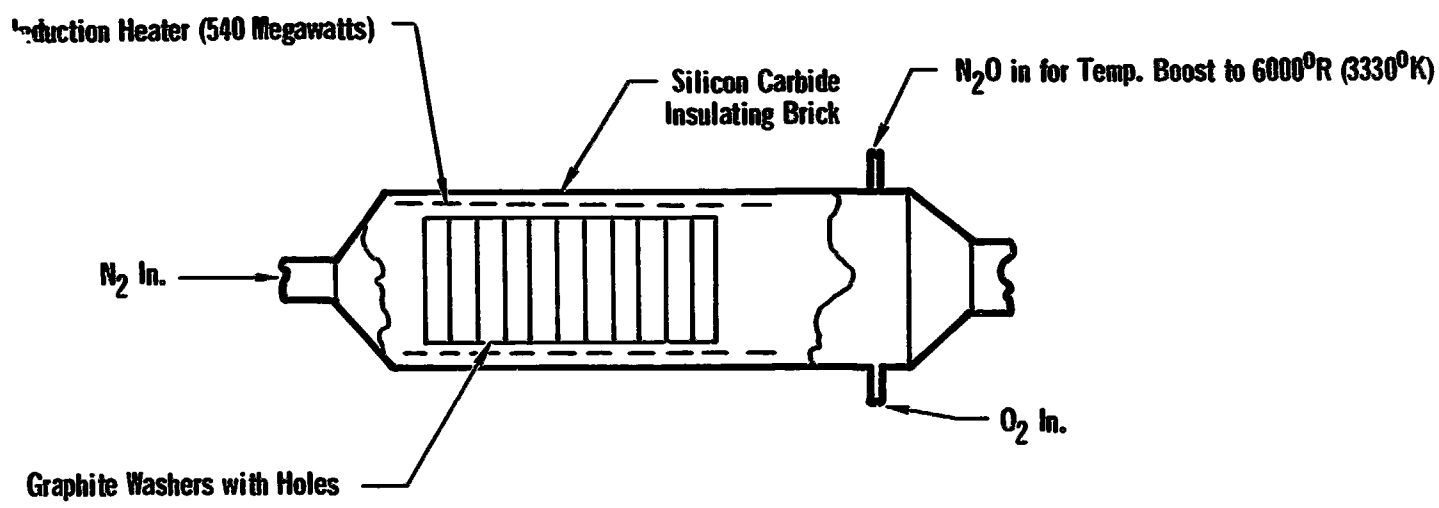
FIGURE 6-54 ENGINE FACILITY E9, SCHEMATIC DRAWING AND PERFORMANCE





Alternate Continuous Heater

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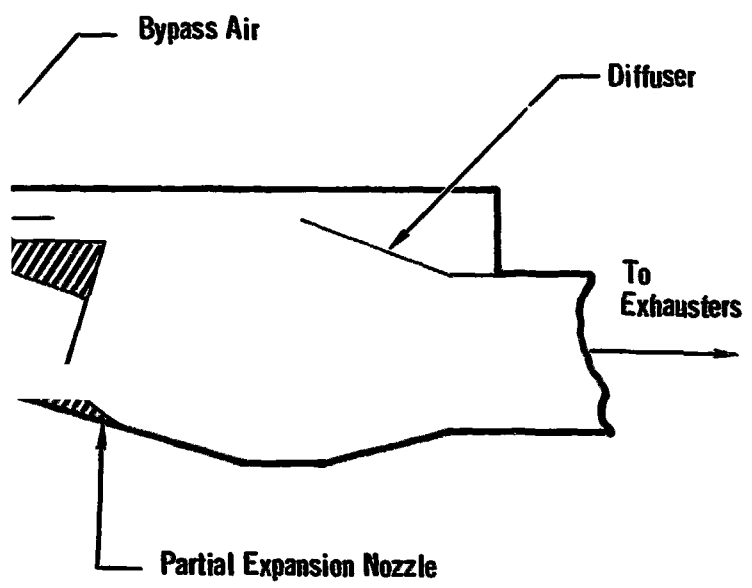
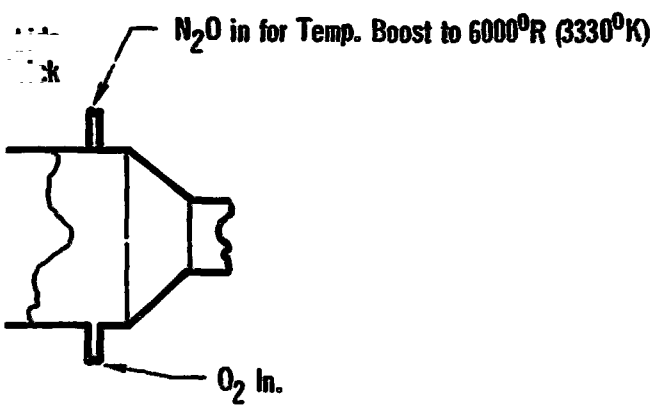
PERFORMANCE





M_∞	Stagnation Pressure (psia)	Stagnation Temperature (°R)	Engine Mass Flow (lbm/sec)
3.0	84 (58)	1090 (605)	180 (81.6)
3.5	126 (87)	1350 (750)	180 (81.6)
4.0	191 (132)	1630 (906)	180 (81.6)
4.5	247 (170)	1900 (1060)	160 (72.6)
5.0	280 (193)	2200 (1220)	140 (63.5)
5.5	318 (220)	2600 (1440)	120 (54.5)
6.0	353 (243)	3000 (1570)	125 (56.6)
6.5	518 (358)	3400 (1890)	130 (59.0)
7.0	900 (620)	3800 (2110)	162 (73.4)
7.5	1300 (896)	4200 (2330)	190 (86.2)
8.0	1915 (1320)	4650 (2580)	203 (92.0)
8.5	3110 (2140)	5100 (2830)	210 (85.2)
	(N/cm^2)	(°K)	(kg/sec)

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E10 600 MEGAWATT ARC-HEATER TEST CELL

Description:

Capable of direct-connect combustion testing of CSJ and SJ modules (10 ft^2). Air supply is heated by 6 Linde arc heaters rated at 100 MW each. Run time will be about 30 minutes. Used primarily for investigation of supersonic combustion.

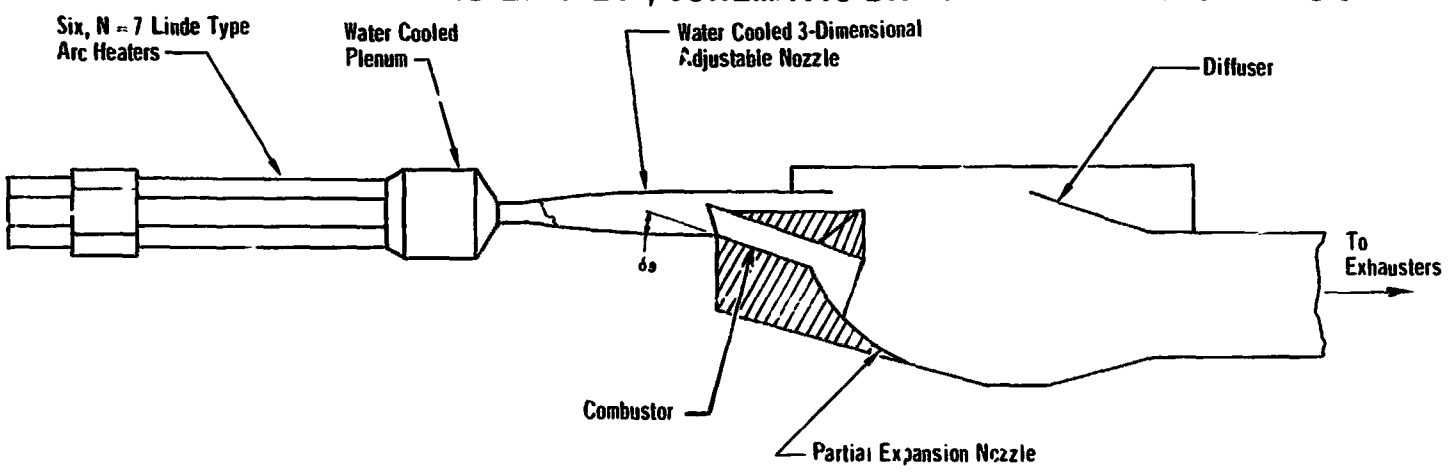
Specifications:

Test Section: .84 ft^2 (.077 m^2)
Mach Range: 7.5 to 11.5 (simulated)
Altitude Range: 80 to 160 kft (24.3 to 48.7 km)
Stagnation Pressure: 1300 to 3000 psia (897 to 2070 N/cm^2)
Stagnation Temperature: 4000 to 10,000°R (2220 to 5550°K)
Mass Flow Range: 45 to 153 lbm/sec (20.4 to 69.3 kg/sec)
Run Time: 30 min.

Features:

1. Air compression and storage system for 30 min blowdown.
2. Steam ejector plant for complete altitude duplication.
3. Six N = 7 Linde type arc heaters.
4. D.C. power supply.
5. Water cooled, 2-dimensional adjustable nozzle.
6. Test cell, with inserts for duplication of engine or vehicle contours.
7. Water cooling system.
8. Cryogenic fuel storage, distribution, and control system.

FIGURE 6-55 ENGINE FACILITY E10, SCHEMATIC DRAWING AND PERFORMANCE



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Mach Number	Stagnation Pressure (psia)	Stagnation Temperature (°R)	Engine Mass Flow (lbm/sec)
7.5	3000 (2070)	4000 (2220)	153 (69)
10.0	3000 (2070)	7200 (4000)	112 (51)
11.4	1800 (1240)	9000 (5000)	56 (25)
12.5	1300 (890)	10000 (5500)	45 (20)
	(N/cm^2)	(°K)	(kg sec)

A summary of the mass flow/Mach number performance characteristics of the proposed engine test facilities is presented in Figure 6-56.

It can be seen that a free jet requires large increases in mass flow over the direct connect technique. These two techniques are represented by facilities E6 and E7. A very attractive alternate to be examined in Phase II is the combination of these two facilities as separate test legs in an integrated facility. Each facility would share the compressor plant, exhausters, data acquisition and computing facilities, fuel storage and distribution systems. For comparison the AEDC T-1 and T-2 airbreathing test cells are shown. Although a mass flow capability of 800 lb/sec (360 kg/sec) is obtainable, the maximum pressure available is 70 psi (48 N/cm^2). E6 provides about twice this mass flow, and rather than being limited to temperature duplication up to Mach 3, E6 extends this capability to Mach 5.5. This region between 3.0 and 5.5 is very important to the development of new high performance, high supersonic Mach number engine concepts.

FIGURE 6-56 ENGINE TEST FACILITIES PERFORMANCE SUMMARY

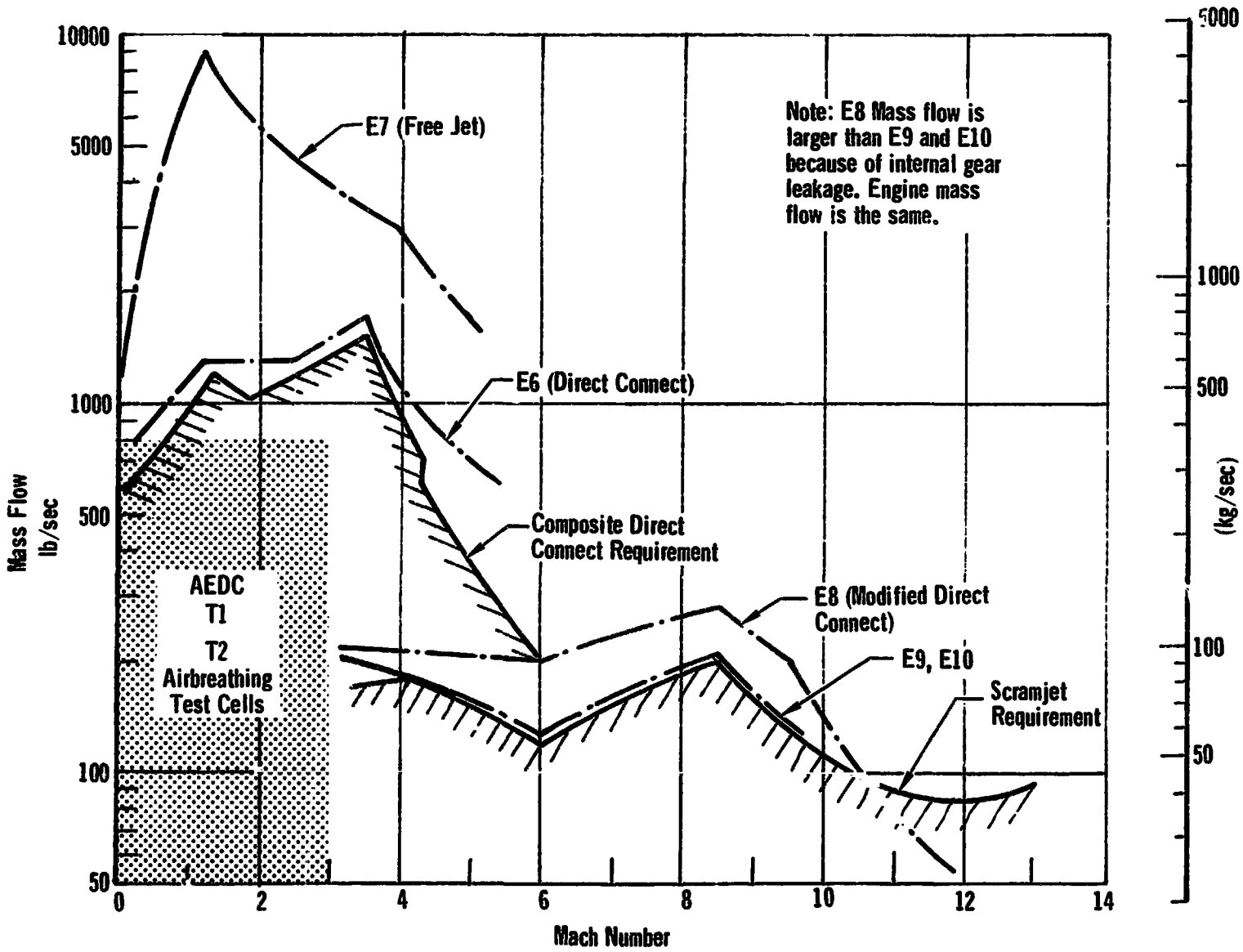
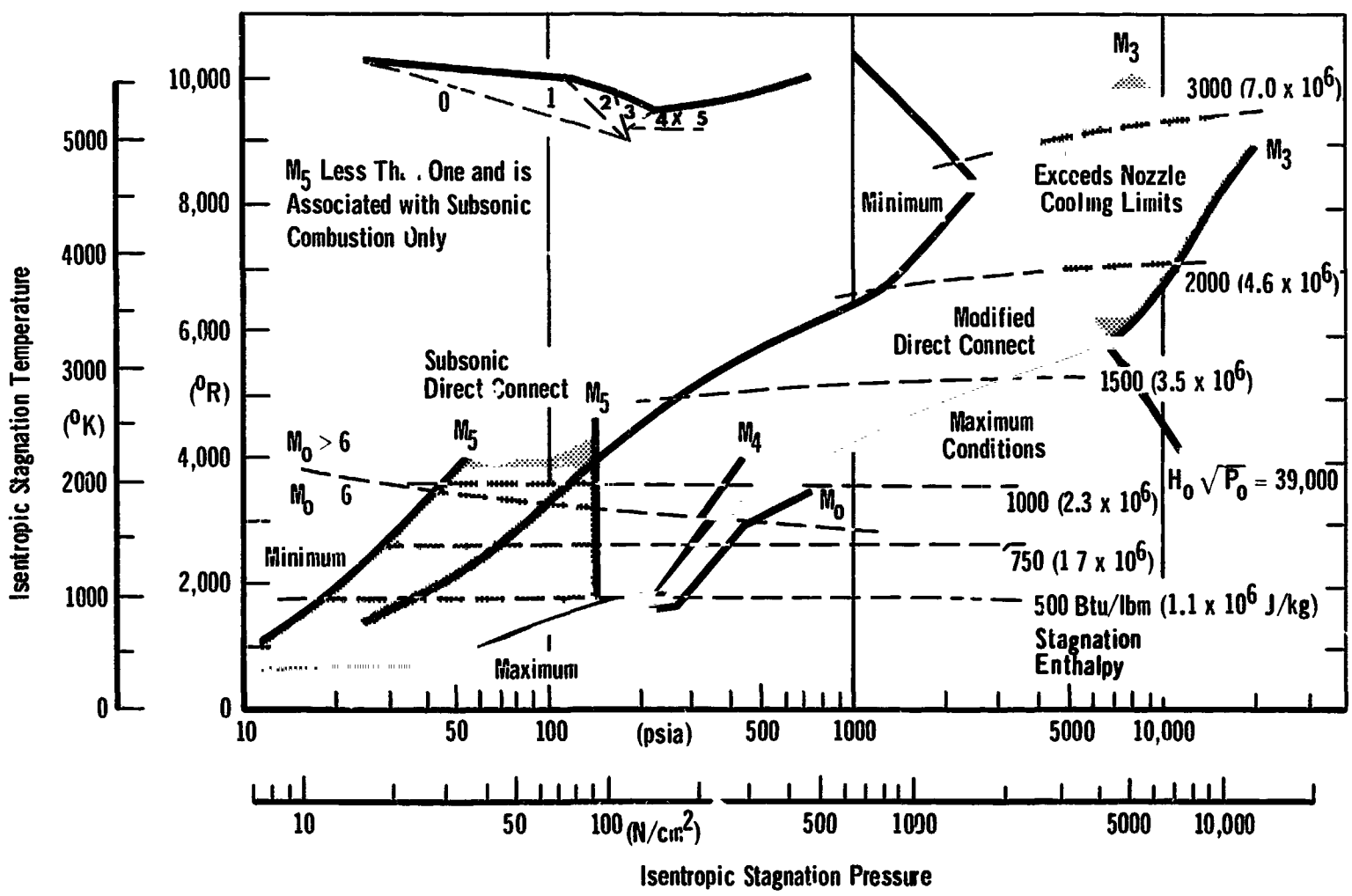


Figure 6-57 summarizes the combination of pressures and temperatures required to simulate the HYFAC flight corridor for different simulation modes.

FIGURE 6-57
SUMMARY OF RESERVOIR CONDITIONS FOR DIFFERENT DEGREES OF FLIGHT STIMULATION REQUIRED ENGINE DEVELOPMENT

Mach Number Designation is Indicative of Degree of Inlet Flow Simulation



6.5.4 ENGINE FACILITY COSTS - Estimated initial development costs and operating costs of the candidate ground test facilities are shown in tabular form in Figure 6-58. These figures give cost breakdowns as well as totals.

The ground rules and methodology used in developing these cost estimates are discussed in detail in Section 6.11.

FIGURE 6-58 COST SUMMARY, ENGINE FACILITIES

Facility Component	Dollars - Thousands					
	E20	E6	E7	E8	E9	E10
Test Cell Complex Services	84,000	24,000	60,000	20,985	24,000	60,000
Steam Ejector	120,000	57,600	120,000	14,200	10,000	7,200
Substation	12,000	12,000	12,000			12,000
N_2 and O_2 Supply	3,000		3,000		[illegible],000	3,000
Gas Turbine Prime Mover				35,000		
Total Service	135,000	69,600	135,000	49,200	13,000	22,200
Major Equipment						
Heaters	6,000	6,000	6,000	5,000	12,000	6,000
Gimballed Nozzle	3,000		3,000			
Total Major Equipment	9,000	6,000	9,000	5,000	12,000	6,000
Data Acquisition System	3,000	3,000	3,000	3,000	3,000	3,000
Instrumentation	1,250	1,250	1,250	1,250	1,250	1,250
Total Data Acquisition and Instrumentation	4,250	4,250	4,250	4,250	4,250	4,250
Grand Total	232,250	103,850	208,250	79,435	53,250	92,450
	Operating Costs					
$/Hour of Occupancy	22,700	9,930	22,000	10,000	18,200	3,800

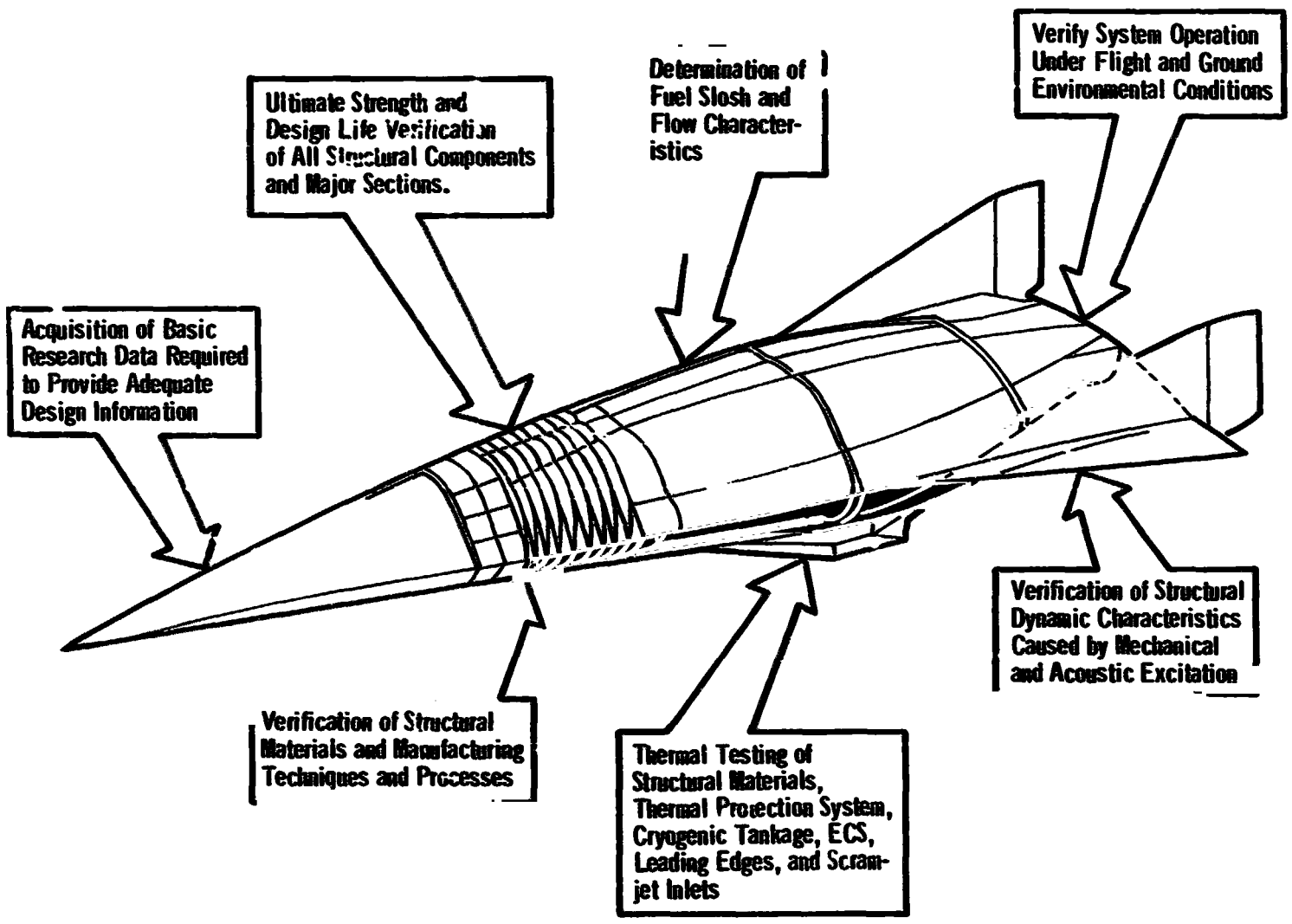
6.6 STRUCTURAL RESEARCH FACILITIES

The development of a hypersonic airframe that will repeatedly survive the hypersonic flight environment and yet remain within reasonable weight limits will require the use of advanced materials and structural concepts. Some of the structural concepts and materials will be taken from existing technology, but many will evolve from research conducted to solve specific hypersonic vehicle technology problems. In either case, the concepts will not have been proven to provide a reasonable level of confidence for an operational system. In order to gain the required confidence to commit a vehicle design to prototype production, significant structural research must be conducted. The prototype design must then be verified by repeatedly subjecting the structure to flight environmental and loading conditions in structural ground research facilities. The scope of the structural research is indicated in Figure 6-59.

6.6.1 CRITERIA - Flight thermal environments, vehicle maneuvers, aerodynamic loading, and vehicle shape are the primary factors that dictate material and structural concept selection. Significant differences exist between the structural concept required for a hypersonic vehicle and a re-entry shuttle. These structural differences will require different structural test facilities for the shuttle and hypersonic vehicle. The shuttle will fly a high angle of attack re-entry trajectory that results in high lift and drag which increases the altitude at which deceleration occurs. This in turn shortens the duration of the heat pulse on the vehicle. Since high angle of attack flight trajectc expose only the lower body and wing surfaces and leading edges to significant heating, many areas of the structure will not require extensive thermal protection. Due to the high altitude-high angle of attack trajectory, the shuttle structure will be subjected to much lower dynamic pressure and wing loadings than will be experienced by a typical hypersonic vehicle. The maximum dynamic pressure experienced by a hypersonic vehicle could exceed 2250 psf (107,700 N/m^2), where a typical shuttle trajectory will only produce a maximum dynamic load of 50 psf (2390 N/m^2). The maximum leading edge temperature for the shuttl s expected to be less than 2200°F (1215°C), where leading edge temperature for the hypersonic trajectory will exceed 3000°F.(1650°C).

Figure 6-60 indicates that a Mach 12 aircraft flying a high aerodynamic heating, high dynamic loading flight trajectory may use substantial quantities of refractory and superalloy materials in its structure. Thus it is necessary to provide test capability which will properly simulate the design environments.

FIGURE 6-59 SCOPE OF NON-FLOW GROUND TESTING



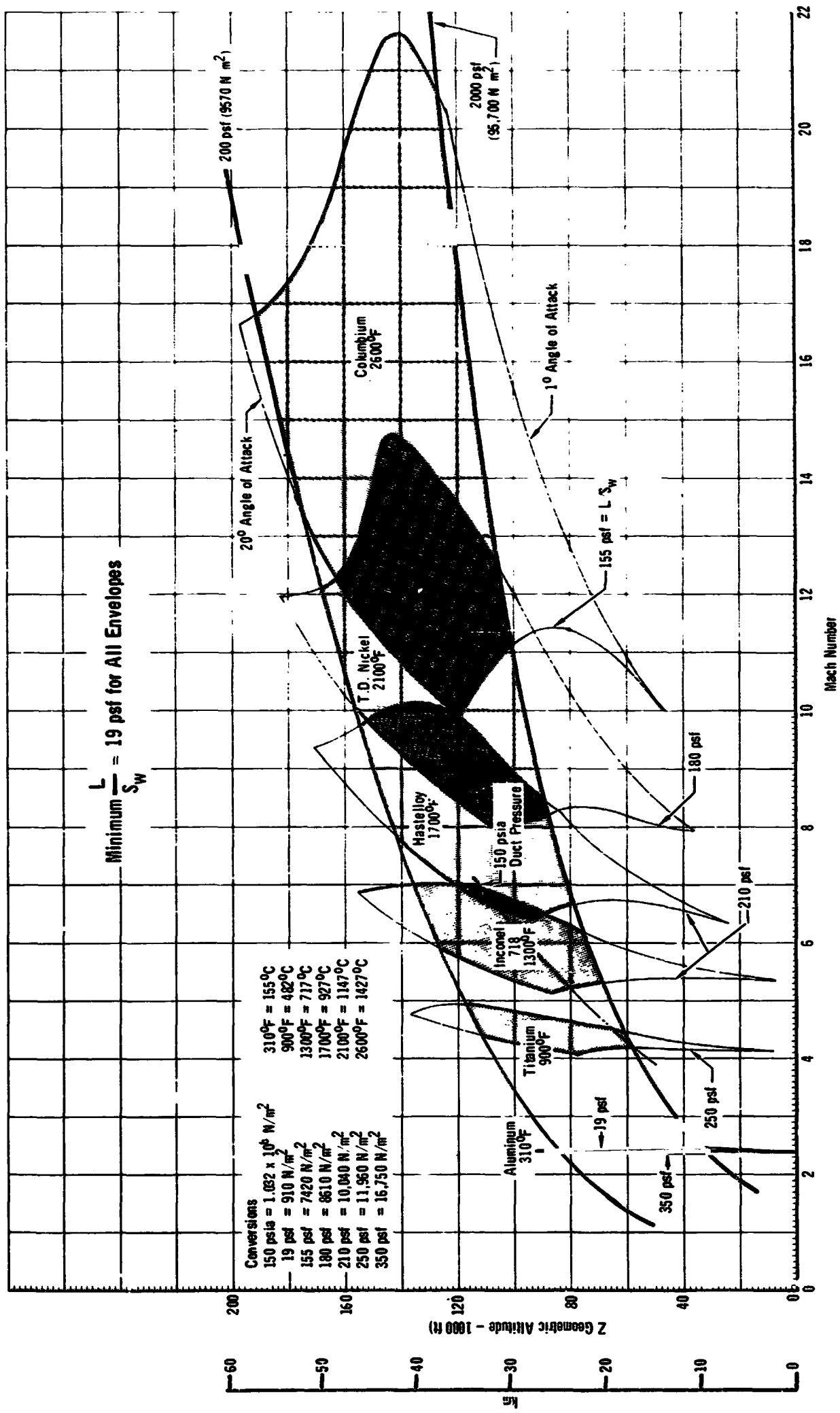


FIGURE 6-60 SUMMARY OF FLIGHT BOUNDARIES BASED ON WING LOADING, LOAD FACTOR, AND MATERIAL TEMPERATURE LIMITS

To provide the most beneficial and cost effective structural ground test facilities, critical environmental and loading conditions must be applied to represent test specimens. The cost of the facility is governed by the number of environments simulated and the size of the test articles. The proposed facilities were chosen such that they could apply flight environments to test specimens as large as full-scale operational vehicles.

The sizes of the test specimens were selected to range from the entire full-scale airframes to a small coupon test specimen. Figure 6-61 shows the representative structural elements of a typical hypersonic vehicle, while Figure 6-62 depicts the types of test articles that may be considered. Their sizes were determined by surveying several military and commercial operational hypersonic vehicles and selecting the largest dimension or most severe environmental parameter. These maximum values or critical parameters for full-scale, major section, component, and coupon-sized test articles are shown in Figure 6-63. The relative size of the different test articles are shown in Figure 6-61.

6.6.2 ANALYSIS - To fully simulate all flight and ground environmental conditions that an operational hypersonic vehicle, or any structural component or system of it, might experience, nine structural research facilities (designated S-1 through S-9) were initially proposed. The four primary environments to be simulated in the structural facilities are thermal, mechanical, altitude, and acoustic. In addition, it may be necessary to test the vehicle simultaneously under a combination of environments. Environments that will be simulated in the structural facility and the largest test article the facility can test are shown in Figure 6-64.

The values for the thermal, mechanical, and altitude environments depend primarily on the flight trajectory, angle of attack, velocity, and the maneuvers the aircraft will experience. For the synthesis of all structural ground research facilities, only the maximum value environments were considered. If the maximum can be achieved, lesser environments can also be simulated.

FIGURE 6-61 REPRESENTATIVE STRUCTURAL ELEMENT OF A HYPERSONIC AIRCRAFT

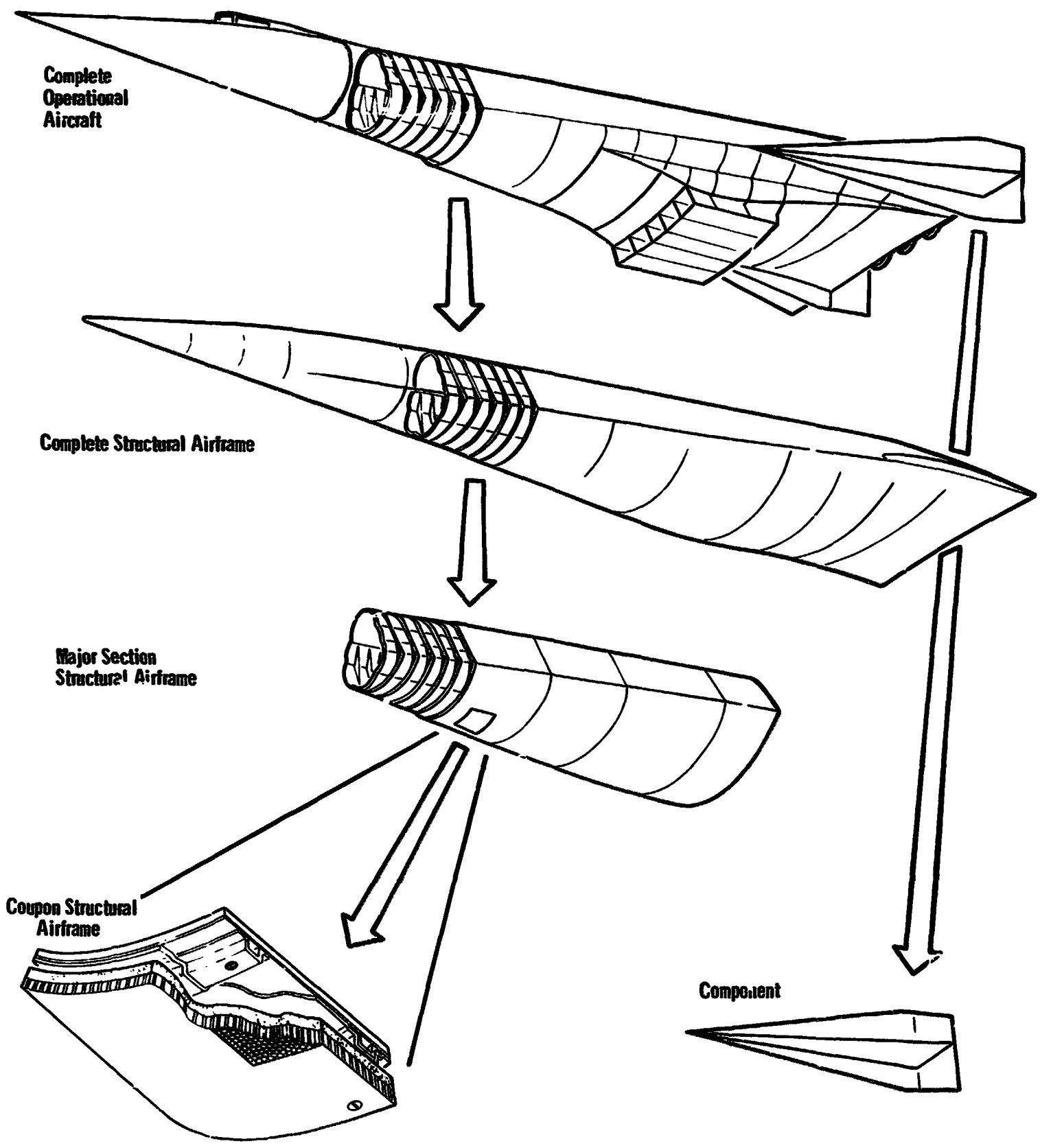


FIGURE 6-62 TEST ARTICLE SIZE

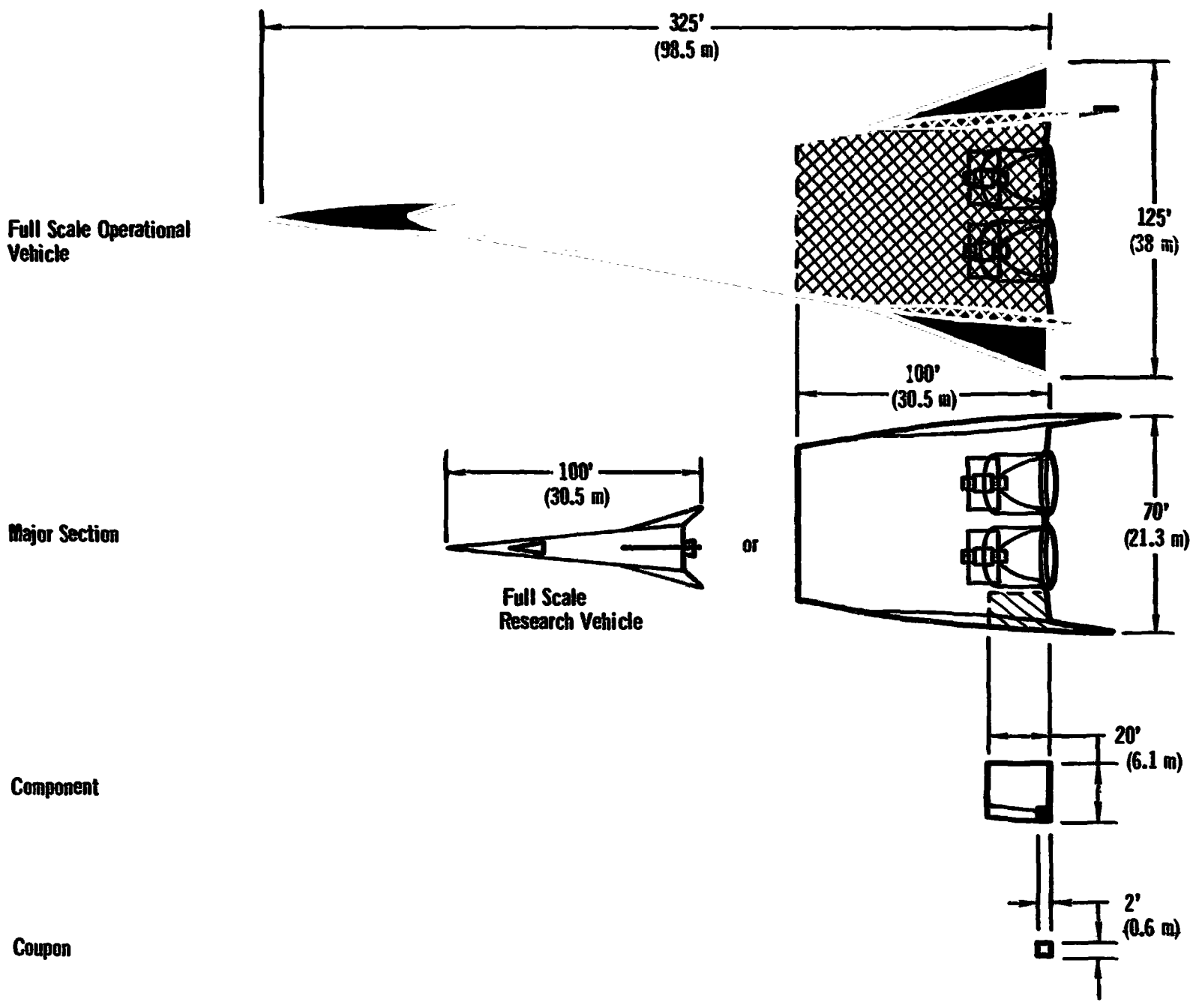


FIGURE 6-63 BASELINE TEST ARTICLE DEFINITIONS

Article Designation	Full Scale Vehicle	Major Section	Structural Component
Characteristic Length – ft (m)	326 (99)	70 (21)	20 (6.1)
Width – ft (m)	124 (38)	79 (21)	20 (6.1)
Height – ft (m)	90 (27)	30 (10)	20 (6.1)
Volume x 10^{-8} – cu ft (m^3)	150 (4.25)	100 (2.830)	7 (0.20)
Weight x 10^{-3} sq ft (m^2)	16 (1.500)	5 (0.470)	0.4 (0.037)
Wetted Area x 10^{-3} sq ft (m^2)	41 (3.80)	15 (1.4)	2.5 (0.23)
Weight x 10^{-3} lbf (N)	1025 (4600)	500 (2220)	50 (222)
Test Surface Load – psf (N/m^2)	2500 (120,000)	2500 (120,000)	2500 (120,000)
Maximum Acoustic Level – dB (N/m^2)	170 (6300)	170 (6300)	170 (6300)
Peak Upper Surface Temperature – ^0F (^0C)	1600 (870)	1600 (870)	1600 (870)
Peak Lower Surface Temperature – ^0F (^0C)	2500 (1440)	2500 (1440)	2500 (1440)
Maximum Altitude – kft (km)	150 (46)	150 (46)	150 (46)
Fuel Volume x 10^{-3} cu ft (m^3)	77 (0.220)	77 (0.220)	3 (0.085)
Fuel Flow gpm (m^3/sec)	60,000 (3.78)	60,000 (3.78)	2100 (0.113)

FIGURE 6-64 STRUCTURAL FACILITY MATRIX DEFINITION

Simulation \ Facility	S1	S2	S3	S4	S5	S6	S7	S9
Thermal Mechanical Altitude	FSV							
Thermal Mechanical	FSV	FSV MS	MS			MS		
Mechanical	FSV	FSV MS				MS	MS	
Thermal	FSV	FSV MS				MS		FSV MS
Thermal Altitude		FSV MS						FSV MS
Acoustic		FSV MS		FSV MS	C			
Thermal Acoustic	FSV MS				C			

Mechanical = Static and/or Dynamic Loads

Largest Test Article = FSV = Full Scale Vehicle
MS = Major Section
C = Component

The static mechanical loads needed to verify the structural airframe depend primarily on the dynamic pressure, wing loading, and inertial loads produced by flight maneuvers. Maximum values of dynamic pressure and wing loading were established to be 2250 psf (107,000 N/m^2) and 250 psf (11,900 N/m^2), respectively, based on the flight boundaries described in Figure 6-4. Maximum inertia loads were established by assuming a vehicle weight of 1,025,000 lb (4,600,000 N) and a maneuver load factor of 5.5 g's. Dynamic loading will require simulating both mechanical and acoustical vibration. The maximum mechanical vibration forces that must be applied to the airframe were assumed to be the weight of the aircraft (1,025,000 lb) times a maximum acceleration of 5.5 g's. Acoustic noise levels up to 170 dB resulting from flow noise and engine turbulence are expected to impinge on the airframe structure.

The thermal environment experienced by the external surface depends on Mach number, altitude, angle of attack, and location on the airframe. The most severe thermal environment occurs at the nose cap, along the leading edges, and at engine inlets. The maximum heat flux experienced by these critical areas was assumed to be 500 Btu/ft^2-sec (5.6×10^6 W/m^2) and the maximum temperature was determined to be 3500°F (1950°C). The average heat flux and temperature over the entire vehicle were assumed to be 20 Btu/ft^2-sec (2.3×10^5 W/m^2) and 2200°F (1215°C), respectively.

The altitude parameter chosen was the maximum expected altitude the operational vehicle would fly or 150,000 ft (46 km). It was also assumed that the altitude simulator facility must duplicate the rate of climb as well as the maximum altitude requirement.

In addition to the simulated environments, the size of the test article must also be considered. The size of the test article dictates the size of the test facility and the quantity of test equipment required. The most cost effective test article is the smallest sized test specimen that yields the desired test data with the required levels of confidence. In Phase I, it was assumed that the full-scale structural airframe would be required to provide adequate test data to verify the structural and thermal design. Smaller test articles may be used where the effects of thermal and structural interactions are not critical to accomplish the test.

6.6.3 FACILITY DESCRIPTION AND COSTS - The nine candidate structural research facilities (S 1 through S 9) were designed to structurally test specimens throughout the full range of environment and load experienced by an operational vehicle. These structural facilities were defined from past advanced vehicle programs, critical operational environments, and regulatory agency specifications (MIL Specifications or FAA). All possible facilities were included in the grouping selected. It was realized that some of these facilities will be more capable of performing the required testing than others, but in order to provide a comprehensive range of facilities to evaluate, these facilities were included in Phase I. The S 8 Facility (Transparency Test Facility) was eliminated from further study because all of its objectives could be accomplished in other facilities.

The building envelope, and test equipment for all the structural test facilities and their associated acquisition costs are described in Figure 6-65 a-i. The primary utility and service requirements of the structural facilities are summarized in Figure 6-66. The facility costs presented in Figure 6-65 were determined using the cost methodology described in Section 6.11.

Facility acquisition and operating costs are presented in Figures 6-67 and 6-68, respectively. Facility costs are compared in Figures 6-69 through 6-71, to show the relation of test article size and environmental simulation capability to acquisition costs. From these comparisons, it can be concluded that facility acquisition costs increase exponentially with test article size and that thermal and altitude environments are the most expensive to simulate.

S1 AIRFRAME STATIC RESEARCH FACILITY

Facility Purpose:

This facility demonstrates the ultimate strength and structural adequacy of the complete full-scale airframe when subjected to statically applied design loads. It was assumed that the entire structural airframe must be tested as a unit in order to detect and account for unknown or unpredictable structural interactions. Tests must be performed under simultaneous applications of mechanical loads and elevated temperatures since the temperature effects on material properties and thermal-structural interactions cannot be compensated for by increasing the static load due to the structure size and temperature range.

Features:

(a) Programmed load application.
(b) Computer monitored data output to present on-line structural limitations
(c) Addition at future date of atmosphere with oxygen concentration consistent with flight for high temperature coated refractory metal structures.
(d) Cryogenic and storable fuel flow.
(e) Refrigeration capability to provide low structural temperatures.

FIGURE 6-65a FACILITY DESCRIPTION AND COSTS – S1

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope 67,500 ft^2 (6260 m^2) plan			
Site Preparation			17,300
Footings and Foundations			24,132
Floors			
Structural Floor 3 ft (0.9 m)-thick steel reinforced concrete on bed rock 20 ft (6.1 m) Deep Excavation			503,500
Lateral 8WF35 beam tie-downs on 25 ft (7.6 m) ctrs. imbedded in structural floor			8,000
Shop and office area 52,000 ft^2 (4,840 m^2)			38,000
Steel Framing Material and Erection			854,500
Walls and Roofs			935,000
Access Doors			133,675
Interior Walls			96,500
Ventilation			9,000

FIGURE 6-65b FACILITY DESCRIPTION AND COSTS – S2A (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Acoustic Shroud			400,000
Interior Walls			96,500
Ventilation			6,000
Heating			50,000
Utilities (Electricity, Gas, Water)			115,000
Subtotal			4,474,988
Contingency 10%			447,000
Subtotal			4,921,988
Architectural and Engineering Fees 6%			295,000
Management and Construction Coordination Fees 4%			196,000
Total Building Envelope			5,412,988
Total Building Envelope Adjusted to 1970 $'s			5,700,000
Services			
Air Supply System 1,000,000 scfm @ 60 psig (28,300 m^3/min @ 41 N/cm^2)	13.50/scfm (480/scmm)		13,500,000
Substation 1,400,000 kVA			35,000,000
Refrigeration System			31,800,000
Water Supply 10,000 gpm @ 80°F (37.8 m^3/min @ 30°C)	20/gpm (5300/m^3/min)		200,000
30,000 gpm @ 80°F (113 m^3/min @ 30°C)	20/gpm (5300/m^3/min)		600,000
Cryogenics 748,000 gal (2,730 m^3) LH_2 Storage	10/gal (2650/m^3)		7,480,000
60,000 gpm (230 m^3/min) LH_2 Flow	70/gpm (18500/m^3/min)		4,200,000
Steam Ejector 1,000,000 scfm (5,700 m^3/min)	120/scfm (4300/scmm)		120,000,000
Total Services			212,780,000

FIGURE 6-65a FACILITY DESCRIPTION AND COSTS – S1 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Brakes		20,000	
Shears		20,000	
Sub Total Struct Fab Area			90,000
General Purpose Laboratory Equipment			1,610,000
Structural Test Fixture			1,447,000
Hydraulic Power Supply (50 Units)	15,000		750,000
Thermal Environment Control System (Ignitrons) - 100 MW 450 Channels @ 250 kW/Channel	5,000/channel		2,250,000
Heaters (Quartz Lamp Banks)	100/ft^2(1080/m^2)		4,060,000
Data Acquisition System 15,000 Channels	1,000/channel		15,000,000
Load Application Control System (500 Channels)	3,000/channel		1,500,000
Load Cylinders (750 Units)	590		444,000
Load Cells (1,000 Units)	1,000		1,000,000
Thermocouples (4,100 Units)	250		1,025,000
Strain Gages (4,100 Units)	250		1,025,000
Deflection Transducers (4,000 Units)	250		1,000,000
Pressure Transducers (100 Units)	250		25,000
Test Control Complex			3,000,000
Total Test Equipment			34,226,000
Grand Total Static Test - Full-Scale Thermal Structure			54,166,000

NOTE: Unless otherwise adjusted, all costs are in 1970 dollars.

SOURCES: (a) Richardson Engineering Service Manual of Commercial-Industrial Estimating and Engineering Standards

(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell-Douglas Corporation Engineering Budget History and Equipment Inventory

S2 DYNAMIC STRUCTURAL EVALUATION FACILITY

Facility Purpose:

This facility establishes thermal, structural dynamic, and acoustic response of the complete airframe or major airframe section thermal-structural systems. It also demonstrates vehicle design-life attainment through structural integrity throughout a life spectrum program of applied thermal, mechanical, and pressure loadings. A nearly real-time thermal program must be applied to obtain thermally induced stress levels in conjunction with applied mechanical and pressure loads. Statically applied mechanical loads, elevated temperature, cryogenic fuel flow, acoustical environment simulation, altitude, and mechanical vibration environments can be simulated on a real-time basis.

Features:

(a) Complete trajectory simulation of environment.
(b) Computer controlled, preprogrammed flight profile, failure monitoring.
(c) Includes cooldown during post cruise descent.
(d) Site compatible with occurrence of major tank rupture.
(e) Conventional and cryogenic fuel storage, distribution and control system.

FIGURE 6-65b FACILITY DESCRIPTION AND COSTS – S2A

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope 67,500 ft^2 (6,250 m^2) plan			
Site Preparation			8,500
Footings and Foundations			20,988
Floors			
Structural Floor 3 ft (0.9 m)-thick steel reinforced concrete on bed rock 20 ft (6.1 m) deep excavation			503,000
Lateral 8WF35 beam tie-downs on 25 ft (7.6 m) ctrs imbedded in structural floor			8,000
Shop and office area 52,000 ft^2 (4,820 m^2) 6 inch (15 cm) slab on grade			38,000
Steel Framing (Material and Erection)			2,154,000
Chamber - Steel in place 350 x 150 x 100 ft (108 x 46 x 30 m)		150,000	
Welding		100,000	
Door and Track		200,000	
Painting		25,000	
Insulating		600,000	
Subtotal Chamber			1,075,000

FIGURE 6-65b FACILITY DESCRIPTION AND COSTS – S2A (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Acoustic Shroud			400,000
Interior Walls			96,500
Ventilation			6,000
Heating			50,000
Utilities (Electricity, Gas, Water)			115,000
Subtotal			4,474,988
Contingency 10%			447,000
Subtotal			4,921,988
Architectural and Engineering Fees 6%			295,000
Management and Construction Coordination Fees 4%			196,000
Total Building Envelope			5,412,988
Total Building Envelope Adjusted to 1970 $'s			5,700,000
Services			
Air Supply System 1,000,000 scfm @ 60 psig (28,300 m^3/min @ 41 N/cm^2)	13.50/scfm (480/scmm)		13,500,000
Substation 1,400,000 kVA			35,000,000
Refrigeration System			31,800,000
Water Supply 10,000 gpm @ 80°F (37.8 m^3/min @ 30°C)	20/gpm (5300/m^3/min)		200,000
30,000 gpm @ 80°F (113 m^3/min @ 30°C)	20/gpm (5300/m^3/min)		600,000
Cryogenics 748,000 gal (2,730 m^3) LH_2 Storage	10/gal (2650/m^3)		7,480,000
60,000 gpm (230 m^3/min) LH_2 Flow	70/gpm (18500/m^3/min)		4,200,000
Steam Ejector 1,000,000 scfm (5,700 m^3/min)	120/scfm (4300/scmm)		120,000,000
Total Services			212,780,000

FIGURE 6-65b FACILITY DESCRIPTION AND COSTS – S2A (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Equipment			
General Purpose Laboratory Equipment			1,610,000
Structural Test Fixture			901,000
Hydraulic Power Supply (50 Units)	15,000		750,000
Thermal Environment Control System (Ignitrons) - 1,400 MV 3,000 Channels @ 500 kW/Channel	5,000/channel		15,000,000
Heaters (Quartz Lamp Banks)			
40 Btu/ft^2/sec over 16,000 ft^2 (45,400 W/m^2 over 1,490 m^2)	600/ft^2 (6450/m^2)		9,600,000
10 Btu/ft^2/sec over 20,000 ft^2 (11,340 W/m^2 over 1,860 m^2)	200/ft^2 (2150/m^2)		4,000,000
120 Btu/ft^2/sec over 4,000 ft^2 (1,360,000 W/m^2 over 370 m^2)	1,500/ft^2 (16,000/m^2)		6,000,000
Data Acquisition System - 17,000 Channels	1,000/channel		17,000,000
Load Application Control System (500 Channels)	3,000/channel		1,500,000
Load Cylinders (750 Units)	590		444,000
Load Cells (1,000 Units)	1,000		1,000,000
Acoustic Generator - 165 dB in 3,000 ft^2 (278 m^2)Plane Wave Tube (Three Hundred 30,000 Acoustic Watt Generators)	15,000		4,500,000
Mechanical Exciter System 30,000 lb (133,000 N) Shaker (100 Units)	210,000		21,000,000
Strain Gages (5,000 Units)	250		1,250,000
Thermocouples (4,000 Units)	250		1,000,000
Fatigue Gages (5,000 Units)	250		1,250,000
Accelerometers (500 Units)	500		250,000
Microphones (500 Units)	500		250,000
Pressure Transducers (100 Units)	250		25,000

FIGURE 6-65b FACILITY DESCRIPTION AND COSTS - S2A (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Deflection Transducers (500 Units)	250		125,000
Test Control Complex			3,000,000
Structural Fabrication Area			
Welders		20,000	
Cutting Equipment		30,000	
Brakes		20,000	
Shears		20,000	
Subtotal Struct Fab Area			90,000
Total Test Equipment			90,545,000
Grand Total Dynamic Structural Evaluation Facility Full-Scale			309,025,000

FIGURE 6-65c FACILITY DESCRIPTION AND COSTS -- S2B

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope 20,000 ft^2 (1,850 m^2) plan			
Site Preparation			7,000
Footings and Foundations			8,900
Floors			
Structural Floor 3 ft (0.9 m)-thick steel reinforced concrete on bed rock 20 ft (6.1 m) deep excavation			126,000
Lateral 8WF35 beam tie-downs on 25 ft (7.6 m) ctrs. imbedded in structural floor			2,000
Shop and office area 6 inch (15 cm) slab on grade			13,000
Steel Framing (Materials and Erection)			540,000
Chamber - 12-Gage Steel in place		37,500	
Welding		25,000	
Door and Track		50,000	
Painting		6,250	
Insulating		150,000	
Subtotal Chamber			268,750

FIGURE 6-65c FACILITY DESCRIPTION AND COSTS – S2B (CONTINUED)

TEST	UNIT COST	EXTENDED COST	TOTAL COST
Acoustic Shroud			100,000
Interior Walls			25,000
Ventilation			1,500
Heating			12,500
Utilities (Electricity, Gas, Water)			28,900
Subtotal			1,123,550
Contingency 10%			112,000
Subtotal			1,235,550
Architectural and Engineering Fees 6%			74,800
Management and Construction Coordination Fees 4%			49,800
Total Building Envelope			1,360,150
Total Building Envelope Adjusted to 1970 $'s			1,450,000
Services			
Air Supply System 700,000 scfm @ 60 psig (19,800 m^3/min @ 41.4 N/cm^2)	13.50/scfm (480/scmm)		9,450,000
Substation 325,000 kVA			8,750,000
Refrigeration System			7,400,000
Water Supply 10,000 gpm @ 80°F (37.8 m^3/min @ 30°C)	20/gpm (5300/m^3/min)		200,000
6,000 gpm @ 80°F (23 m^3/min @ 30°C)	20/gpm (5300/m^3/min)		120,000
Cryogenics 748,000 gal (2,730 m^3) LH_2 Storage	10/gal (2640/m^3)		7,480,000
60,000 gpm (230 m^3/min) LH_2 Flow	70 gpm (18500/m^3/min)		4,200,000
Steam Ejector 200,000 scfm (5,700 m^3/min)	120/scfm (4250/scmm)		24,000,000
Total Services			61,600,000

FIGURE 6-65c FACILITY DESCRIPTION AND COSTS – S2B (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Equipment			
General Purpose Laboratory Equipment			400,000
Structural Test Fixture			91,161
Hydraulic Power Supply (30 Units)	15,000		450,000
Thermal Environment Control System (Ignitrons) - 520 MW 1,100 Channels @ 500 kW/Channel	5,000/channel		5,500,000
Heaters (Quartz Lamp Banks) 40 Btu/ft^2/sec over 5,000 ft^2 (454,000 W/m^2 over 470 m^2)	600/ft^2 (6450/m^2)		3,000,000
10 Btu/ft^2/sec over 10,000 ft^2 (113,400 W/m^2 over 929 m^2)	200/ft^2 (2150/m^2)		2,000,000
Data Acquisition System - 7,800 Channels	1,000/channel		7,800,000
Load Application Control System (200 Channels)	3,000/channel		600,000
Load Cylinders (300 Units)	590		177,000
Load Cells (400 Units)	1,000		400,000
Acoustic Generator - 165 dB in 2,000 ft^2 (1,850 m^2) Plane Wave Tube (Two Hundred 30,000 Acoustic Watt Generators)	15,000		3,000,000
Mechanical Exciter System 30,000 lb (133,000 N) Shaker (60 Units)	210,000		12,600,000
Strain Gages (1,700 Units)	250		425,000
Thermocouples (1,500 Units)	250		375,000
Fatigue Gages (3,000 Units)	250		750,000
Accelerometers (150 Units)	500		75,000
Microphones (150 Units)	500		75,000
Pressure Transducers (100 Units)	250		25,000
Deflection Transducers (150 Units)	250		37,500
Test Control Complex			750,000

FIGURE 6-65c FACILITY DESCRIPTION AND COSTS – S2B (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Structural Fabrication Area			
Welders		20,000	
Cutting Equipment		30,000	
Brakes		20,000	
Shears		20,000	
Subtotal Struct Area			90,000
Total Test Equipment			38,620,661
Grand Total Dynamic Structural Evaluation Facility Component			101,670,661

NOTE: Unless otherwise adjusted, all costs are in 1970 dollars.

SOURCE: (a) Richardson Engineering Service Manual of Commercial-Industrial Estimating and Engineering Standards

(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell-Douglas Corporation Engineering Budget History and Equipment Inventory

S3 THERMAL/MECHANICAL FATIGUE FACILITY

Facility Purpose:

This facility establishes the thermal-structural design-life adequacy of structural components by applying cyclic mechanical loads in conjunction with thermal cycling to induce thermal stresses superimposed upon mechanically generated stresses for nearest approximation of the component flight environments.

Features:

(a) Computer programmed load spectrums, thermal and mechanical.
(b) Addition of environmental chamber in growth version to ensure correct oxygen concentration at altitude for coated retractors, metals, and composites at high temperatures.
(c) Storable and cryogenic fuels.
(d) Cooldown capability to duplicate rapid cooling during post cruise descent.

FIGURE 6-65d FACILITY DESCRIPTION AND COSTS – S3

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope 20,000 ft^2 (1,850 m^2) plan			
Site Preparation			7,000
Footings and Foundations			8,900
Floors			
Structural Floor 3 ft (0.9 m)-thick steel reinforced concrete on bed rock 20 ft (6.3 m) deep excavation			126,000
Lateral 8WF beam tie-downs on 25 ft (7.3 m) ctrs. imbedded in structural floor			2,000
Shop and office area 6 inch (15 cm)-slab floor			13,000
Steel Framing (Material and Erection)			111,680
Walls and Roofs (Material and Erection)			201,600
Interior Walls			3,000
Comfort Conditioning			10,000
Ventilation			2,400
Heating			24,000
Utilities (Electricity, Gas, Water)			62,000
Subtotal			571,580

FIGURE 6-65d FACILITY DESCRIPTION AND COSTS – S3 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Contingency 10%			57,000
Subtotal			628,580
Architectural and Engineering Fees 6%			37,600
Management and Construction Coordination Fees 4%			25,100
Total Building Envelope			691,280
Total Building Envelope Adjusted to 1970 $'s			732,000
Services			
Air Supply System 3,000 scfm @ 120 psig (85 m^3/min @ 82.6 N/cm^2)	13.50/scfm (480/scmm)		40,500
Substation 50,000 kVA			800,000
Refrigeration System			1,140,000
Water Supply 2,000 gpm @ 80°F (2,400 m^3/min @ 30°C)	20/gpm (5300/m^3/min)		40,000
Cryogenics 600,000 gal (2,270 m^3) LH_2 Storage	10/gal (2640/m^3)		6,000,000
10,000 gpm (37.8 m^3/min) LH_2 Flow	70/gpm (18500/m^3/min)		700,000
Total Services			8,580,500
Equipment			
General Purpose Laboratory Equipment			400,000
Structural Test Fixture			108,525
Hydraulic Power Supply (4 Units)	15,000		60,000
Thermal Environment Control System (Ignitrons)			
75 Channels @ 500 kVA	5,000/channel		375,000
100 Channels @ 250 kVA	5,000/channel		500,000

FIGURE 6-65d FACILITY DESCRIPTION AND COSTS – S3 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Heaters			
350 Btu/ft^2/sec over 100 ft^2 (4,000,000 W/m^2 over 10 m^2)	1,500/ft^2 (16,000/m^2)		150,000
70 Btu/ft^2/sec over 100 ft^2 (795,000 W/m^2 over 10 m^2)	950/ft^2 (10,200/m^2)		95,000
8 Btu/ft^2/sec over 1,000 ft^2 (9,000 W/m^2 over 100 m^2)	175/ft^2 (1880/m^2)		175,000
Data Acquisition System - 4,000 Channels	1,000/channel		4,000,000
Load Application Control System (30 Channels)	3,000/channel		90,000
Load Cylinders (40 Units)	590		23,500
Load Cells (80 Units)	1,000		80,000
Thermocouples (1,000 Units)	250		250,000
Strain Gages (1,000 Units)	250		250,000
Fatigue Gages (1,500 Units)	250		375,000
Deflection Transducers (300 Units)	250		75,000
Pressure Transducers (50 Units)	250		12,500
Test Control Complex			750,000
Structural Fabrication Area			
Welders		20,000	
Cutting Equipment		30,000	
Brakes		20,000	
Shears		20,000	
Subtotal Struct Fab Area			90,000
Total Test Equipment			7,859,525
Grand Total Thermal/Mechanical Fatigue Test Facility (S3)			17,312,025

FIGURE 6–65d FACILITY DESCRIPTION AND COSTS – S3 (CONTINUED)

NOTE: Unless otherwise adjusted, all costs are in 1970 dollars.

SOURCE: (a) Richardson Engineering Service Manual of Commercial-Industrial Engineering Standards

(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell Douglas Corporation Engineering Budget History and Equipment Inventory

S4 AIRFRAME ACOUSTIC TEST FACILITY

Facility Purpose:

This facility establishes the response and endurance of the entire full-scale airframe in the high level acoustic environments associated with hypersonic flight. It will also provide overall evaluation of acoustic transmission of personnel enclosure and establish ambient personnel acoustic environments.

FIGURE 6-65e FACILITY DESCRIPTION AND COSTS – S4

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope 26,000 ft^2 (2,410 m^2) plan			
Site Preparation			8,500
Footings and Foundations			15,625
Floors			
Concrete slab 6 inch (15 cm) thick for office and test area			50,000
Acoustic Shroud			880,000
Steel Framing (Material and Erection)			455,100
Walls and Roofs			528,000
Interior Walls			3,000
Comfort Conditioning			5,000
Ventilation			6,000
Heating			50,000
Utilities (Electricity, Gas, Water)			129,000
Subtotal			2,130,225
Contingency 10%			213,000
Subtotal			2,343,225
Architectural and Engineering Fees 6%			141,000
Management and Construction Coordination Fees 4%			94,000
Total Building Envelope			2,578,225
Total Building Envelope Adjusted to 1970 $'s			2,700,000
Services			
Air Supply System 1,000,000 scfm @ 100 psig (28,300 m^3/min @ 68.9 N/cm^2)	13.50/scfm		13,500,000
(To supply Acoustic Generators)	(480/scmm)		
Substation 2,000 kVA			30,000
Total Services			13,830,000

FIGURE 6-65e FACILITY DESCRIPTIONS AND COSTS – S4 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Equipment			
General Purpose Laboratory Equipment			400,000
Structural Test Fixture			901,000
Data Acquisition System - 9,500 Channels	1,000/channel		9,500,000
Acoustic Generator 165 dB in 3,000 ft^2 (279 m^2) Plane Wave Tube (Three Hundred 30,000 Acoustic Watt Generators)	15,000		4,500,000
Data Analyzers (5 Units)	50,000		250,000
Strain Gages (4,000 Units)	250		1,000,000
Fatigue Gages (5,000 Units)	250		1,250,000
Microphones (500 Units)	500		250,000
Structural Fabrication Area			
Welders		20,000	
Cutting Equipment		30,000	
Brakes		20,000	
Shears		20,000	
Subtotal Struct Fab Area			90,000
Total Test Equipment			18,141,000
Total Airframe Acoustic Test Facility (S4)			34,371,000

NOTE: Unless otherwise adjusted, all costs are in 1970 dollars.

SOURCES: (a) Richardson Engineering Service Manual of Commercial-Industrial Engineering Standards

(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell-Douglas Corporation Engineering Budget History and Equipment Inventory

S5 AIRFRAME COMPONENT THERMAL/ACOUSTIC TEST FACILITY

Facility Purpose:

In this facility, structural components in the combined thermal-acoustic environments of hypersonic flight are evaluated. The temperature effects upon material response to high level acoustic loading must be established to ensure structural adequacy for flight application. This facility is especially suited to test composite materials, and brazed components such as may be found in the region of engine inlet and exhaust nozzles and the accompanying thermal/acoustic environment.

Features:

(a) Computer programmed acoustic/thermal inputs.
(b) Heater environment compatible with surrounding sound pressure level.
(c) Atmospheric environmental control (oxygen concentration).
(d) Refrigeration capability to provide low structural temperatures.

FIGURE 6-65f FACILITY DESCRIPTION AND COSTS – S5

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope 16,000 ft^2 (1,485 m^2) plan			
Site Preparation			6,000
Footings and Foundations			7,200
Floors			
Structural floor 3 ft (0.9 m)-thick steel reinforced concrete on bed rock 20 ft (6.3 m) deep excavation			126,000
Lateral 8WF beam tie-downs on 25 ft (7.3 m) ctrs. imbedded in structural floor			8,000
Shop and office area 6 inch (15 cm) slab floor			13,000
Acoustic Shroud			65,000
Steel Framing (Material and Erection)			87,000
Walls and Roofs (Material and Erection)			190,000
Interior Walls			3,000
Comfort Conditioning			5,000
Ventilation			1,200
Heating			12,000
Utilities (Electricity, Gas, Water)			31,000
Subtotal			554,400
Contingency 10%			55,000
Subtotal			609,400

FIGURE 6-65f FACILITY DESCRIPTIONS AND COSTS – S5 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Architectural and Engineering Fees 6%			36,600
Management and Construction Coordination Fees 4%			24,400
Total Building Envelope			670,400
Total Building Envelope Adjusted to 1970 $'s			710,000
Services			
Air Supply System 30,000 scfm @ 100 psig (850 m^3/min @ 68.9 N/cm^2)	13.50/scfm (480/scmm)		405,000
Substation 100,000 kVA			1,600,000
Refrigeration System			2,280,000
Water Supply 4000 gpm @ 80°F (15 m^3/min @ 30°C)	20/gpm (5300/m^3/min)		80,000
Total Services			4,365,000
Equipment			
General Purpose Laboratory Equipment			400,000
Structural Test Fixture			180,875
Thermal Environment Control System (Ignitrons)			
30 Channels @ 500 kW/Channel	5,000/channel		150,000
300 Channels @ 250 kW/Channel	5,000/channel		1,500,000
Heaters			
150 Btu/ft^2/sec over 100 ft^2 (1,700,000 W/m^2 over 9.3 m^2)	1500/ft^2 (16,000/m^2)		150,000
70 Btu/ft^2/sec over 1,000 ft^2 (795000 W/m^2 over 93 m^2)	950/ft^2 (10,200/m^2)		950,000
Acoustic 170 dB (Ten 30,000 Watt Acoustic Generators)	15,000		150,000
Data Acquisition System - 2,100 Channels	1,000/channel		2,100,000
Data Analyzers (2 Units)	50,000		100,000
Strain Gages (250 Units)	250		62,500

FIGURE 6-65f FACILITY DESCRIPTION AND COSTS – S5 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Thermocouples (1,000 Units)	250		250,000
Fatigue Gages (500 Units)	250		125,000
Microphones (50 Units)	500		25,000
Load Cells (30 Units)	1,000		30,000
Structural Fabrication Area			
Welders			20,000
Cutting Equipment			30,000
Brakes			20,000
Shears			20,000
Total Test Equipment			6,263,375
Total Thermal/Acoustic Component Test Facility (S5)			11,338,375

NOTE: Unless otherwise adjusted, all costs are in 1970 dollars.

