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CONFIGURATION DEVELOPMENT STUDY OF THE X-24C HYPERSONIC RESEARCH AIRPLANE

EXECUTIVE SUMMARY

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Lockheed Aircraft Corporation
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16. Abstract

This report summarizes the results of this three phase study and makes recommendations as to the X-24C's value toward furthering hypersonic research and technology.

The results show that a Lockalloy heat-sink structure affords the capability for a "work-horse" vehicle which can serve as an excellent platform for this research.

It was further concluded that the performance of a blended wing body configuration surpassed that of a lifting body design for typical X-24C missions.

The cost of a two vehicle program, less engines, B-52 modification and contractor support after delivery, can be kept within $70M (in Jan. 1976 dollars).

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FOREWORD

This Executive Summary report is submitted to the National Aeronautics and Space Administration in accordance with NASA Contract NAS 1-14222. The work reported herein was performed between April 1976 through May 1976 culminating in an oral presentation at NASA LRC on 27 May 1976. The study was performed by the Advanced Development Projects "Skunk Works" of the California Company, A Division of Lockheed Aircraft, under the supervision of Mr. H.G. Combs, Study Manager. Engineering graphics and supporting text were developed under the direction of Messrs. D.H. Campbell (Propulsion and Thermodynamics), M.D. Cassidy (Aerodynamics), C.D. Sumpter (Structures), E.B. Seitz (Weight), G.J. Kachel and R.P. James (Vehicle Design), J. Walters and consulting services of J. Love (Maintenance), and R.T. Passon (Cost).

SUMMARY

The future development of operational hypersonic cruise aircraft requires a technology base which presently does not exist. To start developing this technology an air-launched rocket powered aircraft, capable of carrying and conducting a variety of experiments at hypersonic speeds, has been proposed. This study effort was to determine if it is practical to develop such a hypersonic flight research facility using today's state-of-the-art at minimum cost and risk. The study was conducted in three phases; Phase I consisted of Design Trades of candidate rocket engines and structure/thermal protection approaches, Phase II evaluated the Growth Potential of the configuration as a function of increased launch weight and Phase III resulted in Concept Refinement.

The study focused on five areas which affect such a design:

- Propulsion concept for boost and cruise,
- Structure and thermal protection approach,
- Aerodynamic performance which could be achieved,
- Operation and maintenance risk over a ten year period,
- The initial cost to procure two vehicles expressed in January 1976 dollars.

The configuration which served as the baseline for Phase I and II was the NASA/USAF X-24C-12I. The concept evolved in Phase III is identified as the X-24C-L301.

It was concluded that it is practical to design, build and operate an X-24C-L301 vehicle. For propulsion the aircraft can use one LR-105 engine (ATLAS sustainer) (or LR-91 TITAN 1, 2nd Stage) for boost and twelve LR-101's (ATLAS verniers) for cruise. This propulsion concept gives more performance at less cost than the other candidate engines because of its higher I_{SP}.

Lockalloy, a composite of beryllium and aluminum, can be used both as a heat sink and structure and eliminates the need for external protective insulation for the short flight times involved. By launching at 31.75 Mg (70,000 lb) from a modified B-52 the X-24C-L301 can cruise for 40 seconds at M = 6.78 on scramjets and has the off-design capability without scramjets of approaching M = 8 with a 453.6 kg (1000 lb) payload, or 70 seconds of cruise at M = 6 with a 2.27 Mg (5000 lb) payload.

A Lockalloy airframe is significantly less costly to operate and maintain than an insulated aluminum design since it is impervious to LOX, hydraulic fluids, fuel, etc., requires no refurbishment and affords simpler preflight/post flight inspections. The costs to procure two X-24C-L301's can be kept within $70M in January 1976 dollars, including spares, AGE and data, but excluding engines and other GFE.

It was further concluded that the X-24C-L301, because it is designed as a "work horse," can materially aid in the development of the technology base for hypersonic cruise aircraft. The large payload bay and interchangeable wings and fins affords a platform for structure and thermal protection system research. These same features allow for planform variation for conduct of hypersonic aerodynamic research. In addition to scramjet development, other propulsion concepts can be validated over a wide range of Mach numbers. The X-24C-L301 cruise capability allows thermodynamic research under steady state conditions.

In summary therefore the X-24C with its large payload capacity and its capability for sustained high Mach number flight can serve as an excellent platform for hypersonic research.

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INTRODUCTION

It is not possible with today's technology to build an operational hypersonic cruise aircraft. Such an aircraft would have to be air-breathing since to carry the oxidizer on board would make the vehicle size and weight prohibitive. No air-breathing hypersonic propulsion systems have been developed for aircraft operating at Mach numbers in the 4 to 6 range and altitudes above 27, 500 meters (90, 000 ft) for long periods of time. It should be possible, however, to build a research airplane which can cruise for short durations at speeds up to Mach 8 and perform the needed exploratory research. Existing rocket propulsion systems can be used to accelerate and cruise the vehicle and materials exist which can provide the thermal protection needed at these speeds. An aircraft of this type can significantly close the technology gaps which presently impede the development of a fully operational hypersonic cruise airplane.

The purpose of the "Configuration Development Study of the X-24C Hypersonic Research Airplane" was to determine if it is practical to design, build, operate and maintain such an air-launched, high performance airplane within today's state-of-the-art and do so within the cost and operational constraints established by the NASA. The use of this hypersonic flight research facility would materially aid in focusing and accelerating the technology development required for future military and civil aircraft operating in the hypersonic environment.

This Configuration Development Study consisted of three phases:

Phase I - Design trades of a baseline X-24C configuration embodying three propulsion system concepts and three thermal protection system approaches to determine the effect on cost and operational feasibility.

Phase II - Evaluation of the effect of increased vehicle size and weight on performance, payload and cost. Select a vehicle size and launch weight for use in Phase III.

Phase III - Development of a conceptual aerodynamic configuration and vehicle design which realizes the potential capability indicated by the prior two study phases. At the conclusion of this study phase, a wind tunnel model of the conceptual design was built and delivered to the NASA.

This Executive Summary provides only the "bottom line" results of the study. The complete details and results of each of the three phases are documented in NASA reports CR-145032 (Phase I), CR-145074 (Phase II), and CR-145103 (Phase III).

X-24C

CONFIGURATION DEVELOPMENT STUDY

Phase I - Design Trades

The objective of the Phase I - Design Trades Study was to conduct a comprehensive trade study of rocket engines and thermal protection systems (TPS) concepts using the existing X-24C-12I configuration (Figure 1) with a fixed launch weight and performance. At the end of Phase I, a rocket engine system and a TPS concept were to be selected for use in Phases II and III.

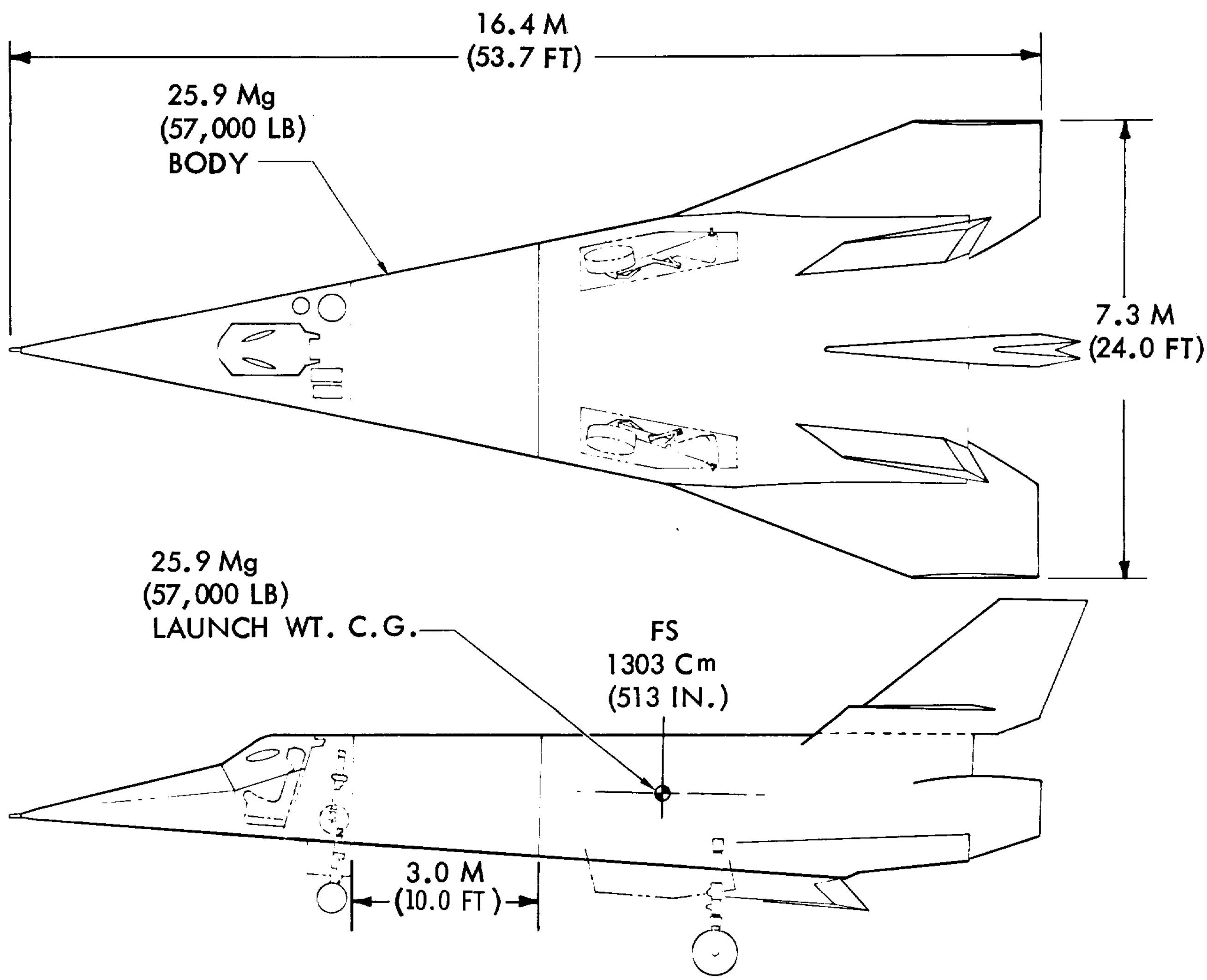


Figure 1 - X-24C-12I Configuration

The trade-off matrix of these various approaches is shown in Table 1.

TPS OPTION / ROCKET ENGINE OPTION	ELASTOMERIC ABLATOR	LI-900 RSI	LOCKALLOY
LR-99/LR-11 LR-105/LR-101 LR-105 THROTTLEABLE	9 CANDIDATE VEHICLES		

TABLE 1. PHASE I TRADE STUDY MATRIX

The NASA established requirements for each candidate X-24C configuration were:

- o Aerodynamic configuration - X-24C-12I (Figure 1),
- o B-52 launched at a launch mass of 25.85 Mg (57,000 lbs),
- o Cruise at Mach 6 for 40 seconds,
- o Carry 3 scramjet modules, and
- o Include a 453.6 kg (1000 lbs) payload in the payload bay as part of the 25.85 Mg (57,000 lbs) maximum launch mass restriction.

The 453.6 kg (1000 lbs) payload represented the weight of a typical experiment that could be carried on the X-24C.

The TPS concepts that were evaluated are shown in Figure 2. The elastomeric ablator is a derivative of the type used on the uprated X-15-2. The LI-900 Reusable Surface Insulation (RSI) is a tile type insulation used on the Space Shuttle. Both of these insulators are used to protect aluminum structure. Lockalloy, being a composite of aluminum and beryllium, serves both as heat sink and structure.

The rocket engine concepts that were evaluated are shown in Figure 3. The LR-99/LR-11 engines were used on the X-15 and X-24B vehicles. The LR-105/LR-101 engines were used on the ATLAS missile. The third concept was a throttleable version of the LR-105. The thrust and I_{sp} of these engines are listed in Table 2.

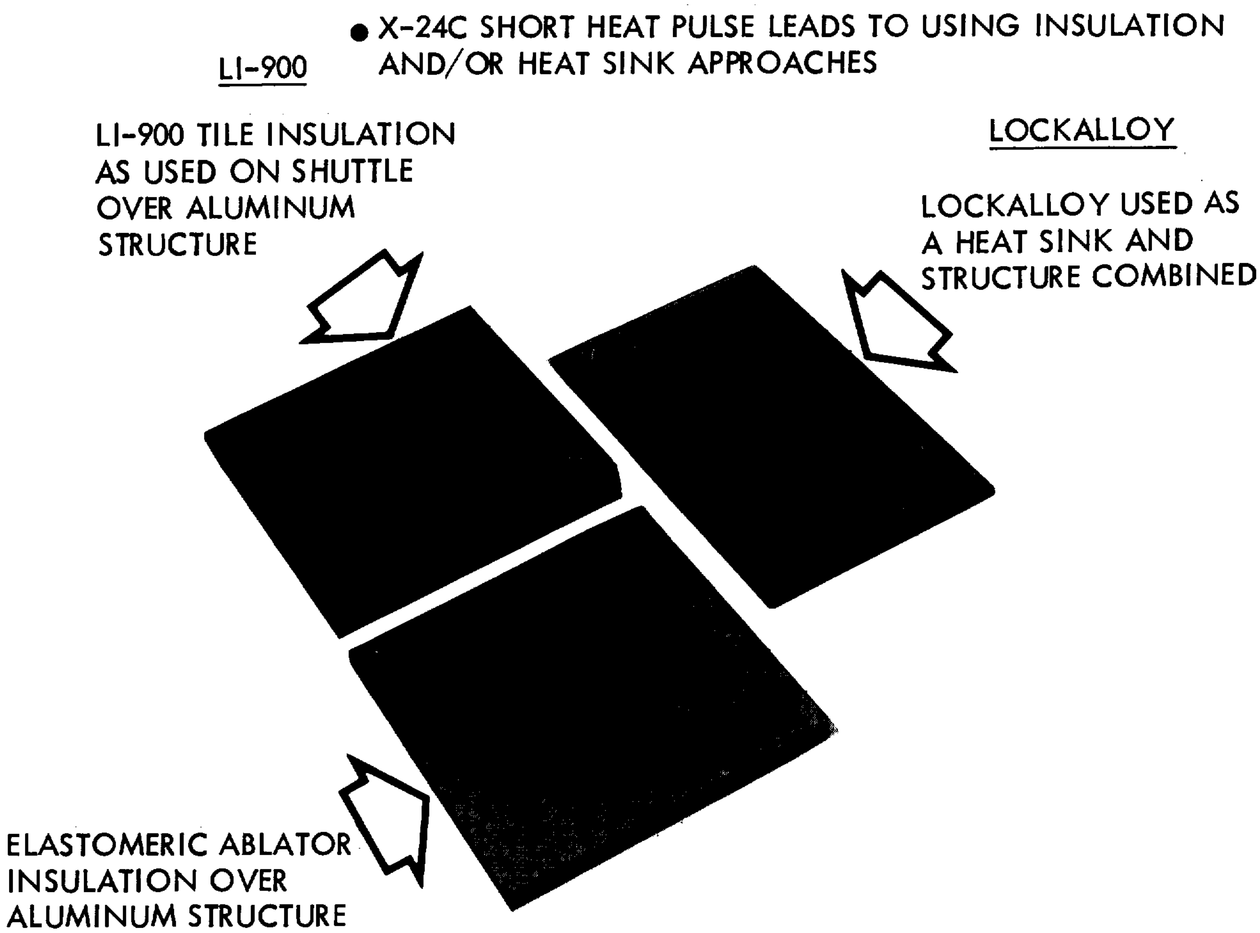


Figure 2. Thermal Protection System (TPS) Concepts

A basis for determining mission performance was established using the following factors:

