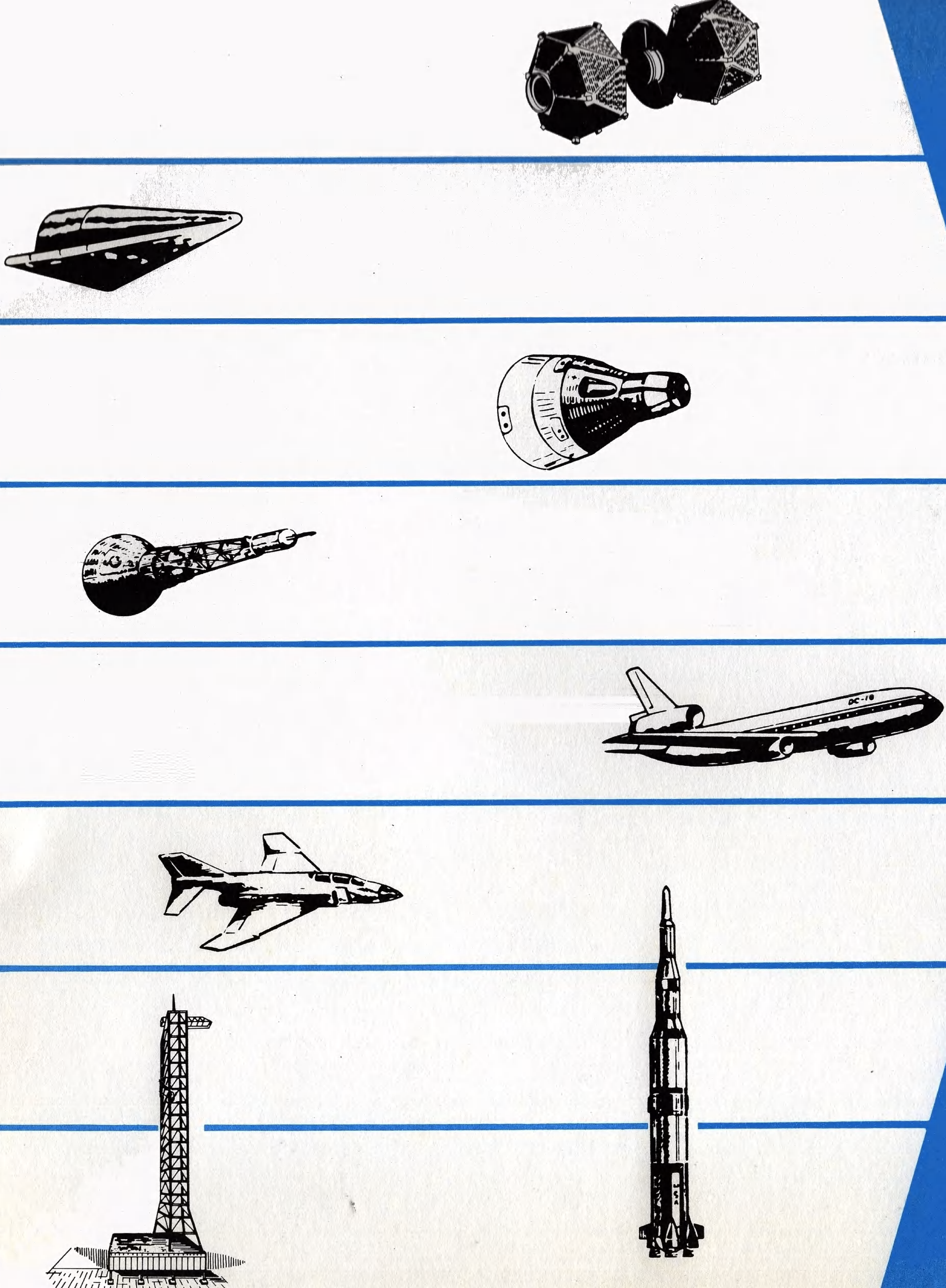

OMSF DESIGN REVIEW

22 February 1972

Phase B Extension

HIGH VALUE SPACE SHUTTLE LOW COST

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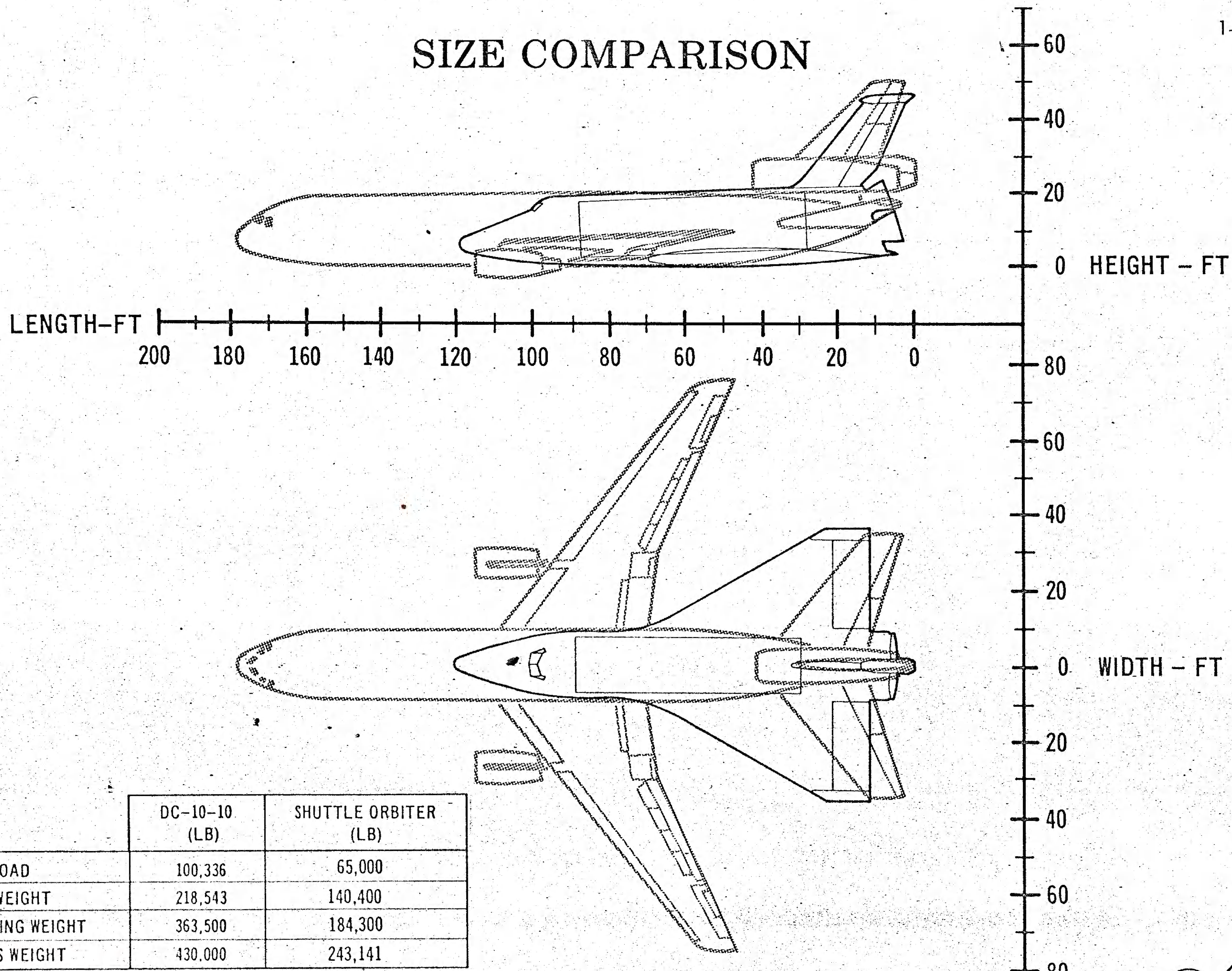
SIZE COMPARISON



	DC-10-10 (LB)	SHUTTLE ORBITER (LB)
PAYLOAD	100,336	65,000
DRY WEIGHT	218,543	140,400
LANDING WEIGHT	363,500	184,300
GROSS WEIGHT	430,000	243,141

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SPACE SHUTTLE DESIGN REVIEW

Phase B System Study Extension

Office of Manned Space Flight
National Aeronautics and Space Administration
Washington, D.C.

22 February 1972

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PARALLEL SOLID BOOSTER ISSUES

ITEM	RESULTS
ALTERNATIVES 2–156 IN. SRM'S VS 4–120 IN. 7 SEGMENT VS 5–120 IN. 7 SEGMENT	• Δ COSTS ($M): | | 2–156 IN. SYSTEM | 120 IN. 7-SEGMENT: 4 SRM SYSTEM | 120 IN. 7-SEGMENT: 5 SRM SYSTEM | PROGRAM: REF / + 1619 / + 2610 RDT&E: REF / –120 / –105 PER FLIGHT: REF / + 3.62 / + 5.62 • CONCLUSION: NUMBERS SRM'S PER STAGE HAS STRONGER IMPACT ON COST THAN SIZE OF INDIVIDUAL SRM
ENVIRONMENT EFFECTS	• NOT A TECHNICAL PROBLEM BUT MAY BECOME A POLITICAL ISSUE – DISPERSION MODELS INDICATE LOW PROBABILITY OF DANGEROUS CONCENTRATIONS – LAUNCH IN RAIN STORMS MAY BE CONSTRAINT
RECOVERY OF SRM'S	• SIGNIFICANT COST SAVINGS Δ COSTS ($M) PROGRAM –646 RDT&E + 46 PER FLIGHT –1.33
RELIABILITY OF SRMS	• ADEQUATE DESIGN MARGINS & GROUND DEVELOPMENT TESTING SHOULD PROVIDE RELIABILITY OF ~ .9981 • ABORT CAPABILITIES SHOULD COVER REMAINDER OF FAILURES

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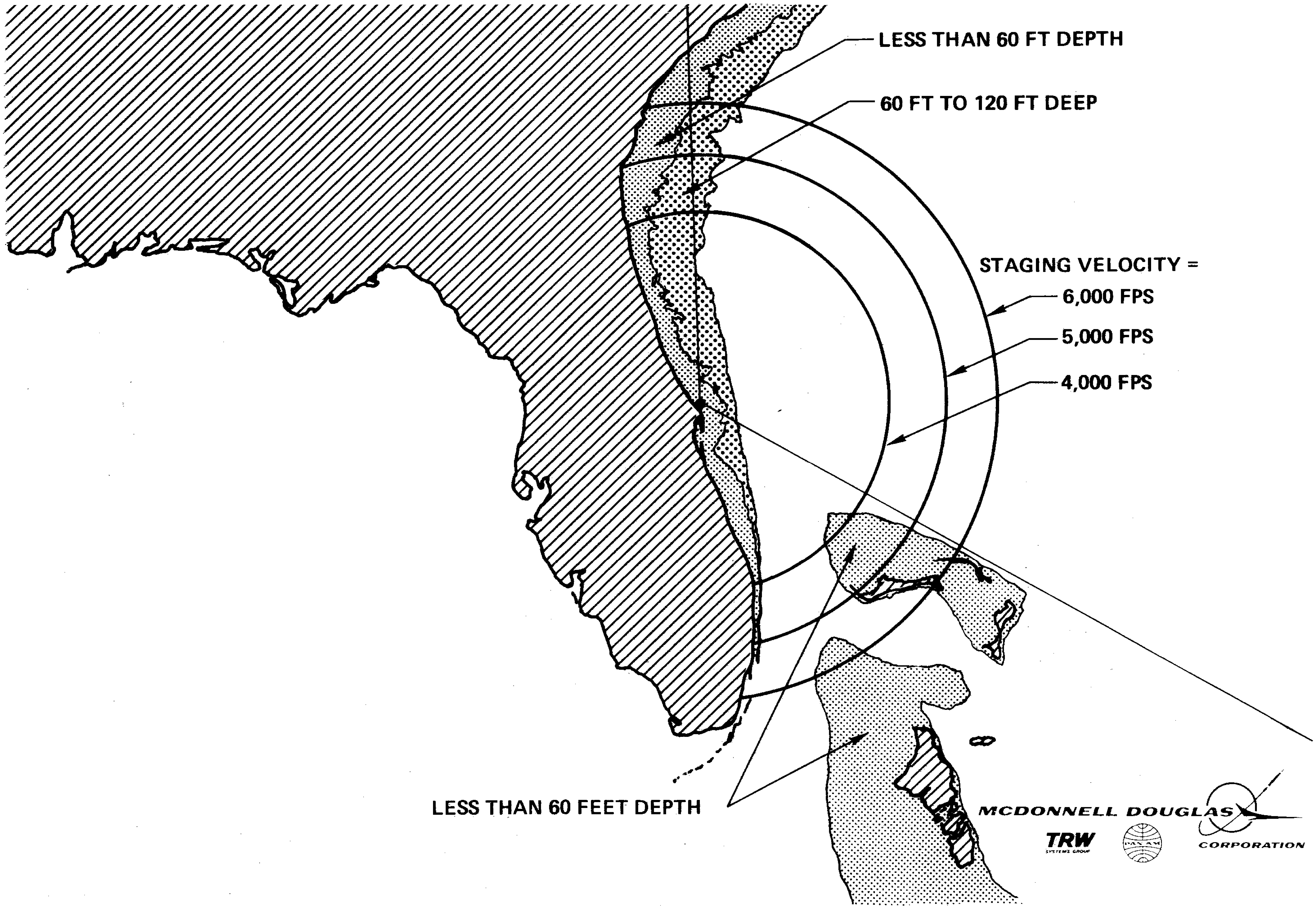
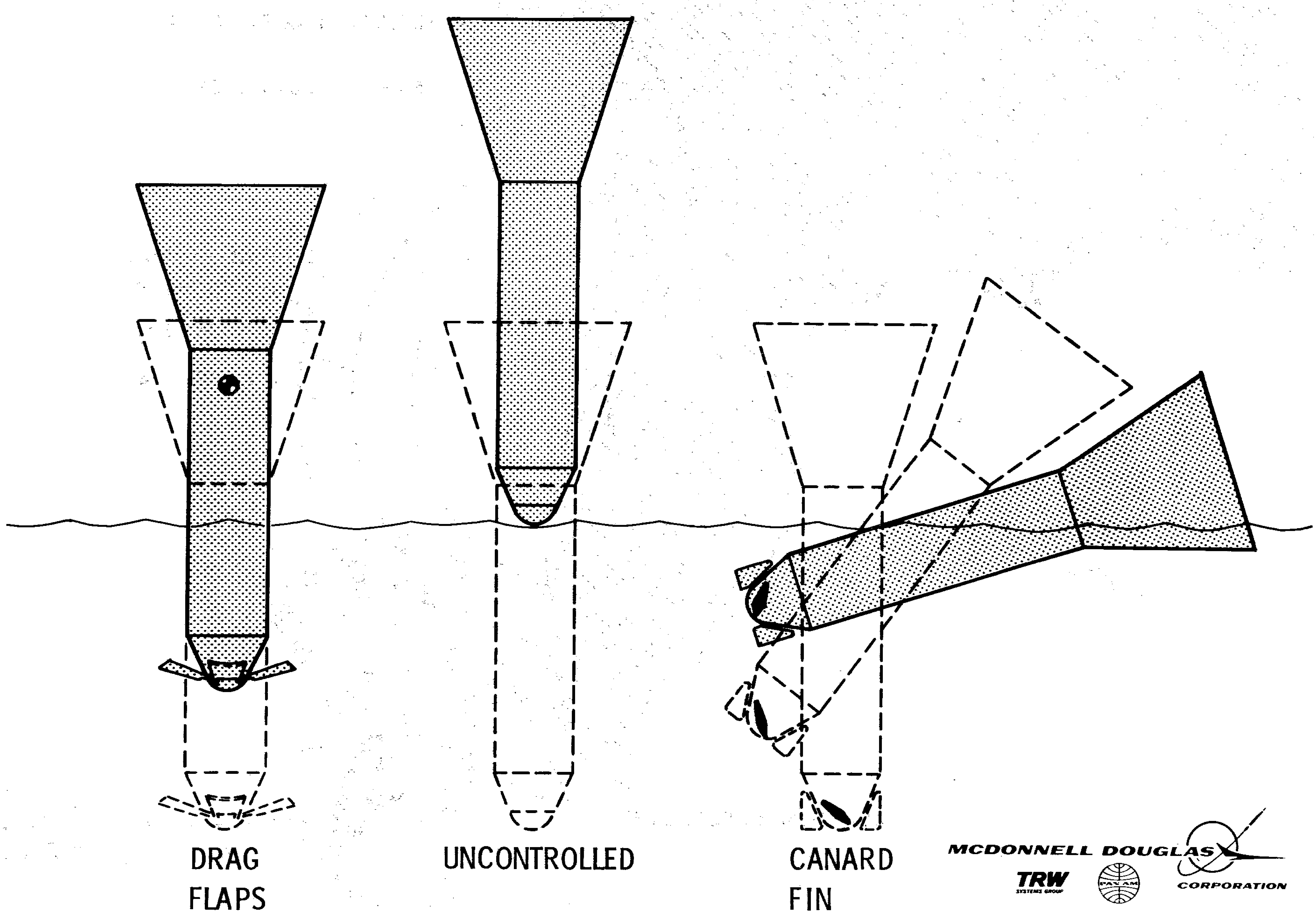
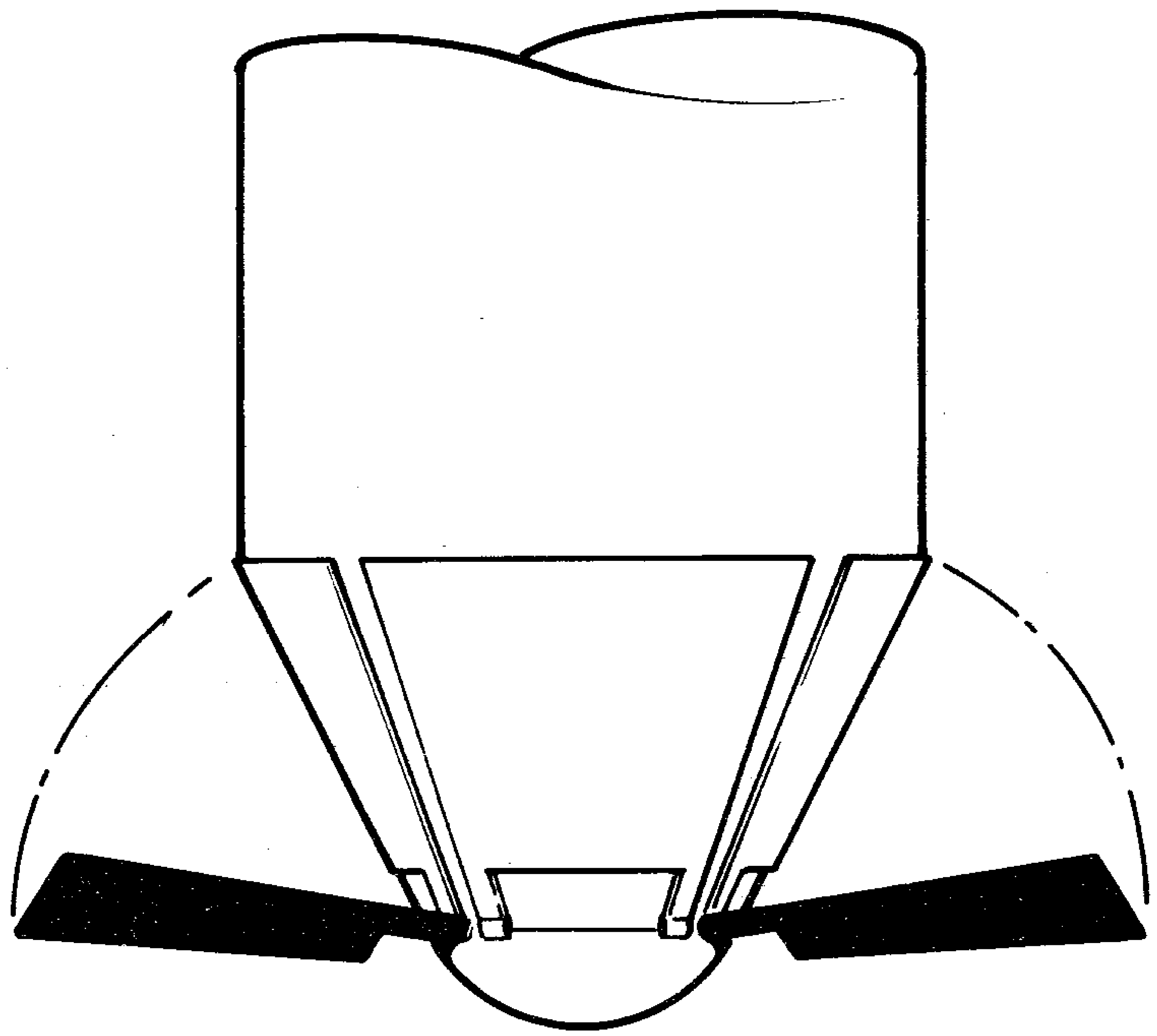
OCEAN DEPTH AND BOOSTER IMPACT POINTS



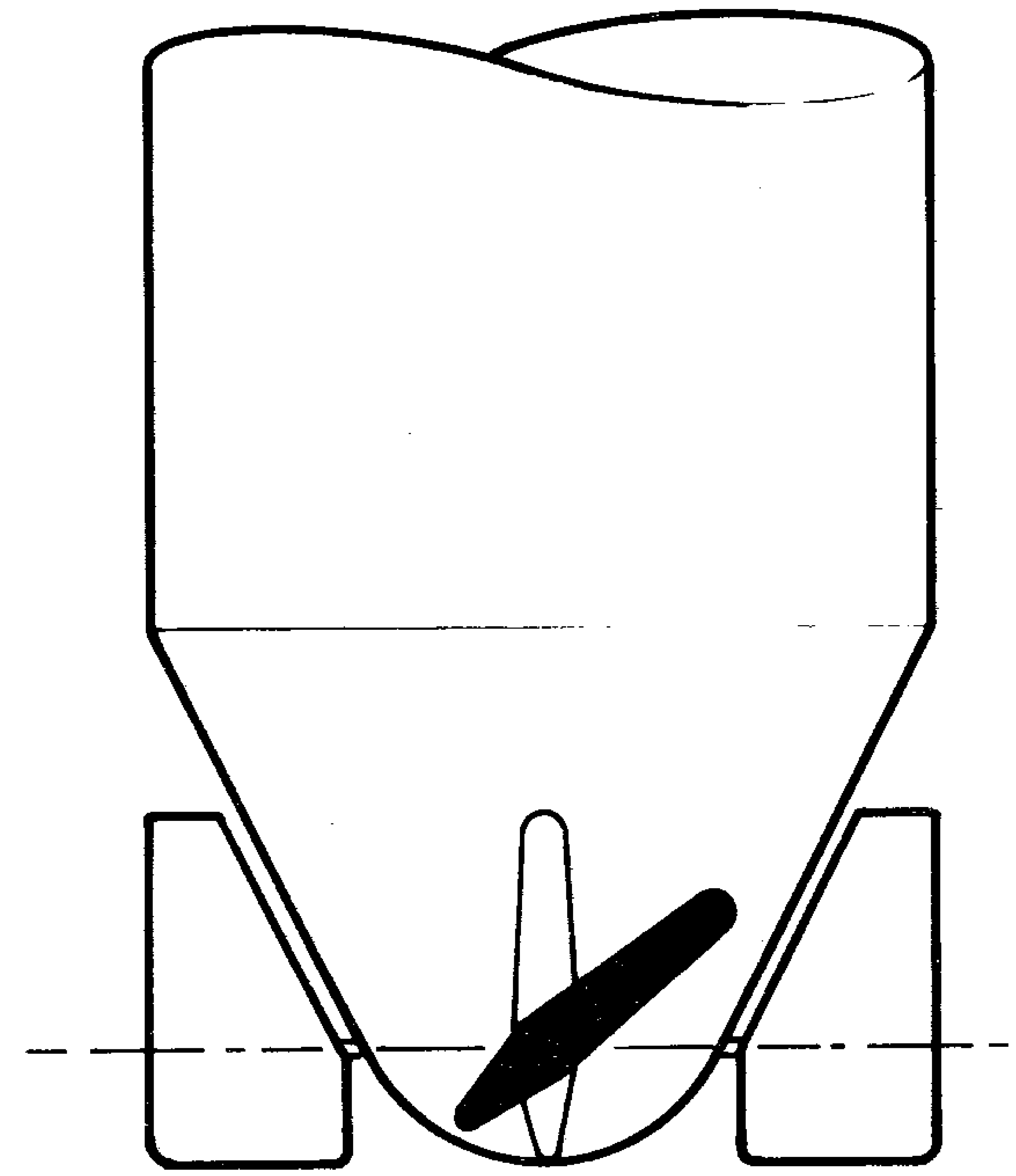
POP-UP PHENOMENA



POP-UP CONTROL CONCEPTS



DRAG FLAP



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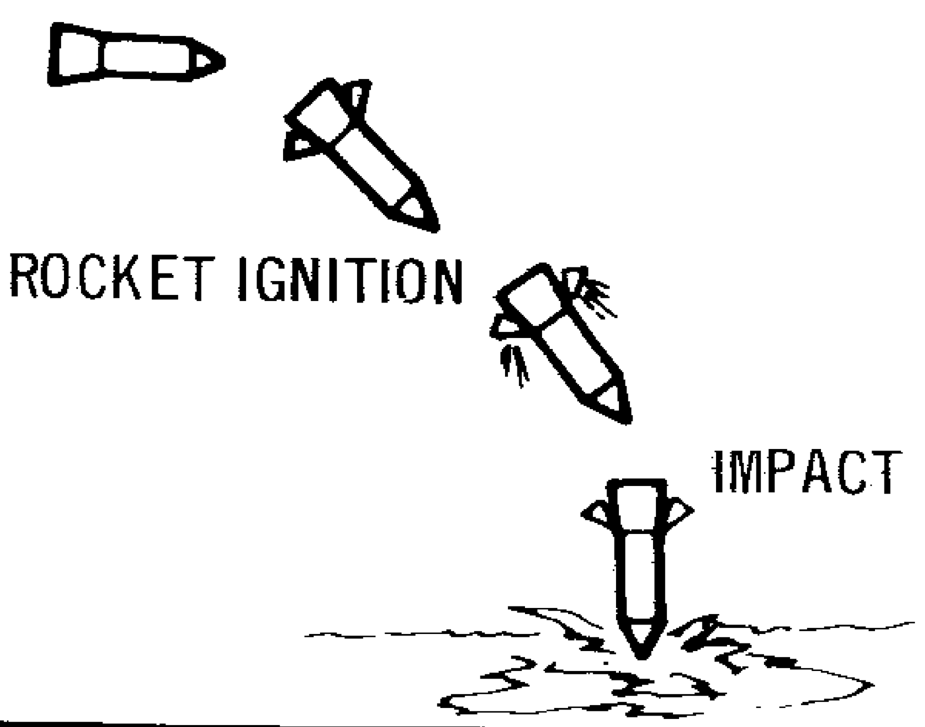
RECOVERY SYSTEM SUMMARY



	PRESSURE FED		PUMP FED
	PARALLEL	SERIES	F-1
RECOVERY WEIGHT (LB)	269,500	748,800	418,900
SYSTEM DESCRIPTION	FLAPS, ROCKETS	FLAPS, ROCKETS	FLAPS, ROCKET/SUSTAINER
FLAP AREA (FT^2)	845	2,880	1,720
TERMINAL VELOCITY (FT/SEC)	430	395	350
ROCKET THRUST ($\bar{M}$ LB)	1.62	4.49	2.51
HARD BURN TIME (SEC)	2.15	2.02	1.84
DESIGN SPLASHDOWN VELOCITY (FT/SEC)	100	100	35
WEIGHT (LB)			
FLAP SYSTEM	15,800	53,930	24,900
BRAKING ROCKET	16,900	44,500	32,300
STRUCTURE INCREMENT	11,400	57,100	9,000
TOTAL	44,100	155,430	66,200

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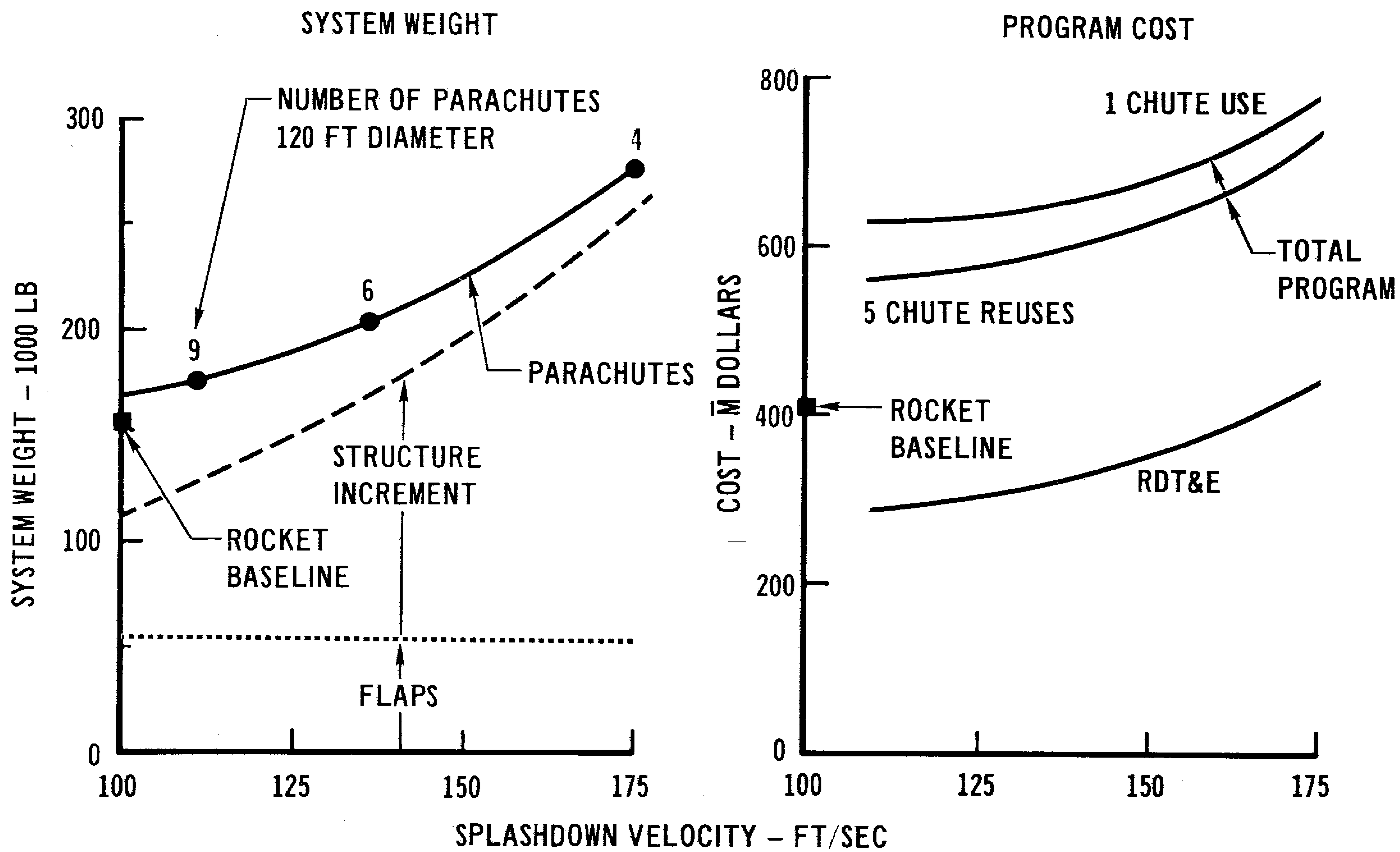
ROCKET VS PARACHUTES

SERIES BURN – PRESSURE FED
RECOVERY WEIGHT = 748,800 LB



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COMPARISON OF ENTRY AND DECELERATION TECHNIQUES

Pressure Fed Boosters

	CONFIGURATION	BRAKING ROCKETS	PARACHUTES
HIGH α ENTRY	• PRODUCES LOW W/C_DA • FIXED GEOMETRY • CONSTRAINS CONFIGURATION • TRIM SENSITIVE TO CG • ENTRY DYNAMIC BEHAVIOR • FULL SCALE HIGH α PREDICTIONS DIFFICULT (SUBCRITICAL/SUPER-CRITICAL FLOW)	• LARGE IMPACT DISPERSIONS • EXTERNAL INSTALLATION OR WEIGHT PENALTY • LOWER COST THAN PARACHUTES	• LARGE CLUSTERED PARACHUTE SYSTEM • PARACHUTE SYSTEM EXTRAPOLATIONS RISKY • FULL SCALE/SYSTEM TESTING PRECLUDED BY SIZE
LOW α ENTRY	• LOW W/C_DA ACHIEVED BY DEPLOYABLE DRAG DEVICES • INHERENT STABLE TRIM AT $\alpha \sim 0^0$ • CONFIDENCE IN AERO PREDICTION • MINIMAL, SCALE MODEL TESTING	• MINIMIZES IMPACT DISPERSIONS • "BURIED" INSTALLATION • LOWER COST THAN PARACHUTES ✓ (SELECTED BASELINE)	• LARGE CLUSTERED PARACHUTE SYSTEM • PARACHUTE SYSTEM EXTRAPOLATIONS RISKY • FULL SCALE/SYSTEM TESTING PRECLUDED BY SIZE

CONCLUSIONS: LOW α ENTRY WITH BRAKING ROCKETS MOST AMENABLE TO ANALYSIS/PREDICTION
LOWEST DEVELOPMENT RISK

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MAX q CONTROL FOR F–1 BOOSTERS

1–363 A

CONTROL OF q_{MAX} BY TRAJECTORY SHAPING WITHOUT THRUST SHAPING

- LOWEST q_{MAX} ATTAINABLE (VERTICAL FLIGHT) IS 720 PSF
- OPTIMUM PERFORMANCE TRAJECTORY HAS q_{MAX} = 900 PSF
- HOLDING TO 750 PSF CAUSES A PAYLOAD PENALTY OF 16 K LB
- MUST THEREFORE HAVE REDUCTION OF THRUST AFTER LIFTOFF

