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ALTERNATE SPACE SHUTTLE CONCEPTS STUDY

Design Requirements and Phased Programs Evaluation

MIDTERM REVIEW

NASA HQ
Washington, D.C.
September 1, 1971

INTRODUCTION

The Alternate Space Shuttle Concepts Study extension midterm results reported herein were generated jointly by the Grumman Aerospace Corporation, the Boeing Company, and their associates. To assure consistency of results, Grumman and Boeing worked together closely, particularly in the areas of costing and concept evaluation/comparison. In general, Grumman concentrated on overall study management, orbiter/external tank design, and development test planning. Boeing concentrated on the design of both interim and fully reusable booster configurations as well as ground operations and maintenance planning. The other team associates and their major areas of participation are shown in the accompanying chart.

GRUMMAN/BOEING SHUTTLE TEAM

GRUMMAN	• SYSTEMS MANAGER • ORBITER
BOEING	• BOOSTER • OPERATIONS
AEROJET GENERAL	• CRYOGENIC TANKAGE
AVCO	• THERMAL PROTECTION SYSTEMS
AVIONS MARCEL DASSAULT	• THERMAL PROTECTION SYSTEMS • INSULATION SYSTEMS
DORNIER	• SUBSYSTEM TECHNOLOGY
EASTERN	• OPERATIONS • MAINTENANCE
	• AVIONICS
NORTHROP	• ORBITER TECHNOLOGY

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GRUMMAN SPACE SHUTTLE ORGANIZATION

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SPACE PROGRAMS

J.G. Gavin
Senior VP

SPACE SHUTTLE
PROGRAM DIRECTOR

L.M. Mead
VP

DEPUTY DIRECTOR
T. J. Kelly
VP

ASSISTANT DIRECTOR
AND
SPACE SHUTTLE
CONTRACT STUDY MANAGER

F. Raymes

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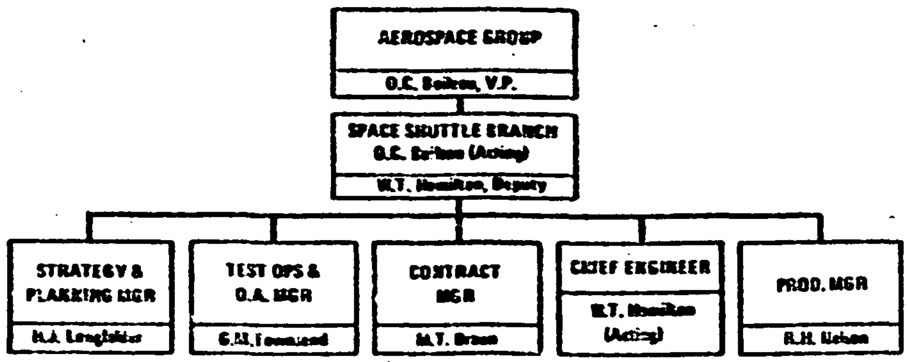
BOEING SPACE SHUTTLE ORGANIZATION



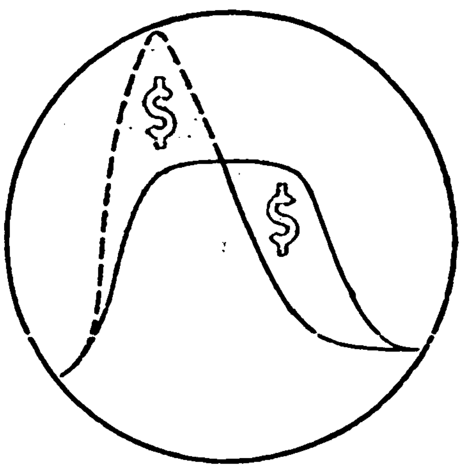
Under the four month extension to its Alternate Space Shuttle Concepts (ASSC) Study, the Grumman/Boeing Team with associates has investigated potentially cost-attractive programmatic and technical alternatives to the 1 July baseline (concurrent development of an orbiter with external hydrogen tanks and booster, both fully reusable). These alternatives include a phased approach, involving orbiter development and operation with an expendable booster for an interim period, as well as design variations to the basic vehicles. This report summarizes the study effort and conclusions achieved at the mid term (two month) milestone.

Specific study issues were addressed in terms of the following tasks, cited in the Contract Extension Study Plan of 7 July:

1. To accomplish conceptual designs of the alternate configurations and define the phased development programs for these alternate configurations
2. To obtain an understanding of the technological, operations, cost, and schedule characteristics of each phased development program alternate and to perform comparative analyses among them
3. To determine the technical and program impact of orbiter payload size and weight and of payload size and weight growth in conjunction with the program growth from an interim expendable to reusable booster
4. To determine the implications of intact "glide/cruise" recovery capability vs abort-to-orbit, using the external hydrogen-oxygen tank single engine orbiter (12 x 40 payload)/interim solid expendable booster configuration.

STUDY OBJECTIVE

Define *Doable & Affordable* Shuttle Program Alternatives to July 1 Concurrent Baseline

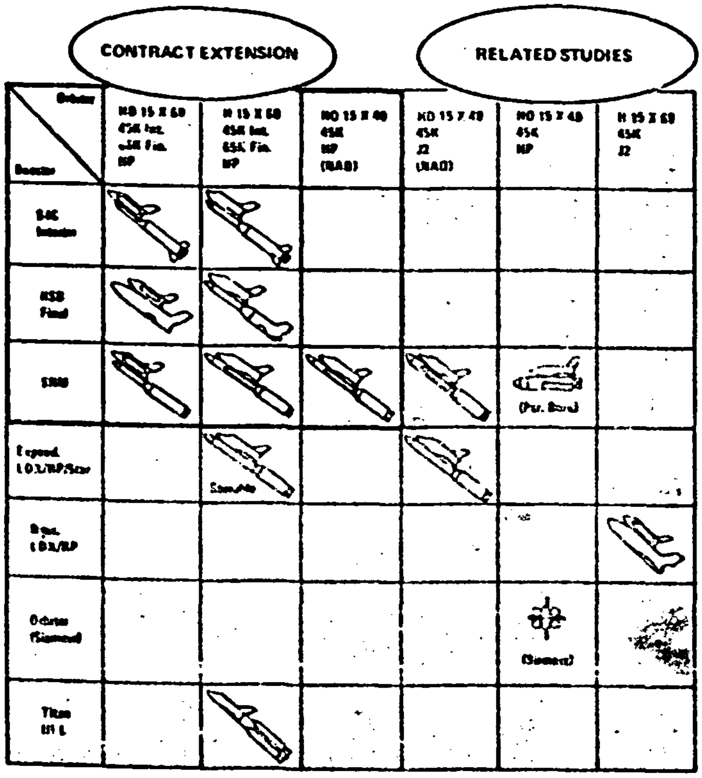


Technical
Management
Programmatic

The current contract extension to the Alternate Space Shuttle Concepts (ASSC) Study addresses the external hydrogen and oxygen tank (HO) orbiter variation to the baseline (H) orbiter, used with expendable interim launch vehicles (S-IC and SRM's) ultimately leading to fully reusable booster operation. Variations in payload bay length and abort requirements were also considered.

In addition, we studied a variety of alternative system configurations with expendable boosters which were directed toward a cost per flight reduction and extended interim operation. Finally, a fully reusable system using existing engines, F-1 and J2, was explored.

All options have been developed to a level which provides a cost and technical comparison with the baseline.


CONTRACT EXTENSION
RELATED STUDIES
Orbiter
Booster
HO 15 X 40
45K
J2
(RAD)
SRB
Titan

BRIEFING OUTLINE

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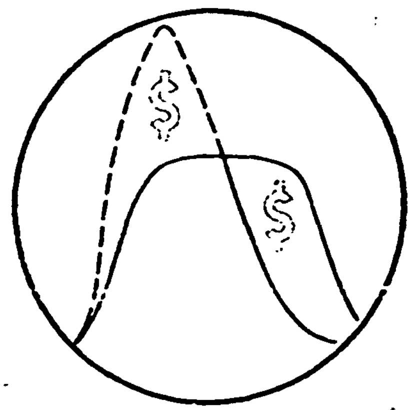
1. *Can we reduce costs if we change Orbiter requirements?*



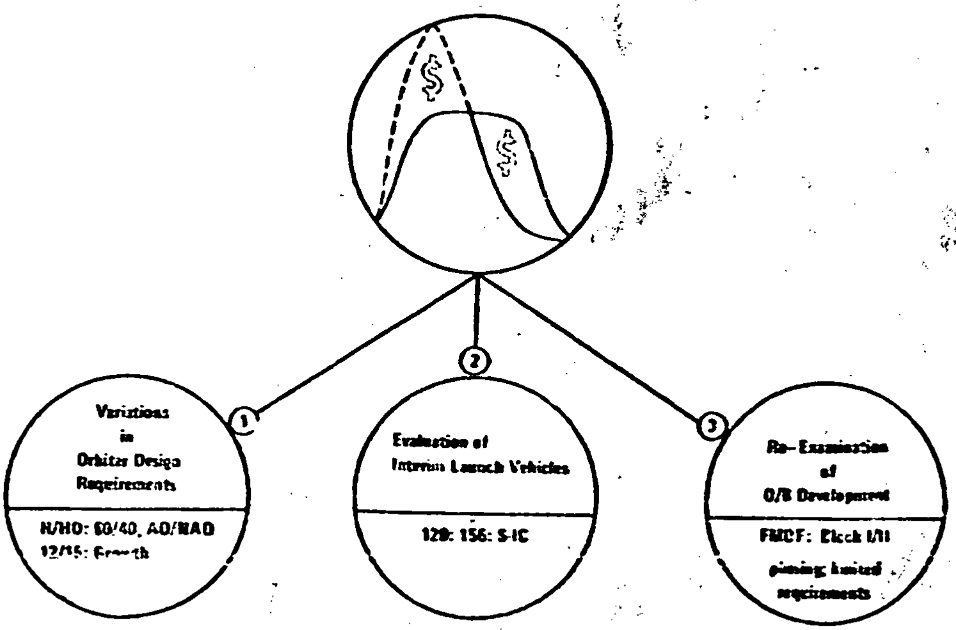
2. *Which is 'best' interim Booster for phased program?*

3. *How can we reduce overall Shuttle program costs?*

Three major areas have been assessed in terms of their influence on shuttle peak annual funding, program cost, and cost per flight.

- Influence of Orbiter Design Requirements – This category has included investigation of:
  - H vs HO external tank configurations
  - Payload bay diameter, length, and growth from 40 to 60 feet in length
  - Abort-to-Orbit (AO) capability vs. No-Abort-to-Orbit (NAO)
- Use of Interim Launch Vehicles – Three different classes of interim boosters have been evaluated:
  - Solid rocket motors; 120 in. and 156 in. diameter
  - Pressure fed liquid rocket boosters using LOX/RP-1 and N_2O_4/UDMH (storable hypergolic) propellants
  - S-IC boosters to both the H and HO configurations
- Re-examination of the Approach to Orbiter/Booster Development – Both schedule modifications and alternate vehicle approaches have been considered as follows:
  - Schedule revisions including the deferring of production vehicles and delay of FMOF
  - Use of Saturn technology (J2 Orbiter/F-1-LO_2/RP booster) in conjunction with Block I/Block II phasing
  - Limited capability approaches including use of low-cost subsystems and the application of an NAO 15x40 orbiter configuration to a reusable LH_2/LO_2 shuttle system.

THREE STUDY ELEMENTS



ORBITER DESIGN REQUIREMENTS

ORBITER DESIGN REQUIREMENTS

3

Changes to orbiter design requirements which have a significant impact on vehicle size and system development cost offer potential cost savings of up to $ 1B in DDT&E. In order to establish which changes are both feasible and worthwhile, we have studied variations in those major orbiter systems which have significant size and development cost impact, i.e., propellant tankage, payload bay size, and engine size and type.

BRIEFING OUTLINE

1. *Can we reduce costs if we change Orbiter requirements?*

- H vs HO
- Payload Length & dia.
- Growth
- AO vs NAO

2. *Which is 'best' interim Booster for phased program?*

3. *How can we reduce overall Shuttle program costs?*

Potential orbiter requirement changes are expresssed in terms of the six issues shown. For each item, alternative configurations were developed with identical characteristics, except for the feature at issue, and then compared in terms of design and operational problems, weight, risk, flexibility, and cost. Of these criteria, only those identifying relevant differences are presented for each study.

The first study compared an HO with an H orbiter, each carrying 65K payload in a 15 x 60 foot bay. All others used HO orbiters with 45K payload except for the growth study, in which the final design carried 65K.

CAN WE REDUCE COSTS IF WE CHANGE ORBITER REQUIREMENTS?

- *Only Hydrogen External, or Oxygen Too?*

  HO vs H

- *Small Payload Diameter, or Large?*

  12' vs 15'

- *Short Payload Bay, or Long?*

  40' vs 60'

- *Can We Start With Short Payload Bay & Grow?*

  40 → 60

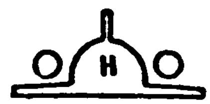
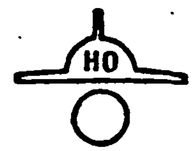
- *Abort Once Around or Gliding Recovery*

  AO vs NAO

The issues that were considered in the H vs HO comparison included the following:

- Orbiter configuration
- External tank configuration
- Qualitative structural/dynamic trends for the orbiter with expendable tanks
- Mated vehicle configuration
- Heat sink booster weight and performance
- Ability of the orbiter to compensate for inert weight growth by growing the main propellant tanks
- Propulsion subsystem and separation system comparison
- External tank and interstage disposal
- Orbiter DDT&E, peak annual funding and cost/flight comparison
- Orbiter core vehicle aerodynamic balance

H vs HO ISSUES

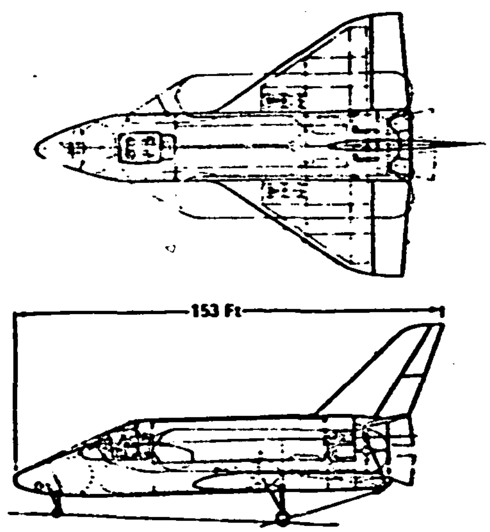
		
• Tank/Orbiter Struct. & Dynamics		
• Heat Sink Booster Weight & Performance		
• Development Schedule Flexibility		
• Subsystems		
• Tank Disposal		
• Cost		
• Aero Balance		

The baseline H 15x60 orbiter, which was used for the H vs HO orbiter comparison, incorporated the following improvements over the H33 orbiter design documented in the Grumman/Boeing Alternate Space Shuttle Concepts Study final report:

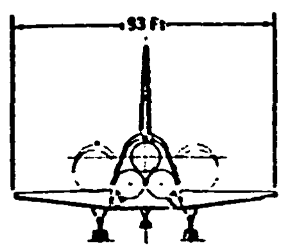
- The airbreathing engine system (ABES) installation was relocated to the aft end of the payload bay resulting in reduced scar weight and increased available fuselage volume
- Main non-integral LO2 tanks extended aft into the area vacated by the ABES reducing the tank diameter and thereby decreasing body cross-sectional area and body wetted surface area
- Relocation of the docking interface from the payload bay to the nose shortened the vehicle by 40 in.

The usable main injection propellant is 780,800 lb resulting in an orbiter ideal Δ V of 18,383 fps. The orbiter T/W at staging is 1.26.

H 15 x 60
(65K PAYLOAD DUE EAST)



GLOW	1,097,888 Lb
Dry Weight	188,353 Lb
Tank Dry Weight	20,203 Lb
Engines (3)	460 K Lb (ea)
Vstage	6775 fps



The dominant problem in configuring the HO 15x60 vehicle is to keep the excursion of the landed cg, with and without payload, within limits acceptable for aerodynamic balance. To minimize this excursion, the main engines with fixed nozzles, are located as far forward as possible with their fuel inlets running under the payload. The OMS oxidizer tanks can then be mounted above the main engines, close to the OMS engines. An alternative engine pattern, locating the engines in the same forward position but radially around the payload centerline in an inverse triangle pattern, reduces the width of the base but the additional exposed wing results in a weight penalty. The base areas are about the same for both engine patterns.

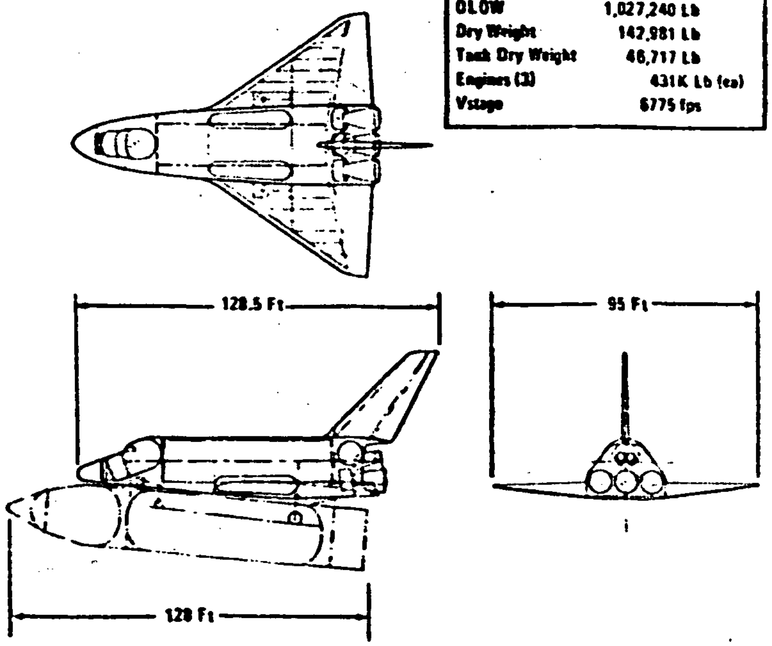
The four-man cabin shows a forward docking system which necessitates a swing-away nose.

Protection of the upper fuselage by the chines during reentry down to $\alpha = 25^{\circ}$ dictates, to a great extent, the plan view shape of the forward fuselage.

The usable main injection propellant is 735,800 lb resulting in an orbiter ideal ΔV of 18,383 fps. The orbiter T/W at staging is 1.26 to be comparable to the baseline H orbiter.

HO 15 x 60
(65K PAYLOAD DUE EAST)

GLOW	1,027,240 Lb
Dry Weight	142,981 Lb
Tank Dry Weight	46,717 Lb
Engines (3)	431K Lb (ea)
Vstage	6775 fps

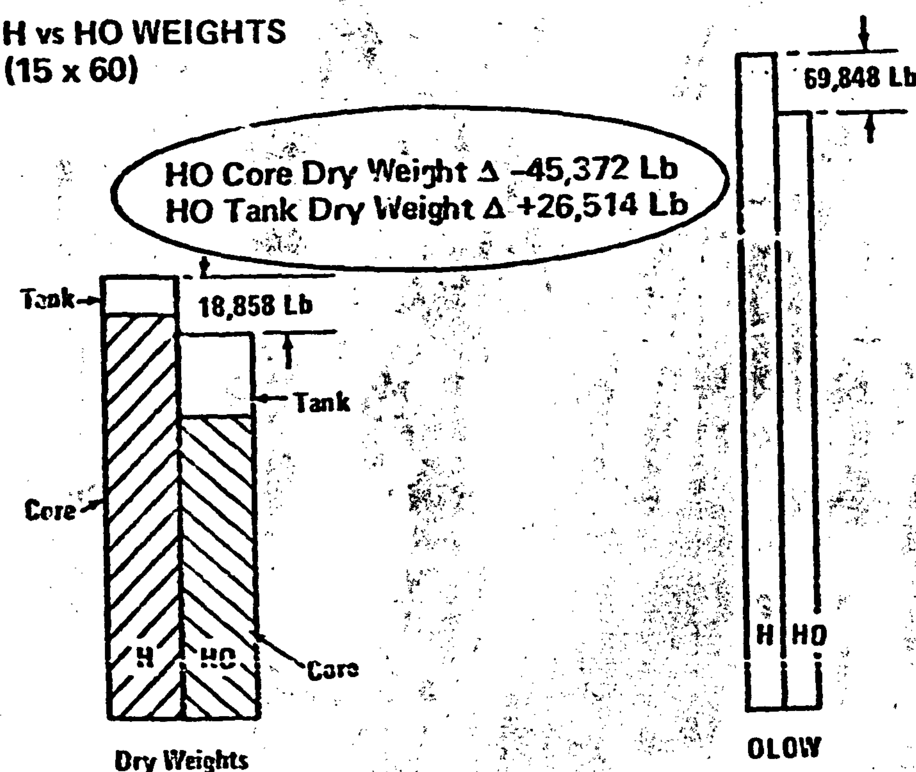


A dry weight comparison of the H vs HO, with 15x60 payload bays, shows that the HO core vehicle dry weight is 24% less than that of the H core vehicle. The H orbiter non-integral main propulsion oxygen tanks, which weigh 11,500 lb, are included in the 45,372 lb dry weight difference.

The body volume of the H and HO core vehicles are 51,500 ft^3 and 34,000 ft^3, respectively. This represents a 34% reduction in body volume for HO over H.

A breakdown of the difference in the H and HO tank dry weights is shown on the next chart.

H vs HO WEIGHTS
(15 x 60)



A configuration and weight comparison of the H orbiter's two 15-foot diameter external LH_2 tanks and the HO orbiter single 22-foot diameter external LH_2/LO_2 tank illustrates the lower weight and simpler structural arrangement of the external LH_2 tanks. The major items in the HO tank that contribute to the dry weight difference of 26,514 lb are the structural and propulsion feed system weights for the LO_2 tank, the increased structural weight of the LH_2 tank (because it is a load carrying structure) and the increased inter-stage weights due to the mid and aft skirts. Both H and HO tanks have a 5% dry weight growth allowance.

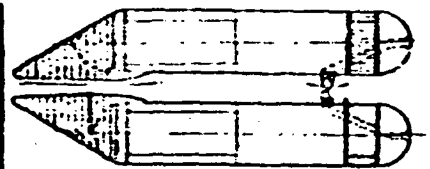
The mass fraction of the H tanks and the HO tank are 0.828 and 0.9264, respectively. The mass fraction is defined as the weight of usable propellant divided by the sum of the usable propellant and the inert weight of the tank.

A sketch of three S-IVB stages is shown alongside the HO tank to illustrate the size of the HO tank.

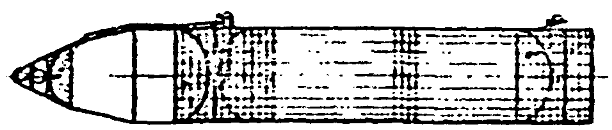
H vs HO EXTERNAL TANKS

Weight Comparison

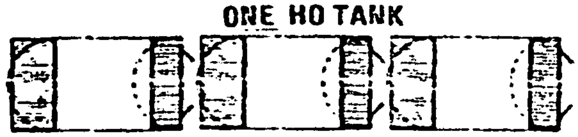
	HO	H (2 Tanks)
LO_2 Tank	4,843	–
LH_2 Tank	17,324	8,772
Nose Cone	885	2,712
Interstage & Attach	11,512	234
TPS	[illegible],506	5,693
Other	[illegible],647	2,792
Dry Weight	4[illegible],717	20,203
Reserves & Resid.	13,284	2,907
Total Weight	60,001	23,110



TWO H TANKS



ONE HO TANK



THREE S-IVB

FRACTURE CONTROL (LOX TANK)

The external HO tank has the obvious advantage of single use and the resulting benefits such as:

- Minimum fatigue damage, flaw growth, and stress corrosion cracking
- Use of minimum factors of safety in design of both LH_2 and LO_2 tanks
- Accessibility during manufacture, NDE, test and service.

TANK COMPLEXITY

The external H tank is less complex than the HO tank as it does not require tank interstage structure or booster attachment structure. The HO tank carries an additional penalty for transmitting booster/orbiter loads.

SEPARATIONS

The HO configuration is preferred due to the simpler tandem separation of the booster and orbiter over the piggy-back H type of separation. In addition, the HO tank separation procedures and mechanization is simpler due to the single tank.

ORBITER POGO

In comparing the length of the LOX lines between the H and HO configuration, the HO line is appreciably longer (approximately 85 feet compared to 23 feet). From prior analysis of the H configuration, no POGO problem was evident; however the longer HO line will tend to increase sensivity of this configuration POGO.

ALL DYNAMICS, OTHER THAN POGO

The HO configuration, being longer than the H configuration, is potentially more sensitive to coupled vehicle dynamics such as "stop sign flutter" and structural bending/control system interactions during launch.

H vs HO QUALITATIVE STRUCTURAL/DYNAMIC TRENDS FOR ORBITER AND DISPOSABLE TANKS

Item / Preferred √	Disposable Tanks H	Disposable Tanks HO
LOX Tank Fracture Control		√
Tank Complexity	√	

Item	Core + Tanks H (Parallel)	Core + Tanks HO (Tandem)
Booster & Tank Separations		√
Orbiter POGO (LOX Line Length)	√	
All Dynamics, Other Than POGO	√	

HO Tanks More Complex

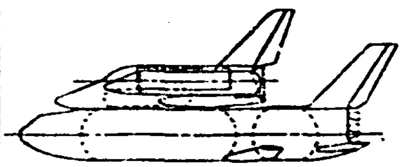
Tit For Tat

The H orbiter is parallel mounted with attachments straddling the booster LH_2 tank. The vehicles are mated horizontally and rolled out to the launch pad on the booster landing gear.

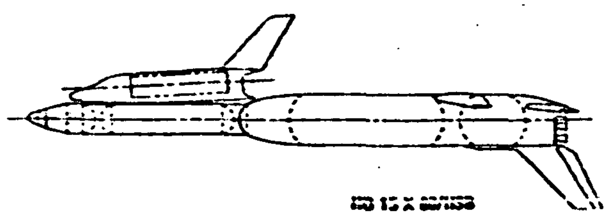
The HO orbiter is tandem mounted on the booster nose and is oriented with its vertical fin opposite to the booster's to avoid impingement of the orbiter's plume on the booster windshield. The stack requires vertical mating and roll out.

H vs HO MATED CONFIGURATIONS

	H	HO
GLOW	3,883,582 Lb	3,714,540 Lb
OLOW	1,097,083 Lb	1,027,240 Lb
BLOW	2,786,500 Lb	2,687,300 Lb
Payload Up	65K Lb	65K Lb
Vstage	6775 fps	6775 fps



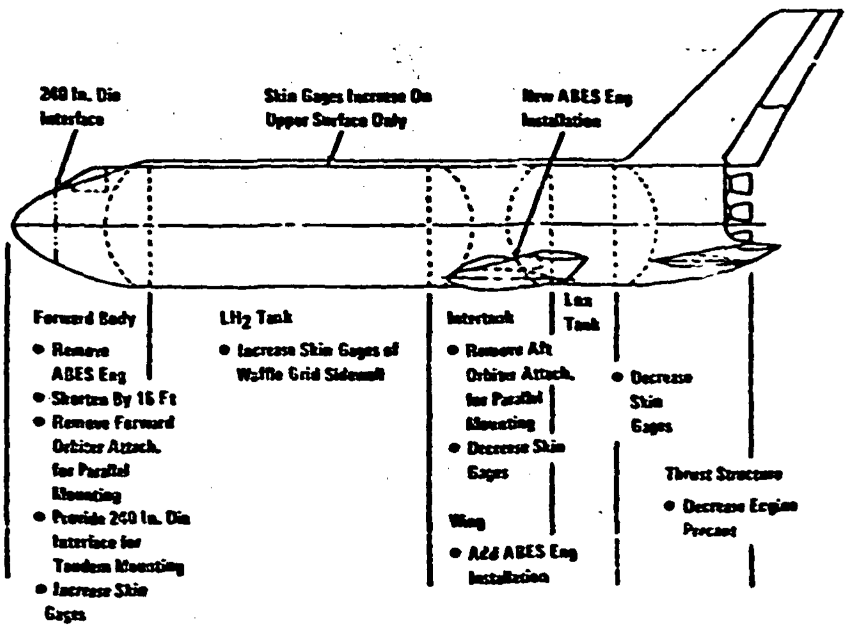
H 15 X 60/HSB



HO 15 X 60/HSB

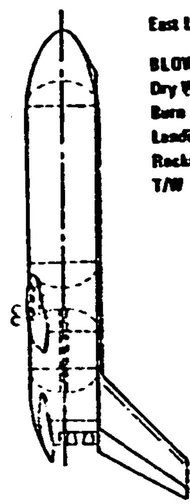
Tandem mounting increases the bending moments on the forward body and the LH_2 tank, resulting in a greater proportion of booster inert weight forward. This weight shift allows a wing-mounted booster air-breather installation. Compared to the H booster, the HO vehicle has heavier nose and LH_2 tank structure, and lighter inter-tank and LO_2 tank structure.