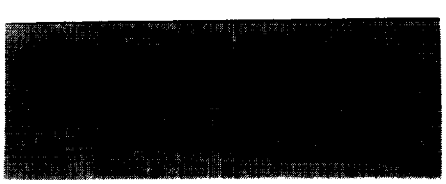
- Cruise 40 seconds at M = 6.0 and 47.9 kPa (1000 psf) dynamic pressure at 27,000 meters (88,360 ft) altitude,

- o Launch from a B-52 at M = 0.85 at 13,720 meters (45,000 ft) altitude,
- o Trimmed lift and drag data for X-24C with 3 scramjet modules supplied by Langley Research Center and extrapolated to $\alpha = 20$ degrees,
- o Rocket performance data supplied by the engine manufacturers,
- o 1962 U.S. Standard Atmosphere, and
- o Maneuver limits, N_z of:

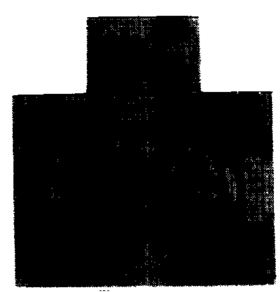
	Mission	Structural Design
Launch and pull-up	0-2.0g	-1.0/+2.5g
At High Mach	0-2.5g	-1.0/+3.0g

LR-99
EXTENDED NOZZLE

LR-105
ATLAS SUSTAINER



LR-11



LR-101
ATLAS VERNIER

PHOTOGRAPHS DEPICT RELATIVE SIZES

FIGURE 3 - CANDIDATE ROCKET ENGINES

These factors were used to develop a mission profile that each of the nine candidate X-24C configurations "flew" in order to determine vehicle design zero fuel weight and anticipated vehicle skin temperatures. For the aluminum airplanes, the thickness of the LI-900 tile and the elastomeric ablator were adjusted to limit the aluminum skin temperature to a maximum of 121°C (250°F). For the Lockalloy heat sink approach, the Lockalloy thickness was adjusted to limit its temperature to 315°C (600°F). The mission profile together with vehicle weight, skin temperature, airspeed, Mach and altitude as a function of the time from launch are shown on Figure 4.

	THRUST - Mg (LB) AT 21,350 M ALT	I_{sp} 21,350 M ALT
LR-99 EXTENDED NOZZLE, THROTTLEABLE	28.1 (62,300)	285 SEC
LR-105T THROTTLEABLE	37.5 (82,620)	306
LR-105DT DERATED, THROTTLEABLE	26.7 (58,900)	300
LR-99 + 2 LR-11 NH_3 FUELED FOR BOOST AND CRUISE	35.9 (79,100)	279
LR-105 + 12 LR-101's FOR CRUISE ONLY	37.5 (82,620)	306
LR-105 + 12 LR-101's FOR BOOST AND CRUISE	45.2 (99,500)	288
LR-105 ALCOHOL FUELD + 2 LR-11's FOR CRUISE ONLY	30.5 (67,200)	289
LR-105 ALCOHOL FUELED + 2 LR-11's FOR BOOST AND CRUISE	38.1 (84,000)	277

Table 2 - Rocket Engine Performance

Based on these data, airframe weights were derived for each of the nine candidate vehicles in order to develop fabrication cost estimates for two vehicles. These costs, shown in Table 3, include engineering development and development testing, tooling, manufacturing labor, manufacturing material and equipment, GFAE and the propulsion/TPS alternatives.

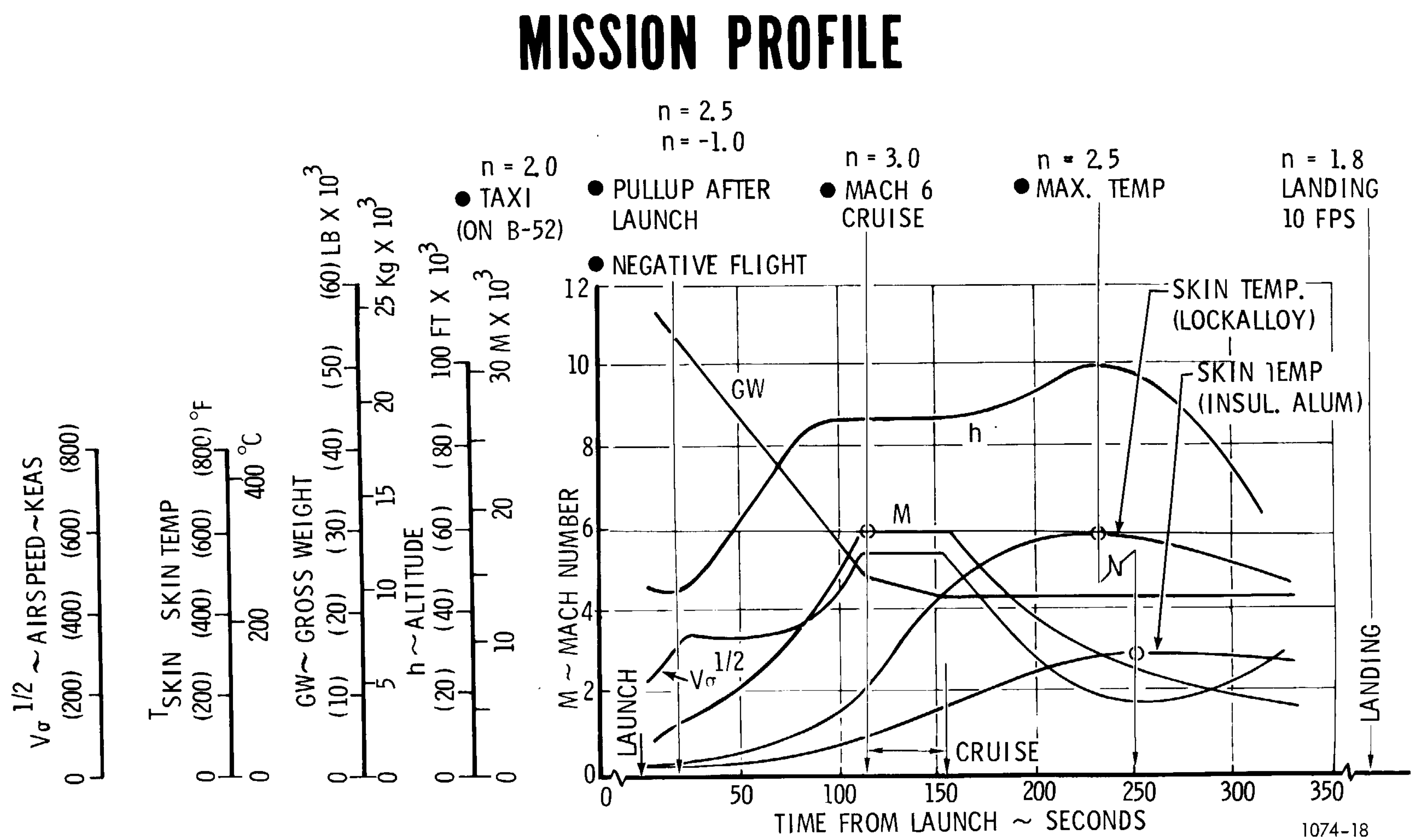


FIGURE 4 - MISSION PROFILE

An assessment was also made of the maintenance required to support two X-24C vehicles each making 12 flights per year for a total of 100 flights each. The results, in terms of manpower (NASA/USAF and Contractor) are shown in Table 4.

A summary of the results of Phase I indicated the following:

- o The LR-105/LR-101 combination using RP-1/LOX propellants has a significant performance advantage over the LR-99/LR-11 concept
- o The Lockalloy airframe and the ablator-covered aluminum airframe are approximately equal in terms of weight and acquisition cost
- o The LI-900 RSI-covered aluminum airplane is more expensive to produce and only a few hundred pounds lighter in weight than the other two TPS approaches.
- o The risks associated with using Lockalloy are procument oriented and are well out of the way before flight while the risks in using the elastomeric ablator continue throughout the X-24C life cycle.

It was recommended that the LR-105/LR-101 be considered the prime propulsion candidate for the Phase II study with the LR-99/LR-11 engines serving as back-up. It was further recommended that the LI-900 RSI covered aluminum airplane and the throttleable LR-105 engine be dropped from further consideration.

(JAN. 1976 DOLLARS IN THOUSANDS)

ROCKET PROPULSION OPTIONS \ STRUCTURE/TPS OPTIONS	LOCKALLOY HEAT-SINK STRUCTURE	ALUMINUM STRUCT. LI - 900 RSI TPS	ALUMINUM STRUCT. ABLATOR TPS
LR-105/ATLAS VERNIER	$53,061	$62,176	$54,076
LR-105/LR-11	$54,391	$63,503	$55,404
LR-99	$53,074	$61,778	$53,678

EXCLUDES:

- AERO CONFIGURATION DEVELOPMENT
- FLIGHT TEST INSTRUMENTATION & PAYLOAD/EXPERIMENT DEVELOPMENT
- B-52 MODIFICATION
- FLIGHT TEST & SUPPORT AFTER DELIVERY
- ROCKET PROPULSION SYSTEMS (COSTS TO BE PROVIDED BY NASA)

Table 3 - Vehicle Price Summary

	ABLATIVE			LI-900			LOCKALLOY		
	LR-99	LR-105 + 2 LR-11	LR-105 + 12 VERN	LR-99	LR-105 + 2 LR-11	LR-105 + 12 VERN	LR-99	LR-105 + 2 LR-11	LR-105 + 12 VERN
FLIGHT LINE	29	29	28	29	29	28	27	27	26
BASE SUPPORT	15	15	14.5	15	15	14.5	14.5	14.5	14
SUB-TOTAL	44	44	42.5	44	44	42.5	41.5	41.5	40
MANAGEMENT SYS. ENG'R	11	11	11	11	11	11	11	11	11
LOCKHEED SUPPORT	12	12	12	12	12	12	12	12	12
CONTRACTOR TPS	7.5	7.5	7.5	18	18	18	.5 FROM BASE SUPPORT	.5	.5
B-52 SUPPORT	7	7	7	7	7	7	7	7	7
* TOTAL	81.5	81.5	80.0	92	92	90.5	72	72	70.5

* DOES NOT INCLUDE CONTRACTOR PROPULSION SYSTEM SUPPORT

Table 4 - Manpower Summary - Two Vehicles

Phase II - Growth Potential

The objective of the Phase II - Growth Potential Study was to evaluate the effect of increased launch weight on performance and cost. This growth potential was to be assessed in terms of Mach number, cruise time, etc., as shown in Table 5. The X-24C-12I configuration (Figure 1) which was launched at 25.85 Mg (57,000 lbs) mass in Phase I was to be launched at 31.75 Mg (70,000 lbs) mass in Phase II. Retained from the Phase I study were two propulsion system arrangements - the LR-105/LR-101 and the LR-99/LR-11 - and two structure/TPS approaches - the Lockalloy heat sink approach and the elastomeric ablator covered aluminum approach.

<table>
<tr><th colspan="3">EVALUATE GROWTH POTENTIAL</th></tr>
<tr><td>VEHICLE</td><td>LAUNCH WT.
-Mg (LB)</td><td rowspan="3">• MAX. MACH NO.
• MAX. CRUISE TIME
• MAX. PAYLOAD
• MINIMUM COSTS
• MINIMUM RISKS
• ETC.</td></tr>
<tr><td>CONCEPT #1</td><td>25.9 (57,000)
31.8 (70,000)</td></tr>
<tr><td>CONCEPT #2</td><td>25.9 (57,000)
31.8 (70,000)</td></tr>
</table>

Table 5 - Phase II Trade Study Matrix

Of primary importance were the constraints imposed on "Stretching" the X-24C concept which would allow it to adequately mate with the B-52 launch aircraft. These constraints on the X-24C are shown in Figure 5.

As indicated in Figure 5, such factors as the B-52 engine jet wake, X-24C center-of-gravity location and ground clearance when mated were important factors in the determination of just how the X-24C could be "Stretched" to a 31.75 Mg (70,000 lbs) vehicle. Additionally, the Phase II design was required to cruise on scramjet power and this necessitated investigating two scramjet module configurations capable of providing cruise without rocket power. The impact of these two potential scramjet installations is shown in Figure 6.