SOURCES: (a) Richardson Engineering Service Manual of Commercial-Industrial Engineering Standards

(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell-Douglas Corporation Engineering Budget History and Equipment Inventory

S6 THERMAL-STRUCTURAL DYNAMIC TANKAGE TEST FACILITY

Facility Purpose:

Tankage systems for standard and cryogenic fuels are developed in this facility. This development requires evaluating the effects of vehicle dynamics upon the fuel tankage regarding fuel slosh, thermal load, pressure, fuel delivery, and tankage structural adequacy; as a result of the extreme thermal range, large capacity, and flight plans associated with the research vehicles.

Features:

(a) Site location consistent with possibility of tank rupture, and minimum damage incurred
(b) Cryogenic and storable fuels
(c) Refrigeration capability to simulate exterior structural cooldown

FIGURE 6-65g FACILITY DESCRIPTION AND COSTS – S6

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope 35,000 ft^2 (3,250 m^2) plan			
Site Preparation			12,000
Footings and Foundations			15,700
Floors			
Structural floor 3 ft (0.9 m)-thick steel reinforced concrete on bed rock 20 ft (6.1 m) deep excavation			250,000
Lateral 8WF35 beam tie-downs on 25 ft (7.3 m) ctrs imbedded in structural floor			8,000
Shop and office area 6 inch (15 cm) slab on grade			38,000
Steel Framing			297,000
Walls and Roofs			449,000
Comfort Conditioning			15,000
Ventilation			4,500
Heating			50,000
Utilities (Electricity, Gas, Water)			100,000
Subtotal			1,239,200
Contingency 10%			123,900
Subtotal			1,362,100

FIGURE 6-65g FACILITY DESCRIPTION AND COSTS – S6 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Architectural and Engineering Fees 6%			81,600
Management and Construction Coordination Fee 4%			54,400
Total Building Envelope			1,499,100
Total Building Envelope Adjusted to 1970 $'s			1,590,000
Services			
Air Supply System 30,000 scfm @ 150 psig (850 m^3/min @ 103 N/cm^2)	13.50/scfm (480/scmm)		405,000
Substation 1,600 kVA			33,600
Refrigeration System			3,650
Water Supply 7,000 gpm @ 80°F (26.8 m^3/min @ 30°C)	20/gpm (5300/m^3/min)		140,000
Cryogenics 1,130,000 gal (4,310 m^3) LH_2 Slush Storage	6/gal (1590/m^3)		6,800,000
70,000 gpm (264 m^3/min) LH_2 Slush Flow	61/gpm (16,000/m^3/min)		4,270,000
Standard Fuel 225,000 gal (852 m^3) JP-4 Storage	4/gal (1060/m^3)		900,000
15,000 gpm (57 m^3/min) JP-4 Flow	9/gpm (2380/m^3/min)		135,000
Foam Quench System			211,000
Total Services			12,864,650
Equipment			
General Purpose Laboratory Equipment			400,000
Structural Test Fixture			455,305
Data Acquisition System - 4000 Channels	1,000/channel		9,000,000
Hydraulic Power Supply (30 Units)	15,000		450,000

FIGURE 6-65g FACILITY DESCRIPTION AND COSTS – S6 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Thermal Control System 650 Channels @ 250 kVA/Channel	5,000/channel		3,350,000
Heaters 25 Btu/ft^2/sec over 6,000 ft^2 (284,000 W/m^2 over 555 m^2)	400/ft^2 (4300/m^2)		2,400,000
Mechanical Exciter System - Eccentric on top of rolling platform - 500 kip (2,220,000 N) capacity	60,000		60,000
Load Cylinders (300 Units)	590		177,000
Load Cells (400 Units)	1,000		400,000
Pressure Transducers (100 Units)	250		25,000
Flow Transducers (100 Units)	250		25,000
Thermocouples (3,000 Units)	250		750,000
Strain Gages (3,000 Units	250		750,000
Deflection Transducers (1,000 Units)	250		250,000
Structural Fabrication Area			
Welders			20,000
Cutting Equipment			30,000
Brakes			20,000
Shears			20,000
Load Application Control System - 200 Channels	3,000/channel		600,000
Total Equipment			19,182,805
Grand Total Tankage Test Facility (S6)			33,637,455

NOTE: Unless otherwise adjusted, all costs are in 1970 dollars.

SOURCES: (a) Richardson Engineering Service Manual of Commercial-Industrial Engineering Standards

(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell-Douglas Corporation Engineering Budget History and Equipment Inventory

S7 CABIN PRESSURIZATION TEST FACILITY

Facility Purpose:

This facility establishes the repeated pressurization fatigue life of the cabin enclosure structure. The effects of structural damage and repairs upon fatigue life of the pressurized enclosure can also be evaluated. The facility will also be used to substantiate cabin design burst pressure.

FIGURE 6-65h FACILITY DESCRIPTION AND COSTS – S7

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope 350 x 40 x 40 ft (107 x 12 x 12 m)			
Site Preparation			45,000
Footings and Foundations			
Floors - 14,000 ft^2 (1,300 m^2) 2 ft (0.6 m) thick			150,000
Steel Framing			
Walls 31,200 ft^2 (2,890 m^2) 12 inches (30 cm) thick			60,000
Control Complex			200,000
Ventilation			
Heating			
Utilities (Electricity, Gas Water)			
Subtotal			455,000
Contingency 10%			45,500
Subtotal			500,500
Architectural and Engineering Fees 6%			30,000
Management and Construction Coordination Fees 4%			20,000
Total Building Envelope			550,500
Total Building Envelope Adjusted to 1970 $'s			580,000
Services			
Air Supply System 3,000 scfm @ 150 psig (85 m^3/min @ 103 N/cm^2)	13.50/scfm (480/scmm)		40,500

FIGURE 6-65h FACILITY DESCRIPTION AND COSTS – S7 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Water Supply 2,000 gpm @ 15 psi (7.6 m^3/min @ 10.3 N/cm^2)	20/gpm (5300/m^3/min)		40,000
Total Services			80,500
Equipment			
General Purpose Laboratory Equipment			400,000
Data Acquisition System - 3,500 Channels	1,000/channel		3,500,000
Pressure Transducers (30 Units)	250		7,500
Strain Gages (1,000 Units)	250		250,000
Fatigue Gages (2,000 Units)	250		500,000
Total Test Equipment			4,651,500
Total Cabin Pressurization Test Facility (S7)			5,335,500

NOTE: Unless otherwise adjusted, all costs are in 1970 dollars.

SOURCES:
(a) Richardson Engineering Service Manual of Commercial-Industrial Engineering Standards

(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell-Douglas Corporation Engineering Budget History and Equipment Inventory

S9 CRUISE-DESCENT THERMAL/VACUUM TEST FACILITY

Facility Purpose:

This facility provides full-scale, real-time evaluation of environmental control systems and equipment in the combined simulated flight thermal-altitude environment. It also provides crew training in operating these systems in the most realistic approximation of flight environment.

FIGURE 6-65i FACILITY DESCRIPTION AND COSTS – S9

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope 67,500 ft^2 (6,260 m^2) plan			
Site Preparation			8,500
Footings and Foundations			20,998
Floors			
Structural Floor 3 ft (0.9 m) thick reinforced concrete on bed rock 20 ft (6.1 m) deep excavation			503,000
Lateral 8WF35 beam tie-downs imbedded in structural floor			8,000
Shop and office area 52,000 ft^2 (4,840 m^2) 6 inch (15 cm) slab on grade			38,000
Steel Framing (Materials and Erection)			2,154,000
Interior Walls (Materials and Erection)			400,000
Chamber - 12 Gage Steel in place		150,000	
Welding		100,000	
Door and Track		200,000	
Painting (2 coat brush)		25,000	
Insulating		600,000	
Subtotal Chamber			1,075,000
Chamber Man-Rating			500,000
Ventilation			6,000
Heating			50,000
Utilities (Electricity, Gas, Water)			115,000
Subtotal			4,878,498
Contingency 10%			487,800
Subtotal			5,366,298

FIGURE 6-65i FACILITY DESCRIPTION AND COSTS – S9 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Architectural and Engineering Fees 6%			321,000
Management and Construction Coordination Fees 4%			214,000
Total Building Envelope			5,901,298
Total Building Envelope Adjusted to 1970 $'s			6,225,000
Services			
Air Supply System 1,000,000 scfm @ 150 psig (28,300 m^3/min @ 103 N/cm^2) (Used for Acoustic Generators)	13.50/scfm (480/scmm)		13,500,000
Substation 1,400,000 kVA			35,000,000
Refrigeration System			31,800,000
Water Supply 30,000 gpm @ 80°F (113 m^3/min @ 30°C)	20/gpm (5300/m^3/min)		600,000
Steam Ejector 1,000,000 scfm (28,300 m^3/min) (Used for Altitude Chamber Pump-Down)	120/scfm (4250/scmm)		120,000,000
Total Services			200,900,000
Equipment			
General Purpose Laboratory Equipment			400,000
Data Acquisition System 10,000 Channels	1,000/channel		10,000,000
Thermal Control System - 3,000 Channels at 500 kW/Channel	5,000/channel		15,000,000
Heaters			
40 Btu/ft^2/sec over 16,000 ft^2 (454,000 W/m^2 over 1,490 m^2)	600/ft^2 (6460/m^2)		9,600,000
120 Btu/ft^2/sec over 4,000 ft^2 (1,360,000 W/m^2 over 370 m^2)	1,500/ft^2 (16,100/m^2)		6,000,000
10 Btu/ft^2/sec over 20,000 ft^2 (113,400 W/m^2 over 1,938 m^2)	200/ft^2 (2150/m^2)		4,000,000

FIGURE 6-65i FACILITY DESCRIPTION AND COSTS – S9 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Transducers (10,000 Units)	250		2,500,000
Total Equipment			47,500,000
Grand Total Cruise - Descent Facility (S9)			254,625,000

NOTE: Unless otherwise adjusted, all costs are in 1970 dollars.

SOURCES:
(a) Richardson Engineering Service Manual of Commercial-Industrial Engineering Standards

(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell Douglas Corporation Engineering Budget History and Equipment Inventory

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FIGURE 6–66 HYFAC NONFLOW STRUCTURAL TEST FACILITY AREA, MAJOR EQUIPMENT, AND UTILITY REQUIREMENTS SUMMARY (ENGLISH UNITS)

Facility	Code	Area Requirements (Gross Sq. Ft.)	Major Equipment Requirements
Static Test – Full Scale Thermal Structure	S1	350 ft x 150 ft Structural Floor 150 ft High Bay. Ceiling and Walls Capable of Up to 2500 psf Load Over 16,000 sq ft. 150 ft x 100 ft Test Hdwe Fabrication Area 60 ft High Bay. 16,000 sq ft Laboratory Office; 2500 sq ft Data Acquisition; 5000 sq ft Test Control.	
Dynamic Structural Evaluation Facility – Full Scale	S2	7500 sq ft Test Control Complex.	350 ft x 150 ft x 100 ft Environmental Chamber for Pressures to 1 Torr. Chamber has Structural Floor, Ceiling, and Walls. 350 ft x 125 ft x 100 ft Self Supporting Acoustic Shroud.
Thermal/Mechanical Fatigue	S3	100 ft x 100 ft Structural Floor 60 ft High Bay. Structural and Non-Structural Ceiling and Walls. 100 ft x 100 ft Test Hdwe Fabrication Area 60 ft High Bay. 1500 sq ft Data Acquisition; 2500 sq ft Test Control Area.	
Airframe Acoustic Test Facility	S4	350 ft x 150 ft x 100 ft Acoustic Test Cell; 2500 sq ft Test Control Complex.	350 ft x 125 ft x 100 ft Self Supporting Acoustic Shroud.
Thermal/Acoustic Component Test	S5	100 ft x 100 ft Structural Floor 100 ft High Bay. Structural Ceiling and Walls. 2500 sq ft Test Control Area.	50 ft x 50 ft x 20 ft Acoustic Reflecting/Absorbing Test Cell. 15 ft x 10 ft x 10 ft Acoustic Shroud.
Tankage Test	S6	250 ft x 100 ft Structural Floor 100 ft High Bay. Structural Ceiling. 100 ft x 100 ft Test Hdwe Fabrication Area. 2500 sq ft Data Acquisition; 5000 sq ft Test Control Complex.	Foam/LH_2 Quench for Entire Building.
Cabin Pressurization Test	S7	350 ft x 150 ft x 100 ft Test Cell Safety Enclosure. 2500 sq ft Test Control Station.	
Cruise Descent Facility	S9	500 sq ft Test Control Complex.	350 ft x 150 ft x 100 ft Environmental Chamber for Pressures to 1 Torr. Man Rated.

2000 psi at 800°F

FOLDOUT FRAME 2

Requirements	Utilities																				Steam Ejector	Fluid Flow				Fluid Storage				Refrigeration				Data Acquisition Channels (Including Spares)	Transducers Required (Incl idin Spares)
	Water							Compressed Air								Substation																			
	2000 gpm at 80°F	2000 gpm at 15 psi	2500 gpm at 80°F	4000 gpm at 80°F	7000 gpm at 80°F	10,000 gpm at 80°F	30,000 gpm at 80°F	3000 scfm at 120 psig	3000 scfm at 150 psig	26,000 scfm at 120 psig	30,000 scfm at 100 psig	30,000 scfm at 150 psig	1×10^6 scfm at 60 psig	1×10^6 scfm at 100 psig	1×10^6 scfm at 150 psig	2000 kVA	50,000 kVA	100,000 kVA	1600 kVA	1,400,000 kVA	1,100,000 scfm	10,000 gpm LH_2	60,000 gpm LH_2	70,000 gpm LH_2 Slush	15,000 gpm JP-4	600,000 gal. LH_2	1,130,000 gal. LH_2 Slush	225,000 gal. JP-4	748,000 gal. LH_2	2200 tons	4400 tons	7100 tons	62,000 tons		
			O							O								O					O						O		O			15,000	12,[illegible]
mental Chamber for Pressures ' Floor, Ceiling, and Walls. porting Acoustic Shroud.						O	O						O							O	O		O						O				O	17,000	16,[illegible]
	O							O									O					O				O				O				4,000	3,8[illegible]
porting Acoustic Shroud.														O		O															O			9,500	10,000
eflecting/Absorbing Test stic Shroud.				O							O							O														O		2,100	1,8[illegible]
uilding.					O							O							O					O	O		O	O						9,000	7,[illegible]
		O							O																									3,500	3,030
mental Chamber for Pressures							O								O					O													O	10,000	10,[illegible]

FOLDOUT FRAME 3

1,100,000 scfm	Beam Injector	Fluid Flow				Fluid Storage				Refrigeration				Data Acquisition Channels (Including Spares)	Transducers Required (Including Spares)	Test Equipment
		10,000 gpm LH_2	60,000 gpm LH_2	70,000 gpm LH_2 Slush	15,000 gpm JP-4	600,000 gal. LH_2	1,130,000 gal. LH_2 Slush	225,000 gal. JP-4	748,000 gal. LH_2	2200 tons	4400 tons	7100 tons	62,000 tons			
			○						○		○			15,000	12,300	Heat Flux: 2.3 Btu/sq ft/sec Over 40,600 sq ft; Fifty 70 gpm at 6000 psi Hydraulic Power Supplies.
○		○							○				○	17,000	16,600	Heat Flux: 40 Btu/sq ft/sec Over 16,000 sq ft, 10 Btu/sq ft/sec Over 20,000 sq ft, 120 Btu/sq ft/sec Over 4000 sq ft, Acoustics: 170 dB in 3000 sq ft Plane Wave Tube; One Hundred 30 kip Shakers.
	○					○				○				4,000	3,850	Heat Flux: 350 Btu/sq ft/sec Over 100 sq ft, 70 Btu/sq ft/sec Over 100 sq ft, 8 Btu/sq ft/sec Over 1000 sq ft.
											○			9,500	10,000	Acoustics: 170 dB in 3000 sq ft Plane Wave Tube.
												○		2,100	1,850	Heat Flux: 150 Btu/sq ft/sec Over 100 sq ft, 70 Btu/sq ft/sec Over 1000 sq ft, Acoustics: Ten 30,000 Acoustic Watt Generators at 170 dB.
				○	○		○	○						9,000	7,200	Heat Flux: 25 Btu/sq ft/sec Over 6000 sq ft.
														3,500	3,030	
													○	10,000	10,000	Heat Flux: 40 Btu/sq ft/sec Over 16,000 sq ft, 120 Btu/sq ft/sec Over 4000 sq ft, 10 Btu/sq ft/sec Over 20,000 sq ft.

FOLDOUT FRAME 1

Facility	Code	Area Requirements	Major Equipment Requirements	12.6×10^{-2} m^3/sec at 26.7°C	12.6×10^{-2} m^3/sec at 10.3×10^4 N/m^2
Static Test – Full Scale Thermal Structure	S1	106.8m x 45.7m Structural Floor 45.7 High Bay. Ceiling and Walls Capable of up to 1.195×10^5 N/m^2 Load Over 1489 m^2 45.7m x 30.5m Test Hdwe Fabrication Area 18.3m High Bay.			
Dynamic Structural Evaluation Facility – Full Scale	S2	1489 m^2 Laboratory Office; 232 m^2 Data Acquisition; 464 m^2 Test Control 697 m^2 Test Control Complex.	106.8m x 45.7m x 30.5m Environmental Chamber for Pressures to 133 N/m^2. Chamber has Structural Floor, Ceiling, and Walls. 106.8m x 38.1m x 30.5m Self Supporting Acoustic Shroud.		
Thermal/Acoustic Component Test	S3	30.5m x 30.5m Structural Floor 18.3m High Bay. Structural and Non-Structural Ceilings and Walls. 30.5m x 30.5m Test Hdwe Fabrication Area 18.3m High Bay. 139m^2 Data Acquisition; 232 m^2 Test Control Area.		O	
Thermal/Mechanical Fatigue	S4	106.8m x 45.7m x 30.5m Acoustic Test Cell.; 232 m^2 Test Control Complex.	106.8m x 38.1m x 30.5m Self Supporting Acoustic Shroud.		
Airframe Acoustic Test Facility	S5	30.5 x 30.5m Structural Floor. 30.5m High Bay. Structural Ceilings and Walls. 232 m^2 Test Control Area.	15.3m x 15.3m x 6.09m Acoustic Reflecting/Absorbing Test Cell. 4.57m x 3.05m x 3.05m Acoustic Shroud.		
Tankage Test	S6	76.3m x 30.5m Structural Floor; 30.5m High Bay. Structural Ceiling. 30.5m x 30.5m Test Hdwe Fabrication Area. 232m^2 Data Acquisition; 464 m^2 Test Control Complex.	Foam/LH_2 Quench for Entire Building.		
Cabin Pressurization Test	S7	106.8m x 45.7m x 30.5m Test Cell Safety Enclosure. 232m^2 Test Control Station;			O
Cruise Descent Facility	S9	464 m^2 Test Control Complex.	106.8m x 45.7m x 30.5m Environmental Chamber for Pressures to 133 N/m^2 Man Rated.		

FOLDOUT FRAME 2

F

Equipment Requirements	Utilities																			Steam Ejector	Fluid Flow			
	Water							Compressed Air							Substation									
	12.6×10^{-2} m^3/sec at 26.7°C	12.6×10^{-2} m^3/sec at 10.3×10^4 N/m^2	15.75×10^{-2} m^3/sec at 26.7°C	25.2×10^{-2} m^3/sec at 26.7°C	44.1×10^{-2} m^3/sec at 26.7°C	63×10^{-2} m^3/sec at 26.7°C	189×10^{-2} m^3/sec at 26.7°C	1.41 m^3/sec at 8.27×10^5 N/m^2	141 m^3/sec at 10.3×10^5 N/m^2	1.22 m^3/sec 8.27×10^5 N/m^2	14.1 m^3/sec at 6.89×10^5 N/m^2	14.1 m^3/sec at 10.3×10^5 N/m^2	47.2 m^3/sec at 4.14×10^5 N/m^2	47.2 m^3/sec at 6.89×10^5 N/m^2	47.2 m^3/sec at 10.3×10^5 N/m^2	2000 kVA	50,000 kVA	100,000 kVA	1600 kVA	1,400,000 kVA	574 kg/sec	63×10^{-2} m^3/sec LH_2	378×10^{-2} m^3/sec LH_2	441×10^{-2} m^3/sec LH_2 Slush	94.5×10^{-2} m^3/Sec JP-4
			O							O								O					O	
.5m Environmental Chamber for Pressures has Structural Floor, Ceiling, and x 30.5m Self Supporting Acoustic						O	O						O							O	O		O	
	O							O								O						O		O
.5m Self Supporting Acoustic Shroud.														O	O									
m Acoustic Reflecting/Absorbing Test x 3.05m Acoustic Shroud.				O							O							O						
Entire Building.					O							O							O				O	O
		O							O															
.5m Environmental Chamber for Pressures ted.							O								O					O				

FOLDOUT FRAME 3

FIGURE 6–66 HYFAC NONFLOW STRUCTURAL RESEARCH FACILITY AREA, MAJOR EQUIPMENT, AND UTILITY REQUIREMENTS SUMMARY (S.I. UNITS)

Station			Steam Ejector	Fluid Flow				Fluid Storage				Refrigeration				Data Acquisition Channels (Including Spares)	Transducers Required (Including Spares)	Test Equipment
100,000 kVA	1600 kVA	1,400,000 kVA	574 kg/sec	63×10^{-2} m^3/sec LH_2	378 x 10^{-2} m^3/sec LH_2	441 x 10^{-2} m^3/sec LH_2 Slush	94.5 x 10^{-2} m^3/Sec JP-4	2265 m^3 LH_2	4260 m^3 LH_2 Slush	850 m^3 JP-4	2830 m^3 LH_2	7740 kW	15,500 kW		218,000 kW			
○					○						○		○			15,000	12,300	Heat Flux: 2.61 x 10^4 Watt/meter^2 Over 3770 m^2; Fifty .441 x 10^{-3} m^3/sec; 41.3 x 10^6 N/m^2 Hydraulic Power Supplies.
		○	○		○						○				○	17,000	16,600	Heat Flux: 4.54 x 10^5 Watt/meter^2 Over 1489 m^2; 1.13 x 10^5 Watt/meter^2 Over 1860 m^2; 1.36 x 10^6 Watt/meter^2 Over 371 m^2 Acoustics: 1 x 10^5 Watt/meter^2 in 279 m^2 Plane Wave Tube; One Hundred 1.33 x 10^5 N Shakers.
				○				○				○				4,000	3,850	Heat Flux: 3.97 x 10^6 Watt/meter^2 Over 30.5 m^2; 7.94 x 10^5 Watt/meter^2 Over 9.29 m^2; 9.08 x 10^4 Watt/meter^2 Over 92.9 m^2.
																9,500		Acoustics: 1 x 10^5 Watt/meter^2 in 279 m^2 Plane Wave Tube.
○													○			2,100	1,850	Heat Flux: 1.7 x 10^6 Watt/meter^2 Over 9.29 m^2: 7.94 x 10^5 Watt/meter^2 Over 929 m^2. Acoustics: Ten 30,000 Acoustic Watt Generators at 1 x 10^5 Watt/meter^2
	○					○	○		○	○				○		9,000	7,200	Heat Flux: 2.84 x 10^5 Watt/meter^2 Over 547 m^2.
		○													○	10,000	10,000	Heat Flux: 4.54 x 10^5 Watt/meter^2 Over 1489 m^2; 1.36 x 10^6 Watt/meter^2 Over 371 m^2; 1.13 x 10^5 Watt/meter^2 Over 1860 m^2

FIGURE 6–67 HYFAC GROUND FACILITY ACQUISITION COST SUMMARY

Facility Component	Dollars - Thousands							
	S1	S2	S3	S4	S5	S6	S7	S9
Building Complex	3,980	4,225	732	1,820	645	1590	580	4,650
Services								
Supply	350	13,500	41	13,500	405	405	41	13,500
Hydraulics								
Cryogenics	11,680	11,680	6,700			11,070		
Substation	1,600	35,000	800	30	1,600	34		35.000
Refrigeration	2,280	31,800	1,140		2,280	4		31,800
Water	50	800	40		80	140	40	600
Steam Ejector		120,000						120,000
Fire Suppression						211		
Standard Fuel						1,035		
Air Filtration								
Disposal Area								
Total Services	15,960	212,780	8,721	13,530	4,365	12,899	81	200,900
Major Equipment								
Environmental Chamber		1,075						1,575
Acoustic Shroud		400		880	65			
Sled Track								
Anechoic Chamber								
Flight Simulators								
Test Fixture	1,447	901	109	901	181	456		
Heaters	4,060	19,600	480		1,100	2,400		19,600
Test Control	3,000	3,000	750					
Thermal Control	2,250	15,000	875		1,650	3,350		15,000
Shakers		21,000				60		
Acoustics		4,500		4,500	150			
Total Major Equipment	10,757	65,476	2,154	6,281	3,146	6,266		36,175
Miscellaneous Equipment	5,394	5,394	743	740	619	2,117	400	400
Data Acquisition	15,000	17,000	4,000	9,500	2,100	9,000	3,500	10,000
Instrumentation	3,075	4,150	963	2,500	463	1,800	758	2,500
Total Data Acquisition and Instrumentation	18,075	21,150	4,963	12,000	2,563	10,800	4,258	12,500
Grand Total	54,116	309,025	17,313	34,371	11,338	33,672	5,319	254,625

FIGURE 6–68 HYFAC GROUND FACILITY OPERATING COSTS SUMMARY

Operating Cost Factor	Dollars Per Hour							
	S1	S2	S3	S4	S5	S6	S7′	S9
Building Depreciation = 2.5 Building Cost in $1000 x 10^{-2}	99	106	18	46	16	40	14	115
Building Maintenance = Building Cost in $1000 x 10^{-2}	40	42	7	18	6	16	6	47
Electricity for Equipment = 1.3 kVA x 10^{-2}	1,300	18,200	650	26	1,300	21		18,200
Electricity for Pumps = 1.3 gpm x 10^{-2} ($8.2 m^3$/sec x 10^{-7})	806	1,300	156		52	1,200	26	390
Electricity for Refrigeration = 1.3 Tons x 10^{-2} (25.2 Watts)	57	806	29		57	92		806
Electricity for Air = 3.9 scfm x 10^{-4} ($1.84 m^3$/sec x 10^{-8})	10	390	1	390	12	12	1	390
Steam = 6 scfm x 10^{-5} (3.45 kg/sec x 10^{-2})		60						
Water = 8.63 gpm x 10^{-4} ($5.44 m^3$/sec x 10^{-7})	2	35	2		3	6	2	26
Equipment Depreciation = 2.5 Equipment Cost in $1000 x 10^{-2}	642	6,825	270	495	150	478	2	5,920
Equipment Maintenance = 2 Equipment Cost in $1000 x 10^{-2}	514	5,450	216	396	188	383	2	4,740
Data Acquisition System Maintenance = 1.25 Data Acquisition in $1000 x 10^{-1}	2,260	2,640	620	1,500	320	1,350	532	1,560
Manpower = 6.67 Data Channels x 10^{-2}	1,200	1,140	321	816	178	680	234	667
Data Acquisition System Depreciation = 7.15 Equipment Cost in $1000 x 10^{-2}	1,290	1,570	350	856	184	772	305	895
Misc. Equipment Depreciation = 7.15 Equipment Cost in $1000 x 10^{-2}	386	386	53	53	44	151	29	29
Misc. Equipment Maintenance = 1.25 Equipment Cost in $1000 x 10^{-2}	67	67	9	9	8	26	5	5
Manpower (Unique Equipment) = No. Men/Item x 10^{1}								
Total Operating Costs $/Hour	8,673	38,957	2,702	4,605	2,569	5,147	1,158	33,790

FIGURE 6-69 STATIC STRUCTURAL EVALUATION FACILITY S1 TEST ARTICLE SIZE AND SIMULATION LEVEL FACILITY COST COMPARISON

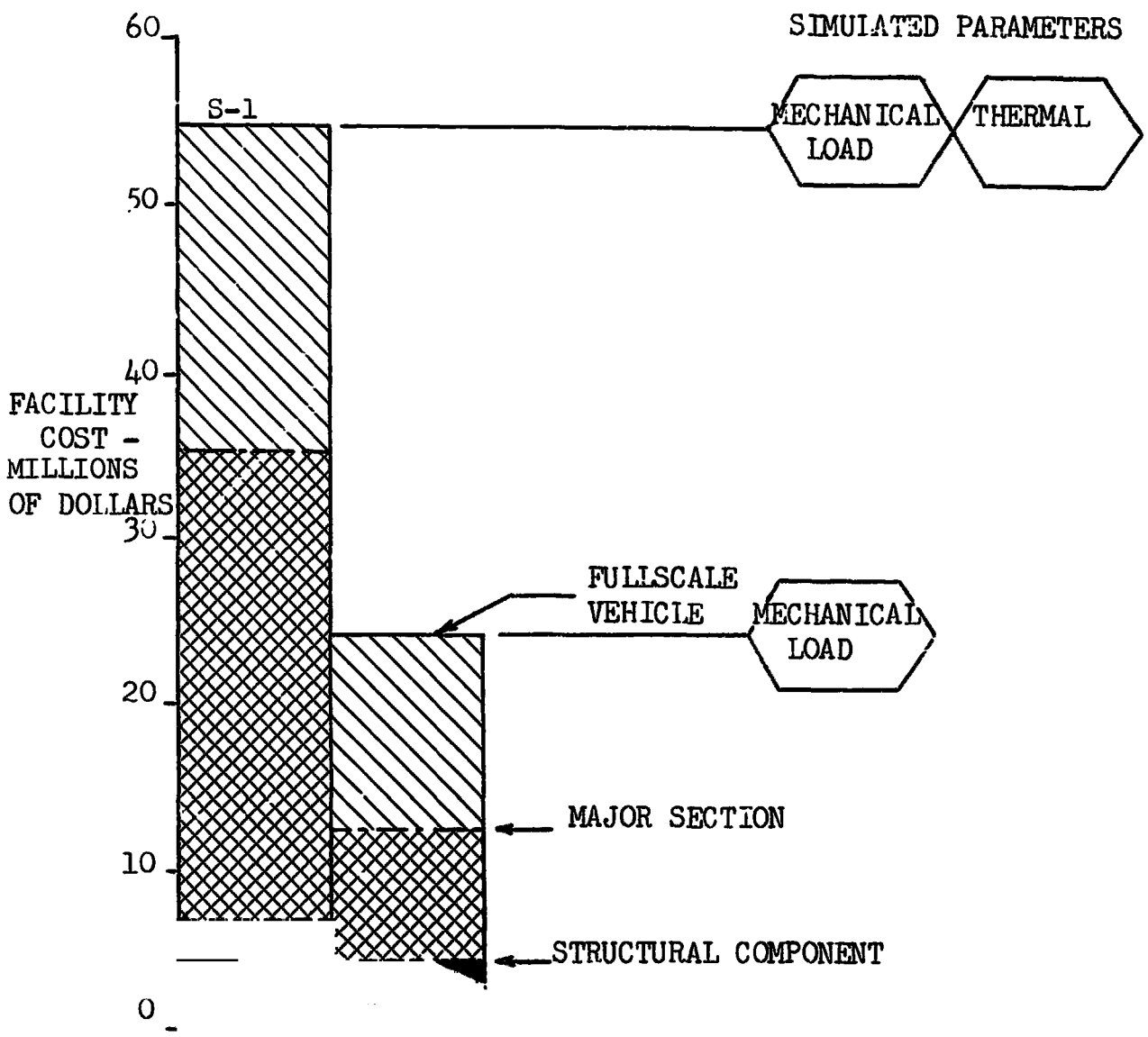


FIGURE 6-70 DYNAMIC STRUCTURAL EVALUATION FACILITY S2 TEST ARTICLE SIZE AND SIMULATION LEVEL FACILITY COST COMPARISON

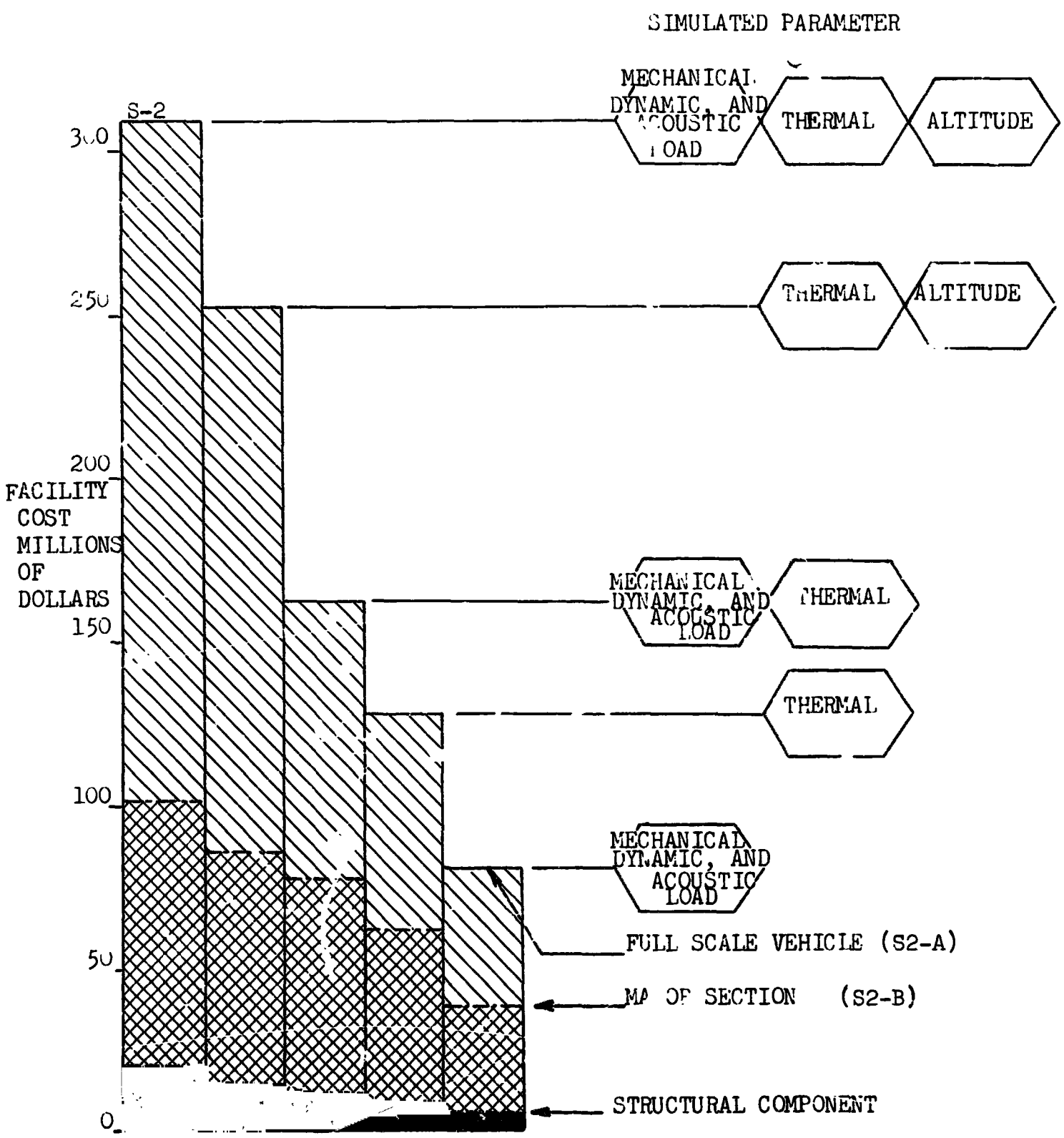
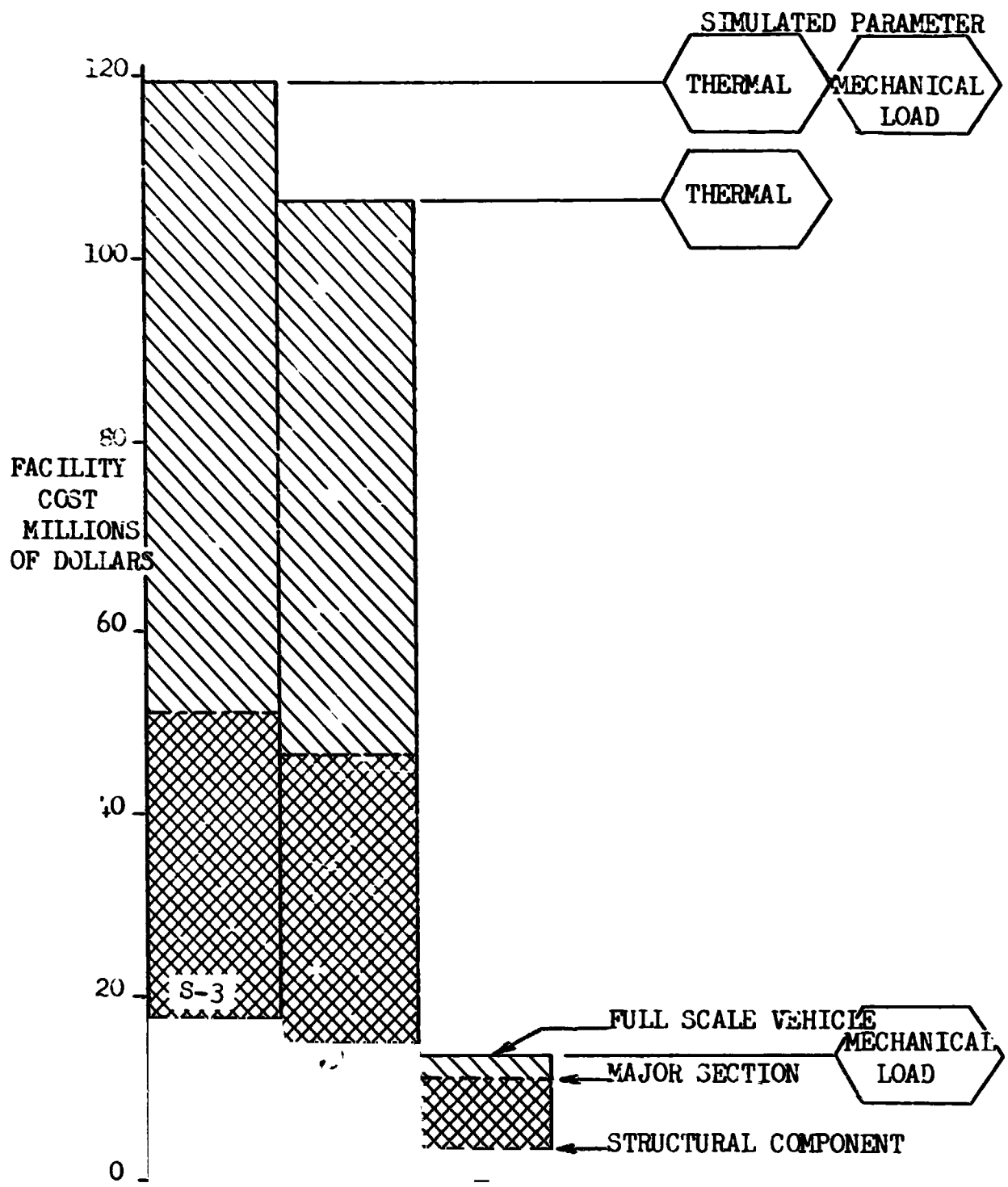


FIGURE 6-71 THERMAL/MECHANICAL FATIGUE FACILITY S3 TEST ARTICLE SIZE AND SIMULATION LEVEL FACILITY COST CORRELATION



6.7 MATERIALS RESEARCH FACILITIES

The problem of developing satisfactory materials for use in reusable hypersonic vehicles presents a major technological challenge. The construction of an airframe that will repeatedly survive the severe re-entry thermal and loading conditions and yet be within reasonable weight limits may require unconventional materials concepts. Heat resistant structural metals and thermal protection system materials constitute the two primary areas requiring materials research, but research must be conducted on virtually every material used in the vehicle.

The concept of these materials research facilities is that they will provide an avenue to translate the extensive materials data obtained on small sized specimens into design data and criteria for practical aircraft structures.

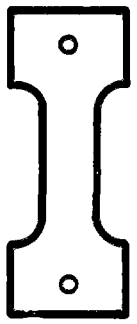
6.7.1 CRITERIA - The ultimate capability of the hypersonic vehicle could well be limited by the ability of the structural materials to withstand critical flight environmental conditions. Shortcomings presently exist in refractory metals, superalloys, high-strength steels, and advanced titanium technology that will require extensive research before actual candidate materials can be selected. Reusable refractory coating systems will be relied on to protect large surface areas of most hypersonic vehicle designs, but sufficient test data is not presently available to reliably demonstrate the system. Likewise, ceramic materials are possible high heat flux area material candidates, but their reliability has not been demonstrated.

Materials available for thermal protection systems have many shortcomings. Passive insulation systems will most likely incorporate a highly efficient, low-density fibrous or powdered material. A large number of silica, alumina, or zirconia based insulation materials now exist that can operate in the 2000-2700°F (1110-1490°C) temperature range, but repeated use at these temperatures under compressive or vibration loading tends to seriously degrade their performance. Further insulation material degradation has been noted when these materials have been exposed to moisture, freezing temperatures, and general weather exposure. New types of metal reflecting foil may be required that do not depend on precious metals for their reflectivity.

6.7.2 ANALYSIS - Materials facilities that provide a complete materials research complex have been proposed for the development of hypersonic vehicle materials. The scope of testing to be conducted in these facilities ranges from basic material research to the development of manufacturing and nondestructive evaluation techniques (see Figure 6-72). The candidate materials research facilities are designed to test material coupons through the full range of expected environmental conditions and to translate the basic material data obtained in the laboratory into viable aircraft structural concepts. Figure 6-73 is a matrix of the simulation and research levels provided by each of the proposed facilities. It indicates the type of material specimens used in each facility.

6.7.3 DESIGN CHARACTERISTICS AND COST SUMMARY - The suggested materials research facility consists of three separate research laboratories (M2, M3, and M4). M1 was judged to be representative of facility capability available in existing facilities as well as the engine facilities with aerodynamic nozzles. The capability of each separate facility is primarily determined by the type and amount of test

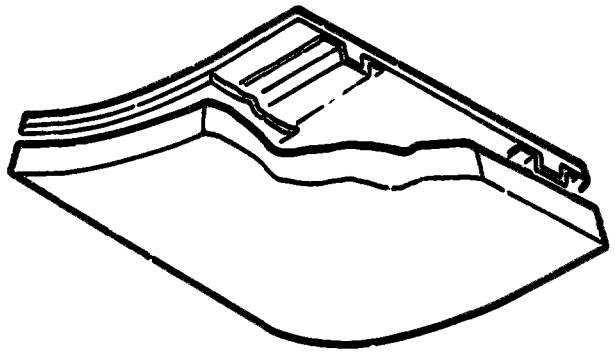
FIGURE 6-72 SCOPE OF MATERIALS TESTING



MATERIALS INVESTIGATION:

Determination of physical, thermal, and chemical properties of potential material candidates.

Type of materials investigated: metals, insulation, ceramics, ablators, protective coatings, lubricants, composites, and polymers.

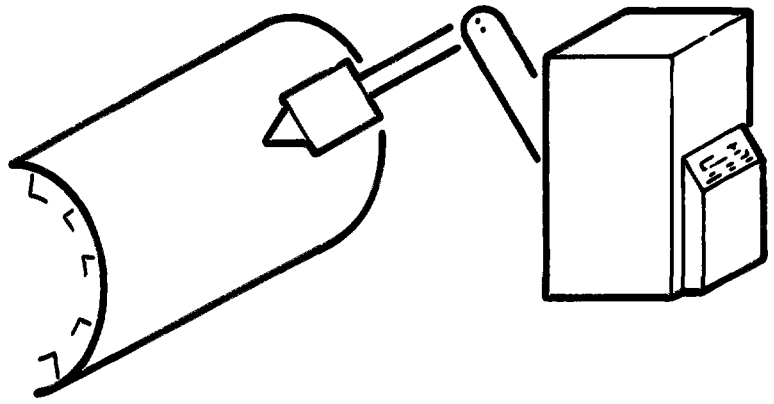


FABRICATION DEVELOPMENT:

Develop basic fabrication methods (forming, welding bonding, brazing.)

Formulate manufacturing processes (heat treat, protective coatings).

Develop manufacturing techniques. Evaluate materials selection and structural designs.



NON-DESTRUCTIVE EVALUATION:

Formulate quality assurance non-destructive test, and inspection techniques.
Develop repair techniques.

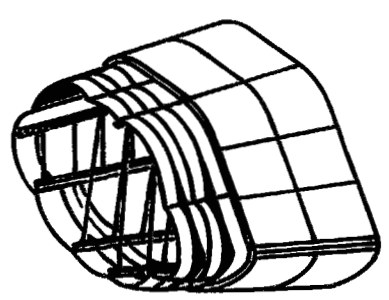
FIGURE 6–73 MATERIALS FACILITIES MATRIX AND TEST ARTICLE DEFINITION

Facility / Simulation	M2	M3	M4
Thermal Mechanical Altitude	MC		SE
Thermal Mechanical	MC	MC	SE
Mechanical	MC	MC	SE
Thermal	MC	MC	SE
Thermal Altitude	MC		SE

Mechanical = Static and/or Dynamic Loads

Largest Test Article = MC = Material Coupon; SE = Structural Element

Material Coupon



Structural Element

equipment contained in the laboratory. A description of each facility with a detailed list of test equipment and costs are presented in Figure 6-74. The primary materials utility and services requirements are presented in Figure 6-75. Estimated facility acquisition costs and operating costs are presented in Figures 6-76 and 6-77.

M2 THERMAL-PHYSICAL-MECHANICAL PROPERTIES RESEARCH FACILITY

Facility Purpose:

This facility is a basic requirement for the development of systems using advanced materials or new applications of standard materials. The facility is used to establish basic information related to anticipated environmental applications. It is necessary that this facility installation have the capacity for the evaluation of material properties over a wide range of thermal-physical conditions.

FIGURE 6-74a FACILITY DESCRIPTION AND COSTS – M2

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope 53,000 ft^2 (4,920 m^2) plan			
Common Building for M2, M3, and M4			
Site Preparation			13,[illegible]
Footings and Foundations			1[illegible],430
Floors			31,800
Steel Framing (Material and Erection)			261,000
Walls and Roofs (Material and Erection)			108,[illegible]00
Interior Walls			91,000
Comfort Conditioning			20,000
Ventilation			7,500
Heating			60,000
Utilities (Electricity, Gas, Water)			140,000
Subtotal			749,730
Contingency 10%			74,900
Subtotal			824,630
Architectural and Engineering Fees 6%			49,500
Management and Construction Coordination Fee 4%			33,000
Total Building Envelope			907,130
Total Building Envelope Adjusted to 1970 $'s			960,000
Services			
Air Supply System 3,000 scfm @ 150 psig (85 m^3/min @ 103 N/cm2)	13.50/scfm (480/scmm)		40,500
15,000 scfm @ 150 psig (255 m^3/min @ 103 N/cm^2)	13.50/scfm (480/scmm)		206,000

FIGURE 6-74a FACILITY DESCRIPTION AND COSTS – M2 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Substation 1,000 kVA			20,000
Water Supply 1,000 gpm @ 80°F (3.8 m^3/min @ 30°C)	20/gpm (5300/m^3/min)		20,000
Cryogenics 37,500 gal (142 m^3) LH_2 Storage	10/gal (2650/m^3)		375,000
37,500 Gal (142 m^3) LOX Storage	8/gal(2110/m^3)		300,000
37,500 Gal (142 m^3) LN_2 Storage	7/gal(1850/m^3)		262,000
37,500 Gal (142 m^3) Std Fuel Storage	4/gal(1060/m^3)		150,000
Total Services Common to M2, M3, M4			1,373,500
Thermal-Physical-Mechanical Properties Laboratory (M2)			
Equipment			
Heaters 450 Btu/ft^2/sec over 1 sq ft (5,100,000 W/m^2 over 0.1 m^2)	12,000/ft^2 (129,000/m^2)		12,000
Tensile Test Machine - 1 x 10^6 lb (4.4 x 10^6 N)			1,000,000
Impact Test Machine - 5,000 ft lb (5,700 j) over -450°F to +4,500°F (-271°C to 2,490°C)			25,000
Creep Test Machines - 20 Kip (89,500 N) over -450°F to +4,500°F (-271°C to 2,490°C) (50 Units)	10,000		500,000
Thermal Properties Determination Apparatus for Determining Conductivity, Emissivity, and Coefficient of Expansion over -450°F to +4,500°F (-271°C to 2,490°C)			35,000
Metallurgical Laboratory			
Electron Microscope 200 kV, 1.5 Å Resolution			110,000

FIGURE 6-74a FACILITY DESCRIPTION AND COSTS - M2 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Scanning Electron Microscope 150 kV, 10 Å Resolution			84,000
Vacuum X-Ray Spectrometer 75 kV, Capable of Hydrogen Detection			11,000
Electron Microprobe, Capable of Helium and Hydrogen Detection			90,000
Low Energy Electron Diffraction Camera			50,000
Hardness Tester			7,000
Microscopes - 200X Magnification			40,000
Metallograph			10,000
Environmental Chamber 30 ft long x 15 ft diameter (9.2 x 4.6 m) rated at 1 torr (133 N/m^2)			740,000
Data Acquisition - 50 Channels	1,000/Channel		50,000
tal Equipment Thermal-Physical-Mechanical operties Laboratory (M2)			2,764,000

Facility Purpose:

The purpose of this facility is to establish the basic combined thermal-mechanical fatigue properties of materials from coupon evaluation, and to establish material application working level allowables. The hypersonic flight regime will require the development of thermal-mechanical fatigue material properties for many materials over a wide range of temperature/heat flux environments.

FIGURE 6-74b FACILITY DESCRIPTION AND COSTS – M3

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Thermal/Mechanical Fatigue Properties Laboratory (M3)			
Equipment			
Fatigue Machine (4 Units)	600,000		2,400,000
Thermal Control System			
Heaters 450 Btu/ft^2/sec over 6 ft^2 (5,100,000 W/m^2 over 1.8 m^2)	12,000/ft^2 (129,000/m^2)		72,000
Data Acquisition System - 500 Channels	1,000/channel		500,000
Strain Gages (25 Units)	250		6,250
Fatigue Gages (50 Units)	250		12,500
Thermocouples (50 Units)	250		12,500
Total Equipment Thermal-Mechanical Fatigue Properties Laboratory (M3)			3,003,250

* Building and Services requirements are shared with M2 and M4

M4 FABRICATION TECHNOLOGY DEVELOPMENT FACILITY

Facility Purpose:

This facility will be used to develop new material handling, forming, and joining techniques for hypersonic flight vehicles.

FIGURE 6-74c FACILITY DESCRIPTION AND COSTS – M4

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Fabrication Technology Facility (M4)			
Equipment			
Salt Bath Furnace			
3 x 4 x 5 ft (.91 x 1.2 x 1.5 m) 1,200-1,800°F (658 - 1,000°C)			50,000
3 x 4 x 5 ft (.9 x 1.2 x 1.5 m) 1,800-2,400°F (1,000 - 1,330°C)			50,000
Induction Furnace 30 kW			20,000
Electron Beam Welder			130,000
Developmental Machine Shop			
Electrical Discharge Machine			50,000
Electrochemical Milling Machine			80,000
Cleaning Facility			10,000
Tube Bender			500
Pressure Forming Apparatus			500
Glass-Shot Peening Apparatus			500
Autoclave 80 x 40 x 20 ft (24 x 12 x 6 m) @ 500 psi (3,440,000 N/m^2) 1,200°F (658°C)			500,000
Vacuum Furnace 10 x 10 x 10 ft (3 x 3 x 3 m) 3,000°F (1,680°C)			500,000
X-Ray Equipment			1,500
Joining Facility			
100 Laser			30,000
300 Ultrasonic Welder			20,000
NC Fusion Welder on 5 Axis Table			25,000
Nondestructive Test Laboratory			
Ultrasonic Cleaner 8 x 40 ft Tank (2.4x12 m)			50,000
Radiograph			50,000
IR Scanner 8 x 40 ft (2.4 x 12 m)			50,000

FIGURE 6-74c FACILITY DESCRIPTION AND COSTS – M4 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Hydroclave 20 ft x 10 ft dia (6.1 x 3 m) 10,000 psi (69,000,000 N/m^2 @ 2,000°F) (1,100°F)			50,000
Hydraulic Press			80,000
Laser Holography 6 x 8 on 50 ft (1.8 x 2.4 x 15 m) Sweep in Anechoic Room			300,000
Total Equipment Fabrication Technology Facility (M4)			2,030,000
Building and Services Requirements are Shared with M2, M3			

NOTE: Unless otherwise adjusted, all costs are in 1970 dollars.

SOURCES:
(a) Richardson Engineering Service Manual of Commercial-Industrial Engineering Standards
(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year
(c) McDonnell Douglas Corporation Engineering Budget History and Equipment Inventory

FOLDOUT FRAME 1

FIGURE 6-75 HYFAC NON-FLOW MATERIALS FACILITY AREA, MAJOR EQUIPMENT, AND UTILITY REQUIREMENTS SUMMARY (ENGLISH UNITS)

Facility	Code	Major Equipment Requirements	Utilities: Water		Utilities: Compressed Air		Utilities: Substation		Fluid Storage		
			1000 gpm at 80°F	2000 gpm at 80°F	3000 scfm at 150 psig	15,000 scfm at 150 psig	1000 kVA	100,000 KVA	37,500 gal. LN_2	37,500 gal. LO_2	37,500 gal. LH_2
Thermal-Physical-Mechanical Properties	M2	30 ft x 15 ft Diameter Environmental Chamber for Pressures to 1 Torr. Tensile Test Machine 1 x 10^6 lb; Impact Test Machine 5 x 10^3 ft-lb; Creep Test Machines. 50 Units Electron Microscope.	○		○		○		○	○	○
Thermal/Mechanical Fatigue	M3	Fatigue Machine Four 1000 Kip Units	○			○			○		○
Fabrication Technology	M4	Autoclave 80 ft x 40 ft x 20 ft at 500 psi and 3000°F; Hydroclave 20 ft x 10 ft Diameter at 10,000 psi and 2000°F.		○				○			

(S.I. UNITS)

Facility	Code	Major Equipment Requirements	Utilities: Water		Utilities: Compressed Air		Utilities: Substation		Fluid Storage			
			6.3 x 10^{-2} m^3/sec at 26.7°C	12.6 x 10^{-2} m^3/sec at 26.7°C	1.41 m^3/sec at 10.3 x 10^5 N/m^2	7.07 m^3/sec at 10.3 x 10^5 N/m^2	1000 kVA	100,000 kVA	141.5 m^3 LN_2	141.5 m^3 LO_2	141.5 m^3 LH_2	141.5 m^3 LP
Thermal-Physical-Mechanical Properties	M2	9.14m x 4.57m Dia. Environmental Chamber for Pressures to 133 N/m^2 Tensile Test Machine 4.44 x 10^6 N; Impact Test Machine 660 m-kg Creep Test Machines 50 Units, Electron Microscope.	○		○		○		○	○	○	○
Thermal/Mechanical Fatigue	M3	Fatigue Machine Four 4.44 x 10^6 N Units.	○			○			○		○	
Fabrication Technology	M4	Autoclave 24.4m x 12.2m x 6.09m at 3.45 x 10^6 N/m^2 and 1651°C. Hydroclave 6.09m x 3.05m Dia at 6.89 x 10^7 N/m^2 and 1111°C.		○				○				

FOLDOUT FRAME 2

Utilities					Fluid Storage				Refrigeration	Data Acquisition Channels (Including Spares)	Transducers Required (Including Spares)	Test Equipment
Water	Compressed Air		Substation									
2000 gpm at 80°F	3000 scfm at 150 psig	15,000 scfm at 150 psig	1000 kVA	100,000 KVA	37,500 gal. LN_2	37,500 gal. LO_2	37,500 gal. LH_2	37,500 gal. JP-4	130 tons			
	○		○		○	○	○	○		50	Installed on Test Equipment	
○		○		○	○		○		○	500	125	Heat Flux: 450 Btu/sq ft/sec Over 6 sq ft.

Utilities					Fluid Storage				Refrigeration	Data Acquisition Channels (Including Spares)	Transducers Required (Including Spares)	Test Equipment
Water	Compressed Air		Substation									
12.6×10^{-2} m^3/sec at 26.7°C	1.41 m^3/sec at 10.3×10^5 N/m^2	7.07 m^3/sec at 10.3×10^5 N/m^2	1000 kVA	100,000 kVA	141.5 m^3 LN_2	141.5 m^3 LO_2	141.5 m^3 LH_2	141.5 m^3 JP-4	457 kW			
	○		○		○	○	○	○		50	Installed on Test Equipment	
○		○		○	○		○		○	500	125	Heat Flux: 5.10×10^6 Watt/meter^2 Over 1.83 m^2.

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FIGURE 6–76 HYFAC GROUND FACILITY ACQUISITION COST SUMMARY

Facility Component	Dollars - Thousands			
	M2	M3	M4	M20
Building Complex (Common)				960
Services				
Air Supply				247
Hydraulics				
Cryogenics				937
Substation				20
Refrigeration				65
Water				20
Steam Ejector				
Fire Suppression				
Standard Fuel				150
Air Filtration				
Disposal Area				
Total Services (Common)				1,374
Major Equipment				
Environmental Chamber	740			740
Acoustic Shroud				
Sled Track				
Anechoic Chamber				
Flight Simulators				
Test Fixture				
Heaters	12			12
Test Control				
Thermal Control		72		72
Shakers				
Acoustics				
Total Major Equipment	752	72		824
Miscellaneous Equipment	1,962	2,400	2,030	6,392
Data Acquisition	50	500		550
Instrumentation		32		32
Total Data Acquisition and Instrumentation	50	532		582
Grand Total				10,132

M20 = M2 + M3 + M4

FIGURE 6–77 HYFAC GROUND FACILITY OPERATING COSTS SUMMARY

Operating Cost Factor	Dollars Per Hour			
	M2	M3	M4	M20
Building Depreciation = 2.5 Building Cost in \$1000 x 10^{-2}	13	13	10	24
Building Maintenance = Building Cost in \$1000 x 10^{-2}	5	5	2	10
Electricity for Equipment = 1.3 kVA x 10^{-2}	13			13
Electricity for Pumps = 1.3 gpm x 10^{-2} (8.2m^3/sec x 10^{-7})	13	13		13
Electricity for Refrigeration = 1.3 Tons x 10^{-2} (25.2 Watts)		4		4
Electricity for Air = 3.9 scfm x 10^{-4} (1.84m^3/sec x 10^{-8})	1	6		7
Steam = 6 scfm x 10^{-5} (3.45 kg/sec x 10^{-2})				
Water = 8.63 gpm x 10^{-4} (5.44m^3/sec x 10^{-7})	1	1		1
Equipment Depreciation = 2.5 Equipment Cost in \$1000 x 10^{-2}	37	19		55
Equipment Maintenance = 2 Equipment Cost in \$1000 x 10^{-2}	29	15		44
Data Acquisition System Maintenance = 1.25 Data Acquisition in \$1000 x 10^{-1}	6	67		74
Manpower = 6.67 Data Channels x 10^{-2}	4	38		37
Data Acquisition System Depreciation = 7.15 Equipment Cost in \$1000 x 10^{-2}	4	37		42
Misc. Equipment Depreciation = 7.15 Equipment Cost in \$1000 x 10^{-2}	140	172	146	456
Misc. Equipment Maintenance = 1.25 Equipment Cost in \$1000 x 10^{-2}	24	30	25	80
Manpower (Unique Equipment) = No. Men/Item x 10^{1}	40	40	200	280
Total Operating Costs \$/Hour	330	455	383	1,140

M20 = M2 + M3 + M4

6.8 FLIGHT SIMULATOR RESEARCH FACILITIES

Manned hypersonic flight will place great demands on pilot skill and judgment. There can be no substitute for a well-trained pilot who is thoroughly knowledgeable about all aspects of the vehicle and its operation. Pilot training can best be obtained by spending long hours at the controls of the vehicle, but this is impossible or impractical for most advanced vehicles. The candidate flight simulator facilities are all extensions of current simulator techniques, with capabilities suited to the hypothesized operational vehicles. Three facilities are proposed, two of which are engineering simulators and one of which is a crew training device. In the engineering simulators, information on human response to the cabin flight environment is gathered in order to define the limits of a pilot's ability to control the aircraft and to establish minimum standards for physical cues required by the pilot. The crew trainer facility is designed with variable flight simulation characteristics, so that the specific characteristics of any actual hypersonic aircraft design may be produced.

6.8.1 CRITERIA - In order to make the simulator as effective as possible, the aircraft cabin, environment, and motion should be realistically simulated. These simulation factors tend to [illegible] the pilot more confidence in the procedures and evaluations carried out on the simulator. The motion simulation apparatus constitutes a major system of the flight simulator. Its function is of particular importance in hypersonic flight vehicles because of the long distance between the vehicle's center of gravity and the cockpit. The relation of pilot location to the vehicle c.g. has a great effect on the pilot's ability to judge and control the true movements of the aircraft's c.g. and landing gear. This pilot judgment is particularly important on landing to gauge the descent rate or control dutch roll oscillation and decrabbing. Other flight problems such as asymmetric loss of engine thrust could cause large and confusing cockpit movements that would require pilot judgment to control.

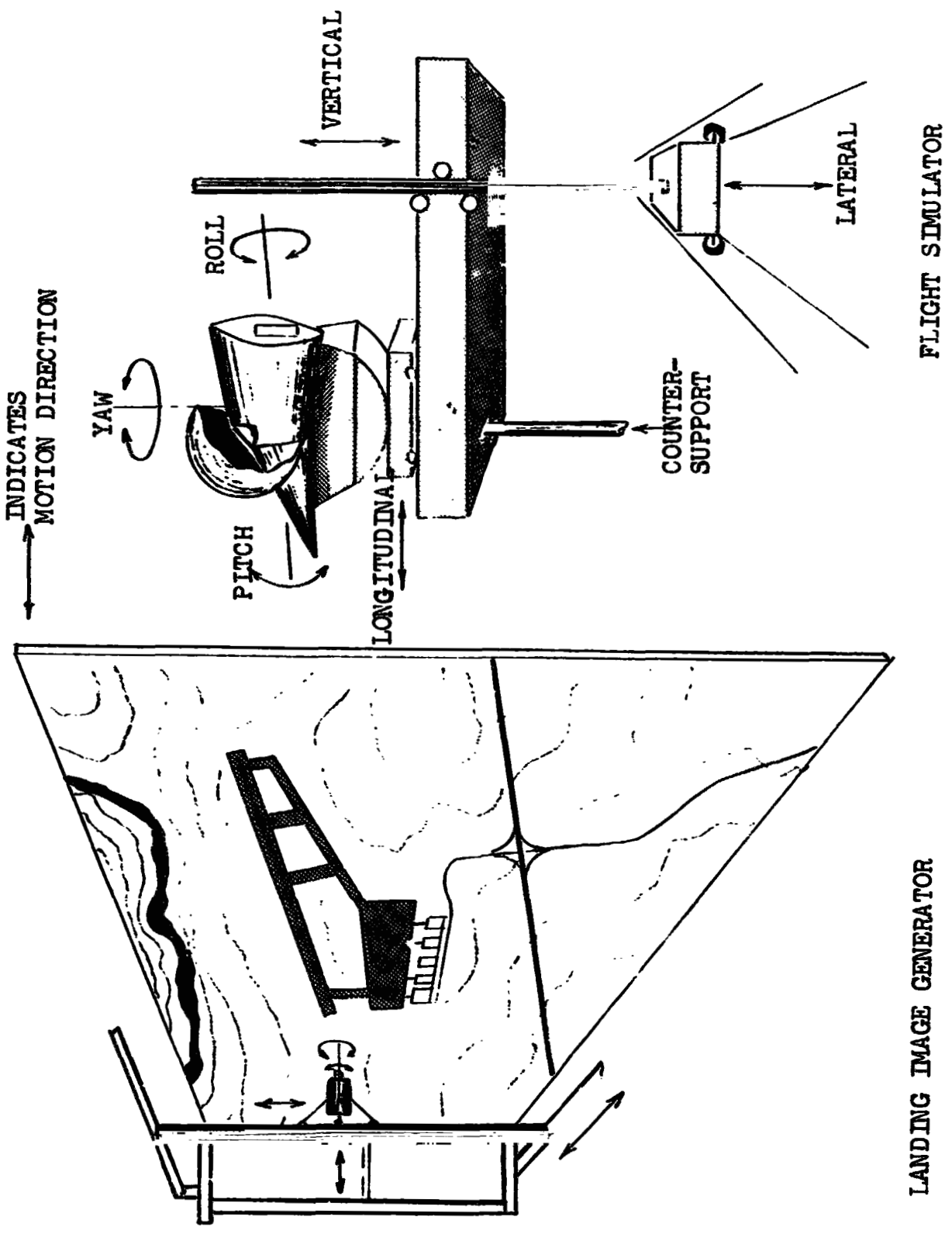
The simulator will have an exact duplicate of the cockpit to provide realistic training to the crew member. The capability of the simulator will depend on the ability of the simulation-computer to accurately reproduce the corresponding physical, electrical, and dynamic response when the aircraft controls are actuated. Visual cues of exterior terrain for takeoff and landing are of great benefit in aiding the pilot to judge distances, flare altitudes, and the control response of the vehicle.

A typical six-degree-of-freedom flight simulator with a visual simulation system is shown in Figure 6-78.

6.8.2 ANALYSIS - Advanced simulators can now provide realistic motion simulation in six degrees of freedom, but physical and economic limitations prevent them from reproducing the magnitude and duration of in-flight accelerations. In-flight movement can, however, be attenuated so as to give realistic responses to the crew while keeping the facility within realistic limits.

Excellent simulator results have been obtained from Apollo and other modern simulators using new hybrid digital-analog computers. These second generation hybrid simulation computers combine the best attributes of the digital and analog computers in a single system.

FIGURE 6-78 FLIGHT SIMULATOR FACILITIES SCHEMATIC



Projections of near-term state-of-the-art advances in visual display technology indicate that large, spherical visual image generators will be capable of projecting large color television pictures on a screen in front of the cockpit windows. The accuracy of the picture and time duration of the approach that can be simulated depend on the topography model that is televised and projected onto the screen.

6.8.3 DESIGN CHARACTERISTICS AND COST SUMMARY - The flight simulator facility consists of three separate simulation facilities (designated FS1, FS2, and FS3) combined in a common building to best utilize common utilities, services, data acquisition, computer services, and personnel. A description of each facility and a detailed list of test equipment determined to be adequate to perform the indicated test function are presented in Figure 6-79 a-d. In Figure 6-80, the costs are shown for the integrated facility. Operating costs are shown in Figure 6-81. A list of utility and service requirements for the flight simulator facility is presented in Figure 6-82.

FIGURE 6-79a COMMONLY SHARED BUILDING AND UTILITY ITEMS FOR THE CREW TRAINER (FS1), TAKEOFF AND LANDING ENGINEERING SIMULATOR (FS2), AND LAUNCH-CRUISE ENGINEERING SIMULATOR (FS3) SIMULATION FACILITY

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope 53,000 ft^2 (4,920 m^2)			
Site Preparation			13,700
Footings and Foundations			16,430
Floors			
Office area and computer complex slab floor			7,200
Elevated floor for computer complex			32,500
Equipment room slab floor			24,600
Steel Framing (Material and Erection)			261,000
Walls and Roofs (Material and Erection)			108,300
Interior Walls			91,000
Ventilati n			7,500
Heating			60,000
Comfort Conditioning			20,000
Utilities (Electricity, Gas, Water)			140,000
Subtotal			782,230
Contingency 10%			78,000
Subtotal			860,230
Architectural and Engineering Fees 6%			51,600
Management and Construction Coordination Fees 4%			34,400
Total Building Envelope			946,230
Total Building Envelope Adjusted to 1970 $'s			1,000,000
Services			
Air Supply System 3,000 scfm @ 150 psig (85 m^3/min @ 103 N/cm^2)			40,500
[illegible] @ 150 psig (113 m^3/min @ [illegible]			54,000

FIGURE 6-79a COMMONLY SHARED BUILDING AND UTILITY ITEMS FOR THE CREW TRAINER (FS1), TAKEOFF AND LANDING ENGINEERING SIMULATOR (FS2), AND LAUNCH-CRUISE ENGINEERING SIMULATOR (FS3) SIMULATION FACILITY (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Hydraulic System 1,500 gpm @ 3,000 psig ($5.7\ m^3/min$ @ $2070\ N/cm^2$)			300,000
Substation			200,000
Refrigeration System			317,000
Total Services			911,500

FLIGHT SIMULATOR FACILITIES FS1 CREW TRAINER FACILITY

Facility Purpose:

This facility will provide function and response training in the flight vehicle crew station environment. The simulation must include critical crewman action-vehicle reaction characteristics in all plausible flight phases to ensure adequate crew response to flight situations.

