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FINAL REPORT

SCHEDULING TECHNIQUE IMPROVEMENT STUDY
for
ADVANCED PROGRAMS

VOLUME I
SUMMARY

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VOUGHT MISSILES AND SPACE COMPANY
DALLAS, TEXAS

FOREWORD

The Scheduling Technique Improvement Study for Advanced Programs was conducted by the Vought Missiles & Space Company, LTV Aerospace Corporation, Dallas, Texas, under Contract No. NAS9-11659. This study was conducted for the Operations Analysis Branch of the Manned Spaceflight Center, National Aeronautics and Space Administration, Houston, Texas. The period of this contract covered twenty (20) weeks, including a two-week final reporting period. Contract dates were from 7 March 1971 through 25 July 1971.

This document is submitted in compliance with NAS9-11659, Paragraph V (Deliverable Items) of Exhibit A to the Statement of Work.

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	7/29/71
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ABSTRACT

This report, in four volumes, is the final report of a twenty-week study conducted by Vought Missiles & Space Company for the Operations Analysis Branch, Manned Spacecraft Center (MSC), NASA, to generate improved techniques for scheduling major advanced programs. Study results directly support on-going and future programs within the National Aeronautics and Space Administration (NASA) as well as having application to any program, new or existing, under cognizance of the U. S. Government and its agencies where the techniques described herein may be utilized to estimate program milestone schedules. The basic technique is termed Time Estimating Relationships (TERs), where relationships are derived from statistical data to relate time to those technical parameters judged to be drivers in subsystem, system or total program scheduled development and delivery.

In addition to TER development, this study also addressed, and has reported herein, a comparative baseline for the scheduling improvement effort. Included are: (1) a master schedule for developing an Advanced Space Transport Program, (2) the Work Breakdown Structure and Dictionary (work statement) for the Program, (3) the detail schedules developed by standard techniques for estimating design and development, and (4) the logic diagrams which identify principle tasks and their sequence. All efforts reported herein are keyed to the Work Breakdown Structure (WBS) developed for an Advanced Space Transport Program in accordance with NASA level designations. This Program is used as the baseline for the study effort and is representative of programs being considered by NASA for operations in earth-to-near earth space environments.

The four volumes which contain the Final Report, under title of "Final Report, Scheduling Technique Improvement Study for Advanced Programs", are subtitled as follows:

Vol. I - Summary

Contains the final oral report presented to MSC covering the results of the entire study, including the TERs developed during the study. Contains, in addition, the objectives, approach and ground rules for generating the TERs, WBS Dictionary, Logic Charts, and Master and Detailed Schedules. The Work Breakdown Structure and Dictionary for the Total Program, for the Air Vehicle, for Integration and Assembly of Air Vehicle Stages and Payload, and for the Payload conclude this volume. A glossary of abbreviations, symbols and terms are included in the preamble to the text.

Vol. II - Stage II, Advanced Space Transport Program

Contains Stage II Work Breakdown Structure Dictionary, Detail Schedules and Logic Diagrams. Stage II (a manned, reusable orbiting transport vehicle) is defined consistently to the 6th (Assembly) Level and to the 7th (Component) Level for certain subsystems.

Vol. III - Stage I, Advanced Space Transport Program

Contains Stage I Work Breakdown Structure Dictionary, Detail Schedules and Logic Diagrams. Stage I (a manned, reusable boost vehicle) is defined consistently to the 5th (Subsystem) Level and to the 6th (Assembly) and 7th (Component) Levels for certain subsystems.

Vol. IV - Ground Support, Test, Training, Investment, Operations; Advanced Space Transport Program

Contains the Work Breakdown Structure Dictionary, Detail Schedules and Logic Diagrams for the major program elements for the life-cycle program other than Air Vehicle. These elements are consistently defined at the 3rd (Project) Level and partially defined at the 4th (System), 5th (Subsystem) and 6th (Assembly) Levels.

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LIST OF ABBREVIATIONS, SYMBOLS, TERMS (GLOSSARY)

A

ABES	Air Breathing Engine System. The turbojet engine system used on Stage I and Stage II for powered cruise and ferry flights. (See WBS Dictionary Elements 1.3.4.5, Stage II, and 1.4.4, Stage I)
ACPS	Attitude Control Propulsion System (see also RCS). The propulsion assembly used to maintain vehicle stability or to enable attitude change while the vehicle is out of the sensible atmosphere. (See WBS Dictionary Elements 1.3.4.4, Stage II, and 1.4.4, Stage I)
ACT	Acquisition, Control and Test (Unit). (See WBS Dictionary Element 1.4.10)
Advanced Space Transport Program	A Life Cycle NASA program defined to design, develop and produce manned, reusable two-stage vehicles whose missions will include delivering and/or retrieving GFE payloads to/from near earth space in support of manned orbiting space stations and space bases, experiments, developments, etc. In addition to vehicles, necessary ground support will also be developed and produced, including the neccessary data, software, training, facilities and investment to commit the Program to 10-year operations. At IOC, the Program is defined to follow a Traffic Model of flights and turnarounds and provides the hardware, software, support and management to complete the designated Life Cycle.
A & E	Architectural & Engineering
Air Vehicle	The assembly of Stage I, Stage II and Payload

AMPR/DCPR Weight	Aircraft Manufacturers Planning Report/ Defense Contractor Planning Report - A vehicle weight which excludes the following items from empty weight: Wheels, Brakes Tires, Tubes; Engines; Rubber or Nylon fuel cells; Starters, Propellers; APU's, Instruments, Navigation Equipment; Batteries, Conversion Equipment; Electrical and Flight Control Equipment; Turrets and Power Mounts; Air Conditioning, Pressurization, Anti-Icing; Cameras
APU	Auxiliary Power Unit (see WBS Dictionary Elements 1.3.6.2, Stage II and 1.4.6, Stage I)
ATC	Air Traffic Control (or Controller)
	B
BIT	Built-in Test. A capability designed into on-board equipment to enable it to be interrogated by the on-board computer for status checks prior to or during flight. May also include self-test and a means to perform manual checkout.
	C
Category I Testing	(AFR 80-14) Subsystem Development Test and Evaluation. Consists of development testing and evaluation of the individual components, subsystems, and, in certain cases, the complete system. In addition to qualification, the testing provides for redesign, refinement, and reevaluation, as necessary. Conducted predominantly by the contractor under (government) control.

Category II Testing	(AFR 80-14) System Development Test and Evaluation. Consists of testing and evaluation spanning the integration of subsystems into a complete system, and development tests of the completed system in as near an operational configuration and environment as practicable. Suitable instrumentation will be employed to determine the functional capability and compatibility of subsystems. Category II is a (government) effort with contractor participation, under (government) control. Actual test operation and maintenance should be performed by (using agency) personnel who have received formal system training.
C & C	Command and Control
CCN	Contract Change Notice

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CDR

Critical Design Review. A formal technical review conducted for each contract end item. Purpose is to determine acceptability of detail design, performance, test, and activation characteristics depicted by the design solution specified in Part II Specifications. Establishes that recommended design adequately satisfies end-item design and test requirements, including interface with personnel, facilities and other system equipment. Critical Design Review establishes: (1) compatibility between the CEI and the Part I Specification; (2) compatibility between the CEI and the Total System; (3) Design Integrity by way of review of both analytical and test data; and (4) the agreed-to Part II Specification which is the basis for inspecting the "First Article". Upon the logic charts CDR's have only been identified at those points in software developments where at firm baseline is necessary against which to manage subsequent changes. Software, since it is used to checkout/verify the airborne/ground systems, must have a baseline or "First Article" for software configuration control.

Precise definition of CDR for hardware configuration items within the logic has not been possible because no logical point is available within the study confines to indicate the transition from development to production. Without such a point, the logical placement of a First Article Configuration Inspection (FACI) could not be determined and the absence of a FACI point removes the requirement for a CDR. However, the earliest that a CDR could occur would be at that point during the qualification test program where (1) Part II Specifications would be complete or would be nearing completion; and (2) sufficient considence would have been acquired to permit the "cutting of metal" for qualification hardware. Calendar points reflecting these points have been identified on the detail calendar schedules.

CEI	Contract End Item (also, CI - Contract Item)
CFE	Contractor Furnished Equipment
Coefficient of Correlation	A pure number which expresses the degree of relationship between two variables. It varies between 0, when there is no correlation, and 1 or -1, when there is perfect correlation. Simply stated, it is a measure of how well the independent variables in a multiple regression equation explain variances in the value of the dependent variables.
Common Support Equipment	Maintenance equipment required to support Program operations but which is not directly involved in the operations, and which is common, i.e., presently in DoD or other government inventory in support of other systems or programs and which is available for use on subject programs.
Configuration (End) Item (also, Contract End Item, or Contract Item)	(MIL-STD-881) An aggregation of hardware/software, or any of its discrete portions, which satisfies an end-use function and is designated by the government for configuration management. During development and initial production, CI's (CEI's) are only those specification items that are referenced directly in a contract. CI's (CEI's) are also any reparable item(s) designated for separate procurement during operations and maintenance (O & M) periods.
CONUS	Continental United States
CRT	Cathode Ray Tube
CO_2	Carbon Dioxide
	D
D & C	Displays and Controls

Depot Level	The level of maintenance representing lowest level maintenance performed on a removed end item, its modules, or components. If the faulty component or module contains reparable parts, these parts are repaired in the depot. If the faulty part is a 'throw-away', a new part is installed in the component or module, checkout is performed, and the repaired component or module is sent back to Intermediate Level maintenance for use when required. (See Intermediate Level)
Design Mission	(Phase B, Advanced Space Transport Program). The Stage II mission which is the basis for Phase B design, and which, it is assumed, will remain unchanged for Phase C/D. This mission is a 100 nm due east circular orbit formed by insertion into a 50 x 100 nm orbit, then circularizing. The Air Vehicle (Stage II, Stage I, and Payload) is considered to be launched from a latitude of 28.5 degrees north. (See also Reference Missions.)
Design Release, Program - 95%	That point in time when all documentation which requires fabrication of hardware components/elements for the initial configuration have been conveyed to the performing organization - normally manufacturing.
Design Release, Structure - 95%	That point in time when all documentation which requires fabrication of structural elements for the initial configuration have been conveyed to the performing organization - normally manufacturing.
Detail	A single element part or drawing

DD 250	A government form and checklist, which when completed and signed off by the approved, requesting agency, represents end item delivery of a system or systems is satisfactory to the government. Following DD 250, end items, together with all necessary documentation, can receive approval of all contract compliance and result in an initial operational capability (IOC).
DIU	Digital Interface Unit (See WBS Dictionary Element 1.3.10.5).
DME	Distance Measuring Equipment
DMGE	Depot Maintenance Ground Equipment (see GSE; also, see WBS Dictionary Element 3.0 and 8.0).
DoD	Department of Defense

E

EAFB	Edwards Air Force Base, California
ECLS	Environmental Control and Life Support
ECLSS	Environmental Control and Life Support Subsystem
ECS	Environmental Control (and Life Support) Subsystem
EMI	Electromagnetic Interference
Empty Weight (Dry Weight)	The dry weight of the vehicle including no useful load or payload.
Endoatmosphere	Inside the sensible atmosphere (See Exoatmosphere).
EVA	Extravehicular Activity

Exoatmosphere	Out of the sensible atmosphere. The specific altitude at which the sensible atmosphere ceases. For purposes of Stage II reentry, consider 300,000 - 400,000 ft altitude as the reentry regime. For purposes of Stage I reentry, an altitude of 142,700 feet is used.
	F
FAA	Federal Aviation Agency
FCE	Flight Control Electronics
fps	feet per second
FSE	Factory Support Equipment. Similar to Ground Support Equipment but non-deliverable (see WBS Dictionary Elements 1.3.1, 1.4.1 and 3.3). FSE supports integration and assembly in handling, transporting, testing and servicing the prototype, flight test or production vehicle fabrication and test functions prior to and during rollout and delivery.
FSN	Federal Stock Number
F-Test	A statistical method for determination of the degree of colinearity which exists between candidate independent variables. The result of F-Tests allow selection of the "best" variable for use when colinearity between candidate variables exists. For example, installed thrust may show a strong relationship and therefore very little or no additional variation will be explained by using both variables rather than just one.
FTV	Flight Test Vehicle. An instrumented Stage (I or II) scheduled for a flight test program. For this study, FTVs are to retrofitted to a Production Vehicle at the end of flight test. (See Production Article)

G

G & N	Guidance & Navigation
GFE	Government Furnished Equipment
GH_2	Gaseous Hydrogen
GN_2	Gaseous Nitrogen
GO_2	Gaseous Oxygen
GSE	Ground Support Equipment, i.e., peculiar and common end item ground hardware/ software required to support the airborne elements in an operating and maintenance sense. Consists of operating ground equipment (OGE) and maintenance and depot maintenance equipment (MGE and DMGE). (See also FSE.) GSE is contract-deliverable.
GSFC	Goddard Space Flight Center

I

I & A	Integration and Assembly
ICD	Interface Control Document (or Drawing). A specification of the physical and functional interfaces between an end-item and other end-items which, due to the nature of the interface, requires formal control. May be both inter-vehicle and intra-vehicle and/or between ground equipment.
ILS	Instrument Landing System
IMU	Inertial Measurement(s) Unit

Integration and Assembly	(MIL-STD-881) The technical and functional activities associated with combining all other equivalent level hardware/software elements into a prime mission product.
Intermediate (Field) Level	The level of maintenance representing maintenance performed on the removed end item. For example, intermediate level maintenance on a vehicle end item (e.g., APU) represents the effort needed to determine which component or module of the faulty APU must be removed and replaced to bring the APU back to satisfactory operation. Testing will determine the faulty component or module. Replacement of the faulty component or module, followed by checkout, will verify that the APU is ready for return to the same or another vehicle when required. Otherwise, the APU is "strapped" as OK and placed 'on the shelf' for use when needed. The faulty component or module, if reparable, is sent to the next maintenance level for test, further maintenance, and checkout. (See Depot Level)
I/O	Input/Output
IOC	Initial Operational Capability
I_{xx}, I_{yy}, I_{zz}	Moments of Inertia in the X, Y, and Z planes of the Stage or Air Vehicle

J

JP	Jet Fuel, i.e., JP-4, JP-5

K

KSC	Kennedy Space Center
KUTD	Keep Up-to-Date

L

LCC	Launch Control Center
L/D	Lift-to-Drag Ratio
Level I, II, III Requirement	NASA requirements for the Advanced Space Transport Program resulting from development of Program, System, Subsystem, and support through Phase B.
L/G	Landing Gear
LH_2	Liquid Hydrogen
Life Cycle	The complete Program cycle, including RDT & E, Investment and Operations phases of the program. Equivalent to NASA Phases C (Design) and D (Development and Operations).
Li OH	Lithium Hydroxide
LO_2	Liquid Oxygen
LOS	Line of Sight
Lot I	The first set of detail and sub-assemblies usually cover test parts, prototype parts, and a flight test article
Lot II	The second set of detail and sub-assemblies cover follow-on flight test articles and production articles.
LOX	Liquid Oxygen
LUT	Launch Umbilical Tower (mobile)

M

Major Assembly	An assembly such as a Wing, Aft Fuselage, etc.

MGE	Maintenance Ground Equipment (see GSE; also, see WBS Dictionary Element 3.0 and 8.0)
MIL-STD-881	Military Standard, "Work Breakdown Structures for Defense Materiel Items"
MLG	Main Landing Gear
MSC	Manned Spacecraft Center (NASA, Houston)
MSFC	Marshall Space Flight Center
Multiple Regression and Correlation	A straight time of regression (projection of trend) does not always satisfactorily describe the association between two variables. Frequently, the relationship is too complex to be described by means of a simple straight line (linear) and therefore a curve must be used. The procedure of establishing linear or curve linear relationships between two variables is simple correlation analysis. In addition, fluctuations in a given series are seldom dependent upon a single factor or cause. The measurement of the association between such a series and several of the variables causing these fluctuations or associated with the dependent variable is known as multiple correlation. Multiple correlation consists of the measurement of the relationship or association between dependent variables and two or more independent variables. This procedure is similar to that for simple correlation (one independent and one dependent variable) with the exception that other variables are added to the regression equation.

N

NLG	Nose Landing Gear
nm	nautical miles

O

OEM	Original Equipment Manufacturer
OGE	Operating Ground Equipment (see GSE; also, see WBS Dictionary Element 2.0)
O/I	Organizational and Intermediate Level (Maintenance)
O & M	Operations & Maintenance
OMS	Orbital Maneuvering System. The on-orbit propulsion system used for circularizing Stage II after orbital injection, for translating to a higher orbit, and for providing retro thrust for Stage deorbit. (See WBS Dictionary Element 1.3.4.3)
Organizational Level	The level of maintenance representing maintenance performed on the as-installed end item. For example, organizational level maintenance on a vehicle end item (e.g., APU) represents the effort needed to verify a fault exists on the installed APU, removal and replacement of the APU in the vehicle, then checkout to verify the replaced APU satisfactorily performs its intended function. The faulty APU is then sent to the next maintenance level for test, further maintenance and checkout. (See Intermediate Level, Depot Level)

P

Payload	A Government Furnished Equipment (GFE) package to be delivered to, or retrieved from, near-earth space by Stage II of the Space Transport Air Vehicle (see WBS Dictionary Element 1.2).

PDR	Preliminary Design Review. A formal technical review conducted for each contract end item. Purpose is to evaluate the progress, consistency, and technical adequacy of the selected design and test approach and establish compatibility with program requirements and preliminary design. Establishes Part I Specification, interface drawings, other Systems Engineering documentation, schedules and costs. Preliminary Design Reviews have been assumed to be convened on each Configuration (Contract End) Item sometime shortly after the start of Phase C/D. The period between Go-Ahead to PDR has been assumed to be spent finalizing Part I specifications and mockups and completing any tradeoff studies, analyses, or revisions to document/specification trees as might be required from Phase C/D negotiations. The PDR freezes physical and functional interfaces and establishes: (1) compatibility between Part I Specification and design approach; (2) integrity of the approach and design; and (3) design producability.
Peculiar Support Equipment	Maintenance equipment, services and software which supports the Program operations but is not directly involved in the operations, and which is peculiar to this Program. (See Common Support Equipment)
PFRT	Preliminary Flight Rating Test
Phase B	Definition Phase (NASA)
Phase C	Design Phase (NASA)
Phase D	Development and Operations Phase (NASA)

Planform Area	The profile area of an air vehicle, or segment thereof. For an aircraft, Planform Area is the area based on Top View viewing. For a missile, Planform Area is the area based on Side View viewing.
PMEL	Precision Measuring Equipment Laboratory
Production Article	A Stage (I or II) scheduled to go directly into the Operating phase of the Program. (See Flight Test Vehicle)
PRS	Precision Ranging System
	R
Ramp Time	Encompasses that activity between flight test vehicle rollout and its first flight such as preflight operations, systems checkout and verification, and taxi runs. (See WBS ID 4.5.3 and 4.5.4 for Stage II and WBS ID 4.6.3 and 4.6.4 for Stage I.)
Ratio-Systems Weight/ Empty Weight	The number arrived at by subtracting the weight of the structural subsystem from the empty weight and dividing the remainder by the empty weight: $\frac{\text{Empty Weight-Structure Weight}}{\text{Empty Weight}}$
RCS	Reaction Control System
RDT & E	Research, Development, Test and Evaluation
Reference Missions	(Phase B, Advanced Space Transport Program). The Stage II missions of major interest in addition to the Design Mission. These missions include: (a) a 100 nm south polar circular orbit (south polar mission), and (b) a 270 nm at 55 degrees inclination orbit (resupply) mission. Insertion of reference missions will be from 50 x 100 nm orbits. (See also Design Mission.)

RF	Radio Frequency
RPP	Reinforced Pyrolized Plastic. A matrix of carbon cloth and resin, which when cured, results in a carbon-carbon material with high heat resistance. Used on vehicle leading edges and nose cap to resist ascent and re-entry heating loads for thermal protection of primary and secondary structure and internal subsystems.
	S
S/A	Subassembly. An assembled unit designed to be incorporated with other units in a product.
SARP	The schedule portion of the Manned Space Flight Schedules as presented in OMSF Program Status Review documents.
SAS	Stability Augmentation System. A Flight Control Electronics design concept used to blend Attitude Control Propulsion with Aerodynamic Flight Controls during reentry from exo to endoatmosphere in order to maintain stabilized vehicle control in this flight regime.
SCU	System Control Unit (see WBS Dictionary Element 1.3.10.3).

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SDR	System Design Review. A formal technical review conducted by the contractor when the definition effort has progressed to the point where the program requirements and design approach are more precisely defined from among alternate design approaches, and the contractor has defined and selected the equipment, personnel, test, procedural data, and facilities required. As a product of this review, which is reviewed by the SPO, a technical understanding is to be reached on the allocation of requirements to (1) the system segments identified in the System Specification, and (2) the CEI's identified in Part I Detail Specifications. This review, if conducted late in Phase B or early Phase C, will provide the necessary basis for completion of preliminary design in Phase C.
SE & I	Systems Engineering & Integration
SPADATS	Space Detection and Tracking System. A North American Air Defense Command System headquartered at Ent, AFB, Colorado, which monitors all space objects for SAC et al.

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Specifications	Use of the terms Part I and Part II (see below) presumes a two-step procurement of Configuration (Contract End) Items. The Part I specification is the first part of the Contract End Item Detail Specification and results from the Program Definition Phase (B). Part I specifies the requirements for design, development, and qualification. For purposes of this study, the Part I specification is considered similar/identical to the Development Specification identified in MIL-STD-490. The Part II specification results from the design and development contract and specifies the detail product configuration and acceptance requirements of the item under the design and development contract. The Part II specification typically provides the basis again which the "First Article" is accepted. Part II, for purposes of this study, is considered similar/identical to the Product Function Specification identified in MIL-STD-490. Both Part I and Part II terms have been applied not only to Airborne Configuration Items but also to: -Integrated Checkout and Servicing GSE for the Transport System (Stage I, Stage II and Payload) -Integrated checkout and Servicing Software -On-Board Checkout Software -Integrated Checkout/Assembly Facilities No attempt has been made to distinguish Configuration (Contract End) Items and their specifications into such categories as Critical, Prime Item, Non-Complex, or Requirement Items.

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Specifications (Continued)	Part I - The design statement specified by Systems Engineering for a required contract end item (CEI). Part I includes: the set of requirements; performance; CEI definition (interface requirements, government designation); design and construction requirements; quality assurance provisions; Category I tests required; and Category II tests required. Part I Specifications are usually available for Preliminary Design Reviews (PDRs).
	Part II - The design statement specified by Design Engineering to satisfy the Part I specifications for a required contract end item (CEI). Part II is a repeat of Part I except to specify the "solution" which has been demonstrated by test to satisfy the requirements. (See Part I). Together, Part I and Part II form the CEI specifications for an end item which can be given to a manufacturer to produce the required end item as a contract deliverable. Part II Specifications are usually available for Critical Design Reviews (CDRs). When a first article is produced, it may be reviewed and approved in First Article Configuration Inspections (FACIs) to enable Category II (System) testing to proceed.
SRA	System Requirements Analysis (see WBS Dictionary Element 5.0).
Stage I	Boost stage of the Space Transport Air Vehicle (see WBS Dictionary Element 1.4).
Stage II	Orbital stage of the Space Transport Air Vehicle (see WBS Dictionary Element 1.3).

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Stage I (or II) System Test and Checkout Specification	A specification which integrates all system test and checkout requirements, criteria, safety, special test, recycle and support considerations into a single, controlled document for the development and conduct of system (Stage I or Stage II) test, checkout, and handling activities. The document specifies design and test configurations for airborne and ground subsystems and facilities associated with each system-level activity.
Static Firing	A full power hold-down test of Stage I or Stage II on the launch pad to verify ascent capability prior to mated flight test.
Structure Weight	The weight of the structural subsystem including fuselage, wings, tail and landing gears.
Systems Weight	Empty weight less structure weight.
	T
TBD	To Be Determined
TER	Time Estimating Relationship
T & H	Transportation & Handling (Equipment)
TPS	Thermal Protection System. The materials and their configuration which covers and protects the Stage from ascent and reentry heating.

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Traffic Model	A 10-year mission model generated by NASA to scope the expected number of flights needed to satisfy the Advanced Space Transport Program operational requirements. Currently, 445 flights are forecast beginning with 10 flights the first year and leveling off to 75 flights, each, in the 9th and 10th years.
Transport System Test and Operations Plan	A master plan that identifies overall test management philosophy, policy and major criteria/requirements relative to test and operational phases of the Transport System. The document provides the top planning within which Stage I and Stage II Test Plans may be developed and also serves to discipline the transition from test/development phase to Operational.
Transport System Test and Checkout Specification	A specification which integrates all test and checkout requirements, criteria, safety, special transport system test, recycle and supports considerations into a single controlled document for development and conduct of total transport system tests. The document provides the exclusive authorized basis for the preparation and execution of all testing performed upon the transport system. (Stage I, Stage II, payload, and support ground systems).
Turnaround Facility	The facility, located at the launch and prime recovery site configured to receive, maintain and prepare Stage I and Stage II for the next mission. (See WBS Dictionary Element 11.0.)
TVC	Thrust Vector Control. The means to control thrust direction by either moving the nozzle (gimballed), or by deflecting the thrust gases, to achieve vehicle pitch or yaw. When nozzles are vectored asymnetically (opposite), roll is achieved. For purposes of this study, TVC means gimballing the nozzles using hydraulic actuators.
Type I Distribution	A frequency distribution or histogram.

U

UHF	Ultra-high Frequency
USB	Unified S-Band

V

VAB	Vertical Assembly Building. A facility for erecting and mating Stage I to Stage II, then mating the Air Vehicle to the Mobile Launch Umbilical Tower for movement to the launch pad.
VHF	Very High Frequency
VMSC	Vought Missiles and Space Company, LTV Aerospace Corporation (Dallas, Texas)
VOR	VHF Omnidirectional Range
VORTAC	VHF Omnidirectional Range/Tactical Air Navigation (Combination)

W

WBS	Work Breakdown Structure
WBS Dictionary	(VMSC) The compendium of WBS Dictionary Elements which, together, establish the complete set of requirements needed to meet Program objectives
WBS ID	Work Breakdown Structure Identification

WBS Dictionary Element	(VMSC) A preliminary Part I Specification for a Work Breakdown Structure element needed to satisfy one or more Program objectives. The element statement also contains a list of the next lower level elements, a functional description of the element, a set of design requirements (if applicable), the direct interfaces with the element, and the tests (if applicable) which must be conducted during the development phase to ensure the element will meet requirements.
Work Breakdown Structure (WBS)	(NASA) A hierachy of levels of hardware oriented (cost) packages. (MIL-STD-881) A product-oriented family tree composed of hardware, software, services and other work tasks resulting from Project Engineering efforts during the development of a defense materiel item, and which completely defines the project/program. A WBS displays and defines the product(s) to be developed and produced and relates the elements of work to be accomplished to each other and to the end product.
W/T	Wind Tunnel
WTR	Western Test Range
	<u>Y</u>
Y_{act}	Y_{actual} is the actual time a previous hardware program required to complete a predetermined schedule milestone. (See Y_{est})

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$Y_{estimate}$ is the predicted time to complete a predetermined schedule milestone. This prediction is the output of a selected regression equation. Within this report Y_{est} is used to present the estimated time required to complete a given schedule milestone for the Advanced Space Transport Program. Y_{est} is further used to compare to Y_{act} for each program in the historical data base. As pointed out in Section 3, Introduction to Time Estimating Relationships (TERs)* the multiple regression model has the capability of taking the independent variables for each program in the historical data base, processing these variables through the selected estimating equation and printing out a comparison matrix with how long the program actually took (Y_{act}) and what the selected equation predicted the program would have taken (Y_{est}). If the difference between Y_{act} and Y_{est} is small, then the equation is further screened for potential deficiencies and may ultimately be used on estimating equation. (see Y_{act})

* Vol. I

SECTION 1

INTRODUCTION TO FINAL REPORT

SECTION 1

INTRODUCTION TO FINAL REPORT

1.1 SUMMARY

This report, in four volumes, presents the results of a 20-week study which Vought Missiles and Space Company (VMSC) conducted for the Manned Spacecraft Center (MSC) of the National Aeronautics and Space Administration (NASA) under Contract NAS 9-11659.

The primary objective of this study was to determine the feasibility of employing Time Estimating Relationships (TERs) to forecast schedules for the development of Advanced Programs being considered by NASA.

It is developed in Section 2 of Volume I that TERs are a credible means for forecasting schedule milestones at whatever level in the program that authentic, statistically correlatable data are available from similar programs, given the advanced system under scrutinity can be effectively defined. Further, it is shown (Appendices to each Volume) that if one compares schedule forecasting by TER methods with the same schedule developed by detail build-up, i.e., conventional methods, there is close correlation and that one may prefer the TER method since it reflects actual historical data inputs (slides, failures, funding problems, etc.) which are usually the unknowns for new programs.

It is cautioned in Section 2 that the novice should not use TER data without adequate guidance. (The same may be said for CER, Cost Estimating Relationships, data.)

1.2 VOLUME I - SUMMARY

This Volume is organized to contain summary data from the four major tasks directed against this study:

- TER Development
- Work Breakdown Structure/Dictionary Generation
- Master/Detail Schedule Generation
- Scheduling Logic Diagram Generation

A brief statement of content for Sections 2 thru 8 is shown below. Supporting data for Section 2 is contained in Section 7 for TER Development, in Section 8 for Total Program impact and in Volumes II, III and IV for Work Breakdown Structure/Dictionary, Detailed Schedules and Logic Diagrams.

Section 2 - Final Presentation, Scheduling Technique Improvement Study for Advanced Programs

- Presents, with facing pages, the vue-graphs presented to MSC during the final oral report summarizing the study.
- Provides inputs, outputs, evaluation and recommendations for utilizing the results in current and future NASA programs.

Section 3 - Introduction To Time Estimating Relationships

- Provides objectives, approach and ground rules used during the study to demonstrate feasibility of employing TERs to forecast schedules on advanced programs.

Section 4 - Introduction To Work Breakdown Structure (WBS) Dictionary

- Provides background on two Work Breakdown Structures (WBS): (a) one generated for a previous VMSC study which could be applied to this study, and (b) the updating of (a) performed during this study.
- Introduces approach to WBS Dictionary generation for this study, including format.
- Denotes allocation of the WBS and Dictionary to the four volumes of the Final Report.
- Denotes utility of the generated data for use in on-going and future NASA programs.

Section 5 - Introduction To Logic Diagrams

- Introduces the Logic generated during the study to tie the entire program together from go-ahead through first mated flight test (see Section 8.0 for definition of the Advanced Space Transport Program, including Air Vehicle requirements).
- States objectives, ground rules and assumptions.
- Denotes allocation of Logic Diagrams to the four volumes of the final report.
- Notes that Connector Code which enables reader to follow trail between diagrams is carried in each Volume (II, III, IV).

Section 6 - Introduction to Master and Detail Schedules

- Introduces objectives, approach and ground rules for generating the Master Schedule (introduced in Section 8 of Volume I and carried in Vols. II - IV for correlation) and the Detail Schedules shown on each Page 1 of the WBS Dictionary elements.

Section 7 - Time Estimating Relationships (TERs)

- Presents the TERs generated during the course of the study
- Shows scope, approach, results and limitations

Section 8 - Advanced Space Transport Program, Air Vehicle, A/V Integration & Assembly, Payload

- Presents the 'Top' WBS Dictionary (and WBS) for an Advanced Space Transport Program used as the baseline for the study, the Air Vehicle WBS Dictionary (and WBS), the Air Vehicle (A/V) Integration & Assembly WBS Dictionary, and the Payload WBS Dictionary.
- Presents the 'Top' Logic Diagram
- Presents the Master Schedule for the baseline Program

Appendix - Comparison of TER Results with Detail Schedule/Logic Diagram Results*

- Compares the TER output with the conventionally-prepared Master and Detail Schedules and Logic Diagram
- Draws conclusions therefrom

*Volumes II, III and IV carry similar comparisons for affected data, as noted below

1.3 VOLUME II - STAGE II

This Volume presents the WBS Dictionary, Detail Schedules and the Logic Diagrams for Stage II, a manned reusable vehicle which delivers/retrieves GFE Payloads into/from near-earth space in accordance with program objectives defined in WBS Dictionary Element 0.0, Advanced Space Transport Program, shown in Section 8 of Volume I.

Appendices: (a) define a baseline concept used for conceptual purposes to illustrate a current contractor's version of Stage II; (b) contain the Index for Logic Diagram 'connectors'; (c) repeat the Glossary carried in Volume I; and (d) compare TER results with Volume II Detail Schedule/Logic Diagram results.

1.4 VOLUME III - STAGE I

This Volume presents the WBS Dictionary, Detail Schedules and the Logic Diagrams for StageI, a manned reusable vehicle which boosts Stage II and its Payload to a point in the ascent trajectory to complete injection and the orbital mission. Basic requirements for Stage I are also contained in WBS Dictionary Element 0.0 (Volume I, Section 8).

Appendices: (a) define a baseline concept used for conceptual purposes to illustrate a current contractor's version of Stage I; (b) repeat the Index for Logic Diagram 'connectors'; (c) repeat the Glossary; and (d) compare TER results with Volume III Detail Schedule/Logic Diagram results.

VOLUME IV - GROUND SUPPORT, TEST, TRAINING, INVESTMENT, OPERATIONS

This Volume presents the WBS Dictionary, Detail Schedules, and the Logic Diagrams for Blocks 2.0 thru 12.0 of the Top Level WBS shown in Section 8 of Volume I.

Appendices: (a) repeat the Index for Logic Diagram 'connectors'; (b) repeat the Glossary; and (c) compare TER results with Volume IV Detail Schedule/Logic Diagram results.

SECTION 2

FINAL PRESENTATION
SCHEDULING TECHNIQUE IMPROVEMENT STUDY FOR ADVANCED PROGRAMS

SECTION 2

FINAL PRESENTATION
SCHEDULING TECHNIQUE IMPROVEMENT STUDY
FOR ADVANCED PROGRAMS

This Section contains the Final Presentation of the Scheduling Technique Improvement Study for Advanced Programs given in vue-graph format to the Manned Spacecraft Center at the conclusion of this twenty-week study.

The format for Section 2 shows the vue-graphs as blacklines on right-hand pages with facing text on left-hand pages using the standardized format of:

. PURPOSE

What single (or multiple) purpose does the vue-graph serve to the message of the presentation?

. MAJOR POINTS

What succinet messages should one draw from the vue-graph?

. DISCUSSION (if required)

What are the rationale and references (if any) for the vue-graph?

The Final Presentation is included in the Final Report: (1) for summarization of Study effort; (2) to show results, i.e., compare schedule predictions by TER methodology with predictions by conventional methodology; (3) to draw conclusions therefrom; and (4) to recommend utilization of this methodology (with continued analyses) in both current and future NASA programs.

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FINAL PRESENTATION

SCHEDULING TECHNIQUE IMPROVEMENT STUDY

FOR ADVANCED PROGRAMS

AUGUST 1971

MSC

NAS9-11659

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VOUGHT MISSILES
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OUTLINE

PURPOSE:

To identify and sequence the subject material of this presentation

POINTS:

- The presentation as included here is a summary of study results and not a cookbook for advanced program schedules.
- The outline as shown addresses each of the study tasks.

OUTLINE

I PROGRAM SCOPE AND OBJECTIVES

II RESULTS

III WORK BREAKDOWN STRUCTURE DICTIONARY

IV LOGIC DIAGRAMS

V DETAIL SCHEDULES

VI MASTER SCHEDULE

VII TIME ESTIMATING RELATIONSHIPS

VIII CONFIDENCE & SCHEDULE GROWTH

IX COMPARISON – TERS – MASTER SCHEDULE

X SUMMARY AND RECOMMENDATIONS

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I PROGRAM SCOPE AND OBJECTIVES

PURPOSE:

To identify the scope and objectives of the study in order that subsequently presented results can be viewed with an appropriate perspective.

POINTS:

This is summary level scope and objectives and subsequent sections will address individual study tasks.

I PROGRAM SCOPE AND OBJECTIVES

PROGRAM OBJECTIVES

PURPOSE:

To summarize the major program objectives, explain need for complimentary study tasks and to summarize time and resources available to accomplish study.

POINTS:

The study was of a feasibility nature in the area of TER development as the study team (customer and contractor) had no assurance that such TER development was possible at the time of go-ahead.

DISCUSSION:

The comparison of TER derived spans with conventionally developed time spans required that schedules have a Statement of Work which is the WBS Dictionary. In order for the user to be aware of the scope of the TER, it was necessary to relate the TER to a flow of activities (Logic Diagrams) and a Work Breakdown Structure. The user also needs the WBS Dictionary for knowledge of scope covered by the TER. The contract was Fixed Price with 3,760 minimum hours guaranteed.

PROGRAM OBJECTIVES

- TO DEMONSTRATE THE FEASIBILITY OF DEVELOPING PARAMETRIC TIME ESTIMATING RELATIONSHIPS FOR USE IN THE SCHEDULING PROCESS

AND ASSUMING SUCCESS

- TO COMPARE AND RESOLVE TER RESULTANT ANSWERS WITH SCHEDULES DEVELOPED THRU MORE CONVENTIONAL PRACTICES

WHICH REQUIRED

- PREPARATION OF A STATEMENT OF WORK – WBS DICTIONARY
- ACTIVITY FLOW AND INTERACTION – LOGIC DIAGRAMS
- PREPARATION OF DETAIL SCHEDULES

FOR

$92,000

WITHIN

20 WEEKS

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PROGRAM SCOPE AND OBJECTIVES

PURPOSE:

To summarize the outputs of the study as required by the contract.

POINTS:

- MSC provided a program baseline for generation of WBS Dictionary, Logic Diagrams, Detail and Master Schedules and for use in exercising the TERs. The baseline program consisted of a two-stage reusable Advanced Space Transport.
- The 13-week review included most of the data used in the study and that data is not included in this presentation but rather is included in the TER section of the final report.
- The final report is in four (4) volumes:

Volume I	-	Total Advanced Space Transport Program Final Presentation TERs Glossary* Comparison TERs Vs Conventional Schedules*
Volume II	-	Stage II (Orbiter)
Volume III	-	Stage I (Booster)
Volume IV	-	All other Program Elements - GSE, Program Management, Spares, Data

*Included in all volumes

- This is the final (20-week) presentation.

PROGRAM SCOPE AND OBJECTIVES

- OUTPUT OF THE STUDY TO INCLUDE:

  FOR A DEFINED PROGRAM

  - WORK BREAKDOWN DICTIONARY (STATEMENT OF WORK)
  - LOGIC NETS
  - DETAIL SCHEDULES
  - MASTER SCHEDULE
  - TERS
  - 2 PRESENTATIONS (13TH AND 20TH WEEKS)
  - FINAL REPORT – 10 COPIES

II TER - RESULTS

PURPOSE:

To provide a summary of TER results relative to major program checkpoints to allow comparisons with present Shuttle baseline schedule.

POINTS:

- With the study objectives fresh in mind, it was considered desirable to immediately summarize the study results in a framework which would allow the audience to compare the results with the current baseline schedules on the Shuttle program.

- Study baseline configuration is not the same as the present Drop-Tank Space Shuttle configuration.

II TER — RESULTS

TER RESULTS - SUMMARY

PURPOSE:

To summarize TER results on the Advanced Space Transport Program assuming a 1 April 1972 Go-Ahead.

POINTS:

- Study baseline assumed structural test article to be the first airframe.
- Study allowed six months credit on Structure only for Phase B work.
- Approximately 3 - 6 months is required to provide the second airframe which is the study 1st Flight Vehicle.
- Main engine go-ahead July 1971.
- Qualified for vertical flight is at the time of accumulation of 25 hours of horizontal flight on #2 Vehicle. This assures #2 first flight 6 months after #1 Vehicle first flight.
- First mated vertical flight assumes 12 months between completion of 25 hours of horizontal flight test and ready for launch. This time span is to refurbish, install and checkout main engines, ferry to launch site, assembly and erection at launch site.

TER RESULTS — SUMMARY

DESCRIPTION OF EVENT	PREDICTED ASSUMING 1 APRIL '72 GO AHEAD	
	STAGE I	STAGE II
95% STRUCTURE DESIGN RELEASE*	NOV '74	AUG '74
ROLL OUT — 1ST VEHICLE	APR '78	JUL '77
FIRST HORIZONTAL FLIGHT	FEB-MAY '79	MAR-APR '78
MAIN ENGINE QUALIFIED**	APR '78	APR '78
QUALIFIED FOR VERTICAL FLIGHT	DEC '80-MAR '81	JUN-AUG '79
FIRST MATED VERTICAL FLIGHT	DEC '81-MAR '82	DEC '81-MAR '82

* ASSUMES 6 MONTHS CREDIT FOR PHASE B
** JULY '71 GO AHEAD

III WBS DICTIONARY

OBJECTIVES, APPROACH/RESULTS, LIFE CYCLE WBS

PURPOSE:

To introduce the subject of Work Breakdown Structure Dictionary - the objectives of the task, the approach utilized in developing the WBS Dictionary and the results of subject effort.

POINTS:

- The WBS Dictionary was required to allow development of detail schedules and to provide scope of TERs.
- Approximately 25% of study resources were utilized on this task.

III WBS DICTIONARY

OBJECTIVES, APPROACH/RESULTS, LIFE CYCLE WBS

OBJECTIVES - WBS DICTIONARY

PURPOSE:

To display the objectives of this study task.

POINTS:

- VMSC did initial work on MIL-STD-881 WBS for MSC on Space Shuttle Cost Analysis. This study updated that work and added the description of the composition of the WBS elements.
- The WBS Dictionary at present basically defines contractor's activities and identifies GFE.
- The WBS Dictionary has been prepared in such a way as to make it relatively time insensitive so long as the subject matter is a reusable two-stage vehicle.
- The WBS Dictionary utilized the MDAC Orbiter and NR Booster 270-day reports as a baseline.
- The WBS Dictionary was used as the basis for the Logic Diagrams and the Detail/Master Schedules, as well as defining the subject program for exercising the TERs.

DISCUSSION:

Study personnel are of the opinion that this WBS Dictionary can be used by NASA as useful tool as it:

- Defines the scope of work which could be used as a check list in reviewing proposals and also structures that scope for possible use in reviewing cost quotes and matching quotes with technical/management proposals.
- Defines interfaces which could trigger pre-planned alternatives, indicate potential problem areas and identify possible interface document requirements.
- Defines baseline, i.e., the entire program from a contractor standpoint is defined and responsibility must be established for each activity if the program is to accomplish its mission.

OBJECTIVES — WBS DICTIONARY

- UPDATE VMSC'S WBS PROVIDED WITH COST STUDY (MIL-STD-881)
  - ALL MAJOR CONTRACTORS (STAGE I, STAGE II, INTEGRATION)
  - ALL GOVERNMENT-FURNISHED ELEMENTS & SERVICES
- PROVIDE CONCEPT-INSENSITIVE DICTIONARY, I.E., WORK STATEMENT, WHICH IS:
  - INTEGRATED, BOTH HORIZONTALLY & VERTICALLY
  - DEVELOPED THRU 6TH LEVEL (STAGE II)
  - DEVELOPED THRU 5TH LEVEL (STAGE I AND ELSEWHERE)
- PROVIDE BASIS FOR THIS STUDY
- PROVIDE NASA WITH USEFUL MANAGEMENT TOOL WHICH
  - DEFINES SCOPE OF WORK
  - STRUCTURES SCOPE
  - DEFINES INTERFACES
  - DEFINES BASELINE

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APPROACH/RESULTS - WBS DICTIONARY

PURPOSE:

To display the approach utilized in developing the WBS Dictionary and to summarize the results.

POINTS:

- The WBS Dictionary could serve as a preliminary system specification or preliminary CEI Part I Specification and did so serve for this study.
- Each WBS Dictionary write-up includes:
  - The requirements peculiar to each element.
  - Establishes the content of the element by defining the next lower levels.
  - Description of the function which the element must perform.
  - Element design requirements and interfaces.
  - Identified known tests for that element.
- The WBS Dictionary carries the program through 10 years of operations.

APPROACH/RESULTS — WBS DICTIONARY

- WBS UPDATED TO INCLUDE:
  - 12 MAJOR ELEMENTS AT 3RD (PROJECT) LEVEL
  - 3 MAJOR ELEMENTS PLUS INTEGRATION & ASSEMBLY (AIR VEHICLE)
    - STAGE I, STAGE II, PAYLOAD
  - ALL SOFTWARE (FLIGHT, OPERATING-GROUND, TEST, TRAINING)
  - INDUSTRIAL & TEST FACILITIES
- "DICTIONARY" $\neq$ WEBSTER
  $\equiv$ PRELIMINARY SYSTEM SPECIFICATION
  $\equiv$ PRELIMINARY CEI PART I'S
  - ESTABLISHES REQUIREMENTS
  - DEFINES NEXT LOWER LEVEL
  - PROVIDES FUNCTIONAL DESCRIPTION
  - SPECIFIES DESIGN REQUIREMENTS
  - ESTABLISHES INTERFACES
  - SPECIFIES TEST REQUIREMENTS
- COMPLETELY INTEGRATES ALL END ITEMS & SERVICES THROUGHOUT LIFE CYCLE (RDT & E, INVESTMENT, O & M)

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LIFE CYCLE WBS - ADVANCED SPACE TRANSPORT PROGRAM

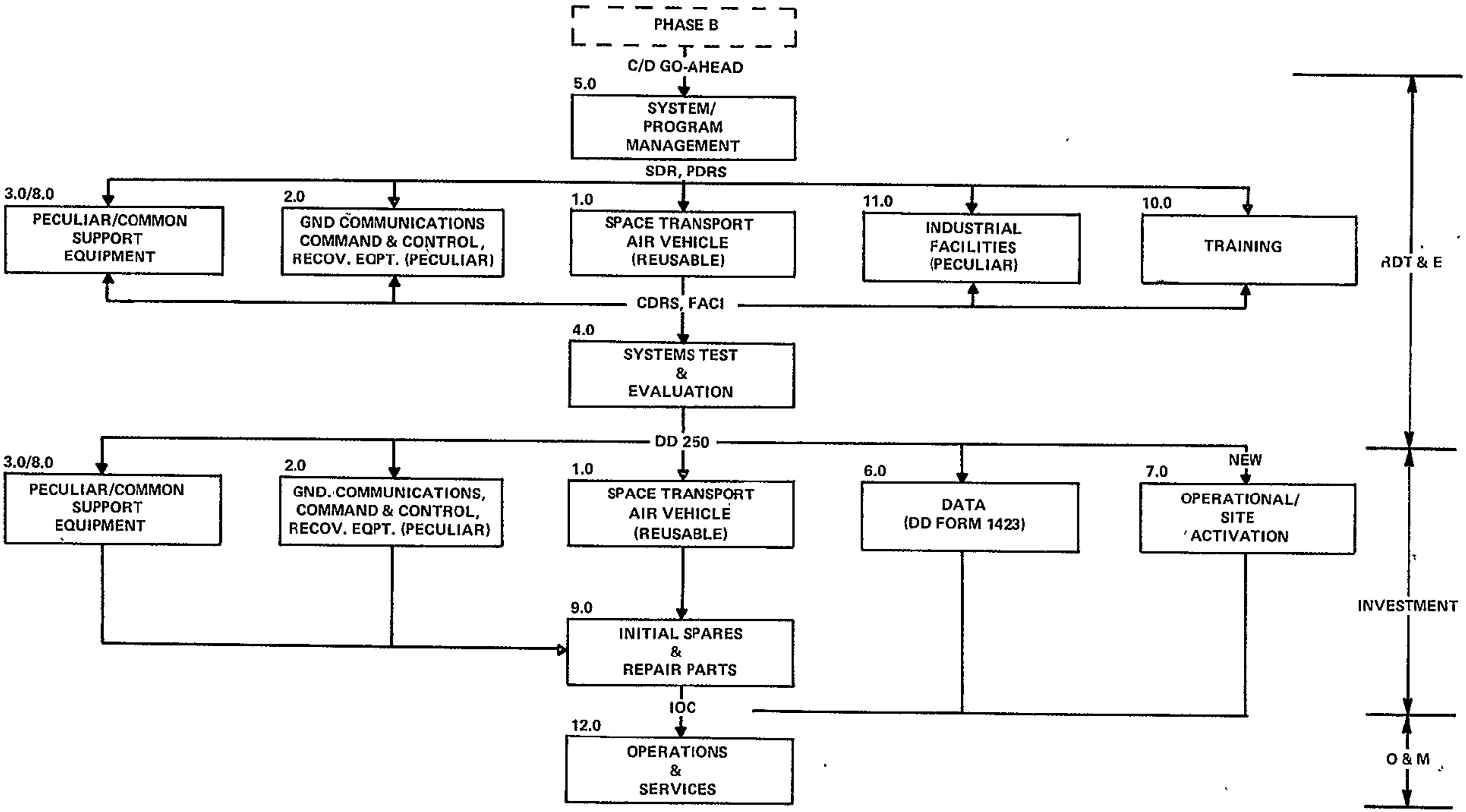
PURPOSE:

To graphically display how the elements of the WBS contribute to the different phases of the Program Life Cycle.

POINTS:

- This breakout could be valuable in achieving consistency among contractor responses to costing exercises.

LIFE CYCLE WBS — ADVANCED SPACE TRANSPORT PROGRAM



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WBS DICTIONARY - AIRFRAME & STRUCTURE (STAGE II)

(EXAMPLE)

PURPOSE:

To provide an example of a WBS Dictonary writeup.

POINTS:

- WBS identification on each element.
- NASA WBS level on each element.
- Requirements are stated first, followed by assemblies which define content. Subsequent pages complete the descriptive material.

WBS DICTIONARY — AIRFRAME & STRUCTURE (STAGE II) (EXAMPLE)

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PAGE 1 OF 7

PROGRAM TITLE ADVANCED SPACE TRANSPORT PROGRAM

WBS NO. 1.3.2

TASK TITLE AIRFRAME AND STRUCTURE (STAGE II)

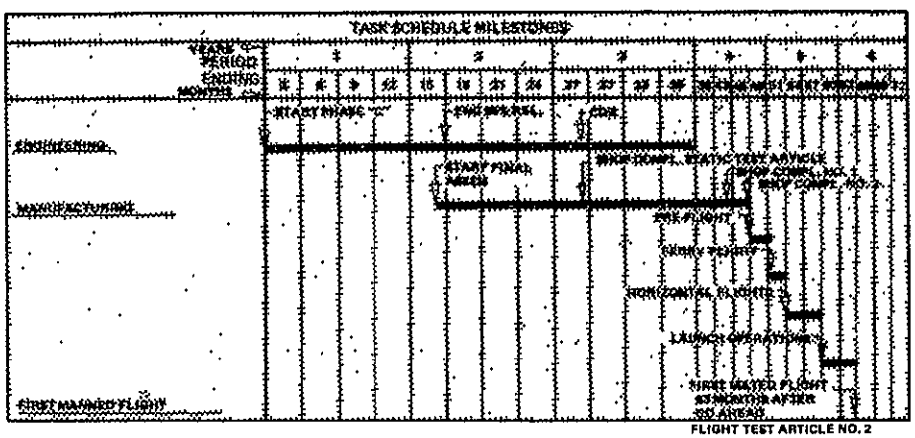
LEVEL 5. Subsystem Level

WBS DICTIONARY

I. REQUIREMENTS

A requirement has been specified (WBS ID 0.0, 1.0, 1.3) for a manned, reusable, i.e. winged, vehicle capable of delivering GFE payloads from earth to near-earth orbits, to deploy these payloads as specified by the mission, to retrieve certain payloads from space, and to safely reenter the earth's atmosphere, cruise to a specified or alternate landing site, and land on a conventional runway similar to landings by conventional military or commercial transport type aircraft. Following landing, a purge and safe operation will be conducted, followed by a ferry flight (if required) to the turnaround facility for post-flight maintenance and refurbishment to prepare for the next mission. Payloads will vary from zero to maximum capability depending on mission requirements.

To meet these requirements, the airframe and structure of Stage II must provide properties and characteristics compatible with the total flight



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WBS CODE 1.3.2 P 2 OF 7

spectrum (pre-flight activities, launch activities, ascent in the Air Vehicle configuration, separation from Stage I, acceleration into a 100 nm circular orbit, required thrusting to a higher orbit, docking with a space station for payload transfer and/or payload deployment to space, payload retrieval from the space station and/or from free space, reentry into the sensible atmosphere, transition to and through the transonic regime, approach, flare, landing, runout, and parking on the airport ramp for post flight servicing). On-board or kit air breathing propulsion will be required for ferry flight. If go-around capability for approach and landing is required, air-breathing propulsion must be already on board.

In addition to payload-carrying/deploying/retrieving capability, the airframe and structure must provide: (1) volume and weight-carrying capability for crew and passengers, (2) for environmental control (active and passive) of the vehicle, its payload and passengers; (3) volume and weight carrying capability for required subsystems (propulsion, secondary power, avionics, safety), and controls (exo and endo atmosphere) to maintain flight attitudes during power-on, power-off flight phases. Finally, the airframe and structure must provide flotation for landing and taxiing and speed reduction capability to bring the vehicle to a safe end-of-runway halt in compliance with landing regulations appropriate to the airport.

Constraints on Stage II, in addition to mission environment compatibility through a specified lifetime, include the following: (1) maintainability, (2) reliability, (3) safety compliance, (4) operability, (5) aerodynamic stability, (6) human factors acceptability, (7) quality assurance, (8) commonality and/or exchangability between vehicle tail numbers, and (9) cost minimization through use of proven technology, good design practice, good production practice, and thorough flight qualification prior to achieving operational status.

II. ASSEMBLIES

The choice of airframe and structure assemblies is, in a sense, dependent on stage configuration. The assemblies listed below and shown on Figure are representative of any conventional commercial or military transport aircraft, however, and include those additional requirements needed for application of an aircraft configuration to a joint space vehicle/aircraft combination.

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IV LOGIC DIAGRAMS

OBJECTIVES, APPROACH, RESULTS

PURPOSE:

To introduce the subject of Logic Diagrams - the task objectives, the approach utilized in developing the Logic Diagram and the results of subject effort.

POINTS:

- The Logic Diagrams are a method for establishing required activity to accomplish an objective.
- The Logic Diagram was required to allow development of the WBS Dictionary and to provide sequence in the detail schedule preparation.
- Approximately 10% of study resources were utilized on this task.

IV LOGIC DIAGRAMS

OBJECTIVES, APPROACH, RESULTS

LOGIC CHARTS

PURPOSE:

To display the objectives of this study task.

POINTS:

- The Logic Diagrams were to concentrate on the air vehicle and particularly on interfaces.
- No time durations were entered on the Logic Diagrams in order that they might be used as a time insensitive tool.
- The study assumed that 5th level WBS elements would essentially be configuration (contract) end items and that specifications would be issued at that level.
- The study assumed that Part I of the CEI specifications would be prepared as a part of Phase B and approved shortly after go-ahead on Phase C/D.

LOGIC CHARTS

OBJECTIVE — LOGICALLY SEQUENCE ACTIVITIES AT THE 5TH WBS LEVEL AS A FRAMEWORK TO DEFINE CONTENTS OF TERS AND DETAIL SCHEDULES.

GROUND RULES

- AIRBORNE
- INTERFACES
- NO TIME/DURATIONS

ASSUMPTIONS

- 2 PART — SPEC PROCUREMENT
- CONFIGURATION (END) ITEM
- PHASE B — PART 1 SPECS

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LOGIC CHARTS

PURPOSE:

To display the approach utilized in developing the Logic Diagrams and to summarize the results.

POINTS:

- Typical approach to developing logic was utilized.
- Basic approach utilized single sheet (600 sq. ft.) covering one wall of study area to develop program logic.
- Data then transferred to small sheets by WBS.
- Logic Diagrams identified several areas which, in study team opinion, warrant trade-offs to achieve optimization.

LOGIC CHARTS

APPROACH

- CRITICAL CATEGORIES OR ACTIVITY
- JOINED RELATED ACTIVITIES
- INTERPRETED EACH CATEGORY
- EXTRACTION/LOGIC PER WBS
- DEFINE TER LIMITS

RESULTS

- TYPICAL 5TH LEVEL PROGRAM LOGIC
- IN-HOUSE TRADE-OFFS/OPTIMIZATION

MASTER LOGIC NETWORK

PURPOSE:

To illustrate areas where study team would recommend Program Management attention at an early point in the program.

POINTS:

- These are the hidden drivers of program cost and schedules.

- Each of these listed areas reflect real possiblities for cost/time reduction, or growth if not addressed early.

DISCUSSION:

Study team opinion is that the WBS Dictionary and the Logic Diagrams provide a tool which Program Management could utilize to major benefit at an early stage. These documents could allow the:

- Formulation and identification of responsibility for each element.
- Determination of end items to allow identification of interfaces.
- Structuring of requests for proposals/quotations.
- Isolation of work and budgets by element, by NASA Center, by phase, by contractor.
- Identification of common elements for possible cost reduction.
- Identification of support needs - FAA, DOD, DOT, etc.
- Identification of software.
- Isolation of optimum points of buy-off.

MASTER LOGIC NETWORK

REVEALED AREAS AND MEANS FOR PROGRAM MGMT ATTENTION: eg.

- WHERE/HOW DATA MGMT/ON-BOARD CHECKOUT SOFTWARE IS COMMITTED
- ASSEMBLY TO ACCOMODATE MODS
- ACCESSIBILITY – AIRBORNE, TOOLS, TEST FIXTURES
- MAINTAINABILITY/REPARABILITY CRITERIA
- SIMULATOR DELIVERABILITY/UTILITY
- INTEGRATED TEST SOFTWARE CONFIGURATION MGMT
- CREW STATION BUILD UP/TEST/INTEGRITY
- COMMON SUPPORT EQUIPMENT/INDUSTRIAL PROPERTY COMMONALITY AND UTILITY
- PECULIAR SUPPORT AND SPECIAL TEST EQUIPMENT UTILITY
- DEDICATED TEST HARDWARE/SOFTWARE AND GEOGRAPHY
- DATA NEEDS & CRITERIA
- LAUNCH/TURNAROUND CREW REQUIREMENTS
- LOT PURCHASING AND INVENTORIES
- GOVERNMENT PROPERTY MAINTENANCE & UTILIZATION
- CALIBRATION NEEDS AND INTERFACES
- INTER-SYSTEM AND INTER/INTRA-CENTER INTERFACES
- POINTS OF BUY-OFF AND RISK
- PLANNING WORK AROUND/RECOVERIES

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LOGIC DIAGRAM - STAGE II STRUCTURE

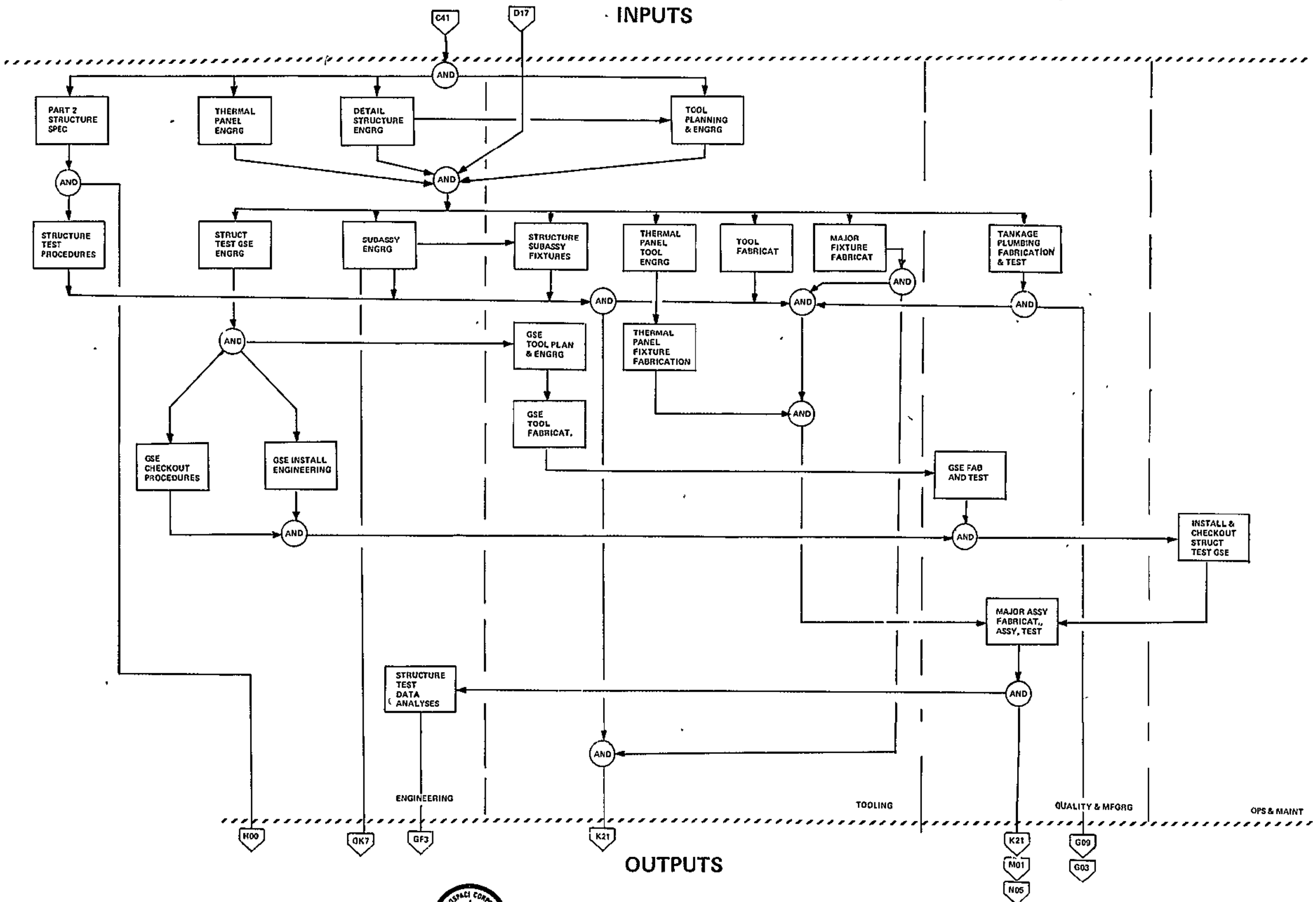
PURPOSE:

To display an example of the Logic Diagrams as developed.

POINTS:

- Input is at the top of the page and output at the bottom.
- Activity is structured by function - i.e., Engineering, Manufacturing.
- Each chart includes WBS identification.

LOGIC DIAGRAM — STAGE II STRUCTURE



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V DETAIL SCHEDULES

OBJECTIVES, APPROACH, RESULT

PURPOSE:

To introduce the subject of Detail Schedules - the objectives of the task, the approach utilized in developing the Detail Schedules and the results of subject effort.

POINTS:

- Detail schedules developed to allow comparison of TER results with conventional scheduing methodology results and to allow preparation of a realistic Master Schedule.

- Approximately 20% of study resources were utilized on this task including the Master Schedule activity.

V DETAIL SCHEDULES

OBJECTIVES, APPROACH, RESULT

OBJECTIVES/APPROACH - DETAIL/MASTER SCHEDULES

PURPOSE:

To display the objectives of this study task and to show the approach utilized in developing the Detail and Master Schedules.

POINTS:

- Used the WBS Dictionary for scope and the Logic Diagrams for scope and phasing.
- Schedules are tied to the WBS and go down to the seventh level in some cases.
- Used specialists for consultation - Engineering, Manufacturing, Materials personnel were solicited for inputs and reviewed results.

OBJECTIVES/APPROACH — DETAIL/MASTER SCHEDULES

DETAIL MASTER SCHEDULES

OBJECTIVES

- GENERATE REALISTIC MASTER SCHEDULE
- GENERATE DETAIL SCHEDULES TO VERIFY MASTER SCHEDULE BASED ON WBS DICTIONARY
- DEVELOP TO 7TH LEVEL (CRITICAL COMPONENTS)
- DEVELOP TO 5TH & 6TH LEVEL ELSEWHERE WHERE DEFINITION AVAILABLE

APPROACH

- UTILIZE AVAILABLE LTV EXPERIENCE
- TAKE ADVANTAGE OF OUTSIDE KNOWLEDGE

  CONSIDERATION OF SKILLS, MFG. AREAS, & TEST FACILITIES
- CONSIDER INTERFACE DATA
- PREPARE INTEGRATED SCHEDULE THRU CONVENTIONAL METHODOLOGY

MASTER/DETAIL SCHEDULE GROUND RULES

PURPOSE:

To present study assumptions on manufacturing lot sizes and manufacturing sequences.

POINTS:

- Two lots for each vehicle - 1st lot to consist of test hardware and 1st flight test vehicle - 2nd lot for balance of flight vehicles.
- Structural test article is fabricated first -- this is different from current shuttle plan.
- Assumes four flight Stage I's and five flight Stage II's.

DISCUSSION:

The study assumption that the structural test article would be the first built causes the first horizontal flight to be 3-6 months later than if the first structure was for a flight vehicle. Due to lack of detail information in the ground test area, test hardware quantities at the subsystem/component level could not be identified at this time.