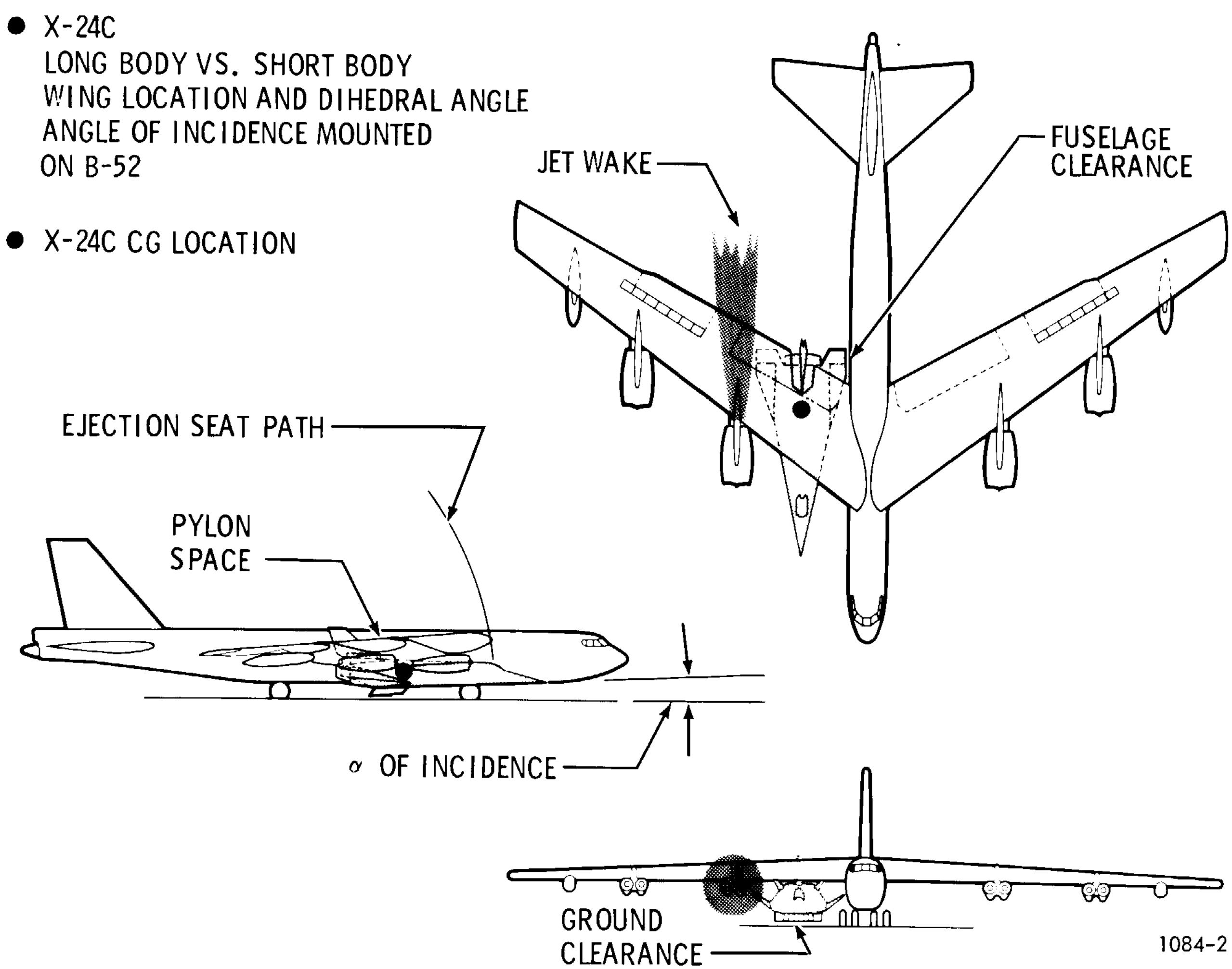


FIGURE 5 - B52 CONSTRAINTS

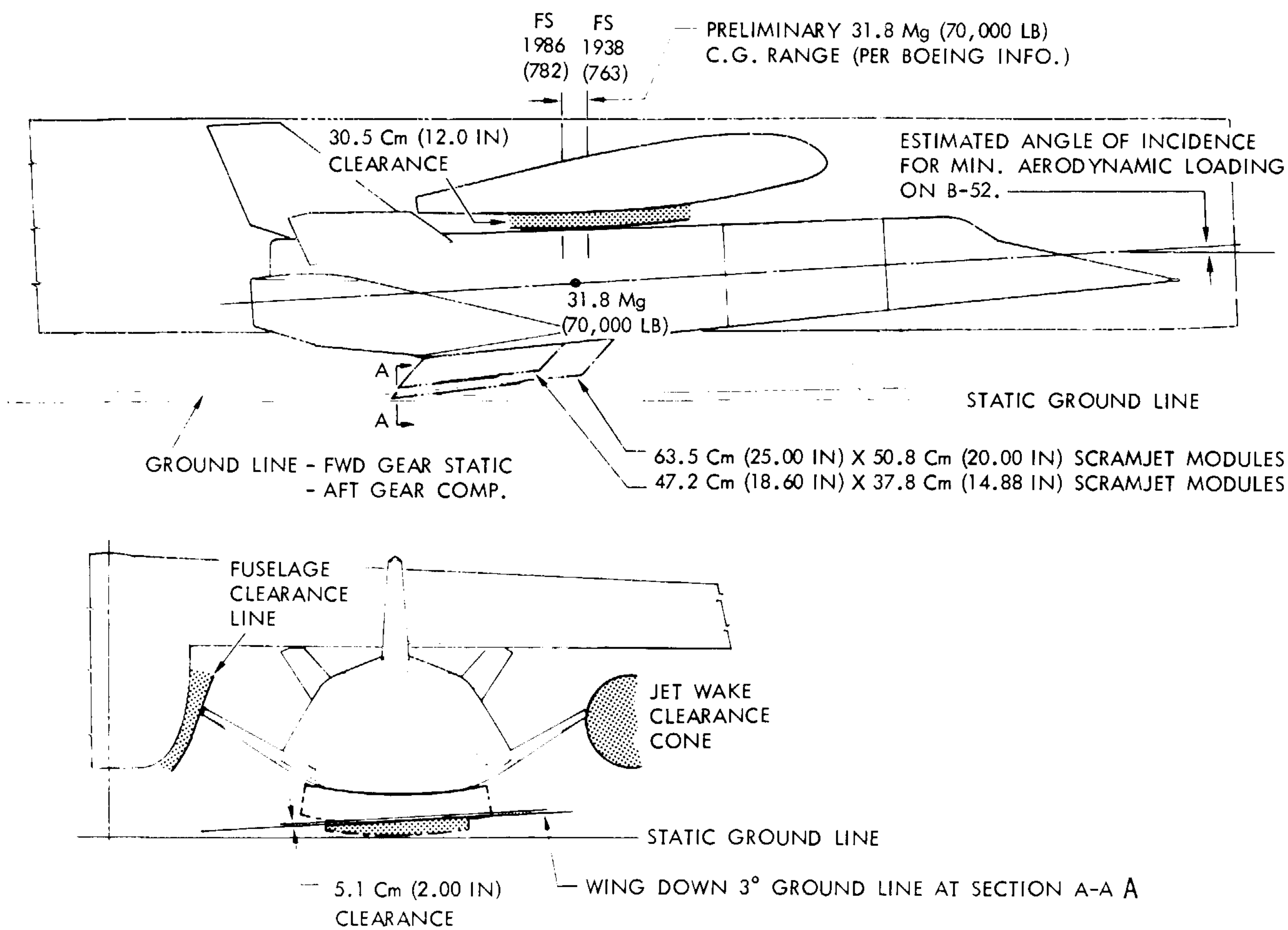


FIGURE 6 - SCRAMJET CLEARANCES

The configuration that resulted from the B-52 constraints is shown in Figure 7.

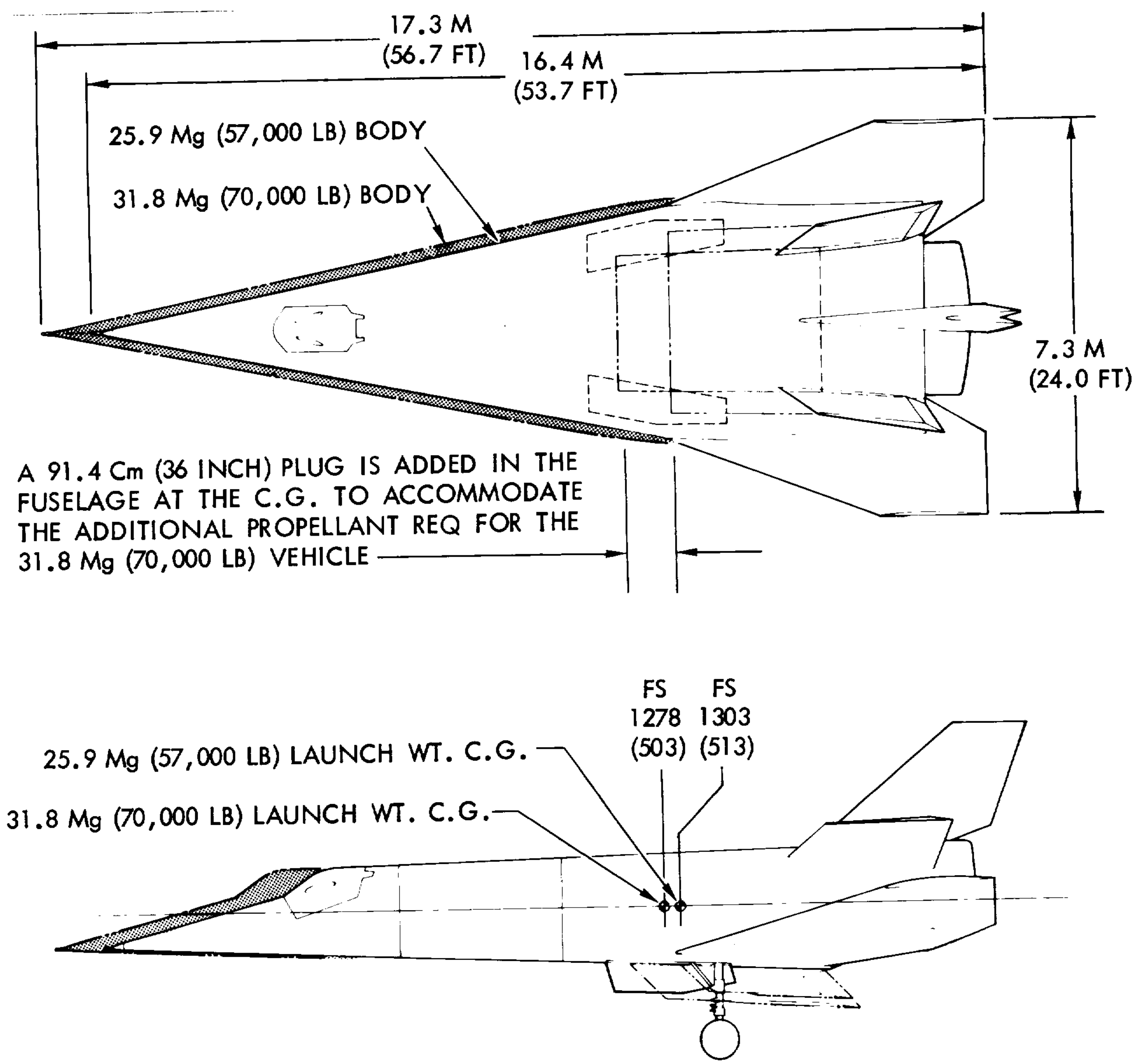


Figure 7. X-24C-12I/25.85 Mg vs 31.75 Mg (57,000 lbs vs 70,000 lbs)

It was this 31.75 Mg (70,000 lbs) configuration that was used throughout the Phase II studies.

The approach used to assess the maximum Mach number attainable for the heavy weight X-24C is shown in Figure 8.

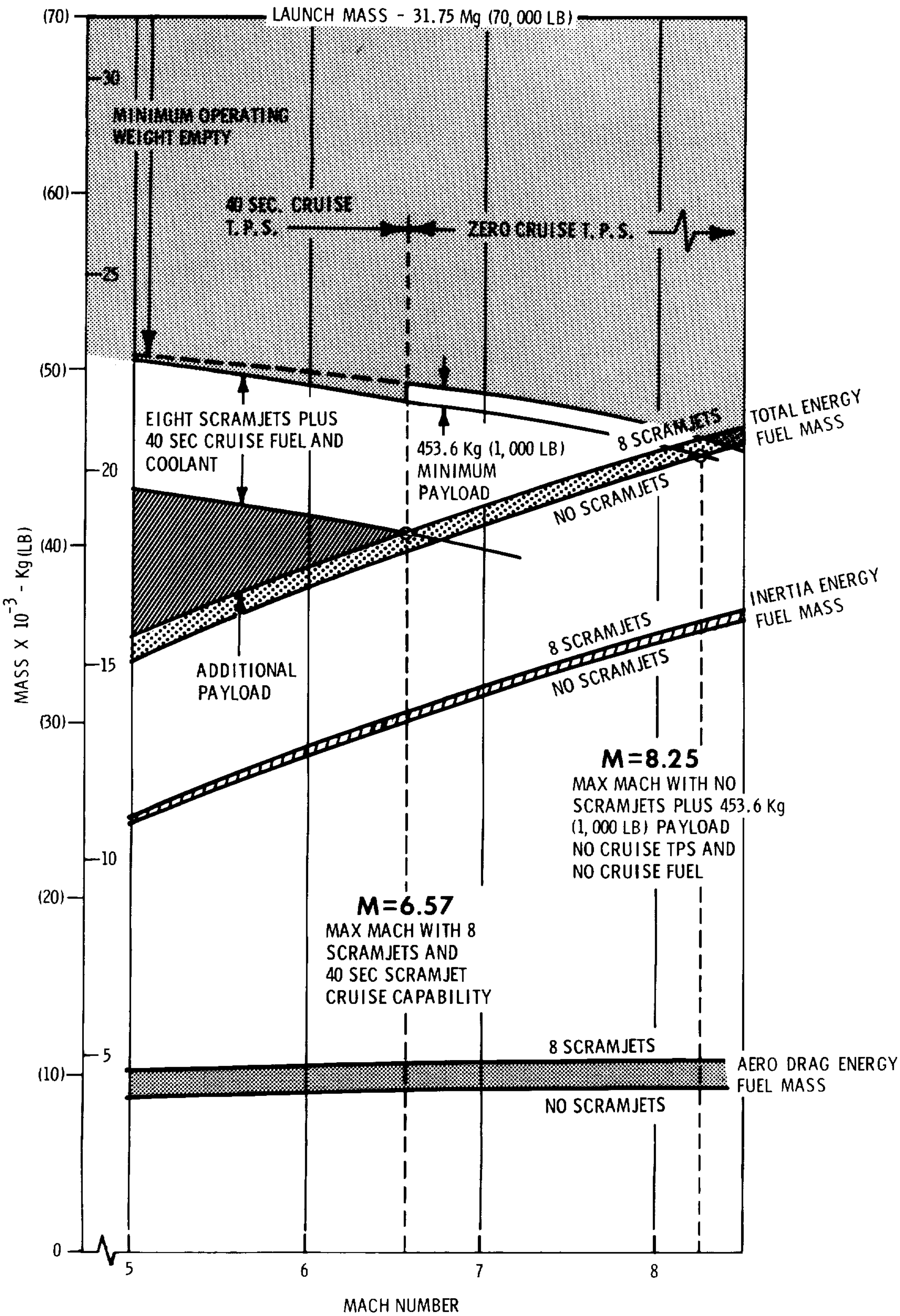


Figure 8. Max. Mach Number Attainable - X-24C

The vehicle concept utilized in this figure is the LR-105/LR-101 propulsion concept and the Lockalloy heat sink approach. Similar data was generated for the other vehicle concepts and is summarized in Table 6.

The "off design capabilities" of two vehicle arrangements were investigated to determine the parameters limiting cruise potential. Each configuration investigated utilized the LR-105 plus 12 LR-101 engine combination, and the Lockalloy heat-sink structure. To illustrate cruise potential, cruise time was selected as the dependent variable with Mach number, rocket fuel, TPS and launch mass as the independent variables. The off design launch mass of the "design point vehicles" were also investigated.

A design point vehicle of 31.75 Mg (70,000 lbs) launch mass, designed to cruise for 40 seconds on scramjets was selected. The second vehicle had a launch mass of 29 Mg (64,000 lbs), but with a structural capability of 31.75 Mg (70,000 lbs) and was to achieve the maximum Mach number possible without cruise.

Figure 9 reflects the results of the investigation of the 31.75 Mg (70,000 lbs) vehicle and can be interpreted as follows; the design point is highlighted by a bold dot at the intersection of heat-sink limit, fuel cruise time, and maximum Mach number attainable. Off design capabilities are indicated by the zone titled "capability with scramjets." Cruise time capability was found to be bounded by rocket fuel capacity below Mach 5.76. From Mach 5.76 to 6.56 the heat sink capability of the vehicle structure limits the amount of cruise time available. As an example consider the mission to cruise at Mach 6. This vehicle has the capability as an 'off design' mission to boost to Mach 6, level off and cruise for 25 seconds on sustainer engines and then continue the cruise on scramjets for a total of 63 seconds.

Interpretation of Figure 10 [29 Mg (64,000 lbs) vehicle] is similar to that for Figure 9.