FIGURE 6-79b FACILITY DESCRIPTION AND COSTS – FS1

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Equipment			
Crew Trainer (FS1) consisting of inertial block, six-degree-of-freedom platform, 1,500 lb (6,660 N) ± 7g longitudinal acceleration, ± 5g vertical acceleration, ± 1g lateral acceleration, 1,000°/sec² roll, 500°/sec² pitch and yaw; crew, instructor, and operator stations; visual display, motion system and software; shaker system (four 10,000 lb (44,480 N) shakers)			8,740,000
Installation (25% of total trainer)			2,180,000
System integration and checkout (2% of total trainer)			175,000
Computing complex with digital and analog computers and peripheral equipment			1,660,000
Total Equipment - FS1			12,755,000

FS2 TAKEOFF AND LANDING SIMULATOR FACILITY

Facility Purpose:

This facility will be used to develop and evaluate visual cues necessary for reliability and safety in takeoff and landing flight phases. It will also be used to establish crew capability or effectiveness under the physical environmental conditions during takeoff and landing.

FIGURE 6-79c FACILITY DESCRIPTION AND COSTS – FS2

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Equipment			
Takeoff and Landing Simulator (FS2) Consisting of inertial block, six-degree-of-freedom platform, 2,500 lb (11,100 N) ± 10 g longitudinal acceleration, ± 7g vertical acceleration, ± 2g lateral acceleration, 1,500°/sec² roll, 1,000°/sec² pitch and yaw; crew, instructor, and operator stations; visual display, motion system and software; shaker system (four 15,000 lb (66,600 N shakers)			9,150,000
Installation (25% of total simulator)			2,290,000
System integration and checkout (2% of total simulator)			183,000
Computing complex with digital and analog computers and peripheral equipment			1,660,000
Total Equipment			13,283,000
Common Building and Utility Costs			911,500
Grand Total - FS2			14,194,500

FS3 LAUNCH-CRUISE SIMULATOR FACILITY

Facility Purpose:

Provides development and evaluation of motion and visual cues during launch, boost, glide, and cruise flight phases. It is also needed to provide assessment of crew performance capabilities during these flight phases.

FIGURE 6-79d FACILITY DESCRIPTION AND COSTS – FS3

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Equipment			
Launch-Cruise Engineering Simulator Consisting of inertial block, six-degree-of-freedom platform, 2,500 lb (11,100N), ± 10g longitudinal acceleration ± 7g vertical acceleration. ± 2g lateral acceleration, 1,500°/sec^2 roll 1,000°/sec pitch and yaw; crew, instructor, and operator stations; visual display, motion system, and software; shaker system four 15,000 lb (66,600 N) shakers			9,150,000
25,000g lb (111,000N) centrifuge with hydraulic pass-thru, air pass-thru, 100 channels of control cabling, 60 ft (18.3 m) radius arm, 200 hp (149 kW) varidrive @ 0-25 rpm			410,000
Installation (25% of total simulator)			2,390,000
System integration and checkout (2% of total simulator)			190,000
Computing complex with digital and analog computers and peripheral equipment			1,660,000
Total Equipment - FS3			13,800,000

SOURCES: (a) Facility Definition Study for a Universal Aircraft Flight Simulator Trainer - F. L. Tuttle, F. A. Brown, W. J. Voss; Conductron - Mo. USAF (FTC) TR-68-6 April 1968

(b) Richardson Engineering Service Manual of Commercial-Industrial Estimating and Engineering Standards 1969

(c) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year.

(d) McDonnell Douglas Budget History and Equipment Inventory

FIGURE 6-30 HYFAC GROUND FACILITY ACQUISITION COST SUMMARY

Facility Component	Dollars - Thousands			
	FS1	FS2	FS3	FS 1, FS 2, FS 3
Building Complex (Common)				1,000
Services				
Air Supply				95
Hydraulics				300
Cryogenics				
Substation				200
Refrigeration				317
Water				
Steam Ejector				
Fire Suppression				
Standard Fuel				
Air Filtration				
Disposal Area				
Total Services (Common)				912
Major Equipment				
Environmental Chamber				
Acoustic Shroud				
Sled Track				
Anechoic Chamber				
Flight Simulators	11,095	11,626	12,140	34,861
Test Fixture				
Heaters				
Test Control				
Thermal Control				
Shakers				
Acoustics				
Total Major Equipment	11,095	11,626	12,140	34,861
Miscellaneous Equipment				
Data Acquisition	1,660	1,660	1,660	4,980
Instrumentation				
Total Data Acquisition and Instrumentation	1,660	1,660	1,660	4,980
Grand Total				41,753

FIGURE 6–81 HYFAC GROUND FACILITY OPERATING COSTS SUMMARY

Operating Cost Factor	Dollars Per Hour			
	FS1	FS2	FS3	FS1, FS2, FS3
Building Depreciation = 2.5 Building Cost in \$1000 x 10^{-2}	10	10	15	25
Building Maintenance = Building Cost in \$1000 x 10^{-2}	4	4	6	10
Electricity for Equipment = 1.3 kVA x 10^{-2}	39	39	78	130
Electricity for Pumps = 1.3 gpm x 10^{-2} (8.2 m^3/sec x 10^{-7})	20	20	20	20
Electricity for Refrigeration = 1.3 Tons x 10^{-2} (25.2 Watts)	2	2	5	8
Electricity for Air = 3.9 scfm x 10^{-4} (1.84 m^3/sec x 10^{-8})	1	2	2	3
Steam = 6 scfm x 10^{-5} (3.45 kg/sec x 10^{-2})				
Water = 8.63 gpm x 10^{-4} (5.44 m^3/sec x 10^{-7})				
Equipment Depreciation = 2.5 Equipment Cost in \$1000 x 10^{-2}	340	354	366	1,020
Equipment Maintenance = 2 Equipment Cost in \$1000 x 10^{-2}	[illegible]	283	292	815
Data Acquisition System Maintenance = 1.25 Data Acquisition in \$1000 x 10^{-1}				
Manpower = 6.67 Data Channels x 10^{-2}				
Data Acquisition System Depreciation = 7.15 Equipment Cost in \$1000 x 10^{-2}				
Misc. Equipment Depreciation = 7.15 Equipment Cost in \$1000 x 10^{-2}				
Misc. Equipment Maintenance = 1.25 Equipment Cost in \$1000 x 10^{-2}				
Manpower (Unique Equipment) = No. Men/Item x 10^{1}	500	500	600	1,000
Total Operating Costs \$/Hour	1,188	1,214	1,384	3,035

FIGURE 6-82 HYFAC NONFLOW FLIGHT SIMULATOR FACILITY AREA, MAJOR EQUIPMENT AND UTILITY REQUIREMENTS SUMMARY (S.I. UNITS)

Facility	Code	Major Equipment Requirements	Utilities: Compressed Air: $1.41\ m^3/sec$ at $10.3 \times 10^5\ N/m^2$	Utilities: Compressed Air: $1.88\ m^3/sec$ at $10.3 \times 10^5\ N/m^2$	Test Equipment
Crew Trainer	FS1	Six-Degree-of-Freedom Platform: 6.8×10^2 kg, + 68.6 m/sec^2 Longitudinal Accel, ± 49 m/sec^2 Vert Accel 9.8 m/sec^2 kg^2 Lateral Accel, 1000°/sec^2 Roll, 500°/sec^2 Pitch and Yaw.	○		270° Computer Controlled Visual Display with 4×10^5 Op/sec 32×10^3 Word Memory; Four 4.44×10^4 N Shakers for Buffet; .948 m^3/sec at 20.7×10^6 N/m^2 Hydraulic Power Supply.
Takeoff and Landing Engineering Simulator	FS2	Six-Degree-of-Freedom Platform: 1.133×10^3 kg, + 98 m/sec^2 Longitudinal Accel, ± 68.6 m/sec^2 Vertical Accel, + 19.6 m/sec^2 Lateral Accel, 1500°/sec^2 Roll, 1000°/sec^2 Pitch and Yaw.		○	270° Computer Controlled Visual Display with 4×10^5 Op/sec 32×10^3 Word Memory; Four 6.67×10^4 N Shakers for Buffet; .948 m^3/sec at 20.7×10^6 N/m^2 Hydraulic Power Supply.
Launch-Cruise Engineering Simulator	FS3	1.12×10^5 kg m/sec^2 Centrifuge: Six Degree-of-Freedom Platform: + 98 m/sec^2 Longitudinal Acceleration, 68.6 m/sec^2 Nm^2/kg^2 Vertical Acceleration, ± 19.6 m/sec^2 Lateral Acceleration, 1500°/sec^2 Roll, 1000°/sec^2 Pitch and Yaw.		○	270° Computer Controlled Visual Display with 4×10^5 Op/sec 32×10^3 Word Memory; Four 6.67×10^4 N Shakers for Buffet; .948 m^3/sec at 20.7×10^6 N/m^2 Hydraulic Power Supply.

FIGURE 6–82 HYFAC NON-FLOW FLIGHT SIMULATOR FACILITY AREA, MAJOR EQUIPMENT, AND UTILITY REQUIREMENTS SUMMARY (ENGLISH UNITS)

Facility	Code	Major Equipment Requirements	Utilities: Compressed Air: 3000 scfm at 150 psig	Utilities: Compressed Air: 4000 scfm at 150 psig	Test Equipment
Crew Trainer	FS1	Six-Degree-of-Freedom Platform: 1500 lb ± 7g Longitudinal Acceleration, ± 5g Vertical Acceleration, ± 1g Lateral Acceleration, 1000°/sec^2 Roll, 5000°/sec^2 Pitch and Yaw.	○		270° Computer Controlled Visual Display with 4 x 10^5 Op sec 32 x 10^3 Word Memory; Four 10 kip Shakers for Buffet; 1500 gpm at 3000 psi Hydraulic Power Supply.
Takeoff and Landing Engineering Simulator	FS2	Six-Degree-of-Freedom Platform: 2500 lb, ± 10g Longitudinal Acceleration, ± 7g Vertical Acceleration, ±2g Lateral Acceleration, 1500°/sec^2 Roll, 100°/sec^2 Pitch and Yaw		○	270° Computer Controlled Visual Display with 4 x 10^5 Op/sec 32 x 10^3 Word Memory; Four 15 kip Shakers for Buffet; 1500 gpm at 3000 psi Hydraulic Power Supply.
Launch-Cruise Engineering Simulator	FS3	25,000 g-lb Centrifuge; Six-Degree-of-Freedom Platform: ± 10g Longitudinal Acceleration, ± 7g Vertical Acceleration, ±2g Lateral Acceleration, 1500°/sec^2 Roll, 1000°/sec^2 Pitch and Yaw.		○	270° Computer Controlled Visual Display with 4 x 10^5 Op/sec 32 x 10^3 Word Memory; Four 15 kip Shakers for Buffet; 1500 gpm at 3000 psi Hydraulic Power Supply.

6.9 FLUID SYSTEMS RESEARCH FACILITIES

Hypersonic vehicles will incorporate large integral and non-integral tanks to store the great quantities of fuel that will be required for the operational mission. Two types of fuel may be used, either storable or cryogenic. Certain design and research problems are common to both types of fuel, while others are peculiar to each. The candidate fluid systems test facilities are designed to test full scale components and systems and to provide full duplication of the local environment. Each of the five facilities have environmental chambers, sized to test specimens ranging from full scale fuel tanks down to fuel system components. Simulation levels range from altitude only to altitude, thermal, three axis acceleration, and dynamic mechanical loading.

6.9.1 CRITERIA - Problems common to storable and cryogenic fuels include: 1) thermal protection of fuel storage tanks, 2) dynamic fuel slosh, and 3) high volume flow-rates required for rapid vehicle refueling. In many hypersonic vehicle designs, thermal balance of the aircraft will depend on the heat absorption characteristics of the fuel. Dynamic slosh may be an important, but virtually unexplored area on past programs. Previous slosh studies were primarily concerned with small, compartmentalized wing or fuselage fuel cells on contemporary jet aircraft or in large vertically accelerated rocket fuel tanks. The hypersonic vehicle will utilize large integral tanks parallel to the vehicle centerline, but these tanks will be subjected to horizontal accelerations, rather than axial vertical accelerations as in a rocket, that will cause long duration slosh modes that could seriously affect the vehicle's weight distribution and dynamic characteristics. High volume refueling flow rates are required to enable military vehicles in particular to have a quick turnaround time for a subsequent mission.

Storable fuels will not pose the technological, operational, handling and safety problems that will be posed by cryogenic fuels. Other than the limited experiences gained from manned spacecraft and research vehicles such as the X-15, cryogenic fuels have not been used in an operational manned aircraft. Operational procedures must be developed for the safe manufacture, storage, and handling of cryogenic fuels at airfields. Cryogenic on-board fuel systems must have increased efficiency and reliability. Cryogenic heat exchangers that operate in high heat flux areas (500 Btu/ft^2-sec or 5.65×10^6 W/m^2) will present major challenges in system design, materials selection, and fabrication techniques, requiring extensive testing under realistic environmental flight conditions.

6.9.2 ANALYSIS - Current state of the art test equipment can simulate most environmental and loading conditions for the fuel storage and distribution systems. The major exception is probably in testing high flow rate cryogenic heat exchangers at high heat transfer rates. A series of five fluid test facilities was synthesized to test both storable and cryogenic fuel systems under operational environments.

6.9.3 DESIGN CHARACTERISTICS AND COST SUMMARY - The fluid systems facility concept consists of five test facilities. Due to the safety problems involved in fluid handling, the facilities must be separated, preventing the use of common buildings and services. The facilities are designed to simulate actual flight environments on test specimens up to the major section size (see Figure 6-83). Fuel slosh testing will be conducted on representative sized tanks. The other levels to be duplicated are: altitude, thermal, dynamic acceleration (3-axis), and dynamic

mechanical loading. The levels of environmental simulation and test article size are shown in Figure 6-83. The mechanical load, altitude chambers, thermal, and vibration test systems are similar to those described in Section 6.6.3. The fuel-flow system was designed to test large-scale test articles and also fluid system components. A fluid flow facility is shown in Figure 6-84.

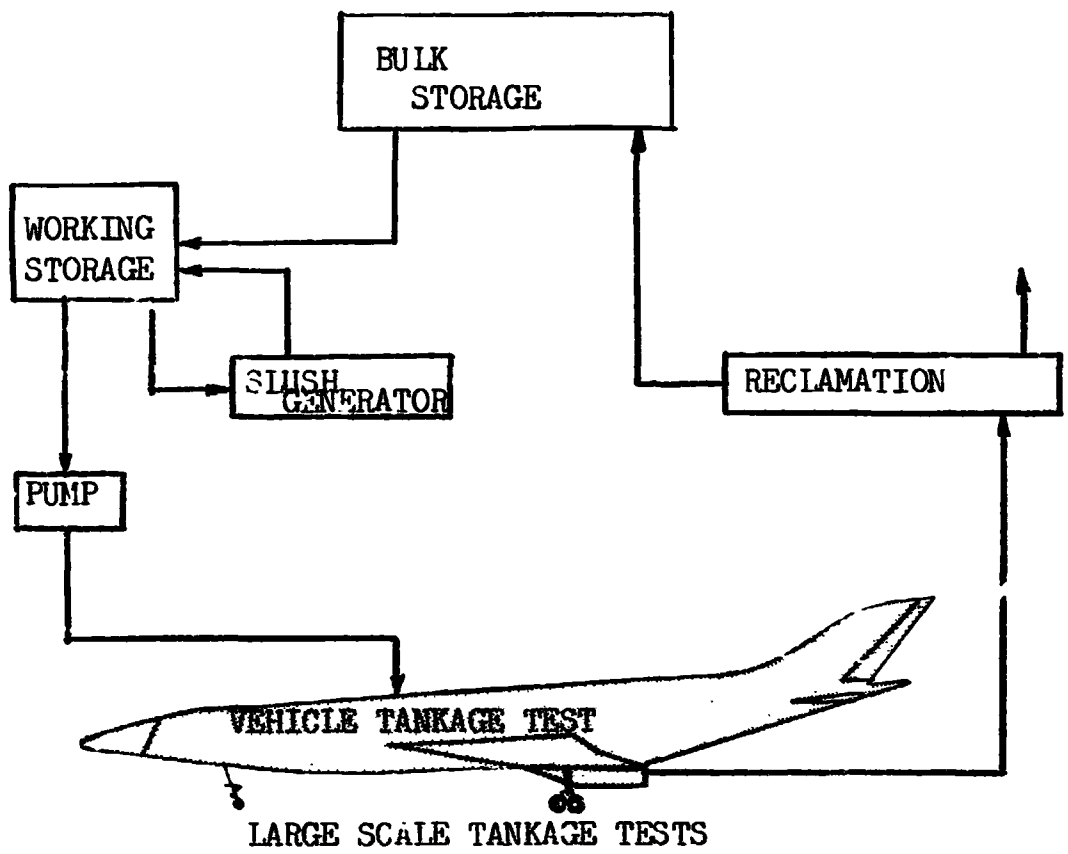
The proposed facilities and test equipment are described in Figure 6-85 a-e. Total facility acquisition and operating costs are shown in Figures 6-86 and 6-87, respectively. Figure 6-88 summarizes the fluid facility utility and service requirements.

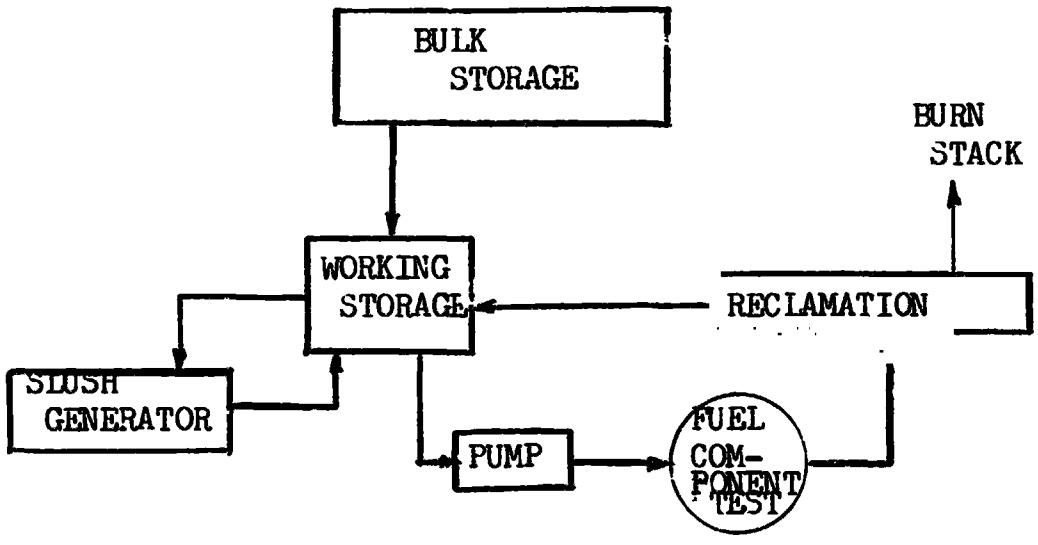
FIGURE 6-83 FLUID SYSTEMS TEST FACILITY MATRIX

Facility / Simulation	F1	F2	F3	F4	F5
Thermal, Mechanical, and Altitude		C	C	MS	
Thermal, Mechanical		C	C	MS	
Mechanical		C	C	MS	
Thermal	MS	C	C	MS	
Altitude	MS	C	C	MS	C
Slosh				MS	
Fuel Flow	MS	C	C	MS	MS

Mechanical = Static and/or Dynamic Loads
FSV = Full-Scale Vehicle
MS = Major Section
C = Component

FIGURE 6-84 CRYOGENIC FUEL TEST SYSTEM SCHEMATIC





FUEL SYSTEM COMPONENT DEVELOPMENT - FUNCTIONAL TESTS

F1 Cryogenic Fluid Heat Exchanger Research Facility

Facility Purpose:

This facility is required to establish the operational characteristics and reliability of crew, passenger, and cargo environmental control systems subjected to simulated flight conditions.

FIGURE 6-85a FACILITY DESCRIPTION AND COSTS – F1

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Services			
Air Supply System 3000 scfm @ 150 psig (85 m^3/min @ 103 N/cm^2)	13.50/scfm (480/scmm)		40,500
Substation 100,000 kVA			1,600,000
Water Supply 2000 gpm @ 80°F (7.6 m^3/min @ 30°C)	20/gpm (5300/m^3/min)		40,000
Cryogenics LH_2 Storage 75,000 gal (284 m^3)	10/gal (2650/m^3)		750,000
Refrigeration			2,280,000
Total Services			4,710,500
Equipment			
Environmental chamber 100 ft (30.4 m) long x 50 ft (15.2 m) diameter with steam ejector			21,100,000
Thermal Control System 450 Channels @ 250 kVA/Channel	5000/Channel		230,000
Heaters 10 Btu/ft^2/sec (110,000 W/m^2) over 10,000 sq ft (929 m^2)	200/ft^2 (2150/m^2)		2,000,000
Data Acquisition 2500 Channels	1000/Channel		2,500,000
Transducers (2500 Units)	250		625,000
Total Equipment			26,455,000
Grand Total Environmental Control Systems Test Facility (F1)			31,165,500

FIGURE 6-85a FACILITY DESCRIPTION AND COSTS – F1 (CONTINUED)

SOURCES:

(a) Richardson Engineering Service Manual of Commercial-Industrial Engineering Standards

(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell-Douglas Corporation Engineering Budget History and Equipment Inventory

F2 Cryogenic Fluid Heat Exchanger Research Facility

Facility Purpose:

Using cryogenic fluids for duct inlet thermal control systems will require the use of this facility for applying high heat transfer rates to structurally loaded heat exchanger systems in order to evaluate heat protection efficiency and structural adequacy in the thermal/mechanical environments experienced in flight.

FIGURE 6-85b FACILITY DESCRIPTION AND COSTS – F2

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Services			
Air Supply System 3,000 scfm @ 150 psig (85 m^3/min @ 103 N/cm^2)	13.50/scfm (480/scmm)		40,500
Substation 25,000 kVA			500,000
Water Supply 1,000 gpm @ 80°F (3.8 m^3/min @ 30°C)	20/gpm (5300/m^3/min)		20,000
Cryogenics 187,000 gal (704 m^3) LH_2	10/gal (2650/m^2)		1,870,000
15 gpm (.05 m^3/min) LH_2 Flow	70/gpm (18,000/m^3/min)		1,050
Refrigeration			570,000
Fire Suppression (Argon Purge)	375/ft^3		37,500
Total Services			3,039,050
Equipment			
Hydraulic Power Supply	15,000		15,000
Load Application Control System 10 Channels	3,000/channel		30,000
Thermal Environment Control System (Ignitrons) 50 Channels @ 500 Channel	5,000/channel		250,000
Heaters 500 Btu/ft^2/sec over 50 sq ft (5,660,000 W/m^2 over 15 m^2)	12,000/ft^2 (129,000/m^2)		600,000
Mechanical Exciter System 10,000 lb (44,400 N) shaker (3 Units)	70,000		210,000

FIGURE 6-85b FACILITY DESCRIPTION AND COSTS – F2 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Data Acquisition System 2,000 Channels	1,000/channel		2,000,000
Transducers (2,000 Units)	250		500,000
Total Equipment Cost			3,605,000
Grand Total Cryogenic Fluid Heat Exchanger Test (F2)			$6,644,050

SOURCES: (a) Richardson Engineering Service Manual of Commercial-Industrial Engineering Standards

(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell Douglas Corporation Engineering Budget History and Equipment Inventory

F3 Cryogenic Fluid Heat Exchanger Research Facility

Facility Purpose:

The use of cryogenic fuels will require the use of this facility for the preliminary design evaluation of materials and system components for operational reliability and safety throughout their applicable thermal/physical environmental range.

FIGURE 6-85c FACILITY DESCRIPTION AND COSTS – F3

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Services			
Air Supply System 5,000 scfm @ 150 psig (141 m^3/min @ 103 N/cm^2)	13.50/scfm (480/scmm)		67,500
Substation 2,000 kVA			60,000
Water Supply 100 gpm @ 80°F (.4 m^3/min @ 30°C)	20/gpm (5300/m3/min)		2,000
Cryogenics 150,000 gal (568 m^3) LH_2 Slush Storage	6/gal (1590/m^3)		900,000
20,000 gpm (76 m^3/min) LH_2 Slush Flow	61/gpm (16,000/m^3/min)		1,220,000
Fire Suppression (Argon Purge)	375/ft^3		5,950
Refrigeration	(13.250/m3)		570
Total Services			2,250,020
Equipment			
Environmental Chamber 20 ft long x 10 ft diameter (6.1 x 3 m) dated at 1 torr (13_ N/m^2)			211,000
Thermal Control System 20 Channels @ 150 kVA/Channel	5,000/channel		7[illegible],000
Heaters 25 Btu/ft^2/sec over 100 ft^2 (284,000 W/m^2 over 9.3 m^2)	400/ft^2 (4300/m^2)		40,000
Mechanical Exciter System 2,000 lb (8,880 N) shaker (6 Units)	15,000		90,000
Data Acquisition System (500 Channels)	1,000/channel		500,000

FIGURE 6-85c FACILITY DESCRIPTION AND COSTS – F3 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Transducers (500 Units)			125,000
Total Equipment			1,041,000
Grand Total Cryogenic Fuel System Components Evaluation Facility (F3)			3,298,020

SOURCES: (a) Richardson Engineering Service Manual of Commercial-Industrial Engineering Standards

(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell Douglas Corporation Engineering Budget History and Equipment Inventory

F4 Cryogenic Fluid Heat Exchanger Research Facility

Facility Purpose:

This facility will be used in establishing the performance characteristics and functional adequacy of cryogenic fuel systems or major subsystems when subjected to flight environment conditions.

FIGURE 6-85d FACILITY DESCRIPTION AND COSTS – F4

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Services			
Air Supply System 15,000 scfm @ 150 psig (124 m^3/min @ 103 N/cm^2)=	13.50/scfm (480/scmm)		206,000
Substation 1,600 kVA			33,600
Water Supply 1,000 gpm @ 80°F (4 m^3/min @ 30°C)	20/gpm (5300 m^3/min)		20,000
Cryogenics 375,000 Gal (1400 m^2) LH_2 Slush	6/gal (1590/m^3)		2,250,000
Storage 70,000 gpm (260 m^3/min) LH_2 Slush Flow	61/gpm (16,100/ m^3/min)		2,560,000
Fire Suppression (Argon Purge)	375/ft^3 (13,250/m^3)		268,000
Refrigeration			570,000
Total Services			5,907,600
Equipment			
Environmental Chamber 100 ft long x 30 ft dia (30.4 x 9.1 m) Rated at 1 torr (133 N/ m^2)			5,300,000
Thermal Control System 200 Channels @ 150 /Chan	5,000/channel		1,000,000
Heaters 25 Btu/ft^2/sec over 1,000 ft^2 (289,000 W/m^2 over 93 m^2)	400/ft^2 (4300/m^2)		400,000
Mechanical Exciter System 2,000 lb (8,880 N) Shaker (30 Units)	10,000		300,000
Data Acquisition System 2,500 Channels	1,000/channel		2,500,000
Transducers (250 Units)	250		625,000
Total Equipment			10,125,000
Grand Total Cryogenic Fuel System Functional Evaluation Facility (F4)			16,032,000

FIGURE 6-85d FACILITY DESCRIPTION AND COSTS – F4 (CONTINUED)

SOURCES:

(a) Richardson Engineering Service Manual of Commercial-Industrial Engineering Standards

(b) Means Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell Douglas Corporation Engineering Budget History and Equipment Inventory

F5 Cryogenic Fluid Heat Exchanger Research Facility

Facility Purpose:

This facility will fulfill requirements for research and development in the storage and handling of cryogenic fuels. The larger vehicle fuel capacity and extreme hazard potential of the cryogenic fuels will require developing safe, efficient storage of fuels and expedient methods to deliver fuel into the vehicle.

FIGURE 6-85e FACILITY DESCRIPTION AND COSTS – F5

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Services			
Air Supply System 5,000 scfm @ 150 psig (141 m^3/min @ 103 N/cm^2)	13.50/scfm (480/scmm)		67,500
Substation 300,000 kVA			465,000
Water Supply 1,000 gpm @ 80°F (4 m^3/min @ 30°C)	20/gpm (5300/m^3/min)		20,000
Cryogenic 748,000 gal (2830 m^3) LH_2	10/gal(2650/m^3)		7,480,000
Storage 70,000 gpm (265 m^3/min) LH_2 Flow	70/gpm(18500/m^3/min)		4,900,000
Fire Suppression (Argon Purge)	375/ft^3 (13,250/m^3)		5,950
Total Services			12,938,450
Equipment			
Environmental Chamber 20 ft long x 10 ft dia (6.1 x 3 m) Rated at 1 torr (133 N/m^2)			211,000
Data Acquisition 500 Channels	1,000/channel		500,000
Transducers (500 Units)	250		125,000
Total Equipment			836,000
Grand Total Cryogenic Fuel Handling Technology Facility (F5)			13,774,450

SOURCES: (a) Richardson Engineering Service Manual of Commercial-Industrial Engineering Standards

(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell-Douglas Corporation Engineering Budget History and Equipment Inventory

FIGURE 6–86 HYFAC GROUND FACILITY ACQUISITION COST SUMMARY

Facility Component	Dollars – Thousands				
	F1	F2	F3	F4	F5
Building Complex					
Services					
Air Supply	41	41	68	206	68
Hydraulics					
Cryogenics	750	1,871	2,120	4,810	12,380
Substation	1,600	500	60	34	465
Refrigeration	2,280	570	1	570	
Water	40	20	2	20	20
Steam Ejector					
Fire Suppression		38	6	268	6
Standard Fuel					
Air Filtration					
Disposal Area					
Total Services	4,711	3,040	2,257	5,908	12,939
Major Equipment					
Environmental Chamber	21,100		211	5,300	211
Acoustic Shroud					
Sled Track					
Anechoic Chamber					
Flight Simulators					
Test Fixture					
Heaters	2,000	600	40	400	
Test Control					
Thermal Control	230	250	75	1,000	
Shakers		210	90	300	
Acoustics					
Total Major Equipment	23,330	1,060	416	7,000	211
Miscellaneous Equipment		45			
Data Acquisition	2,500	2,000	500	2,500	500
Instrumentation	625	500	125	625	125
Total Data Acquisition and Instrumentation	3,125	2,500	625	3,125	625
Grand Total	31,166	6,645	3,298	16,033	13,775

FIGURE 6–87 HYFAC GROUND FACILITY OPERATING COSTS SUMMARY

Operating Cost Factor	Dollars Per Hour				
	F1	F2	F3	F4	F5
Building Depreciation = 2.5 Building Cost in \$1000 x 10^{-2}					
Building Maintenance = Building Cost in \$1000 x 10^{-2}					
Electricity for Equipment = 1.3 kVA x 10^{-2}	1,300	325	26	21	3,900
Electricity for Pumps = 1.3 gpm x 10^{-2} ($8.2 m^3$/sec x 10^{-7})	26	13	261	923	923
Electricity for Refrigeration = 1.3 Tons x 10^{-2} (25.2 Watts)	57	14	2		
Electricity for Air = 3.9 scfm x 10^{-4} ($1.84 m^3$/sec x 10^{-8})		1	3	6	2
Steam = 6 SCFM x 10^{-5} (3.45 kg/sec x 10^{-2})					
Water = 8.63 gpm x 10^{-4} ($5.44 m^3$/sec x 10^{-7})	2	1	1	1	1
Equipment Depreciation = 2.5 Equipment Cost in \$1000 x 10^{-2}	700	108	67	322	329
Equipment Maintenance = 2 Equipment Cost in \$1000 x 10^{-2}	560	82	53	258	263
Data Acquisition System Maintenance = 1.25 Data Acquisition in \$1000 x 10^{-1}	391	312	78	391	78
Manpower = 6.67 Data Channels x 10^{-2}	167	133	33	167	33
Data Acquisition System Depreciation = 7.15 Equipment Cost in \$1000 x 10^{-2}	224	179	45	224	45
Misc. Equipment Depreciation = 7.15 Equipment Cost in \$1000 x 10^{-2}		3			
Misc. Equipment Maintenance = 1.25 Equipment Cost in \$1000 x 10^{-2}		1			
Manpower (Unique Equipment) = No. Men/Item x 10^{1}					
Total Operating Costs \$/Hour	3,427	1,172	569	2,312	5,576

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FIGURE 6–88 HYFAC NONFLOW FLUID RESEARCH FACILITY AREA, MAJOR EQUIPMENT AND UTILITY SUMMARY (ENGLISH UNITS)

FOLDOUT FRAME 1

Facility	Code	Major Equipment Requirements (Gross Sq. Ft.)	Utilities									Fluid
			Water		Compressed Air			Substation				
			100 gpm at 800F	1000 gpm at 800F	3000 scfm at 150 psig	5000 scfm at 150 psig	15,000 scfm at 150 psig	2000 kVA	25,000 kVA	1600 kVA	300,000 kVA	15 gpm LH_2
Environmental Control Systems	F1	100 ft x 50 ft Diameter Environmental Chamber for Pressures to 1 Torr.		○	○							
Cryogenic Fluid Heat Exchanger Test	F2	Argon Fire Suppression System.							○			○
Cryogenic Fuel Handling Technology	F3	20 ft x 10 ft Diameter Environmental Chamber for Pressures to 1 Torr. Argon Fire Suppression System.	○		○	○		○				
Cryogenic Fuel System Components Evaluation	F4	100 ft x 30 ft Diameter Environmental Chamber for Pressures to 1 Torr. Argon Fire Suppression System.		○			○			○		
Cryogenic Fuel System Functional Evaluation	F5	20 ft x 10 ft Diameter Environmental Chamber for Pressures to 1 Torr. Argon Fire Suppression System.		○		○					○	

FOLDOUT FRAME 2

	bstation		Fluid Flow			Fluid Storage					Refrigeration					
	1600 kVA	300,000 kVA	15 gpm LH_2	20,000 gpm LH_2 Slush	70,000 gal. LH_2 Slush	15,000 gal. LH_2 Slush	187,000 gal. LH_2	375,000 gal. LH_2 Slush	75,000 gal. LH_2	748,000 gal. LH_2	110 tons	1100 tons	4400 tons	Data Acquisition Channels (Including Spares)	Transducers Required (Including Spares)	Test Equipment
													O	2,500	2,500	Heat Flux: 10 Btu/sq ft/sec Over 10,000 sq ft
O			O				O		O			O		2,000	2,000	Heat Flux: 500 Btu/sq ft/sec Over 50 sq ft Three 10 kip Shakers.
				O		O					O			500	500	Heat Flux: 25 Btu/sq ft/sec Over 100 sq ft
	O				O			O						2,500	2,500	
		O			O					O				500	500	

FOLDOUT FRAME 1

Facility	Code	Major Equipment Requirements	Utilities									Fluid	
			Water		Compressed Air			Substation					
			0.63×10^{-2} m^3/sec at 26.7°C	6.3×10^{-2} m^3/sec at 26.7°C	14.1 m^3/sec at 10.3×10^5 N/m^2	2.35 m^3/sec at 10.3×10^5 N/m^2	7.07 m^3/sec at 10.3×10^5 N/m^2	100,000 kVA	25,000 kVA	1600 kVA	300,000 kVA	9.45×10^{-4} m^3/sec LH_2	[illegible]
Environmental Control Systems	F1	30.5m x 15.3m Dia Environmental Chamber for Pressures to 133 N/m^2.		○	○								
Cryogenic Fluid Heat Exchanger Test	F2	Argon Fire Suppression System.							○			○	
Cryogenic Fuel Handling Technology	F3	6.09m x 3.05m Dia Environmental Chamber for Pressures to 133 N/m^2 Argon Fire Suppression System.	○		○	○		○					○
Cryogenic Fuel System Components Evaluation	F4	30.5m x 9.14m Dia Environmental Chamber for Pressures to 133 N/m^2 Argon Fire Suppression System.		○			○			○			
Cryogenic Fuel System Functional Evaluation	F5	6.09m x 3.05m Dia Environmental Chamber for Pressures to 133 N/m^2 Argon Fire Suppression System.		○		○					○		

FOLDOUT FRAME 2

FIGURE 6-88 HYFAC NONFLOW FLUID RESEARCH FACILITY AREA, MAJOR EQUIPMENT AND UTILITY SUMMARY (S.I. UNITS)

tation		Fluid Flow			Fluid Storage					Refrigeration					
1500 kVA	300,000 kVA	9.45×10^{-4} m^3/sec LH_2	126×10^{-2} m^3/sec LH_2 Slush	441×10^{-2} m^3/sec LH_2 Slush	56.7 m^3 LH_2 Slush	706 m^3 LH_2	1415 m^3 LH_2 Slush	284 m^3 LH_2	2830 m^3 LH_2	387 kW	3870 kW	15,500 kW	Data Acquisition Channels (Including Spares)	Transducers Required (Including Spares)	Test Equipment
								○				○	2,500	2,500	Heat Flux: 1.13×10^5 Watt/meter^2 Over 929m^2.
		○				○					○		2,000	2,000	Heat Flux: 5.67×10^6 Watt/meter^2 Over 4.64m^2 Three 4.44×10^6 N Shakers.
			○		○					○			500	500	Heat Flux: 2.84×10^5 Watt/meter^2 Over 9.29m^2.
○				○			○						2,500	2,500	
	○			○					○				500	500	

6.10 SUBSYSTEMS, AVIONICS, AND RADIATION RESEARCH FACILITIES

The candidate subsystems test facilities are both designed for tests of full scale components and systems. Complete duplication of the local environment is provided.

Two candidate avionics facilities are proposed, both of which test models of the operational aircraft and its antennae. In such facilities, enough range must be provided for adequate radiation data. They are extensions of current capability in terms of size and represent no increase in technology. For flight conditions of Mach number 12 or less, telemetry can be accomplished at S Band frequencies (2-3 GHz) and communications can be accomplished at X Band frequencies (10 GHz).

The radiation test facility is an attempt to provide a testing capability for the simulation of the radiation and blast environment encountered by potential operational military systems on small sized test specimens.

Test specimens are material samples, structural specimens, avionic systems, and cryogenic tanks.

6.10.1 CRITERIA - The five research facilities were synthesized to develop and test hypersonic vehicle subsystems and components under specialized and unique environmental conditions.

The operational vehicle will require the use of an advanced fire detection and suppression system. In order to gain reliability and confidence in the system, it will be necessary to test the system operation under flight environmental conditions. The system must reliably be able to distinguish between actual fires and the hot environment encountered by the vehicle during hypersonic cruise. In addition, the system must be workable in cryogenic environments.

Landing gear, tires, and energy absorption systems for heavy hypersonic vehicles are of particular importance because of the extreme thermal environments they must endure and the high landing speed characteristics of the vehicle. Special tires, brakes, bearings, and hydraulic systems must be developed for hypersonic use. In order to develop the required landing systems and to minimize the risk of a landing gear failure on an actual landing, a ground test facility is required that will fully simulate the aircraft sink speed and landing energy, and the landing roll-out and braking characteristics of the vehicle.

Military operational vehicles will be required to demonstrate their ability to survive a close proximity nuclear blast. The vehicle will be subjected to mechanical shock, thermal impulses, and nuclear radiation. These environments must be simulated in ground test facilities.

Owing to the sensitivity of the vehicle's aerodynamic configuration to protuberances, flush, recessed antennas must be developed to supply antenna radiation

patterns compatible with communication, navigation and electronic warfare functions. The high dynamic loadings and extreme temperature environment present formidable materials and design problems. Flush, recessed antennas present problems in transmitting and receiving line-of-sight microwave or radio signals. These antennas must be developed under flight environments.

6.10.2 ANALYSIS - The Fire Suppression Systems Test Facility (SS1) will be required to evaluate the fire detection and suppression system under flight environmental conditions. Current environmental test equipment can duplicate the flight conditions. For the protection of test personnel, a catastrophic fire extinguishing system must be incorporated in the test facility. The most effective fire extinguishing system is an argon-foam system. This extinguisher is effective for hydrocarbon fuel fires, but for cryogenic fires where LO_2 is present, no system has been found to be effective.

The Landing Gear Test Facility (SS2) will consist of a drop tower and a sled-track. These facilities are within the present state-of-the-art and should not present any great development problems.

Materials samples, structural components, electronic systems, and cryogenic tanks will be subjected to a simulated nuclear blast in the Nuclear Blast Simulator Facility (R1). The facility was limited to coupon-sized test articles to limit its cost because it will not have a high research value. The avionic systems contained in the vehicle will be tested in two facilities, Anechoic Chamber (A1) and the Microwave Range (A2).

6.10.3 FACILITY DESIGN DESCRIPTIONS AND COSTS - SS1 will subject the entire full-scale aircraft to simulated flight attitude and thermal environments while imposing operational fire hazard conditions. Complete cryogenic and storable hydrocarbon fuel flow is provided.

The Landing Gear Test Facility (SS2) will consist of a drop tower to verify the energy absorption characteristics of the gear and a high load sled track. The drop tower will have a maximum drop height of 75 ft (23.9 m) and a maximum load capability of 750,000 lb (3,330,000 N). The high load sled track will be utilized to test the gear and tires under the high loading and fast touchdown speeds expected of the hypersonic vehicle. A track length of 30,000 ft (9.15 km) was chosen to provide a test time of 45 sec at a maximum speed of 350 knots (180 m/sec). The track should be capable of supporting a 750,000 lb (3,300,000 N) load. The acceleration force will be applied by rocket or turbofan engines.

The Nuclear Blast Simulator (R1) will subject component-sized test articles to intense nuclear radiation, thermal shock, and mechanical shock. Nuclear radiation simulation will include gamma ray, X-ray, and neutron radiation. Thermal pulses up to 1500 B/sec ft^2 (1705 W/m^2) will be simulated.

Antenna radiation patterns and vehicle reflection characteristics will be established in the Anechoic Chamber Facility (A1). The antenna radiation patterns and operational impedance characteristics of the vehicle will be established on the Microwave Range (A2).

A description and a detailed list of test equipment and building costs are presented in Figure 6-89 a-e. A summary of total acquisition costs and facility operating costs are presented in Figures 6-90 and 6-91. Figure 6-92 presents a summary of facility service and utilities.

Figure 6-93 presents a comparison of test article size and environmental simulation levels. From these comparisons it can be readily observed that it is approximately 2.7 times more expensive to simulate both altitude and thermal environments on a full-scale vehicle than to simulate only the thermal environment.

SS1 Fire Suppression Systems

Facility Purpose:

This facility will be required to evaluate the necessarily sophisticated fire detection and suppression systems over the range of all flight environments. The thermal environments induced by hypersonic flight in conjunction with a wide range of ambient pressure environments is conducive to the elevation of fuel oxidation states to a "cool flame" condition (consumption of fuel at very low rates of heat generation). At certain ambient conditions this oxidation process can change to normal, or extremely rapid combustion, with catastrophic results. The facility must, therefore, perform evaluations over all flight plan and abort plan environments.

FIGURE 6–89a FACILITY DESCRIPTION AND COSTS – SS1

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope			
Site Preparation			8,500
Footings and Foundations			20,998
Floors			
Structural Floor 3 ft (1 m) thick steel reinforced concrete on bed rock			503,000
Lateral 8WF beam tie-downs imbedded in structural floor			8,000
Shop and office area 6 inch (15 cm) slab floor on grade			38,000
Steel Framing (Materials and Erection)			2,154,000
Interior Walls (Materials and Erection)			400,000
Chamber - 12 Gage Steel in place		150,000	
Welding		100,000	
Door and Track		200,000	
Painting (2 coat brush)		25,000	
Insulating		600,000	
Subtotal Chamber			1,075,000
Ventilation			6,000
Heating			50,000
Utilities (Electricity, Gas, Water)			115,000
Subtotal			4,378,498
Contingency 10%			437,800
Subtotal			4,816,298

FIGURE 6-89a FACILITY DESCRIPTION AND COSTS – SS1 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Architectural and Engineering Fees 6%			288,000
Management and Construction Coordination Fees 4%			192,000
Total Building Envelope			5,296,298
Total Building Envelope Adjusted to 1970 $'s			5,600,000
Services			
Air Supply System 1,000,000 scfm @ 150 psig (28,300 m^3/min @ 103 N/cm^2)	13.50/scfm (480/scmm)		13,500,000
Substation 775,000 kVA			12,400,000
Water Supply 20,000 gpm @ 80°F (76 m^3/min @ 30°C)	20/gpm (5300/m^3/min)		400,000
Cryogenics 1,500,000 gal (56,800 m^3) LH_2 Storage	10/gal (2650/m^3)		15,000,000
Steam Ejector 1,000,000 scfm (28,300 m^3/min)			120,000,000
Fire Suppression System	311/ft^3 (11,000/m^3)		19,700,000
Total Services			181,000,000
Equipment			
Data Acquisition System 7500 Channels	1,000/Channel		7,500,000
Thermal Control System 1,600 Channels @ 500 kVA/Channel	5,000/Channel		8,000,000
Heaters	300/ft^2 (3230/m^2)		12,200,000
Transducers (7,500 Units)	250		1,875,000
Total Equipment			29,575,000
Grand Total Fire Suppression System Test Facility (SS1)			216,175,000

FIGURE 6-89a FACILITY DESCRIPTION AND COSTS-SS1 (CONTINUED)

SOURCES:

(a) Richardson Engineering Service Manual of Commercial-Industrial Engineering Standards

(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell-Douglas Corporation Engineering Budget History and Equipment Inventory

SS2 Landing Gear Test Facility

Facility Purpose:

This facility will be used to develop landing gear systems, and tires, and to evaluate energy absorbtion capabilities of the landing gear systems. It consists of two basic parts, a drop tower and a high load sled track. The drop tower will be used to simulate vehicle weight and sink speed. A rotating drum will simulate aircraft forward velocity. The sled track will simulate landing run-out. A concrete simulated runway will be laid between the tracks and the sled will provide forward velocity and correct normal loading of the landing gear. In addition to checkout of specific gear systems, the track can be used for hydroplaning tests, anti-skid runway ground tests, and tire tests for all classes of aircraft.

Specifications.

Drop Tower: 75 ft drop (23 m); 750 kip load (3,300,000 N)
Data Acquisition: 200 channels
High Load Sled Track: 30 kft long (10 km)
350 knots (180 m/sec)
750 kip (3,300,000 N)

FIGURE 6-89b FACILITY DESCRIPTION AND COSTS – SS2

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope			
Site Preparation			5,000
Footings and Foundations			3,210
Floors			
Structural Floor 20 ft (6.1 m) deep excavation to bed rock			50,000
Steel Framing (Material and Erection)			43,625
Walls and Roofs (Material and Erection)			16,500
Ventilation			1,200
Heating			7,500
Utilities (Electricity, Gas, Water)			15,000
Subtotal			142,035
Contingency 10%			14,000
Subtotal			156,035
Architectural and Engineering Fees 6%			9,360

FIGURE 6-89b FACILITY DESCRIPTION AND COSTS – SS2 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Management and Construction Coordination Fees 4%			6,240
Total Building Envelope			171,635
Total Building Envelope Adjusted to 1970 $'s			181,000
Services			
Air Supply System 2,000 scfm @ 500 psig (57 m^3/min @ 345 N/cm^2)	13.50/scfm (480/scmm)		27,000
Substation 150 kVA			3,000
Total Services			30,000
Equipment			
General Purpose Laboratory Equipment			400,000
Data Acquisition System 200 Channels	1,000/Channel		200,000
Drop Tower 650 Tons (5,760,000 N)			390,000
Sled Track			
Excavation 60 ft wide x 20 ft deep x 30,000 ft long (18.3 x 6.1 x 9250 m)			2,100,000
Concrete Track Base			13,700,000
Track (Standard Railroad)			4,500,000
Equipment			90,000
Transducers (200 Units)			50,000
Total Equipment			21,430,000
Grand Total Landing Gear Test Facility			21,641,000

SOURCES: (a) Richardson Engineering Service Manual of Commercial-Industrial Engineering Standards

(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell-Douglas Corporation Engineering Budget History and Equipment Inventory

R1 Nuclear Blast Simulation Facility

Facility Purpose:

This facility is required to assess the vulnerability of systems and structural components to the affects of high intensity thermal and nuclear irradiation associated with a proximity nuclear detonation.

FIGURE 6-89c FACILITY DESCRIPTION AND COSTS – R1

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope			
Site Preparation			6,000
Footings and Foundations			6,700
Floors 22,500 ft^2 (2080 m^2) 6 inch (15 cm.) slab floor			22,500
Reactor Pits			10,000
Steel Framing (Materials and Erection)			117,800
Walls and Roofs			177,000
Shielding			1,000,000
Ventilation			2,700
Heating			30,000
Utilities (Electricity, Gas, Water)			58,000
Subtotal			1,430,700
Contingency 10%			43,000
Subtotal			1,473,700
Architectural and Engineering Fees 6%			28,600
Management and Construction Coordination Fees 4%			19,000
Total Building Envelope			1,521,300
Total Building Envelope Adjusted to 1970 $'s			1,551,000
Services			
Air Supply System 1,500 cfm @ 80 psi (43 m^3/min @ 55 N/cm^2)	13.50/scfm (480/scmm)		20,600
Air Filtration System			100,000
Substation 5,000 kVA			125,000

FIGURE 6-89c FACILITY DESCRIPTIONS AND COSTS – R1 (CONTINUED)

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Water Supply 2,000 gpm (6.4 m^3/min) decontamination flush	20/gpm (5300/m^3/min)		40,000
Cryogenics 1,000 gal (3.2 m^3) LO_2 Storage	8/gal (2100/m^3)		8,000
25 gpm (.1 m^3/min) LO_2 Flow	70/gpm (18,500/m^3/min)		1,750
1,000 gal (3.2 m^3) LH_2 Storage	10/gal (2650/m^3)		10,000
25 gpm (.1 m^3/min) LH_2 Flow	70/gpm (18,500/m^3/min)		1,750
1,000 gal (3.2 m^3) LN_2 Storage	7/gal (1850/m^3)		7,000
25 gpm (.1 m^3/min) LH_2 Flow	70/gpm (18,500/m^3/min)		10,000
Total Services			325,850
Equipment			
General Purpose Laboratory Equipment			400,000
Data Acquisition System 100 Channels	1,000/Channel		100,000
High Intensity Nuclear Radiation Sources			
δ - 10^{15} Rad/Sec over 0.5 ft^2 (.04 m^2)			300,000
X - 3 x 10^{13} Rad/Sec over 0.5 ft^2 (.04 m^2)			75,000
N - 10^{14} N/cm^2/sec over 0.5 ft^2 (.04 m^2)			100,000
High Intensity Thermal Radiation Source 1,500 Btu/ft^2/sec over 0.5 ft^2 for 0.5 sec (1.7 x 10^7 W/m^2 over .04 m^2)			100,000
Environmental Chamber 6 ft long x 4 ft diameter (1.8 x 1.2 m) rated at 1 Torr (133 N/m^2)			80,000
Transducers (100 Units)			25,000
Total Equipment			1,180,000
Grand Total Nuclear Blast Simulator (R1)			3,056,850

FIGURE 6-89c FACILITY DESCRIPTION AND COSTS – R1 (CONTINUED)

SOURCES:

(a) Richardson Engineering Service Manual of Commercial-Industrial Engineering Standards

(b) Mean's Average 1968 Construction Cost and Labor Index Historical Average Adjusted to a 1970 Base Year

(c) McDonnell-Douglas Corporation Engineering Budget History and Equipment Inventory

A1 Anechoic Chamber

Facility Purpose:

This facility is necessary to provide a totally absorbing background to simulate free space for the establishment of antenna radiation patterns and vehicle radar reflection characteristics.

FIGURE 6-89d FACILITY DESCRIPTION AND COSTS – A1

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope			
Site Preparation			6,000
Footings and Foundations			16,430
Floors 32,000 sq ft (2970 m^2) 6 inch (15 cm) Slab on Grade			21,400
Steel Framing (Material and Erection)			103,515
Walls and Roofs			112,500
Comfort Conditioning			20,000
Ventilation			7,500
Heating			69,000
Utilities (Electricity, Gas, Water)			140,000
Sub Total			487,345
Contingency 10%			48,700
Sub Total			536,045
Architectural and Engineering Fees 6%			32,200
Management and Construction Coordination Fees 4%			21,400
Total Building Envelope			589,645
Total Building Envelope Adjusted to 1970's			624,000
Equipment			
General Purpose Laboratory Equipment			100,000
Anechoic Chamber 100 ft x 100 ft x 300 ft long (30.4 x 30.4 x 91.2 m)			2,300,000
Model Positioner 100,000 ft lb (135,600 N-m) Capacity			40,000
Data Acquisition System 50 Channels	1000/Channels		50,000
Transducers (50 Units)	250		12,500
Total Equipment			2,502,500
Grand Total Anechoic Chamber (A1)			3,126,500

A2 Microwave Range

Facility Purpose:

This facility is necessary to establish full scale antenna radiation patterns and operational impedance of antenna systems.

FIGURE 6-89e FACILITY DESCRIPTION AND COSTS – A2

ITEM	UNIT COST	EXTENDED COST	TOTAL COST
Building Envelope			
Site Preparation (Include Clearing 640 Acres (2.6 km^2))			326,000
Footings and Foundations			1,200
Floors 900 ft^2 (84 m^2) 6 inch (15 cm)			630
Slab on Grade			
Steel Framing (Material and Erection)			10,300
Walls and Roofs (Material and Erection)			2,500
Comfort Conditioning			600
Ventilation			300
Heating			1,800
Utilities (Electricity, Gas, Water)			4,200
Subtotal			347,530
Contingency 10%			34,700
Subtotal			382,230
Architectural and Engineering Fees 6%			22,900
Management and Construction Coordination Fees 4%			15,300
Total Building Envelope			420,430
Total Building Envelope Adjusted to 1970's			444,000
Equipment			
General Purpose Laboratory Equipment			100,000
Data Acquisition System 50 Channels			50,000
Model Positioner 100,000 ft lb (135,600 N-m)			40,000
Capacity, Transmission Tower			60,000
Transducers (50 Units)			12,500
Total Equipment			262,500
Grand Total Microwave Range (A2)			706,500

FIGURE 6–90 HYFAC GROUND FACILITY ACQUISITION COST SUMMARY

Facility Component	Dollars – Thousands				
	SS1	SS2	R1	A1	A2
Building Complex	5,600	181	1,551	624	444
Services					
Air Supply	13,500	21	21		
Hydraulics					
Cryogenics	15,000		31		
Substation	12,400	3	125		
Refrigeration					
Water	400		40		
Steam Ejector	120,000				
Fire Suppression	19,700				
Standard Fuel					
Air Filtration			100		
Disposal Area			10		
Total Services	181,000	30	326		
Major Equipment					
Environmental Chamber	1,075		80		
Acoustic Shroud					
Sled Track		20,390			
Anechoic Chamber				2,300	
Flight Simulators					
Test Fixture					
Heaters	12,200		100		
Test Control					
Thermal Control	8,000				
Shakers					
Acoustics					
Total Major Equipment	20,[illegible]	20,390	180	2,300	
Miscellaneous Equipment		790	875	140	200
Data Acquisition	7,500	200	100	50	50
Instrumentation	1,875	50	25	13	13
Total Data Acquisition and Instrumentation	9,375	250	125	63	63
Grand Total	216,175	21,641	3,057	3,127	707

FIGURE 6–91 HYFAC GROUND FACILITY OPERATING COST SUMMARY

Operating Cost Factor	Dollars Per Hour				
	SS1	SS2	R1	A1	A2
Building Depreciation = 2.5 Building Cost in \$1000 x 10^{-2}	113	5	39	16	11
Building Maintenance = Building Cost in \$1000 x 10^{-2}	45	2	16	6	4
Electricity for Equipment = 1.3 kVA x 10^{-2}	10,100	2	65		
Electricity for Pumps = 1.3 gpm x 10^{-2} (8.2 m^3/sec x 10^{-7})	260		27		
Electricity for Refrigeration = 1.3 Tons x 10^{-2} (25.2 Watts)					
Electricity for Air = 3.9 scfm x 10^{-4} (1.84 m^3/sec x 10^{-8})	390	1	1		
Steam = 6 SCFM x 10^{-5} (3.45 kg/sec x 10^{-2})	60				
Water = 3.63 GPM x 10^{-4} (5.44 m^3/sec x 10^{-7})	17		2		
Equipment Depreciation = 2.5 Equipment Cost in \$1000 x 10^{-2}	5,050	510	13	58	
Equipment Maintenance = 2 Equipment Cost in \$1000 x 10^{-2}	4,040	408	10	46	
Data Acquisition System Maintenance = 1.25 Data Acquisition in \$1000 x 10^{-1}	391	31	16	8	8
Manpower = 6.67 Data Channels x 10^{-2}	500	13	7	3	3
Data Acquisition System Depreciation = 7.15 Equipment Cost in \$1000 x 10^{-2}	224	18	9	5	5
Misc. Equipment Depreciation = 7.[illegible] Equipment Cost in \$1000 x 10^{-2}		57	63	10	14
Misc. Equipment Maintenance = 1.25 Equipment Cost in \$1000 x 10^{-2}		10	11	2	3
Manpower (Unique Equipment) = No. Men/Item x 10^{1}				250	250
Total Operating Costs \$/Hour	22,415	1,057	279	404	298

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FOLDOUT FRAME 1

FIGURE 6–92 HYFAC NONFLOW SUBSYSTEM NUCLEAR BLAST SIMULATOR, AND AVIONICS TEST FACILITIES AREA, MAJOR EQUIPMENT, AND UTILITY REQUIREMENT SUMMARY (ENGLISH UNITS)

Facility	Code	Area Requirements (Gross Sq. Ft.)	Major Equipment Requirements
Fire Suppression System Test Facility	SS1	100 ft x 50 ft Structural Floor, 100 ft High Bay	350 ft x 150 ft x 100 ft Environmental Chamber for Pressures to 1 Torr. Argon Fire Suppression System.
Landing Gear Test Facility	SS2		Drop Tower with 650 ton Load Capacity, 75 ft Drop; 35,000 ft Long Sled Track.
Nuclear Blast Simulator	R1		High Intensity Thermal Radiation Source 1500 Btu/sq ft/sec; High Intensity Nuclear Radiation Source γ at 10^{15} Rad/sec; X at 3 x 10^{13} Rad/sec; N at 10^{19} N/cm^2/sec; 6 ft x 4 ft Diameter Environmental Chamber for Pressures to 1 Torr.
Anechoic Chamber	A1	900 sq ft Control Complex; 100 ft x 100 ft x 800 ft Microwave Anechoic Chamber –30 dB at 1000 MHz	100,000 ft-lb Model Positioner.
Microwave Range	A2	400 sq ft Control Complex; 1 sq mile Test Range	150 ft High, 100,000 ft-lb Model Positioners.

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FOLDOUT FRAME 2

Major Equipment Requirements	Utilities								Steam Ejector	Fluid Flow			Fluid Storage				Data Acquisition Channels (Including Spares	Transducers Required
	Water		Compressed Air			Substation												
	2000 gpm at 80 psi	20,000 gpm at 80°F	1500 scfm at 80 psig	2000 scfm at 500 psig	1 x 10^6 scfm at 150 psig	150 kVA	5000 kVA	775,000 kVA	1,100,000 scfm	25 gpm LH_2	25 gpm LO_2	25 gpm LN_2	1000 gal. LH_2	1,500,000 gal. LH_2	1000 gal. LO_2	1000 gal. LN_2		
ft x 150 ft x 100 ft Environmental Chamber for Pressures Torr. Argon Fire Suppression System.		O			O			O	O					O			7,500	7,5
Tower with 650 ton Load Capacity, 75 ft Drop; ft Long Sled Track.				O		O											200	
Intensity Thermal Radiation Source 1500 Btu/sq ft/sec; Intensity Nuclear Radiation Source γ at 10^{15} Rad/sec; 3 x 10^{13} Rad/sec; N at 10^{19} N/cm^2/sec; 6 ft x 4 ft meter Environmental Chamber for Pressures to 1 Torr.	O		O				O			O	O	O	O		O	O	100	
000 ft-lb Model Positioner.																	50	50
High, 100,000 ft-lb Model Positioners.																	50	50

FOLDOUT FRAME 3

Fluid Flow			Fluid Storage						
25 gpm LH_2	25 gpm LO_2	25 gpm LN_2	1000 gal. LH_2	1,500,000 gal. LH_2	1000 gal. LO_2	1000 gal. LN_2	Data Acquisition Channels (Including Spares	Transducers Required (Including Spares)	Test Equipment
				○			7,500	7,500	Heat Flux: 18 Btu/sq ft/sec Over 40,000 sq ft
							200	200	
○	○	○	○		○	○	100	100	50,000 sq ft Remote Storage and Disposal area; 1 μ Air Filtration System; Water Flush in Test Areas.
							50	50	
							50	50	

FOLDOUT FRAME 1

Facility	Code	Area Requirements (Gross m^2)	Major Equipment Requirements
Fire Suppression System Test Facility	SS1		106.8m x 45.7m x 30.5m Environmental Chamber to 133 N/m^2 Argon Fire Suppression System.
Landing Gear Test Facility	SS2	30.5m x 15.3m Structural Floor, 30.5m High Bay.	Drop Tower with 5.78×10^6 N Load Capacity, 22. 10,680 m Long Sled Track.
Nuclear Blast Simulator	R1		High Intensity Thermal Radiation Source 1.7 x 10^7 High Intensity Nuclear Radiation Source: γ at 10^3, X at 3×10^{11} Joule/kg/sec; N at 10^{23} Neutron/m^2; 1.83m x 1.22m Dia Environmental Chamber for Pres
Anechoic Chamber	A1	83.6m^2 Control Complex; 30.5m x 30.5m x 91.4m Microwave Anechoic Chamber with 9.9×10^4 Watts/$meter^2$ absorb at 1000 MHz.	
Microwave Range	A2	83.6 m^2 Control Complex; 2.86×10^6 m^2 Test Range.	45.7m High, 1.318×10^4 m-kg Model Positioners.

FIGURE 6–92 HYFAC NONFLOW
AND AVIONICS TEST FAC
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FOLDOUT FRAME 2

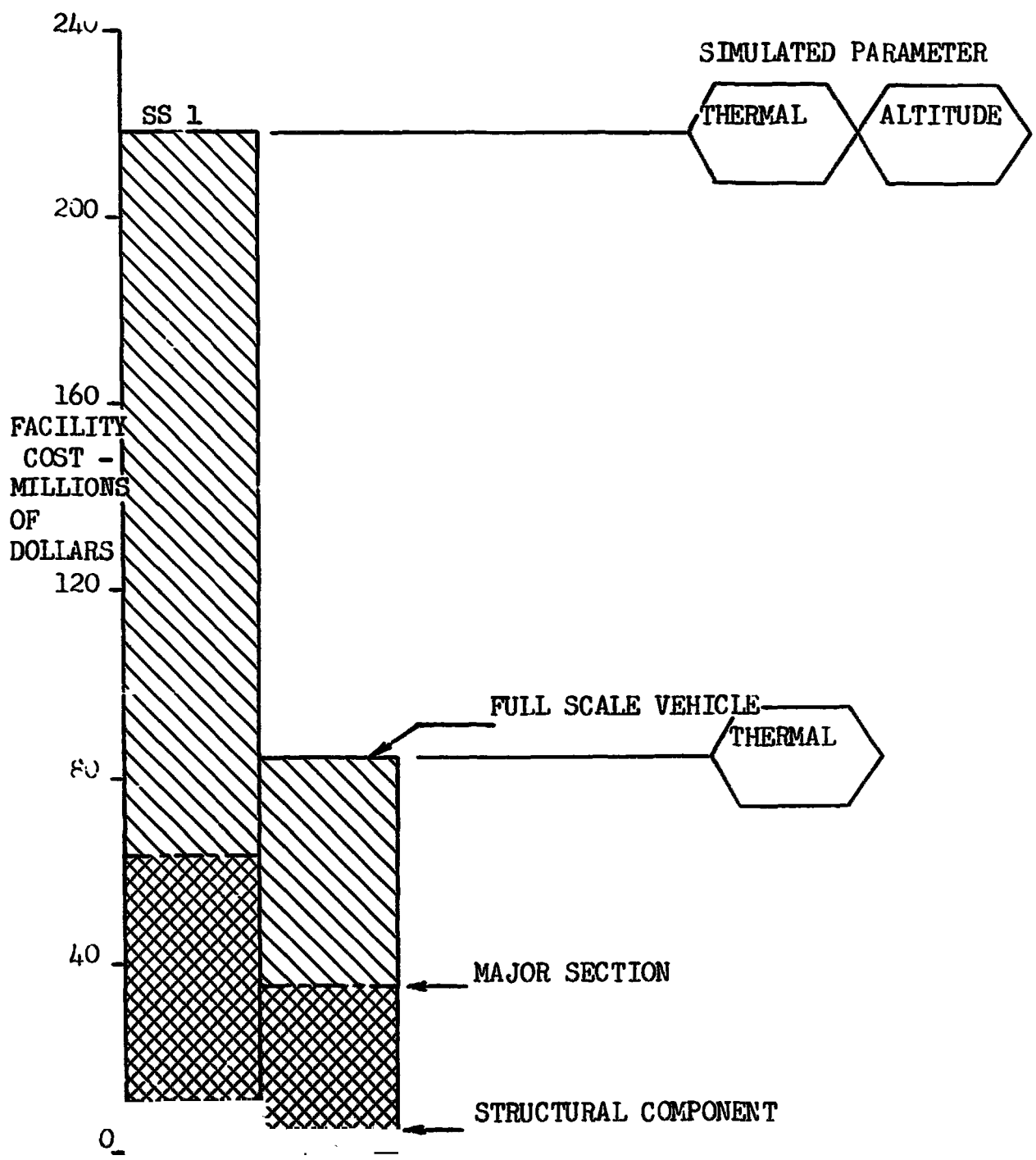
Major Equipment Requirements	Utilities: Water		Utilities: Compressed Air			Utilities: Substation			Steam Ejector	Fluid Flow			Fluid Storage				Data Acquisition Channels (Including Spares)
	12.6×10^{-2} m^3/sec at 55.3×10^4 N/m^2	126×10^{-2} m^3/sec at 26.7°C	0.707 m^3/sec at 5.53×10^5 N/m^2	0.944 m^3/sec at 35.6×10^5 N/m^2	47.2 m^3/sec at 10.3×10^5/m^2	150 kVA	5000 kVA	775,000 kVA	574 kg/sec	15.75×10^{-4} m^3/sec LH_2	15.75×10^{-4} m^3/sec LO_2	15.75×10^{-4} m^3/sec LN_2	3.78 m^3 LH_2	5670 m^3 LH_2	3.78 m^3 LO_2	3.78 m^3 LN_2	
106.8m x 45.7m x 30.5m Environmental Chamber for Pressures to 133 N/m^2 Argon Fire Suppression System.		○			○			○	○					○			7,500
Drop Tower with 5.78×10^6 N Load Capacity, 22.9m Drop; 10,680 m Long Sled Track.				○		○											200
High Intensity Thermal Radiation Source 1.7×10^7 Watts/m^2; High Intensity Nuclear Radiation Source: γ at 10^3 Joule/kg/sec; X at 3×10^{11} Joule/kg/sec; N at 10^{23} Neutron/m^2/sec; 1.83m x 1.22m Dia Environmental Chamber for Press to 133 N/m^2	○		○				○			○	○	○	○		○	○	100
																	50
45.7m High, 1.318×10^4 m-kg Model Positioners.																	50

FIGURE 6-92 HYFAC NONFLOW SUBSYSTEM NUCLEAR BLAST SIMULATOR, AND AVIONICS TEST FACILITIES AREA, MAJOR EQUIPMENT, AND UTILITY REQUIREMENT SUMMARY (S.I. UNITS)

FOLDOUT FRAME 3

Steam Ejector	Fluid Flow			Fluid Storage						
574 kg/sec	15.75×10^{-4} m^3/sec LH_2	15.75×10^{-4} m^3/sec LO_2	15.75×10^{-4} m^3/sec LN_2	3.78 m^3 LH_2	5670 m^3 LH_2	3.78 m^3 LO_2	3.78 m^3 LN_2	Data Acquisition Channels (Including Spares)	Transducers Required (Including Spares)	Test Equipment
○					○			7,500	7,500	Heat Flux: 2.04×10^5 Watt/meter^2 Over 3710 m^2.
								200	200	4640 m^2 Remote Storage and Disposal Area; 1 μ Air Filtration System; Water Flush in Test Areas.
	○	○	○	○		○	○	100	100	
								50	50	
								50	50	

FIGURE 6–93 FIRE SUPPRESSION SYSTEM TEST ARTICLE SIZE – SIMULATION LEVEL FACILITY COST COMPARISON



6.11 COST METHODOLOGY

The major ground research facility costs may generally be broken into three categories: 1) building envelope, 2) test equipment, and 3) services and utilities. The cost of facility site acquisitions were not included because it was assumed that these sites would be already available.

Building envelope costs were developed by sizing the required building complex. Except where special capabilities must be incorporated in the building for unique testing capability, simple, low cost buildings were used for office, laboratory, and test areas. Building floors not subjected to structural load bearing tests are 6 inch (15 cm) concrete. Exterior walls for high-bay test areas are pre-enameled sandwich panels with 1.5 inch (4 cm) thick insulation. Office areas are of curtain-wall construction with continuous windows. Roofs of a built-up type on a metal roof deck support were used for all types of buildings. Special building characteristics were included in each individual building description.