SHUTDOWN ONE ENGINE AT ABOUT 50 SEC

- ENGINE COOLING AFTER CUTOFF REQUIRES ABOUT 10 TO 20 K LB OF FUEL
- FUEL – RICH EXHAUST MAY CAUSE UNPREDICTED BASE HEATING
- CONTROL CAPABILITY WITH 6^{0} GIMBAL IS MARGINAL WITH 4 ENGINES BURNING, PROBABLY INADEQUATE WITH ONE ENGINE OFF

TWO-POSITION ORIFICE CONTROL OF THRUST LEVEL

- START AT T/W = 1.35, T_{SL} PER ENGINE = 1.505 M LB
- AT q = 550 PSF, t ~ 50 SEC, REDUCE T_{SL} PER ENGINE TO 1.30 M LB
- THIS REDUCES PAYLOAD 2.5 K FROM UNCONSTRAINED q_{MAX} CASE
- ROCKETDYNE ESTIMATES HARDWARE COST AT $\$6\overline{M}$
- PROBABLE BEST APPROACH

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MDAC EXPERIENCES WITH BOLTS IN PROPELLANT TANKS

- SATURN S-IVB AND THOR
  - NO MAJOR LEAK PROBLEM WITH BOLTS
  - INFREQUENT PROBLEMS ENCOUNTERED ARE ASSOCIATED WITH POOR WORKMANSHIP - STANDARD REWORK AVAILABLE
  - BOLTS INSTALLED DRY IN LOX TANK
  - MULTIPLE DETANKINGS (4) DIDN'T RESULT IN ANY LEAK
  - SATURN S-IVB EXTERIOR OF LOX TANK COATED WITH STM FLUOROCARBON SEALANT
  - AT CRYOGENIC TEMPERATURES SOME CLEARANCE BETWEEN BOLT HEAD AND PLATE
  - TYPICAL LEAK RATES AT AMBIENT AND CRYOGENIC TEMPERATURE 15 PSI x 0.7×10^{-6} CC/SEC AT 60 PSI 1.3×10^{-5} CC/SEC
- POTENTIAL SHUTTLE APPROACH
  - CRYOGENICALLY COOL CADMIUM BOLTS AND INSTALL DRY IN LOX TANK
  - PROTECT BOLT HEAD FROM WATER INTRUSION USING LOX COMPATIBLE FLUOROCARBON SEALANT
    - MAY PAINT BOLT TO ENHANCE ADHESION

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COST OF WELDED vs BOLTED CONSTRUCTION

Series Burn Pressure-Fed Booster

	2219 ALUMINUM	180 SERIES MARAGING	718 INCONEL AS-WELDED	718 INCONEL AGE WELDS
WELDED				
CURRENT TECHNOLOGY	2,031K	1,024K	3,192K	2,000K
NARROW GROOVE WELDING	1,260K	N/A	N/A	N/A
BOLTED	825K	1,591K	N/A	2,976K

N/A-NOT AVAILABLE

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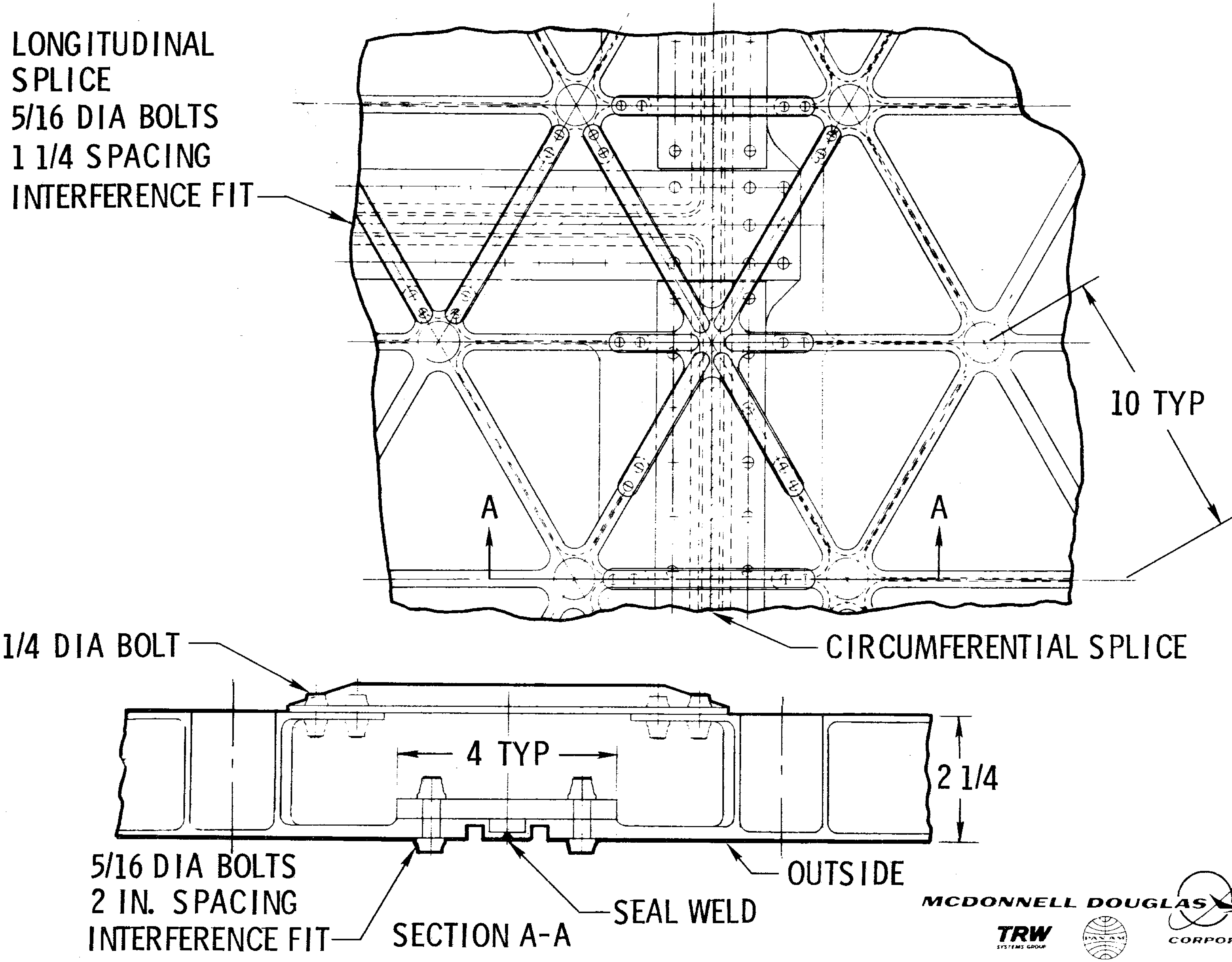
F-1 BOOSTER BOLTED TANK JOINT



SECTION A-A

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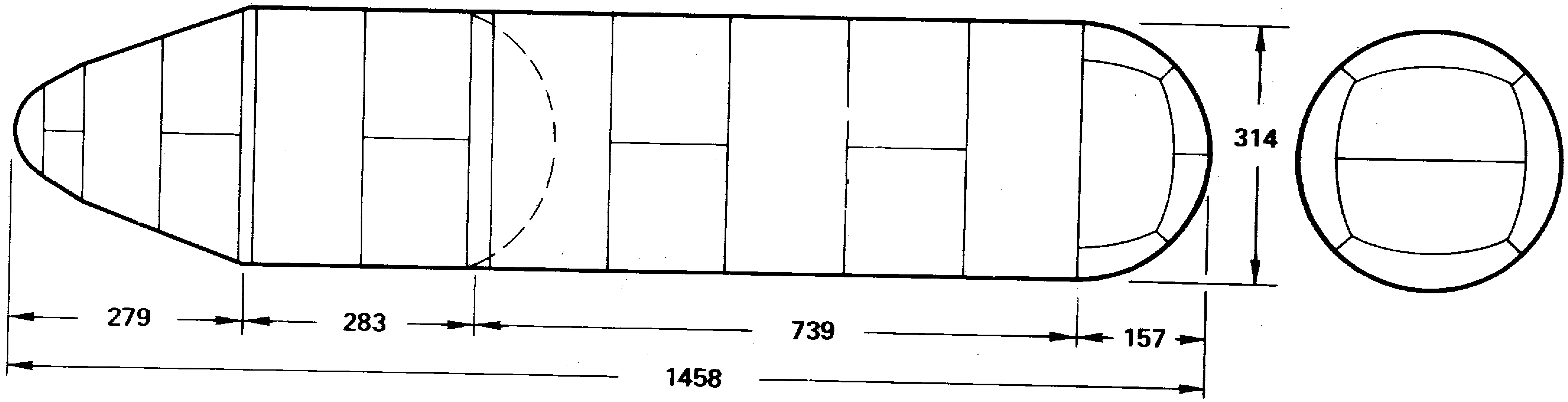
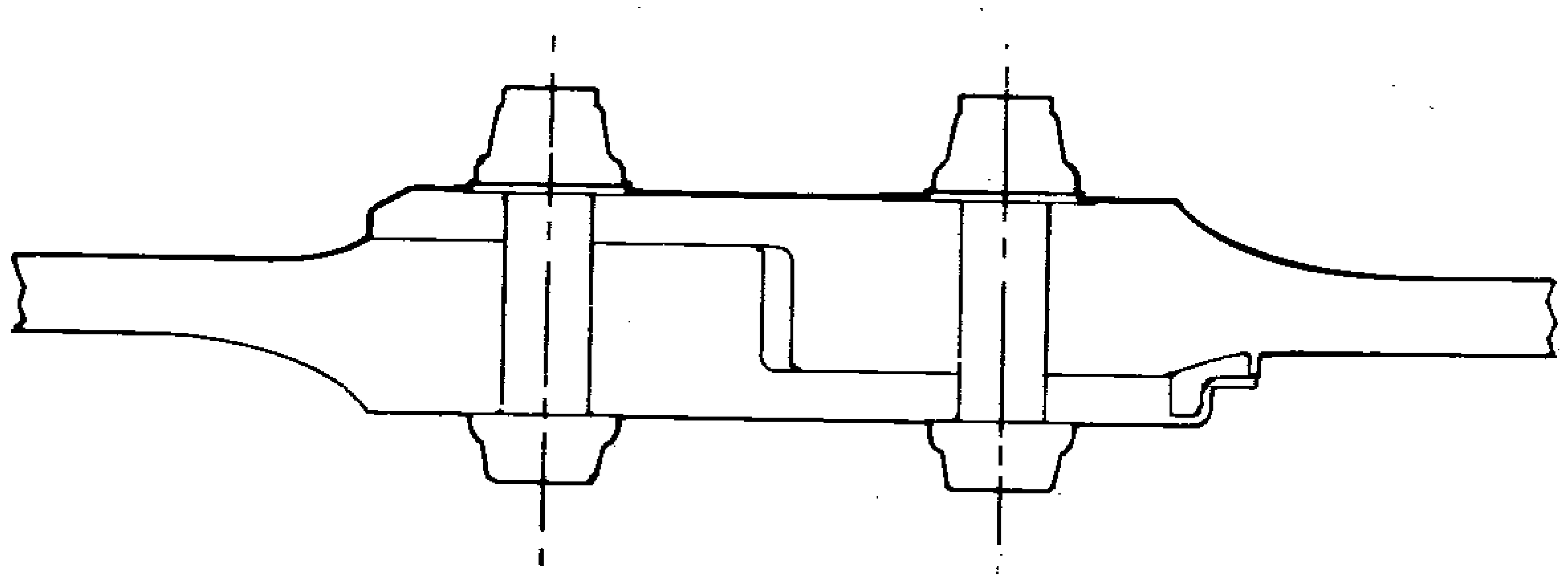
BOLTED VS WELDED ALUMINUM. TANK JOINTS

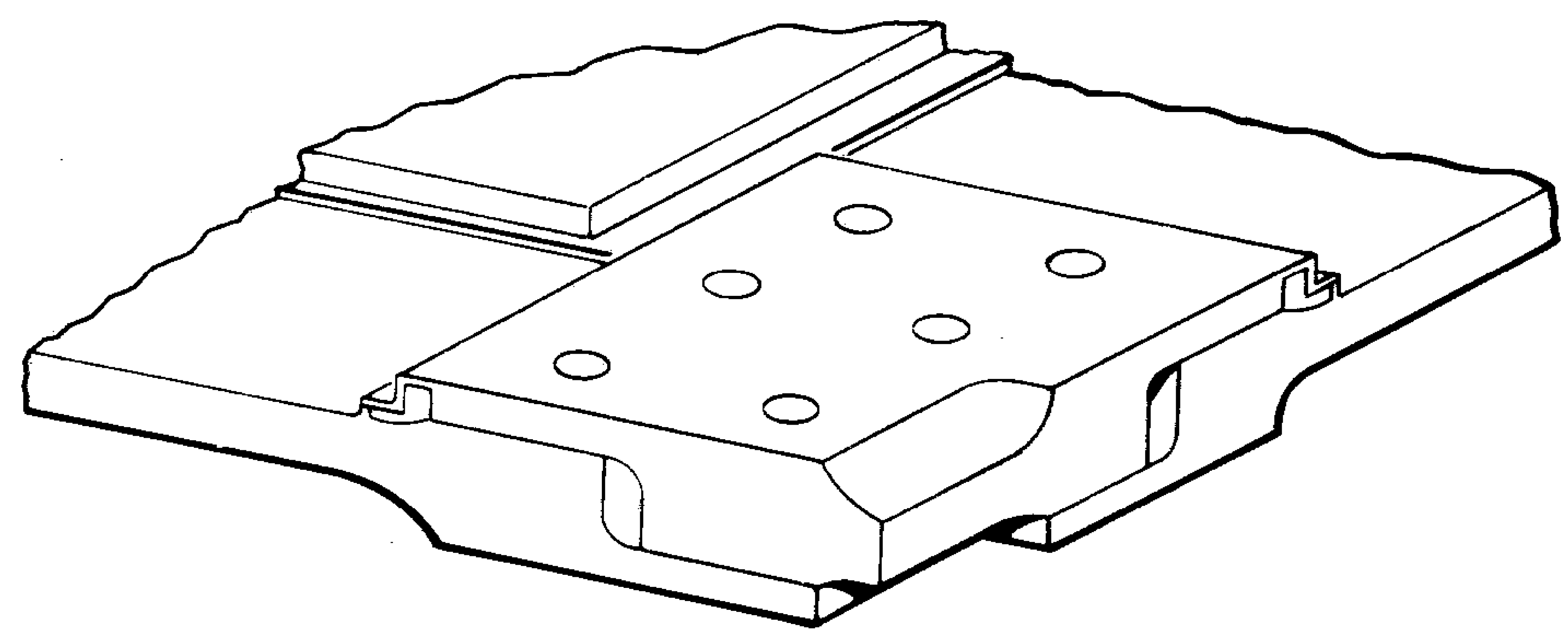
SERIES BURN-PRESSURE FED BOOSTER



- PRESSURE SHELL TOTAL WEIGHT = 180, 300 LB
- JOINT ΔWEIGHT (BOLTED) = +46, 700 LB
- JOINT ΔWEIGHT (WELDED) = +53, 500 LB



Typical Joint



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MATERIAL CONSIDERATIONS
SERIES BURN-PRESSURE FED BOOSTER

- LOX TANK - SUITABLE MATERIALS AVAILABLE BUT SOME DEVELOPMENT REQUIRED
  - MARAGING STEEL (18Ni180 OR 18Ni200)

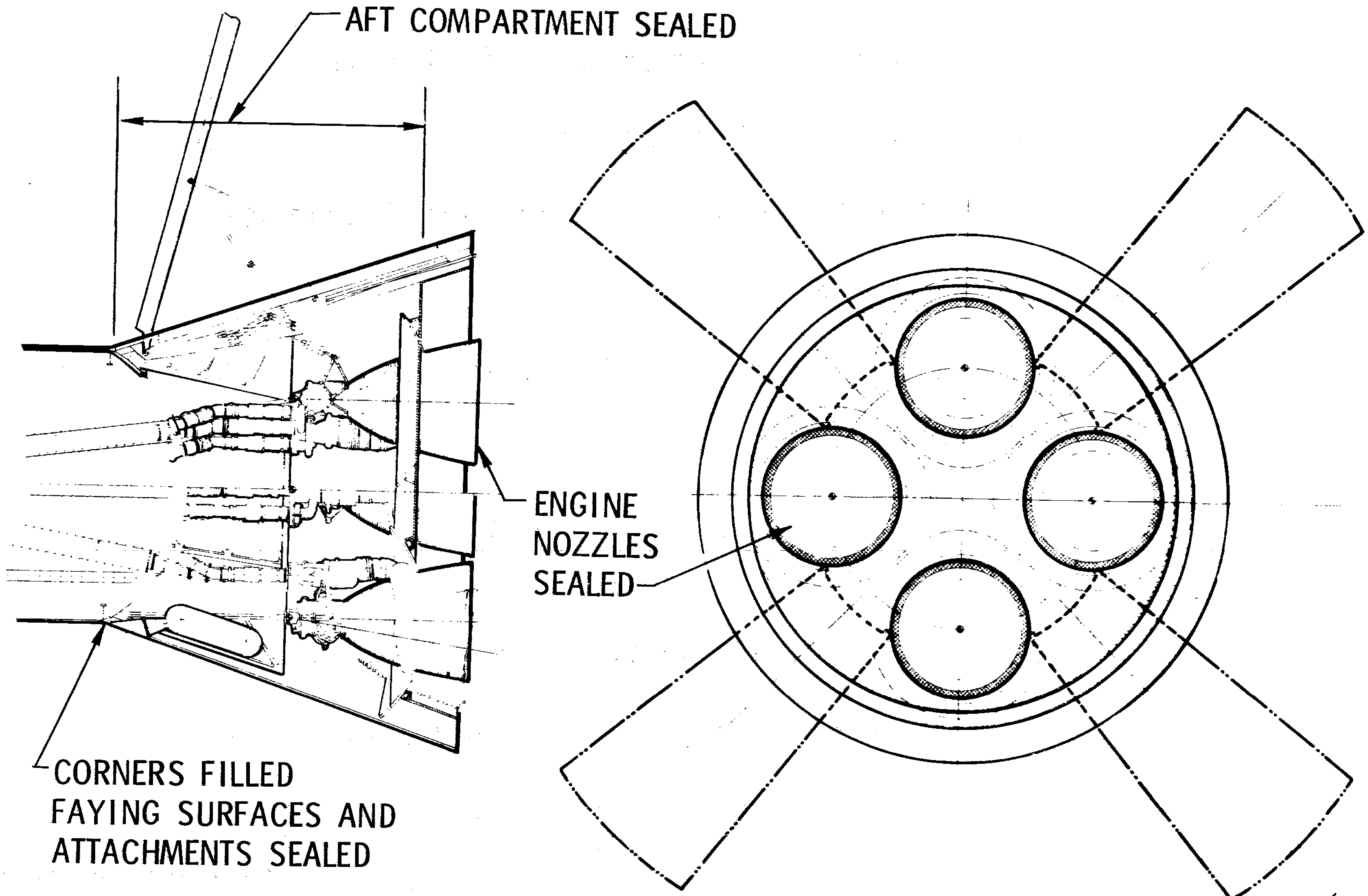
    DEVELOP CONSISTENTLY HIGH CRYOGENIC TOUGHNESS
  - 2219-T87 ALUMINUM

    DEVELOP ECONOMICAL HIGH QUALITY WELDS FOR HEAVY SECTIONS
  - INCONEL 718

    DEVELOP ECONOMICAL FABRICATION - MACHINING, WELDING, HEAT TREATMENT
- AFT SKIRT, THRUST STRUCTURE AND DRAG BRAKES - ALUMINUM
  - HIGH STRENGTH TYPES WITH CORROSION PROTECTION

BOOSTER RECERTIFICATION

1–426 A



- AVIONICS IN SEALED AND PRESSURIZED CONTAINERS
- ENGINES DRAINED AND PURGED AFTER EACH MISSION

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BOOSTER RECERTIFICATION

- MAXIMUM USE OF KSC APOLLO GSE AND FACILITIES
- SEA WATER EXPOSURE PROBLEMS MINIMIZED BY DESIGN
  - SEALED AFT COMPARTMENT AND ENGINES
  - SEALED AVIONICS
  - MATERIALS SELECTED TO REDUCE GALVANIC ACTION
- COMPLETE EXTERIOR FLUSH
- INTERNAL INSPECTION AND FLUSH IF EVIDENCE FOUND OF SALT WATER INTRUSION
- MAXIMUM USE OF AIRLINE PHILOSOPHY
  - ON CONDITION MONITORING
  - FAULT ISOLATION/BUILT-IN TEST CAPABILITY
  - MONITOR PRESSURE DECAY AFTER IMPACT & MEASURE LOADS TO VERIFY STRUCTURAL INTEGRITY
- CRYOGENIC REPROOF OF LOX TANK AFTER EVERY 25 FLIGHTS
  - BOLTED JOINT DESIGN MAY ELIMINATE REQUIREMENT FOR REPROOF

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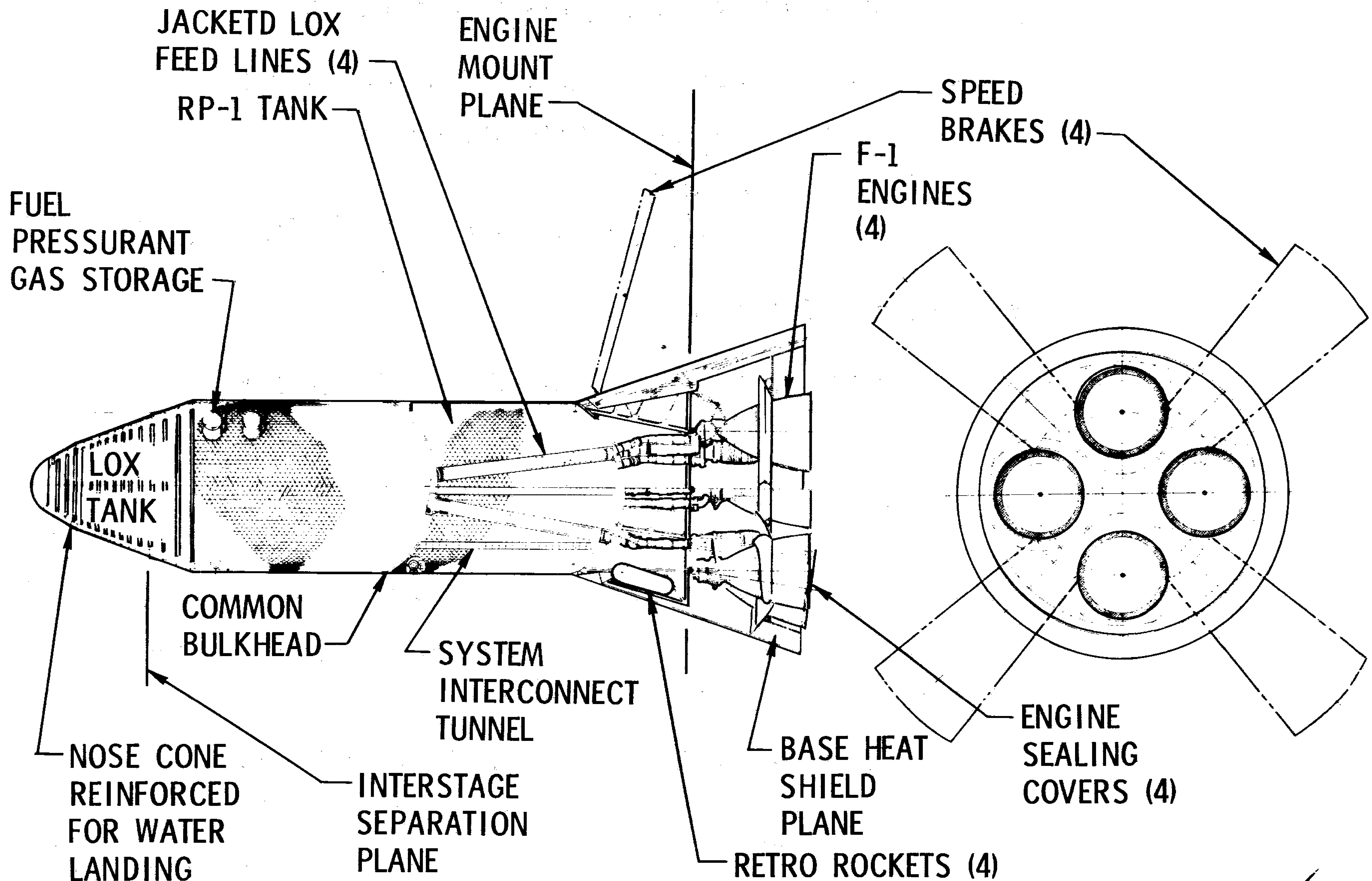
INBOARD PROFILE
SERIES BURN PUMP FED (F-1) BOOSTER



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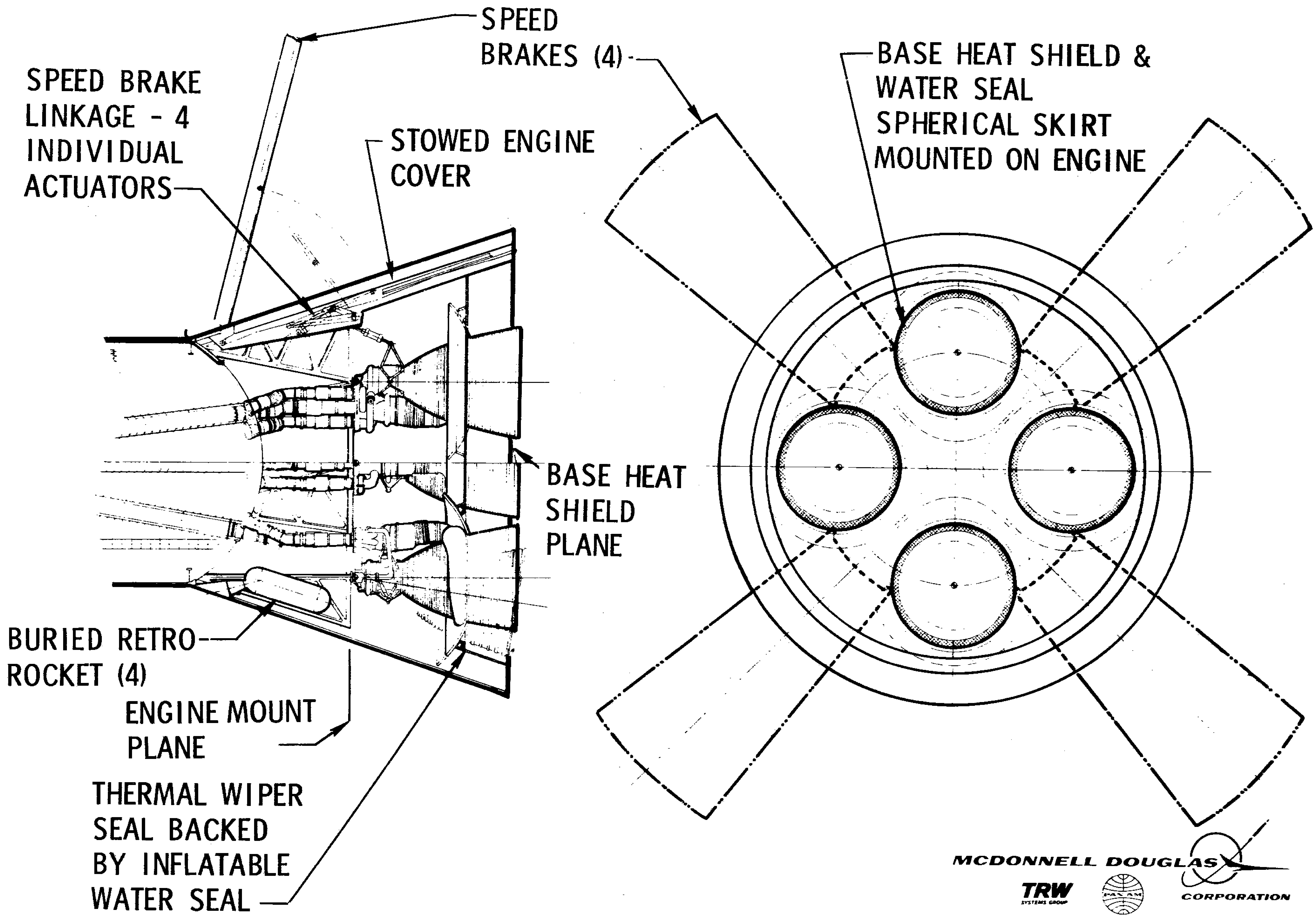
AFT BODY DETAILS

SERIES BURN - PUMP FED F-1 BOOSTER

1-434



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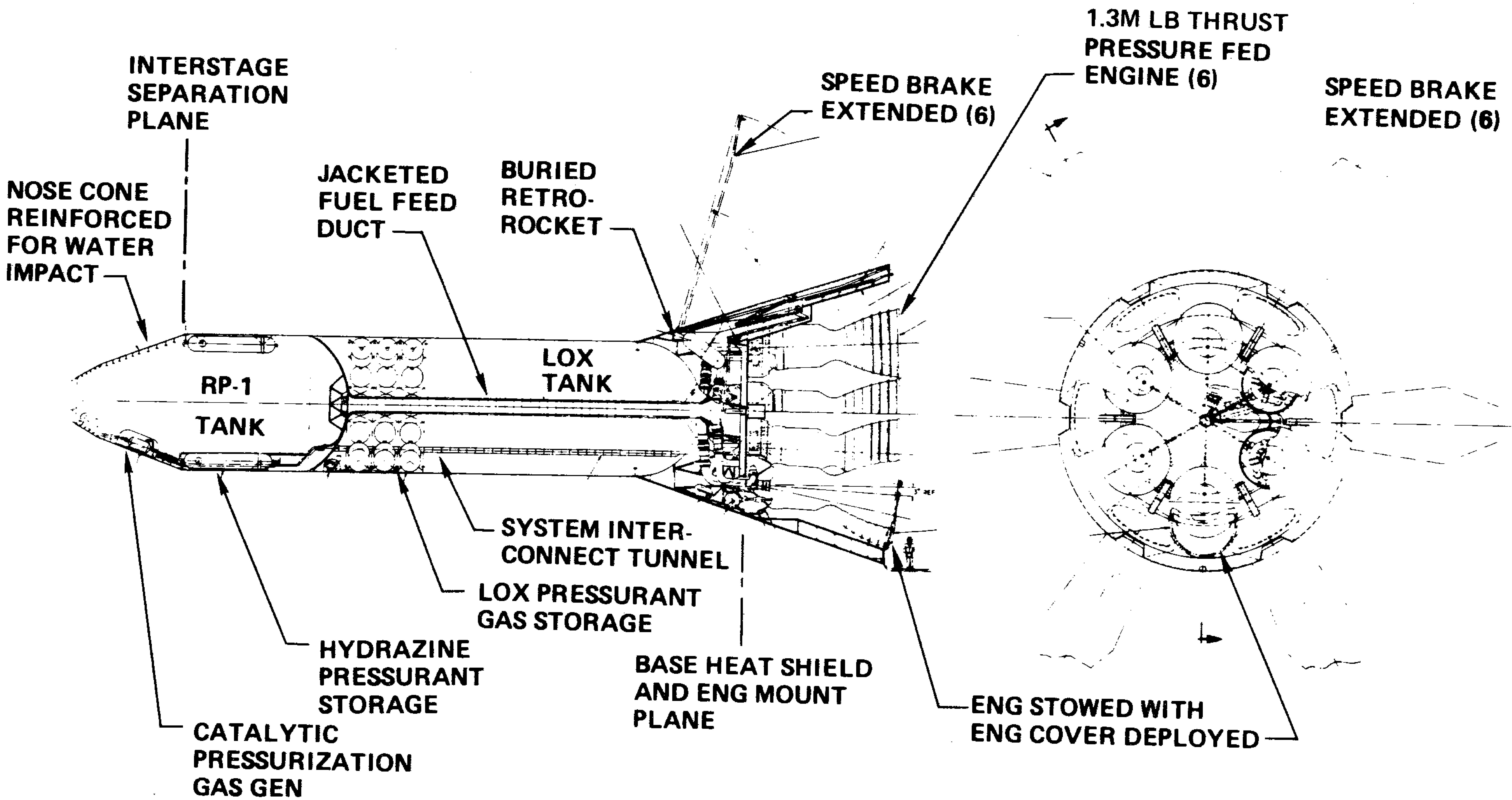
SERIES BURN-PRESSURE FED BOOSTER