BOOSTER STRUCTURAL MODIFICATIONS FOR TANDEM MOUNTING (FROM H TO HO)



Small differences in HO and H booster weights illustrate the minor overall effects due to tandem vs parallel mounting. The slightly higher dry weight of the HO vehicle is compensated by the lower ascent drag of the tandem arrangement to provide approximately equivalent performance.

HO 15 x 60



East Launch

BLOW	2,687,300 Lb
Dry Weight	485,400 Lb
Burn Out Weight	567,270 Lb
Landing Weight	523,100 Lb
Rocket Thrust	5,840,000 Lb
T/W	1.313

HO → H
Δ Dry Weight = +2990 Lb

H 15 X 60

East Launch

BLOW	2,786,500 Lb
Dry Weight	482,410 Lb
Burn Out Weight	569,300 Lb
Landing Weight	521,780 Lb
Rocket Thrust	4,888,800 Lb
T/W	1.235

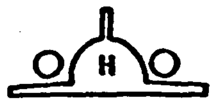
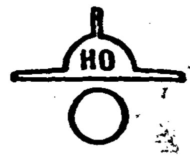
During a nominal mission both H and HO external tanks are jettisoned following orbiter insertion into the 51 x 100 n mi ascent transfer orbit. Initiation of the tank deorbit maneuver is timed so that nominal tank impact is targeted for the baseline impact zone in the Indian Ocean which is approximately the antipode of ETR. The HO tank separation maneuver is considered to be somewhat simpler than H since there is only a single HO tank to separate as compared to the two H tanks.

Both the H and HO tanks will breakup in the upper atmosphere. However, it is expected that the HO tank breakup will occur at a lower altitude than the H tanks due to its heavier structure. A breakup altitude of 240,000 feet for HO tank results in a maximum down-range dispersion for tank fragments of 650 n mi as compared to a breakup altitude of 300,000 feet and a resulting higher maximum down-range dispersion of about 1200 n mi for the H tank fragments.

The probability of H tank fragments surviving reentry is low due to the high tank breakup altitude and the low skin gages of the structure. There is a higher probability that some fragments of the HO tank would survive reentry. The net effect of these tank disposal issues favors HO.

Interstage disposal is an additional issue which is unique to the tandem HO configuration. During an interim program, the interstage can be jettisoned with the expendable booster. However, when the launch configuration includes a reusable booster, then the booster options are to either jettison the interstage if the impact zone is acceptable or design an acceptable scheme of retaining the interstage with the booster. This problem is now under evaluation.

H vs HO, TANK & INTERSTAGE DISPOSAL

• Tank Dispersions		
– Breakup Altitude	300,000 Ft	240,000 Ft
– Fragment Survival Probability	LOW (Burn-Up in Upper Atmosphere)	HIGHER
– Maximum Downrange Dispersion	1200 N Mi	650 N Mi

- HO Tank Separation Simpler

√ HO

- Interstage Disposal
  - Jettison with Interim Booster
  - Options with Final Booster
    - o Retain or Jettison
    - o Difficult Solution

Three major questions arise concerning the operational aspects of configurations employing external tanks. The first is the question of tank disposal on missions where the orbiter injects directly into a high energy orbit, such as 50 by possibly up to 800 n mi. For these missions the nominal 200 fps Δ used to retro the tanks is insufficient, and increasing the retro Δ will also increase tank dispersions. A better approach which will still limit dispersions, is to carry the tanks through the mission, and jettison them at entry interface. Assuming a 600 n mi orbit, the payload penalty associated with this approach is 4000 and 7000 lb for the H and HO configurations, respectively.

The second question is the compatibility of tank jettison procedures with missions which are time critical with rendezvous operations occurring between orbiter burnout and apogee. Since the time required for tank venting prior to jettison could compromise rendezvous, sealing disconnect values of the type used on the Atlas could be used at the tank/ orbiter interface, thus reducing or eliminating the venting time requirements. These valves are of a proven design and represent small weight and cost/flight increments.

The third question is related to tank disposal following aborts that occur prior to nominal booster/orbiter staging. Assuming that the orbiter always would burn its propellants to depletion, the tanks would be jettisoned at a "q" of 10-20 psf in a pressurized condition. The estimated weight penalty for meeting this requirement is approximately 500 lb.

MAJOR EXTERNAL TANK QUESTIONS

QUESTION	ANSWER
1. Tank dispersions for high altitude missions? 600 n mi	1. Dispersions can be kept small by carrying tanks to orbit or deorbit - payload penalty. 4K H; 7KHO
2. Compatability of tank jettison operations with timeline-critical missions?	2. Reduce jettison operations time by retaining residuals. Requires Atlas-type sealing disconnects. Delta weight & cost/flight 150 lb & $30K
3. Aborts prior to nominal booster separation?	3. If early separation required, burn orbiter to depletion. Tanks can be jettisoned at 10-20 psf "q" if pressurized. Weight penalty ≈ 500 lb.

The inherent capability of the H and HO configurations to accommodate unpredicted inert weight growth beyond the present orbiter growth allowance was investigated. Two cases were considered, one in which there is no design allowance for this unpredicted growth and the second where the vehicles were pre-scarred to accommodate unpredicted inert weight growth.

Without design allowance for growth, the options are fairly straightforward. For the H orbiter the only option was to increase the size of the external LH_2 tank and operate the main engines at a lower average mixture ratio. An average mixture ratio of 5.75:1 was chosen since it provides a ratio of 6:1 at nominal separation (yielding maximum EPL in the event of engine failure) which decreases to 5.5:1 at the end of burn. The percent inert weight growth allowance for this case was only 0.7%.

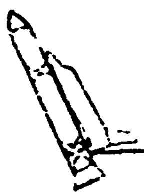
For the HO orbiter, the only option was to add oxygen to the nose of the external HO tank since it is not practical to disturb the tank/orbiter interface geometry or the tank/booster interface geometry. A mixture ratio of 6.25:1 was chosen for the growth version for the same reason discussed in the previous paragraph. This yielded a net growth allowance of 2.7% which represents a relatively modest growth allowance, but certainly a substantial improvement over the H orbiter. A plus for HO.

The second case considered pre-scarred the H orbiter by providing additional body volume so that the diameter of the internal non-integral oxygen tank could be increased by 4 in. This coupled with a large external hydrogen tank would permit an inert weight growth allowance of 8.2% which would double the present H orbiter core plus tank growth allowance. The iterated scar weight penalty to the initial H orbiter design was estimated to be 1020 lb.

The HO orbiter was pre-scarred by increasing the length of the HO tank interstage by 4.2 feet which permits future stretching of both the LH_2 and LO_2 tanks without disturbing the existing structural interfaces. This would permit an inert weight growth of 6.6%, which also doubles the present HO orbiter plus tank growth allowance, at a scar weight penalty in the initial design of 1480 lb. A plus for H, if pre-scarring the orbiter for growth is acceptable.

Based on this analysis, there is no clear cut advantage to either H or HO in terms of development flexibility.

H vs HO, DEVELOPMENT FLEXIBILITY

	Frozen Design O/F = 6.0	Recovery Action	% Inert Wt Growth Allow.	Scar Wt on Initial Design
H 	• No Design for Growth	• Reduce O/F to 5.75 • Longer LH_2 Tanks	0.7	0
	• LO_2 Tank Cavity 3.2% Oversize Dia	• Longer LH_2 Tanks Larger Dia LO_2 Tanks	8.2 ✓	1020
HO 	• No Design for Growth	• Increase O/F to 6.25 • Longer LO_2 Tank Fwd	2.7 ✓	0
	• Interstage 4.2 Ft Overlength	• Longer LH_2 Tank Aft Longer LO_2 Tank Fwd	6.9	1400

Toss-Up

H ADVANTAGES

1. Smaller Lines to Separate - Both designs require 6-line disconnects. The H orbiter has 2-14 in. main lines, 2-6 in. vents, and 2-4 in. recirculation lines, whereas the HO orbiter has a 17 in. LH_2 main line, a 15 in. LO_2 main line, 2-8 in. vents, and 2-4 in. recirculation lines. The HO orbiter requires that LO_2 disconnects and larger, LH_2 disconnects be developed.

2. Less Critical Disconnect Doors - H doors are located on the fuselage sides (1000°F environment) whereas the HO doors are on the bottom (1600°F environment) thus making the HO design more critical from the standpoint of door design and failure sensitivity

3. Smaller Gimbal Angle Travel - Location of the HO external tank requires that the HO orbiter have a total gimbal angle travel of 25° to maintain adequate control in the event of an atmospheric abort. The equivalent total gimbal angle travel for the H orbiter is 20°

HO ADVANTAGES

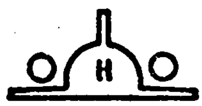
1. No Propellant Management - The HO orbiter single main LO_2 and LH_2 tanks do not require the allocation of reserve propellants to account for non-simultaneous depletion of parallel tanks, as is required for H orbiter dual main LO_2 and LH_2 tanks. This amounts to a 443 lb propellant savings. In addition, the single LH_2 feed line traps 57 lb less propellant

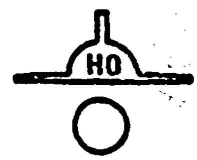
2. Less Pressurant & Simpler Purge System - The lower surface to volume ratio of the HO main propulsion tanks, as compared to the H main propulsion tanks results in less pressurant collapse and thus less trapped gas. The effect is most pronounced on the LO_2 side and results in a 180 lb gas savings. The HO orbiter purge system must purge only the feed lines and not the tanks, resulting in an additional 100 lb hardware saving

3. Separation is Extension of Saturn Technology - The HO orbiter/booster will use a shaped charge severance of the interstage structure, as used in the Saturn booster. The H concept uses a hydraulically actuated linkage to push the vehicles apart

H vs HO, PROPULSION SUBSYSTEM

ADVANTAGES





H	HO
• Smaller LH_2 Lines & No LO_2 Lines to Separate (Total No. Equal to HO)	• Simple Feed; No Propellant Management (-500 Lb Fluid)
• Reclosing Disconnect Openings Less Critical	• Less Pressurant & Simpler Purge System (-280 Lb)
• Smaller Gimbal Angle Travel (±10° vs ± 12.5° for HO) for Atmospheric Abort	• Orbiter/Booster Separation Is Extension of Saturn Technology

√ HO

A comparison of the H 15x60 and the HO 15 x 60 orbiter costs shows a reduction in the HO orbiter core DDT&E of $265M over the H orbiter core, an increased HO tank DDT&E of $175M over the H tank, with a net total HO orbiter DDT&E reduction of $90M.

It should be noted that although the dry weight of the HO orbiter core is 24% lower than that of the H orbiter core, most of this difference is attributable to structural subsystem reductions. A large number of the orbiter subsystems are relatively insensitive to vehicle weight. The structural subsystem related costs amount to about one quarter of the total orbiter core DDT&E cost. This is the major contributor to the $265M HO orbiter core saving. The cost/flight difference of $790K between the H and HO configurations is primarily due to the difference in average production costs between a pair of external H tanks and an external HO tank and its interstage.

H vs HO, COST COMPARISON
(ORBITER ONLY)

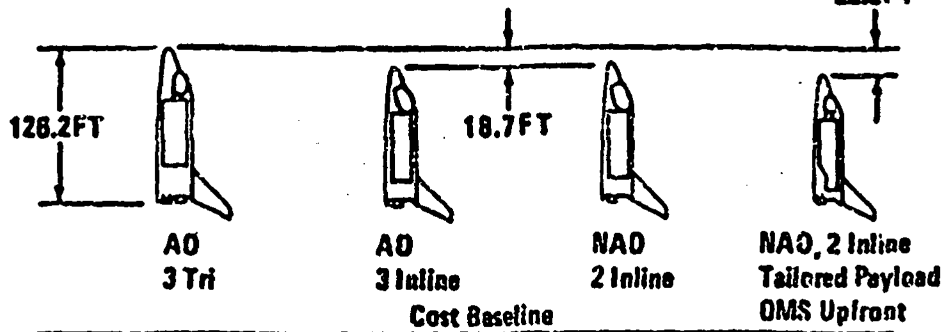
	H	HO	Δ COST (H base)
	($M)		
Core DDT&E	3600	3335	
Tank DDT&E	70	245	
Orbiter DDT&E	3670	3580	-90 M
Peak Annual Funding	929	891	-38 M
Cost/Flight	2.91	3.70	+790 K

H ?HO

Several HO fuselage design options are shown.

The cost baseline, Column 2, has its three high pressure engines in a low horizontal row so that the required straight sections of propellant line run under the payload bay. This results in a payload bay closer to the vehicle center of gravity with an acceptable cg travel of 2%. A modified cockpit arrangement with front docking has helped reduce dry weight. The first column shows the vehicle characteristics with a triangular main engine arrangement. Center of gravity travel of 2.7% is beyond that which can be tolerated with the current 13.8% elevons. The remaining configurations use smaller propulsion installations (NAO) and a tailored payload bay.

HO ORBITER CORE ARRANGEMENTS



Abort to Orbit	✓	✓		
No. Eng/F_{vac}	3/1,379,801	3/1,293,188	2/874,008	2/841,517
C.G. Travel	2.7%	2.0%	≈1.9%	1.3%
Dry Weight	157,085	142,981	131,746	124,441
Landed Weight	199,855	185,751	174,516	167,211

This represents a summary of the issues discussed on the previous pages.

A qualitative analysis of the structural/dynamic trends for the orbiter and the expendable tanks indicates no clearcut advantage for either H or HO.

The tandem HO HSB and the piggy-back H HSB have almost identical weights and performance.

The ability to compensate for inert weight growth of the orbiter by increasing the size of the main propellant tanks shows an advantage for HO if no scar weight is permitted in the initial design and an advantage for H if a modest initial scar weight penalty of about 1000 lb can be tolerated. Therefore, development flexibility is a toss-up.

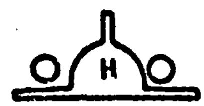
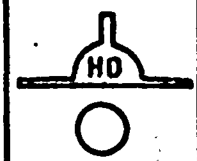
The HO propulsion subsystem is superior to the H because of its simpler feed system resulting from a single main LH_2 and LO_2 tank.

HO tank disposal is slightly favored over H tank disposal because there is only a single tank to separate and the predicted downrange dispersion of the HO tank fragments is about one-half the predicted dispersion of the H tank fragments. However, HO tank interstage disposal with a reusable booster poses a design and/or operations complexity.

A cost comparison indicates a small reduction in HO orbiter peak annual funding and DDT&E costs, but a more substantial increase in cost/flight due to the more expensive expendable tank. There is no obvious winner from the cost vantage point.

With its design, operational, and early funding advantages, the HO configuration warrants further investigation (in structural/dynamic areas related to its tandem arrangement) before a final selection is made.

H vs HO SUMMARY

ISSUE		
• Tank/Orbiter Struct. & Dynamics	TOSSUP	
• HSB Weight & Performance	TOSSUP	
• Development Flexibility	TOSSUP	
• Propulsion		√
• Tank Disposal		√
• Cost		
-Peak Annual Funding		-4%
-DDT&E		-2.5%
-Cost/Flight	-20%	
• Aero/Balance	√	

H?HO

The next six illustrations summarize studies that were performed to identify the potential benefits of reducing the payload bay size. Orbiter designs with payload dimensions of 15x60, 15x40 and 12x40 were compared.

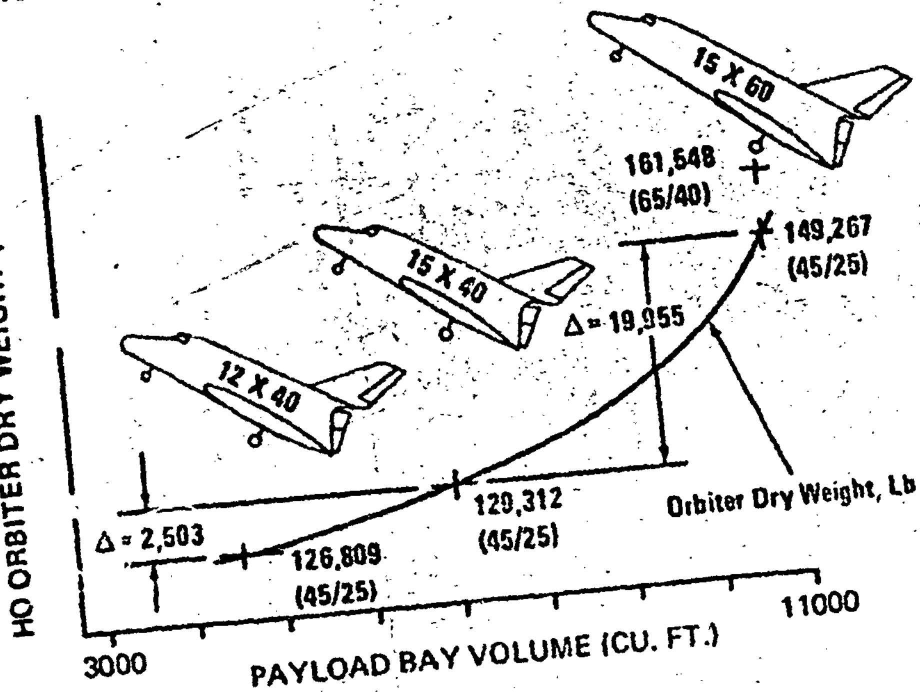
PAYLOAD BAY SIZE

ISSUES

- Aero Balance
- Orbiter Dry Weight
- External Tank Dry Weight
- Orbiter & Tank DDT&E
- PAF

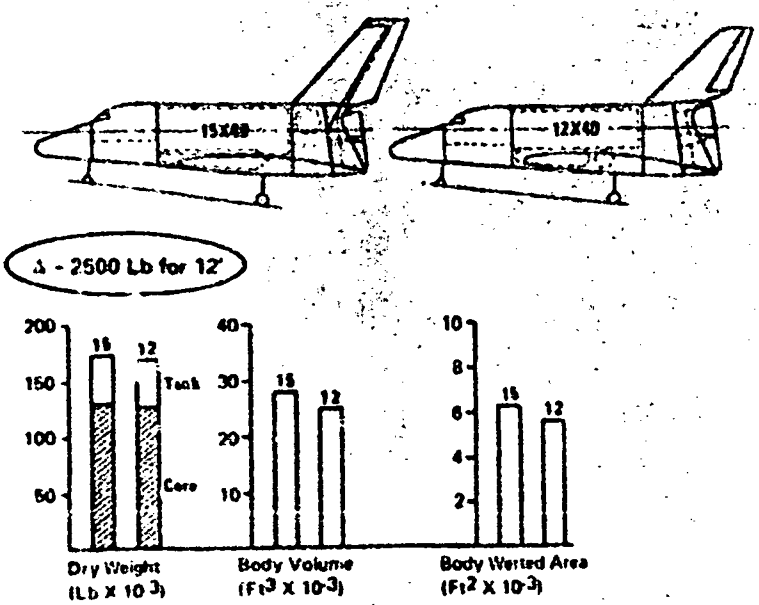
The HO core dry weights are compared for the 12x40, 15x40 and 15x60 vehicles. All three are shown for payloads of 45K up and 25K down. In addition, a 15x60 vehicle with payload capability of 65K up and 40K down is also shown. Note the "knee" in the curve; increasing the payload from 12x40 to 15x40 increases core dry weight by only 2503 lb, while increasing from 15x40 to 15x60 increases core dry weight by 19,955 lb.

ORBITER DRY WEIGHT/PAYLOAD BAY VOLUME
(PAYLOAD UP/PAYLOAD DOWN ~ K LB)



The issue of payload diameter is addressed by comparing the 12x40 and the 15x40 orbiters on the basis of total dry weight (including tanks), body volume and body wetted area. It is concluded that the total orbiter dry weight savings in reducing the payload bay diameter from 15 to 12 feet is small. This small reduction is borne out by the correspondingly small reduction in body volume and body wetted area.

PAYLOAD DIA 15 x 40 OR 12 x 40



The small dry weight reductions in going from 15 to 12 foot diameter payload bays reflect into correspondingly small reductions in orbiter-plus-tank development and peak annual funding requirements. It is therefore concluded that the requirement for a 15-foot diameter payload bay should be retained.

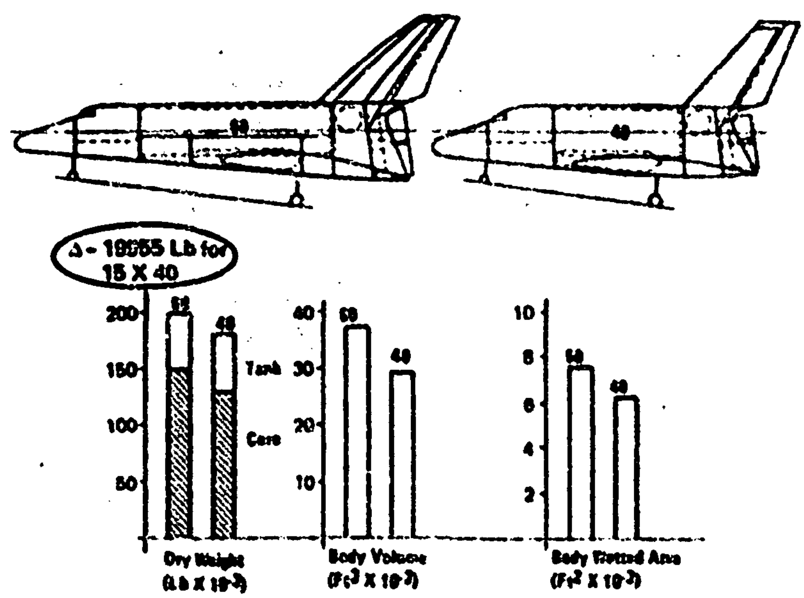
PAYLOAD DIAMETER

ISSUES	15 X 40 →	DIFF.	← 12 X 40
Orbiter Dry Weight	129,312	2,503	126,809
External Tank Dry Weight	43,950	1,022	42,928
Orbiter + Tank DDT&E		$19M	
PAF		$6M	

√15 Ft

The effects of payload bay length were explored by comparing the 15x60 and the 15x40 HO orbiter. It was found that payload bay length is a relatively larger driver than payload diameter on body volume and wetted area, and therefore on dry weight. The core dry weight reduction in reducing the cargo bay length by 20 feet is 19,995 lb.

PAYLOAD BAY LENGTH – 15 x 60 OR 15 x 40



The dry weight reductions in going from 60 to 40 foot payload bay length reflect into orbiter and tank development and peak annual funding reductions of $144M and $31M, respectively. Whether or not these savings should be implemented depends upon analyses of payload requirements.

PAYLOAD LENGTH

Issues	15 X 60 (45K/25K PLD)	Diff	15 X 40 (45K/25K PLD)
• Aero balance	Acceptable		Acceptable
• Orbiter dry weight	149,267	19,955	129,312
• Ext tank dry weight	50,300	6,350	43,950
• Orbiter + tank DDT&E		$144M	
• Peak annual funding		$ 31M	

40' Can Save $

A study was made of the implications of a two-phase orbiter program in which the initial orbiter has a payload bay size of 15x40, and is modified later to a 15x60 payload bay size. The objective of the study was to define the best approach to growth in terms of:

- Minimum scar weight to both the initial and final vehicle
- Minimum rework requirement

The scar penalties considered were weight, cost, aerodynamic performance and risk, and the rework penalties considered were cost and risk. The results were evaluated on potential net benefits in reducing initial development and peak annual funding requirements. This study was done on an HO type orbiter.

ORBITER GROWTH
(15 x 40 to 15 x 60)

- **Best Approach to Growth**

  Minimum Scar to Initial & Final Vehicle vs Minimum Rework

  Scar Penalties:
  - **Weight**
  - **Cost**
  - **Aerodynamics**
  - **Risk**

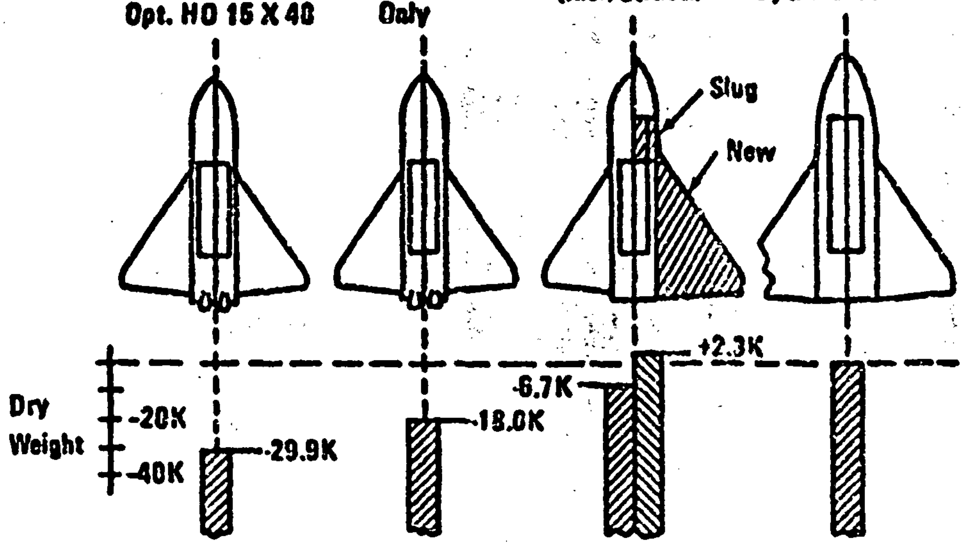
  Rework Penalties
  - **Cost - Structure, Engine**
  - **Risk**
- **Net Benefit of Growth Approach**

Before considering growth, an optimized 15x40 orbiter (shown on the left) was compared with an optimized 15x60 orbiter (shown on the right). The core vehicle of the smaller vehicle was 29,900 lb lighter. Neither vehicle had been scarred for growth. Two potential approaches to growth were then considered. In the first approach (second configuration from the left), the initial vehicle was only scarred to the extent of providing main engines sized for the final vehicle, plus the iteration of weight through the vehicle to carry these larger engines. The initial core weight savings was reduced to 28,000 lb.

Since the rework of this vehicle to the final size would be large, a second and hopefully more practical approach to growth was studied (third configuration from the left). In this case the orbiter scars included the larger engines plus provisions for a new wing and a 20 foot "slug" in the fuselage. These added scars reduced the initial core savings to 6700 lb, and further resulted in a 2300 lb scar remaining in the final 15x60 version.

GROWTH

(HO 15 x 40 → 15 x 60)



Growth NOT Practical

The initial cost saving of the growth approaches (relative to an optimized 15x60) in development and peak annual funding are shown to be small. In addition, the aerodynamic performance of the vehicles are somewhat compromised to achieve the growth, which in turn means that additional risk would be encountered in meeting aero stability requirements. Further, the rework of the initial vehicles to their final versions is estimated to be high, which will substantially increase total program costs. For these reasons it is concluded that payload bay growth is not a practical solution to cost saving, when technical and pre/post-scar cost and risk issues are realistically assessed.

GROWTH SUMMARY

	Approach Scar Limited to SSME vs	Option Practical Growth Scar
Initial Cost Saving Relative to HO 15 X 60		
DDT&E	$117M	$48M
PAF	$ 33M	$13M
Aerodynamics	OK	Compromised
Risk	High (2 Development Programs)	High (Neither Vehicle Optimum)
Rework	Total Redesign (Very High Cost)	Considerable Redesign (High Cost)

Growth Not Practical

The NAO vs AO study starts from a definition of orbiter characteristics needed to perform abort-to-orbit. The orbiter must achieve a once-around orbit with an engine out from nominal staging with OMS propellant augmentation. In the staging velocity (V_{stage}) region of interest, this dictates three orbiter engines and a minimum T/W at each V_{stage} to provide AO capability. The study objectives were to establish whether relaxation of this constraint provided appreciable cost savings and whether NAO was operationally visible.

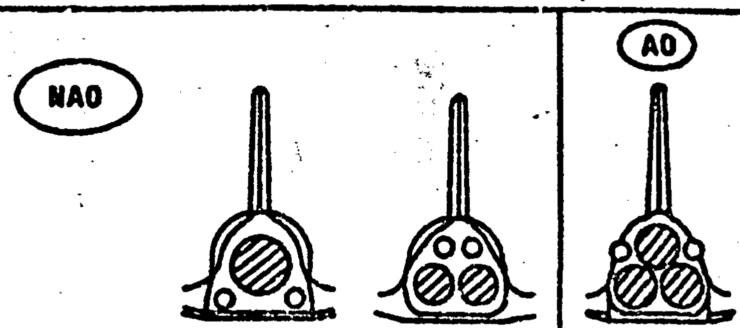
NAO vs AO, ISSUES

- Orbiter Characteristics Required For Abort-to-Orbit With One Engine Out:
  - Number of Engines
  - T/W
- Potential Weight and Cost Savings for NAO
- NAO Abort Footprint

A generic HO, 45K 15x40 orbiter with 2/3 SSME was size-and cost-trended, through a T/W range of 0.7 to 1.3 and V_{stage} range of 4K to 8K fps, for a 12-flight interim program using 2-stage 120 in. SRM boosters. The characteristics of the minimum cost three engine AO are shown. With one less engine, the NAO is 13K lb lighter in dry weight and 23K lb lighter in OLOW than the AO orbiter. Both vehicles stage at 7000 fps to provide heat sink booster compatibility.

