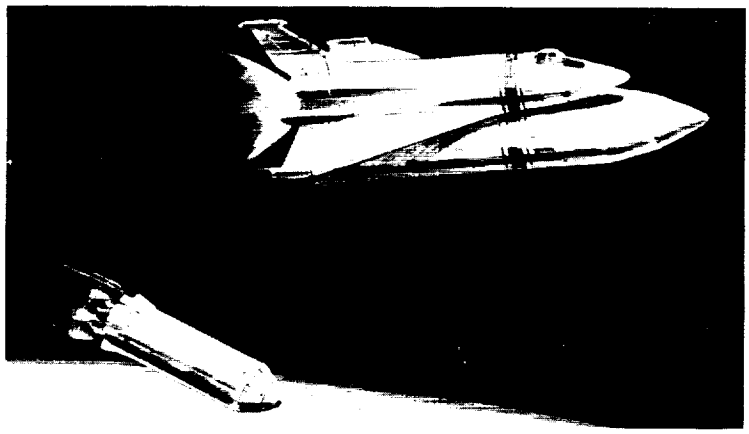
CR 115 285

MSC-03822

SHUTTLE SYSTEMS EVALUATION AND SELECTION

N72-17923



Volume II

BRIEFING

December 15, 1971

CONTRACT NAS 9-11160
MODIFICATION NO. 10S
B35-43 RP-30

CASE FILE COPY

GRUMMAN
BOEING

MSC-03822
VOL II
(Rev.)

SHUTTLE SYSTEMS EVALUATION AND SELECTION

MID-TERM BRIEFING

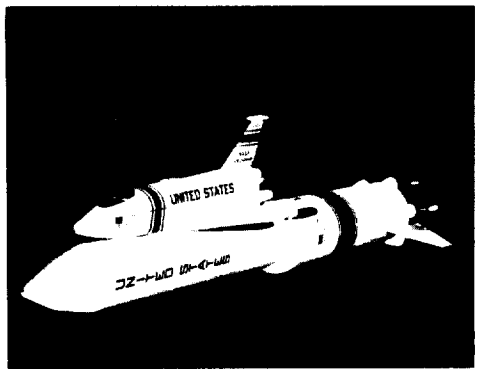
DECEMBER 15, 1971

Volume II – BRIEFING

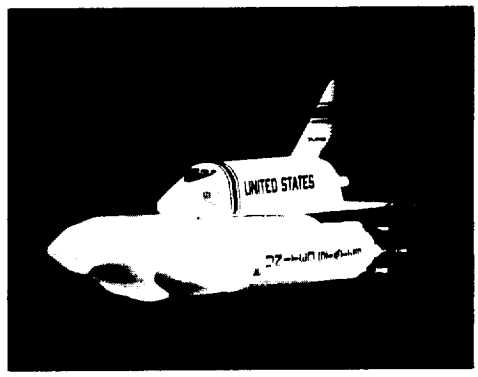
CONTRACT: NAS 9-11160, MOD 10S
DRL: T-752, LINE ITEM 3
DRD: MA-260T, DATA TYPE 2

B35-43 RP-30

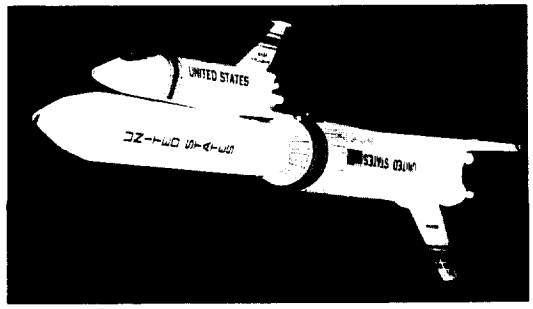
GRUMMAN BOEING



BALLISTIC RECOVERABLE



RAO



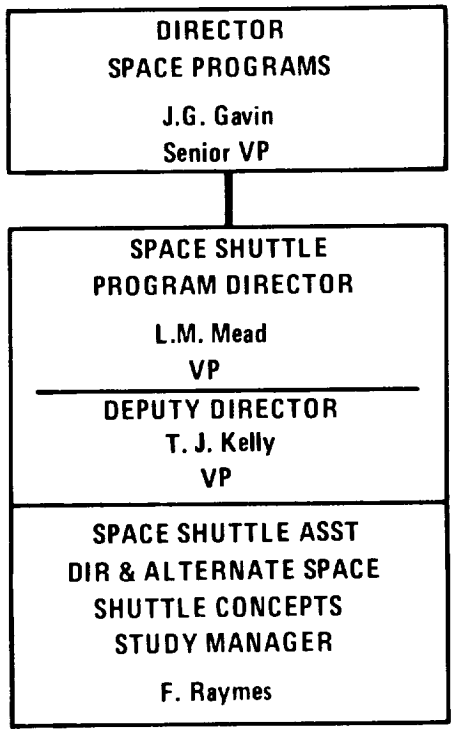
FLYBACK

GRUMMAN
BOEING

GRUMMAN/BOEING SHUTTLE TEAM

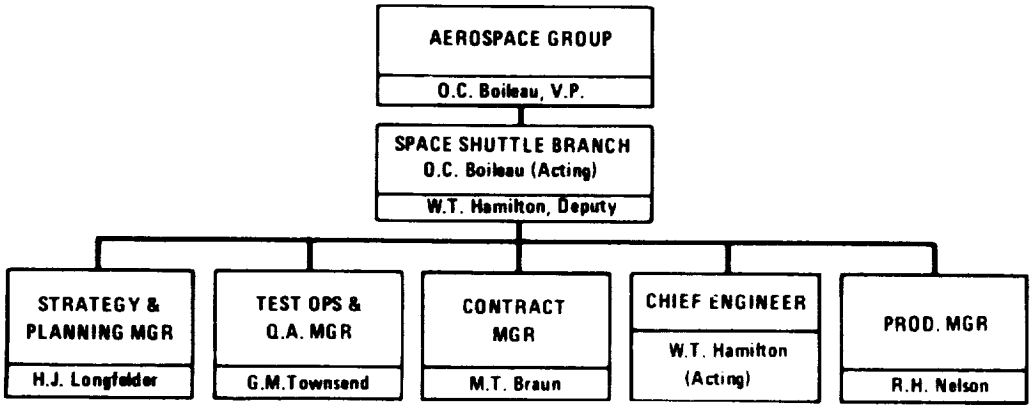
GRUMMAN/BOEING SHUTTLE TEAM	
GRUMMAN	• Systems Manager • Orbiter
BOEING	• Booster • Operations
AEROJET GENERAL	• Cryogenic Tankage
AVCO	• Thermal Protection Systems
AVIONS MARCEL DASSAULT	• Thermal Protection Systems • Insulation Systems
DORNIER	• Subsystems Technology
EASTERN	• Operations • Maintenance
GE	• Avionics
NORTHROP	• Orbiter Technology

GRUMMAN SPACE SHUTTLE ORGANIZATION



GRUMMAN BOEING

BOEING SPACE SHUTTLE ORGANIZATION



BRIEFING OUTLINE

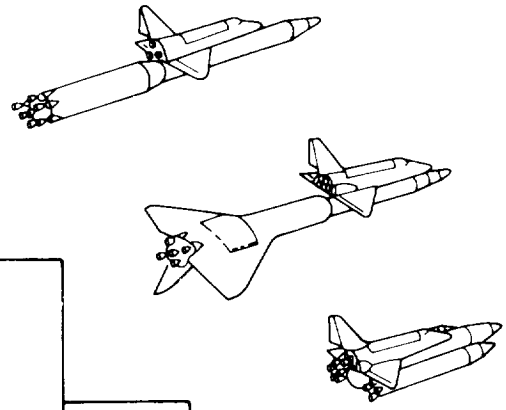
SERIES BURN
Veh Performance
& Selection

PARALLEL BURN
Veh Performance
& Selection

BOOSTER
Design
Status

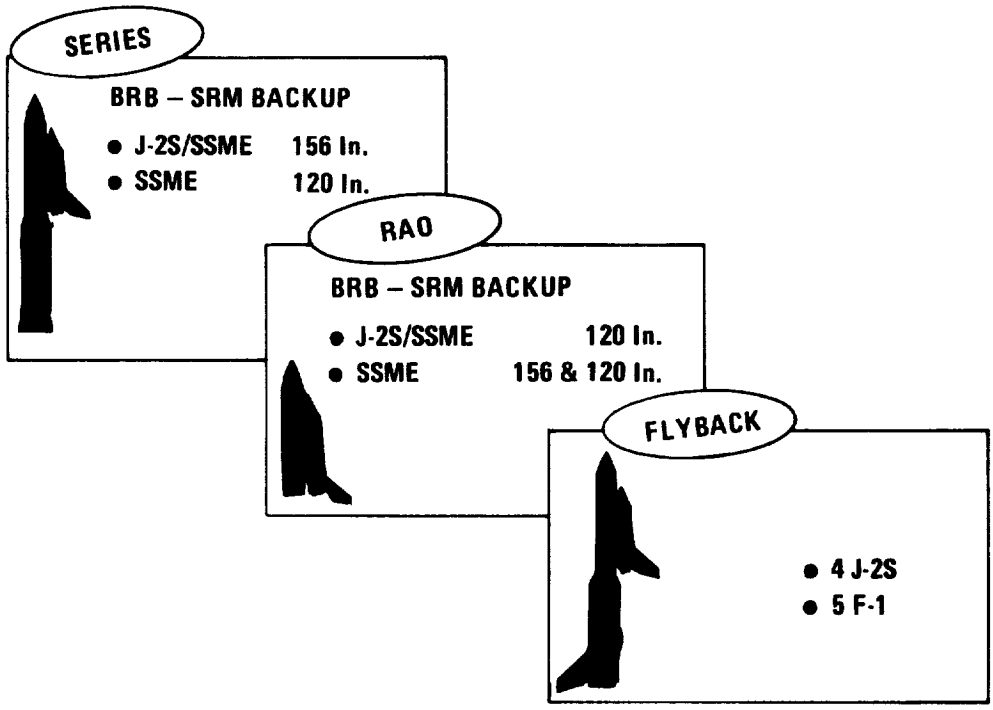
SYSTEM
Comparison &
Evaluation

SUMMARY



GRUMMAN
BOEING

CONFIGURATIONS



MK I/II SYSTEM REQUIREMENTS SUMMARY

	Mk I	Mk II
• Orbiter Main Propulsion	J-2S	SSME
• OMS ΔV, Tank Sized for:	(Use Mk II Tank)	1000 FPS Due East
• TPS	Ablative	Reus Ext Insulation
• Payload Wt, Min/Desired, K Lb	10/25	40 Polar 65 Due East

• Payload Size	15 x 60 Ft
• OMS, RCS, APU Propellant	Storable
• Cross Range	1100 N Mi
• Abort Capability	Intact
• Staging Velocity	6000 ± 1000 FPS
• Wt Contingency, Veh/HO Tank, %	10/2
• ABES for Orbital Flight	In Payload Bay

GRUMMAN BOEING

KEY DESIGN GROUNDRULES

- Mk I/II Configurations Use 1:1 Replacement, SSME for J-2S
- Mk II SSME Constrained to Mk I J-2S Envelope
- Assumed Acceptable Mk I Payload = 20K Lb
- SRMs Sized as Backoff for Series - & RAO-BRB Vehicles

OBJECTIVES

- Compare & Evaluate Flyback, Series-BRB, & RAO Shuttle Systems
- Recommend Most Practical in Light of Technical Funding Limitations
- Report BRB Detail Design Data
- Identify SRM Backup Capability for BRB
- Show Performance/Cost Differences for J-2S/SSME vs SSME Only
- Report Swing-Engine Status

BRIEFING OUTLINE

SERIES BURN
Veh Performance
& Selection

- Series BRB – J-2S/SSME
- Series BRB – SSME Optimized
- Flyback – J-2S

PARALLEL BURN
Veh Performance
& Selection

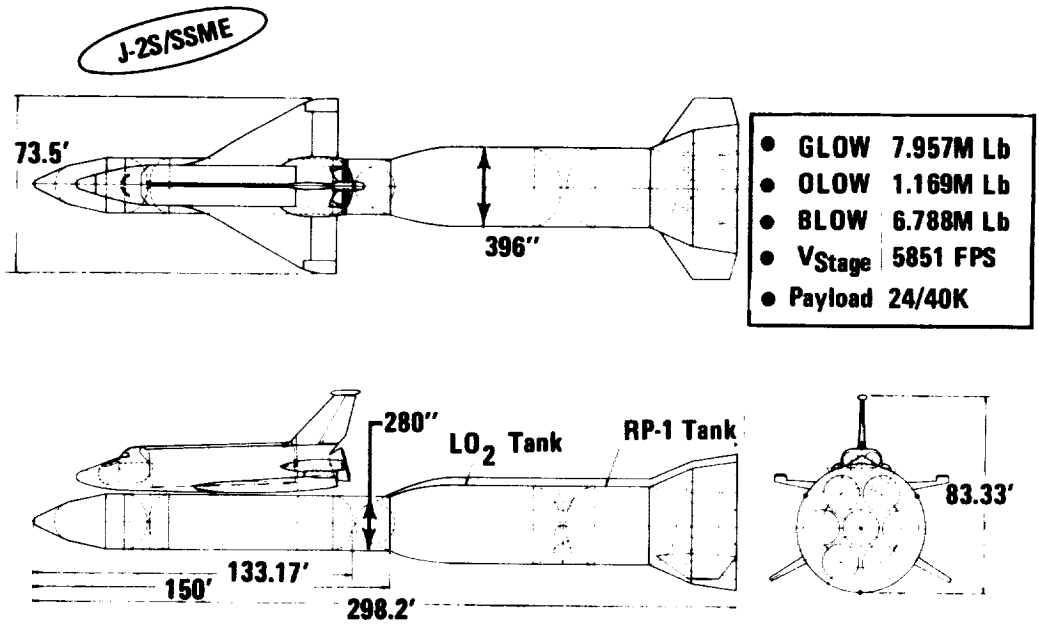
BOOSTER
Design
Status

SYSTEM
Comparison &
Evaluation

SUMMARY

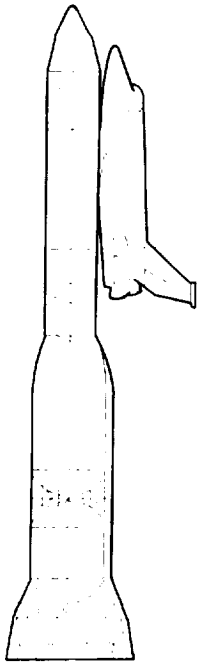
GRUMMAN BOEING

MK I SERIES BALLISTIC LAUNCH CONFIGURATION



- GLOW 7.957M Lb
- OLOW 1.169M Lb
- BLOW 6.788M Lb
- V_{Stage} 5851 FPS
- Payload 24/40K

SERIES BRB – J-2S/SSME & SSME ORBITER



	Mk I *Mk II J-2S/SSME	SSME	Δ
GLOW, M Lb	7.957	6.903	-1.054
BLOW, M Lb	6.788	5.616	-1.172
Booster Inert M Lb	1.262	1.081	-0.181
Booster λ'	0.814	0.807	–
OLOW, M Lb	1.169	1.287	+0.118
Orbiter Dry Wt, K Lb	135.8	147.3	+11.5
Tank Dry Wt, K Lb	52.7	55.8	+3.1
Orbiter Engines	(4) 265K J-2S/SSME	(4) 375K SSME	–
Orbiter T/W	.907	1.165	–
Payload, K Lb	23.8/40	40	+16
V_S, FPS	5851/5794	5003	–

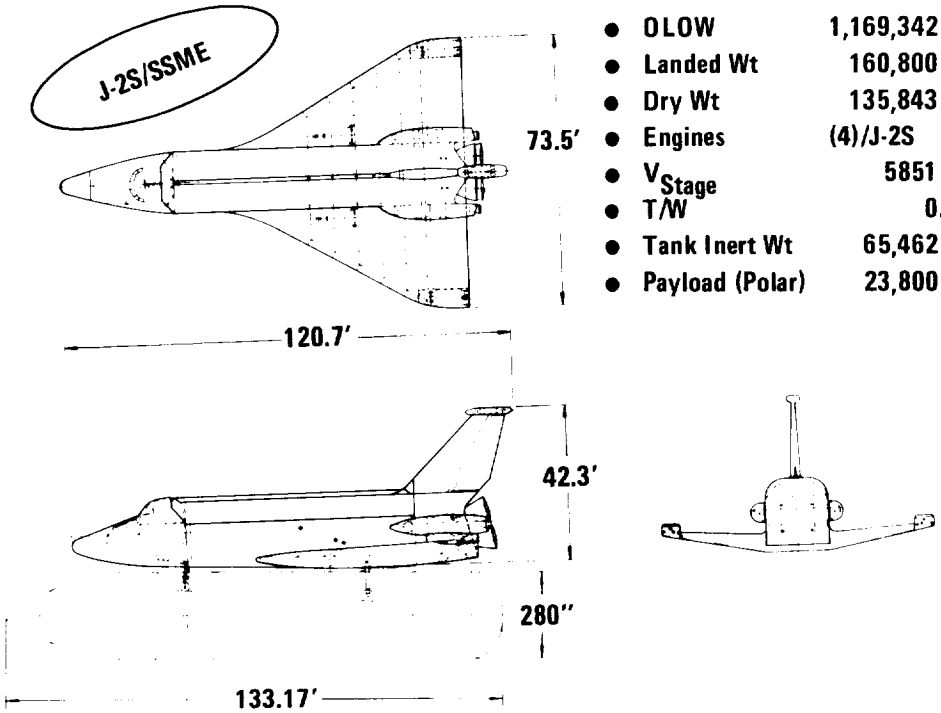
*Characteristics Shown for Mk I

POINT DESIGN LAUNCH VEHICLE WEIGHTS

- Series BRB
- Polar Orbit

J-2S/SSME	Mk I	Mk II
Weight		
Payload	23,800	40,000
Orbiter		
Dry	135,843	133,069
Landed	160,800	177,580
Inject	184,500	199,360
Tank		
Dry	52,674	52,674
Inert	65,462	65,930
Propellant	919,380	919,380
OLOW	1,169,342	1,184,670
Staged Tank Skirt	(7500)	(7500)
Booster		
Inert	1,262,404	1,262,404
Propellant	5,525,396	5,525,396
BLOW	6,787,800	6,787,800
GLOW	7,957,142	7,972,470
Orbiter Ideal ΔV	21,600	21,750
Booster Ideal ΔV	10,513	10,475
V_{Stage}, FPS	5,851	5,794

SERIES BRB – ORBITER/HO TANK



- OLOW 1,169,342 Lb
- Landed Wt 160,800 Lb
- Dry Wt 135,843 Lb
- Engines (4)/J-2S
- V_{Stage} 5851 Fps
- T/W 0.906
- Tank Inert Wt 65,462 Lb
- Payload (Polar) 23,800