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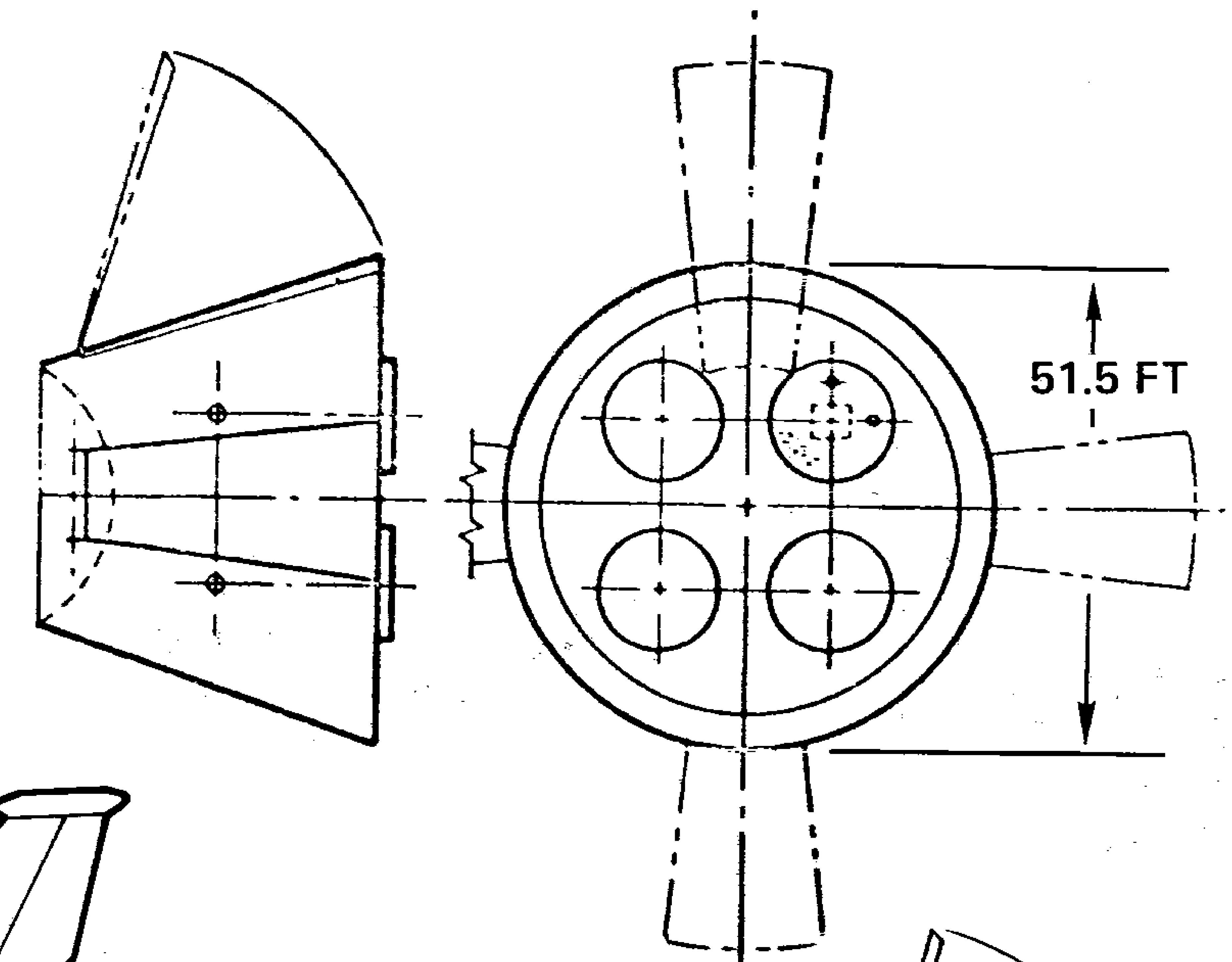
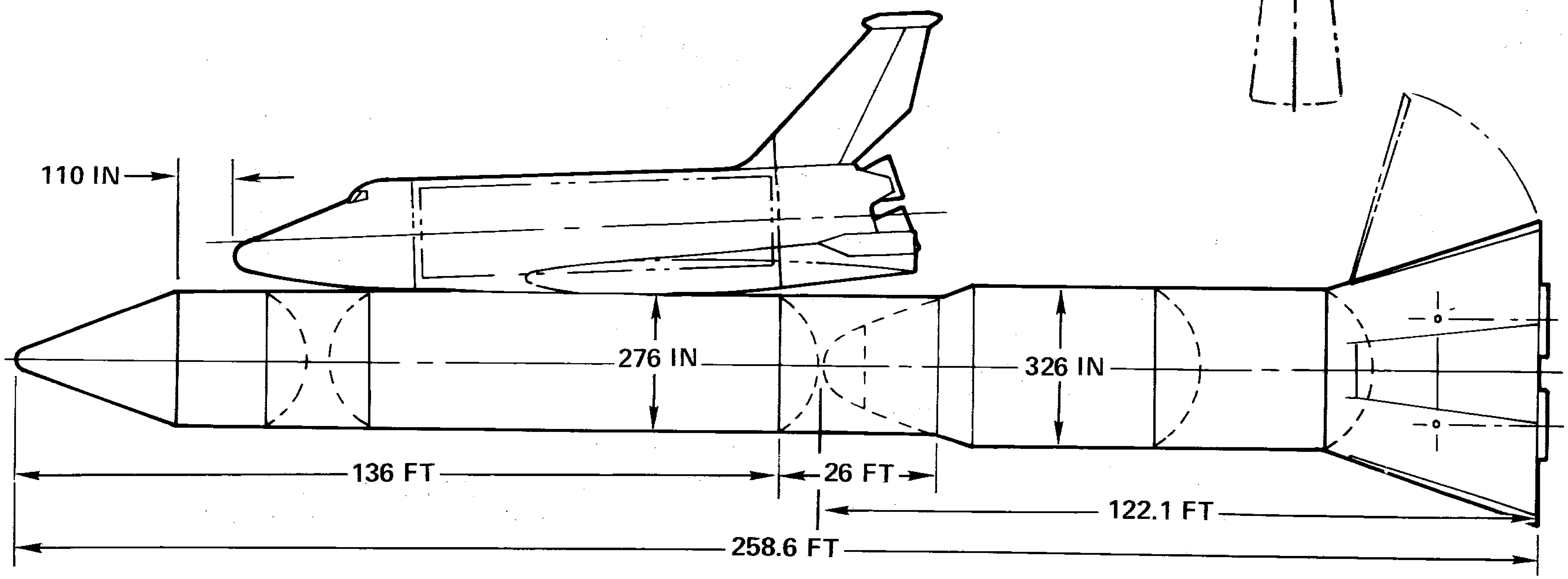
SERIES-BURN F-1 BOOSTER

- DESIGN CHARACTERISTICS
  - GLOW 4,458,300 LB
  - OLOW 1,341,700 LB
  - BLOW 3,116,500 LB
- BOOSTER DATA
  - PROPELLANT WEIGHT = 2,687 K LB
  - BURNOUT WEIGHT = 436,645 LB
  - MASS FRACTION = 0.857
  - I_{SP} (VAC) MIN = 304.1 SEC
  - S.L. THRUST = 4 x 1,505 K LB
  - GIMBAL RANGE = 6 DEG





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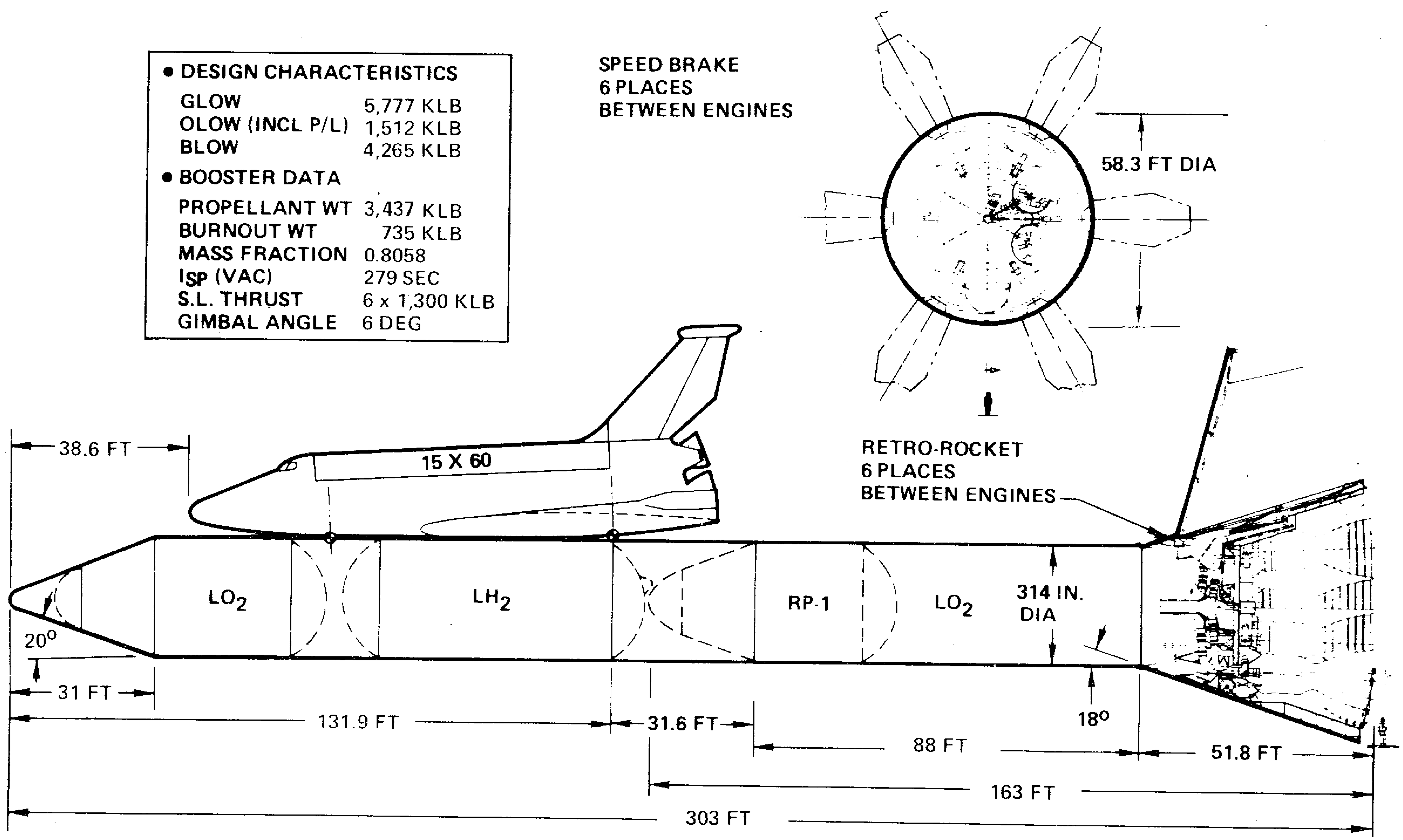
SERIES-BURN PRESSURE-FED

• DESIGN CHARACTERISTICS	
GLOW	5,777 KLB
OLOW (INCL P/L)	1,512 KLB
BLOW	4,265 KLB
• BOOSTER DATA	
PROPELLANT WT	3,437 KLB
BURNOUT WT	735 KLB
MASS FRACTION	0.8058
I_{SP} (VAC)	279 SEC
S.L. THRUST	6 x 1,300 KLB
GIMBAL ANGLE	6 DEG



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PUMP VS PRESSURE FED COMPARISON

1-416

Series Burn

CRITERIA	PRESSURE FED	F-1
WEIGHT (K LB) GLOW DRY	 5778 735	 4458 372 ✓
ENGINE DEVELOPMENT	NEW DEVELOPMENT – POTENTIAL STABILITY PROBLEMS	MINOR CHANGES ✓
EASE OF SEALING ENGINES	6 ENGINES	4 ENGINES SIMPLER ✓
BEEF-UP FOR WATER IMPACT	MODEST DUE TO RUGGED PRESSURE FED SHELL ✓	MORE FRAGILE REQUIRING MORE SOPHISTICATED RECOVERY SYS OR MORE STRUCT-
ENGINE OUT PERFORMANCE	ADEQUATE ✓	MARGINAL FOR T/W & CONTROLLABILITY
PRESSURIZATION SYSTEM	SIMPLE He PLUS HYDRAZINE DECOMPOSITION. MUCH LARGER REQUIREMENTS	SIMPLE He PLUS AUTOGENOUS OXYGEN ✓
MATERIALS	PREFERRED 2219 REQUIRES 4 TO 5 INCH WELDS RESULTING IN SUBSTANTIAL DEVELOPMENT & PRODUCTION PROBLEMS. BOLTED JOINTS LOOK PROMISING.	STRAIGHT FORWARD 2219 ✓
MAX Q CONTROL	CUT ONE ENGINE OR BLEED PRESSURE ✓	USE 2 POSITION ORIFICING TO THROTTLE ✓
ENTRY HEAT PROTECTION	SHELL HEAT SINK ADEQUATE ✓	MODEST WEIGHT ADDITION FOR HEAT SINK
RECOVERY SYSTEM	FLAPS & ROCKETS ΔWT = 155,000 LB	FLAPS AND ROCKETS ΔWT = 66,000 LB ✓
COSTS ($M) TOTAL PROGRAM RDT&E	 10,798 5,678	 10,002 5,018 ✓
DEPTH OF ANALYSIS	SUBSTANTIAL ✓	MODERATE ✓

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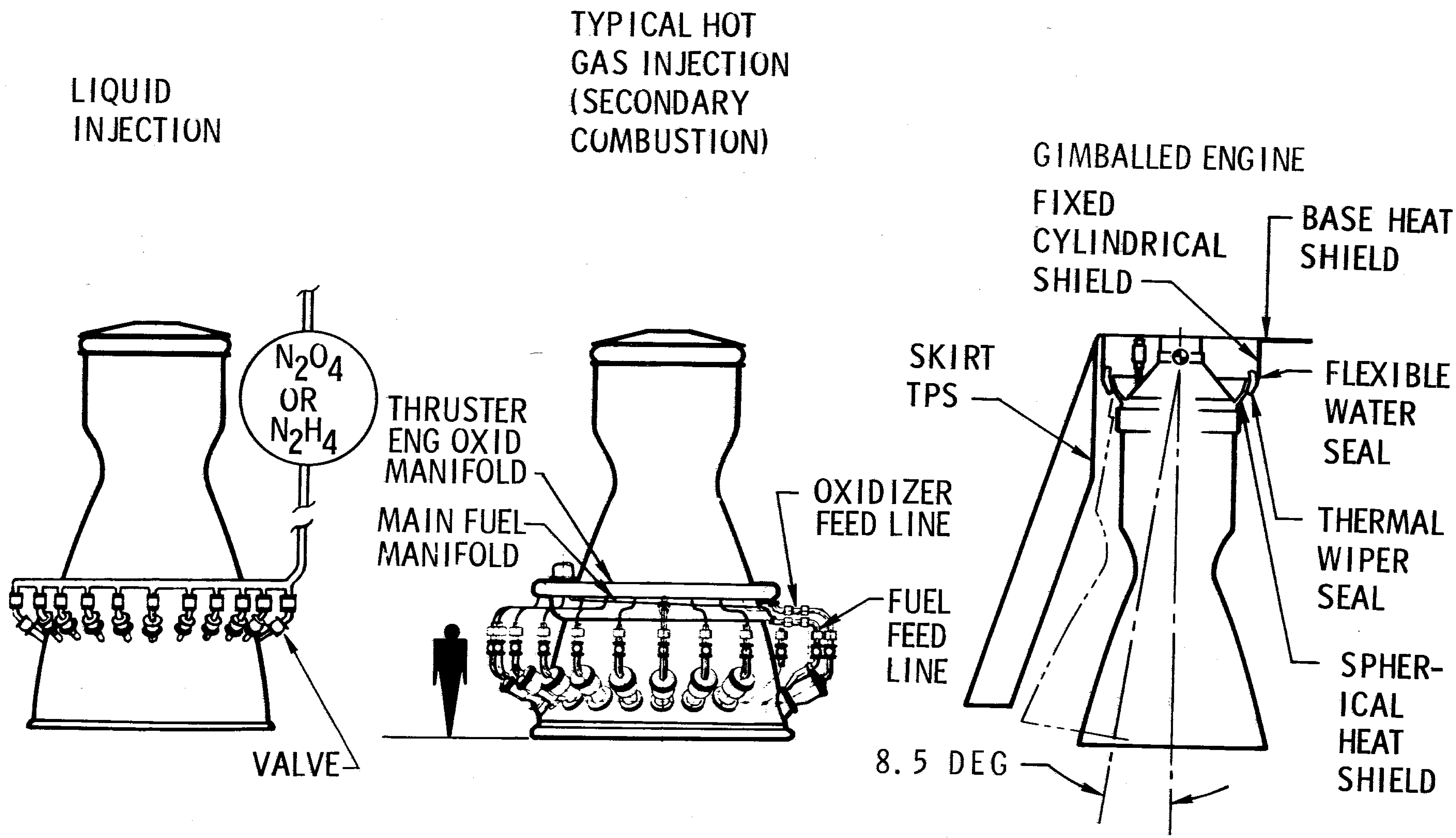
CANDIDATE TVC CONFIGURATIONS

SERIES BURN-PRESSURE FED BOOSTER



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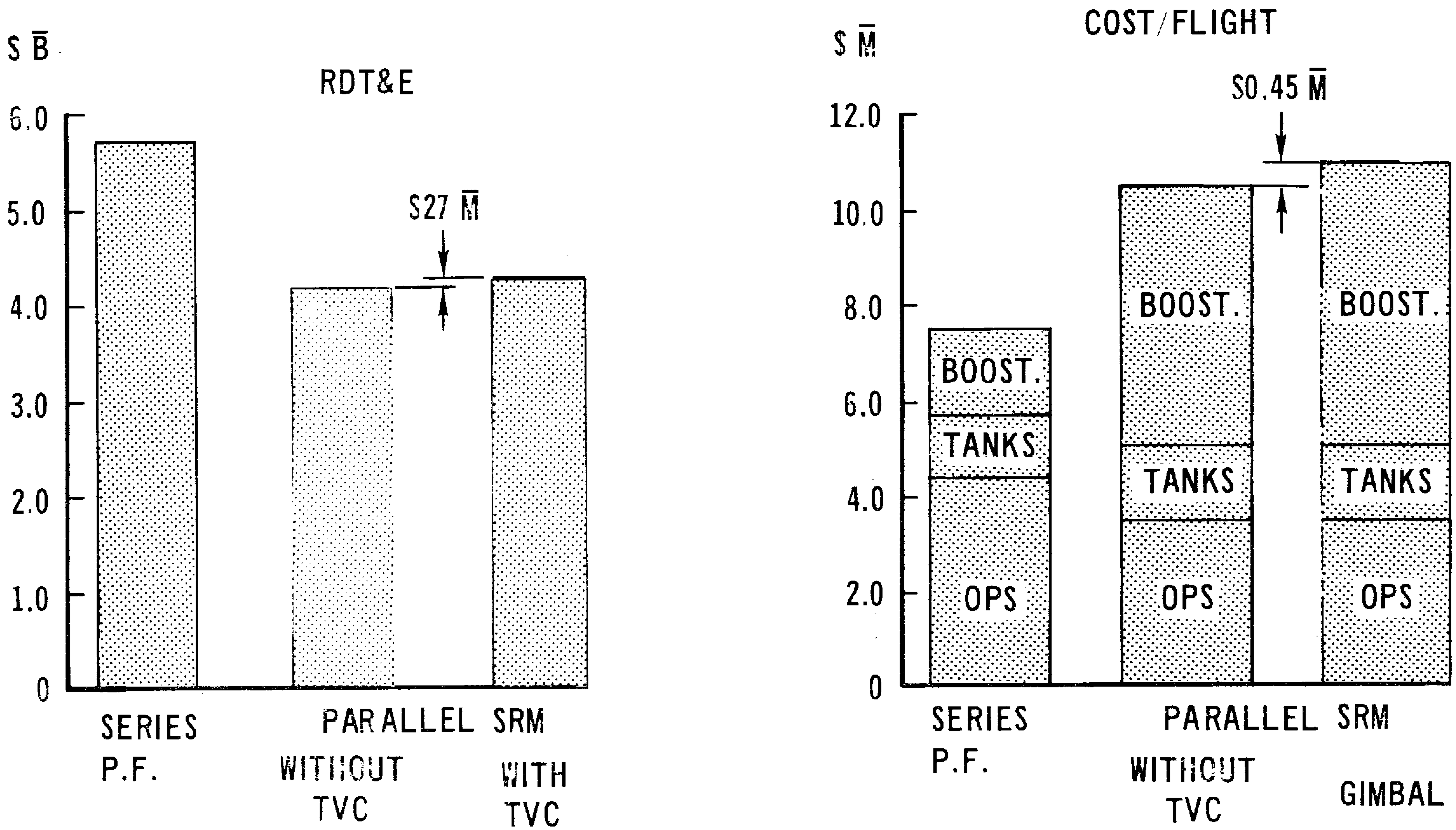
IMPACT OF TVC FOR PARALLEL SRM'S COMPARISON



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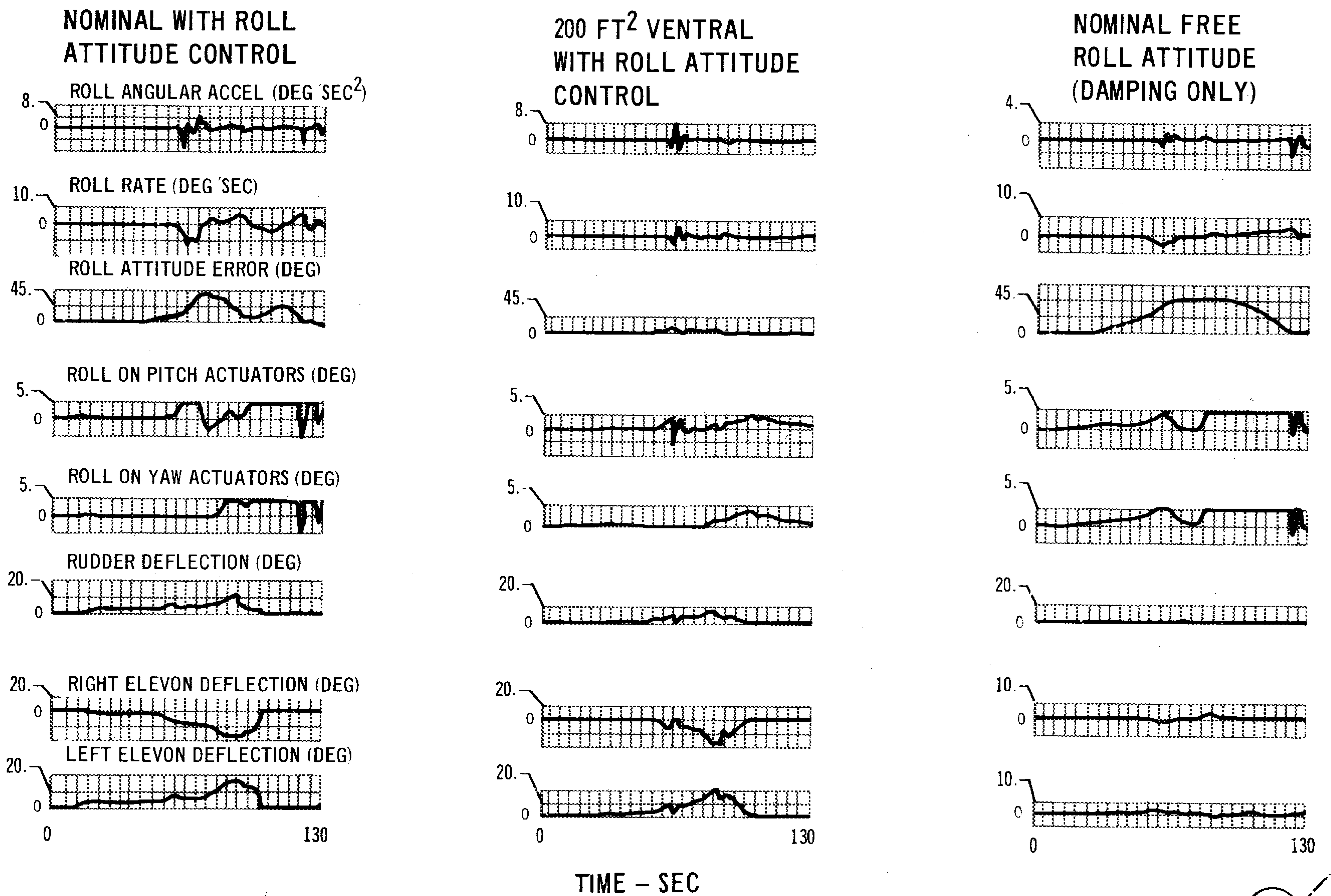
ROLL ASCENT CONTROL SYSTEM RESPONSE

1-395 A

Twin 156–In. SRMs, Parallel Burn

30,000 FT GUST SIDEWIND



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FREE ROLL vs ROLL ATTITUDE CONTROL

Parallel-Burn Solids (2–156 In.)

FREE ROLL	ROLL ATTITUDE CONTROL
• VEHICLE ROLLS AWAY FROM WIND (UP TO 90^0 FOR SIDEWIND)	• REQUIRES 200 FT^2 VENTRAL FIN ON HO TANK (AFT END)
• ORBITER AERO SURFACES REQUIRED FOR ROLL RATE CONTROL	• ORBITER AERO SURFACES USED TO FULL HINGE MOMENT CAPABILITY (26^0 AILERON & 10^0 OF RUDDER)
• ROLL RATES HELD TO LESS THAN 6 DEG/SEC (REQUIRES 3^0 OF AILERON & 8^0 OF RUDDER)	• TRAJECTORY DISPERSIONS (10,000 FT SIDEWIND) VELOCITY = –28 FT/SEC ALTITUDE = 880 FT FLIGHT PATH ANGLE = –0.52 DEG AZIMUTH = 3.4 DEG (CAN BE REDUCED WITH GUIDANCE) TOTAL ΔV DISPERSIONS =–57.1 FPS
• TRAJECTORY DISPERSIONS (10,000 FT SIDEWIND) VELOCITY = 12 FT/SEC ALTITUDE = –320 FT FLIGHT PATH ANGLE = –1.1 DEG AZIMUTH = 5.5 DEG (CAN BE REDUCED WITH GUIDANCE) TOTAL ΔV DISPERSION = –40.9 FPS	• INJECTED WEIGHT PENALTY IS 145 LB IF DROPPED AT M = 2.5 • COST FOR VENTRAL FIN (INCLUDED IN BASELINE COSTS) R&D \$3.5 M PER FLIGHT \$0.120 M TOTAL PROGRAM \$56.9 M

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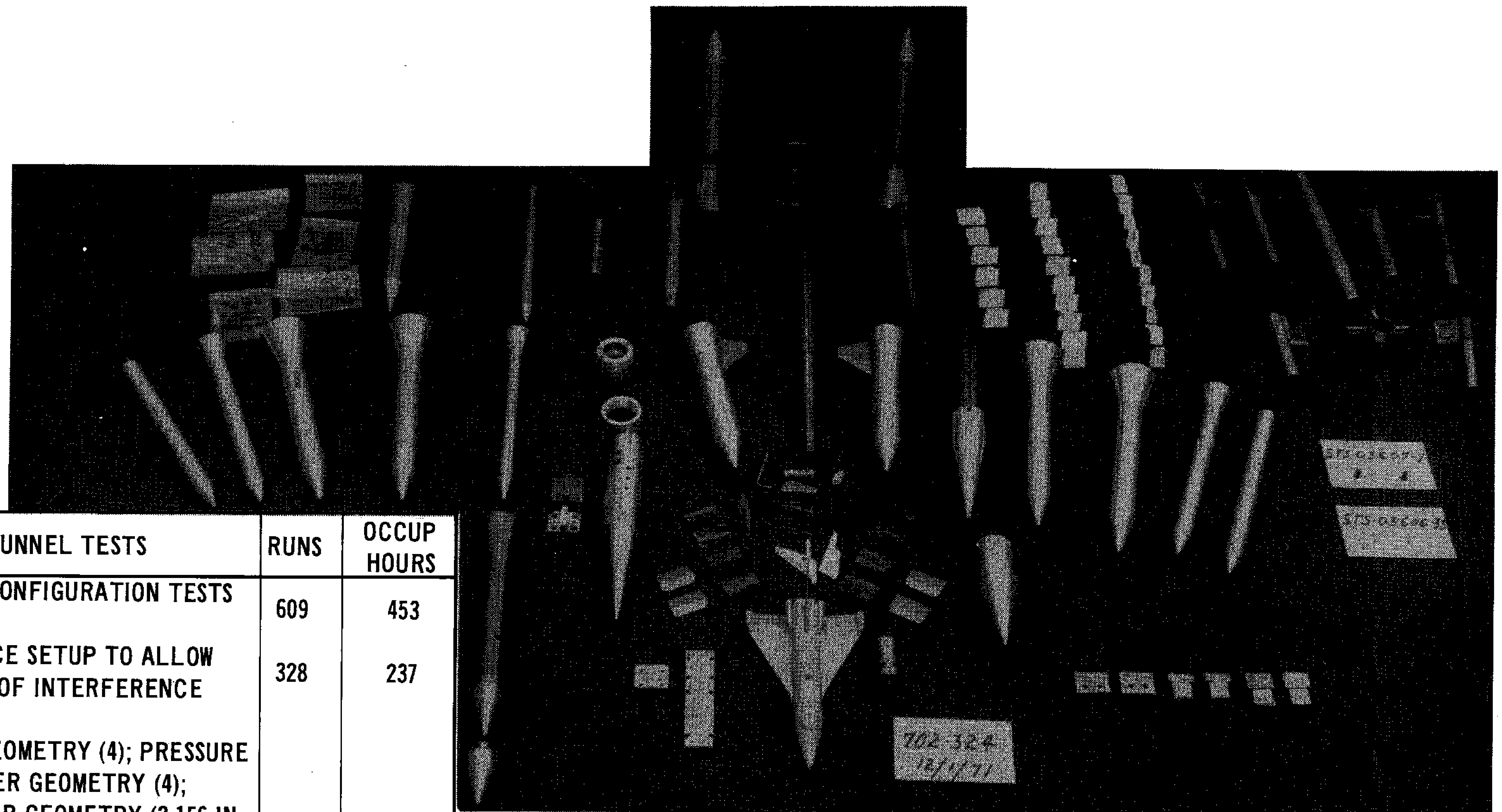
PARALLEL BURN DATA & ANALYSIS BASE



WIND TUNNEL TESTS	RUNS	OCCUP HOURS
MATED ASCENT CONFIGURATION TESTS (0.006 SCALE)	609	453
• DUAL-BALANCE SETUP TO ALLOW EXTRACTION OF INTERFERENCE TERMS	328	237
– HO-TANK GEOMETRY (4); PRESSURE FED BOOSTER GEOMETRY (4); SRM BOOSTER GEOMETRY (2-156 IN., 4-120 IN., 5–120 IN.)		
• SINGLE-BALANCE SETUP	281	216
– INDIVIDUAL COMPONENTS; ORBITER, TANKS, BOOSTERS, ETC.		
– AERODYNAMIC CONTROL EFFECTIVENESS WITH AND WITHOUT SIMULATED ROCKET PLUMES		
COMPUTER ASCENT CONTROL SIMULATIONS	450	

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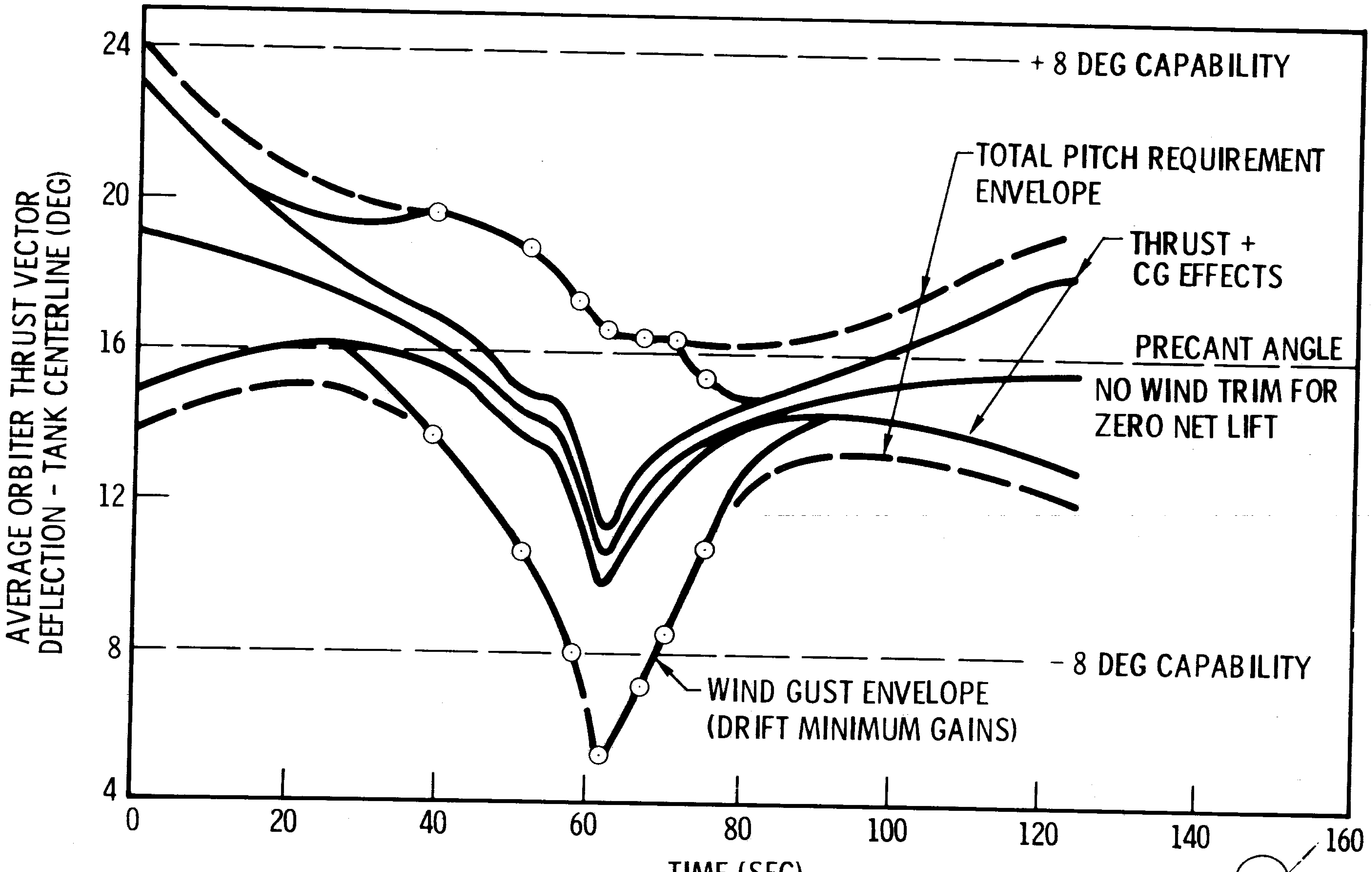
MAXIMUM PITCH THRUST VECTOR DEFLECTION
PARALLEL BURN SOLID (2-156 IN.)



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THRUST AND ECCENTRICITY EFFECTS ON CONTROL REQUIREMENTS

PARALLEL BURN SOLID (2-156 IN.)