MASTER/DETAIL SCHEDULE GROUND RULES

- DETAIL & SUBASSEMBLY LOT SIZES

<u>STAGE I</u>

LOT I
- 1 SET FOR TESTS (AS REQUIRED)
- 1 SET FOR STRUCTURE TEST ARTICLE
- 1 SET FOR FLIGHT VEHICLE #1

LOT II
- 3 SETS FOR FLIGHT VEHICLES 2, 3, & 4

<u>STAGE II</u>

LOT I
- 1 SET FOR TESTS (AS REQUIRED)
- 1 SET FOR STRUCTURE TEST ARTICLE
- 1 SET FOR FLIGHT VEHICLE #1

LOT II
- 4 SETS FOR FLIGHT VEHICLES 2, 3, 4, & 5

- MANUFACTURING SEQUENCE STAGE I

1. ARTICLE – STRUCTURES TEST ARTICLE
2. ARTICLE – FLIGHT TEST VEH #1 (INSTRUMENTED)
3. ARTICLE – FLIGHT TEST VEH #2 (INSTRUMENTED)
4. ARTICLE – FLIGHT TEST VEH #3 (INSTRUMENTED)
5. ARTICLE – PRODUCTION VEH #4

- MANUFACTURING SEQUENCE STAGE II

1. ARTICLE – STRUCTURES TEST ARTICLE
2. ARTICLE – FLIGHT TEST VEH #1 (INSTRUMENTED)
3. ARTICLE – FLIGHT TEST VEH #2 (INSTRUMENTED)
4. ARTICLE – FLIGHT TEST VEH #3 (INSTRUMENTED)
5. ARTICLE – PRODUCTION VEH #4
6. ARTICLE – PRODUCTION VEH #5

- SPARES – TO BE DEFINED

MASTER/DETAIL SCHEDULE GROUND RULES

PURPOSE:

To identify key assumptions utilized in developing the Detail/Master Schedule.

POINTS:

- The integral tanks are schedule pacing items in study team opinion and, therefore, should be released as soon as possible.
- The schedules assume a basic one-shift operation with minimal second/third shift operation due to activities such as material processes which cannot be interrupted once started, the necessity to keep tools hot while working titanium and tests which cannot be interrupted once started.
- The two vehicles will be built in separate plants - i.e., they will not both be fabricated on the same production line.

MASTER/DETAIL SCHEDULE GROUND RULES

AIRFRAME

- EARLY DESIGN RELEASE ON THE LO_2 & LH_2 TANKS (APPROX. 3 MONTHS)
- FABRICATE USING STANDARD AIRCRAFT FACILITIES TECHNIQUES WHICH DO NOT REQUIRE CLASS I, II OR III CLEAN ROOMS
- FABRICATION WILL BE DONE ON A ONE SHIFT OPERATION WITH MINIMUM SECOND & THIRD SHIFT SUPPORT IN THE MACHINE SHOP AREAS DUE TO TYPES OF MATERIALS & PROCESSES REQUIRED
- STAGE I & II WILL BE FABRICATED ON DIFFERENT PRODUCTION LINES
- PRODUCTION QUANTITIES:

STAGE I	1 STRUCTURE TEST ARTICLE 4 FLIGHT VEHICLES
STAGE II	1 STRUCTURE TEST ARTICLE 5 FLIGHT VEHICLES

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WBS DICTIONARY - AIRFRAME & STRUCTURE (STAGE II)

(EXAMPLE)

PURPOSE:

To display an example of the Detail Schedules as developed.

POINTS:

- The Detail Schedules are normally segregated by function, i.e., Engineering, Manufacturing.
- The checkpoints are typical of ones that would be on a program detail schedule.

WBS DICTIONARY — AIRFRAME & STRUCTURE (STAGE II) (EXAMPLE)

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PAGE 1 OF 7

PROGRAM TITLE ADVANCED SPACE TRANSPORT PROGRAM

WBS NO. 1.3.2

TASK TITLE AIRFRAME AND STRUCTURE (STAGE II)

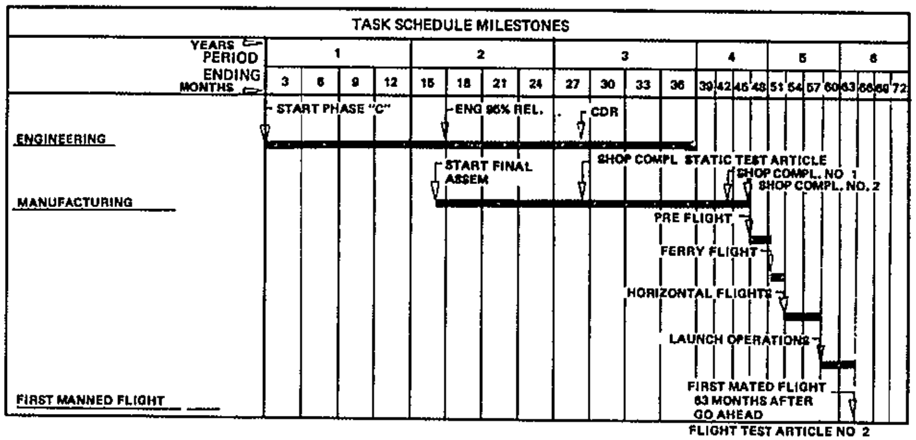
LEVEL 5. Subsystem Level

WBS DICTIONARY

I. REQUIREMENTS

A requirement has been specified (WBS III B.0, 1.0, 1.3) for a manned, reusable, i.e. winged, vehicle capable of delivering GFE payloads from earth to near-earth orbits, to deploy these payloads as specified by the mission, to retrieve certain payloads from space, and to safely reenter the earth's atmosphere, cruise to a specified or alternate landing site, and land on a conventional runway similar to landings by conventional military or commercial transport type aircraft. Following landing, a purge and safe operation will be conducted, followed by a ferry flight (if required) to the turnaround facility for post-flight maintenance and refurbishment to prepare for the next mission. Payloads will vary from zero to maximum capability depending on mission requirements.

To meet these requirements, the airframe and structure of Stage II must provide properties and characteristics compatible with the total flight



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WBS CODE 1.3.2 P 2 OF 7

spectrum (pre-flight activities, launch activities, ascent in the Air Vehicle configuration, separation from Stage I, acceleration into a 100 nm circular orbit, required thrusting to a higher orbit, docking with a space station for payload transfer and/or payload deployment to space, payload retrieval from the space station and/or from free space, reentry into the sensible atmosphere, transition to and through the transonic regime, approach/flare, landing, runout, and parking on the airport ramp for post flight servicing). On-board or kit air breathing propulsion will be required for ferry flight. If go-around capability for approach and landing is required, air-breathing propulsion must be already on board.

In addition to payload-carrying/deploying/retrieving capability, the airframe and structure must provide: (1) volume and weight-carrying capability for crew and passengers; (2) for environmental control (active and passive) of the vehicle, its payload and passengers; (3) volume and weight carrying capability for required subsystems (propulsion, secondary power, avionics, safety, and controls (exo and endo atmosphere) to maintain flight attitudes during power-on, power-off flight phases. Finally, the airframe and structure must provide flotation for landing and taxiing and speed reduction capability to bring the vehicle to a safe end-of-runway halt in compliance with landing regulations appropriate to the airport.

Constraints on Stage II, in addition to mission environment compatibility through a specified lifetime, include the following: (1) maintainability, (2) reliability, (3) safety compliance, (4) operability, (5) aerodynamic stability, (6) human factors acceptability, (7) quality assurance, (8) commonality and/or exchangeability between vehicle tail numbers, and (9) cost minimization through use of proven technology, good design practice, good production practice, and thorough flight qualification prior to achieving operational status.

II. ASSEMBLIES

The choice of airframe and structure assemblies is, in a sense, dependent on stage configuration. The assemblies listed below and shown on Figure are representative of any conventional commercial or military transport aircraft, however, and include those additional requirements needed for application of an aircraft configuration to a joint space vehicle/aircraft combination.

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VI MASTER SCHEDULE RESULTS

PURPOSE:

To introduce the subject of Master Schedule

POINTS:

- This is a summary of the Master Schedule which is not included in this presentation. See Volume I of the Final Report for the Master Schedule as developed during the study.

- There were no program external constraints identified or assumed in the development of this schedule. As a result, the schedule as developed is optimum to the best of study team ability to create an optimum schedule.

VI MASTER SCHEDULE RESULTS

SUMMARY MASTER SCHEDULE
ADVANCED SPACE TRANSPORT PROGRAM

PURPOSE:

To show the summary results of the conventional scheduling methodology.

POINTS:

- This schedule considered progress as reflected in the Phase B 270-day reports.
- First Horizontal Flight on Stage I is estimated at 44.5 months after Phase C/D go-ahead.
- First Horizontal Flight on Stage II is estimated at 46.5 months after Phase C/D go-ahead.
- First Mated Vertical flight is estimated at 63 months after Phase C/D go-ahead.

DISCUSSION:

Based on the conventional scheduling methodology, the vehicles could be ready for horizontal flight approximately three months earlier if the first structure was used for the flight vehicle. Qualified for Vertical Flight occurs at that point in time when Flight Test Vehicle #2 has accumulated 25 hours of horizontal flight. Subsequent activity includes refurbishment, installation and checkout of main engines, ferry to launch site, assembly and checkout prior to vertical launch.

SUMMARY MASTER SCHEDULE

ADVANCED SPACE TRANSPORT PROGRAM

DESCRIPTION	MONTHS AFTER GO AHEAD
PHASE C/D GO AHEAD	0
95% DESIGN RELEASE – STRUCT	15
STRUCTURAL TEST ARTICLE COMPLETED	26
ROLLOUT NO. 1 FTV STAGE I	41
ROLLOUT NO. 1 FTV STAGE II	42
FIRST HORZ. FLT. STAGE I	44.5
FIRST HORZ. FLT. STAGE II	46.5
QUALIFIED ENGINE AVAILABLE	54
QUALIFIED FOR VERTICAL FLT. (25 HOURS HORZ. FLT ON NO. 2 VEH)	57
1ST VERTICAL FLT	63

MONTHS AFTER GO AHEAD: 0 10 20 30 40 50 60 70 80 90 100

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VII TIME ESTIMATING RELATIONSHIPS

PURPOSE:

To introduce the subject of Time Estimating Relationships - the objectives of the task, the approach utilized in developing the TERs and the results of subject effort.

POINTS:

- This presentation includes only summary results - data is included in the TER section of the Volume I portion of the Final Report.
- TERs were developed on Structure, Liquid Rocket Engine, Avionics, Auxiliary Power Units, On-Board Test Equipment, Total Program to First Flight and Horizontal Flight Test Program. These were believed to be the schedule critical areas.
- Data used in developing TERs was unadjusted and not enriched.
- Approximately 45% of study resources were utilized on TER and TER-related activity.

VII TIME ESTIMATING RELATIONSHIPS

TOTAL PROGRAM

HORIZONTAL FLIGHT TEST

STRUCTURE

PROPULSION

AVIONICS

APU

ONBOARD TEST EQUIPMENT

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TERS - OBJECTIVES AND APPROACH

PURPOSE:

To display the objectives of this task and the approach used in developing the TERs.

POINTS:

- Cost Estimating Relationships (CERs) have been used for several years but this study is the first known major attempt at developing the same type of relationships for time.
- Data sources included MSC and MFSC, as well as in-house files.
- Parameters had to be available or determinable from source data for the programs under consideration which was a challenge in maintaining sample size. Consistency in parameters on the same program at varying points in time also presented challenges.
- Selected best equations by review of the parameters, review of the size of the constant, logic of the equation expressions and ability of the equation to predict the input program data.

TERS — OBJECTIVES AND APPROACH

OBJECTIVES

BASED ON THE ASSUMPTION THAT CERTAIN PERFORMANCE/PHYSICAL PARAMETERS WERE LINKED, THRU THE CAUSE/EFFECT MECHANISM, WITH TIME REQUIRED, AND THAT THE RELATIONSHIP – PARAMETERS AND TIME, COULD BE DISPLAYED IN A MATHEMATICAL FRAMEWORK TO DEMONSTRATE THE FEASIBILITY OF DEVELOPING TIME ESTIMATING RELATIONSHIPS.

APPROACH

- GATHER AND ASSIMILATE DATA
- EVALUATE POSSIBLE PARAMETERS
- USE DATA IN MULTIPLE REGRESSION ANALYSIS
- REVIEW AND ANALYZE MULTIPLE REGRESSION RESULTS
- SELECT BEST PARAMETERS
- SELECT BEST EQUATIONS

PURPOSE:

To graphically display methodology utilized in deriving TERs.

POINTS:

- VMSC used a stepwise multiple regression technique to develop the equations. The technique displayed is stagewise, however, the fundamentals are essentially the same.
- This technique, when all amenities are observed, is probably too sophisticated a tool to use in a feasibility program. However, it let VMSC address a lot more areas than would have otherwise been possible.
- Frequency distributions on the data are included in the TER section of the final report.
- Yest Versus Yactual plots are included in the TER section of the Final Report to portray how well the equations predict the input data.

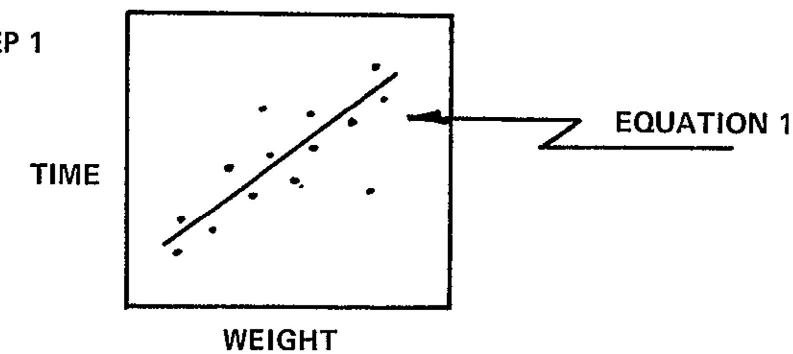
DISCUSSION:

Stagewise regression is depicted here as it is easier to display than stepwise. The basic difference is that in stagewise the previous terms (regression coefficients) of the equation are not modified as a result of inclusion of new variables (constant excepted) whereas in stepwise the previous terms may be changed as a result of adding new parameters.

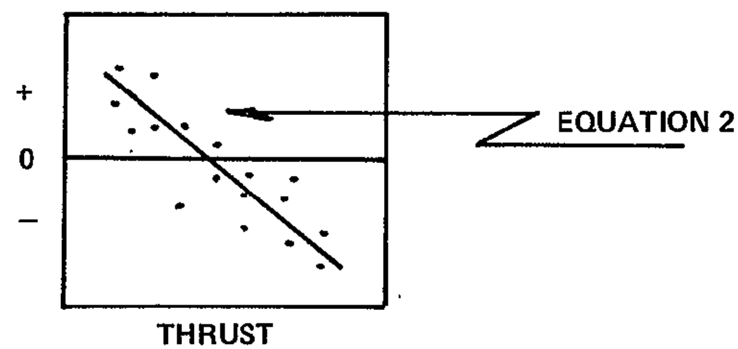
TER DEVELOPMENT – METHODOLOGY

MULTIPLE REGRESSION MECHANICS

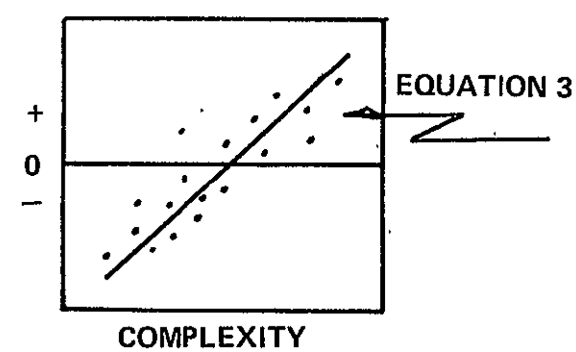
STEP 1



STEP 2



STEP 3



STEP 4: ADD EQUATIONS 1, 2 AND 3

INSERT PARAMETERS OF SUBJECT PROGRAM INTO EQUATION

COMPUTE RESULT FOR SUBJECT PROGRAM

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EQUATION TYPES

PURPOSE:

To present the types of equations resulting from the VMSC Multiple Regression routines.

POINTS:

- Some relationships are not a linear function, therefore the log equations are desireable.
- The VMSC routine provides subject program values for all the types of equations at the inclusion of each new variable.
- In some cases, the TER section of the Final Report provides the recommended equation as well as other equations which can be used assuming lack of data precludes use of the recommended equation.

DISCUSSION:

The study team found that some relationships were best explained by both a linear + log function, for example, weight. Weight has a basic linear relationship with time within narrow confines, however, economies of scale are apparent and for this reason a log-linear function might best be used.

In some cases, the advanced program schedule analysts will not have all the variables available required to utilize the recommended equations and the study team has attempted to include equations which could be used if only certain variables were available.

EQUATION TYPES

- LINEAR $Y_{EST} = K \pm a\,(X_1) \pm b\,(X_2) \text{ - - - } \pm N\,(X_n)$
- LOGARITHMIC $Y_{EST} = K \pm a\,(\mathrm{Ln}\,X_1) \pm b\,(\mathrm{Ln}\,X_2) \text{ - - - } \pm N\,(\mathrm{Ln}\,X_n)$
- LOG-LINEAR $Y_{EST} = K \pm a\,(\mathrm{Ln}\,X_1) \text{ - - - } \pm N\,(\mathrm{Ln}\,X_n) \pm a\,(X_1) \text{ - - - } \pm N\,(X_n)$
- LOG-LOG $Y_{EST} = K\,(X_1)^a\,(X_2)^b \text{ - - - } (X_n)^N$

WHERE: K = CONSTANT
a, b, N = COEFFICIENTS
X_1, X_2, X_n = INDEPENDENT VARIABLES
Y_{EST} = DEPENDENT VARIABLES

TER - SEPARATE APPROACHES

PURPOSE:

To display the three separate approaches utilized by the study team in bounding the program with TER's.

POINTS:

- The first approach was to estimate the individual hardware elements of the program - schedule critical.

- The second approach was to break the program into major phases and estimate each phase

    Go-Ahead to 95% Design Release
    Manufacture of 1st Flight Article
    Roll-out to 1st Horizontal Flight
    Horizontal Flight Test Program

- The third approach as another check was to estimate the total span from program go-ahead to first Horizontal Flight.

- These three methods must all demonstrate internal integrity before VMSC has confidence in the results.

TERS — SEPARATE APPROACHES

3 TOTAL PROGRAM

GO AHEAD TO FIRST HORIZONTAL FLIGHT

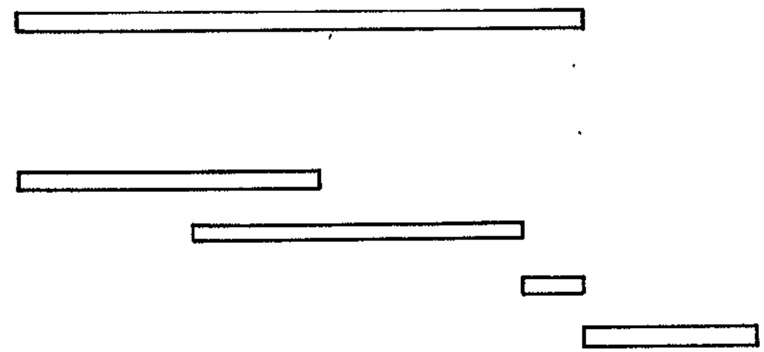
2 TOTAL PROGRAM BY MAJOR ACTIVITY

GO AHEAD TO 95% DESIGN RELEASE

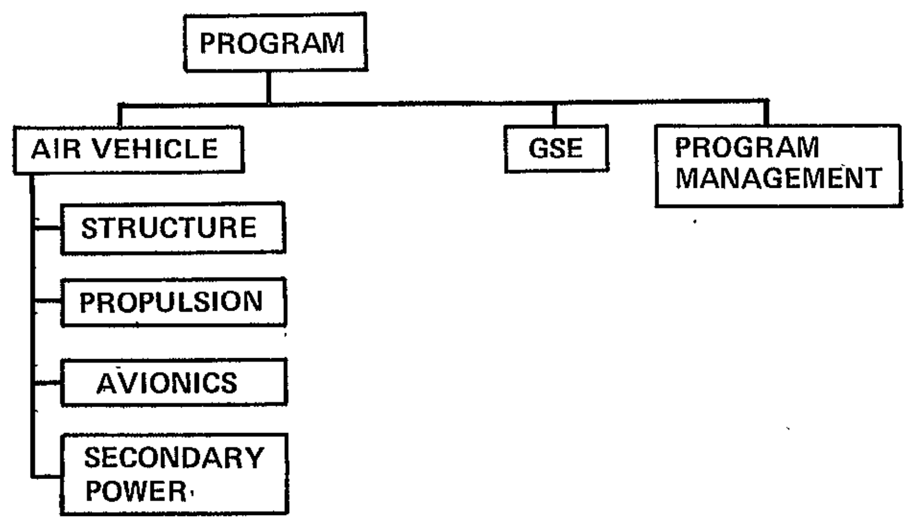
MANUFACTURE 1ST FLIGHT ARTICLE

RAMP TIME TO FIRST HORIZONTAL FLIGHT

HORIZONTAL FLIGHT TEST PROGRAM



1 BY WORK BREAKDOWN STRUCTURE



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TERS - TOTAL PROGRAM
GO-AHEAD TO FIRST HORIZONTAL FLIGHT

PURPOSE:

To present a summary of the TER covering Total Program Go-Ahead to First Horizontal Flight.

POINTS:

- Data from nine (9) programs used in developing the equation.
- The parameters utilized were Systems Weight and Structural Complexity.
- The resulting equation is of the Log type with a coefficient of correlation of .82.
- Results are: Stage I is estimated to have First Horizontal Flight 85.3 months after Go-Ahead.

  Stage II is estimated to have First Horizontal Flight 72.8 months after Go-Ahead.
- Type I Distributions are included in the TER section of the Final Report on input programs as well as other programs considered.

DISCUSSION:

Many other parameters were tried during the study but they proved too sensitive to allow extrapolation, particularily in the case of Stage I. Stage I, for example, has an empty weight approximately twice that of the C5A on 747. Installed thrust when combined with empty weight also proved to be too sensitive to allow extrapolation.

TERS — TOTAL PROGRAM
GO AHEAD TO FIRST HORIZONTAL FLIGHT

PROGRAM DATA USED

- CSM
- SIC
- S-II
- XF4H-1
- F-111
- B-58
- X-15
- XB-70
- CONCORDE

PARAMETERS USED

- SYSTEM WEIGHT
- COMPLEXITY FACTOR (STRUCTURE)

EQUATION	R	1σ
$Y_{EST} = 7.7216 + (13.7561)\,(\text{Ln SYSTEM WT.}) + (13.4443)\,(\text{Ln COMPLEXITY FACTOR})$	.82	9.9

RESULT

STAGE I = 85.3 MONTHS

STAGE II = 72.8 MONTHS

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TERS - TOTAL PROGRAM
DESIGN, MANUFACTURE, RAMP

PURPOSE:

To present a summary of the TER's covering Total Program Design, Manufacturing and Ramp time spans.

POINTS:

- Based on data developed during study, Manufacturing start on first flight article occurs 60% of the way through the Design span to 95% release.
- Data from seven (7) programs was used in developing the equations.
- The parameters utilized were Systems Weight and Structural Complexity.
- Low coefficients of correlation are result of unadjusted data and parameters used in selected equations.
- Results are that: Stage I is estimated to have First Horizontal Flight 82.2 months after Go-Ahead.

  Stage II is estimated to have First Horizontal Flight 71.1 months after Go-Ahead.
- Type I Distributions are included in the TER section of the Final Report on other programs surveyed and considered for use.

DISCUSSION:

Many other parameters were tried during the study but they proved too sensitive to allow extrapolation, particularily in the case of Stage I. Stage I, for example, has an empty weight approximately twice that of the C5A on 747. Installed thrust when combined with empty weight also proved to be too sensitive to allow extrapolation.

TERS — TOTAL PROGRAM
DESIGN, MANUFACTURING, RAMP

PROGRAM DATA USED

CSM
S-II
S-1C
X-15
B-58
XB-70
CONCORDE

DESIGN	95% RELEASE
MFG — 1ST UNIT	ROLLOUT
RAMP	1ST FLIGHT

PARAMETERS USED

SYSTEM WEIGHT
COMPLEXITY FACTOR (STRUCTURE)

EQUATIONS

	R	1σ
DESIGN-TO 95% RELEASE		
$Y_{EST} = 21.2270\ (\text{SYSTEM WT.})^{.1067}\ (\text{COMPLEXITY FACTOR})^{.0828}$	.43	7.3
MANUFACTURING-TO COMPLETE C/O		
$Y_{EST} = 3.5398 + (8.2049)\ (\text{Ln SYSTEM WT.}) + (7.5413)\ (\text{Ln COMPLEXITY FACTOR})$	.70	7.1
RAMP-C/O TO FIRST FLIGHT		
$Y_{EST} = 13.3140 - (0.2713)\ (\text{Ln SYSTEM WT.}) - (9.4324)\ (\text{Ln COMPLEXITY FACTOR})$	.72	3.7

RESULT

	STAGE I	STAGE II
DESIGN*	38.5	34.9
MANUFACTURING	49.7	42.2
RAMP	9.4	8.0
TO FIRST HORIZONTAL FLIGHT	82.2	71.1

* DESIGN IS 60% COMPLETE AT START OF MANUFACTURE

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TER - HORIZONTAL FLIGHT TEST PROGRAM

PURPOSE:

To present a summary of the TER covering the Horizontal Flight Test Program.

POINTS:

- Data on ten (10) programs used in developing TER.
- The parameters utilized were Ratio Systems Weight/Empty Weight, the number of aircraft in the Flight test program, the number of main engines per vehicle, and flight hours accumulated.
- Assumed 160 hours on 1st Vehicle and 25 hours on 2nd Vehicle.
- Results are that it is estimated to take the:

  1st Stage I 25.6 months to accumulate 160 flight hours.
  2nd Stage I 15.9 months to accumulate 25 flight hours.
  1st Stage II 15.6 months to accumulate 160 flight hours.
  2nd Stage II 9.7 months to accumulate 25 flight hours.

DISCUSSION:

The capability now exists, as demonstrated by the DC-10, to fly each vehicle every day after a reasonable period of time; however, it is study team opinion that these vehicles will not achieve that kind of turn time due in large part to the number of engines involved. Refurbishment, installation and checkout of rocket engines, ferry to launch site, assembly and checkout span must be added to these spans before the vehicles achieve mated vertical flight.

TER — HORIZONTAL FLIGHT TEST PROGRAM

PROGRAM DATA USED	NO. OBSERVATIONS
XB-70A	4
X-15	1
C-5A	3
F8U-3	1
F8U 1	2
A7A	1
CONCORDE	1
MIRAGE G	1
DC-10	4
L-1011	2

PARAMETERS USED

RATIO — SYSTEMS WEIGHT/EMPTY WEIGHT
NO A/C IN FLIGHT TEST PROGRAM
NO. OF ENGINES
FLIGHT HOURS

EQUATION

EQUATION	R	1σ
$Y_{EST} = 78.0529\,(\text{RATIO})^{2.9556}\,(\text{NO. ENGINES})^{.2916}\,(\text{NO. AIRCRAFT})^{-.4077}\,(\text{FLIGHT HOURS})^{.2558}$	.58	16.7

RESULTS

STAGE I	VEHICLE NO. 1 –	160 HOURS	=	25.6 MONTHS
STAGE I	VEHICLE NO. 2 –	25 HOURS	=	15.9 MONTHS
STAGE II	VEHICLE NO. 1 –	160 HOURS	=	15.6 MONTHS
STAGE II	VEHICLE NO. 2 –	25 HOURS	=	9.7 MONTHS

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TERS - STRUCTURE

PURPOSE:

To present a summary of the TERs covering the Structure Subsystem.

POINTS:

- Data on 13 programs used in developing TERs.
- The parameters used were Structure complexity, Structure weight Planform area and Mach number at maximum Q on 45000'.
- Developed TER for each of three spans - Design, Manufacturing, Final Assembly and Checkout
- Manufacturing span shown is for 1st unit - irrespective of use.
- Manufacturing starts 60% of the way through the Design span to 95% release on Structure.
- Results - Spans from Go-Ahead to completion of Final Assembly and Checkout of 1st structure are estimated to be:

  Stage I - 49.7 Months
  Stage II - 47.5 Months

DISCUSSION:

The complexity factor shown as a variable is derived by determining the type of material used in percent of total, the type of construction involved by type of material and then determining a weighted average factor for the vehicle. Planform area essentially measures the silhouette a vehicle has when viewed from a point at 90° from the direction of flight.

TERS — STRUCTURE

PROGRAM DATA USED

XC-142	GEMINI – MANNED
DC-10	CSM-009
747	CSM-012
CONCORDE	SIVB 201
SST	SIVB TEST
X-15	1U TEST
B-58	S-II-1
GEMINI GT-1	SIC-1

PARAMETERS USED

COMPLEXITY FACTOR
STRUCTURE WEIGHT
PLANFORM AREA
MACH NUMBER

EQUATIONS

EQUATIONS	R	1σ
DESIGN – 95% RELEASE		
$Y_{EST} = 9.0410 + 10.1366\,(\text{Ln COMPL}) + 1.7269\,(\text{Ln WT.}) + 3.6531\,(\text{Ln PLANFORM}) + 6.23\,(\text{Ln MACH})$	.83	6.2
MANUFACTURE – 1ST ARTICLE		
$Y_{EST} = 10.7034 + 8.1367\,(\text{Ln COMPL}) + .7450\,(\text{Ln WT.}) + 2.3240\,(\text{Ln PLANFORM}) + 1.3283\,(\text{Ln MACH})$	.81	3.9
MANUFACTURING COMPL TO C/O COMPL		
$Y_{EST} = .0953 + 2.3389\,(\text{Ln COMPL}) + .7714\,(\text{Ln WT.}) - .7287\,(\text{Ln PLANFORM}) - 1.1012\,(\text{Ln MACH})$	.73	0.8

RESULTS

	STAGE I	STAGE II
DESIGN	37.6	34.7
MANUFACTURING	24.7	24.2
CHECKOUT	2.4	2.5
GO AHEAD TO COMPL C/O	49.7	47.5

TER - LIQUID ROCKET ENGINE
FIRST TEST, FIRST DELIVERY, PFRT AND QUAL

PURPOSE:

To present a summary of the TERs covering the Liquid Rocket Engine.

POINTS:

- Data on six (6) engines used in developing the TERs
- The parameters used were Dry Weight of the engine, maximum rated duration in terms of burn time, oxidizer flow rate and envelope.
- Developed TERs on four (4) spans - To completion of first test, to first delivery, to completion of PFRT and to completion of Qualification Tests.
- Results - From Go-Ahead to completion of single engine qualification tests is estimated to require 81.3 months.

DISCUSSION:

Several more parameters were tried in developing these TERs; however, the results of F tests to establish colinearity between parameters, indicated that the depicted parameters were predominent. The turbopump development spans are inherent in these TERs as the pumps are an integral part of the engine - oxidizer flow rate is a parameter which reflect turbopump complexity/size. Details on definitions of each of the checkpoints can be found in the TER section of the Final Report.

TER — LIQUID ROCKET ENGINE
FIRST TEST, FIRST DELIVERY, PFRT AND QUAL.

PROGRAM DATA USED

H-1	XLR-87-AJ-5
F-1	XLR-91-AJ-5
J-2S	RL-10-A-1

PARAMETERS USED

DRY WEIGHT
MAX. RATED DURATION (BURNTIME)
OXIDIZER FLOW RATE
ENVELOPE (LENGTH X DIA.)

EQUATIONS	R	1σ
GO-AHEAD TO COMP. 1ST TEST $Y_{EST} = -5.301 + (.0004)(WT._{DRY}) + (.0254)(B_T) + (.0008)(ENVELOPE) - (.0015)(F_R)$	.999	0.1
COMP. 1ST TEST TO 1ST DELIVERY $Y_{EST} = -9.2185 - (.0057)(WT._{DRY}) + (.0528)(B_T) + (.003)(ENVELOPE) + (.0071)(F_R)$	.999	0.2
COMP. 1ST TEST TO COMP. PFRT $Y_{EST} = 12.3344 + (.0026)(WT._{DRY}) + (.0455)(B_T) - (.0017)(ENVELOPE) + (.0081)(F_R)$	.929	3.8
COMP. PFRT TO COMP. QUAL I TESTS $Y_{EST} = -14.0517 - (.0126)(WT._{DRY}) + (.0097)(B_T) + (.0073)(ENVELOPE) - (.0001)(F_R)$	.945	3.5

RESULTS

	SPANTIME (MOS)	MOS AFTER GO-AHEAD
GO AHEAD TO COMP. 1ST TEST	20.5	20.5
COMP. 1ST TEST TO 1ST DELIVERY	40.7	61.2
COMP. 1ST TEST TO COMP. PFRT	46.3	66.8
COMP. PFRT TO COMP. QUAL I TESTS	14.5	81.3

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TER - AVIONICS

PURPOSE:

To present a summary of the TER covering Avionics - i.e., individual module or largest, most complex "black box".

POINTS:

- The TER covers the period from vendor go-ahead to delivery of the first flight article.
- Time before vendor go-ahead can be based on Type I distributions which are shown in the TER section of the final report.
- The number of tiers of subcontractors/vendors involved must be considered before total span from Program Go-Ahead to module delivery can be established.
- VMSC picked the largest module, which happened to be in the Data Management Subsystem, for use in exercising the TER.
- Result - the most complex black box is estimated to be delivered 27.7 months after the ultimate contractor receives Go-Ahead.

DISCUSSION:

Study team opinion is that a better parameter than those utilized is Number of Components. This information was not available on enough programs to allow development of a credible TER, however. The NASA should be aware of the spans required for each tier of subcontractors/vendors as this has a major program impact. VMSC is probably not typical (because of short communication lines to the vendors and small size of the company), but VMSC requires approximately six (6) months, for example, from release of requirements to that time when a supplier is under contract.

TER — AVIONICS

PROGRAM DATA USED

GEMINI
- DIGITAL COMPUTER
- INERTIAL MEASUREMENT UNIT
- RENDEZVOUS RADAR

APOLLO
- PCM — T/M
- ELECTRONIC CONTROLLER

ATM ELECTRONIC CONTROLLER

SDP
- FUNCTION CONTROLLER
- FLIGHT CONTROL ELECTRONICS
- EXPERIMENTS CONTROL UNIT
- POWER DISTRIBUTION UNIT
- GUIDANCE SENSOR
- INERTIAL REFERENCE UNIT

SCOUT TIMER

LM
- ELECTRONIC CONTROL ASSY
- INVERTER
- LIGHTING CONTROLLER
- S-BAND X CEIVER
- AMPLIFIER AND DISPLEXER
- VHF X CEIVER
- SIGNAL PROCESSOR
- LANDING RADAR
- RENDEZVOUS RADAR
- RENDEZVOUS TRANSPONDER
- ATTITUDE CONTROLLER
- DESC. ENGINE CONTROLLER

PARAMETERS USED

VOLUME — CUBIC INCHES
NUMBER OF INTERFACES
NUMBER OF MODULES

EQUATION	R	1σ
$Y_{EST} = -1.8579 + 2.5406\,(\text{Ln VOL}) + 2.0769\,(\text{Ln INT.}) + 3.4885\,(\text{Ln MODULES}) - .0009\,(\text{VOL.}) + .1131\,(\text{INT.}) - .3456\,(\text{MODULES})$	.68	7.1

Y_{EST} = MODULE GO AHEAD TO FIRST FLIGHT ARTICLE DELIVERY — MONTHS

RESULTS

STAGE II (DATA MANAGEMENT) = 25.7 MONTHS

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TER - GAS TURBINE ENGINE (APU)
TIME TO DEVELOP PROTOTYPE

PURPOSE:

To present a summary of the TER covering Auxiliary Power Units (APU).

POINTS:

- The TER predicts time required to develop a prototype suitable for certification testing as a function of shaft horsepower.
- VMSC has provided an estimated additional span required for qualification FAA certification.
- Result - the APU is estimated to be qualified for use on the Advanced Space Transport in:

  32.9 - 38.9 Months after APU Go-Ahead on Stage I

  33.4 - 39.4 Months after APU Go-Ahead on Stage II

DISCUSSION:

APUs appear to be developed in families with considerable growth capability similar to jet engines. The TER was developed based on the data points indicated but has been verified as to its appropriateness with APU manufacturers.

TER — GAS TURBINE ENGINE (APU)
TIME TO DEVELOP PROTOTYPE

PROGRAM DATA USED	PARAMETER USED
AIRESEARCH MFG. DIV. SERIES 85 SERIES 700 SERIES TPE 331 SOLAR AIRCRAFT CO. TITAN MARS JUPITER	SHAFT HORSEPOWER (SHP)

	EQUATION	R
TIME REQUIRED TO DEVELOP PROTOTYPE SUITABLE FOR CERTIFICATION TESTING	$Y_{EST} = [55.741\ (SHP)^{-1.1167}]\ (SHP)$	.999

RESULTS

	STAGE I	STAGE II
PROTOTYPE DEVELOPMENT	26.9 MOS	27.4 MOS
QUALIFICATION OR CERTIFICATION	6 – 12 MOS	6 – 12 MOS
TOTAL APU PROGRAM RANGE	32.9 – 38.9 MOS	33.4 – 39.4 MOS

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TER - ON BOARD SELF DIAGNOSTIC TEST EQUIPMENT
START OF DESIGN TO FIRST DELIVERY

PURPOSE:

To present a summary of the TER for On-Board Self-Diagnostic Test Equipment.

POINTS:

- No TER developed for this area as the driving parameter could not be identified at this point in time.
- This study presents a Type I distribution of the programs/systems considered similar in principle to that which the Advanced Space Transport will have.
- Result - A prototype system can be delivered within 24.2 months after sub-contractor Go-Ahead. The impact of software requirements is not reflected in this estimate.

DISCUSSION:

This subsystem was identified as a TER candidate as it represents one of the more intense technical challenges, not necessarily in terms of State-of-Art, but rather in terms of the interfaces and resulting programming requirements. This Subsystem would be considered GSE if it stayed on the ground but the baseline documents indicate this capability will be airborne. The achievement in this area will depend on the hard specification requirements and the amount of resources the NASA is willing to devote to accomplishing the objectives. This TER is for a system representing approximately the same State-of-Art as the C-System flying now on the DC-10.

TER — ON BOARD SELF DIAGNOSTIC TEST EQUIPMENT
START OF DESIGN TO FIRST DELIVERY

PROGRAM DATA USED

AIDS	ENGINE ANALYZER F4D, F-105
GPATS	F-111, F4
TEAMS	SHIPBOARD AVIONICS
VAST	SHIPBOARD AVIONICS
C-SYSTEM	UNITED AIR LINES

PARAMETERS USED

NONE
(TYPE I DISTRIBUTION DATA ONLY)

RESULTS

FROM DESIGN START TO 1ST DELIVERY 24.2 MONTHS

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VIII CONFIDENCE AND SCHEDULE GROWTH

PURPOSE:

To introduce the subjects of Confidence and Schedule Growth.

POINTS:

- Confidence is a relative measure of how sure the study team is of the results presented and the techniques which allow determination of confidence.

- Schedule growth is the deviation from plan - study team has tried to deal with original baseline or plan.

DISCUSSION:

Schedule growth is the amount of deviation to plan which advanced planners should consider as real situations to be considered in scheduling and funding. Bid-type schedules are usually optimistic because of contractor over optimism, customer pressures, competitive environment, changes and emerging unknowns. This set of circumstances should be taken into consideration at high levels of management to preclude the maximum amount of "surprises". This section attempts to quantify the amount of schedule growth advanced planners should consider in their master planning.

VIII CONFIDENCE AND SCHEDULE GROWTH

CONFIDENCE

PURPOSE:

To depict the techniques used by the study team in attempting to obtain high levels of confidence in the results presented.

POINTS:

- The study team has attempted to be as objective as possible and have presented all information considered pertinent within the limits of time and resources available.
- The TERs present the data used, the equations used, measures of equation accuracy and comparisons, as well as narrative explanation of the processes used, and suggested limitations.
- Other techniques were employed but not included as their meaning, when applied in this activity, were not clearly identifiable and/or understood.

DISCUSSION:

This was a feasibility study and to impose the rigorous statistical tests to the results could have precluded use of a result or stopped an investigation having good probability of ultimate success. Some of the more sophisticated statistical techniques might also preclude the use of these TERs by advanced program schedulers due to lack of familiarity with the processes. The study team has gone as far as confortable in this direction without further analysis of real meaning and/or benefit of more sophisticated measures.

CONFIDENCE

- TOOLS INCLUDED TO AID IN DETERMINATION OF CONFIDENCE
  - FREQUENCY DISTRIBUTIONS OF DATA
  - Y_{EST} VS Y_{ACTUAL}
  - MULTIPLE CORRELATION COEFFICIENT
  - STANDARD DEVIATION OF ERROR
  - DATA FROM SAME CLASS OF VEHICLES
  - DATA UNADJUSTED, NOT ENRICHED
  - COMPARISONS
- OTHER TOOLS INVESTIGATED/EMPLOYED
  - BETA/WEIBULL DISTRIBUTIONS
  - "F" TESTS ON PARAMETERS
  - PROBABILITY PLOTS OF DATA
  - RESIDUAL EVALUATION
  - LINES OF EQUAL CONFIDENCE

SCHEDULE GROWTH

PURPOSE:

To graphically display historical schedule growth relative to basic program activities.

POINTS:

- Based on review of 28 programs the actual/plan time at First Flight was 1.56. (actual/bid)
- Study team used a straight line 1.2% growth per month to adjust the detail schedules for comparison with TER results.

  For Example:

  95% Structure Design Release = 15 Months plan

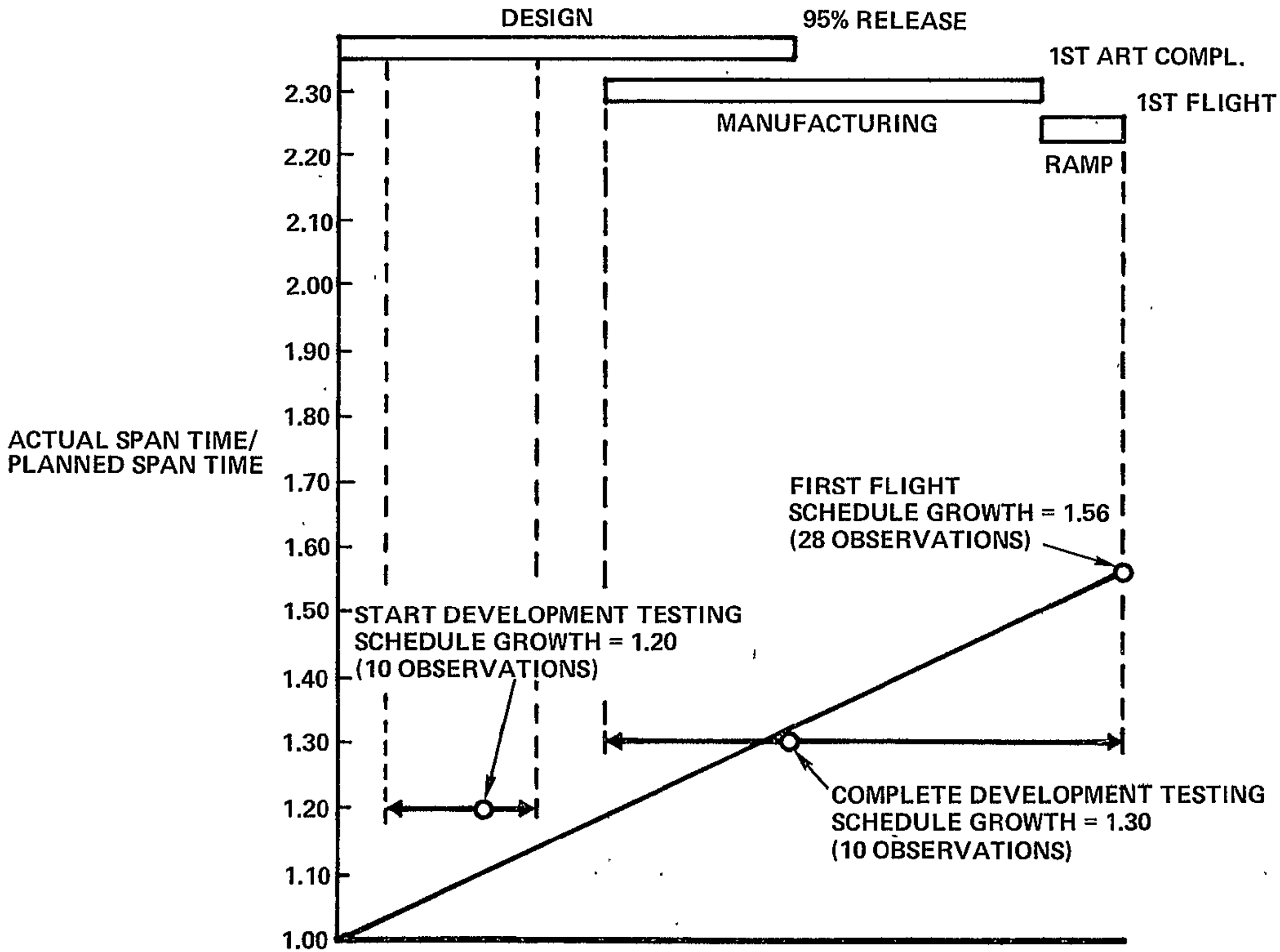
  15 x 1.2 = 18% anticipated growth

  1.18 x 15 months = 17.7 months estimated actual

  17.7 months then compared with TER results.

- Development testing span can vary in terms of start and complete depending on nature of program - this data is included for reference only.
- See the TER section of the Final Report for a more detailed explanation and other data points.

SCHEDULE GROWTH



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IX COMPARISON - TERS VS MASTER SCHEDULE

PURPOSE:

To introduce the subject of comparison of TER results with conventional scheduling methodology results.

POINTS:

- This is a summary comparison and the detail comparison is included as an appendix to each volume of the final report.
- This was the baseline configuration and not the present drop-tank configuration.
- The detail schedule results were adjusted at 1.2%/month for the comparison.
- Early go-ahead on the engine was considered and credit allowed for Phase B work on Structure only.
- Study team was not subject to all the factors which lead to optimistic schedules but it was subject to most changes, emerging unknowns and optimism.

IX COMPARISON — TERS VS MASTER SCHEDULE

SUMMARY MASTER SCHEDULE
ADVANCED SPACE TRANSPORT PROGRAM

PURPOSE:

To graphically display TER results versus conventional scheduling methodology results.

POINTS:

- Nine (9) months early award on the main engine.
- Six (6) months credit for Phase B work on Structure Subsystem.
- Summary Results:

	Months After Go-Ahead			
	Stage I		Stage II	
	Detail*	TERs	Detail*	TERs
First Horizontal Flight	68.3	82.2 - 85.3	72.4	71.1 - 72.8

*As adjusted by 1.2%/month

DISCUSSION:

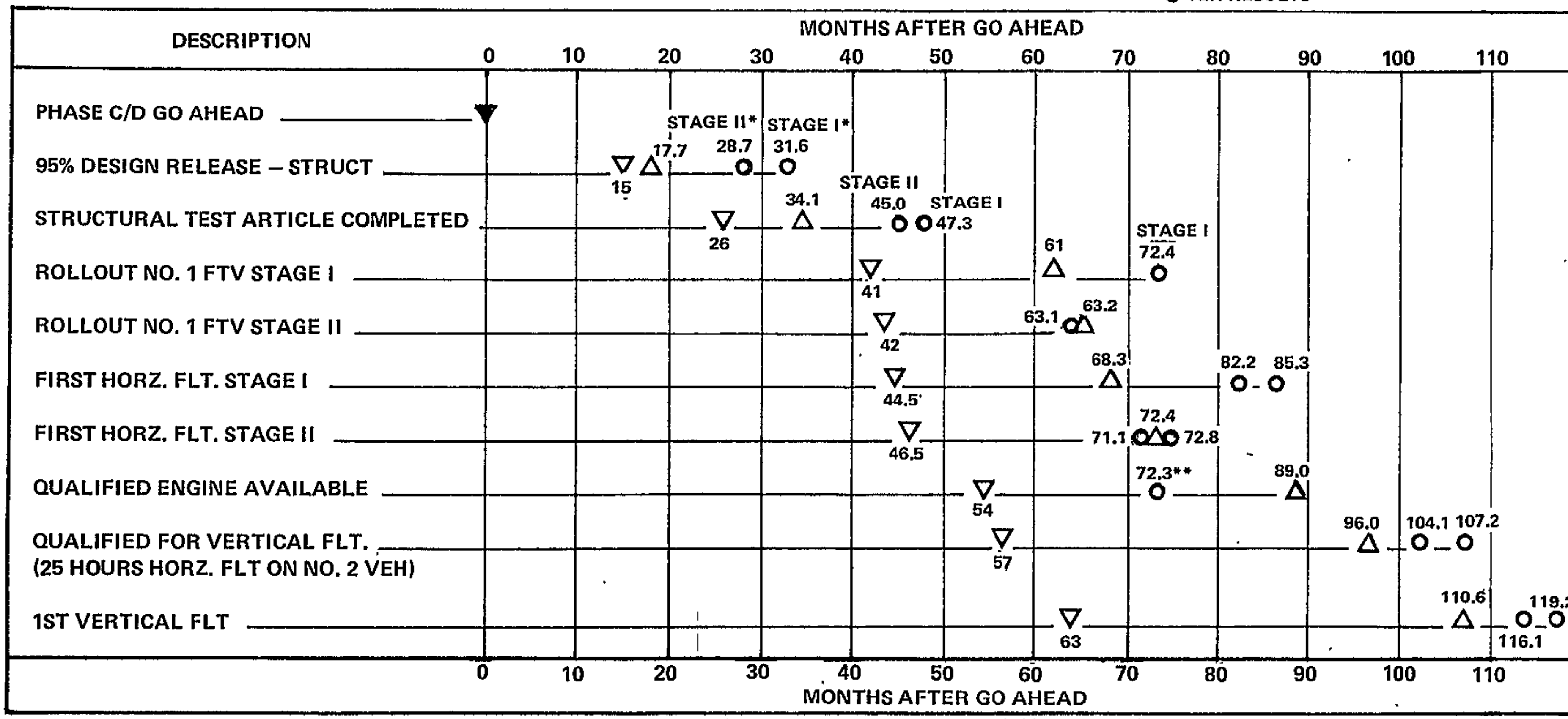
Study team opinion is as displayed, that the Stage II vehicle will be the first to fly and that Stage I will be the pacing element for mated vertical flights. Major rationale for this is the size of Stage I (essentially twice that of the 747/C5A) and the number of engines (12 main and 12 air breathing). This is partially offset by the structural complexity of the Stage II vehicle; however, the estimated slower turn rate between flights on Stage I during Horizontal Flight Test is the deciding factor.

SUMMARY MASTER SCHEDULE

ADVANCED SPACE TRANSPORT PROGRAM

TER COMPARISON

LEGEND:
▽ STUDY DETAIL SCHEDULES
△ DETAIL SCHEDULES ADJUSTED FOR ANTICIPATED GROWTH AT 1.2 PER MONTH
O TER RESULTS



* ASSUMES 6 MONTHS CREDIT FOR PHASE B

** DUE TO EARLY AWARD – 9 MONTHS IN ADVANCE OF PROGRAM PHASE C/D GO AHEAD

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X RECOMMENDATIONS

PURPOSE:

To introduce the section on Summary of results and recommendations for further activity.

POINTS:

- Study team opinion is that the TERs provide the foundation of a technique which could be a valuable Management tool not only in the planning phases of a program but also during the actual program development phase.

- The recommendations, for the most part, address the Management tool possibilities rather than the next step or follow-on activities.

X RECOMMENDATIONS

SUMMARY AND RECOMMENDATIONS

PURPOSE:

To summarize study results and made recommendations as considered appropriate by the study team.

POINTS:

- The study team is convinced that Time Estimating Relationships are feasible and that this represents a breakthrough with almost as much significance as proof that Cost Estimating Relationships were feasible and useful.
- It is possible to quantify schedule growth to the extent that reasonable comparisons between TER results and conventional scheduling methodology results can be compared (and differences acknowledged and planned).
- Consistent data availability was a handicap and will continue to be. The WBS Dictionary and other documentation have the ability to resolve most of this problem within a few years.
- TERs should be used by competent analysts as only one tool in the development of schedules.
- Turning the TERs into nomographs would simplify their use.

SUMMARY AND RECOMMENDATIONS

- SUMMARY
  - TIME ESTIMATING RELATIONSHIPS ARE FEASIBLE
  - TER RESULTS ARE COMPARABLE WITH CONVENTIONAL METHODS
  - AVAILABILITY OF CONSISTENT DATA IS A SEVERE LIMITATION

- RECOMMENDATIONS
  - TERS BE USED ONLY BY KNOWLEDGEABLE PERSONNEL
  - TER RESULTS BE CONFIRMED THRU OTHER METHODOLOGY(S)
  - TO MAKE THE TERS MORE USEABLE – TURN INTO NOMOGRAPHS
  - DEVELOP & USE COMMON WORK BREAKDOWN STRUCTURES (KEY TO INTEGRATION)
  - CONTINUE WORK IN AREA

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FOLLOW ON RECOMMENDATIONS

PURPOSE:

To provide a summary of the recommended future activity.

POINTS:

- Improvement of the TERs would add more parameters and improve existing parameters to reduce scatter in results and thus improve confidence.
- This would quantify the effects of National Priority, funding limitations and State-of-Art which would allow more realistic trade-offs and would also reduce scatter in the data.
- Expansion of the TERs to lower levels of the WBS and adding more subsystems would make the TERs useful for more people and would also cover a larger total percentage of the program.
- Updating data to present configuration and putting time on present configuration logic would provide a valuable Program Management tool for comparative purposes.
- If CERs can be developed utilizing the TER parameters, this would allow integration of cost and schedules and thus allow some tradeoffs and/or sensitivity analysis.
- Integration of Cost and Schedule using same parameters would be valuable to Program Management in evaluating proposals, evaluating alternatives and change board activities.

FOLLOW ON RECOMMENDATIONS

- CONTINUE PRESENT ACTIVITY
  - IMPROVE TERS
    - NATIONAL PRIORITY, STATE OF ART, FUNDING
    - MORE PRECISE PARAMETERS
    - NOMOGRAPHS
  - EXPAND TERS
    - TO LOWER LEVELS OF DETAIL
    - TO MORE SUBSYSTEMS
  - PUT TIME SPAN ON LOGIC NETS
  - UPDATE WBS DICTIONARY
    - TO PRESENT CONFIGURATION(S)
  - EXPAND WBS DICTIONARY
    - TO LOWER LEVELS OF DETAIL
    - TO INCLUDE ALL AREAS OF PROGRAM
- EXPAND ACTIVITY TO INCLUDE COST
  - WBS BY ELEMENT OF COST

WHICH ALLOWS

INTEGRATION OF COSTS AND SCHEDULE
BY
DEVELOPMENT OF CERS USING TER PARAMETERS

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FOLLOW-ON RECOMMENDATIONS - LOGIC

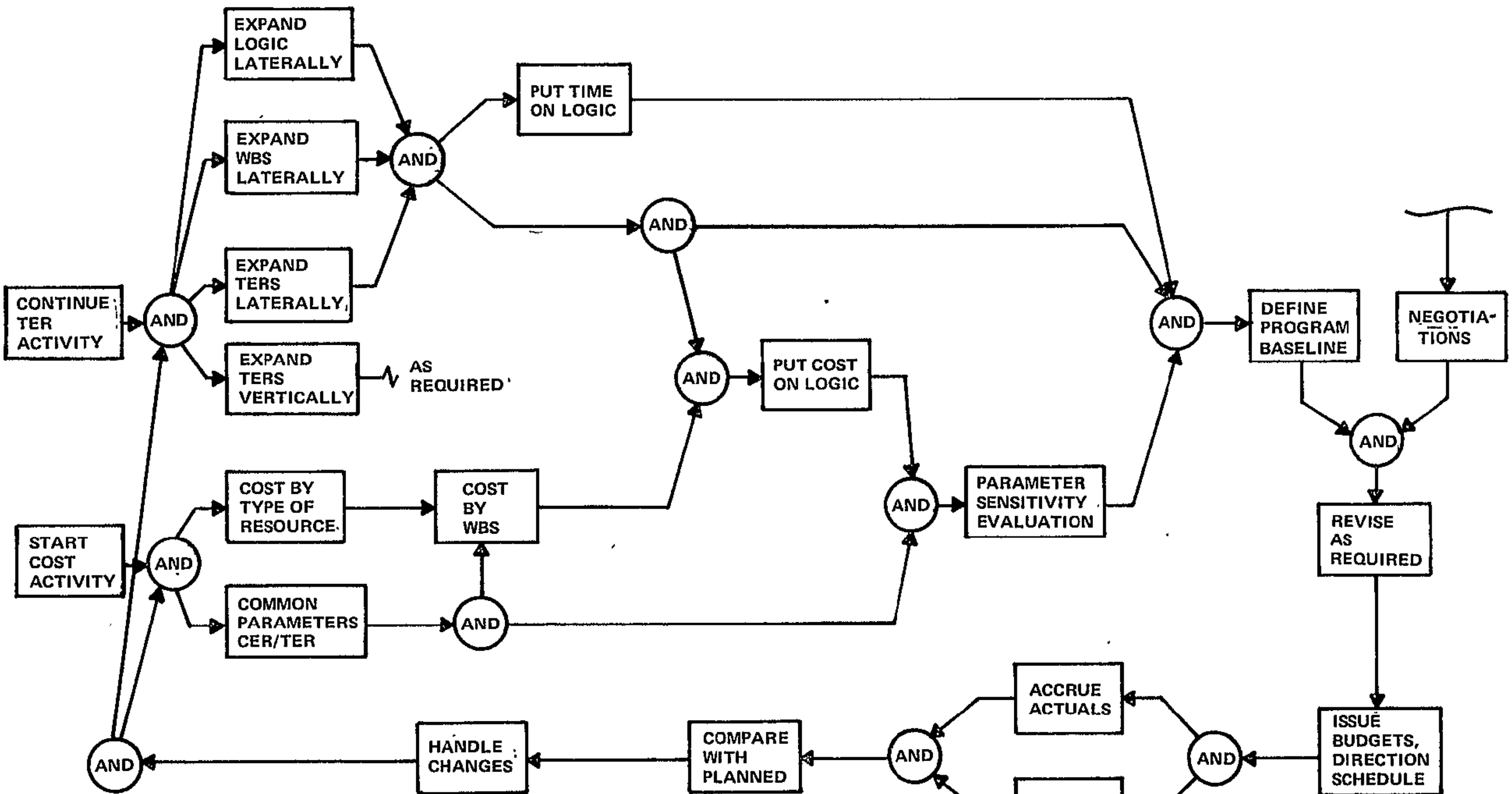
PURPOSE:

To display in logic format the recommendations and the resulting capability which could be achieved.

POINTS:

- This activity would provide Program Management with a potentially powerful tool to evaluate proposals, scope programs, evaluate alternatives and evaluate change impact.
- The tool can be closed loop once the program is underway with constant updating based on program actuals.
- This tool would thus integrate the three (3) elements a Program Manager can use to control a program:
    - Time
    - Money
    - Performance

FOLLOW-ON RECOMMENDATIONS — LOGIC



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INTRODUCTION
TO STUDY TASKS

SECTION 3

INTRODUCTION TO TIME ESTIMATING RELATIONSHIPS (TERs)

SECTION 3

INTRODUCTION TO TIME ESTIMATING RELATIONSHIPS (TERs)

The Time Estimating Relationships (TERs) presented in this volume are intended to provide the advanced program analyst a ready means to predict schedule time spans for new aerospace programs. The estimating equations used to predict time have been developed using multiple regression and correlation techniques. This analytical approach requires the collection of historical schedule data for several previous programs, determination of those candidate independent variables (i.e., weight, thrust, volume) which may predict the time (dependent variable) required to complete certain schedule milestones, attempt to establish a cause and effect relationship between the independent and dependent variables, and finally, prepare a mathematical expression which best describes this relationship. The resulting equations can then be used to make schedule predictions for programs which are in the advanced planning phase.

At the initiation of this twenty-week program, VMSC and NASA personnel were of the opinion that those same variables which drive program cost should also drive schedule time spans. Furthermore, study personnel were of the opinion that no single variable could reasonably be expected to explain every reason for time variations between programs. This led to the selection of multiple regression analyses as a study tool because it would permit the simultaneous evaluation of several candidate variables.

The general approach to development of a TER was to collect all applicable program/subsystem performance and schedule data, provide this data as input to the VMSC multiple regression routine which would quickly quantify in mathematical terms any cause and effect relationships between independent and dependent variables. It is the belief of VMSC that a computerized methodology of this type may be a tool too sophisticated for work of this type, especially when one considers the rather limited universe size to sample from, the relatively small sample sizes (even though sample sizes sometime approach the size of the universe) and statistical regimen which should be observed once the decision to go with a pure statistical approach has been made. Conversely, the computerized model does facilitate rapid assessment of data and does allow the analyst to cover more ground with the time available. Recognizing the potential pitfalls of computer modeling, the consensus of opinion among study team members was that overall program objectives could best be served by using an automated approach, therefore the automated multiple regression technique was utilized throughout this feasibility study.

The regression model employes a step-wise or "build-up" procedure whereby the single independent variable which makes the most contribution is selected first, the second best contributing variable is next included in the equation and so on until all variation is explained or all contributing variables are used up and incorporated into the equation. The outputs of this model include a series of equations in linear, log, log + linear and log-log form with a display of Multiple Correlation Coefficient, which is a measure of how well the procedure is doing in reducing or explaining variation. In addition, the Standard Deviation of Error for each equation form is displayed. Then as a last check, the final equation for each equation set demonstrates how well it can predict each of the programs used in the historical data base by printing out a comparison matrix with how long the program really took (Yactual) and what the estimating equation predicted the program time would have been (Yestimate). This comparison (Yact vs Yest) provided the analyst a visual means to check the utility of each equation without having to graphically plot-up each set of results to "see what is going on".

The resulting equations were then evaluated by study personnel to determine their usefulness based on logic and experience. This evaluation involved review of each term in the equation to determine if the expression moved in the direction logic would indicate as being appropriate, review of the Yactual versus Yestimate to see how well the equation predicted the actual input data, review of the equation result when the subject program independent variables were inserted, review of the Multiple Correlation Coefficient Correlation and the size of the Constant. Only after passing this review, was the equation accepted for use. (See Section 7 of this Volume for the TERs generated during the study.)

TERs were developed for those systems/subsystems which were considered by study personnel and MSC personnel to be schedule critical on the subject program. Following is a listing of the TERs included and short review of the rationale which led to TER development in that particular area.

1. Structure - It was study personnel opinion that this area represented a real possibility for schedule impact due to the environment the structure would see, the materials and type of construction involved, as well as the manufacturing techniques being discussed. Also, this area represents a major portion of the effort required to accomplish the program.

2. Liquid Rocket Engine - It was determined early in this study that the Main Engine would in all probability be a schedule critical path item. The OMS, RCS and ABES engines were considered to require only small to medium advances to current technology while the pressurization, feed and engine gimbal/deployment equipment would require medium technology advances. Since the Main Engine represented a potential medium to large technology challenge, it was selected as a TER candidate.

3. Avionics - This area, particularily in the Data Management System, was considered to be a potential schedule driver. This area also accounts for a large portion of the air vehicle effort. Little previous success in identifying avionics program drivers also prompted the inclusion of this area.

4. APU - NASA (MSC) personnel expressed concern that this hardware element could become a schedule pacing item because it may require LH_2 and LOX as propellants. This requirement could conceivably require a significant advance to the state-of-the-art.

5. Data Management Subsystem Hardware (Checkout) - Since one of the primary objectives of an advanced space transport program would be the development of reusable vehicles with very rapid turnaround time, it is imperative that major subsystems have onboard self-diagnostic checkout capability during all mission phases. This requirement led to an attempt to predict the development time for such a system.

6. Total Program - This TER was developed as a means to check the total of the other TERs. That is, the program span is built up in some detail and VMSC policy is to provide a separate evaluation of the total through a completely different methodology.

7. Horizontal Flight Test Program - The ultimate aim of An Advanced Space Transport test program must be satisfied with mated vertical launches. The aforementioned TERs (1 through 6) basically enable vehicles to begin first Horizontal Flight. To determine the time span before Vertical Flight can begin requires an estimate of the span required to accomplish stated Horizontal Flight Test objectives. Most programs deal with time to first flight and thus more data is available for that point. It was VMSC opinion that the Advanced Space Transport Program should be approached from this type of phased estimating equations, in order to allow most use of available data for the comparable spans.

As is the case with most forecasting techniques, there is a danger is using these methods to extrapolate too far beyond the range of the input data. It is study personnel opinion that the TERs shown in Section 7 are valid for programs whose parameters fall within or relatively close ($\pm$ 10%) to those of the input programs. Knowledge of the state of maturity for the particular technology is mandatory for use, particularly extrapolation, of these TERs. Avionics, materials and power supplies are good examples of rapidly changing technology capability. The user will notice that some of the TERs shown in this report address the "Year of Technology Freeze" or use a similar method for measuring the technology maturity.