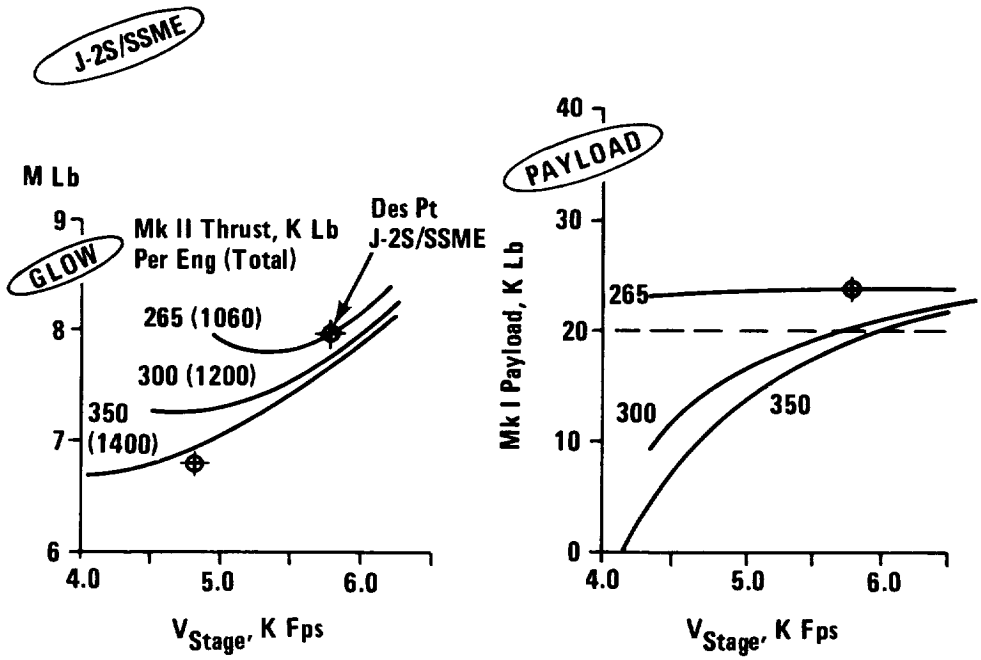
SERIES BRB – HO TANK WEIGHTS – POLAR ORBIT

- Usable Ideal ΔV Propellant: 919,380 Lb

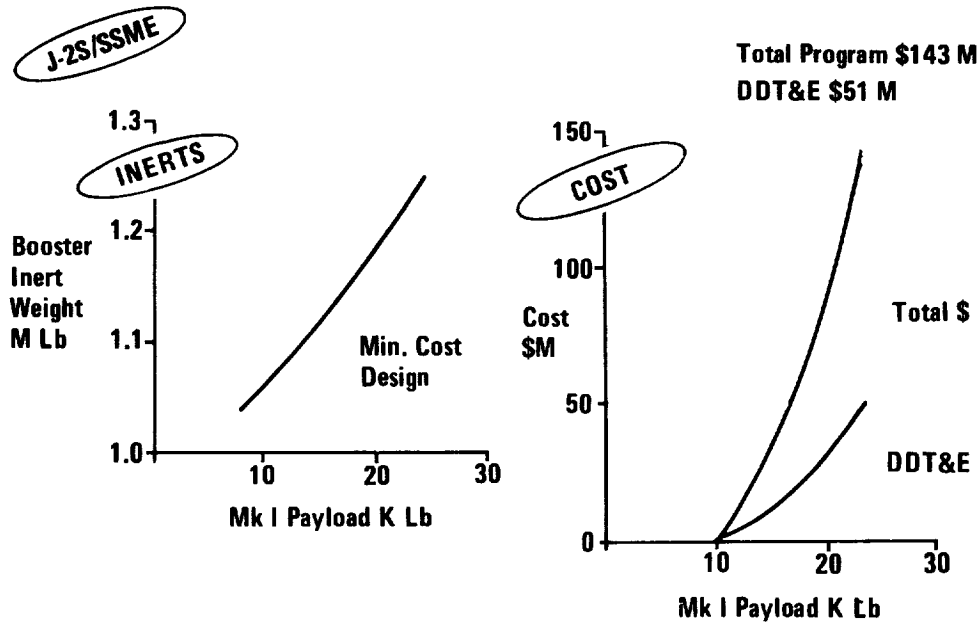
J-2S/SSME

	Mk I
Structure	
LH_2 Tank	23,262
Mid Skirt	5,360
LOX Tank	9,061
Aft Skirt	1,213
Subsystems	
TPS/Insul	4,460
Nose Cone	1,400
Sep/Deorbit	2,680
Propulsion	2,665
Electronics	1,540
Contingency (2%)	1,033
Total Dry Weight	52,674
Residuals	7,050
Reserves	5,738
Total Inert	65,462
λ'	0.9335
Staged Skirt	7,500

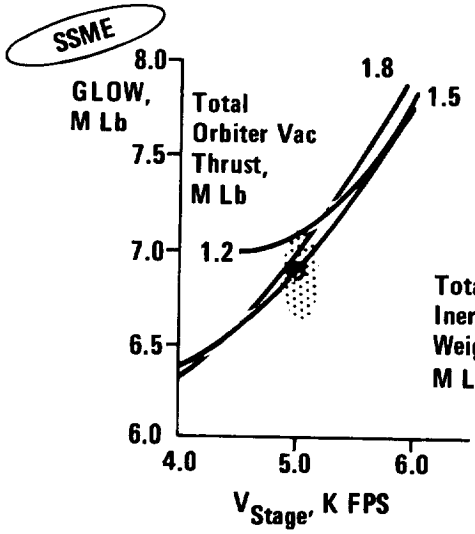
SERIES BRB PERFORMANCE

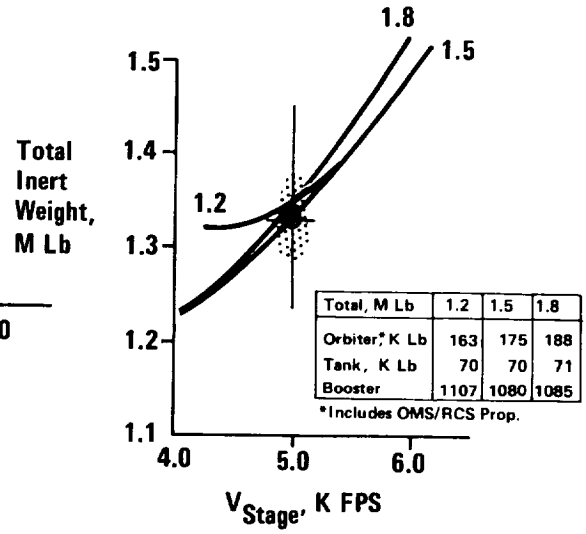


SERIES BRB–COST OF MAX MK I PAYLOAD



SERIES BRB PERFORMANCE – GLOW & TOTAL INERTS

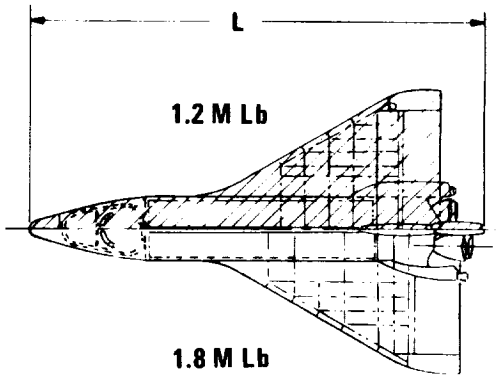




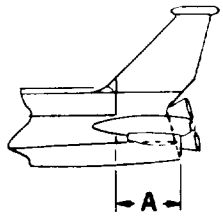
Total, M Lb	1.2	1.5	1.8
Orbiter,* K Lb	163	175	188
Tank, K Lb	70	70	71
Booster	1107	1080	1085

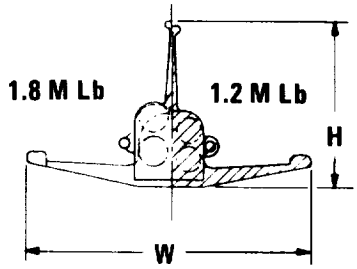
*Includes OMS/RCS Prop.

SERIES BRB – SSME THRUST COMPARISON



Total Thrust	SSME 1.8 M Lb	SSME 1.2 M Lb
Inj, K Lb	228	203
Landed, K Lb	200	178
Dry, K Lb	158.7	136.6
Engine	(4)-450 K	(4)-300 K
I_{SP} Vac	457.2	457.2
ϵ	90	90
O/F	6/1	6/1
L, Ft	121.15	120.7
W, Ft	77.33	73.5
H, Ft	43.67	42.3
A, Ft	21.8	16.75



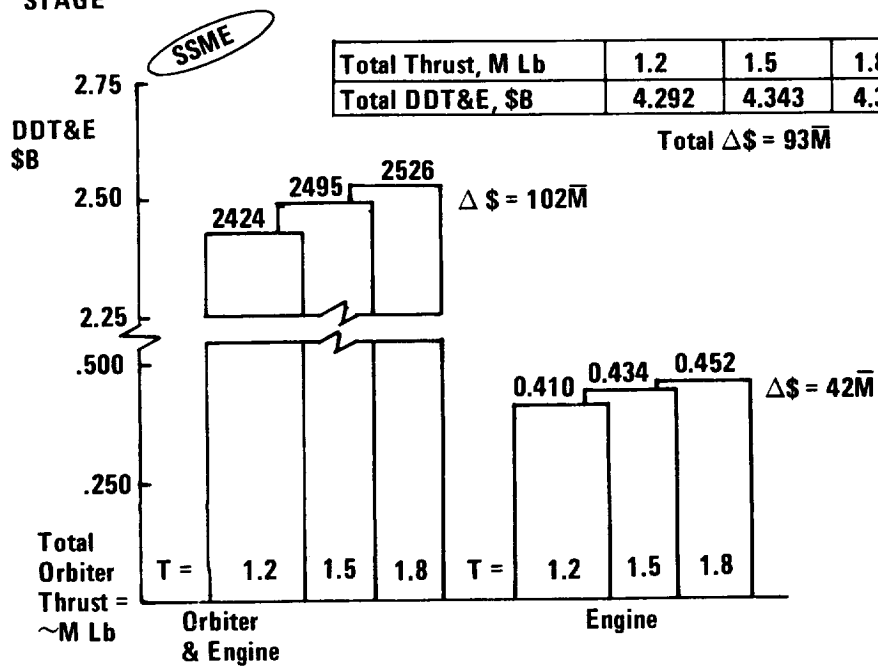


SERIES BRB

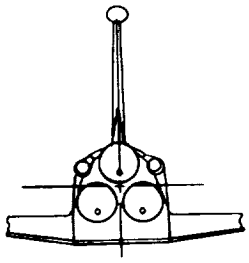
V_{STAGE} = 5000 FPS

Total Thrust, M Lb	1.2	1.5	1.8
Total DDT&E, $B	4.292	4.343	4.385

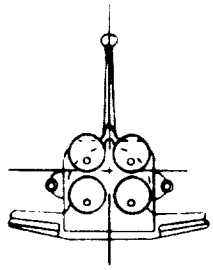
Total $\Delta\$ = 93\overline{M}$

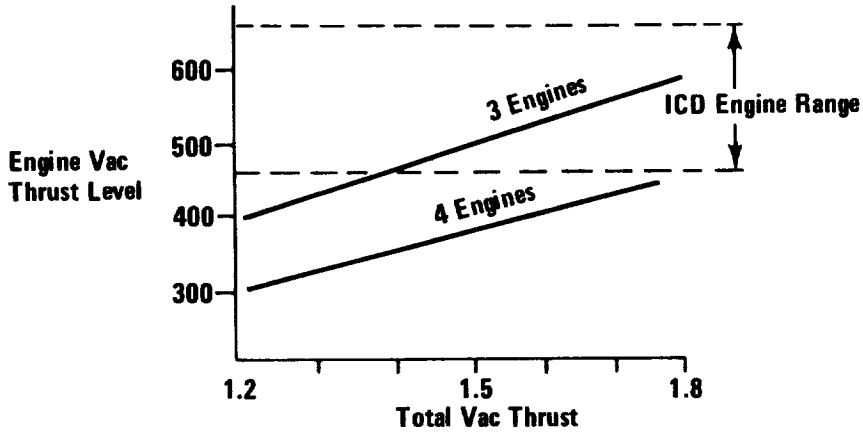


HOW MANY SSME ENGINES IN ORBITER – 3 OR 4?



- Thrust level
- Weight
- Cost
- Abort





SERIES/BRB – HOW MANY ENGINES? – 3 OR 4

WEIGHT

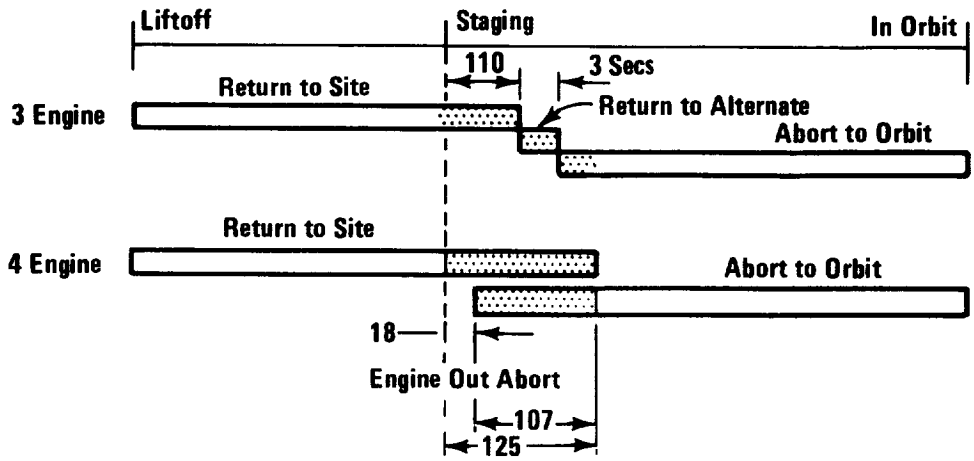
	Delta (4) vs (3)
Main Engine	-1020
Engine Install	+ 230
Aero Surfaces	+563
Body	-63
TPS	+638
Iteration, rem	+159
Total, Lb	+507

COST

	1800 K Lb Thrust		Delta
Thrust	(4)-450K	(3)-600K	(4) vs (3)
Dry Weight, Lb	158,765	158,258	+507
DDT&E, $M			
• Engine	$ 452	$ 472	-$20
• Orbiter	2074	2071	+3
• Total	$2526	$2543	-$17

GRUMMAN BOEING

SERIES/BRB – HOW MANY ENGINES? – ABORT



SERIES/BRB - HOW MANY SSME ENGINES? - SUMMARY

	3	OR 4
• Weight	√	√
• Cost		√
• Abort		√
• Maint and Spares	√	
• Thrust Level	400/500	300/375

GRUMMAN BOEING

J-2S/SSME vs SSME SERIES BURN

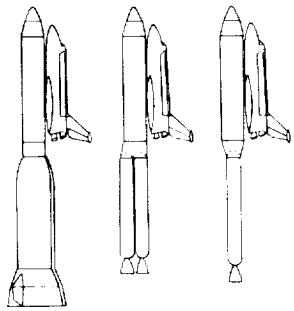
PERFORMANCE

	J-2S/SSME Mk I	SSME 1500K
• GLOW, M Lb	7.957	6.903
• OLOW, M Lb	1.169	1.287
• W_I Bstr, M Lb	1.262	1.081
• Orb Eng No/T_V	4/265	4/375
• V_{Stage}, FPS	5851	5003
• Payload, I/II, K Lb	23.8/40	40

COST

	J-2S/SSME	SSME
• Mk I DDT&E, $B	4.08	4.35
• PAF, $B	1.02	1.07
• Cost/Flt, $M (Not Amortized)	8.11	7.89
• Tot. Prog, $B	10.83	10.40

SERIES BRB/SRM BACKUP - COST/PERFORMANCE



BRB SRM 1-ST. SRM 2-ST.

	J-2S/SSME			SSME		
		156" SRM			SRM	
	BRB	1-ST (3)	2-ST (3)	BRB	156 1-ST (3)	1207 1-ST (6)
PERF, M Lb						
• GLOW	7.96	5.70	5.30	6.90	5.21	5.33
• BLOW	6.79	4.51	4.12	5.62	3.92	4.04
• Bstr Inert	1.26	.573	.513	1.08	.495	.539
COST						
• Mk I DDT&E, $B	4.08	3.16	3.21	4.351	3.51	3.48
• PAF, $B, '75	1.02	0.78	0.79	1.07	0.85	0.86
• Cost/Flt*, $M	8.11	21.97	20.51	7.89	20.4	22.5
• Tot. Prog, $B	10.83	14.49	13.92	10.40	13.67	14.54

*Not Amortized

GRUMMAN BOEING

SERIES/BRB SUMMARY

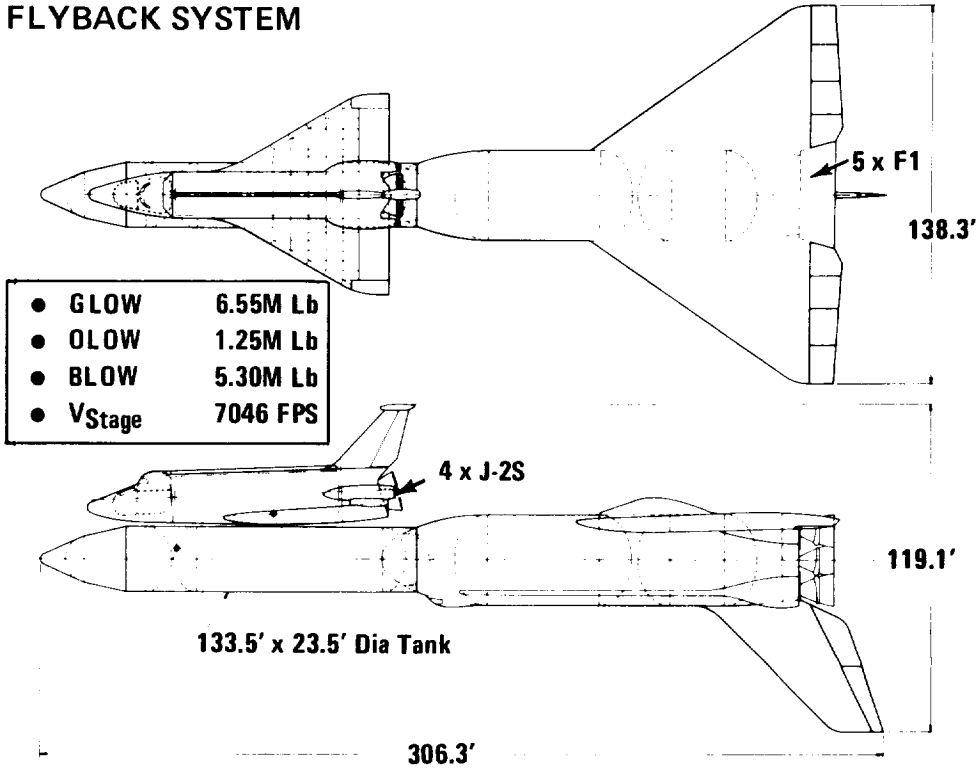
J-2S/SSME

- Requires SSME Thrust = J-2S Thrust (265K)
- GLOW I MLB Higher Than SSME
- DDT&E Lower By $270M, PAF $50 M
- SRM Backoff Available

SSME

- Orbiter Installed Thrust Should Be Near 1.2M Lb for Lowest $DDT\&E_I$
- Four Engine Abort Performance Superior to Three Engines
- SRM Backoff Available

FLYBACK SYSTEM



• GLOW	6.55M Lb
• OLOW	1.25M Lb
• BLOW	5.30M Lb
• V_{Stage}	7046 FPS

GRUMMAN BOEING

FLYBACK/J-2S – WEIGHT SUMMARY – POLAR ORBIT

Payload, Up/Down	55,405/25,000
Orbiter	
Dry	135,843
Landed	162,000
Inject	219,340
Tank	
Dry	56,528
Inert	70,489
Propellant	962,500
OLOW	1,252,329
Booster	
Inert	710,700
Propellant	4,587,600
BLOW	5,298,300
GLOW	6,550,629
Orbiter Ideal ΔV, FPS	20,470
Booster Ideal ΔV, FPS	11,809
V_{Stage}, FPS	7,046