(LIFT-OFF CONDITIONS)

ERROR SOURCE	3σ ERROR	TOP ENGINE DEFLECTIONS (DEG) PITCH ACTUATOR	TOP ENGINE DEFLECTIONS (DEG) YAW ACTUATOR	BOTTOM ENGINES DEFLECTIONS (DEG) PITCH ACTUATORS	BOTTOM ENGINES DEFLECTIONS (DEG) YAW ACTUATORS
THRUST TOLERANCE	±4.2%/MOTOR		±0.68	±0.99	±0.81
LATERAL CG AND THRUST ECCENTRICITY	±0.5% SRM MASS ±0.50 IN SRMECC		±0.66	±0.97	±0.80
YAW-AXIS THRUST MISALIGNMENT	±0.25 DEG/MTR		±1.565	±2.28	±1.86
PITCH-AXIS THRUST MISALIGNMENT (INCLUDES 0.25 DEG CLOCKING)	±0.26 DEG/MTR	±0.75	±3.12	±3.2	±1.56
RSS SUM		±0.75	±3.57	±4.15	±2.77
(RSS SUM IF THRUST MISALIGNMENT IS 0.35 DEG/ENG)		(±1.05)	(±4.94)	(±5.66)	(±3.58)

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ASCENT CONTROL

ITEM	RESULTS
TVC REQUIREMENTS ON PARALLEL SRM	• NOT REQUIRED • DATA & ANALYSIS BASE EXTENSIVE • VEHICLE INHERENTLY STABLE • FREE ROLL CONCEPT VIABLE; DISPERSIONS SMALL • CONVENTIONAL ROLL CONTROL CAN BE MAINTAINED IF FIN ADDED TO TANK WITHOUT TVC • 3^0 OF TVC CAN BE PROVIDED FOR ADDED ASSURANCE FOR MODEST COST GIMBAL / LIQUID INJECTION R&D: \$26.7 $\bar{M}$ / \$37.4 $\bar{M}$ PER FLIGHT: \$0.45 $\bar{M}$ / \$0.86 $\bar{M}$ TOTAL: \$228.1 $\bar{M}$ / \$418.8 $\bar{M}$
TVC REQUIREMENTS ON SERIES CONFIGURATIONS	• 6^0 GIMBAL ANGLE SUFFICIENT TO CONTROL ON ALL 3 AXES • VEHICLES UNSTABLE IN PITCH BY 26 FEET • STABILITY CAN BE PROVIDED & GIMBAL ANGLES CAN BE REDUCED BY ADDITION OF 1040 SQ FT OF FINS AT ADDED PROGRAM COSTS OF R&D: \$15.0 $\bar{M}$ PER FLIGHT: \$0.42 $\bar{M}$ TOTAL: \$201.9 $\bar{M}$ • GIMBALLED ENGINES LESS EXPENSIVE THAN INJECTION SYSTEMS. LOADS ON WATER IMPACT ARE TOLERABLE

MCDONNELL DOUGLAS CORPORATION
TRW SYSTEMS GROUP

ORBITER GROUP WEIGHT COMPARISONS

- EASTERLY MISSION WEIGHTS – LB
- PARALLEL BURN

BAY SIZE	15 x 60 (3–470 K LB)	14 x 45 (3–470 K LB)		14 x 45 (3–420 K LB)	
PAYLOAD WEIGHT REQUIREMENT	65K	45K	ΔWT	45K	ΔWT
WING GROUP	16,214	14,305	–1,909	13,460	–2,754
TAIL GROUP	2,766	2,643	–123	2,550	–216
BODY GROUP	28,620	26,120	–2,500	25,700	–2,920
INDUCED ENVIRONMENT PROTECTION	25,602	22,771	–2,831	22,500	–3,102
LANDING, RECOVERY, DOCKING	7,977	7,249	–728	6,740	–1,237
PROPULSION–ASCENT	23,000	23,000		21,410	–1,590
PROPULSION-CRUISE	0	0		0	
PROPULSION-AUXILIARY	6,483	6,261	–222	5,270	–1,213
PRIME POWER	4,020	4,020		4,020	
ELECT. CONVER. AND DISTRIBUTION	2,530	2,530		2,530	
HYDRAULIC CONVER. AND DISTRIBUTION	1,510	1,510		1,510	
SURFACE CONTROLS	4,997	4,525	–472	4,400	–597
AVIONICS	5,730	5,730		5,730	
ENVIRONMENTAL CONTROL	6,550	6,550		6,550	
PERSONNEL PROVISIONS	800	800		800	
RANGE SAFETY AND ABORT	0	0		0	
BALLAST	0	0		0	
GROWTH UNCERTAINTY	12,008	11,128	–880	10,930	–1,078
SUBTOTAL (DRY WEIGHT)	(148,807)	(139,142)	(–9,665)	(134,100)	(–14,707)
PERSONNEL	1,200	1,200		1,200	
CARGO	65,000	45,000	–20,000	45,000	–20,000
ORDNANCE	0	0		0	
RESIDUAL FLUIDS	2,156	2,156		2,156	
SUBTOTAL (INERT WEIGHT)	(217,163)	(187,498)	(–29,665)	(182,456)	(–34,707)
RESERVE FLUIDS	13,915	12,472	–1,443	12,344	–1,571
INFLIGHT LOSSES	5,443	5,443		5,293	–150
PROPELLANT-ASCENT	0	0		0	
PROPELLANT-CRUISE	0	0		0	
PROPELLANT-MANEUVERS/ACS	15,501	14,290	–1,211	13,700	–1,801
TOTAL (GROSS-WEIGHT) LB	(252,022)	(219,703)	(–32,319)	(213,793)	(–38,229)
ENTRY WEIGHT – LB	197,710	173,045	(–24,665)	168,003	(–29,707)
LANDING WEIGHT – LB	192,659	167,994	(–24,665)	162,952	(–29,707)
LANDED CARGO	40,000	25,000	(–15,000)	25,000	(–15,000)

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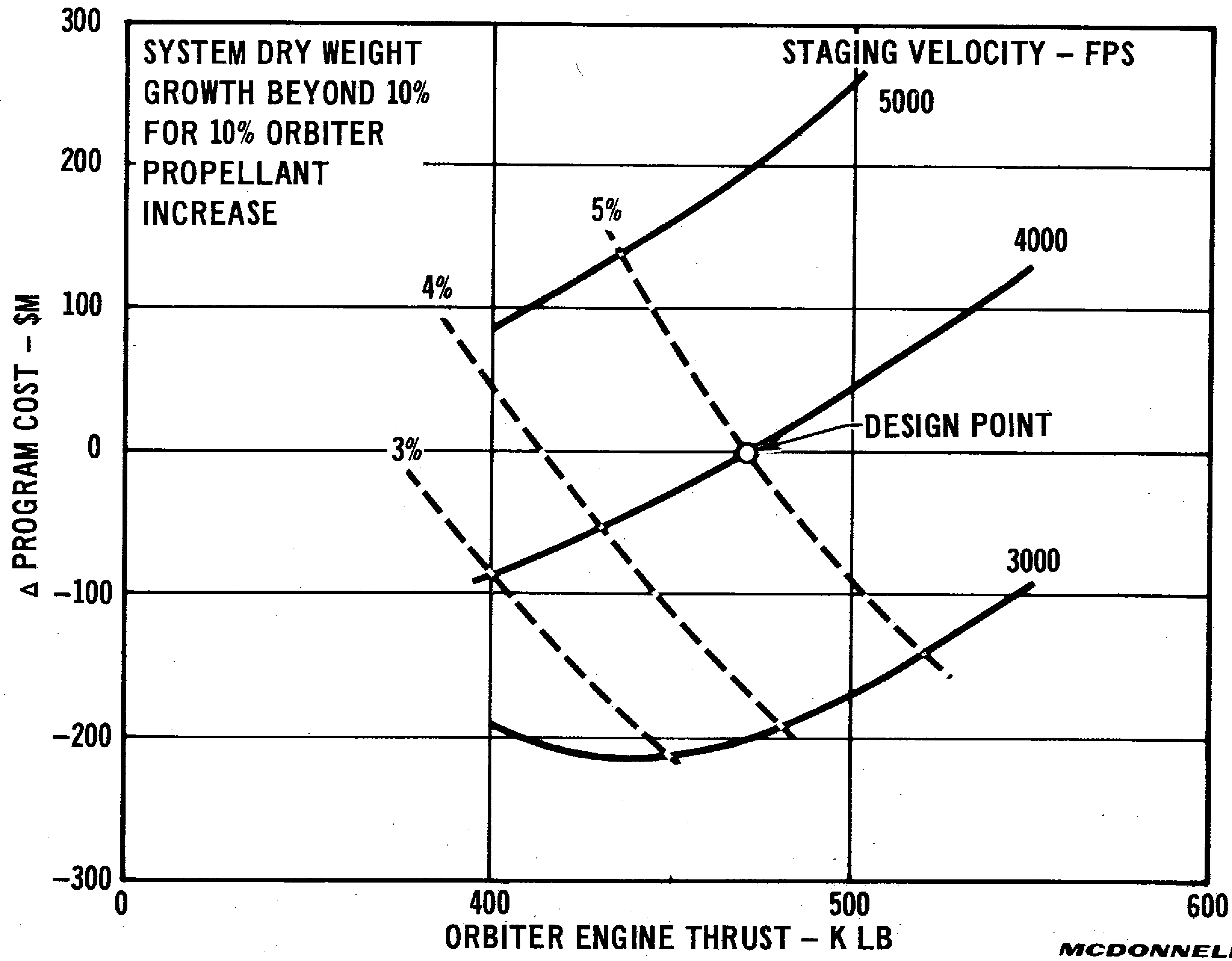
TRW SYSTEMS GROUP

PAN AM

ORBITER THRUST SELECTION

14 x 45, 45 K LB, Series Burn

- PRESSURE FED BOOSTER
- 3 ORBITER ENGINES



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TRW SYSTEMS GROUP
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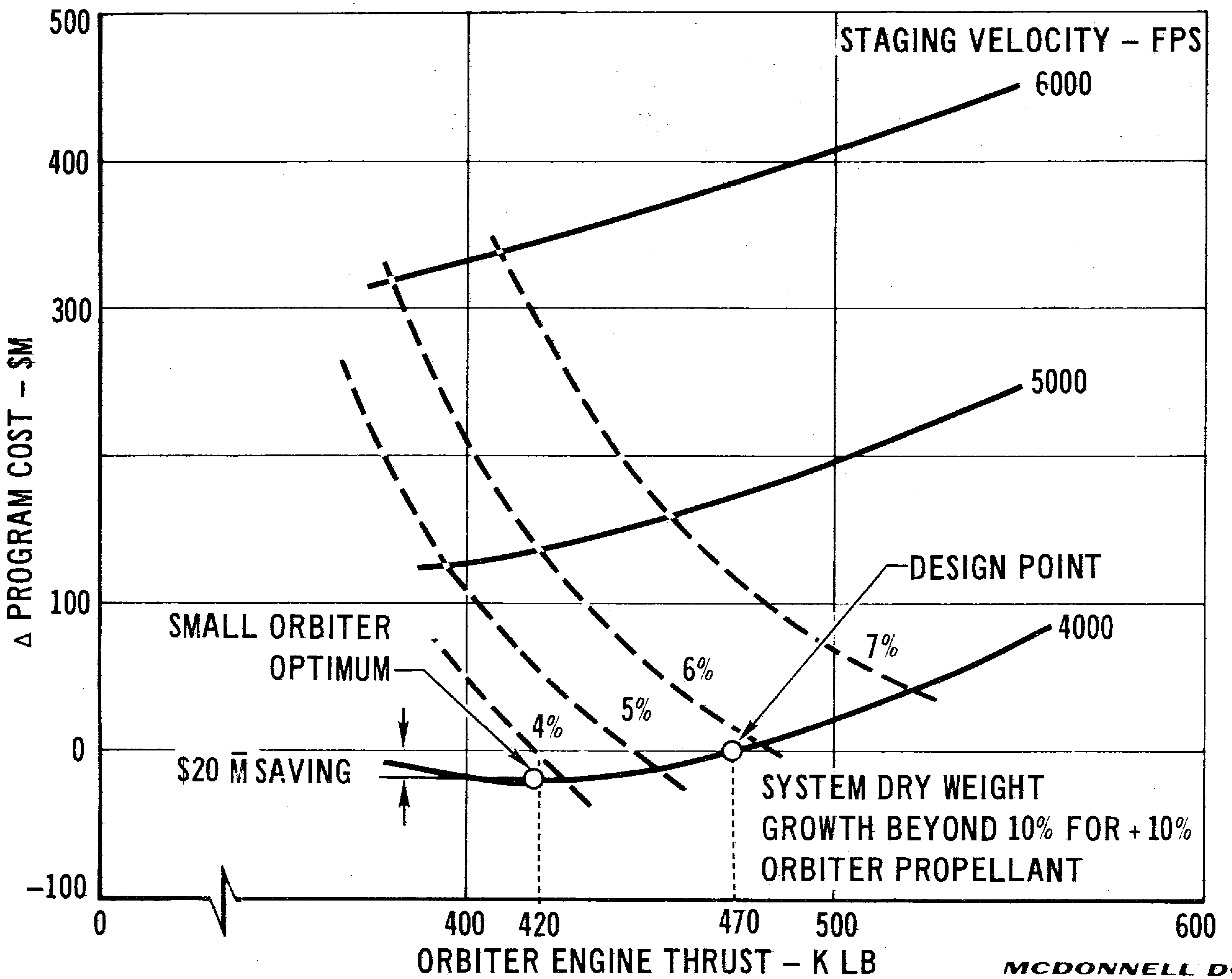
ORBITER THRUST SELECTION

14x45, 45 K LB, Parallel Burn

- 2–156 IN. SRMs
- 3 ORBITER ENGINES



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ORBITER PHYSICAL DIFFERENCES

- 15 x 60 FT VS 14 x 45 FT
  (65 K LB) (45 K LB)

- SERIES BURN
- 3–470 K LB MAIN ENGINES

- FUSELAGE REFERENCE LENGTH SHORTER BY 16 FT ---------- (13%)
- FUSELAGE MOLDLINE WETTED AREA REDUCED 1128 FT^2 ---------- (18%)
- THEORETICAL WING AREA DECREASED 400 FT^2 ---------- (11%)
- WING SPAN REDUCED 4.4 FT ---------- (5.5%)
- VERTICAL FIN AREA DECREASED 38 FT^2 ---------- (9%)
- MAIN GEAR 7 IN. SHORTER ---------- (6%)
- DRY WEIGHT REDUCED 9665 LB ---------- (6%)
- CG TRAVEL REDUCED ---------- (2.5% TO 1.8%)

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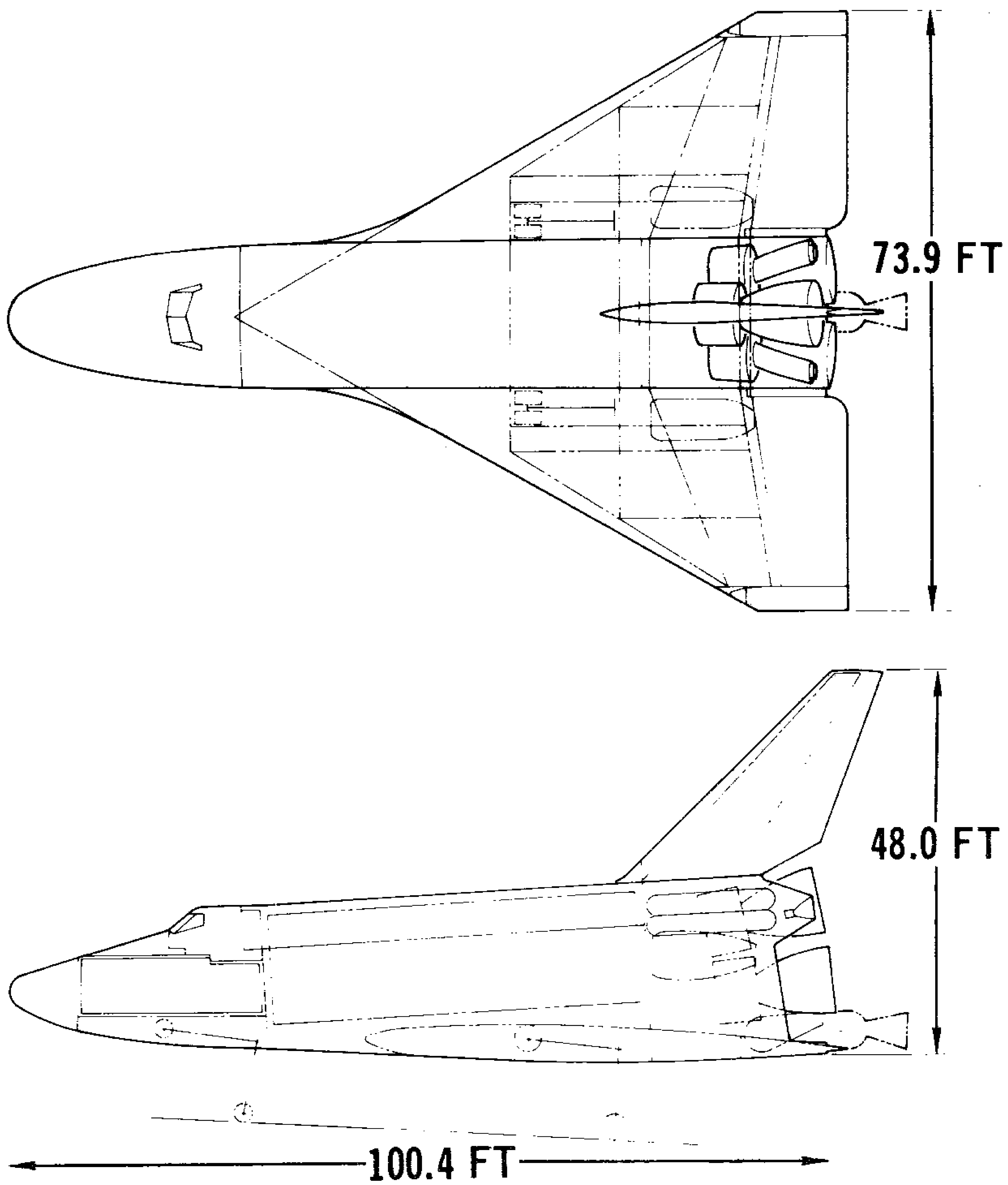
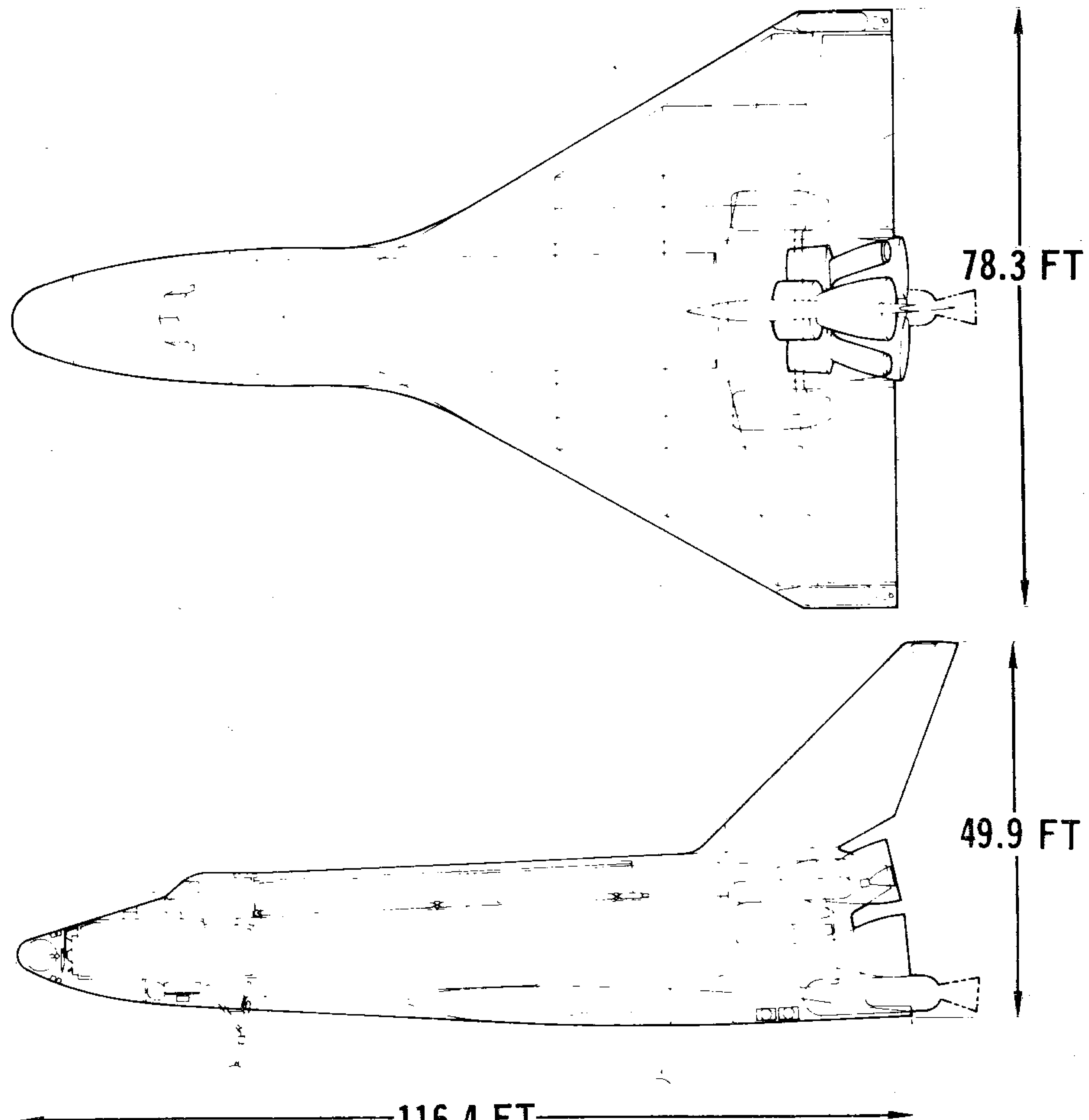
ORBITER COMPARISON

14 x 45, 45 K LB
THREE 470 K LB, HiPc

15 x 60, 65 K LB
THREE 470 K LB, HiPc





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PAYLOAD BAY SIZE & WEIGHT

ITEM	RESULTS		
14 FT x 45 FT, 45/25 K COST SAVINGS PERCENTAGE		SERIES PRESSURE FED	PARALLEL TWIN 156 IN SRM
	TOTAL PROGRAM	4.1 %	5.2 %
	RDT&E	4.3 %	3.0 %
	PER FLIGHT	3.6 %	6.4 %
MISSION CAPTURE IMPACT		% MISSIONS LOST WITH SMALL BAY	
		NASA	DOD
	SINGLE LAUNCH/MISSION	18 %	92 %
	DUAL LAUNCH/MISSION	16 %	33 %
ORBITER DESIGN IMPACT		3-470 K HiPc	3-420 K HiPc
	DRY WEIGHT REDUCTION	-9665 LB	-14,000 LB
	ADDED PROGRAM SAVING FOR REDUCING ORBITER ENGINE SIZE	-	$ 20 M
	• SMALL PAYLOAD ORBITER IS SIMILAR TO LARGE ONE IN CONFIGURATION, WING LOADING AND AFT C.G. LOCATION • SHORTER VEHICLE REDUCES ALLOWABLE C.G. TRAVEL FOR HYPERSONIC TRIM AND SUBSONIC STABILITY • HOWEVER, LIGHTER PAYLOAD AT SHORTER MOMENT ARM REDUCES ACTUAL C.G. TRAVEL AN EQUAL AMOUNT • THEREFORE, OVERALL CONFIGURATION PROBLEMS ARE EQUIVALENT TO THOSE OF LARGE PAYLOAD ORBITER • 3 – 420 K ENGINE ORBITER C.G. SLIGHTLY FORWARD OF 3 – 470 K BUT SLIGHT WING REPOSITIONING BALANCES ORBITER		

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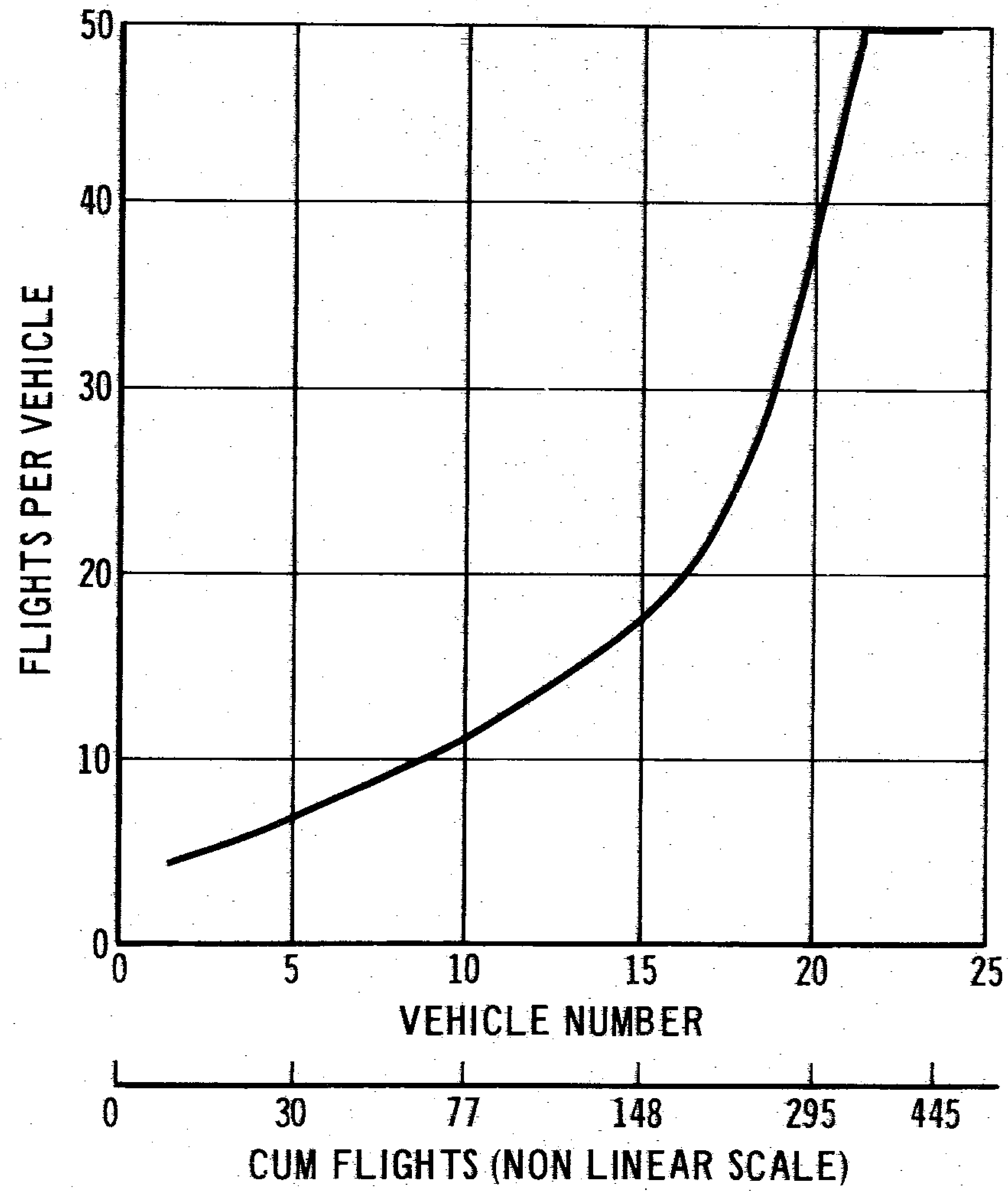
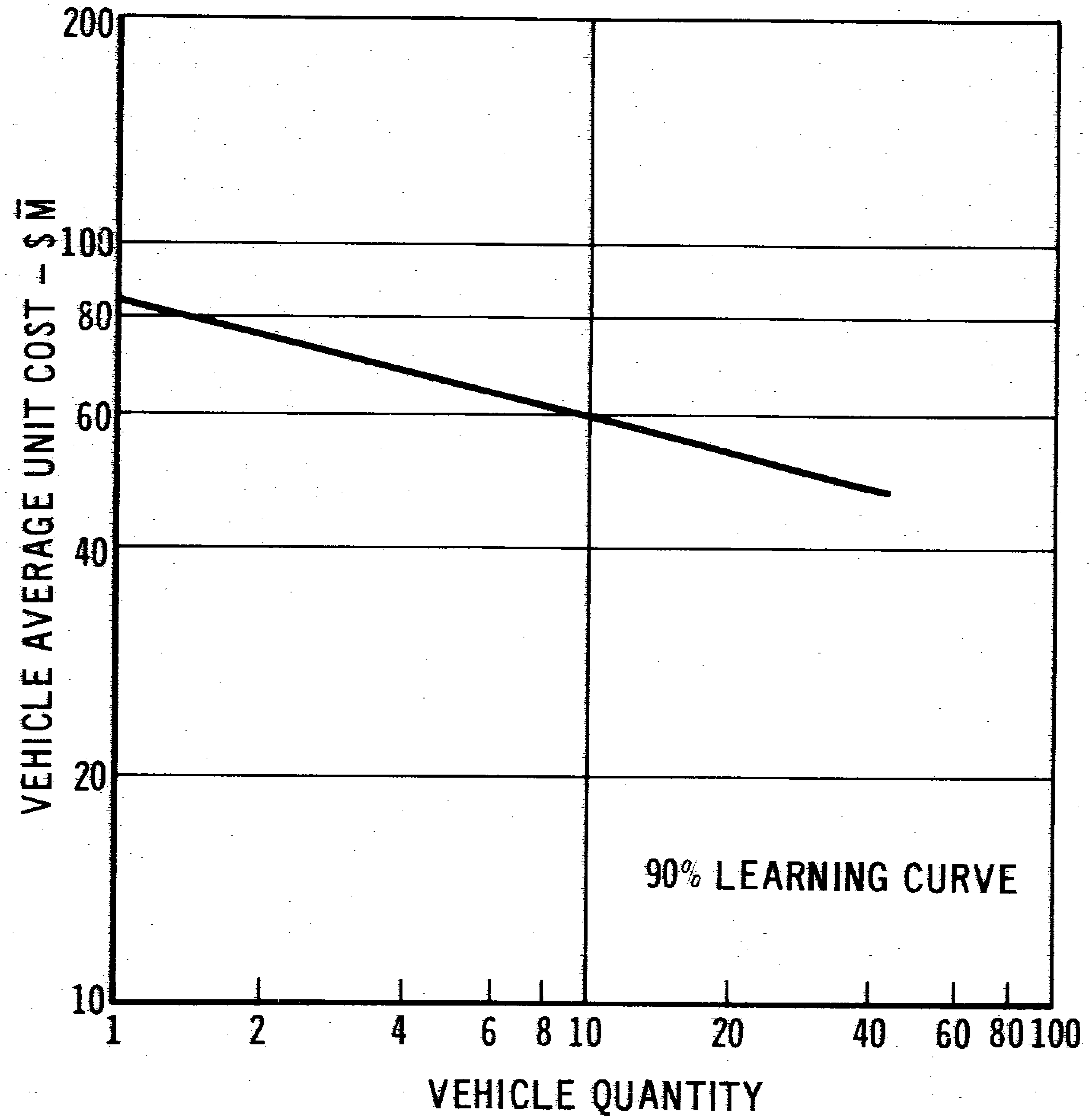
PRESSURE FED BOOSTER COSTING ASSUMPTIONS





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IMPACT OF ALTERNATE COSTING GROUND RULES

MILLIONS OF 1970 DOLLARS

	SERIES PRESSURE FED				TWIN PARALLEL SRM			
BASELINE FIRST HORIZONTAL 9–76 P.F. BOOSTER INVENTORY 23 (5 RDT&E, 18 PRODUCTION) PEAK TRAFFIC 60 FLIGHTS YEAR	TOTAL PROGRAM RDT&E PAF S/FLIGHT			10,798 5,676 1,263(76) 7.50	TOTAL PROGRAM RDT&E PAF S/FLIGHT			10,207 4,126 0.946 (76) 10.49
EARLY HORIZONTAL FLIGHT 12–75	TOTAL PROGRAM RDT&E PAF S/FLIGHT			10,818 5,696 1,283(76) 7.50	TOTAL PROGRAM RDT&E PAF S/FLIGHT			10,227 4,146 0.966 (76) 10.49
PRESSURE FED BOOSTER INVENTORY 6 TOTAL (2 RDT&E; 4 PRODUCTION)	TOTAL PROGRAM RDT&E PAF S/FLIGHT (NO BOOSTER AMORTIZATION)			9,811 5,484 1,213(76) 6.02	NOT APPLICABLE			
PEAK TRAFFIC (FLIGHTS YEAR)		OPS + TANKS	BOOST.	TOTAL		OPS + TANKS	BOOST.	TOTAL
10	S/FLIGHT	9.30	4.68	13.98	S FLIGHT	8.45	6.80	15.25
20	S/FLIGHT	7.50	4.03	11.53	S FLIGHT	6.70	6.10	12.80
40	S/FLIGHT	6.30	2.40	8.70	S/FLIGHT	5.50	5.60	11.10
60	S FLIGHT	6.02	1.48	7.50	S/FLIGHT	5.29	5.20	10.49

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COMPARISON OF MAIN EMPHASIS SYSTEMS

	BURN MODE	SERIES		PARALLEL	
	ENGINE	PRESS. FED	F-1	2-156" SRM	2-156" SRM
	BAY SIZE	15 x 60	15 x 60	15 x 60	14 x 45
STAGING VELOCITY (FPS)		4000	5000	4000	4000
WEIGHTS (K LB)					
PAYLOAD (EAST)		65.0	65.0	65.0	45.0
GLOW		5777.6	4458.3	4315.2	3617.4
OLOW		1512.2	1341.7	1898.6	1691.2
USABLE PROPELLANT		1196.6	1031.2	1577.9	1407.7
ORBITER DRY		148.8	148.8	148.8	139.1
TANK DRY		58.1	53.5	64.8	60.3
BLOW		4265.4	3116.5	2416.5	1926.2
USABLE PROPELLANT		3436.9	2687.3	2 x 1,064.5	2 x 848.5
BOOSTER DRY		734.9	372.3	(2 x 143.8)	(2 x 114.6)
$(T/W)_1/(T/W)_2$		1.35/0.934	1.35/1.053	1.405/0.927	1.405/1.071
COSTS ($\bar{M}$)					
TOTAL PROGRAM		10,798	10,002	10,207	9,681
RDT&E		5,676	5,018	4,126	4,006
PEAK FUNDING (YEAR)		1,263(76)	1,135 (76)	946 (76)	917 (76)
PER FLIGHT (TOTAL)		7.50	7.56	10.49	9.83
OPERATIONS		4.65	5.17	3.80	3.78
TANKS		1.37	1.28	1.49	1.41
EXPENDED BOOSTER HARDWARE		1.48	1.11	5.20	4.64