SECTION 4

INTRODUCTION TO WORK BREAKDOWN STRUCTURE (WBS) DICTIONARY

SECTION 4

INTRODUCTION TO WORK BREAKDOWN STRUCTURE (WBS) DICTIONARY

4.1 INTRODUCTION AND BACKGROUND

VMSC has selected the MIL-STD-881 approach to defining an Advanced Space Transport Program for use as the basis for conducting the Scheduling Technique Improvement Study for Advanced Programs. MIL-STD-881, "Work Breakdown Structures for Defense Materiel Items", 1 November 1968, "establishes criteria governing the preparation and employment of work breakdown structures for use during the acquisition (engineering and operational systems development and follow-on production) of designated defense materiel items." This Standard is also applicable to non-DoD programs with proper interpretation by the preparing organization.

MIL-STD-881 defines a Work Breakdown Structure (WBS) to be "a product-oriented family tree composed of hardware, software, services, and other work tasks which result from project engineering efforts during the development and production of a defense materiel item, and which completely defines the project/program. A WBS displays and defines the product(s) to be developed or produced and relates the elements of work to be accomplished to each other and to the end product." A similar definition by NASA is included in the Glossary contained in this Volume.

During its latter-1970 study for MSC of life cycle costs of two competing in-house Space Shuttle configurations, VMSC prepared a WBS for that study using MIL-STD-881 as a guide and blending the WBS structure for an aircraft with that of a space system to form the WBS for the Space Shuttle.[1] This WBS satisfied all the requirements of the study by defining Booster, Orbiter and Integration oriented elements for the Air Vehicle, GSE, Test, System/Program Management, Data, Operational/Site Activation, Training, Initial Spares and Repair Parts, and Operations & Services to the 5th (Subsystem) Level consistently, and to the 7th (Component) Level for the Air Vehicle stages (Booster, Orbiter). From this WBS, VMSC was able to build an automated cost model which generated RDT & E, Investment and O & M (Operations and Maintenance), i.e., Life Cycle, costs based upon concept definition (weight, thrust, power, quantities, etc.).

The technique for generating costs used CERs (cost estimating relationships) to establish Unit Costs (Theoretical First Unit and, with predicted learning curve factors, Average Unit) to derive vehicle costs, then to input these and other costs per the VMSC-generated WBS to calculate total RDT & E, total Investment, and total O & M costs, the sum of which provided Life Cycle costs. These costs then enabled obligational budget estimages to be derived. Government, i.e., NASA, costs were intentionally omitted.

[1] Final Report, Space Shuttle Cost Analysis Study Phase C/D, LTV Report No. 00.1384, 28 December 1970. Work Request No. H-8229.

As a task for the subject Scheduling Technique Improvement Study, then, VMSC updated its Cost Study WBS: (1) to make it applicable to any advanced two-stage, manned reusable Space Transport program; (2) termed the orbital vehicle as Stage II, the boost vehicle as Stage I, and added a Payload identification; (3) added Industrial Facilities as a major 3rd Level (Project Level) element; (4) updated the Block 2.0 element to better identify Operating Ground Equipment (OGE); (5) updated the Block 4.0 element to better identify Systems Test and Evaluation; and (6) opened up Block 12.0 (was Block 11.0 for the Cost Study) to show the need for a Payload Integration Office and NASA Operations and Services Office for the Operations Phase. Stage II and Stage I elements (to the 7th Level) were updated to a high crossrange, delta wing configuration in keeping with NASA's current objectives for developing highly maneuverable, large payload, air vehicles.

To complete the WBS Task for subject study, VMSC generated a WBS 'Dictionary' to define each element of the revised WBS. The SOW for this task (Task E of the study) called for defining each 'block' of the WBS in terms of the specific 'requirements' which the block covers. Further, the SOW called for this 'Dictionary' to represent MSC's desires and intent for future programs ..... and to emerge from the study to form an end item which can be used by MSC as necessary in future program needs.

4.2 WBS DICTIONARY FORMAT

To meet both the needs of subject study as well as provide MSC with a 'Work Statement' management tool for advanced programs such as the Space Shuttle, VMSC prepared the Dictionary writeups for each significant element in a format which provides the following:

Paragraph I - REQUIREMENTS

Establishes the Program, Project, System, Subsystem, Assembly or Component top requirements, as appropriate to the element's WBS Level.

Paragraph II - DEFINITION

Defines the ensemble of the next lower level elements required to form subject element, as defined by the WBS.

Paragraph III - FUNCTIONAL DESCRIPTION

Describes the element functionally and, at the 5th (Subsystem) Level and higher, describes the development phases which the element must pass through to receive NASA acceptance, viz PDR, CDR, Qual Test, Flight Test.

Paragraph IV - DESIGN REQUIREMENTS

Establishes the Program, Project and System Level requirements (e.g., engine-out landing, fail-operational/fail-safe, etc. as applicable) based upon WBS Dictionary Element 0.0 Para. IV (see Section 8 of this report) as well as design practice requirements for subject element.

Paragraph V - INTERFACES

As applicable, defines both direct interfaces (e.g., within the Stage) and indirect interfaces (within the total Program, viz. Test, GSE, System/Program Management, Training, Spares, etc.).

Paragraph VI - TEST REQUIREMENTS

For vehicle and GSE, specifies the interfacing test blocks (Block 4.0, System Test and Evaluation) to which the element will be sujected following component, assembly and single subsystem testing.

Paragraph VII - REFERENCES

Provides a location for MSC analysts to insert the reference documents they wish to callout for reference data on specific concept definition. VMSC intentionally left this paragraph open (except for an occasional reference as needed) for MSC to utilize as they see fit, it being VMSC's intent to not make the WBS Dictionary concept sensitive.

In addition, the WBS Dictionary Page 1's carry a schedule on them for subject program which details the (e.g.) engineering, tooling and manufacturing milestones needed to accomplish design and development for the subject element defined therein. In some cases, schedules are not shown for the subject element but are shown on lower or higher levels of the subsystem or system Dictionary or may be shown on the Master Schedule (see Section 8 of this Volume), in which case a callout to that effect is noted.

The WBS generated for this study contains 666 'blocks' for the defined Advanced Space Transport Program (Levels 2 thru 7 for Blocks 0.0 and 1.0 thru 12.0). VMSC concentrated on providing 'Dictionary' writeups for the 2nd (Program) Level, 3rd (Project) Level, 4th thru 6th (System thru Assembly) Levels of Stage II (orbital stage), 4th and 5th (System, Subsystem) Levels of Stage I (boost stage), and 4th, 5th and 6th Levels as appropriate for Blocks 2.0 thru 12.0. Accordingly, the 'Dictionary' (WBS's, themselves are contained in the text of the Dictionary as appropriate) provides NASA with a thoroughly integrated, viable management tool which not only served subject study but which has application to many potential needs for planning, augmenting or controlling advanced programs such as the Space Shuttle.

It is believed that the utility of the WBS and WBS Dictionary contained in Section 8 of Volume I and in Volumes II, III and IV lends itself to the following Program needs (both customer, contractor, Intra-Center, affected Government agencies, others):

1. Enables preliminary definition of Interface Control Documents (ICD's)
2. Enables preliminary identification of customer-desired contract end items (CEI's)
3. Enables 'collection' of elements which have properties in common:
   a. To the government (MSC, MFSC, GSFC, Test Facilities, FAA, USAF, KSC, DoD)
   b. To the major contractors (Stage I, Stage II, Integration)
   c. To associate contractors (avionics, for example)
   d. To subcontractors (TPS, APUs, Landing Gear)
   e. To Government Furnished Equipment (Main Engines, Payload)
4. Enables early identification of potential problem areas (using the WBS and the Logic Diagrams, together) whose solutions after contract go-ahead may cause costly slides in costs and schedules.
5. Enables NASA to check contractor proposals for: (a) management approach, design approach, configuration definition and control, test plans, safety plans, maintainability plans, reliability plans, facility plans, data management plans, training plans, manufacturing plans, spares plans, quality assurance plans, and operations plans.
6. Enables collection of hardware, software, consumables, services which are CFE vs GFE.
7. Enables tradeoffs to be made as a function of:
   - Configuration Change
   - Quantity of Flight Test Vehicles and Production Vehicles
   - Changes in Test and Operations plans
   - Adding, modifying, or deleting hardware, software, and service elements
8. Enables cost and schedule tradeoffs to be evaluated as a result of 7, above.
9. Enables NASA to organize its in-house personnel in accordance with end items resulting from the WBS, and to ensure an effective counterpart exists in the affected contractor, associate contractor, subcontractor or affected other-government-agency organizations in order to work the tasks defined by the WBS and its 'Dictionary'.

4.3 WBS DICTIONARY LOCATIONS - FINAL REPORT

Due to the volume of pages resulting from the WBS Dictionary and other Study task efforts, the WBS Dictionary was distributed throughout Volumes I - IV as follows:

Vol I - Section 8 contain WBS Dictionary Element 0.0, Advanced Space Transport Program (Level 2, top level); 1.0, Space Transport Air Vehicle (Reusable) (Level 3); 1.1, Integration & Assembly (Air Vehicle) (Level 4) and 1.2, Payload (Deployable) (Level 4).

Vol II - Contains all of Stage II (WBS ID 1.3) 4th thru 6th Levels (some 7th Levels), numerically presented. The Logic Diagrams for each element (5th Level) are included following the Dictionary writeup.

Vol III - Contains all of Stage I (WBS ID 1.4) 4th and 5th Levels (some 6th and 7th Level schedules are presented). Again, Logic Diagrams are included following the associated Dictionary writeup.

Vol IV - Contains Blocks 2.0 thru 12.0 Dictionary writeups, numerically ordered, with Logic Diagrams, behind associated Dictionary pages.

The Table of Contents in each Volume shows the page number for that Volume where the reader may find the WBS Dictionary and Detailed Schedules (W/S) and the Logic Diagrams (L), if generated. The List of Illustrations in each Volume shows the page number for the Work Breakdown Structures contained in that Volume. Both WBS ID 0.0 and the Master Schedule are repeated in Volumes II - IV for reader correlation between the Dictionary writeup, the Detailed Schedule, and the Master Schedule.

SECTION 5

INTRODUCTION TO LOGIC DIAGRAMS

SECTION 5

INTRODUCTION TO LOGIC DIAGRAMS

5.1 INTRODUCTION, APPROACH AND GROUND RULES

Charts were developed to logically sequence the Space Transport's development activities at the 5th Level of the Work Breakdown Structure and thereby show the contents of TERs and detail schedules.

Chart preparation centered on Stage I and Stage II and the principal interfaces between them and such other program areas as Common Support Equipment, Peculiar Support Equipment, Range Preparation, Payload and activities on integration action.

These latter program areas were developed only to the extent necessary to identify the interface/relationships with Stages I and II. No attempt was made to impose estimates of expected elapsed time upon the activities comprising the logic flow.

Certain assumptions or ground rules were made in developing the Space Transport Program's logic trail. These are presented below:

1. Principle planning documents will exist at the conclusion of Phase B and will be approved and exist at the initiation of Phase C/D to furnish the guidance and philosophy necessary for program execution. Such documents include:

   a. Configuration Management, Accounting and Control Plan
   b. System Safety Plan
   c. Training Plan
   d. Preliminary Logistics Plan
   e. Preliminary Maintenance/Repair Plan
   f. Preliminary Reliability Plan
   g. Program Management Plan
   h. Data Management Plan
   i. Electronic/Automated Data Processing Plan
   j. Quality Assurance Plan
   k. Preliminary System Test and Operations Plan
   l. Facilities Plan

2. Phase B will have been performed in sufficient depth as to yield preliminary Part I specifications. Negotiations for Phase C/D will yield certain revisions to these specifications; revision incorporation along with any necessary tradeoff analyses will be performed early in the Phase C/D Program.

3. The Air Breathing Engine Development will be essentially a modification of an existing engine and will provide common engines to both Stage I and Stage II.

4. The main engine for both Stage I and Stage II will be common. Portrayal of a single development program at the 5th Level of the WBS for the main engine is judged to cloud many of the principal propulsion development activities which would be stage oriented. A Part I main engine specification is shown common between stages but all subsequent activities are portrayed for each stage. Admittedly some activities may be redundant between stages. However, to ensure proper integration with propellant tankage, pressurization, feed, ullage management and purge/drain hardware, a main engine is shown to be developed for both Stage I and Stage II after Main Engine PDR.

5. Integrated checkout/servicing Ground Support Equipment for the vertical (mated) launch portion of the program will be designed to provide both launch checkout as well as post-recovery servicing/maintenance functions. As such, sets of integrated checkout/servicing Ground Support Equipment will be shipped/installed for the horizontal phases of the program to support both Stage I and Stage II horizontal testing but without whatever racks/chassis would be necessary for the vertical program.

6. The Program will be optimally executed which is to say that there will be no external driving forces such as a need date.

7. Go-Ahead will be concurrent to all portions of Phase C/D activity.

8. No commonality will exist between systems of Stage I and those of Stage II except for the ABES at the System Level.

9. A structural test article will be built before the flight articles.

10. The procurring agency will be the using agency.

11. The Program as developed principally addresses the airborne constituents (Stage I and Stage II) with only that attention given to GSE, Facilities, Range and Payload consistent with customer direction.

The approach to logic trail development based on these assumptions/ground rules entailed several stages. Critical categories of airborne program activity as seen from the perspective of the 5th Level of the WBS were identified and joined to form a mainstream of program activity. Those were then assessed as necessary to capture the sequence for other critical categories of activity thus providing the interfaces either between Stages or with the non-airborne elements of the program (e.g., Support Equipment, Facilities, Program Management, and System Integration).

Each resulting activity was then assessed to determine its WBS characterization and the chief function concerned with the activity. Functions used are representative of those used for Cost Information Reporting per Bureau of the Budget Document 22-R260, namely engineering, tooling, manufacturing, quality, operation and maintenance, and program management.

Note that the logic only emphasizes the airborne constituents of the Space Transport Program and does not equitably portray other program elements at the 5th Level of the WBS. Sheets identified by WBS character 0.0.0 portray the program logic at the 2nd Level of the WBS. All other logic is at the 5th Level of the WBS.

5.2 LOCATION OF LOGIC DIAGRAMS IN FINAL REPORT

The Logic Diagrams are included according to WBS ID Number, e.g., 0.0, 1.3.2, etc., and are located immediately behind the corresponding WBS Dictionary Element.

Inasmuch as Logic Diagrams were normally prepared at the 5th (Subsystem Level), they will be found in Volumes II, III and IV for these levels, only. Refer to the Table of Contents under heading 'L' for each Volume for the page which carries the Logic Diagram Sheet 1's.

5.3 LOGIC DIAGRAM CONNECTOR CODE INDEX

Connectors provide the means of following the 'trail' from one WBS element to another. To enable the reader to understand and use the connectors, an Index is included in the Appendix of Volumes II, III and IV. An example shows how to read and use the connectors.

SECTION 6

INTRODUCTION TO MASTER AND DETAIL SCHEDULES

SECTION 6

INTRODUCTION TO MASTER AND DETAIL SCHEDULES

6.1 INTRODUCTION, APPROACH AND GROUND RULES

A Master Schedule along with supporting detail schedules were developed using standard scheduling techniques. Detail Schedule Preparation is centered around the 5th (Subsystem) Level and in some cases, extends down into the 6th and 7th Levels in the Air Vehicle areas.

The Master Schedule (Section 8 of Volume I) has been prepared depicting major check points in the various organizational areas. Shown on the Engineering bar are release dates which must be met in order to allow the Materials, Tooling and Manufacturing Departments sufficient time to perform their tasks. The Tooling lead times are as follows:

Masters
6 Weeks Design
14 Weeks Fabrication

Detail Tools
4 Weeks Design
12 Weeks Fab (Machine)
8 Weeks Fab (Sheetmetal)

Assembly
4 Weeks Design
12 Weeks Fabrication

Major Fixtures
6 Weeks Design
14 Weeks Fabrication

The Manufacturing lead times are as follows:

Detail Fabrication
16 Weeks Sheetmetal (-1 thru -6 Indentured Parts)
20 Weeks Machined Parts (-1 thru -6 Indentured Parts)

Subassemblies
8 Weeks (-1 thru -5 Indentured Parts)

Major Assemblies
Time spans are based on the complexity of the article being fabricated.

Manufacturing Sequence for Stage I

Six (6) articles will be fabricated and are identified as follows:

Structures Test Article - This will be a static and structures test article which can be tested as a major section or as a completed vehicle less installations.

No. 1 Article - This is a fully instrumented Vehicle and will be assigned to a Horizontal Flight Test Program. Upon the completion of the Assigned Flight Test Program, this Article will be updated for mated vertical flights.

No. 2 Article - This is a fully instrumented Vehicle similar to Article No. 1 and will be Horizontal flight tested. The Article will be updated and made ready for mated vertical flights.

No. 3 Article - This is a partially instrumented Vehicle and will go through a Horizontal Flight Test Program. This Article will be updated and made ready for mated vertical flights.

No. 4 Article - This is the first Production Article to be fabricated which will go through normal Horizontal flight C/O and directly into the vertical flight program.

Manufacturing Sequence for Stage II

Structures Test Article - This will be a static and structures test article which can be tested as a major section or as a completed vehicle less installations.

No. 1 Article - This is a fully instrumented Vehicle and will be assigned to a Horizontal Flight Test Program. Upon completion of the Assigned Flight Test Program, this Article will be updated for mated vertical flights.

No. 2 Article - This is a fully instrumented Vehicle similar to Article No. 1 and will be Horizontal flight tested. The Article will be updated and made ready for mated vertical flights.

No. 3 Article - This is a partially instrumented Vehicle and will go through a Horizontal Flight Test Program. This Article will be updated and made ready for mated vertical flights.

No. 4 Article - This is the first Production Article to be fabricated which will go through normal Horizontal Flight C/O and directly into the vertical flight program.

No. 5 Article - This is the first Production Article to be fabricated which will go through normal Horizontal Flight C/O and directly into the vertical flight program.

Detail and Subassembly fabrication will broken down into two lots for Stage I. Lot one will consist of three sets of parts: one set for tests (as required), one set for a structures test article, and one set for flight test Article No. 1.

Lot two will consist of four (4) sets of detail and subassemblies and will be used on Flight Articles 2, 3, 4 and 5.

The selection of two (2) lots was made in order that design changes and tooling update could occur prior to the fabrication of all details.

Stage II, Lot 1 and 2, Detail and Subassembly fabrication is the same as Stage I except that Lot 2 will consist of 6 sets in lieu of 5.

No spares have been included in these lot sizes.

Detail Schedules have been prepared showing the design effort when applicable through development tests, and checkout, tool design and fabrication and the actual manufacturing of the end product.

The Master Schedule includes thirty-nine (39) months of Horizontal flight testing prior to first vertical flights. Eighteen (18) months will be accomplished on Flight Vehicle No. 1, eight (8) months on Flight Vehicle No. 2, nine (9) months on Flight Vehicle No. 3 and four (4) months on Flight Vehicle No. 4.

The Master Schedule covers Phase C/D only and has allowed up to six (6) months credit for work accomplished in the earlier phases.

6.2 LOCATION OF MASTER AND DETAIL SCHEDULES IN FINAL REPORT

The Master Schedule is introduced in Section 8 of Volume I behind the WBS Dictionary Element 0.0, Advanced Space Transport Program. For correlation with lower level WBS callouts to Master Schedule (page 1 of each WBS Dictionary element), a copy of the Master Schedule is also carried in Section 1 of Volumes II, III and IV.

Detail Schedules, where provided, are shown on each Page 1 of the WBS Dictionary elements included in Volumes II, III and IV. Where a Detail Schedule is not provided, reference is shown on each affected Page 1 of the WBS Dictionary Element to lower level elements, to higher level elements, or to the Master Schedule, itself. The Table of Contents for each Volume notes the page number for that volume where either the WBS Dictionary is included, a Detail Schedule is included, or both are included. The heading for this is shown as "W/S".

SECTION 7

TIME ESTIMATING RELATIONSHIPS (TERs)

SECTION 7

TIME ESTIMATING RELATIONSHIPS

This section of the report includes all of the Time Estimating Relationships (TERs) generated by VMSC during the contracted 20-week study.

This section was organized in a manner which does allow the user (i.e., estimating analyst) to extract this total section from the report thus providing a workable document that provides the basic data, as well as the results. In order to provide a complete document pertaining only to TERs, it is recommended the user also extract Section 3.0, Introduction to TERs, from this volume which provides the user with the methodology and approach for developing TERs.

With this philosophy in mind, this section provides its own index, list of illustrations and list of tables. The format for each TER is Scope, Approach, Results and finally Limitations. The Scope briefly describes what is found in that particular TER and in some instances the groundrules used during the study. The Approach explains the methodology employed for generating that particular TER, the input data (in terms of programs considered, independent variables and why selected) and the time spans actually incurred by that particular program for a specific phase. The Results present the selected mathematical expression (equation) for each TER generated by phase (i.e., design, manufacture of 1st flight article, checkout of 1st flight article) and/or total span. The estimated time spans for Stage I and Stage II Air Vehicles of the Advanced Space Transport Program are also presented in the Results section. In addition, Type I frequency distribution plots are presented based on the historical data on the programs used in the data set. The Limitations contain the constraints that should be observed when using the generated TERs and/or Type I distribution data for estimating other advanced program time spans.

INDEX TO SECTION 7

TIME ESTIMATING RELATIONSHIPS (TERs)

LIST OF ILLUSTRATIONS

TIME ESTIMATING RELATIONSHIPS (TERs)

LIST OF ILLUSTRATIONS - Continued

TIME ESTIMATING RELATIONSHIPS (TERs)

LIST OF ILLUSTRATIONS - Continued

TIME ESTIMATING RELATIONSHIPS (TERs)

LIST OF ILLUSTRATIONS - Continued

TIME ESTIMATING RELATIONSHIPS (TERs)

LIST OF TABLES

TIME ESTIMATING RELATIONSHIPS (TERs)

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TIME ESTIMATING RELATIONSHIPS (TERs)

7.1 STRUCTURE

1.0 SCOPE

The purpose of this TER is to develop mathematical expressions which will predict the time spans required for Design, Manufacturing of the first flight or test article, and that time span from completion of manufacture of the first article to complete checkout of the structural element. Included in this TER are the approach or methodology for development of Structure TERs, the data used, the results as well as the limitations associated with the utilization of these TERs.

2.0 APPROACH

Table 7.1-I presents the 29 programs used for developing TERs for the structure subsystem. As shown in this table, some of the time spans were not available in the detail required for the regression analysis, thus each time span had a slightly different set of program input data.

The independent variables selected for the regression analysis were a complexity factor for the structure, the structure weight, the planform area and the velocity at maximum dynamic pressure (maxQ) or at the operating altitude. Other independent variables, such as payload volume and payload weight capability, were also reviewed as potential input elements; however, they were discarded since they were determined not to be primary drivers and these elements were implicit in the final selected parameters. For example, payload volume is implicit in planform area and payload weight capability is implicit in structure weight.

The structure complexity factors were derived utilizing the results of a study conducted by Lockheed Missiles and Space Company as a base (Ref. LMSC-895429, Volume II, dated 30 June 1965). Table 7.1-II shows the complexity factors for the various type of construction as a function of the type of materials employed. The factors in parenthesis reflect the VMSC design complexity factors used for the design time span. (See end of this section for details pertaining to the design complexity factors.)

TABLE 7.1-I
STRUCTURE ANALYSIS INPUT PROGRAMS

Program	Program G/A to 95% Design Release (MO)	Manufacture G/A to Complete 1st Structure Unit (MO)	Final Assembly & Checkout (MO)
X-15	24.0	14.0	2.0
XF8U-1	13.0	---	---
F8U-3	13.0	---	---
XC142	15.0	11.5	2.0
A7A	10.5	---	---
F7U-3	12.0	---	---
XF7U-1	18.0	---	---
Regulus II	15.0	---	---
Regulus I	11.0	---	---
Electra	20.5	---	---
747 Emp	13.0	---	---
B58	45.0	30.0	3.0
B70	36.0	---	---
C141	14.0	---	---
SST (BAC)	52.0	24.0	2.0 (SCH)
SIVB (Test)	12.0	17.5	2.0
SIU 200/500S-11 Struct	10.0	4.5	2.0
SIC-1	19.0	15.0	4.0
Gemini (Unmanned)	9.0	9.5	3.0
Gemini (Manned)	9.0	9.5	5.5
CSM No. 009 (Unmanned)	16.5	19.0	4.5
CSM No. 012 (Manned)	27.0	18.5	3.5
DC-10	22.0	16.0	2.0
747	28.0	24.0	2.0
SIVB No. 201	---	14.5	1.5
SIU-201	---	6.5	1.5
SII-1	---	15.0	2.0
Concorde	---	24.0	2.0

TABLE 7.1-II

COMPLEXITY FACTORS

	Aluminum	Magnesium and Stainless Steel	Titanium	Rene' 41 Inco 718	Lockalloy
Monocoque	0.6 (0.7)	1.0 (0.9)	1.6 (1.0)	1.6	1.8
Skin-Ring-Stringer	1.0	1.7 (1.2)	2.6 (1.5)	2.7	3.0
Integrally or Corrugation Stiffened	1.3	2.2 (1.5)	3.4 (2.0)	3.5	3.9
Honeycomb Sandwich	1.6 (2.0)	2.7 (2.4)	4.2 (3.0)	4.3	4.8
Truss Core Sandwich	1.8	3.1	4.7	4.9	5.4

The structure complexity factor for each of the programs is calculated by determining the percentage of structure for each of the materials and construction type, multiplying this percentage by the applicable complexity factor, and then summing the derived factors to obtain the overall program complexity factor. The complexity factor is important in the analysis since the more complex the material construction and the more difficult the material is to fabricate into the final shape, the longer it will take to produce the final article.

Structure weight is another important independent variable since it reflects, to some extent, the volume or size of the vehicle. Volume/size usually reflects structural complexity and complexity includes fittings, types of adjoinments, flanges, etc., which increase the quantity of necessary drawings. Volume/sizes may be seen to establish drawing requirements, the tooling requirements and thus the time required for design and fabrication of the structural article. In addition, larger vehicles, in most cases, require more subassembly breakbacks to facilitate the fabricating and final assembly operations. The structure weight is the weight of the total structure without any weights associated with any other subsystem. The determination of the structure weight is relatively easy if a detailed weight breakdown of the air vehicle is available. However, if the weight breakdown is not available, but the empty weight is known, the structure weight may be estimated by the utilization of empty weight versus structure weight curve presented in Figure 7.1-1. In the event AMPR (Aircraft Manufacturer's Planning Report) weight is known, the curve presented in Figure 7.1-2, aircraft empty weight versus AMPR weight, may be used to determine the empty weight. Again, using the Figure 7.1-1 curve, the structure weight is estimated knowing the empty weight.

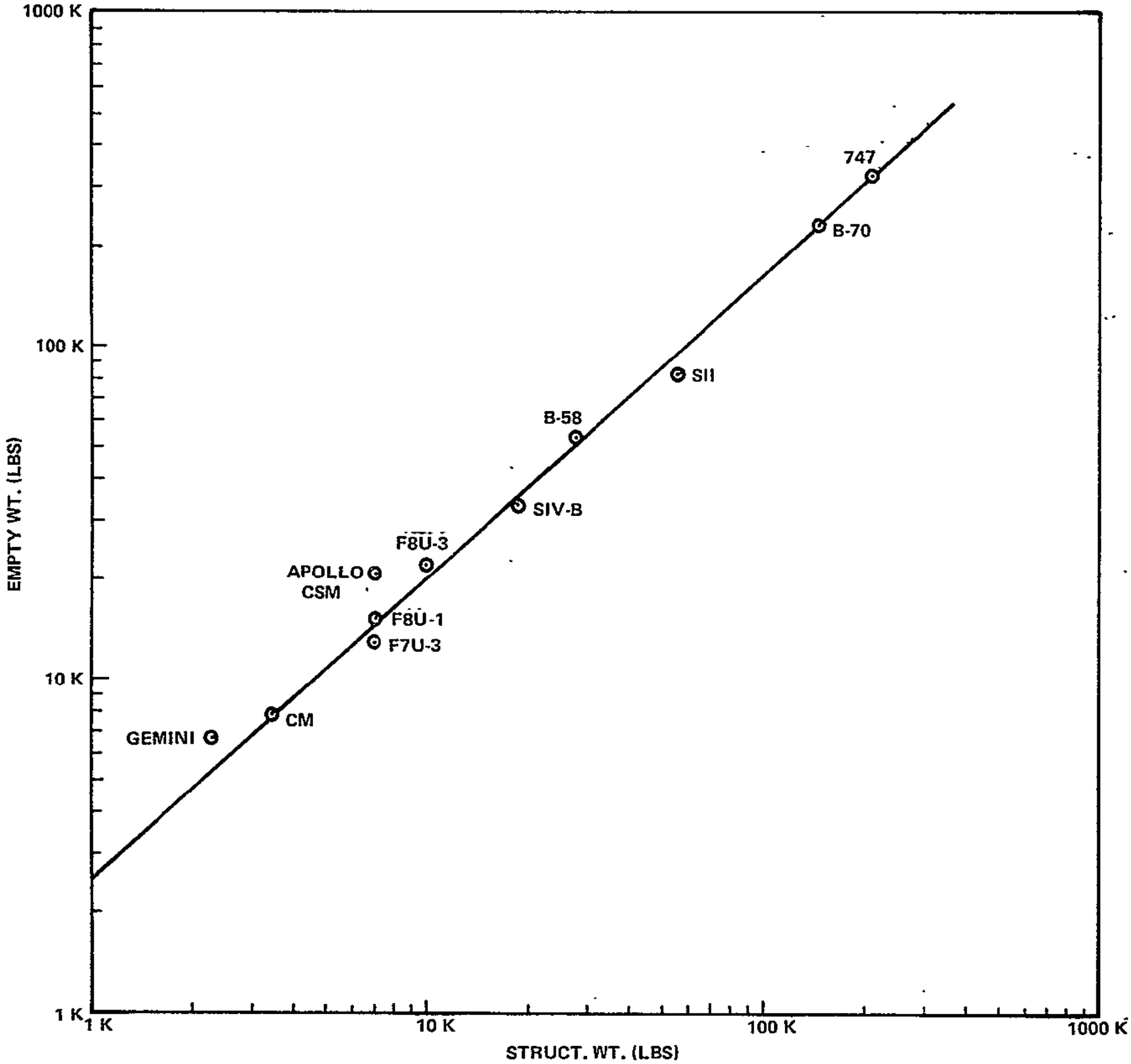


FIGURE 7.1-1 STRUCTURE WEIGHT AS A FUNCTION OF EMPTY WEIGHT

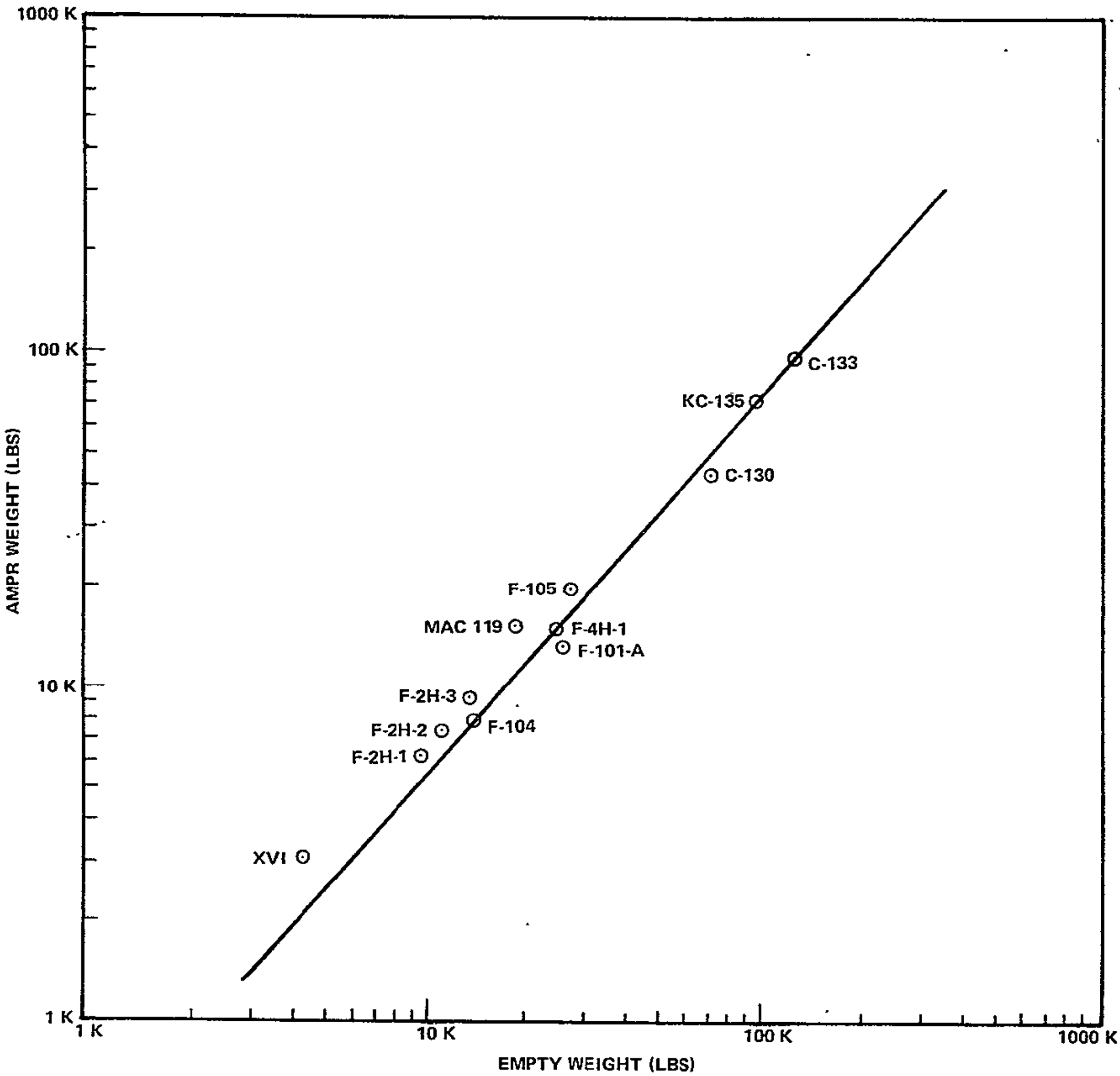


FIGURE 7.1-2 AIRCRAFT EMPTY WEIGHT AS A FUNCTION OF AMPR WEIGHT

Planform area is the area of the vehicle when one is looking down on the vehicle. In the case of boosters, such as SIC, the planform area is the area of the booster when one is looking at the side view, for example, the length times the diameter plus those areas associated with fins, if applicable. As in the case with structure weight, the planform area reflects the size and thus the tooling and subassembly fabrication requirements.

The velocity of the vehicle, in terms of Mach number, is the maximum velocity of the vehicle at its operating attitude in cases of aircraft (approximately 45,000 ft) or at the maximum dynamic pressure (maxQ) for launch vehicle. These conditions were used since this is, in most cases, when the vehicle is subjected to the highest loads to which the structure is designed and fabricated. In addition, the higher the velocity, the higher the aerodynamic heating rate and thus the requirements for heat resistant materials and/or more complex type construction in order to minimize total structure weight. The velocity of the vehicle is related to the complexity factor and, in essence, provides another independent variable to predict the time spans required for each of the various phases from Design to complete structure checkout.

Table 7.1-III presents the regression analysis input data for each of the various programs considered applicable for this study. Shown in this table are the independent variable previously discussed and the actual time spans (dependent) variables for each of the program phases (i.e., Design to 95% complete, Fabrication of the first flight article structure or structure test article, and span from completion of fabrication of the first structure to completion of structure checkout). These data were utilized by the VMSC regression analysis process to develop four types of equations which best fit the data. These equations are linear, log, log-linear and log-log. An analysis of the resulting equation was made and the best equation selected based on (1) the coefficient of correlation (high reflects best fit), (2) a small constant, (3) the independent variables are moving in the right direction (i.e., as weight goes up, time goes up), and (4) sound analytical judgement. Using the output data and the selected formula, a curve was then plotted for each program phase to show the results of the selected predicting formula (Yest) when compared with the actuals (Yact) experience on the various programs. Each program point was plotted and identified to show how the predicting equation fits that program. In the event the point falls to the left of the 45^{o} line (perfect fit line), it indicates the formula is predicting longer time than that which was actually incurred and conversely, when the point falls to the right of the 45^{o} line, the equation is predicting shorter time than that actually experienced.

TABLE 7.1-III STRUCTURE ANALYSIS INPUT DATA (MULTIPLE REGRESSION ANALYSIS)

PROGRAM	INDEPENDENT VARIABLES				DEPENDENT VARIABLES ACTUAL TIME SPANS (Y_{ACT})		
	COMPLEXITY FACTOR (C_X)	STRUCTURE WEIGHT (W_{STR})	PLANFORM AREA (A_{PLAN})	MACH NO. VELOCITY @ 45000 FT (V_{MN})	DESIGN TO 95% RELEASE (MO)	START MFG TO COMPLETE 1ST TEST OR FLT ARTICLE (MO)	COMPLETE MFG TO COMPLETE CHECKOUT (MO)
XF8U-1	1.200 (1.160*)	7.072	1.365	1.500	13.000	–	–
F8U-3	1.200 (1.160)	10.064	1.731	2.000	13.000	–	–
XC-142	1.000	12.500	2.933	.600	15.000	11.500	2.000
A7A	1.000	7.099	1.202	.880	10.500	–	–
F7U-3	1.200 (1.160)	7.004	1.330	1.219	12.000	–	–
XF7U-1	1.200 (1.160)	5.599	1.330	1.009	18.000	–	–
REG II	1.200 (1.160)	7.099	.341	2.000	15.000	–	–
REG I	1.000	4.099	.239	.900	11.000	–	–
ELECTRA	1.000	31.000	5.014	.800	20.500	–	–
747 EMP	1.000	17.506	1.632	.940	13.000	–	–
C-141 EMP	1.000	5.280	1.014	.800	14.000	–	–
DC-10	1.000	150.000	9.702	.890	22.000	16.000	2.000
747	1.000	245.000	12.191	.940	28.000	24.000	2.000
SST-BOE	1.809 (2.010)	240.000	10.691	3.000	52.000	24.000	2.000
X-15	2.419	6.832	.868	3.500	24.000	14.000	2.000
B-58	1.570 (1.480)	28.343	4.257	2.200	45.000	30.000	3.000
B-70	2.650 (2.530)	150.426	7.278	3.000	36.000	–	–
GEM GT1	2.400	2.327	.089	1.639	9.000	9.500	3.000
GEM MAN	2.400	2.327	.089	1.639	9.000	16.500	5.500
CSM 009	2.290 (2.000)	7.155	.264	1.599	16.500	19.000	4.500
CSM 012	2.290 (2.000)	7.155	.264	1.599	27.000	18.500	3.500
SIVB TEST	1.170 (1.130**)	19.181	1.273	1.599	12.000	17.500	2.000
SIU TEST	1.000	1.799	.065	1.599	10.000	4.500	2.000
SIC-1	.950	190.000	4.554	1.599	19.000	15.000	4.000
CONCORDE	1.139	108.000	5.141	2.049	–	24.000	2.000
SIVB 201	1.170 (1.130**)	19.181	1.273	1.599	–	14.500	1.500
SIU 201	1.000	1.799	.065	1.599	–	6.500	1.500
SII-1	1.139	57.125	2.688	1.599	–	15.000	2.000

* THE COMPLEXITY FACTOR IN BRACKETS WAS USED FOR DESIGN TIME SPAN
** THIS COMPLEXITY FACTOR WAS USED FOR MANUFACTURE AND TEST

In order to obtain the total time span from go-ahead to completion of first structure article checkout, it is necessary to account for overlap between Design and Manufacturing. For structure, manufacturing start occurs, based on the data presented in Total Program TER (7.6), when 60% of the design time span is complete. Thus, the total time span for structure is obtained by the following formula:

$$Yest = \text{Design time span } (.60) + \text{manufacturing time span} + \text{checkout time span}$$

For example, if the Design span is 36 months, the manufacturing span 24 months and checkout span is 3 months, the total span for first article is 48.6 months rather than 63 months, which would be the case if each phase was started at the completion of the previous phase.

Type I frequency distribution curves (histograms) were also plotted using the data presented in Table 7.1-III to show pictorially the historic trends of the programs used in this study. In addition, the mean, mode and range were derived based on these observations and a curve plotted through the distribution to show the cumulative percent of observations. These Type I distributions can be used to compare the predicting equations results with the historical data, as well as for use in estimating the time spans required given no independent variables.

3.0 RESULTS

The following equations were selected for the Structure TERs based on the regression analysis technique and the input data presented in the approach section of this TER. In each case the log equation was selected.

1. Program go-ahead to 95% design complete time span

$$Yest = 9.0410 + (10.1366)(\ln C_x) + (1.7269)(\ln W_{STR}) + (3.6531)(\ln A_{PLAN}) + (6.2300)(\ln V_{MN})$$

Where:

Cx is structure complexity factor.

W_{STR} is structure weight in thousands of pounds.

A_{PLAN} is Planform area in thousands of square feet.

V_{MN} is operating velocity at its operational altitude (approximately 45,000 ft) or maximum dynamic pressure (maxQ)for launch vehicles in Mach number

2. Start of Manufacturing to completion of first flight article or first test article time span

   $$Yest = 10.7034 + (8.1367)(\ln C_x) + (0.7450)(\ln W_{STR}) + (2.3240)(\ln A_{PLAN}) + (1.3283)(\ln V_{MN})$$

3. Completion of manufacture of first article to completion of checkout of first article (flight or test)

   $$Yest = 0.0953 + (2.3389)(\ln C_x) + (0.7714)(\ln W_{STR}) - (0.7287)(\ln A_{PLAN}) - (1.1012)(\ln V_{MN})$$

4. Program go-ahead to completion of checkout of first flight article or first test article time span

   Yest = (Design time span) (0.60) + (Manufacture time span) + (Checkout time span)

Tables 7.1-IV, 7.1-V, and 7.1-VI present the input data used and the results for design time span, manufacture time span, and checkout time span, respectively. In addition, these tables present the estimated time span for the Stage I and Stage II of the Advanced Space Transport Program, as well as the coefficient of correlation for the selected equations.

The following is a summary of the estimated time spans in months for Stage I and Stage II for each of the phases:

	Design	Manufacture	Verify Mfgrg. Process	Total
Stage I	37.6	24.7	2.4	49.7
Stage II	34.7	24.2	2.5	47.5

The total estimated structure time span from program go-ahead to complete checkout of the first flight article reflects a 60% design complete prior to start of manufacture.

Figures 7.1-3, 7.1-4, and 7.1-5 present Yest versus Yact for Design, Manufacture, and checkout phases, respectively, utilizing the selected equation and the data presented in Tables 7.1-IV, 7.1-V, and 7.1-VI.

Figures 7.1-6, 7.1-7, and 7.1-8 present the Type I distribution for each phase, i.e., design, manufacture and checkout, utilizing the Yact for each of the programs used in this study. The Yact data is presented in Table 7.1-I, as well as Tables 7.1-IV, 7.1-V, and 7.1-VI.

TABLE 7.1-IV STRUCTURE
PROGRAM GO-AHEAD TO 95% DESIGN RELEASE
(COMPUTER INPUT DATA AND RESULTS)

$$Y_{EST} = 9.0410 + (10.1366)\ (\mathrm{Ln}\ C_X) + (1.7269)\ (\mathrm{Ln}\ W_{STR}) + (3.6531)\ (\mathrm{Ln}\ A_{PLAN}) + (6.2300)\ (\mathrm{Ln}\ V_{MN})$$

PROGRAM	COMPLEXITY FACTOR (C_X)	STRUCTURE WEIGHT (W_{STR})	PLANFORM AREA (A_{PLAN})	VELOCITY @ 45000 FT (V_{MN})	TIME SPAN ACTUAL (Y_{ACT})	TIME SPAN CALCULATED (Y_{EST})
XF8U-1	1.160	7.072	1.365	1.500	13.000	17.586
F8U-3	1.160	10.064	1.731	2.000	13.000	20.856
XC-142	1.000	12.500	2.933	.600	15.000	14.152
A7A	1.000	7.099	1.202	.880	10.500	12.305
F7U-3	1.160	7.004	1.330	1.219	12.000	16.187
XF7U-1	1.160	5.599	1.330	1.009	18.000	14.624
REG II	1.160	7.099	.341	2.000	15.000	14.329
REG I	1.000	4.099	.239	.900	11.000	5.608
ELECTRA	1.000	31.000	5.014	.800	20.500	19.471
747 EMP	1.000	17.506	1.632	.940	13.000	15.390
C-141 EM	1.000	5.280	1.014	.800	14.000	10.575
DC-10	1.000	150.000	9.702	.890	22.000	25.269
747	1.000	245.000	12.191	.940	28.000	27.291
SST-BOE	2.010	240.000	10.691	3.000	52.000	41.082
X-15	2.419	6.832	.868	3.500	24.000	28.605
B-58	1.480	28.343	4.257	2.200	45.000	28.995
B-70	2.530	150.426	7.278	3.000	36.000	41.203
GEM GT1	2.400	2.327	.089	1.639	9.000	13.660
GEM MAN	2.400	2.327	.089	1.639	9.000	13.660
CSM 009	2.000	7.155	.264	1.599	16.500	17.528
CSM 012	2.000	7.155	.264	1.599	27.000	17.528
SIVB TEST	1.170	19.181	1.273	1.599	12.000	19.546
SIU TEST	1.000	1.799	.065	1.599	10.000	3.000
SIC-1	.950	190.000	4.554	1.599	19.000	26.048
STAGE I	1.330	409.826	14.279	2.460	—	37.641
STAGE II	1.420	153.056	8.412	2.460	—	34.671

COEF OF CORRELATION = .834

TABLE 7.1-V STRUCTURE
FROM START OF MANUFACTURE TO COMPLETION OF 1ST FLIGHT OR TEST ARTICLE
(COMPUTER INPUT DATA AND RESULTS)

$$Y_{EST} = 10.7034 + (8.1367)\,(\mathrm{Ln}\ C_X) + (0.7450)\,(\mathrm{Ln}\ W_{STR}) + (2.3240)\,(\mathrm{Ln}\ A_{PLAN}) + (1.3283)\,(\mathrm{Ln}\ V_{MN}).$$

PROGRAM	COMPLEXITY FACTOR (C_X)	STRUCTURE WEIGHT (W_{STR})	PLANFORM AREA (A_{PLAN})	VELOCITY @ 45000 FT (V_{MN})	TIME SPAN ACTUAL (Y_{ACT})	TIME SPAN CALCULATED (Y_{EST})
XC-142	1.000	12.500	2.933	.600	11.500	14.408
DC-10	1.000	150.000	9.702	.890	16.000	19.563
747	1.000	245.000	12.191	.940	24.000	20.531
CONCORDE	1.139	108.000	5.141	2.049	24.000	20.016
SST-BOE	1.809	240.000	10.691	3.000	24.000	26.580
X-15	2.419	6.832	.868	3.500	14.000	20.661
B-58	1.570	28.343	4.257	2.200	30.000	21.280
GEM GT1	2.400	2.327	.089	1.639	9.500	13.517
GEM MAN	2.400	2.327	.089	1.639	16.500	13.517
CSM 009	2.290	7.155	.264	1.599	19.000	16.440
CSM 012	2.290	7.155	.264	1.599	18.500	16.440
SIVB 201	1.130	19.181	1.273	1.599	14.500	15.086
SIVB-TEST	1.130	19.181	1.273	1.599	17.500	15.086
SIU 201	1.000	1.799	.065	1.599	6.500	5.413
SIU TEST	1.000	1.799	.065	1.599	4.500	5.413
SII-1	1.139	57.125	2.688	1.599	15.000	17.706
SIC-1	.950	190.000	4.554	1.599	15.000	18.343
STAGE I	1.300	409.826	14.279	2.460	—	24.695
STAGE II	1.550	153.056	8.412	2.460	—	24.162

COEF OF CORRELATION = .810

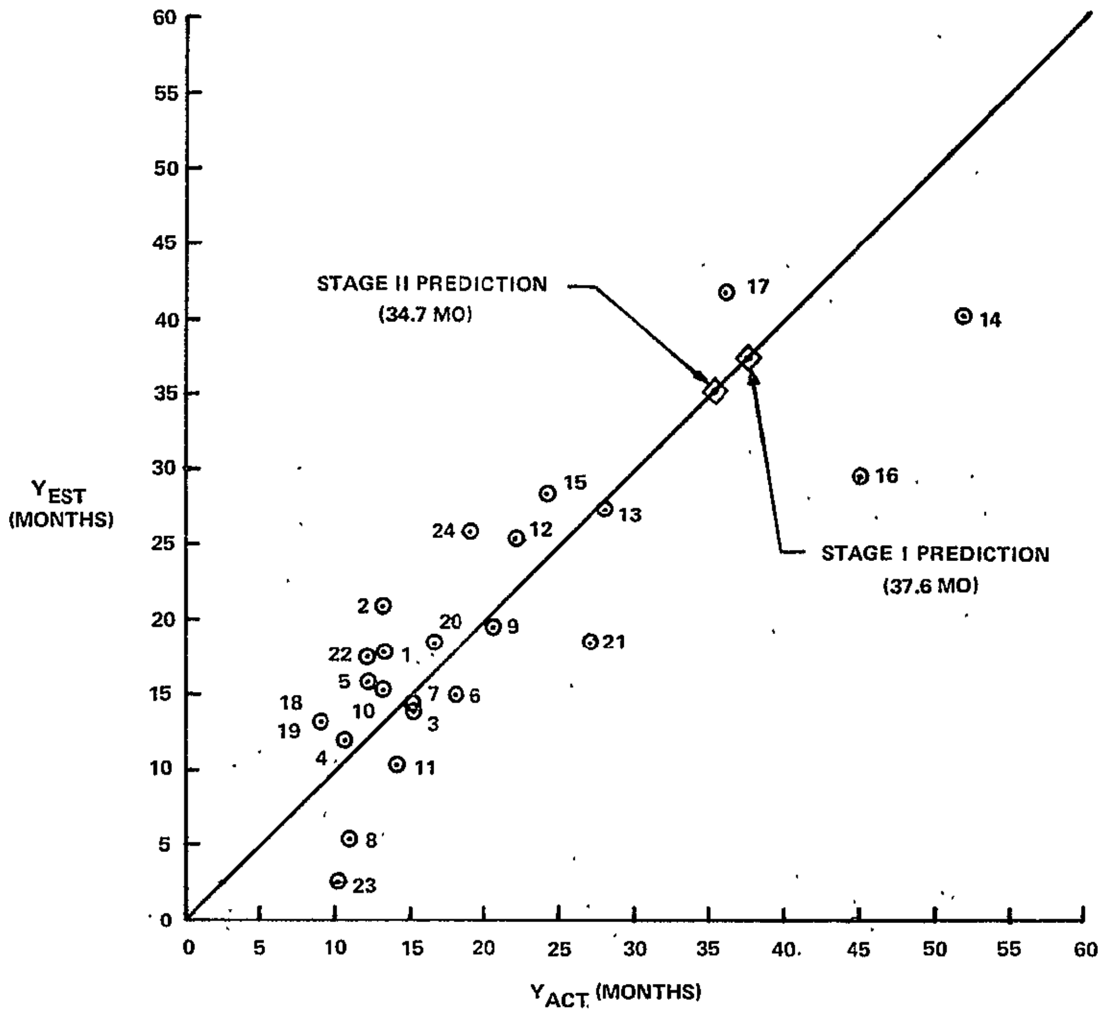
TABLE 7.1–VI STRUCTURE
COMPLETE MANUFACTURE TO COMPLETE CHECKOUT TIME SPAN
(COMPUTER INPUT AND RESULTS)

$$Y_{EST} = 0.0953 + (2.3389)(\ln C_X) + (0.7714)(\ln W_{STR}) - (0.7287)(\ln A_{PLAN}) - (1.1012)(\ln V_{MN})$$

PROGRAM	COMPLEXITY FACTOR (C_X)	STRUCTURE WEIGHT (W_{STR})	PLANFORM AREA (A_{PLAN})	VELOCITY @ 45000 FT (V_{MN})	TIME SPAN ACTUAL (Y_{ACT})	TIME SPAN CALCULATED (Y_{EST})
XC-142	1.000	12.500	2.933	.60	2.000	1.822
DC-10	1.000	150.000	9.702	.89	2.000	2.433
747	1.000	245.000	12.191	.94	2.000	2.585
CONCORDE	1.139	108.000	5.141	2.049	2.000	2.030
SST-BOE	1.809	240.000	10.691	3.000	2.000	2.775
X-15	2.419	6.832	.868	3.500	2.000	2.368
B-58	1.570	28.343	4.257	2.200	3.000	1.806
GEM GT1	2.400	2.327	.089	1.639	3.000	4.005
GEM MAN	2.400	2.327	.089	1.639	5.500	4.005
CSM 009	2.290	7.155	.264	1.599	4.500	4.004
CSM 012	2.290	7.155	.264	1.599	3.500	4.004
SIVB 201	1.130	19.181	1.273	1.599	1.500	1.966
SIVB TEST	1.130	19.181	1.273	1.599	2.000	1.966
SIU 201	1.000	1.799	.065	1.599	1.500	2.023
SIU TEST	1.000	1.799	.065	1.599	2.000	2.023
SII-1	1.139	57.125	2.688	1.599	2.000	2.284
SIC-1	.950	190.000	4.554	1.599	4.000	2.401
STAGE I	1.300	409.826	14.279	2.460	–	2.421
STAGE II	1.550	153.056	8.412	2.460	–	2.458

COEF OF CORRELATION = .733

$$Y_{EST} = 9.0410 + (10.1366)(\ln C_X) + (1.7269)(\ln W_{STR}) + (3.6531)(\ln A_{PLAN}) + (6.2300)(\ln V_{MN})$$



WHERE:

C_X = COMPLEXITY FACTOR
W_{STR} = STRUCTURE WEIGHT (K LBS)
A_{PLAN} = PLANFORM AREA (K FT^2)
V_{MN} = VELOCITY @ 45,000 FT (MACH NO.)

STAGE I PARAMETERS	STAGE II PARAMETERS
C_X = 1.330	C_X = 1.420
W_{STR} = 409.826	W_{STR} = 153.056
A_{PLAN} = 14.279	A_{PLAN} = 8.412
V_{MN} = 2.460	V_{MN} = 2.460

CODE:

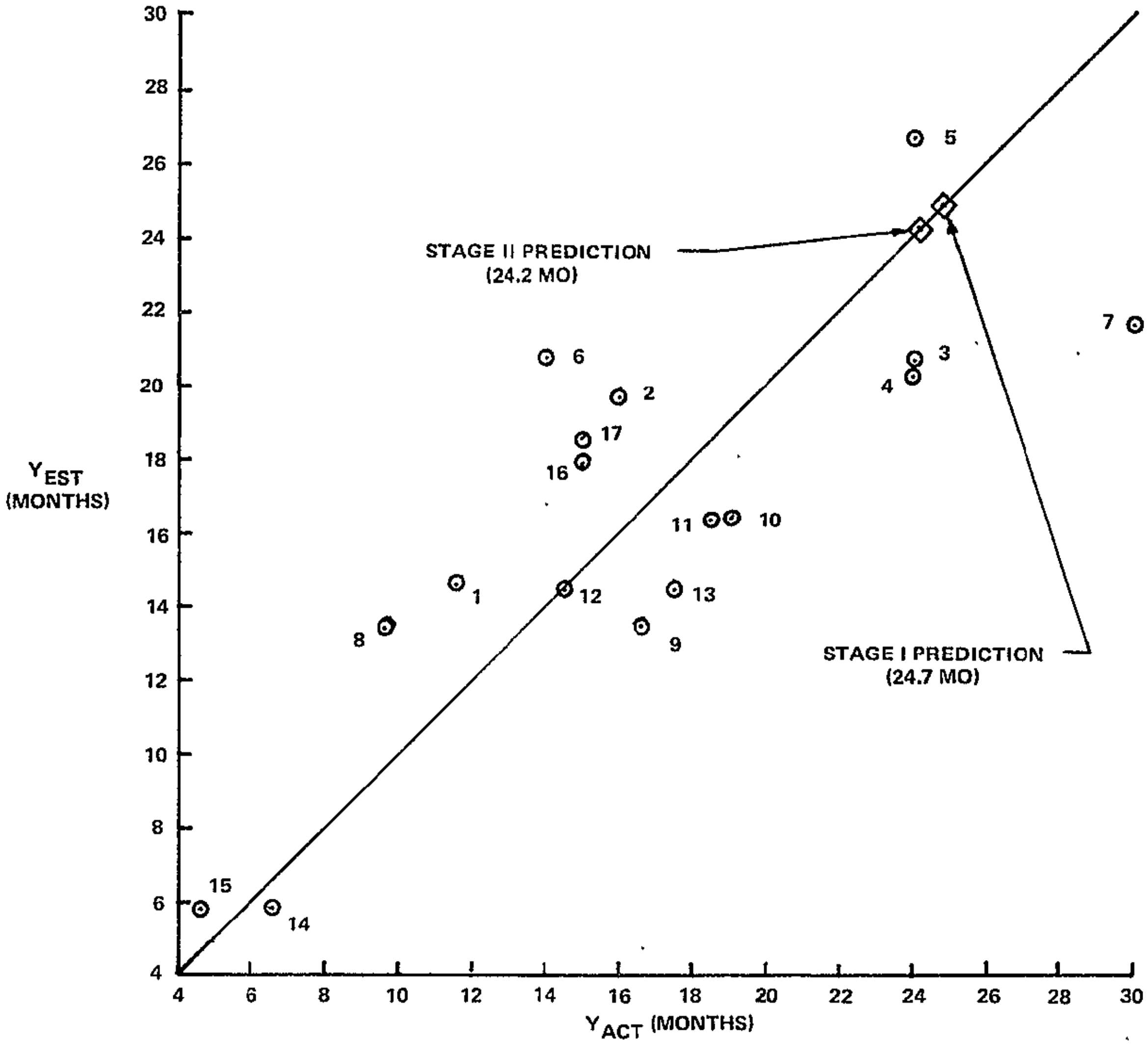
1. XF8U-1
2. F8U-3
3. XC142
4. A7A
5. F7U3
6. XF7U-1
7. REGULUS II
8. REGULUS I
9. ELECTRA
10. 747 EMP
11. C-141 EMP
12. DC10
13. 747
14. SST (BAC)
15. X-15
16. B58
17. B70
18. GEMINI (GT-1)
19. GEMINI (MANNED)
20. CSM (NO. 009)
21. CSM (NO. 012)
22. SIVB TEST
23. S-1U TEST
24. S1C-1

COEF OF CORRELATION = .834

STANDARD DEVIATION OF ERROR = 6.2 MONTHS

FIGURE 7.1-3 STRUCTURE Y_{ACT} VERSUS Y_{EST}
PROGRAM GO AHEAD TO 95 PERCENT RELEASE

$$Y_{EST} = 10.7034 + (8.1367)(\ln C_X) + (0.7450)(\ln W_{STR}) + (2.3240)(\ln A_{PLAN}) + (1.3283)(\ln V_{MN})$$



WHERE:

C_X = COMPLEXITY FACTOR

W_{STR} = STRUCTURE WEIGHT (K LBS)

A_{PLAN} = PLANFORM AREA (K FT^2)

V_{MN} = VELOCITY @ 45,000 FT (MACH NO.)

STAGE I PARAMETERS	STAGE II PARAMETERS
C_X = 1.300	C_X = 1.550
W_{STR} = 409.826	W_{STR} = 153.056
A_{PLAN} = 14.279	A_{PLAN} = 8.412
V_{MN} = 2.460	V_{MN} = 2.460

CODE:

1. XC142
2. DC10
3. 747
4. CONCORDE
5. SST (BAC)
6. X-15
7. B58
8. GEMINI (GT-1)
9. GEMINI (MANNED)
10. CSM (NO. 009)
11. CSM (NO. 012)
12. SIVB (NO. 201)
13. SIVB (TEST)
14. S-1U (NO. 201)
15. S-1U (TEST)
16. SII-1
17. S1C-1

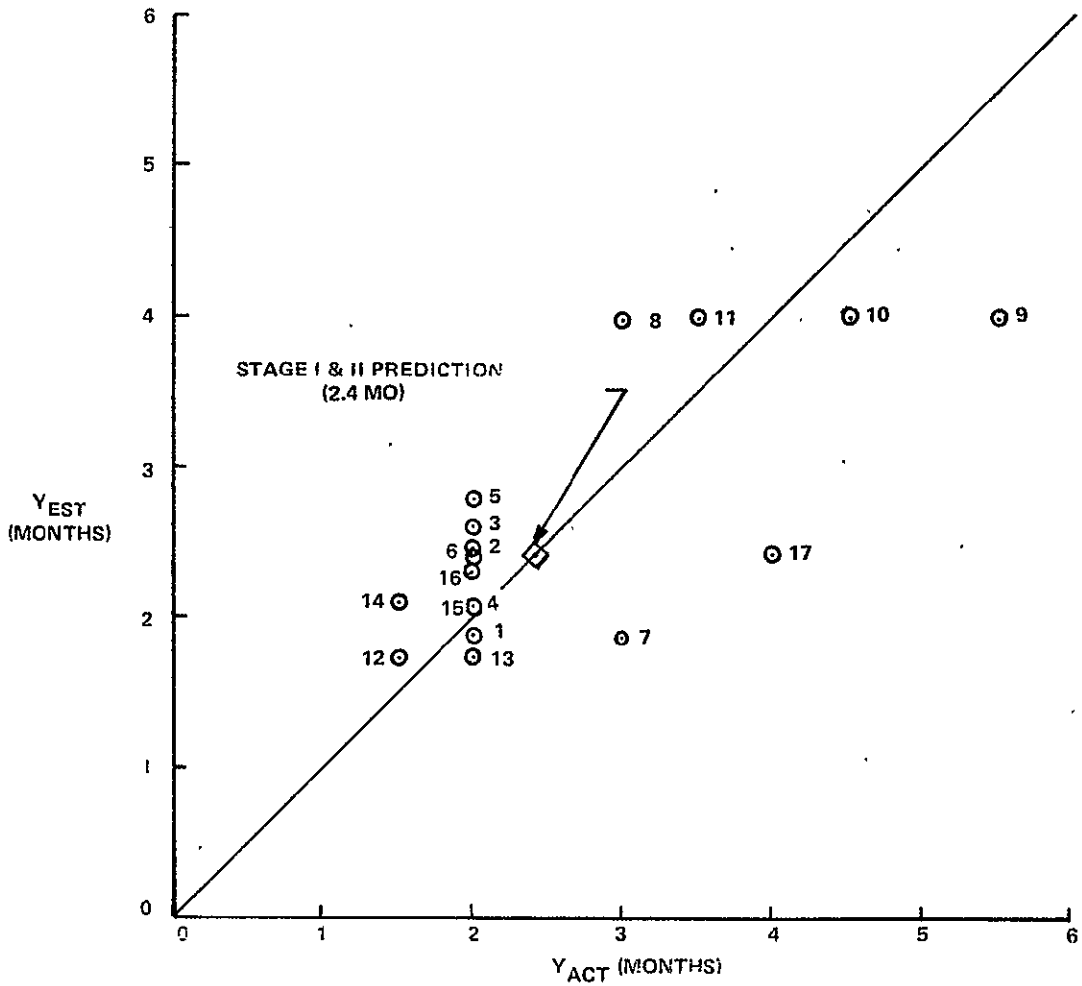
COEF OF CORRELATION = .810

STANDARD DEVIATION OF ERROR = 3.9 MONTHS

FIGURE 7.1-4 STRUCTURE Y_{ACT} VERSUS Y_{EST}

START OF MANUFACTURE TO COMPLETE 1ST FLIGHT ARTICLE OR 1ST TEST ARTICLE

$$Y_{EST} = 0.0953 + (2.3389)(\ln C_X) + (0.7714)(\ln W_{STR}) - (0.7287)(\ln A_{PLAN}) - (1.1012)(\ln V_{MN})$$



WHERE

C_X = COMPLEXITY FACTOR

W_{STR} = STRUCTURE WEIGHT (K LBS)

A_{PLAN} = PLANFORM AREA (K FT^2)

V_{MN} = VELOCITY @ 45,000 FT (MACH NO.)