	DESIGN CONDITION										OFF DESIGN CAPABILITY										
														TPS LIMITED (8)		ROCKET LIMITED (8)			COST - M$ JANUARY 1976 DOLLARS		
VEHICLE CONFIGURATION	LAUNCH MASS kg X 10^{-3} (LB X 10^{-3})	ENGINE	TPS	SCRAMJETS	CRUISE MACH	CRUISE ON ROCKETS	TIME ON SCRAMJETS	ADDI-TIONAL PAYLOAD kg (LB)	OPERATING MASS EMPTY kg X 10^{-3} (LB X 10^{-3})	FUEL CAPACITY kg x 10^{-3} (LB X 10^{-3})	LAUNCH MASS kg X 10^{-3} (LB X 10^{-3})	SCRAMJETS	ADDI-TIONAL PAYLOAD kg (LB)	40 SEC CRUISE TPS M	0 SEC CRUISE TPS = M	WITH SCRAMJETS (5)	WITHOUT SCRAMJETS (6)	WITHOUT SCRAMJETS (7)	ONE VEHICLE	TWO VEHICLES	TWO VEHICLES + INITIAL SPARES, AGE, DATA
1	31.75 (70)	(1)	(3)	8 (CRUISE)	6.57	0 SEC	40 SEC	0	13.24 (29.2)	18.5 (40.8)	29 (64)	0	454 (1000)	6.67	7.85	-	8.12	7.20	44.7	59.0	63.4
2	(9) 29 (64)	(1)		NONE	8.00		0 SEC	454 (1000)	10.2 (22.55)	18.35 (40.45)	31.75 (70)	8 (CRUISE)	0	6.72	7.90	6.46	-	-	43.9	57.9	62.3
3	31.75 (70)	(2)		8 (CRUISE)	5.98		40 SEC	0	13.06 (28.8)	18.69 (41.2)	29 (64)	0	454 (1000)	6.10	7.24	-	7.47	6.72	43.9	57.9	62.3
4	(9) 29 (64)	(2)	(3)	NONE	7.38		0 SEC	454 (1000)	10.0 (22.3)	18.46 (40.7)	31.75 (70)	8 (CRUISE)	0	6.12	7.26	5.83	-	-	43.6	57.6	61.9
5	31.75 (70)	(1)	(4)	8 (CRUISE)	6.80		40 SEC	0	12.88 (28.4)	18.87 (41.6)	29 (64)	0	454 (1000)	6.95	7.12	-	8.42	7.47	48.0	63.8	69.5
6	(9) 29 (64)	(1)		NONE	8.38		0 SEC	454 (1000)	9.9 (21.9)	18.64 (41.1)	31.75 (70)	8 (CRUISE)	0	7.90	8.13	6.65	-	-	48.2	64.3	70.1
7	31.75 (70)	(2)		8 (CRUISE)	6.07		40 SEC	0	12.93 (28.5)	18.82 (41.5)	29 (64)	0	454 (1000)	6.16	6.52	-	7.58	6.32	47.1	62.5	68.1
8	(9) 29 (64)	(2)	(4)	NONE	7.45		0 SEC	454 (1000)	9.9 (21.9)	18.64 (41.1)	31.75 (70)	8 (CRUISE)	0	7.11	7.28	5.95	0	0	47.4	63.1	68.3
9	26.76 (59)	(1)	(3)	3 (CRUISE)	6.00		40 SEC	0	12.1 (26.7)	14.65 (32.3)	24 (53)	0	454 (1000)	6.12	7.29	-	7.70	6.64	39.6	52.3	56.2
10	(10) 24 (53)	(1)		NONE	7.54		0 SEC	454 (1000)	9.3 (20.25)	14.4 (31.75)	26.75 (59)	8 (CRUISE)	0	6.25	7.42	5.86	-	-	39.3	51.9	55.8
11	31.75 (70)	(2)		8 (CRUISE)	5.98		40 SEC	0	13.06 (28.8)	18.69 (41.2)	29 (64)	0	454 (1000)	6.10	7.24	-	7.47	6.72	43.9	57.9	62.3
12	(10) 29 (64)	(2)	(3)	NONE	7.38		0 SEC	454 (1000)	10.1 (22.3)	18.46 (46.7)	31.75 (70)	8 (CRUISE)	0	6.12	7.26	5.83	-	-	43.6	57.6	61.9
13	26.3 (58)	(1)	(4)	8 (CRUISE)	6.00		40 SEC	0	11.95 (26.35)	14.36 (31.65)	23.6 (52)	0	454 (1000)	6.10	6.48	-	7.69	6.62	42.2	56.0	61.0
14	(10) 23.6 (52)	(1)		NONE	7.50		0 SEC	454 (1000)	8.93 (16.68)	14.42 (31.82)	26.3 (58)	8 (CRUISE)	0	7.17	7.34	5.91	-	-	42.5	56.6	61.7
15	31 (68.3)	(2)		8 (CRUISE)	6.00		40 SEC	0	12.72 (28.05)	18.35 (40.45)	28.3 (62.5)	0	454 (1000)	6.11	6.49	-	7.59	6.80	46.6	61.9	67.5
16	(10) 28.3 (62.3)	(2)	(4)	NONE	7.33	0 SEC	0 SEC	454 (1000)	9.77 (21.55)	18.12 (39.95)	31 (68.5)	8 (CRUISE)	0	6.99	7.17	5.90	-	-	46.8	62.2	67.8

(1) LR-105 + 12 LR-101'S
(2) LR-99 + 2 LR-11'S
(3) LOCKALLOY
(4) ABLATOR
(5) ZERO SEC CRUISE ROCKETS
(6) ZERO SEC ROCKET CRUISE FUEL
(7) 40 SEC ROCKET CRUISE FUEL
(8) MAX MACH ATTAINABLE AT q = 47.88 kPa (1000 PSF)
(9) VEHICLE HAS 31.75 Mg (70,000 LB) LAUNCH MASS STRUCTURAL CAPABILITY
(10) VEHICLE HAS STRUCTURAL PROVISIONS TO LAUNCH WITH AN ADDITIONAL CRUISE (8) SCRAMJETS.

Table 6 - Phase II Performance/Cost Summary

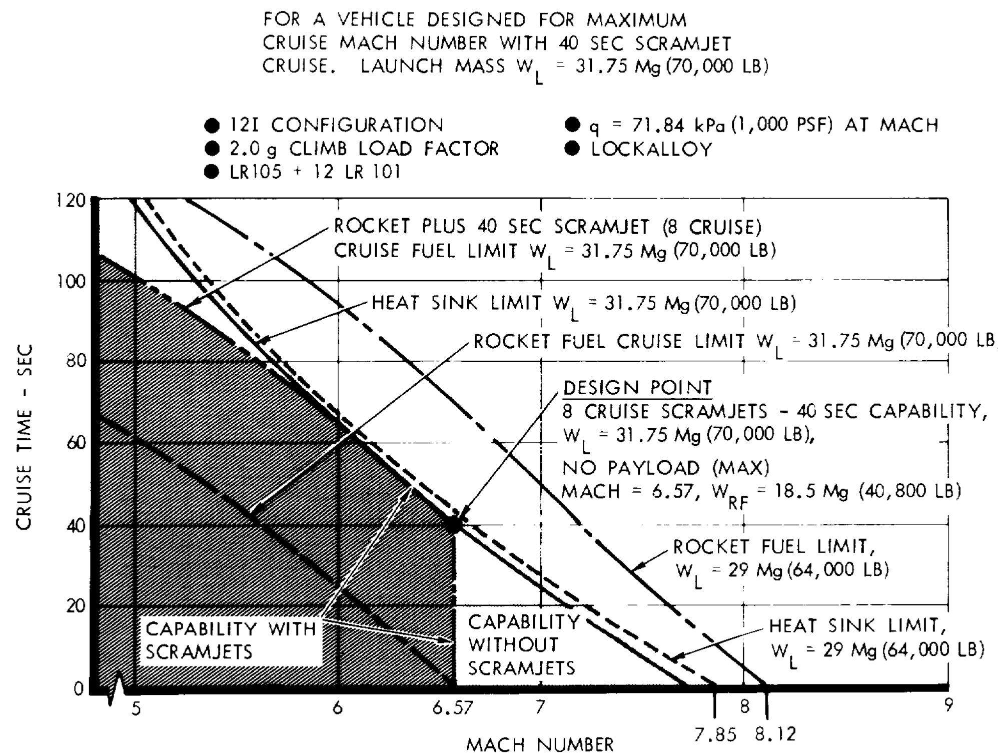


Figure 9. Off Design Capabilities - Design for Scramjet Cruise

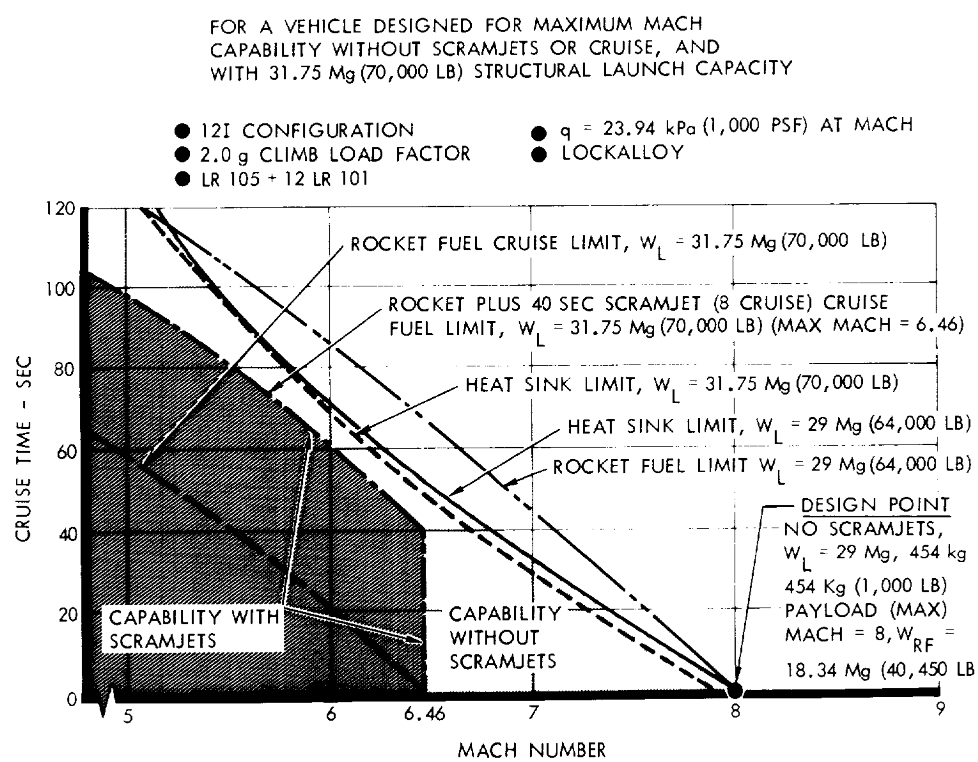


Figure 10. Off Design Capabilities - Design with No Scramjet or Cruise

Recommendations reached by the study include the following:

(1) SLA 220 and LI-900 or other available RSI should be abandoned and a Lockalloy heat sink configuration selected because it insures the following advantages:

- Greatest flight safety
- Least fire hazard - inflight or ground
- Fastest mission turnaround
- Least refurbishment cost per flight
- Simplest, most reliable solution to the airframe thermal protection problem
- Simplest solution to the problem of thermal seals at all service joints
- Does not release particles that deposit on canopy glass, service connections, sensors or which can ingest in scramjet engines
- Cleanest aerodynamic surface
- Greatest growth potential for increased flight Mach numbers.

(2) Select the final concept for the Phase III configuration development that will provide the best attainable X-24C performance at the lowest cost. This concept provides:

- 31.75 Mg (70,000 lbs) launch mass (B-52 limit)
- LR-105 plus 12 LR-101's for the primary propulsion system
- Lockalloy for the combined structure and thermal protection system (TPS)

(3) Other candidate vehicle concepts, including TPS and propulsion, are not ruled out for X-24C procurement. They are within the feasibility envelope as established by the Phase III selection concept.

Phase III - Conceptual Design

The concept selected for refinement in Phase III was required to incorporate the following features:

- Launch mass of 31.75 Mg (70,000 lbs) from a B-52
- Propulsion system consisting of one LR-105 and twelve LR-101's
- Lockalloy heat sink structure
- Cruise capability of 40 seconds at a q = 47.9 kPa (1000 psf) on scramjets
- Interchangeable research payload bay
- Acceptable subsonic and hypersonic stability
- Design must be versatile for meeting research objectives.

The configuration which evolved from Phase III, the X-24C-L301, is shown in Figure 11.

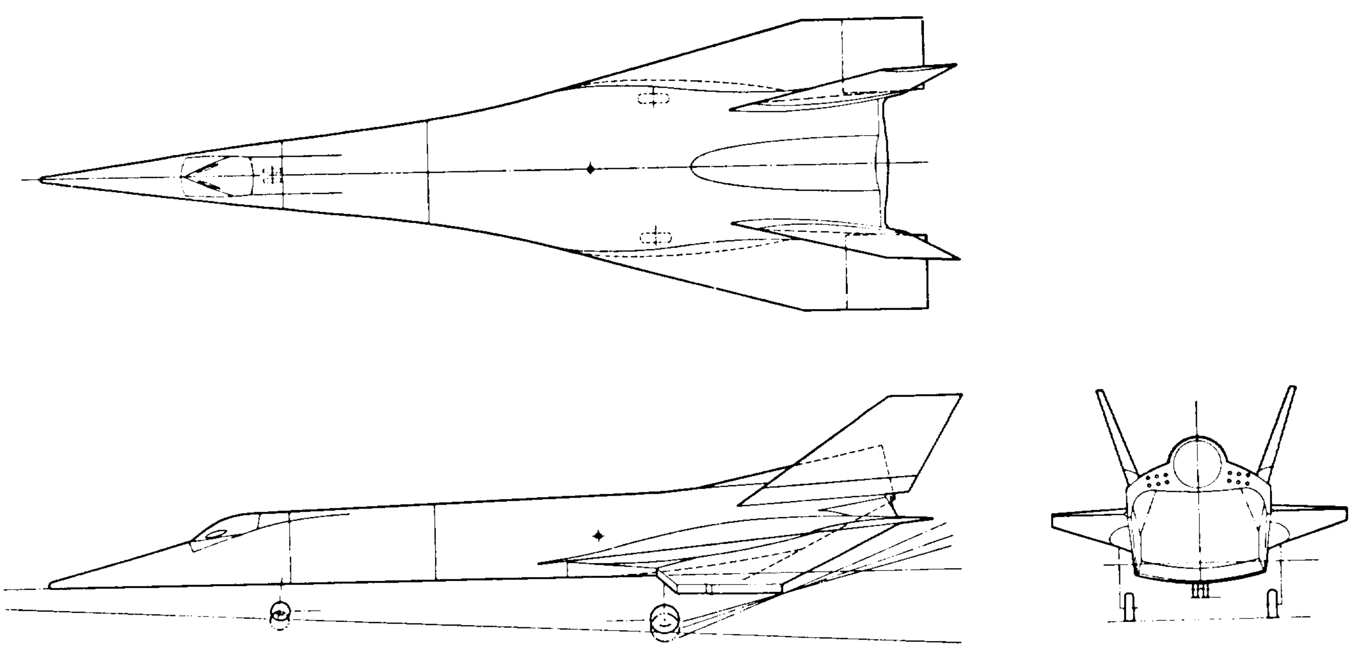


Figure 11. X-24C-L301 Configuration

Figure 12 is a comparison of the L301 to the X-24C-12I used in the prior phases of this study. Note that the L301 is 5.5 meters (18ft-2in) longer and has a 3.7 meter (12 ft) research payload bay in lieu of the 12I's, 3 meter (10 ft) bay.