Test equipment costs were divided into major equipment items and miscellaneous test equipment. Generally, only those items whose cost was more than one million dollars ($1,000,000) were considered as major equipment. Each major item was costed separately in the preceding facility descriptions. All other types of general test equipment were estimated as a lump-sum cost. Data acquisition systems were assumed to be digital systems capable of acquiring, recording, computing, reducing, and printing out all types of test data. Instrumentation costs were extended over a vehicle test program and include thermocouples, strain gages, accelerometers, pressure transducers, deflection transducers, and load cells. The data acquisition and instrumentation system costs were based on past histories of MDC budgets.

The cost of the flow facility test legs, storage tanks, and piping were considered a sub-category of building envelope costs. These costs were estimated by using standard building construction estimating practices and the special techniques outlined in subsequent paragraphs.

Service and utility costs were determined by establishing the kind and amount of utilities needed to perform certain tests in the proposed facilities. The major utility requirements are presented with each individual facility description. Basic utility costs were developed on a per unit basis and are shown in Figure 6-94 along with pertinent operating and equipment facts.

All costs were calculated in 1970 dollars according to the curve shown in Figure 6-95.

6.11.1 GAS DYNAMIC FACILITY COSTS - The costs of GD2 and GD3 were determined from preliminary design studies prepared by Sverdrup, Parcel and Associates, Inc. (St. Louis, Missouri) and Fluidyne Corp. (Minneapolis, Minnesota) for other high Reynolds number test facilities. Cost increments were added to provide for larger compressors, prime movers, fans, and test sections. Major test equipment items were estimated from data provided by past budgets of the MDC Gas Dynamic Laboratory.

The proposed non-continuous hypersonic tunnels (GD4, 7, 15, and 16) were costed by the Utility Factor Method. From the cost histories of previously acquired

FIGURE 6-94 SERVICE AND UTILITY COST SUMMARY

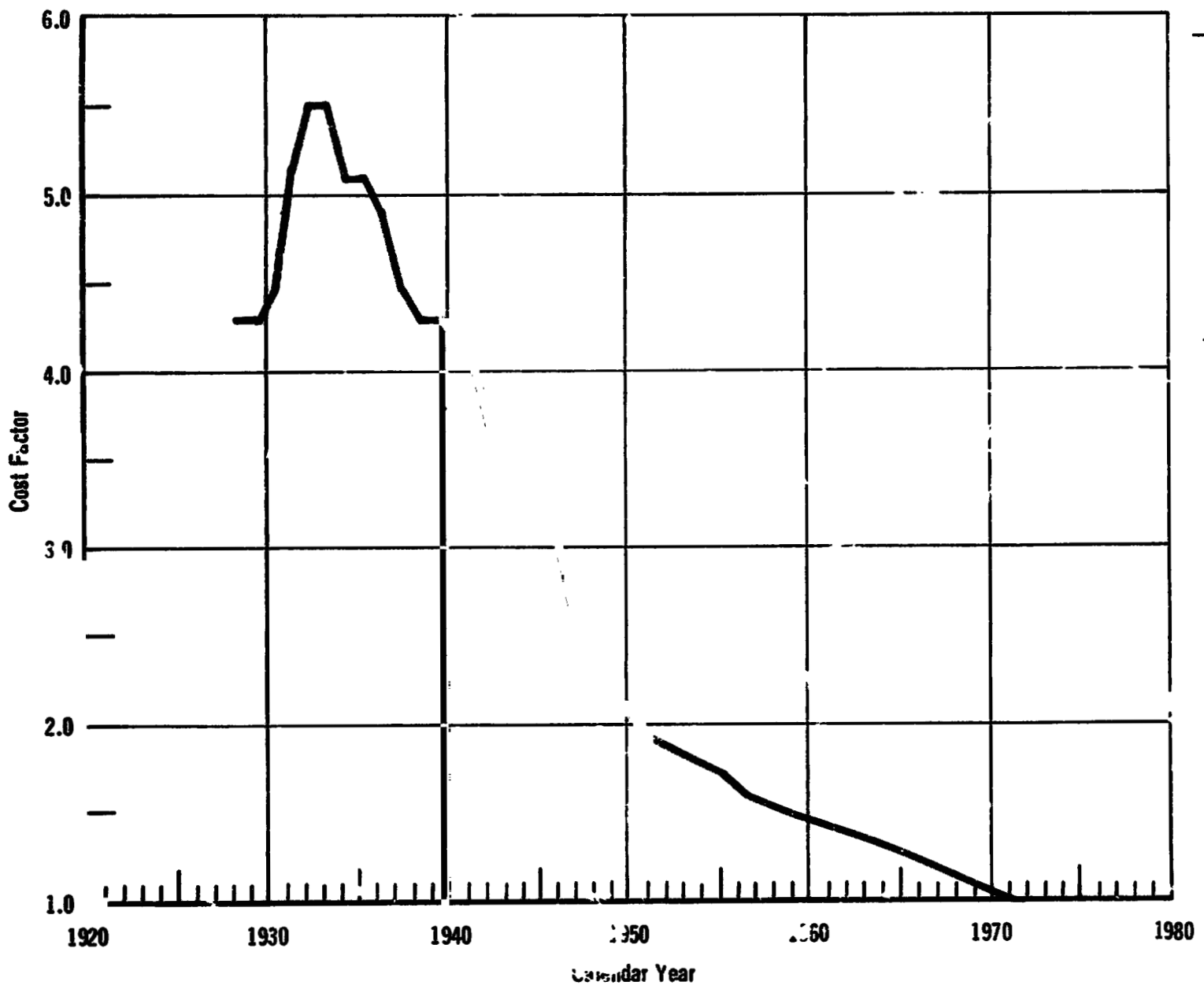
SERVICE	OPERATING FACTORS	EQUIPMENT	COST	SOURCE
Air Supply	o Compressor station capable of delivering one-third of the required scfm flow rate. o Storage on the basis of 10% of 140 minutes multiplied by the maximum flow rate.	o Compressor o Prime mover o Storage tanks o Pipe loop	$13.50/scfm of use ($478.00 per meter^3/sec of use)	
Water Supply	o Process water at 80°F (26.7°C) with a 24°F ΔT (13°C) o Water treatment not required	o Cooling tower section with blowers o Concrete basin o Lift pumps o Pipe loop	$20.00/gpm of use ($90.00 per cu meter/sec of use)	
Substation	o Transformation from nominal 15 kV, 3 Ø supply o 1000 ampere minimum current for each secondary circuit	o Primary air load break switch o Secondary switch-gear o Delta primary/ wye secondary transformer(s)	$20.00/kVA	
Steam Ejector	o One gpm of water provides 500 lb (227 kg) of steam per hour o Chemical steam generator o Short duration high mass flow for chamber evacuation o Low mass flow to maintain 1 torr (133 N/m^2) over sustained periods o Chemicals for steam generator to be brought in via railroad and stored in tank cars on sidings adjacent to facility.	o Steam ejector o Steam generator o Chemical transfer pumps o Water transfer pumps	$120.00/scfm of mass flow ($57.90 per kg/sec of mass flow)	
Cryogenics and Standard Fuel	o Storage and flow requirements	o Pumps o Storage tanks o Pipe loop		

FIGURE 6-94 SERVICE AND UTILITY COST SUMMARY (CONTINUED)

SERVICE	OPERATING FACTORS			EQUIPMENT	COST	SOURCE
Cryogenics and Standard Fuel (Cont)		Costs		Costs		
		Storage (gal)	Pumping (gpm)	Storage (cu meters)	Pumping (m^3/sec)	
	H_2Slush	$6.00	$61.00	$1,585.00	$269.00	
	LH_2	$10.00	$70.00	$2,640.00	$317.00	
	LO_2	$8.00	$70.00	$2,115.00	$317.00	
	LN_2	$7.00	$70.00	$1,855.00	$317.00	
	JP-4	$4.00	$70.00	$1,060.00	$317.00	
Refrigeration	o 1 ton of refrigeration is required to remove 12,000 Btu/hr (12.7 x 10^6 J/hr) from the test specimen			o Compressors o Prime movers o Cooling towers o Chiller pumps o Air handling systems	$500.00/ton ($142.00/kW)	
Hydraulics	o 1500 gpm @ 3000 psi (5.7 m^3/min @ 2070 N/cm^2)			o Pump o Prime mover o Pipe loop	$200.00/gpm ($900.00 per cu meter/sec)	
Air Filtration	o Capable of filtering 1 μ particles in test areas			o Filter o Blower o Air return system	$100,000/ System	
Disposal Area	o Underwater disposal using concrete filled drums				$10,000	
Fire Suppression	o NASA Management Instruction 8825.2 specifying Operational Readiness Inspections in compliance with MSC Safety Manual, Part 7, Man - Rating Requirements, Rev. 8, 15 May 1967 for facilities used for manned testing in vacuum or oxygen rich environments.			o Argon purge and/or foam quench	$3.75/cu ft ($40.30/cu meter)	

FIGURE 6–95 HISTORICAL COST FACTOR FOR EQUIPMENT AND BUILDING CONSTRUCTION ADJUSTED FOR A 1970 BASE YEAR

Means 1968 Yearly Price Index for Equipment and Building Costs, Historical Average



$$\text{Cost Factor for 1970 Costs} = \frac{112}{\text{Price Index}}$$

Year	Index	Year	Index
1970	112	1940	27
1969	106	1939	26
1968	100	1938	26
1967	95	1937	25
1966	92	1936	23
1965	88	1935	22
1964	86	1934	22
1963	84	1933	20
1962	82	1932	20
1961	80	1931	22
1960	79	1930	25
1959	77	1929	26
1958	75	1928	26
1957	73		
1956	70		
1955	66		
1954	64		
1953	63		
1952	61		
1951	59		
1950	56		
1949	53		
1948	53		
1947	48		
1946	39		
1945	34		
1944	33		
1943	32		
1942	31		
1941	28		

hypersonic tunnels, many of which are similar in operating characteristics to the proposed tunnels, a series of curves were developed that showed the correlation of total facility capability to acquisition cost. The facility capability was determined to be a function of run-time and test section diameter. The facilities used to prepare this cost capability correlation curve are shown in Figure 6-96. The facilities' run-times were evaluated and a discretionary percentage value determined. This run-time value (Factor "A") is shown in Figure 6-97. It was judged that a test section diameter of 120 inches (3.0 m) would have a value of 100% because the quality of the data may not significantly improve as the tunnel size was increased above this diameter. In Figure 6-98, a curve was developed that indicates the change in the size factor (Factor "B") as the test section size is increased. The product of the run-time value (Factor "A") and the test section size (Factor "B") is termed the Total Capability Factor. All three factors were determined for each of the existing facilities in Figure 6-96 and were therein presented. The acquisition costs of the existing facilities were plotted against their respective Total Capability Factor and a set of curves was fitted to these data that generally shows the cost-facility capability correlation (Figure 6-99). By applying the same evaluation techniques to the proposed facilities and extrapolating the curves, a cost estimate of the proposed facilities could be determined. A 30 percent increment was added to these estimated costs to provide the necessary services and utilities. Major equipment, data acquisition, and instrumentation cost were determined from MDC Gas Dynamic Laboratory budgets.

The GD12 facility is a proposal to modify the NOL 1000 ft (305 m) Hyperballistics Range by increasing the launcher diameter and allowable pressurization range to 5 atm. (50.7 N/cm^2). The cost estimate of this modification was provided by governmental agency sources.

The GD13 was a proposal to modify the Rocket Sled Test Track at Holloman AFB, New Mexico, to permit operational speeds up to 8000 fps (2440 m/sec) with sustained operation at 7000 fps (2130 m/sec) for two seconds. The cost of these modifications was also provided by governmental agencies.

6.11.2 ENGINE TEST FACILITIES - Because E6 is substantially similar to an upgraded version of the General Electric Company's Altitude Engine Test Facility at Evendale Ohio, the cost of E6 was determined by adding additional cost increments to the GE facility to account for an increase in size, and the addition of steam ejectors, substations, and heaters. Data acquisition and instrumentation costs were based on data provided by AEDC for the operation of their Rocket Test Facility.

The AEDC Rocket Test Facility J-1 Test Cell was used to develop the cost estimates for E7 and E10. Added cost increments were provided for electrical substations, steam ejectors, heater, and an N_2O fuel supply.

6.11.3 STRUCTURAL TEST FACILITIES - Much of the major equipment and building evelope costs for the structures facilities are common to all the proposed facilities. Therefore, the same basic cost estimates could be used for each facility by

FIGURE 6-96 HYPERSONIC WIND TUNNEL FACILITY DATA SHEET

Facility	Year Built	Initial Cost x 10^3	Initial Cost in 1970 $ x 10^3	Utility Factor A	Utility Factor B	Total Utility (A x B)
1. NASA LRC 5MW Arc	1966	35[b]	40	.96	.10	.096
2. NASA LRC 10MW Arc	1963	3175[c]	4660	1.00	.64	.64
3. NASA LRC 20-in. Hypersonic	1962	560[b]	720	.96	.40	.38
4. NASA LRC 20-in. Mach 6	1958	1409[b]	1990	.96	.40	.38
5. NASA LRC 8-ft High Temp	1964	10,537	12,950	.96	.95	.91
6. NASA LRC M8 Variable Density	1960	74[b]	99	.96	.38	.37
7. NASA LRC 20-in. Mach 8.5	1961	507[b]	670	.96	.42	.40
8. NASA Ames 3.5-ft Hypersonic	1960	12,630	16,900	.96	.70	.67
9. AFFDL 50MW Hypersonic	1963	18,500	23,200	1.00	.86	.86
10. NASA LRC Hypersonic Flow App.	1959	280[b]	384	.96	.30	.29
11. NASA LRC 1-ft Hypersonic Arc	1963	226[b]	285	.96	.18	.17
12. NASA LRC Hypersonic Aeroelastic	1967	3148[b]	3510	.92	.75[d]	.69
13. NASA Ames Hypersonic Helium	1960	1776	2360	.96	.40	.38
14. NASA LRC Hypersonic Nitrogen	1964	570[b]	700	.92	.38	.35
15. NASA LRC 22-in. Hypersonic Hel.	1960	997[b]	1330	.92	.45	.41
16. NASA Ames M50 Helium	1964	1530	1880	.96	.50	.48
17. NASA JPL 43-in. Shock	1964	50	61	.37	.71	.26
18. AEDC VKF Tunnel F	1963	5366	6750	.61	.96	.58
19. MAC Hypervelocity Impulse (HIT)	1960	816[b]	1090	.61	.76	.46
20. NASA LRC Hotshot	1962	140[b]	181	.61	.50	.38

[a]Acquisition cost in current dollars for 1970.
[b]Cost is for apparatus only.
[c]Cost of 60-foot (18 m) vacuum sphere appears to be included in cost.
[d]Nominal test section diameter of 4 feet (1.2 m) is assumed.

FIGURE 6-97 UTILITY FACTOR BASED ON TIME DURATION

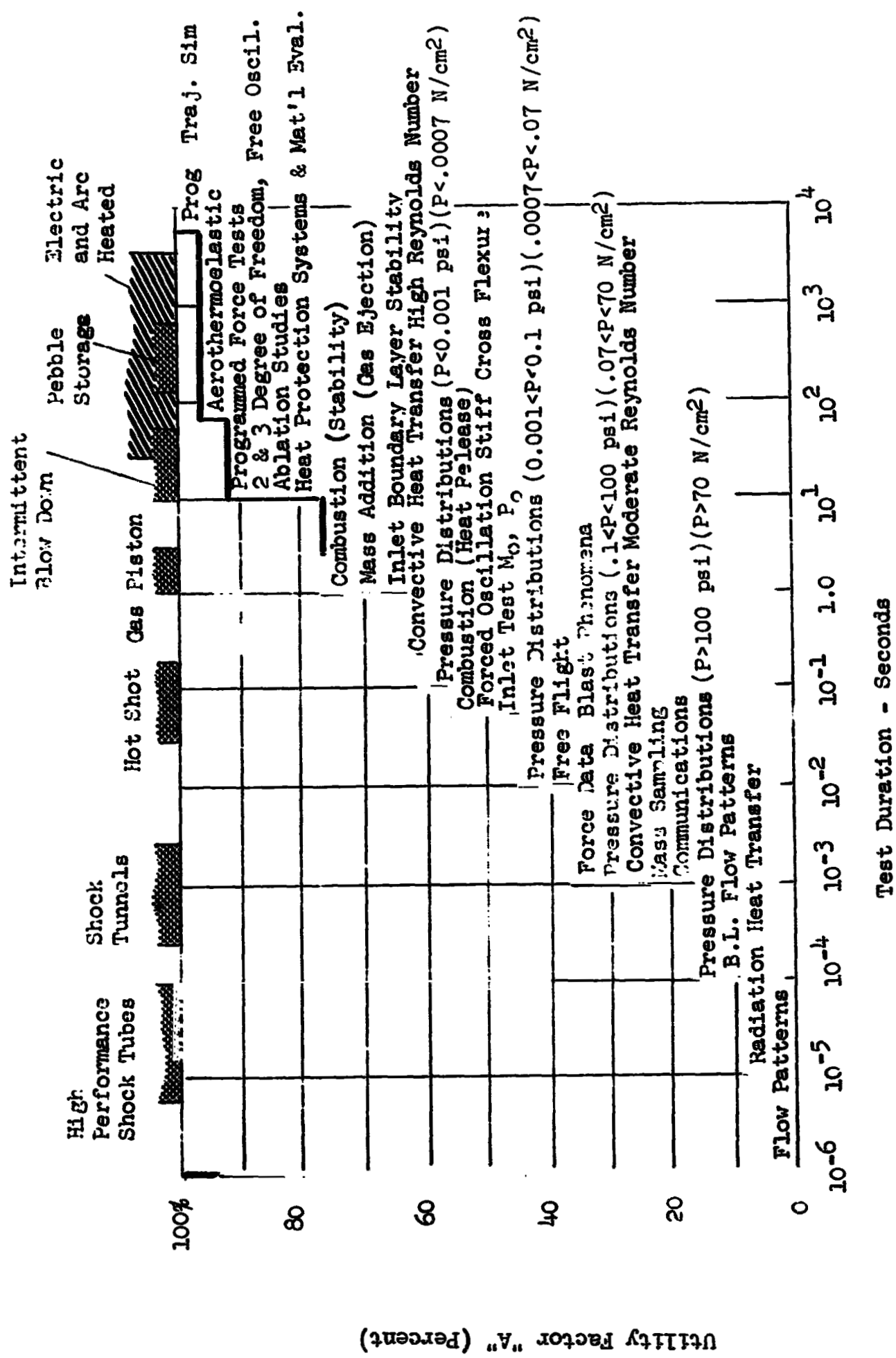


FIGURE 6-98 UTILITY FACTOR COMPONENT BASED ON TEST SECTION SIZE

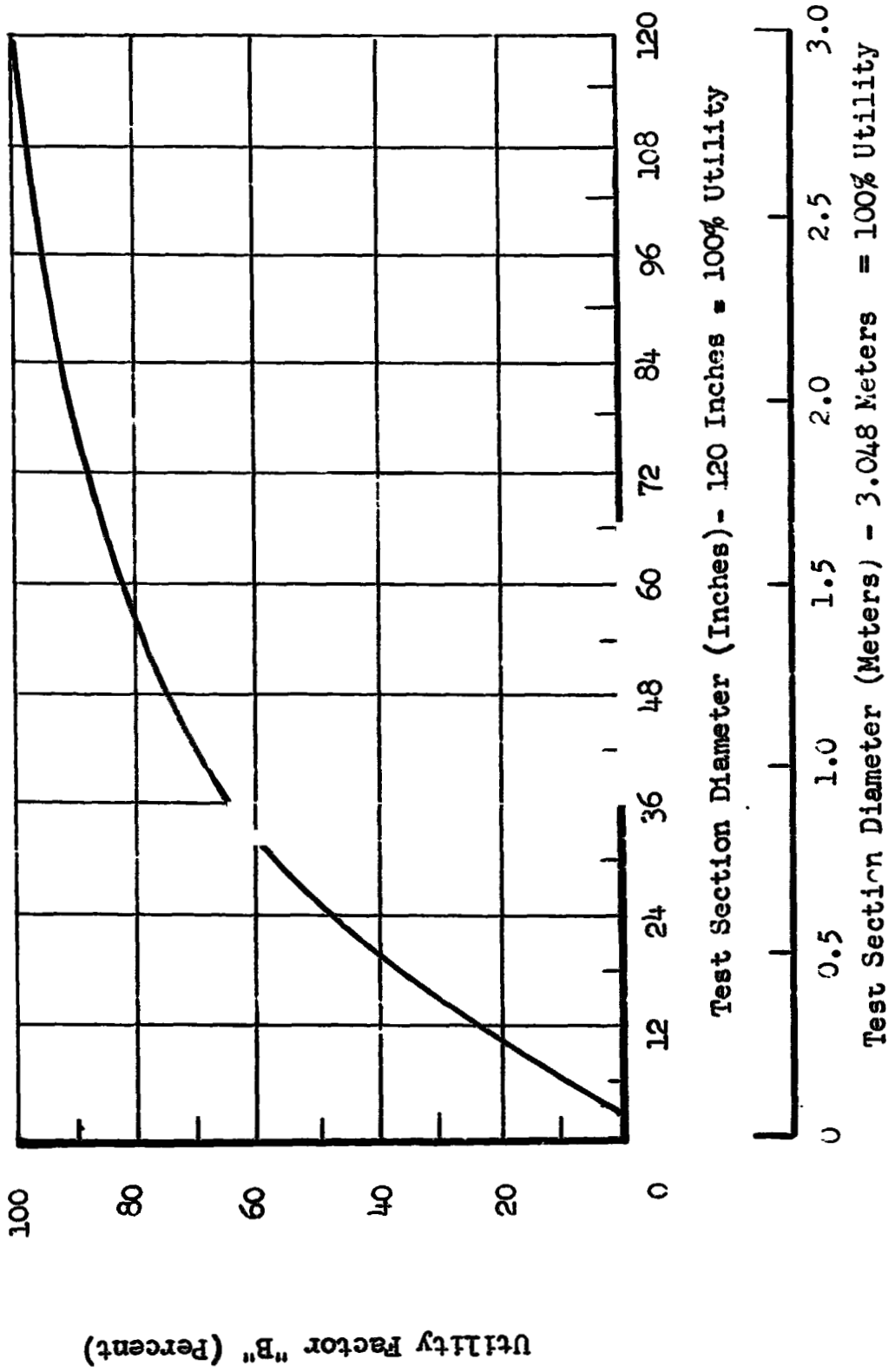
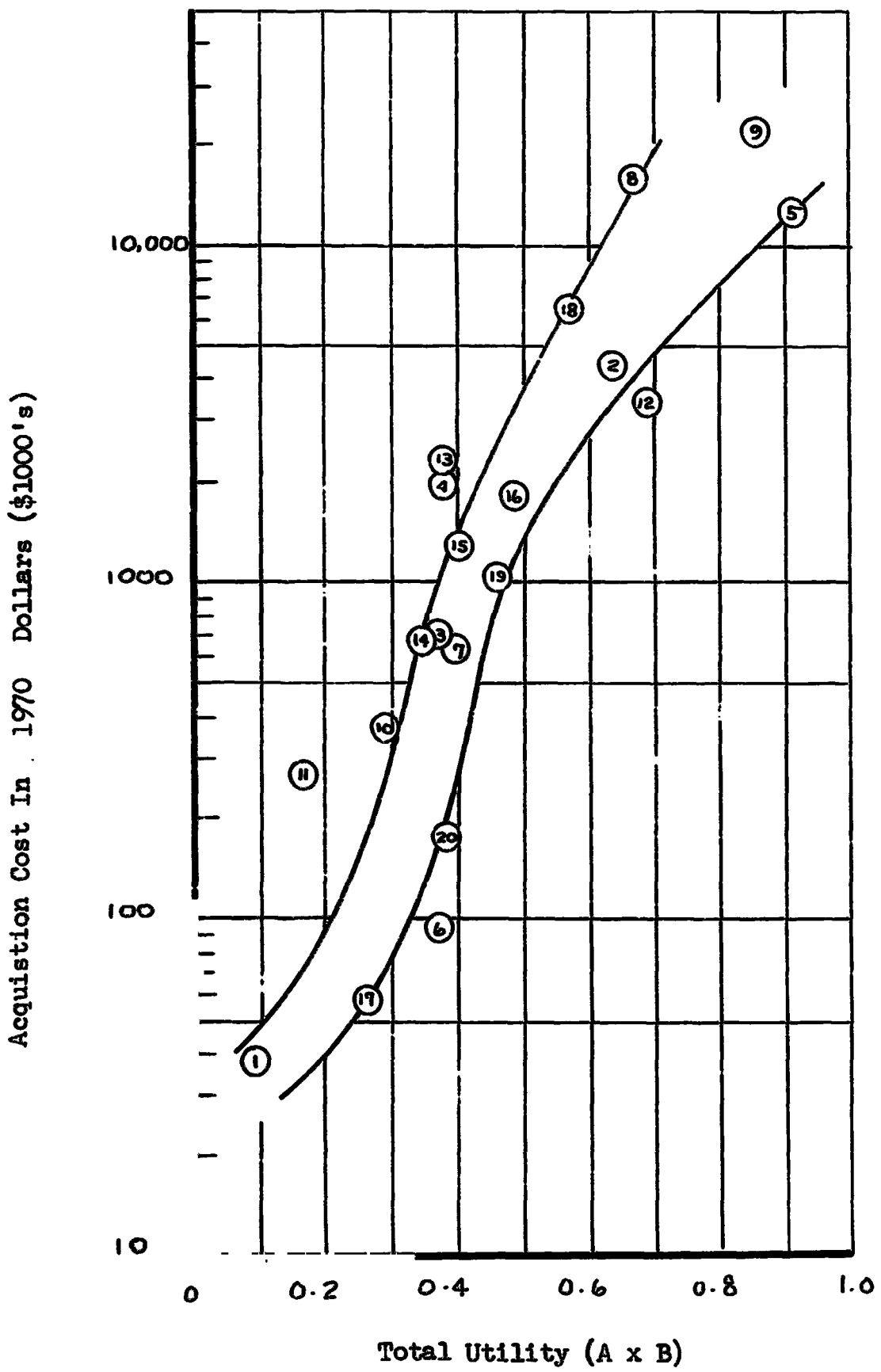


FIGURE 6-99 HYPERSONIC WIND TUNNEL ACQUISITION COST AS RELATED TO TOTAL UTILITY



merely scaling the amount to meet the specific requirements of each facility. The common costs were determined as follows:

Structural Floors - All load bearing floors were designed to react 70,000 lb/ft^2 (3.35 x 10^6 N/m^2) floor loads. For cost purposes, it was assumed these floors must be excavated 20 feet (6.1 m) to bedrock, that they are 3 feet (.91 m) thick with 2 inch (5.1 cm) diameter reinforcing rods 6 inch (15 cm) EWOC (each-way-on center).

Test Fixture - All structural tests that include the application of static mechanical loads will require a rigid fixture to react the applied loads. Past aircraft testing practices have utilized steel beam structures specially constructed to fit around the test article to react the applied loads. Three thousand tons (2.72 x 10^5 kg) of steel are required to construct a test fixture. This tonnage was calculated from a test fixture designed to accept a postulated full-size test article. The cost of this fixture was determined by comparison with similar types of fabrication and erection done at MDC. Costs of fixtures for other structural test facilities were determined by scaling the calculated fixture down to provide a capability to perform tests requiring lesser loads.

Environmental Chambers - Vacuum chambers are required to simulate the altitude environment. The vacuum chambers proposed for S2 and S9 were designed to accommodate the full-scale operational vehicle and to simulate the rate of climb for the vehicle. The total volume of the proposed environmental chamber is 4,500,000 ft^3 (12,7[illegible] m^3).

The vacuum requirements for facilities S2 and S9 are provided for by building a structure with sufficient framing to allow the attachment of a totally welded cold rolled, mild steel skin. Full opening, track mounted, electrically operated doors are provided at one end of the building. Those steel members attaching the side walls to the floor shall be milled on their connecting surfaces to allow the insertion of an inflatable seal. Those steel members providing contact between the doors and the building structure shall be milled to hold an inflatable seal and the doors shall be provided with a sufficient number of screw clamps to maintain the seal. Chamber evacuation to one torr (133 N/m^2) in a very short time period is accomplished by use of steam ejectors operated in conjunction with a LO2-alcohol steam generator. Steam boilers will maintain the vacuum after initial pump down. The chamber was priced by determining the tonnage, fabrication, and erection costs of the steel. All other environmental chambers are priced using a curve (Figure 6-100 relating acquisition costs of environmental chambers to their diameter. The data used to develop these curves is tabulated in Figure 6-101. Chambers whose acquisition cost was less than $100,000 were generally not considered for this example.

Acoustic Shrouds and Generators - Acoustic environments will be simulated by subjecting the test article to a high intensity sound field produced by electromechanical sound generators. The testing concept chosen to test the test articles [illegible] the plane-wave shroud method where the test article is surrounded by a shroud [illegible] mechanical generators create a high intensity sound field that traverses over [illegible] surface. The cost of the acoustic generators was estimated by determining the cost of existing acoustic generation systems and extrapolating the cost

FIGURE 6–100 SPACE CHAMBER ACQUISITION COST AS RELATED TO SPACE CHAMBER DIAMETER

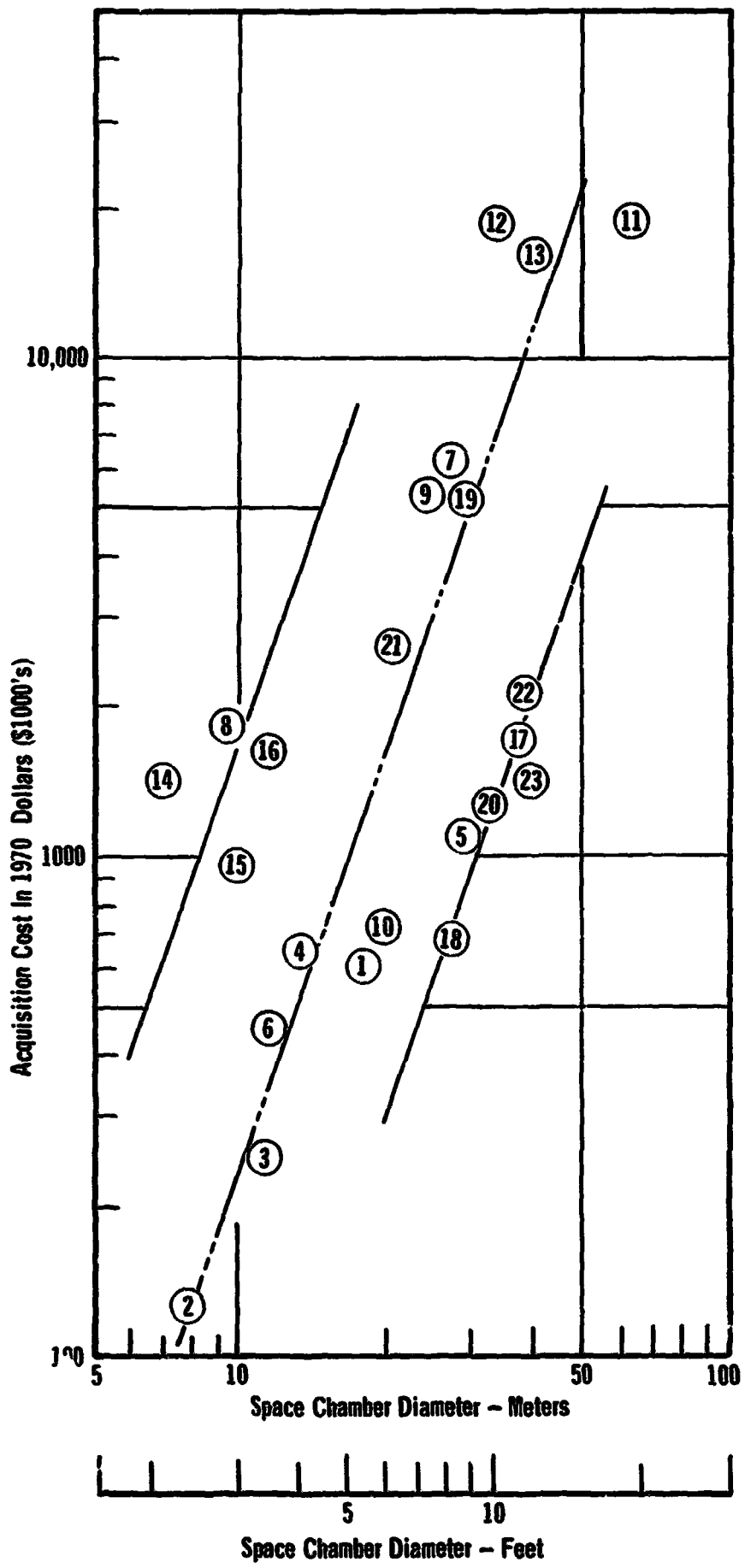


FIGURE 6-101 SPACE CHAMBER FACILITY DATA SHEETS

Facility	Year Built	Initial Cost x 10^3	Initial Cost in 1970 $ x 10^3	Dimensions ft m	Remarks
McDonnell-St. Louis					
1. 18 ft Chamber	1963	497	628	18 dia x 30 (5.5 x 9.1)	Two chambers; one with solar simulation. 36°R (20°K) helium cryopumping. 2 closed cycle helium cryostats also available.
2. 8 ft Chamber	1963	105	132	8 dia x 13 (2.4 x 4)	
3. 11 ft Chamber	1953	155	260	11 x 9 x 25 (3.4x2.7x7.6)	Man rated 34,000 cfm (960 m^3/min)
4. 14 ft Chamber	1959	490	670	14 x 14 x 35 (4.3x4.3x10.7)	Two diffusion-ejector pumps, two 750 cfm (21.2 m^3/min) forepumps; steam ejector system. Man rated.
5. 30 ft Chamber	1963	923	1160	30 dia x 36 (9.1 x 11)	Seven 35 inch (.89 m) fractionating oil diffusion pumps at 110,000 cfm (3100 m^3/min) per pump; two mech pumps at 1000 scfm (28.3 m^3/min) and 250 scfm (7.1 m^3/min); steam ejector at 3300 scfm (93.5 m^3/min). Man rated. Can accommodate 15,000 lb (67,000 N) shaker.
NASA-Goddard					
6. Thermal/Vacuum Chamber	1963	379	475	12 dia x 15 (3.7 x 4.6)	Mechanical and oil diffusion pumps.
7. Space Environ. Sim.	1964	5015	6000	28 dia x 40 (8.5 x 12.2)	Cryopumps; solar simulation.
NASA-JPL					
8. 10 ft Space Sim.	1965	1577	1890	10 dia x 45 (3.0 x 13.7)	7.7 ft (2.35 m) dia solar simulation.
9. 25 ft Space Sim.	1962	4266	5500	25 dia x 90 (7.6 x 27.4)	15 ft (4.57 m) dia solar simulation; 30,000 lb (133,000 N) shaker can be installed.
NASA-MSC					
10. 20 ft Chamber	1964	600	740	20 dia x 22 (6.1 x 6.7)	Oil sealed pump.
11. SESC Chamber A	1966	17,123	19,650	65 dia x 120 (19.8x36.6)	Solar simulation 13 ft dia (3.96 m) x 33 ft (10 m) high; mechanical pumps blowers, 14 oil diffusion pumps; 1350 sq ft (125 m^2) cryopanels.
12. SESC Chamber B	1965	16,123	19,300	35 dia x 43 (10.7x13.1)	Mechanical pumps, blowers, 12 oil diffusion pumps.

Facility	Year Built	Initial Cost x 10^3	Initial Cost in 1970 $ x 10^3	Dimensions ft m	Remarks
AEDC					
13. Aerospace Environmental Chamber (Mark 1)	1966	14,656	16,700	42 dia x 82 (12.8 x 25)	Forty-eight 32-inch (.81 m) diffusion pumps and 36°R (20°K) and 138°R (77°K) cyropanels. Has provisions for high and low frequency shaker system.
14. Aerospace Research Chamber (7V)	1960	1108	1480	7 dia x 12 (2.1 x 3.7)	Two 32-inch (.81 m) diffusion pumps and 36°R (20°K) cryopanels.
15. Aerospace Research Chamber (8V)	1960	745	990	10 dia x 20 (3.05 x 6.1)	127 cfm (3.0 m^3/min) forepump; 6-inch (15 cm) diffusion pump. Used mainly for propulsion system testing.
16. Aerospace Research Chamber (12V)	1960	1231	1650	12 dia x 35 (3.7 x 10.7)	36°R (20°K) cryoarray provides pumping speed of 1,050,000 cfm (30,000 m^3/min) (24 m); 8 ft (2.4 m) dia solar simulator; one 32-inch (.81 m) diffusion pump.
17. GE/Valley Forge	1962	1330 one chamber	1710	39 dia (11.9)	Three chambers of this type; one cryopump and two 32-inch (.81 m) oil diffusion pumps backed by booster and mech pump; 20 ft (6.1 m) dia solar simulation.
18. STL	1962	550	708	28 dia(8.5)	28 sq ft (2.6 m^2) solar simulation.
19. Martin/Denver	1967	5000	5560	29 dia x 45 (8.8 x 13.7)	
20. Xerox/Electro-Optical Sys. Div.	1967	1200	1330	33 dia x 22 (10 x 6.7)	
21. TRW	1966	2400	2760	22 dia x 44 (6.7 x 13.4)	10 sq ft (9.3 m^2) solar simulation; two mech roughing pumps and three 201,000 cfm (5700 m^3/min) oil diffusion pumps, 36°R (20°K) helium cryopump at 4,240,000 cfm (120,000 m^3/min).
22. Philco-Ford/WDL	1967	2000	2220	39 dia(11.9)	36°R (20°K) helium cryopump at 4,240,000 cfm (120,000 m^3/min).
23. Douglas-Santa Monica	19 3	1507	1695	39 dia(11.9)	36°R (20°K) helium cryopump; four oil diffusion pumps @ 1,120,000 cfm (3180 m^3/min); four Roots-type blowers; four mechanical pumps.

for larger systems. In order to cost the acoustic shroud, the shroud was assumed to be made of structural steel. The proposed concepts for acoustical testing were patterned from present tests performed at MDC and at NASA-MSC, Houston. The costs developed for the acoustic system do not include the compressed air required to power the acoustic generators.

Heaters and Thermal Control - Elevated temperature environment up to 3,000°F (1660°C) can most satisfactorily be simulated by quartz infrared heat lamps. For thermal environments in excess of 3,000°F (1660°C), graphite resistance heaters will be used. Ignitron power controllers will be used to regulate both the quartz lamps and graphite heater curves. It was assumed that the electrical power could be purchased from utility networks.

A cost curve (Figure 6-102) was developed from an analysis of heaters required to produce a given heat flux per square foot of area and was used to establish quartz heater cost. Graphite heaters were priced at $12,000 for 400 Btu/ft^2 sec (4.53×10^6 W/m^2). Thermal control consists of a programming capability and a temperature recording/controlling capability using 250 kW ignitron units. Costs are five thousand dollars per channel of thermal control taken from recent MDC purchases plus heaters priced as previously discussed.

Vibration Exciters - Mechanical vibration environments will be simulated through the use of electro-mechanical exciters. The cost of the proposed shakers was based on past MDC expenditures for similar vibration systems.

Hydraulic Load Cylinders - Static and quasi-static mechanical loads will be applied to the test article by hydraulically actuated load cylinders. Computer programmed servo control systems will be used to regulate and apply the mechanical loads. Loads will be monitored by electronic load cells and recorded on the data acquisition system. The cost of the loading system was priced on a per channel basis to include hydraulic pumps, loading cylinders, and controls.

Non-common equipment and facility costs were determined for each facility based on estimates obtained from MDC capital expenditure histories and manufacturer's quotations.

6.11.4 FLIGHT SIMULATION FACILITIES

The flight simulator facility complex, (FS1, 2, and 3), was assumed to be located in one common building. The simulator costs were estimated from information supplied by Conductron-Missouri, manufacturer of such current state-of-the-art simulators as the 747, DC-10, and DC-9 simulators. These present-day systems were upgraded to provide the required 5-degree-of-freedom motion simulation. Additional special equipment requirements are detailed in each facility description set out in Figure 6-75.

6.11.5 MATERIALS TEST FACILITIES

The cost of the materials facilities primarily depend on the type and amount of equipment included in the facility. Large, special items such as vacuum chambers, autoclaves, electron microscopes, etc., were priced from manufacturer's quotations,

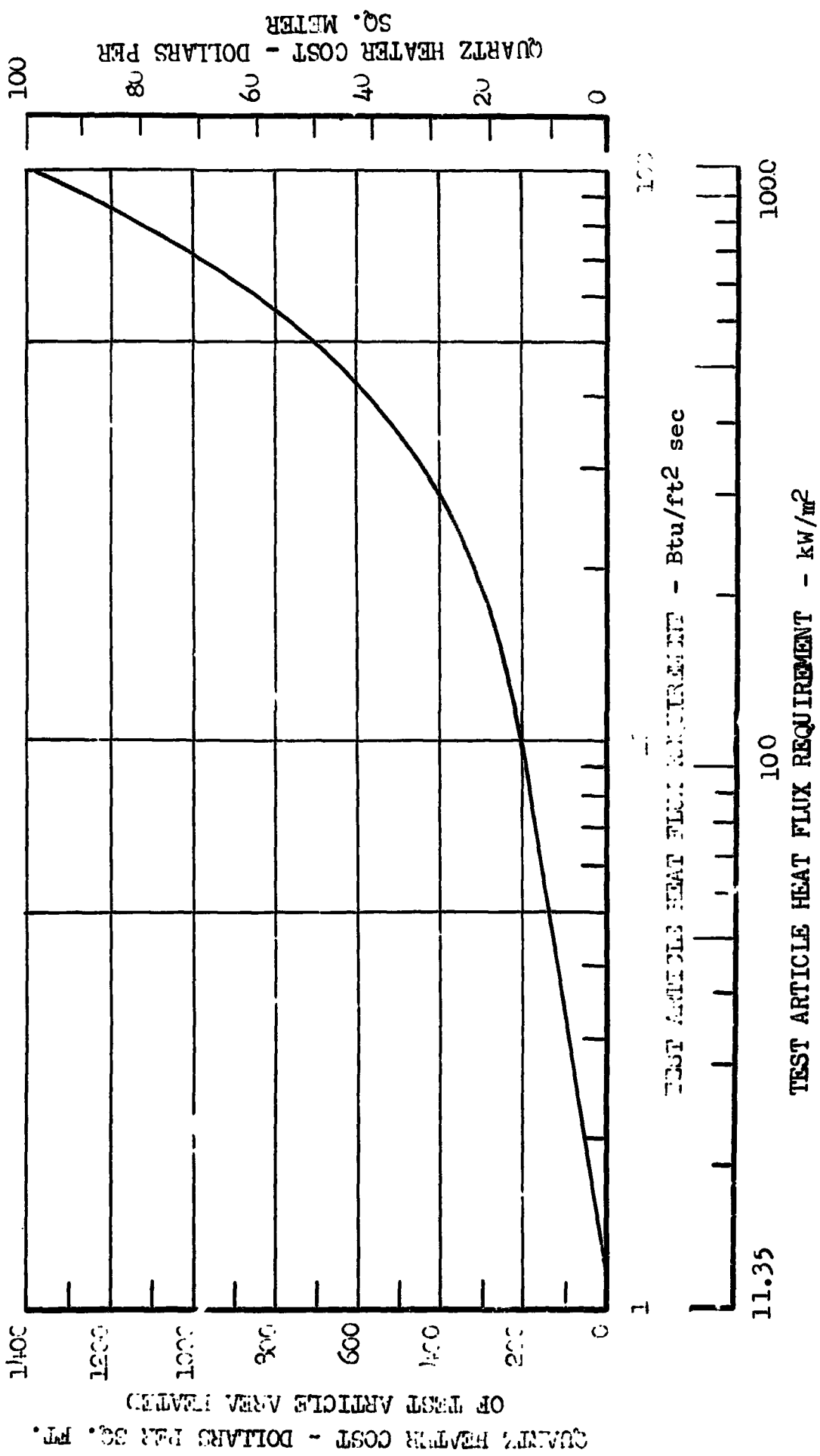


FIGURE 6-102 QUARTZ HEATER COST AS RELATED TO TEST ARTICLE HEAT FLUX REQUIREMENT

past MDC capital expenditure budget histories, and from estimate procedures described in the previous sections. The three materials facilities were consolidated in one building envelope. Much of the small laboratory equipment was treated as miscellaneous equipment and costed as a lump-sum price.

6.11.6 SUBSYSTEM, RADIATION, AND AVIONIC TEST FACILITIES

These facilities contain certain unique test equipment along with standard types of control rooms, offices, etc. The special items are set out in the facility descriptions as shown in Figure 6-89. The cost of the special equipment was determined by manufacturer's quotations or MDC capital expenditure budget. The common construction cost was determined by utilizing generally accepted architectual and engineering building cost estimating methods.

6.12 GROUND TEST FACILITY SUMMARY

A brief summary of the ground test facilities is presented in Figure 6-103. The summary is composed of a statement of facility description, operating characteristics and acquisition and operating costs. Each of the 54 facility concepts postulated are described in this figure, and performance specifications are given for each. Where the facility concept survived the initial screening process and a cost estimate was obtained, a cost breakdown graph is presented. This figure contains the description of:

17 gasdynamic facilities
10 engine facilities
10 structural facilities
4 materials research facilities
3 flight simulator facilities
5 fluid systems research facilities
2 subsystem facilities
2 avionics
1 radiation research facility

FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I

GD1 - High Reynolds Number Subsonic Wind Tunnel

Test Section Size	17 x 24 ft (5.19 x 7.3 m)
Mach Range	0 to .6
Max. Unit Reynolds No. x 10^{-6}	10.5/ft (34.4/m)
At Mach No.	.2
Model Length:	15.8 ft. (4.9m)
Max. Reynolds Number:	160 million
Flight Reynolds No. = 102 million to 567 million	
At Mach No.	.4
Power Required	7,800 kW
Run Time	Continuous

Deleted from further definition during Phase I because GD2 provides same capability in this Mach number range.

GD2 - High Reynolds Number Nearsonic Wind Tunnel

Test Section Size	17 x 24 ft (5.2 x 7.3 m)
Mach Range	0 to 1.0
Max. Unit Reynolds Number x 10^{-6}	22.0/ft (72/m)
At Mach No.	.7
Model Length	15.8 ft(4.8 m)
Max. Reynolds No.	450 million
Flight Reynolds No.	160 million to 1600 million
At Mach No.	.6
Power Required	204,000 kW
Run Time	Continuous

Operating Cost = $6000/occ-hr

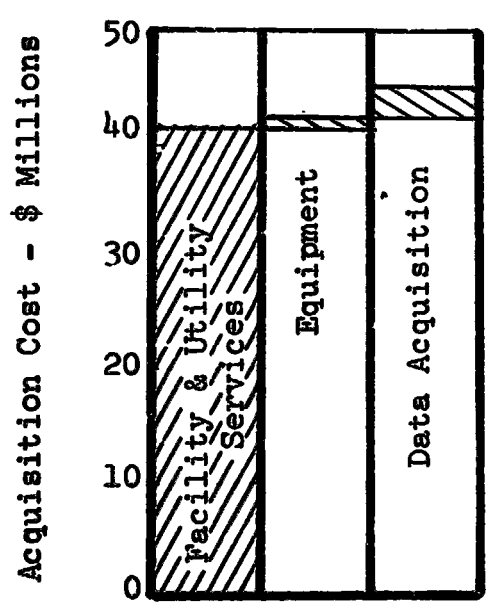
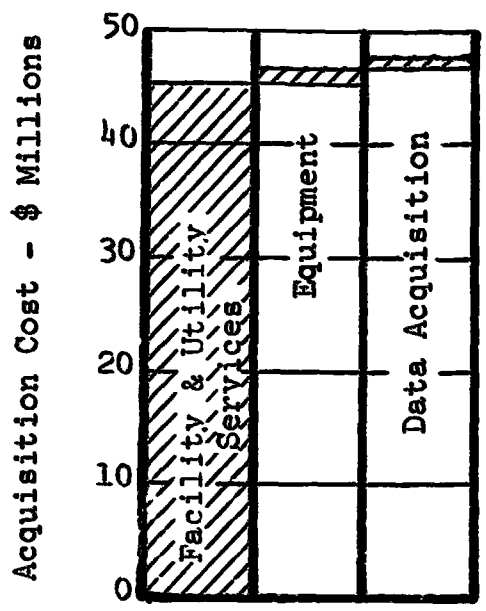


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

GD3 - High Reynolds Number Trisonic Blowdown Wind Tunnel

Operating Cost = $3900/occ-hr

Test Section Size	16 x 16 ft (4.9 x 4.9 m)
Mach Range	.5 to 5.0
Max. Unit Reynolds No. x 10^{-6}	39.0/ft (128/m)
At Mach No.	1.67
Model Length	12.3 ft (3.8 m)
Max. Reynolds No.	625 million
Flight Reynolds No.	400 million to 2600 million
At Mach No.	1.7
Run Time	30 seconds



GD4 - Ludwieg Tube, High Reynolds Number Trisonic Wind Tunnel

Operating Cost = $820/occ-hr or $1640/shot

Test Section Size	9 x 12 ft (2.7 x 3.7 m)
Mach Range	.5 to 3.0
Max. Unit Reynolds No. x 10^{-6}	150/ft (490/m)
At Mach No.	1.2
Model Length	8 ft (2.4 m)
Max. Reynolds No.	1560 million
Flight Reynolds No.	600 million to 2000 million
At Mach No.	1.2
Run Time	.8 to 1.5 seconds

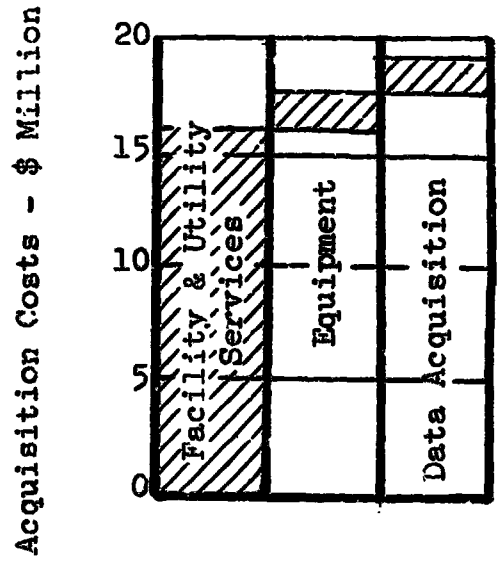


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

GD5 - High Reynolds Number Hot Shot Type Hypersonic Wind Tunnel		
Test Section Size	10 ft dia (305 m)	This facility was deleted from further definition because of the run time capability and fewer operational problems associated with GD7.
Mach Range	8 to 13	
Max. Unit Reynolds No. x 10^{-6}	12/ft 39.3/m	
At Mach No.	8	
Model Length:	7.7 ft (2.35 m)	
Max Reynolds No.:	92 million	
Flight Reynolds No. = 600 million	to 350 million	
At Mach No.	8	
Stored Electrical Energy	1.5 million kJ	
Run Time	200 msec	

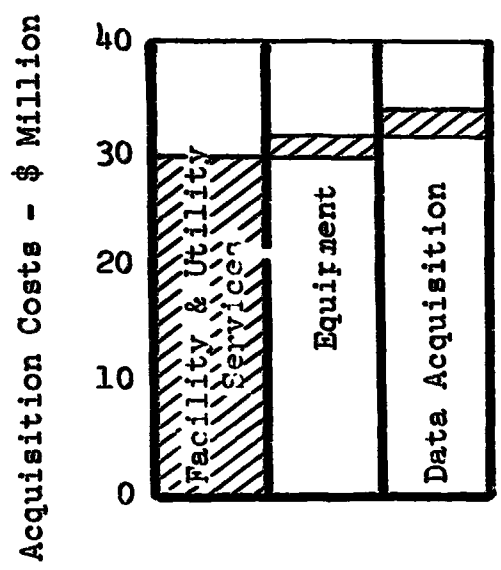
GD6 - High Reynolds Number Shock Tube Driven Hypersonic Wind Tunnel		
Test Section Size	10 ft dia (305 m)	This facility was deleted from further definition during Phase I because of the 1000 times greater run time available with GD7.
Mach Range	8 to 13	
Max. Unit Reynolds No. x 10^{-6}	20/ft 65.6/m	
At Mach No.	8	
Model Length:	7.7 ft (2.35 m)	
Max. Reynolds No.:	150 million	
Flight Reynolds No. = 600 million	to 350 million	
At Mach No.	8	
Run Time	to 3 msec	

FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

GD7 - High RE Gas Piston Driven Hypersonic Wind Tunnel

Operating Cost = $1310/occ-hr or $2630/shot

Test Section Size	10 ft dia (3.05 m dia)
Mach Range	8 to 13
Max. Unit Reynolds No. x 10^{-6}	17/ft (55.7/m)
At Mach No.	8
Model Length	6.8 ft (2.1 m)
Max. Reynolds No.	150 million
Flight Reynolds No.	650 million
At Mach No.	8.0
Run Time	1-4 seconds



GD8 - High Pressure Alumina Storage Heater Tunnel

Test Section Size	12 ft dia (3.68 m)
Mach Range	5 to 10
Max. Unit Reynolds No. x 10^{-6}	5/ft (16.4/m)
At Mach No.	5
Model Length:	7.7 ft (2.35 m)
Max. Reynolds No.	38 million
Flight Reynolds No. = 600 million	to 350 million
At Mach No.	8
Run Time	30 seconds

This facility was deleted from further refinement during Phase I because it is primarily a flight duplication facility rather than a High Reynolds number facility and cannot provide aerodynamic research as effectively as GD15 and GD7.

FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

GD9 - High Pressure Zirconia Storage Heater Tunnel		
Test Section Size	5 ft dia (1.52 m)	Deleted for same reason as GD8, with additional comment that it is very applicable as engine research facility and appears as part of E9
Mach Range	8 to 13	
Max. Unit Reynolds No.	6.0/ft (19.6/m)	
At Mach No.	8	
Model Length:	3.4 ft (1.05 m)	
Max. Reynolds No.:	20 million	
Flight Reynolds Number = 600 million to 350 million		
At Mach No.	8	
Run Time	30 seconds	

GD10 - Multi Recompression Heater Wind Tunnel		
Test Section Size	5 ft dia (1.52 m)	Same comment as for GD9, as appears as engine research facility E8.
Mach Range	5 to 13	
Max. Unit Reynolds No. x 10^{-6}	2.1/ft (6.9/m)	
At Mach No.	5	
Model Length:	3.4 ft (1.05 m)	
Max. Reynolds No.	7.1 million	
Flight Reynolds No. = 82 to 455 million		
At Mach No.	5	
Run Time	1 minute	

FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

GD11 - High Pressure Electric Arc Heated Wind Tunnel

Test Section Size	6 ft dia (1.83 m)	
Mach Range	5 to 13	
Max. Unit Reynolds No. x 10^{-6}	.45/ft (1.47/m)	Same comment as for GD9, and appears as engine research facility E10
At Mach No.	5	
Model Length:	4.1 ft (1.25 m)	
Max. Reynolds No.	2.05 million	
Flight Reynolds No. = 82 million to 455 million		
Run Time	to 30 min	

GD12 - Large Bore Gun Launch Range

Range Size	10' dia x 1000'L (3 m dia x 305 m L)	This facility is the NOL ballistics range modified with a larger gas gun launcher and a 5 atm pressure capability for the range. Up to 10 inch gun bore (.254 m).
Mach Range	$\leq$10.0	
Max. Unit Reynolds No. x 10^{-6}	385/ft (1260/m)	Modification Cost = $1,000,000
At Mach No.	10	
Model Length	2.5 ft (.76 m)	
Max. Reynolds No.	1250 million	
Flight Reynolds No.	500 million	
At Mach No.	10	
Test Time	8 msec	

FIGURE 5-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

GD13 - Holloman Test Track with Extended Track Modification

Track Length	13.4 mi (21,600 m)
Mach Range	≤7
Max. Unit Reynolds No. x 10^{-6}	50/ft (164/m)
At Mach No.	7
Flight Reynolds No.	750 million
At Mach No.	7

Modification Cost = $8,600,000

Model length and test Re not shown because of the large variation in permissible model size dependent on configuration, attitude, etc.

GD14 - Rocket Launched Scale Models (No new launchers proposed - Scout and Athena H are considered adequate)	Wallops (Scout)	White Sands (Athena) 2 Stage	White Sands (Athena) 3 Stage
Max. Mach Number	10.0	10.0	15.0
At Altitude	50,000 ft (15 km)	50,000 ft (15 km)	50,000 ft (15 km)
Max. Unit Reynolds Number x 10^{-6}	11.9 (39/m)	11.9 (39/m)	17.8 (58.3/m)
Model Length:	2.66 ft (8.1 m)	2.66 ft (8.1 m)	2.66 ft (8.1 m)
Max. Reynolds No. x 10^{-6}	31.5	31.5	47.5

Flight Reynolds No.= 106 million to 590 million

At Mach No. 3

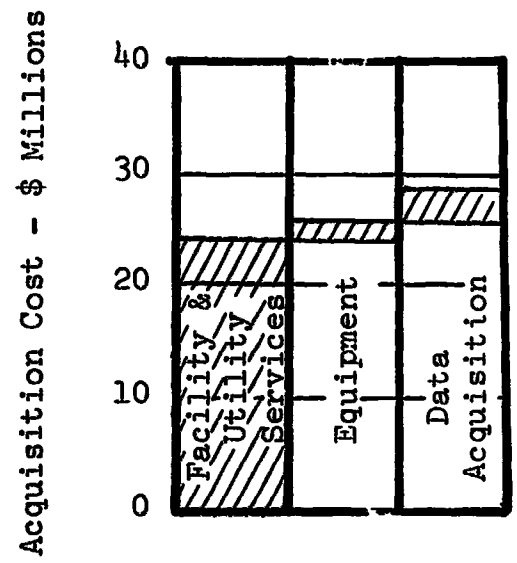
This facility was deleted from further refinement during Phase I because the Reynolds numbers provided were not any greater than that available with wind tunnels and utilization would be far less in terms of number of runs or acquired test data.

FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

GD15 - Electric Heated Hypersonic Blowdown Tunnel

Test Section Size	8.86 x8.86 ft (2.7 x 2.7 m)
Mach Range	3 to 8.5
Max. Unit Reynolds No. x 10^{-6}	34/ft (111/m)
At Mach No.	4.5
Model Length	6.8 ft (2.1 m)
Max. Reynolds No.	300 million
Flight Reynolds No.	1270 million
At Mach No.	4.5
Run Time	20 seconds

Operating Cost = $1190/occ-hr



GD16 - Ludwieg Tube Hypersonic Tunnel

Test Section Size	8.86 x 8.86 ft (2.7 x 2.7 m)
Mach Range	3 to 8.5
Max. Unit Reynolds No. x 10^{-6}	50/ft (164/m)
At Mach No.	3
Model Length	6.8 ft (2.1 m)
Max. Reynolds No.	350 million
Flight Reynolds No.	1850 million
At Mach No.	3
Run Time	1 second

Operating Cost = $850/occ-hr
$3400/shot

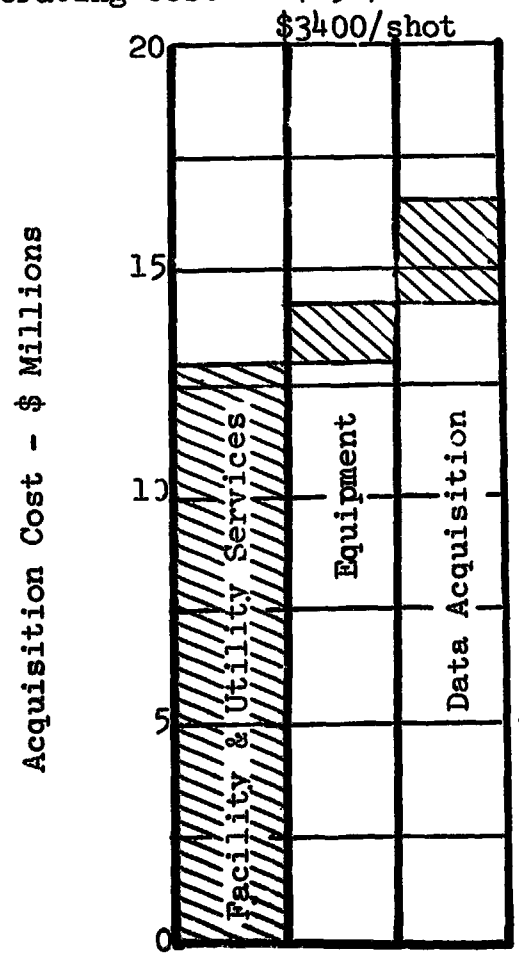


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

GD17 - High Reynolds Number Trisonic Continuous Wind Tunnel

Test Section Size	16 x 16 ft (4.9 x 4.9 m)
Mach Range	.5 to 5.0
Max. Unit Reynolds No. x 10^{-6}	39.0/ft (128/m)
At Mach No.	1.67
Model Length	12.3 ft (3.8 m)
Max. Reynolds No.	625 million
Flight Reynolds No.	400 million to 2600 million
At Mach No.	1.7
Run Time	Continuous
Power Required	1,900,000 hp (1,400,00 kW)

Deleted from further Phase I definition because initial cost estimates ($440,000,000) indicate very high costs but no greater research capability than GD3. Also for minimum cost research programs, GD3 offered lower acquisition as well as operating costs.

E-1 Large Rocket Test Cell (No new facility proposed - Capability of AEDC LRF is adequate)	AEDC LRF Test Cell J4	AEDC RTF Test Cell J3
Cell Diameter	48 ft (14.6 m)	18 ft (5.5 m)
Cell Length	81.5 ft (24.8 m)	40 ft (12.2 m)
Test Altitude	106-140 kft (32-43 km)	50-150 kft (15-46 km)
Thrust Capacity (Current)	500,000 lb (2,220,000 N)	200,000 lb (890,000 N)
(Growth)	1,500,000 lb (6,700,000 N)	

FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

E2 - Wind Tunnels Designed to Test Airbreathing Engines	This concept was discarded early in Phase I. Although these facilities could provide inlet and exhaust nozzle data, using wind tunnel models, neither the run time or flight condition duplication was sufficient to justify these as engine research facilities.
a. Full scale engine and nacelle tests (described under GD3) possible in proposed facilities GD1,2,3. b. Subscale and basic research tests possible in GD5,6,7,8,9,10,11. c. Continuous and intermittent facilities will require addition of exhaust scavenging capability or increased vacuum volume or ejector capability. d. Fuel storage and distribution capability must be provided, as well as engine thrust balances.	
E3 - Turbomachinery Test Facility	
Cell Diameter 16 ft (4.9 m) Cell Length 72 ft (22 m) Mass Flow Rate 1300 lb/sec (590 kg/sec) Altitude 10-60 kft (3-18 km) True temperature duplication, standard and cyrogenic fuels are required.	This facility was found to be better specified as separate free jet and direct connect facilities of greater capability. These facilities were defined as E6 and E7 was dropped.

FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

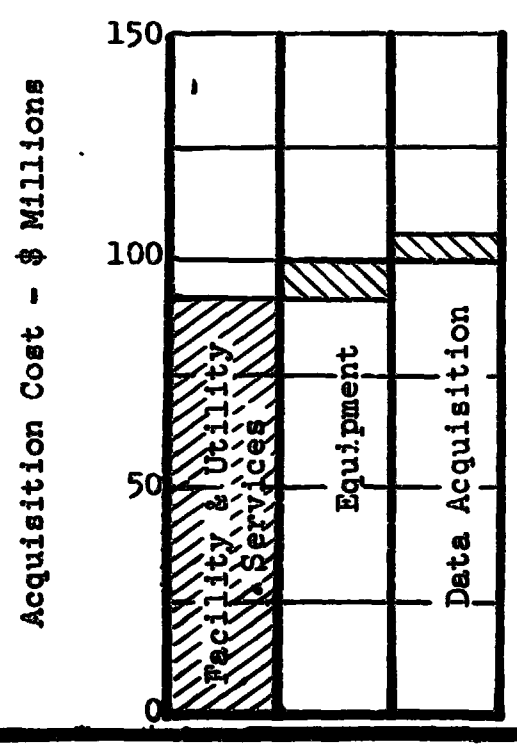
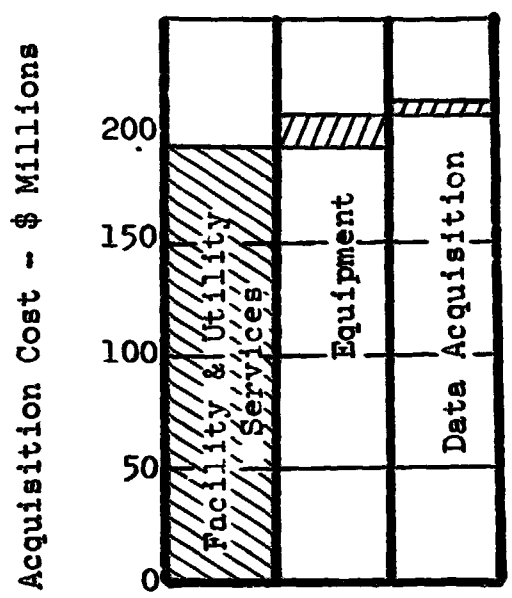
E4 - Exhaust Nozzle Test Facility	Cornell Base Flow Facility
M = 5-13, Z ≤ 150 kft (46 km). For determination of exhaust nozzle performance with properly simulated internal and external flow. This facility can be a modification of any of the proposed hypersonic wind tunnels wherein a model representing the aft end of a vehicle including the engine nozzle/s is placed in the hypersonic flow. Pressure and flow visualization techniques are used to determine nozzle/airframe interaction.	This facility capability was incorporated into the basic engine research facilities and did not require a specialized facility.
E5 - Engine Dynamic Simulator	
A flow facility which can accomodate scaled or full scale engine/inlet sections. Capable of steady running with both small amplitude rapid changes (M, Po, To, α) and programmed gradual changes. Response of duct/inlet system to real time mission profile conditions, gusts, gunfiring, rapid throttle changes, near field acoustic effects to be measured.	This capability is incorporated into engine research facility E7, and is inherent in that facility's research capability.
E6 - Direct Connect Turbomachinery Test Cell	Operating Cost = $9930/occ-hr
Engine Inlet Capture Area: 44 ft^2 (4.1 m^2) Mach Range: 0 to 5 (simulated) Altitude Range: 0 to 85 kft (0-26 km) Weight Flow: 1700 lbm/sec (770 kg/sec) Run Time: Continuous	

FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

E7 - Free-Jet Turbomachinery Engine Facility

Engine Inlet Capture Area	44 ft^2 (4.1 m^2)
Mach Range	0 to 5
Altitude Range	0 to 85 kft (0 to 26 km)
Weight Flow	9100 lbm/sec (4100 kg/sec)
Run Time	Continuous

Operating Cost = $22,000/occ-hr



E8 - Multirecompression Heater Ram/Scramjet Engine Facility

Engine Inlet Capture Area	10 ft^2 (.9 m^2)
Mach Range	3 to 12 (simulated)
Altitude Range	75 to 160 kft (23 to 49 km)
Weight Flow	300 lbm/sec (136 kg/sec)
Run Time	Continuous

Modified Direct Connect

Operating Cost = $10,000/occ-hr

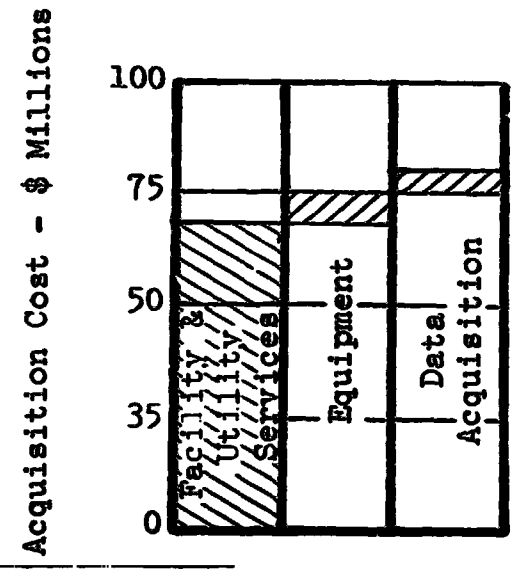
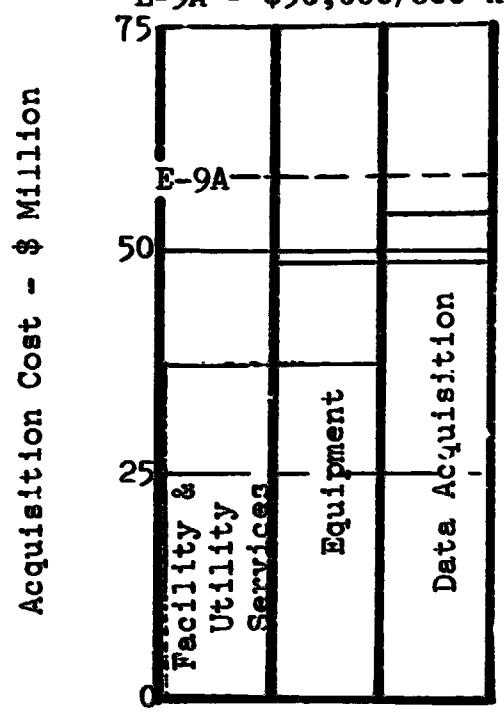


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

E9 - Hybrid Heater Scramjet Engine Facility

Engine Inlet Capture Area	10 ft^2 (.9 m^2)
Mach Range	3 to 8.5 (simulated)
Altitude Range	75 to 160 kft (23 to 49 km)
Weight Flow	300 lbm/sec (136 kg/sec)
Run Time: Combustion Products	Continuous
Air	30 sec
Modified Direct Connect	

Operating Cost = $18,200/occ-hr
E-9A = $50,000/occ-hr



E9A uses the alternate graphite continuous heater.