For comparison with the two engine design, a single engine NAO at the same performance level is defined. Because of its higher specific weight, the one engine design suffers a penalty of 2K lb in dry weight and 7K lb in OLOW. The two-engine NAO configuration was therefore used as the basis for comparison with the AO vehicle.

NAO & AO ORBITER CHARACTERISTICS



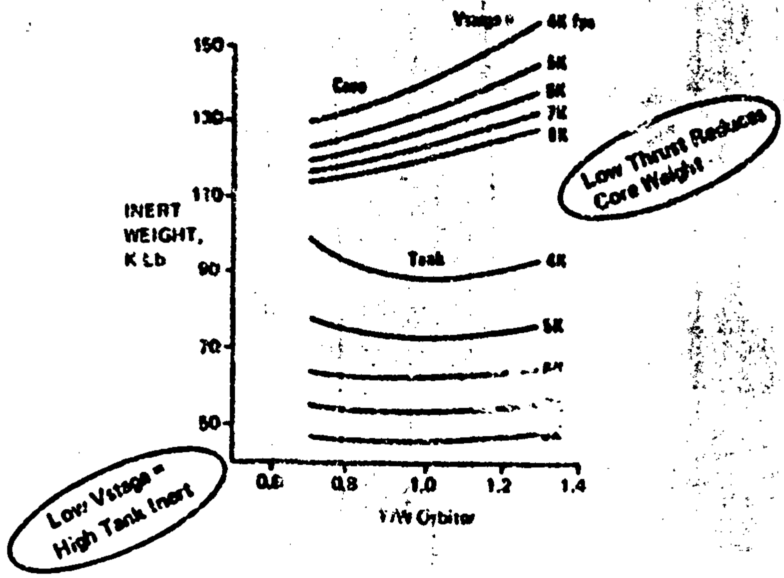
	NAO		AO
Core Dry Weight, Lb	118K	116K	129K
OLOW, Lb	844K	837K	860K
No. of HP Engines S.L. Thrust/Eng, Lb T/W	1 655K 0.9	2 325K 0.9	3 325K 1.3
Vstage, fps	7000	7000	7000

Orbiters: HO 15 X 40 With 45 K Payload

The results of the parametric size-trending is shown in terms of core and tank inert weights. Characteristically, both core and tank inert weights grow at an increasing rate as V_{stage} drops. Higher ideal ΔV and ΔV losses combine to increase propellant requirements non-linearly so as to drive tank weight and core engine weight up sharply.

At a fixed V_{stage}, core weight reduces as thrust drops; tank weight exhibits a reverse trend below $T/W \sim 1.0$, reflecting a propellant penalty based on higher ΔV losses, especially at low V_{stage}. However, at higher V_{stage}, where ΔV losses are less severe, tank weight is relatively independent of T/W.

NAO vs AO, ORBITER & TANK INERT WEIGHT

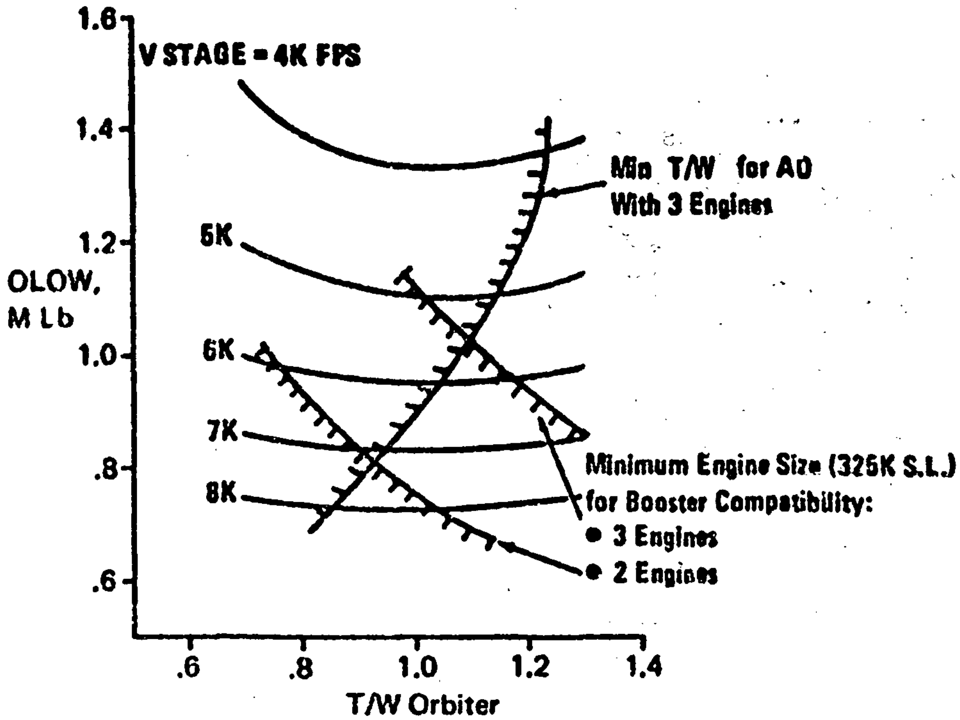


OLOW, as shown, roughly reflects the characteristics of tank rather than core inert weight, since propellant weight, which grows in unison with tank weight, is the major contributor to OLOW.

The "Min T/W for AO" line establishes the AO boundary; its shape reflects the fact that as V_{stage} decreases, ΔV losses increase and a greater T/W is required to achieve orbit. Three-engine vehicles to the right of this line have AO capability. Note that, above 7K fps V_{stage}, low T/W (< 0.95) provides AO capability.

In addition, fixed engine thrust lines are shown for two- and three-engine configurations. The thrust level per engine of 325K S.L. is estimated as the minimum size usable in a 12-engine, 7K fps V_{stage} booster, matching the orbiters under study. These minimum engine lines thus define boundaries for orbiters intended for ultimate use with SSME-powered boosters using common engines.

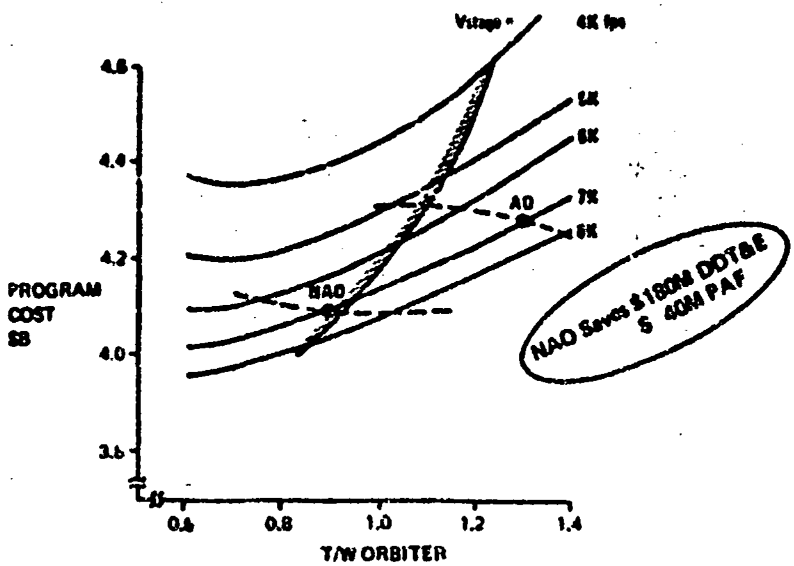
AO & ENGINE CONSTRAINTS



Total costs for a representative interim program, as shown, reflect the characteristics of core inert weight rather than tank weight and OLOW; core DDT&E is the major contributor to program costs rather than propellant and tank hardware for a 12-flight program.

Minimum cost AO (three engine) and NAO (two engine) designs are indicated, at 7K fps V_{stage} (to preserve heat sink booster performance compatibility) and at minimum engine size (to preserve booster SSME commonality). The DDT&E cost saving of $180M for the NAO is derived almost entirely from the deletion of an engine and its 13K lb dry weight advantage.

NAO vs AO, PROGRAM COSTS



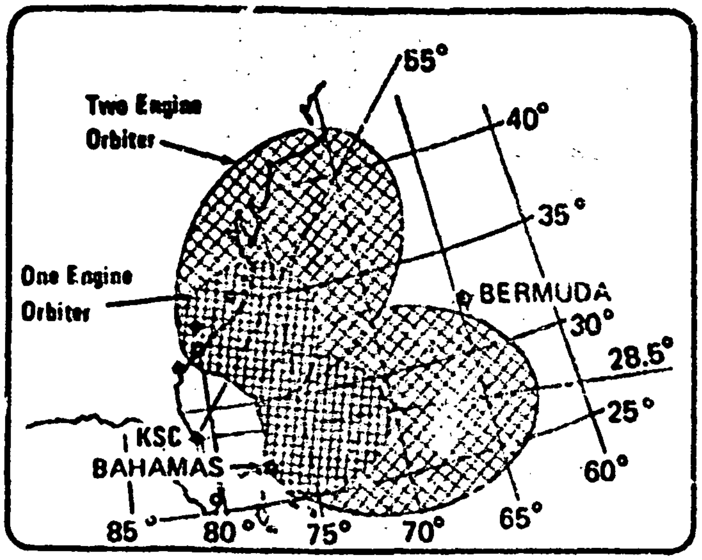
- 12 Flight Program
- No Final Booster or Alternate Landing Site Costs Included
- 2-Stage 120" SRM Booster

Reentry trajectories were developed for both the one- and two-engine NAO orbiters, based on one engine out at a nominal V_{stage} of 7K fps. The single-engine vehicle glides; the two-engine vehicle has powered flight with its remaining engine at Emergency Power Level (ERP), and achieves roughly twice the down range from separation as the one-engine orbiter. Comparative footprints are shown for launches into a 55 deg orbit where both orbiters reach CONUS, and a due East launch where both could reach a portion of the Bahamas. For a launch azimuth between 45 and 87 deg the two-engine vehicle can reach Bermuda, whereas the one engine vehicle is committed to water impact.

As opposed to the AO orbiter which can return to its launch site, both NAO vehicles would require alternate landing site activation and additional mission support effort.

NAO ABORT FOOTPRINTS
(ONE & TWO ENGINE ORBITERS)

- At Nominal Staging ~ 7K fps
- One Engine Out
- Thermal & Struct. Design Limits Not Exceeded



In summary, the two-engine NAO is preferable to one engine on the basis of weight and minimum launch azimuth restriction. Compared to the AO, the two-engine NAO offers a modest weight and potential cost saving. However, its cost advantage will be reduced when the effort to provide offsite recovery is factored in.

Since this study was performed on a single configuration type (HO with SSME and small payload), it is recommended that NAO characteristics be reassessed for the final shuttle configuration before the AO-NAO decision is made.

NAO vs AO SUMMARY
(HO – 15 x 40)

		NAO	AO	Δ
No. of Engines		2	3	
T/W		0.9	1.3	
Dry Weight, K Lb	Core	116	129	-13
	Tank	43	44	-1
	Total	159	173	-14
Costs $M		3640	3820	-180
	PAF	860	900	-40

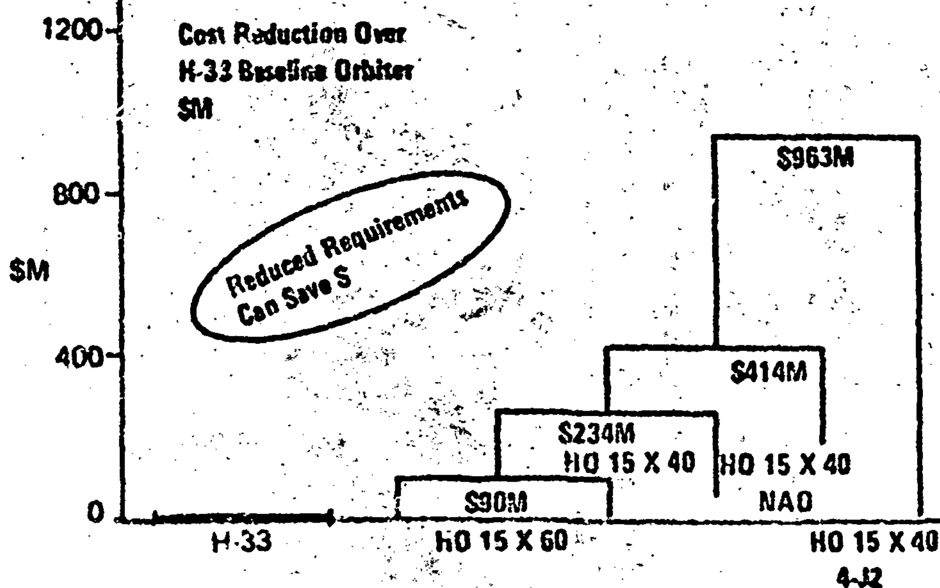
NAO vs AO

- NAO Offers Small Potential Savings With SSME

As an example of the reduction in DDT&E available as orbiter requirements are progressively relaxed, four cost-saving options are shown. Compared to the external LH_2 tank baseline (H33):

- Changing to the external LH_2 plus LO_2 tank design (HO 15 x 60) saves $90M
- Reducing payload bay length from 60 to 40 feet saves an additional $144M
- Reducing the number of engines from three to two, and relinquishing abort-to-orbit capability, produces a further reduction of $180M
- Finally, using existing J2 engines and deferring SSME development saves another $549M

EFFECT OF ORBITER REQUIREMENTS ON DDT&E TO FMOF



As a result of the orbiter requirements studies, we conclude:

- The HO orbiter has a higher cost per flight than the H; however, it offers a reduction in peak annual funding, and DDT&E costs, and some design and operational advantages (simpler propulsion system, and reduced tank dispersions after jettison). Further technical and tank cost analysis is required to make a final determination between the HO and H

- A 12-foot diameter payload bay saves few dollars ($6M in PAF, $19M in DDT&E). The reduced capability is not worth the saving

- A 40-foot long payload bay saves a more significant amount ($31M in PAF, $144M in DDT&E) and is worth considering if payload requirements, when fully defined, permit

- Payload bay growth is not attractive when potential interim vehicle cost savings are weighed against design risk and cost of rework

- NAO can provide worthwhile cost savings ($40M in PAF, $180M in DDT&E) at same V_{stage} and engine size as AO. However operational restrictions and cost of offsite operations may considerably dilute this advantage

CAN WE REDUCE COSTS IF WE CHANGE ORBITER REQUIREMENTS?

- *Only Hydrogen External, or Oxygen Too?*

  HO vs H
  - **Saves DDT&E Cost But Cost/Flight Higher**
  - **Technical Analysis Incomplete**

- *Small Payload Diameter, or Large?*

  12' vs 15'

- *Short Payload Bay, or Long?*

  ?
  40' vs 60'
  - **Saves $; requirements dominate**

- *Can We Start With Short Payload Bay & Grow?*

  ~~40 → 60~~

- *Abort Once Around or Gliding Recovery*

  AO vs NAO
  - **Has Potential**

INTERIM BOOSTERS

INTERIM BOOSTERS

We examined these candidates for an interim-booster.

BRIEFING OUTLINE

1. *Can we reduce costs if we change Orbiter requirements?*

INTERIM BOOSTERS

- **SOLIDS (SRM)**
  260" vs 156" vs 120"
- **EXPENDABLE PRESSURE FED LOX/RP vs STOREABLE**
- **S-IC**
  WET AND DRY CRADLE

2. *Which is 'best' interim Booster for phased program?*

3. *How can we reduce overall Shuttle program costs?*

Comparable costs were achieved by placing emphasis in these areas, which were chosen not only for their cost-driving characteristics but their susceptibility to inconsistencies due to differences in criteria/groundrules.

MAJOR CONCERNS

CONSISTENCY

- Test Plan
- Development Dollars
- Facilities
- Launch Operations

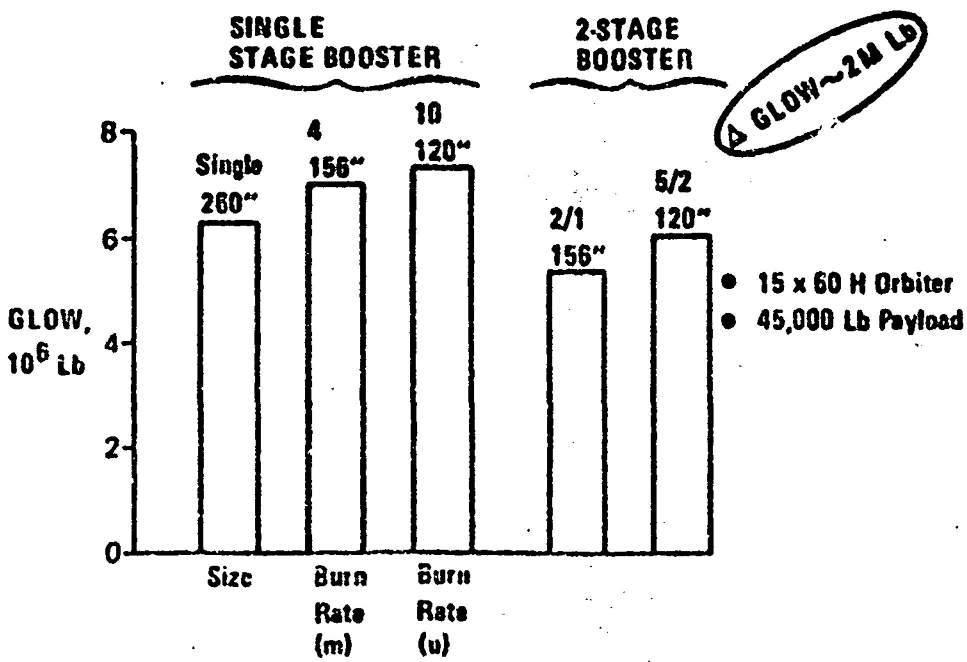
The test program summary for all candidates demonstrates this emphasis on consistency and clearly shows the developmental status of each candidate. The more mature status of both the 120 in. solids and the S-IC allowed reduction of their respective test programs.

INTERIM BOOSTER TEST PROGRAM SUMMARY

Major Ground Tests	120" SRM HO | H	156" SRM HO | H	EPFS HO	EPF LOX/RP HO	S-IC HO	S-IC H
Struct Static	Clustering Structure & Adaptor	Clustering Structure & Adaptor	Full Struct. Test Article	Full Struct. Test Article	Adaptor	Cradle
Full Scale Dynamic	Mated Vehicle	Mated Vehicle	Mated Vehicle	Mated Vehicle	Orbiter/ Adaptor	Orbiter/ Cradle
Clustered Static Firings	0	0	1	1	0	
Devel/PFRT Firings	3/5	5/5	New Engine	New Engine	Engine Firings	
Flight Test Unmanned Flights	1	1		1	0	

The reduction in size and the alleviation of undesirable motor characteristics were the prime factors in the two stage, small diameter SRM evolution. The 260 in. single motor, single stage exceeded reasonable size criteria. The 120 and 156 in. motors in the single stage application exhibited unacceptable/marginal burn rates.

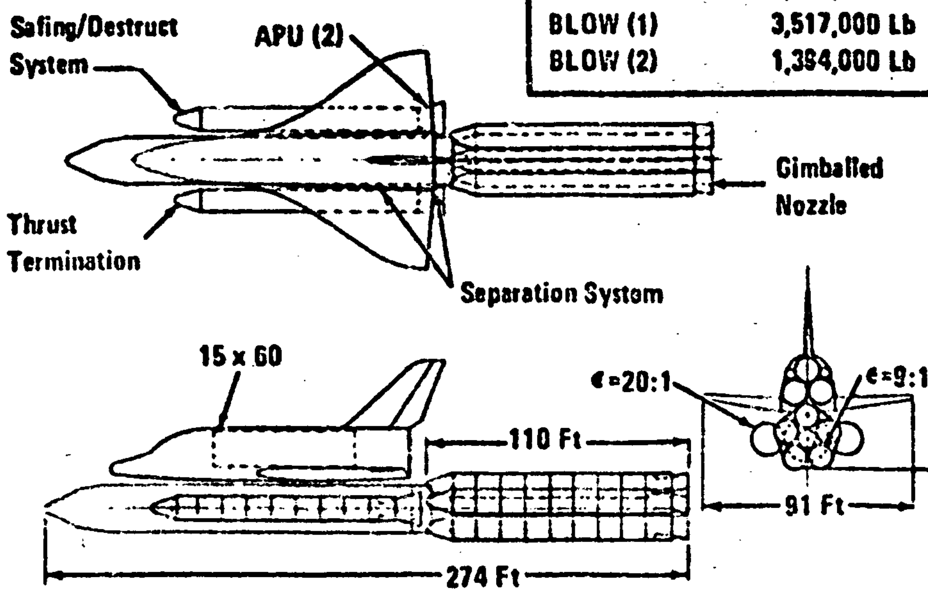
WHY 2 STAGE SRM?



The selected point design for the 120 in. SRM requires a total of seven modified T-IIIM solid motors. Five 1207 motors are clustered in the first stage while the two second stage motors are strapped on to the orbiter external tank. Second stage expansion ratio is 20:1 compared with a first stage ratio of 9:1 in order to increase performance capability. Regressive first stage burning, used to reduce dynamic pressure, causes the requirement for additional second stage performance.

2–STAGE 120" SOLID BOOSTER HO ORBITER

GLOW	6,039,000 Lb
OLOW	1,128,000 Lb
BLOW (1)	3,517,000 Lb
BLOW (2)	1,394,000 Lb

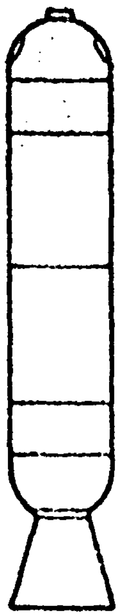


Technical emphasis was placed on the definition and costs of the subsystems required to make a solid rocket motor into a rocket stage. This is a major cost driver on the unit vehicle price, and comprises the hardware listed. Of these elements, clustering structure provides the largest cost impact. In addition to hardware, a substantial cost goes toward system integration and support software functions.

C2

SRM & IGNITER + STAGE EQUIPMENT = CLUSTERABLE STAGE

SRM & Igniter



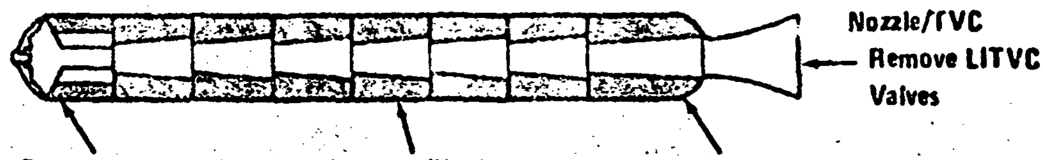
Stage Equipment

- Nose Cone
- Instrumentation
- Telemetry Transmitters
- Thrust Termination Stacks & Ordnance
- Forward Skirt
- Cluster Attach Struct. & Separation Mechanism
- Separation Motors
- Destruct System
- External Insulation
- Cluster Attach Struct.
- Aft Skirt
- Umbilical
- Base Heat Shield
- APU & Fuel Handling
- Nozzle Actuators & Servo Valves
- Control Electronics & Sensors
- Cables
- Plumbing
- Raceway

Clusterable Stage

The revised thrust trace was chosen for the 120 in. SRM since use of the existing grain (with less thrust, 20% longer burn time, and higher losses) would require an additional motor to meet performance requirements. The minimum development of the motor shown represents a lower cost than adding an additional motor/flight.

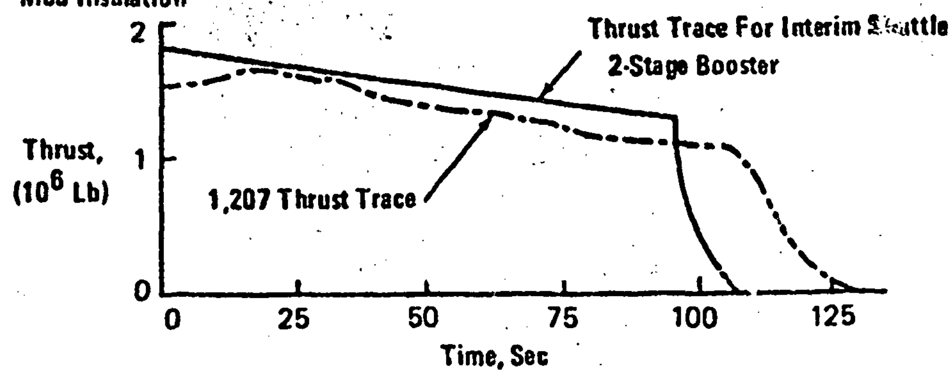
UTC 1207 MODIFICATION FOR INTERIM BOOSTER



Forward Closure
- Case Per UTC 1207
- Mod TT
- Mod Grain Shape
- Mod Propellant
- Mod Insulation

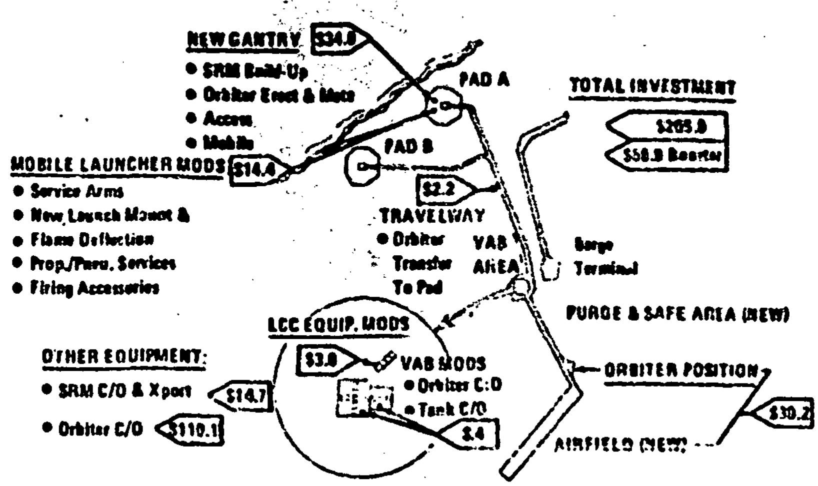
Segment (Typ)
- Case Per UTC 1207
- Mod Propellant
- Mod Inhibitors
- Mod Insulation

Aft Closure
- Mod Grain Shape
- Mod Nozzle Boss
- Mod Insulation



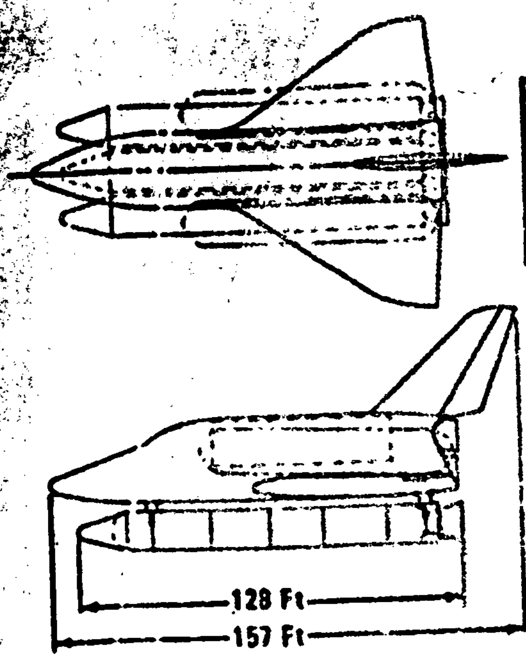
Launch Complex 39 modifications required in support of the 120 in. two-stage SRM booster were kept to a minimum, consistent with the program's interim nature. Essential modifications are concentrated in the changes to the mobile launcher, the requirement for a new gantry, and equipment to handle, transport and checkout the SRM booster.

LAUNCH COMPLEX 39
(INTERIM 120" 2-STAGE – HO ORBITER)

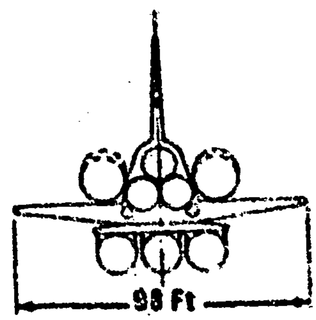


The two-stage 156 in. SRM booster, shown mated with an external hydrogen tank orbiter, requires a total of three new SRM's. Two of these form the f' st stage while the third motor (identical to the first stage motors) performs the second stage function. Although a size advantage is seen for the 156 in. SRM relative to the 120 in. SRM, additional motor development is required.