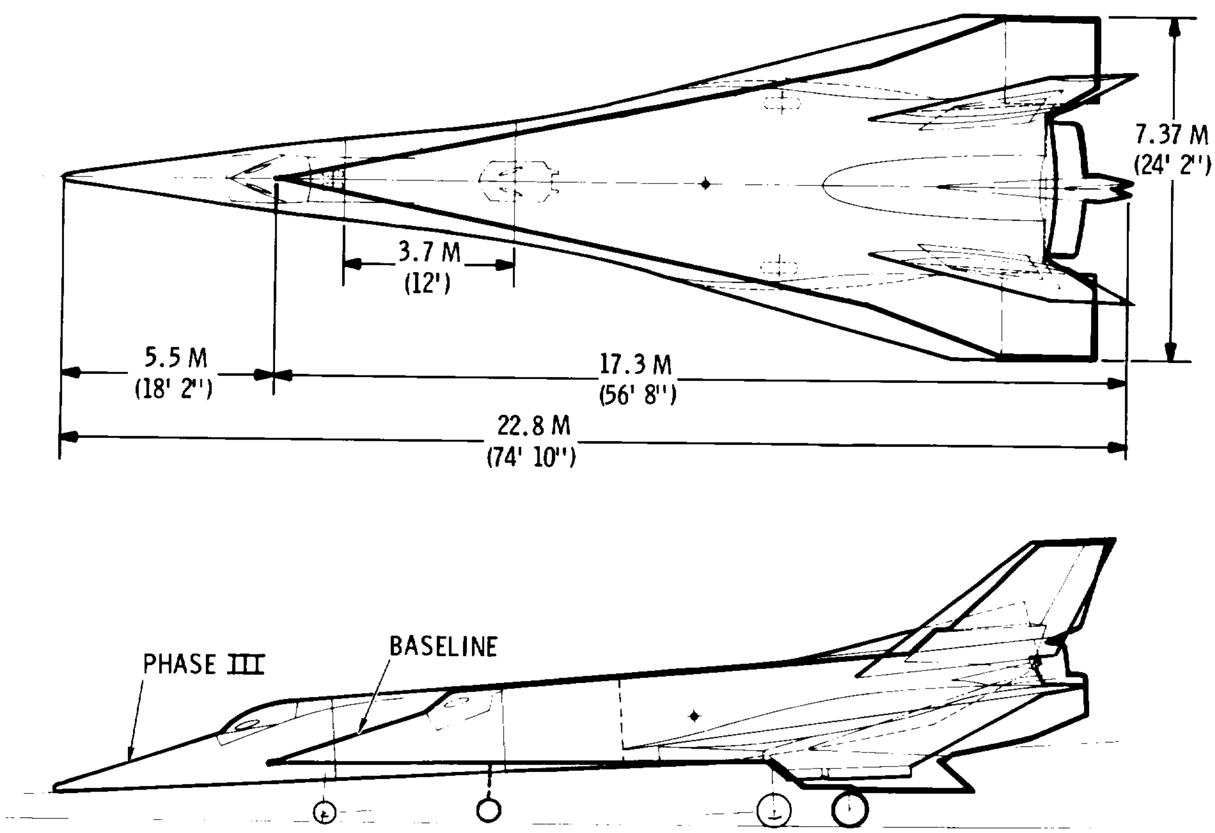


Figure 12. X-24C-12I vs X-24C-L301

The B-52 constraints were important factors in determining the L301 configuration. The size of the X-24C cross-section was limited to the space available under the wing of the B-52. The length of the X-24C was the primary variable used to satisfy fuel volume and "fineness ratio" requirements. Figure 13 shows the constraints imposed by the B-52 aircraft.

The X-24C-L301 payload bay increase compensates for its more slender forebody and provides the internal volume required for the scramjet hydrogen fuel. The main landing gear is located very close to the center-of-gravity so as to protect the nose gear from excessive "slam down" landing loads. The scramjet location is positioned to take advantage of efficient exit nozzle angle, while satisfying ground clearance requirements. The vertical tails are all moving surfaces and are used as speed brakes by moving them symmetrically inward at the leading edges.

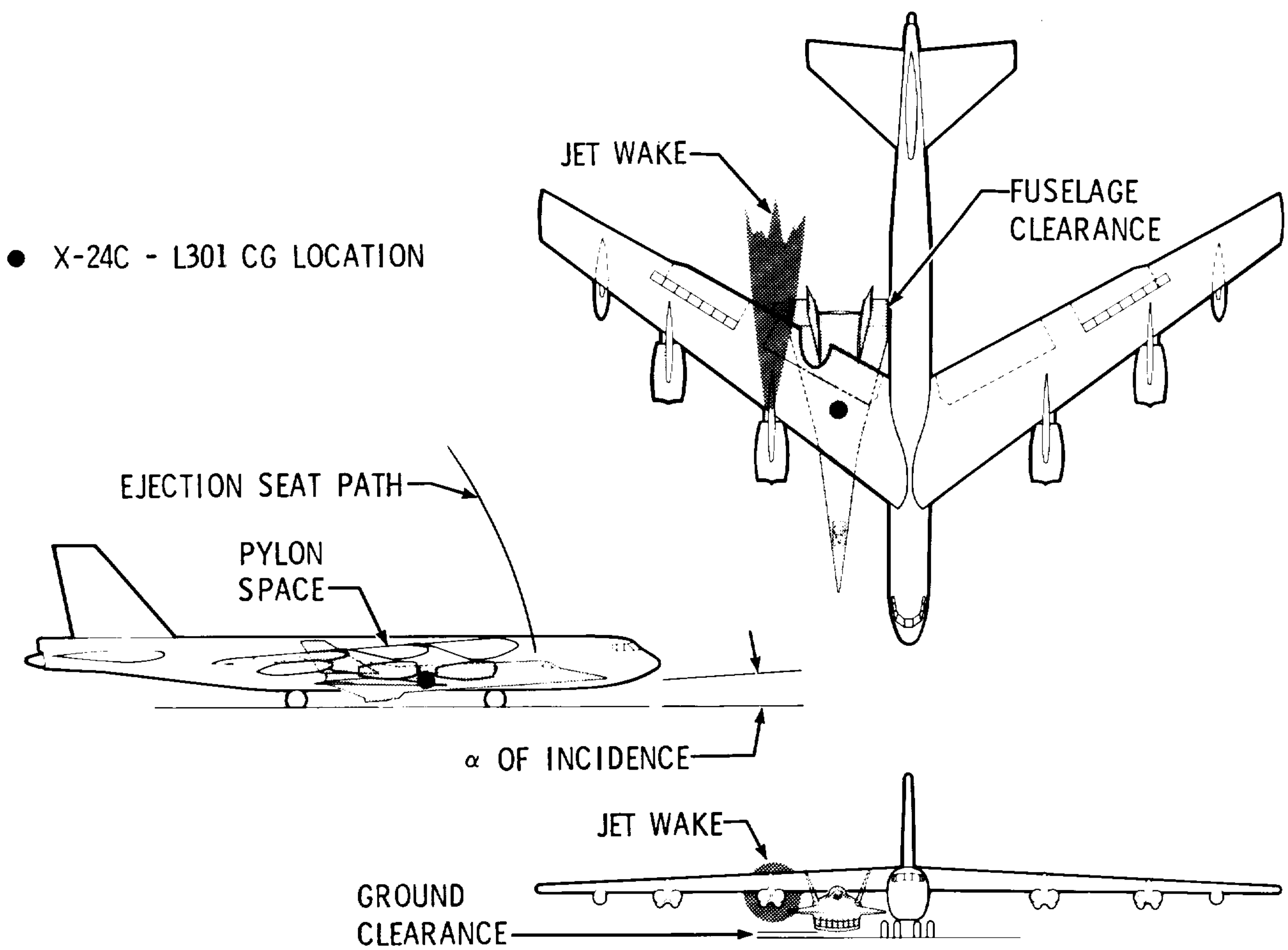


Figure 13. X-24C-L301/B-52 Constraints

The internal arrangement (Figure 14) of this airplane is designed for compatibility with its anticipated operation as a research airplane.

The replaceable payload bay is kept available for a great variety of hypersonic research experiments. The fuel tanks are kept separate from the fuselage structure in order to allow space for the anticipated equipment as well as the unanticipated equipment and test items that will be undoubtedly needed during the life of the vehicle. The wings, vertical tails, and elevons are replaceable so as to be candidates for becoming special test items. The use of Lockalloy panels for the skin structure allows complete access to equipments and systems for ease of maintenance.

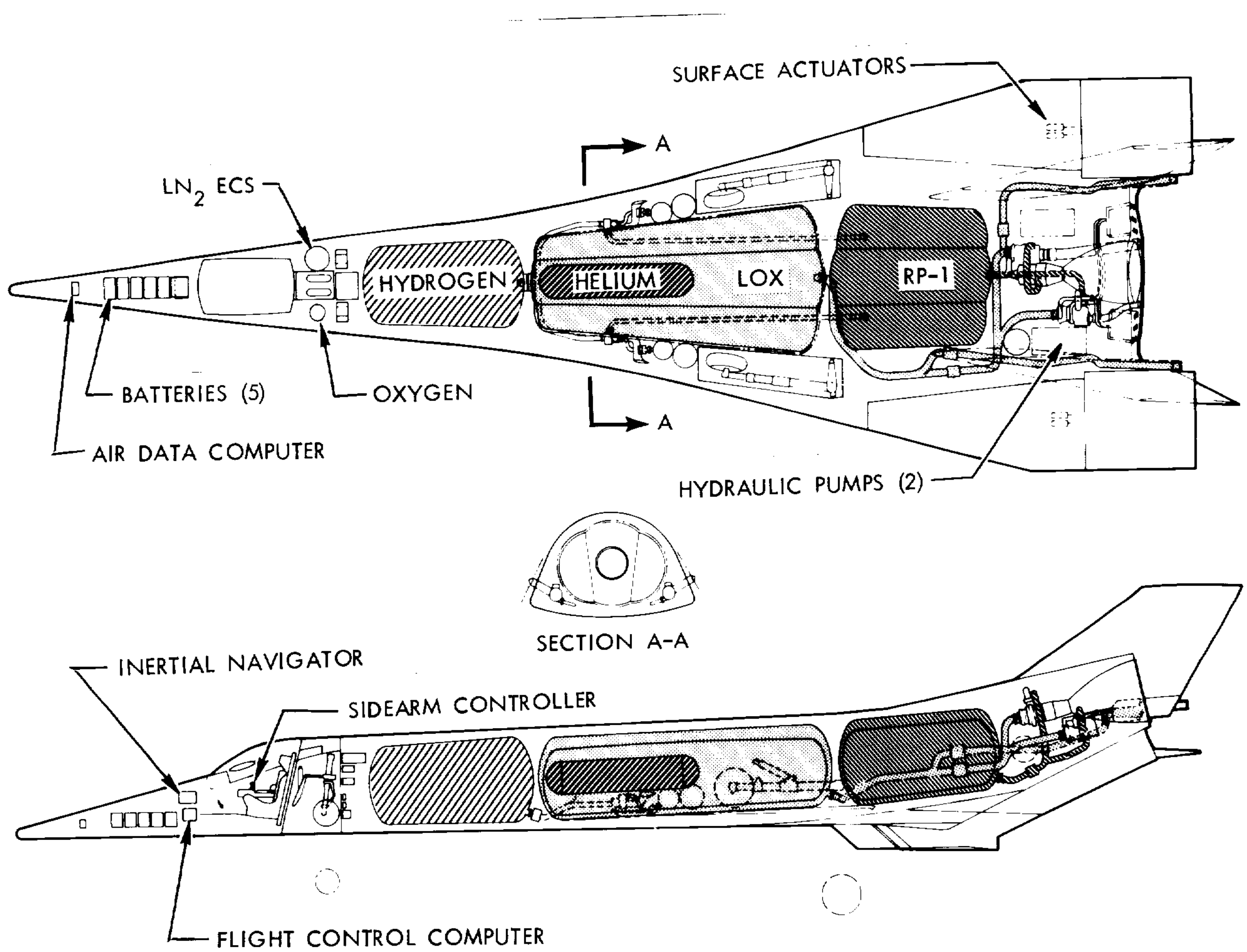


Figure 14. Internal Arrangement

Figures 15 and 16 show the X-24C-L301 configuration features with and without the scramjet package. Integration of a scramjet package of sufficient size to cruise the vehicle within the B-52 size constraints was the driving factor in the configuration evolution. The vehicle height limitation led to a scramjet package which is almost half the allowable vehicle span. A compression surface ahead of the scramjet required additional width. This compression surface had to be of sufficient length and shape to attain flow conditions at the scramjet inlet which are as uniform as practical. To attain the highest level of thrust and minimize the aft c.g. shift from the scramjet, a large integrated half nozzle was used that takes up most of the aft end of the vehicle. The rocket engine installation resulted in some base area with an associated base drag penalty.

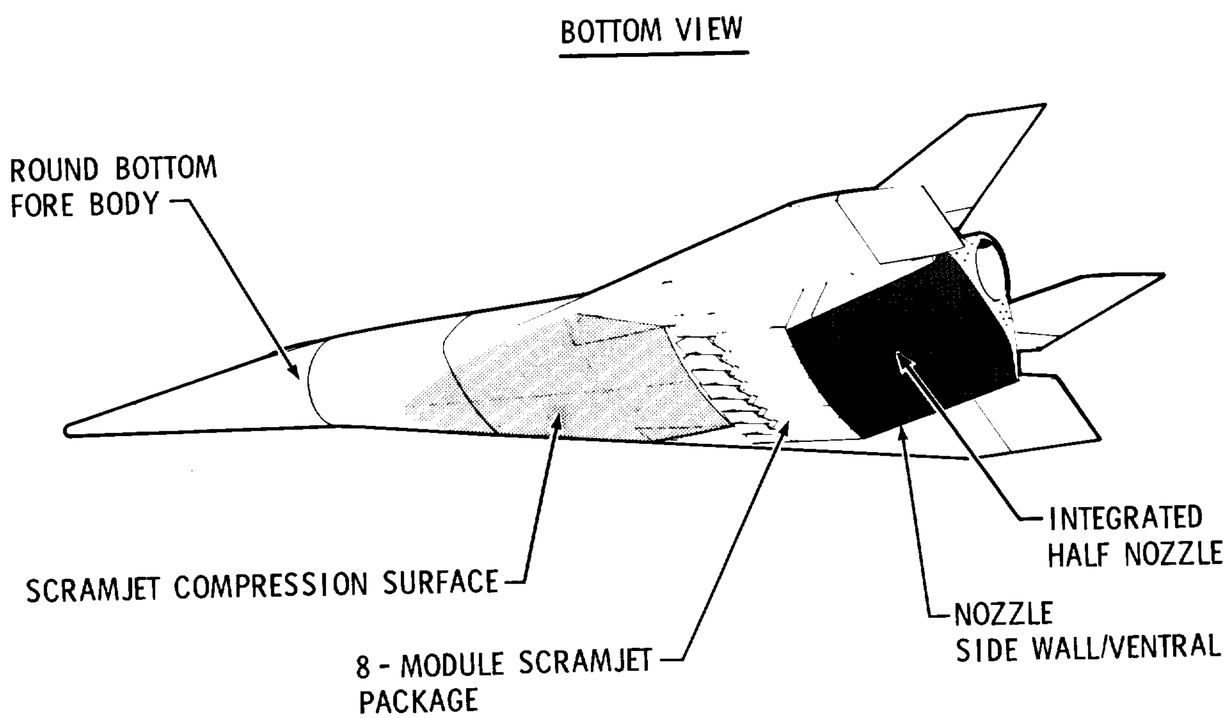


Figure 15. Scramjet System

Nozzle side walls, doubling as ventrals for directional stability, improve nozzle performance and protect the inboard end of the elevons.