E10 - 600 Megawatt Arc Heater

Engine Inlet Capture Area	10 ft^2 (.9 m^2)
Mach Range	6 to 12 (simulated)
Altitude Range	75 to 150 kft (23 to 49 km)
Weight Flow	153 lbm/sec (69 kg/sec)
Run Time	30 min
Modified Direct Connect	

Operating Cost = $3600/occ-hr

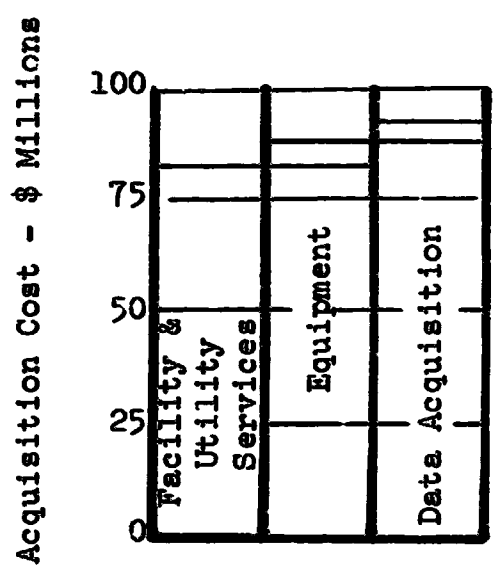
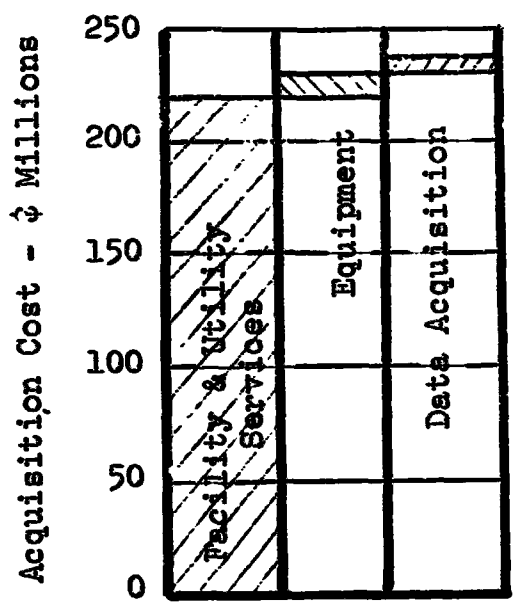


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

E20 - Integrated Turbomachinery Engine Facilities

E6 and E7 test cells operated as integrated facility with combined air supply, exhauster, utilities, control room, etc.

Operating Cost = $22,700/occ-hr



FS1 - Flight Simulator Crew Trainer Facility

Motion Simulation - 6 deg. of freedom
Visual Synthesis - Color TV display, landing image generator, instrument display.
Audio Synthesis - Full stereophonic audio environment
Total cabin environment regulation
Large computer programming capability

Operating Cost = $1200/run hr

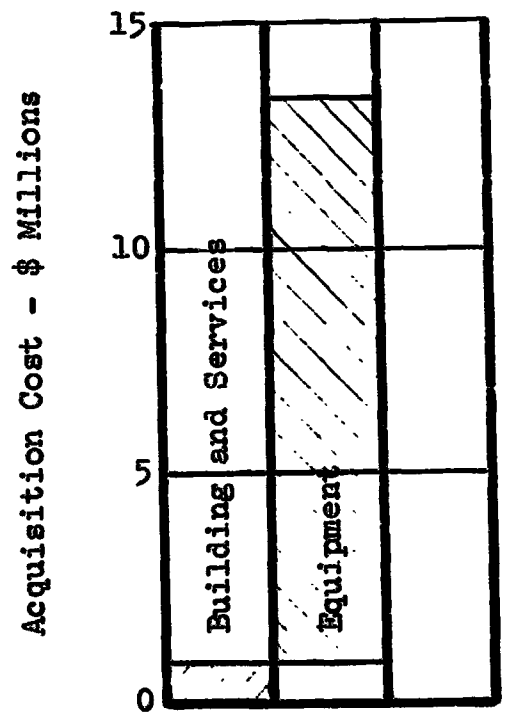
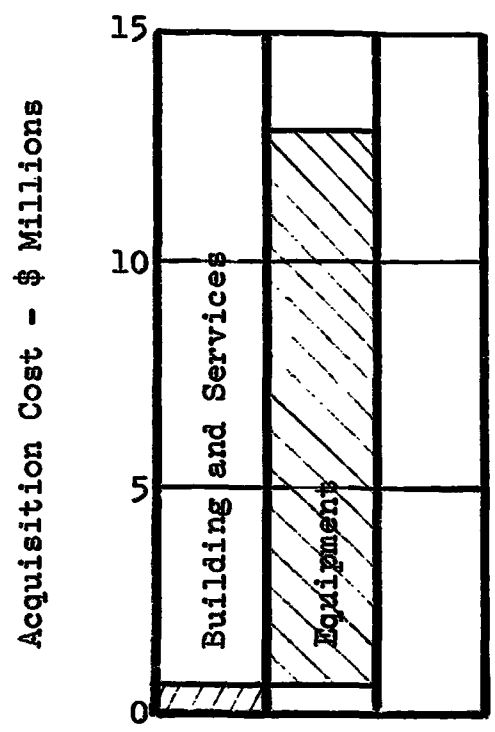


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

FS2 - Takeoff and Landing Simulator

Motion Simulation - 6 deg. of freedom, dynamic takeoff and landing simulation
Visual Synthesis - Color TV
Takeoff and landing image generation, full instrument display
Audio Synthesis - Full stereo audio environment
Total cabin environment regulation
Large computer programming capability

Operating Cost = $1200/run hr



FS3 - Launch Cruise Simulator

Motion Simulation - 6 deg. of freedom, acceleration simulation, sensible acoustic simulation, centrifuge
Visual Synthesis - Full vision instrument display
Audio Synthesis - Full stereo audio environment
Total cabin environment regulation
Large computer programming capability

Operating Cost = $1400/run hr

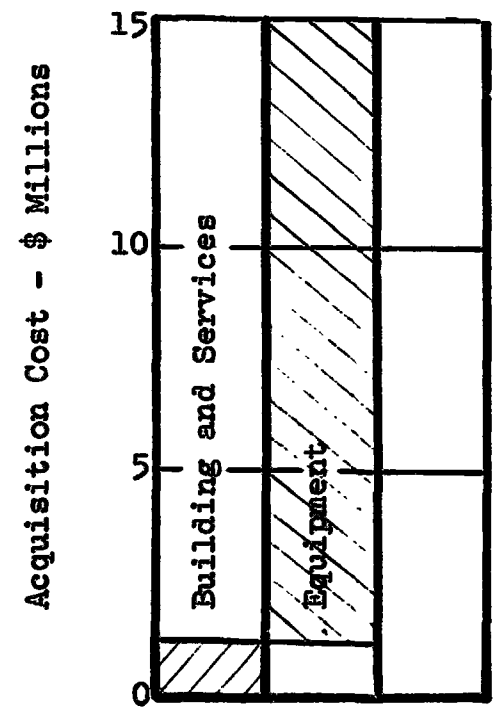


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

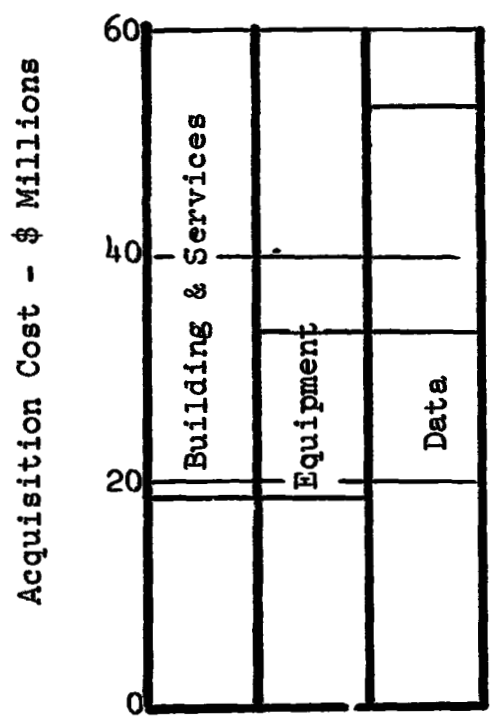
S1 - Airframe Static Test Facility

Structural Floor - 150 x 350 ft (46 x 107 m)
Structural Ceiling - 100 ft high, 4000 kip load (30 m high) (17,800,000 N)
Load Programming - 500 channels @ 50 kip each (222,000 N)

Thermal Programming - 450 channels @ 250 kW

Cryogenic Tankage - 100,000 ft^3, 60,000 gpm ($2830\ m^3$) ($3.78\ m^3$/sec)
Data Acquisition - 15,000 channels

Operating Cost = $8700/run hr



S2A - Airframe Dynamic Structural Evaluation Facility

Structural Environmental Chamber - 150 x 350 x 100 ft high (46 x 107 x 30 m)
Structural Ceiling and Floor - 350 x 150 ft (107 x 46 m) 4000 kip loads (17,800,000 N)
Altitude Simulation - 150,000 ft (46 km)
Load Programming - 500 channels @ 50 kip (222,000 N)
Thermal Programming - 3000 channels @ 500 kW

Cryogenic Tankage - 100,000 ft^3, 60,000 gpm ($2830\ m^3$) ($3.78\ m^3$/sec)
Acoustic Generator - to 170 dB, 9 Million acoustic watts (6300 N/m^2)
Mechanical Exciters - 3000 kip total force (13,300,000 N)
Data Acquisition - 13,000 channels

Operating Cost = $38,900/run hr

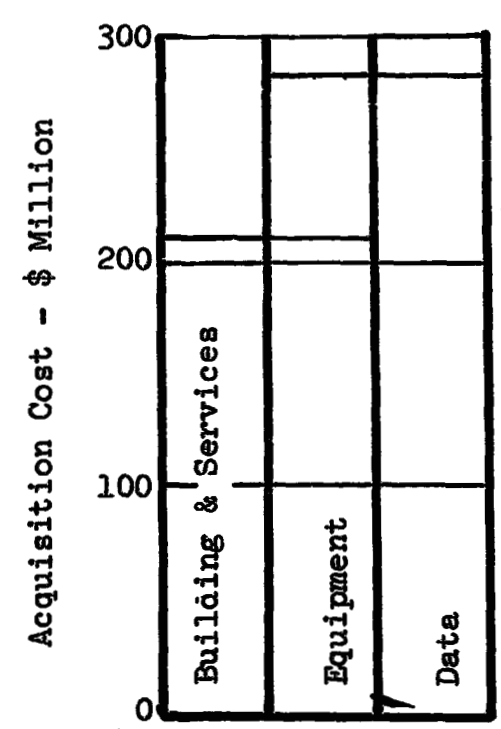
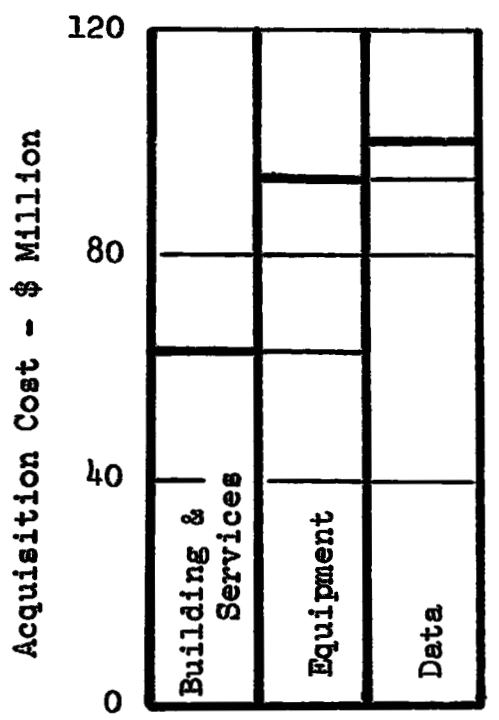


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

S2B - Major Component Dynamic Structural Evaluation Facility

Environmental Chamber-100 x 100 x 50 ft high (30 x 30 x 15 m)
Structural Ceiling and Floor - 100 x 100 ft (30 x 30 m)
2000 kip loads (8,900,000 N)
Altitude Simulation 150 kft (46 km)
Load Programming - 200 channels @ 50 kip (22,200 N)
Thermal Programming - 1100 channels @ 500 kW
Cryogenic Tankage - 100,000 ft^3, 60,000 gpm (2830 m^3) (3.78 m^3/sec)
Acoustic Generator - 170 dB
Mechanical Exciter - 1800 kip total force (8,000,000 N)
Data Acquisition - 7800 channels

Operating Cost = $11,372/run hr



S3 - Thermal-Mechanical-Fatigue Component Test Facility

Fatigue Loading System - 30 channels @ ±50 kip (222,000 N)
Thermal Programming
to 4500°F - 100 ft^2 (2490°C) (9.3 m^3)
to 3000°F - 100 ft^2 (1650°C) (9.3 m^3)
} 75 channels @ 500 kW
to 1500°F - 1000 ft^2 (820°C) (92.9 m^3)
} 100 channels @ 250 kW
Cryogenic Tankage - 80,000 ft^3, 10,000 gpm (2260 m^3) (.63 m^3/sec)
Data Acquisition - 4000 channels

Operating Cost = $2700/run hr

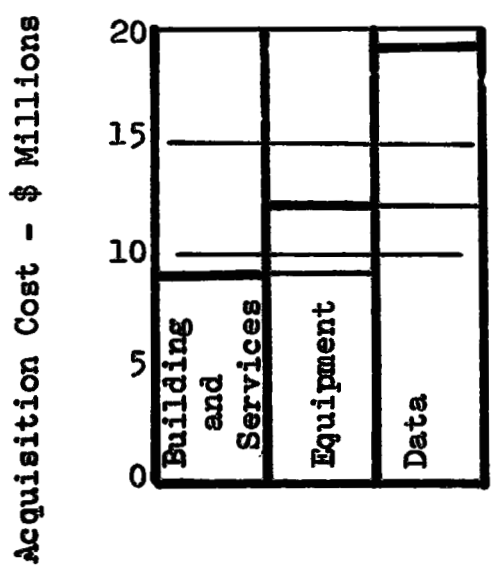


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

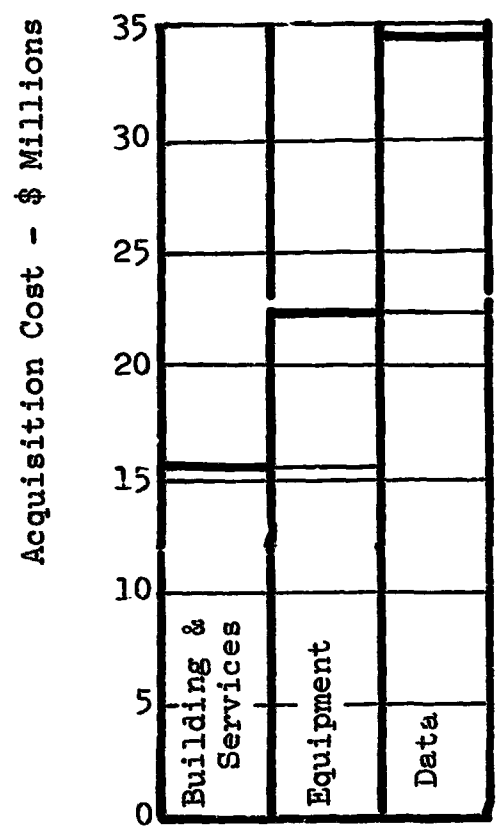
S4 - Airframe Acoustic Test Facility

Operating Cost = $4600/run hr

Acoustic Shroud Enclosure - 350 x 150 x 100 ft (107 x 46 x 30 m)

Acoustic Generator - 170 dB - (0-5 kHz,) 9 Million acoustic watts (6300 N/m^2)

Data acquisition - 9500 channels



S5 - Component Thermal-Acoustic Test Facility

Operating Cost = $2600/run hr

Thermal Acoustic Shroud Enclosure-50 x 50 x 20 ft (15 x 15 x 6.1 m)

Acoustic Generation - 170 dB - (0-5 kHz), 0.3 Million acoustic watts (6300 N/m^2)

Thermal Programming
- to 3500°F over 100 ft^2 - 30 chan. @ 500 kW (1930°C) (9.3 m^2)
- to 1500°F over 1000 ft^2 - 300 chan. @ 250 kW (820°C) (9.3 m^2)

Data Acquisition - 2100 channels

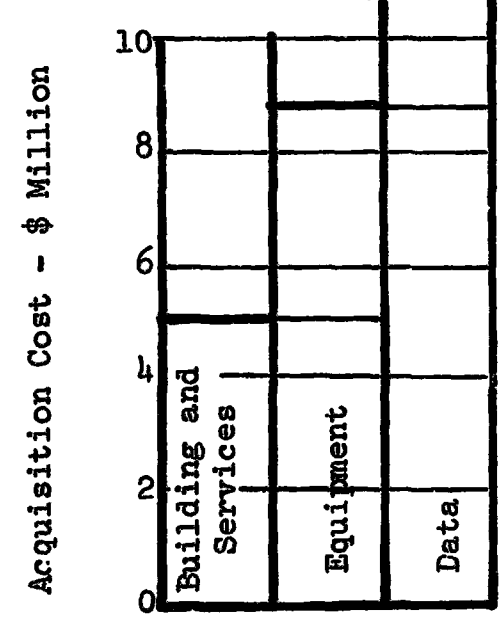


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

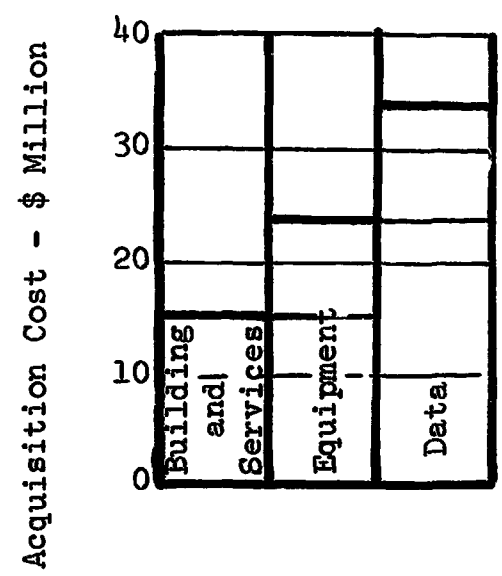
S6 - Tankage Thermal-Structural-Dynamic Test Facility

Structural Floor - 250 x 100 ft (76 x 30 m)
Load Programming - 400 channels

Thermal Programming - 0-25 Btu/ft^2 sec over 6000 ft^2 - 650 channels (570 m^2) (0-28 W/cm^2)

Cryogenic Tankage - 100,000 ft^3 - 70,000 gpm (2830 m^3) (4.4 m^3/sec)
Mechanical Exciter System - 500 kip total (2,222,000 N)
Data Acquisition - 9000 channels

Operating Cost = $5100/run hr



S7 - Cabin Pressurization Facility

Load System - 2000 gpm @ 15 psig (.126 m^3/Sec) (20.5 N/cm^2)
Hydrostatic Test Cell - 350 x 150 x 100 ft (107 x 46 x 30 m)
Data Acquisition - 3500 channels

Operating Cost = $1200/run hr

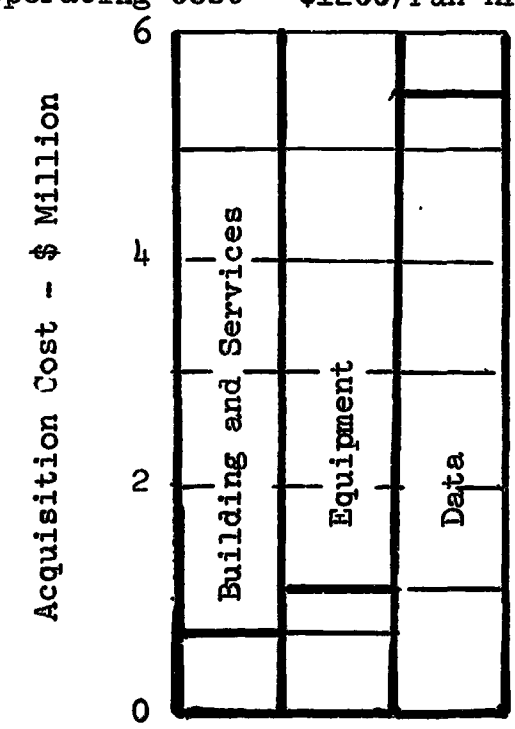


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

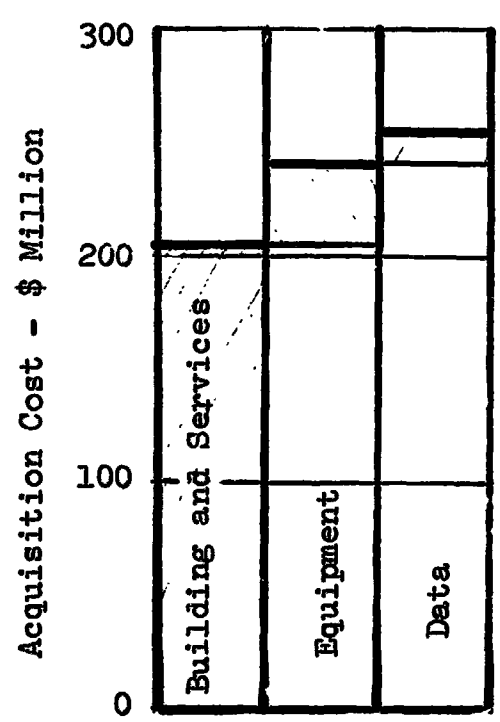
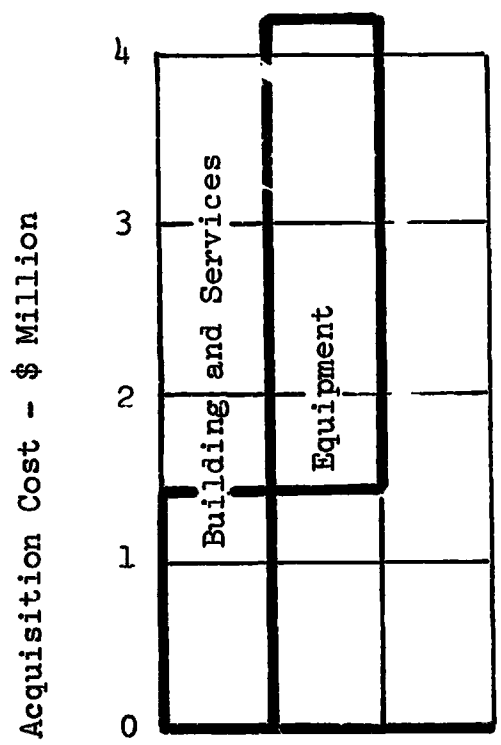
S8 - Transparency Test Facility Thermal Programming - 65 (-54°C) to 2500°F (1370°C) over 500 ft^2 (46 m^2) Data Acquisition - 200 channels	Can be accomplished in engine test facility, utilizing air supply, heater, and refrigeration equipment of E6. Similar to NAATS Air Flow Transparency Tests for F-111 Escape Capsule.
S9 - Cruise-Descent Thermal-Vacuum Test Facility Environmental Control Chamber - 350 x 150 x 100 ft (107 x 46 x 30 m) Altitude Simulation Programming - 150 kft (46 km) Thermal Programming - 3000 channels @ 500 kW Data Acquisition - 10,000 channels	Operating Cost = $33,800/run hr 
M1 - Local Flow Simulation Facility Provides local flow simulation for materials samples where gas composition, local pressure and temperature, and gas velocity are duplicated.	Can be accomplished in existing arc heated facilities, such as high pressure 4 megawatt heaters at AEDC and FDL, and 50 megawatt facility at FDL. Where lower pressures are required, there are many facilities available for local flow simulation on small samples.

FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

M2 - Thermal/Physical/Mechanical Properties Facility

Operating Cost = $300/run hr

Thermal Programming - -450 to 4500°F over 1 ft^2
(5° K to 2800° K) (.09 m^2)
(flux to 450 Btu/ft^2sec)
(510 W/cm^2)
Tensile-Compression Test Machines - 1 x 10^6 lb
(4.5 x 10^6 N)
Impact Test Machines - 5000 (ft-lb)
(6800 Joule)
Creep Test Machines - 20 kip at thermally
(89,000 N)
controlled conditions - 50 channels
Thermal Properties
Conductivity - high/low measurement
Emissivity/Absorbency - solar, total, spectral
Expansion Coefficient - high/low
Environmental Chamber - 15 x 30 ft
(3 x 10 m)
Altitude-150 kft
(46 km)
Data Acquisition - 750 channels



M3 - Thermal/Mechanical Fatigue Facility

Operating Cost = $500/run hr

Thermal Programming - 450 to 4500°F over 6 ft^2
(5° K to 2800° K) (.56 m^2)
(flux to 450 Btu/ft^2sec)
(510 W/cm^2)
Mechanical Load Programming ±1000 kip - 4 units
(4,448,000 N)
Data Acquisition - 500 channels

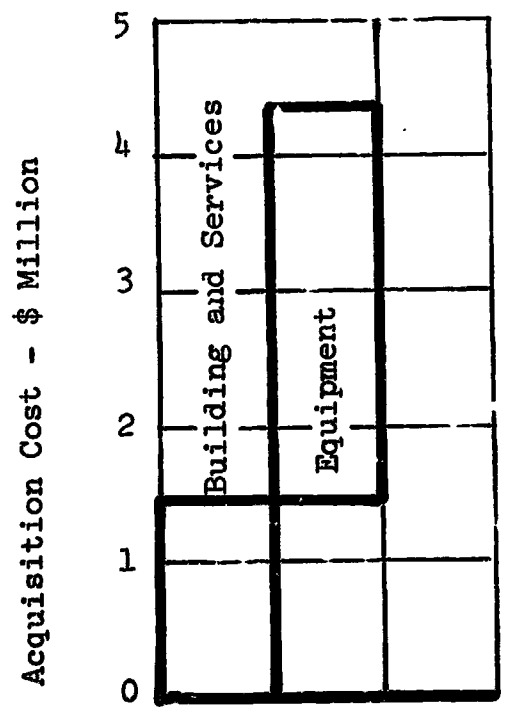


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

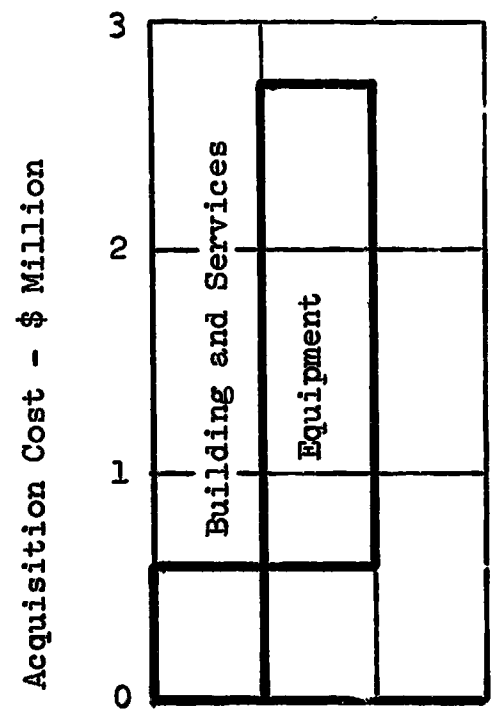
M4 - Fabrication Technology Facility

Hydroclave - 10,000 psi, 2000°F, 20 x 10 ft
(6,890 N/cm^2) (1100° C) (6.1 x 3 m)

Vacuum Furnaces - 10 x 10 x 10 ft (3 x 3 x 3 m),
operate at 3000°F, (1760°C)
free of contaminants

Autoclave - 80 x 40 x 20 ft +500 psid,
(24 x 12 x 6.1 m) (340 N/cm^{2}d)
temperatures to 1200°F
(650° C)

Operating Cost = $400/run hr



F1 - Environmental Control Systems Test

Thermal Programming - -1 to 10 Btu/ft^{2}sec
(-1 to 12 W/cm^2)
over 10,000 ft^2
(929 m^2)

Environmental Chamber - 50 x 100 ft
(15 x 30 m)

Altitude simulation - 150 kft
(46 km)

Fuel Storage - 10,000 ft^3
(283 m^3)

Data Acquisition - 2500 channels

Operating Cost = $3400/run hr

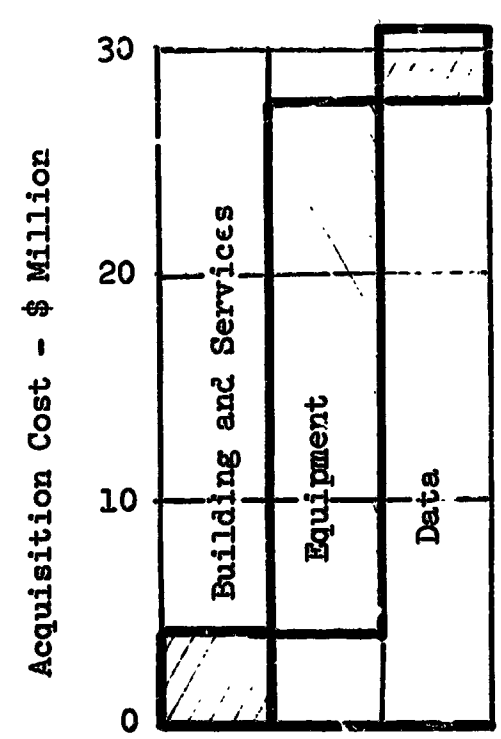
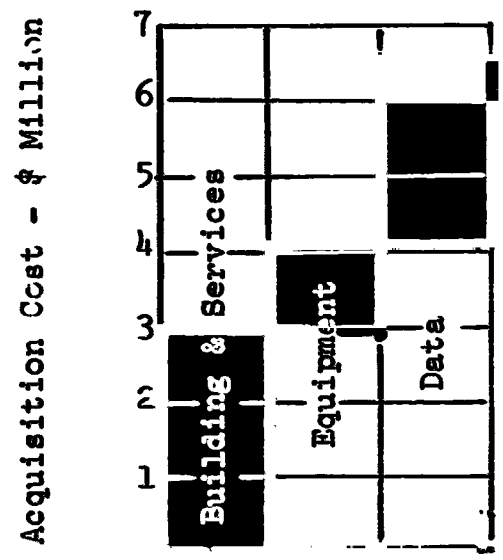


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

F2 - Fluid Heat Exchanger Test Facility

Operating Cost = $1200/run hr

Thermal Programming - 500 Btu/ft^{2}sec (560 W/cm^2) flux over 50 ft^2 (4.6 m^3)
Fluid Systems - 25,000 ft^3 (710 m^3)
storage - 25 lbm/sec flow (12 kg/sec)
Load Programming - Mechanical - 10 kip (44,400 N)
Dynamic - 25 kip total (111,000 N)
Data Acquisition - 2000 channels



F3 - Fuel System Components Test Facility

Operating Cost = $570/run hr

Environmental Chamber - 10 x 20 ft dia (3 x 6.1 m)
Altitude Simulation - 150 kft (46 km)
Heating System - 25 Btu/ft^{2}sec over 100 ft^2 (28 W/cm^2) (9.3 m^2)
Mechanical Exciter System - 6 units 2 kip load cap. (8,800 N)
Cryogenic Tankage - 10,000 ft^3 (283 m^3)
Data Acquisition - 500 channels

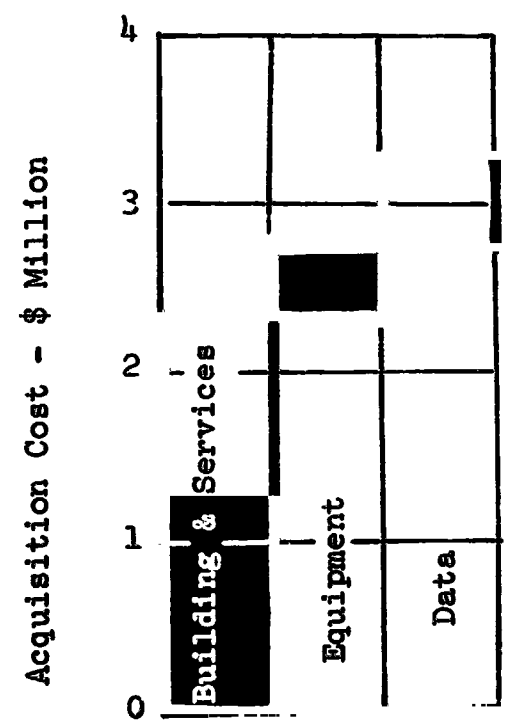
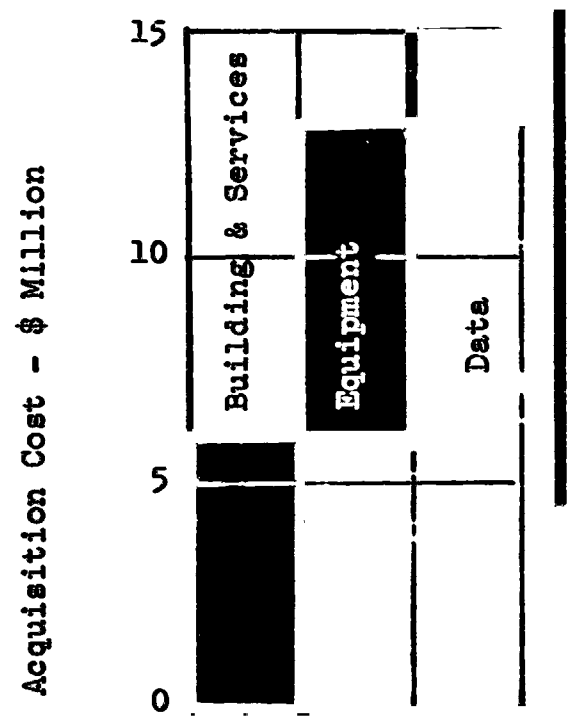


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

F4 - Fuel System Dynamic Facility

Environmental Changer - 100 x 30 ft dia (30.5 x 10 m)
Altitude Simulation - 150 kft (46 km)
Heating System - 25 Btu/ft^2 ssc over 5000 ft^2 (28 W/cm^2) (460 m^2)
Mechanical Exciter System - 30 units @ 2000 lb (8890 N)
Cryogenic Fuel Tankage - 50,000 ft^3 (1410m^2)
70,000 gpm (4.4 m^3/sec)
Data Acquisition - 2500 channels

Operating Cost = $2300/run hr



F5 - Fuel Handling Technology Test Facility

Environmental Chamber - 10 x 20 ft (3 x 6.1 m)
Altitude Simulation - 150 kft (46 km)
Cryogenic Tankage - 100,000 ft^3 (2831 m^3)
Cryogenic Fluid Transfer System - 70,000 gpm (4.4 m^3/sec)
Data Acquisition - 500 channels

Operating Cost = $5600/run hr

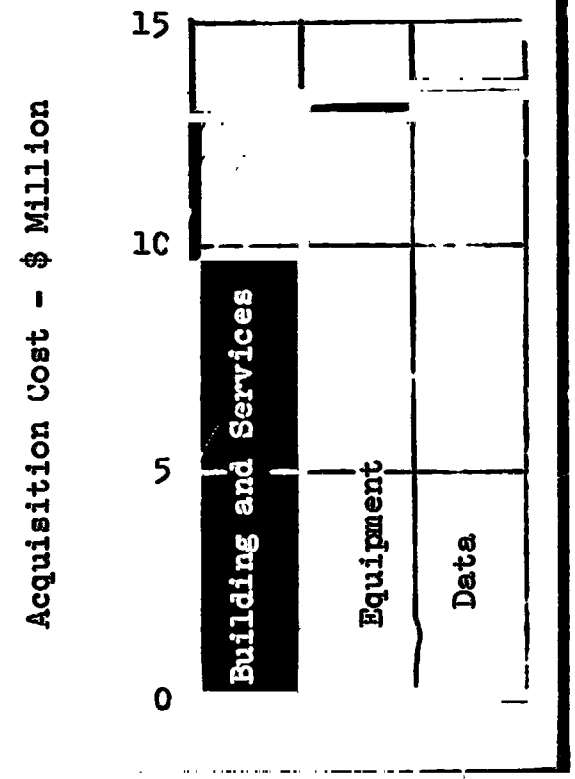


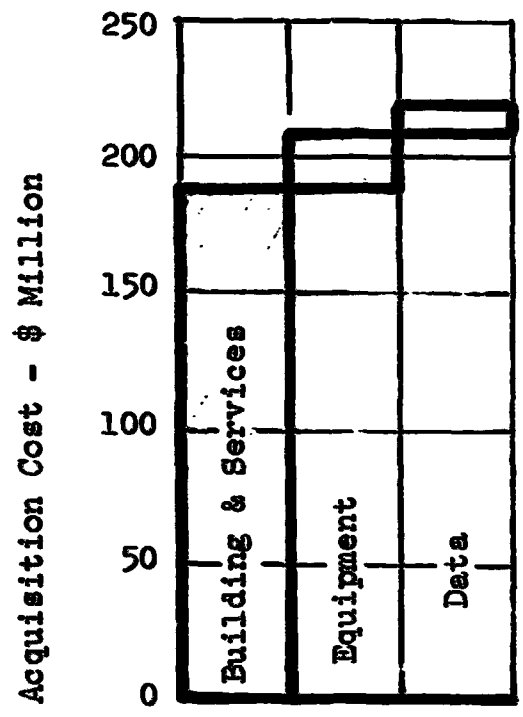
FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

SS1 - Fire Suppression System Test Facility

Fuel Tankage - 200,000 ft^3, 70,000 gpm
(5660 m^3) (4.4 m^3/sec)
Environmental Chamber - 350 x 150 x 100 ft
(107 x 46 x 30 m)
Altitude Simulation - 150 kft
(46 km)
Heating System - 2000°F over 41,000 ft^2
(1100° C) (3800 m^2)

Data Acquisition - 7500 channels

Operating Cost = $22,400/run hr



SS2 - Landing Gear Test Facility

Drop Tower - 75 ft drop, 750 kip load
(23 m) (3,300,000 N)

High load sled/track - 30 kft long,
(10 km)
350 knots, 750 kip
(180 m/Sec) (3,300,000 N)

Data Acquisition - 200 channels

Operating Cost = $1100/run hr

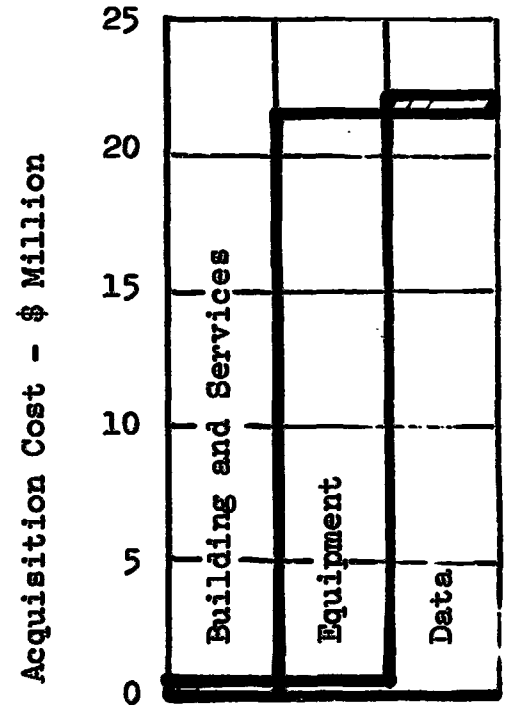


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

R1 - Nuclear Blast Simulator Facility

Thermal Source - 1500 Btu/ft^{2}sec over .5 ft^2
(1700 W/cm^2) (.05 m^2)
for .5 sec

Nuclear Sources

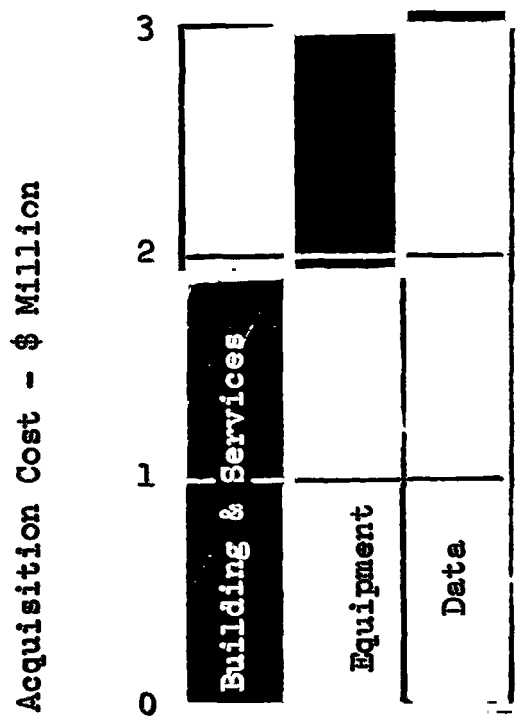
γ-10^5 rad/sec, (10^3 J/kg)

X - 3×10^{13} rad/sec, (3×10^{12} J/kg)

10^{14} neutrons/cm^{2}sec

Data Acquisition - 100 channels

Operating Cost = $280/run hr



A1 Anechoic Chamber

Model Positioning (torque load) - 100 kip-ft
(135,000 N-m)
Anechoic Chamber - 300 x 100 x 100 ft,
(100 x 30 x 30 m)
-30 dB @ 1000 MHz reflectivity

Data Acquisition - 50 channels

Operating Cost = $400/run hr

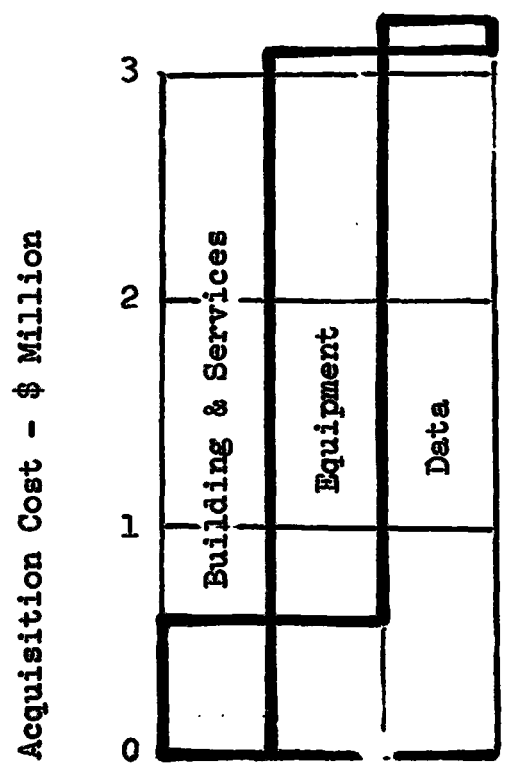


FIGURE 6-103 GROUND TEST FACILITY CAPABILITY AND COST SUMMARY PHASE I (CONTINUED)

A2 - Microwave Range

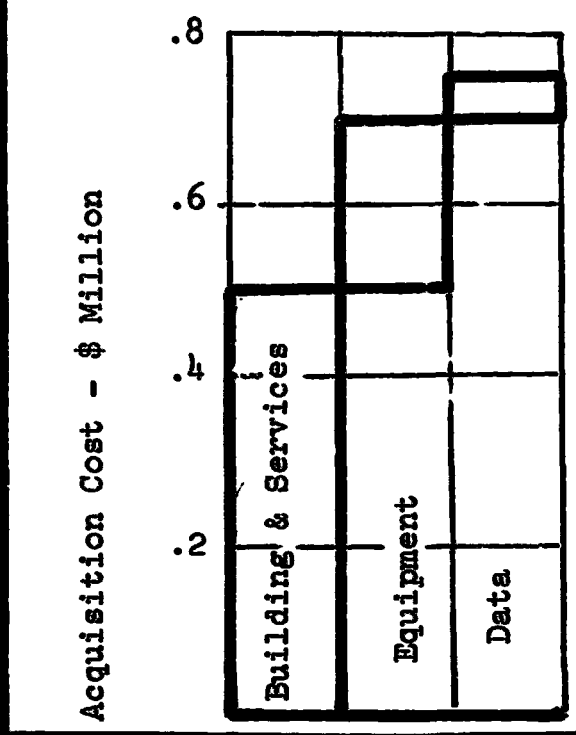
Test Range - 1 x 1 mi
(1.6 x 1.6 km)

Model Positioning (torque load) - 100 kip ft,
(135,000 N-m)

150 ft high
(46 m)

Data Acquisi+ion - 50 channels

Operating Cost = $300/run hr



7. GROUND FACILITY SCREENING AND SELECTION

Fifty-four (54) ground facility concepts were formulated in Phase I, each having a particular capability to contribute to the research required for the potential operational systems. Detailed descriptions of these facilities and their costs are discussed in Section 6.12 (Figure 6-11). This broad spectrum of facilities represented varying degrees of capability improvements over existing facilities. Of these 54 facility concepts, 19 appeared very promising. By combining equipment for efficient utilization, these 19 concepts were reduced to 7 and were retained for further study in Phase II. In addition, 6 other facilities are recommended for further study, even though it is felt that their specific application to the HYFAC program is not great enough to merit inclusion in Phase II. The screening process is shown in Figure 7-1 and illustrates the chronology in which the initial 54 facilities were evaluated, screened, and combined to yield the 7 facilities.

Factors used to judge whether or not a particular facility concept should be continued for further refinement were:

(1) Comparison with Existing Ground Facility Capability - If existing facility capabilities appeared sufficient to accomplish the specified research with little or no modification, then the concept was deleted from further refinement.

(2) Comparison with Other Study Facility Capability - The 54 postulated facility concepts represented a cross section of present experimental research facilities. In some cases, the research accomplished by several different facilities was quite similar, and a clear choice could be made as to the most effective technique to accomplish the necessary research. Much of this rationale is summarized in Figure 7-2.

(3) Contribution to General Aeronautical Research and
(4) Contribution to HYFAC Aircraft Research - This dual evaluation was employed to differentiate those facilities which may have a broad range of applicability to general aeronautical research, from those facilities which had direct and significant application to the HYFAC operational aircraft. As a result of applying this criteria, some facility concepts were qualified with the term "recommended," rather than deleted. This is intended to imply that, although not specifically necessary to accomplish the research for the potential operational hypersonic aircraft, their contribution to other areas of aircraft operation may be significant, and should be considered a concept recommended for further definition and study apart from the HYFAC study. An example of a facility to which this evaluation was applied is GD4, the transonic Ludwieg tube tunnel. For research applicable to large subsonic aircraft, and transonic, low supersonic cruise aircraft, a facility of this type may be mandatory if economical and efficient sustained flight operations in this area are to be realized. However, for aircraft whose time passing through this speed regime is minimal, such fidelity of flow field and Reynolds number simulation is probably not warranted.

(5) Cost Analysis - In addition to providing the necessary research, the facility concepts should provide the needed capability at minimum costs. The facility offering the desired level of capability at minimum costs was generally selected.

FIGURE 7–1
PHASE I FACILITY EVALUATION SUMMARY

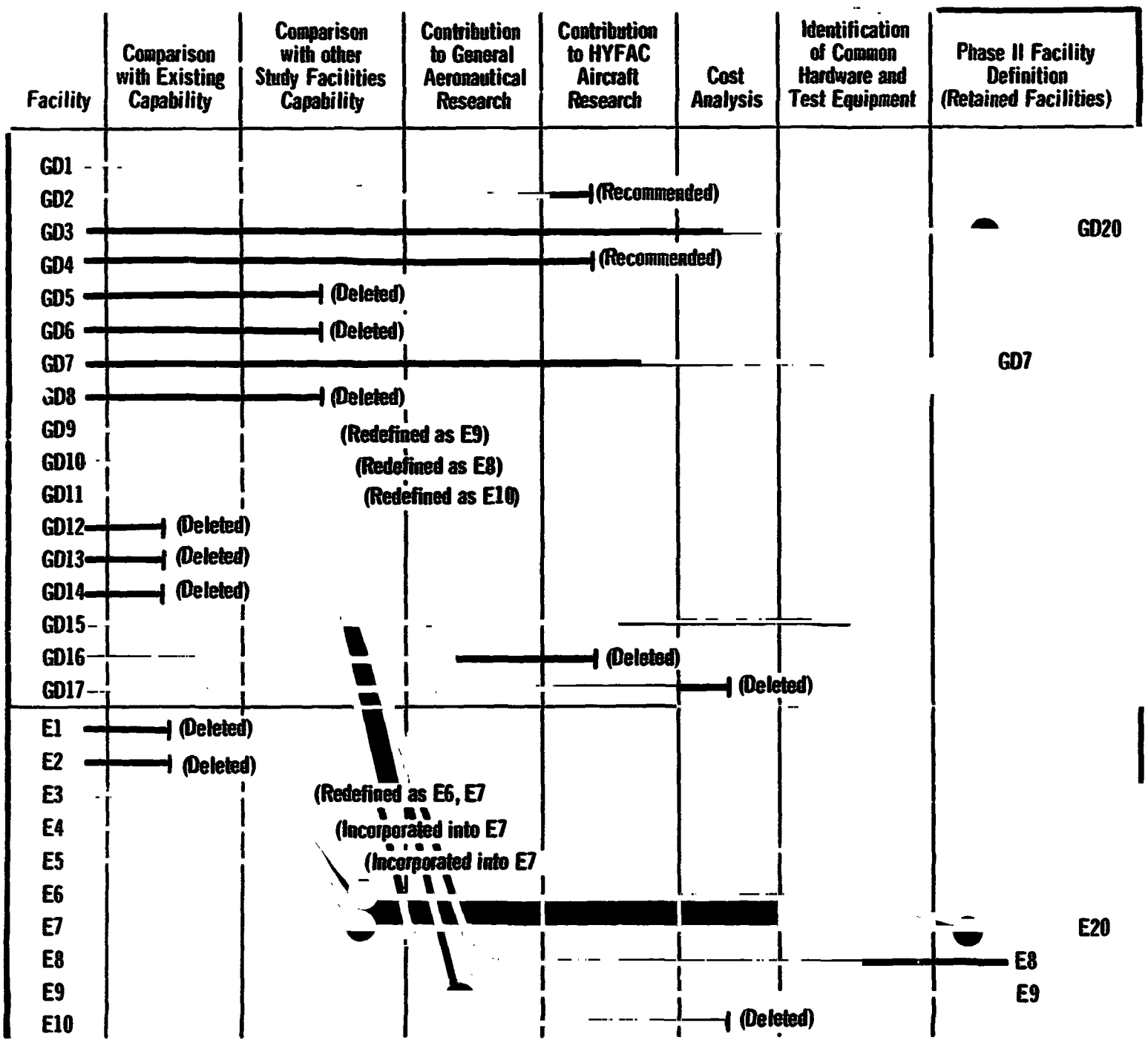
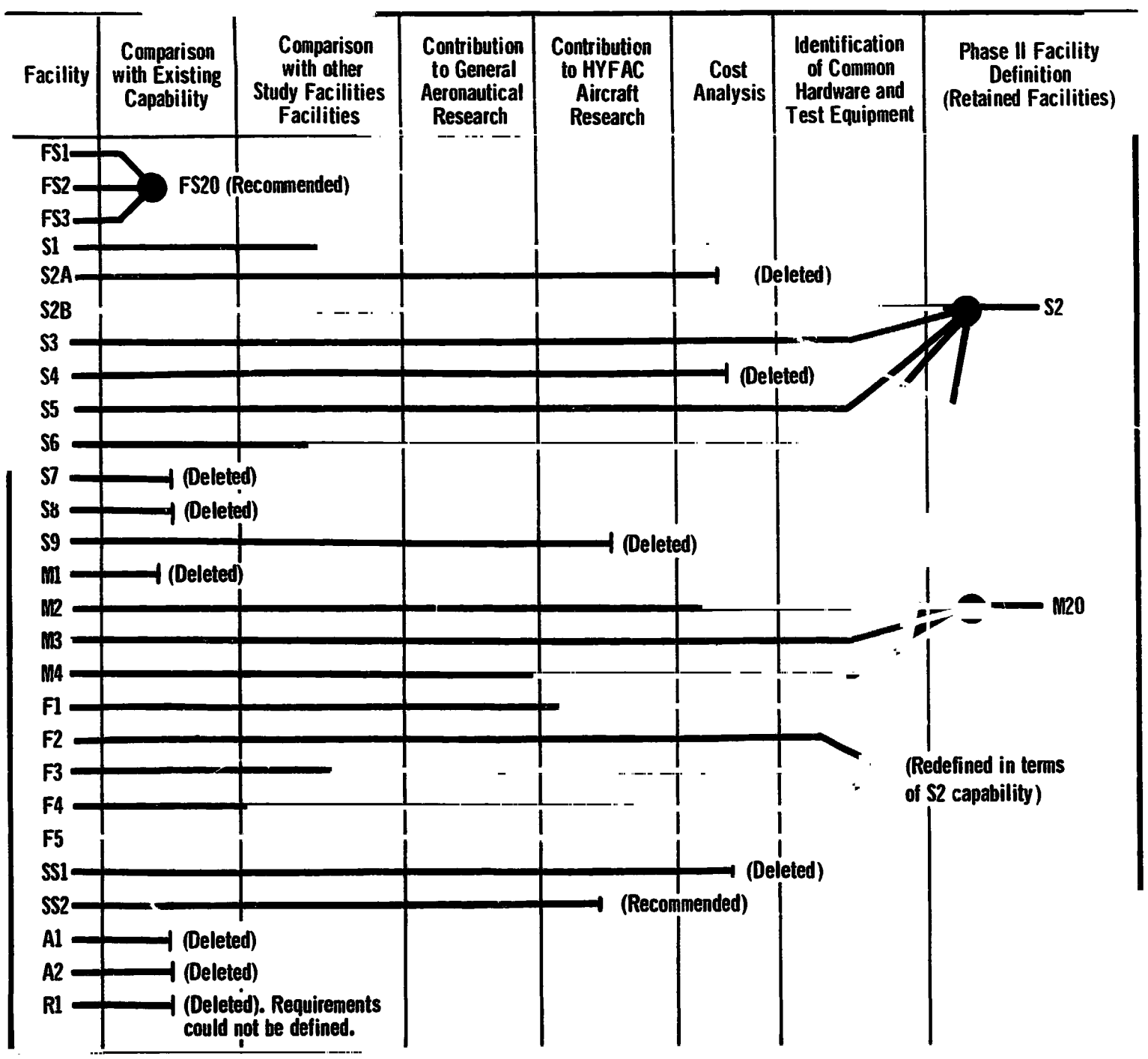


FIGURE 7–1
PHASE I FACILITY EVALUATION SUMMARY (CONTINUED)



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(U) FIGURE 7-2
RESEARCH FACILITY – EVALUATION SUMMARY

FACILITY IDENTIFICATION	DESCRIPTION	COST (1970 DOLLARS)		RESEARCH VALUE		
		FACILITY $ MILLION	OPERATION		ADAPTABILITY	GROWTH CAPABILITY
GD1	Large, pressurized low speed wind tunnel, cont. 17 ft x 24 ft, M < 0.3	–	–	–		Provides the same capal as does GD2 at Mach less than 0.3.
GD2	Large, pressurized near sonic win' 'unnel, continuous $0 \leq M \leq 1$ 17 ft x 24 ft (5.2 m x 7.3 m) 1/5 maximum full scale R_e	$45.020	$6000 per occupancy hour	110.7	Depending on design features, can do many types of tests, related to aeronautical development. Aeroelastic effects, forces and moments, control surface dev., maneuvering devices, high lift devices. Inlet development, steady state and time variant. Buffet research. Boundary layer-shock interaction effects. Propulsion system thrust minus drag determination. Boundary layer noise/structural dynamics. Inlet/airframe compatibility. Captive trajectory, flutter tests.	Basic structure and powe plant limit growth capabil in terms of increased Mac No. and R_e No. most significant growth capability in ancilary equipme to increase testing versatility.
GD3	Large, moderate pressure, blowdown to atmosphere, trisonic wind tunnel $.5 \leq M \leq 5.0$ 16 ft x 16 ft (4.9 m x 4.9 m) 1/5 maximum full scale R_e 30 – 60 sec. run	$48.8	$3900 per occupancy hour	494.9	Same as for above except that high starting loads preclude flutter testing. Time variant inlet testing can be accomplished when the run time is 30 seconds or longer. Sonic boom research.	Pressure capability could increased 50% if includec in original design. Would provide going from 20% scale R_e to 30% full scal R_e which equals the capability of the flight resear aircraft.
GD4	Large, trisonic Ludwieg tube impulse wind tunnel $.5 \leq M \leq 3$ 9 x 12 ft (2.7m x 3.7 m) Near full scale Reynolds number 1 to 4 sec run	$19.6	$820 per occupancy hour $1640 per run	33.1	Relatively restricted due to short run time. Primarily fc verification of data, extrapolations from lower Reynolds No. facilities. Use in areas of: Aerodynamic forces and moments, maneuvering devices, high lift devices, control surface dev. inlet performance and recovery, shock/boundary layer interaction, boundary layer research. Installed propulsion system thrust minus drag, jet effects.	Can extend maximum pres from 500 psi to 750 psi (518N/cm^2) if designed original facility.

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ASSESSMENTS			DISPOSITION	PRIMARY REASONS FOR DISPOSITION
GROWTH CAPABILITY	DEVELOPMENT RISK	OTHER		
rovides the same capability does GD2 at Mach numbers ss than 0.3.			Deleted from Final Phase I Definition	Overlapping capability, better done by GD2
structure and power limit growth capability terms of increased Mach . and R_e No. most nificant growth capa- in ancilary equipment increase testing rsatility.	Drive motor, shell pressure structural requirements, and accessory represent existing hardware and construction techniques. Circuit design proven aerodynamically and facility has little technical risk in achieving performance goals.	Continuous operation, depending on model changes, about 100 angle of attack or yaw sweeps possible per 10 hour operating shift. Remote controlled model essential in minimizing model changes, control surface adjustments.	Recommended as necessary facility for aircraft development.	An excellent facility, however it is primarily a development facility, therefore will not be further refined in Phase II.
essure capability could be creased 50% if included original design. Would going from 20% full ale R_e to 30% full scale which equals the capa- of the flight research craft.	Shell is within state of the art, considering pressures and size. Air storage would require a larger installation than current facilities but could be built with existing hardware. Risk in achieving goals is small.	Blowdown operation, capable of about 16 angle of attack or yaw sweeps per 10 hour operating shift.	Retained for further definition in Phase II.	Contributes significantly to research as well as vehicle development
extend maximum pressure 500 psi to 750 psi (345 to kN/cm^2) if designed into original facility.	Pressure limits are well within construction state of art. Compressor requirements are not severe for short duration facilities such as this. Major development items are high pressure sphere to contain discharge pressure to reduce noise, and quick opening and closing valve in sphere inlet to provide quick starting and stopping capability for facility. Fairly low risk. Model costs could be very high considering strength and surface finish necessary.	Although limited in scope and operation, capable of one angle of attack point per shot, and about 4 shots per 8 hour shift, its importance should not be overlooked. When Convair 990 did not meet cruise spec. It cost company about $50 million or about 3 such facilities. Large costs are required to correct unexpected problems. Such an investment seems justifiable. All body shapes have transonic thrust minus drag problems and could use high R_e.	Recommended as desirable facility for aircraft development programs. Similar to AEDC HIRT facility	Contributes primarily to verification of full scale data extrapolations made from lower Reynolds number data for development programs. Will not be further refined in Phase II.

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FACILITY IDENTIFICATION	DESCRIPTION	COST (1970 DOLLARS)		RESEARCH VALUE		
		FACILITY $ MILLION	OPERATION		ADAPTABILITY	GROWT CAPABILI
GD5	Large hypersonic Hot-shot impulse wind tunnel.	–	–	–	Same size and performance as GD7.	Considering energy required, very limited.
GD6	Large hypersonic shock tunnel	–	–	–	Same size and performance as GD7.	Run time too limited Reynolds numbers com to that available with
GD7	Large hypersonic gas piston driven wind tunnel $8 \leq M \leq 13$ 10 ft diameter (3.05 m) 1/5 maximum full scale R_e 1 to 4 Sec run	$33.12	$1310 per occupancy hour $2630 per run	248.1	Provides 1000 times increase in run time over shock tunnels, as well as considerable Reynolds number increase. With temperature increase, spontaneous hydrogen supersonic combustion, for model scramjet testing.	Growth capability is able, NOL facility is to 60,000 psi (41,500 If mass flow can be possibility of full scale number duplication to Variable angle of attac support system very this facility considerin
GD8	Large alumina storage heater hypersonic wind tunnel. Low R_e.	–	–	–		Capability similar to heater but maximum ture 3000°R (1700°K) c pared to 4500°R (2500° for zirconia.
GD9	Large zirconia storage heater hypersonic wind tunnel. Low R_e.	–	–	–	Rather good as scramjet engine facility.	Redefined as engine E9.
GD10	Multirecompression heated hypersonic wind tunnel. Low R_e.	–	–	–	For aerodynamic facilities with Mach number in excess of 14 the MRCH has application.	Redefined as engine E8.
GD11	Large arc heated wind tunnel. Low R_e.	–	–	–	More applicable as scramjet, or thermodynamic/structural test facility.	Redefined as engine E10.
GD12	Large pressurized ballistic range. (Modified NOL range with 5 atm tank pressure and larger gun) Gun bore – 7 in. (18 cm) Model dia. 5.5 in. (14 cm) Range pressure (maximum 5 atm) (50.5 N/cm^2) $M \ll 11$ Near full scale Re from M = 2 to M = 10. 1000 ft range. (305 m)	1.00 (Modification cost)	$12,000 to $18,000 per shot	6.5	Very little. Lifting body models not regularly tested at angle of attack. Generally zero degrees, or oscillation over $\pm 10^0$. If model lifts too much it flies through tank walls and optical equipment. Data collection very difficult. Telemetry uncertain. Generally limited to gross aerodynamic parameters. More applicable to ballistic weapons for research.	Very little.

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FIGURE 7-2 (Continued)
RESEARCH FACILITY – EVALUATION SUMMARY

ASSESSMENTS			DISPOSITION	PRIMARY REASONS FOR DISPOSITION
GROWTH CAPABILITY	DEVELOPMENT RISK	OTHER		
Considering energy system required, very limited.	High risk in very large energy storage system required.	Operational problems and costs significantly greater, than for GD7.	Deleted from final Phase I refinement.	Lacks capability as represented by GD7.
[illegible] time too limited at high Reynolds numbers compared to that available with GD7.	In terms of operation and data instrumentation GD7 offers much less complexity.	Less than 1 msec run ti at high Reynolds numbers.	Deleted from final Phase I refinement.	Lacks capability as represented by GD7.
Growth capability is considerable, NOL facility is designed to 60,000 psi (41,500 N/cm^2). [illegible] mass flow can be handled, possibility of full scale Reynolds number duplication to M = 11.5. Variable angle of attack model support system very pertinent to [illegible] facility considering run time.	Prototype in development at NOL. Zakkay at NYU has original small facility running. NOL not developing for as high mass flows so that additional development is needed. Probably 95% sure facility will work but 30% chance additional funds will be required to work out bugs.	If facility is increased to full capacity probably a Δcost of 15.0 million necessary, depending on original design assumptions. Facility costs could increase as performance is upgraded because of damage done in event of a failure.	Retained for further definition in Phase II.	Significant research value, and extension of currently available performance
[illegible]bility similar to zirconia [illegible]er but maximum temperature 3000^{0}R (1700^{0}K) compared to 4500^{0}R (2500^{0}K) for zirconia.	Very stable matrix material, few operational problems.	More appropriate as engine facility than high Reynolds number facility in Mach 6 to 14 regime.	Deleted from further definition in Phase II.	Did not really provide significant aerodynamic capability, in terms of Re duplication.
Redefined as engine facility E9.	New stabilized zirconia, cored brick concepts greatly reduce operational problems.		Deleted from further definition in Phase I as GD facility.	Did not really provide significant aerodynamic capability, in terms of R_e duplication.
Redefined as engine facility E8.	Will require very large input shaft powers.	Conceived by Weatherston at Cornell as high Mach number 12,600^{0}R (7000^{0}K) class facility.	Deleted from further definition in Phase I as GD facility.	Did not really provide significant aerodynamic capability, in terms of R_e duplication.
Redefined as engine facility E10.			Deleted from further definition in Phase I as GD facility.	Did not really provide significant aerodynamic capability, in terms of R_e duplication.
Very little.	Risk not too severe. 5 Atm (52 N/cm^2) tank pressure most critical item. Shock wave from model could damage equipment. Equipment failure generally results in severe facility damage.	About 1 or 2 shots per day. As gun approaches maximum performance, usable shots can drop to one out of every three or four.	Recommended as desirable facility for missile development and research programs.	Modification to existing facility. Not retained for further definition in Phase II.

FOLDOUT FRAME 1

FIGURE 7–2 (Continued)
RESEARCH FACILITY – EVALUATION SUMMARY

FACILITY IDENTIFICATION	DESCRIPTION	COST (1970 DOLLARS)		RESEARCH VALUE		
		FACILITY $ MILLION	OPERATION		ADAPTABILITY	GROWTH CAPABILITY
GD13	Holloman AFB rocket sled track (extension of present track to achieve Mach 7)	8.6 (Modification cost)	$12,000 to $20,000 per run	19.7	Primarily for testing of operational components. Aero thermodynamic measurements difficult at best. Small models required because lift can cause sled to lift off track	Doubtful.
GD14	Rocket launched free flight models	–	$750,000 to $1,000,000 per flight for hypersonic speed reduced data	–	For cost of running a major program of 10 launches, $9 million is required, that is, 1/2 to 1/4 the cost of a ground test facility which can accomplish considerable more testing over its lifetime.	Depends primarily on _ of launch rocket_ ..iz
GD15	Large, hypersonic blowdown to atmosphere wind tunnel $3 \leq M \leq 8.5$ 10 ft diameter (3.05 m) 1/5 maximum full scale R_e 20 to 30 sec run	$29.62	$1190 per occupancy hour	245.3	Same comments apply as to GD3, and GD16 except run times are longer than available with existing high R_e number facilities. Very adaptable to do wide range of detailed configuration development tests, because of run time, run frequency. Identical to GD16 in performance except in productivity.	Not much pressure growth capability, but ing stagnation temperat logical potential develo
GD16	Large, hypersonic, Ludwieg tube, impulse wind tunnel. $3 \leq M \leq 8.5$ 10 Ft diameter (3.05 m) 1/5 maximum full scale R_e 1 Sec. Run	$16.60	$850 per occupancy hour $3400 per shot	121.1	For this Mach No. range, this Reynolds number capability represents a run time increase over existing high R_e facilities. Therefore it can do everything current hypersonic impulse tunnels can do, but better. Aerodynamic force and moments. Control surface development. Interference heating. Heat transfer measurement. Shock-boundary layer integration. Inlet performance boundary layer and transition research non-spontaneous, fuel burning for subsonic supersonic combustion.	Not very much growth in pressure. However incre stagnation temperature prove boundary layer en profile duplication very Could provide variable attack capability like in Hotshot tunnel to 20° an attack sweep in one sh creasing productivity by 20 to 30.
GD17	Large, high Reynolds number, continuous trisonic wind tunnel $0.5 < M < 5.0$ 16 x 16 ft (4.9 x 4.9 m) 1/5 maximum full scale R_e	Approx. $430.	Approx. $21,000 per occupancy hour.	500	Same comments as for GD3 except flutter testing is not excluded. Continuous version of GD3.	Growth capability limite because of shell design compressor/drive system limitations.