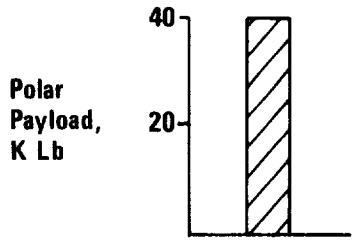
HO TANK WEIGHTS – POLAR ORBIT

- Flyback/J-2S
- Usable Ideal ΔV Propellant: 962,500 Lb

Structure	
LH_2 Tank	23,700
Mid Skirt	5,540
LOX Tank	9,300
Aft Skirt	3,850
Subsystems	
TPS/Insul	4,610
Nose Cone	1,400
Sep/Deorbit	2,700
Propulsion	2,780
Electronics	1,540
Contingency (2%)	1,108
Total Dry Weight	56,528
Residuals	7,200
Reserves	6,761
Total Inert	70,489
λ'	0.9318

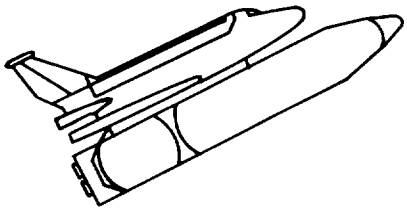
GRUMMAN BOEING

FLYBACK/J-2S – PAYLOAD CAPABILITY



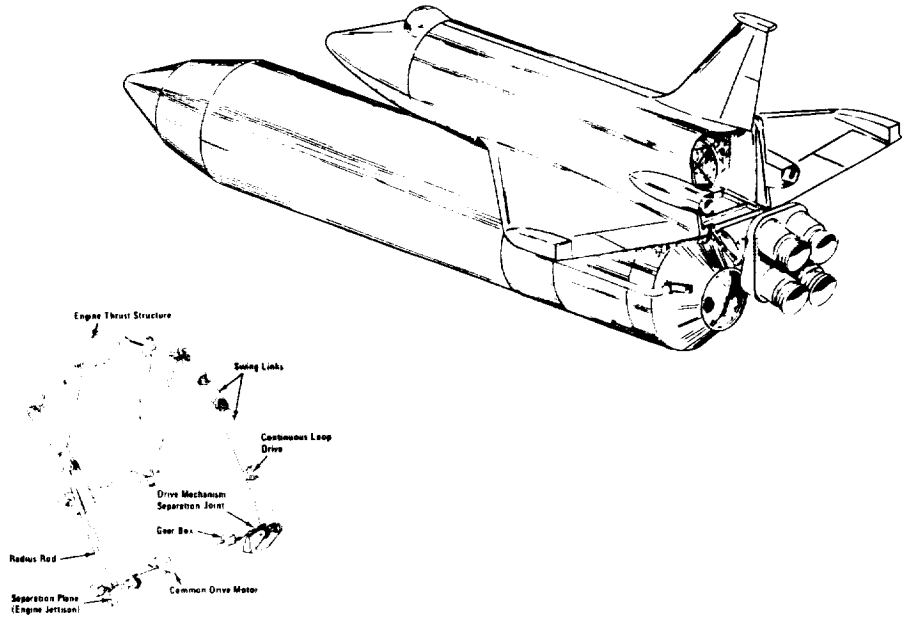
• Engines	(4) J-2S
• OLOW, M Lb	1.252
• BLOW, M Lb	5.298
• GLOW, M Lb	6.550
• V_{Stage}, FPS	7046
• Weight Margin	15K

SWING-ENGINE STUDY STATUS



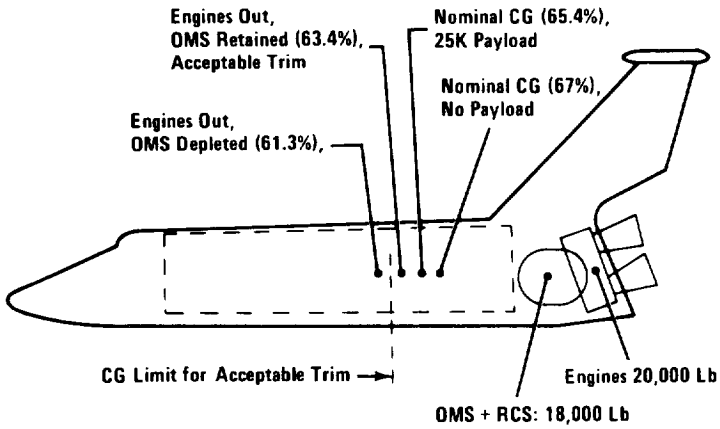
- Permits LOX Tank Location Aft
- Decouples Orbiter/Main Propulsion Development
- Can Be Used as Expendable Stage for Large Unmanned Payloads
- Provides Pad Abort Potential

SWING ENGINE INSTALLATION



SERIES BRB SWING ENGINE OPERATIONS EVALUATION

ASSUMPTION: SEPARATION/RETRACTION MECHANISM FAILURE



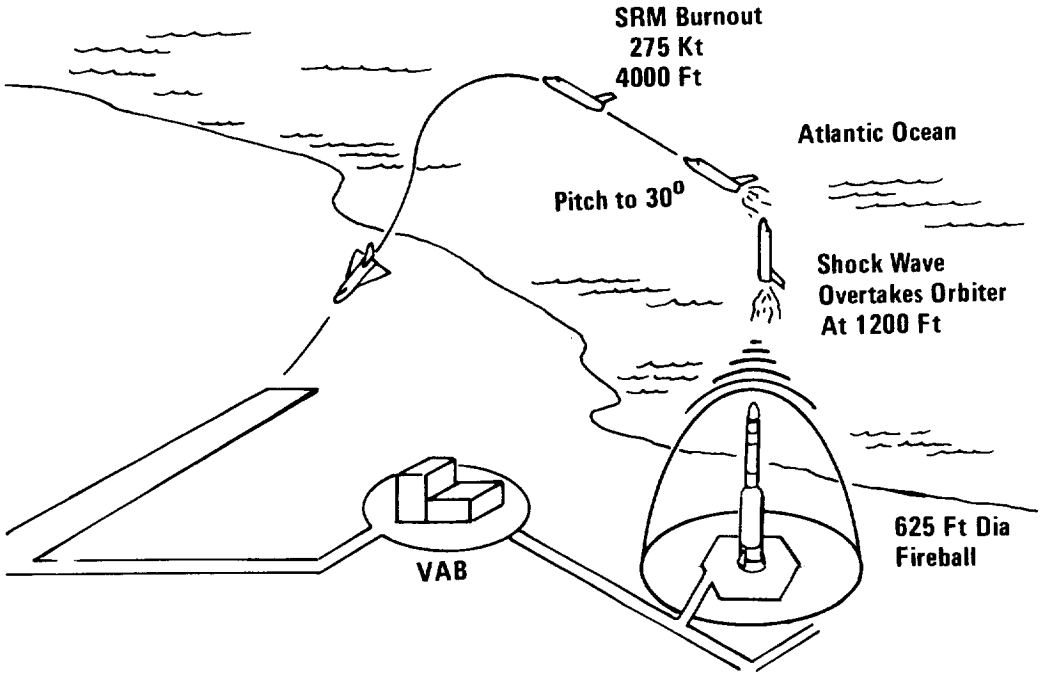
- *Retain Maximum OMS + RCS for Balance*
- Terminate Mission
- Make Normal Entry

SERIES BRB - SWING ENGINE WEIGHT COMPARISON

SAVES 9237 LB

Major Item	BRB Series	Swing Engine	Weight
ORBITER			
(Thrust Structure)	(2,675)		(-2,675)
(Swing Mechanism)	–	(+1700)	(+1700)
Body Group	31,499	30,524	-975
Propulsion Installation	4,400	4,980	+580
(Self-Contained Hydraulics)			
..			
..			
Dry Weight	135,843	135,375	-468
HO TANK			
Propellant	919,380	919,380	
LH_2 Tank	23,262	10,388	-12,924
Mid Skirt	5,360	2,290	-3,070
Aft Skirt	1,213	2,935	+1,723
Thrust Structure	–	2,788	+2,788
TPS/Insulation	4,460	6,700	+2,240
Nose Cone	1,400	1,200	200
Dry Weight	52,674	43,905	-8,769
Inert	65,462	56,500	-8,962
λ'	0.9335	0.942	

SERIES BRB – SWING ENGINE – PAD ABORT



SERIES BRB – SWING ENGINE SUMMARY STATUS

● Weight Reduction Lb	– Orbiter & HO Tank	9,237
	– BLOW	720,988
	– Booster Inert	135,360
● Payload Bay Storage	– Not Possible (PL Bay Dia = 180 In.)	
	– 4 J-2S 230 In. On Diagonal	
	– 3 500K 220 In. Across Base	
● Engine Swing Mechanism	– Needs Further Detailing	
● Orbiter Pad Abort	– Potential Exists	

BRIEFING OUTLINE

SERIES BURN
Veh Performance
& Selection

PARALLEL BURN
Veh Performance
& Selection

BOOSTER
Design
Status

SYSTEM
Comparison &
Evaluation

SUMMARY

- **Sizing**
- **Control**
- **Separation**
- **Configuration Comparison**

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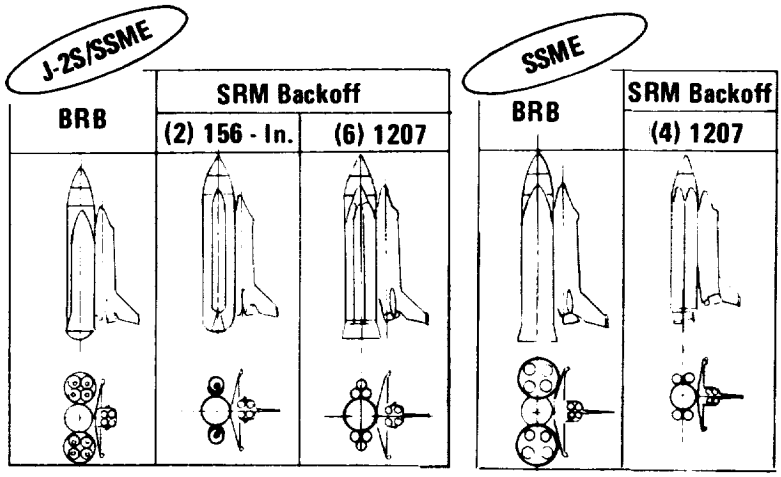
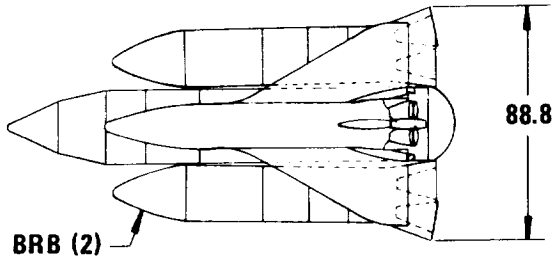
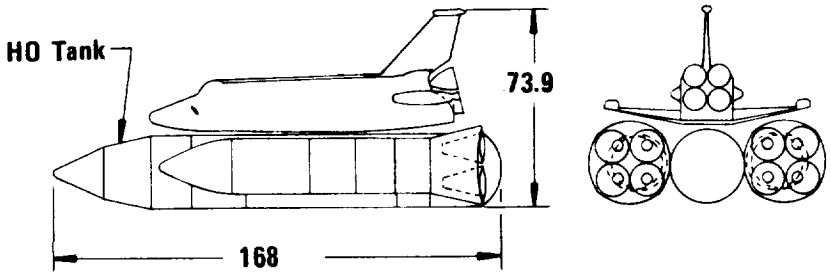
RAO – PRIMARY & SRM BACKOFF CONFIGURATIONS



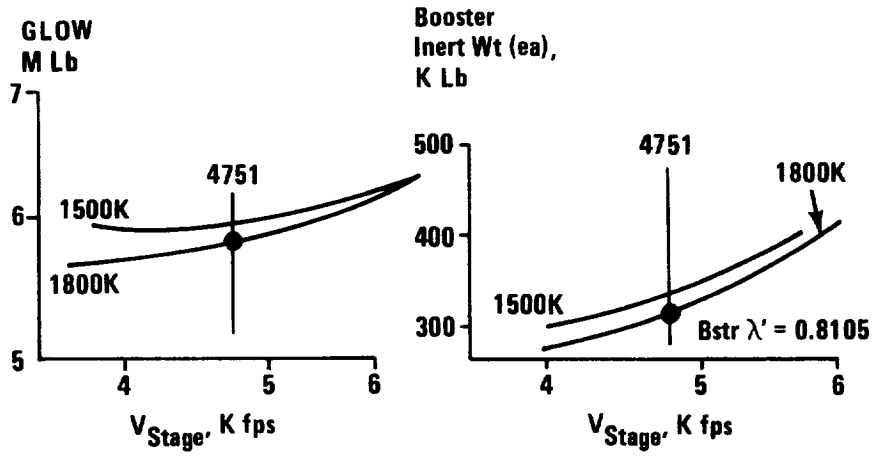
RAO/BRB – SSME ARRANGEMENT



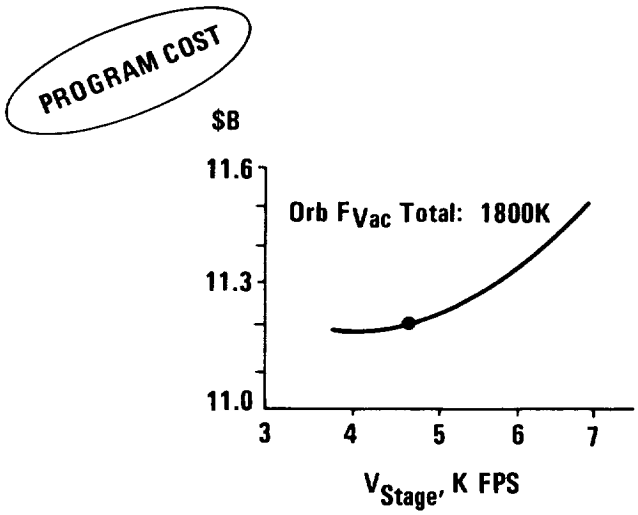
- GLOW 5.760M Lb
- OLOW 2.052M Lb
  - Prop. 1.720M Lb
- Orbiter 228K Lb
- BLOW 3.708M Lb
  - Prop. 2.966M Lb
- F_{Vac} Bstr 8 x 920 K Lb
- F_{Vac} Orb 4 x 450 K Lb



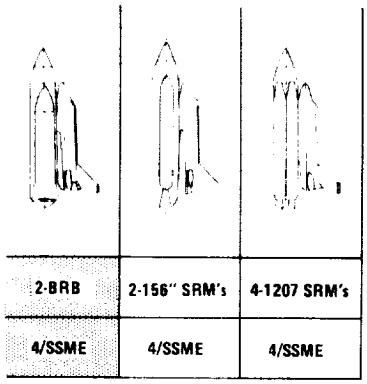
RAO/BRB – SSME SIZING

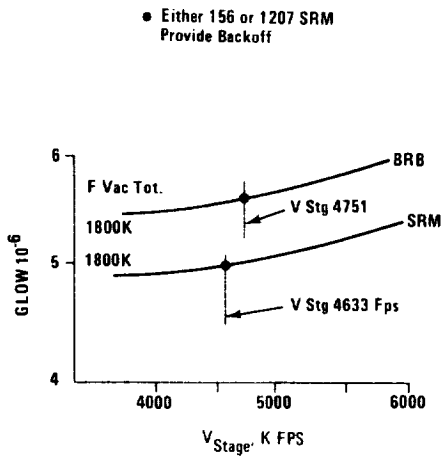


RAO/BRB – SSME – COST

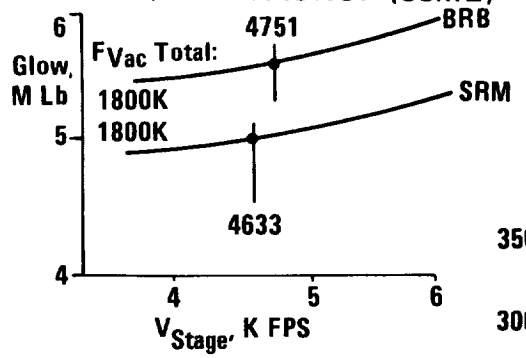


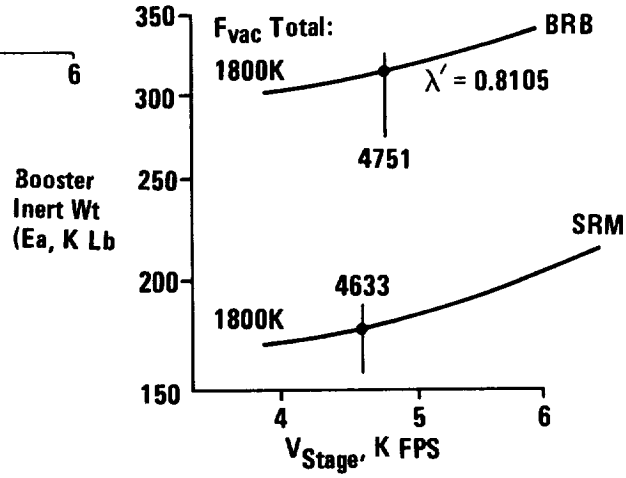
RAO BRB/SRM BACKOFF (SSME)



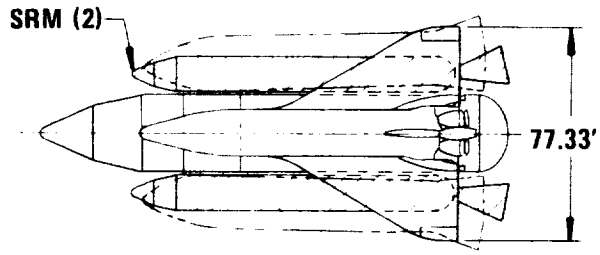


RAO BRB/SRM BACKUP (SSME)



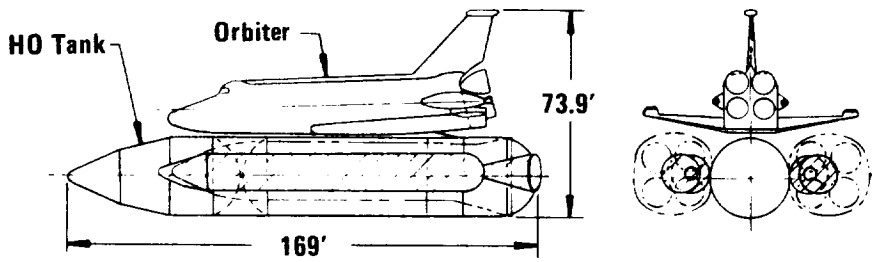


RAO 156" SRM BACKOFF (SSME)

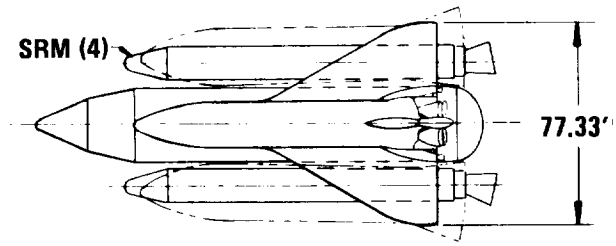


• GLOW		4.775M Lb
• OLOW		2,052M Lb
– Prop.		1.720M Lb
• Orbiter		228K Ln
• BLOW		2.724M Lb
– Prop		2.377M Lb
• F_{Vac} Bstr	2 x	2.595M Lb
• F_{Vac} Orb	4 x	450K Lb