STAGE I PARAMETERS

C_X = 1.300

W_{STR} = 409.826

A_{PLAN} = 14.279

V_{MN} = 2.460

STAGE II PARAMETERS

C_X = 1.550

W_{STR} = 153.056

A_{PLAN} = 8.412

V_{MN} = 2.460

CODE:

1. XC 142
2. DC 10
3. 747
4. CONCORDE
5. SST (BAC)
6. X15
7. B58
8. GEMINI (GT-1)
9. GEMINI (MANNED)
10. CSM (NO. 009)
11. CSM (NO. 012)
12. SIVB (NO. 201)
13. SIVB (TEST)
14. SIU (NO. 201)
15. SIU (TEST)
16. SII-1
17. SIC-1

COEF OF CORRELATION = .733

STANDARD DEVIATION OF ERROR = 0.8 MONTHS

FIGURE 7.1-5 STRUCTURE Y_{ACT} VERSUS Y_{EST}

MANUFACTURE COMPLETE TO CHECKOUT COMPLETE TIME SPAN

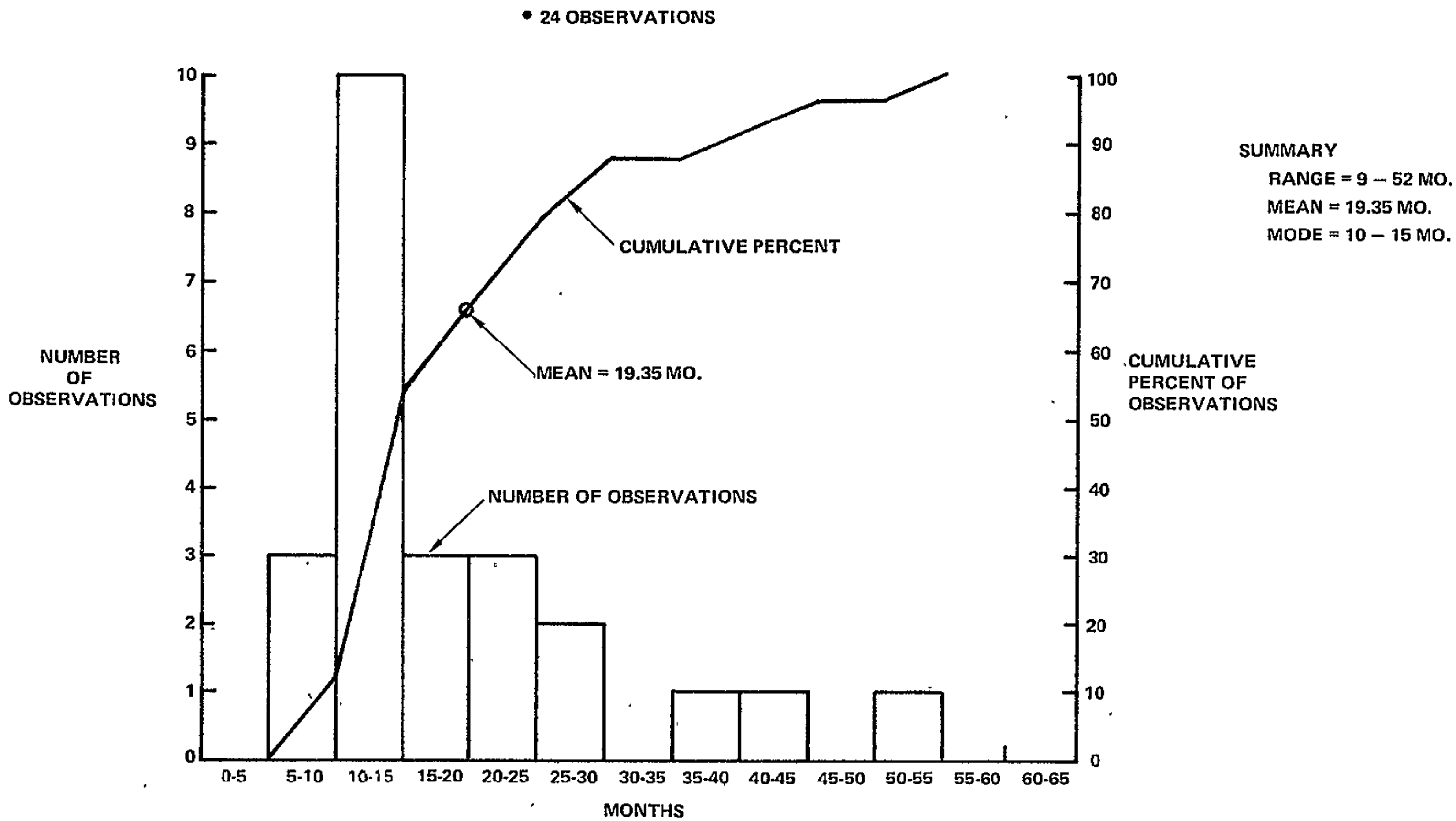
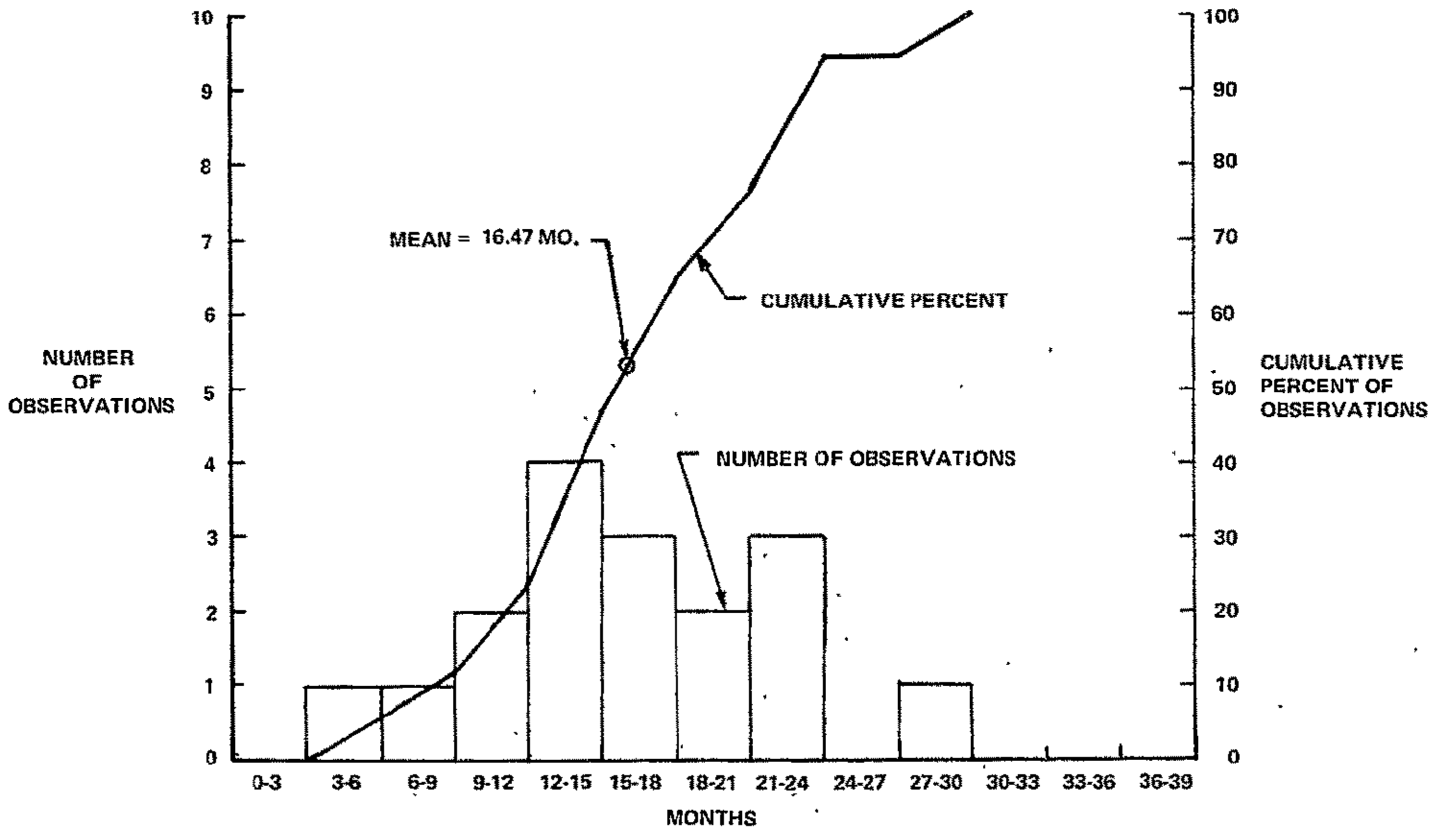


FIGURE 7.1-6 STRUCTURE TYPE I DISTRIBUTION

PROGRAM GO-AHEAD TO 95% DESIGN RELEASE SPAN TIME

• 17 OBSERVATIONS



SUMMARY
RANGE = 4.5 – 30 MO.
MEAN = 16.47 MO.
MODE = 12 – 15 MO.

FIGURE 7.1–7 STRUCTURE TYPE I DISTRIBUTION
MANUFACTURE GO-AHEAD TO COMPLETE 1ST STRUCTURE TIME SPAN

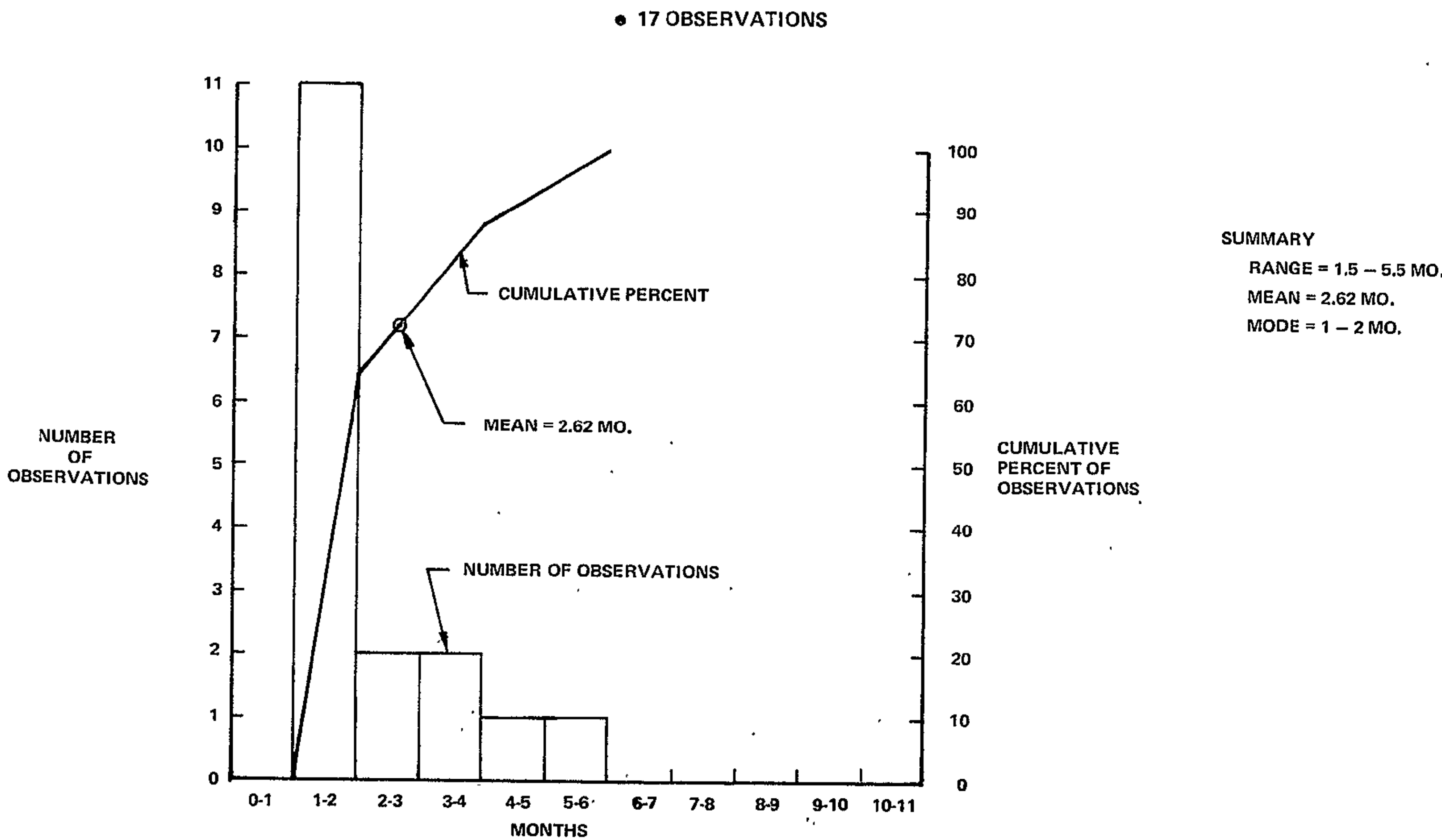


FIGURE 7.1–8 STRUCTURE TYPE I DISTRIBUTION
COMPLETE MANUFACTURE 1ST STRUCTURE TO COMPLETE CHECKOUT

Figures 7.1-9 and 7.1-10 show by bar graph the major milestones associated with the design and the manufacturing phases based on five programs which data to this level of detail was available. The average of these five programs is also presented in these figures to give an indication of when these major milestones might be expected. As can be seen by Figure 7.1-9, master lines are available approximately 55% after program go-ahead, initial design release of structural element occur approximately 60% after program go-ahead, and final structural design loads are available approximately 65% after go-ahead. In Figure 7.1-10, the start of major subassembly occurs approximately 30% after manufacture go-ahead, start final assembly occurs 62% after manufacture go-ahead and start checkout occurs approximately 87% after manufacture go-ahead for the first structural (or flight) article.

During the early conceptual and/or preliminary design phase, the estimating analyst may not know the values for all the independent variables utilized in the selected equations. In this case, the following formulas may be used which utilize only structure complexity factor and structure weight. The results attained from these equations differ slightly from those obtained from the previously selected equations and by the same token, the coefficient of correlation is also lower. As the design progresses and more data becomes available, it is recommended that the selected equations be used for estimating the time spans.

1. Program go-ahead to 95% design release time span

   $$\text{Yest} = 1.3719 + (13.1433)(\text{Ln } C_x) + (5.2927)(\text{Ln } W_{STR})$$

   This formula predicts 36.96 months and 32.61 months for Stage I and Stage II, respectively. The coefficient of correlation was 0.792.

2. Start manufacture to completion of the first structure (flight or test article) time span

   $$\text{Yest} = 4.2039 + (8.8039)(\text{Ln } C_x) + (3.1217)(\text{Ln } W_{STR})$$

   This formula predicts 25.29 months and 23.77 months for Stage I and Stage II, respectively. The coefficient of correlation was 0.783.

3. Complete manufacture of first structure (flight article or test article) to complete structure checkout time span

   $$\text{Yest} = 2.0369 + (1.6982)(\text{Ln } C_x) + (0.0007)(\text{Ln } W_{STR})$$

   This formula predicts 2.49 months and 2.78 months for Stage I and Stage II, respectively. The coefficient of correlation was 0.569.

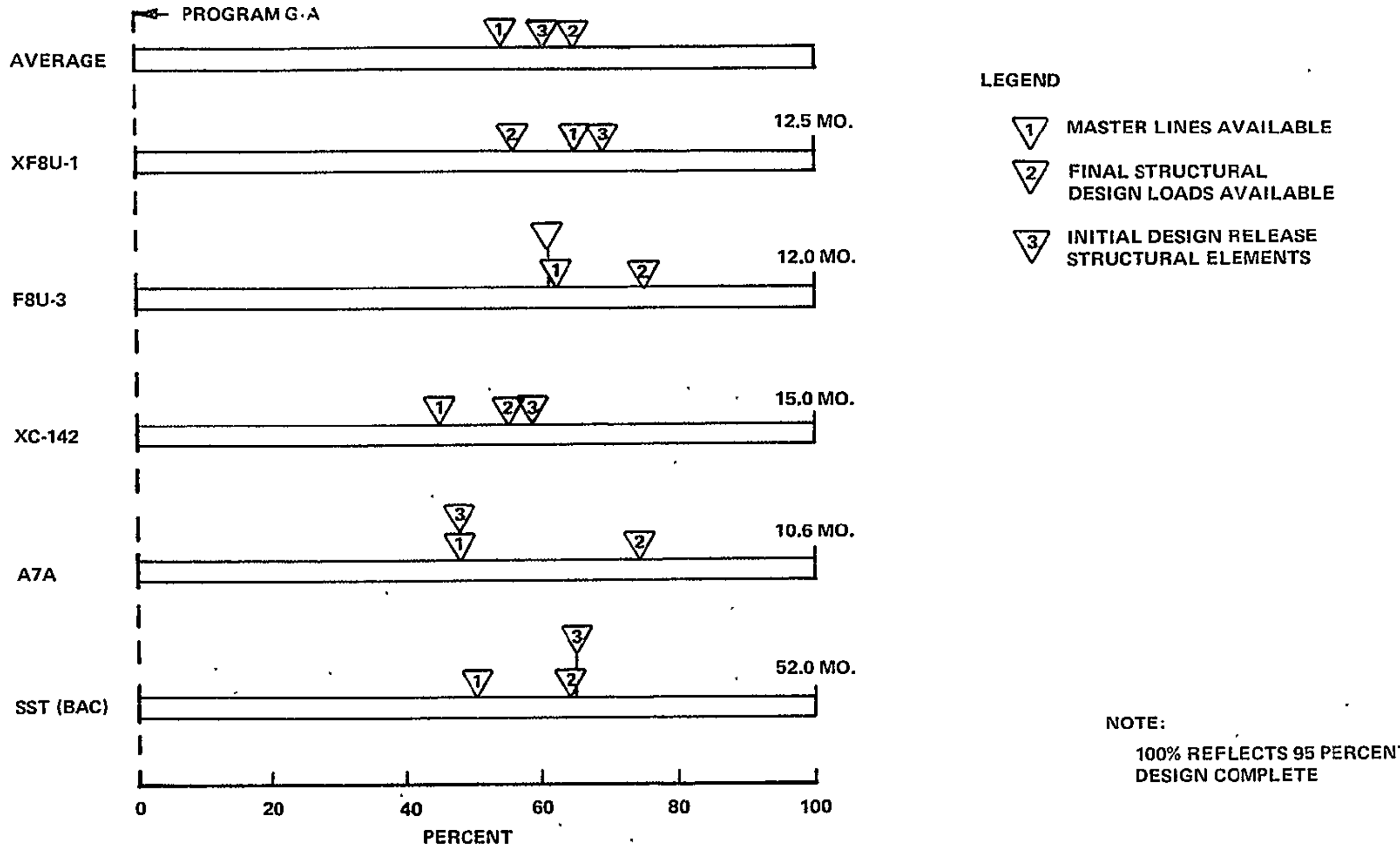


FIGURE 7.1–9 STRUCTURE
ENGINEERING DESIGN SPAN TIME
(FROM PROGRAM GO-AHEAD)

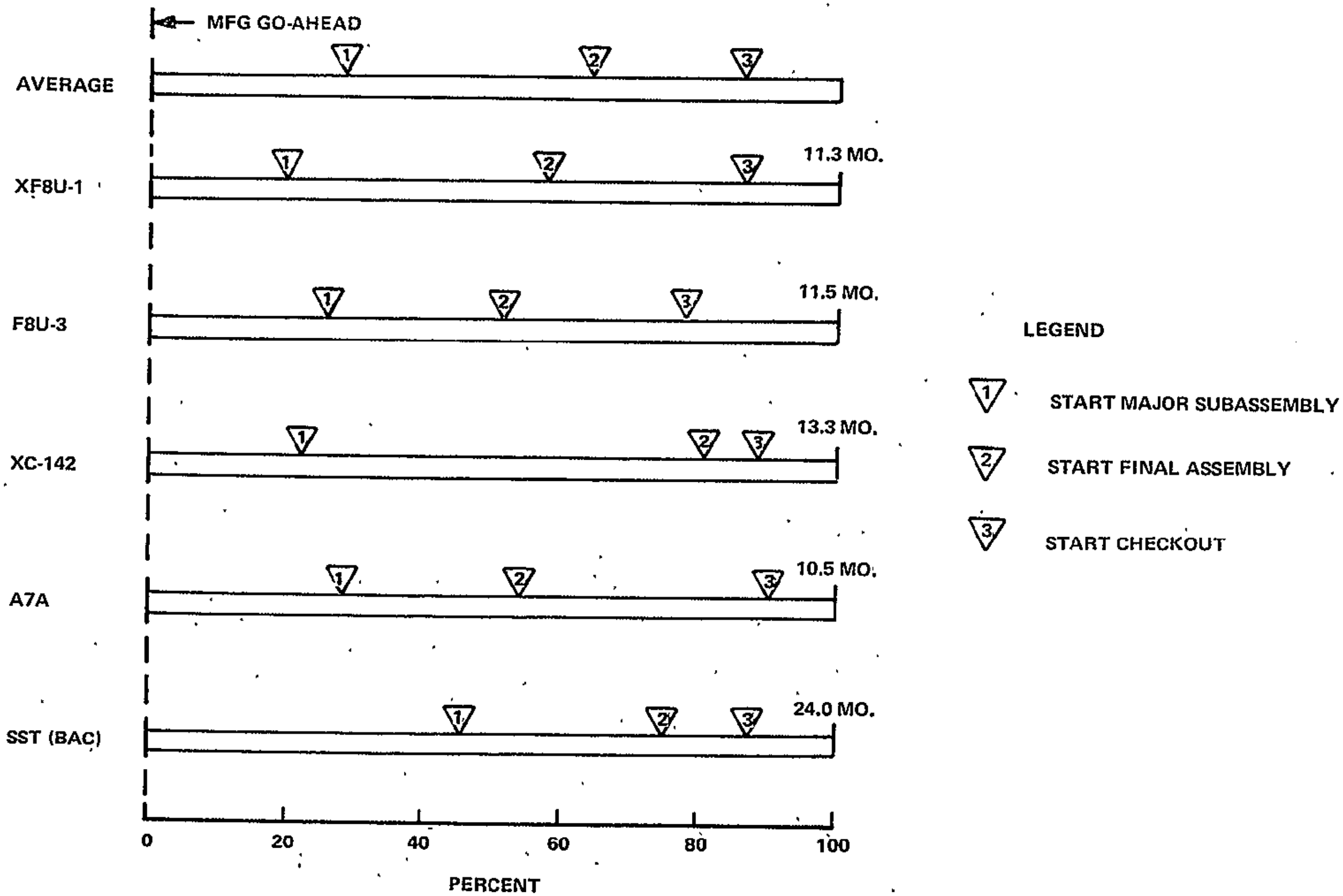


FIGURE 7.1—10 STRUCTURE
MANUFACTURE SPAN TIME 1ST STRUCTURAL (OR FLIGHT) ARTICLE

4. Total span from program go-ahead to complete checkout of the first structure

   Yest = Design span (.60) + manufacture span + checkout span

   This formula predicts 49.96 months and 46.12 months for Stage I and Stage II, respectively.

4.0 LIMITATIONS

The user of this methodology for estimating time spans should be aware that the results obtained are directly related to the size and accuracy of the input data used to derive the mathematical expressions. For example, in this study the program selected for input data were considered representative of the Stage I and Stage II air vehicles. If sounding-rocket estimates were being made, the data base should encompass sounding rocket type vehicles rather than high performance and large aircraft, large launch vehicles and spacecraft. In addition, the analyst should thoroughly review the derived estimates and ascertain if they are logical and realistic when compared to Type I distribution historical data. Other things which should be considered are advances in the state-of-the-art of new materials and new technologies in structural engineering and manufacturing such as bonding or chemical milling, which could have an impact on the predictions.

VOUGHT MISSILES AND SPACE COMPANY - TEXAS

Departmental Correspondence

SUBJECT:	PROGRAM TIME TO FIRST FLIGHT; ORBITER VS. BOOSTER AND COMPLEXITY FACTOR FOR DESIGN VS. TYPE OF CONSTRUCTION AND MATERIAL	MEMO:	3-53400/1IM-36
		DATE:	21 June 1971

To: Mr. D. P. Crain

cc: Messrs. H. H. Edwards
W. F. Goehring
D. M. While

A. Program Time to First Flight, Orbiter versus Booster

1. It is anticipated that the detailed design of these two vehicles will be started simultaneously and be based on a preliminary design that establishes geometry, weight, interfaces, and performance parameters.

2. Both vehicles will be qualified in the atmospheric environment as aircraft first; therefore, design and manufacturing time to first flight will be governed by the airplane systems. The booster design, construction, and first flight will follow that of the Orbiter at a time interval proportional to the differences in size.

3. The space systems for both vehicles will continue in development and qualification while the vehicles are being qualified as aircraft.

4. The Orbiter will not be qualified as a space vehicle until some time after the Booster vehicle due to the added complexity of the space environmental systems and the payload handling and docking requirements.

B. Complexity Factor for Design versus Type of Construction and Material

1. Table 1 represents the relative systems design effort for the various types of materials, and types of construction using semi-monocoque construction in aluminum material as a reference base. These factors are a good approximation of the complexity factor for the total Engineering Department effort.

2. The Orbiter will be constructed from all of the materials and types of construction shown in Table 1 with the majority of the surface material being titanium, stainless steel, and RPP. The type of construction will be semi-monocoque, integrally-stiffened, and honeycomb for primary structure.

3. The Booster will be constructed primarily from aluminum with integrally-stiffened skin construction for primary structure and semi-monocoque for fairings.

H. I. Knight

HIK/jb

COMPLEXITY FACTOR FOR SYSTEMS DESIGNS EFFORT

TYPE OF CONSTRUCTION \ MATERIAL	ALUMINUM	TITANIUM	STAINLESS-STEEL	FIBERGLAS-LAMINATE	RPP
MONOCOQUE	.7	1.0	.9	.9	---
SEMI-MONOCOQUE	1.0	1.5	1.2	1.3	---
INTEGRALLY-STIFFENED	1.3	2.0	1.5	1.7	4.0
HONEYCOMB	2.0	3.0	2.4	2.6	---

7.2 LIQUID ROCKET ENGINE

1.0 SCOPE

The purpose of this TER is to present a method for estimating the time required to design, fabricate, test and qualify a new liquid propellant, rocket engine.

2.0 APPROACH

To develop a TER for high thrust liquid engines, VMSC has collected historical data on six previous engine programs. Table 7.2-I presents a summary of the engine characteristics and associated time spans required to complete various program phases. The independent variables used to predict time include engine thrust, dry weight, maximum rated duration (burntime), flow rate and envelope. It should be noted that the independent variables in Table 7.2-I represent only those variables ultimately used in the estimating equations. Other parameters considered for use in this study included specific impulse, type of propellant, a factor for a reusable engine, and nozzle expansion ratio. These variables were not used because they did not appreciably enhance the ability of the model to predict time. Those variables which were identified to be primary schedule drivers are weight, envelope, and rated duration while flow rate and thrust exhibited only secondary ability to explain schedule variance.

2.1 The schedule milestones which were common to six engine programs are:

(1) Program Go-Ahead

(2) Completion of the First Main Stage Engine Test

(3) First Engine(s) Delivery

(4) Completion of Preliminary Flight Rating Tests (PFRT)

(5) Completion of Phase I Qualification Testing (QUAL I Testing)

2.2 For purposes of this study, the above scheduled milestones are defined as follows:

(1) Program Go-Ahead - The date on which formal program award was made. Very often engine contractors have completed some percentage of applicable work at program go-ahead, however, it is extremely difficult to determine when this actually started and what impact it might have had on the overall program schedule.

TABLE 7.2-I LIQUID ROCKET ENGINE CHARACTERISTICS AND SPAN TIMES

OBSERVATION	INDEPENDENT VARIABLES					DEPENDENT VARIABLES (MOS.)			
ENGINE PROGRAM	THRUST (K#)	DRY WT. (#)	BURNTIME (SEC)	FLOWRATE (#/SEC)	ENVELOPE (IN²)	G/A TO 1ST TEST	C - 1ST TEST TO 1ST DELIV.	C - 1ST TEST C-PFRT	C - PFRT TO C-QUAL I
H-1	165	1,632	165	455	6,082	4	12	–	–
H-1	188	1,632	165	505	6,082	4	37	44	7
F-1	1522	18,340	165	3922	34,692	30	28	40	9
J-2S	230	2,754	500	457	9,620	16	34	34	21
[1] XLR-87-AJ-5	430	3,258	165	1087	11,036	8	22	18	27
XLR-91-AJ-5	100	1,102	270	204	7,289	8	22	12	32
RL-10-A1	15	273	470	30	2,612	9	22	27	9
SPACE TRANSPORT MAIN ENGINE	550	7,730	500	2376	16,059	COMPUTE FROM DERIVED EQUATIONS			

NOTES:

[1] THIS TURBOPUMP FED ENGINE CONSIST OF TWO GIMBAL MOUNTED REGENERATIVELY COOLED THRUST CHAMBER ASSEMBLIES, TWO TURBOPUMP DRIVE ASSEMBLIES, TURBOPUMP GEARBOX PRESSURIZATION SYSTEM, AND MISSILE PROPELLANT TANK PRESSURIZATION SYSTEMS ALL OF WHICH ARE MOUNTED ON A COMMON FRAME. FOR PURPOSES OF THIS STUDY, THE ENTIRE ASSEMBLY HAS BEEN CONSIDERED A SINGLE ENGINE.

(2) Completion of the First Main Stage Engine Test - The date on which the engine injector and turbopump assemblies (development test articles) are first successfully tested. Since these two assemblies are program critical, it is imperative that the selected injector/pump concept be verified early in the program. Engine run time in this testing phase is by necessity of short duration. For example, a typical single run may last five seconds.

(3) First Engine(s) Delivery - That date on which the initial engine or set of engines are delivered to the procuring agency or contractor. At this time, the engines may begin the clustered qualification testing phase.

(4) Completion of Preliminary Flight Rating Tests (PFRT) - The date on which the prototype engine successfully completes the first phase of qualification testing. PFRT is conducted to demonstrate the suitability of the rocket engine for use in experimental vehicle (R&D) testing. The engine is, however, designed to comply with Qualification test requirements (i. e., to qualify the engine for the design environment). In addition, the required status of development and substantiation is limited to that established by the PFRT requirements which may be incomplete with respect to qualification test standards. Preliminary flight rating is predicated on successful completion of an endurance run of some predetermined time (for example, fifty seconds). It should be noted that before PFRT can begin, each test engine has completed Quality Conformance (acceptance) tests.

(5) Completion of Phase I Qualification Testing - The date on which the rocket engine successfully completes the model qualification test program. The purpose of qualification tests is to demonstrate the suitability of the rocket engine for production by obtaining data on performance repeatability, reliability, durability, and operating life. Before this testing phase is completed, the rocket engine has been demonstrated at maximum rated duration. In the normal course of manufacturing, certain other qualification tests are conducted. These tests include Quality Evidence tests which are conducted to demonstrate that materials, parts, and components comply with engine manufacturer's specifications and drawings and Change Verification tests which are conducted only when changes in design, materials, or processing were incorporated following completion of PFRT or Qualification tests.

(6) General Notes of Explanation - The following notes of explanation are provided only to give analyst additional information pertinent to the rocket engine program.

(a) The pressurization and feed system essentially follows the same program flow as indicated in steps one (1) thru five (5).

(b) Clustered engine qualification test activity can begin with the delivery of the first set of engines and will continue until the entire propulsion subsystem has been flight qualified to the satisfaction of the procuring agency or contractor.

(c) The Limitations section of this TER presents additional information about the program time spans not included by this TER.

2.3 These scheduled milestones were then used to reflect the time span required to complete the given milestone, thus yielding the dependent variables on Table 7.2-I. The above schedule span times are divided into end-to-end segments, that is, there is no overlap between spantimes; therefore, to calculate the total time required to complete QUAL I Testing, one must first determine the time from program go-ahead to completion of the first main stage test, add that to the time between completion of the first test and completion of PFRT, and finally add the time between completion of PFRT to the completion of QUAL I Testing. The result of this A + B + C process equals the total time required to complete vendor qualification testing on a new engine. It should be further noted that it is not necessary to add the spantime for first engine delivery to arrive at a total propulsion program estimate. This milestone was included only to provide the analyst additional scheduling information.

3.0 RESULTS

The recommended time estimating equations for a large liquid engine may be summarized as follows:

(1) From contractor go-ahead to completion of the first main stage, single engine test:

$$\text{Yest} = -5.301 + (.0004)\,(\text{Dry Weight}) + (.0254)\,(\text{Burntime}) + (.0008)\,(\text{Envelope}) - (.0015)\,(\text{Flow Rate})$$

Where:

Dry Weight is expressed in pounds.
Burntime is maximum rated duration expressed in seconds.
Envelope is engine length times diameter expressed in square inches.
Flow Rate is expressed in pounds of oxidizer per second.
Thrust is expressed in thousands of pounds at sea level.

(2) From completion of the first main stage test to delivery of the first unqualified engine(s).

Yest = -9.2185 - (.0057) (Dry Weight) + (.0528) (Burntime) + (.003) (Envelope) + (.0071) (Flow Rate)

(3) From completion of the first main stage test to completion of PFRT.

Yest = 12.3344 + (.0026) (Dry Weight) + (.0455) (Burntime) -(.0017) (Envelope) + (.0081) (Flow Rate)

(4) From completion of PFRT to completion of QUAL I Testing.

Yest = -14.0517 - (.0126) (Dry Weight) + (.0097) (Burntime) + (.0073) (Envelope) - (.0001) (Flow Rate)

Table 7.2-II presents the Advanced Space Transport main engine results using the above equations.

TABLE 7.2-II

PROPULSION SUBSYSTEM RESULTS

	From Go-Ahead To Completion of First Engine Test (Mos)	From Completion of 1st Engine Test to Delivery of First Engine (Mos)	From Completion First Engine Test to Completion of PFRT (Mos)	From Completion of PFRT to QUAL 1 Testing (Mos)
Spantime of the Event	20.5	40.7	46.3	14.5
Months After Program Go-Ahead to Complete Event	20.5	61.2	66.8	81.3

3.1 Figures 7.2-1, 7.2-2, 7.2-3, and 7.2-4 provide a summary of each of the above equations, the coefficient of correlation, the independent variables used for the advanced space transport main engine, and a comparison of how well the selected equations predict each of the six programs used in the data base. If there had been perfect correlation and the equation explained all variations, then all of the data points would have fallen on the 45° slope line. Data points which lie above the line indicate the equation has predicted too much time when compared to the actual and; conversely, if the data point lies below the line, the equation has predicted too little time when compared to actual schedule performance.

3.2 As often is the case, the advanced program analyst will not have all the required input variables for a given subsystem. Typically, only two performance variables are known about a new liquid engine, these are thrust and dry weight. The following equations present a method for determining expected schedule time spans with these two variables:

(1) From go-ahead to completion of the first main stage test.

Yest = -130.174 - (31.592) (Ln Thrust) + (40.167) (Ln Dry Weight) + (.031) (Thrust) - (.0027) (Dry Weight)

Coefficient of Correlation = .988

(2) From completion of the first test to delivery of the first unqualified engine.

Yest = -256.475 - (61.426) (Ln Thrust) + (79.680) (Ln Dry Weight) + (.089) (Thrust) - (.01) (Dry Weight)

Coefficient of Correlation = .887

(3) From completion of the first test to completion of PFRT

Yest = -260.644 - (66.356) (Ln Thrust) + (83.389) (Ln Dry Weight) + (.08) (Thrust) - (.008) (Dry Weight)

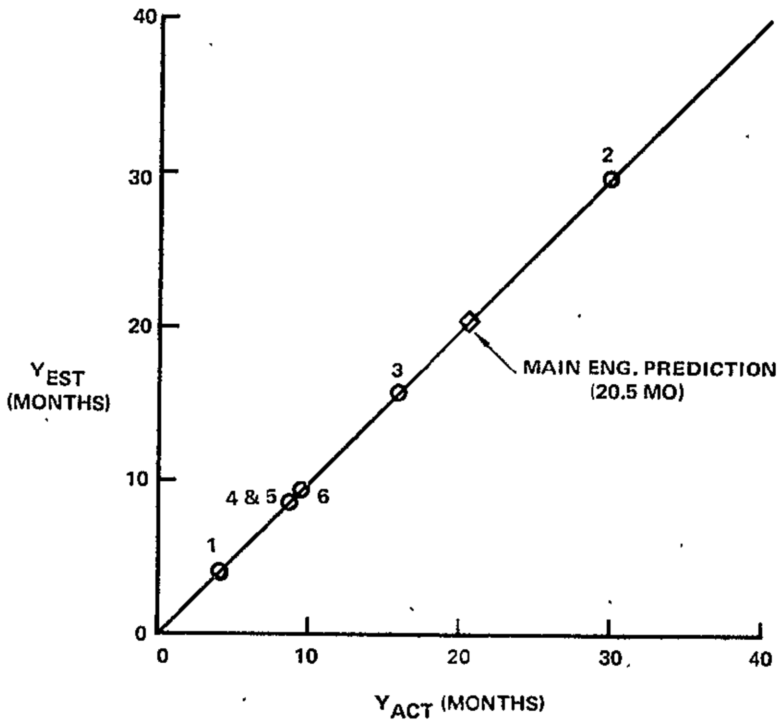
Coefficient of Correlation = .954

(4) From completion of PFRT to completion of QUAL I Testing

Yest = -6.763 + (3.732) (Ln Thrust) + (1.424) (Ln Dry Weight) + (.015) (Thrust) - (.003) (Dry Weight)

Coefficient of Correction = .594

$$Y_{EST} = -5.301 + (0.0004)(W_{DRY}) + (0.0254)(B_T) + (0.0008)(E_V) - (0.0015)(F_R)$$



WHERE:

W_{DRY} = ENGINE DRY WEIGHT (LBS)
B_T = MAX. RATED BURNTIME (SEC)
E_V = ENVELOPE (SQ. IN.)
F_R = FLOW RATE (LBS/SEC)

MAIN ENGINE PARAMETERS:

W_{DRY} = 7,370
B_T = 500.00
E_V = 16,059
F_R = 2376

CODE:

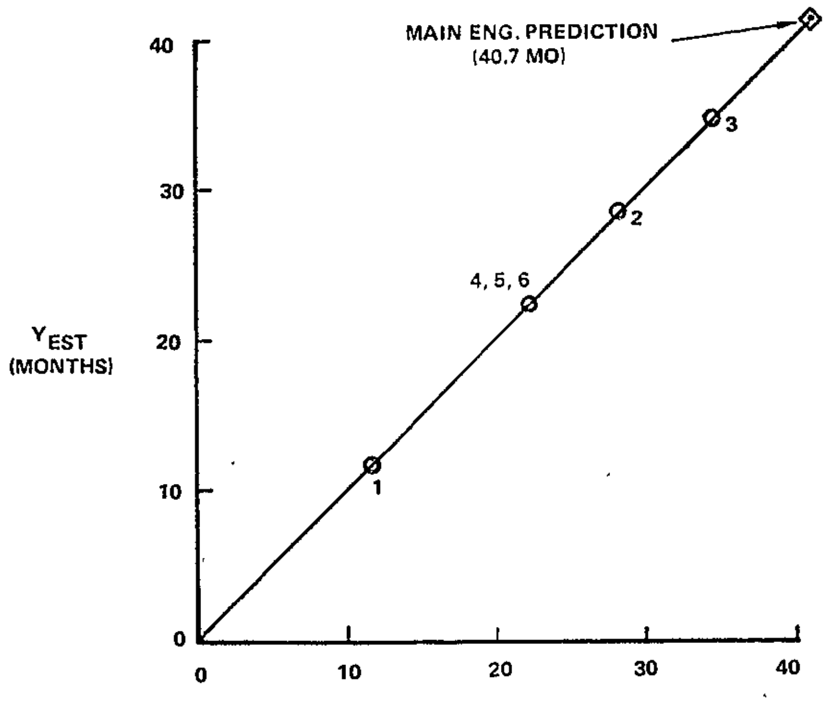
1. H-1
2. F-1
3. J-2S
4. XLR-87
5. XLR-91
6. RL10-A1

COEF OF CORRELATION = .999
STANDARD DEVIATION OF ERROR = 0.1 MONTHS

FIGURE 7.2-1 MAIN PROPULSION

PROGRAM GO-AHEAD TO COMPLETION OF 1ST SINGLE ENGINE TEST SPAN TIME

$$Y_{EST} = -9.2185 - (0.0057)(W_{DRY}) + (0.0528)(B_T) + (.003)(E_V) + (.0071)(F_R)$$



WHERE:

W_{DRY} = ENGINE DRY WEIGHT (LBS)
B_T = MAX. RATED BURNTIME (SEC)
E_V = ENVELOPE (SQ. IN.)
F_R = FLOW RATE (LBS/SEC)

MAIN ENGINE PARAMETERS:

W_{DRY} = 7,370
B_T = 500.00
E_V = 16,059
F_R = 2376

CODE:

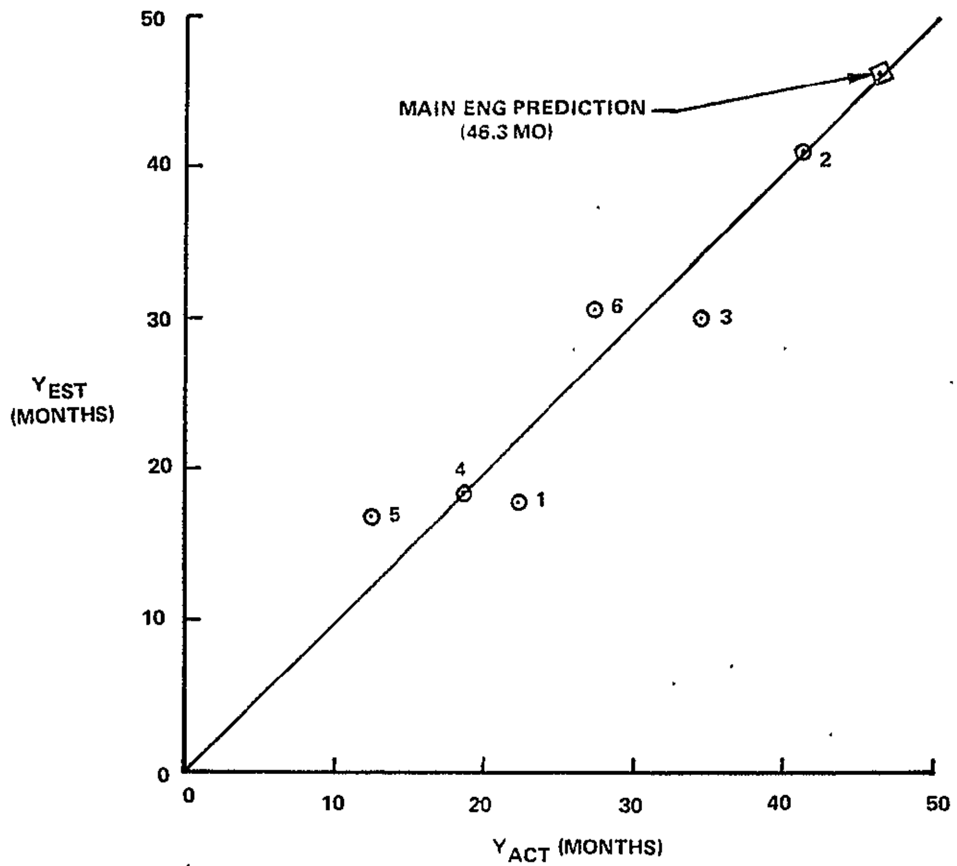
1. H-1	4. XLR-87
2. F-1	5. XLR-91
3. J-2S	6. RL10-A1

COEF OF CORRELATION = .999
STANDARD DEVIATION OF ERROR = 0.2 MONTHS

FIGURE 7.2-2 MAIN PROPULSION

COMPLETION OF 1ST ENGINE TEST TO DELIVERY OF 1ST ENGINE SPAN TIME

$$Y_{EST} = 12.3344 + (0.0026)(W_{DRY}) + (0.0455)(B_T) - (0.0017)(E_V) + (0.0081)(F_R)$$



WHERE:

W_{DRY} = ENGINE DRY WEIGHT (LBS)

B_T = MAX RATED BURN TIME (SEC)

F_R = FLOW RATE (LBS/SEC)

E_V = ENVELOPE (SQ. IN.)

MAIN ENGINE PARAMETERS:

B_T	= 500.00
W_{DRY}	= 7,370
E_V	= 16,059
F_R	= 2376

CODE:

1. H-1	4. XLR-87
2. F-1	5. XLR-91
3. J-2S	6. RL10-A1

COEF OF CORRELATION = .929

STANDARD DEVIATION OF ERROR = 3.8 MONTHS

FIGURE 7.2-3 MAIN PROPULSION

COMPLETION OF 1ST ENGINE TEST TO COMPLETION OF PFRT SPAN TIME

$$Y_{EST} = -14.0517 - (0.0126)\,(W_{DRY}) + (0.0097)\,(B_T) + (0.0073)\,(E_V) - (0.0001)\,(F_R)$$

WHERE:

W_{DRY} = ENGINE DRY WEIGHT (LBS)
B_T = MAX. RATED BURN TIME (SEC)
E_V = ENVELOPE (SQ. IN.)
F_R = FLOW RATE (LBS/SEC)

MAIN ENGINE PARAMETERS.

W_{DRY} = 7,370
B_T = 500.00
E_V = 16,059
F_R = 2376

CODE:

1. H-1
2. F-1
3. J-2S
4. XLR-87
5. XLR-91
6. RL10-A1

COEF OF CORRELATION = .945

STANDARD DEVIATION OF ERROR = 3.5 MONTHS

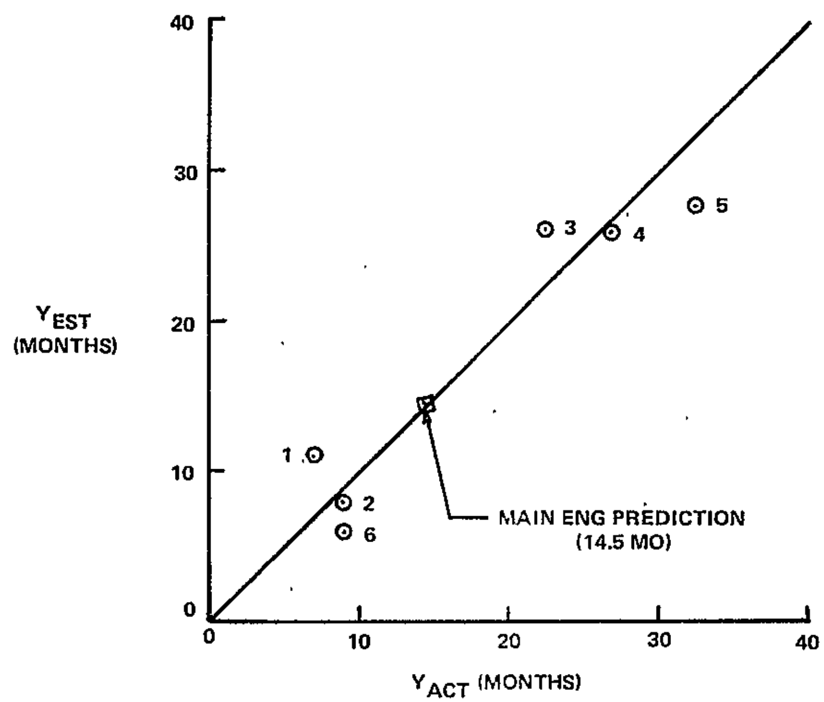


FIGURE 7.2-4 MAIN PROPULSION

COMPLETION OF PFRT TO COMPLETION OF QUAL I TEST SPAN TIME

3.3 It has been previously noted that thrust is a secondary schedule driver and weight tends to be a primary driver. The combination of these two parameters provide an adequate predictor of time, however, when ample engine performance data is available, it is recommended that the first set of TERs be used, since they provide more reliable results.

4.0. LIMITATIONS

The user of this method should be aware that the sample size for this TER is rather small (six observations). If additional observations are available, they should be integrated into the data set and a new estimating equation derived. An alternative approach would be to test the new data through the above equations and then check the derived results against the actual schedule history of the new data. If there is significant variance, then a new estimating equation may be required, however, if the difference between Y actual and Y estimate are small, then in all probability, the TER is still valid.

4.1 As has been pointed out in the introduction to TERs, the user of this methodology should be aware of advances in technology. Consideration should be given to the particular mission (i.e., performance requirements) of the engine, changes in types of propellants and materials used in construction, changes in testing techniques to accommodate engine complexity and modularity, and in general, the analyst should be aware of any advances which might cause schedule performance for a new engine to vary from the norm of the data base used to develop this TER.

4.2 This TER presents a method for estimating only the engine vendor prime areas of responsibility (i.e., deliver individually qualified engines or engine assemblies). This does not include all the time the vendor must expend in support of clustered testing. Figure 7.2-5 can provide the reader additional insight as to what this TER includes.

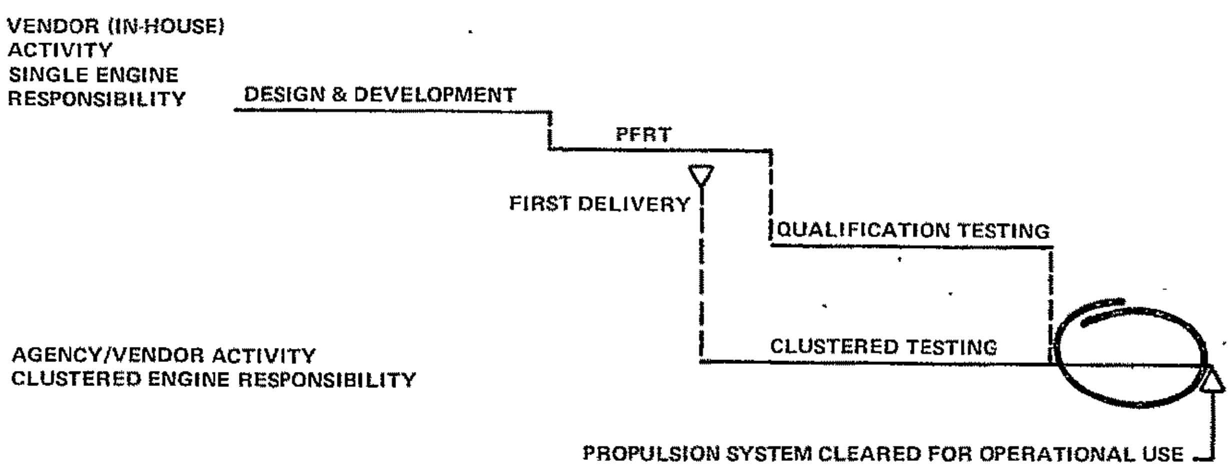


FIGURE 7.2-5 TYPICAL LIQUID ENGINE PROGRAM

As evidenced by Figure 7.2-5, there is an overlap between qualification (in-house) testing and clustered testing. Part of this overlap is addressed by the TERs for PFRT and QUAL I testing, however, the remaining (circled) portion of the schedule has not been addressed by a TER. The spantime for clustered testing is a function of the availability of test facilities, test objectives, engine complexity, degree of modularity (i.e., the number of subassemblies that comprise an engine), and the amount of risk the procuring agency or contractor is willing to accept before the propulsion system is cleared for operational flight.

7.3 AVIONICS

1.0 SCOPE

The purpose of this TER is to develop methodology which will provide the advanced program analyst a tool to predict the time spans associated with avionics subsystems. There exists, three separate major phases associated with a typical avionics subsystem, i.e., (1) prime contractor go-ahead on the Air Vehicle to release of a contract to an avionics vendor, (2) major subcontractor (avionic subsystem) go-ahead to delivery of the first flight article, and (3) the integration of the avionic subsystem into the Air Vehicle and checkout. This TER addresses only the first two aforementioned phases. It should be noted that this study concentrated on individual modules (black boxes) rather than a complete avionics subsystem and for the Advanced Space Transport Program Air Vehicle only the largest, most complex module was used in the analysis since it will typically represent the pacing item. Included in this TER are the approach or methodology for development of time span estimates, the data used and the results, as well as the limitations associated with the utilization of these TERs.

2.0 APPROACH

Two different approaches were used for developing methods of estimating or predicting time spans associated with the development of avionics subsystem. These approaches were the Type I distribution and the multiple regression analysis. In both approaches, the analyses were conducted at the individual module (black box) level rather than at the complete avionic system level since it was of the study personnel opinion that it would be more meaningful and accurate.

TYPE I DISTRIBUTION APPROACH

The Type I distribution approach encompassed gathering data in terms of the actual times required for (1) program go-ahead to module go-ahead and (2) module go-ahead to delivery of the first flight article module. The program go-ahead reflects the go-ahead by the prime contractor for the Air Vehicle. The module go-ahead reflects the go-ahead by the major avionics subcontractor to design, fabricate, and qualify the individual modules. The time between the prime contractor go-ahead and the major subcontractor go-ahead reflects developing subsystem requirements, developing statements of work, soliciting quotes from vendors and finally negotiating the subcontracts with the successful major subcontractor. It should be noted that there may be other tiers of contractors below the major subcontractor level for avionic subsystems.

The data gathered, at the individual module level, is presented in Table 7.3-I. This data was plotted for Type I distribution analysis and the mean, mode and range derived, as well as computing the cumulative percent of observation curve. In addition, the individual avionic subsystem elements (i.e., communication system) were analyzed within each program to determine the time between module go-ahead and the delivery of the last module within that particular system. This represents the point in time when the prime contractor of the Air Vehicle can start the integration of that system for final checkout, verification and qualification. It should be noted that this TER does not encompass the prime contractor's effort of integrating the avionic subsystems into the air vehicle. A Type I distribution was developed reflecting the module go-ahead to last module delivery within that particular system. The time span for delivery of first module to delivery of last module is obtained by computing the differences between module go-ahead to first module delivery and module go-ahead to last module delivery (first flight article).

MULTIPLE REGRESSION ANALYSIS

The multiple regression analysis approach was employed only for the module go-ahead to first flight article delivery time span. This was due to the fact that the data was not consistent in the detail required to conduct the regression analysis on Program go-ahead to module go-ahead nor first module delivery to delivery of the last module within a particular avionic subsystem because of the number of tiers of subcontractors involved. The input data was used for the regression analysis is presented in Table 7.3-II. As can be seen in Table 7.3-II, three independent variables were used, specifically (1) the volume of the module, (2) the number of interfaces of the module, and (3) the number of modules associated with the individual module (assembly) being considered. The volume of the module was selected since it reflects the amount of packaging required for the individual grouping of boxes and assuming that space available is a constraint which is related to the time span required. The number of interfaces reflects both external and internal interfaces that particular module (assembly) has to accommodate, which is indicative of the complexity. The number of boxes is related to the number of functions of the module (assembly). Other independent variables, such as number of individual components and/or active elements, mean time between failure and density were considered as potential candidates; however, the information was not available in sufficient quantity for such entry in the data set.

TABLE 7.3-I AVIONICS SUBSYSTEM TYPE I DISTRIBUTION INPUT DATA

AVIONIC ELEMENT	PROG G/A TO MODULE G/A (MO)	MODULE G/A TO 1ST DELIVERY (MO)
B58 IR BEACON	–	18.0
B58 PI BEACON	–	19.0
B58 FLT. CONTROLS	12.0	37.0
B58 NAV. BOMBING	10.5	–
B58 ACT. DEF. SYS.	21.5	26.0
B58 ECM	16.5	33.0
B58 CIVIL NAV. AIDS	20.0	37.0
B58 LONG RANGE COMM.	–	18.0
B58 HIGH FREQ COMM	20.0	34.0
B58 EMERG. RADIO	–	7.0
B58 D.C. POWER	16.0	34.0
B58 A.C. POWER	16.0	36.0
MARK II (F-111)	–	19.0
ILASS (LIGHT AIRCRAFT)	–	31.0
A-NEW (ASW COMPLEX)	–	24.0
AWADS (ADV. WEATHER DEL)	–	13.0
F8U-3 AVIONICS	5.0	–
XC142 AVIONICS	7.5	–
A7A AVIONICS	2.0	–
I-HAS (HELICOPTER)	–	16.0
LEM RF EQUIP	18.0	20.0
LEM MODULATION EQUIP	18.0	20.0
LEM ANTENNA EQUIP	20.0	18.0
LEM STAB. & CONTROL	25.0	7.5
LEM PWR GEN. SUBSYS.	11.0	28.0
LEM INVERTER	23.0	14.5
LEM AUX. BATTERY	25.0	12.5
LEM TRANSDUCER	23.5	8.5
LEM SIG. COND.	24.5	7.5
LEM CWEA	19.0	11.0
LEM DSEA	22.0	11.5
LEM PCMTEA	11.0	20.5
LEM ELEC. CONT ASSY (ECA2)	–	16.5
LEM ELEC. CONT ASSY (ECA3)	–	19.0
LEM LIGHT CONT ASSY	–	9.5
LEM PCM & TIME ELECT ASSY	–	16.5
LEM DIG. MISSION CLOCK	–	36.5
LEM S-BAND TRANSCEIVER	11.5	31.0
LEM S-BAND PWR. AMP. & DIPLEX	11.5	33.0
LEM VHF TRANSCEIVER	11.5	40.0

AVIONIC ELEMENT	PROG G/A TO MODULE G/A (MO)	MODULE G/A TO 1ST DELIVERY (MO)
LEM SIG. PROCESSOR	11.5	21.0
LEM LDG RDR & ANTENNA	–	42.0
LEM REN RDR ELECT	–	37.0
LEM REN RDR ANTENNA	6.0	37.0
LEM REN RDR TRANSPDR	5.0	34.0
LEM ATT CTL ASSY	–	29.5
LEM DES ENG CTL ASSY	–	21.5
LEM RATE GYRO ASSY	16.0	21.5
LEM GUID. & NAV.	7.0	37.5
SDP FLT. CONT. UNIT	6.0	14.0
SDP FLT. CONT. ELECT.	6.0	17.0
SDP ELECT. CONT. UNIT	6.0	17.0
SDP SENSOR	6.0	17.0
SDP INER. REF. PLATFORM	6.0	16.0
SDP PWR. DIST. UNIT	6.0	16.0
A7A COMPUTER	–	22.0
APOLLO GUID. & NAV.	5.5	–
APOLLO COMPUTER	7.0	28.0
APOLLO INER. MEAS. UNIT	5.0	24.0
APOLLO GUID. EQUIP. ASSY	5.0	31.0
APOLLO GUID OPTICS	7.0	28.0
APOLLO COMM (NO. 009)	2.0	37.0
APOLLO ANTENNA (NO. 009)	8.0	27.0
APOLLO RF EQUIP. (NO. 009)	2.0	39.0
APOLLO CONT. EQUIP. (NO. 009)	2.0	36.0
APOLLO FUEL CELLS	3.5	21.5
APOLLO PCM T/M (NO. 009)	20.5	15.0
APOLLO PCM T/M (BLK II)	–	9.0
APOLLO ECS CONTR.	–	12.0
GEM DIG. COMP.	2.5	27.0
GEM INER. MEAS. UNIT	2.5	16.0
GEM STAB. & CONT. COMP.	4.0	11.0
GEM HORIZ. SENSOR	3.0	26.0
GEM REN. RDR & TRANS.	3.0	28.0
GEM ATT. CONTL & MAN. ELECT.	3.0	12.0
GEM INST & DATA MGMT	5.0	14.0
GEM ELECTRICAL	2.5	23.0
GEM TGT L/V PROG MR.	1.0	21.0
GEM TGT L/V PCM T/M SYS.	1.0	21.0

TABLE 7.3-II
AVIONICS SUBSYSTEM
MODULE GO-AHEAD TO 1st FLIGHT ARTICLE DELIVERY SPAN TIME
(COMPUTER INPUT DATA)

Program	Independent Variables			Dependent Variable
	Avionics Volume (A_{Vol})	Number of Interfaces (N_{Int})	Number of Modules (N_{Box})	Time Span Actual (Y_{Act})
Gemini Digital Computer	2419.000	10.000	1.000	27.000
Gemini IMU	5356.000	5.000	3.000	16.000
ATM Elec. Ctlr.	375.000	5.000	1.000	12.000
Apollo PCM T/M	1462.000	22.000	10.000	18.000
Apollo Elec. Ctlr.	324.000	6.000	1.000	12.000
SDP Function Ctlr.	103.000	5.000	1.000	14.000
SDP Flight Ctlr.	336.000	7.000	1.000	17.000
SDP Experiments Ctlr.	580.000	5.000	1.000	17.000
SDP Pwr. Distribution	200.000	4.000	1.000	16.000
Gemini Rendz. Radar	7652.000	7.000	3.000	28.000
SDP Guid. Sensor	2490.000	7.000	2.000	17.000
SDP IRU	978.000	3.000	4.000	16.000
Scout Timer	22.000	6.000	1.000	9.000
LEM ECA-2	732.000	14.000	6.000	16.500
LEM ECA-3	448.000	13.000	3.000	19.000
LEM Inverter	643.899	8.000	4.000	33.000
LEM Lighting Ctlr.	151.400	14.000	6.000	9.500
LEM S-Band Transceiver	907.899	26.000	12.000	31.000
LEM Amp & Diplexer	700.000	6.000	3.000	33.000
LEM VHF Transceiver	546.799	13.000	6.000	40.000
LEM Signal Processor	371.200	24.000	4.000	21.000
LEM Lndg. Radar	3270.000	110.000	12.000	42.500
LEM Rendz. Radar	1591.000	50.000	17.000	37.000
LEM Rendz. Transponder	802.000	14.000	5.000	34.000
LEM Attitude Ctlr.	116.000	21.000	3.000	29.500
LEM Desc. Eng. Ctlr.	3188.000	23.000	4.000	21.500

ATM - Apollo Telescope Mount
Elec. - Electronic
Ctlr. - Controller
SDP - Special Defense Program
Pwr. - Power
Rendz. - Rendezvous
Guid. - Guidance
IRU - Inertial Reference Unit
Amp. - Amplifier
Lndg. - Landing
Desc. - Descent
Eng. - Engine

The largest module on the Advanced Space Transport Program Air Vehicle was selected to predict the estimated time associated with the Stage I and Stage II. This module is located in the Stage II Air Vehicle Data Management package. Its characteristics were 7500 cubic inches in volume, had 15 interfaces, and consisted of seven boxes.

The data presented in Table 7.3-II was inputted into the VMSC regression model which developed four different types of mathematical expressions (formulas) which best fit the input data. These output data were reviewed and analyzed and the best equation selected for estimating the time span for the Advanced Space Transport Program Air Vehicle(s). After the best equation was selected, the input data (Yact) and the results (Yest) were plotted to show how well the input data fit the selected equation. The Yest is plotted against the ordinate scale and the Yact plotted against the abscissa. A 45^{o} line is constructed originating at the intersection of the ordinate and abscissa, thus any point falling to the left of this line reflects the equation predicting longer time than that actually incurred and conversely any point falling to the right of the line reflects predictions shorter than that actually incurred.

3.0 RESULTS

Figures 7.3-1, 7.3-2 and 7.3-3 present the Type I distribution (histograms) results for Program go-ahead to module go-ahead (major avionics subcontractor), module go-ahead to delivery of first flight article module, and module go-ahead to last module delivery within that particular subsystem, respectively. Included in these figures are the range of the data, the mean and the mode, as well as the cumulative percent of observations curve.