ALL CONFIGURATIONS HAVE 3-470 K HiPc ORBITER ENGINES

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OVERVIEW OF CONCEPT SIZES & COSTS

		SERIES BURN				PARALLEL BURN	
	BOOSTER	LIQUID			SOLID CLUSTER	TWIN LIQUID	TWIN SOLID
	MATING	TEL			TEL	TSL	TSL
	ENGINE SYSTEM	6/PF	4/F-1	10/HiPc	3-156"	2x6/PF	2-156"
LARGE ORBITER 15 x 60	GLOW (K LB)	5,777	4,458	3,144	4,539	4,800	4,315
	RELATIVE STAGE V (FPS)	4,000	5,000	5,000	4,000	4,000	4,000
	COSTS ($M)						
	TOTAL PROGRAM	10,798	10,002	10,599	11,335	9,980	10,207
	RDT&E	5,676	5,018	5,217	4,215	4,948	4,126
	PER FLIGHT	7.50	7.56	7.91	12.58	7.47	10.49
SMALL ORBITER 14 x 45				(9/HiPc)			
	GLOW (K LB)	5,000	3,485	2,760	3,886	3,917	3,617
	RELATIVE STAGE V (FPS)	4,000	5,000	5,000	4,000	4,000	4,000
	COSTS ($M)						
	TOTAL PROGRAM	10,351	9,800	10,272	10,788	9,404	9,681
	RDT&E	5,432	4,904	5,066	4,081	4,676	4,006
	PER FLIGHT	7.23	7.44	7.73	11.76	7.07	9.83

TEL = HO TANK END LOADED; TSL = HO TANK SIDE LOADED BY BOOSTERS
ALL CONFIGURATIONS HAVE 3-470 K HiPc ORBITER ENGINES

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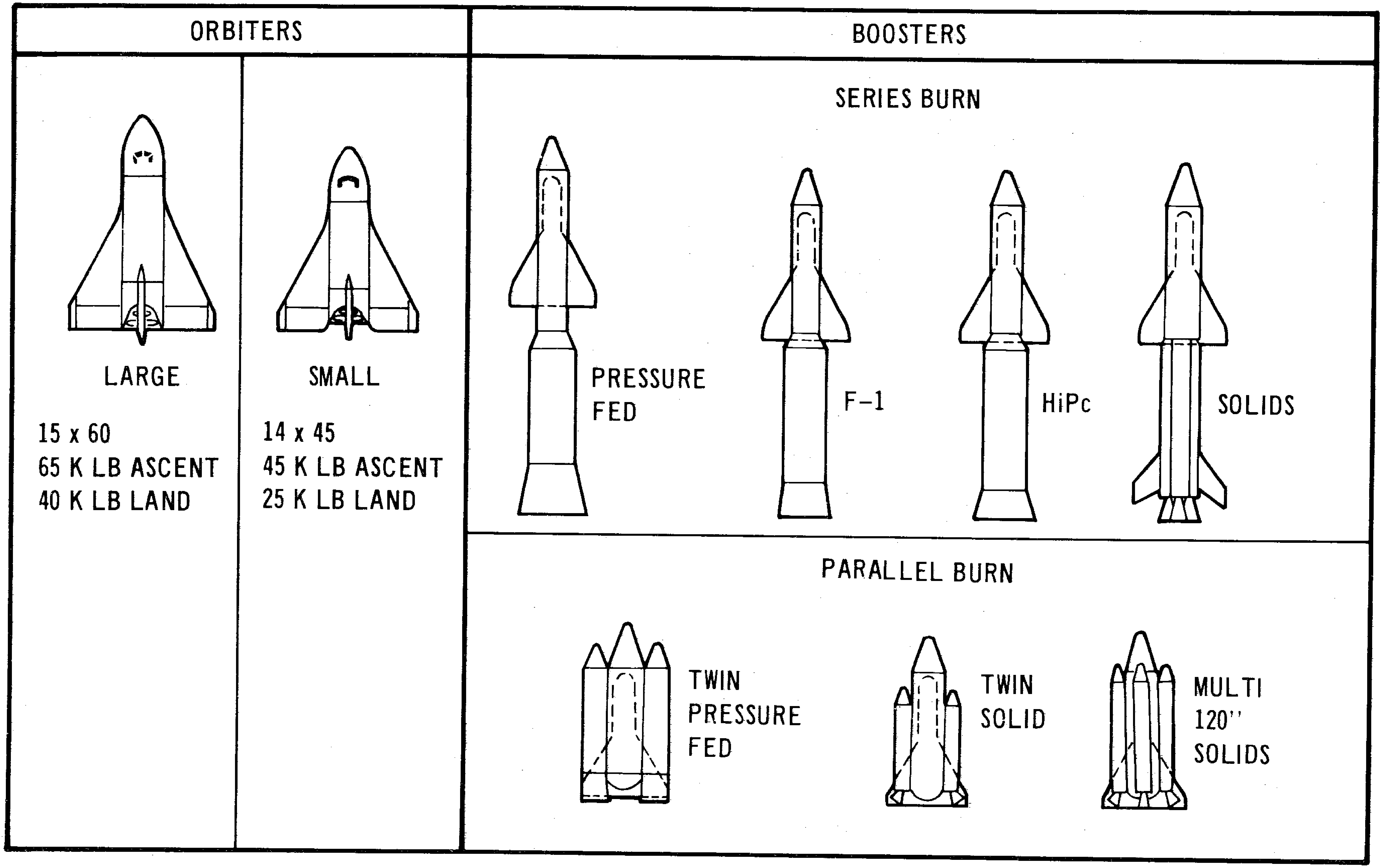
SHUTTLE SYSTEM CONCEPTS



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AGENDA

INTRODUCTION

KEY ISSUES

- SYSTEM COST COMPARISONS
- PAYLOAD SIZE AND WEIGHT
- ASCENT CONTROL
- ALTERNATE SERIES LIQUID BOOSTER SYSTEMS
- ALTERNATE PARALLEL SOLID BOOSTER SYSTEMS
- MASS FRACTION UNCERTAINTY IMPACT
- SYSTEM DESIGN OPTIMIZATION
- ABORT AND SEPARATION
- SERIES vs PARALLEL BURN
- RISKS

SYSTEM RECOMMENDATIONS

- ABORT
- ORBITER THRUST LEVEL
- BOOSTER SYSTEM SELECTION

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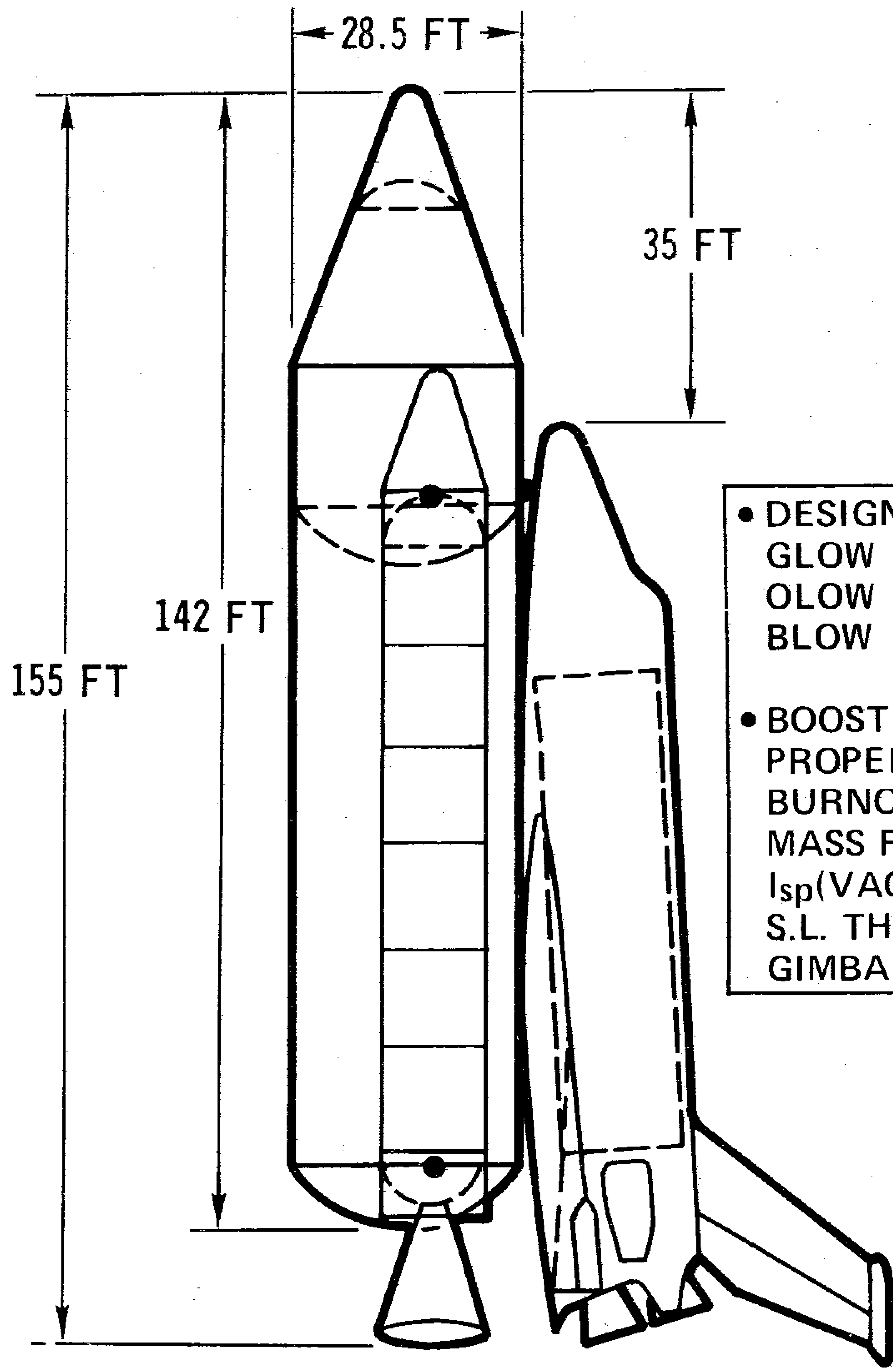
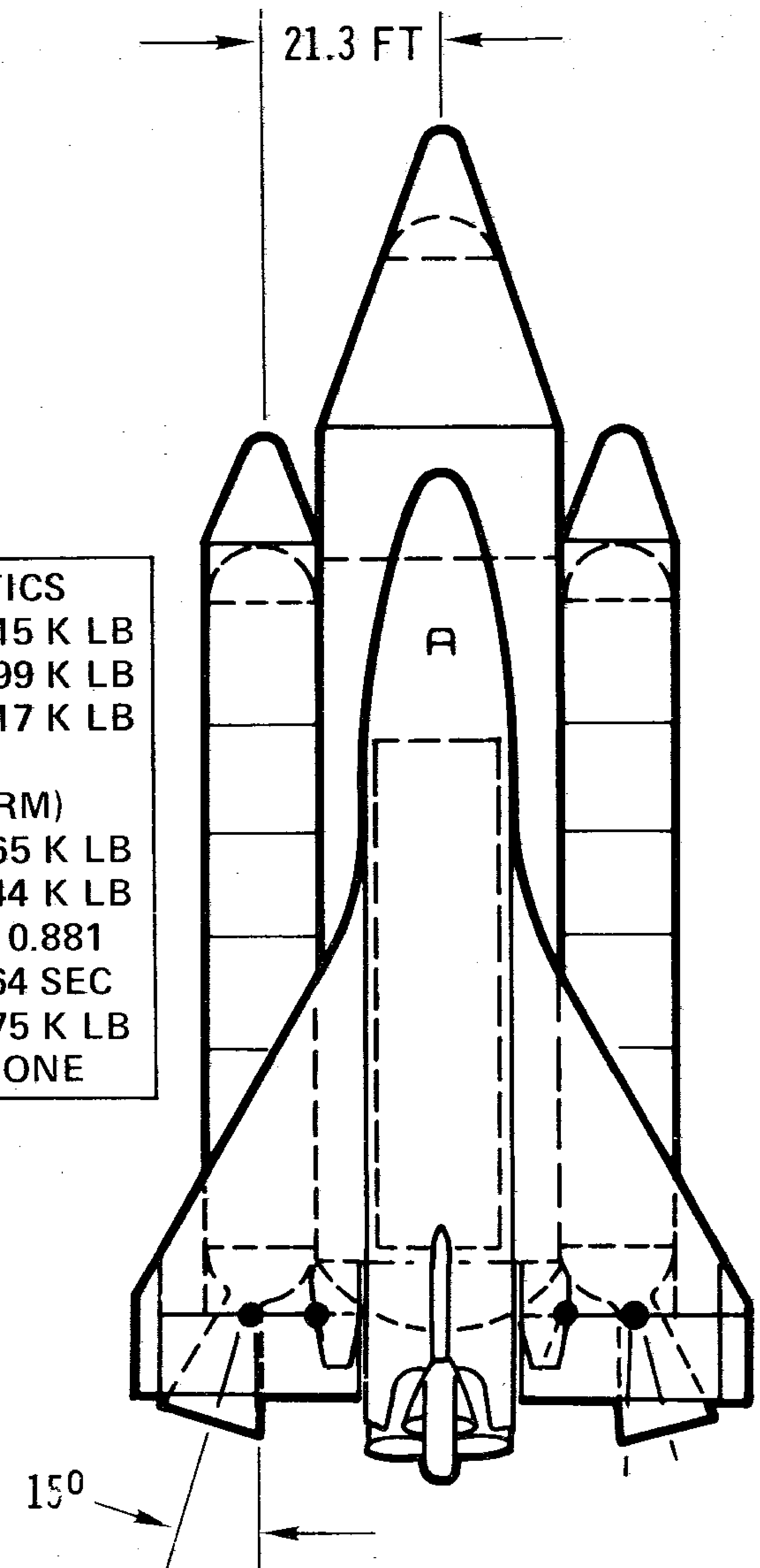
PARALLEL BURN CONFIGURATION

Twin–156 In. SRMs



• DESIGN CHARACTERISTICS	
GLOW	4,315 K LB
OLOW	1,899 K LB
BLOW	2,417 K LB
• BOOSTER DATA (PER SRM)	
PROPELLANT WT	1,065 K LB
BURNOUT WT	144 K LB
MASS FRACTION	0.881
I_{sp}(VAC)	264 SEC
S.L. THRUST	2,575 K LB
GIMBAL ANGLE	NONE



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SOLID-ROCKET PARALLEL-BURN SYSTEMS COMPARISON

BAY SIZE	15 x 60			14 x 45	
BOOSTER	2-156 IN.	4-120 IN.	5-120 IN.	2-156 IN.	4-120 IN.
WEIGHTS (K LB)					
PAYLOAD (EAST)	65.0	65.0	65.0	45.0	45.0
GLOW	4315.2	4662.4	5246.1	3617.4	4382.2
OLOW	1898.6	1853.1	1733.8	1691.2	1572.4
USABLE PROPELLANT	1577.9	1533.8	1417.7	1407.7	1292.3
ORBITER DRY	148.8	148.8	148.8	139.1	139.1
TANK DRY	64.8	63.5	60.6	60.3	57.2
BLOW	2416.5	2809.8	3512.3	1926.2	2809.8
USABLE PROPELLANT	2 x 1064.5	4 x 607.4	5 x 607.4	2 x 848.5	4 x 607.4
BOOSTER INERT	(2 x 143.8)	(4 x 95.0)	(5 x 95.0)	(2 x 114.6)	(4 x 95.0)
COSTS ($M)					
TOTAL PROGRAM	10207	11826	12817	9681	11628
RDT&E	4126	4006	4021	4006	3906
PEAK FUNDING (YR)	946(76)	922(76)	975(81)	896(76)	887(76)
PER FLIGHT (TOTAL)	10.49	14.11	16.11	9.83	13.94
OPERATIONS	3.80	4.06	4.19	3.78	4.01
TANKS	1.49	1.47	1.42	1.41	1.35
EXPENDABLE BOOSTER HARDWARE	5.20	8.58	10.50	4.64	8.58

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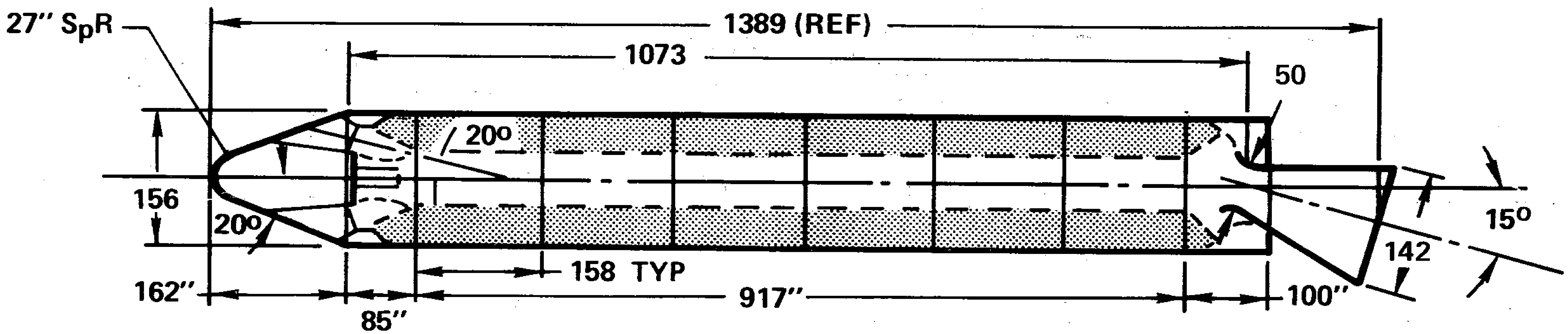
BOOSTER CHARACTERISTICS
PARALLEL 156 SRM CONFIGURATION

TT ROTATED 90 DEGREES



SRM CHARACTERISTICS	
PROP WT	1,058,700 LB
THRUST AT SL	2,575,000 LB
SPECIFIC IMPULSE, VAC	264 SEC (MIN)
NOZZLE EXPANSION RATIO	8
WEB/ACTION TIME	120/130 SEC
THRUST REGRESSIVITY	40%
MEOP	1,000 PSIA
TVC	NONE
CASE AND DOME MATERIAL	D6AC STEEL
YIELD STRENGTH	195,000 PSI
CASE YIELD/MEOP RATIO	1.25
PORT AREA/THROAT AREA	1.3

SRM STAGE WEIGHTS	
SOLID ROCKET MOTOR	118,470
AFT SKIRT AND LAUNCH STRUCTURE	8,630
TANK ATTACH AND SEPARATION	11,850
NOSE FAIRING & TUNNEL	900
THRUST TERMINATION	2,110
AVIONICS	310
GROWTH/UNC	7,280
TOTAL INERT WT	149,550
PROPELLANT	1,058,700
TOTAL WT	1,208,250
EXPENDED PROP AND INSUL	1,064,500
BURNOUT WT	143,756
$\lambda' = \frac{\text{EXPENDED MASS}}{\text{BLOW}}$	0.881

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BOOSTER RDT&E COST COMPARISON
TWIN PARALLEL BURN (156 IN. SRMs)
$M (1970)

	UTC	AEROJET	LOCKHEED PROPULSION	THIOKOL	MDAC	MDAC (BASELINE)
PROPELLANT WT/SRM (M LB)	1.245	1.000	1.231	1.200	1.230	1.059
STAGE HARDWARE	INCL	INCL	INCL	INCL	INCL	INCL
TVC	YES	YES	YES	YES	YES	NO
THRUST TERMINATION	YES	YES	YES	YES	YES	YES
STATIC FIRING (NO.)	12	8	9	10	12	11
FLIGHTS (HARDWARE) (NO.)	6	6	6	6	6	5
RDT&E COST						
SRM	151.8	~83.1	133.5	NA	190.4	153.4
STAGE	19.6	~28.1	48.2	NA	157.1	105.1
SUBTOTAL	171.4	111.2	181.7	118.2	347.5	258.5
FACIL (DEV/PROD)	69.0	112.4	91.2	118.0	66.7	57.0
TOTAL	240.4	223.6	272.9	236.2	414.2	315.5

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BOOSTER INVESTMENT COST COMPARISON

1-398 A

Twin Parallel Burn (156 in. SRMs)

	UTC	AEROJET	LOCKHEED PROPULSION	THIOKOL	MDAC	MDAC (BASELINE)
PROPELLANT WT/SRM	1.245	1.000	1.230	1.200	1.230	1.059
TVC	YES	YES	YES	YES	YES	NO
FLIGHTS, HARDWARE QUANTITY	439	440	440	440	440	440
LAUNCH RATE/YEAR	60 MAX	60 MAX	60 MAX	60 MAX	60 MAX	60 MAX
INVESTMENT COST						
SRM	1825.6	1424.7	2377.0	NA	2148.8	1870.5
STAGE	665.5	413.4	620.1	NA	797.8	547.7
TOTAL	2491.1	1838.1	2997.1	2455.8	2946.6	2418.2
(AVERAGE/FLIGHT)	(5.68)	(4.18)	(6.81)	(5.58)	(6.70)	(5.50)

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BOOSTER COSTS
PARALLEL 156 SRM CONFIGURATION

1970 $M

	SRM	STAGE	TOTAL
DDT&E			
DESIGN, DEVELOPMENT & TEST	20.0	26.6	46.6
GROUND TEST HARDWARE (11 STATIC FIRINGS)	37.7	5.7	43.4
FLIGHT TEST HARDWARE (5 FLIGHTS)	35.9	14.0	49.9
GSE	9.3	5.8	15.1
TOOLING	38.6	33.0	71.6
PROJECT MANAGEMENT, SYSTEM ENGR, & SUPPORT	11.9	20.0	31.9
SUBTOTAL	153.4	105.1	258.5
FLT TEST SUPPORT	–	–	7.0
FACILITIES – DEVELOPMENT	0*	0*	0
FACILITIES – PRODUCTION	57.0	0*	57.0
TOTAL	210.4	105.1	315.5
INVESTMENT (AVG COST 440 FLTS)			
10 PER YEAR BOOSTER PAIR	4.9	1.8	6.7
20 PER YEAR BOOSTER PAIR	4.5	1.5	5.7
40 PER YEAR BOOSTER PAIR	4.2	1.3	5.5
60 PER YEAR BOOSTER PAIR	4.1	1.2	5.3

NOTE – BASED ON PROP. WT OF 1,058,700 LB PER SRM

*ASSUMED AVAILABLE

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TRW SYSTEMS GROUP

ENVIRONMENTAL EFFECTS OF SOLID BOOSTERS

- CONCERN — HCl CONCENTRATION, DISPERSION & POTENTIAL TOXICITY (CO & Al_2O_3 CONSIDERED TO BE NON-HAZARDOUS BUT MAY BE A NUISANCE FACTOR)
- DATA SOURCES — MSFC, THIOKOL, GCA
- BASIS OF DATA — WORST ATMOSPHERE CONDITIONS –
  ON-SHORE BREEZE & TEMPERATURE INVERSION
  CONCENTRATION MEASURED AT GROUND LEVEL –
  KNOWN MIXING ACTION EXISTS TO TOP OF BOUNDARY LAYER
- CURRENT CONCLUSIONS
  - NORMAL LAUNCH ASCENT TRAJECTORY
    FOR WINTER LAUNCH OR SUMMER NIGHT LAUNCH:
    - NO SIGNIFICANT HCl HAZARD

    FOR SUMMER DAY LAUNCH:
    - POTENTIAL HCl HAZARD
      - LAUNCH IN RAIN, MIST OR NEAR-PRECIPITANT CONDITIONS
      - CONDITIONS MAY OCCUR FOR 10–20% OF KSC SUMMER DAYS
  - ABORTED LAUNCH (HELD DOWN FOR FULL SRM BURN) POTENTIAL HAZARD
    EXCEEDS FOR SOME PERIOD 5 PPM 24–HOUR MAN EXPOSURE ALLOWABLES
    TIED-DOWN ABORT HAS LOW PROBABILITY
    DOES NOT EXCEED 30 PPM 10–MINUTE MAN EXPOSURE ALLOWABLE

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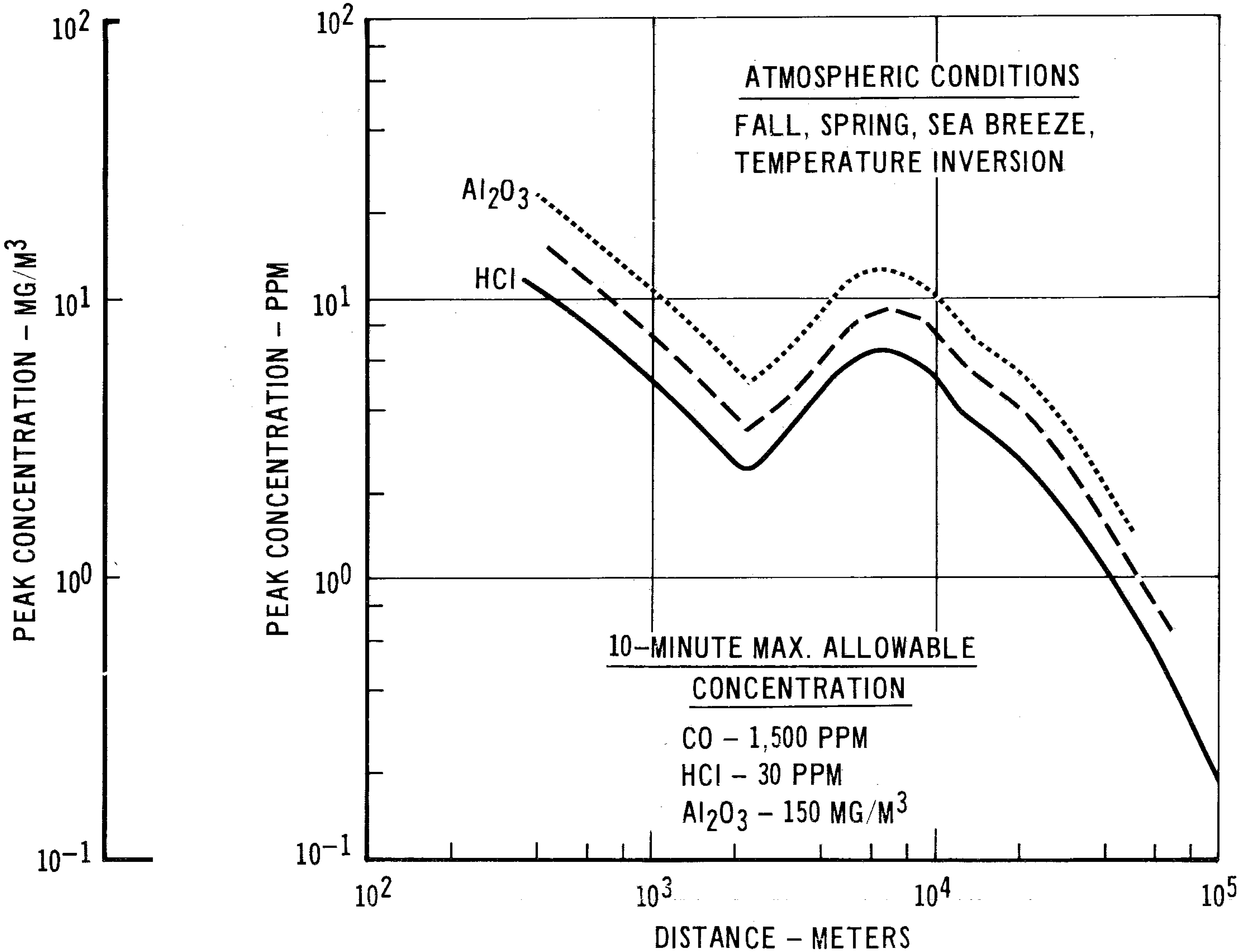
TRW SYSTEMS GROUP

PEAK CONCENTRATION (HCl, CO, AND Al_2O_3)

Downwind, Pad Abort



REFERENCE: THIOKOL/GCA

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RECOVERABLE SRMs

- **RECOVERY SYSTEM**

  24-FT DIA BALLUTE DEPOYED AT STAGING – STABILIZES VEHICLE & REDUCES TERMINAL VELOCITY TO 395 FPS

  RETROCKETS WITH SUSTAINER FIRED AT 470 FT BY RADAR ALTIMETER – DESIGN SPLASHDOWN V = 35 FPS

- **SRM WEIGHT INCREMENTS (EACH) – LB**

BALLUTE	2,000
RETROROCKETS	15,000
STRUCTURAL BEEF-UP	7,000
U/G	700
MOTOR RESIZING	500
	25,200
PROPELLANT	37,300
TOTAL	62,500

- Δ GLOW 125,000

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RECOVERABLE SRM COST ANALYSIS

- GROUNDRULES

USES PER SRM	10
BALLUTE USES	1

- REFURBISHMENT COST ASSUMPTIONS (% STAGE COSTS)

CASE	10	AVG 64.5 % OF RECURRING COST
NOZZLE	90	
OTHER SRM HARDWARE	100	
PROPELLANT	100	
STAGE STRUCTURE & SYSTEMS	20	

- COST SUMMARY

BOOSTER	EXPENDABLE SRMs	RECOVERABLE SRMs
	MILLIONS OF DOLLARS	
RDT&E		
SRM / STAGE STRUCTURE	259	264
RECOVERY SYSTEM	0	37
TOTAL	259	301
OPERATIONAL HARDWARE		
STAGES	2418	581
REFURBISHMENT	0	1181
MISC CHANGES (e.g. PROGRAM MANAGEMENT, RECOVERY)	0	−32
TOTAL BOOSTER	2677	2031
PROGRAM		
TOTAL PROGRAM	10,207	9561
RDT&E	4126	4172
PAF YEAR	946 (76)	948 (76)
PER FLIGHT (TOTAL)	10.49	9.16
OPERATIONS	3.80	3.80
TANKS	1.49	1.49
EXPENDED BOOSTER HARDWARE	5.20	3.87

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SRM FLIGHT STATISTICS

VEHICLE	MOTOR FIRINGS	FAILURES	HUMAN ERROR	CASE BURNTHROUGH	NOZZLE FAILURES	ORDNANCE AUTO-IGN.
THOR, STRAP-ONS	486	1	1	–	–	–
TITAN, STRAP-ONS	34	0	–	–	–	–
MINUTEMAN	1298	11	4	4	1	2
SCOUT	310	5	1	1	3	–
TOTAL	2128	17	6	5	4	2

FAILURE CAUSE	SHUTTLE APPLICABILITY	SHUTTLE PREDICTION WITH DESIGN IMPROVEMENT
DESIGN DEFICIENCY		
5–CASE BURNTHROUGH	5	0
4–NOZZLE FAILURES	2	0
2–ORDNANCE AUTO-IGNITION	2	0
HUMAN ERROR		
1–MANUFACTURING	1	1
4–WORKMANSHIP	3	3
TOTAL	13	4

RELIABILITY (BASED ON APPLICABLE FAILURES) = 2111/2124 = 0.9939

INCORPORATION OF PROPOSED REMEDIES SHOULD INCREASE THE DEMONSTRATED RELIABILITY TO 2120/2124 = 0.9981

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SOLID ROCKET MOTOR FAILURE HISTORY ASSESSMENT

QUANTITY	PROBLEM	REMEDY	SHUTTLE ABORT CONSIDERATION
5	CASE BURNTHROUGH 1 – SCOUT 3RD STAGE 1 – MINUTEMAN 1ST STAGE 3 – MINUTEMAN 3RD STAGE	INCREASE CASE INSULATION THICKNESS; USE TWO "O" RINGS BETWEEN SEGMENTS.	IF BURNTHROUGH OCCURS ADJACENT TO HO TANK OR ORBITER, TIMELY SENSING MAY NOT BE FEASIBLE AND ABORT NOT POSSIBLE.
4	NOZZLE BURNTHROUGH/EROSION 1 – SCOUT 1ST STAGE NOZZLE BURNTHROUGH	INCREASE NOZZLE INSULATION THICKNESS.	ABORT REQUIRED, TERMINATE THRUST IN BOTH SRMs.
	1 – SCOUT 4TH STAGE – GRAPHITE THROAT FRACTURED, PLUGGED THROAT & CAUSED CATASTROPHIC CASE RUPTURE.	–	GRAPHITE THROAT MATERIAL NOT USED IN LARGE MOTORS. NOT APPLICABLE.
	1 – SCOUT 4TH STAGE – ONLY 1/2 TOTAL IMPULSE DELIVERED, CAUSE UNKNOWN; POSSIBLY CAUSED BY THROAT EJECTION AND RESULTING PROPELLANT EXTINGUISHMENT.	–	GRAPHITE THROAT MATERIAL NOT USED IN LARGE MOTORS. NOT APPLICABLE.
	1 – MINUTEMAN 2ND STAGE NOZZLE BURNTHROUGH FOLLOWING INNER SHELL EJECTION RESULTING FROM POOR BONDING.	TIGHTEN QUALITY CONTROL & INSPECTION PROCEDURES.	ABORT REQUIRED, TERMINATE THRUST IN BOTH SRMs.