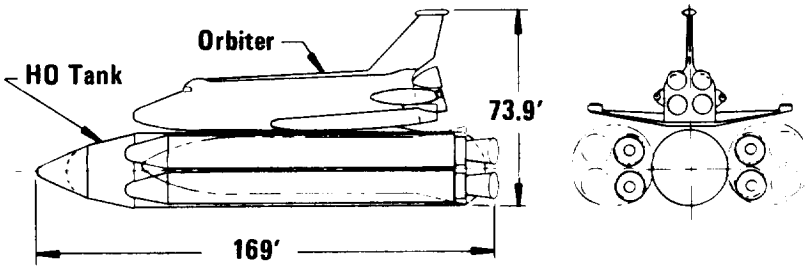
Orbiter & Tank Identical to BRB Orbiter/Tank



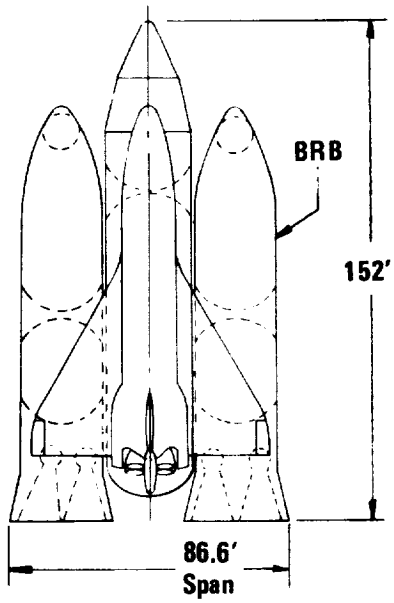
RAO/BRB – 120-IN. SRM BACKOFF (SSME)



• GLOW	4,772M Lb
• OLOW	2,052M
• Prop.	1,721M
• Orbiter	228K
• BLOW	2,719M
• Prop.	2,360M
• F_{Vac} Bstr	4 x 1270K
• F_{Vac} Orb	4. 450K

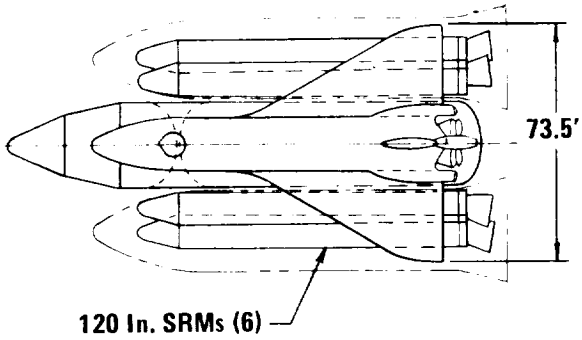


RAO/BRB – J-2S/SSME ARRANGEMENT

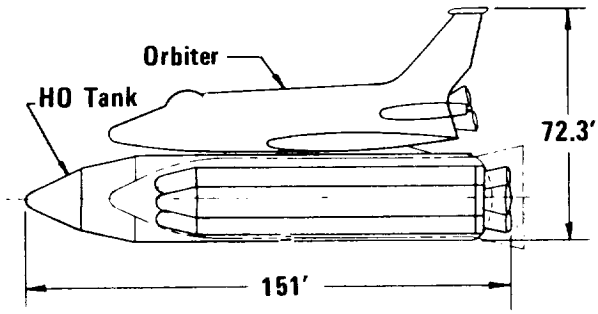


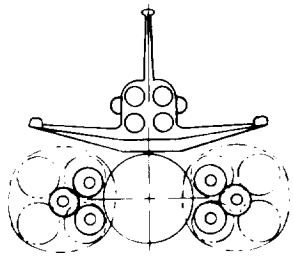
Mk II Weights	
	BRB
GLOW, M Lb	6.957
OLOW, M Lb	1.647
Prop., M Lb	1.363
Orbiter	199.0
BLOW, M Lb	5.309
Prop., M Lb	4.332
F_{Vac} Bstr K Lb	9.974
F_{Vac} Orb, K Lb	1.060

RAO/120-IN. SRM BACKOFF (J-2S/SSME)

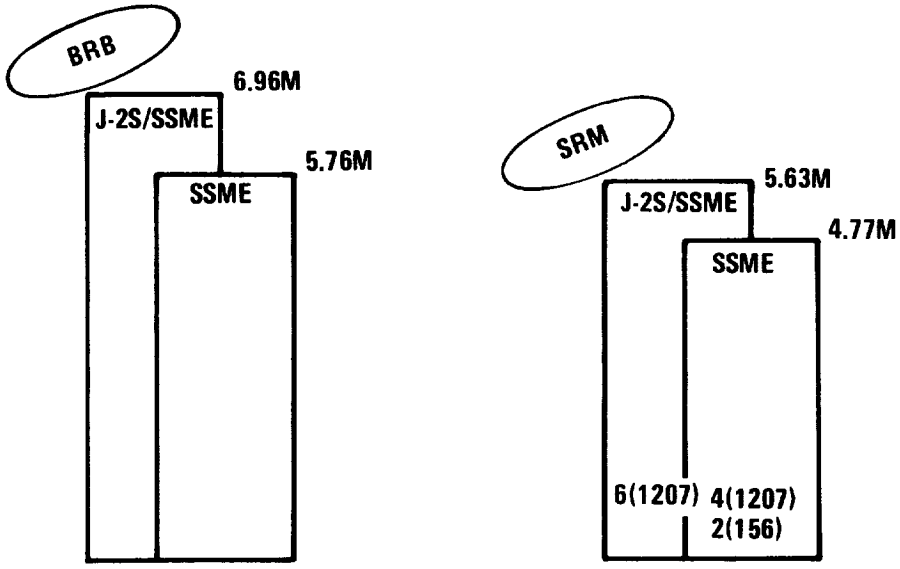


	120-In.
GLOW, M Lb	5.625
OLOW, M Lb	1.647
Prop., M Lb	1.363
Orbiter, K Lb	199.3
BLOW, M Lb	3.977
Prop., M Lb	3.437
F_{Vac} Bstr, M Lb	6.859
F_{Vac} Orbiter, M Lb	1.060



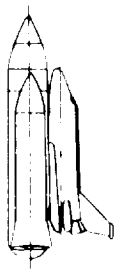


RAO GLOW COMPARISON FOR SSME vs J-2S/SSME



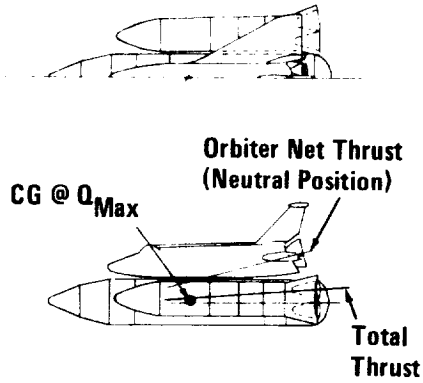
RAO CONTROL EVALUATION

Objective: Eliminate TVC from BRB



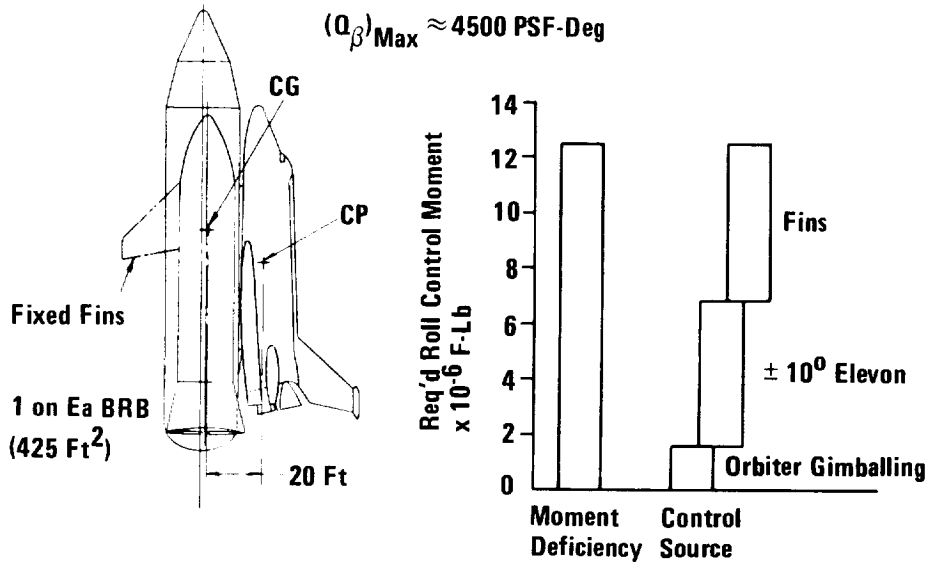
- **Nominal Flight**
- **Orbiter or Booster Engine Failure**
- **3 or 4 Engines**

RAO/BRB – SSME CONTROL FOR NOMINAL FLIGHT



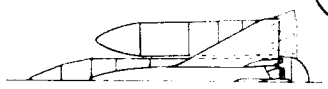
- For Dynamic Pitch and Yaw Control At Q_{Max} – No Booster TVC Required
- Roll Control Is Major Problem

ROLL CONTROL DURING ASCENT



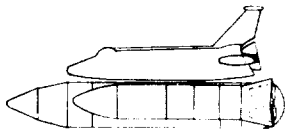
- Weight 5.2K Lb, Incl: – Jettison Hardware

RAO/BRB/SSME - CONTROL UNDER ENGINE FAILURE CONDITIONS



CRITICAL CONTROL CONDITIONS

	Gimbal Angle Margin at Q_{Max} (Avail Gimbal Angle: ±10 Deg)	
	Pitch (Upper Orb Eng Out)	Yaw (Booster Eng Out)
SSME/BRB	6-1/2	0
J-2S/BRB	8	0



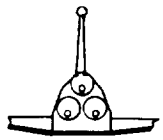
- Assume Abort Reqd for All Engine Failures
- Bstr Eng Failure Req Auto Shutdown of Opp Eng
- Roll Buildup at 1.2 deg/sec^2

RAO/BRB – SSME: HOW MANY ENGINES? FOR CONTROL

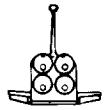
Assuming:

- No TVC in Booster
- $\pm 10^0$ ICD Gimbal Angle
- Upper Orbiter Engine-Out Critical
- Q_{MAX} Imposes Greatest Demand

Pitch Gimbal Margin for Q_{MAX} Control:



3^0



6^0

With One Engine Out, 4-Engine Orbiter Provides More Control Margin & More Than Doubled Control Authority

RAO – CONTROL/TVC CONCLUSIONS

- For Nominal Flight - No TVC Required
  - Pitch & Yaw Control OK
  - Roll Stabilization Requires Fins
- Engine-Out Conditions Critical
  - Control Margins Appear Acceptable, But
  - Are Based on Analysis & Rel W.T.
  - Need More Wind Tunnel Test & Simulation
- Cannot Conclusively Prove No TVC Required - Do Not Use as Configuration Discriminator
- If Full TVC Were Used on BRB Would add $\Delta\sim$ 250K GLOW

RAO/BRB-SSME – HOW MANY SSME ENGINES

3 or 4

• Installed Weight	Close
• System Cost	4
• Better Installation	3
• Reduced Operations, Spares, & Cost	3
• Better Control Potential	4
• Improved Abort Operation	4

SELECT 4 x 450 K
(396 K S.L.) FOR RAO

GRUMMAN BOEING

RAO/BRB SSME vs J-2S/SSME SUMMARY COMPARISON

PERFORMANCE

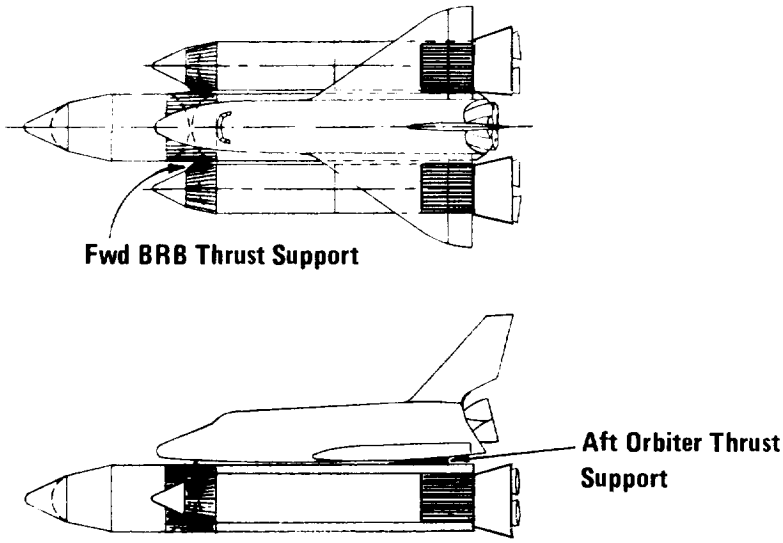
	SSME	J-2S/SSME
GLOW	5.76 M	6.96 M
OLOW Lb	2.05 M	1.65 M
Wt Bstr Lb	.742 M	.977 M
Orb Eng No/T_V	4/450 K	4/265 K
V_{Stage}	4793	5901
Payload I/II - Lb	40 K	21/40 K

COST

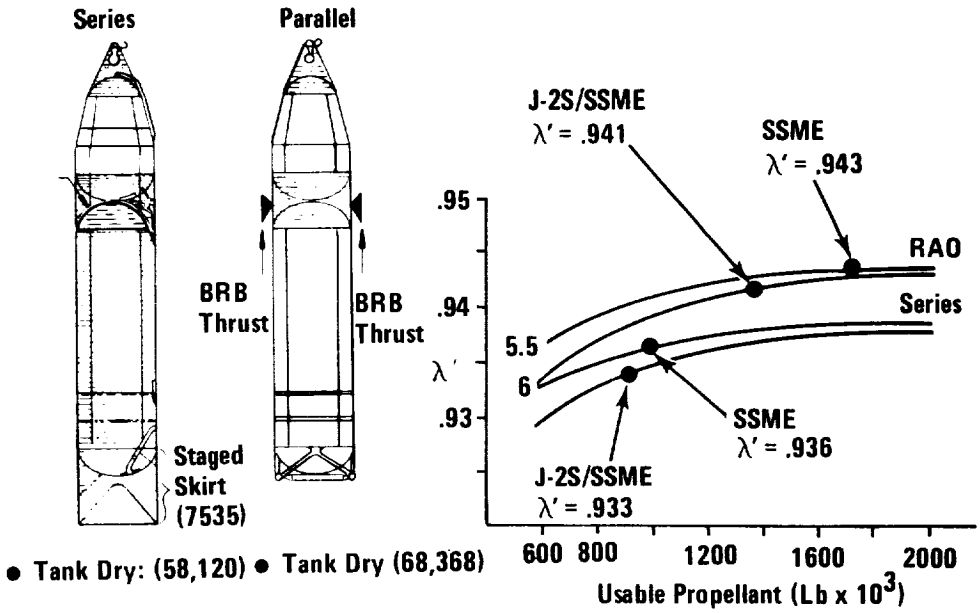
	SSME	J-2S/SSME
Mk I DDT&E	4.02 B$	3.69 B$
PAF	.97 B$	.92 B$
Cost/Flt*	8.20 M$	8.13 M$
Tot Prog	10.10 B$	10.45 B$

*Not Amortized

RAO/BRB – SSME: BOOSTER HO TANK SUPPORTS

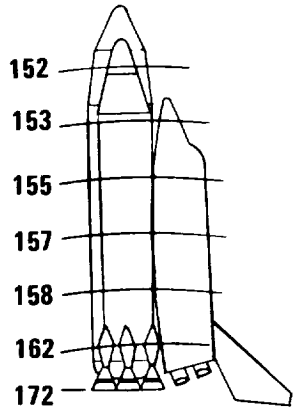


HO TANK COMPARISON



● Tank Dry: (58,120) ● Tank Dry (68,368)

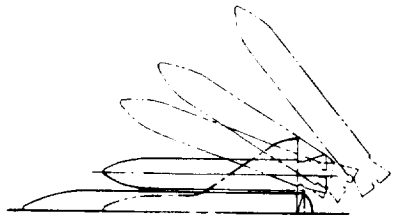
RAO/BRB – SSME – ACOUSTIC SOUND PRESSURE LEVEL AT LIFTOFF



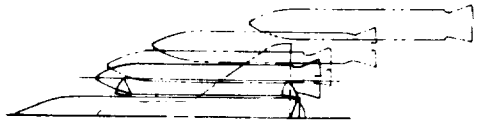
- Orbiter Structural Penalty of 1450 Lb.