The forebody bottom was rounded rather than extending the scramjet compression surface to the nose in order to reduce its longitudinal destabilizing effect at hypersonic speeds.

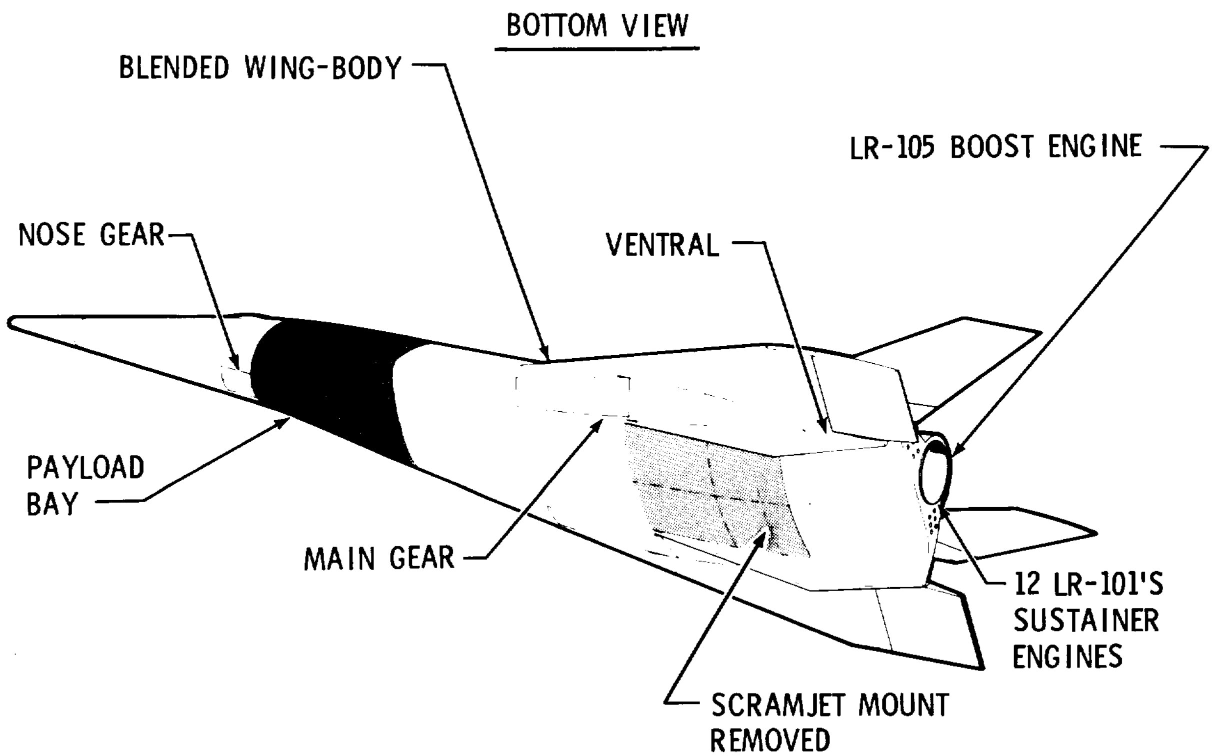


Figure 16. Clean

The basic fuselage, where the scramjet mounts, curves up to reduce the residual nozzle and aft body drag throughout the Mach range. This also leaves volume in the scramjet mount for scramjet valves, plumbing, attachment structure, etc. The most effective portion of the ventrals are retained in the clean configuration. Wing-fuselage blending is used to house the forward swinging main gear. The nose gear retracts vertically behind the pilot with no effect on frontal area.

The forward and aft positioning of the payload bay and scramjets should be noted in Figure 15. Although these positions are functionally very good it must be recognized that they lead to sizeable center-of-gravity travel as the payload varies.

A study requirement was the identification of equipment and systems that are available in GFAE stores, or an alternative, those available from existing programs which could be adapted, at reasonable cost, to the X-24C program. Table 7 lists these major equipment items, and their availability as GFAE or CFE.

A brief description of the X-24C-L301 functional systems follows:

- The electrical system consists entirely of silver-zinc batteries.
- Three hydraulic systems are required, two for surface controls and the third for monitoring.
- The air conditioning system utilizes liquid nitrogen.
- Main and nose landing gears are from the F-106 and C-140A aircraft, respectively.
- Cockpit instrumentation similar to X-15 and X-24B aircraft.
- The flight control system is three channel fly-by-wire employing a side-arm controller. No mechanical back-up is provided.
- Navigation computation and display is provided by a modified F-5E Inertial Navigation System.
- A fixed hemispherical probe using dual transducers provides the required air data information for display and flight control system.
- Helium is used to pressurize the RP-1 and LOX tanks and is also used for engine purge following shutdown.

SYSTEM	QTY	GFAE SOURCE	CFE QTY
AVIONICS			
UHF RADIO AN/ARC-159	2	DRYDEN	
AIR DATA PROBE			1
AIR DATA MODULES			2
INERTIAL NAV. SYSTEM			1
INTERCOMM. SET	1	X-15/X-24B	
RADAR BEACON	1	X-15/X-24B	
HYDRAULIC SYSTEM			
DC PUMP MOTORS	3	X-15/X-24B	
HYDRAULIC PUMPS	3	X-15/X-24B	
ACCUMULATORS			3
PRESSURE REGULATORS			3
FILTER ASSEMBLY			3
SHUT-OFF VALVES			3
RELIEF VALVES			3
ELECTRICAL SYSTEM			
BATTERY	5	X-15/X-24B	
LANDING GEAR			
NOSE GEAR	1	C-140	
MAIN GEAR (SET)	1	F-106	
NOSE GEAR AIR BOTTLE			2
MAIN GEAR AIR BOTTLE			4
REGULATOR VALVES			3
CROSS OVER VALVES			1

	SYSTEM	QTY	GFAE SOURCE	CFE QTY
	COCKPIT & FURNISHINGS			
	ATTITUDE DIRECTOR IND.	1	X-15/X-24B	
	ANGLE OF ATTACK IND.	1	X-15/X-24B	
	SIDE SLIP IND.	1	X-15/X-24B	
	BAROMETRIC ALTIMETER	1	X-15/X-24B	
	AIRSPEED/MACH IND.	1	X-15/X-24B	
	DYNAMIC PRESSURE IND.	1	X-15/X-24B	
	ELAPSED TIME IND.	1	X-15/X-24B	
	CLOCK	1	X-15/X-24B	
	"G" METER	1	X-15/X-24B	
	VERTICAL VELOCITY IND.	1	X-15/X-24B	
	LONGITUDINAL VELOCITY IND.	1	X-15/X-24B	
	INERTIAL HEIGHT IND.	1	X-15/X-24B	
	CABIN PRESSURE IND.	1	X-15/X-24B	
	WHISKEY COMPASS	1	X-15/X-24B	
	HYDRAULIC PRESSURE IND.	3	X-15/X-24B	
	STANDBY ATTITUDE IND.	1	X-15/X-24B	
	DUAL ELEVON POSITION IND.	1	X-15/X-24B	
	RUDDER POSITION IND.	1	X-15/X-24B	
	SPEED BRAKE POSITION	1	X-24B	
	D.C. VOLTMETER	4	X-15/X-24B	
	LOX TANK PRESSURE IND.	1	X-15/X-24B	
1	RP-1 TANK PRESSURE IND.	1	X-15/X-24B	
2	ALCOHOL TANK PRESSURE IND.	1	X-15/X-24B	
2	H_2O_2 GAS TURBINE PRESSURE IND.	1	X-15/X-24B	
3	AMONIA TANK PRESS. IND.	1	X-15/X-24B	
	EJECTION SEAT			1
	LOX CONVERTER			1

NOTE: 1 LR-105/LR-101 CONFIGURATION ONLY.
2 LR-105/LR-11 CONFIGURATION ONLY.
3 LR-99 CONFIGURATION ONLY.

Table 7 - Major Equipment Items

SYSTEM	QTY	GFAE SOURCE	CFE QTY
COCKPIT ENCLOSURE			
CANOPY JETTISON INIT.			1
CANOPY JETTISON THRSTR			1
CANOPY WINDSCREEN	2	X-15	
GAS GENERATOR			1
ACTUATING CYLINDER			1
ENVIRONMENTAL CONTROL			
DEWAR, 50 LITER LN_2			1
CONTROL PANEL	1	X-15/X-24B	
LN_2 GAGE	1	X-15/X-24B	
REGULATOR			1
TRANSDUCER			1
VALVE			1
SWITCH			1

SYSTEM	QTY	GFAE SOURCE	CFE QTY
FLIGHT CONTROL SYSTEM			
RUDDER PEDALS (SET)	1	X-15/X-24B	
YAW FEEL SPRING ASSY.	1	X-15/X-24B	
YAW TRIM ACTUATOR	1	X-15/X-24B	
MACH/ALPHA TRIM ACT.	1	X-15/X-24B	
RUDDER POWER ACT.	1	X-15/X-24B	
LEFT ELEVON POWER ACT.	1	X-15/X-24B	
RIGHT ELEVON POWER ACT	1	X-15/X-24B	
PITCH BIAS ACTUATOR	1	X-15/X-24B	
SPEED BRAKE ACTUATOR	1	X-15/X-24B	
LOWER FLAP POWER ACT.	1	X-24B	
TRIPLEX SERVO ACT'S.			4
SIDE-ARM CONTROLLER			1
FLIGHT CONTROL COMP.			1
CONTROL PANEL			1
RUDDER PEDAL POS. XDCR.			1
RATE/ACCELERATION ASSY.			3
STATUS PANEL			1

Table 7 - Major Equipment Items (continued)

Gaseous nitrogen is used to cold start and purge the two turbo-pumps associated with the LR-105 and LR-101 engines. Use of two turbo-pumps allows the flexibility to operate on the LR-101's, at reduced speeds, should the LR-105 fail to start.

The rocket boosted performance capability with cruise scramjets is shown in Figure 17 and without scramjets in Figure 18.

The capability of the Phase III vehicle is significantly improved over the Phase II configuration. The design point for the Phase III vehicle was for 40 seconds of scramjet cruise at M = 6.6 and a launch mass of 31.75 Mg (70,000 lbs). The Phase III vehicle is capable of the design performance with a partial propellant load of 17.48 Mg (38,540 lbs) and a launch mass of 30.8 Mg (67,900 lbs).