2 STAGE 156" SOLID BOOSTER H ORBITER

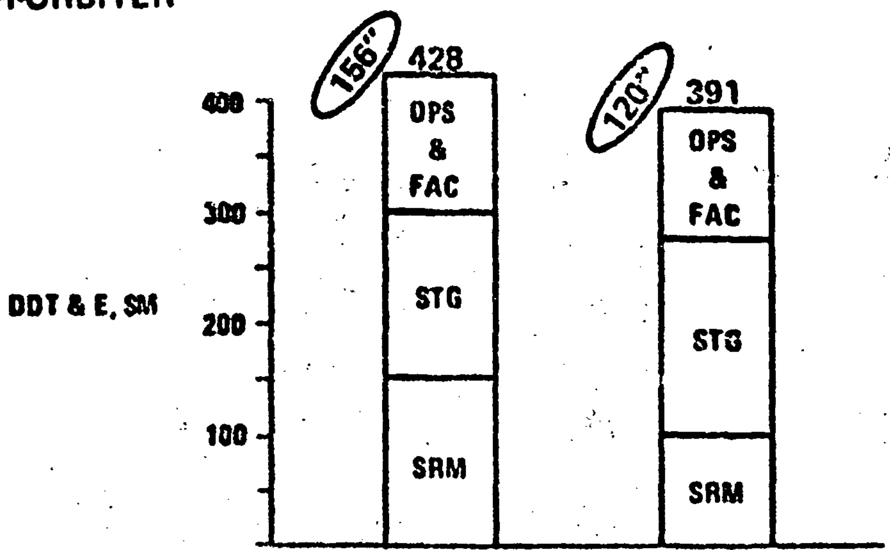


GLOW	5,276,000 Lb
OLOW	1,076,000 Lb
BLOW (1)	2,800,000 Lb
BLOW (2)	1,400,000 Lb



The 120 in. SRM advantage of lower cost motor development and operational facilities more than compensate for its higher "stage" (vs motor) costs. The higher "stage" costs derive from the complex structure required to cluster the large number of motors when compared to the 156 in. SRM.

SRM BOOSTER COMPARISON
H-ORBITER



	156"	120"
1st Stage SRM	2	5
2nd Stage SRM	1	2
BLOW - 10^6 Lb	4.2	4.9
Program $ (FMOF + 11 Flts)	707 M	697 M

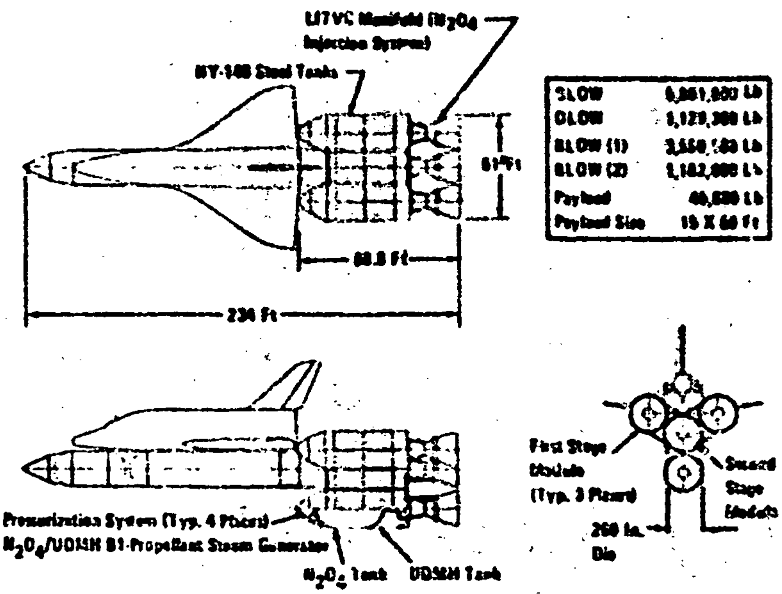
For expendable pressure fed (EPF) boosters, the propulsion design, a simple scalable engine, and the stage design philosophy for minimum cost, are the key drivers.

WHAT IS AN EXPENDABLE PRESSURE FED (EPF) BOOSTER?

- System Based On Simple Scalable Engine
- Simple Subsystems (Low Part Count)
- Low Cost Structure
- All Design Decisions - Cost, Not Weight

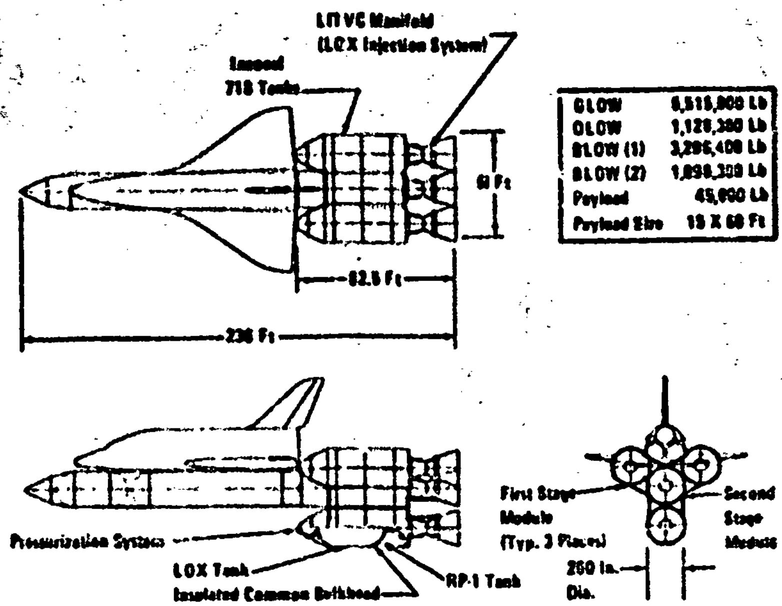
The EPF booster requires four, 260 in. propulsion modules in a two-stage arrangement to boost the HO orbiter. With all modules identical to reduce development requirements, three are used for the first stage and the fourth performs the second stage function.

EXPENDABLE PRESSURE FED N_2O_4/UDMH BOOSTER



The LOX/RP-1 pressure fed vehicle carries the same design characteristics as the N_2O_4 vehicle - four modules in a two-stage configuration. A key difference is the use of Inconel 718 for tank material as opposed to HY140 seen on the N_2O_4 vehicle. (HY 140 has unacceptable fracture toughness at LOX temperatures.)

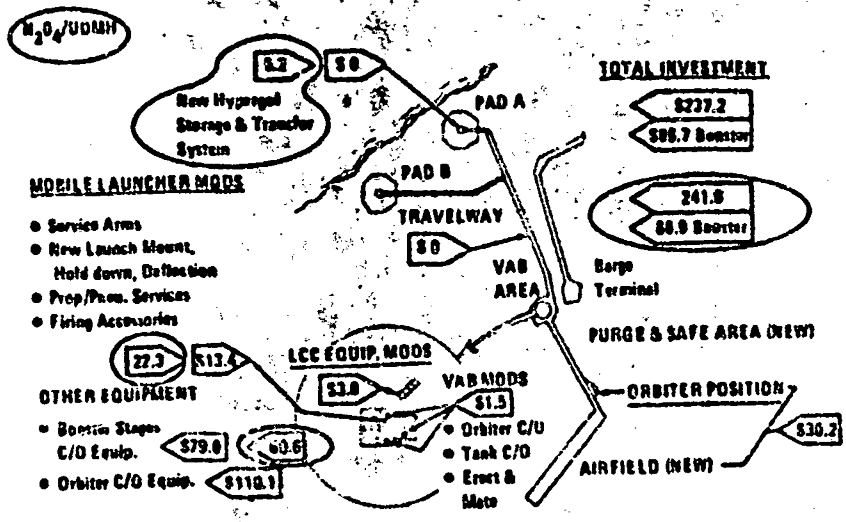
EXPENDABLE PRESSURE FED LOX/RP-1 BOOSTER



GLOW	6,515,800 Lb
OLOW	1,128,380 Lb
BLOW (1)	3,296,400 Lb
BLOW (2)	1,898,300 Lb
Payload	45,000 Lb
Payload Size	15 X 60 Ft

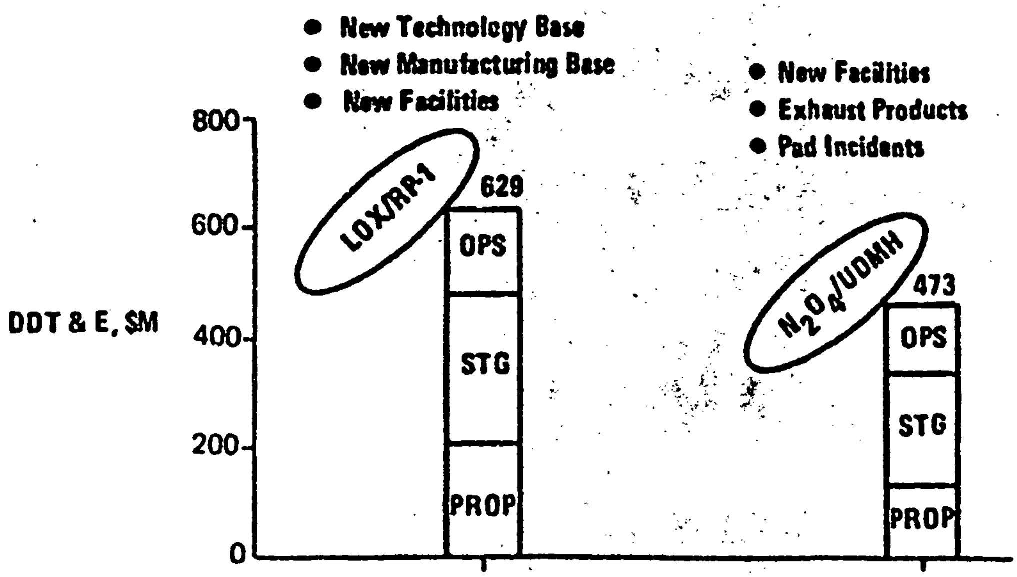
Changes to Launch Complex 39 for launching the EPFS are due to booster checkout and the need to handle large quantities of booster propellant. (The EPFS requirements for ground checkout are more costly than those for the solid motors.) The SRM's on the other hand require larger handling equipment expenditures than the EPFS.

LAUNCH COMPLEX 39 FACILITY MODS
(LOX/RP 2 STAGE – HO ORBITER)



The pressure fed LOX/RP-1 developmental status clearly puts it at a disadvantage when compared with the more mature N_2O_4 vehicle propulsion system. The increased stage costs for the cryogenic vehicle together with this propulsion system disadvantage make the N_2O_4 vehicle a clear choice over the LOX/RP-1 configuration.

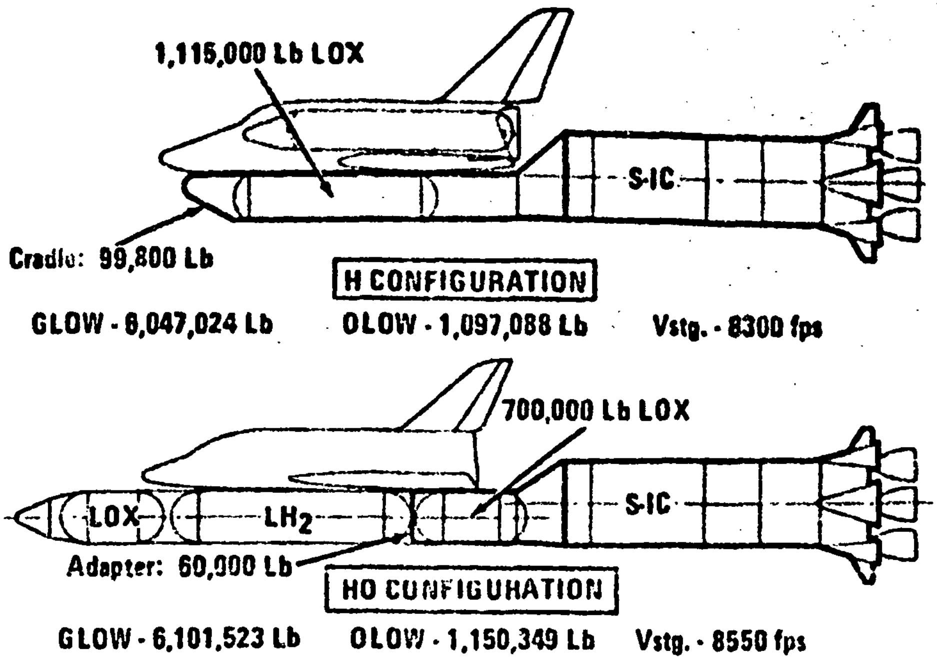
EPF COMPARISON



BLOW -10^6 Lb	4.4	4.7
Program $(FMOF + 11 Flts)	959M	699M

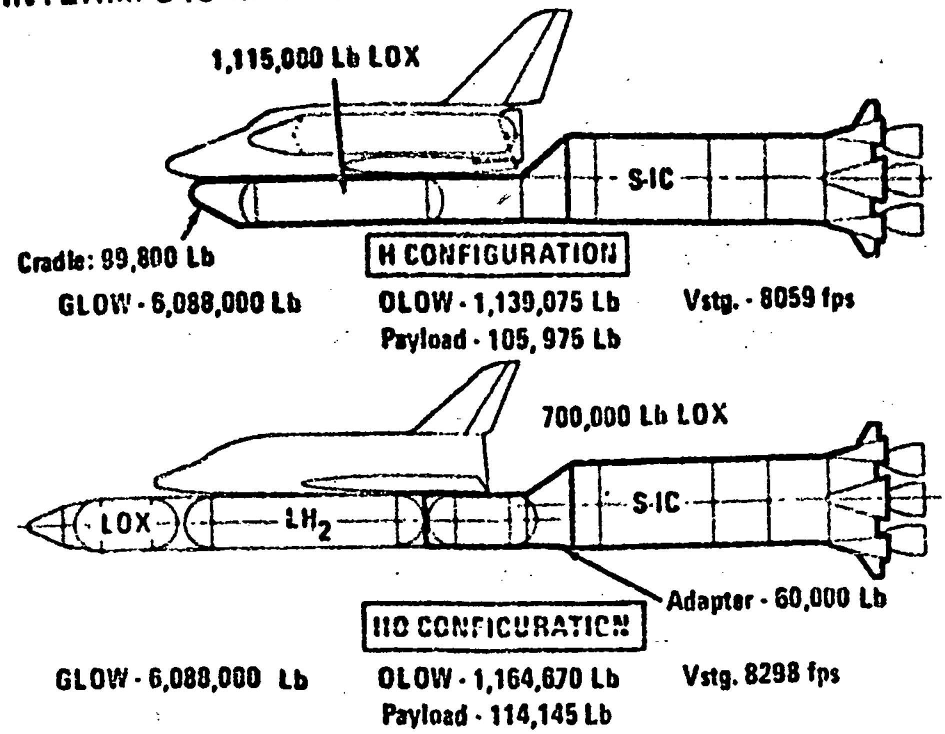
Initial study baselines for the S-IC were "wet cradle" configurations based on previous analyses for internal tanked orbiters. The "wet" cradle moves LOX forward to provide ample control authority with standard fins.

INTERIM S-IC BASELINE CONFIGURATIONS
(65,000 LB PAYLOAD)



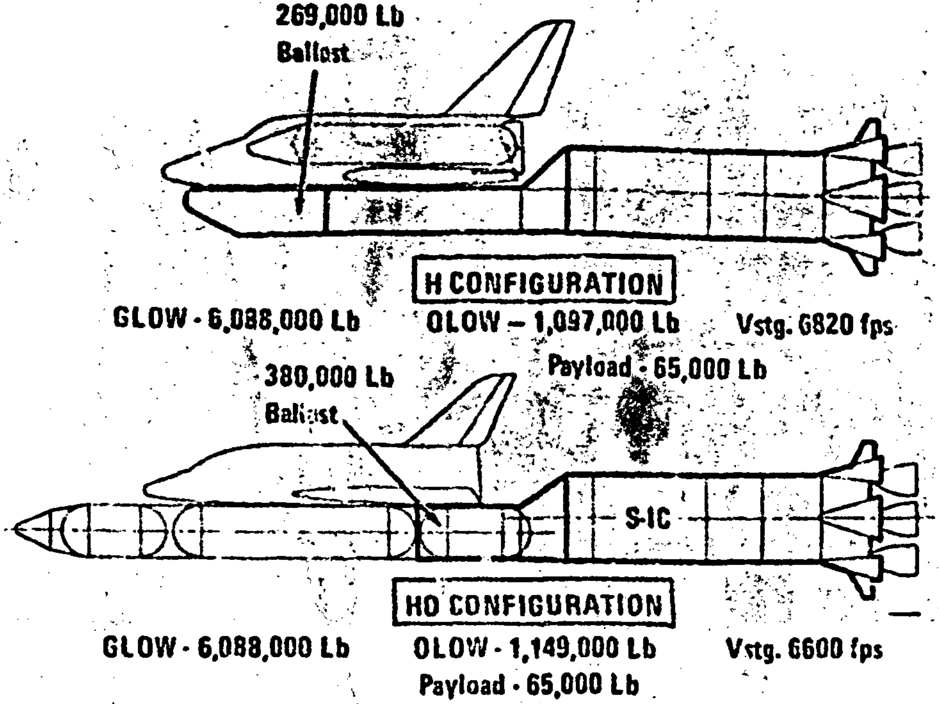
An evaluation of the baseline (65K payload) vehicle performance and trajectory data showed that the 50x100 n mi orbit could be achieved with approximately 35,000 lb of unused orbiter ascent propellant. Utilization of this propellant results in an additional payload capability of 41K for the H and 49K for the HO orbiter.

INTERIM S-IC MAX. CAPABILITY



Taking advantage of some of the excess performance capability of the S-IC led to the dry cradle configuration shown here. The dry cradle has sufficient inert ballast forward to assure boost control. These "dry cradle" vehicles shown were the vehicles costed.

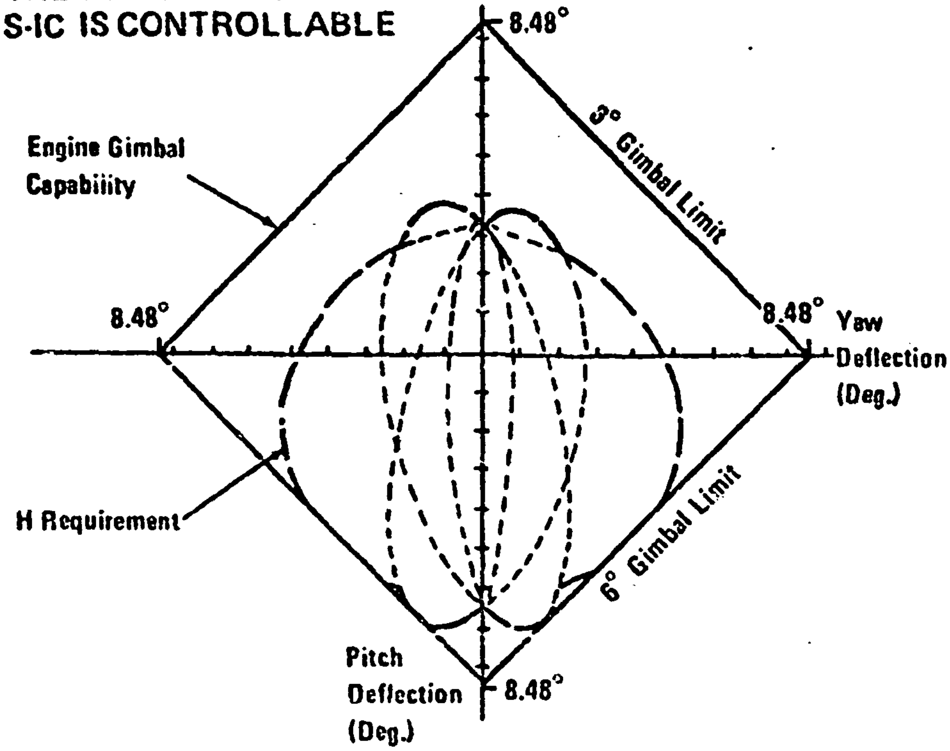
THE COSTED CONFIGURATIONS
DRY CRADLE



With the orbiter pitch plane oriented in the pitch plane of booster engines 2 and 4, sufficient control authority throughout boost is achieved within the booster engines' 6 deg square pattern gimbal capability.

The chart shows a composite of maximum outboard engine gimbal traces, all within the 6 deg square pattern. This chart was developed for the H dry cradle configuration.

THE INTERIM DRY CRADLE S-IC IS CONTROLLABLE

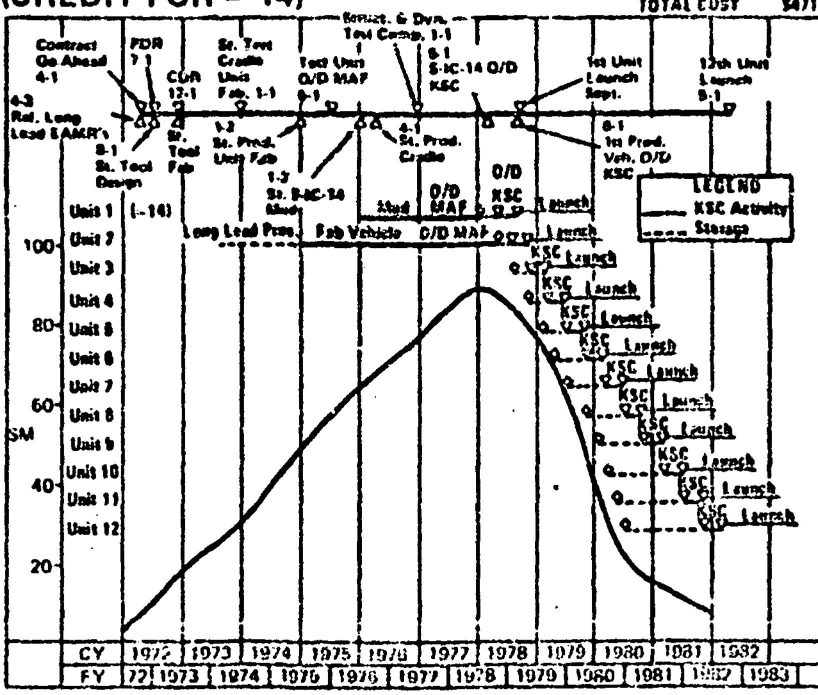


The interim S-IC program annual costs are shown to peak at $86.5M in mid FY 1978. Interim S-IC total program costs are $471.3M.

This program cost data is based on FMOF in September 1978 (using S-IC-14) plus 11 additional production vehicles manufactured at a rate sufficient to suit the schedule shown.

S-IC/DRY CRADLE – 12 UNIT BUY (CREDIT FOR – 14)

PEAK FUNDING $96.5M/1978
TOTAL COST $471.3M



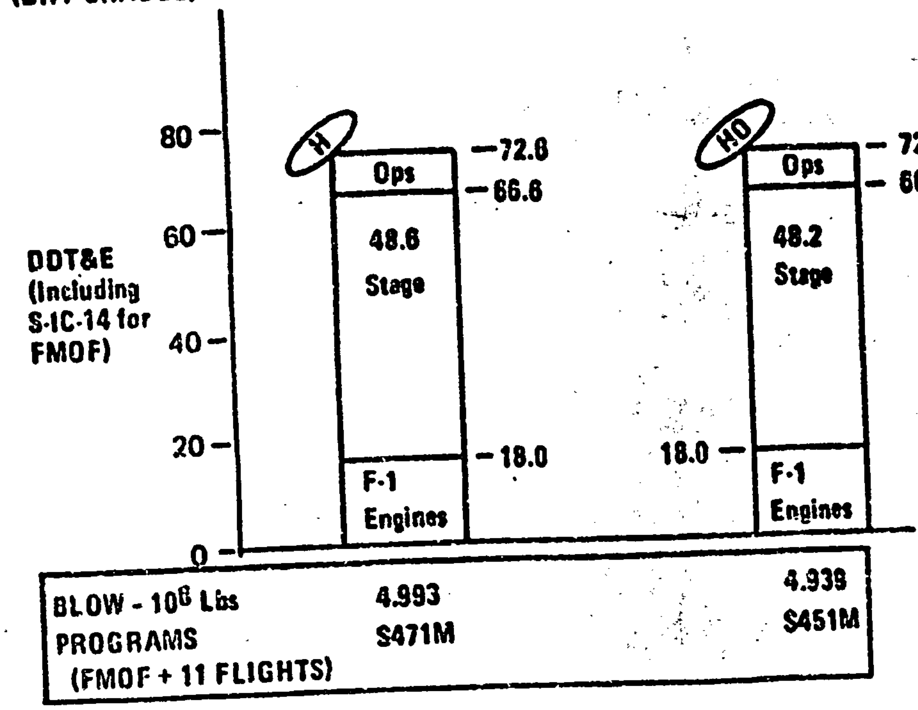
This summary shows the substantial decrease in the S-IC costs achieved in concurrence with MSFC since the June 1971 baseline. Prime factors are the dry cradle, launch, and SE&I costs for S-IC only (not Saturn), and the use of leftover hardware.

WHAT IS DIFFERENT ON INTERIM S-IC?

JUNE BASELINE (6-29-71) 15 UNIT BUY	SEPTEMBER BASELINE (9-1-71) 12 UNIT BUY
• Wet Cradle	• Dry Cradle
• Install F-1 Engines at MAF	• Install F-1 Engines at KSC
• Stage Checkout at MAF (Duplicates Subsequent KSC Checkout)	• Stage Checkout at KSC Only
• MAF Support to Launch Thru S-IC-20	• MAF Support to Launch Thru S-IC-21
• MSFC Estimate of Launch Operations	• BATC Estimate of Launch Operations
• 1971 $	• 1970 $
• KSC Logistics Spares Program Independent of MAF Production Program	• KSC Logistics Spares Program Provided by MAF Production Program Until Late in Launch Schedule
• Convert Stage Telemetry to UHF	• Use Existing VHF Telemetry
• Standard F-1 Engines	• Low Cost F-1 Engine Insulation
• Stage Identical to -15	• Cost Reduction Changes (MSFC Concurrence)
• System Engineering & Integration Included in Stage Cost	• SE & I Stage Only
• 15 Production Units	• 11 Production Units + Credit for S-IC-14
• Recurring Cost $63.9 M/Stage • Non-Recurring Cost $148 M	• Recurring Cost $38.2 M/Stage • Non-Recurring Cost $72.6

Examining cost variations for the S-IC DDT&E versus orbiter configuration shows them to be relatively insensitive to the H vs HO issue.

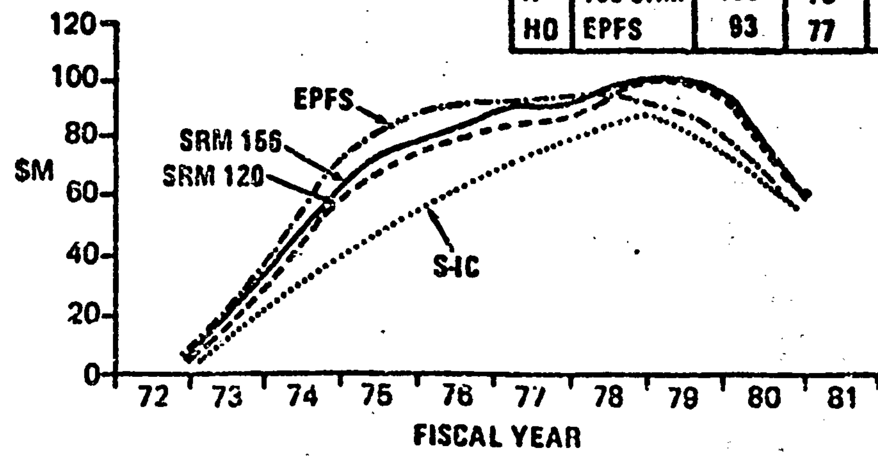
S-IC COST COMPARISON
(DRY CRADLE)



Comparison of interim booster annual costs shows that funding requirements are minimized through FY 80 with the Dry Cradle S-IC.