Table 7.3-III presents the input data and the results based on the selected equation for module go-ahead to delivery of the first flight article module time span. The following equation was selected and is a log-linear type:

$$\begin{aligned} Yest = {} & -1.8579 + (2.5406)(\ln A_{vol}) + (2.0769)(\ln N_{Int}) + (3.4885) \\ & (\ln N_{Box}) - (0.0009)(A_{vol}) + (0.1131)(N_{Int}) - (0.3456)(N_{Box}) \end{aligned}$$

where:

A_{vol} is the volume of the module in cubic inches.
N_{Int} is the number of external and internal interfaces
N_{Box} is the number of individual black boxes in the module

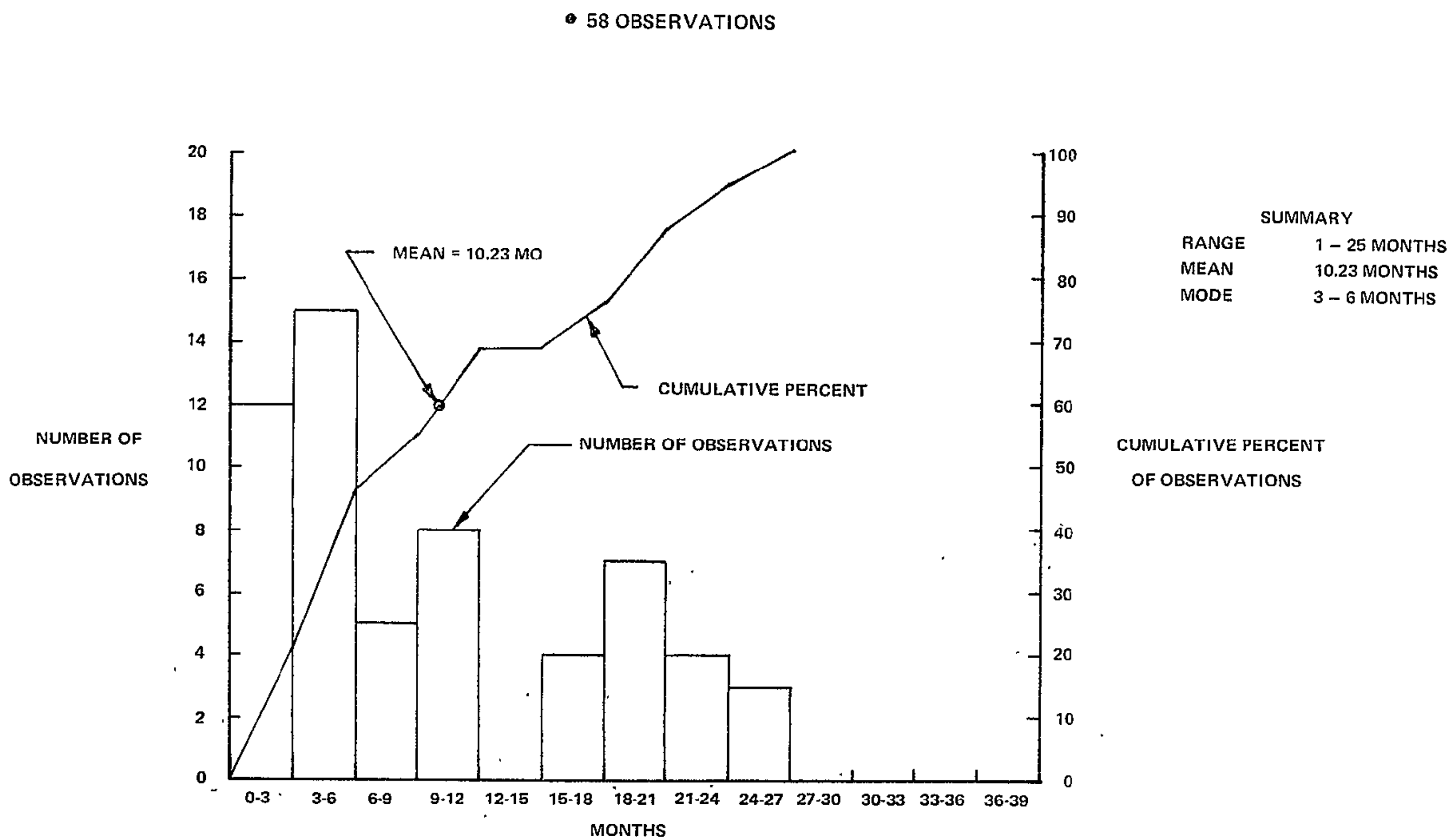


FIGURE 7.3-1 AVIONICS SUBSYSTEM
PROGRAM GO-AHEAD TO MODULE GO-AHEAD SPAN TIME

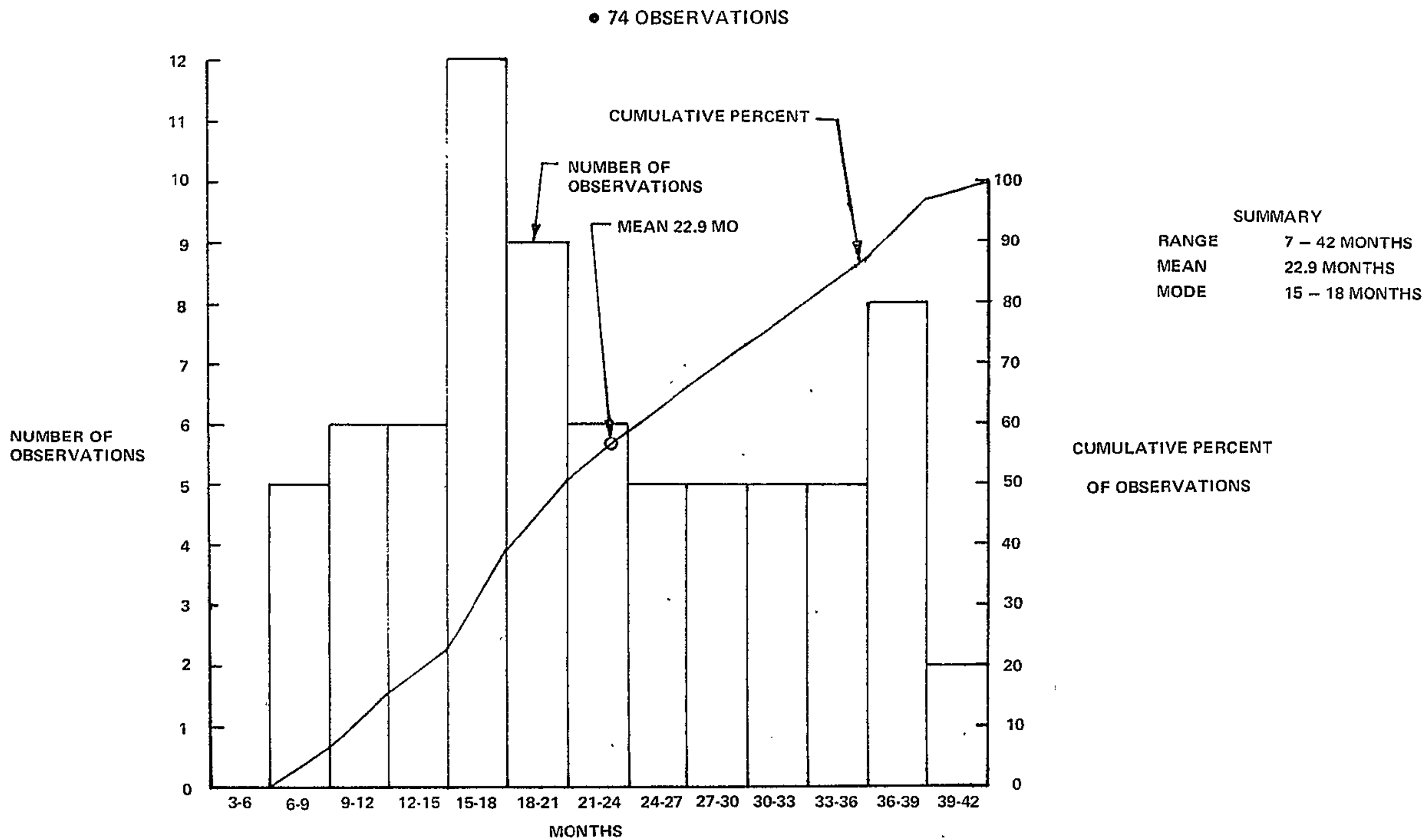


FIGURE 7.3-2 AVIONICS SUBSYSTEM
MODULE GO-AHEAD TO 1ST FLIGHT ARTICLE DELIVERY SPAN TIME

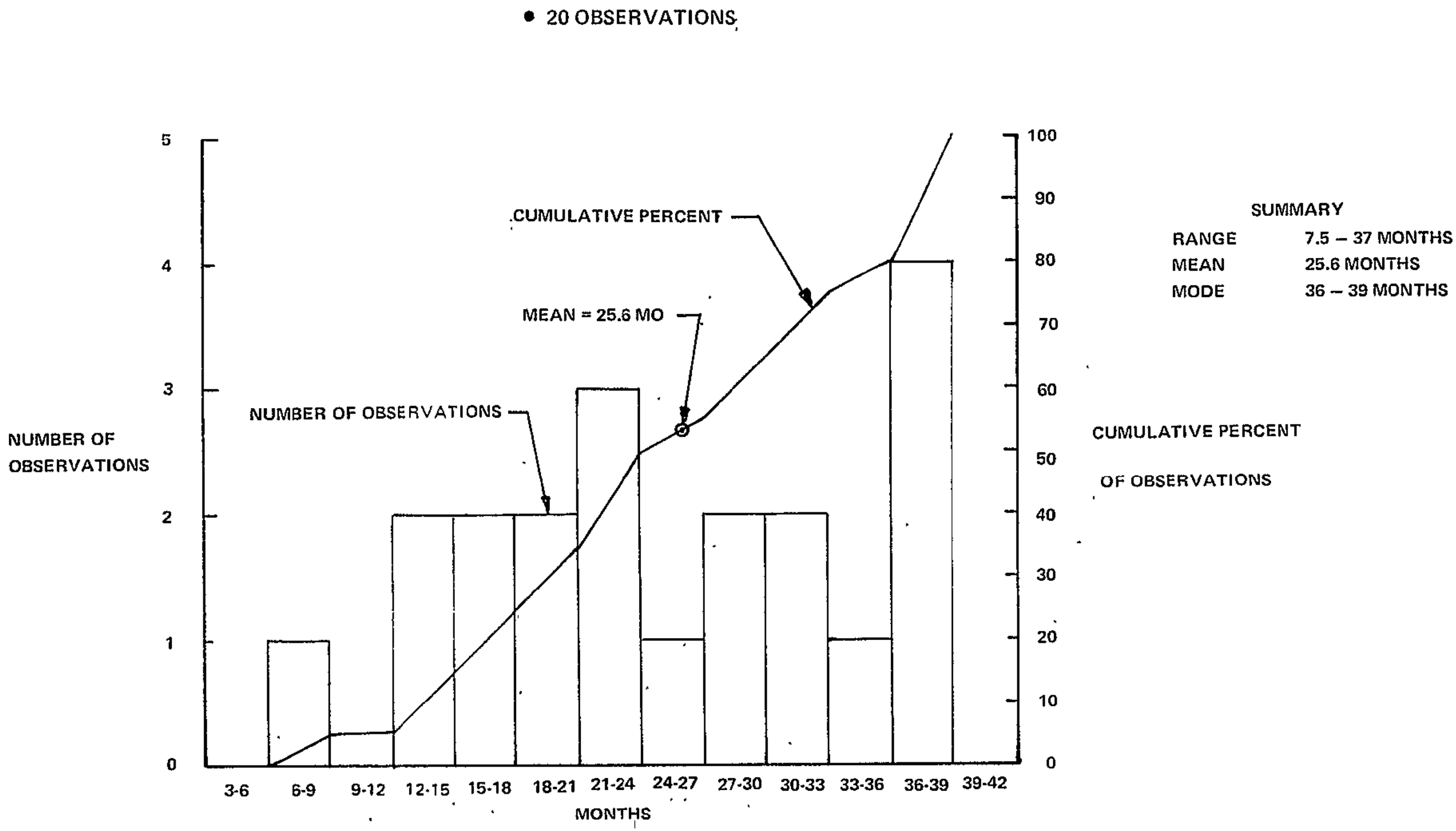


FIGURE 7.3-3 AVIONICS SUBSYSTEM
MODULE GO-AHEAD TO LAST MODULE DELIVERY (1ST FLIGHT ARTICLE)

TABLE 7.3–III AVIONICS SUBSYSTEM

MODULE GO-AHEAD TO 1ST FLIGHT ARTICLE DELIVERY SPAN TIME
(COMPUTER INPUT DATA & RESULTS)

$$Y_{EST} = -1\ 8579 + (2.5406)\ (\text{Ln}\ A_{VOL}) + (2.0769)\ (\text{Ln}\ N_{INT}) + (3.4885)\ (\text{Ln}\ N_{BOX})$$
$$-\ (0.0009)\ (A_{VOL}) + (0.1131)\ (N_{INT}) - (0.3456)\ (N_{BOX})$$

PROGRAM	AVIONICS VOLUME (A_{VOL})	NUMBER OF INTERFACES (N_{INT})	NUMBER OF MODULES (N_{BOX})	TIME SPAN ACTUAL (Y_{ACT})	TIME SPAN CALCULATED (Y_{EST})
GEM DIG COMPUTER	2419.000	10.000	1.000	27.000	21.324
GEM IMU	5356.000	5.000	3.000	16.000	21.834
ATM ELEC CTLR	375.000	5.000	1.000	12.000	16.424
APOL PCM T/M	1462.000	22.000	10.000	18.000	28.824
APOL ELEC CTLR	324.000	6.000	1.000	12.000	16.591
SDP FUNCT CTLR	103.000	5.000	1.000	14.000	13.387
SDP FLT CTLR	336.000	7.000	1.000	17.000	17.106
SDP EXPRMTS CTLR	580.000	5.000	1.000	17.000	17.348
SDP PWR DISTRIB	200.000	4.000	1.000	16.000	14.408
GEM RENDZ RADAR	7652.000	7.000	3.000	28.000	21.597
SDP GUID SENS	2490.000	7.000	2.000	17.000	22.326
SDP IRU	978.000	3.000	4.000	16.000	20.828
SCOUT TIMER	22.000	6.000	1.000	9.000	10.029
LEM ECA-2	732.000	14.000	6.000	16.500	25.481
LEM ECA-3	448.000	13.000	3.000	19.000	22.841
LEM INVERTER	643.899	8.000	4.000	33.000	22.670
LEM LTG CTLR	151.400	14.000	6.000	9.500	22.000
LEM S-BND TRANSCEIVR	907.899	26.000	12.000	31.000	28.857
LEM AMP & DIPL	700.000	6.000	3.000	33.000	21.350
LEM VHF TRANSCEIVR	546.799	13.000	6.000	40.000	24.640
LEM SIG PROCES	371.200	24.000	4.000	21.000	25.609
LEM LNDG RADAR	3270.000	110.000	12.000	42.500	42.484
LEM RENDZ RADAR	1591.000	50.000	17.000	37.000	33.227
LEM RENDZ TRANSPD	802.000	14.000	5.000	34.000	25.360
LEM ATT CTLR	116.000	21.000	3.000	29.500	21.609
LEM DESC ENG CTLR	3188.000	23.000	4.000	21.500	28.333
STAGE II	7500.000	15.000	7.000	--	25.744

COEF OF CORRELATION = .681

The results obtained for the Stage II module using this formula was 25.7 months with a coefficient of correlation of .681. Figure 7.3-4 presents a plot of the Yest versus Yact based on this selected equation.

Table 7.3-IV presents the results obtained on the avionics subsystem analysis for the Advanced Space Transport Program using the largest module (Data Management) located in the Stage II Air Vehicle as the pacing items for the module (vendor) go-ahead to delivery of first flight article module, and Type I distributions for the other time spans. Also shown in this table are the results from the Type I distribution for the module go-ahead to first flight article delivery which compare favorably with that obtained from the selected equation; 22.9 months based on the Type I distribution versus 25.7 months based on the selected equation.

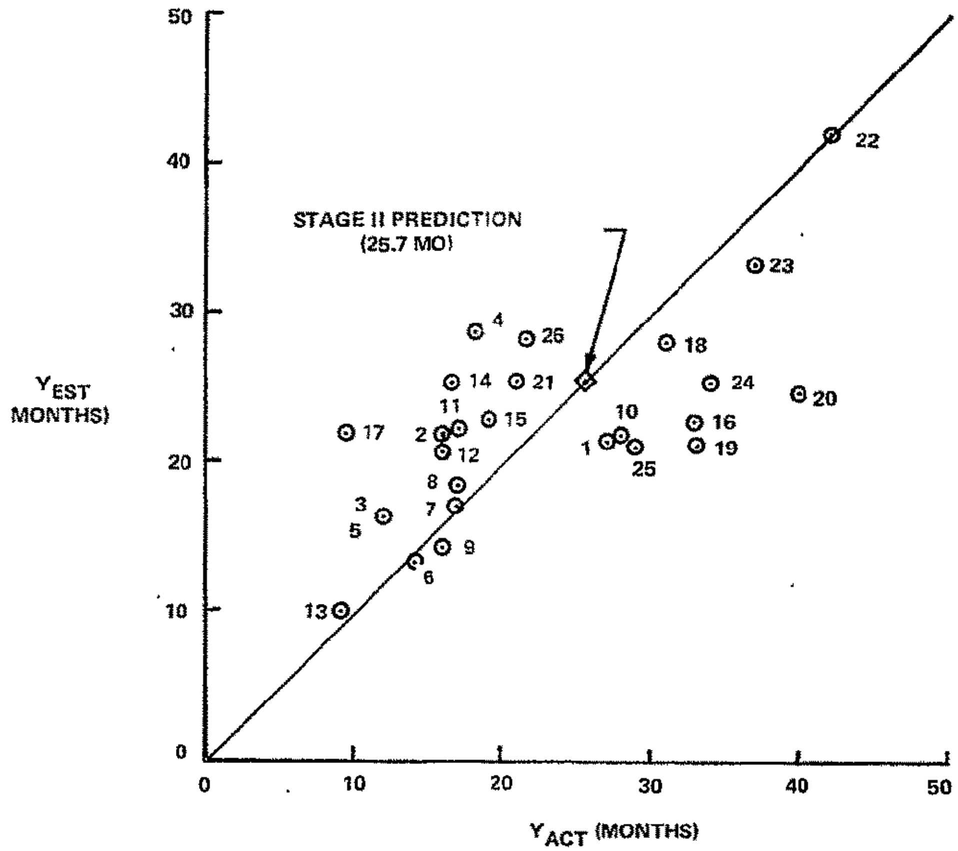
During the early conceptual and/or preliminary planning phase, the analyst may not know the values for all the independent variables utilized in this selected equation. In this case, it is recommended that Type I distributions be used as a base for estimating time spans until the independent variable data becomes available.

4.0 LIMITATIONS

The analyst should insure that the input data, used for selecting equations, bound the item (module) being estimated. This is particularly true if Type I distributions are used for estimating early in the conceptual design phases. In addition, advances in technology should also be considered, since this factor may have a severe impact on the time spans being estimated.

The other area which may have a severe impact on the time spans being estimated is the number of tiers of contractors that may be involved in the program. The Program go-ahead to module (major avionics subcontractor) go-ahead reflects a single tier in this study. For each subsequent tier, it is recommended that an additional six (6) to ten (10) months be added to account for developing requirements, preparing statements of work, soliciting vendor quotes and negotiating subcontracts.

$$Y_{EST} = -1.8579 + (2.5406)(\mathrm{Ln}\ A_{VOL}) + (2.0769)(\mathrm{Ln}\ N_{INT}) + (3.4885)(\mathrm{Ln}\ N_{BOX}) - (0.0009)(A_{VOL}) + (0.1131)(N_{INT}) - (0.3456)(N_{BOX})$$



WHERE:

A_{VOL} = AVIONICS VOLUME (IN^3)
N_{INT} = NUMBER OF INTERFACES
N_{BOX} = NUMBER OF MODULES IN SUBSYSTEM

STAGE II PARAMETERS:

A_{VOL} = 7500.0
N_{INT} = 15.0
N_{BOX} = 7.0

CODE:

1. GEM DIG. COMPUTER
2. GEM IMU
3. ATM ELEC CTLR
4. APOL PCM T/M
5. APOL ELEC CTLR
6. SDP FUNCT CTLR
7. SDP FLT CTLR
8. SDP EXPRMTS CTLR
9. SDP PWR DISTRIB
10. GEM RENDZ RADAR
11. SDP GUID SENS
12. SDP IRU
13. SCOUT TIMER
14. LEM ECA-2
15. LEM ECA-3
16. LEM INVERTER
17. LEM LTG CTLR
18. LEM S-BND TRANSCEIVR
19. LEM AMP & DIPL
20. LEM VHF TRANSCEIVER
21. LEM SIG. PROCES.
22. LEM LNDG. RADAR
23. LEM RENDZ RADAR
24. LEM RENDZ TRANSPD
25. LEM ATT CTLR
26. LEM DESC ENG CTLR

COEF OF CORRELATION = .681

STANDARD DEVIATION OF ERROR = 7.1 MONTHS

FIGURE 7.3—4 AVIONICS SUBSYSTEM
MODULE GO-AHEAD TO 1ST FLIGHT ARTICLE DELIVERY SPAN TIME

TABLE 7.3-IV

AVIONICS SUBSYSTEM RESULTS

Program	Program Go-Ahead to Module Go-Ahead (MOS)	Module Go-Ahead to 1st Module Del. (MOS)	1st Module Del. to last Module Delivery (MOS)	Total Timespan (MOS)
STAGE II Air Vehicle (Type I Distributions)	10.23	22.9	2.7	35.83
STAGE II Air Vehicle (Type I Dist. + Equation)	10.23	25.7	2.7	38.63

7.4 SMALL GAS TURBINE ENGINE (AUXILIARY POWER UNIT)

1.0 SCOPE

The purpose of this TER is to present a method for estimating the time required to design, fabricate, test and qualify a new gas turbine engine for application as an airborne auxiliary power unit (APU).

2.0 APPROACH

The TER for APUs is based on data collected regarding two contractors which have for sometime been active in the field of ground and airborne power supplies. These contractors are the AiResearch Manufacturing Division of the Garrett Corporation and the SOLAR Aircraft Company, a subsidiary of International Harvester Corporation. Table 7.4-I presents a summary of the gas turbine engine characteristics and associated time spans required to develop a prototype suitable for certification testing.

Table 7.4-II presents Type I distribution data and includes four (4) additional observations which were not included in the data set for the APU TER. Figure 7.4-1 incorporates the information contained in Table 7.4-II into histogram format.

2.1 The dependent variable used as input to the multiple regression model was months of development time per shaft horsepower and the independent variable used was shaft horsepower. Other engine parameters considered as candidates included dry weight, shaft horsepower per pound of weight, shaft horsepower per month of development time, and calendar year of design freeze. These variables were not used because of the cumbersome resulting equations and the fact that they did not appreciably influence the results (i.e., explain variance) when compared to the results of the selected equation.

3.0 RESULTS

The output of the regression model is an equation which predicts the development time in months per shaft horsepower. As evidenced by Figure 7.4-2, the resulting equation does a good job in explaining variance (i.e., the difference between Yact and Yest is small). It can further be seen in Figure 7.4-2 and Table 7.4-I that the dependent variable

TABLE 7.4-I

GAS TURBINE ENGINE CHARACTERISTICS

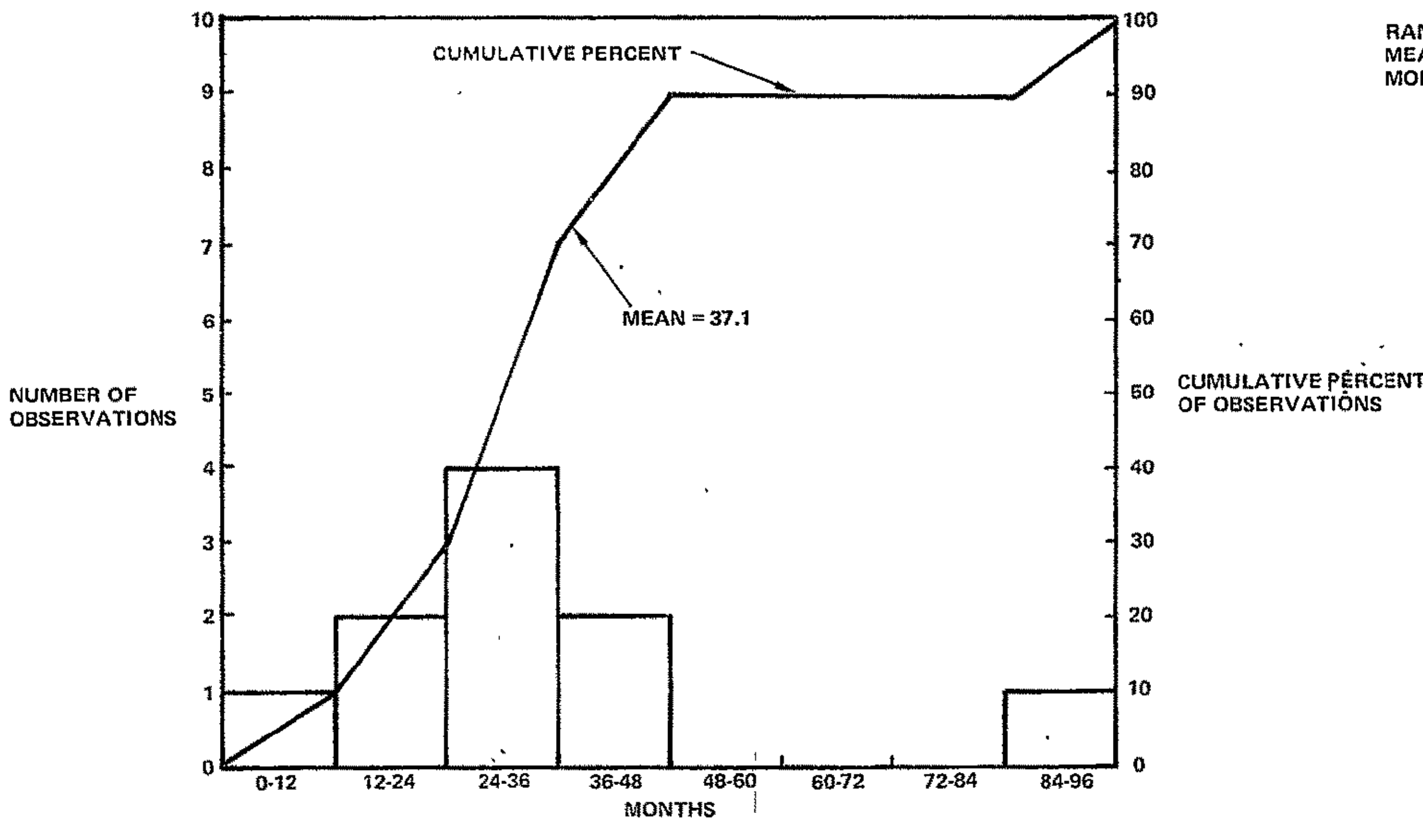
Description	SHP	Weight (Lbs)	SHP/Lb	Devl. Time (Mos)	Mos/SHP
AiResearch Mfg. Div					
85 Series	325	322	1.01	24	.0738
700 Series	1250	600	2.08	17	.0136
TPE 331	575	290	1.98	36	.0626
Solar Aircraft Co.					
Titan Engine	80	52	1.54	30	.3750
Mars Engine	50	80	.62	36	.7200
Jupiter Engine	600	1000	.60	36	.0600

TABLE 7.4-II

GAS TURBINE ENGINE CHARACTERISTICS

Description	SHP	Weight (Lbs)	Devl. Time (Mos)
AiRsearch Mfg. Div.			
85 Series	325	322	24
700 Series	1250	600	17
TPE 331	575	290	36
165 Series	200	375	42
TSE 231	474	171	12
Experimental Model	400	200	96
Solar Aircraft Co.			
Titan Engine	80	52	30
Mars Engine	50	80	36
Jupiter Engine	600	1000	36
Saturn Engine	1250	950	42

• 10 OBSERVATIONS



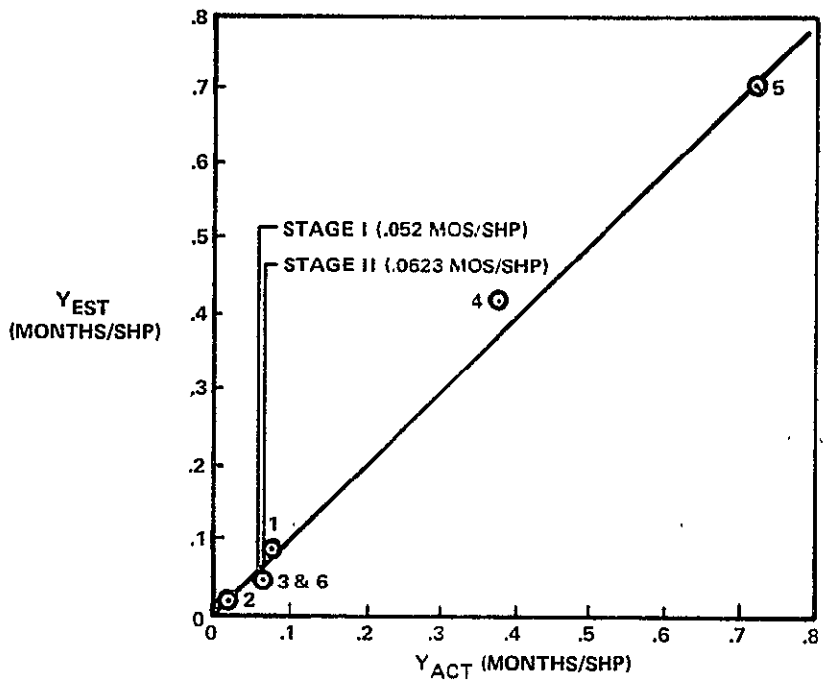
SUMMARY

RANGE	12 - 96 MONTHS
MEAN	37.1 MONTHS
MODE	24 - 36 MONTHS

FIGURE 7.4-1 GAS TURBINE ENGINE (APU)

TIME TO DEVELOP A QUALIFIABLE PROTOTYPE

$$Y_{EST} = 55.741\ (SHP)^{-1.1167}$$



WHERE:

SHP = SHAFT HORSEPOWER

PARAMETERS:

STAGE I = 517 SHP
STAGE II = 440 SHP

CODE:

1. 85 SERIES
2. 700 SERIES
3. TPE 331
4. TITAN
5. MARS
6. JUPITER

COEFFICIENT OF CORRELATION = .982
STANDARD DEVIATION OF ERROR = 0.012 MONTHS

NOTE: THE RESULT OF THIS EQUATION IS MONTHS PER SHP. TO CONVERT THE RESULT TO TOTAL MONTHS, MULTIPLY THE RESULT BY THE CORRESPONDING SHAFT HORSEPOWER.

STAGE I .052 X 517 = 26.9 MOS
STAGE II .0623 X 440 = 27.4 MOS

FIGURE 7.4-2 GAS TURBINE ENGINE – APU

DESIGN, FABRICATE, TEST (NOT INCL. QUAL/CERTIFICATION TEST) (months/shaft horsepower) is expressed in decimal form. To convert this result into estimated months, the result is multiplied by the shaft horsepower (SHP).

Example 1:

PREDICTION	MOS/SHP		SHP		MONTHS
Stage I estimate is	.0520	X	514	=	26.9
Stage II estimate is	.0623	X	440	=	27.4

Figure 7.4-3 represents graphical comparison of those same programs which were portrayed in Figure 7.4-2 but each data point has been multiplied by its corresponding shaft horsepower.

3.1 Rather than present a two-step procedure for computing the development time for an APU, the steps above have been condensed into one equation form. Accordingly, the recommended estimating equation for predicting the time to develop a new gas turbine engine suitable for certification testing is of the following form:

$$Y_{est} = 55.741\,(SHP)^{-1.1167}(SHP)$$

Where:

SHP is estimated engine shaft horsepower.

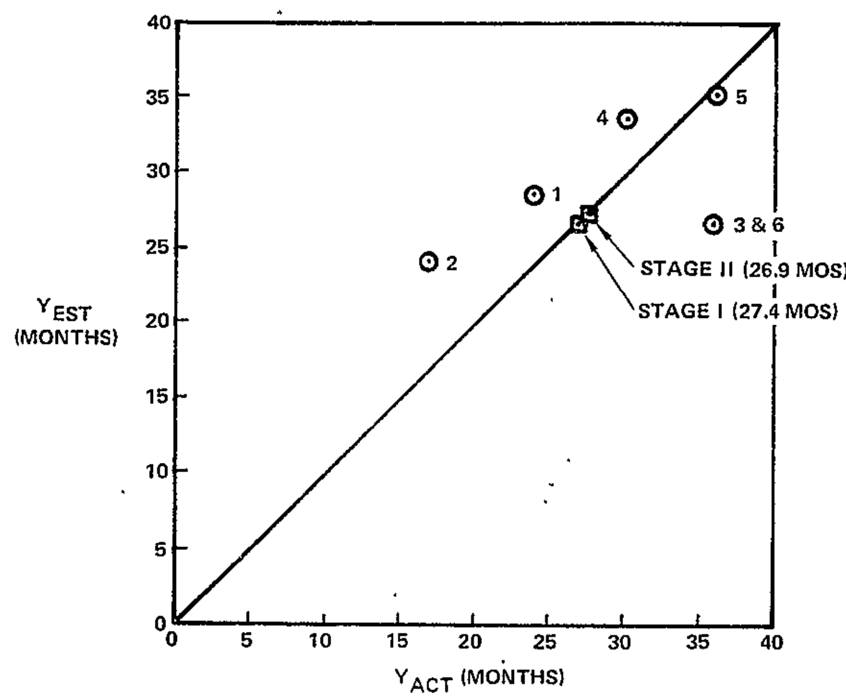
Table 7.4-III presents a summary of study results for APUs. Included in this table is a comparison of Yactual and Yestimate for both estimating equations which appear on Figures 7.4-2 and 7.4-3.

This TER does not include the air vehicle prime contractor's time required to select an APU subcontractor (typically 6 to 10 months), nor the time required to test and integrate the APU into the air vehicle (data for this schedule span not available at this time). Additionally, the above equation will predict only that time required to design, fabricate and conduct APU vendor demonstration tests. If the prototype unit is to be formally qualified to the equivalent of either MQT testing or FAA certification testing, an additional six to twelve months should be added to the above TER. The testing time span is a function of the sophistication of the unit, testing techniques employed, failures during testing, and item schedule criticality.

4.0 LIMITATIONS

The user of this method should be aware that the sample size for this TER is rather small (six observations). If additional observations are available, they should be integrated into the data set and a new TER derived. An alternative approach would be to test new data through the

$$Y_{EST} = 55.741\ (SHP)^{-1.1167}\ (SHP)$$



WHERE:
SHP = SHAFT HORSEPOWER

TRANSPORT PARAMETERS
STAGE I = 517 SHP
STAGE II = 440 SHP

CODE:
1. 85 SERIES
2. 700 SERIES
3. TPE 331
4. TITAN
5. MARS
6. JUPITER

FIGURE 7.4-3 GAS TURBINE ENGINE – APU

DESIGN, FABRICATE, TEST (NOT INCL. QUAL/CERTIFICATION TEST)

TABLE 7.4-III

SMALL GAS TURBINE ENGINE - APU
GO-AHEAD TO COMPLETION OF PROTOTYPE UNIT

DESCRIPTION	ACTUAL SHP	ACTUAL MOS/SHP	ACTUAL DEVL. TIME (MOS)	CALCULATED MOS/SHP	CALCULATED DEVL. TIME (MOS)
85 Series	325	.0738	24	.0873	28.4
700 Series	1250	.0136	17	.0194	24.2
TPE 331	575	.0626	36	.0462	26.6
Titan Engine	80	.3750	30	.4179	33.4
Mars Engine	50	.7200	36	.7063	35.3
Jupiter Engine	600	.0600	36	.0440	26.4
Stage I	517			.0520	26.9
Stage II	440			.0623	27.4

NOTE:

1. The equation, $Yest = 55.741\ (SHP)^{-1.1167}$, calculates the months per shaft horsepower. (See Figure 7.4-2).

2. The equation, $Yest = 55.741\ (SHP)^{-1.1167}(SHP)$, calculates the months of development time. (See Figure 7.4-3).

above equation and then check the derived results against the actual schedule history. If there is significant variance, then a new equation may be required; however, if these variances are negligible, the TER is still valid.

As has been pointed out previously, the user of this methodology should be aware of advances in technology. Since the late 1950's, the ratio of shaft horsepower per unit weight has been on a steady increase and with new materials technology advances, the output to weight ratio should continue to grow and broader ranges in operating temperatures and greater variety of fuel types are inevitable.

It should further be recognized that competition between companies in this field is quite keen. This competition has made members of the industry extremely flexible and able to respond to a new product need with maximum efficiency in minimum time.

7.5 DATA MANAGEMENT SUBSYSTEM HARDWARE (CHECKOUT)

1.0 SCOPE

The purpose of this section is to present the findings of an investigation to determine the time required to design, fabricate, qualify and deliver the first set of checkout hardware.

2.0 APPROACH

At the onset of this investigation, it was determined by study team members that a TER attempt should be directed toward ground support equipment (GSE) hardware and software. A historical survey of available in-house and out-of-house schedule data would indicate that GSE seldom becomes a schedule-pacing item. This indication may be partially due to the type of reporting techniques (i.e., track a GSE schedule item only when it becomes a schedule critical item) and/or the means by which the GSE elements were contracted for and controlled (i.e., their role in integration, facilities, servicing and handling, communications, etc.). Thus, it was determined that a TER at the total GSE level was not feasible at this time.

The next step in this evaluation process was to determine which GSE element would be most affected by a reusable Space Transport System. Investigation into this region led study team members to believe that traditional vehicle test and checkout would undergo substantial change since a great many of the checkout functions and responsibilities would be moved from ground systems to the airborne Data Management subsystem.

Analyses of Phase B contractor's plans regarding the preliminary design criteria for the Data Management system revealed that such a system would provide the following test and checkout capabilities:

a. Provide a constant status of predetermined elements of subsystem performance.

b. Compare operational measurements to a stored set of predetermined, acceptable conditions and criteria.

c. When an anomoly is recognized, stimulate the proper subsystems and fault isolate to a functional path for in-flight operation and to the lowest replaceable unit for ground test.

d. Notify select subsystems, including the personnel sub-subsystem (both crew and ground) that a problem exists.

e. Evaluate the extent and impact of the problem and initiate and follow-up a recovery mode which was predetermined to resolve/remedy the problem.

f. The checkout system itself would retain a self test/verification capability. As previously noted in item c, the actual extent of this capability is not clearly defined.

g. The system would contain an inherent flexibility to have tolerances or instructions altered, interrupted, and removed/replaced upon command.

After reviewing these criteria, Self Diagnostic Testing systems were assessed for comparison at the system level. Table 7.5-I and Figure 7.5-1 presents Type I distribution data for self-diagnostic test equipment for programs which are considered representative of 1970 through 1972 technology (assumed technology freeze dates for implementation into the design of the Advanced Space Transport System).

TABLE 7.5-I

SELF-DIAGNOSTIC TEST EQUIPMENT

SYSTEM	SPAN-START DESIGN OF SYSTEM TO FIRST DELIVERY	APPLICATION
AIDS	36	Engine Analyzer, F4D
GPATS	24	F-105, F-111, F-4
TEAMS	18	Shipboard Avionics
VAST	24	Shipboard Avionics
C-System	19 (29 Operational)	United Air Lines

Table 7.5-I indicates that the time required to design and deliver a self-diagnostic testing system, including software ranges from 18-36 months. The mean is 24.2 months. Two (2) considerations for these data must be acknowledged:

1. Of the systems comprising these data, AIDS is considered more representative of the Advanced Space Transport Program's Data Management System because of the magnitude of functions the AIDS tests. The respective 36-month time span should therefore be weighted by some amount unknown to the study team.

2. Software, considered much less complex than what would be necessary to meet the above Data Management System criteria, is inherent in the Table 7.5-I figures. Software development was the schedule driver for these systems.

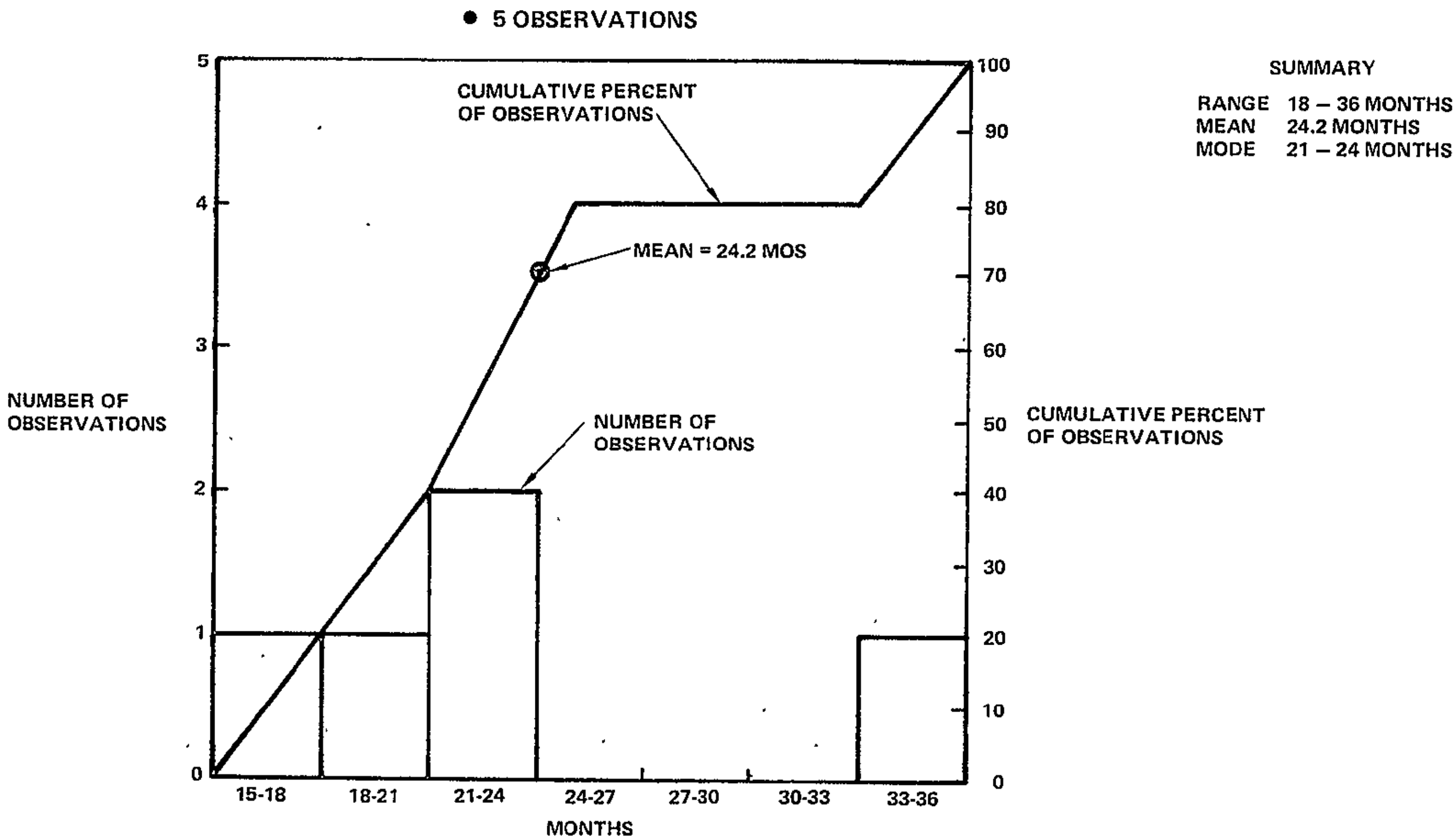


FIGURE 7.5-1 ON BOARD SELF DIAGNOSTIC TEST EQUIPMENT

START OF DESIGN TO DELIVERY OF HARDWARE

Recognizing these considerations, the mean was compared with the results of the 7.3 TER for Avionics/Data Management which treated only the largest, most complex, black box. The Avionics/Data Management TER (7.3) yielded 22.9 months. No specific conclusion can be formulated from the comparison despite team members opinion that Table 7.5-I data are likely to be representative of hardware elements of the on-board checkout and test equipment. However, some significant insight to the impact from software complexity and its development time can be gained from the comparison

Referring to the criteria for the Data Management System discussed earlier, Data Management System software may be safely assumed to be extremely complex and sophisticated. Recall that the mean of 24.2 includes software which is very significantly less complex and less sophisticated than that assumed for the Data Management System and which paced each of the system's development. Recall, too, that 22.9 months (TER 7.3) reflects only the time to get the largest, most complex, black box and total Data Management System functional exercising, testing, and checkout, as well as system software debugging cannot occur until after the 22.9 months. From this insight some significant period of time may be expected to follow the 22.9 months based on Data Management System software complexity and sophistication.

In addition to researching and assessing test and checkout capabilities/ systems at the system level, the criteria for the described Data Management System were reviewed for the types of technical parameters involved in the functions of the system. Total telemeter bit rate was selected as a candidate parameter and analyzed from two (2) aspects to investigate possible trends:

1. The overall bit rate capability as a function of the related states of the art;
2. The bit rates used on actual programs in the past.

Referring to Figure 7.5-2, past telemeter rates would indicate only those percentages of total capability shown to have been realized. Assuming these estimates provide some indication of trend, the percent of total available capability to be realized in any time frame is somewhat less than 100%. If the trend projection holds true to form, the estimated acquisition/ transmission capability for the first quarter 1972 (assumed technology freeze point) will be on the order of 25 megabits/sec. (state-of-the-art) while the estimated realization of this capability will be 420 kilobits/sec. A review of Phase B contractor's plans indicates that the total Data Management System capabity (i.e., design goal at the 1972 technology freeze point) will

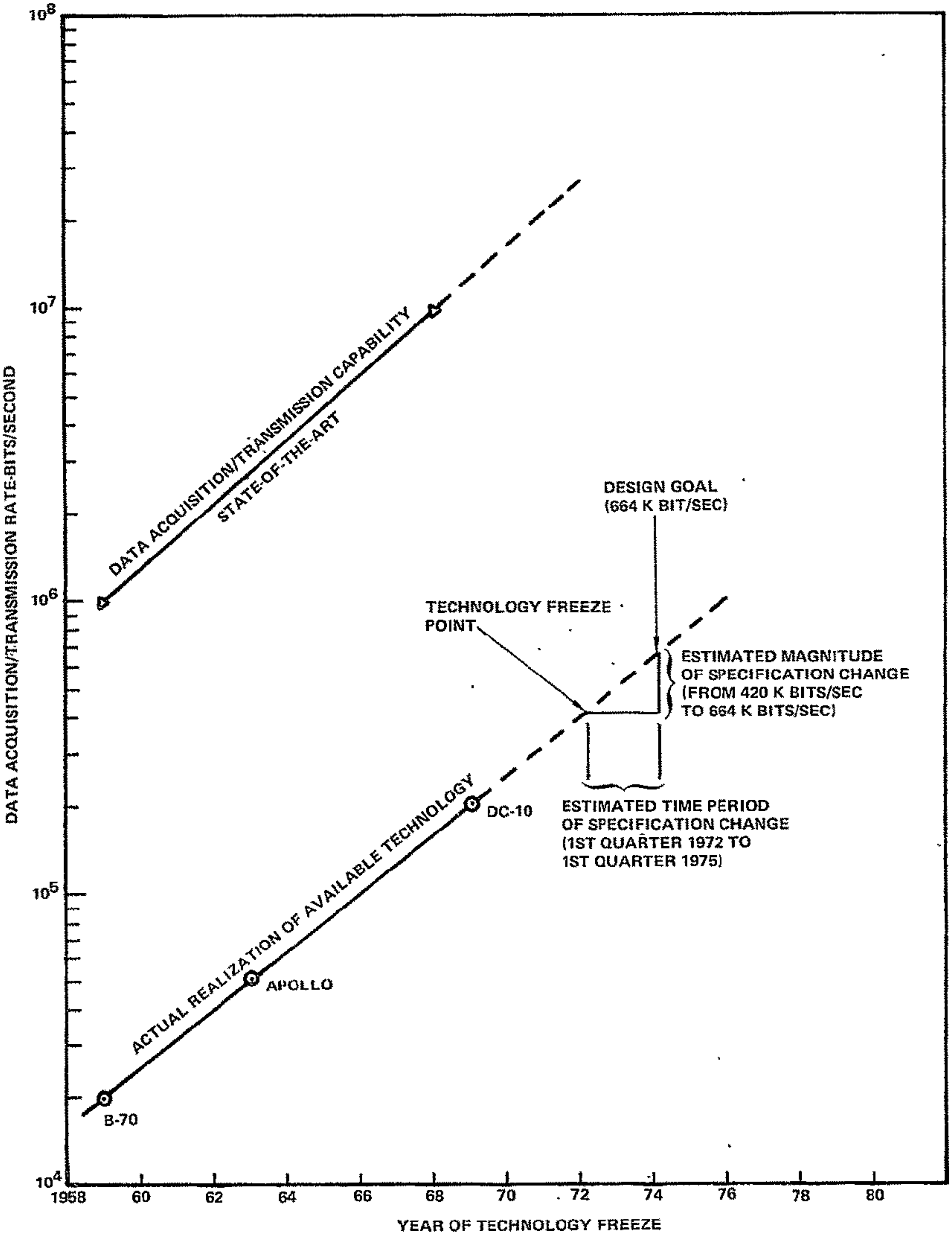


FIGURE 7.5-2 DATA ACQUISITION/TRANSMISSION TECHNOLOGY

COMPARISON OF STATE-OF-THE-ART AND ACTUAL REALIZATION OF AVAILABLE TECHNOLOGY be approximately 664 kilobits/sec (four (4) data busses with 166 kilobit/sec capacity each). As evidenced by Figure 7.5.2, the estimated year at which this goal is anticipated to be met is early 1975 or two (2) years after the technology freeze point.

Several things could explain this variance:

1. Some technology associated with the Data Management System (not necessarily technical, but perhaps management or training) will have an advance in its application or state-of-the-art, thereby significantly changing the shape of the realization curve; or

2. Regarding the telemeter rate by itself, the design goal will not be achieved in the expected time frame; the additional capability to get 664 kilobit/sec. could be furnished via design specification change packages some time after Data Management System design freeze. The estimated technical and schedule impact from such a change are indicated on Figure 7.5-2.

3. Regarding the telemeter rate as reflecting total Data Management System complexity, bit rate is not adequate to reflect the complexity and sophistication of the described Data Management System.

The latter explanation is favored because analysis of the criteria for the Data Management System indicates the total capability to be provided to be much more than a simple reflection of telemeter bit rate. Although bit rate is truly a part, Data Management as described includes facets of instrumentation, command, and GSE functions plus others which heretofore have been part of different subsystems including the personnel subsystem.

3.0 RESULTS

Although considered possible to compile the technical parameters which in total would express the Data Management System in its interface with software and GSE, time and resources were not available within this study's scope, objectives, and limitations. The investigation of a TER for checkout hardware has served to identify a vitally important judgement about the Advanced Space Transport Program's development, namely: The Data Management System is judged to be a high risk development for the following reasons:

1. The system described is a unique entity;

2. The system possesses the largest quantity and most complex of the program's interfaces;

3. To verify the systems test and checkout capability, some development GSE and software may be anticipated.

4. The software associated with the system is complex, sophisticated, critical to the system's delivery, and is a major unknown in the system's development span.

4.0 LIMITATIONS

Not applicable

7.6 TOTAL PROGRAM

1.0 SCOPE

The purpose of this TER is to develop mathematical expressions which will predict time spans required for the air vehicle elements of the Advanced Space Transport Program. It encompasses the time from go-ahead by the prime contractor(s) to the first horizontal flight by the vehicles (Stage I and Stage II). This TER does not include vertical flights (singular or mated) nor the complete horizontal flight test program required to qualify the vehicles prior to vertical flight. Two separate approaches were utilized for this TER - one being a TER for the total time span and the other by dividing the program into three distinct phases, namely (1) design (to 95% release), (2) manufacture and checkout of the first flight vehicle, and (3) the time between vehicle rollout and first horizontal flight designated as ramp time. With the latter approach, the results of the individual TERs are combined to obtain the total span time.

2.0 APPROACH

Data in terms of the actual time spans required to develop and manufacture the first flight vehicle was collected on 25 aerospace programs which were considered representative of the Advanced Space Transport Program air vehicles. This data is presented in Table 7.6-I and was used to plot Type I distributions (histograms) to show pictorially the historic trends of the programs used in this study. The mean, mode and range were derived based on the observations and a curve plotted through the distributions to show the cumulative percent of observations. These Type I distributions can be used to compare the historical data results with the TER formula predictions and thus gain confidence with the TER predictions.

A TER was developed for the total time span using the data presented in Table 7.6-II which represented nine programs. These data were used as input to VMSC regression analysis routine in order to derive mathematical expressions that could be used for predicting the time spans associated with Stage I and Stage II air vehicles of the Advanced Space Transport Program. As shown in this table, the independent variables used for this analysis were air vehicle system weight and structure complexity factor. The system weight is the weight associated with all the air vehicle subsystems, excluding structure

TABLE 7.6-I TOTAL PROGRAM – GO AHEAD TO FIRST FLIGHT
TYPE I DISTRIBUTION INPUT DATA

PROGRAM	PROGRAM PHASE TIME SPAN – MONTHS			TOTAL TIME SPAN MONTHS
	DESIGN	MANUFACTURE	RAMP	
MERCURY	22.0	23.0	4.5	39.0
GEMINI	13.7	31.5	3.8	39.2
CSM	29.0	39.5	6.5	63.0
LM	44.0	43.5	8.5	76.0
S-IC	30.0	33.5	15.5	70.0
S-II	29.0	39.0	15.0	74.0
F-102	–	–	–	42.0
YF-104	–	–	–	29.0
YF-105A	–	–	–	52.0
A7-A	–	–	–	18.0
A5	–	–	–	23.0
XF4H-1	–	–	–	43.0
F-111	33.0	11.0	3.0	39.0
B58	48.0	33.0	2.0	54.0
X-15	24.0	16.0	5.0	42.0
B70	36.0	48.0	4.0	81.0
YC-130	–	–	–	23.0
C-141A	–	–	–	33.0
DC-9	–	–	–	30.0
737	–	–	–	36.0
727	–	–	–	40.0
C5A	21.0	19.0	3.5	33.5
747	28.0	26.0	4.5	40.5
CONCORDE	33.0	41.0	7.0	61.0
SST	56.0	29.0	4.0	71.0

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TABLE 7.6-II

TOTAL PROGRAM-REGRESSION ANALYSIS INPUT DATA
(GO-AHEAD TO FIRST FLIGHT)

PROGRAM	SYSTEM WEIGHT (KLBS)	COMPLEXITY FACTOR	TIME SPAN (MOS)
CSM	14.045	2.290	63.000
SIC	110.000	.950	70.000
S-II	25.975	1.140	74.000
XF4H-1	13.250	1.200	43.000
F-111	14.490	1.200	39.000
B-58	27.217	1.570	54.000
X-15	7.041	2.420	42.000
B-70	80.574	2.650	81.000
Concorde	62.000	1.140	61.000

and is an indicator of vehicle complexity. Complexity factor is associated with the air vehicle structural subsystem. These complexity factors are identical to those used for the structure TER (reference section 7.1). The methodology for deriving these complexity factors is also found in the structure TER. Other independent variables were reviewed and considered as potential candidates, such as system weight to empty weight ratio, total thrust, empty weight, payload volume and/or weight capability, but discarded inasmuch as they either produced unrealistic results or were implicit in one of the selected independent variables.

The VMSC regression analysis routine develops mathematical expressions of four different types; linear, log, log-linear and log-log. These derived expression results are analyzed and the best equation selected based on (1) the coefficient of correlation, i.e., how well the input data fits the derived equation; (2) the constant being a low influence to the results of the equation if possible; (3) the independent variable contribution is moving in the right direction, i.e., as weight and complexity increase the contribution increases; and (4) sound analytical judgment. Using the routine output data, a curve is plotted for each program input data point of Yact versus Yest to show pictorially how well the input data fits the equation. If the data point falls directly on the 45° line, it indicates perfect fit. Data points which fall to the left of the line indicate the formula is predicting longer time than that actually incurred and conversely data points falling to the right of the 45° line indicate the formula is predicting shorter time than the actual.

BUILD-UP TIME SPAN APPROACH

The build-up time span approach divided the total span into three phases; design, manufacturing of the first flight article including checkout, and ramp time. For this approach the data on 14 programs were utilized for the Type I distribution analysis. These data are presented in Table 7.6-I. The data was not available to the detail required on some of the programs used in the total time span approach, thus were deleted from this approach.

The input data for the multiple regression analysis is presented in Table 7.6-III. As can be seen in this table, the same independent variables, i.e., system weight and complexity factor, were used for the buildup approach that were used for the total time span approach. It should be noted that only seven programs were used in this approach, whereas nine were used in the total time span approach.

TABLE 7.6-III

TOTAL PROGRAM MULTIPLE REGRESSION ANALYSIS INPUT DATA

Program	Independent Variables		Dependent Variables		
	System Wt. (K Lbs)	Complexity Factor	Time Span - Months Design	Manufacturing	Ramp
CSM	14.045	2.290	29.00	39.50	6.50
SIC	110.000	.950	30.00	33.50	15.50
S-11	25.975	1.140	29.00	39.00	15.00
B-58	27.217	1.570	48.00	33.00	2.00
X-15	7.041	2.420	24.00	16.00	5.00
B-70	80.574	2.650	36.00	48.00	4.00
Concorde	62.000	1.140	33.00	41.00	7.00

As described in the total span approach, regression analysis was conducted on the input data presented in Table 7.6-III in order to obtain mathematical expressions which best fit the data. These expressions are analyzed and the best equation is selected for use in estimating the times associated with the Stage I and Stage II of the Advanced Space Transport Program. The data (Yact vs. Yest) is again plotted for the selected equations. These plots provide an indication of how well the input data fits the derived equation.

In order to obtain the total span time from program go-ahead to first horizontal flight, it is necessary to sum the individual phases taking into consideration the overlap between design and manufacturing. For the total program, manufacturing start occurs when 60%, based on a Type I distribution presented in the results section, of the design time span is complete, thus the total time span can be obtained by the following formula:

Yest = Design time span (.60) + Manufacturing & Checkout Time span + Ramp time span

For example, if the design time span is 30 months, the manufacturing and checkout time span is 42 months and the ramp time span is eight months, the total span will be 68 months rather than 80 months which would be the case if each phase was completed prior to start of the subsequent phase.

3.0 RESULTS

Since two different approaches were used to estimate the air vehicle total program time span from program go-ahead to first horizontal flight, the result section will be divided into three sections, specifically (1) total time span approach, (2) build-up time span approach, and (3) a summary which compares the two approaches.

TOTAL SPAN APPROACH

Figure 7.6-1 presents a Type I distribution plot based on the 25 aerospace program historical data (actual time spans) presented in Table 7.6-I. As can be seen in this figure, the mean of average of these programs was 47.7 months; however, the range was 18-81 months. The Advanced Space Transport Program air vehicles are much larger and more complex than most of those included in the data set and it is the study personnel opinion that the estimate for this time span should be toward the high end of the Type I distribution.

The following formula was selected from the multiple regression analysis output data set using the input data presented in Table 7.6-II. This formula is a log type expression and had a coefficient of correlation of 0.819.

$$Yest = 7.7216 + (13.7561)(\text{Ln } W_{SYS}) + (13.4443)(\text{Ln } C_x)$$

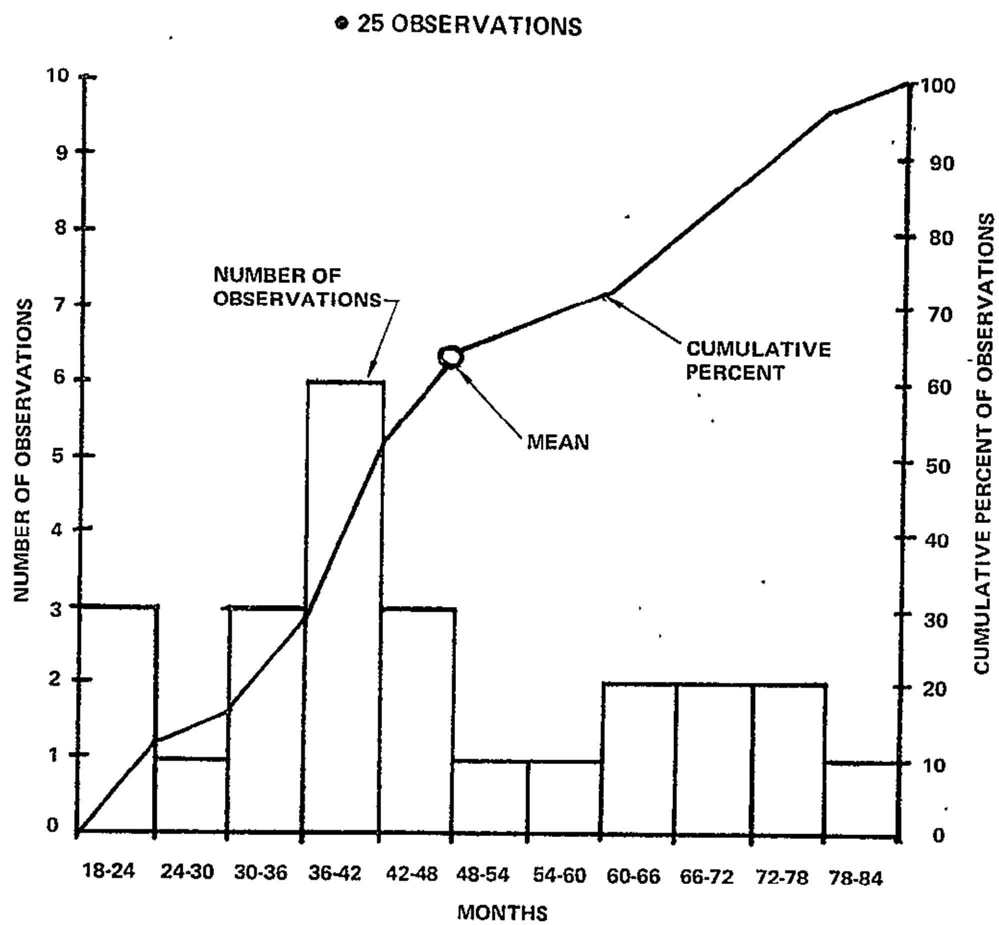
Where:

Yest is Program go-ahead to first horizontal flight time span in months

W_{SYS} is the air vehicle system weight in thousands of pounds

C_x is the structural subsystem complexity factor

Using this formula and the Stage I and Stage II air vehicle parameters, Table 7.6-IV presents the estimated time span for the Advanced Space Transport air vehicles, from program go-ahead to first horizontal flight.



SUMMARY

RANGE	18 – 81 MONTHS
MEAN	47.7 MONTHS
MODE	36 – 42 MONTHS

FIGURE 7.6-1 TOTAL PROGRAM
GO-AHEAD TO FIRST FLIGHT TIME SPAN

TABLE 7.6-IV

TOTAL PROGRAM RESULTS
(PROGRAM GO-AHEAD TO FIRST HORIZONTAL FLIGHT)

Air Vehicle	System Weight (K Lbs)	Complexity Factor	Time Span (Mos)
Stage I	217.674	1.300	85.3
Stage II	74.144	1.550	72.8

Figure 7.6-2 presents the actual time span (Yact) versus the equation estimated time span (Yest) using the input data independent variables and aforementioned formula. The actual data used for plotting Figure 7.6-2 is presented in Table 7.6-V.