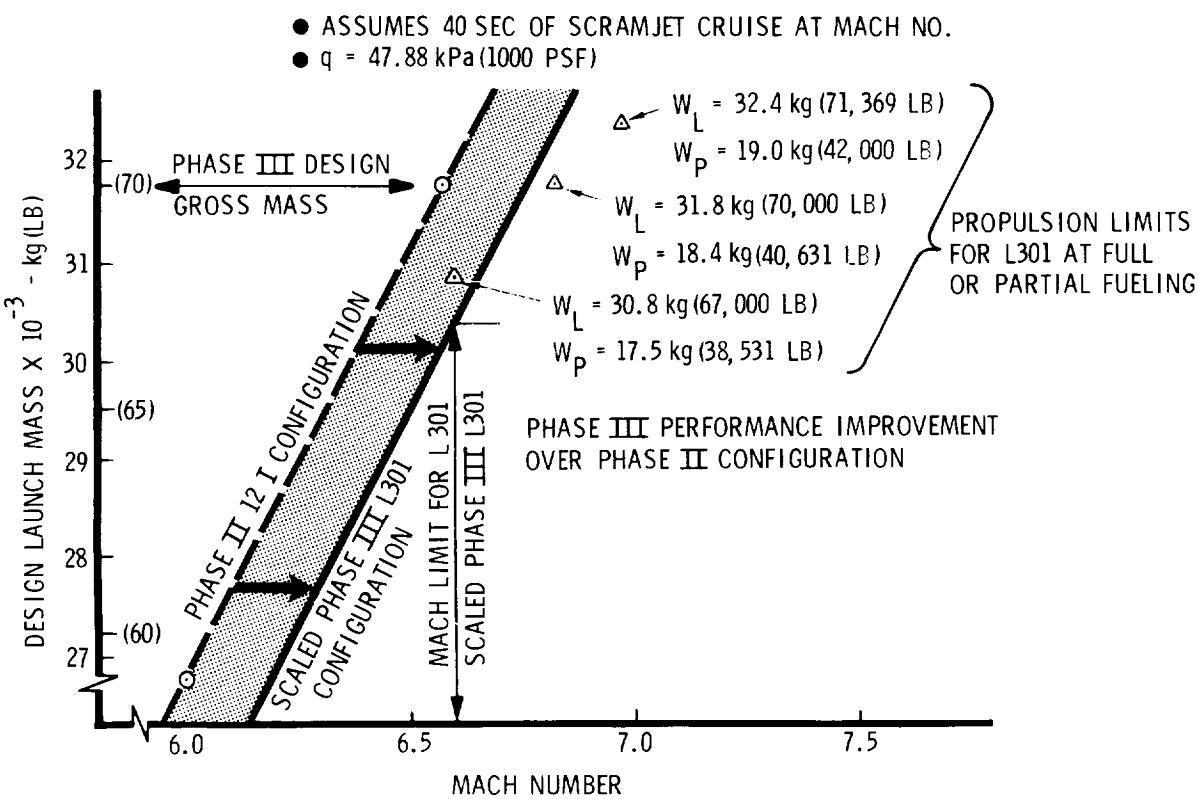


Figure 17. Performance with Scramjets

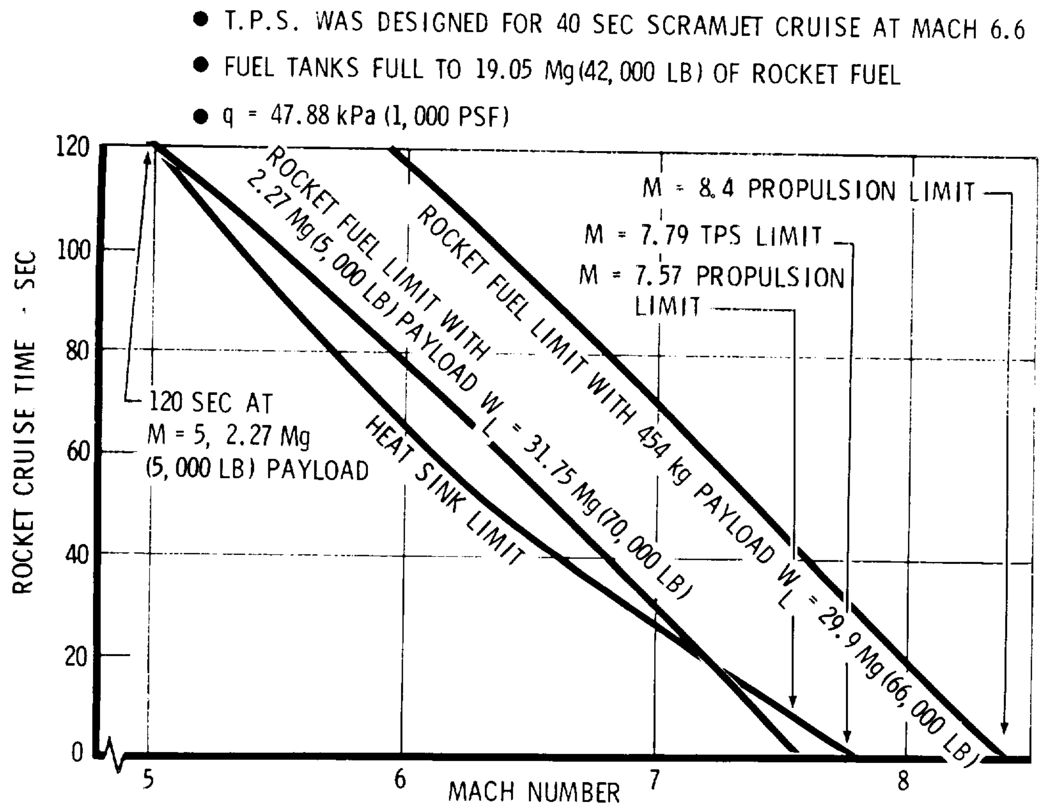


Figure 18. Performance Without Scramjets

At the design launch mass of 31.75 Mg (70,000 lbs) the Phase III vehicle with cruise scramjets can boost to M = 6.82. However, the TPS will not allow 40 seconds of cruise at q = 47.9 kPa (1000 psf). On this first design iteration the Phase III vehicle was sized for 19 Mg (41,900 lbs) of propellant, an intentional excess for contingency. Using the full 19 Mg (41,900 lbs) of propellant gives a launch mass of 32.4 Mg (71,400 lbs) and a boost to M = 6.97. Again, the TPS will not allow 40 seconds of cruise but approximately 25 seconds at q = 47.9 kPa (1000 psf).

The M = 6.6 cruise case carries excess propellant capacity, vehicle size, and structural capability. The M = 6.82 and 6.97 cases are short on TPS and structural capability. A totally consistent vehicle to meet the 40 second cruise criteria is in between. Based on Phase II results a consistent vehicle was estimated and scaled to yield scramjet cruise Mach number capability versus launch mass for the improved Phase III configuration. A consistent Phase III vehicle with 31.75 Mg (70,000 lbs) launch mass could cruise for 40 seconds at M = 6.76. A Mach 6.6 cruise vehicle would launch at 30.3 Mg (67,900 lbs). A Mach 6.0 cruise Phase III configuration could launch at approximately 22.9 Mg (50,490 lbs).

Without scramjets, the performance capability of the Phase III vehicle with 19 Mg (41,900 lbs) of propellant will provide excellent research potential. Figure 18 shows this in terms of rocket cruise time versus Mach numbers for q = 47.9 kPa (1000 psf). With the full 19 Mg (41,900 lbs) of propellant and 2.3 Mg (5000 lbs) of payload the vehicle without scramjets would launch at 31.75 Mg (70,000 lbs). This would give zero cruise time at M = 7.57 or 120 seconds at M = 5.0. A TPS limited, zero cruise time, q = 47.9 kPa (1000 psf) Mach number of 7.79 can be attained with approximately 1.81 Mg (4000 lbs) of payload.

A boost capability with 19 Mg (41,900 lbs) of propellant and 454 kg (1000 lbs) of payload would be M = 8.4. From Phase II (41,900 lbs) experience, it was estimated that M = 8.4 would be within the TPS capability at approximately q = 23.9 kPa (500 psf). Even at q = 47.9 kPa (1000 psf) the overheating may be found tolerable as flight experience is accumulated, particularly since a factor of safety of 1.25 was used for all heating load calculations.

All of the preceding work was concentrated on the development of a viable aircraft design to meet specific performance parameters specified by the NASA. At this point the question of "what can such a vehicle do?" Is addressed. The primary purpose for the X-24C has always been to assist in the development of the technology base for future hypersonic cruise vehicles. The major obstacles which must be overcome are in the areas of propulsion and structure/TPS research.

Without a propulsion system there cannot be a hypersonic airbreathing cruise vehicle. The hydrogen burning scramjet shows promise as the future cruise propulsion means. The X-24C-L301 can accommodate sufficient scramjet modules to cruise at Mach 6 for 40 seconds. The payload bay can contain sufficient hydrogen to actively cool the scramjet structure before, during and after cruise as well as the necessary cruise fuel. The X-24C can materially aid in the development of the propulsion system that is also required for acceleration to and deceleration from scramjet cruise mach. This is possible because of the installation of a combination of thrusting and cruise rocket engines for operation over a wide range of mach numbers. The data required cannot be obtained in toto from ground and tunnel testing.

Concurrently with the propulsion research, the necessary structure/TPS research can be accomplished. The payload bay can accept major fuselage structure and liquid hydrogen tank system tests. The interchangeable wings and fins can be fabricated of various materials and measurements made, under steady-state conditions, of theircapability to withstand the thermal environment. Of primary importance will be the development of structure and materials to handle the inlet duct pressures and temperatures attendant to multi-mode engine operation of these speeds.

Other areas requiring development are radomes, windows and antennas. From a military point of view the capability to successfully launch/eject stores at hypersonic speeds needs validation if such aircraft are ever to be built.

Figure 19 visually portrays the type of research and development of technology that the X-24C can materially aid in advancing. This vehicle, designed to be a "work horse" with its minimum maintenance and rapid turn-around capability, can serve as an excellent platform for hypersonic research.

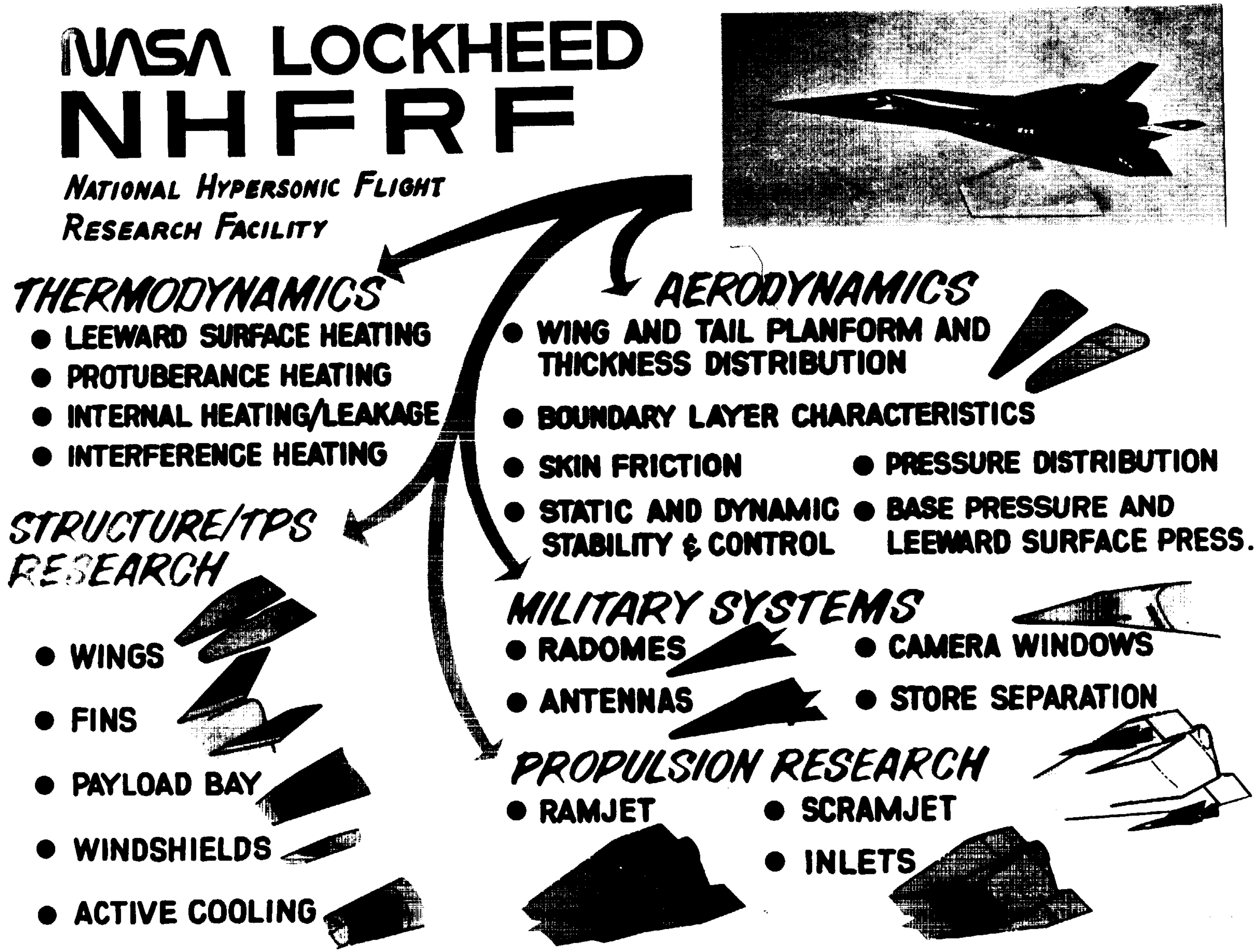


Figure 19. Research Capability of National Hypersonic Flight Research Facility

The study contract Statement of Work provides that at the start of Phase III "the contractor shall be supplied with a total initial cost figure. With this cost figure, the contractor shall apply the 'design to cost' approach to the Phase III conceptual design." This value, based on data derived in Phase II, was established at $63.4 million for two vehicles. It is based on the following premises and exclusions:

- Includes initial spares, AGE and tech data
- Stated in January 1976 dollars
- Excludes:
  - Aero configuration development wind tunnel program
  - Flight test instrumentation and payload/experiment development
  - B-52 modification
  - Flight test and vehicle support after delivery
  - Rocket propulsion systems

It should be noted that these exclusions are cost estimating premises only and all of these items must be provided for in the funding for an X-24C development program. In particular, the wind tunnel test program, excluded from prior cost studies by definition, must be conducted by the airframe contractor and will be added to Phase III costs.

Table 8 provides a side-by-side comparison of many of the factors which were analyzed in developing the cost of the Phase III vehicle vs. those used for the Phase II and Phase I study vehicles. The "plus" symbol indicates the item of greater complexity with a resultant effect of increasing vehicle or program cost. A "plus" to the right hand side indicates increased complexity and cost for the Phase III vehicle as compared to the Phase II vehicle. A "plus" to the

⊕ = ITEM OF GREATER COMPLEXITY/COST

ITEM	PHASE II	PHASE III
AERODYNAMIC CONFIGURATION	X-24C - 12 I	X-24C - L301
THERMAL PROTECTION SYSTEM	LOCKALLOY HEATSINK SKIN ⊕	SAME AS PHASE II
PROPULSION SYSTEM	MAIN BOOST - LR 105 CRUISE - 12 LR 101'S	SAME AS PHASE II ⊕ EXCEPT ADD: • IN FLIGHT PURGE * • COLD START
LAUNCH MASS (WITH 8 CRUISE SCRAMJETS)	31.75 Mg (70,000 LB) ⊕	SAME AS PHASE II
DCPR MASS	8.07 Mg (17,790 LB)	8.47 Mg (18,676 LB) ⊕ (BASIC A/C WITH SCRAMJET PROVISIONS ONLY - 18,295 LB)
SURFACE WETTED AREA	204.4 m^2 (2,200 FT^2)	233.0 m^2 (2,508 FT^2) ⊕
VERTICAL CONTROL SURFACES	⊕ THREE	TWO
SPEED BRAKES	SEPARATE SPLIT FLAP ⊕ AND ACTUATOR SYSTEM ON CENTER VERTICAL	INCLUDED IN ALL MOVEABLE VERTICAL TAIL SYSTEM
PAYLOAD BAY STRUCTURE	⊕ DUAL WALL CONSTRUCTION	SINGLE WALL - COMPARABLE TO MAIN FUSELAGE STRUCTURE
COMPOUND CONTOUR LOCKALLOY SKIN PANELS	NIL	⊕ APPROX. 50 (7% OF TOTAL)
TOOLING FOR LOCKALLOY	⊕ FORMED ON HEATED CERAMIC DIES	COLD FORMING SINGLE CURVATURE
FUNCTIONAL SYSTEMS (CONTROLS, AVIONICS, FUEL, ECS, ELECTRICAL, HYDRAULICS GEAR, COCKPIT FURNISHINGS, ESCAPE)	ESSENTIALLY THE SAME ⊕	
PARTS COUNT	⊕ ESSENTIALLY THE SAME	
SCRAMJET INSTALLATION	ESSENTIALLY THE SAME ⊕	
CONTRACTOR PERFORMS COMPLETE AERO DEVELOPMENT WIND TUNNEL TESTING (USING GOVT FACILITIES)	SUPPLEMENTAL TESTING ONLY	INCLUDED ⊕
CONTRACTOR SUPPLIES "BOILER PLATE" FUEL RIG FOR POWER PLANT TESTING AT RPL	EXCLUDED	INCLUDED ⊕
GOVERNMENT FURNISHED ITEMS AND SUPPORT	⊕ SAME, EXCEPT AS NOTED ABOVE	

* 2ND TURBO-PUMP

Table 8 - Phase II vs Phase III Complexity Factor Comparison

left represents reduced complexity. A "plus" on the centerline indicates no change. It should be noted that two items, the complete wind tunnel test program and a fuel system functional mockup for rocket engine testing at the Edwards AFB Rocket Propulsion Lab, are added to the program costs as requested by NASA. These are tasks that must be performed by the airframe contractor.

In addition to consideration of the foregoing complexity factors, all significant purchased equipment and Lockalloy pricing has been updated by revised supplier quotations as of August 1976.

Did the vehicle as initially configured meet the design-to-cost objective? The requirement to meet the Phase III constraints imposed by scramjet integration, B-52 compatibility, drag reduction and stability improvements which, in turn, created the increased complexity previously described, has caused the initial vehicle to exceed the design-to-cost objective by 7 percent. However, this vehicle also exceeds the Phase III performance target. The comparison is summarized as follows:

	Design-to-Cost Objective	Phase III Vehicle	Cost Increase From Complexity Factors
Two vehicles plus initial spares, AGE and data	\$63.4M	\$67.9M	\$4.5M (7%)
Added Elements:			
Wind Tunnel Test		\$ 1.5M	
Fuel Test rig for RPL		.5M	
Adjusted Total		\$69.9M	

Although the basic vehicle did not meet the design-to-cost objective, subsequent sections of this report will address a vehicle that will meet the objective.