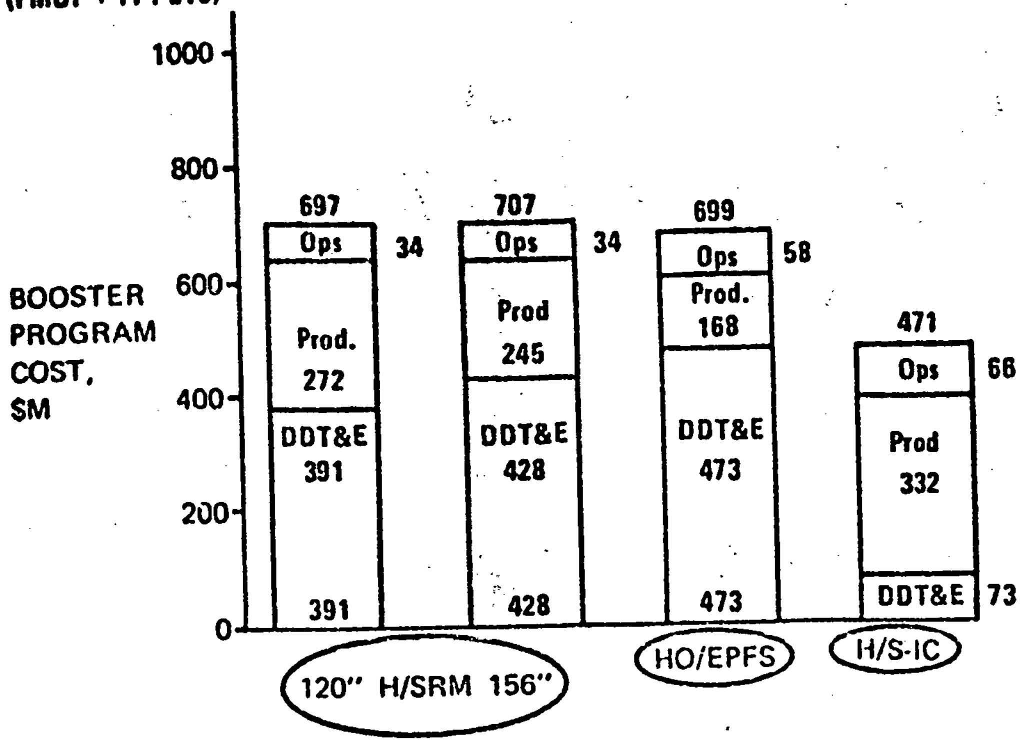
INTERIM BOOSTER ANNUAL COSTS
(FMOF + 11 FLTS)

Orb	Booster	Peak Fund	Yr	Total Prog
H	S-IC	86	78	471
H	120 SRM	100	78	687
H	156 SRM	100	78	707
HO	EPFS	93	77	699



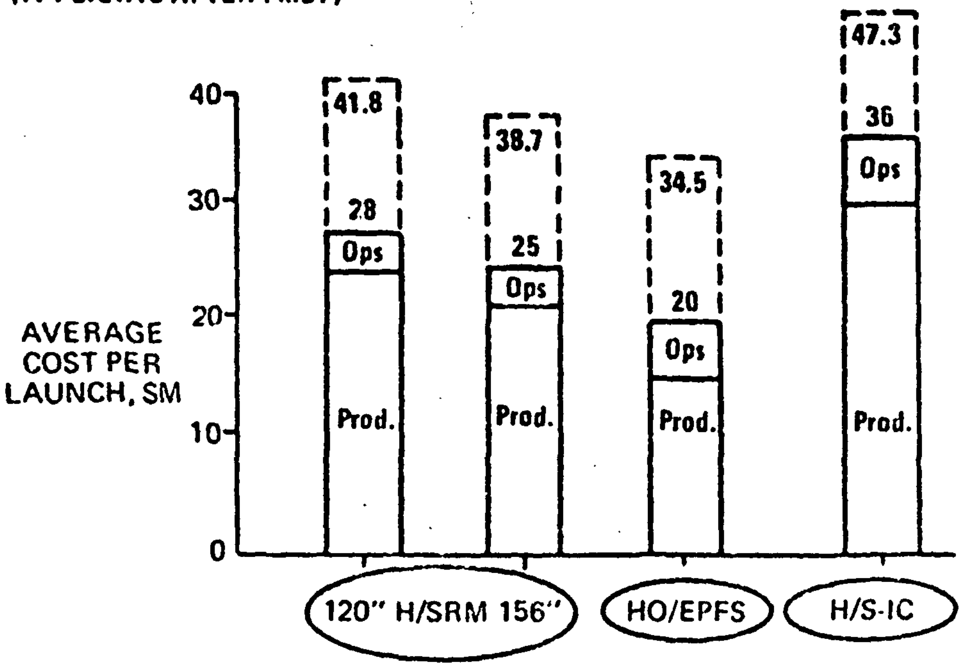
Total program cost breakdowns for each booster show the S-IC to be lowest because of substantially lower developmental costs. These savings in initial investment offset by a substantial margin the associated production and operational costs.

INTERIM PROGRAM COST, BOOSTER ONLY
(FMOF + 11 FLTS)



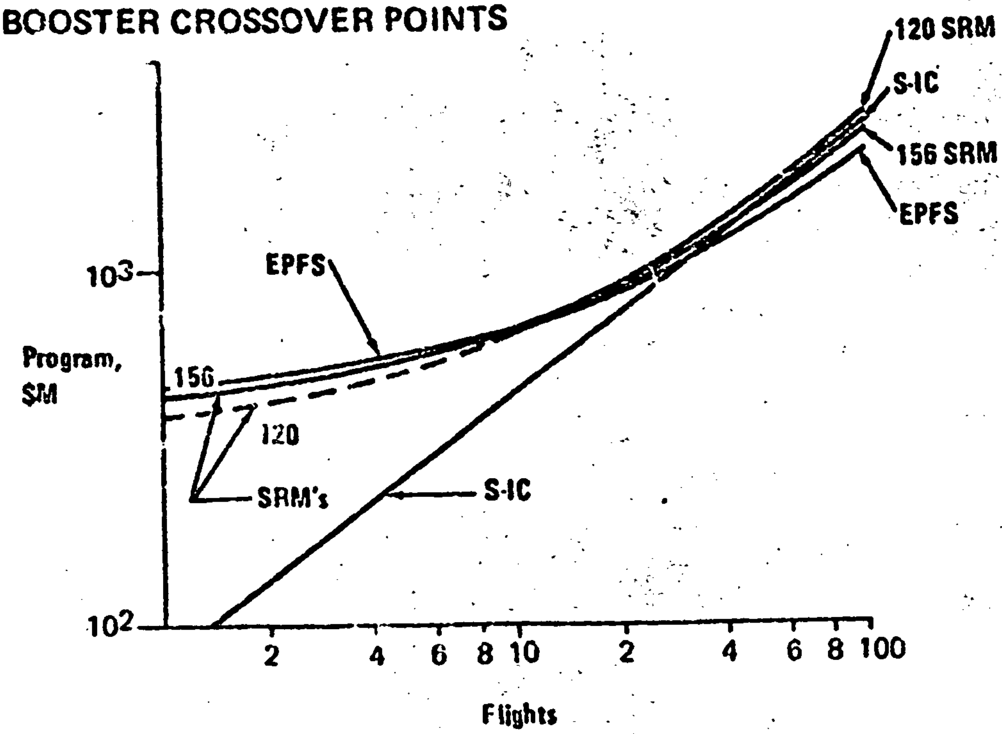
The lowest cost per flight of the interim boosters considered is the expendable pressure fed storable. Note that flight cost is inversely proportional to the initial development investment.

BOOSTER PLUS ORBITER AVERAGE COST PER LAUNCH
(11 FLIGHTS AFTER FMOF)



The initial low development costs of the S-IC allow it to absorb the higher per launch costs while maintaining its cost advantage for any program less than 30 flights.

BOOSTER CROSSOVER POINTS



The S-IC's cost advantages, due to its low initial investment, make it a clear winner for a true interim program. If the interim program extends, the S-IC still maintains its cost advantage up to 30 flights. Beyond this number, the alternative boosters are competitive, although none provide a significant cost margin out to 100 flights.

INTERIM BOOSTER CONCLUSIONS

- "True" Interim - S-IC Clean Winner
- "Extended" Interim - Choice Depends on Number of Flights

CONCURRENT PROGRAM COSTS

This section of the briefing addresses cost reduction of concurrent programs.

BRIEFING OUTLINE

1. *Can we reduce costs if we change Orbiter requirements?*

2. *Which is 'best' interim Booster for phased program?*

3. *How can we reduce overall Shuttle program costs?*

CONCURRENT PROGRAMS

H33 Baseline
- LO_2/LH_2 15 x 60

Limited Capability
- LO_2/LH_2 15 x 40 · HO/NAO · low cost subsystem · SSME

Saturn Technology
- B1/B11 Capability 15 x 60

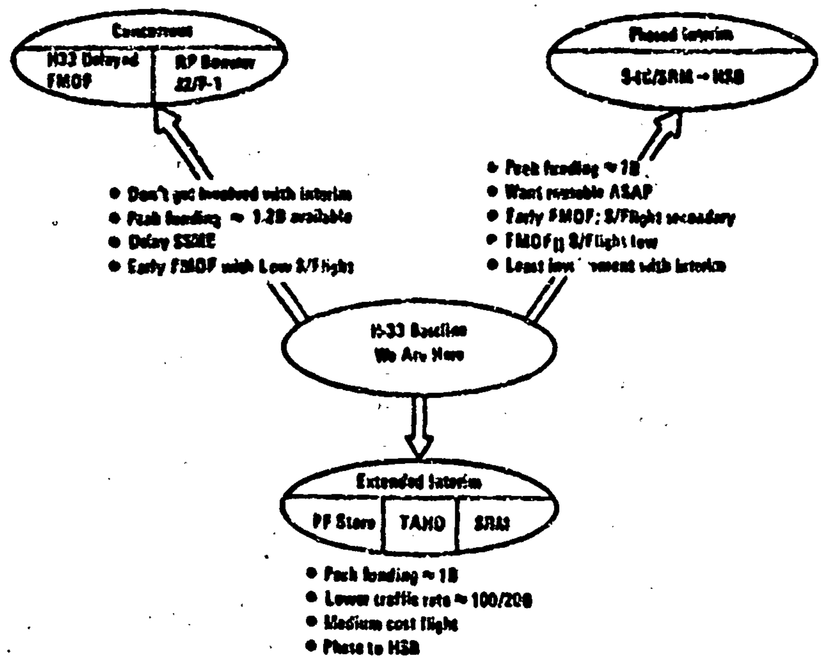
Starting from the baseline H33 space shuttle (external hydrogen tank orbiter/heat sink booster) there are three available courses for reducing overall shuttle program costs.

First we can retain the concurrent program and reduce peak funding with a delay in the first manned orbital flight (FMOF). Alternatively we could delay the space shuttle main engine and proceed with existing Saturn technology using a J2 engined orbiter with an F-1-engined RP booster.

Secondly we can select a phased interim program which permits us to meet the scheduled FMOF for the orbiter with an expendable booster thereby delaying development of the reusable booster until we have passed peak orbiter funding requirements. Thus the interim program is planned at the outset to become a fully reusable system as soon as available funding will allow.

The third alternative is the extended interim program. In this program the expendable boosters would be able to operate economically at lower traffic rates (100/200 flights vs 445 flights) and thus permit a longer delay in phasing the reusable booster.

HOW CAN WE REDUCE OVERALL SHUTTLE PROGRAM COSTS?

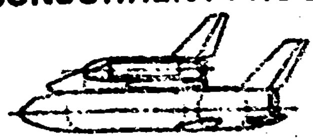


For the three reusable orbiter/booster concurrent development programs shown, the key issues are:

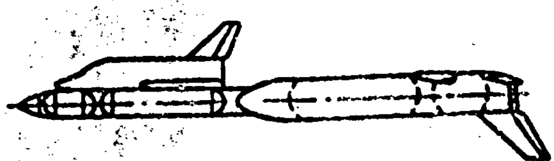
- To what extent can peak shuttle funding be reduced if we maintain basic requirements for planned FMOF and the five orbiter/four booster operational fleet?

- To what extent can peak shuttle funding be reduced if we changed basic program requirements for FMOF, full system capability and the shuttle main engine?

CONCURRENT PROGRAMS

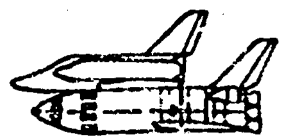


H33 Baseline
LO_2/LH_2
15 X 60
SSE



Limited Capability
LO_2/LH_2
15 X 40
SSE

NAO-HO/HSB



HJ2/R–S-IC
LO_2/RP
15 X 60
J2/F1
BI/BII SUBSYS

We have updated our basic assumptions to the MSC cost and schedule groundrules for the extended study. The new program milestones (namely phase C/D go ahead and FMOF) allow four more months for overall development than those considered in our July H33 Cost and Schedule Estimate Plan. We have added another production orbiter and booster to obtain the stipulated fleet size of five orbiters and four boosters. No learning has been considered for the manufacture of reusable flight vehicles. A 90% learning curve was used for estimating expendable tank costs. We have also assumed that no ground test hardware will be recycled for operational use.

KEY COSTING ASSUMPTIONS

	Extended ASSC Study
No. of Operational Flights	445 Reusable Booster
No. of Operational Launch Sites	1 (KSC)
No. of Launch Pads	2
No. of Development Flight Test Orbiters/Boosters	2/2
No. of Operational Orbiters/Boosters	2/2+3/2=5/4
Major Assembly	Michoud
Flight Test	KSC
Phase C/D Go-Ahead	Apr. 72
First Horizontal Flight	May 77
First Manned Orbital Flight	Sept. 78
Costs in 1970 Dollars	Yes
Contractor Effort (Less Fee)	Included
Primary Engine Costs	Included
Airbreather Engine Costs	Included
Commonality	Main Rockets Only
Government-Funded Facilities	Included
- Launch - Refurbishment	
- Recovery - Flight Test	
Propellant Costs	Included
Training Costs	Included
Government Operations & Test	Excluded
Shuttle Program Management & Integration	Contractor Support

There are three ways to reduce peak funding requirements for a reusable orbiter/booster concurrent development program.

First, defer the manufacture of production vehicles not required to meet FMOF past the peak funding years. This requires that the program be initially planned and managed from the outset to meet this cost objective. For example, we would plan to make dual use of key manufacturing personnel by relocation to support flight test operations, maintain tooling and equipment, maintain flight vehicles, etc. Accordingly, we would also delay material procurement to meet the production schedule.

Secondly, delay the scheduled FMOF to a point where a slowdown and corresponding stretch out in the overall development effort will also reduce peak funding.

Third, plan the initial flights with low cost vehicle subsystems. Low cost subsystems are synonomous with reduced systems capability, such as designing for a two day APU-battery mission instead of a seven day fuel-cell mission. Alternatively, it could also mean designing with existing technology and not upgrading at a later date, such as switching from a cryogenic ACPS to a hypergolic ACPS.

APPROACH TO REDUCE PEAK COSTS

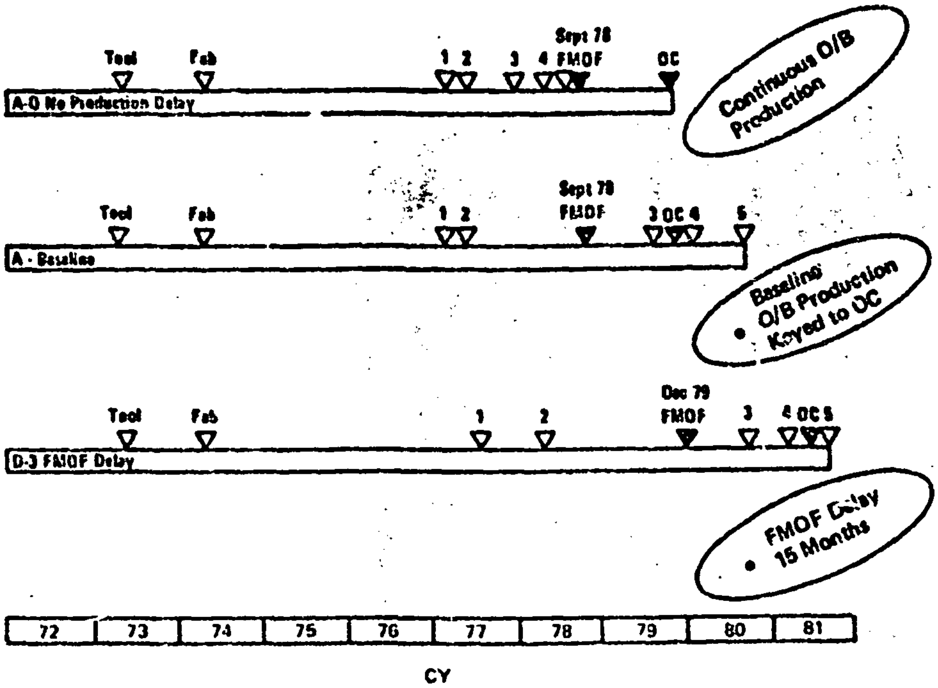
- Defer Production Vehicles
- Delay FMOF
- Use Low Cost Subsystems

There are two general categories of available schedule options, those that maintain the baseline September 1978-FMOF (Option A) and those that delay FMOF (Option D-3).

A further alternative within the baseline FMOF milestone lies in varying the production rate planned for the three additional orbiters (and two additional boosters) required for operations but not needed for development flight testing. The choice lies in maintaining a continuous production line between flight vehicles 2 and 3 versus a planned production delay keyed to the operational capability (OC) milestone. In the continuous production schedule all major articles, including the structural and propulsion test articles, are built on four month centers. In our baseline Option A schedule, only the development, ground, and flight test articles are built on four month centers. Fabrication of the third flight vehicle starts 26 months after the second flight vehicle. The remaining vehicles are then built on seven month centers.

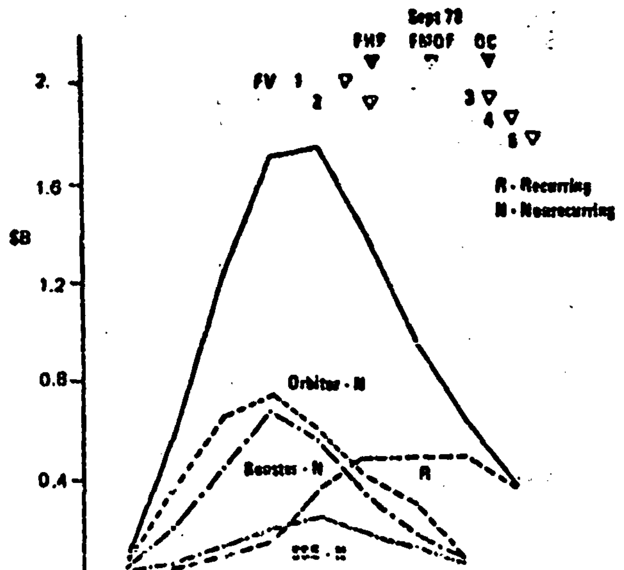
In Option D-3, FMOF was delayed to the end of the decade (December 1979). With 15 months added to the overall development schedule we maintained the same requirements for engineering/tooling information release as Option A and then stretched out the remaining development activity. As a consequence, the fabrication of major development articles was extended to 10 month centers with 30 months between the 2nd and 3rd flight vehicles and 5 month centers for the subsequent production vehicles. As in the baseline schedule we scheduled the 1st flight vehicle for FHF and the 2nd vehicle for FMOF.

H33 – 15 x 60 PROGRAM SCHEDULE OPTIONS



The peak funding relationship for the H33 baseline schedule is illustrated by this chart. Peak funding ($1.72B) occurs in FY 76. This is attributed to $1.38B in non-recurring costs for development of the orbiter, booster and main engine and $.34B in recurring production. The close relationship between completion of the two flight test vehicles and peak funding is also shown.

H-33 — 15 x 60 BASELINE, COST/SCHEDULE
(OPTION A)



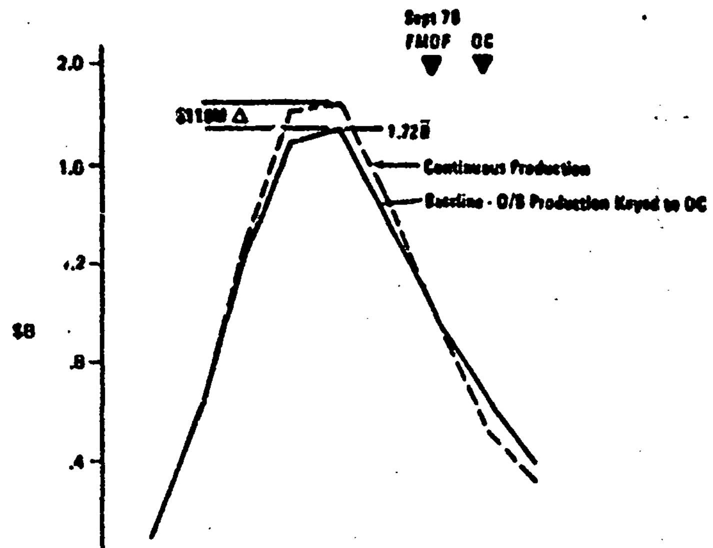
CY		72	73	74	75	76	77	78	79	80	81

FY	72	73	74	75	76	77	78	79	80	81-88
$B	.00	.69	1.23	1.70	1.72	1.37	.95	.63	.37	1.72

DDT&E to FMOF	5.48B/ 7.10B
Peak Annual Fund	1.72B
Total Prog	10.3B
Cost/Flt (I/R)	4.47M

The fiscal advantages of keying orbiter/booster production to the planned OC milestone are evident when compared to a program schedule geared to maintain continuous production. Scheduling the 3rd flight article to meet the September 1979 milestone for OC will save $110M in peak funding.

H33 – 15 x 60 BASELINE OPTION A COSTS

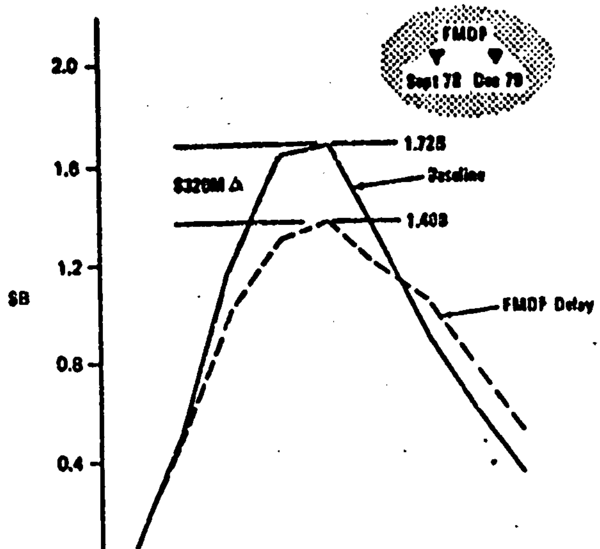


CY		72	73	74	75	76	77	78	79	80	81
FY	72	73	74	75	76	77	78	79	80	81-89	
$B	.06	.59	1.26	1.80	1.83	1.43	.93	.60	.29	1.72	Continuous Prod
	.08	.59	1.23	1.70	1.72	1.37	.95	.63	.37	1.72	Baseline

One of the methods of reducing peak year funding is to extend the FMOF date and stretch program costs over a longer time period.

The dotted line on the accompanying chart depicts the effect of a 15-month schedule extension to FMOF. Note that the early year's funding requirements are not significantly changed from the baseline while a reduction of $320M in the peak year is achieved.

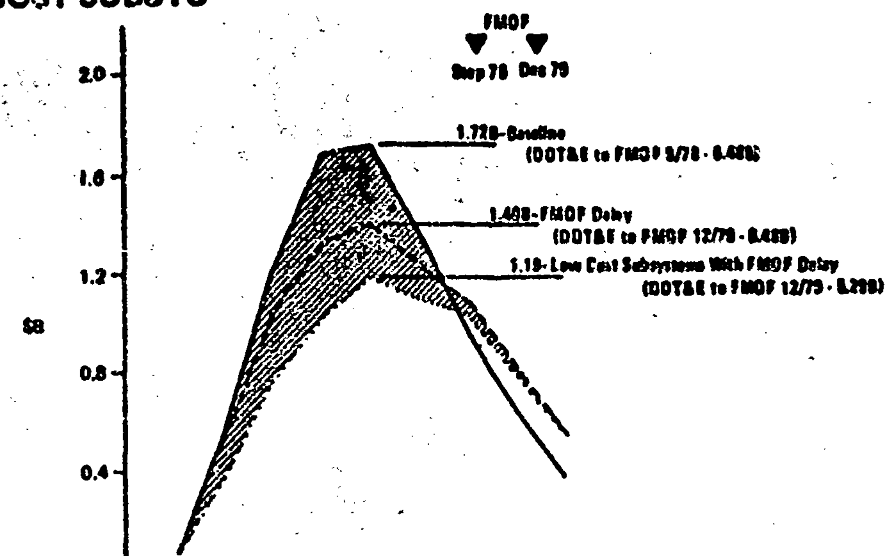
H33 – 15 x 60 EFFECT OF FMOF DELAY



CY		72	73	74	75	76	77	78	79	80	81	
FY	72	73	74	75	76	77	78	79	80	81-89/90		
$B	.06	.50	1.23	1.70	1.72	1.37	.95	.63	.37	1.72	Baseline	
	.06	.64	1.04	1.32	1.40	1.22	1.09	.81	.67	/2.28/	FMOF Delay	

Lowest H33 funding requirements are obtained by combining the FMOF delay with the use of low cost subsystems on both orbiter and booster. The net effect lowers the peak funding requirement to $1.19B. As a consequence of using low cost subsystems the development cost to FMOF is also reduced to $5.29B.

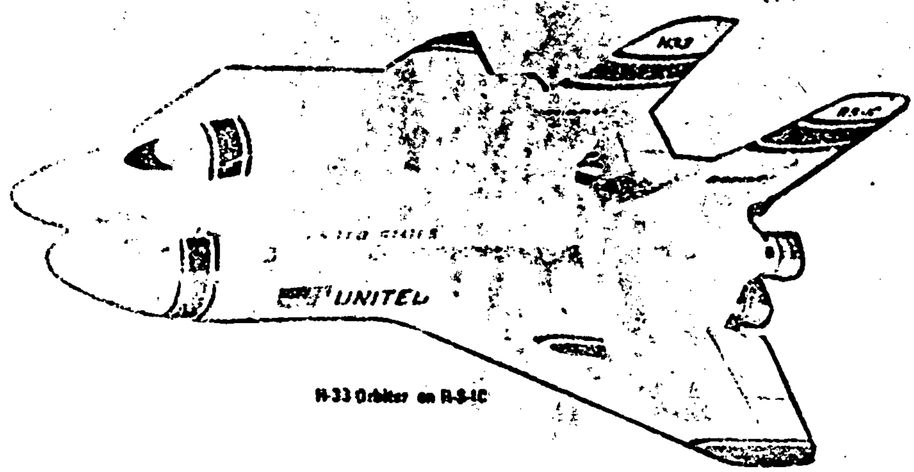
H 33 – 15 x 60 WITH FMOF DELAY & LOW COST SUBSYS



CY		72	73	74	75	76	77	78	79	80	81
FY	72	73	74	75	76	77	78	79	80	81-80/89	
$B	.06	.50	1.23	1.70	1.72	1.37	.95	.63	.37	1.72/	Baseline
	.06	.54	1.04	1.32	1.40	1.72	1.09	.81	.67	/2.28	FMOF Delay
	.05	.36	.76	1.01	1.19	1.10	1.04	.79	.67	/2.28	Low Cost Sub Systems

The team has developed a shuttle program concept which we believe to be superior to any of the alternatives previously examined. It combines low peak funding, low cost per flight when operational, and both booster and orbiter reusability at FMOF in 1978.

HJ2 ORBITER/R--S-IC BOOSTER



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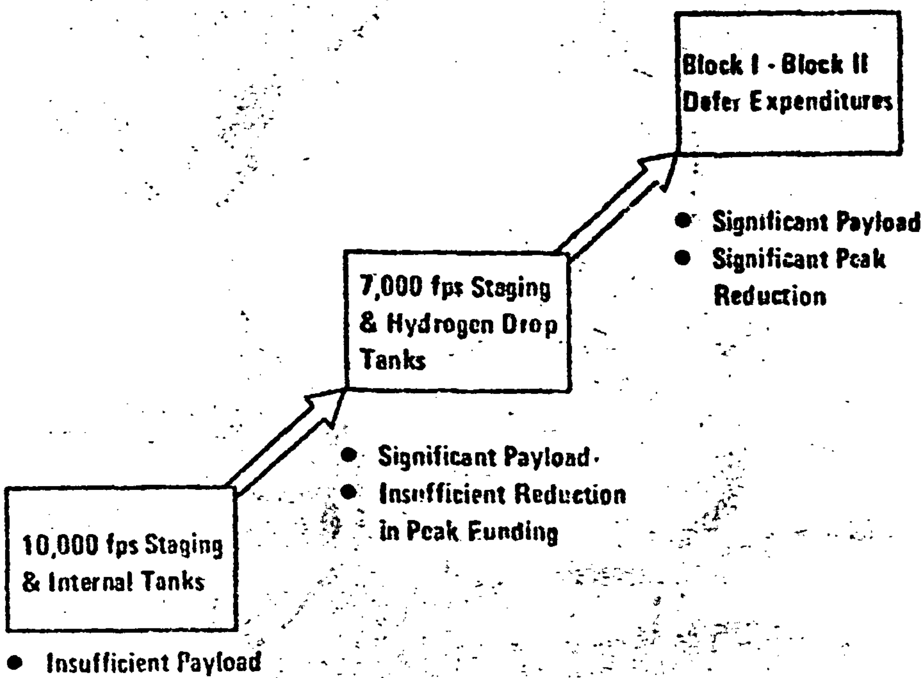
Early studies of a reusable LOX/RP shuttle booster concentrated on internally tanked orbiters with high staging velocity (around 10,000 feet per second). Use of the RP booster resulted in insufficient payloads to meet shuttle requirements. The hydrogen drop tank orbiter concept which allows lower staging velocity (around 7,000 feet per second) and which allows heat sink booster design permitted the use of the S-IC size and liftoff weight with adequate payloads. This system however did not provide the target reduction in peak funding. The further introduction of a block program approach to subsystems, selectively deferred or eliminated certain DDT&E expenditures to a more acceptable funding level.