RAO – BOOSTER SEPARATION

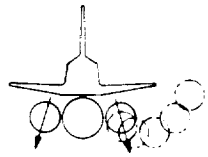
– Peel-Off Passive



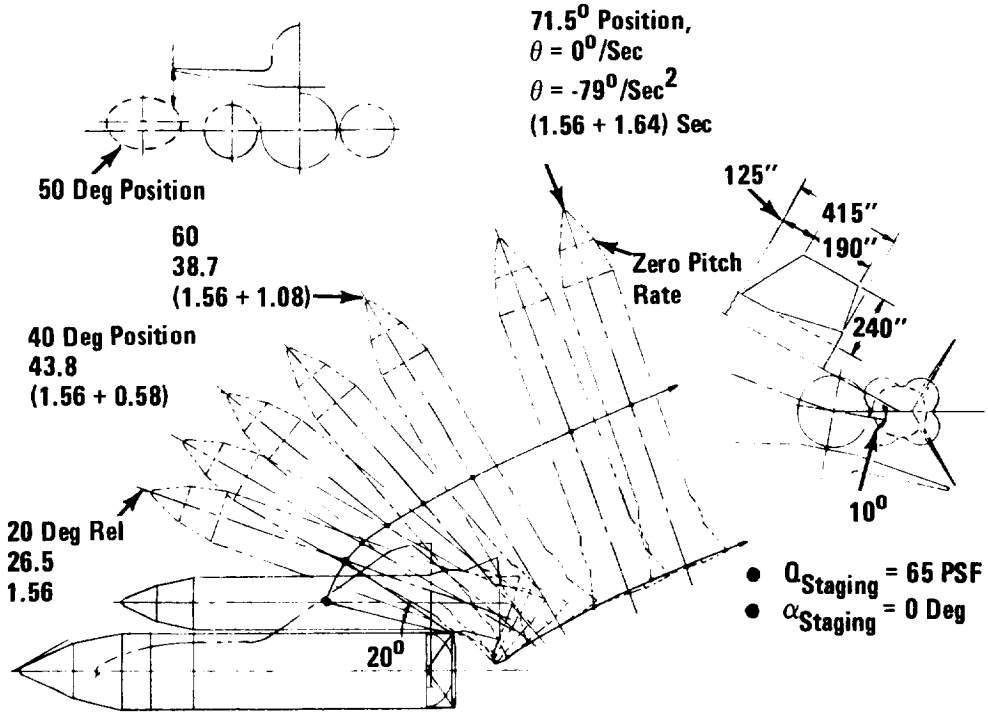
– Parallel Links Active



– SRM Active



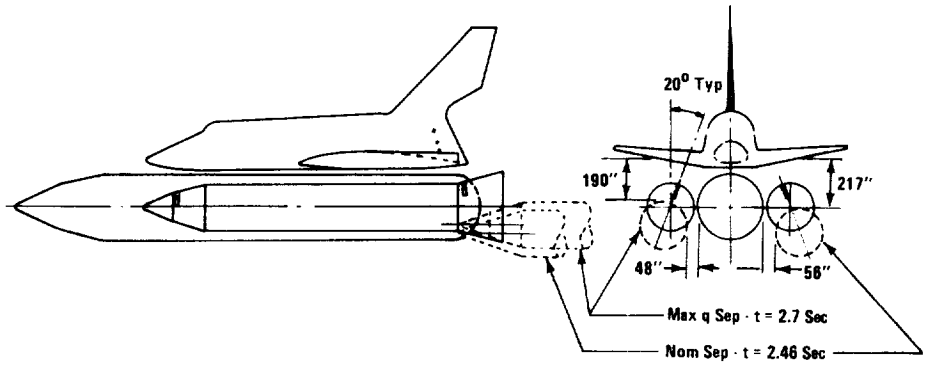
RAO–BOOSTER SEPARATION



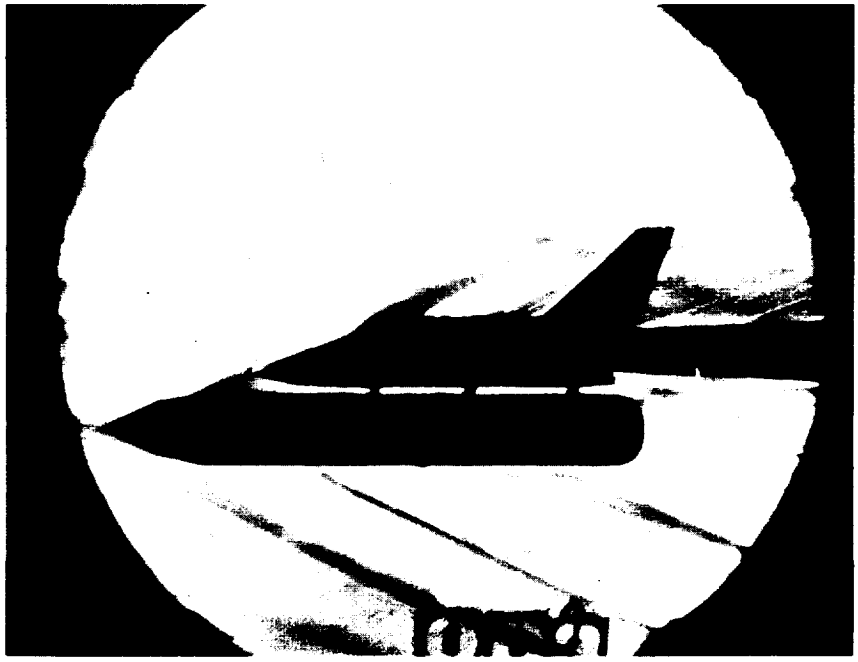
- $Q_{Staging}$ = 65 PSF
- $\alpha_{Staging}$ = 0 Deg

BOOSTER SEPARATION – ROCKET ASSISTED

	Weight · Lb		
	Total SRM	Struct Support	Total
Nominal	3820	454	4274
Max-q	8060	786	8846



RAO WIND TUNNEL – MACH 3.0



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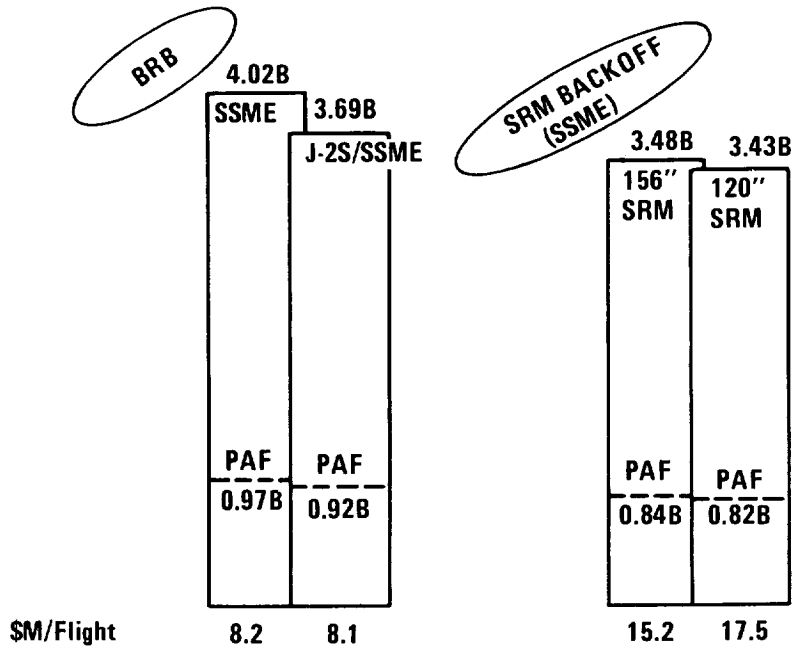
RAO – BOOSTER SEPARATION CONCLUSIONS

- Loading Conditions Critical for Max Q Separation - Doubles Nominal Design Loads
- Passive Peel-off System OK for Nominal Max Q
- Prefer Active SRM Ejection at 9,000 Lb Weight Penalty

RAO ENGINE & BOOSTER COSTS

Mk I, DDT&E, & PAF



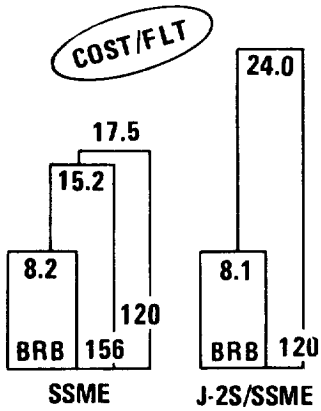
RAO/BRB/SRM BACKOFF

PERFORMANCE	SSME			J-2S/SSME	
	BRB	Solids		BRB	Solids
		2 - 156	4 - 1207		6 - 1207
GLOW, M Lb	5.76	4.78	4.77	6.96	5.63
OLOW, M Lb	2.05	2.05	2.05	1.65	1.65
BLOW, M Lb	3.71	2.72	2.72	5.31	3.98
ORB Inert, K Lb	167	167	167	141	142
Bstr Inert, K Lb	742	347	359	977	539
Tank Inert, K Lb	103	103	103	85	85

RAO BRB/SRM BACKOFF

COST

	SSME			J-2S/SSME	
	BRB	Solids		BRB	Solids
		2 - 156	4 - 1207		6 - 1207
Mk I DDT&E $B	4.02	3.48	3.43	3.69	3.02
PAF '75 $B	.97	.84	.82	.92	.72
'84		.93	1.09		1.40
Tot Prog - $B	10.10	11.49	11.91	10.45	15.26



RAO CONFIGURATION CHARACTERISTICS

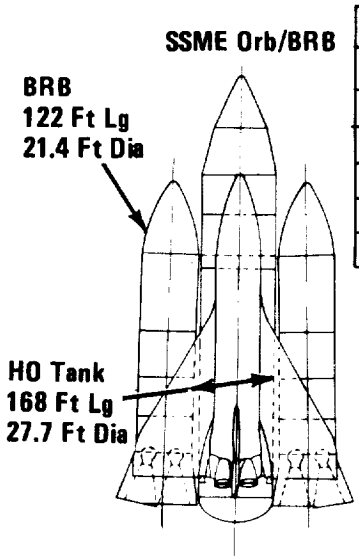
	BRB				SRM
			Opt/SSME		Mk II J-2S/SSME
	Opt SSME	Mk II J-2S/ SSME	156-In. SRM	120-In. SRM	120-In. SRM
GLOW, M Lb	5.760	6.957	4.775	4.772	5.625
T/W lo	1.25	1.25	1.25	1.25	1.25
V_{Stage}, FPS	4793	5901	4672	4518	5683
t_{Stage}, Sec	137	156	132	125	139
q_{Stage}, PSF	64	11	96	128	33
T/W_{Stage}	1.189	0.826	1.173	1.154	0.802
Alt Stage, K Ft	140	196	129	121	165
Q_{Max} PSF	633	647	659	686	688
W_{Stage}, M LBS	1.513	1.283	1.533	1.558	1.322
	ORBITER				
Injection K Lb	228	199.3	228	228	199.3
Payload (Polar, Lb	40	40	40	40	40
No. Engines	4	4	4	4	4
F_{Vac}/Eng, K Lb	450	265	450	450	265

RAO CONFIGURATION CHARACTERISTICS

	BRB		SRM		
			Opt/SSME		Mk II J-2S/SSME
	Opt/ SSME	Mk II J-2S SSME	156-In. SRM	120-In. SRM	120-In. SRM
HO TANK					
Liftoff K Lb	1.824	1.447	1.824	1.824	1.447
Propellant, M Lb	1.720	1.362	1.720	1.720	1.362
Inert, K Lb	104	85	104	104	85
	0.9425	0.941	0.9425	0.9425	0.941
Dia meter, Ft	27.7	27	27.7	27.7	27
Length, Ft	168	145.7	168	168	145.7
BOOSTER					
No	2	2	2	4	6
Liftoff, Ea, M Lb	1.854	2.654	1.362	0.680	0.663
Propellant, Ea, M Lb	1.483	2.166	1.188	0.587	0.573
Inert, Ea K Lb	371	488	174	89.9	89.9
	0.800	0.816	0.872	0.863	0.864
No Engines, Ea	4	4	1	1	1
Fsl Ea, M Lb	0.725	0.978	2.285	1.141	1.028
Diameter, Ft	21.4	25	13	10	10
Length, Ft	122	126.7	133	112	112
Mk I Payload, K Lb		21			21

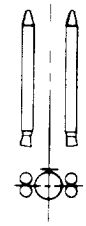
GRUMMAN BOEING

SELECTED RAO CONFIGURATION



	SSME/BRB	SRM Backoff
GLOW, M Lb	5.76	4.77
Tot, Inert, M Lb	1.012	0.629
Engines	4/450K	4/450K
Mk I DDT&E	4.02B	3.43B
PAF, $M	972	823
Cost/Flt, $M	8.2	17

BACKOFF
4 x 1207 In.



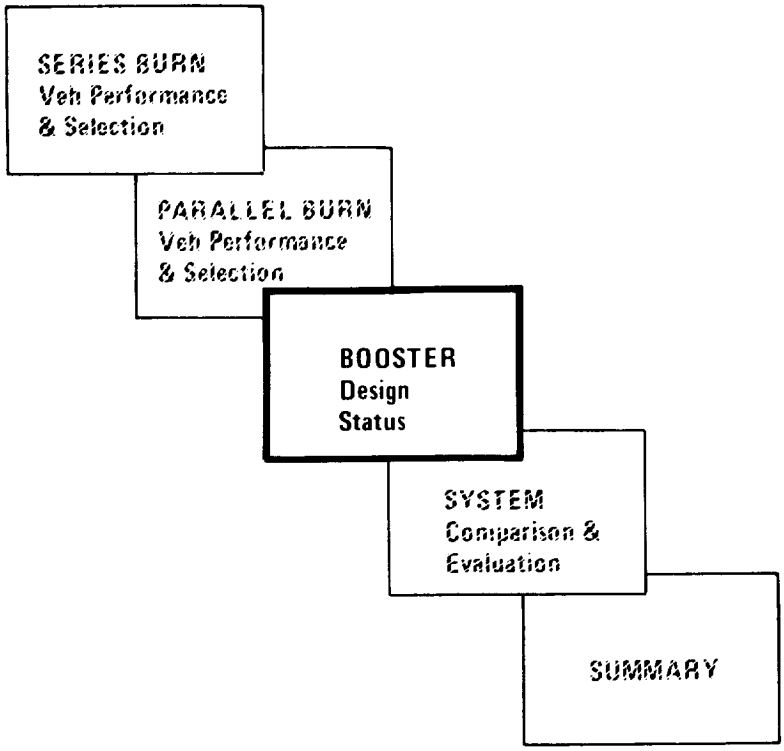
CONCLUSIONS

- Lower GLOW
- Smaller Booster, Thus Lower Development Risk
- Better SRM Backup - Lower Cost/Flight
- Better Potential to Minimize or Eliminate Booster TVC

RAO SUMMARY

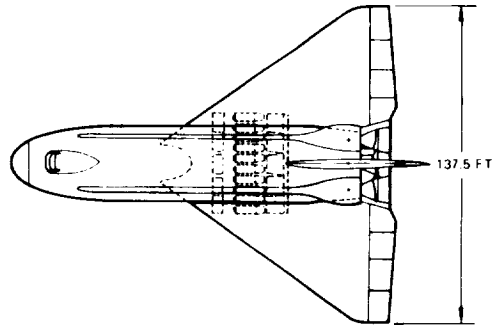
- Control – Assume For Now TVC Required
- Separation More Complex – Needs Work
- 4 SSME (450K) Better Than J-2S/SSME Combination
- SRM Backoff Available: 2 x 156" or 4 x 1207

BRIEFING OUTLINE

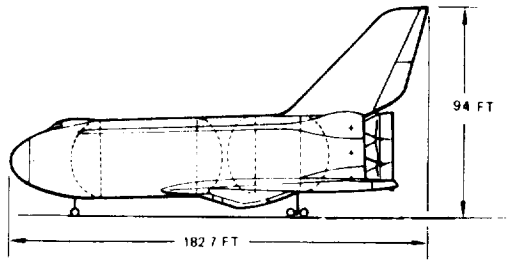


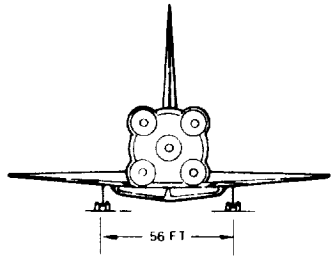
GRUMMAN
BOEING

LOX/RP FLYBACK CONFIGURATION
979-061A

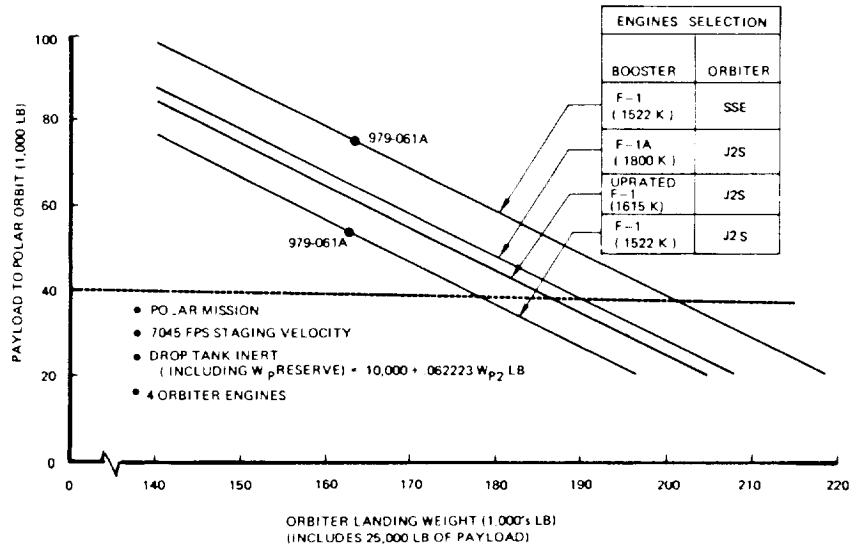


WING AREA	9,000 FT^2
VERTICAL TAIL AREA	1,500 FT^2
MAIN ENGINE TYPE/THRUST	F-1/1.522 × 10^6 LB
A/B ENGINE NO./TYPE	10/F101/F1283
LANDING APPR. SPEED	174 KNOTS
NOMINAL LANDING WEIGHT	614,800 LB
ENTRY WEIGHT	672,400 LB
ASCENT PROPELLANT	4,587,600 LB
BLOW	5,298,300 LB
OLOW	1,260,800 LB
GLOW	6,559,100 LB
BOOSTER MASS FRACTION	0.866
THRUST/WEIGHT LIFT-OFF	1.16



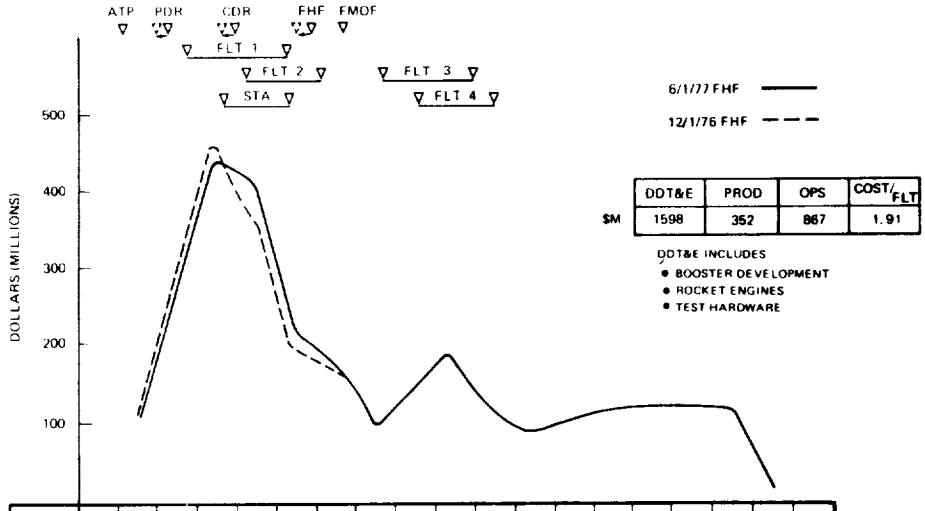


LOX/RP FLYBACK BOOSTER
ACCOMMODATION OF ORBITER WEIGHT GROWTH



GRUMMAN BOEING

LOX/RP FLYBACK BOOSTER PROGRAM COST



	DDT&E	PROD	OPS	COST/FLT
$M	1598	352	867	1.91

FY	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
COST	—	102	272	440	394	214	166	92	142	187	119	89	102	118	119	120	119	20	

BALLISTIC RECOVERED BOOSTERS

WHAT WE FOUND OUT (SEPT, OCT.)