Table 9 is a breakdown by major cost element for one or two scramjet vehicles. Engineering includes design, design support, wind tunnel testing, mockups, materials/structures and functional system development testing, flight test planning, the functional mockup for rocket testing and all required engineering test parts and materials. Tooling includes planning and quality assurance as well as fabrication and assembly labor. Lockalloy material cost is included under Manufacturing Material and Equipment. GFAE includes the landing gear, communications systems and an allowance to refurbish other GFAE from the X-15 and X-24B programs. Spares and AGE are provisioned on the same basis as for Phase I and Phase II of this study. All estimates except for GFAE include an allowance for contractor fee of 10 percent.

(JAN 1976 DOLLARS IN THOUSANDS)

	ONE VEHICLE	TWO VEHICLES
ENGINEERING	$18,036	$18,582
TOOLING	12,055	12,611
MFG LABOR	11,785	21,213
MFG MATL AND EQUIP	7,500	12,369
GFAE	344	688
SUB-TOTALS	$49,720	$65,463
INITIAL SPARES, AGE AND DATA	3,900	4,400
TOTAL - PHASE III	$53,620	$69,863

Table 9 - Phase III Vehicle Cost Estimates

Trade-off studies in Phase II have established a relationship between cost and launch mass for X-24C vehicles of the same configuration. This relationship remains valid even though the vehicle changes. Figure 20 displays the cost vs launch mass relationship. The design-to-cost objective for Phase III is \$63.4 million for two vehicles, a value established based on a 31.75 Mg (70,000 lbs) mass/8 scramjet/Mach 6.57 Phase II vehicle. (It should be observed that the Phase II vehicle was not viable for the required mission.) Cost vs launch mass from the Phase II study is shown for reference. For a given launch mass the Phase III vehicle will cost approximately 7 percent greater than the vehicle from Phase II.

Two plot points are significant on the Phase III cost line. The upper point is the Phase III vehicle which actually has a capability of a 32.39 Mg (71,400 lbs) mass when fully fueled. The vehicle which meets the design-to-cost objective will have a launch mass of 29.03 Mg (64,000 lbs).

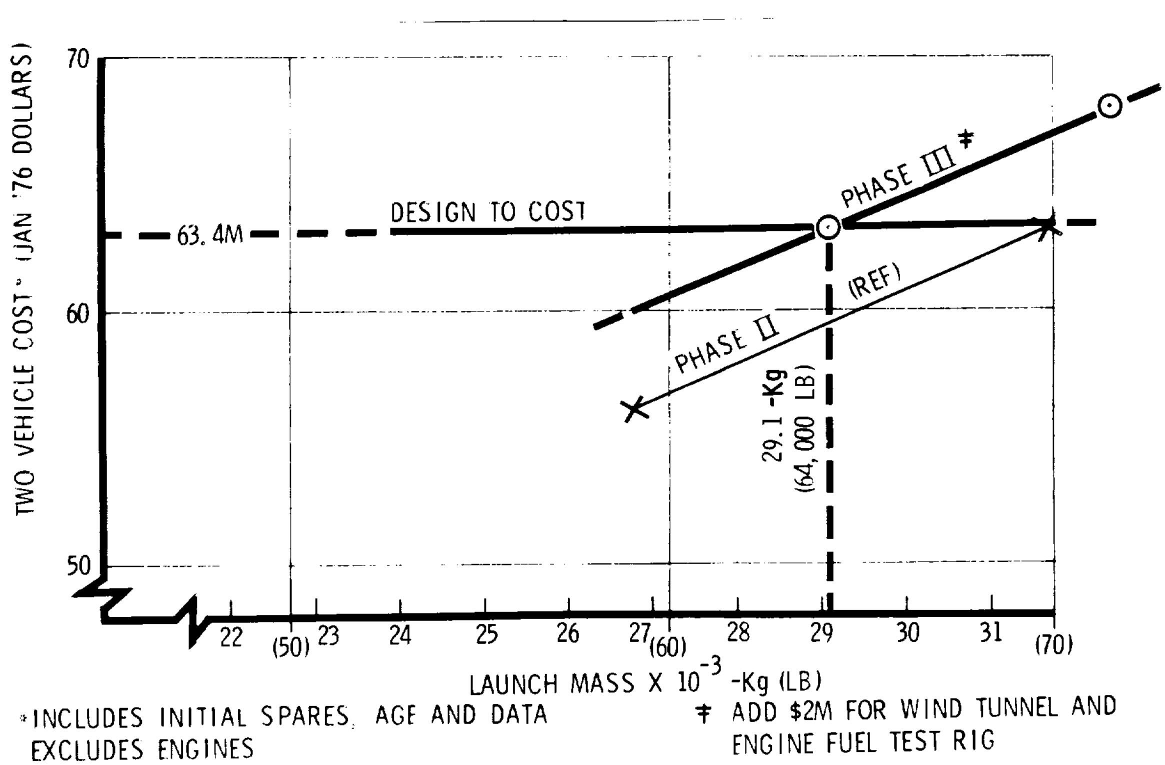


Figure 20. Phase III Scramjet Vehicle Cost vs Launch Mass

Figure 21 shows the relationship between vehicle cost and Mach number, a relationship also validated in Phase II of the study. In this case the upper point on the Phase III cost line is the Phase III vehicle which has a capability of Mach 6.85 cruise for 40 seconds with 8 scramjets.

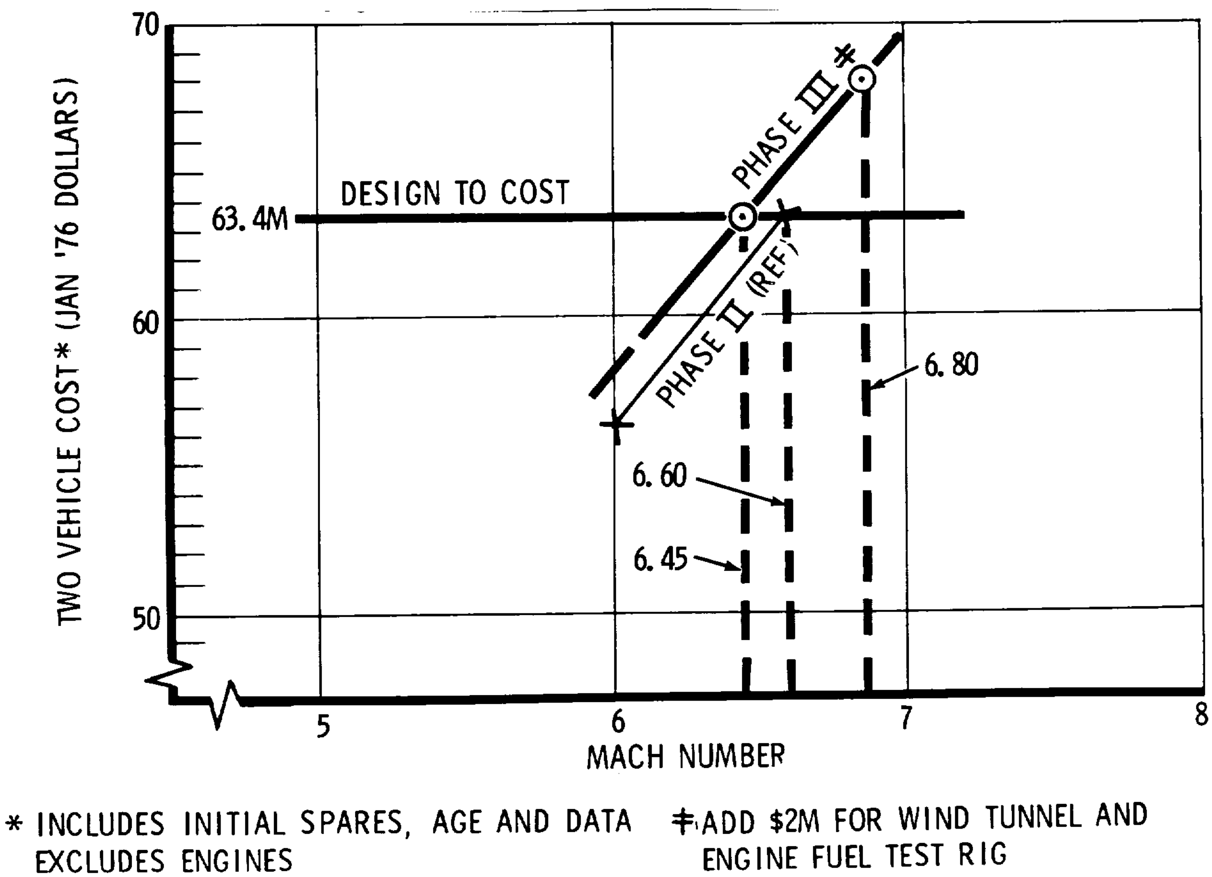


Figure 21. Phase III Scramjet Vehicle Cost vs Mach Number

For a given Mach number the vehicle cost is only 3 percent greater than the cost of the X-24C Phase II vehicle. The "design-to-cost" vehicle will have a capability of Mach 6.45 for 40 seconds at a launch mass of 29.03 Mg (64,000 lbs). Two Mach 6.0 vehicles can be produced for approximately $58 million.

It should be noted on both Figure 20 and Figure 21 that the $2 million for wind tunnel tests and engine fuel test rig are excluded in order to make a direct comparison to Phase II data.

One of the premises supplied by NASA at the inception of this study specified that "prototype or model shop type management and methods" should be utilized in the vehicle development program. To illustrate how the Lockheed Skunk Works views the importance of this aspect of the proposed X-24C program and its potential impact on cost, Table 10 lists data from two other studies and Lockheed ADP's estimate of "Skunk Works" vs a more standard Government contracting and management approach. Data is based on actual cost performance on the models listed.

DEVELOPMENT CONTRACT COST RATIOS

DATA BASED ON:			
LOCKHEED-CALIFORNIA CO. STUDY	"PROTOTYPE"	"MINIMAL"	"NORMAL"
USN/CARRIER ONBOARD DELIVERY (COD) (JAN 1972)	1.0	1.77	2.03
	"CO. FUNDED"	"FLY-BEFORE-BUY"	"CONCURRENCY"
ROCKWELL STUDY			
NASA REPORT CR114368-UTX/T-39 (SEPT 1971)	1.0	1.45	1.72
	"SKUNK WORKS"	STANDARD GOVT DEV. CONTRACT	FULL MIL-SPEC PRODUCTION
SKUNK WORKS ESTIMATE (AUGUST 1976)	1.0*	1.5	NOT APPLICABLE FOR NHFRF

*BASED ON C-130, U-2, JETSTAR, YF-12, SR-71 AND PROPOSED NHFRF

Table 10 - Development Contract Cost Ratios

It should be noted that, while there are differences in the terminology used by various organizations, there is a correlation between the cost relationships. The Skunk Works believes that costs can increase as much as 50 percent over the Phase III estimates in this study if full standard procedures are used.

The optimum schedule for the X-24C Phase III first vehicle is 24 to 27 months from go-ahead to delivery to NASA/USAF. A second vehicle can be delivered 6 months later. Funding limitations which cause program schedules to be significantly stretched from the optimum have an adverse effect on cost. This results from both the economic escalation normally encountered and the inefficiencies of retaining a design team and other specialists for longer periods. Stretching the X-24C schedule by 12 months will add 8 to 10 percent to X-24C Phase III costs. Skunk Works experience strongly indicates that a contractor should be permitted to design and develop a new aircraft at his own optimum pace for maximum effectiveness.

As a result of this study, it is evident that it is practical to design and build a high performance NHFRF vehicle with today's state-of-the-art.

- The vehicle launched at 31.75 Mg (70,000 lbs) from the B-52, can cruise for 40 seconds at Mach 6.78 on scramjets.
- The vehicle as designed for scramjet cruise at Mach 6.6 has a capability of approaching Mach 8 with 453.6 kg (1000 lbs) of payload in lieu of scramjets.
- This same vehicle has the capability of cruising on rockets, without scramjets, for approximately 70 seconds with 2.27 Mg (5000 lbs) payload at Mach 6.

The X-24C two vehicle cost can be kept within $70M in January 1976 dollars, including spares, AGE, and Data, but excluding engines and other GFE.

In order to reduce cost the X-24C vehicle can be scaled to lesser launch mass and lesser capability.

- For a Mach 6 maximum scramjet cruise capability the two vehicles can be produced for under \$60M.

For the design-to-cost target (\$63.4M) the vehicle capability is Mach 6.45, 40 seconds scramjet cruise at a launch mass of 29.03 Mg.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions reached at the end of this study are:

1. Research Capability - The X-24C with its interchangeable wings and fins, large payload capacity, its capability for sustained high Mach number flight and its ability to cruise over a wide range of Mach number can serve as an excellent platform for hypersonic research. Figure 19 visually portrays the type of research and development of technology that such a vehicle can materially aid in advancing.

2. Propulsion - It is technically feasible to use the LR-105 engine in the X-24C-L301 design. Using the LR-105 engine fan boost and twelve LR-101's for cruise provides more performance at less cost than the LR-99 with two LR-11's. The lower I_{sp} of the LR-99 means that it takes a 31.75 Mg (70,000 lbs) launch mass to the same mission as an LR-105 powered vehicle launching at 25.9 Mg (59,000 lbs). The Aerojet LR-91 engine is a possible alternate to the LR-105.

3. Structure and Thermal Protection - A Lockalloy heat sink airplane can be developed and built at approximately the same initial cost as an aluminum airplane protected by SLA-220 or shuttle type RSI.

4. Performance - By launching an LR-105 powered L301 airplane at 31.75 Mg (70,000 lbs) a 40 second cruise scramjet test package can be carried to approximately M = 6.8. Without the scramjet test package the L301 can carry a 453.6 kg (1000 lbs) research payload to Mach 8 or a 2.27 Mg (5000 lbs) payload to Mach 7.7. The performance and research capability of the X-24C increases greatly with increasing launch weight. The X-24C should be launched as heavy as the B-52 will permit.

5. Operation and Maintenance - The Lockalloy airplane will be significantly less expensive to operate and maintain than an insulated aluminum airplane. The exact amount of the Lockalloy airplane cost saving was not accurately determined because of lack of experience data on the serviceability of SLA-220 and RSI. The research capability, versatility, and improved turn around capability of the Lockalloy airplane is superior to the SLA-220 and RSI covered airplane.

6. Initial Cost - The 31.75 Mg (70,000 lbs) launch mass X-24C-L301 can be kept within $70 million dollars (Jan. 1976). This cost includes spares, AGE and data, but excludes engines and GFE. Only $10 million dollars can be saved by scaling the X-24C down from its Mach = 6.8 performance to Mach = 6.0 performance with scramjets. Since essentially all the program operating costs remain the same, the $10 million dollars is a small fraction of the total program cost. Therefore it would be false economy to sacrifice this performance and research capability to save the $10 million dollars.

Lockheed recommends that the X-24C-L301 hypersonic research vehicle be built. This recommendation is predicated on the future need for an Air-breathing Hypersonic Cruise Airplane. Fundamental research should address the aerodynamic, thermodynamic, structure, materials and propulsion fields. It should be noted that the output of this research can be used in both commercial and military applications. The X-24C hypersonic research airplane can be an extremely important tool which can supplement ground-based research and extend hypersonic technology into the real-world environment of hypersonic flight.