TABLE 7.6-V

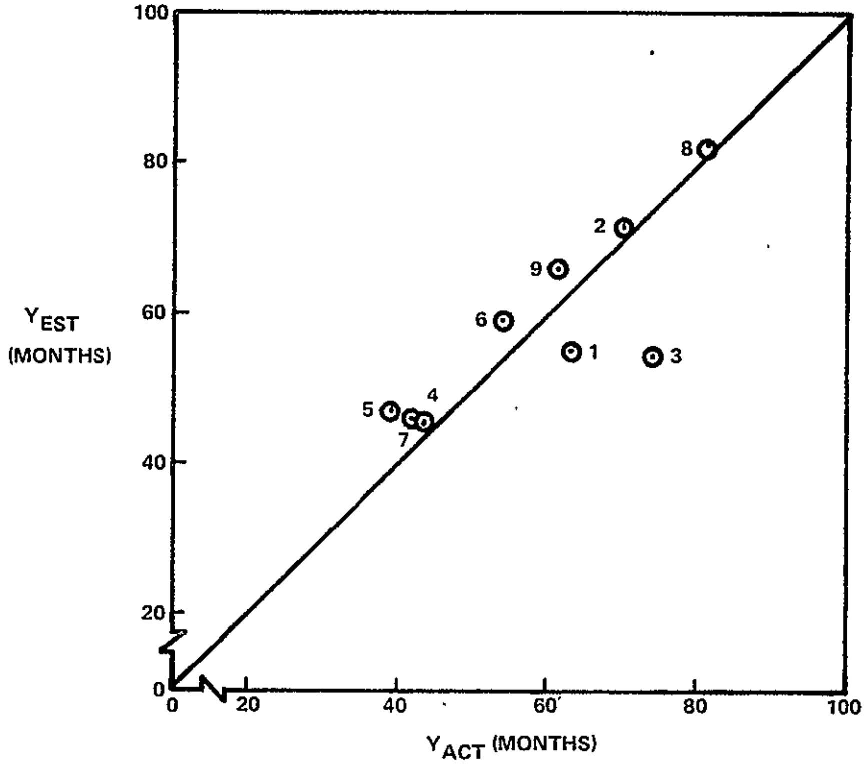
TOTAL PROGRAM RESULTS - TOTAL SPAN APPROACH
(INPUT DATA (YACT) VERSUS ESTIMATED (YEST) TIME SPANS)

Program	Actual Time Span (Input Data) Months (Yact)	Estimated Time Span (Equation Prediction) Months (Yest)
CSM	63.000	55.208
SIC	70.000	71.692
S-II	74.000	54.288
XF4H-1	43.000	45.718
F-111	39.000	46.949
B-58	54.000	59.233
X-15	42.000	46.451
B-70	81.000	81.201
Concorde	61.000	66.256

BUILD-UP TIME SPAN APPROACH

Figures 7.6-3, 7.6-4 and 7.6-5 present the Type I distribution data based on the actual time spans associated with the historical programs used in this study and presented in Table 7.6-I. These figures reflect program go-ahead to 95% design release, manufacturing of the first flight article, and the ramp time spans. As can be seen by these figures, the average time spans based on historical data are 34.4, 33.3, and 6.7 months, respectively.

$$Y_{EST} = 7.7216 + (13.7561)\,(\mathrm{Ln}\ W_{SYS}) + (13.4443)\,(\mathrm{Ln}\ C_X)$$



WHERE:

Y_{EST} = TIME SPAN IN MONTHS

W_{SYS} = SYSTEM WEIGHT IN THOUSANDS OF POUNDS

C_X = STRUCTURE COMPLEXITY FACTOR

	STAGE I	STAGE II
Y_{EST}	85.3	72.8 MO.
W_{SYS}	217.674	74.144
C_X	1.300	1.550

CODE:

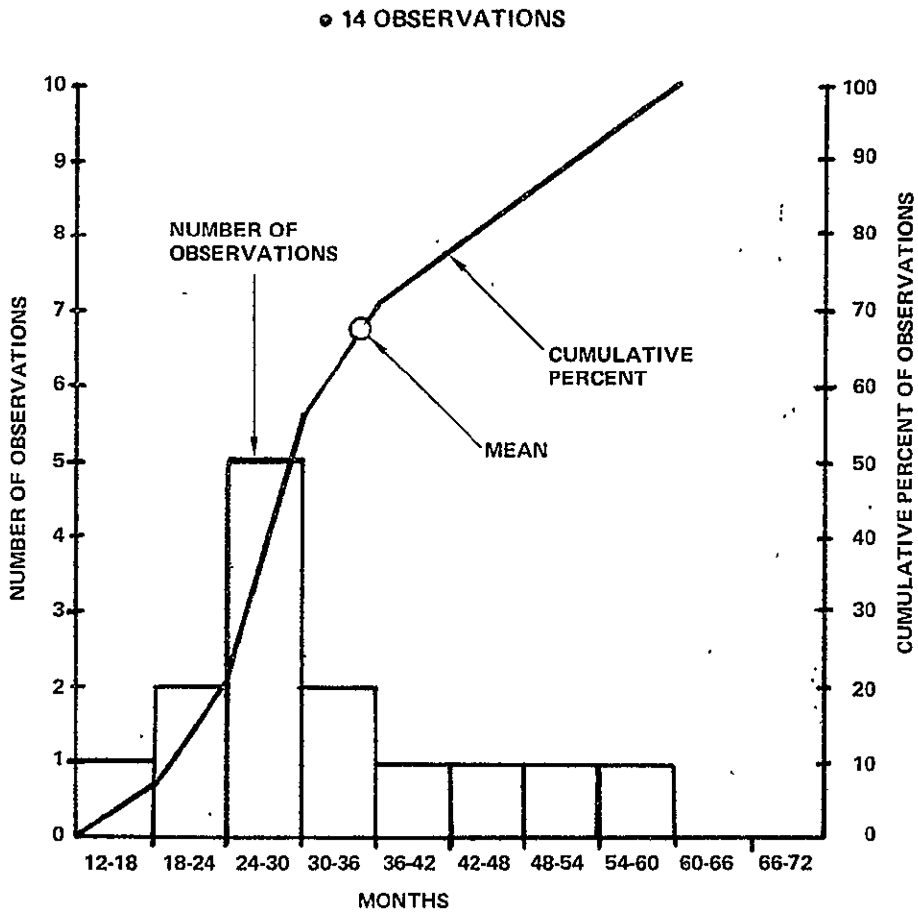
1. CSM
2. SIC
3. SII
4. XF4H-1
5. F-111
6. B58
7. X-15
8. B70
9. CONCORDE

COEFFICIENT OF CORRELATION = 0.819

STANDARD DEVIATION OF ERROR = 8.6 MONTHS

FIGURE 7.6-2 TOTAL PROGRAM Y_{ACT} VERSUS Y_{EST}

(PROGRAM GO-AHEAD TO 1ST HORIZONTAL FLIGHT)

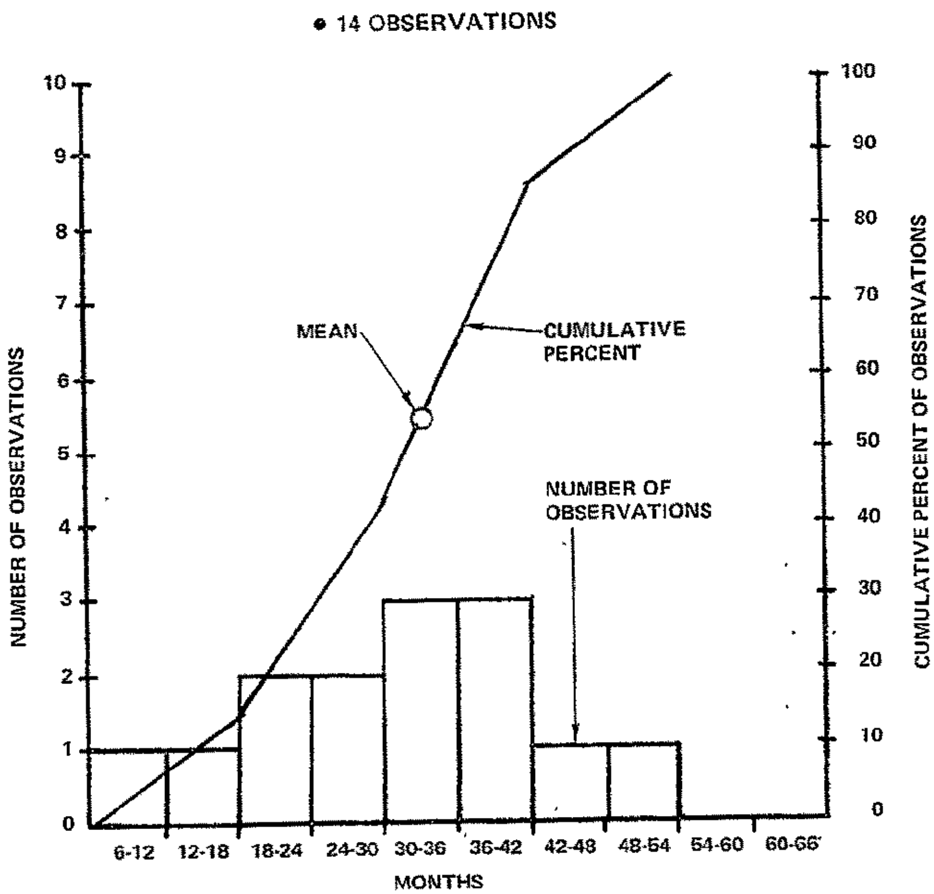


SUMMARY

RANGE	13.7 – 48.0 MONTHS
MEAN	34.4 MONTHS
MODE	24 – 30 MONTHS

FIGURE 7.6-3 TOTAL PROGRAM

GO-AHEAD TO 95% DESIGN RELEASE TIME SPAN



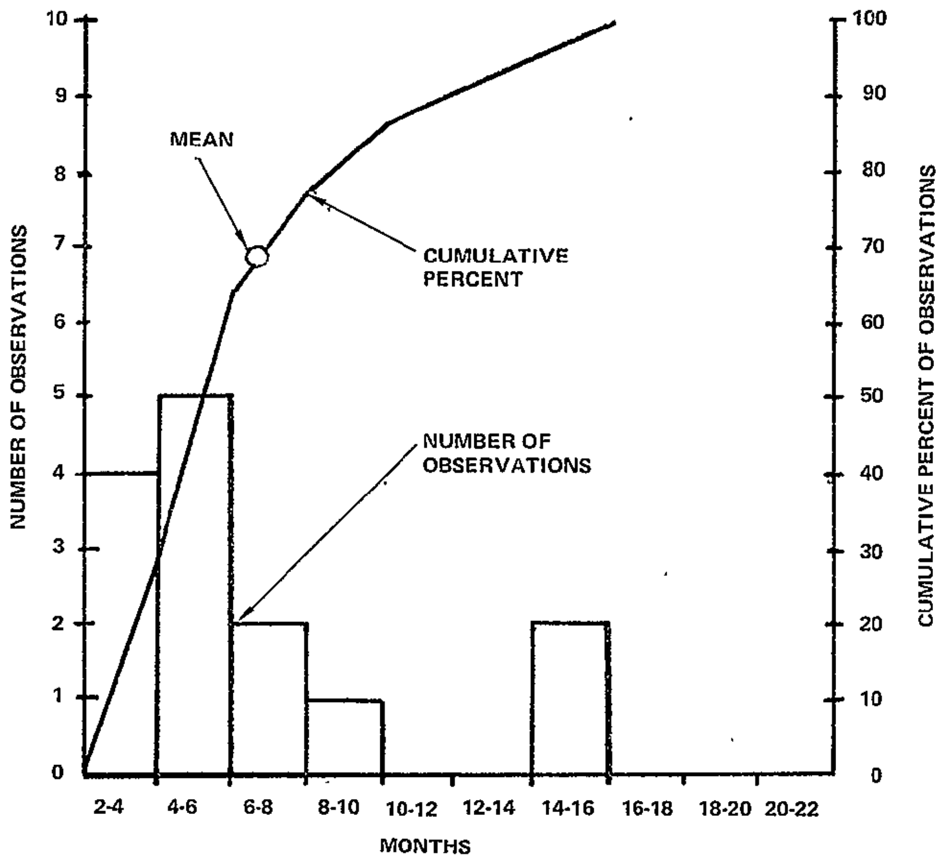
SUMMARY

RANGE	11.0 – 48.0 MONTHS
MEAN	33.3 MONTHS
MODE	30 – 42 MONTHS

FIGURE 7.6-4 TOTAL PROGRAM

MANUFACTURING OF 1ST FLIGHT ARTICLE TIME SPAN

• 14 OBSERVATIONS



SUMMARY

RANGE	2.0 – 15.5 MONTHS
MEAN	6.7 MONTHS
MODE	4 – 6 MONTHS

FIGURE 7.6-5 TOTAL PROGRAM

RAMP TIME SPAN – ROLLOUT TO 1ST FLIGHT

The following formulas were selected from the multiple regression analysis for each of the aforementioned phases using the input data presented in Table 7.6-III.

1. Program go-ahead to 95% design release time span. (This formula had a coefficient of correlation of 0.426 and is of the log-log type.)

   $$Yest = 21.2270\ (W_{SYS})^{.1067}\ (C_x)^{.0828}$$

   The results of this equation were 38.5 and 34.9 months for Stage I and Stage II, respectively.

2. Manufacture and checkout of the first flight vehicle. (This formula had a coefficient of correlation of 0.703 and is a log type expression.)

   $$Yest = 3.5398 + (8.2049)\ (Ln\ W_{SYS}) + (7.5413)\ (Ln\ C_x)$$

   The results of this equation were 49.7 and 42.2 months for Stage I and Stage II, respectively.

3. Ramp (rollout to first horizontal flight) time span. (This formula had a coefficient of correlation of 0.721 and is a log type expression.)

   $$Yest = 13.3140 - (0.2713)\ (Ln\ W_{SYS}) - (9.4324)\ (Ln\ C_x)$$

   The results of this equation were 9.4 and 8.0 months for Stage I and Stage II, respectively.

4. Total time span, from program go-ahead to first horizontal flight, using 60% design complete prior to manufacturing is as follows:

   $$Yest = \text{Design Span } (.60) + \text{Manufacture Span} + \text{Ramp Span}$$

   Using the results of the aforementioned equations (1, 2 and 3) the results of this equation were 82.2 and 71.1 months for Stage I and Stage II, respectively.

Based on the selected equations, Table 7.6-VI presents the results of the input data and the predicted time span estimates for the three phases used in the build-up approach. The independent input variables are presented in Table 7.6-III.

TABLE 7.6-VI

TOTAL PROGRAM RESULTS - BUILD-UP SPAN APPROACH
(INPUT DATA (YACT) VERSUS ESTIMATED (YEST) TIME SPANS)

Program	Design (Months)		Mfg. (Months)		Ramp (Months)	
	Actual	Predicted	Actual	Predicted	Actual	Predicted
CSM	29.000	30.140	39.500	31.467	6.500	4.782
SIC	30.000	34.904	33.500	41.719	15.500	12.522
S-11	29.000	30.377	39.000	31.252	15.000	11.194
B-58	48.000	31.349	33.000	34.049	2.000	8.163
X-15	24.000	28.127	16.000	26.218	5.000	4.448
B-70	36.000	36.758	48.000	46.902	4.000	2.930
Concorde	33.000	33.332	41.000	38.390	7.000	10.958

Figures 7.6-6, 7.6-7 and 7.6-8 present plots of Yact versus Yest for the design, manufacturing and ramp phases, respectively, using the data presented in Table 7.6-VI. Figure 7.6-9 presents the data utilized in arriving at the .60 design span complete prior to start of manufacturing.

COMPARISON OF TOTAL SPAN APPROACH TO BUILD-UP SPAN APPROACH

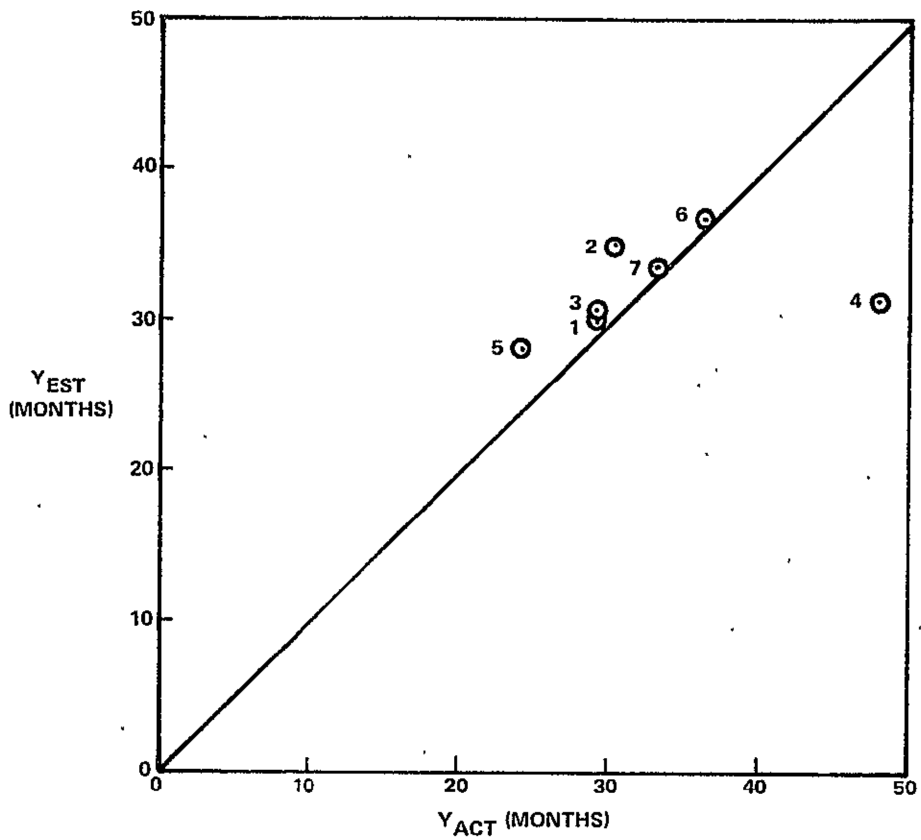
Table 7.6-VII presents a summary of the total span approach to the build-up span approach for estimating the time span for the Advanced Space Transport Program air vehicles from program go-ahead to first horizontal flight. Also included for reference are the results based on the Type I distributions which may not be good indicators since the Stage I and Stage II air vehicles are larger and more complicated than most of those programs used for developing the Type I distributions.

TABLE 7.6-VII

COMPARISON OF TOTAL SPAN APPROACH TO BUILD-UP SPAN APPROACH
(PROGRAM GO-AHEAD TO FIRST HORIZONTAL FLIGHT)

	Type I Distribution (Mos)	Stage I Prediction (Mos)	Stage II Prediction (Mos)
Design	34.4	38.5	34.9
Manufacture	33.3	49.7	42.2
Ramp	6.7	9.4	8.0
Total (Build-up)	60.6	82.2	71.1
Total (Total Span)	47.7	85.3	72.8

$$Y_{EST} = 21.2270\,(W_{SYS})^{.1067}\,(C_X)^{.0828}$$



WHERE:

Y_{EST} = TIME SPAN IN MONTHS

W_{SYS} = SYSTEM WEIGHT IN THOUSANDS OF POUNDS

C_X = STRUCTURE COMPLEXITY FACTOR

	STAGE I	STAGE II
Y_{EST}	38.5 MO.	34.9 MO.
W_{SYS}	217.674	74.144
C_X	1.300	1.550

CODE:

1. CSM
2. SIC
3. SII
4. B58
5. X15
6. B70
7. CONCORDE

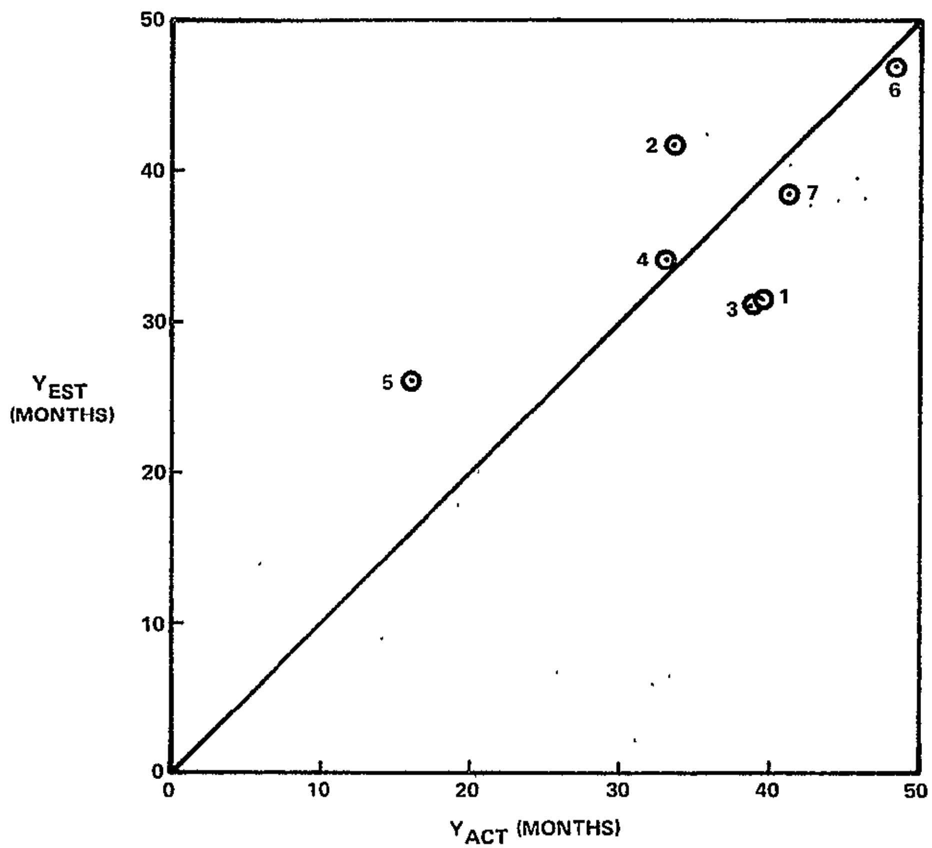
COEFFICIENT OF CORRELATION = 0.426

STANDARD DEVIATION OF ERROR = 7.3 MONTHS

FIGURE 7.6-6 TOTAL PROGRAM Y_{ACT} VERSUS Y_{EST}

(PROGRAM GO-AHEAD TO 95% DESIGN RELEASE)

$$Y_{EST} = 3.5398 + 8.2049\ (\ln W_{SYS}) + (7.5413)\ (\ln C_X)$$



WHERE:

Y_{EST} = TIME SPAN IN MONTHS

W_{SYS} = SYSTEM WEIGHT IN THOUSANDS OF POUNDS

C_X = STRUCTURE COMPLEXITY FACTOR

	STAGE I	STAGE II
Y_{EST}	49.7 MO.	42.2 MO.
W_{SYS}	217.674	74.144
C_X	1.300	1.550

CODE:

1. CSM
2. SIC
3. SII
4. B58
5. X15
6. B70
7. CONCORDE

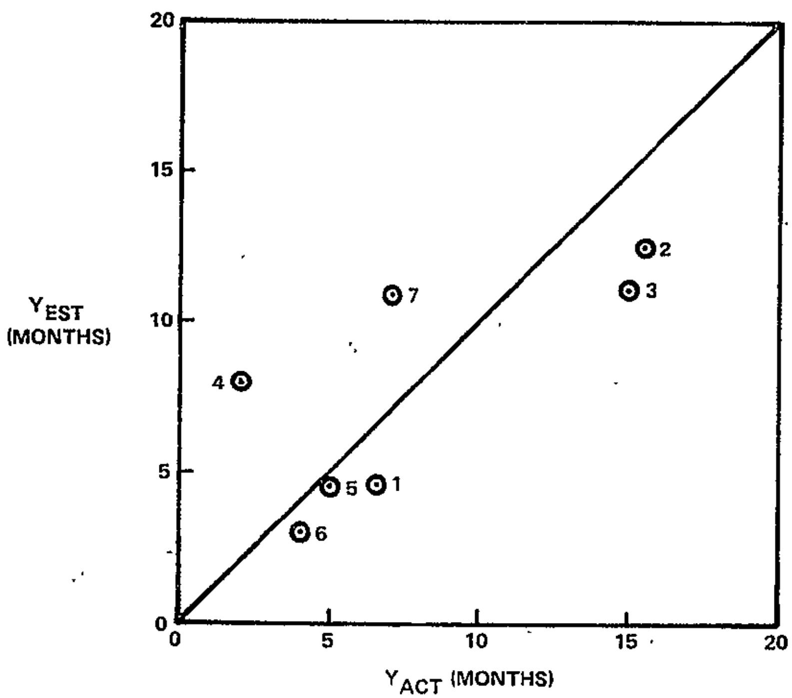
COEFFICIENT OF CORRELATION = 0.703

STANDARD DEVIATION OF ERROR = 7.1 MONTHS

FIGURE 7.6-7. TOTAL PROGRAM Y_{ACT} VERSUS Y_{EST}

(START MANUFACTURING TO 1ST FLIGHT ARTICLE)

$$Y_{EST} = 13.3140 - (0.2713)\ (\ln W_{SYS}) - 9.4324\ (\ln C_X)$$



WHERE:

Y_{EST} = TIME SPAN IN MONTHS

W_{SYS} = SYSTEM WEIGHT IN THOUSANDS OF POUNDS

C_X = STRUCTURE COMPLEXITY FACTOR

	STAGE I	STAGE II
Y_{EST}	9.4 MO.	8.0 MO.
W_{SYS}	217.674	74.144
C_X	1.300	1.550

CODE:

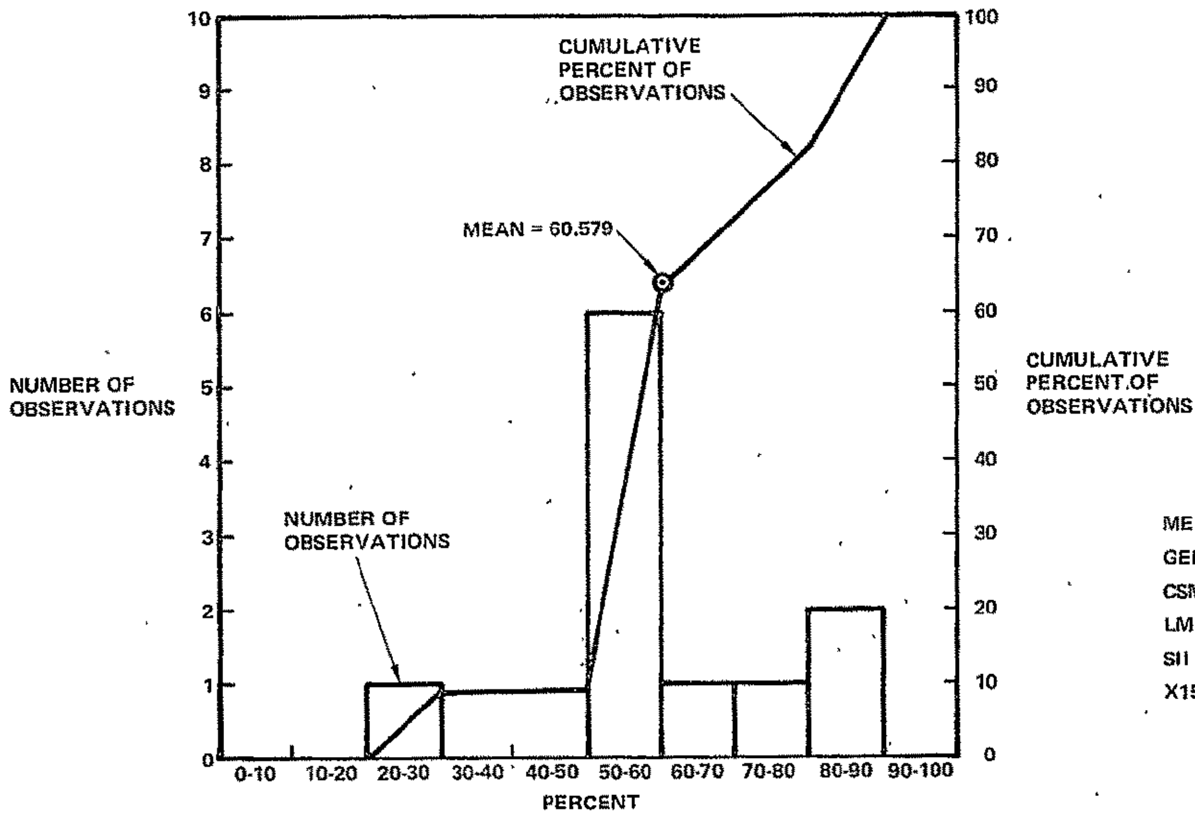
1. CSM
2. SIC
3. SII
4. B58
5. X15
6. B70
7. CONCORDE

COEFFICIENT OF CORRELATION = 0.721

STANDARD DEVIATION OF ERROR = 3.7 MONTHS

FIGURE 7.6-8 TOTAL PROGRAM Y_{ACT} VERSUS Y_{EST}

(RAMP TIME SPAN – ROLLOUT TO 1ST HORIZONTAL FLIGHT)



SUMMARY:

RANGE = 29.19 TO 87.5 PERCENT
MEAN = 60.579 PERCENT
MODE = 50.0 TO 60.0 PERCENT

INPUT DATA (PERCENT)

MERCURY	52.27	B70	80.55
GEMINI	29.19	B58	52.77
CSM	58.62	C5A	52.38
LM	54.54	747	53.84
SII	68.96	F111	75.75
X15	87.50		

FIGURE 7.6-9 TOTAL PROGRAM

PERCENT DESIGN COMPLETE AT MANUFACTURE START.

4.0 LIMITATIONS

The user of this methodology should be cautioned that the derived mathematical expressions (equations) considered are valid only for programs similar to those utilized in equation development. Other independent variables which may be considered for deriving new equations should be analyzed very thoroughly prior to use, as study personnel have found that this area, in particular, may be extremely sensitive to certain parameters.

7.7 HORIZONTAL FLIGHT TEST PROGRAM

1.0 SCOPE

The purpose of this TER is to develop mathematical expressions and/or methodology which will predict the time spans required to conduct the horizontal flight test program for the Advanced Space Transport Program air vehicles. Following the horizontal flight testing, the air vehicles are refurbished and considered qualified for vertical flight.

The duration of a flight test program is a function of the number of measurements required to meet the test objectives. The number of measurements are a function of the number of flight hours per flight, the number of flights and the number of vehicles included in the flight test program. How soon the vehicle(s) can be turned around between flights is a function of the test philosophy, data acquisition capability, data reduction capability, data analysis capability, length of time required to calibrate or recalibrate, and the length of time required to install modifications and retest. The above described activities then determine the duration required to accomplish a flight test program.

For the Advanced Space Transport Program, the following requirements are established as a baseline for the Horizontal Flight Test Program:

Stage I	Vehicle #1	160 Hours
Stage I	Vehicle #2	25 Hours
Stage II	Vehicle #1	160 Hours
Stage II	Vehicle #2	25 Hours

Included in this TER are the approach utilized for development of the TER(s), the input data, the results, and the limitations associated with the utilization of these TER(s). In addition, an unbiased opinion was solicited from VMSC flight test personnel requesting air vehicle turn-around time estimates for the Advanced Space Transport Program horizontal flight test program. An in-house memorandum containing this data is presented at the end of this TER. (See Enclosure (1) of this section.)

2.0 APPROACH

Flight test program data was gathered on 11 aerospace programs which were considered representative of a horizontal flight test program. These data are presented in Table 7.7-I. As can be seen, in this table, four independent variables were selected for the multiple regression

TABLE 7.7-I

HORIZONTAL FLIGHT TEST
(Multiple Regression Input Data)

Program	Independent Variables				Dependent Variable
	System Weight To Empty Weight Ratio	Number of Engines	Number of Aircraft	Number of Flight Hours	Number of Months
XB-70	.351	6.000	1.000	16.000	7.500
XB-70	.351	6.000	1.000	21.300	10.000
XB-70	.351	6.000	1.000	71.000	40.000
XB-70	.351	6.000	2.000	184.200	19.500
X-15	.507	1.000	3.000	27.500	77.000
C-5A	.300	4.000	8.000	1850.000	18.000
C-5A	.300	4.000	4.000	250.000	10.500
C-5A	.300	4.000	4.000	200.000	9.700
F8U-3	.348	1.000	1.000	150.000	18.000
F8U-1	.348	1.000	2.000	579.000	33.000
XF8U-1	.348	1.000	1.000	100.000	7.000
A-7A	.522	1.000	7.000	387.000	6.000
Concorde	.364	4.000	2.000	500.000	27.000
Mirage G	.493	1.000	1.000	400.000	26.000
DC-10	.300	3.000	4.000	679.000	8.000
DC-10	.300	3.000	4.000	765.000	8.500
DC-10	.300	3.000	4.000	250.000	4.000
DC-10	.300	3.000	5.000	1050.000	9.500
L-1011	.300	3.000	2.000	64.000	3.000
L-1011	.300	3.000	2.000	130.000	5.000

analysis. These independent variables were (1) a ratio of the system weight to empty weight, (2) the number of engines, (3) the number of aircraft in the flight test program, and (4) the number of flight hours. It should be noted that there were four observations for the XB-70 and DC-10, three observations for the C5A, two observations for the F8U-1 and L-1011. The remaining programs have one observation each. The reason for this approach was the data available did not, in all cases, specify the actual history by aircraft number. The Table 7.7-I data were inputted into the VMSC multiple regression analysis routine which developed four different equation types that best fit the data. These equation types are linear, log, log-linear and log-log. The output data is analyzed and the best equation selected for use in estimating the time spans associated with the Advanced Space Transport horizontal flight test program. The input data (Y_{act}) was plotted against the (Y_{est}) in order to show how well the selected equation fit the input data. The abscissa was the Y_{act} axis and the Y_{est} the ordinate axis, thus any point falling to the left of a 45° line (which reflects perfect fit) indicates the formula is predicting longer time than that actually incurred and; conversely, any point falling to the right of the line reflects a prediction that is shorter than that incurred.

In order to provide a means for computing turnaround time associated with the air vehicles, data was collected on several programs to determine the number of hours per flight historically experienced on previous aerospace programs. This data are presented in Table 7.7-II.

TABLE 7.7-II

HOURS/FLIGHT

Observation	No. Vehicles	No. Flights	Flight Hours	Hours/Flight
1. F-14	1 (#2 Proto)	2.0	3.1	1.55
2. XB-70A	1 (#1 Proto)	12.0	16.1	1.34
3. XB-70A	1 (#1 Proto)	15.0	21.3	1.42
4. XB-70A	2 (#1 & #2 Proto)	95.0	184.2	1.92
5. F8U-3	1 (#1)	135.0	202.0	1.50
6. F8U-3	1 (#2)	100.0	150.0	1.50
7. Mirage G	1 (#1 Proto)	316.0	400.0	1.27
8. Dassault Mercure	1	6.0	8.8	1.47
9. Concorde	2 (#1 & #2 Proto)	63.0	104.0	1.65
10. DC-10	Unknown	400.0	765.0	1.91
Sum		1144.0	1854.3	15.55
Average Hours/Flight				1.55
Weighted Averaged Hours/Flight		$\frac{1854.3}{1144.0}$		1.62

From Table 7.7-II the average hours per flight is approximately 1.5 hours duration. The Advance Space Transport air vehicle ferry range is given as 400 miles with a ground speed of approximatel y 250 miles per hour. This would indicate a potential flight duration of 1.6 hours. Based on these two observations, it was assumed by study personnel that the hours/flight would be 1.5 hours each. Using this 1.5 hours/flight; the number of flight hours required per air vehicle and the regression analysis results for flight test time spans, the turnaround time was computed for each of the air vehicles involved in the horizontal test program prior to vertical flight. As a second check on the turnaround time results obtained by the methodology described above, data was collected on several programs to determine the turnaround time experienced on previous programs. Table 7.7-III presents this data which reflects an average turnaround per flight of 9.4 days.

TABLE 7.7-III

TURNAROUND TIME/FLIGHT/AIRCRAFT

Observation	No. Flights	Months	Avg. Turn Time/Flight
F-14A #1	2	.3	9.0 Days
F-14A #2	2	.1	3.0 Days
XB-70A	12	7.5	18.7 Days
XB-70A	15	10.0	20.0 Days
XB-70A	71	40.0	16.9 Days
X-15	150	77.0	30.0 Days
F8U-3 #1	135	18.0	4.0 Days
Concorde #1	39	6.0	4.6 Days
Concorde #1	45	10.0	6.7 Days
Concorde #2	24	4.0	5.0 Days
Mirage G	316	26.0	2.4 Days
Dassault Mercure	6	.25	1.3 Days
DC-10	400	8.5	1.27 Days
Sum	1217	207.6	122.9
Average Turn/Flight			9.4 Days
Weighted Average Turn/Flight			5.1 Days

The data presented in Table 7.7-III with the exception of the F-14 and F8U-3 was plotted against the calendar year of the first flight to provide an indication of how the advancement in the data acquisition/reduction process can reduce the vehicle turnaround time span. This data is presented in the Limitation section of this TER since it was not used for the analysis.

To determine the time span required for the air vehicle modification and checkout, prior to vertical launch and after completion of the horizontal flight test, an analysis was made on the time required for the SIC stage of Saturn V. The SIC is considered representative of the types of operations required for the Advanced Space Transport air vehicles. The total time span from first horizontal flight to having an air vehicle qualified for vertical launch is obtained by summing the horizontal flight time span with the refurbish and checkout time span.

3.0 RESULTS

The following mathematical expression (equation) was selected based on the best formula developed using the input data presented in Table 7.7-I. This equation is a log-log type and had a coefficient of correlation of .580.

$$Y_{est} = 78.0529 (W_{Ratio})^{2.9556} (N_{Eng})^{.2916} (N_{AC})^{-.4077} (N_{FH})^{.2558}$$

Where:

Y_{est} is the time span in months to accumulate the flight hours.

W_{Ratio} is the system to empty weight ratio.

N_{Eng} is the number of engines (air breathing).

N_{AC} is the number of aircraft in the flight test program.

N_{FH} is the number of flight test hours

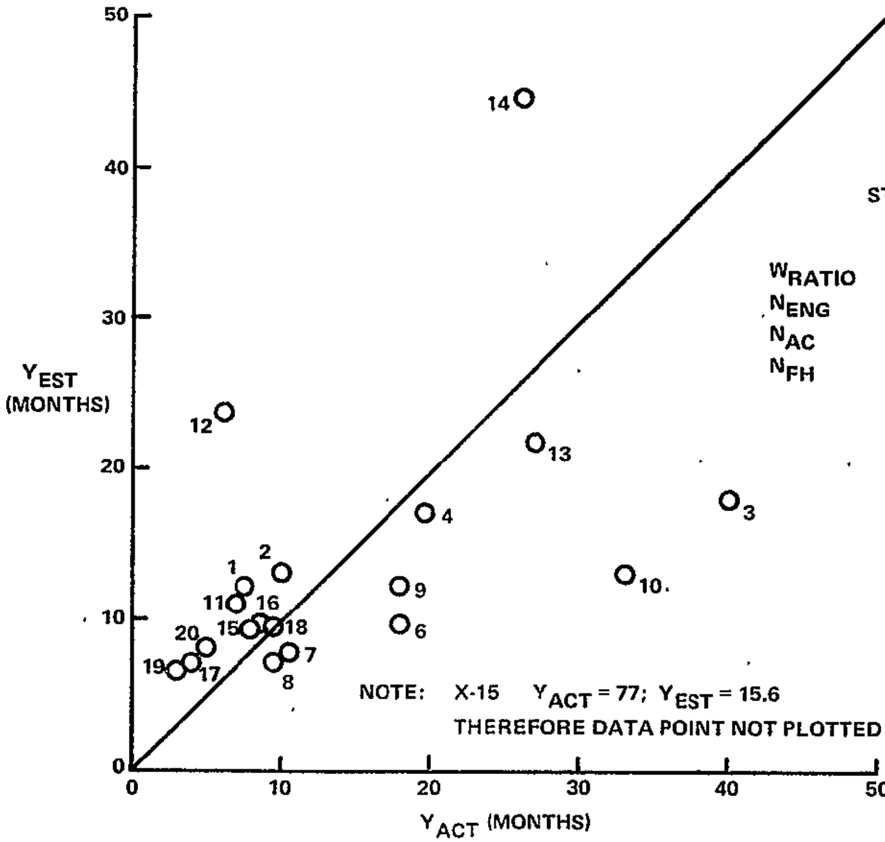
Figure 7.7-1 presents the actual time (Yact) versus the estimated time (Yest) based on the input data and the above equation. The results, using the above equation and the Advanced Space Transport air vehicle characteristics are presented in Table 7.7-IV. These time spans reflect the time associated with qualifying the air vehicle for vertical flights.

TABLE 7.7-IV

HORIZONTAL FLIGHT TEST PROGRAM TIME SPANS

Vehicle	Ratio-Systems Weight/Empty Weight	No. Engines	No. of Air-Craft in Program	Flight Hours	Months After First Flight
Stage I #1	.326	4	1	160	25.6
Stage I #2	.326	4	1	25	15.9
Stage II #1	.346	12	1	160	15.6
Stage II #2	.346	12	1	25	9.7

$$Y_{EST} = 78.0529\,(W_{RATIO})^{2.9556}\,(N_{ENG})^{.2916}\,(N_{AC})^{-.4077}\,(N_{FH})^{.2558}$$



WHERE:

- Y_{EST} = HORIZONTAL FLIGHT TEST PROGRAM TIME SPAN (MONTHS)
- W_{RATIO} = SYSTEM WEIGHT TO EMPTY WEIGHT RATIO
- N_{ENG} = NUMBER OF ENGINES
- N_{AC} = NUMBER OF AIRCRAFT
- N_{FH} = NUMBER OF FLIGHT HOURS

	STAGE I PARAMETERS		STAGE II PARAMETERS	
	VEHICLE NO. 1	VEHICLE NO. 2	VEHICLE NO. 1	VEHICLE NO. 2
W_{RATIO}	0.346	0.346	0.326	0.326
N_{ENG}	12.0	12.0	4.0	4.0
N_{AC}	1.0	1.0	1.0	1.0
N_{FH}	160.0	25.0	160.0	25.0

CODE:

1. XB-70 OBSER. NO. 1
2. XB-70 OBSER. NO. 2
3. XB-70 OBSER. NO. 3
4. XB-70 OBSER. NO. 4
5. X-15
6. C-5A OBSER. NO. 1
7. C-5A OBSER. NO. 2
8. C-5A OBSER. NO. 3
9. F8U-3
10. F8U-1
11. XF8-U-1
12. A7A
13. CONCORDE
14. MIRAGE G
15. DC-10 OBSER. NO. 1
16. DC-10 OBSER. NO. 2
17. DC-10 OBSER. NO. 3
18. DC-10 OBSER. NO. 4
19. L-1011 OBSER. NO. 1
20. L-1011 OBSER. NO. 2

COEFFICIENCT OF CORRELATION = .576
STANDARD DEVIATION OF ERROR = 16.7 MONTHS

FIGURE 7.7-1 HORIZONTAL FLIGHT TEST PROGRAM

It should be noted that in this study only the horizontal flight testing up to the point where the air vehicle was qualified for first vertical flight was considered. Therefore, subsequent air vehicles (i.e., #3 and on) horizontal flight testing was not included in the analysis.

In order to determine the average turnaround time span estimates, the number of flight hours required was divided by the number of hours per flight (1.5 hours/flight used in this study). The number of flights was then divided into the number of months estimated by the above equation, resulting in the number of months per flight. This data was then multiplied by 30 to obtain the equivalent number of days between flights or turnaround time. These data are presented in Table 7.7-V.

TABLE 7.7-V

AIR VEHICLE TURNAROUND TIME SPAN

Vehicle	Flight Hours	Flights	Months	Months/Flight	Turnaround Time (Days)
Stage I #1	160	107	25.6	.239	7.2
Stage I #2	25	17	15.9	.935	28.1
Stage II #1	160	107	15.6	.146	4.4
Stage II #2	25	17	9.7	.57	17.1

The reason for the longer turnaround time on Vehicle #2 is that due to the reduced number of horizontal flight hours required, the turnaround time is higher up on the learning curve than that for Vehicle #1. It should be noted that based on historical data (presented in Table 7.7-III) the average turnaround time is 9.4 days, thus the values presented above appear to be realistic estimates.

As a separate check on the time span required for Horizontal Flight Test, the technical personnel of VMSC were requested to estimate the time required for vehicle turnaround. This response is included at the end of this section. (Departmental Correspondence 3-56000/1AVO-145, dated 6 July 1971) The results of this estimate are summarized as follows assuming 1.5 hours/flight.

Vehicle	Hours	Flights	Months	Turnaround - Days
Stage I #1	160	107	24.9	7.0
Stage I #2	25	17	5.4	9.4
Stage II #1	160	107	24.9	7.0
Stage II #2	25	17	5.3	9.4

Study personnel are of the opinion that the equation prediction methodology is a more valid device for estimating the time spans associated with the horizontal flight test program, thus they were used for the remaining portion of the analysis.

The other time span element to be considered before the air vehicle is ready for vertical flight is that effort associated with refurbishing (i.e., installing live main rocket engines), final checkout and acceptance testing. This effort is estimated to be equivalent to the Saturn SIC from completion of static firing to launch ready. Presented in Table 7.7-VI are the actual times experienced on Vehicles SIC-501 and SIC-505 launch vehicles.

TABLE 7.7-VI

SIC REFURBISHMENT AND FINAL CHECKOUT TIME SPAN

	SIC-501 (Months)	SIC-505 (Months)
Refurbishment and Checkout	4.0	3.5
Acceptance Testing	2.5	3.5
Ferry to Launch Site	1.0	1.0
Assembly, Checkout and Launch Preparation	12.0	5.0
Static Firing to Launch Ready	19.5	13.0

Based on the SIC-505 data and the fact that the Advanced Space Transport air vehicles will not require the one month to ferry it to the launch site, 12 months are allocated to the air vehicles for this effort.

Table 7.7-VII summarizes the time span from first horizontal flight to an air vehicle ready for first vertical launch. These data indicate the first mated flight can occur on Vehicle #2 27.9 months after the first horizontal flight of Vehicle #2, which is when the booster (Stage I Vehicle #2) has been qualified and ready for launch. Stage I appears to be the pacing air vehicle based on the results of this study. Vehicles #1 may not have attained the full 160 horizontal flight hours before Vehicle #2 is ready for first vertical flight.

TABLE 7.7-VII

FIRST HORIZONTAL FLIGHT TO READY FOR VERTICAL FLIGHT TIME SPAN

Vehicle	Horizontal Flight Test Time Span (Mo)	Refurbish and Checkout Time Span (Mo)	Total Time Span (Mo)
Stage I #1	25.6	12.0	37.6
Stage I #2	15.9	12.0	27.9
Stage II #1	15.6	12.0	27.6
Stage II #2	9.7	12.0	21.7

4.0 LIMITATIONS

The user of this methodology for estimating time spans should be aware that the results obtained are directly relative to the size and accuracy of the input data used to derive the mathematical expression. In addition the analyst should thoroughly review the derived estimates and ascertain if they are logical and realistic when compared to other programs of like nature. Advancement in the state-of-art should also be given serious consideration such as increased capability in obtaining and reducing data; however, other factors, such as air vehicle readiness or availability may then be the driving factor when considering turn-around time.

Figure 7.7-2 shows the turnaround time-average per aircraft - in days for several aircraft plotted against year of first flight. This figure depicts the technology advance which is largely a function of telemeter capability, and resulting data acquisition and analysis time. Through the mid-50's, T/M transmission was basically analog and limited to approximately 10-15K bits per second. In about 1955, frequency systems came into use - duration and amplitude modulation and coding which would handle up to about one (1) megabit/second. In the 1959 time span, pulse coding and higher density data streams came into use with capability of 1 + megabit/second. In 1968, the capability had advanced to 10 megabit/second. This capability, coupled with onboard checkout, hardware and software, has cut the turnaround time required to the levels shown in Figure 7.7-2.

The DC-10, for example, can handle 500,000 bits/second and McDonnell-Douglas attributes the system with reducing flight test time. Thus, the technology will allow one (1) day turnaround on the vehicle; however, VMSC is of the opinion that the vehicles under consideration in this study will not be turned that fast due to the nature of the program, the number and cost of the vehicles. Figure 7.7-3 shows, for example, the type of activity and their impact on turnaround time as experienced on the X-15 vehicle. "Figure 7.7-3 shows a breakdown of time involved

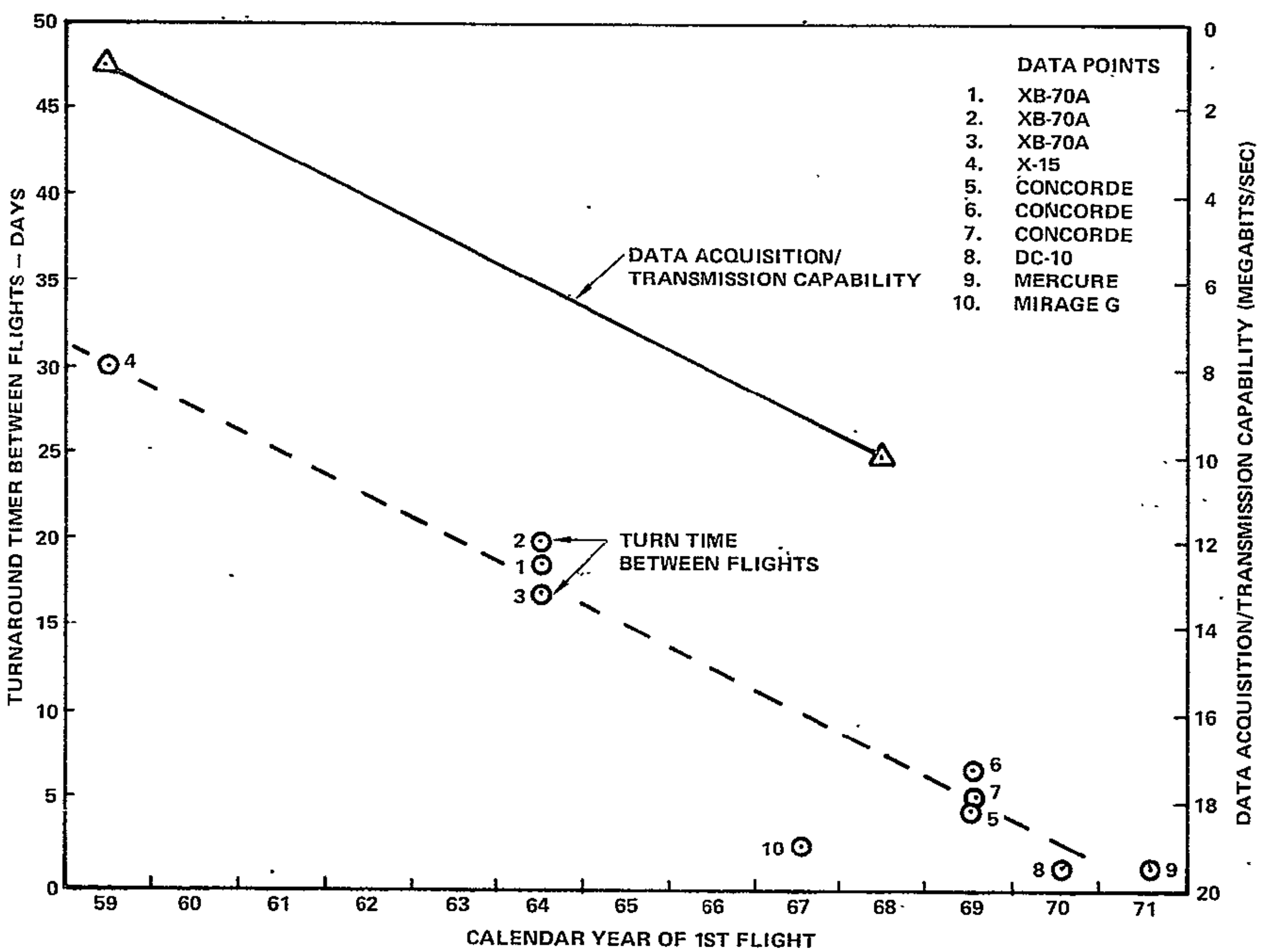


FIGURE 7.7-2 TURNAROUND TIME – DAYS VS YEAR OF FIRST FLIGHT

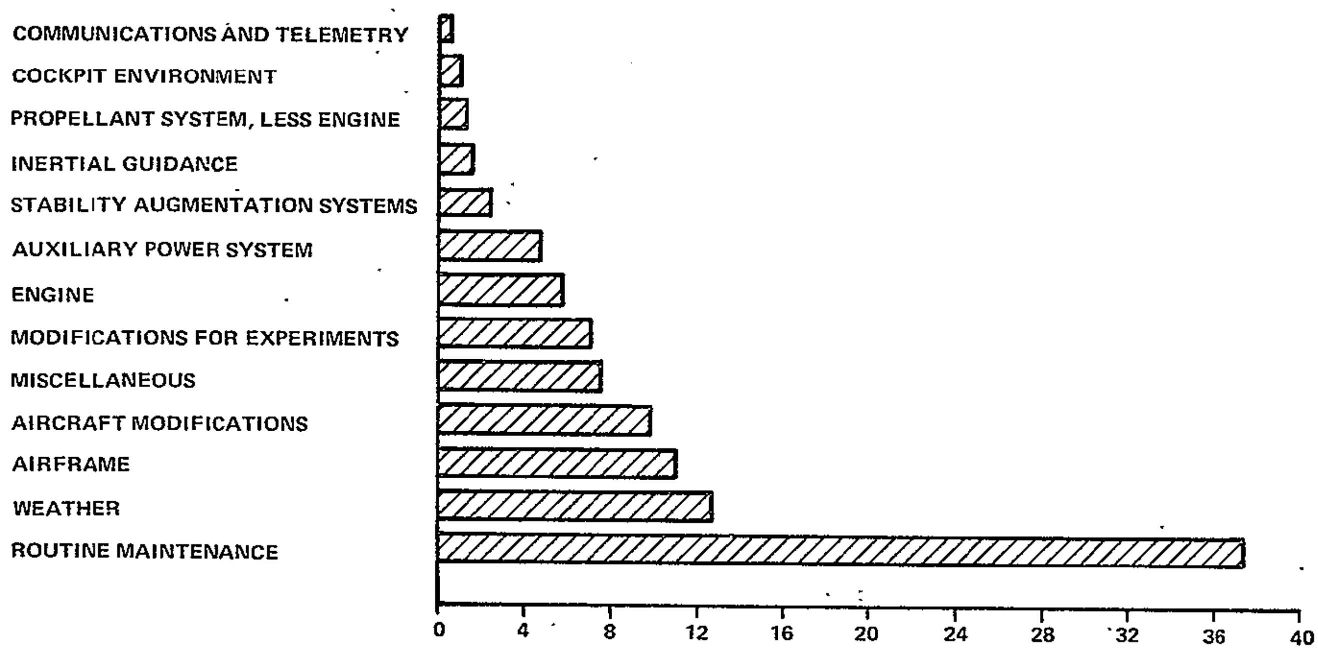


FIGURE 7.7-3 X-15 DISTRIBUTION OF TURNAROUND TIME IN PERCENT
SEPTEMBER 1961 TO JULY 3, 1965

in turnaround of the three X-15 airplanes from September 1961 to July 1965. Only the predominant cause of turnaround delay was tabulated for each day; minor items which occurred simultaneously were not accounted for. Routine maintenance and preflight preparation absorbed almost 38 percent of the total time, followed by weather at greater than 12 percent. Airframe problems were third, at almost 11 percent; landing-gear malfunctions and canopy-glass failures early in the program contributed heavily to this category. No deterioration of the basic structure has been evident. There has been buckling and deformation of some of the nonload-carrying members, but the integrity of the structure has not been compromised. In fact, inspection during the turnaround cycle has made it possible to detect progressive failures before they become serious. Aircraft modifications, which were fourth, consisted primarily of routine design improvements and accident repair. The 'miscellaneous' category includes the more than 150 days from the date of the X-15-2 accident in November 1962 until the contract was signed to rebuild and modify the aircraft for research flights to a Mach number of 8, including the use of the aircraft as the test-bed for supersonic-combustion ramjet flight tests. The 'engine' category includes engine changes as well as corrective engine maintenance without removal. "

As stated previously, the state-of-art, technology, and actual accomplishment would indicate the capability exists to fly these vehicles on a daily basis after a reasonable period of time. However, logic and experience of VMSC flight test personnel who have been involved in flight tests of high performance aircraft, indicate that this should not be expected on the Advanced Space Transport air vehicle. One of the main points these personnel keep addressing is that of the number of engines involved. The history of flight test experience with engines and engine controls, coupled with this program requirement for deployment and retraction of these engines, is one factor which they indicate will negate relatively short turn times.

VOUGHT MISSILES AND SPACE COMPANY - TEXAS
Departmental Correspondence

SUBJECT: Shuttle Vehicle Turnaround Time Information for the Horizontal Flight Test Program

DATE: 6 July 1970

FILE: 3-56000/1AVO-145

TO: Mr. D. P. Crain

FROM: W. M. Menco
J. J. Rogers

1. Determination of a turnaround time requirement for the shuttle vehicles (both the Booster vehicle and the Orbiter vehicle) during the horizontal subsonic flight test phase of the program must be based on a number of considerations, such as:

a. Instrumentation requirements for the various tests,

b. Vehicle system and subsystem modification requirements,

c. Pre/Post flight vehicle maintenance and checkout requirements,

d. Real time and post flight data reduction and analysis requirements, and

e. Test documentation requirements.

These factors are all interrelated, and as such, the turnaround time requirement for the test vehicles is dependent upon how each of the requirements are implemented into the test program.

2. It is known that each vehicle flight test, or series of flight tests, will schedule specific test objectives to demonstrate an acceptable level of vehicle airworthiness and flight safety. Such objectives as stability and control, performance, propulsion, structures, subsystem performance, GN & C subsystem, night flight and unpowered approach and landings will necessarily be investigated as a part of each flight test. However, each of the objectives will schedule a planned number of dedicated flight hours, wherein at some time during the tests each objective will be primary while others are secondary, dependent upon the particular test plan for the particular flight.

3. In order to accomplish the broad spectrum of objectives as a part of each flight, it is assumed that the Development Flight Instrumentation (DFI) aboard the vehicle is of sufficient quality and quantity to provide adequate data for analysis. If this is the case, then vehicle instrumentation modifications will be at a minimum, thereby reducing the need for:

a. Installation of additional DFI and instruments and wiring,

b. Extended pre/post flight checkout times of additional instrumentation,

c. Installation of modifications, and checkout of the ground instrumentation system for data display, reduction and analysis, and

d. Changes to test documentation.

Reduction of such modifications between flights, to the vehicle, checkout equipment and ground stations, would thereby enhance the turnaround capability for the test vehicles.

4. However, based upon previous flight test program experience, problems will be encountered during the flight test program which will require:

a. Addition of special instrumentation,

b. Modifications to the vehicle structure and/or systems and subsystems, and ground support equipment,

c. Revisions to test documentation for alternate or additional tests, and

d. Additional time for the analysis of data to pinpoint the causes of problems and/or potential problems.

Realistically, these factors will have an effect of extending the turnaround capability, dependent upon the type of problem(s) experienced.

5. Although specific time periods for these general problem areas cannot be quantitized, an estimate can be made based on experience. We estimate that the turnaround time for Vehicle #1, following a problem-free ferry flight from Pt. Mugu to EAFB, will be approximately one month. This amount of time will be required between flights since we are testing a new vehicle, and a complete checkout of the vehicle structure and all systems will want to be made, regardless of whether or not any problems were experienced during the ferry flight. During this period, a thorough analysis of all data from the ferry flight will be accomplished, to exclude the possibility of any problem and/or potential problem being overlooked which may not have been evident on the Checkout and Fault Isolation systems.

6. Following the first test flight at EAFB, the turnaround time can probably be reduced to three weeks, again dependent upon a problem-free test. This three-week turnaround period can then be used for the next three flights. As the test program continues, the turnaround time can be reduced to two weeks through the remaining first six months. This would give a total of 12 flights in six months. By this time, the experience gained from a flight, maintenance, checkout and data analysis standpoint would allow a one-week turnaround for the remainder of the first year. This one-week turnaround would be continued into the second year, and by the time Vehicle #2 was ferried to EAFB, the vehicle can be turned around twice a week, to the completion of horizontal flight tests on Vehicle #1. For the overall horizontal flight test program on Vehicle #1, the turnaround time between flights would average about one a week, for the total 160 hours of flight.

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7. Vehicle #2 will be fully configured for flight and space test with DFI installed, and will supplement the horizontal subsonic flight tests of Vehicle #1. These flight tests will determine vehicle airworthiness and will demonstrate its readiness for the ferry flight to KSC. Although Vehicle #2 is configured for space flight, an abbreviated plan from that of Vehicle #1, based on experience of testing Vehicle #1, should be followed for subsonic flight testing of this vehicle after its ferry flight from Pt. Mugu to EAFB. That is, an approximate one month turnaround would be required for the first flight test at EAFB, followed by a three week turnaround for the next flight, a two week turnaround for the next flight, and then a one week turnaround for subsequent flights, for a total of 25 hours of subsonic flight testing.

J. J. Rogers
Test Operations Engineer

W. M. Menco
Project Engineer, Test Operations Engineering

/ss

7.8 CONFIDENCE

1.0 The body of this report, particularly in the TER section, includes several tools for determination of confidence which can be placed in the resultant answers. These tools include for example:

a. Type I Distribution - Several of the TERs present a frequency distribution of the data utilized in deriving the equations. This provides the user with a means for comparison of the input with the resultant output. The data, for the most part, displays a degree of skewness to the right which is the direction one would expect. The data is not normally distributed.

b. Yest Vs Yactual - Several of the TERs have been plotted to depict how well the equation predicts the input data.

c. Multiple Correlation Coefficient - Each of the equations presented include the Multiple Correlation Coefficient which is another measure of how well the equation predicts the input data.

d. Standard Deviation of Error - Each of the equations presented include the Standard Deviation of Error which is a measure of the goodness fit of the equations to the data. The lower the Standard Deviation, normally, the better the equation.

$$\text{STANDARD DEVIATION OF ERROR} = \sqrt{\frac{\Sigma\,(Y_{ACT} - Y_{EST})^2}{N-1}}$$

e. Limitations - Each of the TER descriptions includes a set of limitations or caveats study personnel recommended in using the TER.

f. Data - For the most part, the data is of the same class of vehicles as those being estimated using the TERs. This was by design rather than by accident, as study personnel are of the opinion that there may well be classes of vehicles and that data for one class may not represent a different class of vehicles.

g. Unadjusted Data - The data used in deriving these equations has not been enriched or adjusted. As a result, it is "noisy" which leads to low Multiple Correlation Coefficients. This study has not included all factors which influence time required, i.e., national priority, funding restrictions and state-of-art breakthrough required. There is no reason to believe that the subject program will not experience the same conditions as affected the input data.

h. Comparisons - The results have been compared with results obtained through conventional scheduling methods and resultant differences reviewed and evaluated. Several equations/methodologies have been employed to select the "best" equation, including review of parameters, equations and higher level comparisons. This includes, for example, evaluation and independent estimates by division technical personnel.

2.0 In addition to those tasks noted above as being included in the study results, several other approaches to confidence determination have been reviewed to varying levels. These include:

a. Beta Distributions - The resultant answers were assumed to be of a Beta distribution form, i.e., extremes known and a routine developed which would yield a Beta distribution from the input data. Study personnel are of the opinion that the distribution is not fixed at either extreme and that the method is too sophisticated for use at this time on the data.

b. Weibull Distribution - The resultant answers were assumed to be of a Weibull distribution form, i.e., lower extreme known and a routine developed which would yield such a distribution from the input data. Study personnel are of the opinion that the distribution type is appropriate, however again, that the method is too sophisticated for use at this time on the data.

c. Parameter Selection Through the Use of F Tests - To preclude the possibility that selected independent variables exhibit colinearity between each other, the VMSC multiple regression routine employs the standard F test. This test determines the degree, if any, of colinearity between variables and, based upon predetermined criteria, rejects those variables which exhibit this tendency. The unfortunate result of this selection process is that very often variables which have historically demonstrated cause and effect relationships are not considered in final estimating equations. For example, engine thrust has historically demonstrated an ability to predict cost of new engine systems. When the F test was employed on the TER for propulsion, thrust was deleted from all equation forms. It is the opinion of this study team that thrust or some derivative of the thrust function is casually related to schedule performance. The only way to get the influence of the thrust variable is to completely relax the F test criteria and allow this parameter to influence the resulting equation in whatever way it will. Another example may be demonstrated here. When the F test criteria were employed on certain forms of equations within the TER for structure, the resulting equations had only one variable which had passed the test, that variable was complexity factor. Other parameters such as weight, Mach number, and planform area had been deleted as independent variables in the equations. Even though the F test was employed to aid in selection of independent variables for the propulsion and structure TERs, it is recommendation of this study team that, until more subsystem physical and performance parameters are identified and made available for general use, the statistical screening techniques such as F tests, be relied upon as indicators of potential problems between variables. These problems should be closely scrutinized by the analyst before variables are deleted from the estimating equation.

d. Probability Plots of Data - Another method has been reviewed and offers some merit though not included at this time. This involves plotting the input data on Probability paper, then superimposing the standard deviation from the equation to evaluate skewness and effect. The probability plots have essentially been made with the Type I distributions noted in 1.a above.

e. Residual Evaluation - The team has evaluated the residuals on variances, at the total program level, and assigned weighting factors to such things as:

1. State of Art
2. National Priority
3. Funding
4. Problems

and had reasonable success in reducing variation. However, this was a subjective evaluation and a more objective approach to these factors would be required prior to any wide agreement. This is a method which offers promise given more data and time.

f. Lines of Equal Confidence - This is an appropriate technique when dealing with one independent variable. However, since the team is dealing with multiple variables, it is team opinion that the mathematical calculations required to establish Lines of Equal Confidence are not worthwhile, would be difficult to display and more difficult to understand and use.

3.0 Summary - It is study team opinion that the TERs presented in this report are valid to the extent noted by the standard deviation which accompany each equation. After a comprehensive review of historical data, parameters, components of resulting equations and results, it is the opinion of this study team that TER results represent estimates with at least a 50% confidence level. Any other statements would try the intellectual honesty of the team and, therefore, are not recommended at this time.

7.9 SCHEDULE GROWTH

1.0 SCOPE

If one reads the trade literature, there has been increasing attention brought to bear on the apparent fact that a majority of aerospace programs have cost more than the original plan and that actual schedule accomplishment was later than originally planned. This widely publicized growth in both cost and required time is a result of several factors, including over optimisim on the part of contractors, pressures from customers, competitive environment, changes, emergence of unknowns and unanticipated problems. This study attempts to quantify this schedule growth in order to allow comparison of TER results with schedules developed through normal scheduling methodology. The TERs have been developed based on actual program results and thus should reflect what the realistic outcome will be when the program is complete. Aerospace planners do a competent job in developing schedules for bid purposes but the competitive environment, changes and emerging unknowns may make their bid-type schedules overly optimistic. One of the purposes of this section is to provide a tool to allow comparison of these conventionally developed schedules with the time spans as predicted by the TERs. The other purpose of this section is to identify some of the causes of schedule growth and to quantify the impact of these causal factors to the extent possible.

Schedule growth is the term used in this report to denote deviation from plan. That is, the amount of time, more or less than indicated as the baseline plan. For a measure of the amount of schedule growth, this study deals with the ratio $\frac{\text{actual}}{\text{plan}}$. This ratio can be calculated using days, weeks, months or years. For example, if we had a situation when the plan was 12 months, and the actual was 24 months, the ratio would thus be $\frac{24}{12} = 2.00$ or 100% growth.

2.0 APPROACH

The approach, in identifying the amount of growth one should expect to see from a "bid-type" schedule, was to collect program history and quantify schedule position versus plan at various points of time in the programs. The approach to identifying causes of growth and resulting impact was to review the SARP reports available and categorize and quantify the identified schedule problems.

2.1 Schedule Growth - Actual Versus Plan - Data on several programs were collected to determine the amount of schedule growth experienced at various points in the program. Several program check points were identified where program data were available. For example, the actual/plan on the start of Development Testing was collected on ten (10) programs with the result being that the average ratio of actual/plan of these ten (10) programs was 1.20. That is on the average, the programs were 20% behind schedule at the start of Development Testing. This data is summarized in Table 7.9-I.

TABLE 7.9-I

Program Check Point	No. of Observations	Actual Time / Planned Time
Start Development Testing	10	1.20
Complete Development Testing	10	1.30
First Flight	28	1.56
First Delivery (For Customer Flight Test)	4	1.44
Complete Development (RDT&E)	34	1.50
Release for Production	10	1.20

Figure 7.9-1 provides a non-dimensional plot of this data to aid in visualizing status at points in time.