FOLDOUT FRAME 2

ASSESSMENTS			DISPOSITION	PRIMARY REASONS FOR DISPOSITION
GROWTH CAPABILITY	DEVELOPMENT RISK	OTHER		
Doubtful.	Burning of slippers severe limitation. Risk increases with increasing Mach No. above about 3.5. Considering vibration, etc., Accuracy of data is not sufficient to see differences from low Re data.		Recommended as desirable facility for component development.	Modification to existing facility, not retained for further definition in Phase II.
Depends primarily on the size of launch rockets utilized.		Considered an existing capability, high research value in atmospheric research and other areas.	Deleted from further definition in Phase I.	According to NASA Langley, Wallops Island capability is adequate and is expensive in terms of data quantity returned.
[illegible] much pressure [illegible] capability, but increas- [illegible] stagnation temperature logical potential development	Comments are similar to GD3. Heater size is very large, as is mass flow. Compressor for intermittent tunnel within present capability. Design of pressure vessels, shell, heater are challenge but careful design should permit high degree of confidence. Prototype heater may be required to confirm heat transfer.	Blowdown operation capable of about 6 to 9 angle of attack or yaw sweeps per 10 hour operating shift. Logical combination with GD3, in a two leg facility each operating 10 hours a day.	Retained for further definition in Phase II.	Good research value, provided that its capability is needed.
[illegible] very much growth in pressure. However increases in stagnation temperature to im- [illegible] boundary layer enthalpy [illegible] duplication very feasible. [illegible]ld provide variable angle of [illegible] capability like in MCAIR [illegible] tunnel to 20° angle of [illegible]k sweep in one shot, increasing productivity by factor of [illegible] to 30.	Higher than GD4. Development of heated expansion/storage tube will require prototype development on smaller scale, such as Huntsville facility. Dumping the hot gases into dump sphere also requires some investigation.	Would be a logical thing to combine GD4 and GD16 into two legs of single facility considering like requirements and shot rate. Two shots per 8 hour shift. One angle of attack point per shot (see growth cap.) 1 angle of attack sweep with variable angle of attack system.	Rejected for further definition in Phase II. If AEDC would build HIRT facility GD16 would be reasonable addition (see GD4).	Does not provide any additional performance than GD15, but is significantly less productive in terms of run efficiency.
[illegible] capability limited because of shell design and compressor/drive system limitations.	Fabrication of a tunnel circuit of this size and pressure capability would challenge current technology. Risk considerably higher than GD3. Compressor plant volume flow 80 times largest current plants.	Continuous operation not as productive when many model changes associated with research must be accommodated.	Deleted from further definition in Phase I.	Acquisition and operational costs greatly exceed GD3 for nearly the same capability.

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FACILITY IDENTIFICATION	DESCRIPTION	COST (1970 DOLLARS)		RESEARCH VALUE		
		FACILITY $ MILLION	OPERATION		ADAPTABILITY	GROWTH CAPABILIT
E1	Large engine rocket test cell (LRF at AEDC)					The only addition whi necessary is additiona storage for large rocke now testing storable
E2	Wind tunnels adapted for engine tests.				This concept is valid for continuous facility concepts where provisions can be made to handle exhaust gases. This concept could not be reasonably applied to intermittent high Reynolds number facilities.	
E3	Turbomachinery engine facility.					
E4	Exhaust nozzle test facility.					
E5	Engine dynamic simulator.					
E6	Direct connect turbomachinery test cell. Flight duplicated conditions to M = 5. Sea level to M = 1.2. 2000 psf (95,700 N/cm^2) q to M = 4.3. 150 psi (103 N/cm^2) duct pressure to M = 5.5. Maximum Engine 35 sq ft (3.3 m^2) A_c.	104.0	$9930 per occupancy hour.	183.9	Adaptable to either conventional direct connect or modified direct connect to achieve simulation of dynamics of terminal shock stability. Storable or cryogenic fueled engines. Adaptable to turbojets/turboramjets as well as turbofans with supplemental equipment.	Not la ge in growth Can handle very large up to 1650 lb/sec (75 mass flow and 35 sq capture area. Basic potential is in test div and technique develop well as increased mas
E7	Free jet turbomachinery test cell. Same as above except maximum Mach number is 4.	208.0 Combined E6 E7 as combined facility costing $232 million. Designated as E20 in Phase II.	$22,000 per occupancy hour.	211.3	Primarily for inlet/engine compatability testing with dynamics of actual bleed, spill, ramps, and engine interacting. Inlet to supersonic nozzle can be screened to simulate total pressure field adjacent to fuselage, wing. Logical combination with E6.	Same as above. Present limit. For inlets with 17 sq capture area. Angles up to 20^0, duct height ratios from 1 to 3. For inlets with 35 sq capture area, up to 10 of attack. For duct he width ratios from 0.8

FIGURE 7-2 (Continued) FOLDOUT FRAME

RESEARCH FACILITY – EVALUATION SUMMARY

ASSESSMENTS			DISPOSITION	PRIMARY REASONS FOR DISPOSITION
GROWTH CAPABILITY	DEVELOPMENT RISK	OTHER		
The only addition which might be necessary is additional LH_2 storage for large rocket test cells now testing storable fuels .		Current capability at AEDC will accommodate projected needs for HYFAC aircraft.	Deleted from further definition in Phase I.	AEDC provides capability with existing facilities for engines many times larger than any used by the potential operational aircraft.
			Deleted as viable concept for Phase I gas dynamic facilities.	Gas dynamic facilities did not provide necessary engine test conditions. Those that did were redesignated as engine test facilities.
		This facility represents a combined free jet, direct connect facility. In order to better establish requirements associated with each mode of testing, facility was separated into E6 and E7 facilities.	Deleted as separate facility concept.	Redefined as E6 and E7.
			Deleted as separate facility concept.	Test capability can be achieved in any of gas dynamic facilities or engine test facilities as special test setup.
			Deleted as separate facility concept.	Test capability represented in each of engine test facilities.
Not large in growth potential. Can handle very large engines up to 1650 lb/sec (750 kg/sec) mass flow and 35 sq ft (3.3 m^2) capture area. Basic growth potential is in test diversity and technique development, as well as increased mass flows.	Although large, it does not exceed present capability in construction techniques, hardware performance, or equipment. Risk is primarily in design of large components. Similar to T-1 and J-2 at AEDC except flight simulation is carried to Mach 5.5 instead of 3.0.	Continuous operation, could do continuous 150 hour PFRT if required. Required by full scale M = 3.5 TJ and M = 4.5 TRJ if full temperature range is desired.	Retained for further refinement in Phase II	Required to research, develop, and qualify engines
Same as above. Present limit. For inlets with 17 sq ft (1.6 m^2) capture area. Angles of attack up to 20^0, duct height-to-width ratios from 1 to 3. For inlets with 35 sq ft (3.3 m^2) capture area, up to 10^0 angle of attack. For duct height-to-width ratios from 0.8 to 1.5.	No facility of this type and scope in existance. Major development design problems will be heater and adjustable nozzle. However pressures and temperatures within state of art. Air supply will have greater risk and careful development is necessary, because of its size and power required.	Will be able to test dynamics of turbojet/ramjet conversion. Size of nozzle, and temperature, pressure duplication make it a logical materials/structural test facility for full scale components, especially for duplication low altitude flight and composite structure research.	Retained for further refinement in Phase II	Required to research, develop, and qualify engines. Necessity for this facility closely associated with need for inlet/engine/exhaust nozzle compatibility verification and research.

FOLDOUT FRAME 1

FIGURE 7–2 (Continued)
RESEARCH FACILITY – EVALUATION SUMMARY

FACILITY IDENTIFICATION	DESCRIPTION	COST (1970 DOLLARS)		RESEARCH VALUE		
		FACILITY $ MILLION	OPERATION		ADAPTABILITY	GROWT. CAPABILI
E8	Multirecompression heater engine test facility. Duplicated conditions, Mach number just ahead of cowl. Corresponding to flight Mach number 6 _ M _ 12 Test ram, scramjet engines for 10 sq ft (0.93 m^2) capture area, from 75,000 to 160,000 ft (23 to 49 km) altitude. Continuous run time.	79.4	$10,000 per occupancy hour.	273.8	Although primarily for scram, convertible scramjet combustor development, the facility has many other applications. Transition from subsonic to supersonic combustion can be tested, as well as flight profiles between M 6 to M 12. Continuous run time provides a reasonable time schedule for PFRT. Development of heat exchanger panels, inlet heat transfer, boundary layer research, transpiration cooling, and inlet flow interaction can be undertaken.	Growth capability lies the versatility of the Redesign of the rotor provide higher enthalp provide presently unol conditions for reentry weapons. Addition of 2.7 m) diameter aerod system will permit conditions up to Mach components, and heat research. This facilit facili, for nozzle ex with suitable exhaust
F9	Hybrid heater engine test cell. Duplicated conditions. 3 M _ 9.0 Ramjet, scram, c-scram jet test, duplication local Mach number just ahead of cowl. Engine capture area 10 sq ft. (0.93 m^2). Continuous run time with combustion products. 30 second run time with clean air.	Hybrid 53.2 Graphite 55.0	$18,200 per occupancy hour.	232.2	The primary purpose is to provide ramjet, and convertible scramjet operation test conditions from initial light off through conversion, and into the supersonic combustion operation. The dualheater system reduces operational costs and risks, yet provides thermal preconditioning capability and run time sufficient for PFRT operational tests. One minute per hour used for air flow to obtain performance data. Excess O_2 is used in combustion products to simulate 20% excess oxygen in air, and permit engine operation.	Same as above, for E8. of N_2O (nitrous oxide) to exit of graphite can exit temperature to 5 (3100 to 3300°K). Hand pressurized N_2O is C_2H_2, and developmen factory storage and han is yet to be realized necessary test facilitie crement of 5 million for nozzle diffuser, for Mach 10 aerodynam system. Size growth c with carbon combustor nificant, with capabilit accommodate up to 30 capture area.
E10	Very large, arc heated ramjet test facility. Same as E8 run time – 30 min.	92.4	$3800 per occupancy hour.	211.8	Can provide large structural testing capability. At Mach 10, a 9 ft (2.7 m) diameter nozzle can be used compared to the 3.5 ft (10.6 m) nozzle on the 50 megawatt facility at FDL. Major structural sections can be tested at duplicated flight conditions for about 30 minutes duration. Trajectory time history can be duplicated. Heat transfer limitations restrict operation to $\sqrt{P_0 H_0} \cdot 39{,}000$ Btu/lb(atm)$^{1/2}$ $(2.78 \times 10^7 \frac{J}{kg}\left(\frac{N}{cm^2}\right)^{1/2}$	Primarily the same as using existing arc heate nology. Lower pressure ance than E8. Same c E8, for use and cost for large diameter aero nozzles.

FOLDOUT FRAME 2

ASSESSMENTS			DISPOSITION	PRIMARY REASONS FOR DISPOSITION
GROWTH CAPABILITY	DEVELOPMENT RISK	OTHER		
Growth capability lies primarily in the versatility of the basic facility. Redesign of the rotor system to provide higher enthalpies could provide presently unobtainable conditions for reentry ballistic weapons. Addition of a 5 to 9 ft (1.5 to 2.7 m) diameter aerodynamic nozzle system will permit duplicated flight conditions up to Mach 10 on structural components, and heat transfer research. This facility is a logical facility for nozzle exhaust testing with suitable exhauster addition.	This concept has not been operationally developed. Not included in the cost but required would be a subscale develooment facility costing about $15 million dollars. Although technically sound, translation into practical hardware will require development period. Cost could be increased by at least 150%. Risk is significant. Requires total installed horsepower exceeding one million horsepower (746,000kW)	This is the only concept which takes up where pebble heaters leave off, which can give clean uncontaminated air over this pressure temperature range. With reference to growth potential, reduction of supply pressure, but maintenance of the same mass flow can provide test sections up to 15 ft (4.6 m) diameter at Mach 12. A cost increment for nozzle diffuser hardware and increased exhauster capability of 5 million.	Retained for further refinement in Phase II.	Required for ramjet research, high research value. New concept. Significant increase in existing capability, but with risk.
Same as above, for E8. Addition of N_2O (nitrous oxide) injection to exit of graphite can raise the exit temperature to 5600 to 6000°R (3100 to 3300°K). Handling of pressurized N_2O is similar to C_2H_2, and development of a satisfactory storage and handling system is yet to be realized for quantitized necessary test facilities. Cost increment of 5 million necessary for nozzle diffuser, exhausters for Mach 10 aerodynamic nozzle system. Size growth capability with carbon combustor is significant, with capability to accommodate up to 30 ft^2 (2.9 m^2) capture area.	The combustor is similar to the 8-foot structures tunnel at LRC, the difference being that carbon black is used as a fuel, preventing water vapor in the combustion products which affects both the hydrogen combustion and metal oxidation resistance. Pebble bed is well within state of the art. Graphite heater is like Lewis Plumbrook heater except operated continuously. Risk technically is minimum. Hardware-wise some components need development to minimize present risks. As with all large storage heaters, material selection and performance is a factor.	This facility is an attempt to achieve part of the capability of E8 using available technology. The hybrid nature of the facility is due to the run time limitation of air storage heaters of the alumina, zirconia type. and the requirement for 50 hours qualification for PFRT and thermal preconditioning of cryogenic cooled inlets before sudden exposure to a 30 second full temperature run. For the hybrid heater system, the run time is continuous with the combustion heater, and is 30 seconds every half hour for the pebble bed operation. For the graphite heater version the run time is continuous up to the limits of the oxygen supply system, about 4 hours.	Retained for further refinement in Phase II as the combined zirconia heater carbon combustion facility.	Same as E8 except requires less facility development, could be operational at an earlier date, with less risk. New concept high potential at reduced costs.
Primarily the same as E8 except using existing arc heater technology. Lower pressure performance than E8. Same comments as E8, for use and cost increments for large diameter aerodynamic nozzles.	Greatest risk is in plenum chamber for 6 arc heaters. Repair and maintenance costs high for arc heaters. Electrode life about 100 hours or less. Risks not significant on tunnel, hardware, construction. Some risk on operation and control of 6 adjacent arc heads, excessive plenum chamber heat losses. Some very non-uniform enthalpy distributions in test section have been reported when heaters are operating at maximum power.	Significant copper contamination in flow from 0.1 to 1%. 6 – (N 7) Linde type arc heads, nominally rated at 50 megawatts operated at 125 megawatts each. Based on N = 4 heater, nominally a 16 megawatt heater, but operated at 30 minutes at 40 megawatts, and has achieved levels of 50 megawatts.	Rejected for further refinement in Phase II.	Not equal to performance of E8 and E9, with possibly much higher repair and maintenance costs. Questions could arise as to influence of even the small quantity of metal contamination in airstream where heat transfer is involved.

FOLDOUT FRAME 1

FACILITY IDENTIFICATION	DESCRIPTION	COST (1970 DOLLARS)		RESEARCH VALUE		
		FACILITY $ MILLION	OPERATION		ADAPTABILITY	GROWTH CAPABILIT
FS 1	Six degree of freedom with audio-visual-physical synthesis programmed through large hybrid computer. Crew trainer.	13.5	1200	98.7	Adaptable to wide range of vehicle simulations through programming and minor hardware changes.	Basic installation limit: tional size growth range capability of growth thr proved resolution, frequ response, and elemental improvement exists.
FS 2	Same as FS 1 with greater acceleration rates for engineering evaluation.	14.0	1200	79.1	Same as FS 1	Same as FS 1
FS 3	Same as FS 1 with greater acceleration rates and centrifuge mounted for sustained acceleration for engineering evaluation.	15.0	1800	138.4	Same as FS 1	Same as FS 1
FS 20	Complexing of FS 1, FS 2, FS 3 facilities to share building, services, computer.	38.8	3000			Would offer one complex services now available in separate facilities
S1	Steady state low level overall structural heating with static load application on entire airframe. Test area 150 x 350 ft (46 x 107 m). 500 Load channels. 450 Thermal control channels. 15,000 data channels. 1000 K ft^3 fuel tankage (28,300 m^3).	54.9	8221	136.7	Adaptable to any smaller sized test article with proportional increases in heating level. Adaptable to transient heating and loading with limitation based on size of initial services installed. Complete full scale aircraft.	Basic structure and ins services limit size ran growth. Distribution of ing and loads improvabl increasing quantity of system control units. A growth version of existi ities with upgraded quar and graphite heaters.
S2A	Nearly total dynamic thermal-physical environment simulation on entire airframe 150 x 350 x 100 ft (46 x 107 x 30 m). Environmental chamber. 500 Load channels. 3000 Thermal control channels. 9M Acoustic watts. 13,000 Data channels. 100 K ft^3 fuel tankage (2830 m^3).	309	38,167	148.7	Adaptable to any smaller sized test article. Use of facilities of this magnitude for smaller test articles would be very uneconomical with respect to operating costs. Any combination of facilities could be utilized for variations in levels of thermal-physical environment simulation. Complete full scale aircraft.	Basic chamber and insta services would limit gro Heating and loading tion could be improved additional equipment.

FOLDOUT FRAME 2

FIGURE 7-2 (Continued)
RESEARCH FACILITY – EVALUATION SUMMARY

ASSESSMENTS			DISPOSITION	PRIMARY REASONS FOR DISPOSITION
GROWTH CAPABILITY	DEVELOPMENT RISK	OTHER		
Basic installation limits operational size growth range. However, capability of growth through improved resolution, frequency response, and elemental hardware improvement exists.	Computer, mechanical, and audio systems within existing capabilies. Video system resolution and display range are currently not within capability. However, existing approaches are marginally acceptable.	Primarily to research crew station concepts, train pilots of research aircraft, and evaluate operational aircraft pilots and standards.	Recommended. Not further refined in Phase II.	Small increment over existing technology. Existing facilities can accomplish with modification.
Same as FS 1	Same as FS 1		Recommended. Not further refined in Phase II.	Upgraded and existing facilities can accomplish necessary research.
Same as FS 1	Same as FS 1 with additional complexity risk resulting from centrifuge mount and associated transmission system problems.		Recommended. Not further refined in Phase II.	Same as FS2.
Would offer one complex, services now available only in separate facilities	New risk is time sharing of services and computer.	Would provide unified complex for research, but additional costs to acquire complete facility could better upgrade existing facilities.	Recommended. Not further refined in Phase II.	Same as FS2 except representing integrated capability.
Basic structure and installed services limit size range growth. Distribution of heating and loads improvable by increasing quantity of test system control units. A basic growth version of existing facilities with upgraded quartz lamp and graphite heaters.	Quantities of control channels fall within plausible operable ranges through direct computer control systems. The test utilization of large quantities of cryogenic fuel portends a high risk without prior fuel handling technique developments.	Although the research value per dollar is high, this facility represents largely a facility for an SST aircraft, upgraded in thermal heating capacity.	Deleted from further refinement in Phase II. Capability included in S2 facility.	Not sufficient increment over existing facilities.
Basic chamber and installed services would limit growth. Heating and loading distribution could be improved through additional equipment.	The environmental chamber and pumping system are possible using existing technology. The thermal mechanical, dynamic, and acoustic sources are within technology capacity by use of multiples of existing type hardware, the simultaneous application of these systems and the reliability of the systems involved to perform as an integrated test system portends a very high risk level.	A facility of this type would be required to answer major structural problems associated with HYFAC vehicles. If test article size can be reduced while maintaining research value, this facility may become more realistic in terms of research return per dollar.	Not recommended at this stage because of high cost & risk compared to S2B. Will be studied as an alternate to S2B in Phase II.	Only facility of its kind to do this kind of testing, in spite of low research value per dollar

FOLDOUT FRAME 1

FIGURE 7-2 (Continued)
RESEARCH FACILITY – EVALUATION SUMMARY

FACILITY IDENTIFICATION	DESCRIPTION	COST (1970 DOLLARS)		RESEARCH VALUE		
		FACILITY $ MILLION	OPERATION		ADAPTABILITY	GROWTH CAPABILIT
S2B	Nearly total dynamic thermal physical environment simulation on major component 100x100x50 ft(30x30x15 m) environment chamber 200 Load channels 1100 Thermal control channels 6M acoustic watts 7800 Data channels	101.7	11,372	145	Same as S2A except for full scale major section of aircraft.	Same as S2A
S3	Thermal and repeated mechanical loads testing of structural component 175 Thermal control channels 30 Load channels 80k cu ft (2300 m^3) fuel tankage. 4000 Data channels	17.3	2702	184.1	Adaptable to perform individually applied thermal or mech. loads either statically or in a fatigue program. Full scale component of aircraft.	Basic structure and in-stalled services limit article size or range parameters. Additional systems would increas bution capability.
S4	Acoustic environment test on airframe 150x350x100 ft (46x107x30 m) acoustic shroud. 9000k Acoustic Watts 9500 Data channels	34.6	4411	86.5	Very limited – shroud must be sized with respect to test article. Acoustic system in modular form is adaptable to article variations. Full scale major section of aircraft.	Limited by initial serv stalled. Distribution by addition of source c modules.
S5	Thermal acoustic test on airframe component 50x50x20 ft (15x15x6m) acoustic shroud. 300k Acoustic watts 330 Thermal control channels 2100 Data channels	11.5	2323	224.4	Acoustic shroud has limited adaptability to test article configuration variations. Thermal and acoustic systems could operate independently.	Same as S4.
S6	Thermal structural dy-namic test of large fuel tanks 100x250 ft (30x76 m) structural floor 400 Load channels 650 Thermal control channels 100k ft^3 (2800 m^3) fuel storage 9000 Channels data	33.7	5147	96.2	Load and thermal control systems can be applied inde-pendently. Full scale tank-age assembly of aircraft.	Initial sizing of bldg services limit growth. and load distribution by additional control
S7	Hydrostatic test cell 35x150x100 ft (11x46x30m) 3500 channels data	5.4	1158	4.2	Very limited	Easily expanded

FOLDOUT FRAME 2

ASSESSMENTS			DISPOSITION	PRIMARY REASONS FOR DISPOSITION
GROWTH CAPABILITY	DEVELOPMENT RISK	OTHER		
Same as S2A	Same as S2A with somewhat diminished risk due to fewer control channel systems involved, less complex test setup.		To be studied as part of parametric study in Phase II. To maintain research value while reducing costs.	
Basic structure and installed services limit testable article size or range of test parameters. Additional control systems would increase distribution capability.	Same as S1. Test system reliability diminishes with increased test temperature and number of test control parameters.	With power, equipment, and capability of S2, this facility capability could be integrated into S2 complex, using a fraction of the total system capability.	Retained for further refinement in Phase II as a part of a basic S2 facility complex.	Good research return, accomplishes significant research
Limited by initial services installed. Distribution improved by addition of source control modules.	Risk involved in synchronization of multiple modular acoustic generators and accomplishment of airframe distribution requirements.	Acoustic shrouds of this magnitude are well beyond current technology.	Deleted for further refinement in Phase II.	Insufficient increment over present facilities considering costs, questionable as to necessity of testing such large specimens considering risks.
Same as S4.	Same as S4 with additional synchronization of thermal program. Risk compared to S4 is low for this size system.	Same comment as for S3. Acoustic shroud of this size is extrapolation of current technology.	Retained for further refinement in Phase II as a part of the basic S2 facility complex.	High research return
Initial sizing of bldg and services limit growth. Thermal and load distribution improved by additional control units.	Same as S1	Requirement for complete tankage system test is not completely justified. Single tank element may suffice.	Retained for further refinement in Phase II as a part of the basic S2 facility complex.	Low research return for dollar, however can utilize S2 hardware at low cost for component sized test articles.
Easily expanded	None	Basically same facilities as required for qualification of commercial aircraft fuselages.	Deleted for further refinement in Phase II.	Can be accomplished in existing facilities.

FOLDOUT FRAME 1

FACILITY IDENTIFICATION	DESCRIPTION	COST (1970 DOLLARS)		RESEARCH VALUE		
		FACILITY $ MILLION	OPERATION		ADAPTABILITY	GROWTH CAPABILITY
S8	Thermal structural test of transparencies -65 to 1300°F (-54 to 705°C) over 50 sq ft (4.6 m^2)	–	–	–	Usable for low level local flow test. Full scale crew station.	Limited by initial installation
S9	Thermal vacuum test of airframe 150x350x100 ft (46x107x30 m). 3500 channels thermal control 10,000 data channels	254.8	33,300	1.1	Limited, full scale major section of aircraft.	Limited by initial installation size.
M1	Local flow simulation on material test coupons.				Can provide determination of local flow environments on wide range of materials and shapes.	
M2	Determination of thermal, physical, and mechanical properties of materials. Heating to 4500°F (2480°C). 50 creep test machines. Thermal properties determination. 1M lb (4,448,000 N) tensile machine. Environmental chamber. 750 data channels.	4.2	800	181.0	Adaptable to full range of materials.	Growth limited by initial Capability improvable by modifications or additions.
M3	Determination of thermal/ mechanical fatigue properties of materials. Heating to 4500°F (2480°C). 4 fatigue loading machines . 500 data channels .	4.4	800	152.1	Same as M2	Same as M2
M4	Development of methods and procedures for fabrication of advanced structures. Hydroclave - 10 ksi (6900 N/cm^2). 3000°F (1650°C) vacuum furnace. Autoclave - 500 psi (345 N/cm^2) Nondestructive test.	2.5	300	175.8	Adaptable to all material fabrication techniques currently envisioned as applicable to hypersonic aircraft.	Large, provides capabilit research fabrication techn so that material data obta in the laboratory can be lated into practical structi Suitable for verification tests in S2.
F1	Environmental control systems evaluation. 50 x 100 ft (15 x 30 m) environmental chamber. 100,000 Btu/sec (105 x 10^6 J/sec) thermal control. 10,000 ft^3 (283 m^3) fuel storage. 2500 data channels.	31.1	3303	51.2	Adaptable to component thermal vacuum tests and thermal tests and thermal structural test.	Structural test capability able by load system acqu Otherwise growth limited installation.

FOLDOUT FRAME 2

FIGURE 7-2 (Continued)
RESEARCH FACILITY – EVALUATION SUMMARY

ASSESSMENTS			DISPOSITION	PRIMARY REASONS FOR DISPOSITION
GROWTH CAPABILITY	DEVELOPMENT RISK	OTHER		
Limited by initial installation	Slight.	If existing facilities cannot accommodate, air supplies from E6 or E7 can accomplish with special test setup.	Deleted for further refinement in Phase II.	Currently existing systems capable of task performance
Limited by initial installation size.	Same as S2B with respect to thermal system and environmental chamber.	Could be partially accomplished in S2.	Deleted for further refinement in Phase II.	No significant research value. Applicable research can be largely accomplished in S2.
		Many arc heated facilities can provide local flow simulation on reasonable sized specimens.	Deleted for further refinement in Phase II.	Existing arc heaters are capable of performing this task.
Growth limited by initial sizing. Capability improvable by equipment modifications or additions.	Slight.		Retained for further refinement in Phase II	Very high research value per dollar, very necessary research.
Same as M2	Small risk in reliable thermal-mechanical systems integration at extreme levels.		Retained for further refinement in Phase II	Same as M2
Large, provides capability to research fabrication technology so that material data obtained in the laboratory can be translated into practical structures. Suitable for verification tests in S2.	Small risk in overall facility elements integration. Some risk in large autoclave development.		Retained for further refinement in Phase II	Same as M2
Structural test capability attainable by load system acquisition. Otherwise growth limited by initial installation.	Only development risk is fuel system integration. Hardware based on existing components and performance levels.	Components can be developed in existing facilities. Where necessary, S2 can provide capability.	Retained as part of S2.	Existing capability significant enough so as not to warrant a separate new facility.

FOLDOUT FRAME 1

FIGURE 7–2 (Continued)
..RCH FACILITY – EVALUATION SUMMARY

FACILITY IDENTIFICATION	DESCRIPTION	COST (1970 DOLLARS)		RESEARCH VALUE		
		FACILITY $ MILLION	OPERATION		ADAPTABILITY	GROWTH CAPABILITY
F2	Fluid heat exchanger development and evaluation. Heating to 500 Btu/sq ft sec. (5.7×10^6 J/m^{2}sec). 25,000 ft^3 (700 m^3) fuel storage. Mechanical and dynamic loads. 2000 data channels.	6.6	1074	52.5	Adaptable to component thermal structural test. Necessary item in development of scramjet engine.	Basic installation limit. however, high power lev valved offer wide area c lesser power densities addition of power distrit equipment.
F3	Functional test and development of fuel system components. 10x20 ft (3x6 m) environmental chamber. 10,000 ft^3 (283 m^3) fuel tankage. 2500 Btu/sec (2.6 J/sec) heating system. 6 dynamic loads. 500 data channels.	3.3	545	171.5	Adaptable to thermal-altitude – Structural dynamic test similar to S2 testing, on much smaller scale.	Limited by initial syste installation.
F4	Fuel system functional evaluation. 30x100 ft (9x30 m) environmental chamber. 1250 Btu/sec (1.3×10^6 J/sec) heating system. 50,000 ft^3 (1410 m^3) fuel storage. 30 dynamic loads. 2500 data channels.	16.0	2189	198.5	Accomplished as part of research programs conducted in S2.	Limited by equipment, . ance, and quantity.
F5	Fuel handling technology development. 10x20 ft (3x6 m) environmental chamber. 100,000 ft^3 (2830 m^3) fuel storage. 500 channels data.	13.7	5550	63.4	Limited by initial system installed.	Growth possible only thr major system additions.
SS1	Fire detection and suppression systems development and evaluation. 200,000 ft^3 (5700 m^3) fuel storage. 150x350x100 ft (46x1[illegible] m) environmental chamber. 2000°F/41,000 sq ft (1100°C/3800 m^2) heating system. 7500 channels data.	216.3	22,048	81.4	Adaptable to perform S9 testing by data system growth also adaptable to S1, S2A testing by load systems addition.	Limited growth unless cant money is expended achieve S1, S2 type capa

FOLDOUT FRAME 2

ASSESSMENTS			DISPOSITION	PRIMARY REASONS FOR DISPOSITION
GROWTH CAPABILITY	DEVELOPMENT RISK	OTHER		
[illegible] installation limits growth, however, high power levels involved offer wide area coverage at lesser power densities through the addition of power distribution equipment.	Safe operation with integrated heat-fuel systems. High power density over large areas presents a development risk.	The radiation heating capability of S2 will be utilized to accomplish this work.	Retained for further refinement in Phase II as part of S2.	Required for cryogenic fuel engines. Large research return.
Limited by initial system installation.	Not very great, considering size.	To develop components for fuel systems under realistic environmental conditions.	Retained for further refinement as part of S2 facility.	Large research return. Required for system research and development
Limited by equipment, performance, and quantity.	Utilizing existing facilities, risk is primarily associated with damage resulting from failures in systems under test.	Fuel system research and development accomplished in S2.	Retained as part of S2 capability.	High research value, necessary for research in fuel dynamics with horizontal tanks
Growth possible only through [illegible] system additions.	Considerable risk due to equipment needed and hazards involved.	For development of operational techniques of handling fueling of hypersonic airplanes. Large hydrogen rocket test facilities could be adapted.	Retained for further refinement as part of S2 facility.	Primarily for development of operational equipment. Could be essential for quick turnaround military missions.
Limited growth unless significant money is expended to achieve S1, S2 type capabilities.	Very high due to potential catastrophic failure hazard with large fuel quantities and necessary failure initiation tests probably necessary for deployment of operational craft in launch vehicle and commercial applications.	Valid data can probably be obtained on smaller scale tests using existing facilities with large hydrogen supplies.	Rejected for further refinement in Phase II. Can use S2 capability for partial accomplishment of necessary research.	Can be accomplished in existing facilities, on subscale models at less cost and risk. Costs too high compared to need.

FOLDOUT FRAME 1

FACILITY IDENTIFICATION	DESCRIPTION	COST (1970 DOLLARS)		RESEARCH VALUE		
		FACILITY $ MILLION	OPERATION		ADAPTABILITY	GROWT CAPABILI
SS2	Landing gear/tire development, evaluation. 75 ft - 750 kip (23 m - 3,340,000 N) drop tower. 30,000 ft, 350 knots, 750 kip track. 200 data channels.	21.7	1047	12.0	Very limited.	Limited by initial inst
R1	Nuclear blast effects determination. 1500 Btu/sq ft sec (17×10^6 J/m^{2}sec) thermal source. γ, X, neutron radiation sources.	3.1	274	0.0 Overall evaluation could be different for military systems alone.	Very limited. Specific application to military systems – aircraft and missile.	Limited by initial Some growth potential intensity development.
A1	Anechoic chamber 100x100 x300 ft (30x30x90 m) 100 kip ft model positioner (1.356×10^5 N-m).	3.2	401	24.7	Limited, specialized application.	Limited by frequency characteristics and Operating frequency
A2	Outdoor range. 1 x 1 mile (1.6 x 1.6 km) microwave range. 100 kip-ft - 150 ft high (1.366×10^5 N-m - 46 m) model positioner.	0.8	295	0.0	Very little.	Dependent upon initia s'ection.

FOLDOUT FRAME 2

FIGURE 7-2 (Concluded)
RESEARCH FACILITY – EVALUATION SUMMARY

ASSESSMENTS			DISPOSITION	PRIMARY REASONS FOR DISPOSITION
GROWTH CAPABILITY	DEVELOPMENT RISK	OTHER		
Limited by initial installation.	Limited risk on track development for high loads.	Track facility where dynamics of landing loads under simulated runway, speed, and attitude can be evaluated.	Recommended as a facility which is required for aircraft development in general.	Continued refinement in Phase II could not be justified based on application to hypersonic aircraft alone.
Limited by initial installation. Some growth potential in source intensity development.	Environments generated are lethal, and safety is a prime factor. Some requirements are beyond current technology.	Nature of data, and classification of requirements, techniques, and data preclude its consideration, although vital for HYFAC potential operational aircraft M1, M2, M3, and M4.	Recommended as necessary to development of military systems.	Very specialized and beyond scope of this study, however essential to military systems.
Limited by frequency absorption characteristics and model scale – operating frequency requirements.	Low	Existing facilities can accommodate complete fighter aircraft.	Deleted for further refinement in Phase II.	Insufficient increment over existing facilities. Can be accomplished in existing facilities.
Dependent upon initial site selection.	Low	Primarily associated with development of production aircraft.	Deleted for further refinement in Phase II.	Existing microwave range facilities adequate.

(6) Identification of Common Equipment - The plant equipment necessary to support the operation of the testing device can exceed its cost by many times. Examination of the various ground facilities indicated that many of them required common support equipment. Current experience in operating ground facilities showed that many types are not continuously in operation. It appeared that, through proper scheduling, a number of these facility concepts could be combined to share common support equipment, without seriously impairing the usefulness of the individual facilities concerned.

The integration of several structural facilities into S2 is an example of this. Facilities S3, S5, S6, F4, and F5 are all facilities which provide a significant research value and minimal costs. These facilities generally do not require extremely large equipment capability individually, but collectively represent a significant requirement. Facility S2 has a significant equipment capability because it is associated with structural research on full sized structural sections. Such large scale programs generally require a number of years to accomplish and do not require continuous operation of the facility. It appeared that a logical approach would be to use the increased portion of the total S2 facility equipment to support the smaller facilities to reduce to total investment in support equipment. The generally shorter and less complicated research programs accomplished with the S3, S5, S6, F4, and F5 facilities could be integrated into the comprehensive, longer duration, but sporadic programs associated with S2. The resulting facility provides for more complete utilization of the support equipment without adversely affecting the overall effectiveness of the individual facility elements.

7.1 FACILITY CAPABILITY

The first step in the screening process was to determine the contribution of that facility to satisfy the major technical problems outlined in the Research Objectives. The evaluation was conducted according to the procedures set forth in Section 3 which provided that certain key parameters be used to assess facility capability in relation to nine types of operational vehicles. The parameters used to evaluate the ground research facilities were as follows:

Gasdynamic	- Reynolds number, Mach number, run time, and model size.
Engine Test	- Reynolds number, Mach number, run time, incorporation of engine in airframe structure, air quality (temperature and chemical composition), and size of test engines.
Structural Test	- Size of test specimens, degree of environmental simulation, and ability to satisfactorily demonstrate structural design by experimental data.
Materials Test	- Levels and types of laboratory environmental simulation, reserach equipment, and size of prototype test articles, that may be produced in laboratory manufacturing facilities.

Flight Simulators - Simulation of 6 degrees of f[illegible]dom, motion-control-response simulation, system flexibility, and audio-visual display capability.

Fluid Systems Test - Fuel (cryogenic and hydrocarbon) storage, operating pressure, fuel flow-rates, test article size, and environmental simulation capability.

Subsystems, Avionics, and Radiation Test - Test article size and environmental simulation capability

The capability of each facility was compared first with existing facilities, in order to determine incremental improvement; and second with other ground facilities in the study to determine common capabilities.

Each ground facility is generally designed to operate in a specific region or accomplish specific tasks, although there is some overlap in capability. Even when the same Research Objective applies to different facilities, each facility accomplishes a different part of the objective. Thus, each facility should be evaluated on its own unique contributions to the overall research effort. Most of the ground facility evaluations were made on this basis.

There are a few examples, however, where two facilities accomplish essentially the same tasks, but are based on different concepts and entail different costs. One such example is GD15 and GD16. Both provide Reynolds number simulation in the Mach 4.5 to 8.5 regime, have the same size test section, and can perform essentially the same research, although not with the same degree of accomplishment, as indicated by the following data:

Basis for comparison: An aerodynamic research program consisting of 240 test conditions with 26 data points per test point (0 to 25° angle-of-attack), for a total of 6240 data points.

Facility	GD15	GD16	
Angle-of-attack capability during run	Variable	Pre-set	Variable
Occupancy (weeks)	6	624	24
Occupancy costs (1970 dollars)	$464,000	$21,200,000	$816,000
[illegible]	$74.30	$3400.00	$132.20

[illegible], GD15 offers the best productivity as measured by 46% low[illegible], and 75% shorter test programs. This combined

savings accumulated over the twenty year or longer useful life which is typical of wind tunnels should many times exceed the 12 million dollar difference in initial acquisition costs.

Other considerations, particularly the magnitude of the starting loads in a Ludwieg tube facility (GD16) make the technical risk of the Ludwieg tube facility considerably greater. From both a cost and technical risk viewpoint, therefore, GD15 appears to be the better choice.

Certain non-quantitative judgmental factors were applied to all facilities in each category. These included versatility, growth potential, and development risk, among others. These characteristics obviously affected the results of the study in some cases. These are discussed below, where significant, and are also contained in the summary chart (Figure 7-2).

7.1.1 COMPARISON WITH EXISTING GROUND FACILITY CAPABILITY - If the postulated facility was merely a restatement of an existing capability, and if the existing capability appeared to be sufficient to accomplish the specified research with minimal or no modification, the concept was deleted from further analysis. Of the original 54 facilities examined, 14 were eliminated by this comparison. These included:

GD12,GD13 - These two facilities represented modifications to existing facilities, namely the Holloman Sled Track, and the NOL Aeroballistic Range. The capability represented by these proposed modifications was judged sufficient in terms of their applicability to manned aircraft flight. Since the design and planning for these facilities is underway, no additional effort was deemed necessary in this study.

GD14 Rocket Launched Free Flight Models - Historically, rocket powered models were used whenever ground facility capability was lacking. For example, most of the transonic research in the early 1950's was accomplished using rocket powered models. In the context of present ground research facilities, operations such as NASA's Wallops Island facility provide adequate specialized research capability when necessary. As a generalized research facility, sufficient return is not obtained for the money invested.

E1 Large Rocket Engine Facility - The present capability represented by AEDC, Marshall, Edwards Air Force Base, and other similar installations provides adequate research capability for any rocket engine associated with the nine potential operational hypersonic aircraft.

E2 Wind Tunnels Accommodating Engine Testing Capability - As defined in this study, the gasdynamic facilities were Reynolds number simulators only. Since the attainment of flight duplicated temperatures was not included in the wind tunnel definitions, their capability for engine testing is less than that represented by existing propulsion wind tunnels.

S7 Cabin Pressurization Facility - Existing capability was judged as adequate.

S8 Transparency Test Facility - The utilization of existing engine facilities as hot gas sources was considered adequate to qualify canopy structures. If new capability is required at a future date, the candidate engine facilities could supply

the correct air flow conditions. This need not be a separate facility.

M1 Local Flow Simulation Facility - Considering the defined test article sizes, existing facilities were judged as adequate for small scale materials research. If larger test article sizes are desired, facilities such as E6 and E9 could provide necessary local flow simulation.

FS1, FS2, FS3 Flight Simulator Facilities - Although larger in terms of motion capability, this group of facilities was judged to be improvements to the current excellent research capability represented by existing facilities, such as the Ames moving base simulators. A combination of the capabilities of the three flight simulator facilities into a single integrated facility, designated as FS20, is a recommended facility in the sense that this test capability will be an integral part of any new aircraft research program. Improvements in existing facilities should provide adequate growth potential.

A1, A2 Antenna Research Facilities - Both of these facilities were restatements of existing capability.

R1 Nuclear Radiation Simulation Facility - The classification associated with military requirements precluded a meaningful facility definition. For non-military missions, both ground radiation and nuclear engine radiation simulation was judged adequate using existing facilities.

7.1.2 COMPARISON WITH OTHER STUDY FACILITY CAPABILITY - Each facility was also compared with the others in the study. If the capabilities appeared to be duplicated, the facility which accomplished the required task most efficiently was retained and others deleted. Of the 40 remaining at this point in the study, 10 facilities were deleted in this step. They were:

GD1 Subsonic Wind Tunnel - Essentially duplicated by the low Mach number capability of GD2.

GD5, GD6 Hypersonic Impulse Tunnels - Neither of these two concepts offered the run time advantages of GD7, nor the potential of reduced operational complexity and instrumentation sophistication. For example, GD7 had about 1000 times the run time capability as GD6 for similar test conditions.

GD8 Alumina Storage Heater Hypersonic Wind Tunnel - This facility was deleted because of insufficient Reynolds number capability. More suitable as an engine test facility.

GD9, GD10, GD11 True Temperature Wind Tunnels - These definitions were inconsistent with the ground rules developed for the gasdynamic facilities and were redefined as E9, E8, and E10 respectively.

E3 Turbomachinery Engine Facility - In order to provide clearer definition of equipment size and costs, this facility was separated into a direct connect (E6) and free jet (E7) legs.

E4, E5 This capability is characteristic of engine research facilities in general and was judged not sufficiently demanding to warrant separate facilities. Capability incorporated into E7.

7.1.3 CONTRIBUTION TO GENERAL AERONAUTICAL RESEARCH AND TO HYFAC AIRCRAFT RESEARCH - Evaluations of individual facilities with respect to each Research Objective are presented in Appendix A. A graphical summary of the results of this evaluation is given in Figure 7-3. The applicable Research Objectives and the ability to accomplish them are illustrated in Figure 7-3 for each surviving facility. Inspection of the bar charts illustrates the wide variations as to number of Research Objectives applicable, and the degree of accomplishment. Comparison of GD3, E7, S1, F1, F4, and GD7 will point out some of the variation possible. The versatility of facilities like GD3, which has some 41 applicable Research Objectives compared to the more specialized facilities like S4 or S6 with only a few applicable Research Objectives is an important factor contributing to the facility research value.

Using the analysis techniques presented in Section 3, the contributions of each facility to each of the potential operational hypersonic aircraft (Volume VI) were determined and are tabulated in Figure 7-4. These individual ratings can be averaged over the nine reference vehicles, and these results are presented in Figure 7-5.

As a result of the analysis with respect to the research value, both as applied in general aeronautics, and specifically to HYFAC, the following 5 facilities were eliminated from the remaining 30 concepts.

GD2 Provides a significant research value for generalized research, but lesser research value specifically related to the potential operational hypersonic aircraft. Recommended as a desirable facility because of its application to subsonic and near sonic flow research, but not retained for further development within this study.

GD4 The transonic Ludwieg tube tunnel. For research applicable to large subsonic aircraft, and transonic, low supersonic cruise aircraft, a facility of this type may be mandatory if economical and efficient sustained flight operations in this area are to be realized. However, for aircraft whose time passing through this speed regime is minimal, such fidelity of flow field and Reynolds number simulation is probably not warranted. Same recommended status as GD2.

GD16 Because of its Ludwieg tube concept, the uncertainty in the actual magnitude of the tunnel starting loads could reduce its effectiveness. This facility was therefore rated considerably lower in research value than GD15. The same research capability represented by GD15 provided better research return.

S9 The very low research value of this facility did not warrant further consideration

SS2 This facility had a very low research value in terms of the HYFAC potential operational aircraft. However, in terms of new landing system research for very large transports, unprepared field conditions, and multiple surface landing capability, SS2 could provide significant research capability. Such concepts as air cushion landing gears could be extensively refined in such a facility. This facility is recommended as a desirable facility, although not retained for further refinement in this study.

FIGURE 7-3 GROUND FACILITY CAPABILITY TO ACCOMPLISH RESEARCH OBJECTIVES, SUMMARY

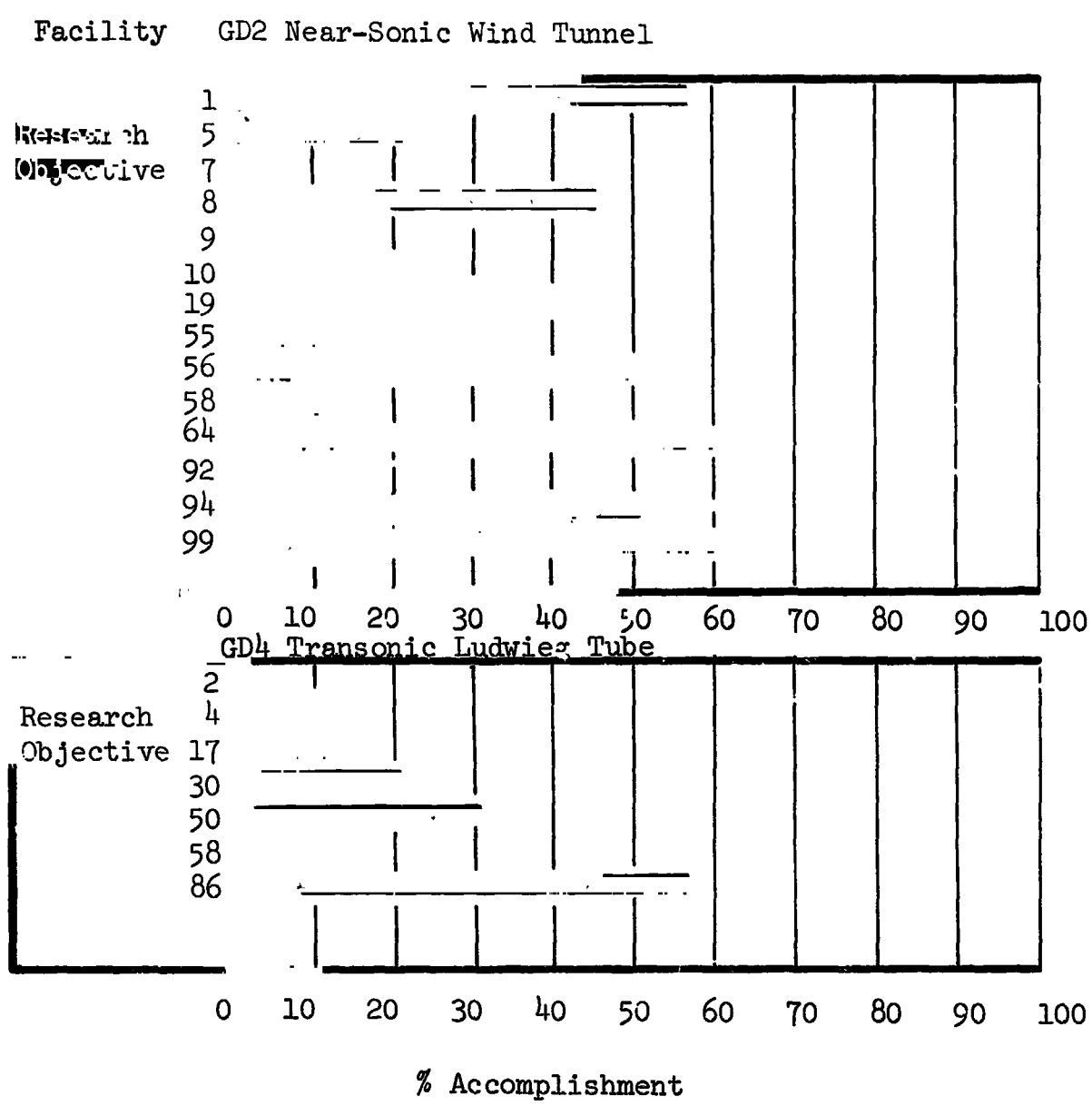


FIGURE 7-3 GROUND FACILITY CAPABILITY TO ACCOMPLISH RESEARCH OBJECTIVES, SUMMARY (CONTINUED)

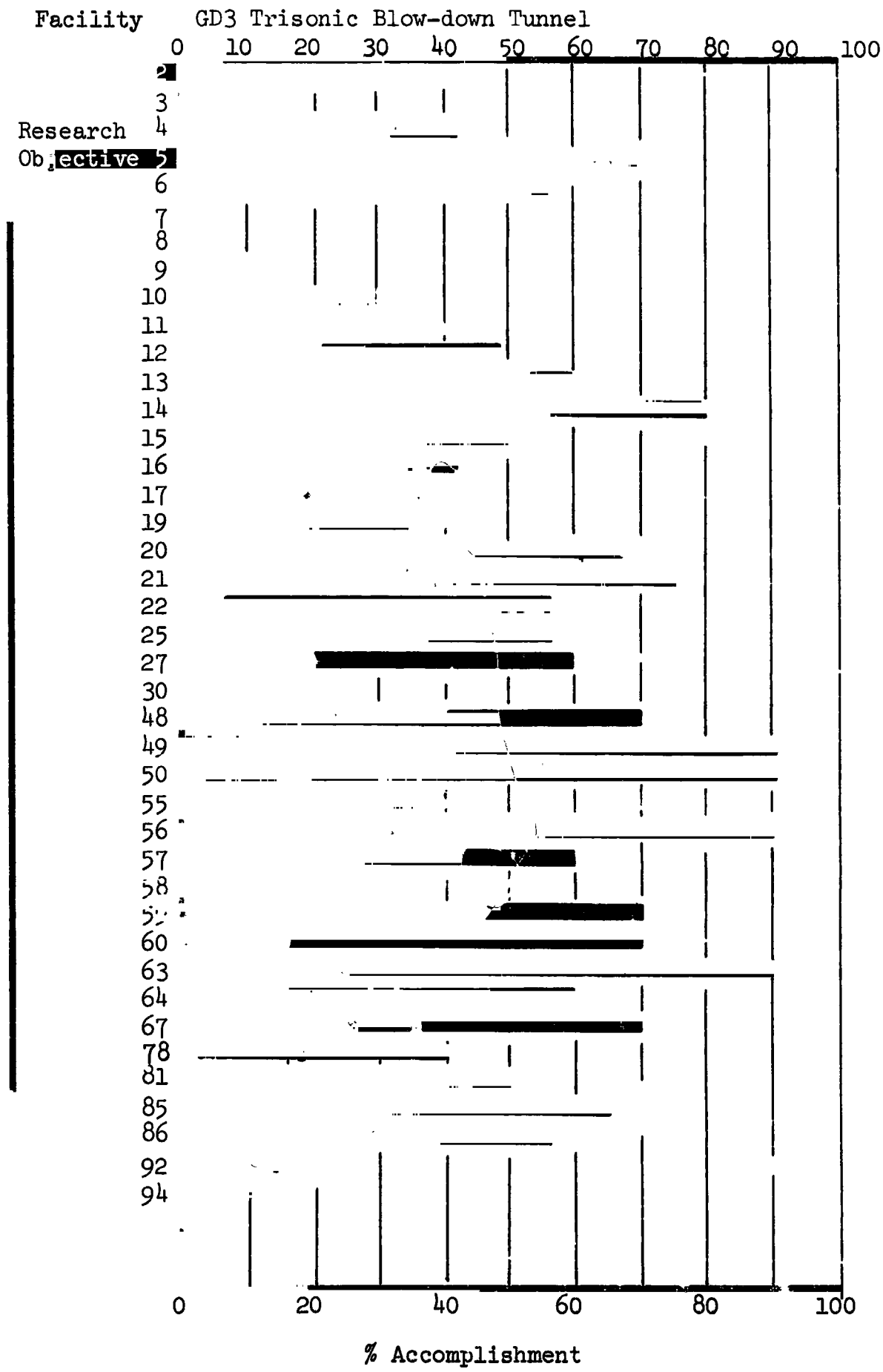


FIGURE 7-3 GROUND FACILITY CAPABILITY TO ACCOMPLISH RESEARCH OBJECTIVES, SUMMARY (CONTINUED)

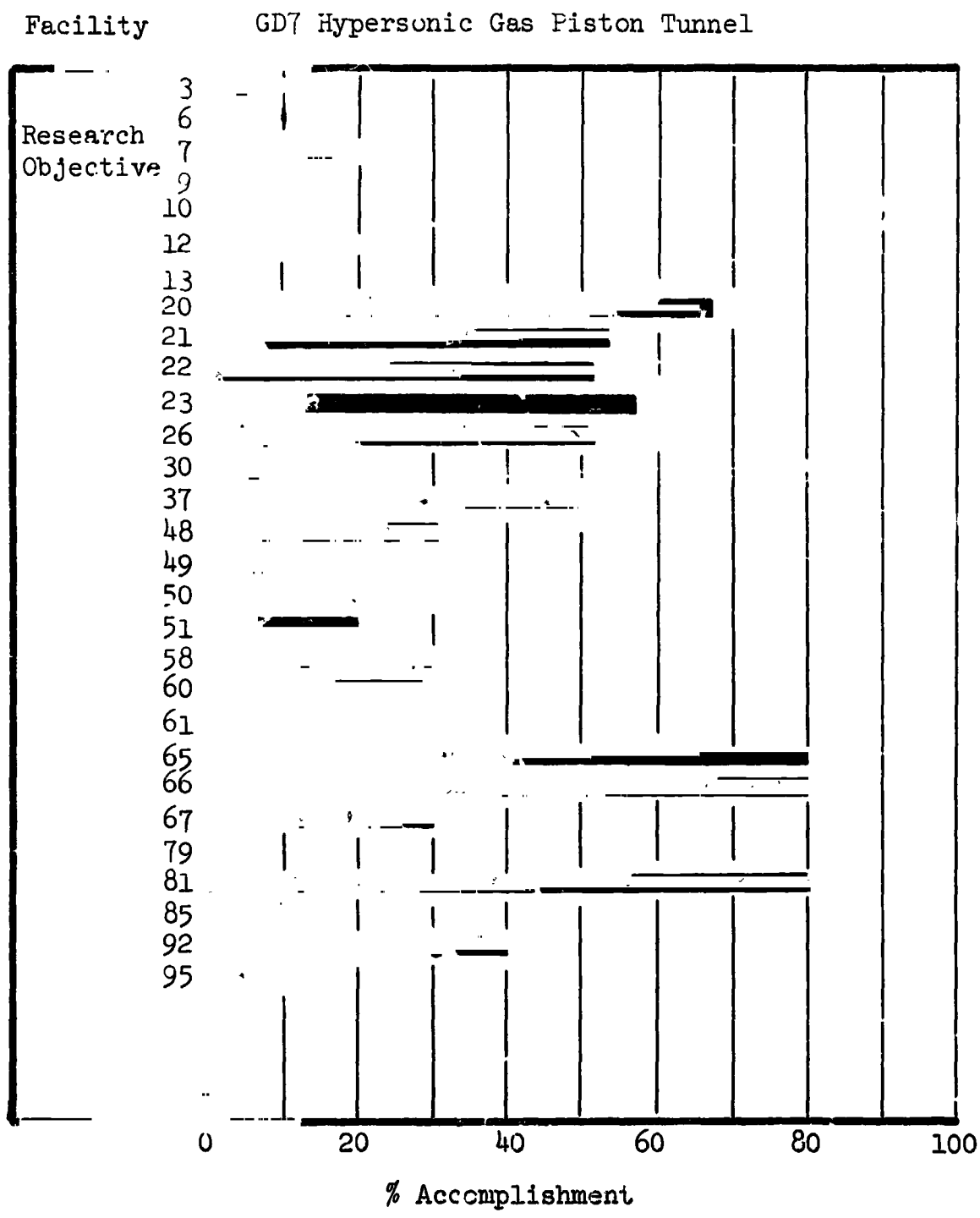


FIGURE 7-3 GROUND FACILITY CAPABILITY TO ACCOMPLISH RESEARCH OBJECTIVES, SUMMARY (CONTINUED)

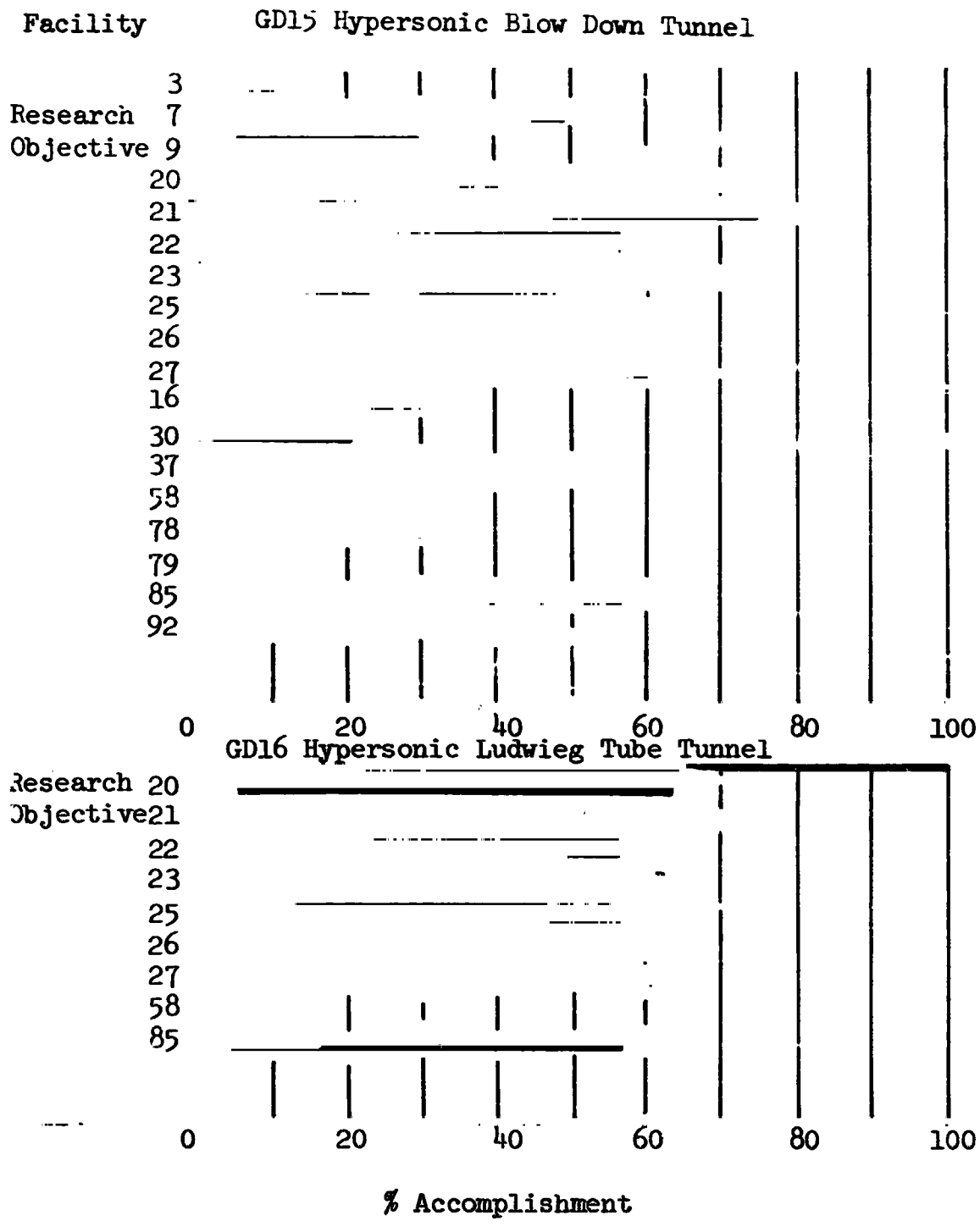


FIGURE 7-3 GROUND FACILITY CAPABILITY TO ACCOMPLISH RESEARCH OBJECTIVES, SUMMARY (CONTINUED)

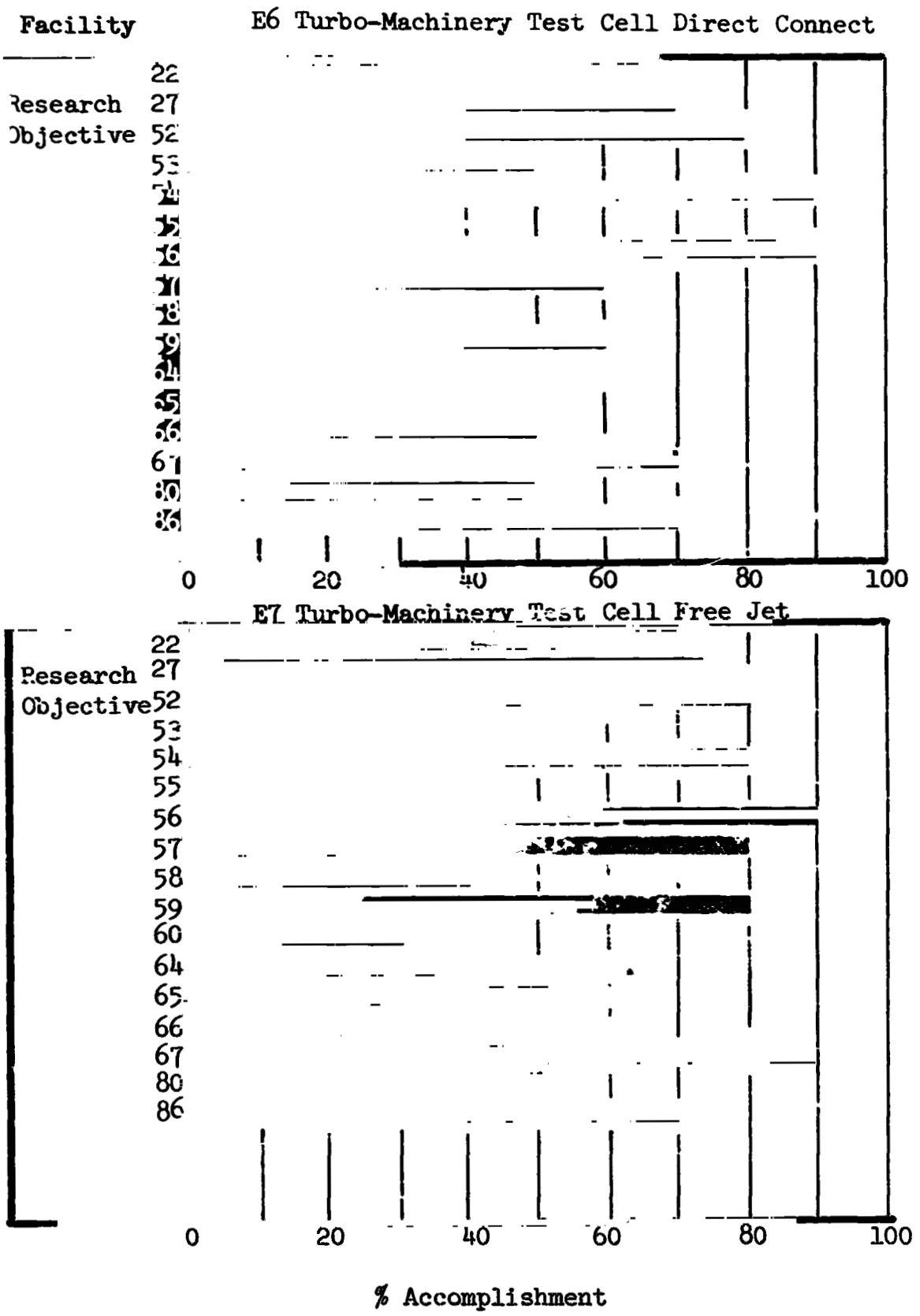


FIGURE 7-3 GROUND FACILITY CAPABILITY TO ACCOMPLISH RESEARCH OBJECTIVES, SUMMARY (CONTINUED)

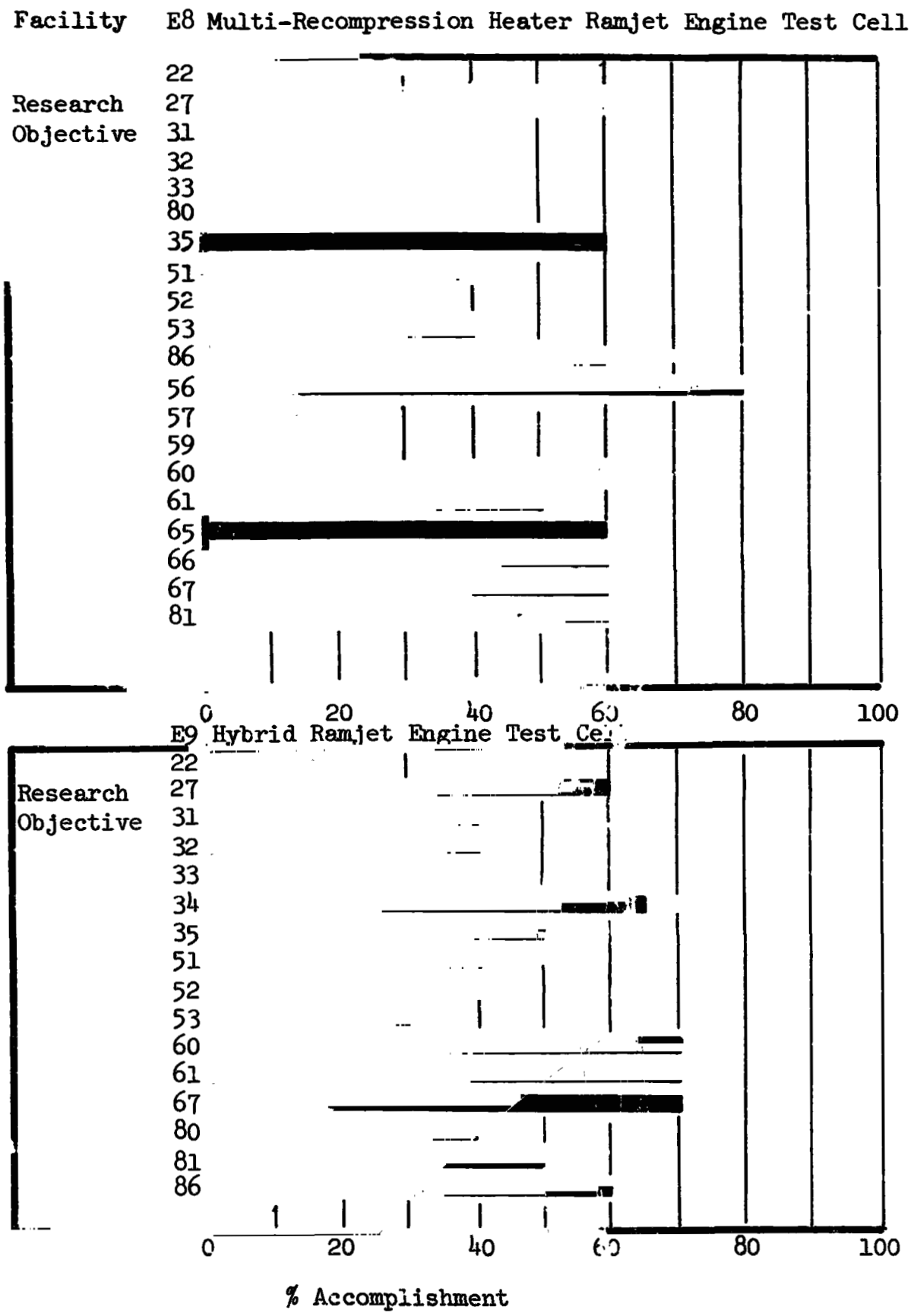


FIGURE 7-3 GROUND FACILITY CAPABILITY TO ACCOMPLISH RESEARCH OBJECTIVES, SUMMARY (CONTINUED)