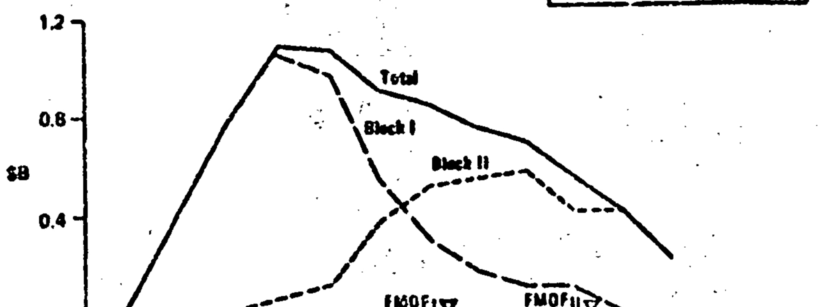
REUSABLE S-IC (R–S-IC) CONCURRENT PROGRAM EVOLUTION



The low peak funding ($1.09B) associated with this program stems largely from the use of existing Saturn engines and the application of a low cost Block I/Block II subsystem concept. Early Block I operations are conducted with the four vehicles used during flight test (i.e., two orbiters and two boosters). During FY 75 peak funding, Block I costs ($1.06B) encompass $529M for the orbiter, $424M for the booster, $17M on the J2/F-1 engines and $90M for flight test preparation and management. Block II subsystems are introduced in the remaining production vehicles (three orbiters and two boosters) scheduled to phase into operation by September 1981.

CONCURRENT HJ2/R–S-IC
(3 YEAR BLOCK I SUBSYSTEMS OPERATIONS)

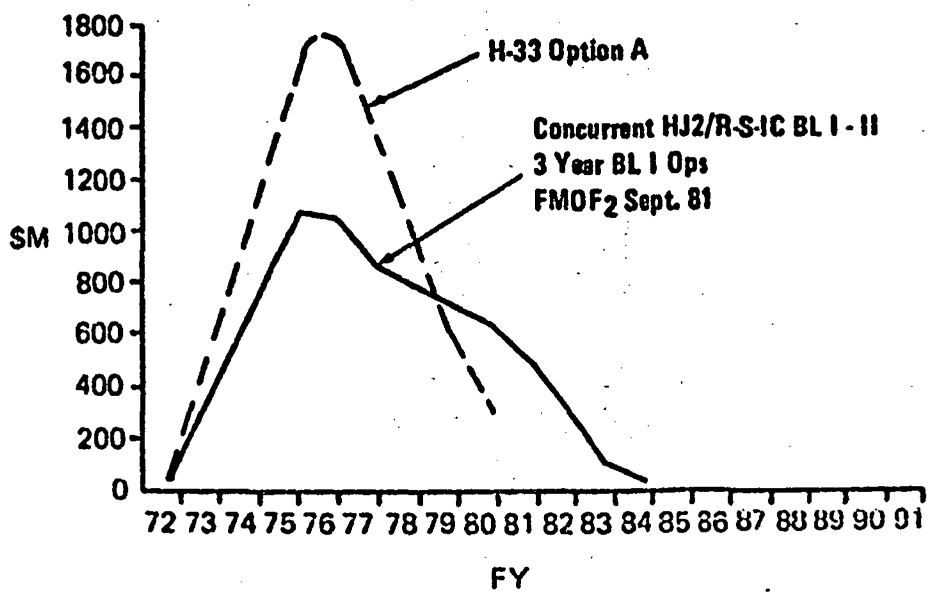
DDT&E to FMOF	3.65B/ 5.31B
Peak Annual Fund.	1.09B
Total Prog	9.17B
Cost/Flt 12 @ 3/yr	15.8M
445 Flt	4.3M



CY	72	73	74	75	76	77	78	79	80	81	82	83	84	85
FY	72	73	74	75	76	77	78	79	80	81	82	83	84	85-93
$B	.06	.39	.78	1.09	1.07	.90	.83	.75	.69	.53	.36	.19	.12	1.41

When compared to the baseline H33 program fiscal savings are achievable with the HJ2/R-S-IC program both during early build up and the period of peak funding. The HJ2/R-S-IC program saves $1.16B in total program and $.63B in peak funding requirements.

REUSABLE S-IC BLOCK I - II PROGRAM COST COMPARISON



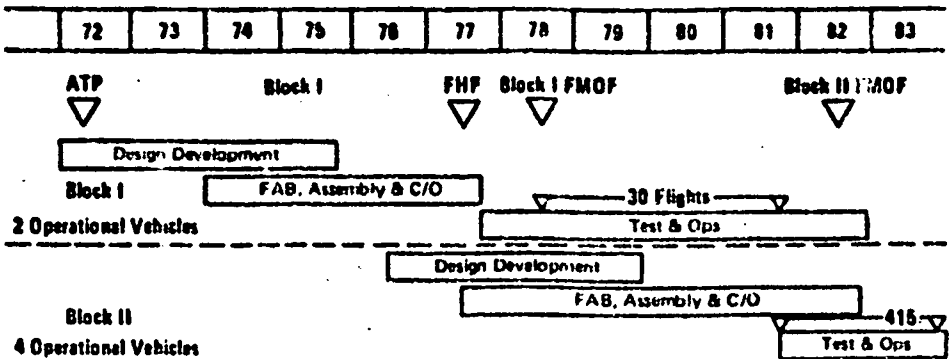
Groundrules for formulation of the program were developed to allow a "product improvement" growth from Block I capability to later full operational capability, while providing maximum suppression of peak funding and program cost to reach Block I FMOF. The groundrules minimize dead-end developments.

REUSABLE S-IC BLOCK I BOOSTER CONFIGURATION GROUND RULES

- Maintain Heat Sink Structure Concept
- Structure Adaptable to Full Block II Mission Capability Without Change
- "Concurrent" Development of Orbiter and Booster
- Maximum Utilization of Apollo Hardware & Development Experience (Engines, Propulsion System, Etc.)
- Use F-1 and J2 Engines
- No Redesign of Distributive Systems for Block II
- H Type Orbiter With Piggyback Mount
- One Month Turnaround
- Maintain S-IC Tank Size & Geometry

Developments to be deferred were selected on the basis ..f significant savings in Block I development cost while not impacting utility of the Block I system. The Block I system can carry sufficient traffic to prove out the basic capabilities of the shuttle system and provide growth in utility to attain the low cost, mission flexibility goals of the shuttle.

REUSABLE S-IC BLOCK I-II PROGRAM



		Block I	Block II
BOOSTER	Main Engines	5F-1's	5F-1As
	Avionics	Commercial Based, Min. On-Board C/O	Automatic Landing & Complete On-Board C/O
	ACPS	Storable Bi-Propellant	Same
FACILITIES	Checkout	Delay Mult. Pos.	Implement Mult. Pos.
	Pads	1	2
ORBITER	Main Engines	5J2's	J2S
	Avionics C	Commercial, Space, and Military Based, Min. On-Board C/O	Automatic Landing & Complete On-Board C/O
	ACPS	Storable Bi-Propellant	Same

Examination of all potentially reasonable alternatives for Block I engines led to the selection of F-1/J2 as sufficient in performance for Block I while providing minimum cost.

REUSABLE S-IC BLOCK I PROGRAM
(ENGINE SELECTION ALTERNATIVES)

Engines Block I 5 on Booster 5 on Orbiter	P/L 28.5° n mi Orbit	Est. Engine Cost thru Block I Operation $\$10^6$	Advantages & Disadvantages
F-1/J2	47,000	61.8	Fall Back, BEO* Least Cost Growth Risk Max Use of Available Engines
F-1A/J2S	81,500	217.7	Eliminates OMS Engine Requirement No Added Block II RDT&E Cost
F-1A/SSE (250K)	107,500	671.8	No Added Block II RDT&E Cost
F-1A/J2	65,500	113.2	No Added Block II RDT&E Cost
F-1/J2S	64,000	166.3	Fall Back, BEO* Eliminates OMS Engine Requirement

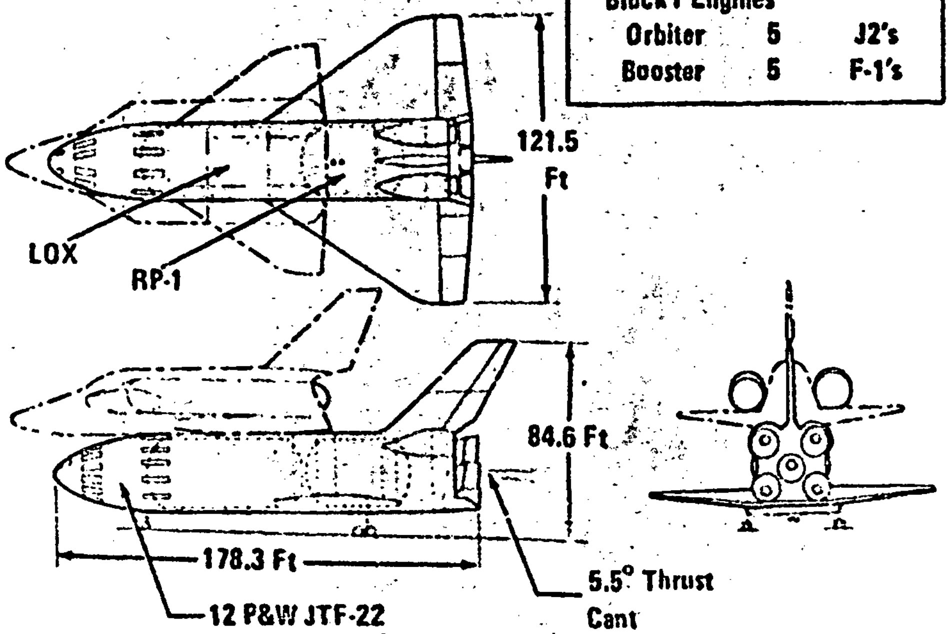
*Booster Engine Out

NOTE: Orbiter Design Payload 65K

The selected configuration is compatible with maximum use of existing S-IC structure and systems. It retains S-IC tank volumes and propulsion systems. The delta wing can be integrated with the S-IC structural arrangement. In comparison to a hydrogen booster, its dry weight (553,400 lb) is 15% greater, but its size is smaller, with 22% less total wetted area.

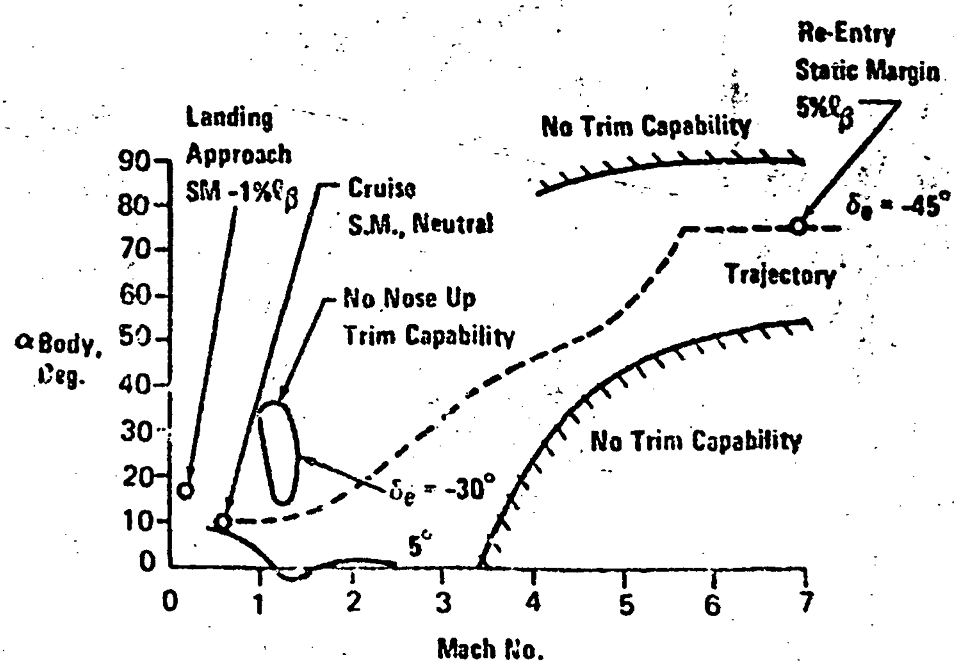
REUSABLE S-IC MODEL 979 049A

GLOW	6,470,700 Lb	
OLOW	1,166,500 Lb	
BLOW	5,304,000 Lb	
Block I Engines		
Orbiter	5	J2's
Booster	5	F-1's



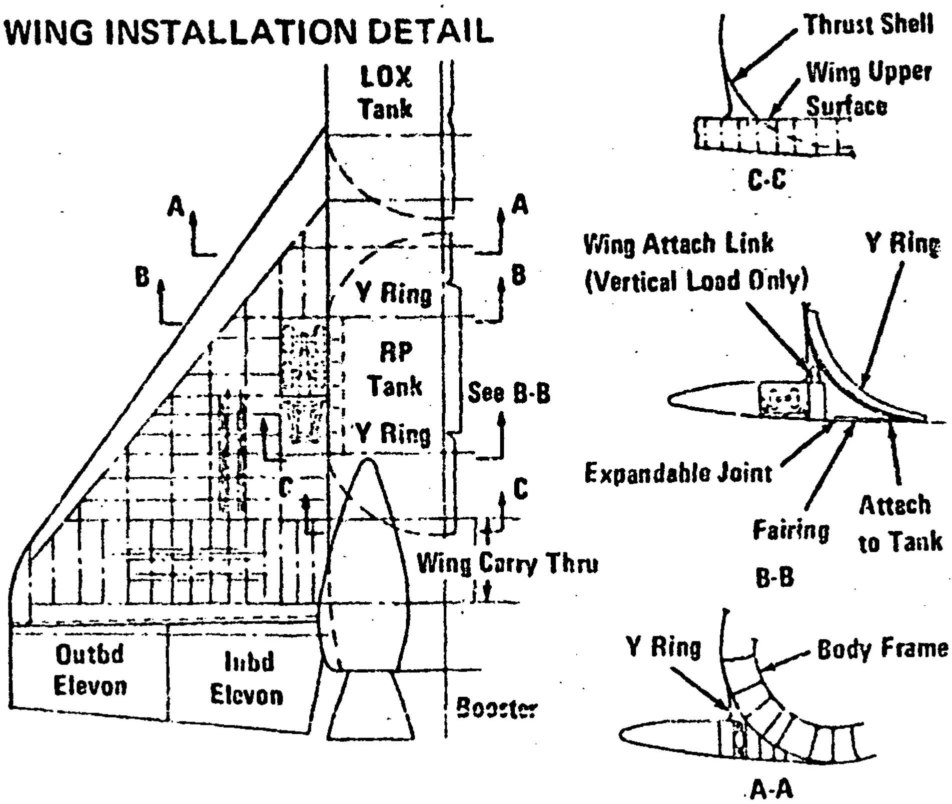
The aerodynamic configuration is stable and trimmable. Similar to a delta-wing orbiter, it provides some commonality with the orbiter in configuration development.

REUSABLE S-IC BOOSTER
LONGITUDINAL TRIM & STABILITY



The structural design has been developed in sufficient detail to assure integrability with the S-IC, define major structural interfaces, and to determine applicability of recosting S-IC hardware. These designs have been analyzed for structural loads and heating histories based on ascent and descent trajectories generated for the R-S-IC system.

WING INSTALLATION DETAIL



Configuration layout and subsystem requirement studies have been performed on the reusable S-IC configuration. These studies have verified that use can be made directly or with small modification of several important components taken from the Apollo program. The thrust structure will have to be modified to account for the 5.5 deg cant of the engine and for attachment of the vertical fin.

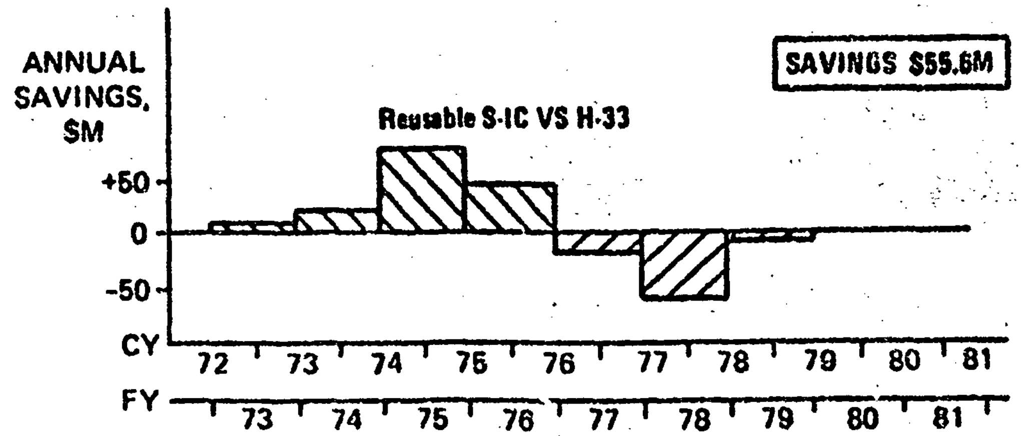
APOLLO COMPONENTS UTILIZATION

BOOSTER	% USED
• F-1 Engines	100
• LOX Tank	100
• RP-1 Tank	90
• Fwd Skirt	0
• Intertank	0
• Thrust Structure	25
• Fairings & Fins	0
• Propellant Delivery System	90
• Propellant Pressurization System	100
• Subsystems	75
• Retro-Rockets	0

ORBITER	
• J-2 Engines	100

Cost differences from the baseline H33 Booster were developed in detail, and analyzed by association with specific changes to ensure understanding and credibility. These changes included those that would increase costs as well as those that would decrease costs. As an example, the design and construction of a forward fuselage to accept the greater number of airbreathing engines (12 instead of 8) resulted in a cost increase of $12M as shown.

BOOSTER AIR FRAME COST SAVINGS
(DOES NOT INCLUDE TOOLING)



Program Change	Savings
• No Horizontal Stabilizer	$ 34.2M
• 12 A/B Engines Instead of 8	$-12.2M
• Simpler Thrust Structure Because of Fewer Main Engines	$ 19.4M
• Simpler Uninsulated RP Tank Instead of LH_2 Tank	$ 20.2M
• Other	$ -6.0M

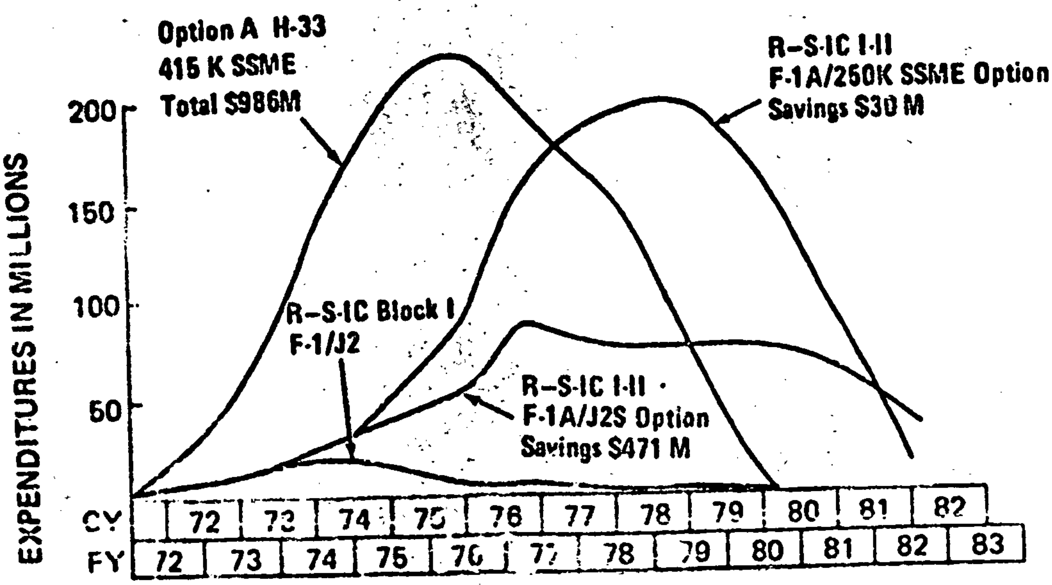
The direct engineering effort included in the reusable S-IC program cost estimate is compared to actuals for the 747, S-IC and SST programs.

REUSABLE S-IC BOOSTER DDT&E
TOTAL DIRECT ENGINEERING EFFORT
(COMPARISON WITH 747, S-IC, AND SST PROGRAMS)

Program	Total Hours (Millions)	Remarks
747	17.1	Thru 1st Airplane
SST	18.1	Design, & Test of 2 Prototype Airplanes Plus 100 Hours of Flight Test
S-1C	15.1	To First Launch
H-33	40.9	Option A to Sept. 1981
R-S-1C	37.7	Block II FMOF (Sept. 1981)

Applying the proven Apollo technology engines to the shuttle can cut engine costs in half. As shown, the F-1A and J2S engine modifications can be performed at a low funding level over a long period. Basic performance of the F-1A and J2S have already been demonstrated (Ref. NAS 8-18734 and NAS 8-19). The remaining task is to demonstrate engine life extension.

MAIN ENGINE COST
REUSABLE S-IC vs H-33



Approximately equal, and acceptably low costs per flight, are demonstrated by the fully operational H33 (SSME orbiter and booster) and the 049 Block II (F-1A booster/J2S orbiter) shuttle systems.

AVERAGE BLOCK II COST PER FLIGHT, $M

	H-33 OPT A	049 Block II	Δ$	Reason
Propellants	0.45	0.24	-.208	Cheaper Propellant
Vehicle Refurbishment	1.35	1.54	+.194	Additional ACPS, F-1A Refurbishment No GH_2 Safing or LH_2 Tank Refurbishment
Facility Refurbishment	.58	.43	-.155	
Ops & Support	.81	.81	—	
Expendable Tanks	1.06	1.07	+.010	Larger LH_2 Tank
System Engineering & Management	0.22	0.21	-.01	
Total	$ 4.47	$ 4.31	-.167	

PARAMETRIC COSTS

The breakdown of HB2/R-S-IC Block I development cost to FMOF shows the result of using low cost vehicle subsystems and existing main engines. The total Block I-II cost to Block I FMOF is $5.31B.

BLOCK I DDT&E (FMOF 1978)

Booster	$1.501
Orbiter	2.083
Engines	0.061
Total	$3.645

We have concluded on the basis of the foregoing analysis that the reusable S-IC booster mated with an external hydrogen tank J2 orbiter is best able to retain NASA shuttle program goals within probable funding limitations. It provides a development program which meets performance requirements, makes maximum use of Apollo/Saturn experience and available off-the-shelf equipment, has no major dead ended developments and has significantly lower funding and technical risk than any concurrent program analyzed to date. In addition the reusable Block I-II program results in lower total program costs and operational cost per flight (under $5M).

C3

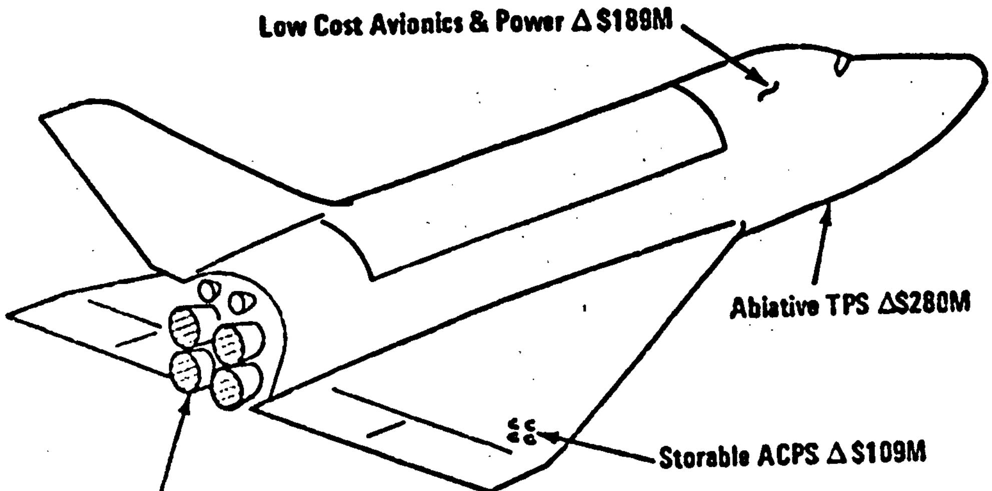
CONCLUSION

REUSABLE S-IC/BLOCK I-II PROGRAM

- Reduces Peak Funding $600M (DDT&E $3,645B (Block I)
- Reduces Program Risk
- Makes Maximum Use of Available Hardware
- Eliminates Dead Ended Development
- Reduces Cost ~ $1B
- Cost/Flight Close to H-33

There are a number of areas in which the Block I-II approach can be applied to the orbiter to achieve appreciable savings ($1.39B) in the early part of the program. Several of these (avionics, power, ACPS) gain from common usage between the orbiter and booster.

USE OF EXISTING TECHNOLOGY FOR ORBITER



Δ $ Cost Reduction DDT&E
Over H-33 $1.39B

The design definition was utilized in a bottoms-up cost analysis to determine funding level reductions and cost savings over the comparable H33 (hydrogen booster) program. Roughly two thirds of the savings are due to the LOX/RP-1 selection, with the other third attributable to the Block I-II reusable S-IC program approach.

REUSABLE S-IC BLOCK I - II SAVINGS OVER H-33 BASELINE PROGRAM

	Peak Year (1976) Savings
Booster	$202.3M
• Main Propulsion	45.0
• Air Frame	75.0
• Avionics	65.0
• Tooling	100.0
• ACPS	40.0
• Other	-122.7
Orbiter	205.7
Main Engine	153.0
Flight Test & Operations	15.6
Mgt.	26.4
Total Savings	$603.0

In addition to the reusable S-IC approach for getting costs down (as discussed on the preceding pages) we evaluated what could be achieved by pulling out all the stops on requirements reductions for a cryogenic (high pressure engine) concurrent program. This chart demonstrates a typical example of this limited capability, all cryogenic approach:

- Payload bay is decreased in size
- Payload weight is decreased
- Low cost subsystems are used
- Abort-to-orbit capability is relinquished
- FMOF is delayed 15 months

Relaxing all of these constraints reduces peak annual funding from the baseline peak of $1.7B to $1.12 B and total program costs by $1.86B.

LIMITED CAPABILITY SYSTEM

MAD-HO/HSS

Payload	15 X 40
	45K/25K
GLOW	3360K
OLOW	827K
Core Dry	118K

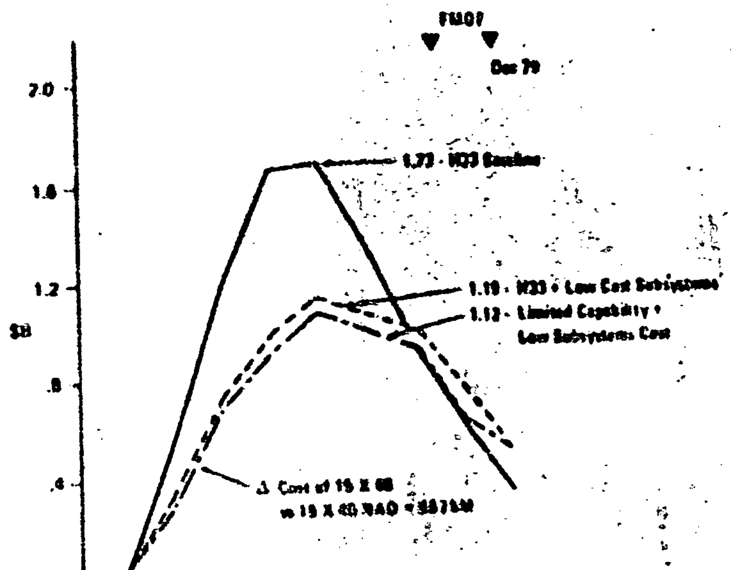
DDT&E to FMOF	4.97B/
	6.41B
Peak Annual Fund.	1.12B
Total Prog	8.47B
Cost/Flight 3/Yr	18.6M

- Delay FMOF -15 Months
- Low Cost Subsystems

This chart compares the baseline H33 program to a delayed FMOF/low cost subsystems H33 program and to the limited capability NAO-HO/HSB all cryogenic approach defined on the preceding page.

FMOF delay combined with low cost subsystems reduces the peak $530M and reduces total program $1.2B. Payload reduction and no-abort-to-orbit reduce the peak another $70M and total program an additional $675M.