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SOLID ROCKET MOTOR
FAILURE HISTORY ASSESSMENT
(Continued)

QUANTITY	PROBLEM	REMEDY	SHUTTLE ABORT CONSIDERATION
2	AUTO IGNITION OF THRUST TERMINATION ORDNANCE 2 – MINUTEMAN 3RD STAGE	PROVIDE AMPLE INSULATION.	MUST PROVIDE SENSING SYSTEM AND THRUST TERMINATE REMAINING SRM; DEGRADED MISSION MAY BE POSSIBLE.
5	HUMAN ERRORS. 1 – SCOUT 1ST STAGE WRONG PHENOLIC USED IN THROAT OVERWRAP DEGRADED MISSION RESULTED.	TIGHTENED QUALITY CONTROL AND IMPROVED INSPECTION PROCEDURES.	ABORT NOT REQUIRED – ACCEPT DEGRADED MISSION
	1 – MINUTEMAN 1ST STAGE SHIPPING PARTS NOT REMOVED. EXIT CONE BURNTHROUGH OCCURRED.	TIGHTENED QUALITY CONTROL AND IMPROVED INSPECTION PROCEDURES	PECULIAR TO SWIVEL NOZZLE DESIGN – THEREFORE <u>NOT APPLICABLE</u>.
	1 – MINUTEMAN 2ND STAGE TVC GAS GENERATOR NOT ARMED.	TIGHTENED QUALITY CONTROL AND IMPROVED INSPECTION PROCEDURES.	PECULIAR TO MM TVC INSTALL – <u>NOT APPLICABLE</u>.
	2 – MINUTEMAN 3RD STAGE IGNITION FAILURE – SQUIB NOT CONNECTED THRUST TERMINATOR SNAP RING INSTALLED INPROPERLY RESULTING IN PREMATURE MISSION TERMINATION.	TIGHTENED QUALITY CONTROL AND IMPROVED INSPECTION PROCEDURES.	ABORT BY HOLDING DOWN. REDUNDANT IGNITION SYSTEMS SHOULD BE USED

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SOLID ROCKET MOTOR FAILURE HISTORY ASSESSMENT (Continued)

QUANTITY	PROBLEM	REMEDY	SHUTTLE ABORT CONSIDERATION
	HUMAN ERRORS (Continued) 1 – THOR ON FIRST TAT LAUNCH THE ELECTRICAL PLUG TO ONE SRM WAS MATED BUT NOT LOCKED. LIQUID MOTOR IGNITION SHOCK DISCONNECTED THE PLUG.	RELOCATED PLUG TO PERMIT ADQUATE INSTALLATION & INSPECTION	ABORT BY HOLDING DOWN – REDUNDANT IGNITION SYSTEMS SHOULD BE USED.

MOL SRM MALFUNCTION DETECTION

MALFUNCTIONS

- PAD ABORT – SINGLE SRM IGNITION
- AFTER LIFT-OFF ABORT – DIVERGENT (INDUCED ANGULAR MOTION TO VEHICLE)
  - SINGLE SRM BURNTHROUGH
  - LOSS OF TVC (TVC NULL)
  - NOZZLE FAILURES

  – NONDIVERGENT (NO INDUCED ANGULAR MOTION TO VEHICLE)
  - MALFUNCTIONS CAUSING NO IMMEDIATE PERFORMANCE LOSS
  - UPPER STAGE MALFUNCTIONS (LEAKS ETC.)

SENSING PROVISIONS

* – STAGE "0" INSTRUMENTATION FOR $\frac{\delta P}{\delta T}$ SENSING
– LONGITUDINAL ACCELEROMETER
– GUIDANCE QUALITY LIGHTS
– ABORT LIGHT
* – THRUST VECTOR CONTROL PRESSURE SENSING
– FLIGHT DIRECTOR SYSTEM
– EVENT TIMER
– INCREMENTAL VELOCITY INDICATOR
* – SRM HOT WIRE DISCONTINUITY
* – STAGE "0" PITCH & YAW OVER-RATE OR ROLL DIVERGENCE
* – SINGLE SRM IGNITION

*INDICATES DUAL-REDUNDANT ABORT DISCRETES SENT TO SPACECRAFT FROM SRM BOOSTER

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MOL SRM MALFUNCTION DETECTION
(Continued)

- OVERRATE SENSOR – RATE INDICATOR LIGHT TESTED AT 5.5°/SEC AND 8°/SEC OPTIMUM WAS BETWEEN THESE POINTS.

  FLIGHT DIRECTOR INDICATOR NEEDLES WERE CALIBRATED TO:
  - HIGH RANGE 10°/SEC (MARKED AT 8°)
  - LOW RANGE 5°/SEC
- ROLL OVERRATE – ROLL DIVERGENCE = 10°/SEC
- SRM HOT LINE (ABORT LIGHT)
  - TVC INJECTANT LEAK
  - NOZZLE BETWEEN AFT CLOSURE & THROAT
  - NOZZLE BETWEEN THROAT AND EXIT CONE
  - PREMATURE SEPARATION – ONE SRM
  - STRUCTURAL FAILURE OF PROPELLANT TANKS
- BREAK WIRES
  - SRM NOZZLE GRID FOR SINGLE IGNITION SENSING
  - IF ΔT BETWEEN GRIDS $> \approx$ .25 SEC THRUST TERMINATE
- MOL DESIGN EXPERIENCE SHOWED THAT –

  BURN THROUGH DETECTION NET IS INEFFECTIVE SAFETY MEASURE
  DESTRUCT SYSTEM (SHAPED CHARGE) AN ADDED HAZARD
  THESE SYSTEMS WERE DISCARDED

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SRM MALFUNCTION DETECTION

FAILURE MODE	CAUSE	DETECTION METHODS	PREVENTATIVE MEASURES	CONSEQUENT ACTIONS
NO IGNITION	• LOSS OF IGNITION SIGNAL • IGNITER MISFIRE, ETC	• CHAMBER PRESSURE • NOZZLE EXIT BURN WIRE	• REDUNDANT IGNITION SYSTEMS • HOLDDOWN UNTIL CHAMBER PRESSURE BUILDUP	HOLD DOWN ON PAD
CASE BURN THROUGH	• CRACKED PROPELLANT GRAIN • BONDING FAILURE • INSULATION DEFECT	• CHAMBER PRESSURE	• NDT INSPECTION OF GRAIN, LINER, BOND THROUGH X-RAY ULTRASONICS, ETC. • LIBERAL INSULATION DESIGN MARGINS	TERMINATE THRUST OF BOTH SRM's AND ABORT ORBITER
NOZZLE BURN THROUGH	• INSULATION OR BONDING FAILURE 'CRACK	• CONTROL SYSTEM' GUIDANCE MEASUREMENTS • CHAMBER PRESSURE	• NDT INSPECTION OF NOZZLE • LIBERAL INSULATION DESIGN MARGINS	TERMINATE THRUST OF BOTH SRM'S AND ABORT ORBITER
"O" RING LEAKAGE	• SEAL FAILURE AT SEGMENT JOINTS OR NOZZLE JOINT	• CHAMBER PRESSURE	• REDUNDANT SEALS • SEAL INTEGRITY CHECKED AFTER MOTOR ASSEMBLY	TERMINATE THRUST OF BOTH SRM's AND ABORT ORBITER
PREMATURE SEPARATION	• ATTACH STRUCTURE FAILURE • PREMATURE SIGNAL	• BREAK WIRE	• ADEQUATE MARGIN • ADEQUATE INTERLOCKS AND REDUNDANCY	TERMINATE THRUST OF REMAINING SRM AND ABORT ORBITER

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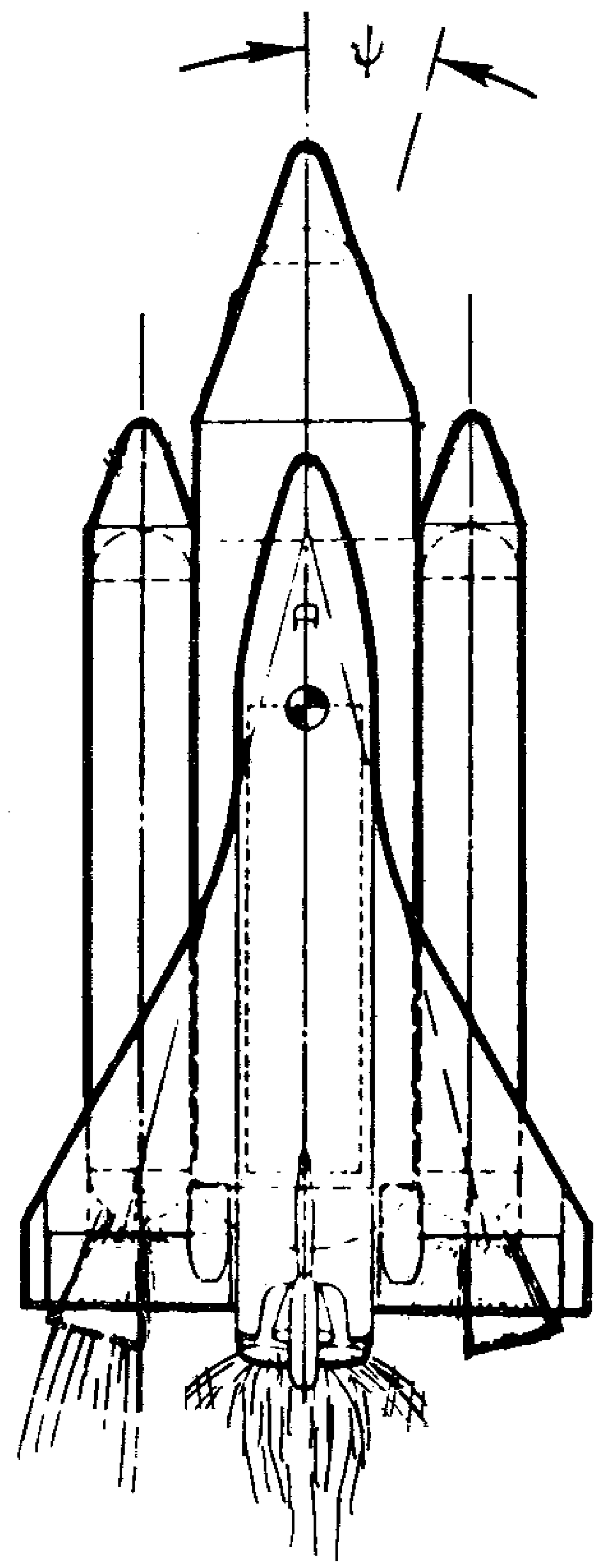
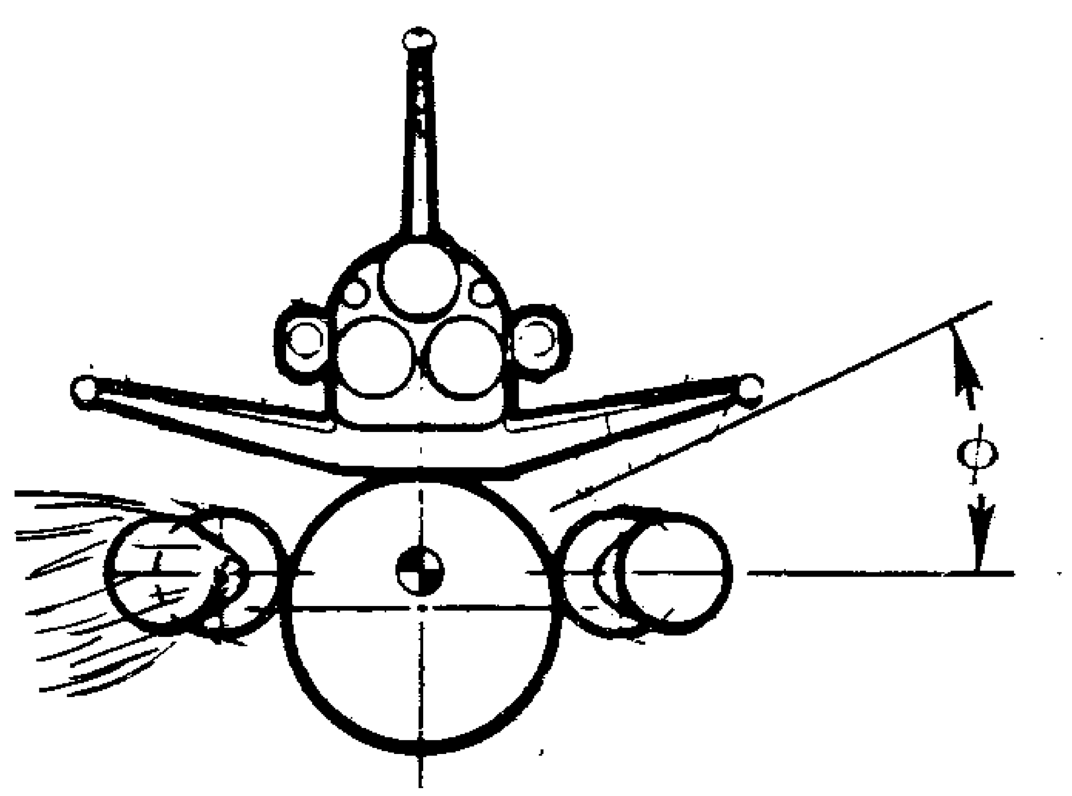
SHUTDOWN TRANSIENT MOTIONS





ABRUPT SHUTDOWN OF ONE SRM TEN SECONDS AFTER LIFTOFF

TIME AFTER SHUTDOWN (SEC)	ROLL		YAW	
	ϕ (DEG)	$\dot{\phi}$ (DEG/SEC)	ψ (DEG)	$\dot{\psi}$ (DEG/SEC)
0	0	0	0	0
1	0.3	2.0	1.0	2.5
2	3.5	6.0	4.0	3.2
3	10.0	10.5	7.2	3.6

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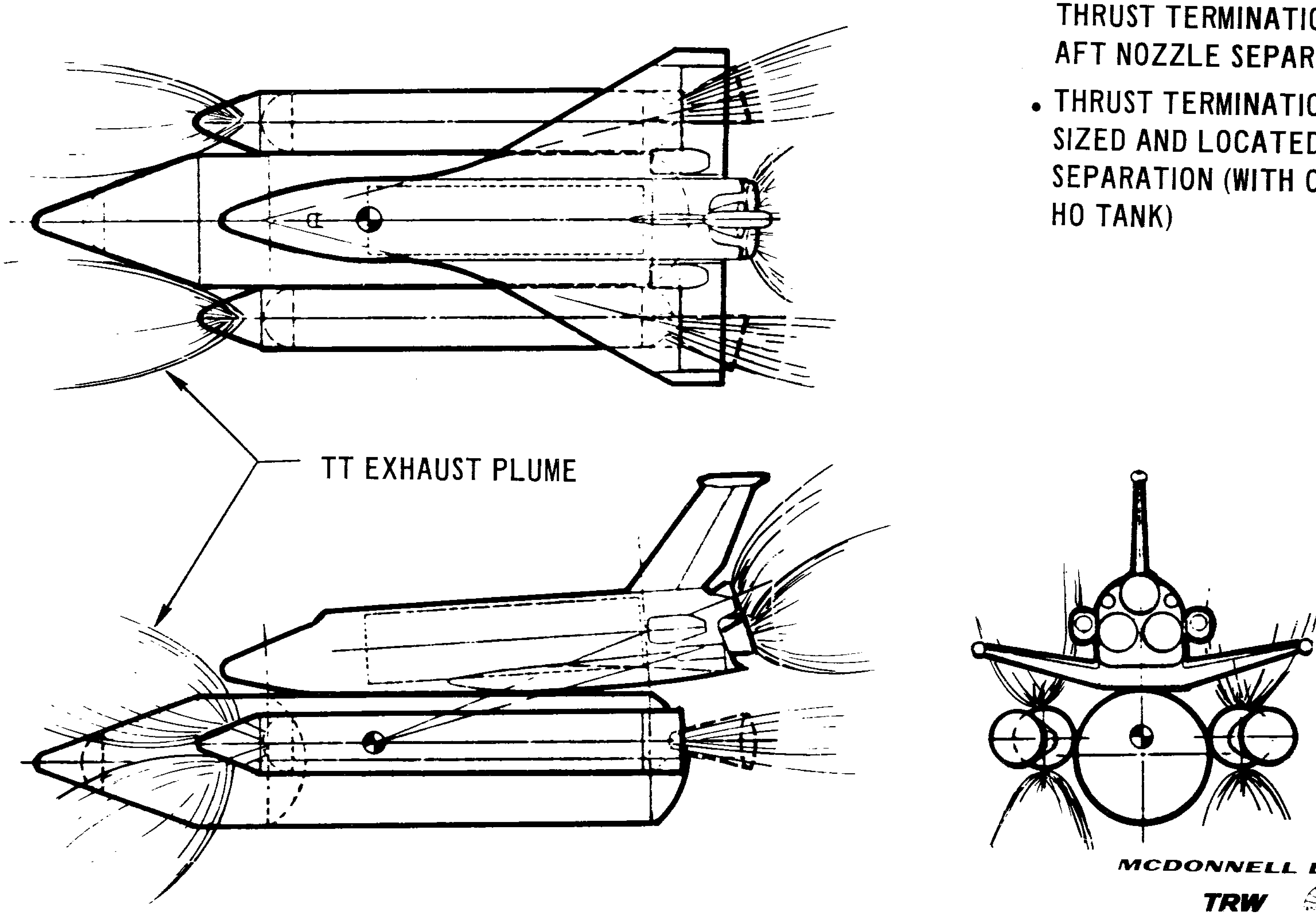
THRUST TERMINATION
PARALLEL 156 SRM CONFIGURATION

- ORDNANCE INITIATED FORWARD THRUST TERMINATION PORTS AND AFT NOZZLE SEPARATION
- THRUST TERMINATION PORTS SIZED AND LOCATED TO PROVIDE SEPARATION (WITH OR WITHOUT HO TANK)



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MASS FRACTION UNCERTAINTY ISSUE

ITEM	RESULTS
BOOSTER MASS FRACTIONS	• SERIES PRESSURE FED: $\lambda' = f$ (PROPELLANT & THRUST) $\simeq 0.806$ UNCERTAINTY $\Delta\lambda \pm 0.01$ PARALLEL SRM: $\lambda' = 0.881$ UNCERTAINTY $\Delta\lambda \simeq \pm 0.005$ IMPACT OF $-\Delta\lambda'$ UNCERTAINTY: Δ PROGRAM COST ($\bar{M}$) SERIES PRESSURE FED: + 195 — PARALLEL 156 IN. SRM: + 59
HO TANK MASS FRACTIONS	• TANK $\lambda' = f$ (PROPELLANT & CONFIGURATION) SERIES HO $\lambda' \simeq 0.952$ PARALLEL HO $\lambda' \simeq 0.960$ UNCERTAINTY $\Delta\lambda' \simeq -0.005; +0.002$ IMPACT OF $-\Delta\lambda'$ UNCERTAINTY: Δ PROGRAM COST ($\bar{M}$) SERIES PRESSURE FED: + 157 — PARALLEL 156 IN. SRM: + 227 • CONCLUSION: PRELIMINARY DESIGN UNCERTAINTIES WILL NOT REVERSE COMPARISON CONCLUSIONS

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SYSTEM DESIGN OPTIMIZATION ISSUES

ITEM	RESULTS
ORBITER THRUST LEVEL	• LARGE ORBITER – 470 K LB ENGINE AND 4,000 FPS V_S NEAR OPTIMUM PROGRAM COST • SMALL ORBITER – COULD REDUCE ENGINE THRUST TO 420 K LB SAVING $20 $\bar{M}$ PROGRAM COST – NOT SIGNIFICANT IMPROVEMENT.
STAGING VELOCITY	• 4,000 FPS FOR PRESSURE-FEDS AND SOLIDS: 5000 FPS FOR F–1 SERIES
LIFT-OFF T/W (SERIES BURN)	• PROGRAM COST $20 $\bar{M}$ CHEAPER AT $T/W_1 = 1.35$ THAN AT 1.25 • GROWTH ACCOMMODATION ALMOST DOUBLED WITH $T/W_1 = 1.35$
SYSTEM DESIGN	

SYSTEM DESIGN	SERIES BURN PRESSURE FED	PARALLEL TWIN 156 IN. SRM	SERIES F–1
LIFT-OFF T/W	1.35	1.40	1.35
STAGING VELOCITY (FPS)	4,000	4,000	5000
GROWTH CAPABILITY WITH +10% HO TANK & PROPELLANT SYSTEM U/G BEYOND 10%	3.6%	3.0%	3.8%

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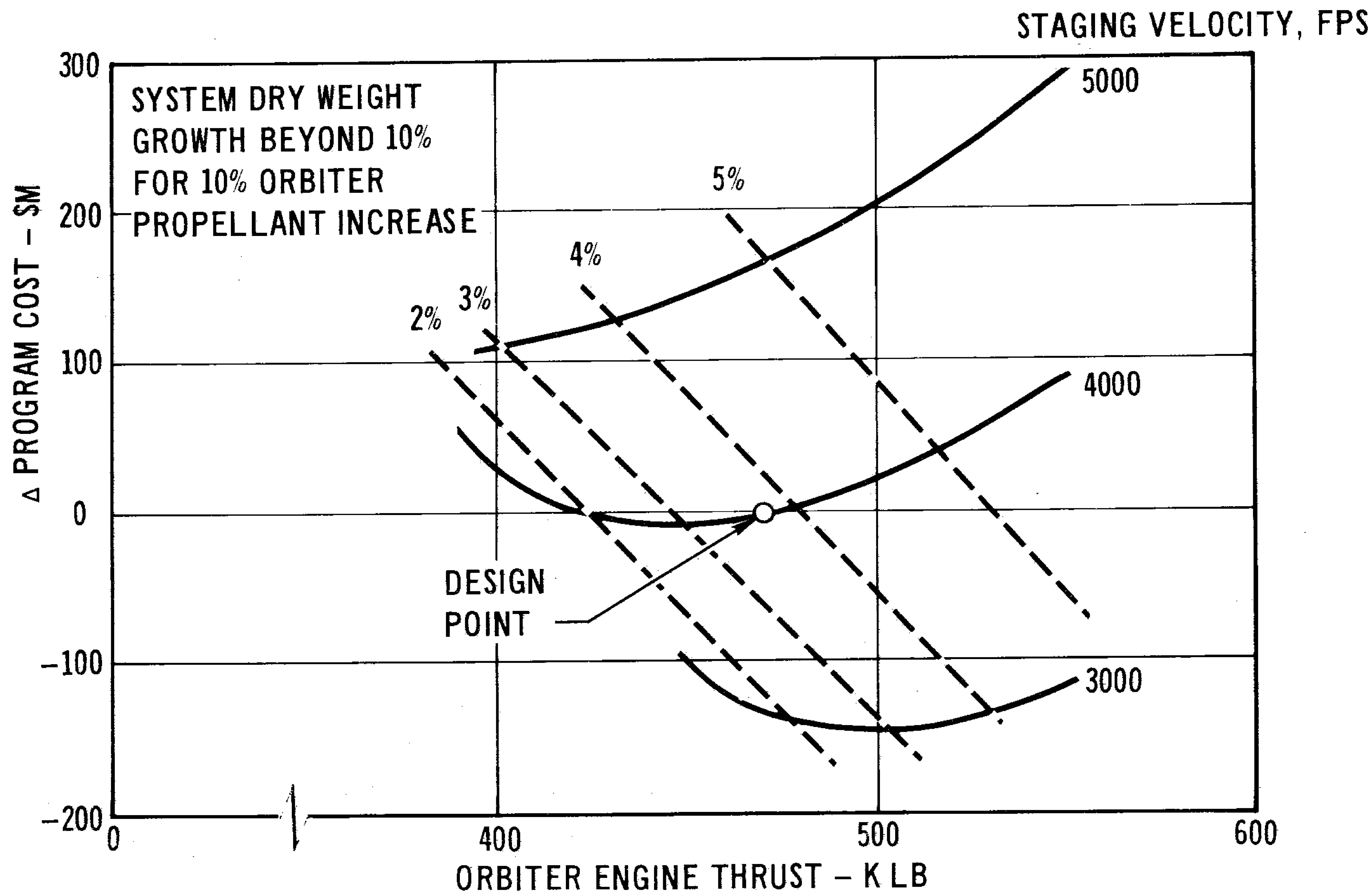
ORBITER THRUST SELECTION

15x60, 65 K LB, Series Burn

- PRESSURE FED BOOSTER
- 3 ORBITER ENGINES



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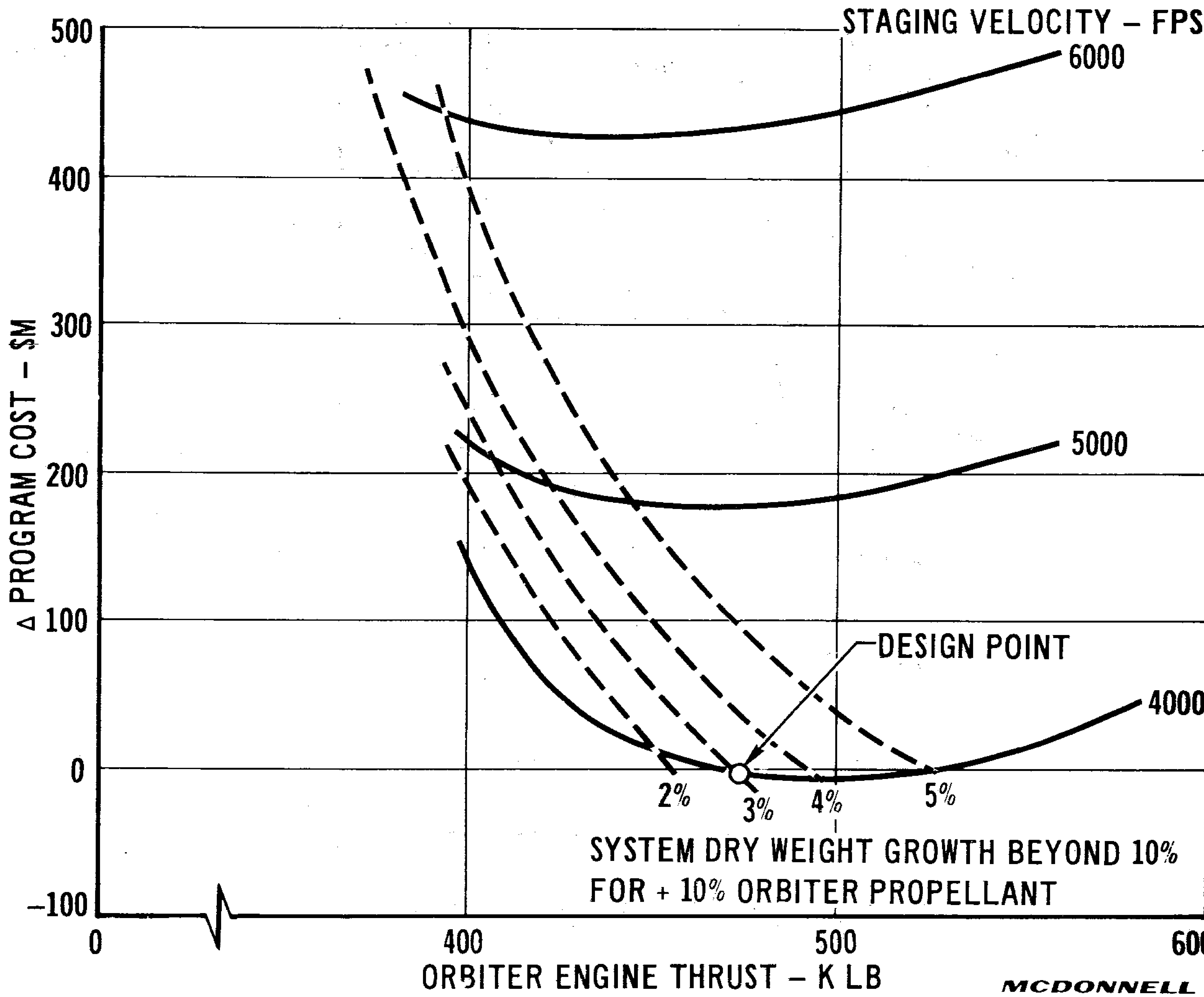
ORBITER THRUST SELECTION

15x60, 65 K LB, Parallel Burn

- 2–156 IN. SRMs
- 3 ORBITER ENGINES



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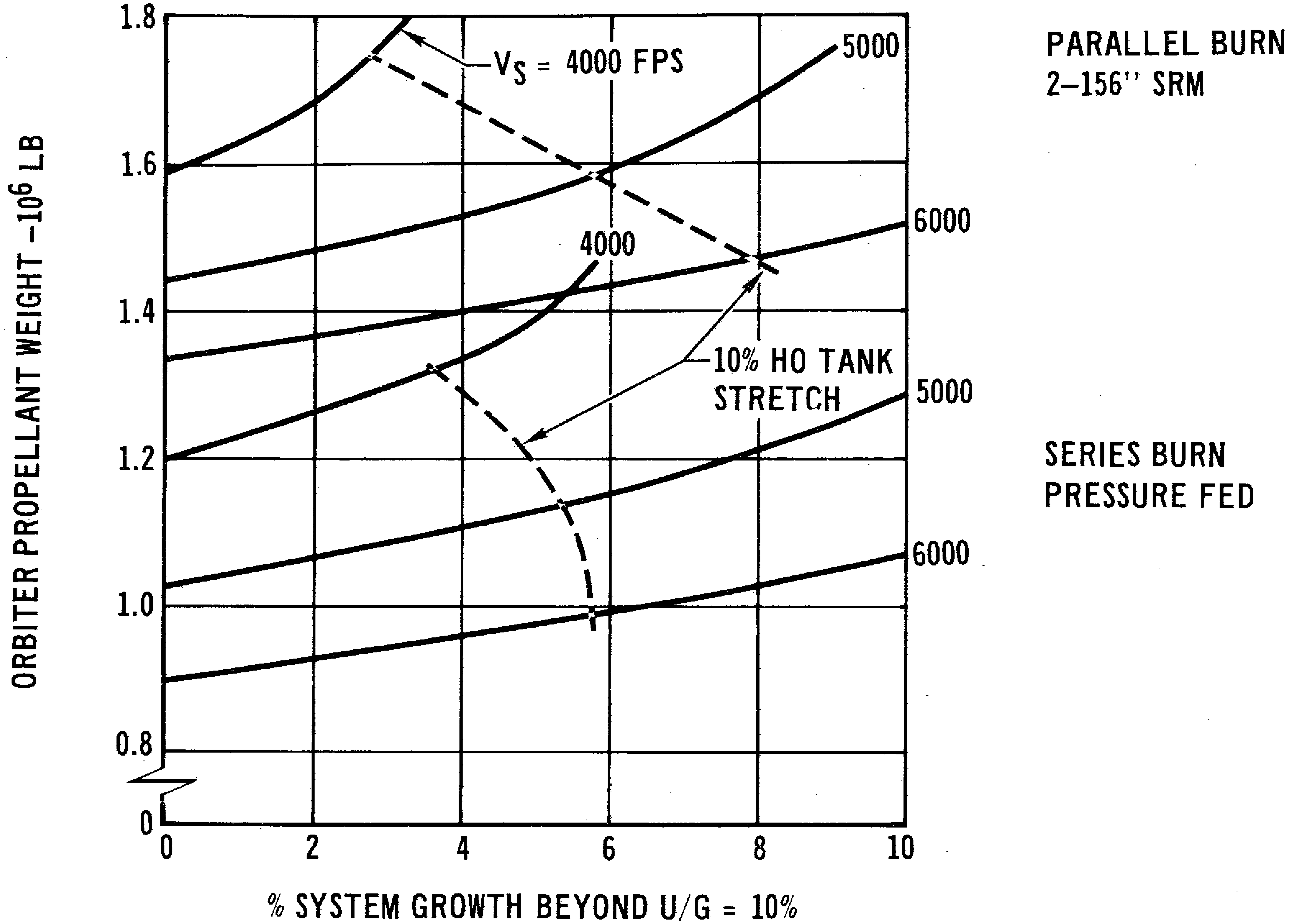
GROWTH ACCOMMODATION

• LARGE ORBITER 15' x 60' BAY



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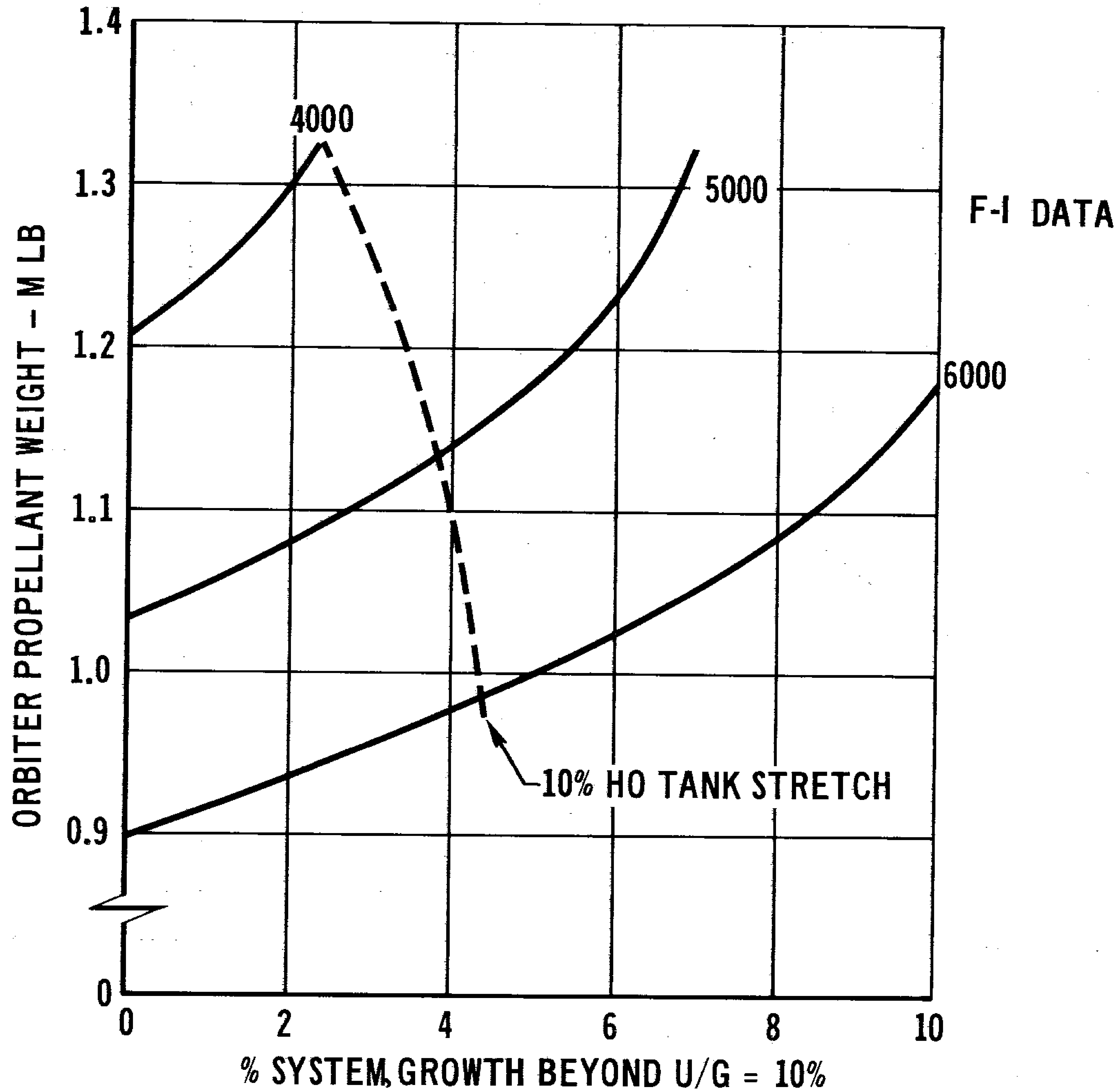
GROWTH ACCOMMODATION