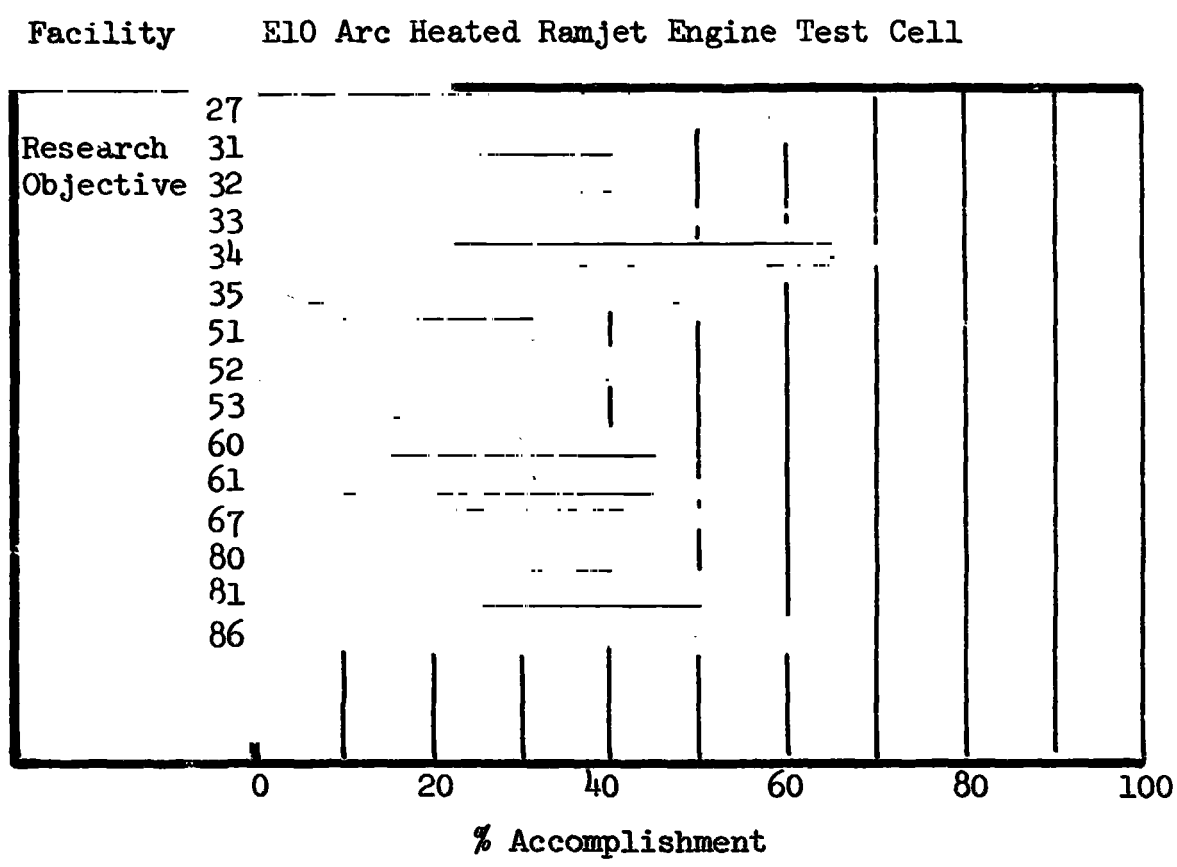


FIGURE 7-3 GROUND FACILITY CAPABILITY TO ACCOMPLISH RESEARCH OBJECTIVES, SUMMARY (CONTINUED)

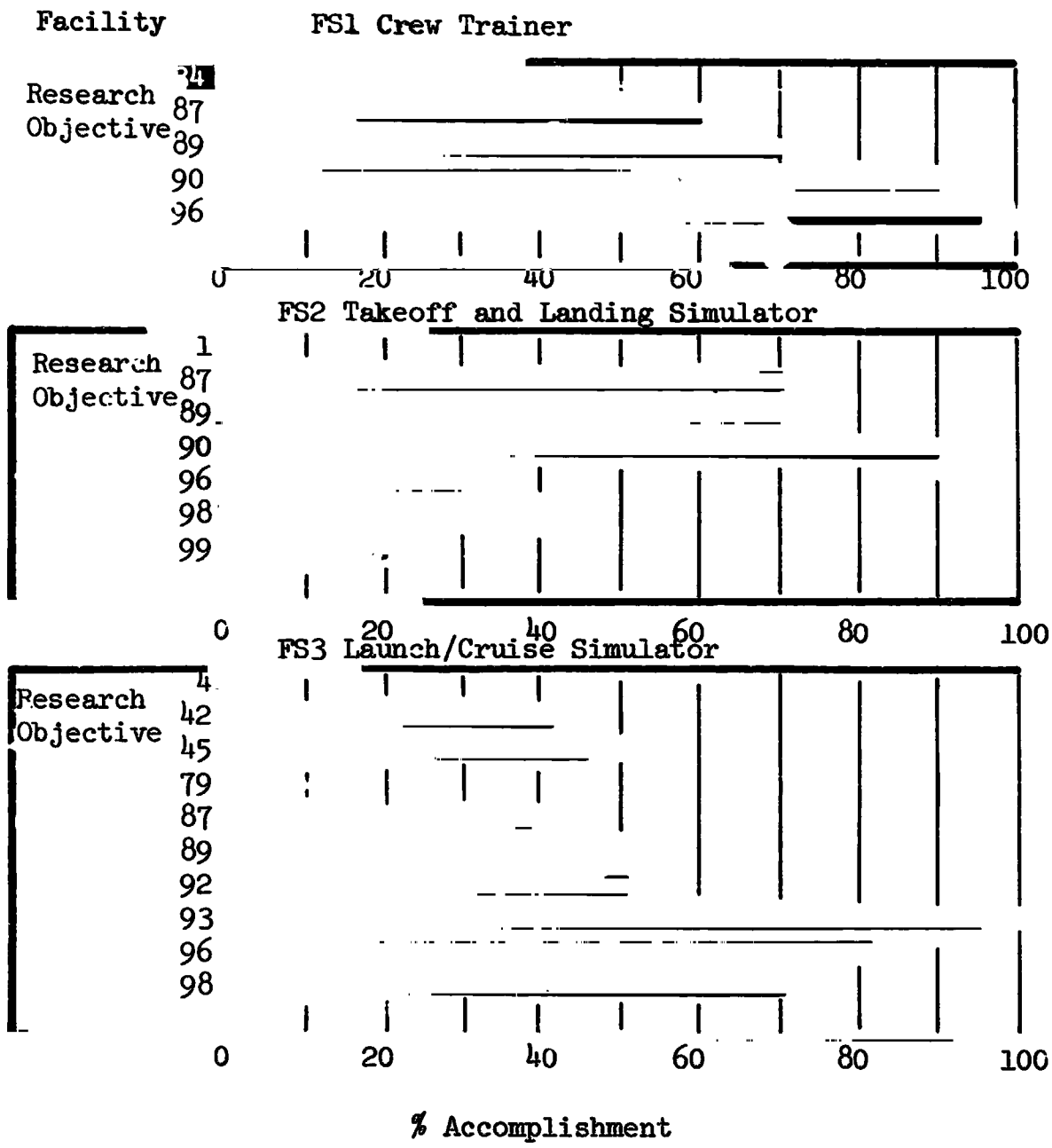


FIGURE 7-3 GROUND FACILITY CAPABILITY TO ACCOMPLISH RESEARCH OBJECTIVES, SUMMARY (CONTINUED)

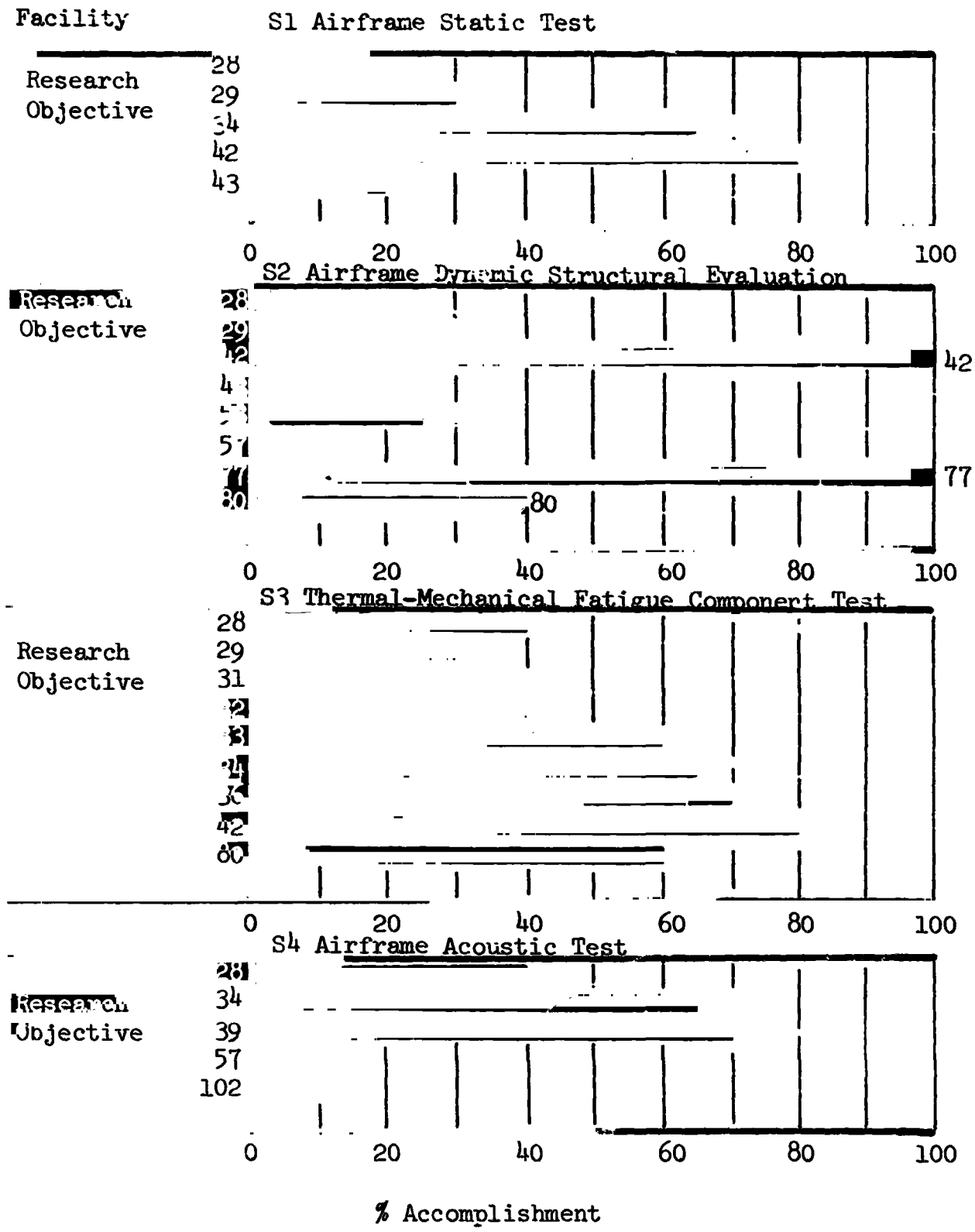


FIGURE 7-3 GROUND FACILITY CAPABILITY TO ACCOMPLISH RESEARCH OBJECTIVES, SUMMARY (CONTINUED)

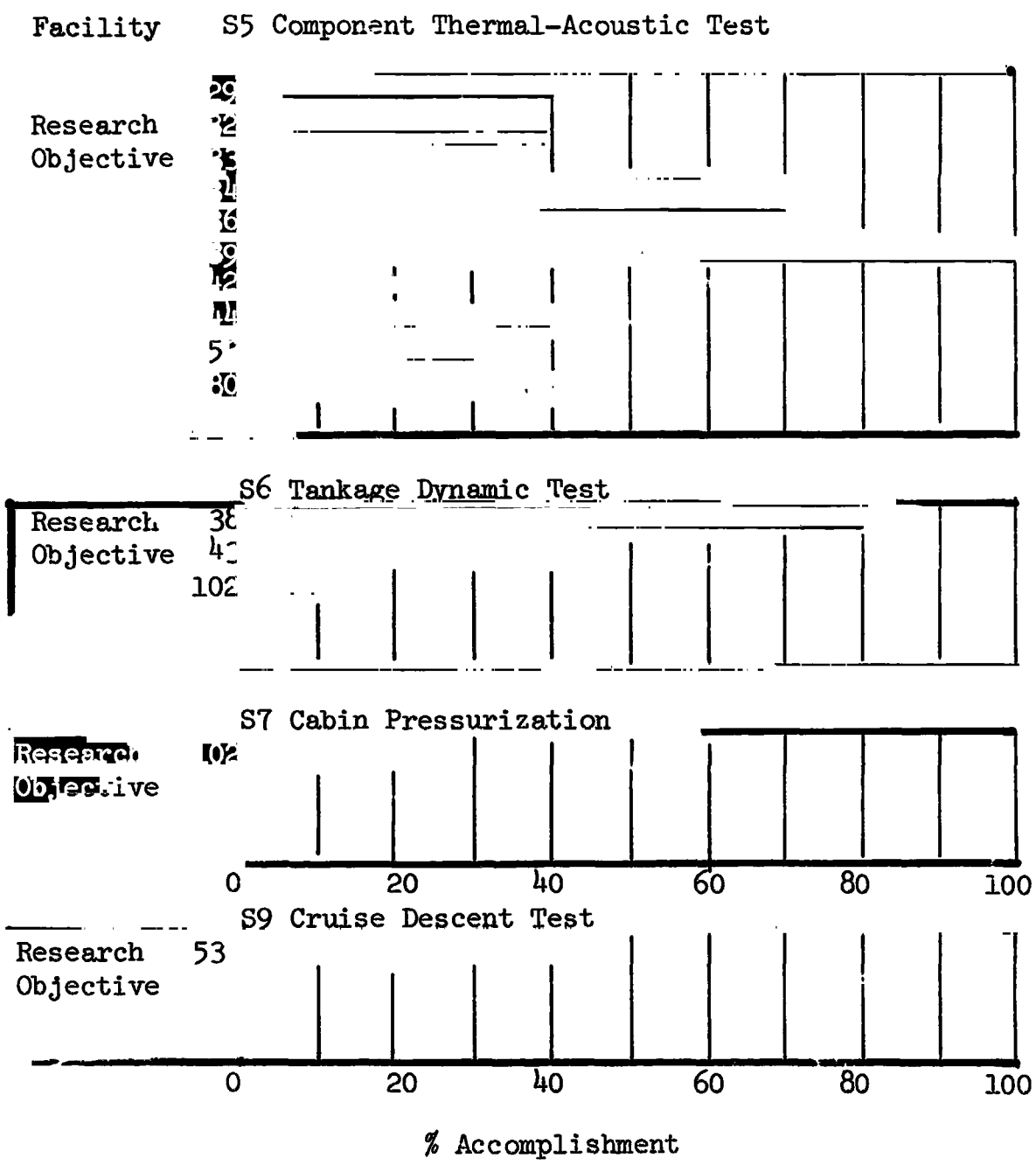
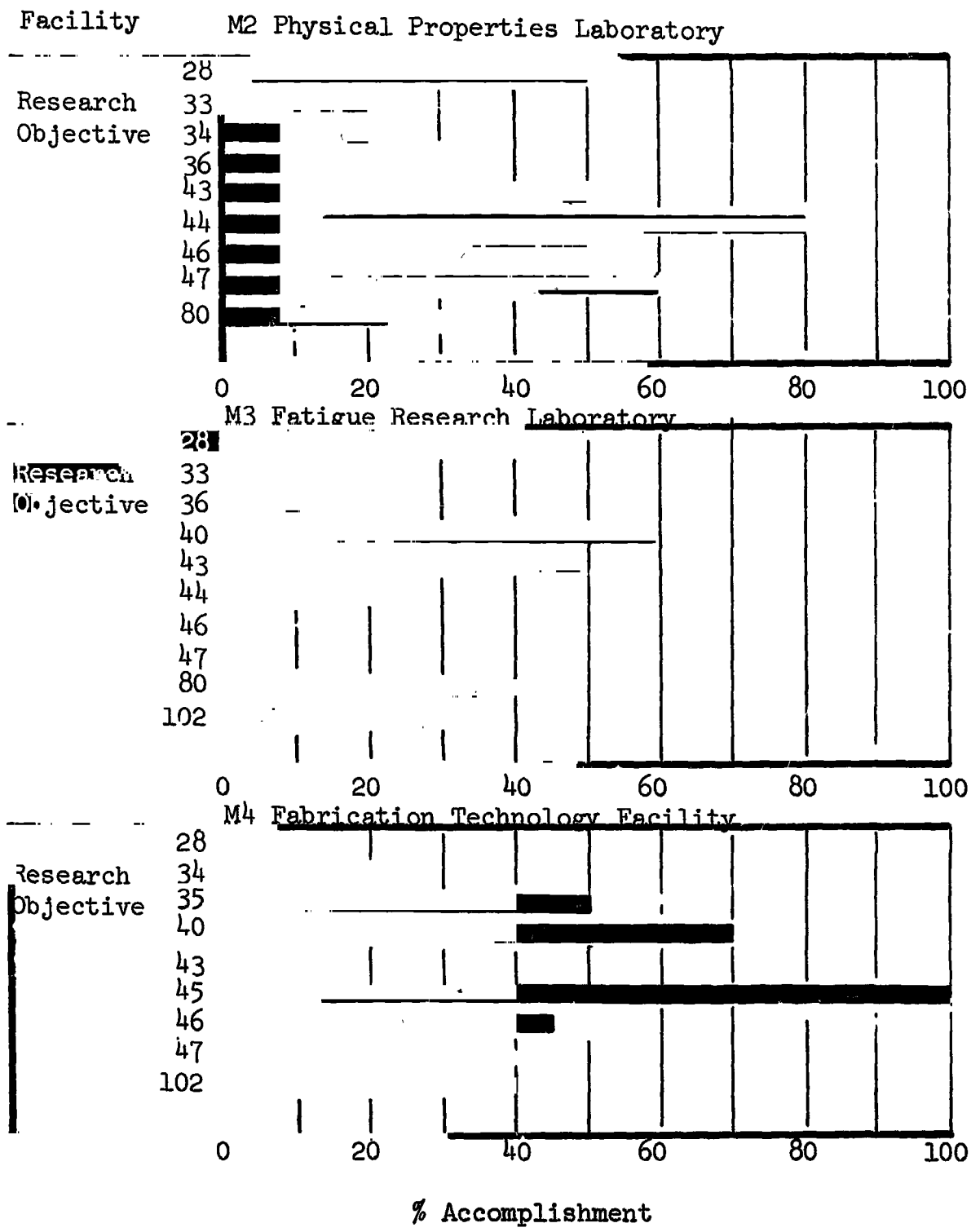


FIGURE 7-3 GROUND FACILITY CAPABILITY TO ACCOMPLISH RESEARCH OBJECTIVES, SUMMARY (CONTINUED)



(U) FIGURE 7-3 GROUND FACILITY CAPABILITY TO ACCOMPLISH RESEARCH OBJECTIVES, SUMMARY (CONCLUDED)

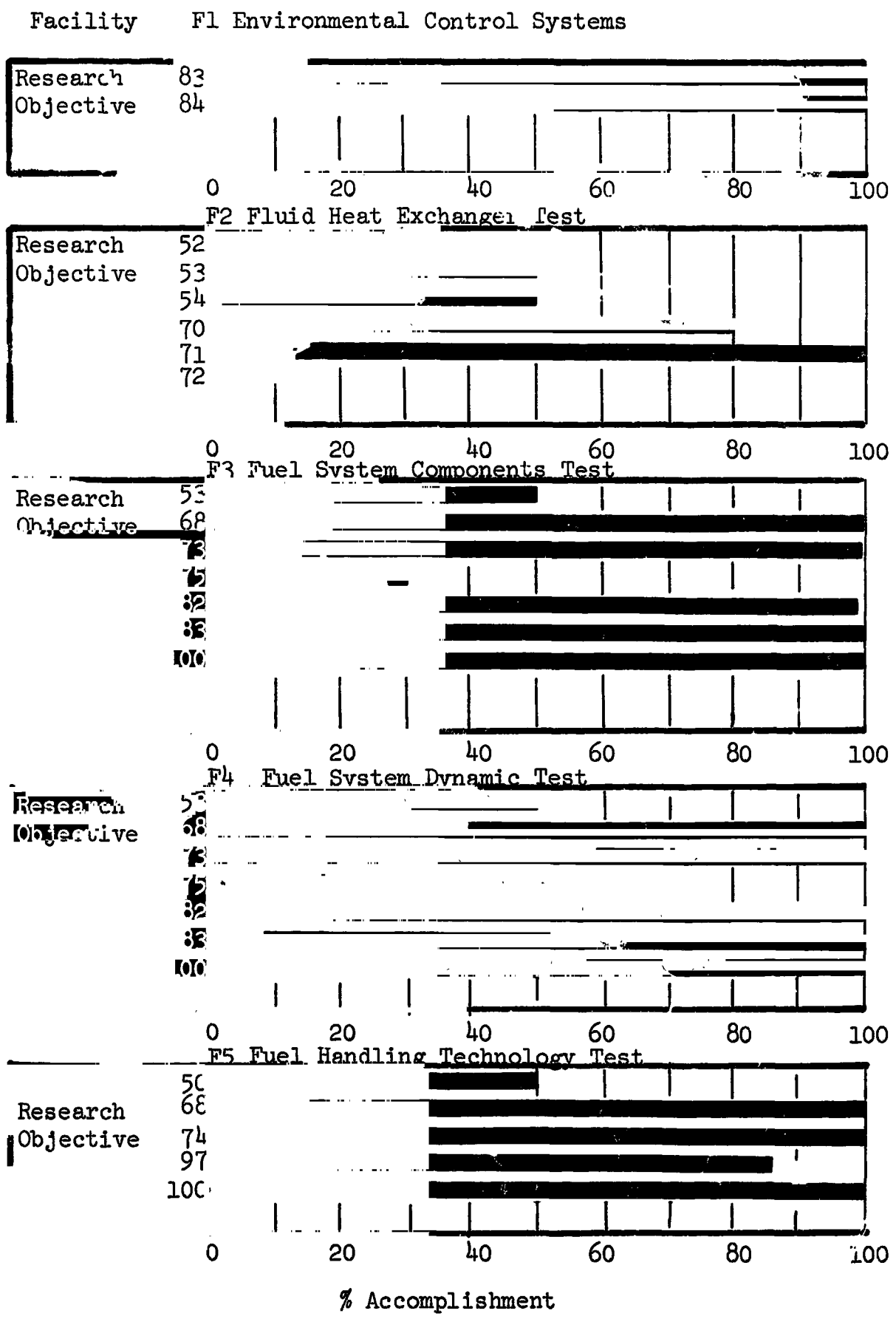


FIGURE 7-4 RESEARCH VALUES FOR GROUND FACILITIES

Facility Code	Potential Operational Systems							
	L1	L2	L3	L4	C1	C2	M1	M2, M3
GD2	114	90	140	110	122	87	108	120
GD3	484	445	347	363	660	379	690	371
GD4	28	28	30	29	42	28	42	29
GD7	302	348	260	369	128	306	110	317
GD12	6	6	8	7	7	6	6	7
GD13	19	18	25	20	20	19	19	20
GD15	283	282	289	285	230	240	194	240
GD16	121	121	123	122	125	116	125	117
E6	240	125	120	87	289	106	282	76
E7	267	178	120	108	319	140	310	97
E8	298	315	203	314	270	285	233	279
E9	197	315	203	336	159	291	159	302
E10	184	276	190	293	159	253	159	262
FS1	96	96	99	99	102	102	97	97
FS2	73	73	82	82	84	84	74	80
FS3	135	135	137	137	153	152	118	136
S1	141	141	141	141	139	139	123	138
S2	155	155	148	148	154	153	133	146
S3	186	186	185	185	183	183	186	182
S4	89	88	82	81	88	88	86	80
S5	235	234	227	227	232	231	195	224
S6	107	107	107	107	106	106	45	106
S7	4	4	4	4	4	4	4	4
S9	7	7	0	0	8	7	0	0
M2	188	188	188	188	186	186	150	186
M3	159	159	159	159	158	158	121	157
M4	178	178	178	178	177	177	168	176
F1	77	39	38	38	77	38	41	37
F2	74	74	39	39	74	39	39	39
F3	216	185	173	173	216	181	66	173
F4	249	211	206	206	249	206	74	205
F5	76	76	75	75	77	77	0	75
SS1	100	101	67	67	104	70	69	67
SS2	12	12	12	12	12	12	12	12
R1	0	0	0	0	0	0	0	0
A1	25	24	23	23	25	23	29	24
A2	0	0	0	0	0	0	0	0
Total Required	3329	3291	3068	3236	3156	3098	2623	3136

FIGURE 7-5 FACILITY RESEARCH VALUE SUMMARY
(Values Averaged Over All Nine Operational Systems)

Ground Facility	Average Value
GD2	110.7
GD3	494.9
GD4	33.1
GD7	248.1
GD12	6.5
GD13	19.7
GD15	245.3
GD16	121.1
E6	183.9
E7	211.3
E8	273.8
E9	232.2
E10	211.8
FS1	98.7
FS2	79.1
FS3	138.4
S1	136.7
S2	148.7
S3	184.1
S4	86.5
S5	224.4
S6	96.2
S7	4.2
S9	4.1
M2	181.0
M3	152.1
M4	175.8
F1	51.2
F2	52.5
F3	171.5
F4	198.5
F5	63.4
SS1	81.4
SS2	12.0
R1	0.0
A1	24.7
A2	0.0

7.1.4 COST ANALYSIS - As part of the evaluation, costs of each facility were assessed in relation to research value, according to the methodology described in Section 6.11. As a result of this cost analysis, 6 more facilities were dropped from Phase II consideration, leaving 19 remaining facilities. These facilities were as follows:

GD17, is a continuous version of GD3. At 8 times the cost of GD3 with essentially the same research value, its continued refinement could not be justified. As is generally true for high Reynolds number facilities, continuous facilities generally cost many times more than intermittent facilities, while not adding significantly to the overall research capability.

E10 Arc Heated Scramjet Engine Facility - The repair and maintenance costs, gas contamination by electrode material, and mass flow limitation for the arc heaters were not offset by increased research value so that the E10 concept was not competitive with E8 or E9.

S1 Static Structural Research Facility - The cost of providing a new static structures facility did not seem consistent with either what was currently available (such as for the 747 or C5A) nor what was required in terms of the rapidly varying conditions experienced by a hypersonic aircraft. If such capability is required it could be made a part of the S2 capability, considering the floor space and equipment already allocated to this facility.

S2A Dynamic Structural Evaluation Facility - This facility is the S2 facility sized to accommodate a complete hypersonic airframe while S2B is sized to accommodate a major structural section test article. The large increase in acquisition cost of S2A over S2B, without a corresponding improvement in Research Value, has led to its elimination as the candidate baseline structural facility for Phase II in favor of S2B. Further refinement of costs and capability of a complete airframe sized structural facility will be done in Phase II however, with this capability representing a facility alternate. A second alternate will also be examined, this facility being sized to accommodate a structural component test article.

S4 Airframe Acoustic Test Facility - Insufficient increment over existing facilities considering the cost and the questionable necessity for testing such large specimens, considering the risks.

SS1 Fire Suppression Facility - Although an essential consideration for operational aircraft, the cost of doing the complete job in terms of the research return is too small to justify a separate facility.

Figure 7-6 presents the research value versus cost for the ground facilities listed in Figure 7-3. The influence of the facility Mach number range on the determination of the research value is shown in the graph for the gasdynamic facilities. GD3 is a trisonic blowdown facility with a maximum Mach number of 5, as indicated by the aircraft system callouts. [illegible] provides considerably more of the total research for the M1 and C1 aircraft than the remaining systems which have operating Mach numbers in excess of 6. However, for GD7, [illegible] ist[illegible]n impulse facility with an operating range of Mach number 8 to 13, [illegible] [illegible]n is reversed, its major contribution being to the higher Mach numb[illegible]

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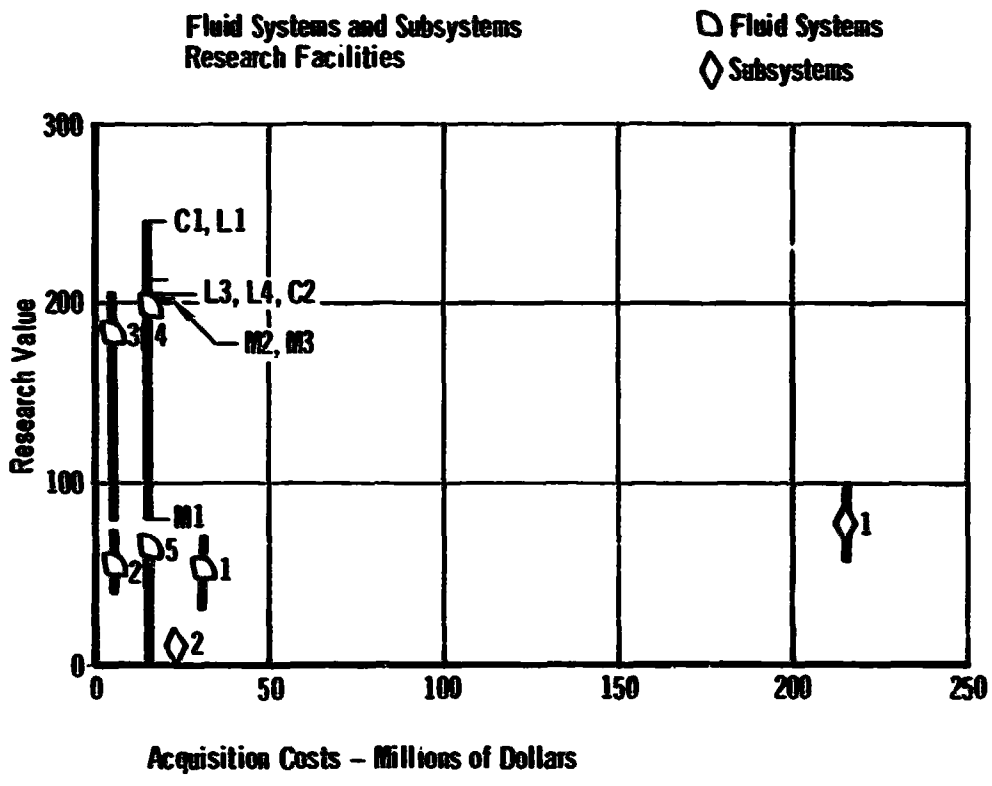
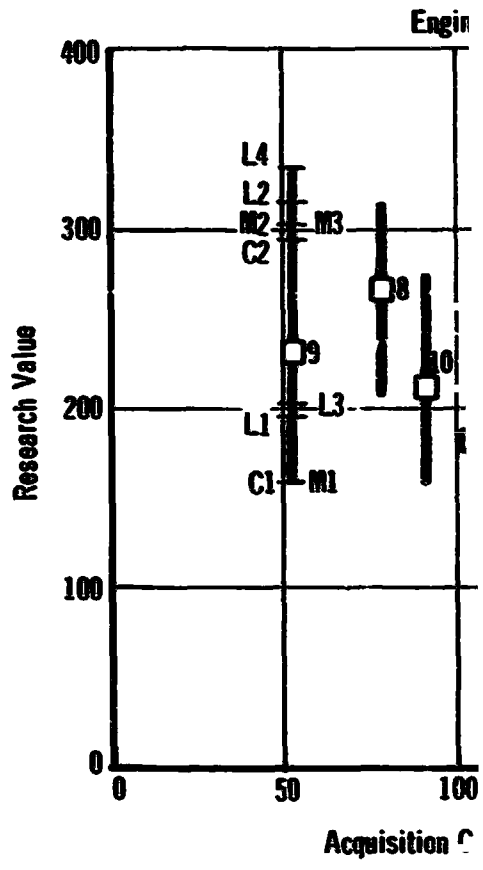
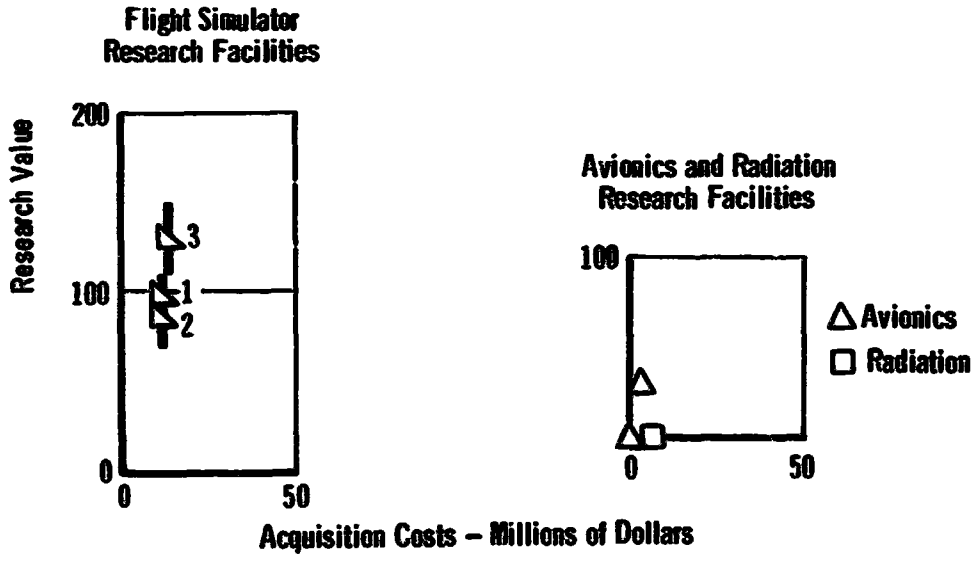
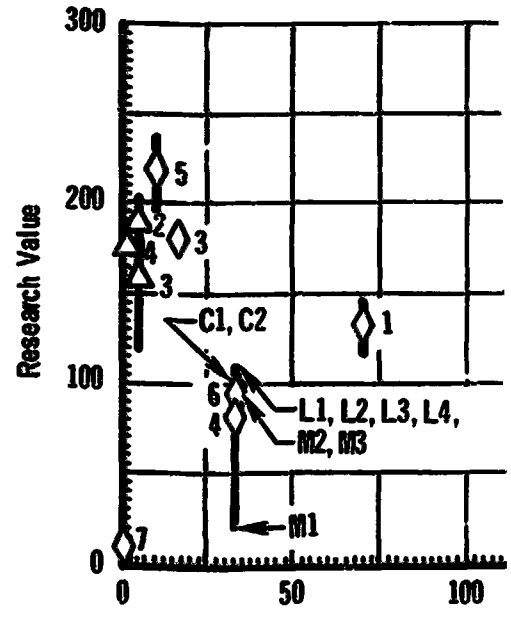
FIGURE 7–6
GROUND FACILITY EVALUATION – ACQUISITION COSTS vs RESEARCH VALUE









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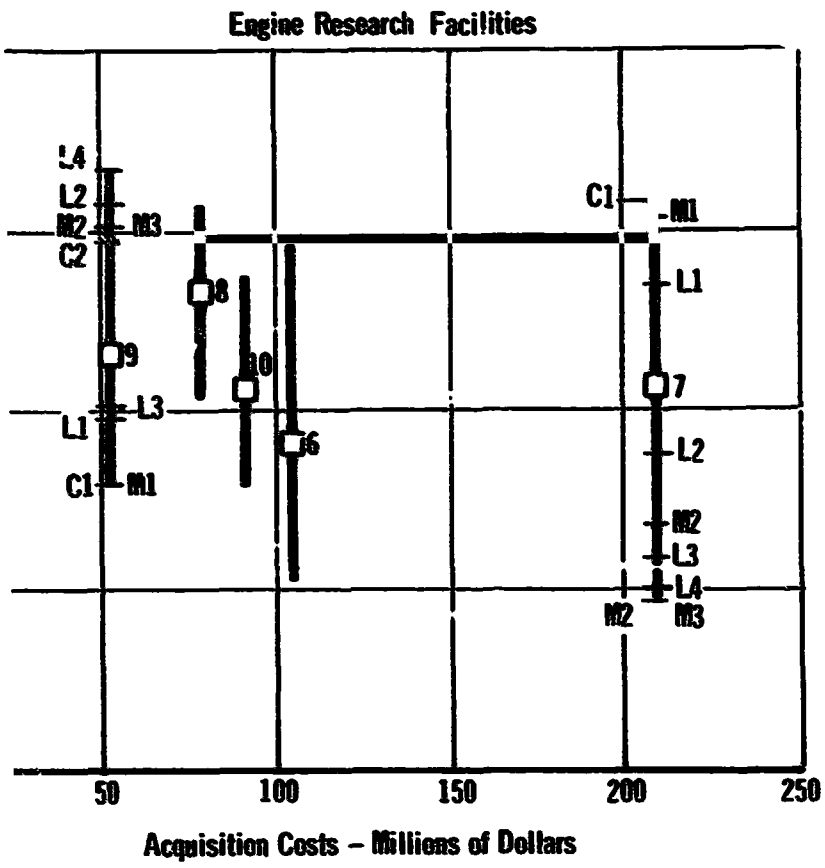
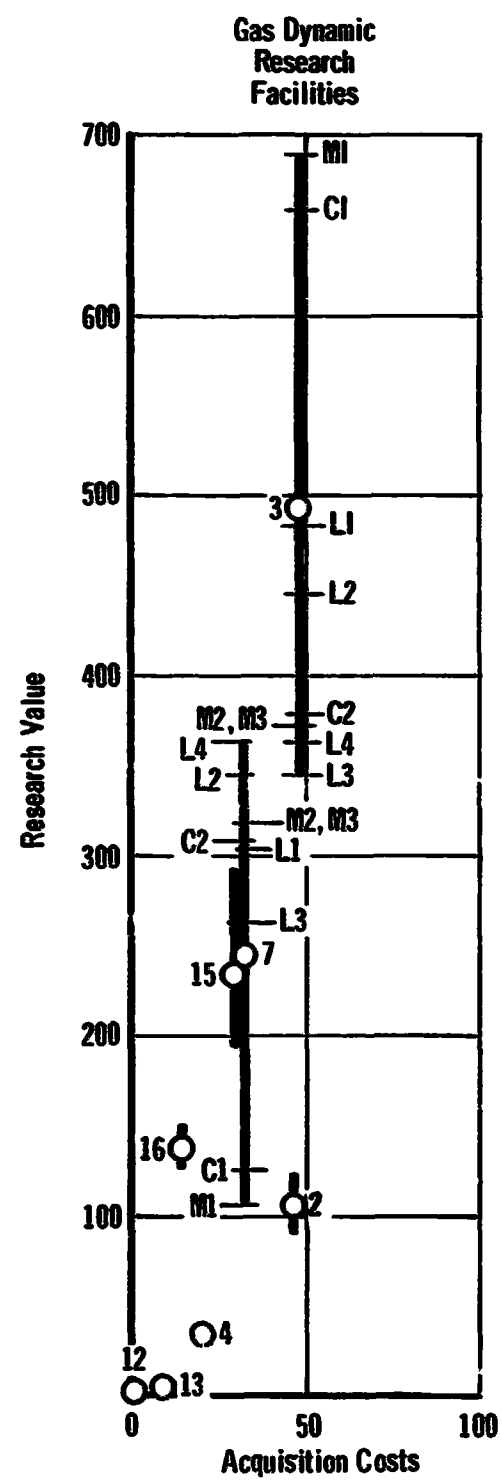
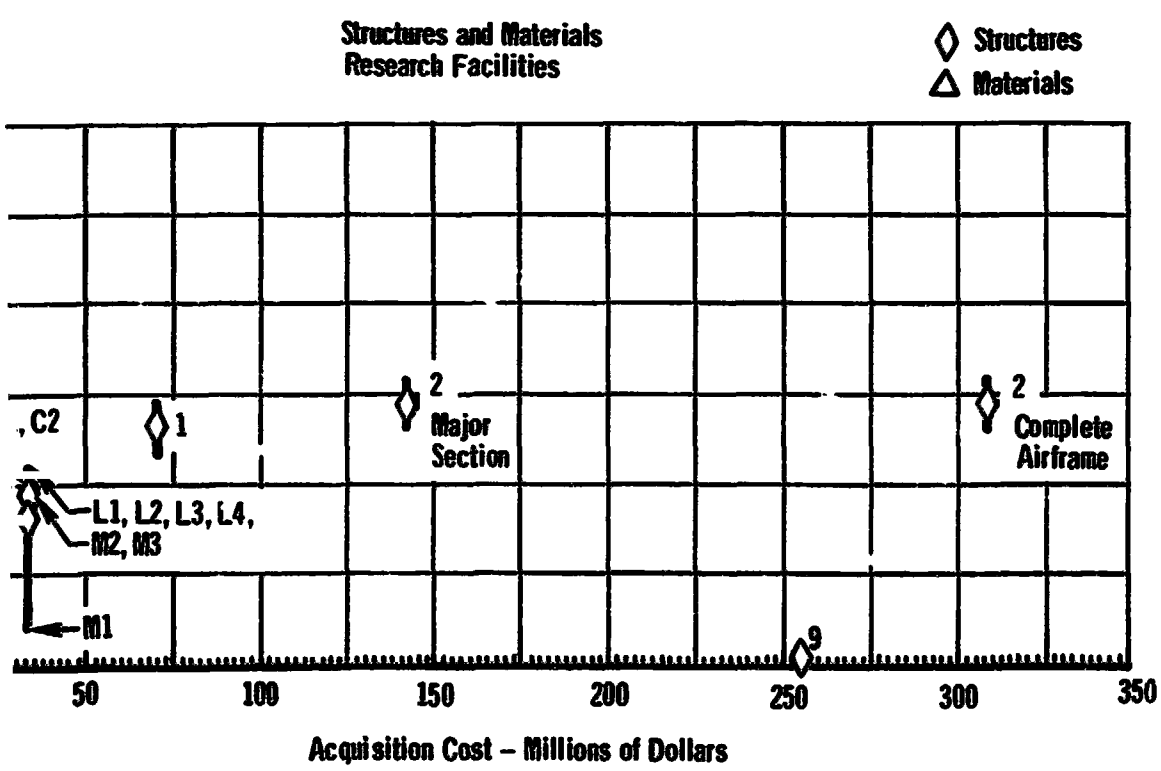


Notes:

1. Enclosed number in symbol represents facility code as given in Figure 6–79.
2. Bar represents range of research values for the nine operational systems contained in Volume VI.
3. Callouts on bar refer to potential operational vehicle codes in Volume VI, and Figure 2–2.





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Similarly, the influence of engine type is clearly shown in the graph for the engine facilities. Those potential operational hypersonic aircraft utilizing turbojet or turboramjets rate higher for E7, a turbomachinery engine facility than for E9, a scramjet engine facility. For those aircraft systems requiring a scramjet engine, the situation is reversed.

In general, the gasdynamic facilities achieve the highest research value, with the engine and structures facilities achieving the highest costs. Some of the best ratings in terms of research value per invested dollars are achieved by the fluid systems, materials research, and specialized structures facilities. In most facility categories there are facilities which achieve very low research value, and in some cases even at very high costs.

A complete summary of the evaluations and factors which entered into the decision of selecting or rejecting various facility concepts is contained in Figure 7-2. The figure presents in one place a complete statement of the factors which affected the facility selections.

7.1.5 IDENTIFICATION OF COMMON EQUIPMENT - The cost of plant equipment necessary to support the operation of the facility can exceed the cost of the facility itself by many times. Examining the various ground facilities revealed many items of common support equipment. Current experience in facility operation indicates that some types would not be used continually. It appeared that through proper scheduling, a number of facility concepts could be combined to share common equipment without impairing usefulness. The integration of several structural facilities into S2 is an example. The generally shorter, less complicated research associated with S3, S5, S6, and the fluid systems facilities could be integrated with the comprehensive and longer duration, but sporadic, programs associated with S2. The resulting facility provides for more complete utilization of support equipment. At this point the 19 individual facilities recommended for continued refinement in Phase II were:

GD3	Blow-Down Trisonic Wind Tunnel	Very high research return
GD7	Hypersonic Gas Piston Wind Tunnel	Significant improvement in current capability
GD15	Blow-Down Hypersonic Wind Tunnel	High research return
E6	Direct Connect Turbomachinery Engine Facility	Provides necessary research and development of engines for operational and research vehicles
E7	Free Jet Turbomachinery Engine Facility	Same as for E6
E8	Multi-Compression Heater Scramjet Engine Facility	New concept for research and development of scramjet engines
E9	Hybrid Heater Scramjet Engine Facility	New concept - could provide needed research at greatly reduced costs

S2B	Airframe Dynamic Structural Evaluation Facility	Only facility of its kind to do total structural research
S3	Thermal-Mechanical Fatigue Component Facility	High research value
S5	Thermal-Acoustic Facility	High research value
S6	Tankage Thermal/Structural Facility	High research value
M2, M3, M4	Materials Research Laboratory	Very high research value per dollar
F1	Environmental Control Systems Evaluation Facility	High research value
F2	Heat Exchanger Facility	Required for cooled engine/inlet concepts, high research
F3	Fuel System Component Facility	High research value, required for horizontal tank fluid dynamics
F4	Fuel System Dynamic Facility	High research value, required for horizontal tank fluid dynamics
F5	Fuel Handling Technology Facility	Necessary for fast turnaround military applications

7.2 RECOMMENDED PHASE II FACILITIES

The previous 19 facilities have been assembled into compatible groupings which can share common equipment without adversely affecting the overall research capability. As indicated in Figure 7-1, these are

GD20	GD3 GD15	Share common compressors, control room, data systems, air storage
GD7		
E20	E6 E7	Share common compressor plants, heaters, exhausters, control rooms, data systems
E8		
E9		
S2	S2B S3 S5 S6 F1 F2 F3 F4 F5	Share common radiation heaters, cryogenic fuel supplies and pumps, load cells, control systems, electrical substation

M20	M2 M3 M4	Share common building, analysis laboratory, support equipment

The facilities recommended for further study in Phase II represent a collection of gasdynamic, engine test, structural materials, and fluid test facilities that will enable a broad base of research and development to be conducted for a hypersonic vehicle program. The facilities selected were chosen because they provided a needed increase of research capability over existing facilities and are considered to be of the greatest significance to the program. The fact that a large number of the facilities were not included for further study does not imply that these facilities have no value, but rather that their application or contribution to hypersonic technology is not of a sufficient scale to justify further study. It must also be pointed out that a facility may only have a limited use to fulfill a specific test requirement, but this specialized facility is a necessary element in the development of the aircraft.

8. REFERENCES

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APPENDIX A

RESEARCH OBJECTIVE/FACILITY CORRELATION

A tabulation of the Research Objective/test facility correlation applicable to the potential operational vehicles is presented in this Appendix. This tabulation is categorized by objectives, indicating the applicable operational aircraft, candidate test facilities, the portion of the objective fulfilled in each facility, and test facility limitations, where appropriate. For some objectives, a discernible difference may be realized in application of a specific Research Objective/facility correlation to the potential operational vehicles. For these cases, an appropriate grouping of operational vehicles (e.g., Rocket Boost vs Airbreathing) is identified and the test facility capability determined accordingly for each objective. When evaluating flight facilities it was assumed that all vehicles 1) can perform "fly along" experiments to supplement their inherent research capabilities and 2) provide direct contribution to research requirements through concept demonstration. Details of the evaluation process appear in Section 3.3.1 of this report.

Research
Objective 1

PURPOSE: To determine low speed aerodynamic characteristics of hypersonic aircraft.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this research objective provides information to determine the take off and landing characteristics for all the baseline operational aircraft.

EXISTING GROUND TEST CAPABILITY: Current facilities (typically NASA/AMES low speed and 12' pressure tunnels along with the 5 degree of freedom flight simulator) can potentially satisfy 51% of the research objectives. Primary limitations are in accommodation of model size, velocity range of the low speed tunnel, and test section size for the 12' tunnel.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Potential new facilities are identified below, and indicate a significant (20%) increase in the ability to satisfy the research objectives via ground testing.

GD2 is sufficient to handle the wind tunnel requirements, about 56% of the overall research objective. The flight simulator facility, FS2, can accommodate an additional 4% of the total objective because of the added degree of freedom.

Complete fulfillment of the remaining portions of this objective requires flight demonstration.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All manned flight facilities and either the air launch or HTO unmanned flight facilities add to the satisfaction of this objective. Principal payoffs, as shown below, are contributed by the HTO manned aircraft. Air launch and VTO configurations are proportionately downgraded. The low speed facilities satisfy a large percentage of the objectives because they are representative of the all body hypersonic configuration.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE	REMARKS
220,221,280 - 283	No Contribution	Unmanned, Rocket Boosted (Staged)
284,285	10%	Unmanned
205-208	60%	Mach 6 Shape, Air Launch
270,271	60%	Mach 12 Shape, VTO
231-235	70%	Mach 12 Shape, Larger Vehicle Air Launch
200,201	70%	TRJ Flexibility, Wing Body and All Body
290	75%	Variable Stability Model, F106 Conversion
291,292	90%	All Body Shape, Design Specifically for Low Speed Test
210-215, 250-259	95%	Most Representative of Operational Vehicles

Research
Objective 2

PURPOSE: To determine transonic and subsonic aerodynamic characteristics of hypersonic vehicles.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this research objective provides information for aerodynamic assessments of high subsonic speed and transonic drag characteristics for all of the baseline operational aircraft.

EXISTING GROUND TEST CAPABILITY: Current facilities (typically AEDC subsonic and transonic tunnels, NAR trisonic tunnel, or NASA/MSFC prototype tunnel) can achieve an estimated 46% of the research objectives. Principal limiting factors are test section size, model scale, and prototype tunnel run time.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Existing capabilities may be extended about 30% by utilization of the potential new facilities GD3 and GD4. Respectively, these will satisfy an estimated 49% and 8% (non-overlapping) of the overall research objective. Limiting parameter in each case is run time.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All of the potential new flight facilities can contribute to the goals specified. The variable stability model is speed limited and not representative of the hypersonic shape, but other low speed aircraft can satisfy up to 50-60% of the objective. The larger sized vehicles, with the exception of the rocket boosted, staged concepts, contribute proportionately more, as shown below.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE	REMARKS
290	40%	Variable Stability F-106, Speed Limited
291	50%	Subsonic only
220,221,280-283	50%	Staged, Unmanned
204,284,285	50%	Unmanned
292	60%	Small Size (volume), JP Fueled TJ
200,201	70%	Small Size (volume), JP Fueled TRJ
205,208	90%	Air Launched, Sized for Mach 6
270-271	90%	VTO, Subsonic and Transonic, Rocket
210-215,231-235,250-259	95%	Closely Representative of Operational Vehicle

Research
Objective 3

PURPOSE: To determine supersonic and hypersonic characteristics of hypersonic aircraft.

RELATIONSHIP TO OPERATIONAL VEHICLES: Exploration of the supersonic and hypersonic flight regimes contributes significantly to all operational vehicles, but in varying proportion depending upon overall speed range of interest. For this reason, the operational vehicles have been grouped as follows

Group A (to Mach 6); C-1, M-1
Group B (to Mach 12); L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Existing facility performance, relative to the vehicle requirements, is judged to be 22% and 24%, respectively, for Group A and B operational vehicles. Current capabilities are typified by the AEDC 16' Supersonic tunnel, Cornell 96" shock tube, and NOL Hypervelocity tunnels; used in conjunction with the NASA/AMES flight simulator. Primary limitations are found to be test section size and model size, along with run time for the hypersonic tunnels.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The new facilities, although also limited by run time and test section size, increase current capability by about 15% for each Group of operational vehicles. Differences are due primarily to relative speed ranges involved.

FACILITY	% OVERALL OBJECTIVE SATISFIED		REMARKS
	Group A	Group B	
GD3	24%	14%	Limited Test Section, Reynolds Number, Run Time
GD7	12%	3%	Low Run Time
GD15	N/A	10%	Limited Test Section, Model Size, Run Time
FS3	4%	4%	Relatively Small Portion of Overall Task

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All flight facilities with the exception of the subsonic configuration, -291, contribute to the satisfaction of this objective. Numerical variations between Group A and Group B reflect the comparison of operational speed range with facility capability. Generally the Mach 12 vehicle provides the flexibility to satisfy all the Mach 6 tasks except as noted.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE		REMARKS
	GP A	GP B	
290	40%	30%	Variable Stability Subsonic Aircraft
292	50%	40%	Limited to Mach 2, Relatively Small
204	70%	40%	Unmanned, Air Launch Mach 6
220,221	70%	50%	Unmanned, Rocket Boost (Staged)
200,201	85%	70%	Limited to Mach 4.5, Relatively Small
205-215	95%	90%	Nearly representative of Mach 6
231-285	100%	95%	Nearly representative of Mach 12

Research
Objective 4

PURPOSE: To develop correlative testing techniques for adequate simulation of Reynolds number, Mach number, and boundary layer phenomena using subscale model testing.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective will allow effective scaling of aerodynamic parameters for all operational vehicles. The impact varies according to the relative magnitude of the vehicle speed range as compared to facility capability. The operational vehicles were grouped according to speed category:

Group A (to Mach 6); C1, M1
Group B (to Mach 12); L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Existing facility capability is typified by the AEDC 16' supersonic tunnel and the NASA/MSFC Ludweig Tube Prototype. Current performance of this objective can reach to within 70% of satisfaction of the Group A vehicles and 40% for Group B. Principal limitations are test section size and Model Re scaling along with run time limitations for the hypersonic portion. Numerical differences are due to the relative facility capability to encompass the flight speed range.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The new facilities are also somewhat limited by test section size and run time but represent an increase in test capability of nearly 20%. For Group A, GD3 and 4 contribute about 60% and 30% (same overlap), respectively, to the overall objective. For Group B, these values reduce to 42% and 9%, respectively, and are virtually additive to cover the entire speed range.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All of the hypersonic (>Mach 4.5) flight facilities contribute to satisfaction of this objective by providing full-scale data. The unmanned vehicles were downgraded on the basis of overall flexibility. Numerical differences reflect the relative comparison of speed range/facility capability as applied to the objectives for each group.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE GP A	GP B	REMARKS
200,201	80%	60%	Limited to Mach 4.5 (Potential to Satisfy 100% of M-1 Operational Vehicle Objectives)
204,220,221	90%	75%	Unmanned, Mach 6
280-285	95%	100%	Unmanned, Mach 12
205-215	100%	80%	Speed Limited to Mach 6
231-271	100%	100%	Full Mach Number Range, N_{RE} about 30% of that for Mach 12 Operational Vehicles.

Research
Objective 5

PURPOSE: To define requirements necessary to provide good handling qualities for hypersonic aircraft.

RELATIONSHIP TO OPERATIONAL VEHICLES: Definition of handling qualities and systems requirements necessary to improve flight control systems for hypersonic flight is applicable to all operational vehicles considered. The degree of capability inherent in each facility is dependent upon the speed class involved. For the facility correlation the operational vehicles were grouped as follows:

Group A (to Mach 6); C1, M1
Group B (to Mach 12); L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Existing ground test facilities are estimated to have sufficient capability to satisfy 65% of the total research objective for either Group A or Group B. Typical facilities, with additive capabilities are the NASA/AMES 40' x 80', AEDC 16' Supersonic, and NOL Hypersonic tunnels in conjunction with the current NASA/AMES flight simulator. The principal limitations imposed are due to Mach Number range, test section size, and model scaling. Run time presents some problem for hypersonic data acquisition.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Implementation of the potential new facilities listed below provide an increase in current capability of about 30%. For the most part, the contributions of each facility are additive. Numerical differences between Groups reflect the matching of facility capability with operational speed range.

FACILITY	% OVERALL OBJECTIVE SATISFIED		REMARKS
	GP A	GP B	
GD2	21%	17%	Small Test Section, Model Scaling, Limited to Mach 1
GD3	17%	14%	Small Test Section, Limited to Mach 5
GD7	N/A	7%	Mach 8-13, Limited Run Time
FS3	42%	42%	Nearly Completes Simulator requirements

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The unmanned flight facilities do not contribute to the satisfaction of this objective. The lower speed vehicles were downgraded because of speed range. The Mach 12 flight facilities satisfy nearly all Mach 6 objectives.

Research
Objective 5 cont.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE GP A	GP B	REMARKS
291	50%	40%	Subsonic, All Body Configuration
290	80%	60%	Variable Stability, Low Speed
200,201,292	80%	60%	Relatively Small, JP Fueled, Speed Limited
205-208	95%	90%	Air Launched, Relatively Small, Mach 6
210-215	100%	90%	Limited to Mach 6
231-235	100%	95%	Air Launched, Mach 12
270,271	100%	95%	VTO, Mach 12
250-259	100%	100%	Closely Represent Operational Vehicles to Mach 12

Research
Objective 6

PURPOSE: To evaluate techniques for positioning control and lifting surfaces and inlet location to obtain favorable aerodynamic influence.

RELATIONSHIP TO OPERATIONAL VEHICLES: Interference effects play an important role in configuration development for all operational vehicles. The dominance of these effects is a function of the design speed range for the vehicle. For purposes of evaluating facility capabilities, the operational vehicles were grouped as follows:

Group A (to Mach 6); C1, M1
Group B (to Mach 12); L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Existing capability is estimated at 60% of the objective fulfilled for Group A and 54% for Group B. Typical facilities which apply are the NASA/AMES 12' pressure tunnel, AEDC 16' Supersonic and NOL Hypervelocity tunnels. Principal limitations are size of test section, Reynolds number capability for the model size required, and hypersonic tunnel run time.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The overall capability can be improved by nearly 20% with the use of GD3 for Group A and GD3 and GD7 for Group B.

For Group A vehicles, GD3 can provide 70% of the desired objectives; being slightly limited by Mach Number Range.

GD3 and GD7 have additive capabilities and provide 56% and 8%, respectively, of Group B requirements. Run time is limited in the higher Mach Number tunnel.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The low speed vehicles have no contribution to this objective. Maximum benefit is achieved with air breathing cruise vehicles. The unmanned vehicles were downgraded because of relative limitations on flight envelope flexibility. Numerical differences between Group A and Group B are a result of relative speed range of the particular Group, as compared to the specific facility being investigated.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE GP A	GP B	REMARKS
281-285	50%	35%	Rocket Cruise, Unmanned
233-253,270	50%	40%	Rocket Cruise
204,220,221	80%	40%	Air Breathing Cruise, Unmanned, Mach 6
200,201	85%	50%	Composite Engine, Mach 4.5
205-215	95%	70%	Air Breathing Cruise, Mach 6
280	95%	85%	Convertible Scramjet, Mach 12
231,232,254-259,271	100%	95%	Air Breathing Cruise, Mach 12

Research
Objective 7

PURPOSE: To evaluate configuration shaping/propulsion system design techniques to obtain propulsive lift with the aid of favorable nozzle/airframe interaction.

RELATIONSHIP OF OPERATIONAL VEHICLES: Virtually all the potential operational vehicles can benefit from expansion of the engine exhaust over the aft portion of the aircraft body to obtain a force component producing lift. One exception is the Mach 4.5 M1 vehicle. The turboramjet engines are installed far aft and do not use the airframe for exhaust expansion.

EXISTING GROUND TEST CAPABILITY: It is estimated that approximately 35% of the objective can be accomplished in existing wind tunnel facilities. An example of those which can be used additively to explore the Mach Number range are the NASA/AMES low speed, AEDC 16' transonic, and AEDC 16' supersonic tunnels, and the Cornell base flow facility. All these are continuous run facilities, and the principal restrictively factors are test section size and model scale.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The use of potential new ground facilities can virtually double existing capability (≈95% addition). The facilities can be used additively (each to cover a given flight range) to the extent shown below.

FACILITY	% OVERALL OBJECTIVE SATISFIED	REMARKS
GD2	2%	Limited by Test Section Size and Model Scale
GD3	2%	Limited by 30 sec Run Time
GD7	16%	Limited by 1-4 sec Run Time
GD15	48%	Limited Model Scale and Run Time

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Only the winged body, airbreathing boost vehicles contribute to the satisfaction of this research objective. The rocket boosted and staged vehicles are not designed to use propulsive lift. The airbreathing all body vehicles are limited because of the transonic drag rise associated with the configurations. Capability to perform the required research is tabulated below.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE	REMARKS
200	50%	Winged Body TRJ, Limited to Mach 4.5
204	60%	Unmanned Winged Body TRJ, Limited to Mach 6
205,210	70%	Winged Body TRJ, Limited to Mach 6
212	70%	Winged Body TRJ, Limited to Mach 6
257	95%	Winged Body TJ+CSJ, Capability to M 12

Research
Objective 9

PURPOSE: To evaluate stability and control characteristics of hypersonic aircraft especially as influenced by propulsion system integration and aerothermoelastic effects.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this research objective will impact design of all the potential operational vehicles. For the most part, the magnitude of these effects are influenced by the operating speed range. For purposes of evaluation, the operational vehicle were broken into two groups each a composite of the speed range as related to facility capabilities.

Group A (To Mach 6); C1 and M1
Group B (To Mach 12); L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Existing ground facilities can contribute about 38% and 32% to the definition of stability coefficients for Group A and B, respectively. Both groups use wind tunnel facilities typified by the NASA/AMES low speed, AEDC 16' transonic and supersonic, and No. 2 hypervelocity tunnels. Limitations on capability are generally test section size, model scaling, and run time.

CAPABILITY PROVIDE BY NEW GROUND TEST FACILITIES: The potential new facilities can contribute in somewhat additive fashion to increase current capability by about 100%. The facilities, as identified below, will supplement existing capability. Numerical differences between operational groups reflect the greater relative percentage applicable to that Mach number range.

FACILITY	% OVERALL OBJECTIVE SATISFIED GP A	GP B	REMARKS
GD2	10%	5%	Small Test Section and Model Scale, Subsonic
GD3	15%	9%	Good to Mach 5, Low Run Time
GD7	N/A	10%	Limited Run Time, High Speed End
GD15	30%	30%	Limited Test Section Size, Model Scale, Run Time

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All the high speed (Mach 4.5 - 12) flight facilities can contribute to varying degrees. The unmanned vehicles were downgraded because of inflexibility. Rocket boosted and staged vehicles were downgraded because of their small contribution to inlet development. Numerical differences between groups is primarily due to the relative comparison of vehicle flight speed with facility capability.

FLIGHT FACILITY	% OVERALL OBJECTIVE SATISFIED GP A	GP B	REMARKS
204,220,221	60%	30%	Unmanned, Limited to Mach 6
214	50%	40%	All Rocket, Limited to Mach 6
233,234	60%	50%	Air Launch, Mach 12
250-253, 256,270,281,282	60%	50%	All Rocket, Mach 12

Research
Objective 9 cont.

FLIGHT FACILITY	% OVERALL OBJECTIVE SATISFIED GP A	GP B	REMARKS
200,201	70%	60%	Limited To Mach 4.5
280,283	70%	60%	Unmanned, Staged CSJ to Mach 12
284,285	70%	60%	Unmanned, All Rocket to Mach 12
207,208,213	75%	65%	Composite Cycles with a Rocket to Mach 6
215	75%	65%	Composite Cycle to Mach 4.5
205,206,210-212	80%	65%	Composite Cycles to Mach 6
231,232,235	80%	70%	Air Launch Composite Cycles to Mach 12
254,255,271	85%	75%	Rocket/CSJ to Mach 12
257-259	90%	80%	Composite Cycles to Mach 12

Research
Objective 10

PURPOSE: To develop design techniques for integration of stages into the overall vehicle configuration in an effort to improve aerodynamic characteristics for each stage, as well as the composite vehicle, throughout the applicable flight regime.

RELATIONSHIP TO OPERATIONAL VEHICLES: All multi-stage launch vehicles (potential operational vehicles L1-L4) can benefit from configuration development directed specifically toward stage integration. Careful review of individual and composite shapes can be expected to provide generally improved drag profiles and vehicle performance throughout the flight path of each stage.

EXISITING GROUND TEST CAPABILITY: Currently, the use of wind tunnel facilities typified by the NASA/AMES 12' pressure tunnel, AEDC 16' supersonic, and NOL hypervelocity tunnels can provide additive contributions amounting to the performance of 57% of the research objectives. Test section size and reduced model scale are limiting factors.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The use of the potential new ground test facilities, GD2, GD3, and GD7, additively by their respective Mach number range, can increase current capability by nearly 50%. The increment contribution of each of these is 26%, 28%, and 12%, respectively. Principal limitations are Mach number range for GD2 and GD3, test section and Reynolds number scaling for GD2, and low run time (1-4 seconds) for GD7.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The flight test facilities, although not similar to the staged operational vehicles, generally contribute in proportion to their capability to provide test time at a given Mach number. No credit was given to the subsonic all body vehicle (-291); and the unmanned vehicles were downgraded 10% due to their relative inflexibility.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE	REMARKS
290,292	10%	Low Speed and Transonic End
204,220,221	40%	Unmanned, Mach 6 Design
280-285	50%	Unmanned, Mach 12 Design
200,201	60%	Mach 4.5 Design
205-215	80%	Mach 6 Design
231-271	90%	Mach 12 Design

Research
Objective 11

PURPOSE: To determine separation techniques for two-stage, recoverable hypersonic vehicles which will provide positive and controllable separation.

RELATIONSHIP TO OPERATIONAL VEHICLES: The potential operational vehicles identified by L1-L4 are directly influenced by satisfaction of this research objective. The results will contribute directly toward configuration development and definition of vehicle control parameters during the separation sequence.

EXISTING GROUND TEST CAPABILITY: Existing facilities can satisfy 70% of the research objective. The major tasks are definition of stage interaction forces and the definition of a viable separation sequence. This may be accomplished with the aid of the Holloman AFB rocket sled to supplement wind tunnel capabilities characterized by the AEDC 16' supersonic tunnels. Wind tunnel facilities are limited by test section size and Reynolds number/model scale.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The addition of GD3, which can accomplish 35% of the research objective, increases the total capability of ground facilities to about 75%. GD3 will be used to supplement existing capability in the high supersonic (to Mach 5) speed range although some improvement may still be desirable at the upper end (> Mach 5).

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Although some of the flight test facilities are staged concepts, not all are laterally staged as in the case of recoverable boosters. Therefore, the flight facility contribution is generally in proportion to design Mach Number and available test time at lower Mach Numbers. No credit is given to the subsonic all body vehicle (-291). The variable stability F106 and Mach 2 all-body aircraft offer potential for definition of the low speed end. The unmanned vehicles were downgraded 10% to account for their relative inflexibility.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE	REMARKS
290,292	10%	Low Speed and Transonic End
204,220,221	40%	Unmanned Mach 6 Design
280-285	50%	Unmanned Mach 12 Design
200,201	60%	Mach 4.5 Design
205-215	80%	Mach 6 Design
231-271	90%	Mach 12 Design

Research
Objective 12

PURPOSE: To improve fundamental knowledge of hypersonic boundary layer behavior in an adverse pressure and shock interaction environment.

RELATIONSHIP TO OPERATIONAL VEHICLES: The satisfaction of this objective provides valuable data for configuration development for all the potential operational vehicles. Typical examples are impact upon control surface location and airbreathing inlet development. To evaluate this objective, the operational vehicles were broken into two groups to provide closer correlation on the basis of speed:

Group A (To Mach 6); L1, M1
Group B (To Mach 12); L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Supersonic and hypersonic wind tunnel facilities, characterized by the AEDC 16' supersonic and No. 2 hypervelocity tunnels, can satisfy the objective for Group A and Group B to the extent of 60% and 51%, respectively. Limiting parameters are generally tunnel size and model scale as well as run time for the hypersonic facility.

CAPABILITY PROVIDE BY NEW GROUND TEST FACILITIES: The adaptation of GD3 and GD7 can increase ground test capability by about 40%. While GD7 does not apply to Group because of the Mach number range, it can contribute 12% toward the overall objectives for Group B aircraft. GD3 contributes 70% and 49% for Group A and B, respectively. The principal limitation for GD3 is Mach number ($\approx$5.0), while GD7 can only provide 1-4 seconds run time.

CAPABILITY PROVIDE BY NEW FLIGHT FACILITIES: All high speed flight facilities contribute to satisfaction of this research objective. The Mach 12 vehicle can also provide an extension capability for definition of Group A vehicles. The unmanned vehicles were downgraded to some extent by their inflexibility. Other differences are proportional to speed envelope.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE		REMARKS
	GP A	GP A	
200,201	80%	60%	Limited To Mach 4.5
205-215	100%	80%	Limited To Mach 6
231-271	100%	100%	Full Capability to Mach 12
204,220,221	95%	75%	Unmanned, Mach 6 Design
280-285	100%	95%	Unmanned, Mach 12 Design

Research
Objective 14

PURPOSE: To develop techniques for prediction of buffet onset for low aspect ratio configurations, including the contribution of longitudinal bending and wing bending responses.

RELATIONSHIP TO OPERATIONAL VEHICLES: The satisfaction of this research objective contributes to configuration development for all hypersonic aircraft, and is necessary to adequately define aircraft stability and control capabilities along with overall assessment of external load patterns.

EXISTING GROUND TEST CAPABILITY: Current wind tunnel capabilities, typified by the AEDC and NAR transonic tunnels, can satisfy up to 60% of the defined objective. Principal limiting factors are test section and model size and, in some cases, speed range of the tunnel.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The added capability which may be realized by utilizing the GD3 tunnel is approximately 30%. GD3 can perform an estimated 80% of the overall task and is limited to some degree by test section size and Reynolds number/model scale.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The flight facilities generally contribute in proportion of their design speed, overall size, and shape, as noted below. Unmanned vehicles were hampered by their lack of flexibility to identify and explore the buffet regime.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE	REMARKS
204,220,221,280-285	10%	Unmanned
290	20%	Variable Stability F106
291	50%	Subsonic, All Body
292	60%	Low Supersonic, All Body
200,201	80%	Mach 4.5 Design
205-215	90%	Mach 6 Design
231-271	95%	Mach 12 Design

Research
Objective 15

PURPOSE: To evaluate configuration shaping techniques and determine the effect of shape changes and flight path variation on sonic boom intensity near field, and far field noise levels.

RELATIONSHIP TO OPERATIONAL VEHICLES: All hypersonic vehicles will generate overpressures and noise levels which may be annoying or destructive along the ground track. Satisfaction of this objective may alleviate this potential early in the configuration development phase.