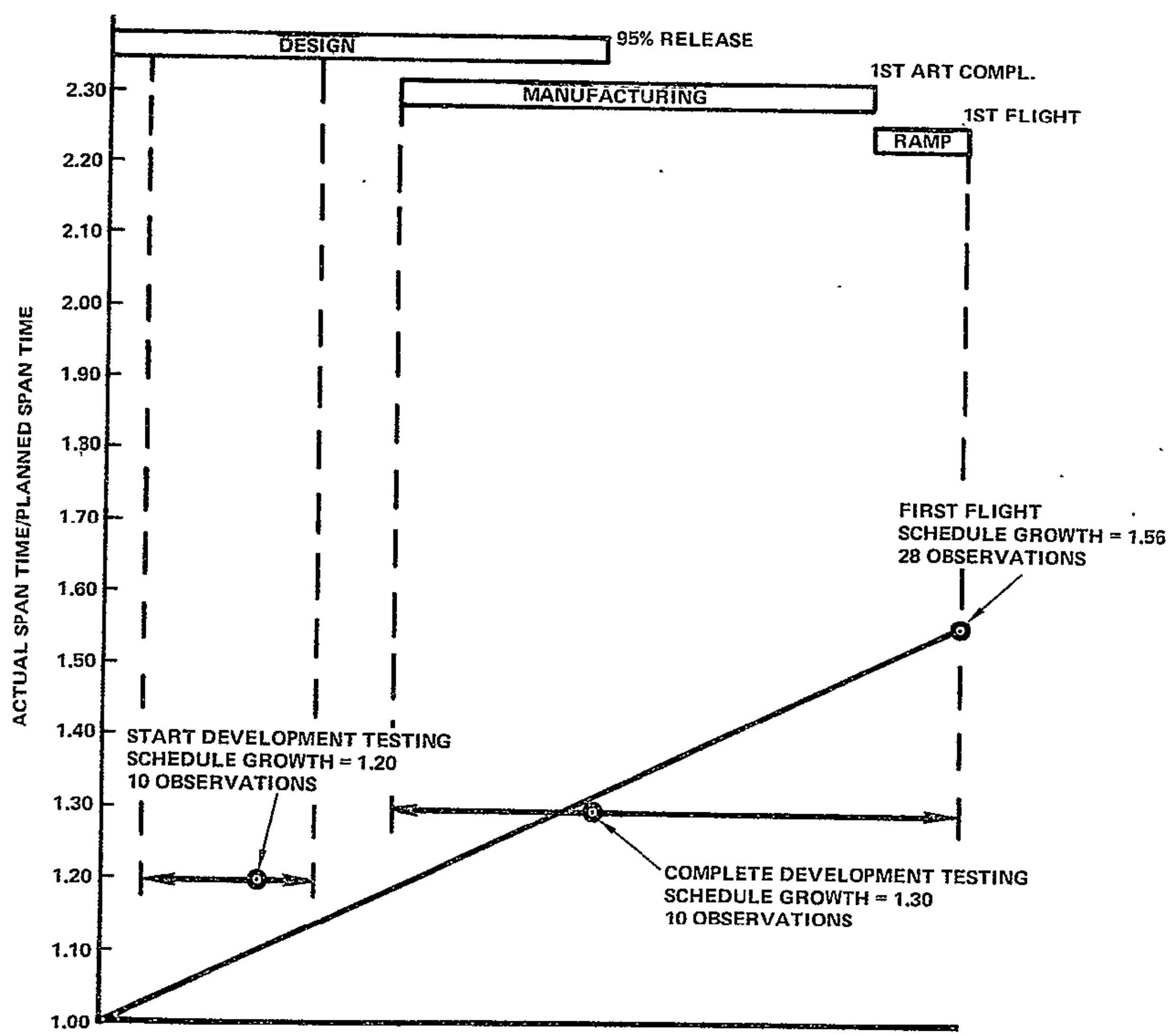

FIGURE 7.9-1 SCHEDULE GROWTH

Relative spans are shown in terms of when Development Testing is initiated and completed on programs in general. Development tests will typically start, based on discussions with several Project Engineers, as early as three months after go-ahead but usually no later than twelve months after go-ahead. Development Testing will normally be complete at about the same time as 95% design release but may extend in some cases all the way to first flight. These two checkpoints are included for reference as they indicate trends which should be considered. Trends are believed to be as depicted by the table and figure for the following reasons. As the design progresses, more unanticipated or unplanned problems arise as the number of technical decisions required is increasing and as a result the program continues to fall behind. There is an acceleration of this type of situation following first flight because the flight test program uncovers more problems requiring correction in a shorter period than analytical or ground test would uncover. However, at about this point in time, the entire technical team is available to work the problems and recovery of the schedule begins. Repetitive type operations in the shop and flight test can be augmented by additional shifts for quick problem resolution which is not practical during the design span. At approximately the time of first operational delivery, the schedule will have been completely recovered, as all the contractor's resources are devoted to that end and manpower application can solve schedule problems in this phase of the program. For example, the 747 was back on schedule at Vehicle #6 after being behind schedule at first flight and completion of the flight test program. The LM program is a good example of this type of situation. Figure 7.9-2 depicts the history of the LM program checkpoints which could be traced through successive SARP reports. Open triangles indicate scheduled dates and solid triangles represent actual dates. The percent growth for each checkpoint is also indicated based on spans shown on first plan available. This may not have been the original plan, but it is an accurate approximation of how program milestones tend to slide downstream as the program progresses.

2.3 As the majority of schedule data is at first flight, that checkpoint will be used in this study for adjustment. Using a straight-line relationship from go-ahead to first flight as shown by Figure 7.9-1 to adjust the schedules developed through conventional means would yield the following result:

<u>Months to First Flight Based on Detailed Schedules</u>

Stage I	45 Months
Stage II	46.5 Months

Stage I 56% Growth to 1st Flight/45 Months = 1.244% Growth/Month
Stage II 56% Growth to 1st Flight/46.5 Months ≐ 1.20% Growth/Month

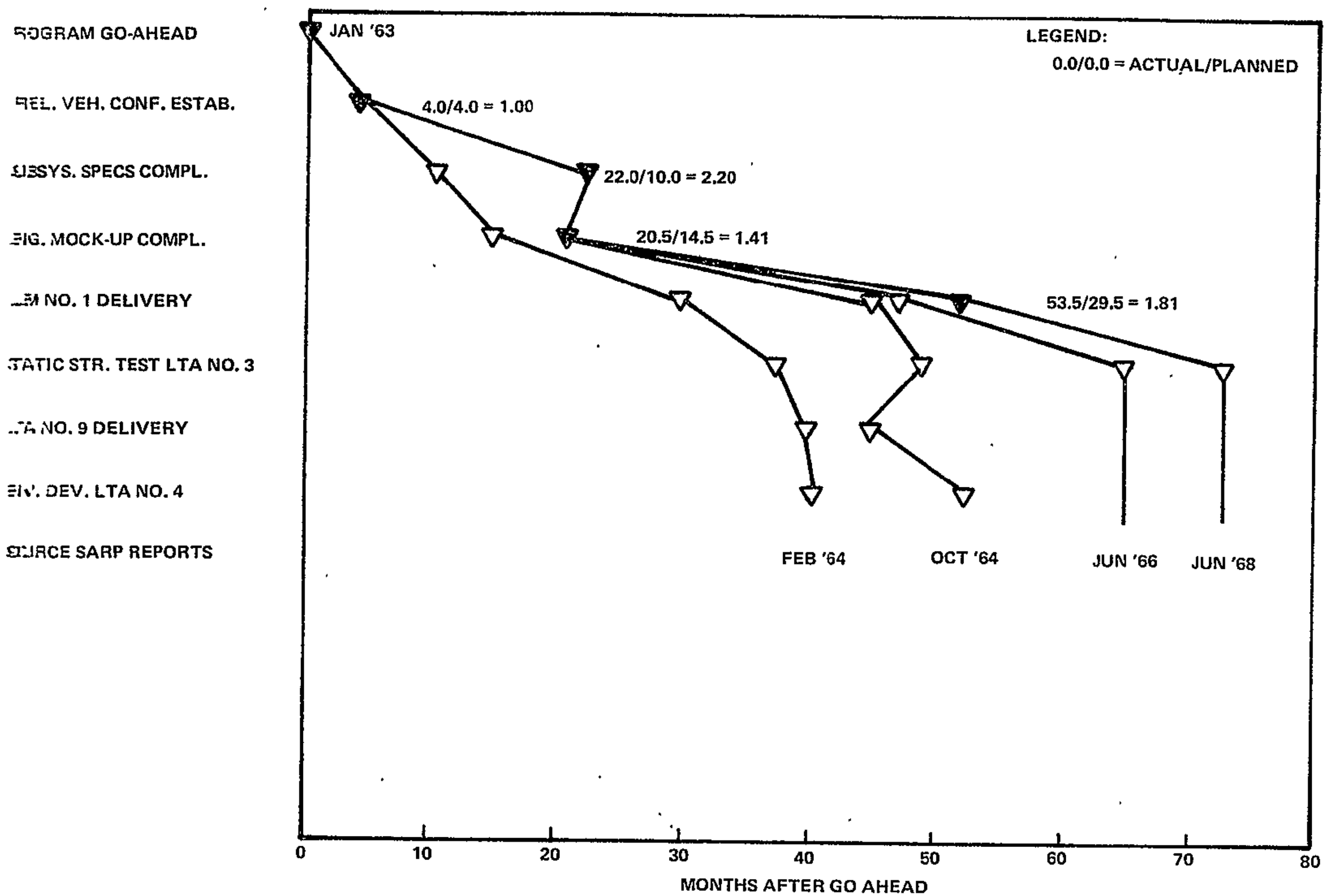

FIGURE 7.9-2 LM SCHEDULE GROWTH

The detail schedules as presented in this study were not subject to the competitive environment as experienced by the programs included in Table 7.9-I data; however, they are subject to over optimism, changes and emerging unknowns. Also the schedules will not be adjusted to account for prior work accomplished except for the structure subsystem. Accordingly, the detail schedules generated in this study are adjusted at the rate of 1.2% growth/month to compare with TER generated spans which is approximately the rate experienced on the programs included in the data base.

2.4 Cause of Growth and Impact - The causes of schedule growth as experienced by the Apollo Program have been sampled and classified as to kind. Using all the SARP reports available to VMSC, 99 activities/ events which were behind schedule, and where causal factors were explained, were identified and classified as impacting design or manufacturing. The results of this survey indicated that design-type problems accounted for 39% of the schedule slides, manufacturing-type problems accounted for 59% of the schedule slides, and redirection accounting for the remaining 2%. The data has been analyzed and plotted as Figures 7.9-3 through 7.9-13 to show the distribution of time slippage involved. This sample, then, is an indication of the causes of schedule slides and their impact. For example, Figure 7.9-5 shows the Test Failures (included as a design problem) occurred seven times in the data sample and that the schedule slides resulting from these failures ranged from one (1) month to six (6) months with the mean being 3.8 months. The individual causes are shown, i.e., Test Failures; summaries by Design and Manufacturing shown and finally a "pie chart" depicting all noted causal factors.

3.0 RESULTS

Based on this survey, the study team will use 1.2% growth/month as an indication of the amount of slide which could be expected from the study-developed detail schedules.

4.0 LIMITATIONS

Obviously care should be exercised in use of this adjustment factor as there are many programs not subject to the same environment as that noted which causes growth. Many programs are completed on time as the schedules made at the beginning of the program are realistic, include allowances for unknowns, and run into no unanticipated problems.

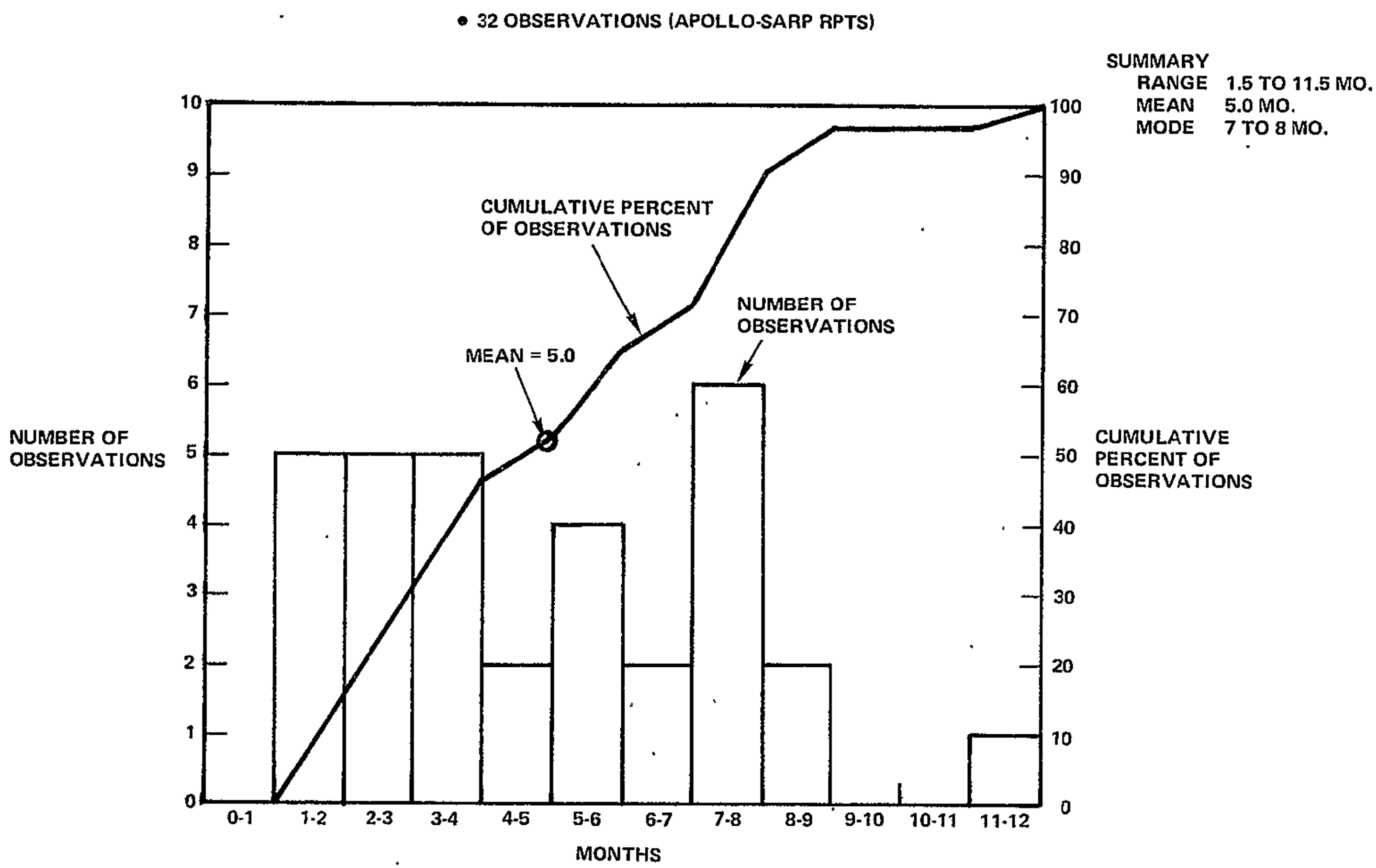

FIGURE 7.9-3 TOTAL PROGRAM SCHEDULE GROWTH

DESIGN PROBLEMS

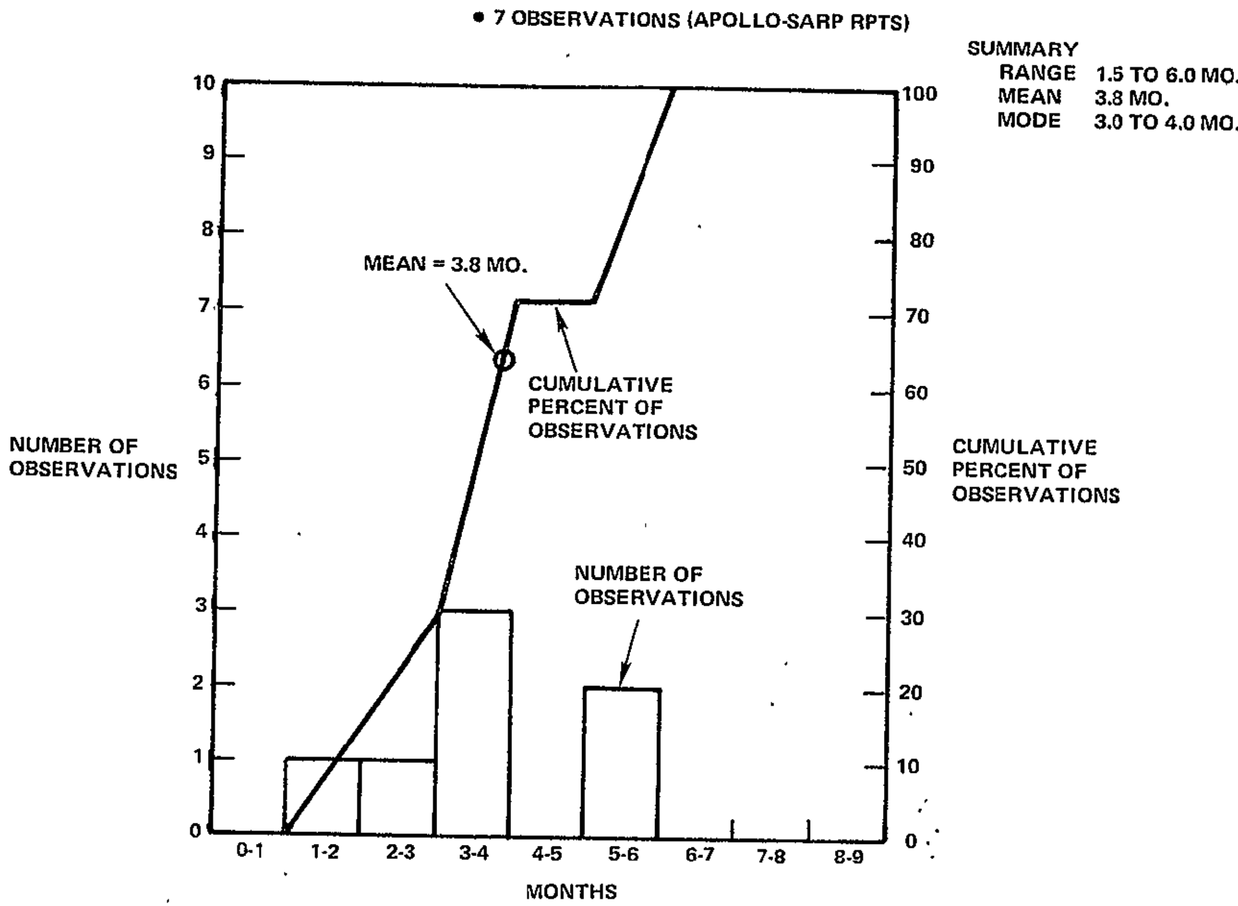

FIGURE 7.9-4 TOTAL PROGRAM SCHEDULE GROWTH

ST FAILURES

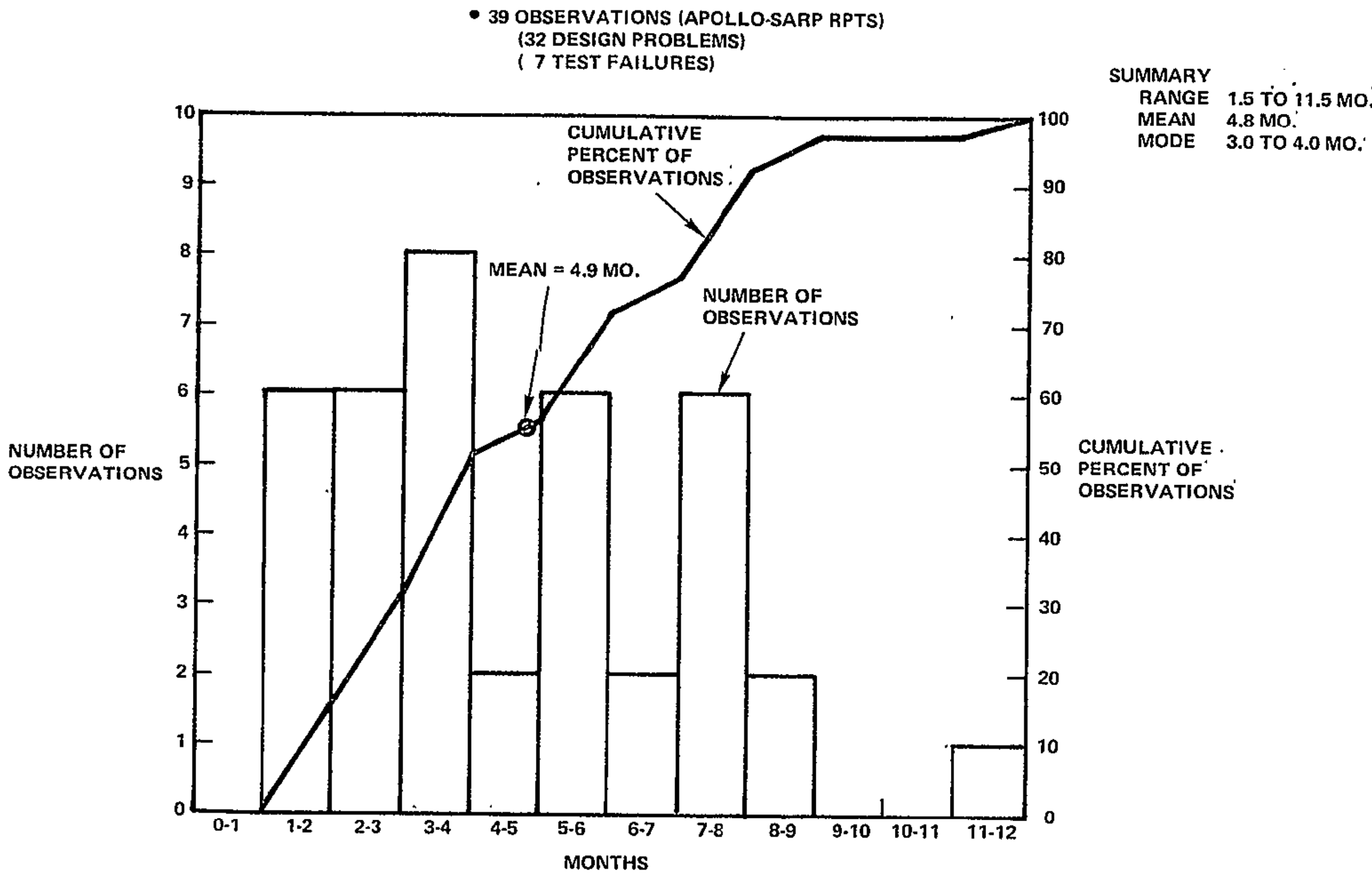

FIGURE 7.9-5 TOTAL PROGRAM SCHEDULE GROWTH

DESIGN PROBLEMS & TEST FAILURES

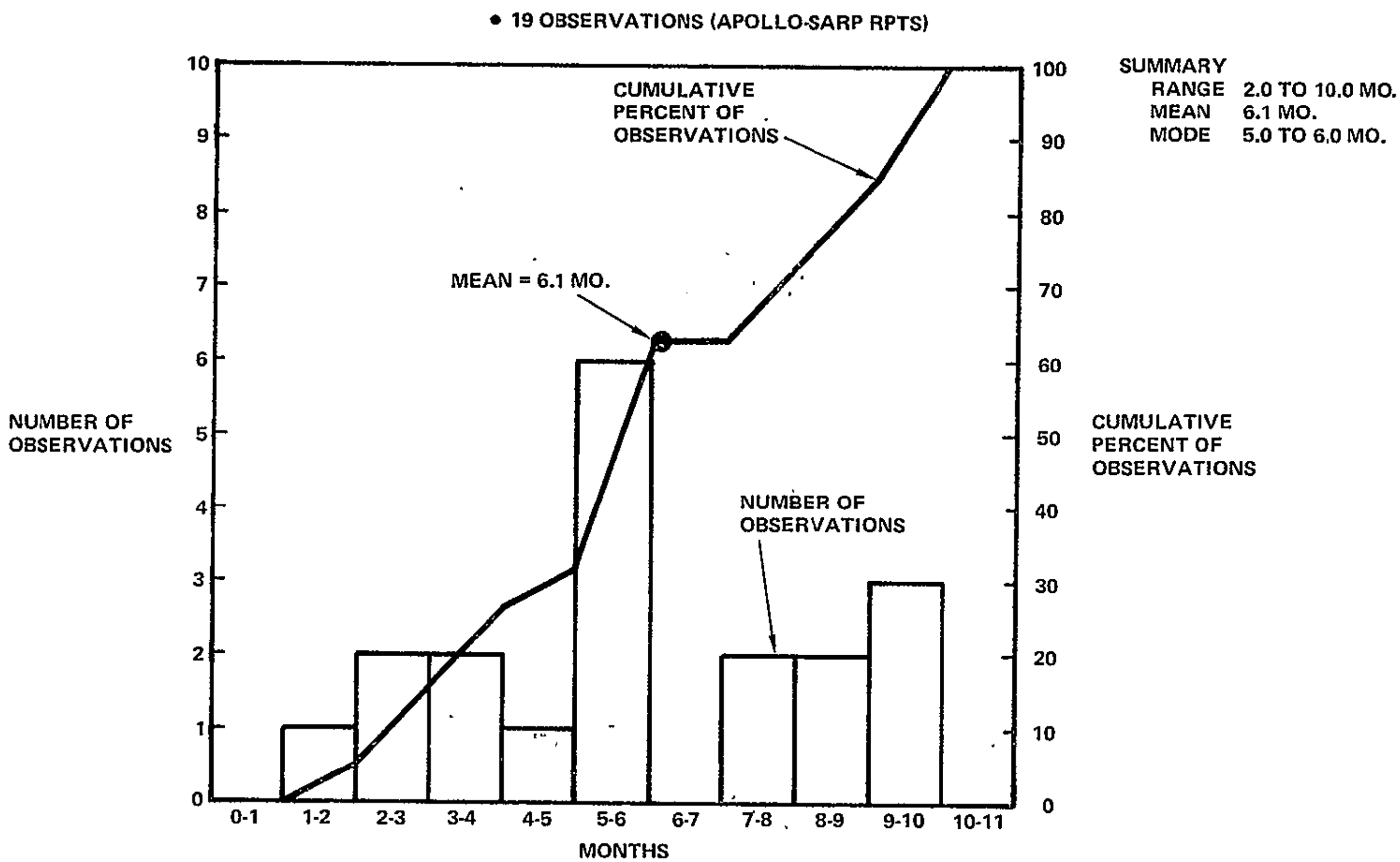

FIGURE 7.9-6 TOTAL PROGRAM SCHEDULE GROWTH

LATE DELIVERY

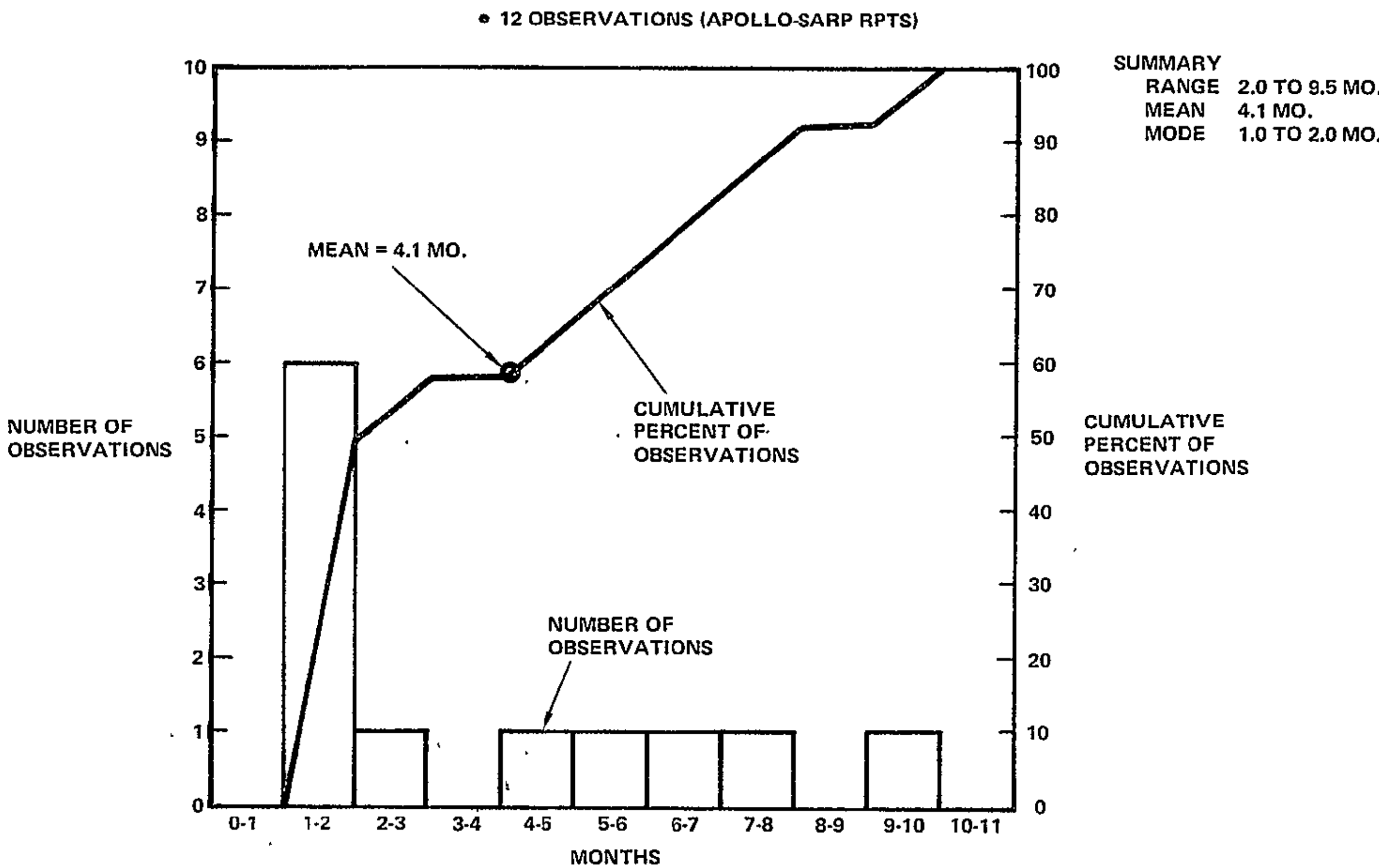

FIGURE 7.9-7 TOTAL PROGRAM SCHEDULE GROWTH

TOOL UNAVAILABILITY

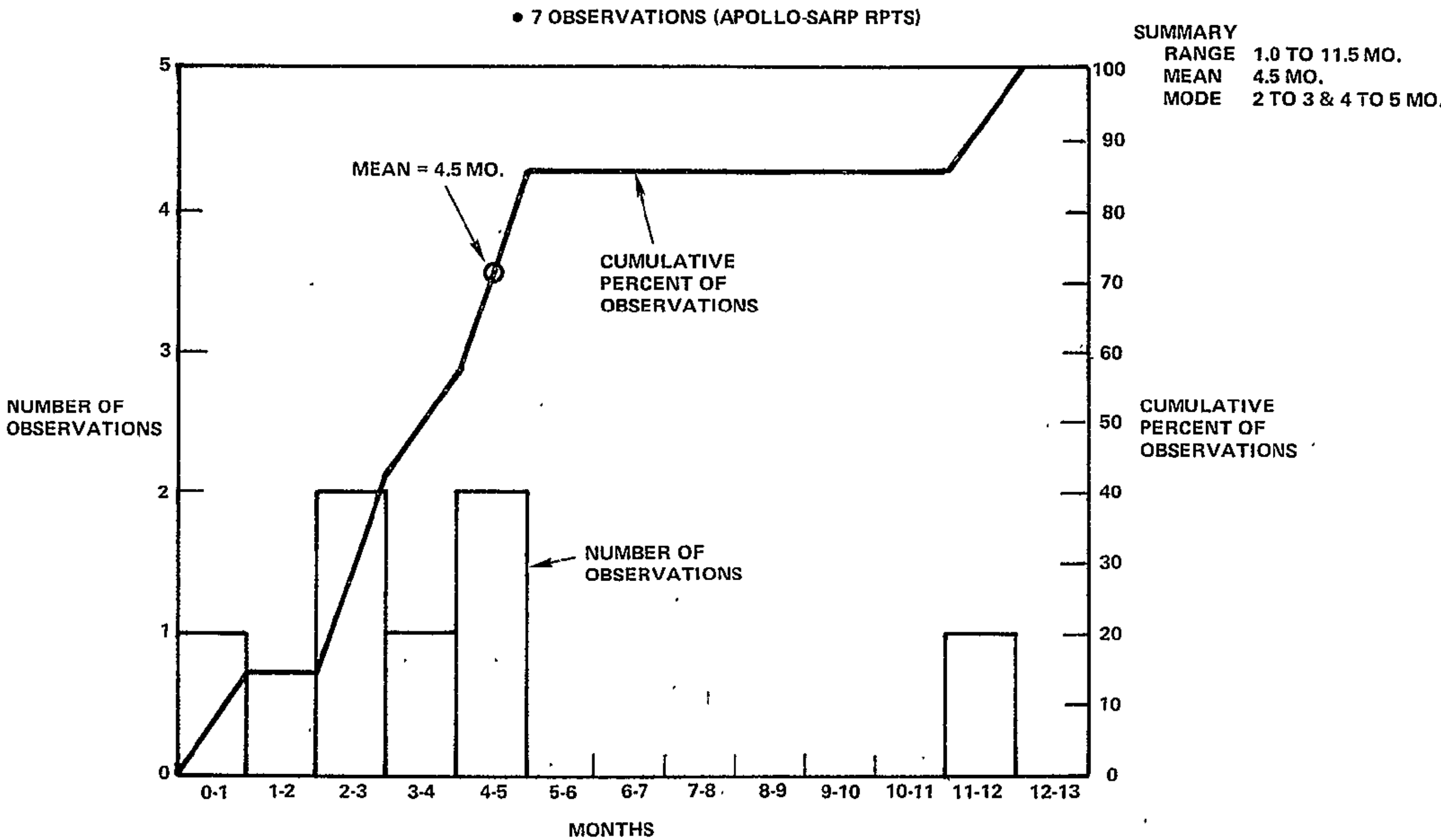

FIGURE 7.9-8 TOTAL PROGRAM SCHEDULE GROWTH

TOOL CERTIFICATION

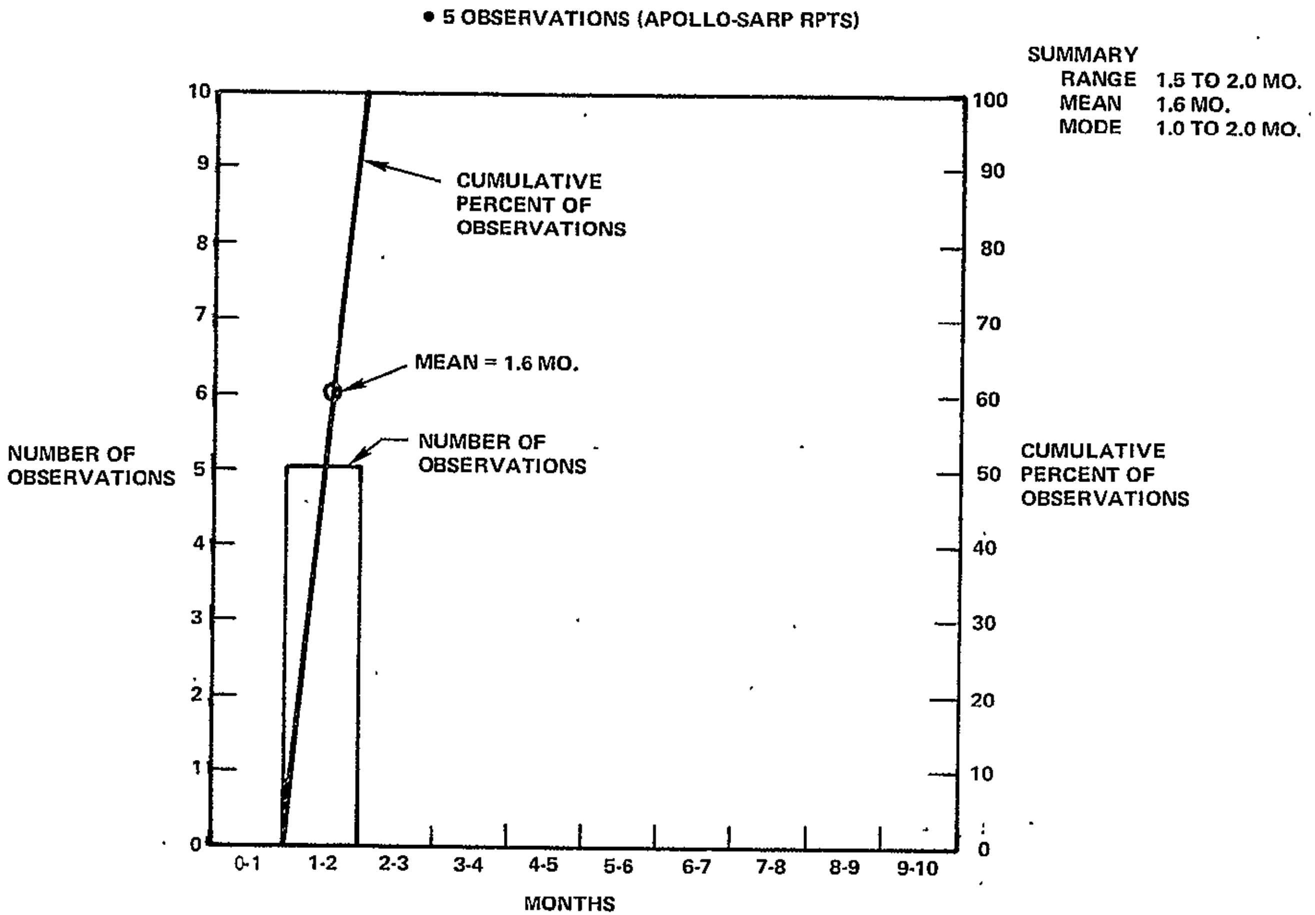

FIGURE 7.9-9 TOTAL PROGRAM SCHEDULE GROWTH

GSE UNAVAILABILITY

FOLDOUT FRAME 1

FOLDOUT FRAME 2

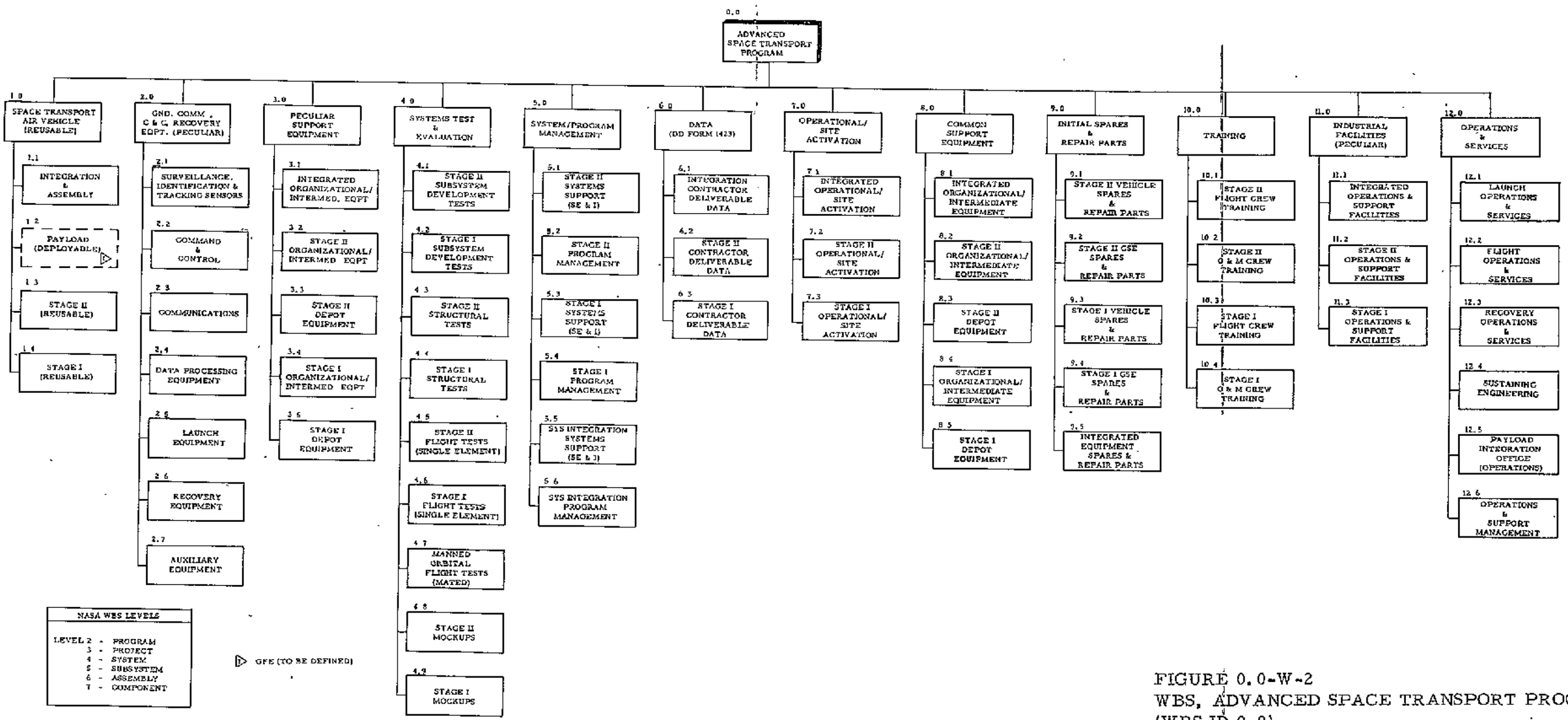

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FIGURE 0.0-W-2
WBS, ADVANCED SPACE TRANSPORT PROGRAM
(WBS ID 0.0)

a design constraint in the RDT&E and Investment Phases, and an operational constraint in the Operations phase) and of other Government Provisioning such as Astronauts, government-furnished test facilities, and government-furnished launch and mission equipments and services. Contract-furnished elements in Phase C/D will include Contract End Item (CEI) Specifications, System Test Plans, Manufacturing Plans, Facility Plans, Training Plans, Logistic Support Plans, Program Management Plans, Operations Plans and other Program need plans. The transition from Phase C to Phase D will be based upon customer approval of these plans in Preliminary Design Reviews of the vehicle stages and of ground equipments required to support the vehicle. Major Phase D milestones will include Critical Design Reviews (CDRs), Qualification Acceptance Tests, Preliminary Flight Rating Tests (PFRTs), Structural Test, flight hardware production acceptance, Horizontal Flight Test, single-element Vertical Flight Test,[2] mated Vertical Flight Test, retrofit of Flight Test Vehicles (FTVs) into production vehicles, and production vehicle delivery and acceptance. At an appropriate point in the Program, an Initial Operational Capability (IOC) will exist as the basis for conducting NASA's operational phase. Currently, a 445-flight Traffic Model is the basis for the Operations and Services phase of the Advanced Space Transport Program.

IV. DESIGN REQUIREMENTS

Current design requirements for the baseline Advanced Space Transport Program (termed Space Shuttle Program) are stated as NASA Level I, II and III Requirements, Ref. A. These requirements are to be used as guidelines for the Advanced Space Transport Program, subject to modification as the Program develops. Level I and II requirements which are currently applicable at the Program Level are noted below. Level III requirements are stated with the respective WBS Identification.

A. Level I Requirements

1. The Space Transport vehicle shall be two-stage, reusable.

2. Payloads shall be equal to or less than 15 feet in diameter and 60 feet in length including handling rings, attachment fittings for the deployment mechanism and docking, and cargo bay storage fittings. The standardized deployment mechanism(s) and tie points shall be charged to Stage II (space orbiter) and shall not occupy the clear volume. Deployment clearance shall be provided by Stage II.

-----

[2] Current planning calls for tie-down Static Firings, only.

3. (a) The design mission shall be 100 nm due east circular orbit. The design mission insertion orbit shall be 50 x 100 nm and for purposes of performance calculations the vehicle shall be considered to be launched from a latitude of 28.5 degrees north.

   (b) The reference missions of major interest are:

   (1) 100 nm south polar circular orbit (south polar mission).
   (2) 270 nm at 55 degrees inclination (resupply mission)

   (c) Insertion of reference missions will be from 50 x 100 nm orbits.

4. Stage II shall have a nominal hypersonic aerodynamic cross range capability of 1100 nm. (In any case, Stage II shall have adequate cross range capability to insure a once-around return to the launch site for all azimuths during an operational mission.)

5. Mission duration from liftoff to landing of at least seven days of self-sustaining lifetime shall be provided. For missions in excess of seven days, the weight of the expendables shall be charged against the payload.

6. The Space Transport Air Vehicle shall be capable of operating within the cargo range from zero to maximum capability.

7. Stage II shall have sufficient propellant to provide 1,500 fps on-orbit delta V capability (in excess of the amount required to attain the design insertion orbit) with a maximum payload for the 270 nm at 55 degrees inclination reference mission. The Stage II on-orbit delta V capability of 1,500 fps is intended to provide for translation maneuvers only and does not include an allowance for on-orbit or entry attitude control. The tanks shall be sized to provide 2,000 fps on-orbit delta V capability for the S polar mission and 900 fps for the easterly mission.

8. Stage I (booster) and Stage II shall be baselined to have go-around capability. (Except go-around not required when ABES removed.)

9. The Stage I and Stage II crew and the Stage II passengers environment shall be shirtsleeve.

10. Stage I shall be capable of returning to the launch site.

11. Air vehicle stages shall be capable of ferry flights between airports.

12. Integrated vehicle vertical takeoff and individual vehicle horizontal landings shall be the vehicle mode of operations.

13. A communication satellite system is assumed to be available.

14. The launch rate will vary from a minimum of 25 to a maximum of 75 per year (total of 445 in 10 years).

15. The Space Transport will have an all-azimuth launch capability.

16. The Space Transport shall provide safe mission termination capability. This includes rapid crew and passenger egress prior to liftoff and intact abort after liftoff. Intact abort implies the capability of Stage I and Stage II to separate and continue flight to a safe landing; Stage II to land with a full payload.

17. 550,000 lb. sea level thrust bell-type engines will be baselined in both stages. Stage I shall be baselined as a 12-engine vehicle.

18. The intended combined storage and operational service life of this system is 10 years after IOC. A Stage I/Stage II life of (at least) 100 missions will be provided with a cost effective level of refurbishment and maintenance. Increase the assumed useful life of the Space Transport from 100 to 500 missions for cost amortization purposes (not for design purposes).

19. For the design reference (resupply) mission rescue operations (including personnel transfer) must be completed within 48 hours after notification.

20. JP will be baselined as fuel for all airbreathing engines. The airbreathing engines shall be capable of being removed from Stage II with minimum scar weight. Stage II shall be capable of flight with or without the airbreathing engines installed.

21. All subsystems except primary structure and pressure vessels shall be designed to fail operational after the failure of the most critical component and to fail safe for crew survival after the second failure. Electronic systems shall be designed to fail operational after failure of the two most critical components and to fail safe for crew survival after the third failure. Individual subsystems may be revised by Level II design where improvements in cost and effectiveness would result. The Space Transport Main Engine shall be designed to fail safe for crew survival after the failure of the most critical component. The main engine electronic system shall be designed to fail operational after the failure of the most critical component and to fail safe for crew survival after the second failure.

   - Launch Critical/Safety Critical GSE - Fail Operational/ Fail Safe
   - Turnaround Critical GSE (14 day turnaround) - Fail Operational/Fail Safe
   - All other GSE - Fail Safe

22. Survivability against hazards from radiation as specified in Joint DOD/NASA Survivability Characteristics documents dated 16 June 1969.

23. Total Space Transport turnaround time from landing to launch readiness should be less than two weeks. The removal and replacement time shall be minimized with onboard checkout and module accessibility.

24. Launch trajectory load factors shall not exceed 3 g's and entry trajectories shall not exceed 3 g's for Stage II.

25. Stage II crew/passengers compartment atmosphere and total pressure shall be compatible with the space station and space base.

26. Vehicle payload is baselined to be 65,000 lbs into the due east 100 nm circular orbit with the airbreathing engines removed from Stage II. The weight of passengers and removable provisions for passengers shall be charged to the payload. Stage II shall have the capability of landing 40,000 lbs of payload with nominal wing and load factors (air breathing engines removed) and large (heavier) payloads with reduced structural safety factors.

27. Stage II shall be capable of a once-around trajectory with a one engine-out condition at and/or after Stage I/Stage II separation for the design and reference missions.

28. Stage I and Stage II shall be designed for maximum interchangeability (common components and spares to be interchangeable).

B. Level II Requirements

1. Mission Requirements

(a) Each element of the Space Transport shall have a two-man flight crew and shall be flyable under emergency conditions by a single crewman.

(b) Attitude restrictions to maintain communications between the Transport and other operating elements and the earth shall be minimized.

(c) Subsonic in-flight refueling shall not be used to meet design mission requirements. (Stage I shall be designed to retain the option for in-flight refueling and downrange landing operations. This shall include (1) design of systems for altered reentry conditions associated with off loading of JP cruise fuel, and (2) design of body structure for future incorporation of in-flight refueling equipment.)

(d) The main propulsion system of Stage I and Stage II shall be series burning.

(e) Trade studies shall be performed to affirm or disprove the desirability of the following requirements: Stage I and

Stage II shall be capable of pilot-controlled landings under FAA Category II conditions. Autopilot systems and navigation aids similar to systems used in commercial aircraft shall be included. (Stage II shall be capable of automatic landings with a backup capability of pilot controlled landings with following minimums: 1,000 ft. ceiling and 1 mile visibility.)

(f) Launch phasing capability for day and night rendezvous and docking with a space station is desirable.

2. Flight Mechanics

2.1 Mission Analysis & Vehicle Performance

(a) The Space Transport shall be designed to launch on time for all azimuths.

(b) A single main engine out on Stage I shall permit nominal mission continuation; on Stage II, a safe abort capability.

2.2 Flying Qualities

(a) Landing characteristics and handling qualities shall not require skills more demanding than those required for operational land-based aircraft.

(b) Visibility from the cockpit during landing shall be comparable to high-performance aircraft standards.

2.3 Guidance and Control

The Space Transport attitude shall not be constrained by the guidance system.

3. Test and Checkout

The design should provide the capability to checkout the vehicles in a mated and unmated configuration.

4. Maintainability

(a) Any peculiar GSE required to support a remote site landing should be packaged in a manner to be easily flown into the site.

(b) Subsystems shall be designed to the lowest replaceable modular level for ease of removal and replacement, making use of aircraft practice.

(c) Systems that are intended to operate in zero or multiple g environment must be capable of test and verification in a one g environment during ground maintenance.

5. Commonality

(a) Designed on-board development equipment should be modularized and separate from operational equipment to permit conversion of the vehicle to operational status with minimum impact.

(b) All space transport hardware shall be designed to the greatest extent possible to permit commonality of systems, subsystems, components and parts for common use and interchangeability between Stage I, Stage II, and other program elements.

(c) Design of element interfaces should allow complete interchangeability between any production stage that may be arbitrarily selected to be mated.

6. Reliability and Quality Assurance

(a) In systems where redundance is needed, the Space Transport Systems shall be developed to provide redundant full mission capability and shall avoid minimum-requirement, minimum-performance backup system concepts.

(b) Redundant paths, such as fluid lines, electrical wiring, connectors, and explosive trains, shall be located to insure that an event which damages one line is not likely to damage the other.

(c) In addition to the primary structure and pressure vessels, the following subsystems shall be considered exempt from the fail safe criteria, but shall be appropriately designed for the necessary reliable operation:

(1) Secondary structure

(2) Landing gear

(3) Stage II main propulsion

(4) Passive TPS

(5) Interior insulation

(6) Main propulsion feed lines

The following non-electronic susbystems shall be considered exempt from the fail safe criteria. They shall be appropriately designed for the necessary reliable operation:

(1) Electro-Explosive devices (separation ram, drag (pilot) chute Mortar)

(2) Drag chutes

(3) Main gear wheel brakes

(4) Gear-up actuation

(5) Gas or fluid lines for ECLSS, Main Propulsion, OMS, ACPS, APU, ABES, and brakes

The following avionics subsystems shall be designed to failure criteria as indicated:

(1) Have same redundancy as the units served. This applies to the Data Bus and DIU's.

(2) Fail operational after failure of the two most critical components. This applies to landing aids, rendezvous sensors, and communications.

7. Safety

(a) The vehicle shall incorporate on-board provisions to quickly and easily place the space transport in a safe condition following landing and permit unaided crew and passenger egress.

(b) All components associated with enabling the crew to recognize and correct critical systems malfunctions should be functionally independent of ground support and external interfaces.

(c) Automated critical control functions shall provide for crew-initiated override/interrupt capability.

(d) The system should be designed such that a failure in either stage will not impair the safety of the other.

(e) Hazardous/emergency condition warnings originating within either stage shall be presented immediately to the other stage for simultaneous crew alert.

(f) Where LH_2 is stored near or used in conjunction with LOX, a TNT equivalent factor of 20% shall be used for calculating the explosive yield of an unconfined propellant mix for determining safety quantity/distance relationships. Calculation of TNT equivalency factors for confined spills and mixtures of LH_2 alone or LH_2 and LOX combined shall be made on an individual case basis.

8. Interfaces

Separation systems should be capable of being initiated from either Stage II or Stage I.

9. Avionics

(a) Stage II and Stage I shall have self-operating aircraft type crash recorders equipped with locating beacons.

(b) The data system will provide self-validation and error protection.

(c) Antenna systems that require pointing for acquisition will be pointed automatically without requiring a man in the loop except to initiate the command. Maintaining acquisition will also be automatic.

10. Propulsion

(a) There shall be no propellant cross feed between stages.

(b) The propulsion systems shall be capable of safe shutdown at any time.

(c) Requirements for helium shall be minimized.

(d) Main Propellant Tank Sizing Requirements. For propellant tank sizing both Stages are designed with 0.67% excess propellant volume to accommodate propellant loading below nominal engine specific impulse.

11. Electrical Power

Batteries for use in contingency situations shall not require preconditioning before accepting loads.

12. Mechanisms and Devices

Hard attach points shall be provided for handling large components as well as the complete transport vehicle. Connections shall be minimized and, when possible, joints shall be provided to enable breaking-down of large items to a transportable size.

13. Cryogenics.

Capability to jettison or deplete propellants prior to landing shall be provided.

14. Operations

14.1 Flight Operations

Continuous communications and tracking is not required.

14.2 Ground Operations

(a) The launch pad, the primary landing site, and the servicing facility shall be in the same general location.

(b) The Space Transport shall have minimal assembly and checkout requirements at the launch pad.

(c) Use of specialized facilities (e.g., clean room, altitude chambers, etc.) shall be minimized.

(d) Systems sensitivity to weather conditions during assembly, checkout, and launch shall be minimized.

(e) Service lines at the launch pad should be minimal, preferably only for the main propulsion system propellants.

(f) The design should eliminate the need to change a system's condition (late in the countdown) as a prerequisite for launch; designs which require a transition from one stable condition to another should be minimized.

(g) The design should consider no umbilical disconnect actuation systems after ignition. Functional interfaces (except hold-down) required after ignition should be designed to separate as a direct result of vehicle motion. Umbilicals that contain functions or services necessary to maintain the vehicle in a safe condition - or return it to a safe condition - should not be disconnected prior to first motion of the vehicle. Umbilical couplings and electrical connectors when grouped into one common umbilical assembly shall not contain individual locking mechanics.

(h) Space Transport launch sites may be located at KSC, Western Test Range or an inland site.

(i) The Space Transport elements should have the capability to land horizontally on runways no longer than 10,000 feet (sea level on a standard day).

(j) The design should provide effective and compatible ingress/

egress modes for the crew and passengers during ground operations and require minimum specialized equipment.

(k) Stage II and Stage I shall be capable of being mated in either the vertical or horizontal position.

V. TEST REQUIREMENTS

A. Test requirements for the Space Transport Air Vehicle are specified under the Air Vehicle subsystems, WBS Blocks 1.3 (Stage II) and 1.4 (Stage I), covering component and individual subsystem tests. Combined subsystem test requirements as well as system tests are specified under Block 4.0, Systems Test and Evaluation.

B. Ground Support Equipment tests are specified under WBS Blocks 2.0 (Ground Communications, Command and Control, Recovery Equipment (Peculiar)) and 3.0 (Peculiar Support Equipment). Common Support Equipment (Block 8.0) is not expected to require other than receiving/inspection testing after receipt from government stores.

C. Training Equipment, if deliverable, will be tested under Block 10.0.

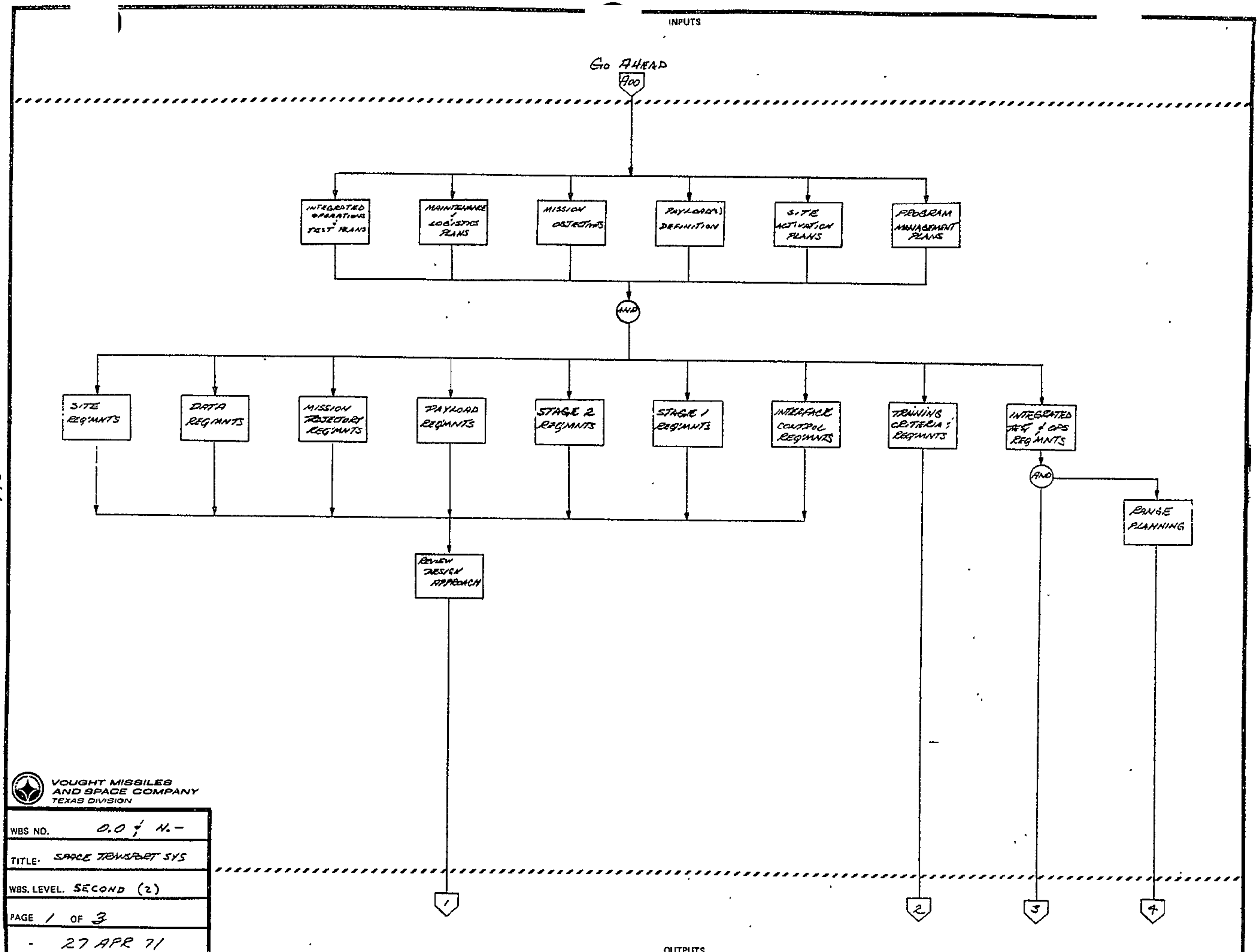
D. Payload Equipment is treated as GFE and will be independently tested under GFE specification. Integrated testing with the Air Vehicle is specified in Block 12.0.

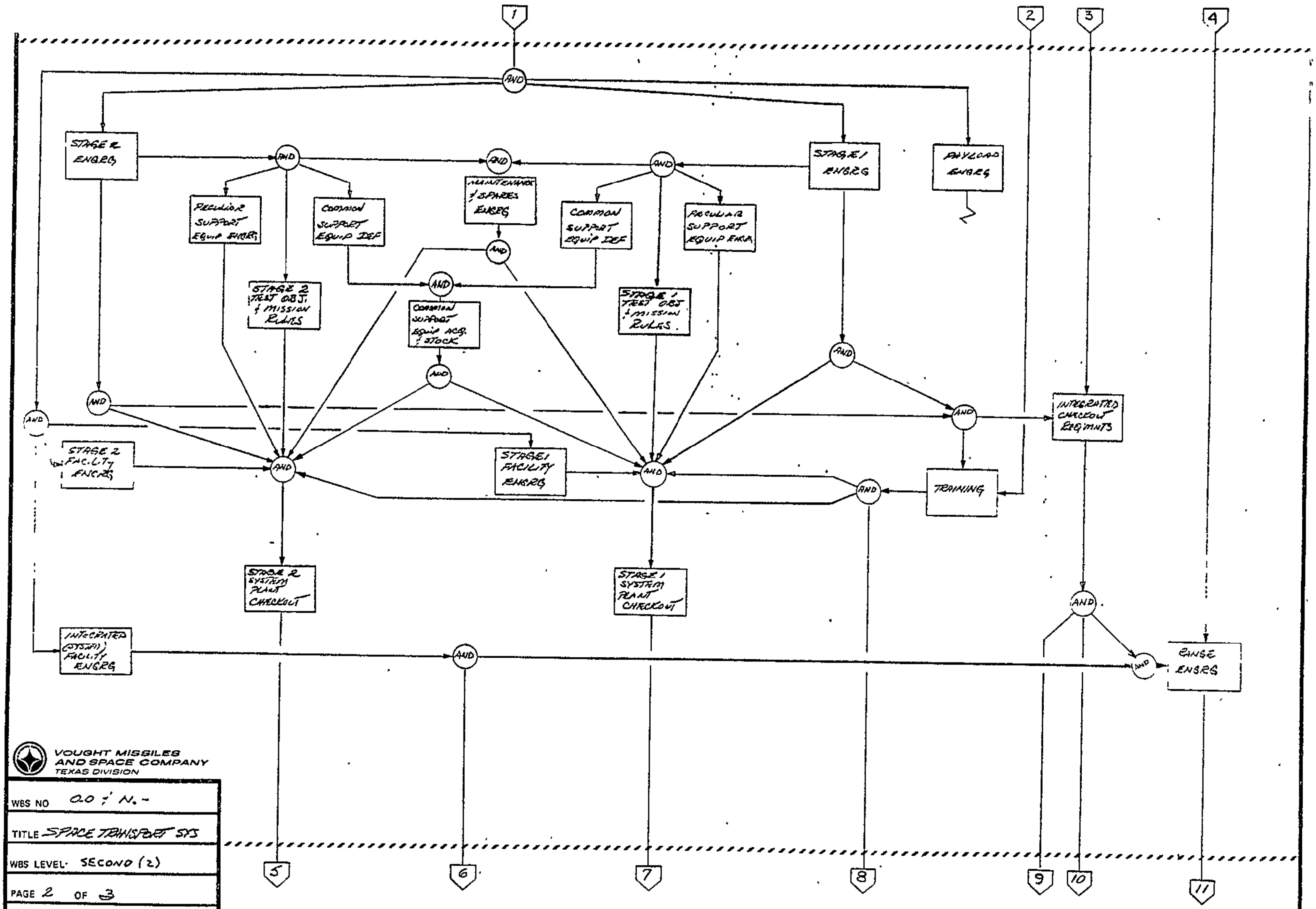
E. Test facilities will be inspected and tested under facility specifications derived in Block 5.0 and as required for Category I and II tests defined in Block 4.0.