PUMP FED SYSTEMS

• LARGE ORBITER 15' x 60' BAY



NOTE: 1% U/G ≃ 1,600 LB PAYLOAD (F–1 & HiPc) AT V_S = 5000 FPS

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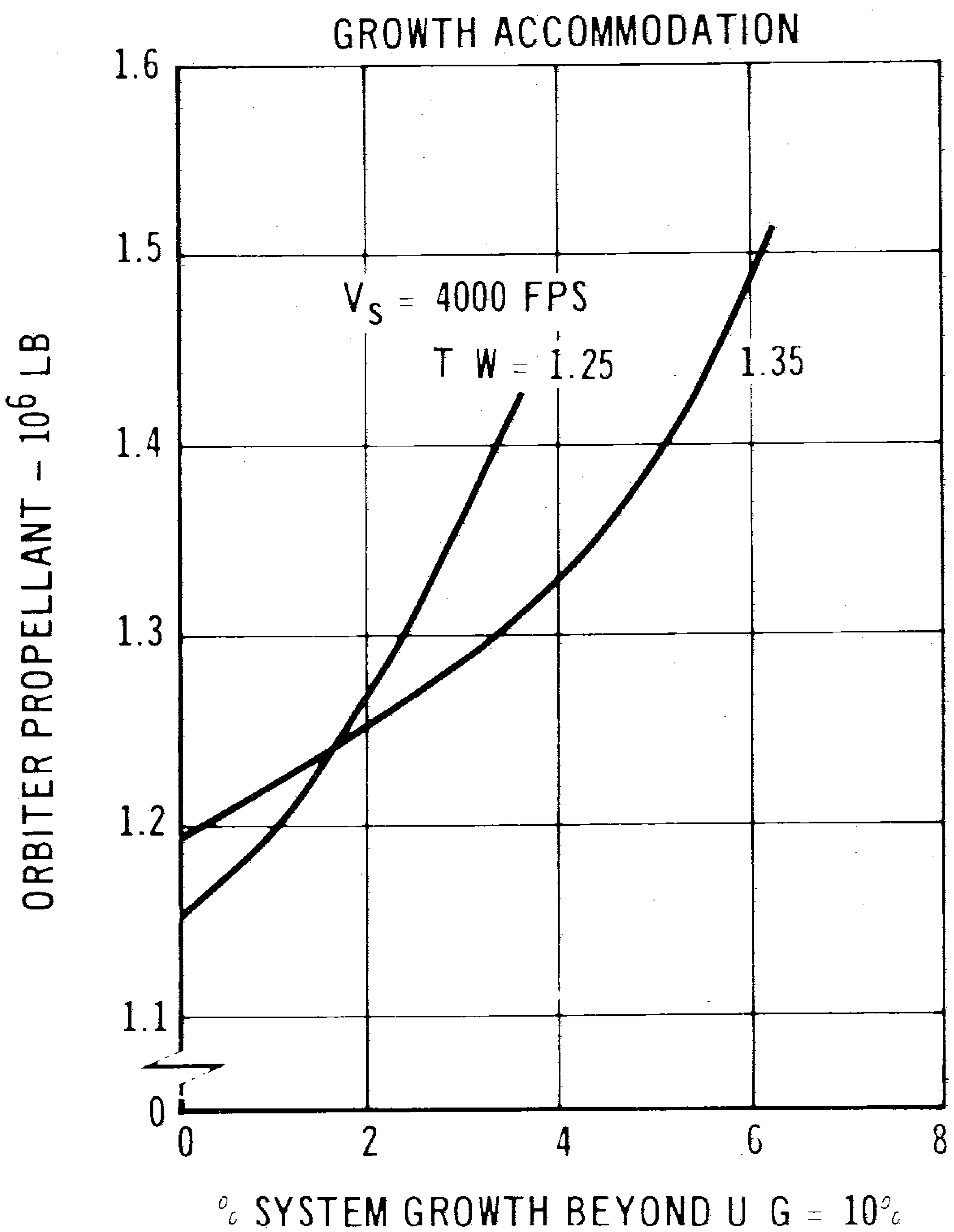
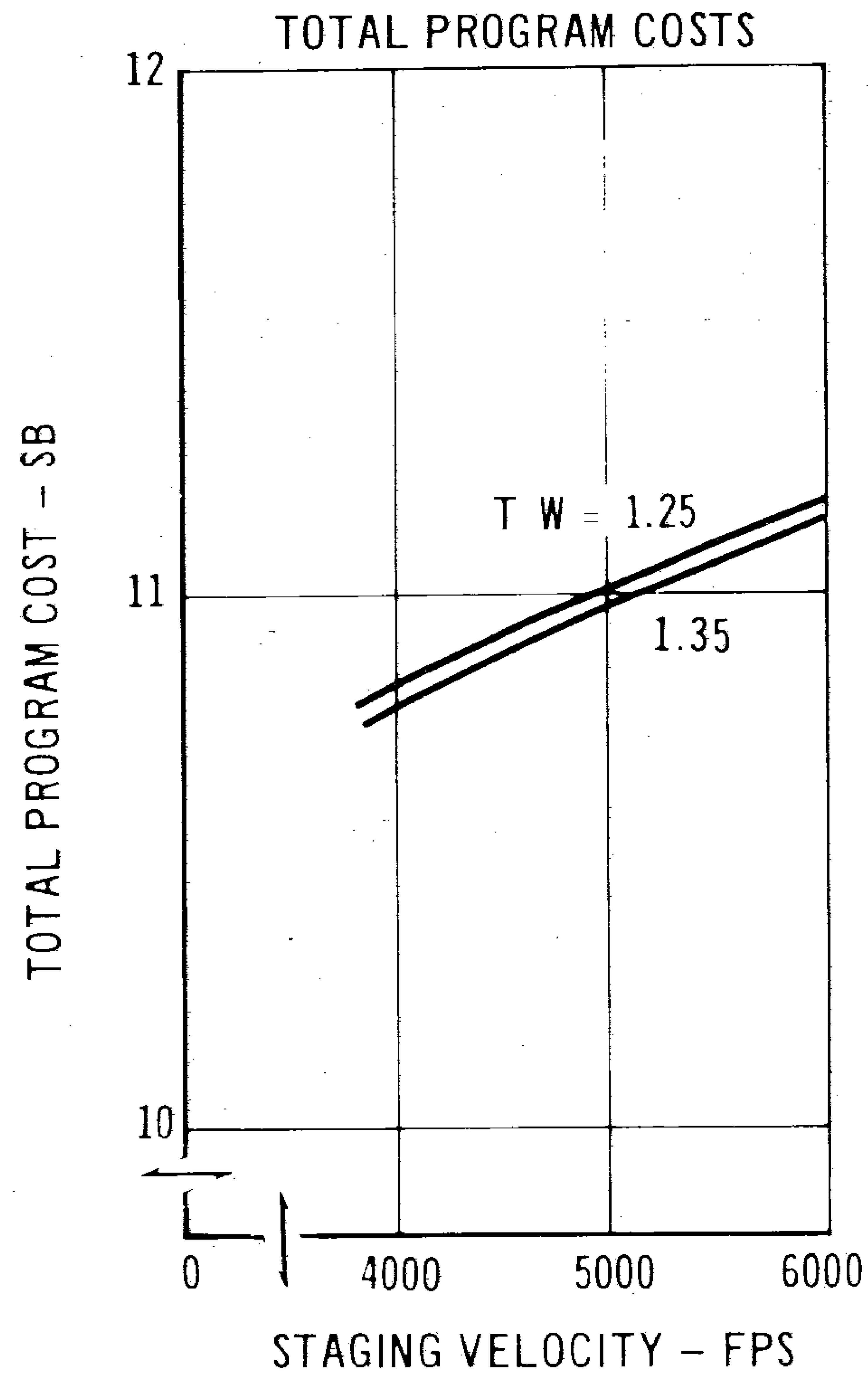
IMPACT OF $(T/W)_1$ ON GROWTH AND COST

- SERIES BURN – PRESSURE FED BOOSTER
- LARGE ORBITER





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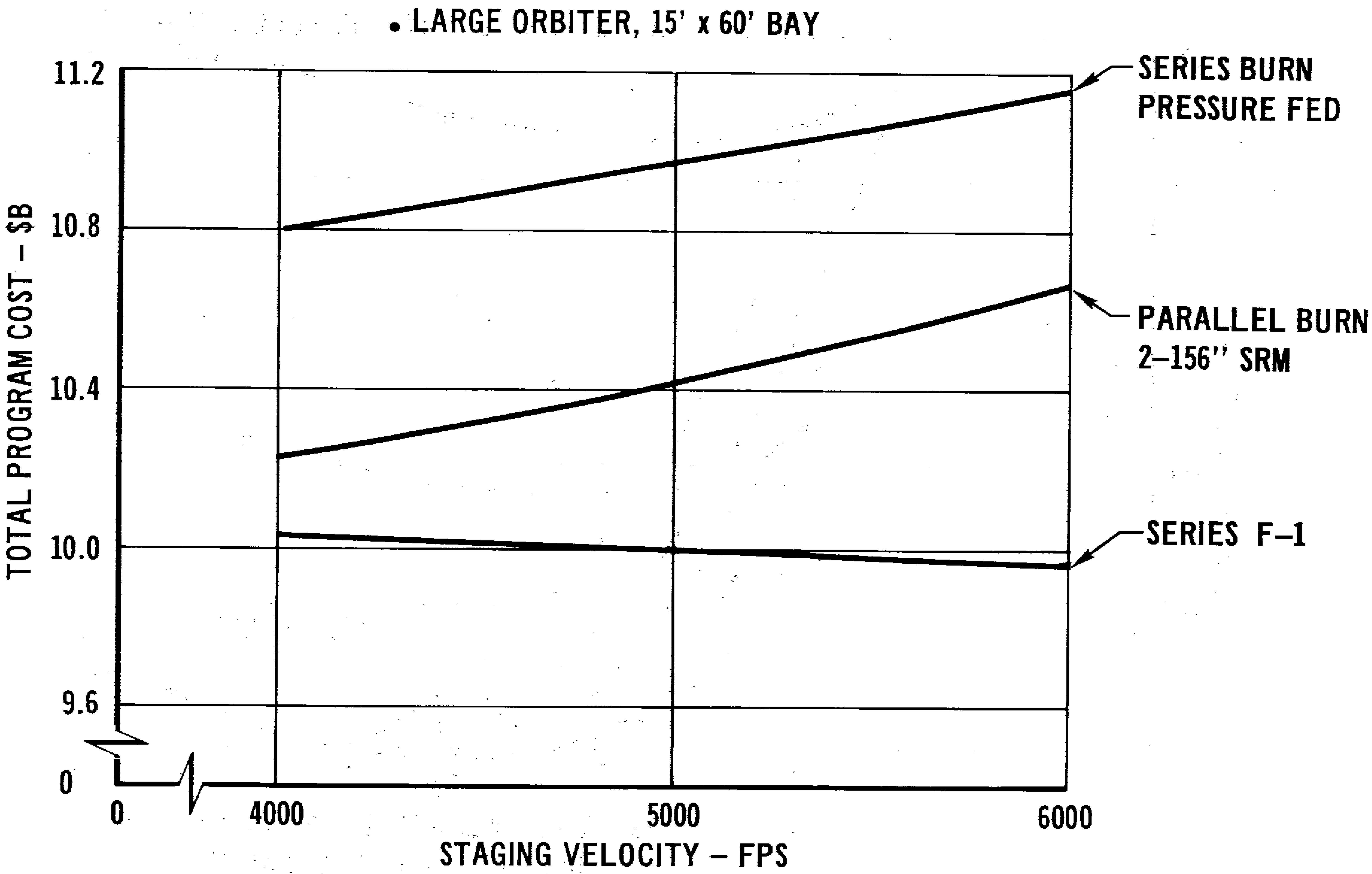
TOTAL PROGRAM COST vs STAGING VELOCITY



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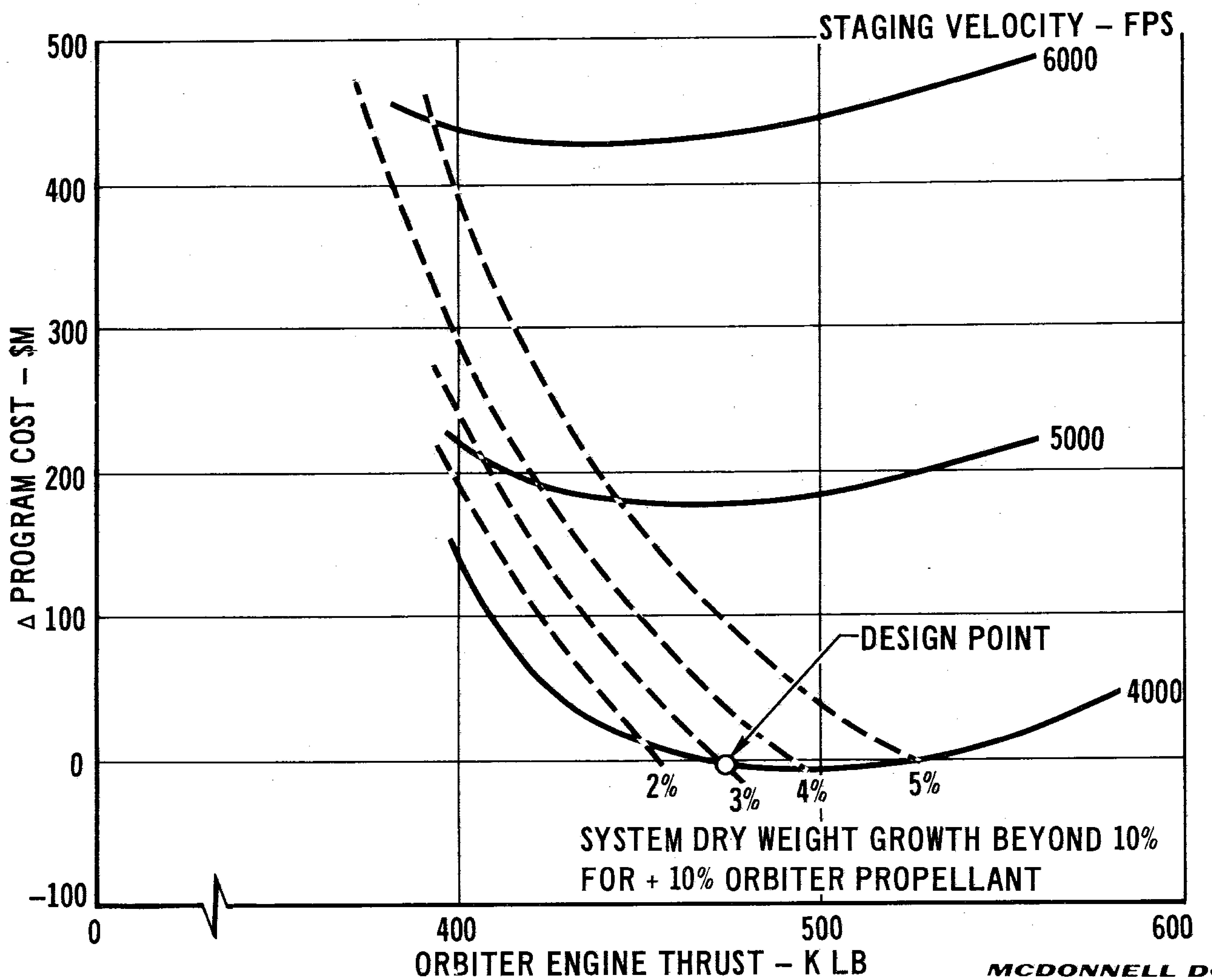
ORBITER THRUST SELECTION

15x60, 65 K LB, Parallel Burn

- 2-156 IN. SRMs
- 3 ORBITER ENGINES



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ABORT AND SEPARATION ISSUES

ITEM	RESULT
ABORT SEPARATION	• CAN BE PERFORMED IN ALL REGIMES FOR SERIES OR PARALLEL BURN SYSTEMS
INTACT ABORT GAPS	• CAN BE ELIMINATED BY INCORPORATING PAD ABORT AND HIGH q SEPARATION SYSTEMS
TOTAL COST	• TOTAL ABORT CAPABILITY INCLUDING GROUND TEST ~ $ 240 $\bar{M}$ • FULL VERTICAL FLIGHT DEMONSTRATION ~ $ 425 $\bar{M}$ (PARALLEL) OR $ 585 $\bar{M}$ (SERIES)

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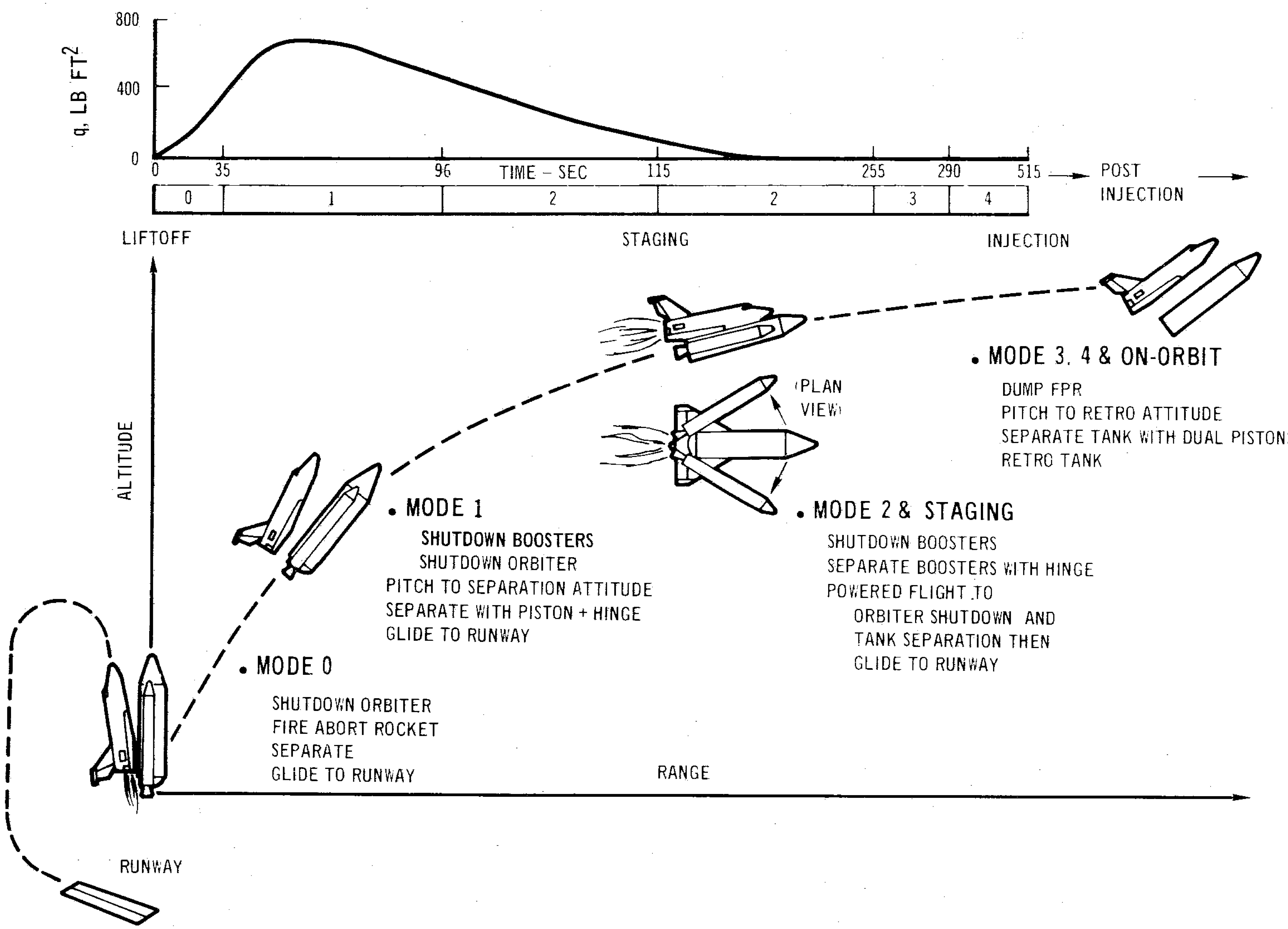
SEPARATION MODES FOR ABORT

Parallel Burn



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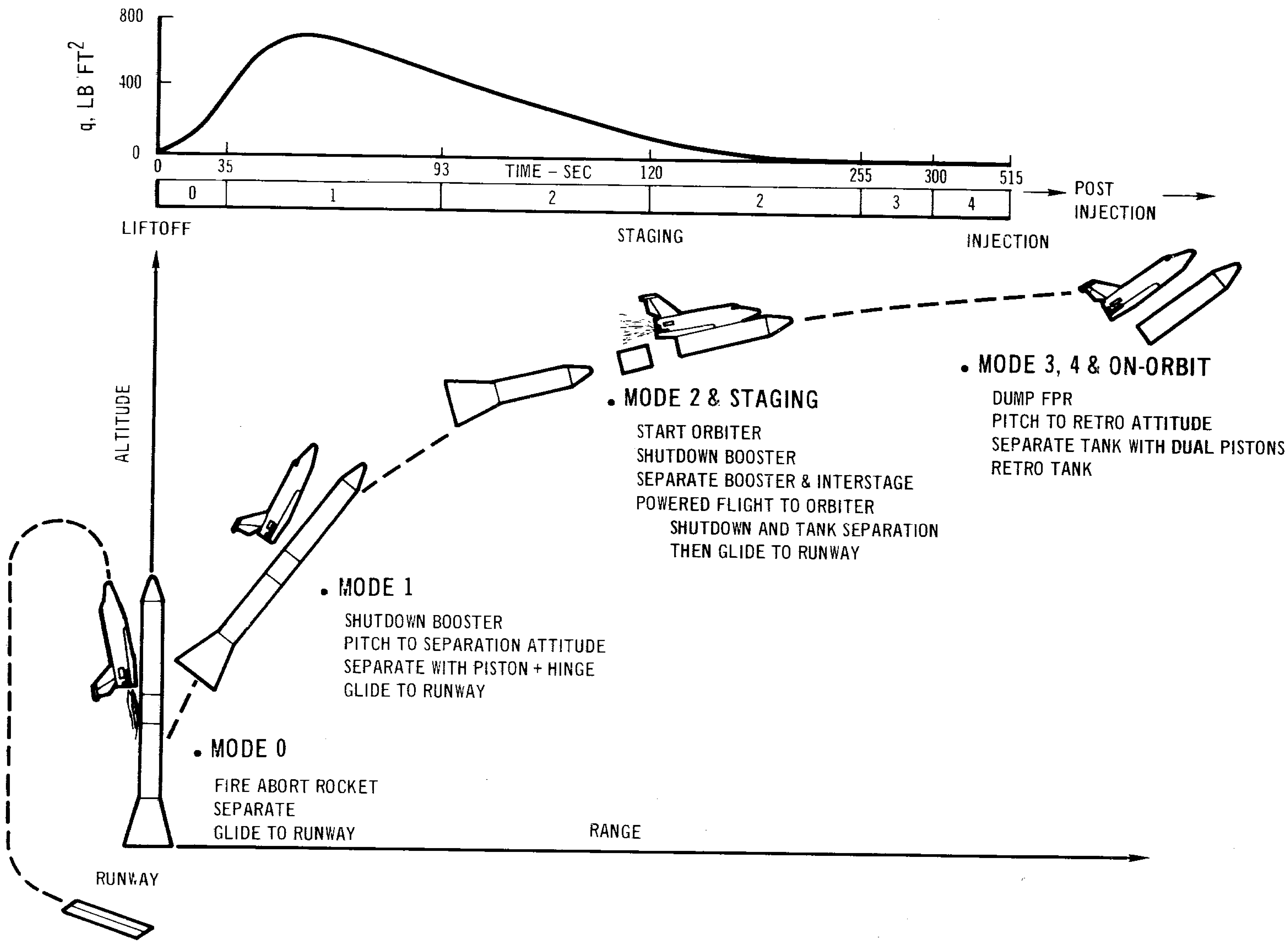
SEPARATION MODES FOR ABORT

Series Burn



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ABORT SEPARATION COMPARISON

Series vs Parallel

- EITHER CONCEPT CAN MEET AN INTACT ABORT REQUIREMENT
- ONLY SIGNIFICANT DIFFERENCE IS SEPARATION

MODE 0	• ORBITER SEPARATES FASTER IN SERIES SINCE ENGINES NEED NOT BE SHUTDOWN
MODE 1	• PITCH TO FAVORABLE ATTITUDE ($\Delta \alpha =$ 4.2 DEG FOR SERIES, AND 3.4 DEG FOR PARALLEL) • LIQUID ENGINE SHUTDOWN FOR BOTH (BOOSTER IN SERIES, ORBITER IN PARALLEL)
MODE 2	• SERIES INTERSTAGE BOOSTER SEPARATION IS "CLEANER" THAN PARALLEL HINGED SRM SEPARATION WHICH MUST CLEAR WING • ORBITER ENGINE STARTUP ADDS 3 TO 5 SEC TO SERIES SEPARATION SEQUENCE • SRM THRUST TERMINATION ADDS COMPLEXITY TO PARALLEL SEPARATION
MODE 3 & 4	• NO SIGNIFICANT DIFFERENCES BETWEEN SERIES AND PARALLEL

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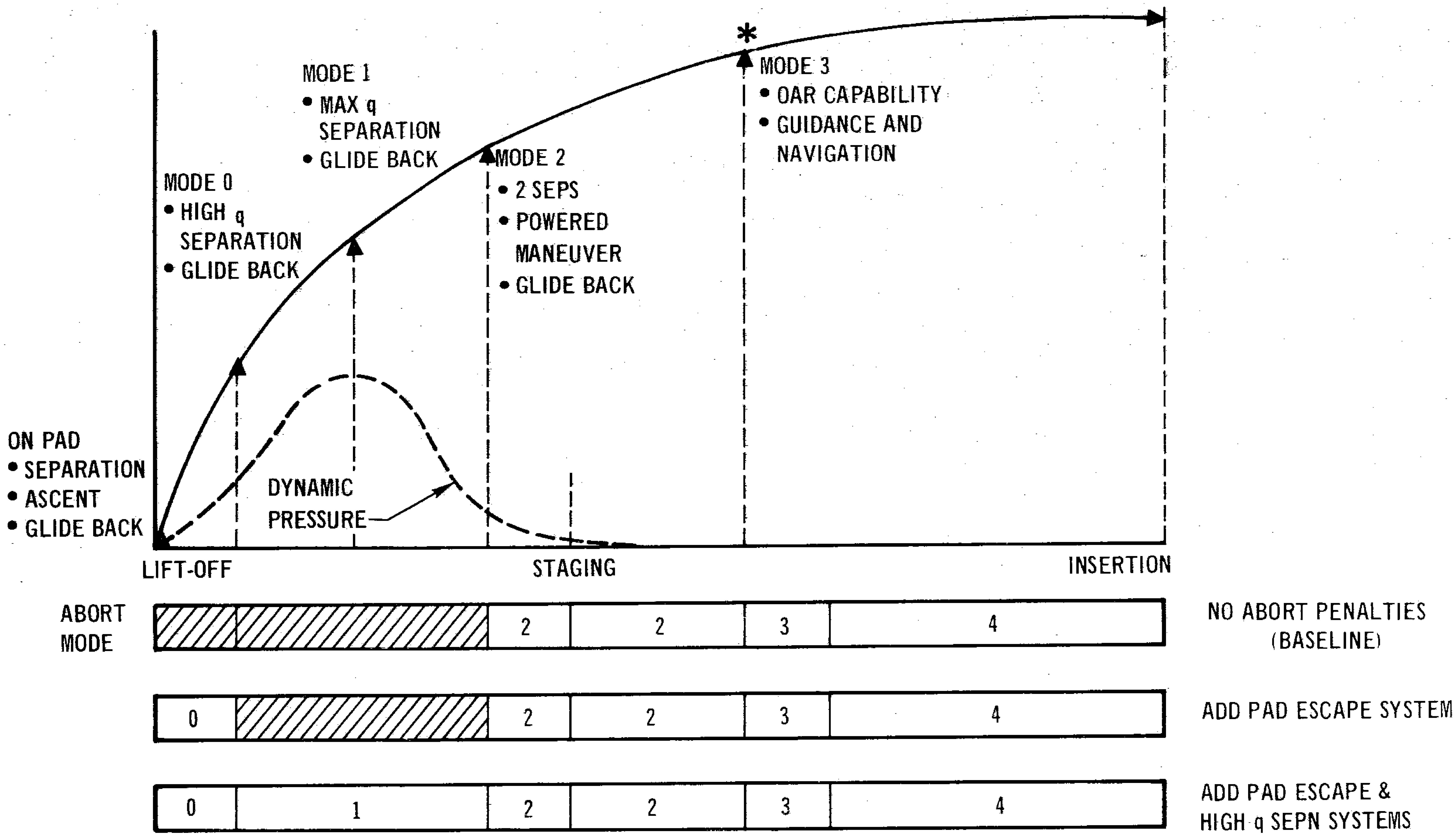
ABORT GAPS



*105–110% EPL REQUIRED

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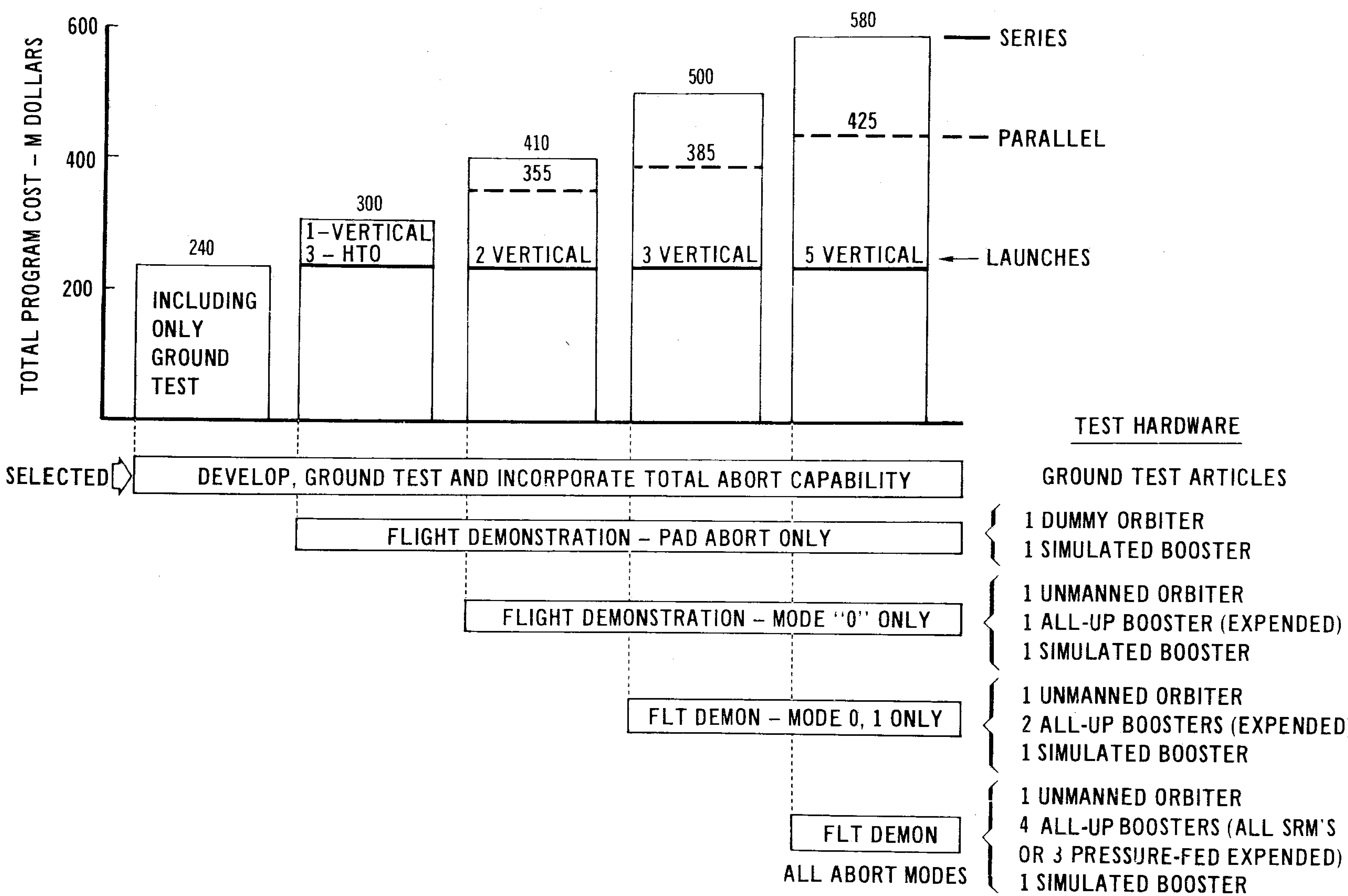
WEIGHT AND COST PENALTIES TO ELIMINATE ABORT GAPS

ABORT CAPABILITY	ORBITER DRY WEIGHT INCREMENT (LB)	PROGRAM COST INCREASE FOR ABORT (GROUND TEST ONLY) ($M)	
		SERIES BURN	PARALLEL BURN
BASELINE	REF	REF	REF
BASELINE + PAD ABORT (ROCKET)	+3300	+208	+213
BASELINE + PAD ABORT + HIGH Q ABORT SEPARATION	+5300	+240	+245