- COST DRIVERS
- IMPACT DAMAGE UNCERTAINTY
- PROPULSION SYSTEM SCHEDULE

WHAT WE DID (NOV DEC)

- λ' CHANGES TO INCREASE
- $ – CHANGES TO REDUCE
- DESIGN FOR IMPACT LOADS
- PROPULSION CHANGES FOR DEVELOPMENT SCHEDULE

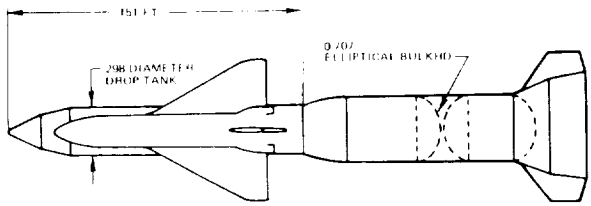
GRUMMAN BOEING

CONFIGURATIONS

- 2 BASELINES
  - LOX – RP SERIES BURN (MODEL 979-150A)
  - LOX – RP PARALLEL BURN (MODEL 979-151)

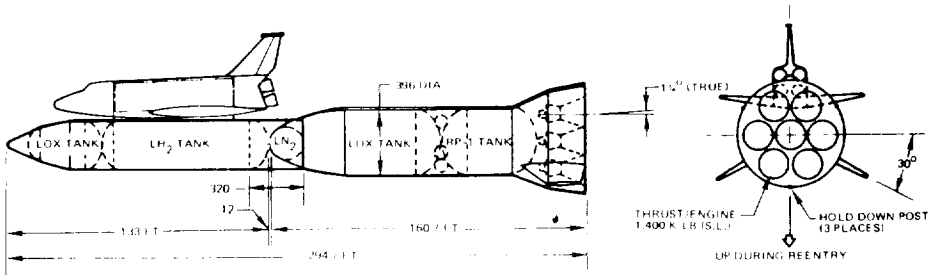
- ALTERNATES
  - LOX – PROPANE SERIES (979-148)
  - SRM BACKOUT (SERIES) (979-158A)
  - 2-STAGE LOX/RP SERIES (979-152)
  - SRMB BACKOUT (PARALLEL) (979-147)

LOX/RP-1 SINGLE STAGE BRB MODEL 979-150 A



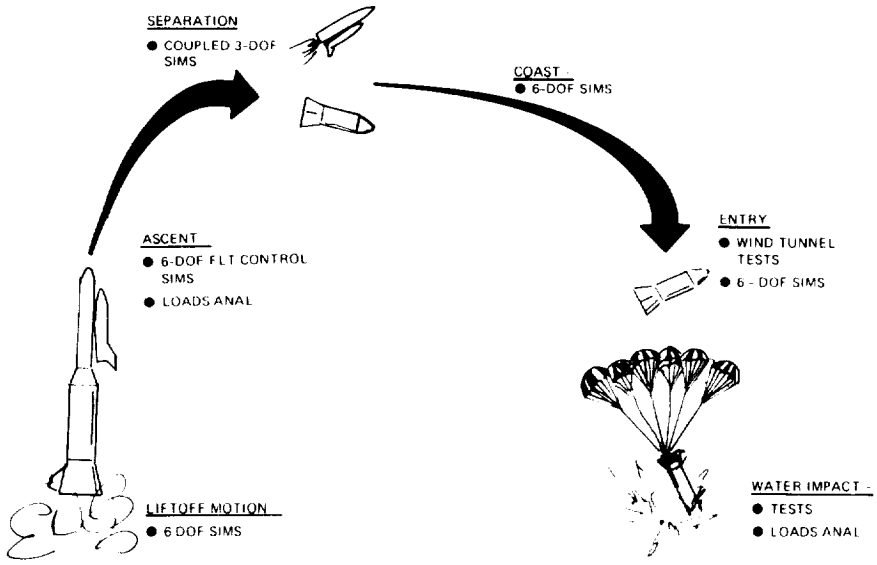
DESIGN CHARACTERISTICS

GLOW	7,875,300 LB
BLOW	6,568,300 LB
OLOW	1,307,000 LB
BOOSTER PROPELLANT WEIGHT	
ASCENT	5,155,000 LB
LITVC (FREON)	160,000 LB
HYDRAZINE	24,800 LB
V_{STAGE}	5,500 FT/SEC
λ	0.813
BOOSTER WEIGHT	
BURNOUT INERT	1,228,500 LB
IMPACT	1,197,900 LB
ORBITER WEIGHT	
INJECTION	200,744 LB
LANDING	163,261 LB



GRUMMAN BOEING

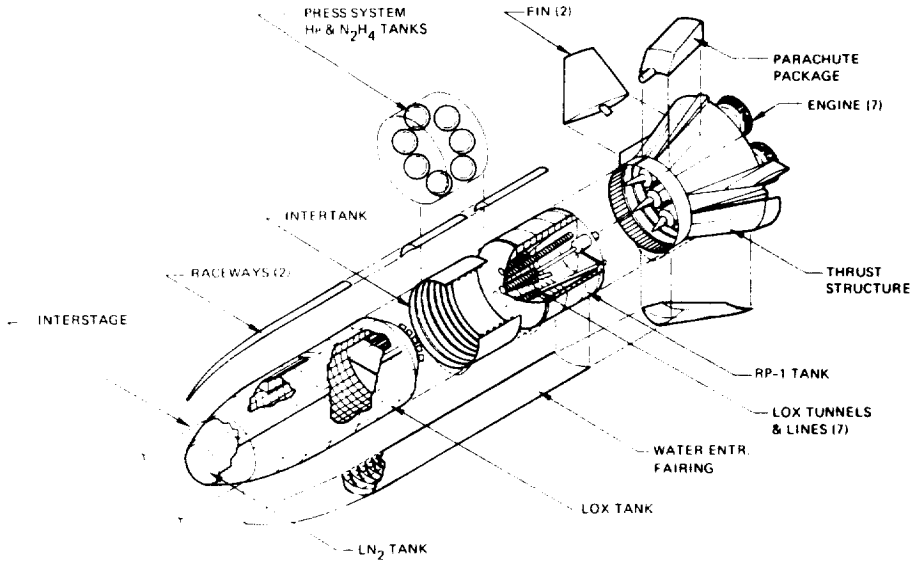
BRB BASELINE MODEL 979-150 ENGINEERING ANALYSES



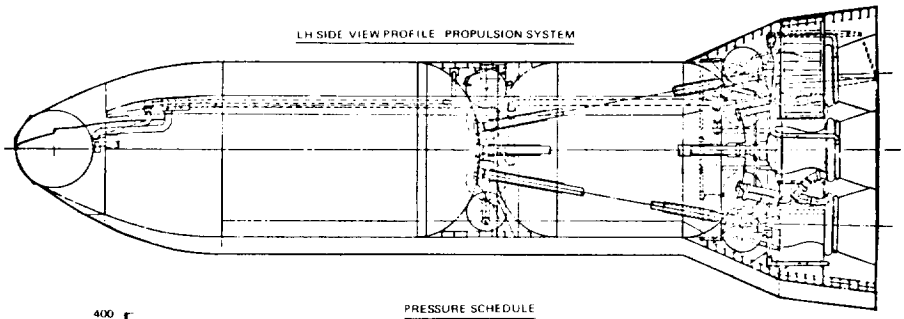
BRB CRITICAL PROBLEMS

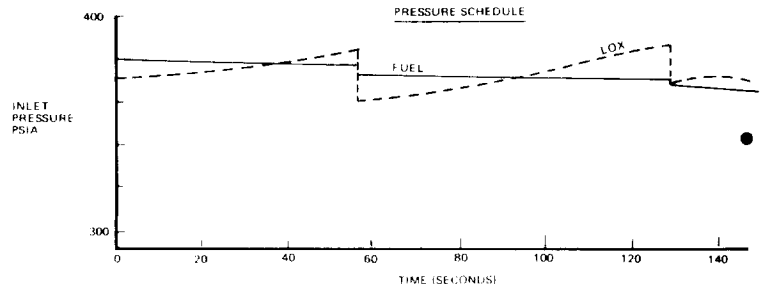
- THRUST VECTOR CONTROL
- THRUST CHAMBER/VEHICLE INTEGRATION
- PRESSURIZATION SYSTEM
- REENTRY AERODYNAMIC CONTROL
- PARACHUTE RECOVERY SYSTEM
- WATER IMPACT
- MATERIAL AND WELD DEVELOPMENT

GENERAL ARRANGEMENT – MODEL 979-150A



PROPULSION SYSTEM LAYOUT (CONFIGURATION 979-150)

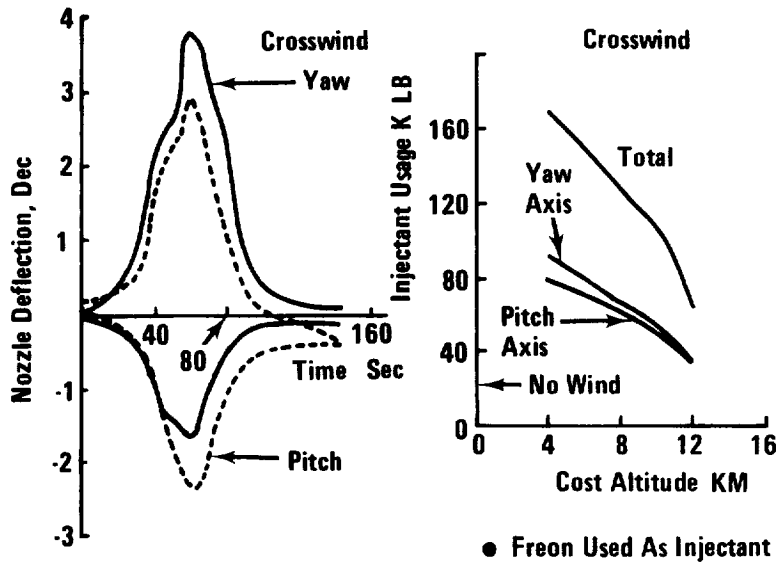




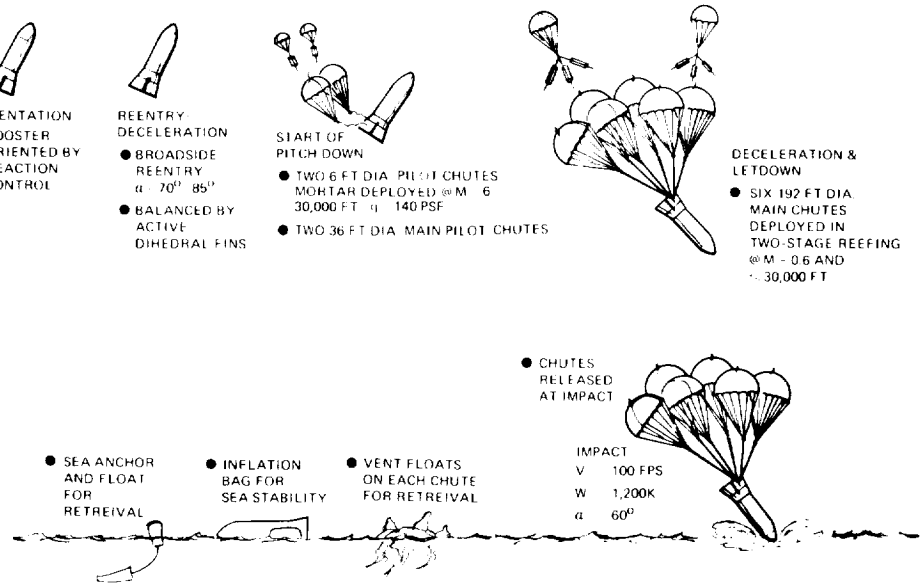
- POGO ANALYSIS

GRUMMAN BOEING

LITVC REQUIREMENTS

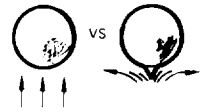


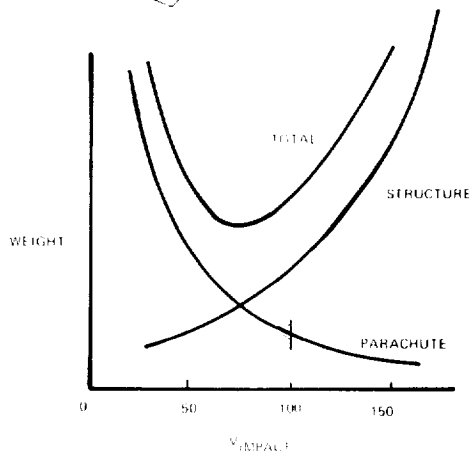
RECOVERY SEQUENCE BOOSTER – MODEL 979-150

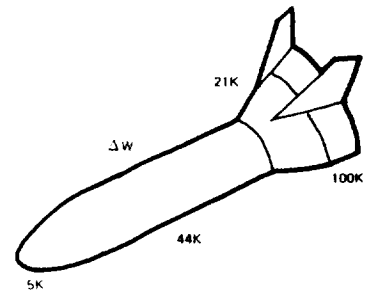


WATER IMPACT

- ANALYSIS
- TEST
- CONSULTANTS

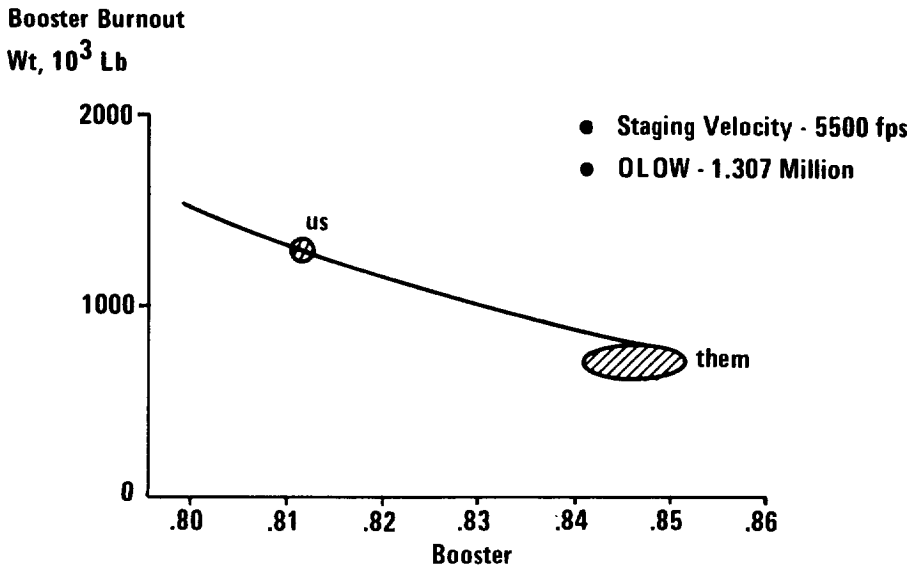






- V_{IMPACT} = 100 FT / SEC
- $\Delta\lambda$ -0.031
- STRUCTURAL DAMAGE → 0

IMPACT WEIGHT IS SENSITIVE TO λ'



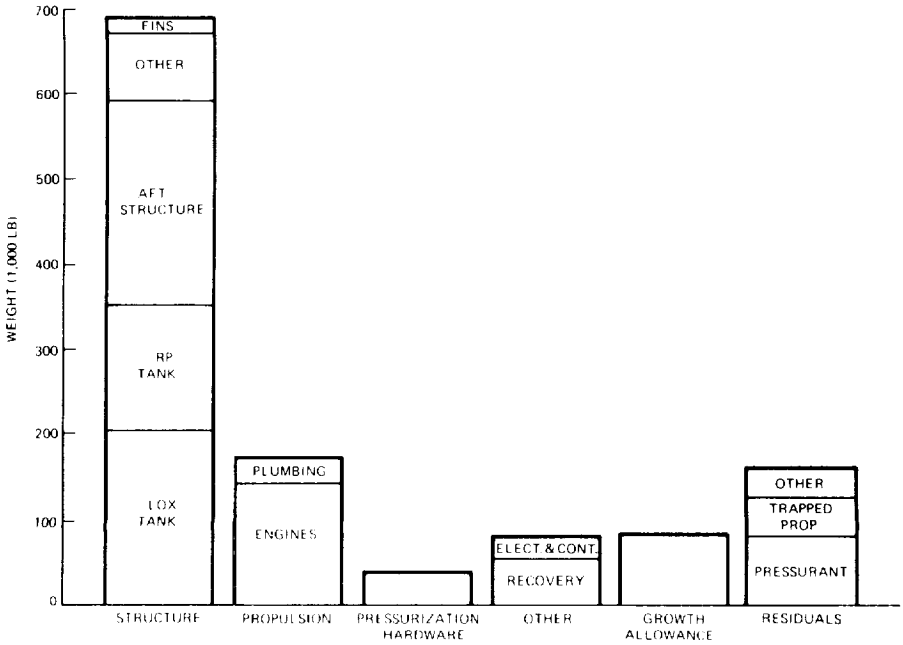
WEIGHT STATEMENT — MODEL 979-150A

STRUCTURE			690,800
INTERSTAGE JOINT		6,000	
OXIDIZER TANK		203,020	
LN_2 TANK	12,940		
NOSE SECTION	67,400		
CYLINDER	85,140		
AFT BLKHD & RING	26,100		
ANTI-SLOSH	11,440		
INTERTANK		26,800	
FUEL TANK		150,200	
FWD BLKHD & RING	28,240		
CYLINDER	61,180		
AFT BLKHD & RING	35,190		
ANTI-SLOSH	6,390		
OXIDIZER FEED TUNNELS	19,200		
AFT SECTION		239,210	
SKIRT STRUCTURE	177,600		
THRUST STRUCTURE	54,980		
BASE HEAT SHIELD	6,630		
RECOVERY SYSTEM PROV	8,070	8,070	
RACEWAY & KEEL		38,350	
RACEWAY	3,950		
KEEL	34,400		
PAINT & SEALANT		1,150	
FINS (2)		18,000	
PROPULSION			170,800
ENGINES (7)		143,400	
OXIDIZER FEED SYSTEM		19,940	
FUEL FEED SYSTEM		4,320	
FILL & DRAIN		870	
MISC SYSTEMS		2,250	
PRESSURIZATION			38,200
LN_2 TANK		(STRUCTURE)	
N_2H_4 TANK		5,160	
H_e BOTTLES		18,560	
GAS GENERATOR		1,700	
HEAT EXCHANGERS		4,200	
THRUSTERS		2,000	
DISTR HARDWARE		6,580	

STAGE CONTROL			21,400
LITVC HARDWARE		17,950	
RCS HARDWARE (REENTRY)		550	
FIN ACTUATION SYSTEM		2,900	
ELECTRICAL/ELECTRONICS/ORDNANCE			3,000
POWER		2,260	
AVIONICS		210	
INSTRUMENTATION		200	
ORDNANCE PROV.		130	
DESTRUCT PROV		200	
RECOVERY SYSTEM			56,000
MAIN CHUTES (6)		48,300	
DROGUES (2)		2,300	
CANNISTERS & ATTACHMENTS		5,400	
WEIGHT GROWTH (10% DRY WT LESS ENGINES)			83,700
BOOSTER DRY WEIGHT			1,063,900
UNUSABLE FLUIDS & GASSES			159,400
TRAPPED ASCENT PROPELLANT		45,200	
PRESURIZATION		81,900	
HYDRAZINE	13,900		
HELIUM	2,860		
NITROGEN	65,140		
BIAS & OUTAGE PROPELLANT		27,000	
TRAPPED		5,300	
BOOSTER STAGING WEIGHT			1,223,300
THRUST DECAY PROPELLANT			5,200
BOOSTER BURNOUT (INERT) WT			1,228,500
USABLE PROPELLANTS			5,339,800
ASCENT PROPELLANT		5,155,000	
LITVC FLUID		160,000	
EXPENDED HYDRAZINE		24,800	
BOOSTER LIFTOFF WEIGHT			6,568,300

λ BOOSTER $\frac{5,339,800}{6,568,300}$ 0.813

INERT WEIGHT DISTRIBUTION – MODEL 979-150A



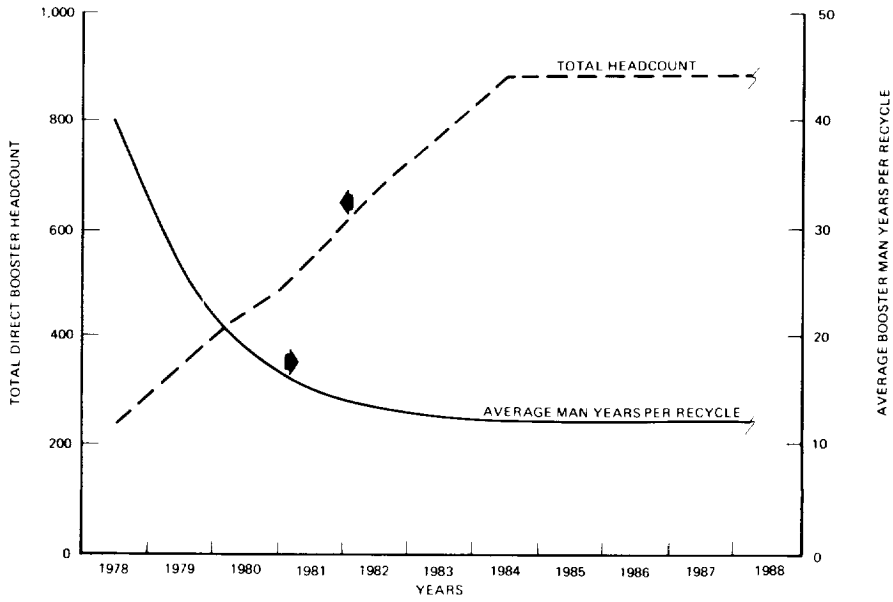
BRB LOX/RP – 979-150 REFURB AND CHECKOUT MANPOWER