VI. REFERENCES

A. Study Control Document, Phase B, 1 March 1971 (NASA)

(Others to be defined)


INPUTS
GO AHEAD
A00
INTEGRATED OPERATIONS & TEST PLANS
MAINTENANCE & LOGISTICS PLANS
MISSION OBJECTIVES
PAYLOAD(S) DEFINITION
SITE ACTIVATION PLANS
PROGRAM MANAGEMENT PLANS
AND
SITE REQ'MNTS
DATA REQ'MNTS
MISSION TRAJECTORY REQ'MNTS
PAYLOAD REQ'MNTS
STAGE 2 REQ'MNTS
STAGE 1 REQ'MNTS
INTERFACE CONTROL REQ'MNTS
TRAINING CRITERIA & REQ'MNTS
INTEGRATED T&E & OPS REQ'MNTS
AND
RANGE PLANNING
REVIEW DESIGN APPROACH
1
2
3
4
OUTPUTS
VOUGHT MISSILES AND SPACE COMPANY
TEXAS DIVISION
WBS NO. 0.0 & N.-
TITLE: SPACE TRANSPORT SYS
WBS. LEVEL. SECOND (2)
PAGE 1 OF 3
27 APR 71



VOUGHT MISSILES AND SPACE COMPANY
TEXAS DIVISION

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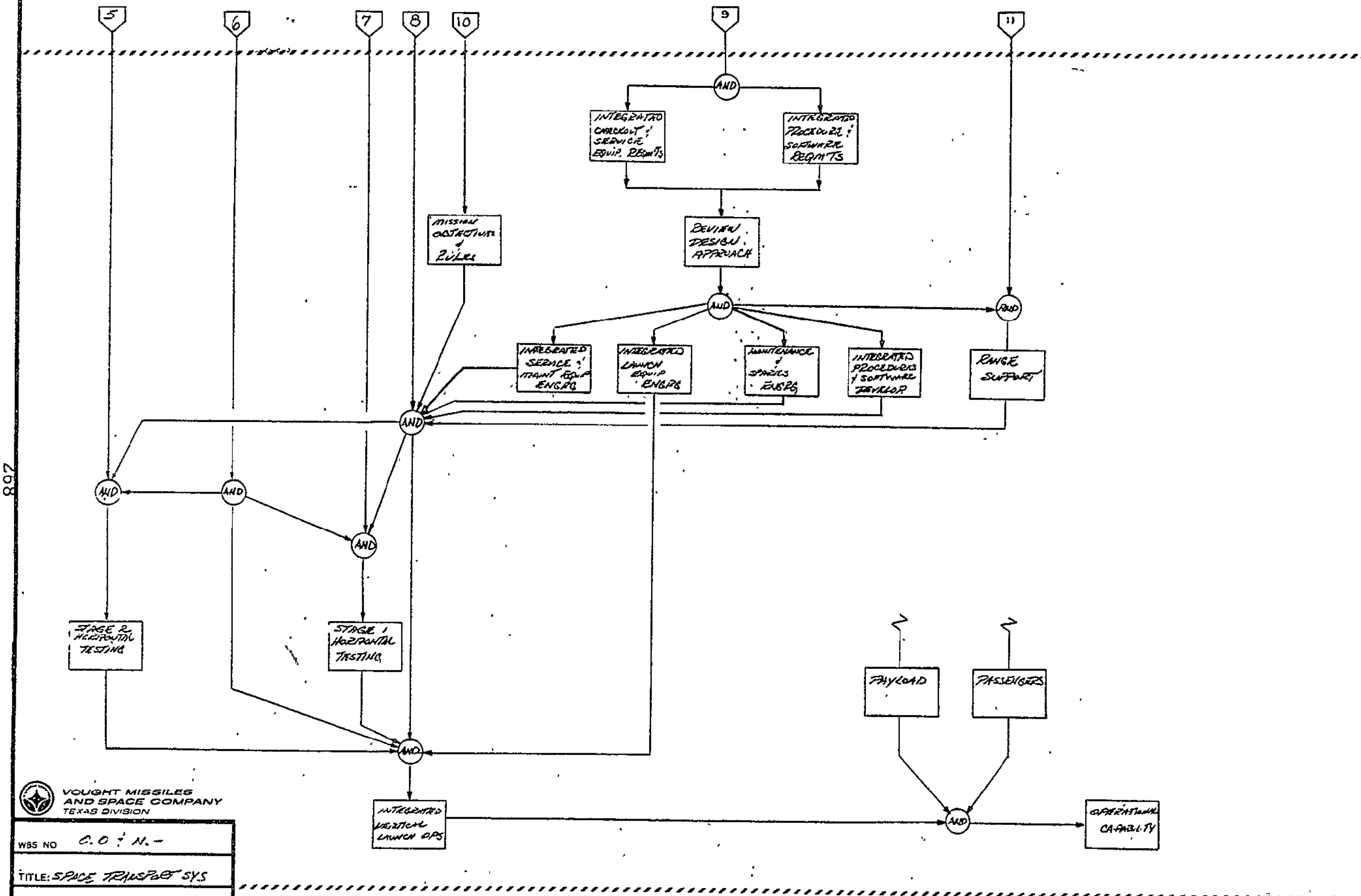
TITLE SPACE TRANSPORT SYS

WBS LEVEL SECOND (2)

PAGE 2 OF 3

DATE 27 APR 71

OUTPUTS



VOUGHT MISSILES AND SPACE COMPANY
TEXAS DIVISION

WBS NO C.0 & N.-

TITLE: SPACE TRANSPORT SYS

WBS LEVEL SECOND (2)

PAGE 3 OF 3

DATE 27 APR 71

OUTPUTS

FOLDOUT FRAME 1

FOLDOUT FRAME 2

MASTER SCHEDULE - ADVANCED SPACE TRANSPORT PROGRAM

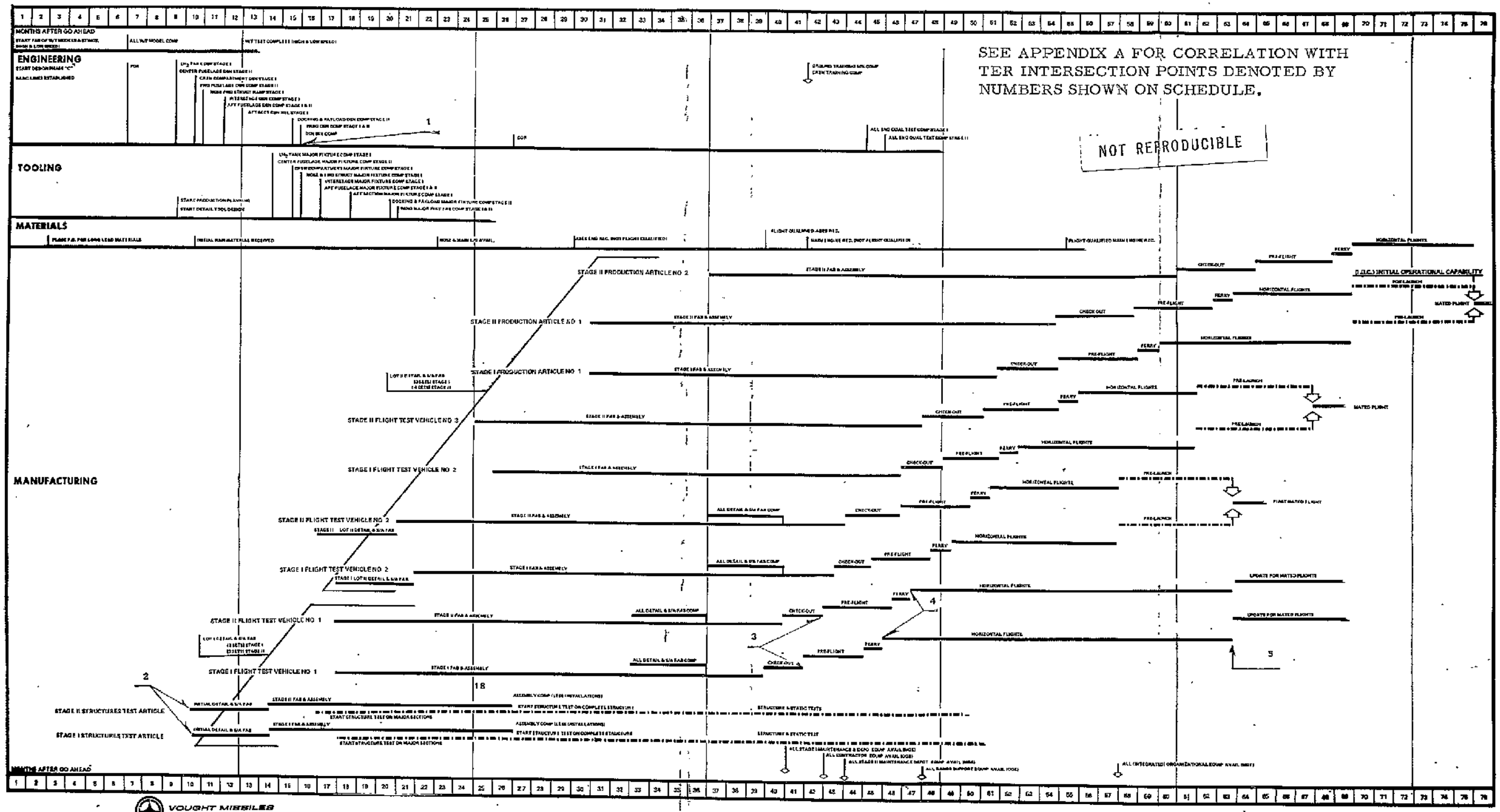


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FIGURE 0.0-W-1 MASTER SCHEDULE

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PROGRAM TITLE: ADVANCED SPACE TRANSPORT PROGRAM

WBS NO. 1.0

TASK TITLE: SPACE TRANSPORT AIR VEHICLE (REUSABLE)

LEVEL: 3, Project Level

WBS DICTIONARY

I. REQUIREMENTS

A requirement has been specified (WBS ID 0.0) for a two-stage reusable Space Transport Air Vehicle capable of deploying GFE payloads to and from near earth missions in support of NASA's Advanced Space Transport Program. The design mission for the baseline vehicle is 100 nm due east circular orbit. Reference missions of major current interest are 100 nm south polar circular orbit (south polar mission) and 270 nm at 55 degrees inclination (resupply mission). Program phases shall include a Design Phase (Phase C) and a Development and Operations phase (Phase D).

II. SYSTEM DEFINITION

Four major elements define the Space Transport Air Vehicle. These

TASK SCHEDULE MILESTONES

PERIOD ENDING

SEE LOWER LEVELS FOR DETAIL SCHEDULES

elements, denoted on Figure 1.0-W-3, cover design, individual component and subsystem development, manufacture, assembly and integration of components, assemblies, subsystems and systems into one of four potential configurations: Structural Test Vehicle (basic airframe, only, Stage I and Stage II), Single Element Flight Test Vehicle, Mated Flight Test Vehicle, and Production Vehicle. WBS Identification 4.0, Systems Test and Evaluation, further defines the first three configurations. Production vehicles result from retrofit of flight test vehicles (Block 4.0) as well as additional manufacture as required for an Initial Operational Capability (IOC) from Block 1.0.

The WBS identification of the Space Transport Air Vehicle is as follows:

1.1 Integration and Assembly
1.2 Payload (Deployable) (GFE, To Be Defined)
1.3 Stage II (Reusable)
1.4 Stage I (Reusable)

III. FUNCTIONAL DESCRIPTION

At Phase C go-ahead, final design of the Air Vehicle and support elements will be initiated. Preliminary Design is assumed to be completed (Phase B). Air Vehicle PDRs (WBS 5.0) will be held to review Part I specifications of the Contract End Items (CEIs) which each major contractor, together with NASA, have defined. These will establish the design which must be satisfied with CEIs Part II (WBS 1.0). Development tests of components, assemblies, and single subsystems will be performed under WBS 1.0 as appropriate. Combined subsystem tests will be performed under WBS 4.0, including final Wind Tunnel tests which confirm aerodynamic, aerothermodynamic and stage separation objectives. Structural tests of individual stages will also be performed under WBS 4.0. Drawings, specifications, subsystem hardware procurement, and flight test article manufacture and qualification testing will be performed under WBS 1.0, drawing on WBS 4.0 for acceptance of combined testing to provide proof of meeting performance, safety, human factors, maintainability, reliability, operability and other program specifications. Tool design, factory support equipment (FSE) design, test facility interface design (4.0), and the procurements thereof, are also part of WBS 1.0. Finally, production and acceptance of both test and production hardware are included in WBS 1.0 to deliver prototypes, structural test vehicles, flight test vehicles, retrofitted flight test

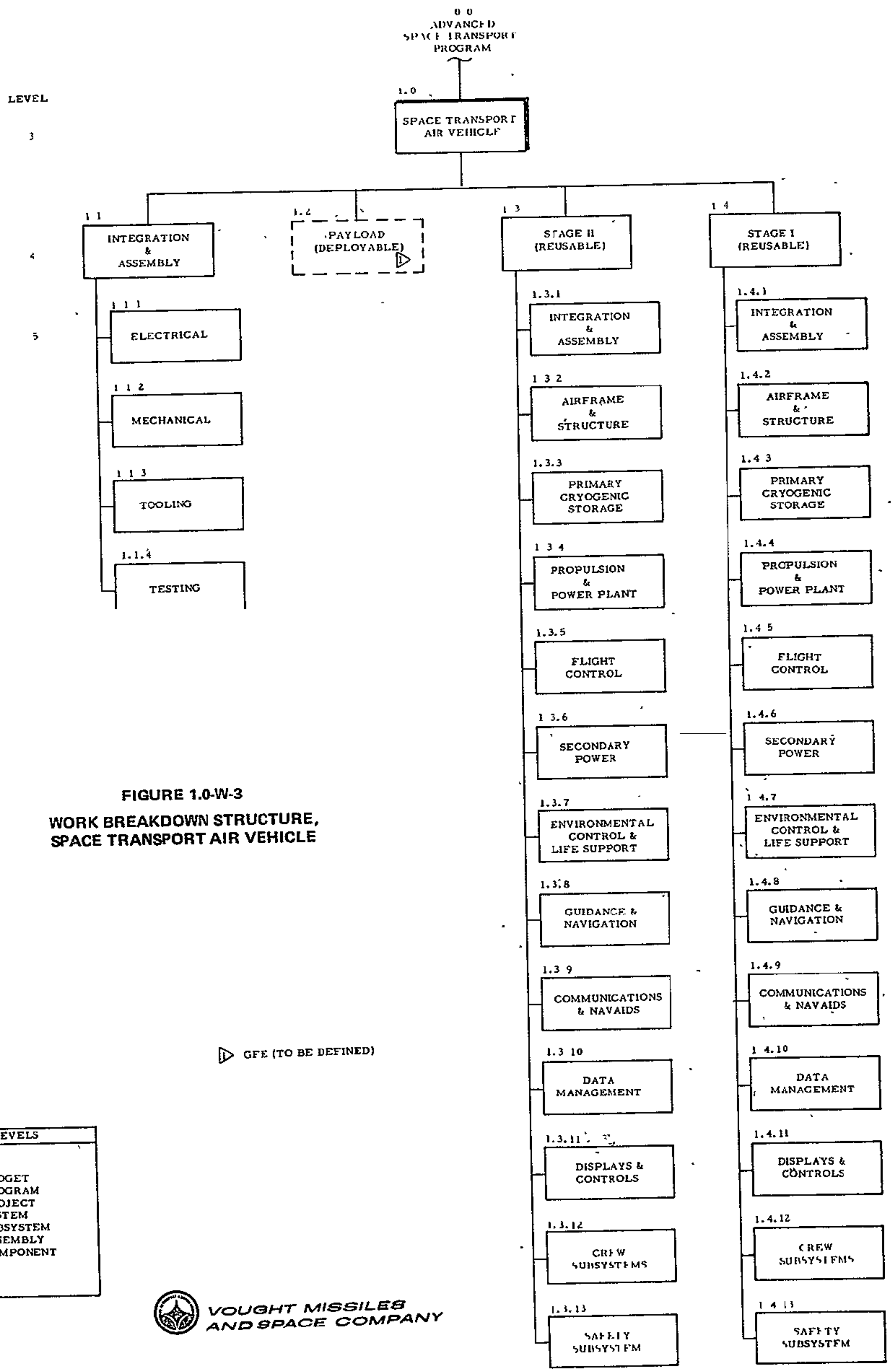

FIGURE 1.0-W-3

WORK BREAKDOWN STRUCTURE, SPACE TRANSPORT AIR VEHICLE

▷ GFE (TO BE DEFINED)

NASA WBS LEVELS

LEVEL 1 - BUDGET
2 - PROGRAM
3 - PROJECT
4 - SYSTEM
5 - SUBSYSTEM
6 - ASSEMBLY
7 - COMPONENT

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vehicles to be used for operations, and production vehicles to be used for operations. Where ballasting is required to simulate engines and other mass properties, WBS 1.0 will provide these per specification. Installation of instrumentation and telemetry kits needed for verification of component/assembly/subsystem performance, as well as their appropriate schedule point removal, are also included in WBS 1.0. The main engines of Stage I and Stage II are baselined as GFE. Thus, their development, production and test are included under WBS 1.0 with Preliminary Flight Rating Test (PFRT) and cluster tests being performed under WBS 4.0. Air Vehicle spares and repair parts are manufactured under WBS 1.0 as called for by WBS 4.0 and 9.0. The production facility and production equipments needed to produce both GFE and CFE Air Vehicle elements are defined in WBS 11.0.

IV. DESIGN REQUIREMENTS

The major design requirements for the Air Vehicle are specified on WBS Dictionary Element 0.0, Advanced Space Transport Program, Paragraph IV. Design requirements for Stage II and Stage I are specified on WBS Dictionary Elements 1.3 and 1.4, respectively.

V. TEST REQUIREMENTS

Test requirements for the Air Vehicle are specified under WBS Dictionary Element 4.0. Individual subsystem, assembly and component tests are specified under Element 1.3 (Stage II) and 1.4 (Stage I) subsystems as appropriate.

VI. REFERENCES

(To be added).

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PROGRAM TITLE ADVANCED SPACE TRANSPORT PROGRAM

WBS NO. 1.1

TASK TITLE INTEGRATION AND ASSEMBLY (AIR VEHICLE)

LEVEL 4, System Level

WBS DICTIONARY

I. REQUIREMENTS

A requirement has been specified (WBS ID 0.0, 1.0) for a two-stage reusable Space Transport Air Vehicle capable of deploying GFE payloads to and from near earth missions in support of NASA's Advanced Space Transport Program. The design mission for the baseline vehicle is 100 nm due east circular orbit. Reference missions of major current interest are 100 nm south polar circular orbit (south polar mission) and 270 nm at 55 degrees inclination (resupply mission). Program phases shall include a Design Phase (Phase C) and a Development and Operations phase (Phase D). Integration and Assembly of the two major components of the Air Vehicle (Stage II, WBS ID 1.3; and Stage I, WBS ID 1.4) are required to accomplish Mated Flight Test Vehicle flights (WBS ID 4.7) and Operational flights (WBS ID 12.0). Design and development of the tooling, equipments and testing required to achieve this capability are

TASK SCHEDULE MILESTONES

PERIOD ENDING

SCHEDULE NOT GENERATED FOR THIS ELEMENT. SEE MASTER SCHEDULE.

covered under WBS ID 1.1.

II. SUBSYSTEM DEFINITION

Four major elements define Integration and Assembly (Air Vehicle). These elements, shown on Figure 1.0-W-3, cover the analysis, design, development and procurement of the mechanical, electrical, tooling and test documentation required to combine the Stage II and Stage I systems into an Air Vehicle for mated flight test, and to integrate the GFE Payload with Stage II, then combine this assembly with Stage I for Operational flights.

The WBS identification of Integration and Assembly (Air Vehicle) is as follows:

- 1.1.1 Electrical
- 1.1.2 Mechanical
- 1.1.3 Tooling
- 1.1.4 Testing

III. FUNCTIONAL DESCRIPTION

Following Phase C go-ahead, individual Stage system definition will be completed such that a PDR may be held on each vehicle end item (CEI) agreed upon between NASA and the major Space Transport contractors. Currently, these include Stage II, Stage I and Main Engine (GFE) suppliers. Inherent in the integration of these for test purposes are the requirements for Integration and Assembly which result in a capability for mated flight test implying: (1) Stage I and Stage II will properly mate and separate in a physical and functional sense, (2) that undesired loads are not imposed on either stage due to the mated or separating modes in pre-launch, launch and ascent, and (3), that the requirements for hard line communications (voice, data, control) between stages is safe (before joining), is functional (after joining) and is freed properly (after separation). Further, since the operational requirements on the stages impose reusability (100 missions or greater), the joining/separation process should not impose undue wear and tear on components, thus causing high maintenance.

In addition to Stage I/Stage II integration, a requirement is imposed on Stage II to interface with a GFE Payload in the Operational Program phase.

It is therefore required that Integration and Assembly definition proceed along with Stages I and II definition such that Stage PDR's and Main Engine PDR incorporate requirements for Air Vehicle Integration and Assembly. These requirements will be satisfied (CEIs Part II) by Stage designs which incorporate recognition of the Integration and Assembly functions in ICD specifications, vehicle design drawings, test specifications, etc. involving Stage I-to-Stage II and Stage II-to-Payload. Confirmation of design and test documentation will be obtained in wind tunnel tests, mating and separation tests (simulated) and in combined systems tests (structure, power, avionics, etc.).

Elements which must be analyzed, evaluated, specified and developed in WBS ID 1.1 include mechanical and electrical equipment (master gages, handling, services, testing); test planning to establish test procedures for mating, separating, verifying structural, mechanical, electrical and avionic interfaces; and designing and developing the tooling associated with Integration and Assembly (Air Vehicle).

Constraints placed upon this task include those from Systems Effectiveness: Reliability, Maintainability, Safety, Human Factors, Value Engineering and Quality Assurance. Inasmuch as the Integration and Assembly (Air Vehicle) is a repetitive task (Mated Flight Test and Operational Mission flights), the equipments required (WBS 1.1.1, 1.1.2), tests required (1.1.4) and tooling required (1.1.3) lend themselves to GSE coverage, rather than to FSE identification.

DESIGN REQUIREMENTS

NASA Level I and Level II requirements affecting Integration and Assembly (Air Vehicle) are specified in WBS Dictionary Element 0.0, Advanced Space Transport Program. Specifically, Paragraphs IV.A.2 (Payload Definition), IV.A.6 (Cargo range), IV.A.12 (Vehicle Configuration), IV.A.16 (Safe Mission Termination), IV.A.18 (Mission Life), IV.A.21 (Fail Operational/Fail Safe requirements), IV.A.23 (Turnaround time), IV.A.26 (Payload weights), IV.A.28 (Stage Interchangeability), IV.B.3 (Test and Checkout), IV.B.5 (Commonality), IV.B.6 (Reliability and Quality Assurance), IV.B.7 (Safety), IV.B.8 (Interfaces), IV.B.10 (Propulsion), IV.B.12 (Mechanisms and Devices), and IV.B.14 (Ground Operations) should be considered as affecting WBS 1.1.

V. INTERFACES

Major interfaces which exist through the WBS between Block 1.1 and other elements of the Program are noted below.

WBS ID	Interface	Type of Interface
1.2/1.3	Payload-to-Stage II	Stage II Volume, mass properties, deployment/retrieval, communications, tie-downs, etc. to accommodate Payload.
1.2/1.4	Payload-to-Stage I	Stage I mass properties to transport and launch Stage II with or without Payload present
1.3/1.4	Stage I-to-Stage II	Physical (mating or separation of structural, electrical and avionics which pass between stages); aerodynamic/aerothermodynamic/structural (loads, whether they be stress, strain, heating, air-induced, gust-induced, other).
5.0	System/Program Management	Requirements, including PDRs, CDRs, test requirements, effectiveness requirements, etc. for Integration and Assembly (Air Vehicle).
3.0/8.0	Peculiar/Common Ground Support Equipment	Definition of Integration and Assembly Mechanical and Electrical Equipment, Tooling, and Test Procedures as Peculiar or Common Support Equipment.
4.7	Mated Flight Test	Mating of Stage I and Stage II (Launch Phase) and of Separation (Flight Phase)
9.0	Initial Spares and Repair Parts	I&A Spares and Repair Parts definition/procurement/delivery/storage
12.0	Operations and Services	445 flight Traffic Model employing I&A of Air Vehicle elements, separation of stages, and deployment/retrieval of payloads.

Other interfaces include training of personnel in the I&A tasks (WBS ID 10.0) and the impact of the Industrial Facility (WBS 11.0) on this task.

VI. TEST REQUIREMENTS

Specific tests associated with Integration and Assembly of the Air Vehicle are defined under WBS Dictionary Elements 4.7.1.1, Integrated Operations and Services (mated flight test) and 12.1.1, Integrated Operations and Services (Operational flights).

VII. REFERENCES

(To be added).

PROGRAM TITLE ADVANCED SPACE TRANSPORT PROGRAM

WBS NO. 1.2

TASK TITLE PAYLOAD (DEPLOYABLE

LEVEL 4, System Level

WBS DICTIONARY

I. REQUIREMENTS

A requirement has been specified by the National Aeronautics and Space Administration and other Government agencies for certain payloads to be transported from earth to near-earth space and for other payloads to be returned from near-earth space to earth in support of advanced U.S. space programs. The means to transport these payloads is identified by NASA as an Advanced Space Transport Vehicle which is reusable, i.e., capable of safe return to earth following a mission with subsequent turnaround capability in an established time period. The shape, volume, weight and support requirements of the various types of GFE payloads place various constraints on the design and development of the Advanced Space Transport Program elements. WBS Dictionary Element 1.2 is therefore included to specify Payload interfaces to this Program as appropriate.

TASK SCHEDULE MILESTONES

PERIOD ENDING																		
	SCHEDULE NOT GENERATED																	

II. SUBSYSTEM DEFINITION

Specific elements of the GFE Payload are not identified at this time. Preliminary designers of the Space Transport Vehicle have, however, been given certain characteristics concerning the Payload. These are stated below.

A. Payload Size/Weight

1. Payloads shall be equal to or less than 15 feet in diameter and 60 feet in length including handling rings, attachment fittings for the deployment mechanism and docking, and cargo bay door fittings. The standardized deployment mechanism(s) and tie points shall be charged to the Space Transport Stage II (Space orbiter). Deployment clearance shall be provided by Stage II.

2. Vehicle payload is baselined to be 65,000 lbs. into a due east 100 nm circular orbit (design mission) with the air-breathing engines removed from Stage II. The weight of passengers and removable provisions for the passengers shall be charged to the payload. Stage II shall have the capability of landing 40,000 lbs of payload with nominal wind and load factors (airbreathing engines removed) and large (heavier) payloads with reduced structural safety factors.

B. Payload Launch Frequency

The launch rate will vary from a minimum of 25 to a maximum of 75 per year (total of 445 in 10 years).

C. Type of Payloads/Deployment Altitudes

1. Payloads are generalized into the following categories:

a. Satellites
b. Experiments
c. Propulsive stages plus payloads
d. DoD payloads
e. Space rescue

FOLDOUT FRAME 1

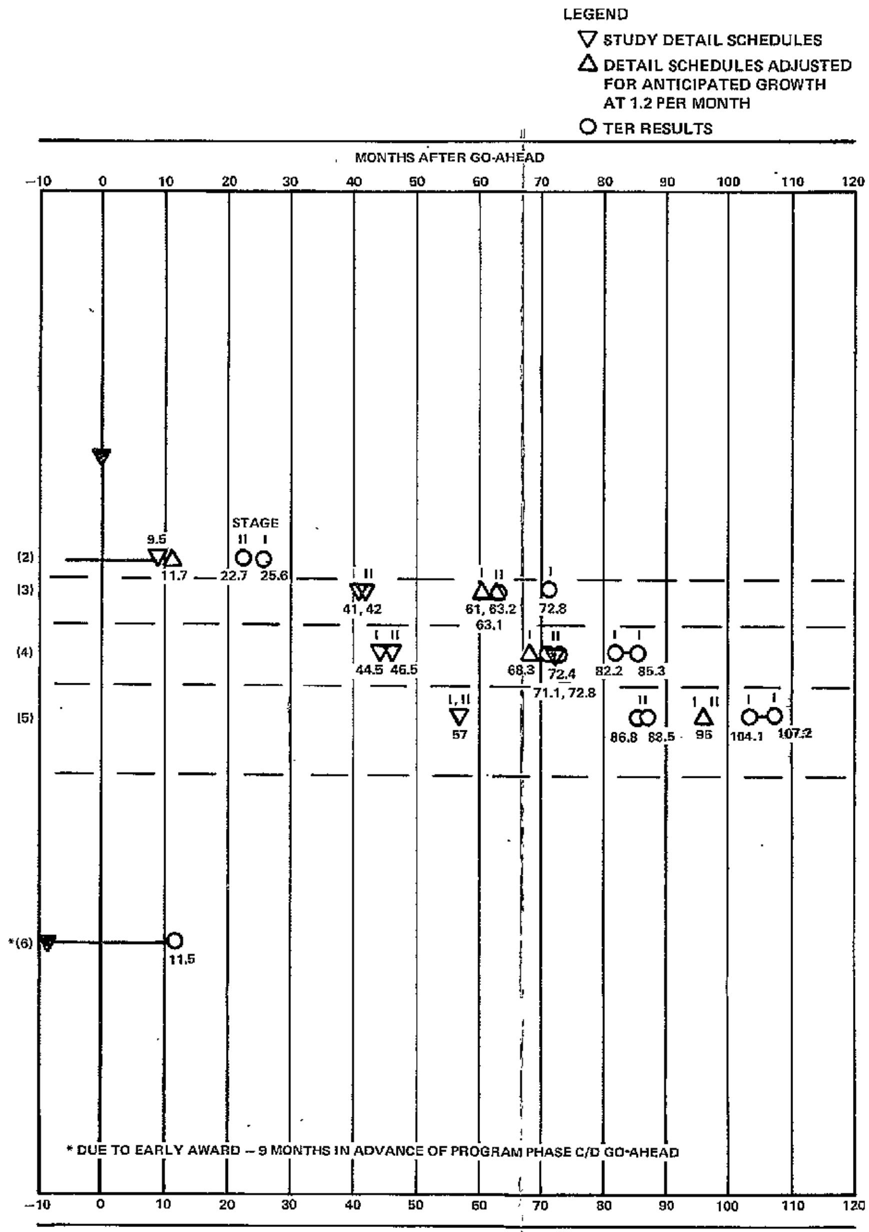
APPENDIX A

COMPARISON OF TER RESULTS WITH DETAIL SCHEDULE/LOGIC RESULTS

Time Estimating Relationships intersect logic and schedules at those points indicated below and within the respective WBS elements. The points of intersection shown below are also identified on those schedules and logic charts containing the particular TER event.

TER Number & Description	Point	WBS	Particular TER Event
7.6 Total Program			Phase C/D go-ahead. Note this point is identified as "go-ahead" or "A00" on logic and schedules.
	(1)		Total program 95% airborne engineering design release.
	(2)		Start detail fabrication.
	(3)	4.5.3.0.0 4.6.3.0.0	Rollout first horizontal flight test vehicle.
(7.7) Horizontal Flight Test	(4)	4.5.6.0.0 4.6.6.0.0	Start horizontal flight testing.
	(5)	4.5.6.0.0 4.6.6.0.0	Complete horizontal flight testing; i.e., obtain sufficient data/confidence to commence vertical flight test phase vehicles 1 and 2.
7.2 Liquid Rocket Engines			Go-ahead for the main engine contract. Note — This point precedes Phase C/D go-ahead and is not shown on logic or schedules.
	(6)	5.1.1.0.0 5.3.1.0.0	Completion of the first main engine test. Note — This point and the inherent data contribute to the engine trade-off studies for both Stage 1 (5.3.1.0.0) and Stage 2 (5.1.1.0.0)

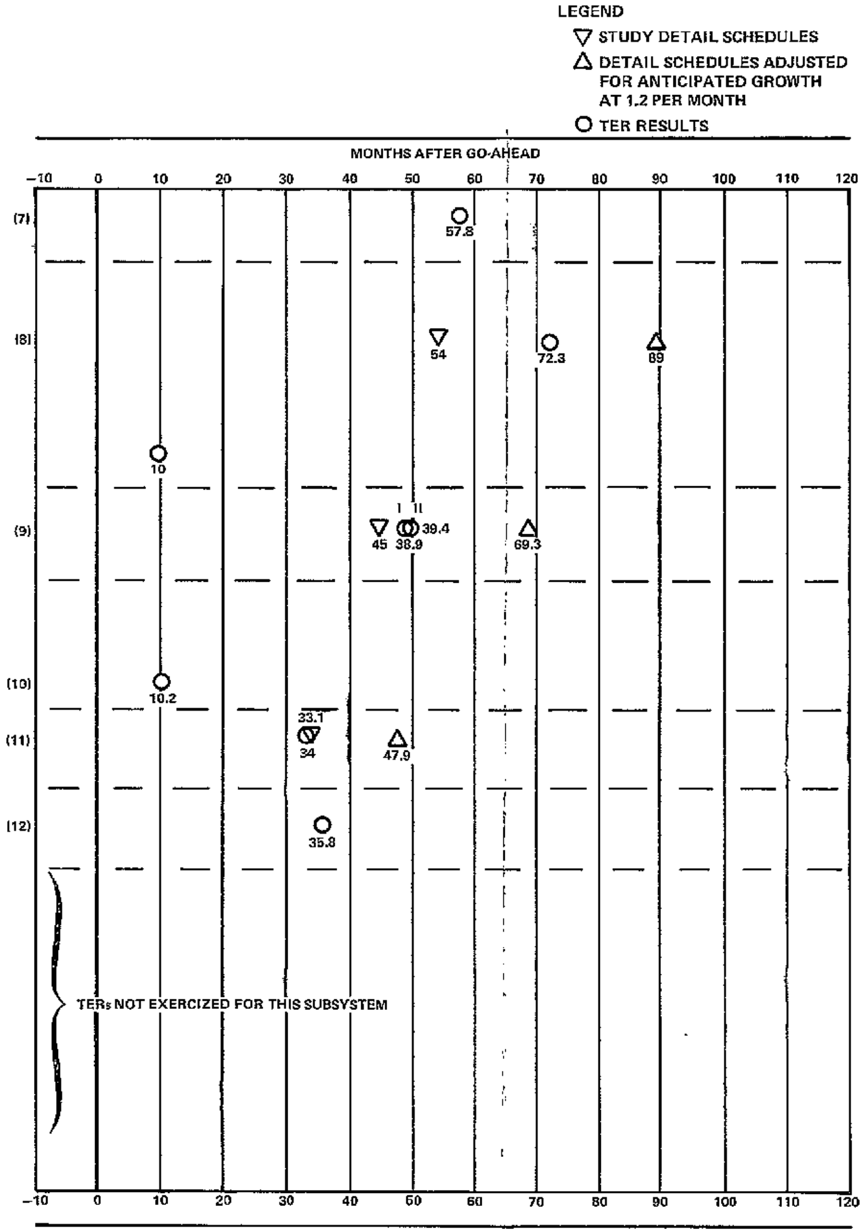
FOLDOUT FRAME 2



FOLDOUT FRAME 1

TER Number & Description	Point	WBS	Particular TER Event
	(7)	4.1.8.0.0 4.2.8.0.0	Single engine PFRT. Recall the logic displays this point admittedly redundantly for both Stage 1 (4.2.8.0.0) and Stage 2 (4.1.8.0.0).
	(8)	4.1.8.0.0 4.2.8.0.0	Single engine qualification testing complete. Same remarks as above.
7.4 Small Gas Turbine Engines			Go-ahead for auxiliary power unit. Note — This point is not shown on logic or schedules. Includes 10 months for vendor selection.
	(9)	1.3.6.0.0 1.4.6.0.0	Qualification of auxiliary power unit as necessary to deliver units to program for Stage 1 (1.4.6.0.0) and Stage 2 (1.3.6.0.0)
7.3 Avionics			Phase C/D go-ahead. Note — This point is identified as "go-ahead" or "A00" on logic and schedules.
	(10)	1.3.10.0.0 1.4.10.0.0	Go-ahead to the vendor for the largest, most complex black box.
	(11)	1.3.10.0.0 1.4.10.0.0	Receipt of the first black box for buildup/assembly of the data management hardware.
	(12)	1.3.10.0.0 1.4.10.0.0	Receipt of the last black box, thereby completing hardware buildup/assembly.
7.3 Avionics			Phase C/D go-ahead. Note — This point is identified as "go-ahead" or "A00" on logic and schedules.
	(13)	1.3.8.0.0 1.4.8.0.0	Go-ahead to the vendor for the largest, most complex black box.
	(14)	1.3.8.0.0 1.4.8.0.0	Receipt of the first black box for buildup/assembly of the prototype guidance and navigation subsystem.
	(15)	1.3.8.0.0 1.4.8.0.0	Receipt of the last black box, thereby completing hardware buildup/assembly

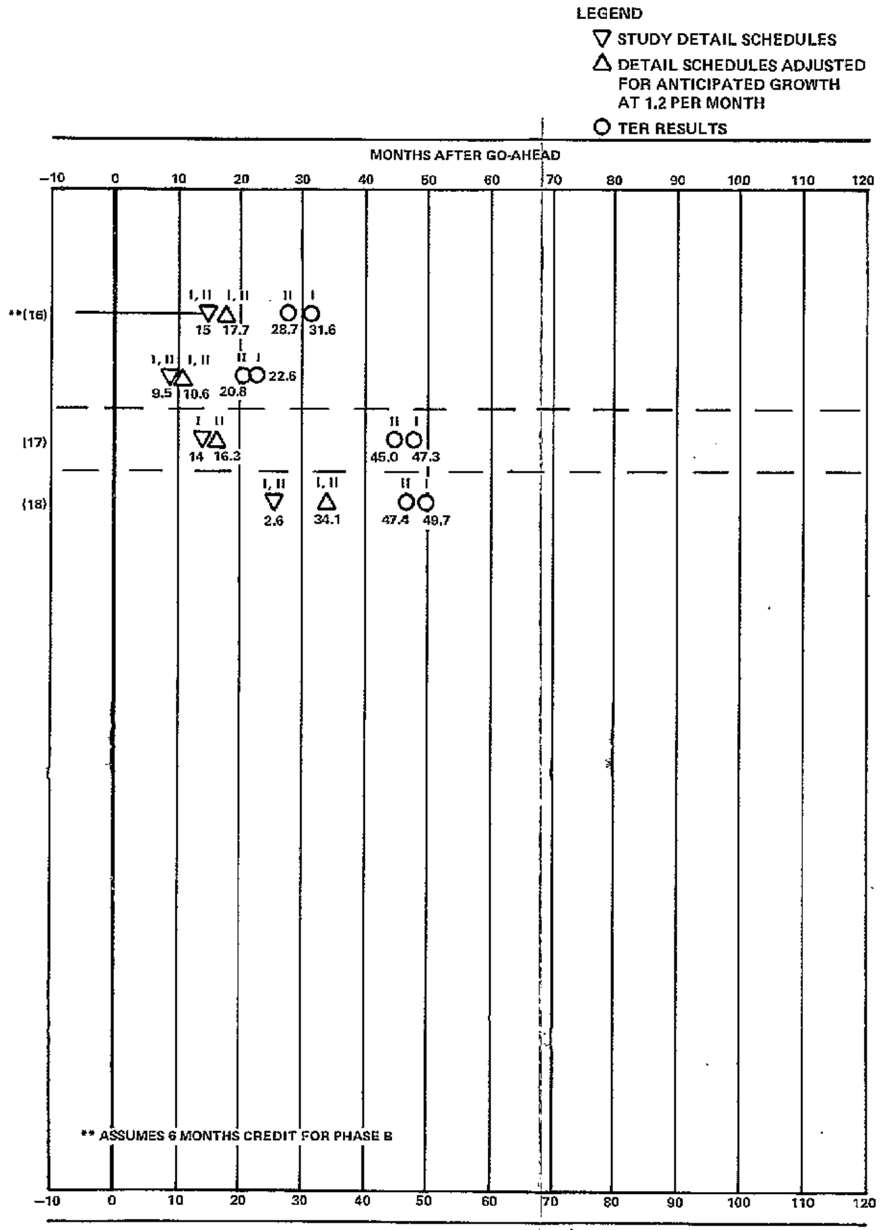
FOLDOUT FRAME 2



FOLDOUT FRAME 1

FOLDOUT FRAME 2

TER Number & Description	Point	WBS	Particular TER Event
7.1 Structure			Phase C/D go-ahead. Note — This point is identified as "go-ahead" or "A00" on logic and schedules.
	(16)	1.3.2.0.0 1.4.2.0.0	95% structural engineering design release.
			Start detail fabrication. Note — This point does not appear on logic or schedules at the 5th WBS level; it does appear as (2) at program level.
	(17)	4.3.2.0.0 4.4.2.0.0	Complete manufacturing and start assembly of structural test article.
	(18)	4.3.2.0.0 4.4.2.0.0	Complete final assembly of structural test article.



APPENDIX

2. Altitudes to which the Space Transport must deliver/retrieve these payloads are as follows:

   a. 100 nm circular
   b. 200-270 nm elliptic
   c. 270 nm circular

3. Inclinations for payload delivery are as follows:

   a. 28.5-33 degrees
   b. 55-63 degrees
   c. 90-100 degrees

III. SPACE TRANSPORT PROGRAM INTERFACES

A. The Payload interfaces with Stage I and Stage II of the Space Transport Air Vehicle in WBS ID 1.0 as a design constraint:

1. On both Stage I and Stage II as a mass varying from zero to max. weight, I_{xx}, I_{yy}, I_{zz}.

2. On Stage II as a weight, volume, shape, size constraint and as a deployment constraint. If monitoring of the payload is required, a communications and data management constraint will also be placed on Stage II.

B. The Payload interfaces with Stage I and II in the Operations phase in WBS ID 12.0, specifically in the pre-launch phases of receiving/inspection, loading aboard Stage II, launch countdown, flight, space deployment, space retrieval, entry, approach and landing, recovery and turnaround.

C. A Payload Office is established in WBS ID 12.0 to handle Payload-to-Space Transport interfaces during Operations. A need for same in the Development Phase is provided under WBS ID 5.5.3, System Integration.

IV. REFERENCES

(To be added).

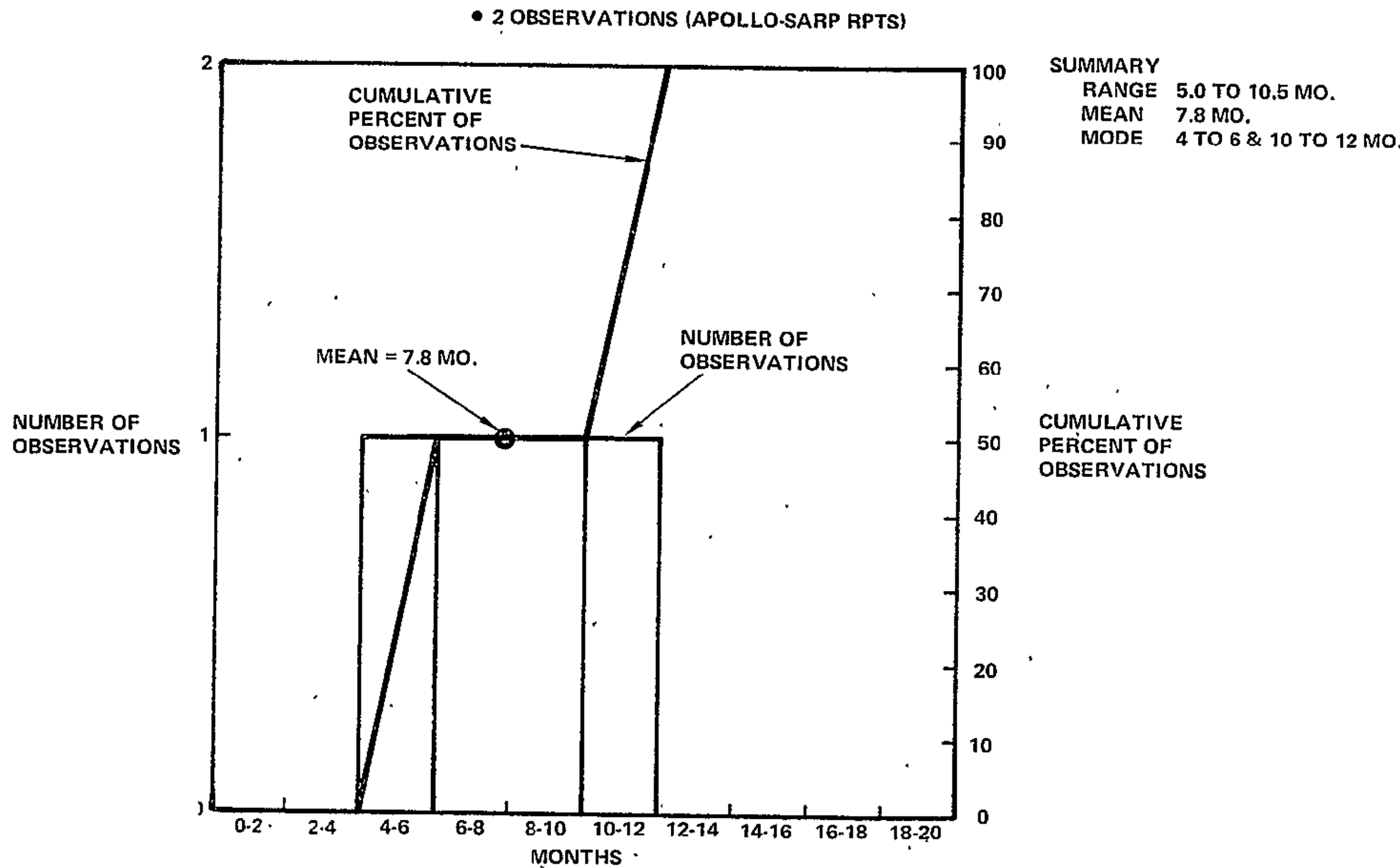


FIGURE 7.9-10 TOTAL PROGRAM SCHEDULE GROWTH REDIRECTION

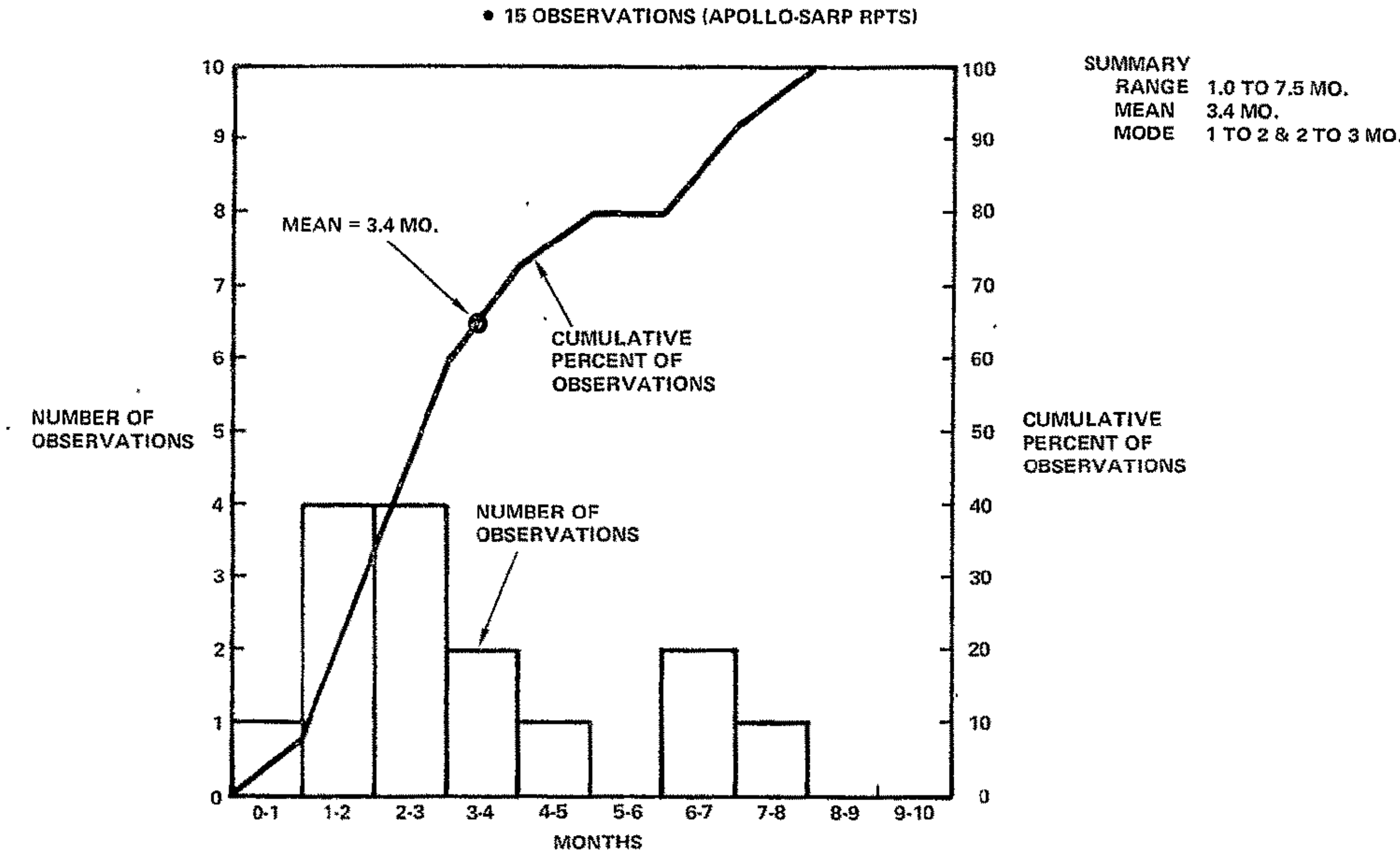


FIGURE 7.9-11 TOTAL PROGRAM SCHEDULE GROWTH

PART SHORTAGE

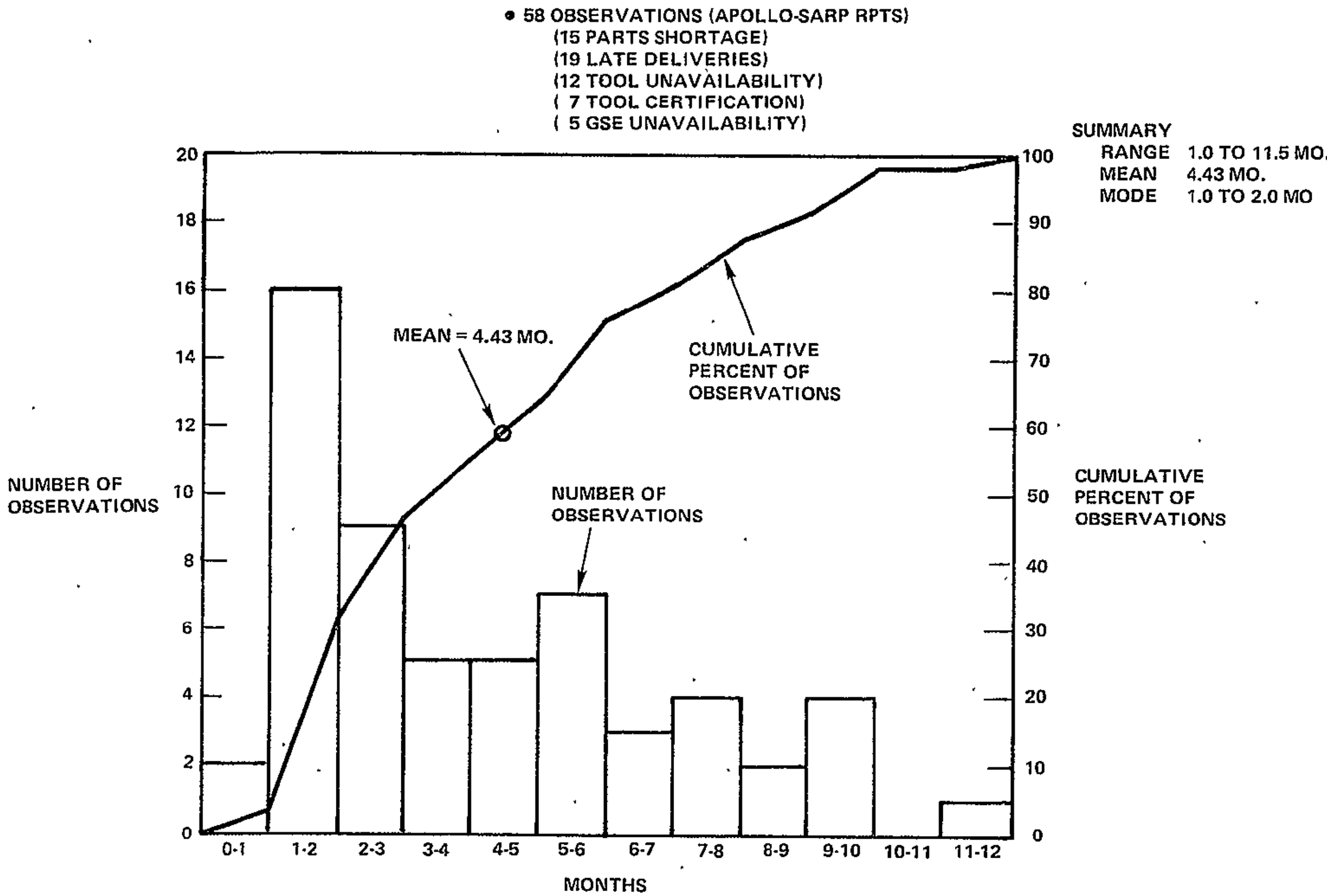


FIGURE 7.9-12 TOTAL PROGRAM SCHEDULE GROWTH

MANUFACTURING

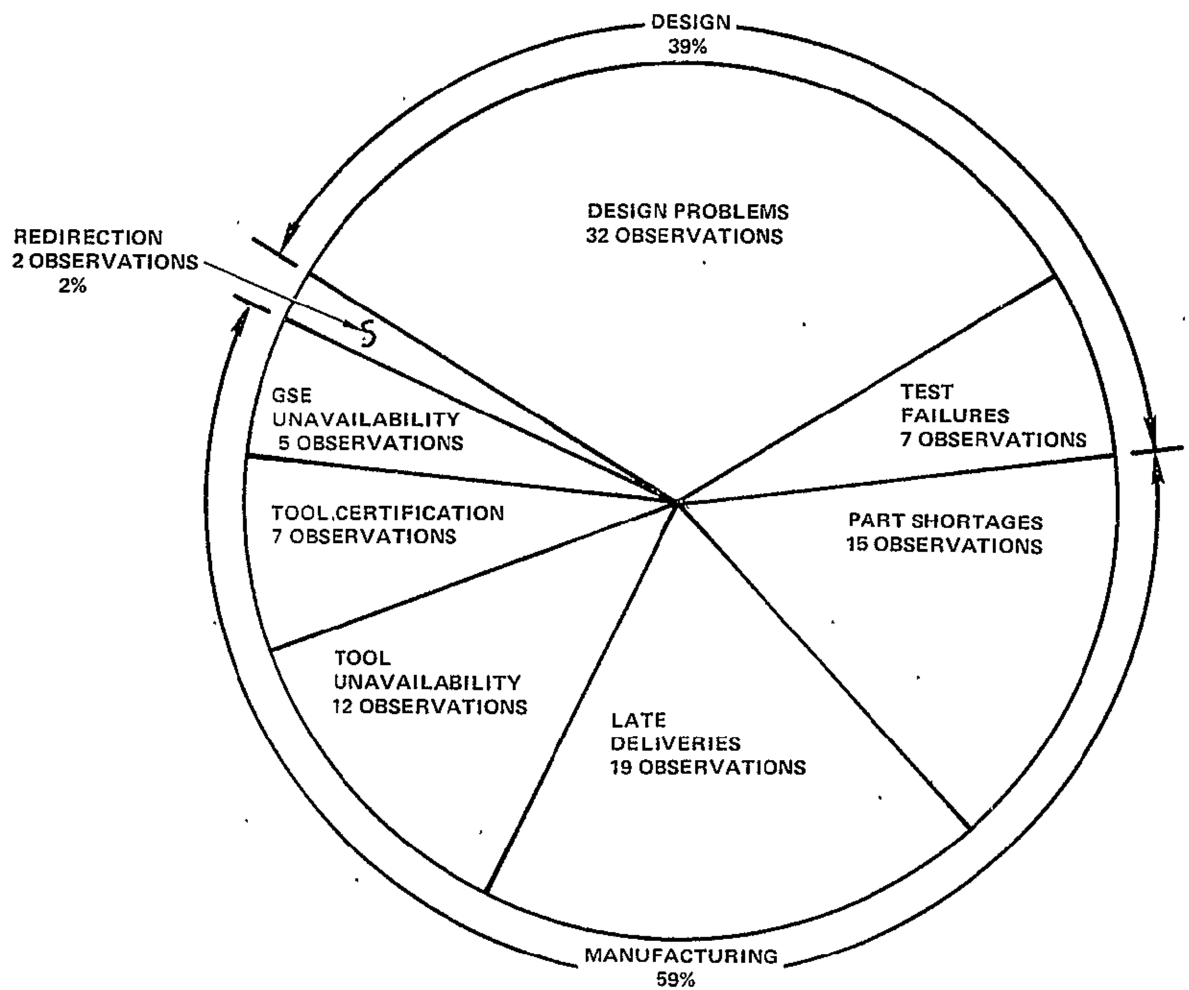


FIGURE 7.9-13 TOTAL PROGRAM SCHEDULE GROWTH

(APOLLO-SARP RPTS)

7.10 BIBLIOGRAPHY

Section 7.10 presents a summary bibliography of data sources. The intent of this bibliography is to give the reader some insight as to sources for schedule information and not completely document a reference for each data point used in this study. The following pages present in matrix form several reference documents/sources and each TER section to which these sources are applicable.

7.10 BIBLIOGRAPHY

	Total Program	Horizontal Flight Test	Structure	Propulsion	Avionics	APU	Outboard Test Equip.	Confi-dence
Aviation Week 1963 thru 1971	X	X	X	X	X		X	
Space Daily 1963 thru 1971				X	X			
DMS Market Intelligence Reports	X	X	X		X		X	X
Congressional Hearings	X							
NASA TN D-3734 (X-15)	X	X						
Lockheed M & S Rept LMSC 855429	X		X					
VMSC In-House Records	X	X	X	X	X	X		
Missiles and Rockets				X	X			
"The Weapons Acquisition Process"								X
SARP Reports	X		X	X	X			X
Rand Report P-1821								X
AIAA Paper 68-212 (AF Tech)			X					
NASA SP4002 (Gemini)								
NASA SP45 (Mercury Project Summary)	X							X
Apollo Opns Hndbk SID 66-1508					X			
Air Force Journal		X						
Janes "All The World's Aircraft"	X	X	X	X				X
Aerospace Industries Yearbook	X							
Defense Science Board-R & D Mgmt.	X							
Rand Report 61-PR	X							
NASA SP-60 (X-15 Research Results)	X							
DOT-SST Schedule	X		X					
Space/Aeronautics			X		X			
Gemini Familiarization Manual			X		X			
Saturn V - Payload Planner's Guide			X					
Conversations with Aerospace Companies								
Vought Aeronautics Co.	X	X	X		X			
Collins Radio Co.							X	
Menasco			X					
AiResearch Mfg. Div						X		

	Total Program	Horizontal Flight Test	Structure	Propulsion	Avionics	APU	Outboard Test Equip.	Confi- dence
Solar Aircraft Co.						X		
NAR - L.A. Division	X		X					
Software Age			X					
Aerospace Corporate Annual Rpts.						X		
Liquid Propellant Eng. Manual-PIA				X				
MSC Mgmt, Document Fed '70 (Propulsion Branch)				X				
Mercury Familiarization Manual					X			
AFG, 2, Vol. I					X			
Airline Management							X	
XB-70A Ground Test-AD 814-191		X					X	
XB-70Airborne Data Acq. AD 814-191		X					X	
Rand Report P-1821								X
AIAA-The Supersonic Transport	X							
Technical Information Summaries for Saturn V Flight Vehicles	X		X					
Apollo Familiarization Manual	X		X		X			
Apollo Operations Handbook - CSM & LM	X		X		X			
Project Gemini Chronology	X		X					

SECTION 8

ADVANCED SPACE TRANSPORT PROGRAM, AIR VEHICLE, A/V INTEGRATION & ASSEMBLY, PAYLOAD

SECTION 8

ADVANCED SPACE TRANSPORT PROGRAM, AIR VEHICLE, A/V INTEGRATION & ASSEMBLY, PAYLOAD

This Section introduces data generated during the course of the Scheduling Technique Improvement Study which served as the baseline for TER development reported in Sections 2, 3 and 7, preceding. In addition, this data served as a baseline for comparison of TER results with conventional scheduling results as reported in the Appendices to Volumes I through IV and summarized in Section 2, preceding.

In Section 8, an Advanced Space Transport Program is introduced and defined via the Work Breakdown Structure (WBS) Dictionary, Logic Diagram and Master Schedule approach and format respectively discussed in Sections 4, 5 and 6, preceding. Within the 'top' WBS Dictionary text (WBS ID 0.0, ADVANCED SPACE TRANSPORT PROGRAM), the 'top' Work Breakdown Structure is shown. Twelve major elements are noted to break out at the 3rd Level of the Life Cycle Program, the first element being the SPACE TRANSPORT AIR VEHICLE (WBS ID 1.0), a reusable vehicle consisting of two manned stages, one of which carries a deployable payload to or from near-earth space as defined within the 'top' WBS Dictionary Element.[1] Immediately behind the 'top' WBS Dictionary Element, the 'top' Logic Diagram is presented and carries the Program from Go-Ahead through RDT & E and Investment to an Operational Capability. Following the 'top' Logic Diagram, a Master Schedule depicts the Program in terms of major tasks within Engineering, Tooling, Materials and Manufacturing disciplines from Go-Ahead through IOC.

Continuing after the Program presentations (2nd Level), the WBS Dictionary is presented for the AIR VEHICLE (WBS ID 1.0), for Air Vehicle INTEGRATION & ASSEMBLY (WBS ID 1.1), and for the Deployable PAYLOAD (WBS ID 1.2). Volumes II - IV then continue the definition (Dictionary, Detail Schedules and Logic Diagrams) for STAGE II (WBS ID 1.3) (Volume II), for STAGE I (WBS ID 1.4) (Volume III), and for all remaining 3rd Level Elements (WBS ID 2.0 - 12.0) (Volume IV).

[1] VMSC with MSC approval chose this Program, for this study, since it represents one of both current and future interest to NASA and other government agencies interested in the development of systems to operate in near-earth space in the late 1970's and on.

It will be noted on the Master Schedule, on Detail Schedules and on certain Logic Diagrams throughout Volumes I - IV that a code number (viz., 1, 2, 3, . . .) has been affixed. This number is placed there to denote where the Schedule or Logic relates to the TER effort described in Section 7 of this Volume. Appendices within each Volume explain the coding and the relationship which was found to exist between TER results and conventional Detail Scheduling and Logic Diagram results.

VOUGHT MISSILES
AND SPACE COMPANY

PROGRAM TITLE ADVANCED SPACE TRANSPORT PROGRAM

WBS NO. 0.0

TASK TITLE ADVANCED SPACE TRANSPORT PROGRAM (PHASE C/D

LEVEL 2, Program Level

WBS DICTIONARY

I. REQUIREMENTS

A requirement has been specified by the National Aeronautics and Space Administration for an Advanced Space Transport Program which will design, develop, test and employ reusable two-stage vehicles, together with an operational support capability, to be used for supplying and returning GFE payloads to and from near-earth space. Program phases will include a Design Phase (Phase C) and a Development and Operations Phase (Phase D). The System Definition Phase (Phase B), is assumed to be completed, establishing initial requirements on the Air Vehicle, Ground Support, Development Test and generalized Operations Plan. The current on-going program, termed the Space Shuttle Program, is the baseline for the Advanced Space Transport Program.

TASK SCHEDULE MILESTONES

PERIOD ENDING

SCHEDULE NOT GENERATED FOR THIS ELEMENT. SEE MASTER SCHEDULE.

II. PROJECT DEFINITION

Twelve major elements comprise the Advanced Space Transport Program. These elements, denoted on Figure 0.0-W-2, cover Research, Development, Test and Evaluation (RDT&E); Initial Investment to achieve IOC; and 10-year Operations.[1] Their Work Breakdown Structure identification is as follows:

RDT&E

1.0 Space Transport Air Vehicle (Reusable)
2.0 Ground Communications, Command and Control, Recovery Equipment (Peculiar)
3.0 Peculiar Support Equipment
4.0 Systems Test and Evaluation
5.0 System/Program Management
8.0 Common Support Equipment
10.0 Training
11.0 Industrial Facilities (Peculiar)

Initial Investment

6.0 Data (DD Form 1423 or its NASA equivalent)
7.0 Operational/Site Activation
9.0 Initial Spares and Repair Parts (Initial production buy: Air Vehicles (1.0), GSE (2.0, 3.0, 8.0))

Operations (10-year)

12.0 Operations and Services

III. FUNCTIONAL DESCRIPTION

At Phase C go-ahead, final design of the Air Vehicle, Ground Support Equipment (GSE), and additional development and test support capability will be initiated. Three major categories of Program effort are identified throughout the Program: Stage II Vehicle and Support; Stage I Vehicle and Support; and, Integrated Vehicle and Support. A fourth and fifth category include the Program interface of Payload (assigned as GFE, which becomes

[1] The Master Schedule, Figure 0.0-W-1, follows the Logic Diagrams included at the end of this Dictionary Element description.