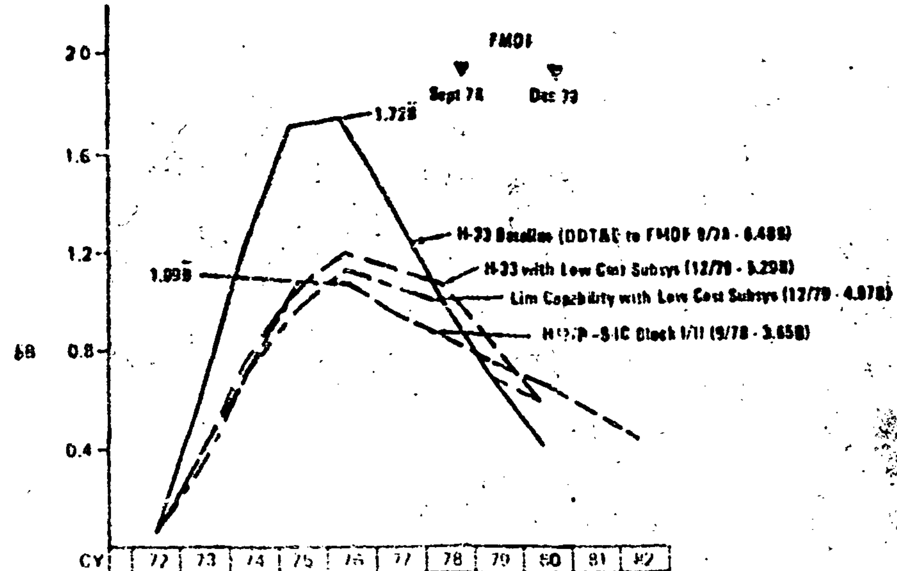
H33 – 15 x 60 vs HO 15 x 40 NAO COST COMPARISON



CY	72	73	74	75	76	77	78	79	80	81	
FY	72	73	74	75	76	77	78	79	80	81-85.89	
$B	.08	.59	1.23	1.70	1.72	1.37	.95	.63	.37	[illegible]	H33 - Baseline
	.08	.36	.76	1.01	1.19	1.10	1.04	.79	.67	7.28	H33 - Low Cost S/S } W/FMOF Delta
	.04	.31	.70	.95	1.12	1.04	.97	.67	.53	2.03	NAO/H69 - Low Cost S/S

The HJ2/R-S-IC program can achieve the same reduction in fiscal funding from the H33 baseline as the two low cost subsystem programs with delayed FMOF. The difference between the low cost H33 15x60 and HO 15x40 NAO programs with the HJ2/R-S-IC is only $100M. The HJ2/R-S-IC program, which reaches an earlier peak (FY 1975) due to its earlier FMOF, relies upon its application of existing J2/F-1 engines to minimize peak funding requirements. Accordingly it also has the lowest development cost to FMOF ($3.65B).

CONCURRENT PROGRAMS – COST COMPARISON



FY	72	73	74	75	76	77	78	79	80		
$B	.06	.50	1.23	1.70	1.72	1.37	.95	.83	.37	H-33 Baseline	W/F MOF DELAY
	.05	.36	.75	[illegible]	1.19	1.10	[illegible]	.79	.57	H-33 - Low Cost S/S	W/F MOF DELAY
	.04	.34	.70	.95	1.12	1.04	.97	.69	.53	SAO/ICB - Low Cost S/S	
	.06	.39	.78	1.09	1.07	.90	.83	.75	.69	H02/R-S-IC - BLK I/BLK II	

Our studies have shown that the best way to minimize H33 baseline funding requirements (for Sept 78 FMOF), is to key the production vehicles to the planned OC milestone. In addition, we have shown that the funding requirements for the baseline H33 concurrent program ($1.72B) can be reduced by another $500-600M. A reduction of this magnitude necessitates a change in shuttle system requirements and groundrules. This can be accomplished in two ways: first by using low cost subsystems with a delay in FMOF; and second, by using existing Saturn engines. The combined effect of delayed FMOF and using lower cost (limited capability) subsystems will achieve the maximum saving for the H33 baseline (15x60/65K). If we go to a limited capability design with a smaller and lighter payload (15x40/45K) plus no abort-to-orbit capability, the overall costs may be reduced further. The difference in total program costs between the 15x40 NAO-HO and H33 (15x60) is only $675M and $70M in peak funding.

The HJ2/R-S-IC program uses existing J2/F-1 engines coupled with Block I-II subsystems to achieve an equally low funding requirement. By excluding the development of a new shuttle main engine, the HJ2/R-S-IC is able to provide full systems capability (15x60/65K), lowest peak funding, and lowest development cost to Sept 78 FMOF.

CONCURRENT PROGRAM CONCLUSIONS

- Key Production Vehicles to Planned OC
- To Reduce H-33 Baseline Funding
  - Delay FMOF
  - Use Low Cost Subsystems
- Limited Capability (15 X 40 NAO-HO) vs H-33 (15 X 60) Savings
  - With Common Subsys, $675M Total Prog, $70M Peak Funding
  - With Low Cost Subsys Only NAO, $1862M Total Prog, $280M PAF
- $1.1 - 1.2B Peak Funding Achievable Two Ways
  - H-33 or Limit Capability with Low Cost Subsys/FMOF Delay
  - HJ2/RS-IC (Sept 78 FMOF)
- HJ2/RS-IC Provides Full System Capability At Lowest Peak Funding And DDT&E to FMOF

B

PHASED PROGRAM COSTS

BRIEFING OUTLINE

1. *Can we reduce costs if we change Orbiter requirements?*

2. *Which is 'best' interim Booster for phased program?*

3. *How can we reduce overall Shuttle program costs?*

PHASED PROGRAMS

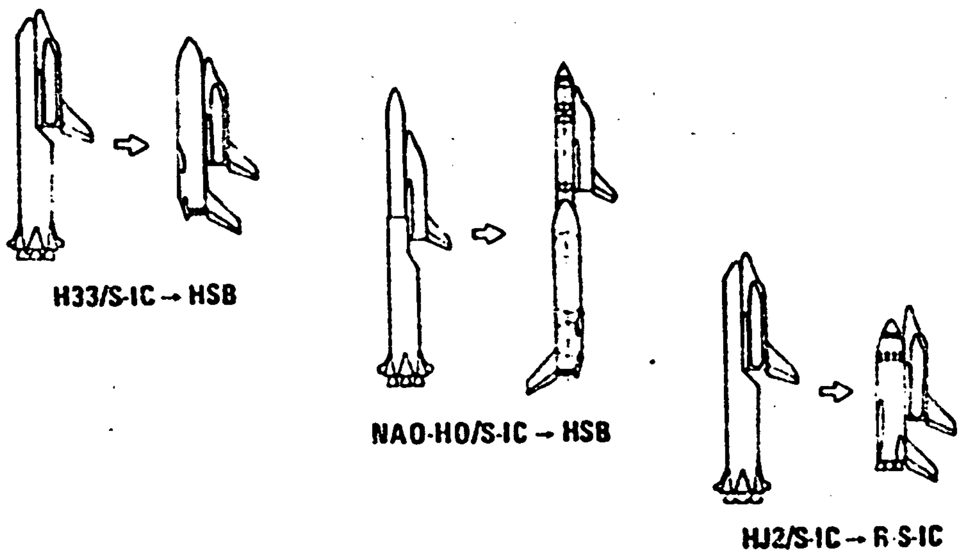
- H33/S-IC → HSB
- 15 x 60
- Limited Capability
- HO/NAO/S-IC → HSB
- 15 x 40
- Saturn Technology
- HJ2/S-IC → R–S-IC
- 15 x 60

For the three phased program configurations shown, the key issues are:

- What is the required interim operational period to minimize peak annual funding?

- How can peak shuttle funding be reduced if we change basic program requirements for full system capability and the shuttle main engine?

PHASED PROGRAM CONFIGURATIONS



The phased program groundrules shown conform to those established by the NASA/MSC Cost Analysis Branch on July 12, 1971 and forwarded to the Phase B study extension contractors.

PHASED PROGRAM GROUND RULES

- **Orbiter**
  - ATP April 72
  - FHF May 77
  - FMOF Sept 78
  - 5 Flight Articles
- **Interim Booster**
  - Option A - 0 Flights
  - Option B - 9 Flights Sept 78 - May 81
  - Option C - 12 Flights Sept 78 - May 82
- **REUSABLE BOOSTER**
  - Option A - FMOF Sept 78 - OC Sept 79
  - Option B - FMOF Sept 81 - OC Sept 82
  - Option C - FMOF Sept 82 - OC Sept 83
  - 4 Flight Articles

In addition to the NASA phased program groundrules, the following additional groundrules were established by Grumman/Boeing and included in all phased program costs:

- Reusable Booster Sustaining - An annual cost beginning with program award and continuing until reusable booster DDT&E build-up. It covers the cost of such items as monitoring orbiter progress and assuring orbiter/booster interface maintenance

- Orbiter Conversion - Covers the additional cost of converting orbiters used in the interim program to operational program configuration

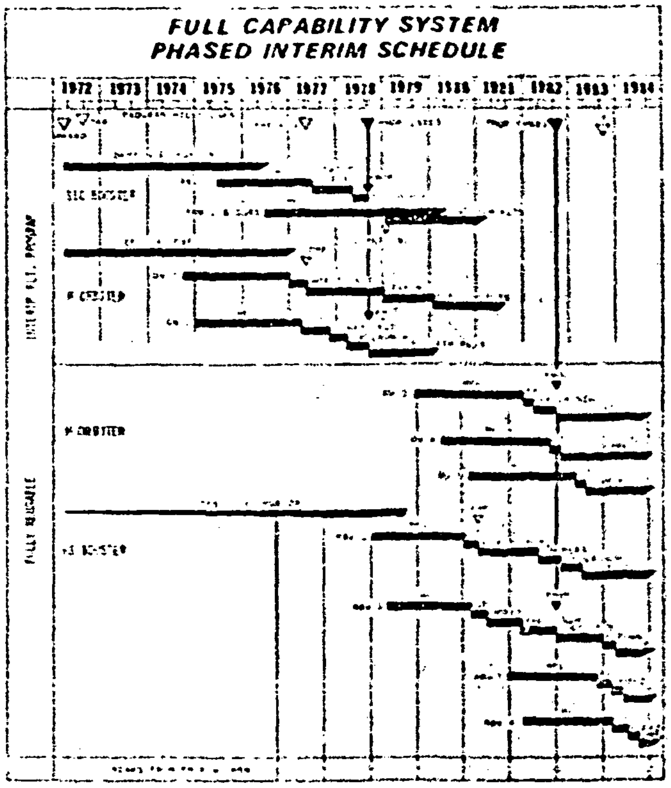
- Added Wind Tunnel - Cost arising from additional wind tunnel testing in the interim flight configuration

- Orbiter Flight Control - Additional avionic hardware/software required to control the interim booster from the orbiter

INTERIM PROGRAM COSTING ASSUMPTIONS

- Reusable Booster Sustaining, $25M Each Year of Delay
- Orbiter Conversion Interim/Reusable Booster, $50M
- Added Wind Tunnel Separation Tests, $10M
- Orbiter Flight Control Avionic/Interim Booster Interface, $5M

With postponement of reusable booster development, much of the technological risk involved is removed. Technological problem solutions achieved during orbiter program development will be adapted to the booster during its initial design phases; rather than during advanced design where technology changes impose redesign requirements. Booster development will be undertaken during a period when the orbiter is fully developed with the major portion of the booster development occurring after the orbiter has begun horizontal flight testing. Due to the low flight rate during the interim program, the two orbiters procured during the test phase are adequate for the interim flight program. Additional orbiter production may therefore be delayed to control peak annual funding requirements.

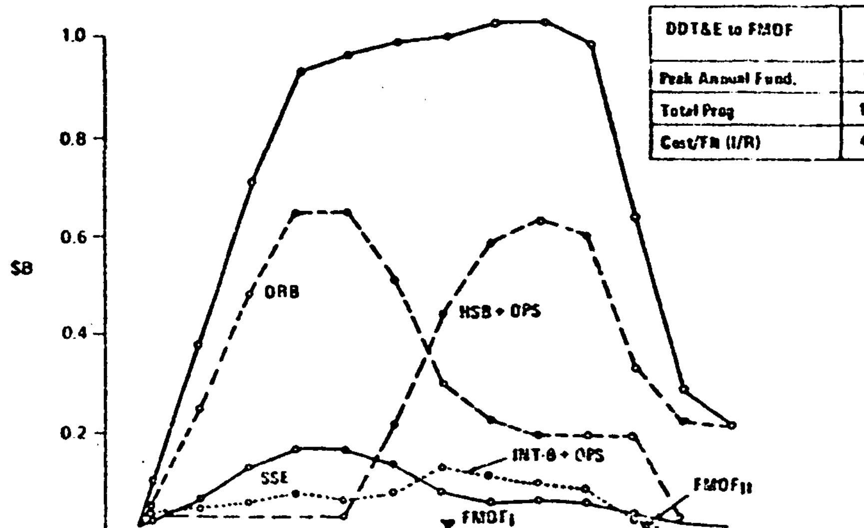

FULL CAPABILITY SYSTEM
PHASED INTERIM SCHEDULE
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984

Interim booster development, procurement, and operations costs are a very small part of annual program funding. However, they allow sufficient delay in starting the reusable booster program to keep annual funding to approximately the \$1.0B level desired. In addition DDT&E remains below the \$5B level through FMOF.

The high interim flight cost is due mainly to the limited learning attendant with the short interim booster production and operation. The low flight rate defined for interim program (3 flights/year) results in largely sustaining operations manpower costs. However the low total number of launches in the interim program adds only 4% in nonrecurring and 4% in recurring costs to the concurrent program.

H-33 (15 x 60)/S-IC → HSB PHASED INTERIM PROGRAM
(4 YEARS INTERIM OPTION C)

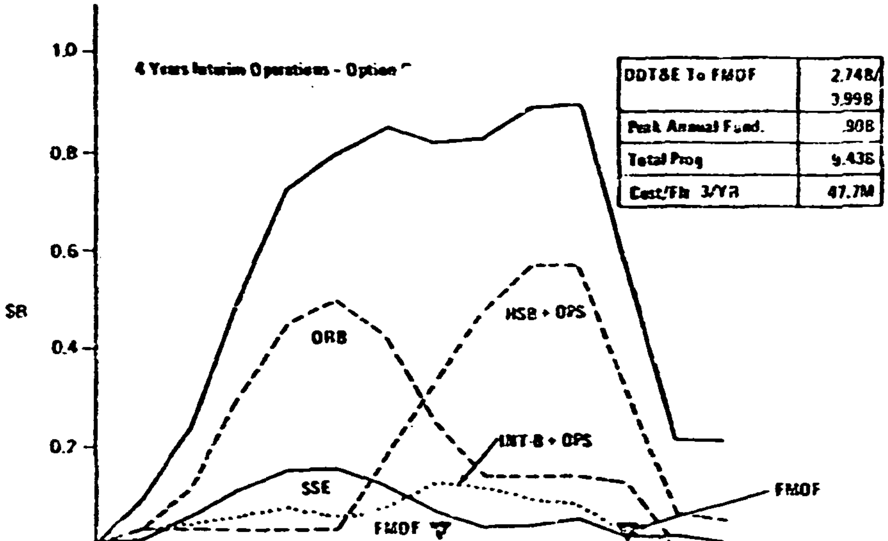
DDT&E to FMOF	3.69B/ 4.87B
Peak Annual Fund.	1.06B
Total Prog	11.16B
Cost/Flt (I/R)	47.3/4.47M



CY	72	73	74	75	76	77	78	79	80	81	82	83	84	85
FY	72	73	74	75	76	77	78	79	80	81	82	83	84	85-93
$B	.03	.38	.72	.94	.99	1.01	1.03	1.06	1.05	1.01	.65	.29	.24	1.77

The lower costs for the limited capability phased interim program is achieved through the reduction in orbiter size stemming from relaxed abort requirements and low cost subsystems. These cost reductions occur early in the development cycle and are primarily responsible for the reduction in cost to FMOF and force the peak funding year to 1980. In this phased program, the effect of the reduced orbiter size on reductions in booster size and cost coupled with reduced orbiter operations costs are the major contributor to reduced peak funding in 1980.

LIMITED CAPABILITY PHASED INTERIM PROGRAM
(15 x 40 NAO-HO/S-IC →HSB – LOW COST SUBSYSTEM)

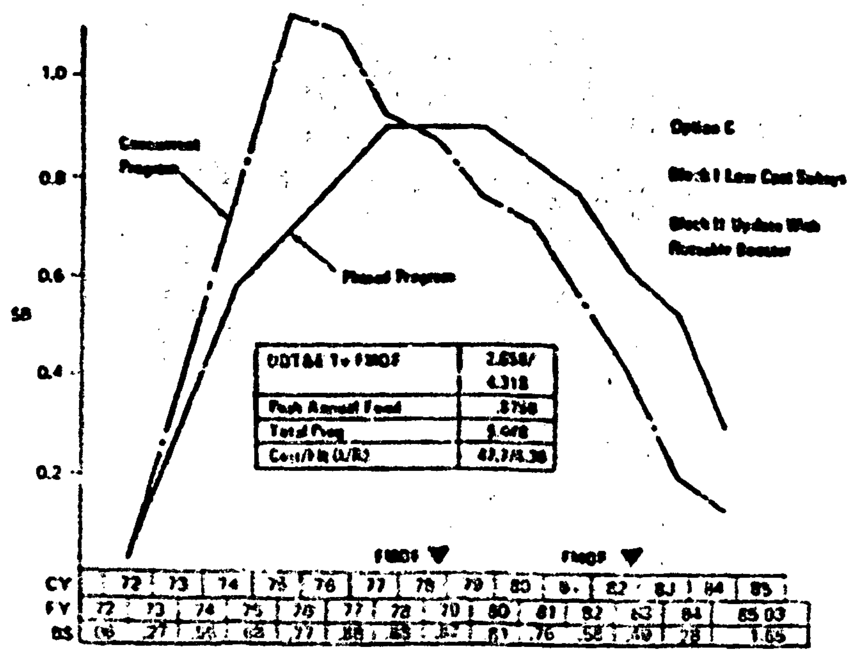


CY		72	73	74	75	76	77	78	79	80	81	82	83	84	85
FY	72	73	74	75	76	77	78	79	80	81	82	83	84	85-93	
$B	.08	.24	.51	.72	.79	85	.82	.83	.89	.90	.54	.21	.21	1.84	

C

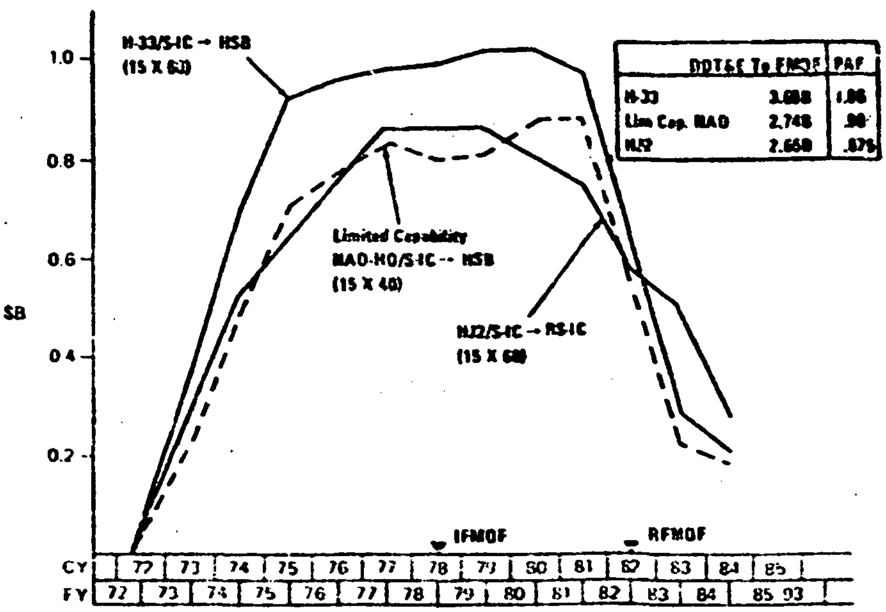
Another alternative directed at maximum reduction of early development costs involves use of existing Apollo-developed hardware. Through use of J2 and F-1 engines, S-IC cryo tankage in the booster and low cost subsystems as previously described, peak funding can be reduced to $1.09B. By phasing the HJ2/R-S-IC program with an interim S-IC for a four year period, peak annual funding requirements can be further reduced to below $900M and DDT&E to FMOF can be reduced to $6.25B. This represents a substantial reduction in funding requirements in the early years of the shuttle development program.

HJ2/S-IC → R–S-IC PHASED 4 YEARS INTERIM PROGRAM



Comparison of phased interim programs shows the substantial reductions that can be achieved with the full capability IU2/S-IC ⟶ R-S-IC approach in cost to FMOF, peak annual funding and early funding requirements. The IU2/S-IC ⟶ R-S-IC full capability program is competitive from a cost standpoint with the limited capability NAO-NO/S-IC HSB program.

COMPARISON, PHASED INTERIM PROGRAMS



Our studies have indicated that through program phasing, several configurational approaches can achieve NASA's desired goals of $1.0B peak annual funding and $5.0B for development costs to FMOF. To achieve minimum peak funding, both a four-to five-year interim operational period and orbiter production phased to support the reusable booster operation are required. These items are necessary to afford sufficient uncoupling of the orbiter and reusable booster peak funding requirements.

Further extensions of the interim program beyond five years will increase interim program costs and have no further effect on peak funding since the orbiter and booster are fully uncoupled and the peak funding requirements are being driven by the individual orbiter and booster funding requirements. With the addition of low cost subsystems in the initial operational phase and extensive use of presently developed hardware, peak funding can be further reduced to below $900M. The HO2/S-IC ——→R-S-IC combines all these funding advantages and achieves the lowest peak funding and the lowest development cost to FMOF of all the configurations studied.

CONCLUSIONS, PHASED INTERIM PROGRAM

- 4-5 Years Interim Operation Required for Minimum PAF
- 0.85 to 1.0B PAF Achievable
- HJ2/S-IC→R-S-IC Lowest PAF & DDT&E to FMOF
- Orbiter Production Phased to Support Reuseable Booster

EXTENDED

EXTENDED INTERIM PROGRAMS

The "extended interim" program represents a possible alternative to either the concurrent or phased interim programs. This approach addresses the case in which lower traffic rates are anticipated over an extended time period. Higher cost per flight is balanced by the early savings accruing from extended deferral of fully reusable booster development.

Three candidate configurations, each utilizing external HO tanks and an expendable booster, have been evaluated:

- Thrust Augmented HO - Employs twin 156-in. solid rockets burning in parallel with three orbiter-mounted high pressure engines

- Pressure Fed Storable - Utilizes a two stage N_2O_4/UDMH booster burning in series with a three-engined orbiter

- Two-Stage Solid - Uses a total of seven, 7-segment solid rockets burning in a 5-2 sequence. Orbiter characteristics are identical to those of the pressure fed storable configuration

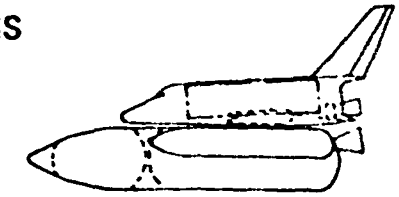
All orbiter configurations are sized to accommodate 15-foot diameter by 60-foot long payload dimensions.

This facet of the ASSC study extension effort is directed toward the determination of the best configuration for the extended interim application in terms of lowest cost, lowest technical risk, and most acceptable operational characteristics.

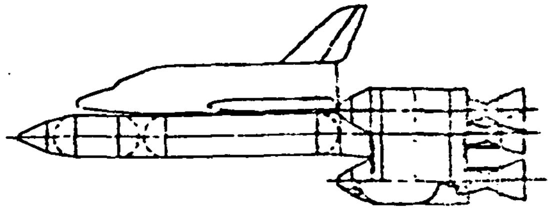
EXTENDED INTERIM PROGRAMS

- Lower Traffic Rate 100/200
- Peak Funding ~ $1B
- Medium Cost/Flight
- Phased Into HSB

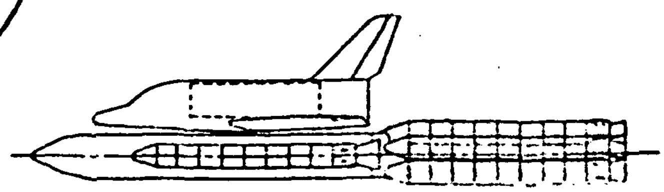
Which Best For 100-200 Flight Program?



Thrust Augmented HO (TAHO)



Pressure Fed Storable (PFS)



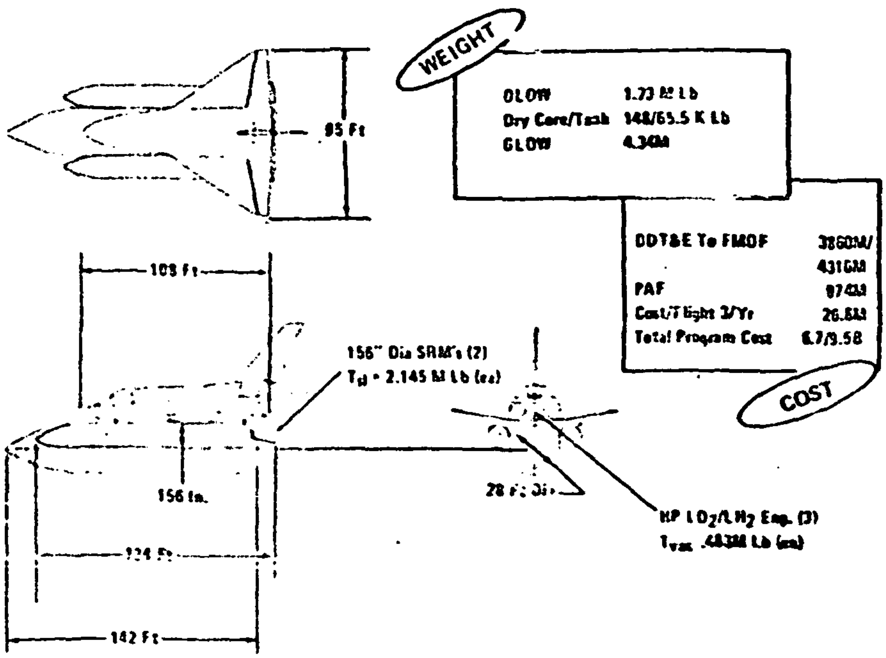
2-Stage Solid (SRM)

The thrust augmented HO configuration comprises a three-engined delta-wing orbiter, a belly-mounted external HO tank sized for orbiter burn from liftoff to injection, and two fixed-nozzle, 156-in. diameter solid rocket motors side-mounted to the HO tanks. Orbiter engines and the SRM's are burned in parallel up to SRM burnout/jettison at 5168 fps. Orbiter engine burn continues through injection. Control during boost is provided by orbiter engine thrust vector control.

The bulk of the orbiter liftoff weight of 1.73M lb is attributable to the 1.41M lb of main injection propellant required for burn from liftoff to orbiter injection. Lightweight HO tank design is acheived on this configuration by pickup of SRM thrust loads and LO_2 tank drag loads at the orbiter forward attachment point, thus reducing the axial loads sustained by the aft-located external LH_2 tank. Downstream introduction of a tandem-mounted heat sink booster would require external tank redesign to accommodate introduction of axial loads at the tank aft end.

DDT&E and total cost to first manned orbital flight are $3860M and $4310M, respectively. Peak annual funding required during development is $974M. Total program costs for 100 and 445 flights are $6.7B and $9.5B, respectively.

THRUST AUGMENTED HO

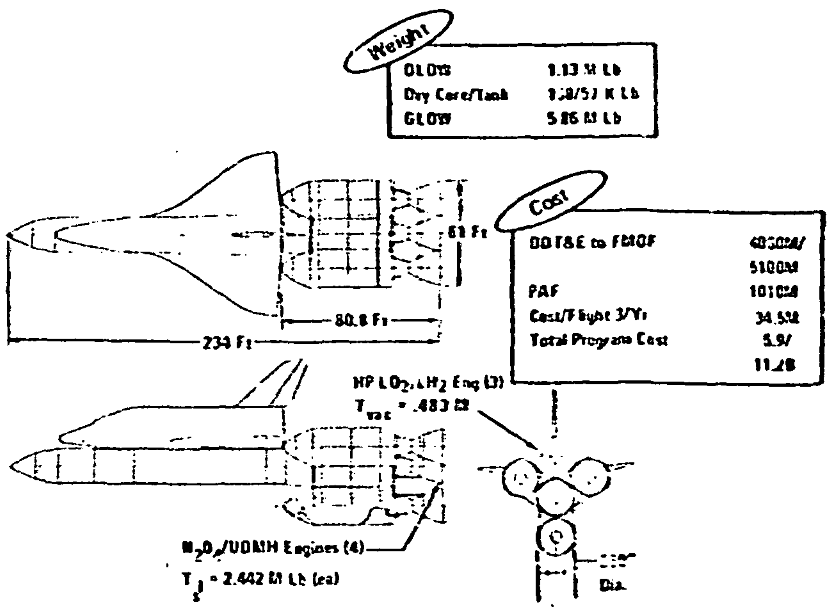


The pressure fed storable configuration utilizes a 1.13M lb external HO tank orbiter plus a two-stage expendable liquid rocket booster consisting of four identical tankage/engine modules. The three outboard booster modules, clustered at 120 deg intervals around the core module, comprise the booster first stage. The core module provides second-stage thrust and also serves to transmit both first and second stage thrust loads to the external HO tank via a conical interstage skirt. First and second stage burnout occurs at 2875 and 6200 fps, respectively. Control during boost is provided by liquid injection thrust vectoring of the booster engines.