EXISTING GROUND TEST CAPABILITY: Existing wind tunnel facilities can contribute to the satisfaction of 40% of the research objective. Typical capabilities are defined by the AEDC 16' transonic tunnel. Generally, the test section and accommodated model size are small.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The capability represented by GD3 contributes 50% toward satisfaction of the overall objective, providing an estimated increase of about 40% when used to supplement existing facilities. The test section and model size are limiting factors along with the 30 second run time.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All the facilities with transonic/supersonic capability can contribute to some extent. The unmanned contribution is minimal, particularly with the staged vehicles. Size is also an important parameter here, so that the smaller air launch vehicles contribute to a lesser degree. Individually, none of the vehicles can satisfy the shape investigation; this is a comparison that must be made between vehicles or with ground facility extrapolations.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE	REMARKS
220,221,280-283	5%	Staged, Unmanned
270,271	10%	VTO
205-208,231-235,284	20%	Air Launched
290	25%	Variable Stability F106
292	25%	All Body, JP fueled, Mach 2 Design
200,201	40%	JP Fueled, Mach 4.5
210-215	45%	Sized for Mach 6
250-259	50%	Sized for Mach 12

Research
Objective 16

PURPOSE: To develop correlation methods for prediction of heat transfer and drag for turbulent boundary layers.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective enables high confidence definition of environmental profiles for all the potential operational vehicles during the early stages of configuration development. The operational vehicles were grouped into two broad categories to more nearly match the speed range with the facility envelope. These are:

Group A (to Mach 6) C1, M1
Group B (to Mach 12) L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: The objective can be satisfied with current wind tunnel facilities to the extent of 60% for Group A and 44% for Group B. Representative facilities are the AEDC 16' supersonic tunnel in conjunction with the No 2 hypervelocity tunnel for Group B correlation. Limiting factors are test section size and model scale accommodated along with hypersonic tunnel run time.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The addition of the potential new facilities, GD3 and GD15, will provide an overall increase in capability of about 50%. These facilities are used with very little overlap in capability.

FACILITY	% OVERALL OBJECTIVE SATISFIED		REMARKS
	GP A	GP B	
GD3	35%	42%	Greater Speed Range Beneficial, Low Run Time
GD15	30%	24%	Limited to Mach 8.5, Low Run Time

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All potential new transonic and supersonic flight facilities can contribute to satisfaction of this objective. The unmanned vehicles have been downgraded on the basis of inflexibility. Other vehicles contribute in proportion to their flight speed. Numerical differences between speed groupings is a result of greater relative capability of the flight facility contribution as a percentage of overall requirement.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE		REMARKS
	GP A	GP B	
290	15%	10%	Speed Limited, Variable Stability F106
292	25%	10%	Speed Limited, All Body Mach 2
200,201	80%	60%	Mach 4.5 Design
204,220,221	80%	60%	Unmanned, Mach 6 Design
205-215	95%	75%	Mach 6 Design
280-285	95%	80%	Unmanned, Mach 12 Design
231-271	100%	95%	Mach 12 Design

Research
Objective 18

PURPOSE: To investigate the location and use of reaction control engines to supplement aerodynamic controls at high altitude.

RELATIONSHIP TO OPERATIONAL VEHICLES: If fruitful, the satisfaction of this objective can provide a significant contribution to reduction of overall control surface size, deflection angles, and resultant heat loads and power requirements for those vehicles with cruise speeds greater than Mach 6. The potential operational vehicles are L1-L4, C2, M2, M3.

EXISTING GROUND TEST CAPABILITY: Numerous ground test facilities, Environmental/Altitude Chambers, exist which can be utilized for development of the rocket motors required. These will contribute about 80% toward satisfaction of the overall research objective. The remaining 20% requires flight test to determine aerodynamic control/reaction control system interaction.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: No additional ground facilities are required to satisfy this objective.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Some contribution can be realized by all the potential new supersonic flight facilities. The lower speed vehicles can be used to demonstrate functional capability, as can the unmanned vehicles. The latter were downgraded because of the desirability to have pilot reaction/response. Contribution to the overall objective is otherwise proportional to design speed/equilibrium altitude.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE	REMARKS
290,292	5%	Functional Check Only - Speed/Altitude Limited
204,220,221	20%	Unmanned, Mach 6 Design
280-285	30%	Unmanned, Mach 12 Design
200,201	60%	Mach 4.5 Design
205-215	80%	Mach 6 Design
270,271	90%	Mach 12 Design, VTO
231-259	100%	Mach 12 Design

Research
Objective 1.1

PURPOSE: To determine aerodynamic control system effectiveness as a function of installed location and flight environment; to determine deflected control surface heat load as a function of deflection angle in the hypersonic environment.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective will provide valuable design data for control surface placement, control power, and thermal protection requirements for all the potential operational vehicles. The operational vehicles were grouped into two speed categories to better match vehicle speed with facility capability. These are:

Group A (to Mach 6) C1, M1
Group B (to Mach 12) L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: It is estimated that 70% of the objective can be satisfied for Group A vehicles and 64% for Group B with the use of existing wind tunnel facilities. Current capability is represented by the NASA/AMES low speed, AEDC 16' supersonic, and NOL Hypervelocity tunnels. Test section size and model scaling are generally limiting factors, with run time contributing to hypersonic test limits.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The addition of the facilities noted below, with generally additive capability, will provide an overall increase in existing capability of nearly 40%. Numerical difference between groups is due to greater relative portion of Group A performed in lower speed facilities.

FACILITY	% OVERALL OBJECTIVE SATISFIED		REMARKS
	GP A	GP B	
GD2	43%	34%	Limited Test Section Size, N_{RE} Scaling
GD3	35%	28%	Restrictive Speed Range, Size, Scaling
GD15	N/A	12%	Restrictive Speed Range, Run Time

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All supersonic flight facilities contribute to the satisfaction of this objective, although the contribution of both the variable stability F106 (-290) and Mach 2 design all body is minimal. The unmanned vehicles were downgraded slightly, along with another reduction for the staged vehicles due to their relative inflexible flight profile. The remaining rating differences are proportioned to flight speed; with numerical differences between Groups attributed to the relative matching of operational speed range with facility capability.

Research
Objective 1[illegible] cont.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE GP A	GP B	REMARKS
290	5%	5%	Variable Stability F106, Speed Limited
292	10%	5%	All body, JP Fueled, Mach 2 Design
220,221	60%	30%	Staged, Unmanned Mach 6 Design
200,201	70%	40%	Mach 4.5 Design
204	70%	60%	Air Launched, Unmanned Mach 6 Design
205-215	80%	60%	Mach 6 Design
280-285	80%	70%	Unmanned Mach 12 Design
231-271	90%	80%	Mach 12 Design

Research
Objective 20

PURPOSE: To extend current capability in the prediction of aerothermal parameters in a 3-dimensional hypersonic flow field.

RELATIONSHIP TO OPERATION VEHICLES: Satisfaction of this objective will enable high confidence prediction of the thermal protection requirements for all the potential operational vehicles. These have been divided into two groups, according to speed ranges, to relate more closely to facility capabilities. The groups are:

Group A (to Mach 6); C1, M1
Group B (to Mach 12); L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Present ground test facilities, typified by the AEDC heated tunnels, "B" and "C", and 16' supersonic tunnel can obtain 55% of the desired objective for both operational vehicle groups. Limiting factors are Reynolds number/Model size and lack of true temperature capability.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The use of potential new facilities can provide a substantial (20%) increase in current capability. The new tunnels, GD3, GD15, and GD16 for Group A; GD7, GD15, and GD16 can combine to accommodate larger models of the Group A and Group B vehicles. The combination can satisfy 67% of the overall research objectives. Limiting factors are again model size and Reynolds number capability along with deficiencies in flow temperature simulation.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The flight facilities are grouped into the same overall class as the operational vehicles. Only the supersonic vehicles apply. Satisfaction of the research objective is not dependent in this case on the subtleties of vehicle design differences but rather upon the design limits for test operation. The numerical difference between Group A and B is due to the increased capability of a Mach 12 flight facility to handle Mach 6 objectives with an effectively increased test time.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE GP A	GP B	REMARKS
200-221	82%	75%	Design to Mach 6, Local Shape Variation Only
231-285	90%	82%	Mach 12 Design, Local Shape Variation Only

Research
Objective No. 21

PURPOSE: To investigate the effects of shaping and protuberances on vehicle drag and local surface temperatures in a hypersonic environment.

RELATIONSHIP TO OPERATIONAL VEHICLES: All the operational vehicles will benefit from the satisfaction of this objective by virtue of increases in overall vehicle performance (via drag reduction) and definition of thermal protection requirement for the objective/facility correlation. The potential operational vehicles were broken into two groups:

Group A (to Mach 6); C1, M1
Group B (to Mach 12); L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Current ground facilities, typified by the AEDC heated tunnels "B" and "C" and the 16" supersonic tunnel, will satisfy 48% of the objectives for each vehicle group. Principal limitations are Reynolds Number/Model size (≈1% capability) and lack of adequate real gas temperature effects.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Increases in ground test capability of about 18% are available through the combined use of GD3, GD15, GD16, E6, E7 for Group A and GD7, GD15, GD16, E8, E9, for Group B. The gas dynamics (GD) facilities each contribute about 56% (with overlap) to the satisfaction of the objectives for both Groups. The engine test facilities provide high temperature gas flow and contribute 70% (Group A) and 20% (Group B) toward the overall research objective. Primary limitations are Reynolds number and Model size for the gas dynamics facilities; run time and high temperature flow capability relative to overall Mach number requirement for the "E" facilities.

CAPABILITY PROVIDE BY NEW FLIGHT FACILITIES: The research objective will be partially fulfilled by all high supersonic and hypersonic flight facilities. Since the objective requires the full utilization of steady state test time, differences between launch mode and engine selection do not predominate. Flight facilities contribute as tabulated below. The principal limitation is lack of the ability to provide variations in shape, except with "fly-along" test panels.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE		REMARKS
	GP A	GP B	
200-215	74%	60%	Design To Mach 6
231-285	80%	74%	Mach 12 Design

Research
Objective 23

PURPOSE: To determine the effects of transpiration and ablative cooling techniques on skin friction and heat transfer.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective provides a measure of how external thermal protection techniques can be used to effectively protect launch vehicles; and to gain insight into the effect on aerodynamic performance. The applicable operational vehicles are the reusable launch vehicles L1 through L4.

EXISTING GROUND TEST CAPABILITY: Current ground facilities, typified by the AEDC 5 MW and AVCO 10 MW heated tunnels, can satisfy 52% of the desired objective. Principal limitations involve Reynolds number/model scale, and Mach number capability.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The additional capability inherent in the development of the potential new engine test and gas dynamic facilities can result in an increase of 20% over existing capability. The contribution of the new facilities is nearly additive for GD7 and GD15 at 40% each. Either E6 or E7 can provide about 80% of the temperature environment with E8 and E9 downgraded to 75% because of Model scale. The E10 facility can also be adapted to contribute about 70%. Principal limitations are Reynolds number/model scaling and Mach number range.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The potential new flight facilities which have hypersonic test capability (Mach 6 and Mach 12) contribute to the satisfaction of this objective in proportion to their speed range. The Mach 6 vehicles can satisfy about 70% of the overall objectives, limited principally by the maximum design flight speed. The Mach 12 vehicles will contribute up to 88% of the overall objective. The limiting factor here is the inability to make changes in overall configuration, although "fly-along" parcels may potentially be used to vary test specimen configuration.

Research
Objective 25

PURPOSE: To determine the effects on aerodynamic heating caused by flow through gaps resulting from adjacent aircraft surfaces and rapid changes in operational altitude.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective will provide a more complete definition of thermal protection requirements for all the potential operational vehicles. For purposes of comparison with facility capabilities the operational vehciles were grouped according to two primary speed ranges:

Group A (to Mach 6) C1, M1
Group B (to Mach 12) L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: With the use of existing ground facilities, such as the AEDC real temperature tunnels, "B" and "C", and 16' supersonic tunnel, current capability is 50% of the overall research objective for both vehicle groups. Limiting factors are Reynolds number/model scale and inability to provide real gas effects throughout the spectrum.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Additional test capability is available through the use of the potential new gas dynamics facilities, GD7, GD15, GD16 for Group A vehicles and GD7, GD15, GD16 for Group B. The overall contribution is approximately 56%, reflecting an increase of 12% over existing potential. The facilities would be used to fill the entire Mach number range but have overlapping capabilities in terms of real gas effects and Reynolds number/model scale, which are two principal limitations of the ground facilities.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The flight facilities can satisfy the full expense of Mach numbers, real gas effects, model size, as well as 80% of the Reynolds Number requirements. However, the extent of their contribution toward fulfilling the research objective is based upon the design flight speed and resultant test time available at lower speeds.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE		REMARKS
	GP A	GP B	
200-221	78%	60%	Design to Mach 6
231-271	90%	78%	Mach 12 Design

Research
Objective 27

PURPOSE: To develop methods for prediction of heat transfer in the engine exhaust impingement area.

RELATIONSHIP TO OPERATIONAL VEHICLES: All the operational vehicles (with the exception of M1 which has aft-mounted engines without exhaust deflection) require accurate definition of the heat transfer rates and thermal protection requirements in the engine exhaust area. The potential operational vehicles have been grouped according to flight speed to allow closer comparison with nominal facility capabilities. Groups are:

Group A (to Mach 6); C1
Group B (to Mach 12); L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Current propulsion test facilities at AEDC, the AEDC 16' supersonic and transonic tunnels, and the NASA/Langley high temperature structural tunnel can satisfy up to 72% of the research objective. The principal limitation is that only a partial simulation of the total environment is possible at any one time.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Potential new facilities can duplicate current capability, as shown below, but cannot contribute any more than 5-7% of the unfilfilled research objective. Again, the principal limitation is due to only partial simulation of the aerothermal environment at any one time. For objectives applicable to Group A, GD facilities 3, 15, 16 and Engine facilities E8, E9, E10 each contribute 60% (overlapping capability), and engine facilities E6 and E7 contribute 74%. For Group B, GD7, E8, E9, E10 each contribute 60%, GD15 and GD16 contribute 40%. E6 and E7 provide 74%, or the full range of ground capability.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The requirement for flight test is manifested by the need to combine the environmental conditions (real gas, temperature, flow, radiative environment, and local shape) to achieve a definitive test. The hypersonic airbreathing cruise facilities all contribute to satisfaction of the research objective, in proportion to their speed/test time capability.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE GP A	GP B	REMARKS
200, 201	80%	70%	Mach 4.5 Design
204-213, 215-221	80%	80%	Design/Sized to Mach 6
231, 232, 235,254,255 257-259,271,280,283	90%	90%	Design/Sized to Mach 12

Research
Objective 28

PURPOSE: To develop efficient reusable thermal protection systems for cryogenic propellant tankage; from external radiative shingles through internal insulation/vapor barrier systems.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of the research objective applies to all operational vehicles, but the impact on the M1 concept is relatively small since a storable fuel system is employed. The cryogenic vehicles were divided into Groups, to reflect matching of vehicle operational range with flight facility design speed range as follows:

Group A (to Mach 6); C1
Group B (to Mach 12); L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Existing facilities can incrementally satisfy 75% the research objective through a component and scale tank development program. Typical facilities include the wide collection of manufacturing and cryogenic test facilities within NASA as NASA/Lewis, NASA/MSFC, NASA/KSC, and with NASA/Langley. However none of these can combine the environmental heat load and cryogenic capability.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITES: Potential new facilities will fulfill 100% of this objective. S1 and S2 (which have an identical capability for this objective) provide 20%; S5 and S6 contribute 40% each (with overlapped capability for thermal simulation); M2 and M3 each provide 50% of the total capability required (with nearly common capability for this objective). M4 can contribute up to 10% to the overall task. There is no numerical difference in capability as applied to the identified speed ranges. The described facilities fulfill the objectives of their individual tasks.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All the cryogenic flight facilities satisfy the total objective (through feasibility demonstration). to an extent determined by speed range/severity of the thermal environment.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE GP A	GP B	REMARKS
200,201	60%	30%	Storable, Limited to Mach 4.5
204-215	100%	70%	Mach 6 Design, Flight Environment
215-252,254,255,257-281, 283-285	100%	100%	Full Mach 12 Design Environment
253,256,282	60%	60%	Storable, Mach 12 Environment

Research
Objective 29

PURPOSE: To develop shell theory (as applied to noncircular fuselage and tank structures) to improve confidence in analysis of stress levels associated with combined mechanical/thermal loads and their impact on airframe life.

RELATIONSHIP TO OPERATIONAL VEHICLES: This is a basic technology objective, which relates directly to design concepts applicable to all the potential operational vehicles.

EXISTING GROUND TEST CAPABILITY: Existing ground test facilities, static structural laboratories, and structural heating chambers can adequately satisfy the experimental requirements associated with this research objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The addition of the potential new facilities S1, S2, and S6 will enhance current capability by providing large-scale along with improved data acquistion capabilities. The capabilities are nearly totally redundant and satisfy 100% of test requirements.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All hypersonic (Mach 6-12) flight facilities contribute to this research objective by providing an assessment of structural endurance over the aircraft lifetime/duty cycle. Applicable flight facilities are -205 through -285.

Research
Objective 30

PURPOSE: To develop efficient structural/tankage concepts for hypersonic aircraft.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this research objective will enable high confidence design of lightweight structural and tankage concepts for all the potential hypersonic operational systems.

EXISTING GROUND TEST CAPABILITY: The experimental portion of this objective (empirical determination of loads and thermal environment) can be satisfied in existing facilities. Typically representative facilities include the AEDC 16' supersonic tunnel, heated tunnel "B" and numerous static load facilities; which, when used in combination, can provide the required design data.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The potential new wind tunnels can also contribute to development of efficient shapes. These include GD3, GD4, GD7, and GD15 which each contribute up to 20% of the total capability. GD3 and GD4 have overlapping capability, GD15 has capabilities redundant to GD3 and GD4 and also to the lower Mach limit of GD7.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All hypersonic shapes, including the subsonic and low supersonic all body vehicles, culminate the test requirements for this objective. Measured flight data will enable correlation of ground test results with flight vehicle performance.

Research
Objective 32

PURPOSE: To develop efficient reusable leading edge structural concepts and define applicability according to flight regime.

RELATIONSHIP TO OPERATIONAL VEHICLES: The satisfaction of this research objective leads to the development of efficient leading edge protection for all the potential operational vehicles. The vehicles have been grouped according to speed range to provide closer correlation with flight facility capability.

Group A (to Mach 6); C1. M1
Group B (to Mach 12); L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Existing ground facilities, typified by the high temperature AEDC tunnels, "B" and "C", can accomplish up to 75% of the desired research objective. The principal limiting factor is Reynolds number/model scaling and real gas (temperature) capability.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The addition of the potential new facilities, E8, E9, E10, S3, and S5 enables completion of all the ground test objectives. Each of these facilities can individually contribute 40% to satisfaction of the overall objective. As applied to this objective, the engine test facilities have redundant capabilities and are flow facilities only. Structural objectives are picked up in the "S" facilities which have overlapping thermal programming capability. The ground facility capability applies equally to Group A and Group B vehicles.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Installation on the leading edges of hypersonic flight facilities will allow total fulfillment of the objective in the combined aerothermal/structural environment. The Mach 6 vehicles do not contribute to the Mach 12 leading edge development, since one primary goal is matching of the leading edge material/concept with flight regime.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE		REMARKS
	GP A	GP B	
200-221	100%	—	Limited to Mach 6 Environment
231-285	100%	100%	Mach 12 Design

Research
Objective 33

PURPOSE: To develop thermal protection systems and sealing and actuation techniques for control surfaces.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective will enable the use of workable aerodynamic control concepts for all the potential operational vehicles at minimum installed system weight and power.

EXISTING GROUND TEST CAPABILITY: All ground test requirements may be satisfied in existing facilities (typified by the high temperature tunnels, AEDC "B" and "C", AEDC 16' supersonic, and NOL hypervelocity tunnels).

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Additional test facilities E8, E9, E10, S2, S3, S5, M2, M3 can be used in conjunction with existing facilities to satisfy the ground test objectives. The engine test tunnels, E8-E10, can each provide 40% of the total capability. Structural test objectives can be met in S2 and S5; which each provide 40% and have redundant thermal programming capability over S2 and S5, and can accomplish 60% of the research objective.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Flight performance can be evaluated with the aid of all the potential new flight facilities. These can satisfy 100% of the research objectives, and with interchangable concepts can be used for total development of control systems for hypersonic vehicles.

Research
Objective 34

PURPOSE: To develop long-life, regeneratively cooled structural panels for application to high heat flux areas, such as hypersonic inlet structures and propulsion components.

RELATIONSHIP TO OPERATIONAL VEHICLES: The satisfaction of this objective has potential application to all the operational systems.

EXISTING GROUND TEST CAPABILITY: The structural panel development can be accomplished in combinations of existing facilities typified by the NASA/Langley high temperatures tunnel, and several superalloy manufacturing facilities in the aerospace industry.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: New facilities can also contribute to the overall objective as shown below:

FACILITY	PRINCIPAL PURPOSE	% OVERALL OBJECTIVE SATISFIED	REMARKS
E8, E9, E10	Flow Heating Profile Definition	65%	Redundant Capabilities
S1	Static Test	65%	Programmed Thermal & Structural Load
S3	Fatigue Test	65%	Cryogenic Flow Capability
S4, S5	Dynamic, Acoustic Evaluation	65%	Acoustic Some Redundancy With S1, S3
M2	Manufacturing, Inspection	20%	Mechanical Properties Evaluation
M4	Brazing	20%	Vacuum Furnace

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The flight facilities which employ convertible SCRAMJET cruise systems will provide feasibility demonstrations for the structural concepts, and through the use of interchangable cooling panels offer potential to totally satisfy the research objectives. Applicable vehicles are all Mach 12 designs: 231, 232, 235, 254, 255, 257-259, 271, 280, 283.

Research
Objective 37

PURPOSE: To determine the effects of separation forces on the structural dynamic characteristics of launch vehicles.

RELATIONSHIP TO OPERATIONAL VEHICLES: The potential operational vehicles, L1-L4, require careful analysis of separation mechanics and definition of relative motion of each stage to provide a reliable system.

EXISTING GROUND TEST CAPABILITY: Approximately 80% of the research objectives can be satisfied in existing wind tunnel facilities, supplemented by the Holloman AFB sled track. Principal limitations are Mach Number and run time along with Reynolds number/model size.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Our extension to the Holloman AFB sled track (GD13) to reach Mach 7 and the use of GD7 will enable completion of the ground test objectives. These facilities contribute 50% and 60%, respectively, to overall objectives with only a slight degree of overlap. They cover nearly the entire Mach range. Low speed definition may be picked up in existing tunnels for the specific shapes involved.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The potential new flight facilities do not contribute to the satisfaction of this objective. The noted staged concepts, 220, 221, 280-283, are staged off conventional vertical launch boosters i.e. Thor, Atlas.

Research
Objective 38

PURPOSE: To determine inertial and dynamic effects of fuel slosh in low aspect ratio hypersonic aircraft with large volume tankage.

RELATIONSHIP TO OPERATIONAL VEHICLES: This research objective is applicable to all the operational vehicles, except M1 which is a relatively small volume JP fueled aircraft.

EXISTING GROUND TEST CAPABILITY: No existing facilities can satisfy the test objectives at the mechanical excitation rates required.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The construction of the potential new facility S6 will contribute toward satisfaction of 80% of this research objective. The principal limitation foreseen at this time is adequate definition and simulation of an identical operational environment.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All the cryogenically fueled (LH_2) hypersonic flight facilities have large enough tankage to satisfy 90% of the research objectives - with the exception of the unmanned staged vehicles which are deficient in simulated operational flight profile as well as tank size. Applicable vehicles are 205-215 (to Mach 6), 231-271 (to Mach 12) and 284, 285 (unmanned to Mach 12).

Research
Objective 29

PURPOSE: To determine correlation parameters descriptive of the effects of near field noise on minimum gauge structures, composites, and non-metallic structures.

RELATIONSHIP TO OPERATIONAL VEHICLES: The satisfaction of this research objective enables high confidence design of minimum weight structural components for all potential operational vehicles.

EXISTING GROUND TEST CAPABILITY: This research objective can be satisfied in existing ground facilities, typified by the acoustic facilities at NASA/MSFC and Wyle Laboratories.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The potential new ground test facilities S4 and S5 can also accommodate the test requirement. S4 capability is estimated at 70% and S5 at 100%. S5 also provides a thermal programming capability to simulate the flight environment.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The potential new flight facilities offer no contribution to the satisfaction of this objective but would employ the results.

Research
Objective 40

PURPOSE: To develop non-destructive testing and inspection procedures for complex advanced structural concepts.

RELATIONSHIP TO OPERATIONAL VEHICLES: The use of sandwich structural panels, reinforced composite structures, diffusion bonded materials, and coatings on all the potential operational vehicles necessitates satisfaction of this research objective.

EXISTING GROUND TEST CAPABILITY: All test requirements can be satisfied in existing materials development laboratories and structural test facilities throughout the aerospace industry, as well as at major structural research centers such as NASA/Langley.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The potential new ground test facilities, M3 and M4, can each contribute 60% and 70%, respectively, to the overall objective, resulting in satisfaction of all the ground test requirements.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Flight facilities cannot contribute to satisfaction of this research objective but will employ the results.

Research
Objective 41

PURPOSE: To develop techniques for accurate estimation of component and structural mass fractions.

RELATIONSHIP TO OPERATIONAL VEHICLES: The satisfaction of this objective will provide greater capability in parametric design and scaling of flight vehicles, and as such, is applicable to all operational vehicles.

EXISTING GROUND TEST CAPABILITY: Ground testing is not appropriate for this objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Ground testing is not appropriate for this objective.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Flight testing is not appropriate for this objective.

Research
Objective 42

PURPOSE: To verify structural and thermo structural integrity through full-scale component testing.

RELATIONSHIP TO OPERATIONAL VEHICLES: This objective is applicable to all the potential operational vehicles and will result in maximum confidence level development of the noted flight systems.

EXISTING GROUND TEST CAPABILITY: Existing facilities typified by those at the AF Flight Dynamics Laboratory, NASA/Langley, and NASA/Flight Research Center will contribute to 60% of the overall research objective. The limiting factors are incremental testing requiring movement between facilities which precludes the capability to superimpose test environments.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Additional capability provided by the S2 facility will accomplish all the research objectives. Other potential new facilities which offer incremental contribution are S1, 80%; S3, 80%; S5, 20%; and SS2, 15%.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Flight facilities do not contribute to satisfaction of this objective except as demonstrator vehicles.

Research
Objective 43

PURPOSE: To develop reusable thermal protection systems for protection of primary structure.

RELATIONSHIP TO OPERATIONAL VEHICLES: Development of these systems offers significant weight reductions for all the potential operational vehicles. For comparison with the flight facility capabilities, operational vehicles have been divided into two groups:

Group A (to Mach 6); C1, M1
Group B (to Mach 12); L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Existing facilities can satisfy approximately 75% of this objective. These are characterized by NASA facilities at MSFC, KSC, Lewis, and Langley. The principal limitation is in capability to perform integral structural and thermal load programming while serviced with liquid hydrogen.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The additional capability is provided by the use of the S1 and S2 (20%), S5 and S6 (40%) structural facilities; M2 and M3 (50%), M4 (10%) materials development facilities will enable total satisfaction of the research objective. S1 and S2 are redundant for this objective; S5, S6, M2, and M3 overlap in the thermal programming capability.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All the hypersonic flight facilities contribute to the satisfaction of this objective. The noted differences in capability reflect the matching of facility test time and maximum temperature envelope with operational vehicle requirement.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE GP A	GP B	REMARKS
200-221	100%	70%	Mach 6 Maximum Design
231-285	100%	100%	Full Thermal Environment

Research
Objective 44

PURPOSE: To define the mechanical and physical properties of advanced materials.

RELATIONSHIP TO OPERATIONAL VEHICLES: The utilization of metal matrix composite materials, high temperature titaniums, superalloys, and refractories in the design of all the potential operational systems requires complete definition of the properties of these materials.

EXISTING GROUND TEST CAPABILITY: Existing facilities typified by many throughout the industry can contribute 100% to fulfillment of this objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The potential new materials laboratories, M2 and M3, have an additive capability of 80% and 20%, respectively, to totally satisfy this research objective. M3 adds a mechanical load programming capability.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Flight facilities will not contribute to satisfaction of this objective.

Research
Objective 45

PURPOSE: To improve manufacturing and fabrication techniques for complex structural concepts.

RELATIONSHIP TO OPERATIONAL VEHICLES: The use of welding, diffusion bonding, high temperature brazing, and composite material forming techniques for all the potential operational vehicles requires satisfaction of this objective.

EXISTING GROUND TEST CAPABILITY: Existing fabrication and manufacturing development facilities throughout the industry, at Wright Field, and within NASA can accomplish this objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: In addition to existing facilities, complete capability is also offered by M4, which incorporates a 300°F (149°C) vacuum furnace.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Flight facilities do not contribute to the satisfaction of this research objective.

Research
Objective 46

PURPOSE: To develop high temperature components for hypersonic aircraft.

RELATIONSHIP TO OPERATIONAL VEHICLES: The requirement to provide high temperature bearings, lubricants, closure seals, tires, windshields, and radomes is mutually applicable to all the potential operational vehices. These have been divided into groups to correlate speed range with facility capability. The groups are:

Group A (to Mach 6); C1, M1
Group B (to Mach 2); L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Existing facilities, such as the high temperature load facilities at the AF Flight Dynamics Laboratory and NASA/Langley, can satisfy 100% of the research objectives.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: In addition to existing facilities, the potential new materials test laboratories can provide a nearly additive contribution of 50% for M2, 5% for M3, and 45% for M4. M[illegible] and M2 overlap their thermal programming capabilities. The drop test facility, SS2, can also contribute to landing gear development and other dynamic tests to about 5% of the total test requirement.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All the hypersonic flight facilities can contribute according to their maximum exposure to the high Mach number thermal environment. Installed systems as well as "fly-along" concepts are appropriate.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE		REMARKS
	GP A	GP B	
200-221	100%	70%	Mach 6 Design Limit
231-285	100%	100%	Complete Thermal Environment

Research
Objective 46

PURPOSE: To develop hypersonic airbreathing inlet systems capable of efficient operation over a wide flight regime.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective applies to all operational vehicles except L3 which is entirely rocket-powered. The operational vehicles were broken into three groups to provide a closer correlation with facility capabilities.

Group A (Mach 4.5) M1
Group B (Mach 6) L1, C1
Group C (Mach 12) L2, L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Existing facilities characterized by the NASA/AMES and AEDC tunnels contribute 80%, 70%, and 60% for Groups A, B, and C, respectively. Principal limitations are Reynolds number capability and sustained Mach number.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Some improvement, nominally 50% over existing capability, is provided by the addition of GD3 and GD7. The numerical difference between groups is due to the relative percentage of testing applicable to that Mach range.

FACILITY	% OVERALL OBJECTIVE SATISFIED			REMARKS
	GP A	GP B	GP C	
GD3	90%	80%	70%	Offers improvement in Reynolds number
GD7	N/A	N/A	30%	Run Time limited

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All flight facilities with hypersonic cruise capability can contribute as shown below. Rocket vehicles were downgraded as were the fixed inlet (ramjet) installations because they could only contribute flow field data rather than variable point operation, recovery, etc. The numerical difference between groups reflects degree of applicability to the Mach number range.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE			REMARKS
	GP A	GP B	GP C	
200, 201	95%	70%	N/A	Turboramjet Operation to Mach 4.5
204-206	50%	95%	N/A	Air Launched Operation to Mach 6
207, 213	10%	95%	N/A	Ramjet Operation @ Mach 6
210-212	60%	95%	N/A	Mach 6 Design Point
220, 221	N/A	90%	N/A	Boosted to Mach 6 RJ
231, 257	20%	30%	95%	TJ+CSJ
232, 254, 255, 271	N/A	N/A	95%	Rockets+CSJ
280	N/A	N/A	90%	Staged to CSJ
233-253, 256, 270 281-285	N/A	N/A	30%	Flow Field only

Research
Objective 55

PURPOSE: To investigate methods to reduce engine noise during takeoff and landing.

RELATIONSHIP TO OPERATIONAL VEHICLES: This research objective is particularly applicable to the commercial operational vehicles, C1 and C2, which have a potentially high flight frequency.

EXISTING GROUND TEST CAPABILITY: Existing ground test facilities such as those at Edwards AFB and NASA/Langley will enable satisfaction of static noise reduction for the turbine modes, amounting to approximately 50% satisfaction of the overall objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The addition of the lower speed gas dynamic and engine facilities GD3, GD4, E6, and E7 will enable exploration of techniques for noise reduction in a simulated aerodynamic environment. The contribution of each of these is estimated at 30% with some overlap in Reynolds number capability.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The airbreathing accelerator horizontal take-off flight facilities generally contribute 95% to satisfaction of the overall objective. The remaining 5% depends upon specific design and operational characteristics of the C1 and C2 vehicles. Applicable flight facilities are 200, 201, 205, 206, 210-212, 231, 257.

Research
Objective 56

PURPOSE: To study ramjet combustion problems when operated for thrust augmentation at transonic and low supersonic flight speeds.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective will facilitate definition of the capability of individual operating modes of composite engines, as installed in the potential operational concepts, L1, C1, M1.

EXISTING GROUND TEST CAPABILITY: Existing facilities, typified by that at the Ordnance Aerophysics Laboratory, can satisfy 80% of the overall objective. The principal limitation is model scale.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The addition of GD3, GD4, E6, E7, E8 to current facilities will increase overall capability to 90% (attainable in either GD4, E6, or E7). GD3 contributes 30% (limited by flow capability and enthalpy), while E8 contributes 80% (limited in size).

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All ramjet flight vehicles with variable operational capability can contribute full-scale simulation and will satisfy 95% of the research objective. The remaining portion is a function of the operational vehicle detailed design.

Applicable flight facilities are 207, 212, 213, 220, 221 (ramjet vehicles) and 231, 232, 254, 255, 257, 271, 280 (convertible scramjet).

Research
Objective 57

PURPOSE: To develop and demonstrate large-scale turboramjet systems.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective enables design and development of all the turboramjet powered operational vehicles, L1, L2, C1, M1. These were grouped to show facility application on the basis of speed range.

Group A (Mach 4.5) M1
Group B (≈Mach 6) L1, L2, C1

EXISTING GROUND TEST CAPABILITY: Existing capabilities amount to 60% for Group A and 40% for Group B, based on the relative Mach number matching. Principal limitations are inability to cover the entire flight range and model size. Typical facilities are the engine test calls at AEDC and OAL.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The addition of GD 3, E6, E7 and E8 to existing facilities can increase overall capability by nearly 50%. The gas dynamic facility offers higher Reynolds number while E6, E7 and E8 offer higher Reynolds number and enthalpy. Structural and flow facilities contribute to component development for the engines.

FACILITY	% OVERALL OBJECTIVE SATISFIED		REMARKS
	GP A	GP B	
GD3	40%	30%	Flow Field Definition, Low Temp Air
E6	70%	60%	Direct Connect Heated Flow
E7	90%	80%	Free Jet Heated Flow. Variable Angle of Attack
E8	N.A	20%	Mach 6 Lower Limit
S2, S5, S9, F3	N/A	10%	Component Development Only
S4	10%	10%	Component Development Only
SS1	10%	N/A	Component Development Only

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All the turboramjet flight facilities contribute to the satisfaction of this objective by performance throughout the entire flight envelope. The Mach 4.5 engines are JP fueled, however, while LH_2 has been selected for Mach 6.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE		REMARKS
	GP A	GP B	
200, 201	95%	N/A	JP Fueled
204-206, 210, 211	N/A	95%	LH_2 Fueled

Research
Objective 56

PURPOSE: To develop background data for engine mode selection as a function of specific mission requirements and engine operating characteristics.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective provides valuable configuration and propulsion system design and mission planning data for all the potential operational vehicles.

EXISTING GROUND TEST CAPABILITY: The experimental tasks for this objective can be performed in existing facilities to an extent comparable to satisfying 60% of the overall research objective. Typical facilities are AEDC wind tunnels and engine test cells along with those at OAL and NASA/AMES. Limiting factors are generally test section size and model scale.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The potential new facilities can contribute portions totalling 90% of the overall experimental requirements. The facility capabilities are additive based on Mach number and Reynolds number range.

GD2, 4, 12, and 16 each contribute 10% of the required performance while GD3, 7, 13, 15, and E6-10 each provide 30% of the total capability. The higher Mach number facilities are limited in terms of run time and overall model size. A considerable portion of the overall task is analytical.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Those HTO flight facilities which incorporate composite engine cycles can contribute fixed design point operational data. Facility capabilities are proportional to Mach number limits.

FLIGHT FACILITIES	% CONTRIBUTED TO OVERALL OBJECTIVE	REMARKS
200,201	30%	Mach 4.5 TRJ
210-214	50%	Mach 6 Design Cruise
254, 255, 257, 271	80%	Mach 12 Cruise

Research
Objective 6C

PURPOSE: To develop and demonstrate large-scale convertible Scramjet engine systems.

RELATIONSHIP TO OPERATIONAL VEHICLES: The L2 operational vehicle, which employs the convertible Scramjet concept, requires component development and integration of that system into attractive vehicle design in order to develop the overall flight system.

EXISTING GROUND TEST CAPABILITY: Current capability can only achieve 20% of the required research. Typical facilities are the supersonic tunnels at NASA/AMES and AEDC, and the high temperature tunnels at AEDC, OAL, and NOL. Limitations are primarily total mass flow and enthalpy capability along with test section size.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The current capability is nearly tripled by the additional Reynolds number, Mach number, and enthalpy capability obtainable from the new facilities identified below. Some overlap is evident. on the basis of flow environment, but differences in accommodated model size offer significant benefit.

FACILITY	% OVERALL OBJECTIVE SATISFIED	REMARKS
GD3	40%	Limited to Mach 5, Cold Flow
GD7	30%	Limited Run Time, Cold Flow
E7	30%	Free Jet to Mach 5, Limited Model Size
E8	60%	Mach 6-12, Limited Run Time
E9	70%	Includes Structural Qual Capability
E10	50%	Combustion Tests

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The flight facilities which incorporate convertible Scramjet systems can contribute to the satisfaction of this objective to an extent dependent upon the flight profile. Rocket acceleration precludes the design of the convertible portion for the lower Mach numbers.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE	REMARKS
232, 254, 255,271, 280	80%	Rocket/CSJ to Mach 12
231, 257	95%	TJ/CSJ to Mach 12

Research
Objective 61

PURPOSE: To develop and demonstrate large-scale SCRAMJET powered hypersonic systems.

RELATIONSHIP TO OPERATIONAL VEHICLES: The operational vehicles employing SCRAMJET propulsion concepts require design and development of the engine system and its control, cooling, and burner components to allow effective incorporation into operational vehicle design. Applicable operational vehicles are L4, C2, M2, M3.

EXISTING GROUND TEST CAPABILITY: Approximately 20% of the research objective is attainable in existing ground facilities. Representative capability is typified by the supersonic tunnels at AEDC and NASA/AMES for flow-field definition; and high temperature/combustion flow at OAL in the supersonic regime.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Current capability can be tripled by implementing the engine test facilities E8, E9, and E10 in conjunction with flow definition from GD7. The facility capabilities overlap on the basis of flow environment with practical limitations noted below for each.

FACILITY	% OVERALL OBJECTIVE SATISFIED	REMARKS
GD7	30%	Limited Run Time, Cold Flow
E8	50%	Mach 6-12, Limited Run Time
E9	70%	Includes Qualification Capability
E10	50%	Can Accommodate Combustion Tests

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The SCRAMJET flight vehicles contribute 90% toward satisfaction of the research objective as applied to the operational vehicles. Applicable vehicles are 231, 257 (TJ/CSJ), 232, 254, 255, 271, 280 (ROCKET/CSJ). These have Mach 12 cruise capability but the SCRAMJET does not correspond to a point design for that Mach Number.

Research
Objective 62

PURPOSE: To demonstrate HTO with a rocket, and operation throughout an extensive flight envelope.

RELATIONSHIP TO OPERATIONAL VEHICLES: This objective must be satisfied to provide high confidence point design and development for operational vehicles employing liquid rocket propulsion. Applicable operational vehicles are L3, L4, M2, M3.

EXISTING GROUND TEST CAPABILITY: Ground test facilities are not applicable to this objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Ground test facilities are not applicable to this objective.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All rocket accelerated horizontal take-off facilities contribute 95% to the total satisfaction of this objective as applied to the noted operational vehicles. The remaining portion requires exact configuration and control response data of the operational vehicle point designs. Applicable flight facilities are 213, 214 (Mach 6 capability), and 250-256 (Mach 12 capability).

Research
Objective 64

PURPOSE: To evaluate the suitability of auxiliary turbojets for landing hypersonic vehicles.

RELATIONSHIP TO OPERATIONAL VEHICLES: Four operational vehicles, L3, L4, M2, and M3, require development of this technique before it can become an operational reality and an acceptable design alternative to unpowered landings.

EXISTING GROUND TEST CAPABILITY: The ground test facilities contribute only to engine development (current capabilities adequate) and flow field/stability studies during transition. This accounts for 10% of the total research objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The potential new ground test facilities, GD2 and E7, also contribute about 10% to total satisfaction of the overall objective, which is the full extent of ground test requirement.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Current capabilities exist at NASA/AMES and NASA/Flight Research Center to perform flight test for transition phases but no vehicle exists.

None of the potential flight facilities are applicable.

Research
Objective 65

PURPOSE: To provide improved nozzle performance and integrated airframe/nozzle configurations to maximize net thrust.

RELATIONSHIP TO OPERATIONAL VEHICLES: All of the airbreathing operational vehicles benefit from the satisfaction of this objective by potentially lower base drag and higher propulsion cycle efficiency. The applicable operational vehicles have been divided into two groups to match vehicle speed range with facility capability.

Group A (Mach 4.5-7); L1, C1, M1
Group B (to Mach 12); L2, L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Existing ground facilities, typified by the AEDC tunnels "B", "C" and "F", the NASA/AMES hypersonic tunnel, and the Cornell facilities, can accommodate 20% of the research objectives for Group B and 50% for Group A. Principal limits are test section size, Reynolds number/model scaling limits, and equivalent flow enthalpy.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The addition of GD7 along with the engine test cells can provide a 50% increase in current capability. The noted capabilities overlap from the standpoint of Mach number and flow range as noted.

FACILITY	% OVERALL OBJECTIVE SATISFIED		REMARKS
	GP A	GP B	Limited Run Time
GD7	80%	70%	To Mach 13, Cold Flow
E6	40%	N/A	Direct Connect to Mach 5 Nozzle Only
E7	50%	N/A	Free Jet to Mach 5
E8	30%	50%	Small-Scale, Mach 6 to 12
E9	N/A	50%	Engine Operational/Qualification Runs
E10	N/A	50%	Direct Connect Combustion Testing

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All airbreathing cruise flight facilities contribute to the satisfaction of this objective. Mach 6 flight facilities do not contribute to Group B objectives and vice versa because of the uniquene f the engine designs: i.e. $\geq$ M6 $\Rightarrow$ CSJ; $\leq$M6 $\Rightarrow$ TRJ or RJ. The RJ powered vehicles e downgraded because of fixed point operation.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE		REMARKS
	GP A	GP B	
200,201	80%	N/A	Turboramjet to Mach 4.5
205, 206, 210-211	95%	N/A	Turboramjet to Mach 6
212	95%	N/A	TJ/RJ to Mach 6
207, 213, 220, 221	50%	N/A	Rocket/RJ Mach 6 Design
231, 257	N/A	95%	TJ/CSJ to Mach 12
232, 254, 255, 271, 280	N/A	95%	Rocket/CSJ to Mach 12

Research
Objective 67

PURPOSE: To determine engine/inlet compatibility criteria of high total pressure recovery, wide Mach range inlets.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this research objective provides design data for all the airbreathing operational vehicles. These have been grouped according to speed class to provide a closer correlation with facility capabilities. The groups are:

Group A (Mach 4.5); M1
Group B (≈Mach 6); L1, C1
Group C (to Mach 12); L2, L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Current facilities have a capability to meet 70%, 50%, and 20% of the research objectives for Groups A, B, and C, respectively, Typical facilities are the AEDC supersonic and heated tunnels, the NASA/AMES supersonic, hypersonic tunnels, and NOL hypervelocity tunnels. Limiting factors are test section, model size, flow temperature, and run time for the hypersonic tunnels.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Current capabilities can be increased to allow 90% accomplishment of the overall objective. This is realized by the partially additive contribution of the gas dynamic and engine test facilities which can contribute on an individual basis as noted.

FACILITY	% OVERALL OBJECTIVE SATISFIED			REMARKS
	GP A	GP B	GP C	
GD3	70%	50%	N/A	Cold Flow, Limited to Mach 5
GD7	N/A	N/A	30%	Cold Flow, Limited Model Size, Run Time
E6	70%	60%	N/A	Direct Connect to Mach 5
E7	90%	80%	30%	Free Jet to Mach 5
E8	N/A	20%	60%	Mach 6-12; Small-Scale
E9	N/A	N/A	70%	No External Flow
E10	N/A	N/A	50%	Direct Connect Small-Scale

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All hypersonic flight facilities with airbreathing acceleration capability contribute to satisfaction of the research objective. The relative capability is a function of test Mach Number and speed group Matching.

Research
Objective 67 cont.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE			REMARKS
	GP A	GP B	GP C	
200, 201	95%	65%	N/A	TRJ to Mach 4.5
204-206	65%	95%	N/A	TRJ to Mach 6
207, 213	N/A	95%	N/A	Rocket/RJ @ Mach 6
210, 211	65%	95%	N/A	TRJ to Mach 6
212	65%	95%	N/A	TJ/RJ Mach 6 Design
220, 221	N/A	95%	N/A	Staged to Mach 6 RJ
231, 257	N/A	N/A	95%	TJ/CSJ, Mach 12 Cruise
232, 254, 255, 271	N/A	N/A	95%	Rocket/CSJ, Mach 12 Cruise
280	N/A	N/A	N/A	Staged/CSJ, Mach 12 Cruise

Research
Objective 68

PURPOSE: To develop operational systems and procedures for thermal conditioning, storage, and safe handling of cryogenic propellants.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective directly impacts the development of all the cryogenically fueled operational vehicles; L1-L4, C1, C2, M2, M3.

EXISTING GROUND TEST CAPABILITY: The capability exists to totally satisfy this objective in existing ground facilities, typified by the cryogenic storage and flow facilities at NASA/MSFC, NASA/Lewis, NASA/KSC, and at the NASA/AEC Nevada test site.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The potential new facilities, F3, F4, and F5, can also fully contribute to the satisfaction of this objective.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Flight test facilities do not apply to the satisfaction of this objective.

Research
Objective 69

PURPOSE: To develop correlative techniques to define fluid/thermodynamic interaction for cryogenic fluids in sloshing horizontal tankage.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective will allow high confidence level development of all the operational vehicles employing cryogenic propellants.

EXISTING GROUND TEST CAPABILITY: There is no existing ground test capability for large-scale horizontal tanks in a dynamic (mechanically excited) environment.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The potential new facilities, F3 and F4, can contribute 50% and 70%, respectively, to satisfaction of the overall objective. The F3 capabilities are totally included in F4. The F4 facility has improved data acquisition, mechanical excitation, and environmental (altitude) simulation capability. Limiting factors are scaling data to flight vehicles and exact simulation of the dynamic environment.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All flight facilities employing cryogenic propellants can contribute up to 95% of the research objective as applied to the operational vehicles. These are: 204-252, 254, 255, 257-281, 283-285.

Research
Objective 70

PURPOSE: To develop regenerative hydrogen heat exchange and control systems compatible with aircraft heat fluxes and fuel flow rates.

RELATIONSHIP TO OPERATIONAL VEHICLES: This objective has potential application to all cryogenically fueled operational vehicles. The vehicles have been grouped according to broad speed class for correlation with flight facilities. These are

Group A (Mach 6); L1, C1
Group B (to Mach 12); L2-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Existing ground facilities (primarily fluid storage and handling) can accommodate 15% of the overall research objectives. The capability does not exist for safe handling of LH_2 in a high heat flux environment.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The fluid flow/heat flux capabilities contributed by F2 extend current capability to 80% of the overall objective. The remaining 20% is limited by high confidence definition of the heat load, local hot spots, and operational engine control.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All hypersonic cruise flight facilities contribute toward satisfaction of this objective. The rocket-powered vehicles were downgraded since they must perform the appropriate testing with "fly-along" experimental hardware.

FLIGHT FACILITIES	% CONTRIBUTED TO OVERALL OBJECTIVE GP A	GP B	REMARKS
204-213, 220, 221	95%	60%	Mach 6 Design Point
233, 234, 250-252 284, 285	70%	70%	Rocket-Mach 12 "Fly Along" Experiment
281, 282	N/A	70%	Staged To Mach 12 "Fly Along" Experiment
231, 232, 235, 254, 255, 257-259, 271, 280, 283	N/A	95%	Mach 12 Airbreathing Cruise

Research
Objective 71

PURPOSE: To improve performance potential of hydrocarbon fuels.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective by increasing fuel thermal stability limits and energy content can lead to improved performance for the M1 vehicle, and may also enable a viable alternative to fuel selection for the L1, L2, and C1 vehicles.

EXISTING GROUND TEST CAPABILITY: Current facilities, typically the Fuels Development Laboratory and Fuel Systems Simulator at Wright Field, offer the potential to fully satisfy this research objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The objective may also be fulfilled in the potential new facility, SS1, which also adds an altitude simulation capability.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Flight facilities are not applicable for satisfaction of this objective.

Research
Objective 72

PURPOSE: To determine additional fuel system requirements imposed by the use of thermally stable and endothermic fuels.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective contributes directly to the design and development of the M1 operational vehicle, and is contingent upon the success realized in Research Objective 71 for application to other operational vehicles (L1, L2, C1).

EXISTING GROUND TEST CAPABILITY: Current facilities, at Wright Field, NASA/Lewis, and within the petroleum industry, contribute about 50% to satisfaction of the research objective. Primary limitation is altitude simulation/heat flux capability for large-scale systems.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Additional capability, provided by the implementation of F2 and SS1, can completely satisfy this objective. These facilities contribute 10% and 100%, respectively, to the satisfaction of the overall objective. The 10% represents a direct addition to current capability and accomplishes high heat flux/high temperature component development.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Flight facilities are not applicable to satisfaction of this objective.

Research
Objective 73

PURPOSE: To provide cryogenic fuel system components with reduced weight and increased reliability.

RELATIONSHIP TO OPERATIONAL VEHICLES: The application of LH_2 to (all operational vehicles except M1) reusable aircraft systems demands improvement of static and dynamic seals and rotating machinery operating in a cryogenic environment.

EXISTING GROUND TEST CAPABILITY: Existing cryogenic flow facilities, typified by those at NASA/MSFC, NASA/Lewis, and NASA/KSC, can satisfy 100% of the research objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The capability provided within either the F3 or F4 test facilities also can result in total satisfaction of the research objective.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Flight facilities are not applicable to satisfaction of this research objective.

Research
Objective

PURPOSE: To develop cryogenic tankage concepts and fuel system operation and control techniques.

RELATIONSHIP TO OPERATIONAL VEHICLES: Development of all the potential operational aircraft which use cryogenics requires satisfaction of this objective for maximum system performance at minimum weight.

EXISTING GROUND TEST CAPABILITY: Existing ground test facilities, typified by the NASA cryogenic flow facilities, and planned AF Flight Dynamics Laboratory test capability, will satisfy 20% of the overall research objective. Primary limitation is the combination of storage, heating, and altitude simulation capability.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The potential new facilities F3 and F4, can satisfy 30% and 70% of the research objective. These facilities overlap in heating and storage capability, but F4 offers greater data acquisition, mechanical excitation, and scale test size for altitude simulation. Actual flight heat load, sloshing, and pressurization environment is required to complete the objective.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All cryogenically fueled flight facilities offer the potential to satisfy 90% of the research objective as applied to the operational vehicles. The remaining portion is dependent upon design and trajectory peculiar for those vehicles. Applicable facilities are 204-221 (Mach 6) and 231-252, 254,255, 257-281, 284, 285 (Mach 12).

Research
Objective 76

PURPOSE: To determine the capability of flush-mounted recessed antennas.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective will allow high confidence definition of emission and reception patterns for communication, navigation, and electronic warfare functions as they apply to all the operational aircraft.

EXISTING GROUND TEST CAPABILITY: This objective may be totally satisfied in existing facilities typified by the many vendor outdoor antenna pattern test ranges and anechoic chambers.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The potential new facility, A1, can also satisfy 100% of this research objective.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Flight facilities are not applicable to satisfaction of this research objective.

Research
Objective 78

PURPOSE: To investigate stability augmentation systems and recovery from pilot-induced oscillations in the hypersonic flight regime.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective contributes to the design and development of all the operational vehicles with the exception of M1 which is a winged body configuration operating at a lower Mach number. The operational vehicles were grouped to provide a closer correlation with flight facility Mach number capability.

Group A (Mach 6) C1
Group B (to Mach 12) L1-L4, C2, M2, M3.

EXISTING GROUND TEST CAPABILITY: Current facilities, typified by the NOL hypervelocity and MDC HIT tunnels, along with the moving-base simulator at NASA/AMES, can satisfy 50% of the overall objectives for Group A and B. Both groups are limited by test-section/model size and run time.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Current capability can be increased by more than 50% with the additive contributions of GD15 and FS3. The new facilities will contribute 30% and 45%, respectively, toward satisfaction of the overall objective. Flight conditions are necessary to satisfy the remaining portion.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The potential new flight facilities can contribute significantly to the development of stability augmentation systems; generally in proportion to their overall speed/altitude capability. The unmanned vehicles were downgraded because of their relative inflexibility without the pilot.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE GP A	GP B	REMARKS
200, 201	80%	60%	Limited To Mach 4.5
204, 220, 221	30%	20%	Unmanned To Mach 6
205 - 215	95%	75%	Mach 6 Design
280 - 285	40%	30%	Unmanned To Mach 12
231 - 271	95%	95%	Nearly Approximates Full Range To Mach 12

Research
Objective 79

PURPOSE: To develop air data measurement techniques applicable to hypersonic aircraft.

RELATIONSHIP TO OPERATIONAL VEHICLES: New data measurement devices, such as laser densitometers, must be developed for all the potential operational vehicles. The vehicles are grouped according to flight regime to provide a closer correlation with facility capabilities.

Group A (to Mach 6); C1, M1
Group B (to Mach 12); L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Current wind tunnel facilities, typified by the NASA/AMES and AEDC supersonic tunnels and the NOL hypervelocity tunnel, can contribute toward satisfaction of this research objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: In addition to existing capability, the new facilities will offer an additive contribution to the overall objective as follows.

FACILITY	% OVERALL OBJECTIVE SATISFIED GP A	GP B	REMARKS
GD3	24%	14%	Limited Test Section Size, Reynolds Number
GD7	12%	3%	Low Run Time
GD15	N/A	10%	Limited Test Section, Model Size, Run Time

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All hypersonic flight facilities contribute to the satisfaction of this objective. The contribution is measured in terms of Mach number capability for the test vehicles.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE GP A	GP B	REMARKS
200, 201	80%	50%	Limited To Mach 4.5
204-221	100%	70%	Limited To Mach 6
231-285	100%	100%	Mach 12 Capability

Research
Objective 80

PURPOSE: To develop control surface actuation techniques and devices.

RELATIONSHIP TO OPERATIONAL VEHICLES: All the operational vehicles require development of control actuators (including pneumatic and hydraulic drive systems and components) which are compatible with the operational environment. Vehicles have been grouped according to speed range in order to provide closer correlation with facility capabilities.

Group A (to Mach 6); C1, M1
Group B (to Mach 12); L1-L4, C2, M2, M3

EXISTING GROUND TEST CAPABILITY: Current capability, typified by the AEDC high temperature tunnels and NASA/Langley high temperature structural tunnel, can fulfill this entire objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: In addition to existing capability, implementation of the following potential new facilities adds to the extent noted. This may prove beneficial to the extent that some tasks may be combined within one facility.

FACILITY	% OVERALL OBJECTIVE SATISFIED GP A	GP B	REMARKS
E6	45%	N/A	Direct Connect, Limited to Mach 5
E7	50%	N/A	Free Jet, Limited to Mach 5
E8, E9, E10	40%	30%	Mach 6-12, Small-Scale
S2	40%	40%	Static Test Altitude Environment
S3	60%	60%	Fatigue and Thermal Load Programming
S5	40%	40%	Static Test, Acoustic & Thermal Environment
M2, M3	20%	20%	Materials Development

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All hypersonic flight facilities contribute to the satisfaction of this objective. The contribution is measured in terms of Mach number capability for the test vehicles.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE GP A	GP B	REMARKS
200, 201	80%	50%	Limited to Mach 4.5
204-221	100%	70%	Limited to Mach 6
231-285	100%	100%	Mach 12 Capability

Research
Objective 82

PURPOSE: To develop auxiliary power units for rocket-and ramjet-powered aircraft.

RELATIONSHIP TO OPERATIONAL VEHICLES: All of the operational vehicles require development of secondary power generation systems to supply the aircraft during the rocket and ramjet (or SCRAMJET) cruise modes.

EXISTING GROUND TEST CAPABILITY: Many facilities are currently operational (such as the turbopump development test stands and jet engine test cells) throughout the industry which can completely satisfy this research objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: In addition to current capability, either of the potential new ground test facilities, F4 or F5, may also be used to fulfill the entire objective.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All test facilities which incorporate ramjet or rocket propulsion modes contribute to satisfaction of the research objective. The turboramjets were downgraded because of the relatively low percentage of operation without core engine power.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE	REMARKS
200, 201	60%	JP TRJ (To Mach 4.5)
204-206, 210, 211, 215	70%	LH_2 TRJ (To Mach 6)
207, 208, 212-214, 220-285	100%	LH_2 Rocket/RJ/CSJ/TJ

Research
Objective 83

PURPOSE: To develop environmental control systems utilizing cryogenic propellants as a heat sink.

RELATIONSHIP TO OPERATIONAL VEHICLES: All operational vehicles, with the exception of M1, realize a significant weight savings by utilizing the cryogenic fuel as a direct heat sink for the ECS.

EXISTING GROUND TEST CAPABILITY: Existing ground capabilities (typified by the cryogenic storage and flow facilities at NASA/MSFC, NASA/Lewis, and NASA/KSC) can fully satisfy this research objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The potential new ground facilities F1, F3, and F4 will also be capable of development of the cryogenic ECS systems and contribute 100%, 80%, and 100%, respectively, toward satisfaction of the overall objective. F3 is short on data acquistion and altitude simulation capability

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All cryogenically fueled flight test facilities contribute to total satisfaction of this objective. Applicable vehicles are 204-214, 220-252, 254, 255, 257-281, 283-285.

Research
Objective 34

PURPOSE: To develop environmental control systems for Mach 4 to 6 storable hydrocarbon fueled vehicles.

RELATIONSHIP TO OPERATIONAL VEHICLES: This objective is directly applicable to M1, with potential application to L1 and C1 contingent upon the success of Research Objective 71.

EXISTING GROUND TEST CAPABILITY: This objective may be completely satisfied within existing ground test facilities, typified by altitude simulation, static heating, and fuel flow facilities available throughout the industry.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The potential new ground test facilities, F1, F3, and F4 will contribute 100%, 80%, and 100%, respectively, to the satisfaction of the overall objective. F3, primarily a component development facility, is limited on data acquisition and environmental simulation.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The potential new flight facilities (200, 201, and 215) satisfy the entire objective. These are the only flight test facilities employing storable hydrocarbon fuels.

Research
Objective 95

OBJECTIVE: To develop launch techniques for internally stored weapons.

RELATIONSHIP TO OPERATIONAL VEHICLES: The military operational vehicles, M1, M2, and M3 must store AAM and ASM weapons internally. As a result, systems must be developed to enable effective use of the weapons. The operational vehicles were divided into two groups to provide closer correlation with facility capability.

Group A (Mach 4.5); M1
Group B (Mach 12); M2, M3

EXISTING GROUND TEST CAPABILITY: This objective may be satisfied (to the extent of 60% fulfillment of Group A and 56% for Group B) in existing facilities typified by the NOL 16' supersonic tunnel and NOL hypervelocity tunnel (Group B). Limitations are generally test section and model size, as well as run time for the hypersonic tunnel.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The addition of GD3 and GD7 test capability will increase the ability to satisfy the overall objectives by 10%. GD3 contributes 65% and 52% for Groups A and B, respectively, while GD7 contributes 10% for Group B (additive capability). Primary limitations are test section and model size, Mach range for GD3 (Group B), and run time for GD7.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All the hypersonic shapes can contribute to the satisfaction of this research objective according to Mach number capability. The unmanned vehicles were downgraded due to their relative inflexibility of operational testing.

FLIGHT FACILITY	% CONTRIBUTED TO OVERALL OBJECTIVE GP A	GP B	REMARKS
200, 201	95%	60%	Limited to Mach 4.5
204, 220, 221	30%	20%	Unmanned, to Mach 6
205-215	95%	75%	Limited to Mach 6
281-285	40%	25%	Unmanned, to Mach 12
231-271	95%	95%	Mach 12 Capability

Research
Objective 87

PURPOSE: To evaluate terminal approach methods and low speed handling qualities.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective provides valuable configuration development and control requirement data for all potential operational vehicles.

EXISTING GROUND TEST CAPABILITY: Existing ground test facilities, typified by the NASA/AMES and NASA/Langley flight simulators, can satisfy 60% of the overall objective. Limiting factors are dynamic simulation and 6th degree of freedom.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The potential new ground test facilities, FS1, FS2, and FS3, contribute 60%, 70%, and 40% to satisfaction of the overall objective, with some overlapping capability. FS1 provides crew training and familiarization with controls; FS2 is designed primarily for takeoff and landing simulation; and FS3 is a cruise simulator.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The subsonic all body (291) and variable stability F106 (290) can fulfill 100% and 95% of the overall research objective.

Research
Objective 89

PURPOSE: To investigate man-machine compatibility as related to control and navigation of hypersonic vehicles.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective is a prerequisite for the successful operation of all potential operational vehicles.

EXISTING GROUND TEST CAPABILITY: Current ground simulation facilities can satisfy 90% of the overall objectives.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The potential new facilities, FS1, FS2, FS3, can individually contribute 70%, 70%, and 50%, respectively, to satisfaction of the overall research objective. FS1 is a crew simulation; FS2 and FS3 are designed for landing and takeoff and cruise simulation, respectively. The individual capabilities overlap to some extent but will combine to satisfy 95% of the overall objective.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All manned flight facilities can contribute to the total fulfillment of this objective. These are: 200, 201, (Mach 4.5); 205-215 (Mach 6); and 231-271 (Mach 12).

Research
Objective 21

PURPOSE: To develop effective communication techniques for safe flight planning.

RELATIONSHIP TO OPERATIONAL VEHICLES: The satisfaction of this research objective is necessary for all operational and flight test vehicles.

EXISTING GROUND TEST CAPABILITY: Ground test facilities do not apply to this objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Ground test facilities do not apply to this objective.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: This objective must be satisfied prior to utilization of the identified flight test facilities.

Research
Objective 92

PURPOSE: To assess variations in launch trajectories to assess axial and normal accelerations loads.

RELATIONSHIP TO OPERATIONAL VEHICLES: This is an analytical objective requiring satisfaction to facilitate lightweight design of all operational vehicles.

EXISTING GROUND TEST CAPABILITY: Ground test facilities do not apply for the satisfaction of this objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Ground test facilities do not apply for the satisfaction of this research objective.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Flight test facilities do not apply to the fulfillment of this objective.

Research
Objective 94

PURPOSE: To develop emergency abort, dump, and escape procedures.

RELATIONSHIP TO OPERATIONAL VEHICLES: The satisfaction of this objective reduces the operational risk for all the potential operational systems.

EXISTING GROUND TEST CAPABILITY: The existing wind tunnel flight simulation and static fluid test facilities can satisfy 75% of the overall objectives. Limiting factors are test section size and model scaling for the wind tunnels, and availability of hazardous test facilities (to simultaneously accomplish fuel dump and heating).

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The addition of the potential new facilities will increase overall capability about 10%. The low overall contributions shown are, to a large extent, due to the scope of task requiring that particular facility.

FACILITY	% OVERALL OBJECTIVE SATISFIED	REMARKS
GD2	5%	Low Speed Portion Only
GD3	8%	Transonic Separation Studies
GD7	5%	High Speed Separation Studies
FS1, FS3	10%	Abort Simulation
SS1	60%	Hot Fuel Dump and Spill Testing

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Flight facilities do not contribute toward satisfaction of this objective.

Research
Objective 95

PURPOSE: To determine the effects of flight aspect and perturbations of aerodynamic environment on overall flight performance.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective will provide an analytical description of non-steady state factors which influence configuration development and flight operation for all the operational vehicles.

EXISTING GROUND TEST CAPABILITY: Ground test facilities are not applicable for satisfaction of this objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Ground test facilities are not applicable for satisfaction of this objective.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Flight test facilities are not applicable for satisfaction of this objective.

Research
Objective 96

PURPOSE: To define aircraft operating margins and determine capability to operationally adhere to these.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective contributes to definition of realistic operating restrictions for all the operational aircraft.

EXISTING GROUND TEST CAPABILITY: Existing simulation equipment at NASA AMES and NASA Langley can satisfy 30% of the overall objective. The principal limitation is overall motion and acceleration simulation.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Additional ground test capability will be provided to satisfy 95% of the overall objective. Individual capabilities for the potential new facilities, FS1, FS2, and FS3, are 30%, 95% and 80%, respectively. FS1 is limited in acceleration and motion since it is a crew-training device rather than an engineering tool.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All the manned hypersonic flight facilities will totally satisfy this objective. Applicable vehicles are: 200; 201 (Mach 4.5); 205-215 (Mach 6); and 231-271 (Mach 12).

Research
Objective 97

PURPOSE: To develop leak detection methods for cryogenic propellant tanks.

RELATIONSHIP TO OPERATIONAL VEHICLES: The satisfaction of this objective is necessary to provide high confidence development of LH_2 fueled aircraft.

EXISTING GROUND TEST CAPABILITY: A large number of existing cryogenic storage and handling facilities have the capability to completely fulfill this objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Addition of F5 and SS1 will supplement current capabilities. These new facilities will enable accomplishment of 80% and 100% of the overall objective. F5 is limited by virtue of its relatively small data acquisition system.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: Flight test facilities are not applicable for the satisfaction of this objective.

Research
Objective 98

PURPOSE: To investigate concepts to provide an atmosphere of motion and security for passengers in windowless aircraft.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective will provide human factors data to enable development of the operational vehicles C1 and C2 with maximum passenger appeal.

EXISTING GROUND TEST CAPABILITY: Existing flight simulation devices may be used to accomplish 50% of the overall research objective. Principal limitation is overall limits of motion and acceleration simulation.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The capability provided by the potential new ground facilities, FS2 and FS3, will additively accomplish the entire objective. FS2, a takeoff and landing simulator, will contribute 40%; FS3, a cruise simulator, will contribute 70%.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The new flight facilities are not applicable toward satisfaction of this research objective.

Research
Objective 99

PURPOSE: To investigate forced rotation techniques to enable short takeoff.

RELATIONSHIP TO OPERATIONAL VEHICLES: Applicable operational vehicles are L3, L4, M2, and M3 - all rocket acceleration. Satisfaction of this research objective will contribute to definition of low speed stability aspects of forced rotation.

EXISTING GROUND TEST CAPABILITY: Existing ground test facilities (typified by the NASA/AMES low speed tunnel and five degree-of-freedom simulation) will contribute 43% toward satisfaction of the research objective. Principal limits are model size and exhaust pumping (for rocket flow) for the tunnels as well as motion and acceleration limits for the simulation.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The addition of GD2 and FS2 will increase total capability to satisfy 54% of the overall objective. Individual contributions are 48% for GD2 and for FS2, directly additive.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All the rocket accelerated flight facilities (not staged) will contribute 95% to fulfillment of the overall objective. These are: 207, 208, 213, 214 (Mach 6); and 232-256, 258, 259, 284 (Mach 12). None of the flight facilities currently employ canard control surfaces.

Research
Objective 101

PURPOSE: To develop specifications for Air Traffic Control procedures and ground-based navigation system.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective is necessary for the safety of all potential operational vehicles.

EXISTING GROUND TEST CAPABILITY: Ground test facilities are not applicable to the fulfillment of this objective.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: Ground test facilities are not applicable to the fulfillment of this objective.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: The potential new flight facilities are not applicable to the satisfaction of this objective.

Research
Objective 102

PURPOSE: To develop inspection and repair techniques for hypersonic vehicle structures.

RELATIONSHIP TO OPERATIONAL VEHICLES: Satisfaction of this objective is applicable to the maintenance of all the potential operational vehicles.

EXISTING GROUND TEST CAPABILITY: This research objective may be totally fulfilled in existing structural fabrication and assembly facilities.

CAPABILITY PROVIDED BY NEW GROUND TEST FACILITIES: The potential new ground facilities, S4, S6, S7, M3, and M4, can incrementally contribute to the satisfaction of this objective. S4 (acoustic), S6 (dynamic tankage), and S7 (cabin pressurization) each contribute 10%. M3 (fatigue facility) contributes 30%; and M4 (fabrication facility) contributes 40%.

CAPABILITY PROVIDED BY NEW FLIGHT FACILITIES: All flight test facilities, by virtue of their demonstration of concept feasibility, can each fully satisfy this research objective.