SINGLE CREW - 2 SHIFT
TO RECYCLE 1 BOOSTER

MECHANICS AND TECHNICIANS:	
STRUCTURES	6
ELEC. PWR., NETWORKS AND INSTR.	12
RANGE SAFETY, SEPARATION & ORDNANCE	8
PNEU. & PROP. FEED	10
PROPULSION (MAIN ENGINES)	35
LITVC AND FLIGHT CONTROL	30
REENTRY/RECOVERY	9
GROUND SUPPORT EQUIPMENT	32
TOTAL MECHS. & TECHS.	142
ENGINEERING @ 20% (10% AFTER FIRST TWO YEARS)	
QUALITY CONTROL @ 15%	
PLANNING AND SCHEDULING @ 10%	92
SAFETY, RECORDS AND MISCELLANEOUS @ 5%	
DIRECT SUPERVISION & CLERICAL @ 15%	
SINGLE CREW TOTAL	234

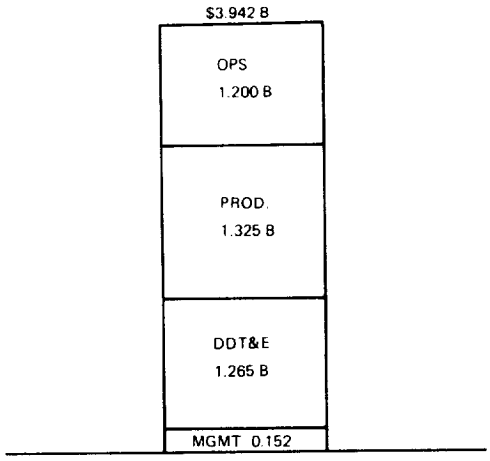
S-1C EQUIVALENT
IS 210 MEN

BOOSTER REFURB AND CHECKOUT MANPOWER – 979-150



GRUMMAN BOEING

PROGRAM COST (BILLIONS) – MODEL 979-150

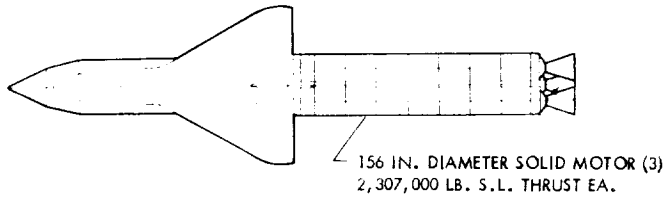


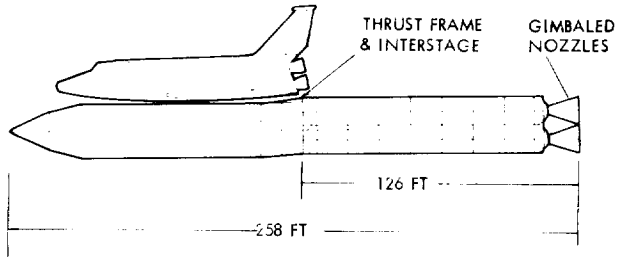
TOTAL = $3.942
COST/FLIGHT = $2.7

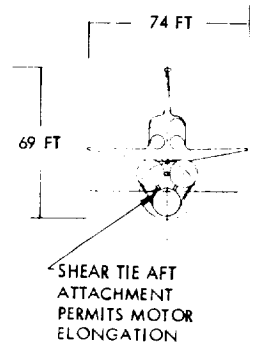
156 INCH SRM-HO SERIES BURN
MODEL 979-158A

DESIGN DATA

GLOW		5,535,000 LB.
BLOW		4,350,000 LB.
OLOW		1,185,000 LB.
BOOSTER	W_P	1,271,000 LB.
	χ	.877
	P_c	750







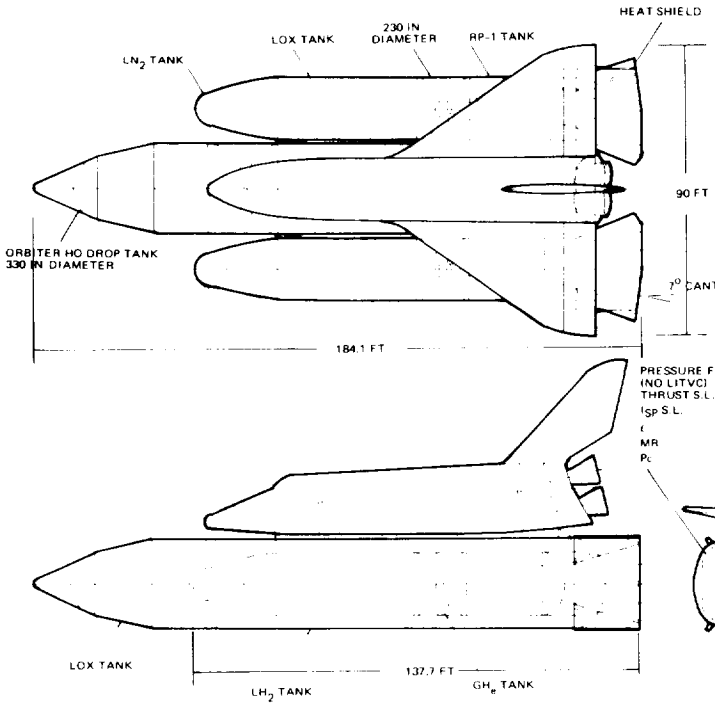
GRUMMAN
BOEING

979-158A SRM WEIGHT DATA

- 156" Dia o Sea Level Thrust = 2.307×10^6 LBF o Nozzle Type – Flex Seal
- P_C NOM = 750 PSI o Case Matl 6 DAC o $N_{Motors} = 3$
- $\lambda = .893$ o $\lambda' = .877$

		Weight – Lb
• Basic Motor		(144,500)
– Case	95,900	
– Insulation & Slivers	21,500	
– Liner	2,800	
– Thrust Termination	2,300	
– Ignition System	1,200	
– Nozzle	17,300	
– TVC System	3,500	
• Separation System		(2,800)
• Equipment		(2,500)
– Destruct	800	
– Electrical	800	
– Instrumentation	900	
• Stage Provisions		(19,000)
– Forward Skirt Assembly	3,300	
– Cluster/Attach	6,300	
– Interstage	4,400	
– Aft Skirt Assembly	2,900	
– Base Heat Shield	2,100	
• External Finish		(1,500)
• Growth	Module Inerts – Each	(8,600)
• Useful Propellant – Each		178,900
		1,271,100
	Total Module – Each	1,450,000
	Total Stage BLOW	4,350,000

PARALLEL BURN (RAO)
BALLISTIC RECOVERABLE BOOSTER – MODEL 979-151



DESIGN CHARACTERISTICS

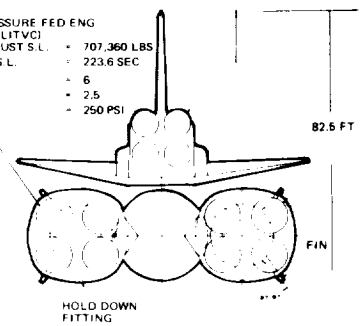
PAYLOAD	40,000 LBS
GLOW	5,761,000 LBS
BLOW	1,854,000 LBS EACH
PROPELLANT	1,483,000 LBS EACH
OLOW	2,063,000 LBS
PROPELLANT	1,720,000 LBS
ORBITER INJ WT.	229,033 LBS
V_{STAGE}	4,793 FPS
THRUST/WT. (LIFTOFF)	1.26
MAX. "q"	633 PSF

SSME

THRUST VAC	= 450,000 LBS EA	
I_{SP} VAC	= 457.2 SEC	
ϵ	= 6	90
MR	= 6	
GIMBLE	= ±10°	

PRESSURE FED ENG (NO LITVC)

THRUST S.L.	=	707,360 LBS
I_{SP} S.L.	=	223.6 SEC
ϵ	=	6
MR	=	2.5
P_c	=	250 PSI



GRUMMAN BOEING

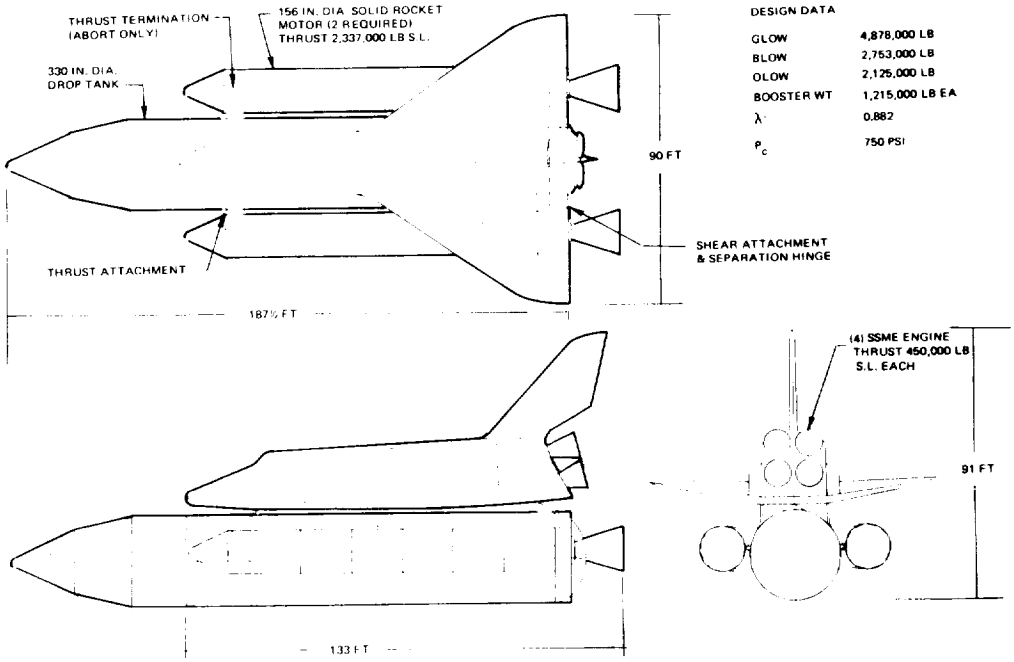
WEIGHT STATEMENT – BRB (RAO)
MODEL 979-151

STRUCTURE		210,400
OXIDIZER TANK	59,700	
INTERTANK	8,800	
FUEL TANK	48,200	
AFT SECTION	11,800	
ATTACH STRUCTURE	10,900	
RACEWAYS & KEEL	1,200	
PAINT & SEALANT	550	
FINS (2)	3,250	
PROPULSION		56,500
ENGINES (&) (7)	48,500	
OXIDIZER FEED SYSTEM	5,830	
FUEL FEED SYSTEM	1,210	
FILL AND DRAIN	260	
MISC. SYSTEMS	640	
PRESSURIZATION		14,100
STAGE CONTROL		300
RCS HARDWARE (REENTRY)	300	

ELECTRICAL/ELECTRONICS/ORDNANCE	2,400
RECOVERY SYSTEM	18,000
WEIGHT GROWTH	25,300
MODULE DRY WEIGHT	327,000
UNUSABLE FLUIDS & GASES	42,600
TRAPPED ASCENT PROPELLANT	12,500
PRESSURIZATION	22,600
BIAS & OUTAGE PROPELLANT	7,500
MODULE STAGING WEIGHT	369,600
THRUST DECAY PROPELLANT	1,400
MODULE BURNOUT (INERT) WT.	371,000
USABLE PROPELLANTS	1,483,000
ASCENT PROPELLANT	1,476,200
EXPENDED HYDRAZINE	6,800
MODULE LIFTOFF WEIGHT	1,854,000
BOOSTER LIFTOFF WEIGHT	3,708,000

$$\lambda' \text{ BOOSTER} = \frac{2{,}966{,}000}{3{,}708{,}000} = 0.80$$

156 INCH SRM – HO PARALLEL BURN (RAO)
MODEL 979-147



DESIGN DATA

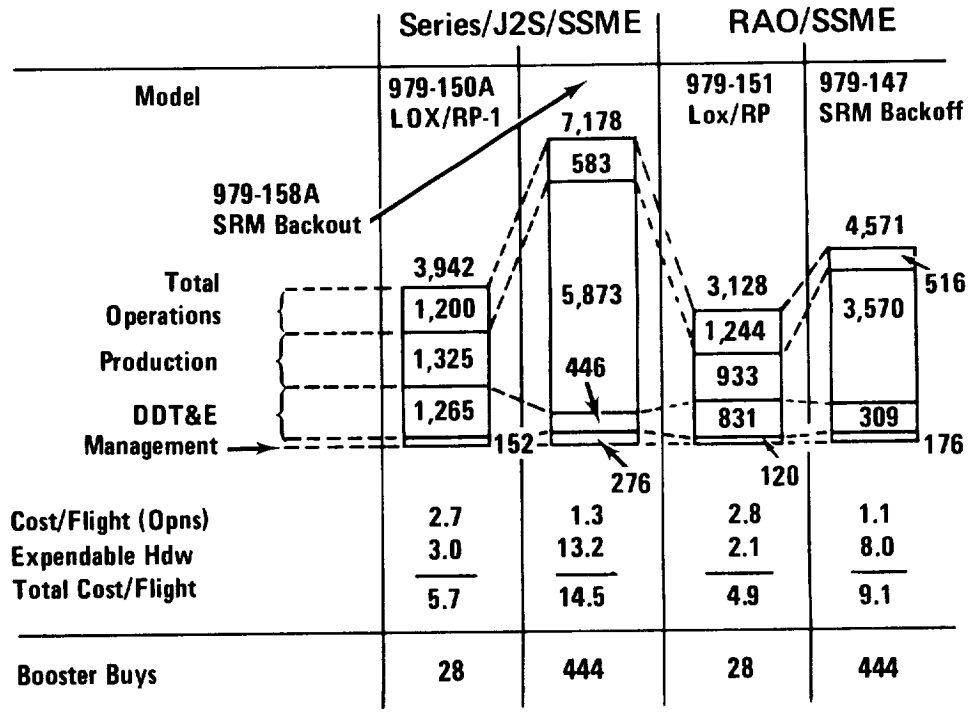
GLOW	4,878,000 LB
BLOW	2,753,000 LB
OLOW	2,125,000 LB
BOOSTER WT	1,215,000 LB EA
λ	0.882
P_c	750 PSI

GRUMMAN BOEING

BRB BOOSTER COMPARISON

BLOW LB	Series Burn J2S/SSME 6,568,300	Parallel Burn SSME 5,761,000	J2S/SSME 6,958,000
W_{INERT} LB	1,228,500	742,000	977,300
V_{STAGE} fps	5,500	4,793	5,922
Length (Ft)	160.7	136.7	136.7
Tank Dia (Ft)	33.0	19.2	21.3
Max Weld Thickness (In.)	3.5	2.0	2.2
Thrust (SL) Eng (Lb)	(7) 1,400,000	(8) 746,000	(8) 1,000,000
LITVC	Freon	None (?)	None (?)
Fins	Moveable	Fixed (?)	Fixed (?)
Staging q, (psf)	22.0	113.0	11.0

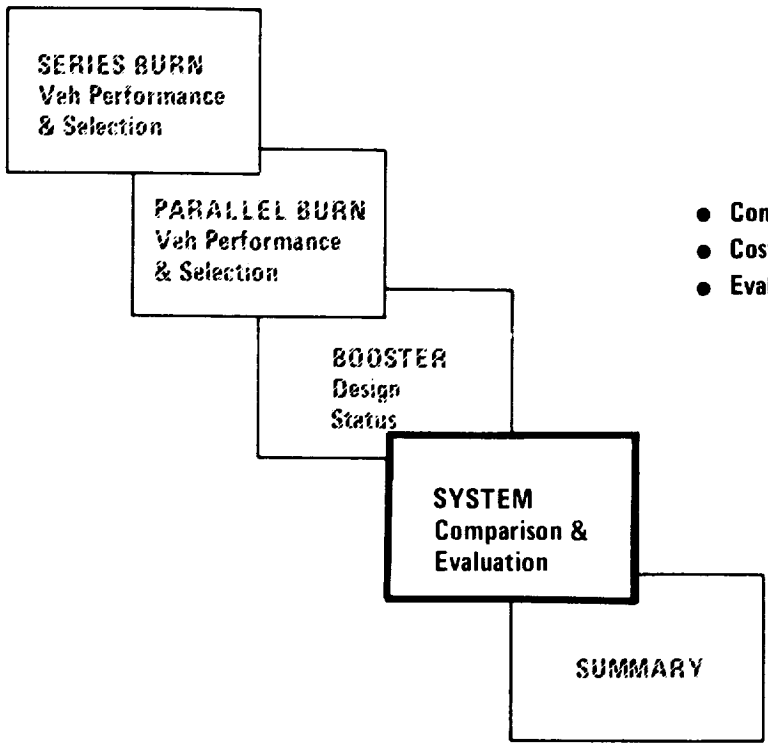
BOOSTER COST COMPARISON ($M)



CONCLUSIONS

- BRB Is a Viable System
- Recovery Weight Sensitive to Impact Problems
- DDT&E Series – $1.26B
  Parallel – $0.89B
- SRM Backout for Both Series, Parallel
  - o Cost/Flight Higher
  - o Lower DDT&E
- LOX/RP vs LOX/Propane
  - o Take Your Pick