Orbiter main propulsion consists of three high-pressure LO_2/LH_2 engines each providing 483,000 lb vacuum thrust. Booster engines utilize N_2O_4/UDMH pressure fed propellant. Sea level thrust rating of each engine is 2.4M lb. All-up weight of the stacked configuration is 5.86M lb.

DDT&E and total cost to first manned orbital flight are \$4060M and \$5100M, respectively, with peak funding totaling slightly over \$1B. Total cost for 100 and 445 flight programs are \$6.9B and \$11.2B, respectively.

PRESSURE FED STORABLE

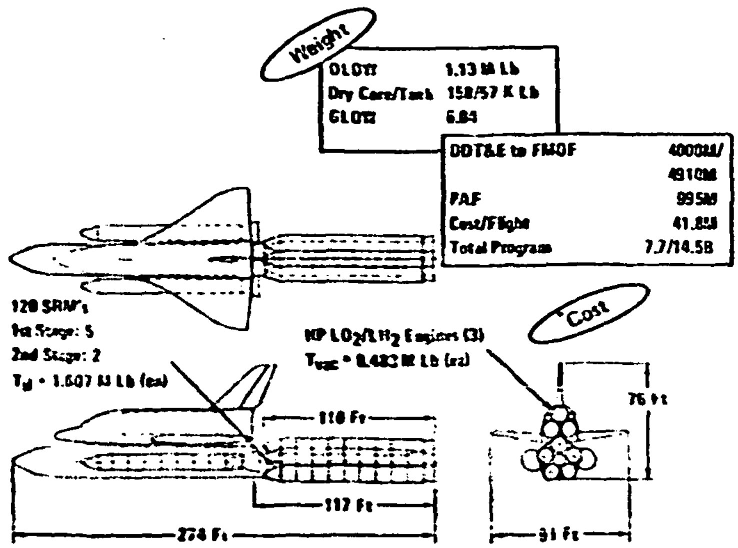


The "two-stage solid" configuration employs a 1.13M lb external HO tank orbiter (identical to that used in the pressure-fed storable configuration) plus a two-stage solid rocket booster comprising seven, 120-in. diameter SRM's in a 5/2 configuration. The five-engined first stage cluster is tandem-mounted to the external HO tank: thrust loads are transmitted to the tank via a conical interstage skirt.

The second-stage SRM's are installed symmetrically on each side of the external tank in the plane passing through the tank centerline. Movable nozzles are incorporated on all SRM's to provide thrust vector control during the boost phase. First and second stage burnout velocities are 1952 and 6178 fps respectively. Lift-off weight of the configuration is 6.04M lb.

DDT&E and total cost to FMOF are $4000M and $4910M, with peak funding totaling $995M. Cost per flight, on a three flight per year basis is $41.8M. Total costs for 100 and 445 flight programs are $7.7B and $14.5B respectively.

2 – STAGE SOLID



Basic configuration characteristics and costs are summarized in the table opposite. Significant points are:

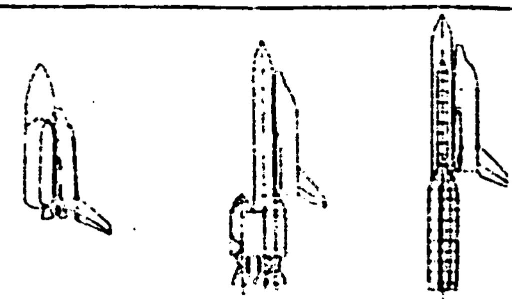
- All orbiters are sized for the same payload volume; expendable boosters for the PFS and the two-stage SRM are sized for 45K payloads rather than 65K

- TAHO external tank dry weight constitutes a higher percentage of total (core and tank) dry weight as a consequence of the parallel burn approach

- The twin fixed-nozzle SRM's utilized in the TAHO configuration represent the simplest booster configuration of the three alternates considered

- TAHO costs are lower than those of the PFS or two-stage SRM configurations, particularly in the area of cost per flight (lower by 22% and 36% respectively on a three flight per year basis)

EXTENDED INTERIM CONFIGURATIONS



Characteristics/Costs			TAHO	PFS	2-Stage SRM
• Payload	-	Dimensions/Weight	(15 X 60)/65	(15 X 60)/45	(15 X 60)/45
• Weights	-	GLOW	4.34M	5.95M	6.04M
		OLOW	1.73M	1.12M	1.13M
		Core Dry	148K	158K	158K
		Tank Dry	65.5K	57K	57K
• Ascent	-	Control	Orbiter Engine (JATO SRM)	UTVC	GIMB. TVC
		Burn	[illegible]	Series	Series
		Vstage	5168 fps	6200 fps	6170 fps
• Cost		DDT&E to FMOF	3850 M/4250 M	4050M/5166M	4008M/4910M
		PAF	974M	1010M	995M
		Cost/Flt (12 @ 3/Yr)	26.8M	34.5M	41.8M
		Total 100/445 Flights	5579/9470M	6632/11,200M	7700/14,500M

The chart opposite reflects a comparative evaluation of the three candidates for an "extended interim" program in terms of program costs and key performance/operational parameters. Where one configuration exhibits a clear advantage in a given evaluation category, the appropriate parameter has been "boxed".

Although all candidates represent technically feasible approaches, it is concluded that the thrust augmented HO configuration affords the best selection on the basis of cost, technical risk, and operational characteristics.

EXTENDED INTERIM COMPARISONS

		TAHO 	PFS 	SRM 
LOWEST	Cost/Flight (12 Flt @ 3/yr) $M	$\boxed{26.8}$	34.5	41.8
LOWEST	Peak Annual Funding $B	.974	1.81	.995
LOWEST	DDT&E to FMOF $B	$\boxed{3.860/4.25}$	4.86/5.10	4.80/4.91
LOWEST	Facil & OPS Costs (Over 10 Yr) $M	620	730	630
LOWEST	Total Prog $ (100/445) $B	$\boxed{6.68/9.47}$	6.9/11.2	7.7/14.5
LOWEST	Technical Devel Risk	$\boxed{\text{"JATO"}}$	HYPERGOL CLUSTER	2 Stage SRM
MINIMUM	Scar For Transition to HSB	Vstage 5168 ORB/TVC	Vstage 6200 Gnd/Bstr/TVC	Vstage 6178 Gnd/SRM/TVC
FEWEST	Boost Stages	$\boxed{1}$	2	2
BEST	Operational Safety	$\boxed{\text{ORB. THRUST @ L/O}}$	In Flt Start	SRM Thrust Term & In-Flt. Start
Booster Exhaust @ Liftoff (Lb/Sec)		$\boxed{\text{13,730 (2 SRM)}}$	35,600 (4 HG)	33,600 (5 SRM)

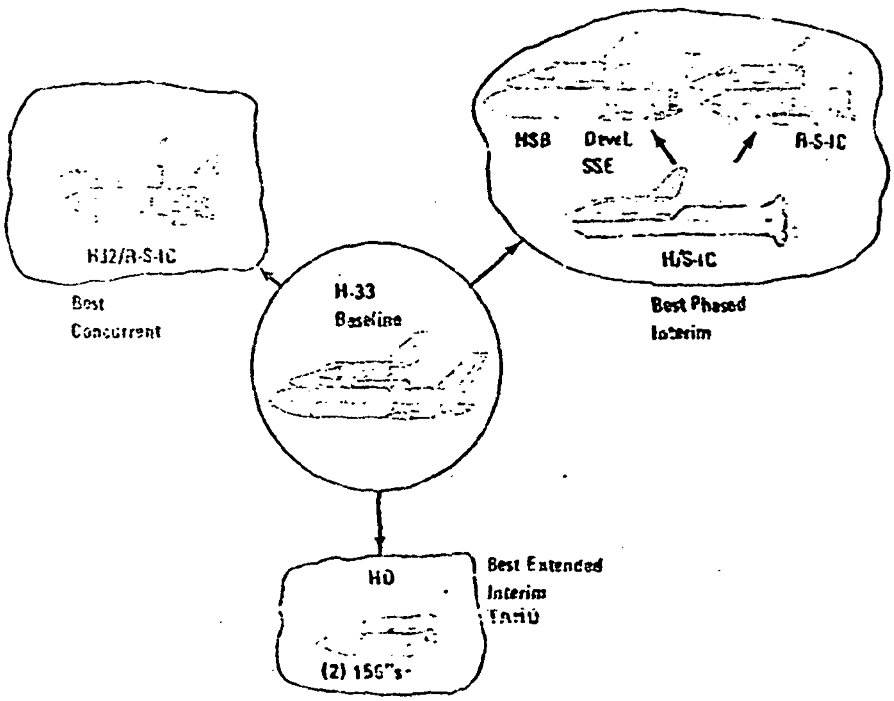
CONCLUSION

THRUST AUGMENTED HO (JATO)
IS BEST CHOICE

SUMMARY

SUMMARY

SUMMARY EVALUATION ALL PROGRAMS



Use of the S-IC as a low cost interim booster was initially suggested in the Dec [illegible] Mid-Term ASSC Report. Further development of this approach has brought it even closer to being a "use as is" extension of existing S-IC capability.

First the reduction of V_{stage} to 7000 fps by baselining of external tank orbiters greatly increased the S-IC performance margin within the 3g design limit for the orbiter.

Next the large fin modification (900 ft^2) was eliminated by the "wet cradle" concept which, by placing a LOX tank forward in the strong back, moved the launch cg forward far enough to remain within the S-IC engine gimbal control capability. This involved a relatively simple propellant feed system modification, but nevertheless a modification.

Finally the "wet cradle" has been supplanted by the "dry cradle" approach which, by further taking advantage of the increased performance margin, gets the cg within S-IC gimbal capability using fixed ballast (concrete) in the cradle.

This simplification coupled with TBC/MSFC cost reductions clearly show the S-IC to be the best expendable interim booster choice.

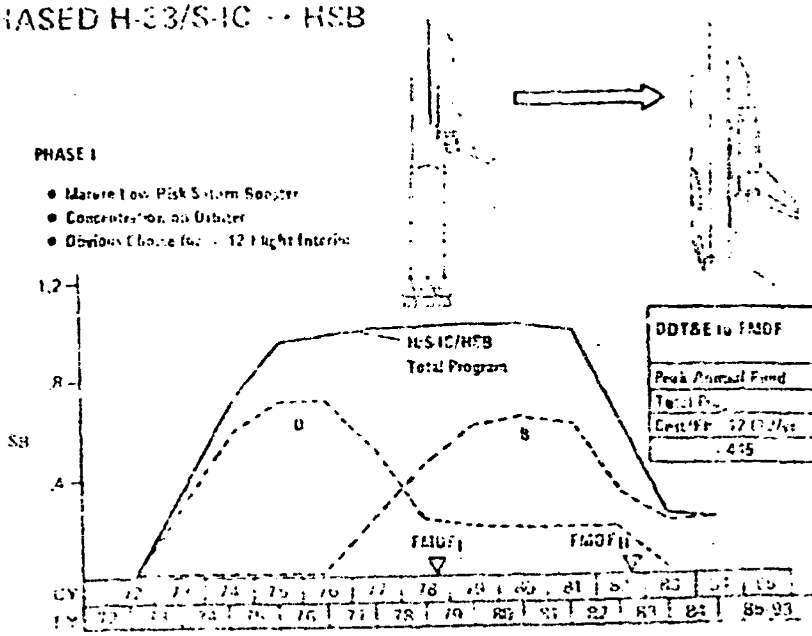
Since the cost per flight of an expendable interim S-IC is high, it is only cost effective if phased out after relatively few (approximately 12) flights. On the other hand, to keep peak annual funding down we recommend delaying HSB funding buildup a minimum of four years.

Interim booster funding requirements are therefore based on a launch rate of three per year. Peak annual funding approaching [illegible] is achieved.

PHASED H-33/S-IC — HSB

PHASE I

- Mature Low Risk System Booster
- Concentration on Orbiter
- Obvious Choice for ~ 12 Flight Interim

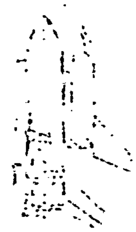


DDT&E to FMOF	3.092/ 3.516
Peak Annual Fund	1.066
Total Prog	[illegible]
Cost/Flt	[illegible]
.435	4.[illegible]

Reduction of V_{stage} to 7000 fps by the baselining of external tank orbiters has raised the S-IC performance margin sufficiently for a heat sink fully reusable S-IC booster to be considered. The resulting shuttle system meets all of the basic shuttle objectives (full reusability, low cost per flight, early FMOF) with a concurrent program which has a substantially reduced peak annual funding requirement ($1.09B vs $1.72B for the baseline system).

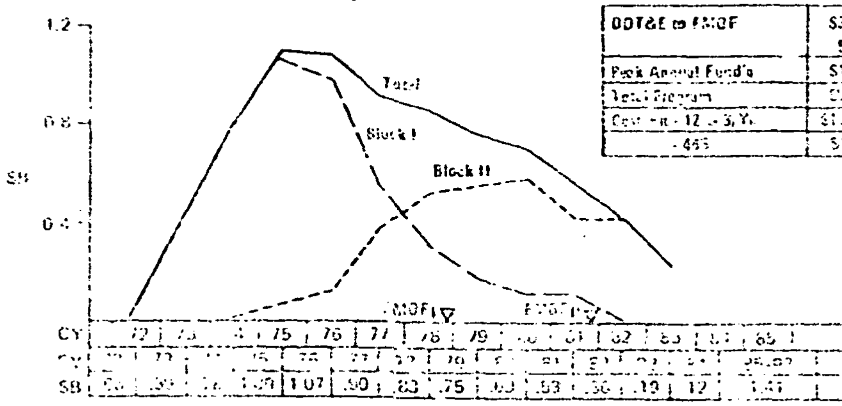
This has been achieved by making effective use of Apollo/Saturn technology through eliminating development of a new booster propulsion system, through use of the J2 engine in the orbiter, and through the initial use of low cost (Block I) subsystems in both vehicles. Provisions for changeover to operationally more desirable (Block II) subsystem features, once the peak funding requirement has been passed, are included in the cost estimate for this program.

CONCURRENT [illegible] ORBITER/R–S-IC BOOSTER



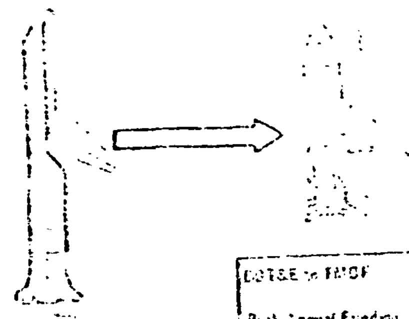
- Retains Basic Shuttle Objectives
  - 2 Stage
  - Low Cost Flight
- Exploits Saturn Technology
- Close to Peak & DDT & E Funding Targets
- Limits Dev & Risk to Airframe

DDT&E to FMOF	$3.65B/ 5.31B
Peak Annual Fund'g	$1.03B
Total Program	$5.17B
Cost/Flt - 12 [illegible]	[illegible]
- 445	[illegible]



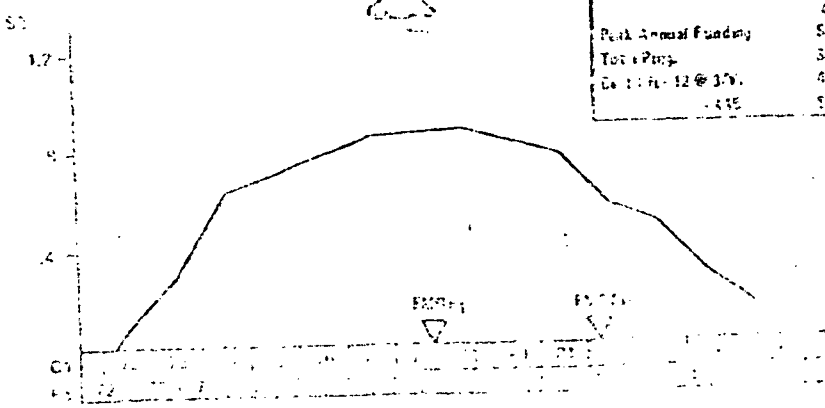
Phasing an interim expendable "dry cradle" S-IC (approximately 12 flights) with a fully reusable "winged" S-IC takes maximum advantage of existing Apollo/Saturn technology. By combining the basic features of the two programs described on the immediately preceding pages, the lowest possible peak annual funding is achieved, all basic Shuttle objectives are met, and an operational cost per flight competitive with the baseline system is realized.

PHASED HJ2/S-IC → R-S-IC



- Lowest Possible DDT&E & PAF to FMOF₁
- Mature Low Risk Saturn Booster
- Concentrate on Orbiter

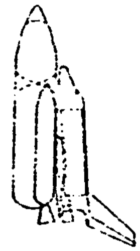
DDT&E to FMOF	2.65B7
	4.31B
Peak Annual Funding	$925o
Total Prog.	39.44B
Cost thru FY 12 @ 10%	47.3[illegible]
+4.5B	[illegible]



The thrust augmented external HO tank (TAHO) system is a derivative of the A3A parallel burn "stage-and-a-half" configuration of the original ASSC study. It features simple, strap-on, fixed nozzle 156-in. SRM's, an SSME powered orbiter and a large external HO tank. The "JATO booster" simplicity of this system results in low peak funding requirements to FMOF (approximately $1B) and medium costs per flight ($26.8M average for the first 12 flights and $10.6M average for 445 flights). Three operational drawbacks to this system are apparent: (1) SRM exhaust products at liftoff; (2) the dropping of a pair of SRM cases on each flight, and (3) insufficiently low cost/flight to capture all potential shuttle traffic. All three of these disadvantages could be overcome by starting up a phased reusable booster and smaller HO tank after funding requirements for the initial system drop off (i.e., downstream of FY '78).

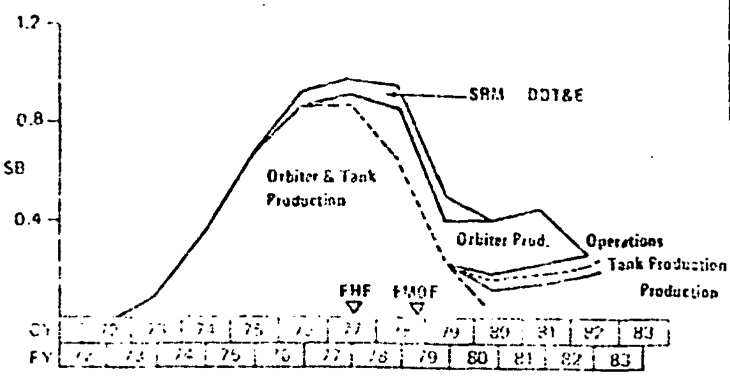
EXTENDED INTERIM PROGRAM

TA10



- Emphasizes Orbiter Development
- Intermediate Cost/Flight
- Peak Funding & DDT&E on Target
- Can Evolve to 2 Stage System

DDT&E to FMOF	3.96B/ 4.25B
Peak Annual Fund	.975
Total Prog. ([illegible])	9.53
Total Prog. (10%)	6.78



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By plotting cost per flight vs total cost to FMOF, the various program alternatives can be readily assessed relative to one another.

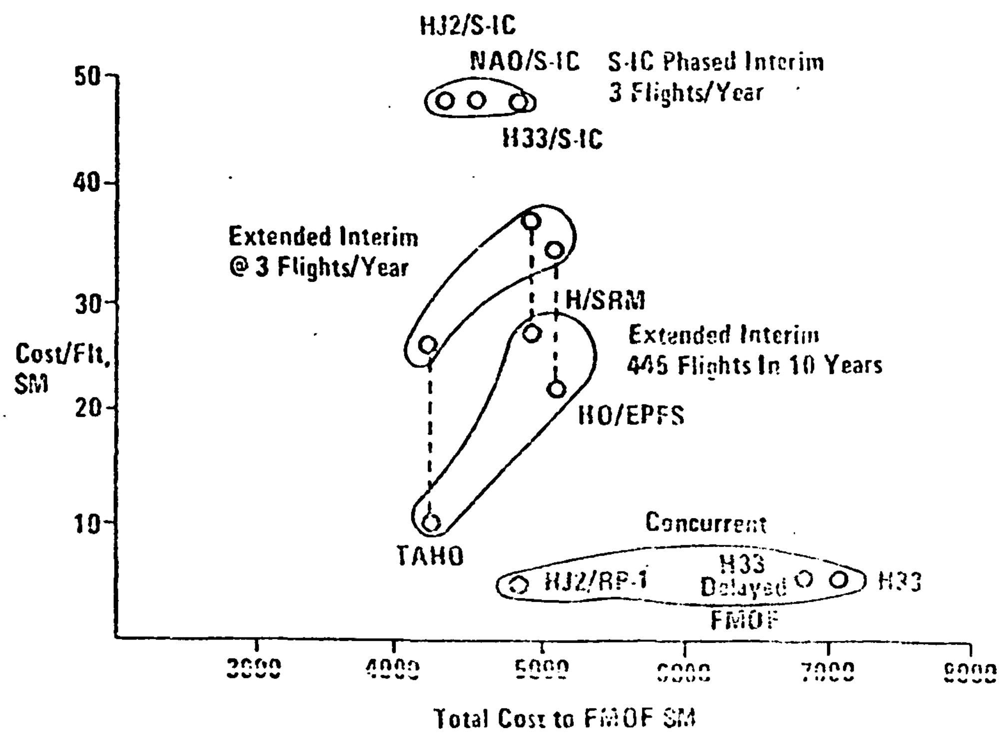
All of the phased interim program cost results are grouped at a relatively high cost per flight and therefore the use of an interim booster should be held down to as few as possible while meeting the objective of delaying reusable booster development funding. We believe that 12 flights at a rate of approximately three flights per year would be sufficient.

All of the extended interim programs have intermediate costs per flight with the TAHO showing the lowest overall cost to FMOF. Even at the extreme of 445 flights, the extended interim programs are not sufficiently competitive to capture all potential traffic.

The concurrent baseline H33 program has the desired low cost per flight but is expensive in cost to FMOF. Delay of FMOF drives peak funding down but understandably makes little difference in total cost to FMOF.

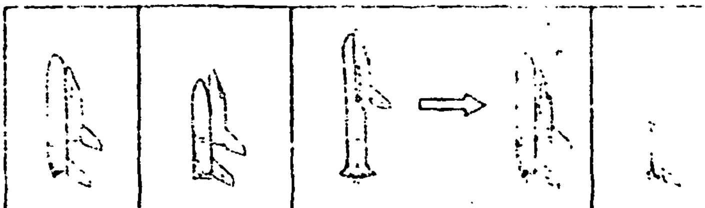
The HJ2/R-S-IC (RP-1) concurrent program with a cost per flight competitive with the baseline and a significant saving to FMOF (without delaying FMOF) is clearly the best approach to meeting the basic shuttle program goals within expected funding limitations.

SHUTTLE DEVELOPMENT OPTIONS



This summary comparison chart is provided for ready reference to the properties of the vehicles discussed in the presentation.

SUMMARY COMPARISON



	Baseline (H-33)	HJZ/R-S-IC Concurrent Block I	Phased Interim	H-33/S-IC - HSB Final	Ext. Int. (TAHO)
Payload Dimensions/Weight	(15 X 60)/65K	(15 X 60) 47K*	(15X60)/65K	(15X60)/65K	(15X60)/65K
GLOW	[illegible]	6.537M	[illegible]	3.993M	[illegible]
BLOW	2.787M	5.384M	4.390M	2.787M	2.61M
OLOW	1.097M	1.166	[illegible]	1.697M	1.73M
Core/Tank Dry Wt	[illegible]	194/22.7K	[illegible]	162/20.2K	[illegible]
Engines Orb/Bstr	3-450K 12/400K	5J2/5F1	[illegible]	3-460K 12/403K	3-493K/2 156" SRM's
DDT&E Thru FMOF	6478M/7100M	3650M/5310M	3057M/4870M		3900M/4250M
Peak Annual Funding	1722M	[illegible]	[illegible]		974M
Cost/Flight 445 Flts	4.47M	[illegible]	—	4.47M	10.5M
312 Flts	15.6M	15.9M	[illegible]		[illegible]

*J2S/F1A 65K P.L.

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The HO orbiter approach transfers structural complexity from the vehicle to the tank and tank/booster interface. The HO cost per flight exceeds that of an H orbiter, and it now appears that the production cost of an HO tank/interstage structure will exceed that of two H tanks. Additional time will be required to more accurately define the H/HO relationship.

Low cost interim subsystems show peak funding advantages in all programs. The Block I/Block II subsystem approach is strongly advocated for the shuttle system finally selected.

Combining the orbiter requirements reductions which have been considered (payload bay diameter and length, payload weight, no abort-to-orbit (NAO) and substitution of J2 engines) reduces the baseline program peak funding approximately $200M and saves a total program cost of approximately $1.05B.

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CONCLUSIONS

ORBITER RELATED

(1) o HO Orbiter Core
- Structurally Simpler
- Less Costly
- Harder To Balance

o HO Tank Development more Complex

o HO Cost Per Flight Higher than H

o Choice of H vs HO Not Clear Cut Yet
- Needs Concentration For Next Two Months

(2) o Low Cost Subsystems will save Early Dollars
- Include in Selected Orbiter

(3) o Combining all Orbiter Requirement Reductions (15 X 40, NAO, J2)
- Saves Total Progr ≈ $1.0B
- Reduces Peak ≈ $200M

Three alternative program approaches have been evaluated relative to the fully-reusable concurrent H33 baseline program.

The concurrent Saturn technology program retains the basic shuttle system goal of full reusability while achieving substantial cost reductions relative to the baseline.

The Saturn S-IC is clearly the best phased interim booster. It eliminates booster development risk in the early years of the program and therefore permits full concentration on orbiter development. Its use should be limited to approximately 12 flights.

The best of the extended interim programs is the parallel burn, thrust augmented HO (TAHO) program which uses two 156 in. fixed nozzle, solid rocket motors for boost assist. Due to an insufficiently low cost per flight in the operational phase, eventual phasing to a reusable booster is recommended.

CONCLUSIONS

THREE ALTERNATE PROGRAM PATHS SIGNIFICANTLY REDUCE COSTS OVER JULY CONCURRENT PROGRAM

(1) Concurrent HO & R S-IC

- Retains Key Shuttle Goals
  - Low Cost/Flt
  - Early FMOF
  - Re-Use
- $5.31B to FMOF
- $1.09B Peak

(2) Phased Interim 8-12 Flts

- S-IC Only Min Risk Int. Booster
- Phase with Either HOB or R S-IC
- $4.67B to FMOF
- $1.06B Peak

R S-IC

H/S-IC

Best Phased Interim

(2) Extended Interim

- Attractive if Phased Interim + 100/200 Flights
- Can Evolve to Reusable System Later [illegible]
- Several Candidates – TAHO Looks Good
- [illegible]
- .97B Peak
- All Need Further Analysis

To complete our presentation we briefly want to address the recommendations we would make in the light of the position NASA is facing. In view of the forthcoming budget decisions, the very real fiscal limitation, and the desirability of retaining decision flexibility downstream in the program: we would recommend that you take the following three steps now:

First:

- Move now on the external tank orbiter with J2 engi[illegible]
- Complete the HO system evaluation during the next two months so that a decision between H and HO can be made on data of comparable maturity. We believe this to be entirely consistent with your procurement schedule.
- Slow down the SSME development for the next six months.

Second:

The selection of the interim booster is not time critical. However, if going ahead with a booster selection is desirable, the S-IC is clearly the best choice for a phased interim program [illegible] 9 to 12 flights. The selection of this option would provide the minimum possible booster development risk thus permitting maximum concentration on orbiter development.

Third:

Because the reusable R-S-IC S[illegible] derived system offers the very real possibility of retaining a concurrent shuttle program within approximately $1B peak funding and, at the same time results in a low cost per flight, we propose an intensive evaluation of the R-S-IC for the next [illegible] months.

This combination of steps [illegible] permits the initiation of the orbiter [illegible] as soon as practical within the assum[illegible] limitations and keeps open the option [illegible] program phasing or program concurre[illegible] the next 12 months.