BRIEFING OUTLINE



- Comparison Process
- Cost
- Evaluation

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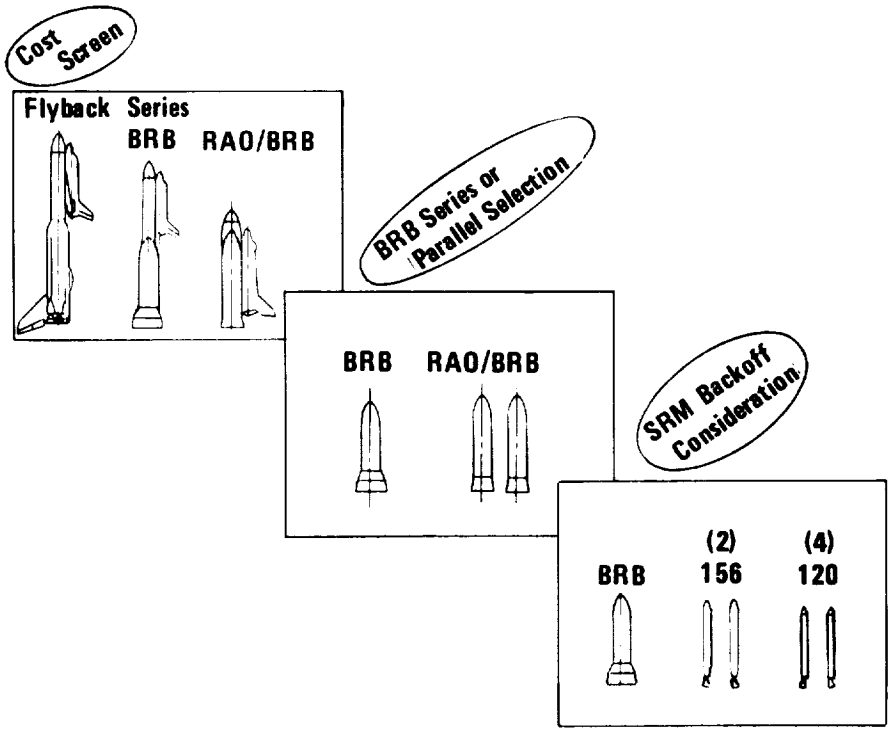
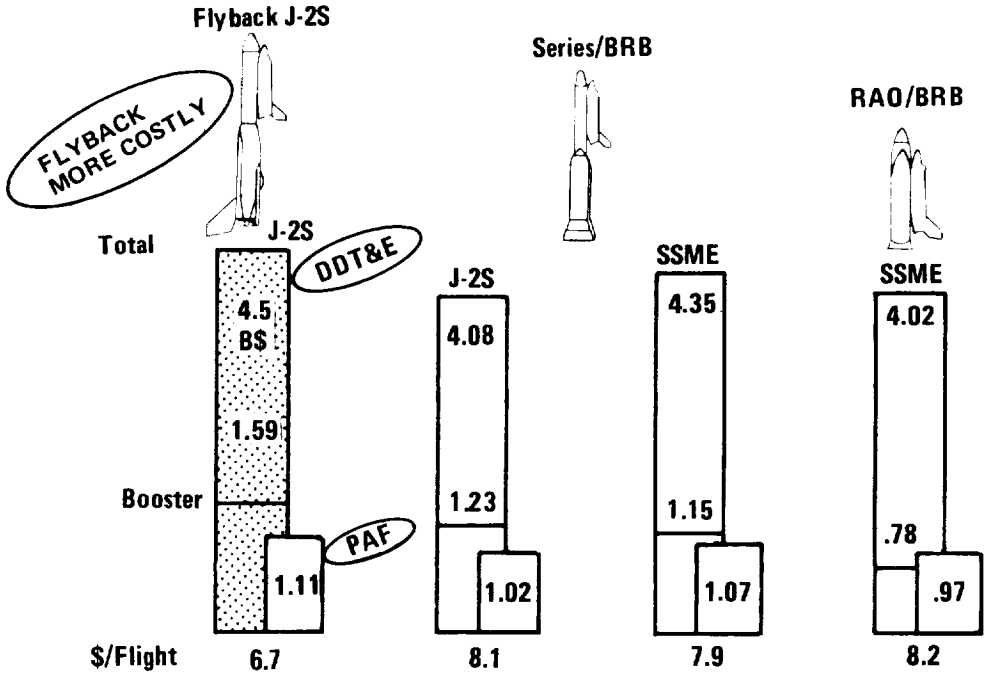
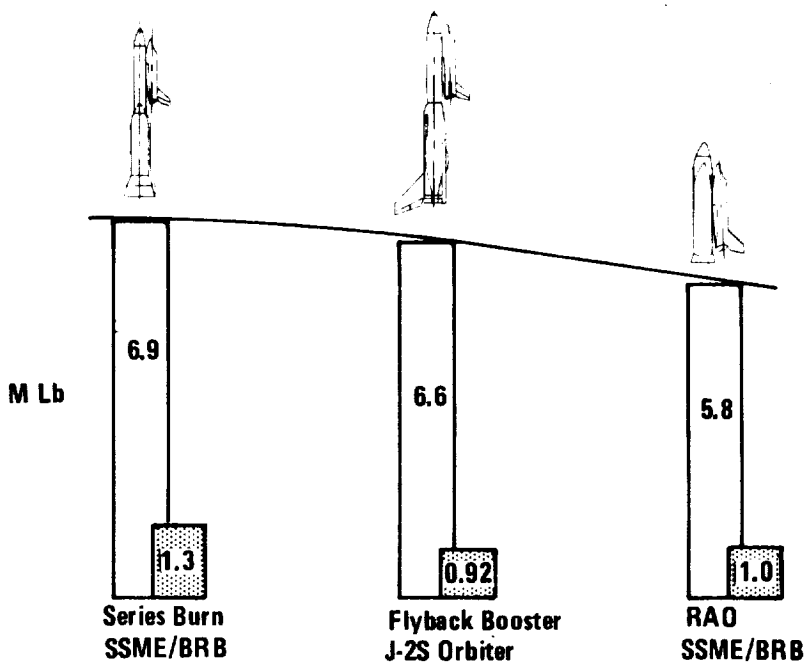
CONFIGURATION SELECTION – A 3-STEP PROCESS



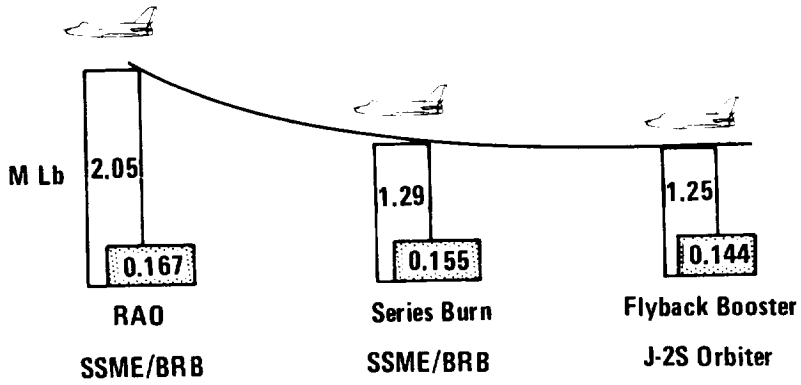
COST COMPARISON



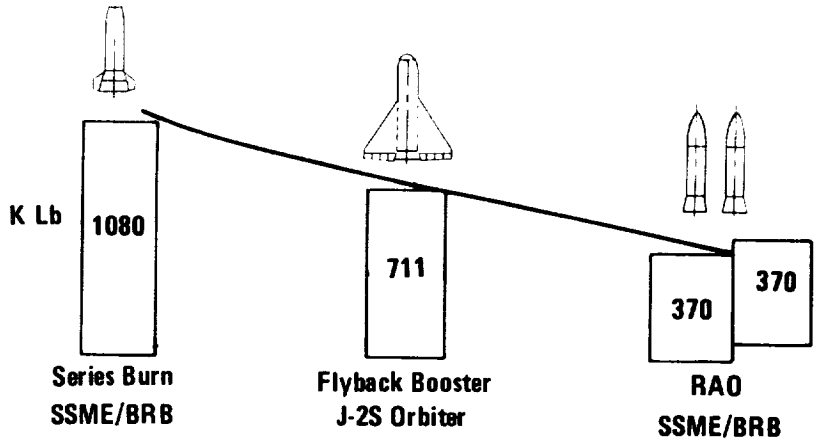
GLOW & TOTAL INERT COMPARISON



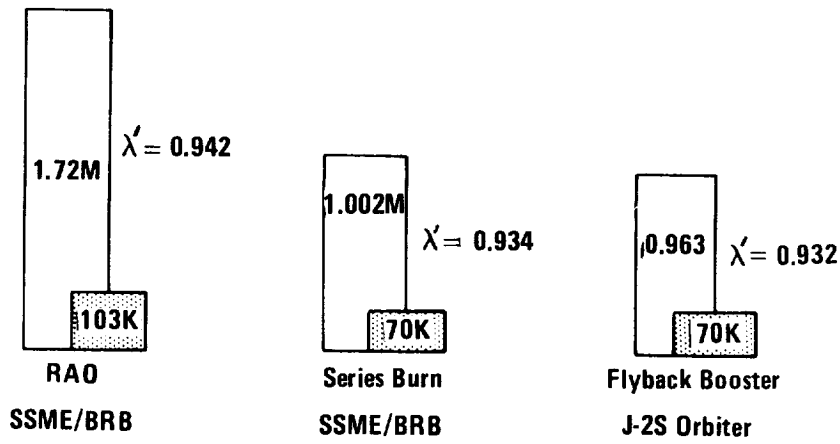
ORBITER OLOW & INERT WEIGHT COMPARISON



INERT WEIGHT COMPARISON BOOSTER



HO TANK PROPELLANT & INERT WEIGHT COMPARISON



DETAILED PHYSICAL CHARACTERISTICS SUMMARY

	Flyback J-2S/SSME	Series Burn BRB/SSME	RAO BRB/SSME
GLOW, M Lb	6.55	6.9	5.76
OLOW, M Lb	1.25	1.29	2.05
Orbiter Inert, K Lb	144	155	167
Orbiter Dry, K Lb	136	147	158
BLOW, M Lb	5.3	5.6	3.71
Booster Inert, K Lb	711	1081	742
Tank Inert, K Lb	70.5	70.3	103
Booster λ	0.866	0.8075	0.80
Tank λ	0.932	0.934	0.943
V_{Stage}, FPS	7046	5003	4793
q_{Stage}, PSF	18	62	64
No./Ea Booster, Dia Ft	1/33	1/33	2/21.4
Booster Length, Ft	165	146	122
Tank Diameter, Ft	24	24	27.7
Tank Length, Ft	133	136	168
Stack Height, Ft	306	283	168
Bstr Eng, No./SL Thrust, M Lb	5/1.52	7/1.23	8/.725
Bstr Eng I_{SP} Vac, Sec	304.7	275.7	284.5
Orb Eng No./Vac. Thrust, K Lb	4/265	4/375	4/450
Orb Eng I_{SP} Vac, Sec	436	457.2	457.2
T/W, Liftoff/Staging	1.16/0.845	1.25/1.163	1.25/1.19
Bstr Propellant, M Lb	4.59	4.73	2.97
Tank Propellant, M Lb	0.963	1.002	1.72

SUMMARY COST EVALUATION

SERIES vs RAO

	Series		RAO
	J-2S/SSME	SSME	SSME
Mk I DDT&E B	4.08	4.35	4.02
Peak Annual $ B	1.02	1.07	.97
Cost/Flight BRB M	8.1	7.9	8.2
Cost/Flight SRM M	21.97 (156")	20.36 (156")	17.47(120")
Total Prog. - BRB B	10.83	10.40	10.10

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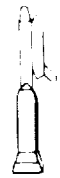
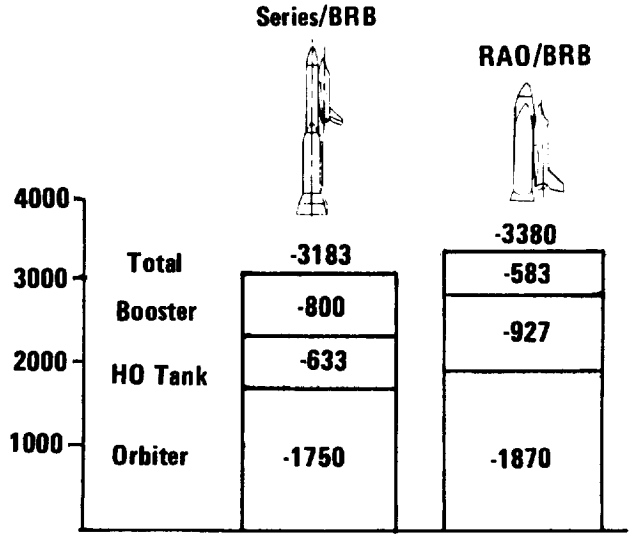
EVALUATION SUMMARY

	Series SSME/BRB	RAO SSME/BRB	
			
Lower DDT&E $B	√ 4.35	√ 4.02 + Bstr TVC	
Requires TVC	√ —	√ —	STANDOFF
Better Abort Capability (No Alt Ldg Site Req'd)	√ —	√ —	
More Practical/Lower Cost SRM $M/Flt	20	√ 17	
Lower Booster Inert Weight K Lb	1080	√ 2 x 370	FAVORS RAO
Simpler Booster Separation	√ 1	2	
Cleaner Orbiter/Booster Interface	√ —	—	
Lower Payload Sensitivity Lb/%	√ 3183	3380	
Lower Cost of Payload Assurance $/% Wt Incr	√ 13	25	FAVORS SERIES
Light Orbiter (Inert Wt) K Lb	√ 155	167	

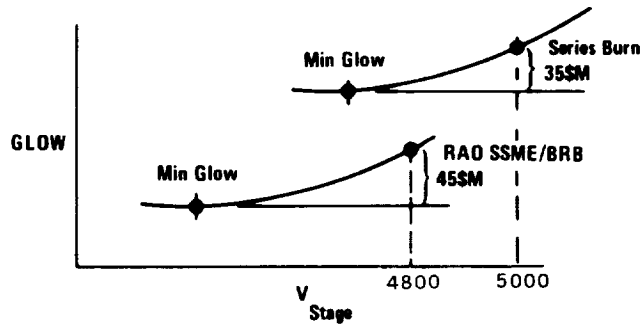
PAYLOAD SENSITIVITIES



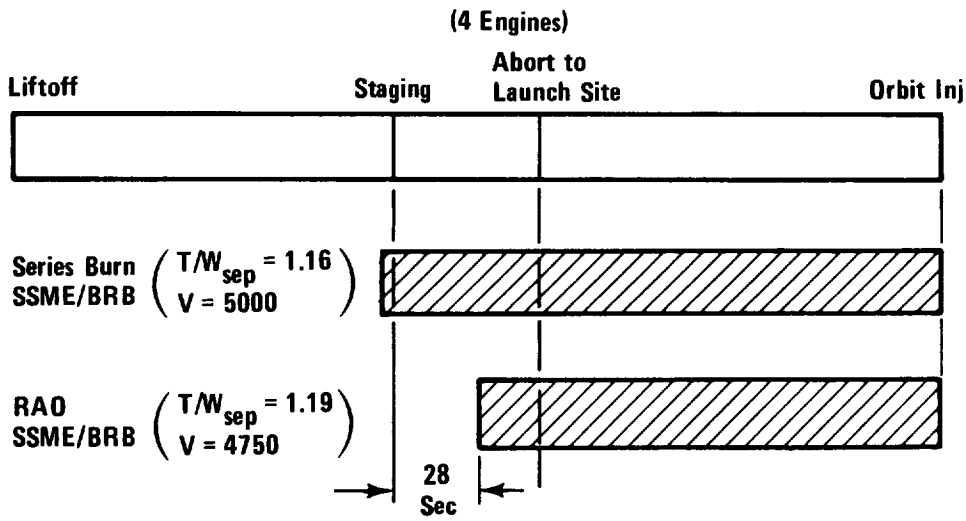
Orbiter Sensitivity Based on
Injected Wt - Payload

COST OF PAYLOAD ASSURANCE

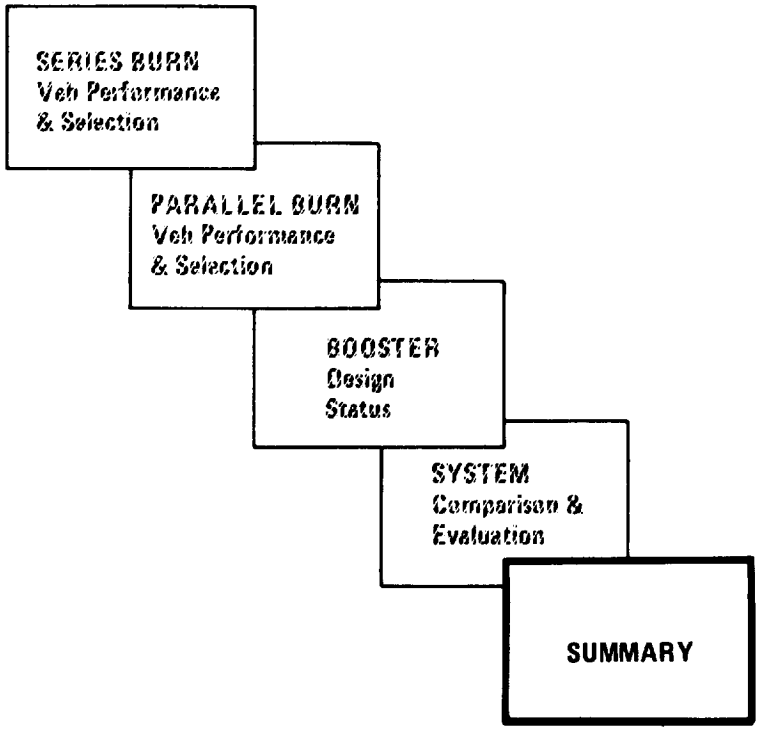
	Series Burn SSME/BRB	RAO SSME/BRB
DDT & E Cost to Provide Payload Margin	35 $M	45
Prog Cost Δ/Percent Total Inert Weight Increase	13 $M	25



ABORT CAPABILITY COMPARISON SERIES vs RAO



BRIEFING OUTLINE



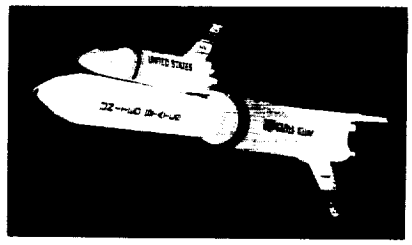
CONCLUSIONS

ASSUMPTIONS

(A) Minimize Cost For DDT&E & Peak Annual Funding

(B) Minimize Development Risk/Overrun Potential

(C) Low Cost Per Flight But Not Overriding (A) & (B)



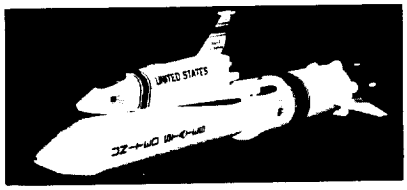
FLYBACK

Higher Development & Peak Funding Requirements Compared to Alternates Available. The Risk in Costs Occur in The Early Years

CONCLUSIONS

ASSUMPTIONS

(A) Minimum Cost to DDT&E & Peak Annual Funding
(B) Minimize Development Risk/Overrun Potential
(C) Low Cost Per Flight But Not Overriding (A) & (B)
(D) Cost Effective SRM Backup



BRB SERIES vs BRB RAO

- SERIES BRB Large, Somewhat More Expensive System
- Separation & Orbiter Interface Simpler

But
- SRM Backoff & Cost/Flight Higher

- RAO BRB Smaller, Somewhat Lower Cost System
- Separation & Orbiter Interface Significantly More Complex

But
- SRM Backoff Simpler & Cost Per Flight Lower

SERIES BRB ENGINE SELECTION SUMMARY

- With J-2S/SSME GLOW Is Higher by 1M Lb But DDT&E Is Lower By $270M Over Opt SSME

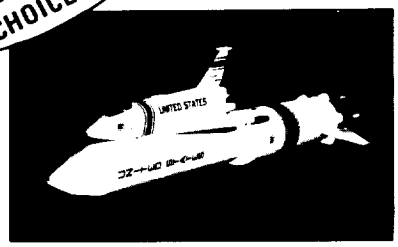
If Optimized SSME Is Desired:

- Orbiter Installed Thrust Should Be Near 1.2M Lb for Lowest $DDT\&E_I$
- With Four Engines Having Better Abort Performance Than Three

CONCLUSIONS

The Issue: Technical Choice Versus Fiscal Backoff Selection

TECHNICAL CHOICE



Series

- Technically Simpler System
- Less Payload Sensitivity

BACKOFF SRM

- RAO Provides Backoff at Lower Cost/Flight

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