TOTAL COST TO ELIMINATE GAPS AND DEMONSTRATE CAPABILITY



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DISCRIMINATORS: SERIES BURN LIQUIDS vs PARALLEL BURN SOLID BOOSTERS

1–214 A

ITEM	SERIES LIQUIDS	PARALLEL SOLIDS	REMARKS
• ENGINE GIMBAL TRAVEL – ORBITER	√		NO ASCENT CONTROL BY ORBITER IN SERIES BURN.
– BOOSTER		√	NO TVC ON PARALLEL BURN SOLIDS.
– THRUST MISALIGNMENT VARIATIONS	√		THRUST IMBALANCE SOLID TO SOLID, BUT ORBITER ENGINES CAN HANDLE.
• CONFIDENCE ORBITER ENGINE START		√	IGNITED FROM LIFT-OFF
• HO TANK MASS FRACTION		√	LOADING CONDITIONS MORE FAVORABLE FOR TWIN SOLIDS
• WEIGHT		√	PARALLEL LIGHTER IN GLOW 1.46 M LB PR.FD. 0.143 M LB F–1
• RECOVERY, REFURBISHMENT		√	RECOVERY NOT REQUIRED FOR SOLIDS
• STRUCTURAL DYNAMICS	√	√	LONG, AND FLEXIBLE FOR SERIES, VS ASYMMETRICAL FOR PARALLEL.
• BASE HEATING	√		BASE OF HO TANK AND ORBITER EXPOSED. 500 LB TPS PENALTY
• ORBITER DRY WEIGHT	√	√	PARALLEL SAVES 55 LB (INSIGNIFICANT)
• ACOUSTICS	√		
– PAYLOAD			PAYLOAD FARTHER FROM BOOSTER ENGINES, BUT TWIN SOLID ENVIRONMENT O.K.
– BASE OF ORBITER			OVERALL SOUND PRESSURE LEVEL ON ORBITER HIGHER FOR PARALLEL, BUT RSI ATTENUATES TO NO PENALTY.
• ABORTS	√	√	NO ABORT GAPS, BOTH BOOSTERS REQUIRE THRUST TERMINATION
– PROBABILITY OF LOSS OF THRUST OF A BOOSTER ENGINE		√	SOLIDS HIGHLY RELIABLE
– DIFFICULTY OF THRUST TERMINATION	√		SOLIDS REQUIRE BLOW OUT PARTS
• SEPARATION	√		SIV–B TYPE SEPARATION vs HINGED ROTATING METHOD
• GROWTH CAPABILITY	√	√	NEARLY EQUAL AT V_S = 4000 FPS
• COSTS – TOTAL PROGRAM		√	
– RDT&E		√	
– COST/FLIGHT	√		

PARALLEL SOLIDS	SERIES LIQUIDS	
	PF	F–1
10,207	10,798	10,002
4,126	5,676	5,018
10.49	7.50	7.56

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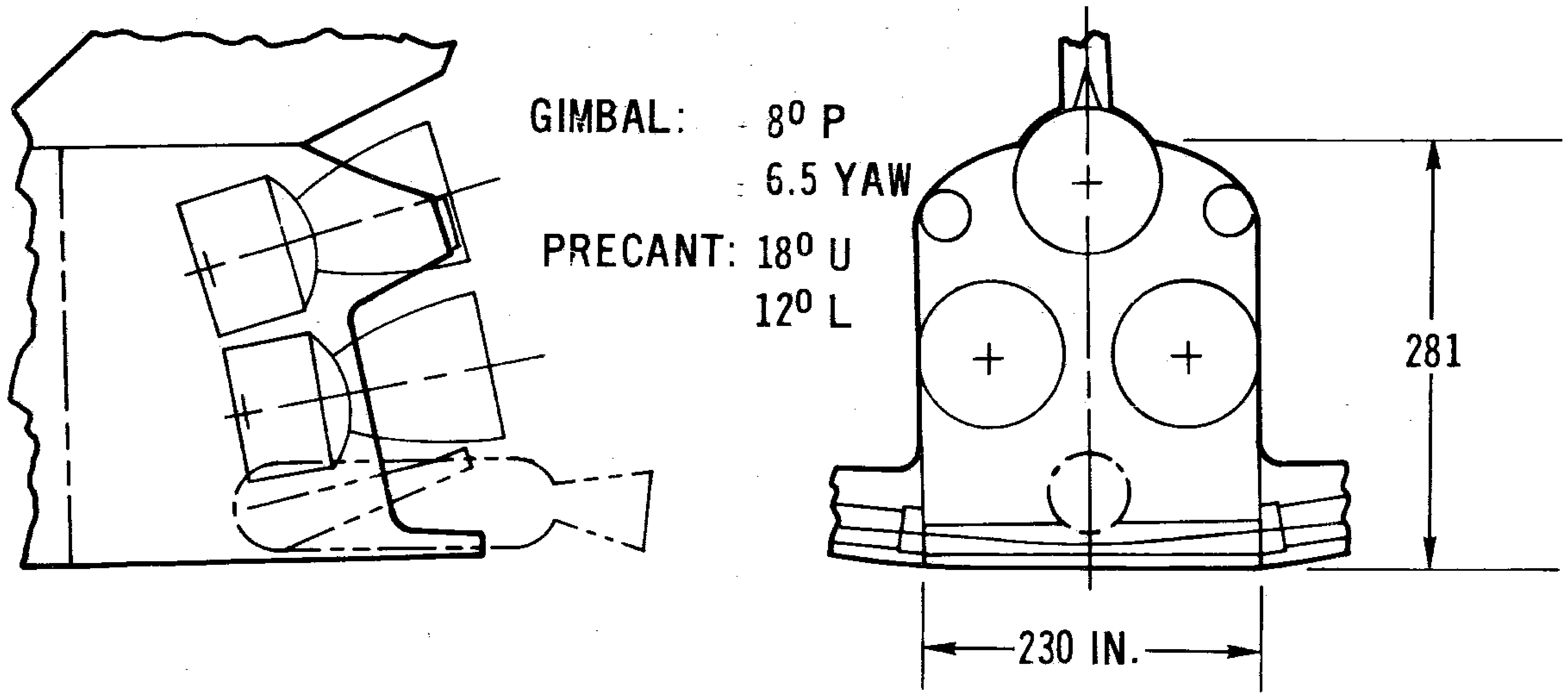
SERIES vs PARALLEL BURN ORBITER DIFFERENCES

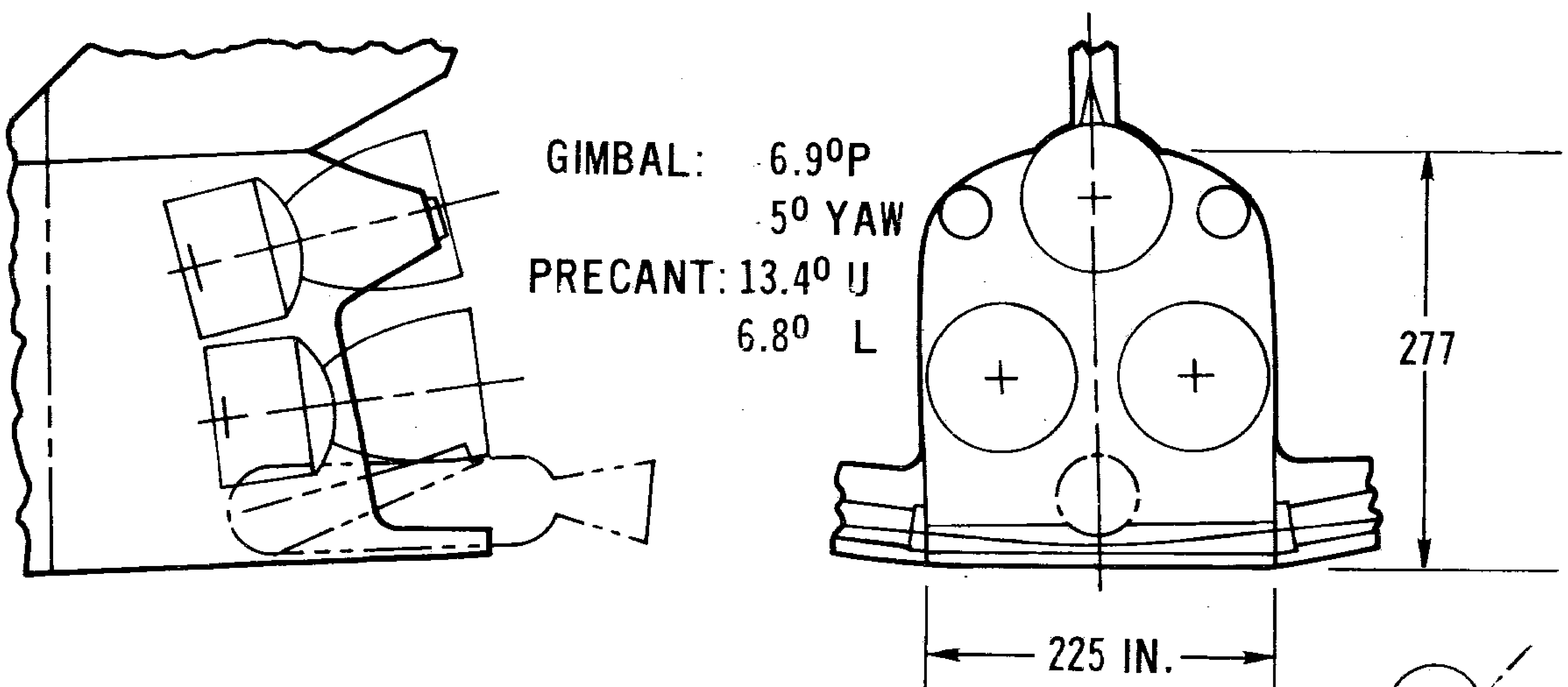
Parallel Burn

FUSELAGE LENGTH 132.8 FT
BASE AREA 352 FT^2
FUSELAGE SIDEWALL 7484 FT^2
LO_2 FEED LINE – SINGLE, 17 IN. DIA
NO RECIRCULATION SYSTEM
NET WEIGHT 55 LB LIGHTER



Series Burn

FUSELAGE LENGTH 133.1 FT
BASE AREA 331 FT^2
FUSELAGE SIDEWALL 7327 FT^2
LO_2 FEED LINE – TWO, 12 IN. DIA
RECIRCULATION SYSTEM REQUIRED



MCDONNELL DOUGLAS CORPORATION
TRW

ORBITER CORE WEIGHT CHANGES (LBS)

1-356

Series to Parallel Burn

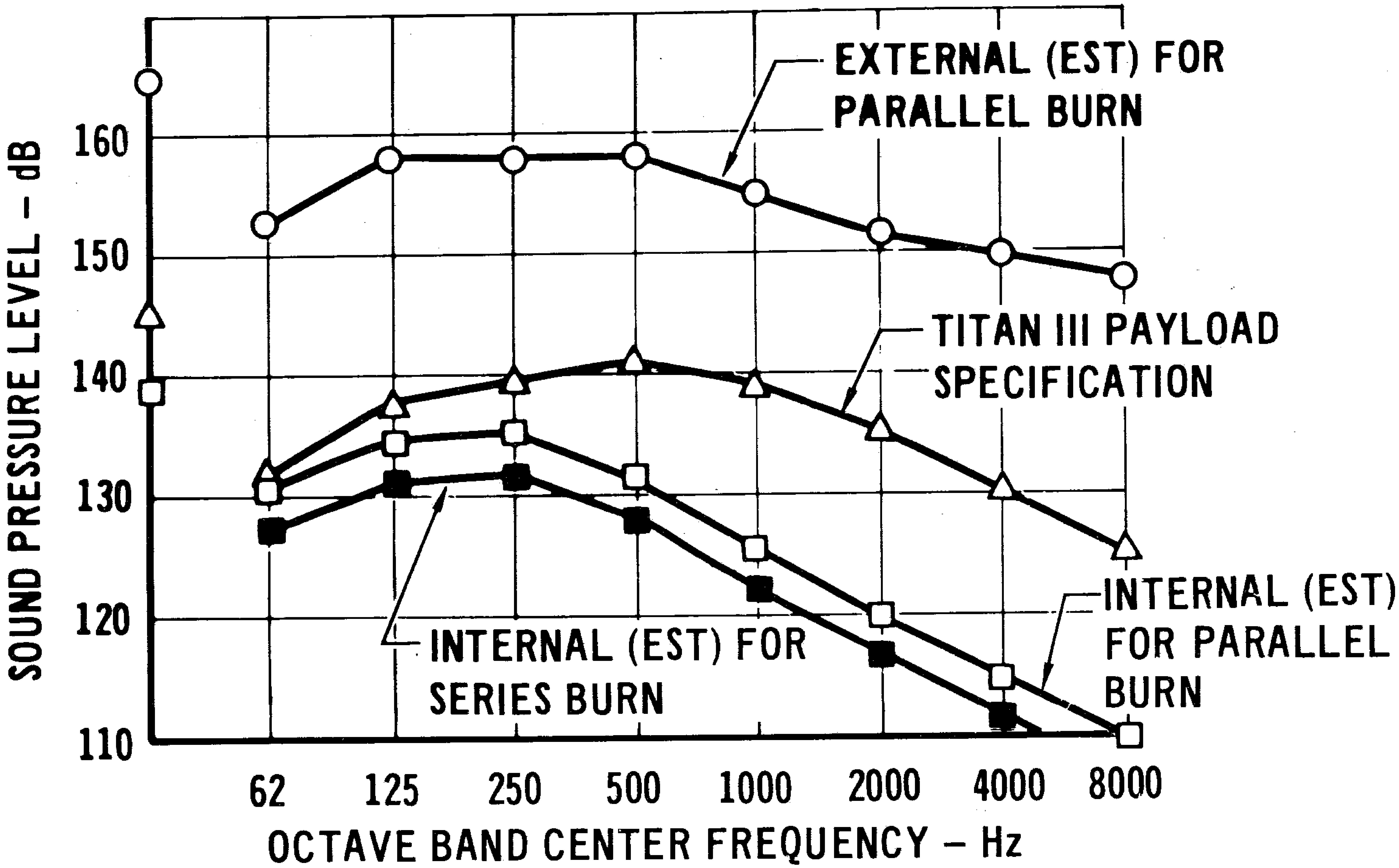
PROPULSION FEED SYSTEM	
ELIMINATE RECIRCULATION SYSTEM	–750
PLUMBING	–150
APU	
LONGER ASCENT TIME	+100
BASE HEATING	
HIGHER AFT END HEATING	+120
PRECANT & GIMBAL ANGLE CHANGE	
INCREASED BODY WETTED AREA	+490
INTERCONNECT BACKUP	+ 40
THRUST STRUCTURE	+100
VERTICAL TAIL	
INCREASED RUDDER LOADS	+400
WING	
DECREASED DOWN LOADS	–100
FUSELAGE	
REDUCED DOWN BENDING	–300
UNCERTAINTY/GROWTH MAINTAINED AT 10%	– 5
NET EFFECT	– 55

MCDONNELL DOUGLAS

TRW

ACOUSTIC ENVIRONMENT
PAYLOAD COMPARTMENT

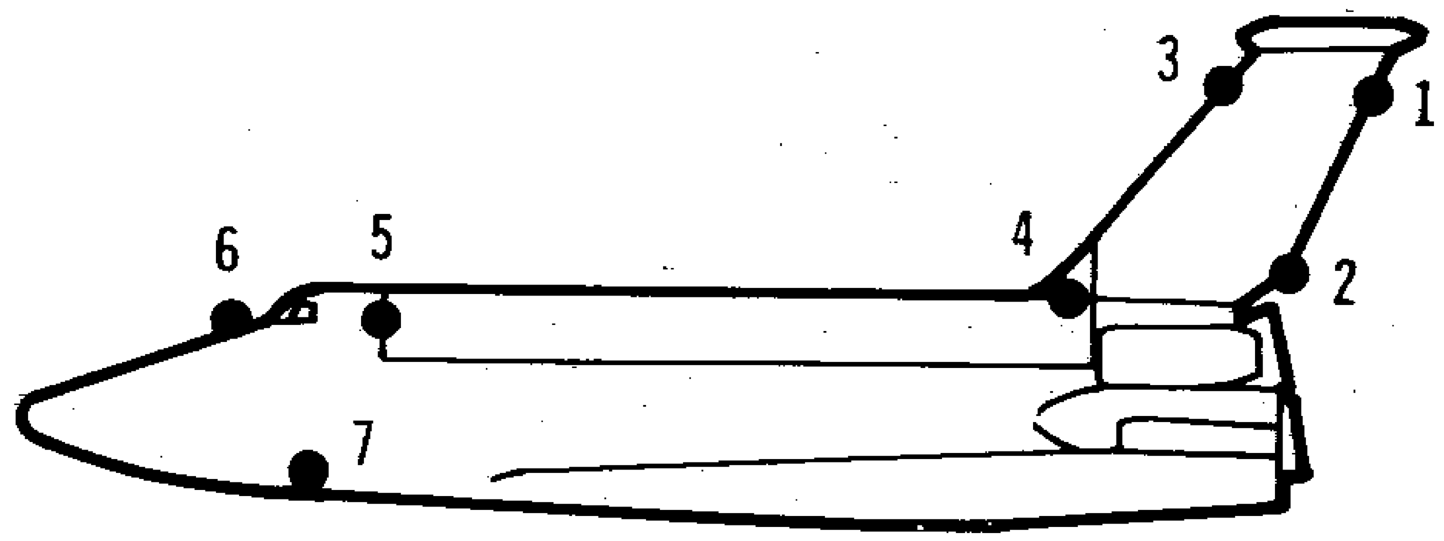
POGP
249-1271 A



NOTES: 1. AN ATTENUATION VALUE OF 25 dB OVERALL WAS USED.
2. INCLUDES A 3 dB MARGIN FOR DESIGN

EXTERNAL ACOUSTICS

ENVIRONMENT



	LAUNCH*		ASCENT**	
	SERIES BURN	PARALLEL BURN	SERIES BURN	PARALLEL BURN
1	156.1	164.6	161	161
2	155.7	165.9	161	161
3	155.6	163.6	155	155
4	155.0	163.3	146	146
5	152.7	158.2	161	161
6	152.4	157.6	148	148
7	152.6	158.0	155	160

* BASED ON TEST FIRINGS OF SATURN J–2 ENGINES AT NASA–MSFC

** BASED ON AMES WIND TUNNEL TEST DATA

RSI STRUCTURE CAPABILITY

ACOUSTIC TESTING TO DATE
- RSI BONDED TO BERYLLIUM PANEL
  - PANEL SIZE: 12x 24 x 0.8 INCHES
- PANEL 1 FIBERGLASS CORE 159 db OVERALL
  - TWO TILES 12 x 12 x 1.5 FOR 900 SEC
- PANEL 2 TITANIUM CORE 158 db OVERALL
  - ONE TILE 12 x 12 x 1.5 FOR 900 SEC
  - FOUR TILES 6 x 6 x 1.5
- REPRESENTS 10 MISSIONS

PREDICTED ACOUSTIC ATTENUATION FOR ORBITER BASED ON SIMILAR TESTS ON ABLATORS
- RSI ON FOAM ISOLATOR BONDED TO ALUMINUM SKIN-STRINGER PANEL
  - 25 db

PLANNED ACOUSTIC TEST
- RSI ON FOAM ISOLATOR BONDED TO AN ALUMINUM SKIN-STRINGER PANEL
  - PANEL SIZE: 12 x 24
    - SKIN .020 AL
    - STRINGER .040 x 1 AL
  - ONE TILE 10.6 x 10.8 x 1.8
  - FOUR TILES 5.3 x 5.4 x 1.8
  - TESTS – ACOUSTIC ATTENUATION
    - –ACOUSTIC TEST 165 db FOR 90 SEC, 20 MISSIONS AT 90 SEC EACH PLANNED
  - DATA AVAILABLE ABOUT 1 MARCH 1972

MCDONNELL DOUGLAS
TRW
CORPORATION

SYSTEM TECHNICAL RISK COMPARISON

- LARGE ORBITER, 15' x 60' BAY
- EASTERLY MISSION, 65 K LB PAYLOAD

	SERIES			PARALLEL
	PRESSURE FED	PUMP FED		SOLIDS
	6 PR FD	4 F-1	10 HiPc	TWIN 156 IN.
BOOSTER SIZE	735 K LB LANDING WT 4	374 K LB LANDING WT 3	302 K LB LANDING WT 2	EXPENDABLE: LANDED INERT WT NOT A FACTOR. 1
ASCENT FLIGHT MECHANICS & CONTROL	UNSTABLE VEHICLE REQUIRES GIMBALED BOOSTER ENGINES. 2.5	SIMILAR TO PRESSURE FED BOOSTER ADEQUATE GIMBALING ALREADY AVAILABLE. MARGINAL CONTROL WITH ONE ENGINE OUT 3	SAME AS F-1 EXCEPT BETTER ENGINE-OUT CAPABILITY 2.5	STABLE VEHICLE. NO BOOSTER TVC. 2
ASCENT AERO-DYNAMICS	HIGH DRAG CAUSED BY AFT FLARE. ORBITER AERO SURFACES EFFECTIVE FOR CONTROL. 3	SAME AS PRESSURE FED. 3	SAME AS F-1. 3	LOWER DRAG. REDUCED ORBITER CONTROL SURFACE EFFECTIVE-NESS. 1

(CONTINUED)

RISK: 1 = LOWEST; 4 = HIGHEST

MCDONNELL DOUGLAS CORPORATION
TRW

SYSTEM TECHNICAL RISK COMPARISON

1-259 A

- LARGE ORBITER, 15' x 60' BAY
- EASTERLY MISSION, 65 K LB PAYLOAD

	SERIES			PARALLEL SOLIDS TWIN 156"
	PRESSURE FED 6 PR FD	PUMP FED 4 F-1	PUMP FED 10 HiPc	
LOADS	←EXPERIENCE LOWER MAX αq & MAX βq.→ ←ACOUSTIC ENVIRONMENT IS LOWER ON ORBITER SINCE BOOSTER ENGINES ARE CONSIDERABLE DISTANCE FROM ORBITER.→ ←HIGHER BODY BENDING LOADS ON BOOSTER→			HIGHER MAX αq AND βq. LOWER WINGLOADS AND BODY BENDING MOMENTS. HIGHER TAIL LOADS AND INTERFERENCE PRESSURES. MORE SEVERE ACOUSTIC ENVIRONMENT IMPOSED ON ORBITER.
	2	2	2	4
SEPARATION NOMINAL STAGING	←CONVENTIONAL TYPE BOOSTER SEPARATION.→ ←STATE-OF-THE-ART INTERSTAGE SEPARATION MECHANISM IS USED.→			MORE COMPLEX SYSTEM REQUIRED TO ASSURE WING CLEARANCE.
POST INJECTION	←SAME ORBITER-TO-HO-TANK SEPARATION MECHANISM FOR ALL BOOSTER CONCEPTS (DUAL PISTON).→ ←ONLY MINOR CHANGES REQUIRED TO ACCOUNT FOR DIFFERENT TANK WEIGHT AND CG.→			
	2	2	2	4

RISK: 1 = LOWEST; 4 = HIGHEST

(CONTINUED)

MCDONNELL DOUGLAS CORPORATION
TRW SYSTEMS GROUP

SYSTEM TECHNICAL RISK COMPARISON

- LARGE ORBITER, 15' x 60' BAY
- EASTERLY MISSION, 65 K LB PAYLOAD

	SERIES			PARALLEL
	PRESSURE FED	PUMP FED		SOLIDS
	6 PR FD	4 F–1	10 HiPc	TWIN 156 IN.
ABORT	LOW PROBABILITY OF OCCURRENCE. ← THRUST TERMINATION CAN EASILY BE ACCOMPLISHED. → ← SHORTEST PITCH MANEUVER TIME TO SEPARATE → 1	← HIGHER PROBABILITY OF ENGINE-OUT OCCURRENCE → 3	BOOSTER ENGINE OUT LEAST DAMAGING. 3	LOWEST PROBABILITY OF OCCURRENCE. THRUST TERMINATION IS REQUIRED AND ADDS COMPLEXITY. LOWER FORCE TO SEPARATE 3
BOOSTER ENGINE	NEW ENGINE DEVELOPMENT: PRESSURE THROTTLING PLUS ENGINE SHUT-DOWN. COMBUSTION INSTA-BILITY CONCERN. 4	EXISTING ENGINE WITH STABLE COMBUSTION. SEA WATER EFFECTS UNCERTAIN. 2	ORBITER ENGINE WITH DIFFERENT NOZZLE. (NEW DEVELOPMENT) MOST SENSITIVE TO WATER RECOVERY. 3	ADDITIONAL MOTOR DEVELOPMENT REQUIRED. SIMPLEST PROPULSION SYSTEM NO REFURBISHMENT REQUIREMENTS. 1

RISK: 1 = LOWEST; 4 = HIGHEST.

MCDONNELL DOUGLAS CORPORATION
TRW SYSTEMS GROUP
PAN AM

SYSTEM TECHNICAL RISK COMPARISON

- LARGE ORBITER, 15' x 60' BAY
- EASTERLY MISSION, 65 K LB PAYLOAD

	SERIES			PARALLEL SOLIDS TWIN 156"
	PRESSURE FED 6 PR FD	PUMP FED 4 F-1	PUMP FED 10 HiPc	
BOOSTER PROPULSION	COLD HELIUM/N_2H_4 PRESSURIZATION SYSTEM. MAXIMUM RESIDUALS EASIEST TURN AROUND. 3	DEVELOP COLD HELIUM AUTOGONQUS PRESSURIZATION SYSTEM. FEWER ENGINES. LACKS ENGINE OUT CAPABILITY. 2	AUTOGONQUS PRESSURIZATION SYSTEM. SMALLEST RESIDUALS. ENGINE SEALING. MOST ENGINES. 4	NO RECOVERY. SIMPLE PROPULSION. 1
BOOSTER/ORBITER/ TANK ATTACHMENTS AND BOOSTER	←CYLINDRICAL LOAD DISTRIBUTION SUPPORT.→ ←MINIMUM THERMAL INTERFERENCE PENALTIES.→ ←LEAST ACOUSTICAL PENALTY SINCE ORBITER IS FURTHEST FROM BOOSTER ENGINES.→ ←REQUIRE WATER IMPACT DEVELOPMENT TESTS AND MUST BE REUSABLE.→ TANK MATERIAL SELECTION PROBLEM REQUIRE THICK LANDS FOR WELDS 4	←MORE DIFFICULT WATER IMPACT DEVELOPMENT.→ ←MORE SUSCEPTIBLE TO ENTRY THERMAL PROBLEMS.→ 2.5	2.5	POINT LOAD SUPPORT. HIGHER THERMAL INTERFERENCE PENALTIES. HIGH ACOUSTIC PENALTY ON ORBITER & HO TANK NO RECOVERY REQUIRED. SIMPLE MONOCOQUE SHELL. 1.0

RISK: 1 = LOWEST; 4 = HIGHEST

(CONTINUED)

MCDONNELL DOUGLAS CORPORATION

TRW SYSTEMS GROUP

SYSTEM TECHNICAL RISK COMPARISON

- LARGE ORBITER, 15' x 60' BAY
- EASTERLY MISSION, 65 K LB PAYLOAD

	SERIES			PARALLEL SOLIDS
	PRESSURE FED	PUMP FED		
	6 PR FD	4 F–1	10 HiPC	TWIN 156 IN.
BOOSTER RECOVERY SYSTEM	REQUIRES RECOVERY ROCKET DEVELOPMENT. HIGHEST RECOVERY WT. TERMINAL VELOCITY HIGHER. HIGHER IMPACT g'S BUT NOT CRITICAL. SPLASH DOWN VELOCITY HIGHER. HIGH RECOVERY SYSTEM WT. 2	REQUIRES ROCKET DEVELOPMENT. LOWER RECOVERY WT. TERMINAL VELOCITY LOWER. SPLASH DOWN VELOCITY LOWER. LOWER IMPACT. LOWER RECOVERY SYSTEM WT. RELATIVELY FRAGILE STRUCTURE. 3	SIMILAR TO F–1 BUT LOWER TERMINAL VELOCITY AND LIGHTER WT. CRYO INSULATION REUSABILITY QUESTIONABLE. 4	RECOVERY NOT REQUIRED. 1
OPERATIONS COMPARISON	SIMPLER PROPULSION SYSTEM. RUGGED VEHICLE. LARGER VEHICLE. ← BOOSTER RECERTIFICATION REQUIRED. 2	EASIER TO RETRIEVE THAN HiPc. LESS HAZARDOUS THAN LH_2/LOX. (BOOSTER RECERTIFICATION REQUIRED.) 3	SMALLEST WEIGHT. HAZARDOUS LH_2/LOX. MORE ENGINES TO MAINTAIN. (BOOSTER RECERTIFICATION REQUIRED.) → 4	SIMPLER SYSTEM AND SUBSYSTEM CHECKOUT. SIMPLER LAUNCH PROPULSION. NO BOOSTER RECERTIFICATION REQUIRED. 1

RISK: 1 = LOWEST; 4 = HIGHEST.

(CONTINUED)

MCDONNELL DOUGLAS CORPORATION, TRW SYSTEMS GROUP, PAN AM

SYSTEM TECHNICAL RISK COMPARISON

- LARGE ORBITER, 15' x 60' BAY
- EASTERLY MISSION, 65 K LB PAYLOAD

	SERIES			PARALLEL
	PRESSURE FED	PUMP FED		SOLIDS
	6 PR FD	4 F–1	10 HiPc	TWIN 156 IN.
TESTING & DEVELOPMENT	REQUIRE NORMAL STRUCTURAL TESTING, RECOVERY, ENTRY, RETRIEVAL AND VERTICAL FLIGHT TESTS. MOST OF LATER TESTS ARE NOT COMPLICATED. 3	3	3	LEAST DEVELOPMENT TESTING REQUIRED. REQUIRES SOME COMPLEX TESTING 1
DEPTH OF ANALYSIS	SUBSTANTIAL ANALYSIS IN MOST AREAS. MODERATE ANALYSIS IN REMAINING AREAS. 1.5	SUBSTANTIAL ANALYSIS IN SOME AREAS. MODERATE ANALYSIS IN OTHER AREAS. 3	MODERATE ANALYSES IN MOST AREAS. 4	SUBSTANTIAL ANALYSIS IN MOST AREAS. MODERATE ANALYSIS IN REMAINING AREAS. 1.5

RISK: 1 = LOWEST; 4 = HIGHEST.

(CONCLUDED)

MCDONNELL DOUGLAS
TRW
CORPORATION

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ISSUES OF PRIMARY CONCERN

SERIES BURN PRESSURE FED	SERIES BURN PUMP FED F-1	PARALLEL BURN 156 IN. SOLIDS
• RDT&E COST	• RDT&E COST	• PER FLIGHT COST
• WATER RECOVERY AND RECERTIFICATION	• WATER RECOVERY AND RECERTIFICATION	• POTENTIAL POLLUTION
• NEW ENGINE DEVELOPMENT (POTENTIAL STABILITY PROBLEMS)	• ENGINE WATER IMMERSION EFFECTS AND REFURBISHMENT	• MALFUNCTION DETECTION
	• ENGINE-OUT LOSS OF BOOSTER	• MORE COMPLEX SEPARATION PROVISIONS

MCDONNELL DOUGLAS
TRW SYSTEMS GROUP
CORPORATION

SYSTEM TECHNICAL RISK COMPARISON

- LARGE ORBITER, 15' x 60' BAY
- EASTERLY MISSION, 65 K LB PAYLOAD

ITEM	WEIGHT FACTOR	SERIES									PARALLEL SOLIDS		
		PRESSURE FED			PUMP FED								
		6 PRESSURE FED	BASE RISK FACTOR	WTD. RISK FACTOR	4 F-1	BASE RISK FACTOR	WTD. RISK FACTOR	10 HiPc	BASE RISK FACTOR	WTD. RISK FACTOR	TWIN 156"	BASE RISK FACTOR	WTD. RISK FACTOR
BOOSTER SIZE	1	HEAVIEST	4	4		3	3	LIGHTEST	2	2	LIGHT & EXPEND-ABLE	1	1
ASCENT FLIGHT MECHANICS & CONTROL	2	FINS?	2.5	5	FINS? MARG'L ENG. OUT	3	6	FINS?	2.5	5	TVC?	2	4
ASCENT AERODYNAMICS	1	AERO DRAG	3	3	SAME AS PRESSURE FED	3	3	SAME AS PRESSURE FED	3	3	LOW DRAG	1	1
LOADS	1	BODY BENDING	2	2	SAME AS F–1	2	2	SAME AS F–1	2	2	ACOUSTIC HIGHER αq βq	4	4
SEPARATION	1	CONVEN-TIONAL	2	2	CONVEN-TIONAL	2	2	CONVEN-TIONAL	2	2	WING CLEARANCE	4	4
ABORT	2	LOW PROB-ABILITY	1	2	HIGHER PROBABILITY	3	6	HIGHER PROBABILITY	3	6	LOW PROB-ABILITY THRUST TERMINATION REQUIRED	3	6

MCDONNELL DOUGLAS CORPORATION
TRW SYSTEMS GROUP

SYSTEM TECHNICAL RISK COMPARISON

1–424 B

(Continued)

- LARGE ORBITER, 15' x 60' BAY
- EASTERLY MISSION, 65 K LB PAYLOAD

ITEM	WEIGHT FACTOR	SERIES									PARALLEL SOLIDS		
		PRESSURE FED			PUMP FED								
		6 PRESSURE FED	BASE RISK FACTOR	WTD. RISK FACTOR	4 F-1	BASE RISK FACTOR	WTD. RISK FACTOR	10 HiPc	BASE RISK FACTOR	WTD. RISK FACTOR	TWIN 156"	BASE RISK FACTOR	WTD. RISK FACTOR
BOOSTER ENGINE	2	NEW	4	8	EXISTING	2	4	MOD. FROM ORBITER	3	6	SOME DEVELOPMENT SIMPLE SYSTEM	1	2
BOOSTER PROPULSION	1	HEAVY RESIDUALS	3	3	FEWER ENGINES	2	2	LARGEST NO. OF ENGINES	4	4	NO REUSE REQ'D	1	1
ATTACHMENT & BOOSTER STRUCTURE	2	RUGGED TANK MATERIAL	4	8	WATER IMPACT CRITICAL	2.5	5	SAME AS F-1	2.5	5	BREAKUP ACCEPTABLE	1	2
BOOSTER RECOVERY SYSTEM	2	ROCKETS	2	4	WITH SUSTAINER ROCKETS	3	6	WITH SUSTAINER ROCKETS	4	8	EXPENDABLE	1	2
OPERATIONS	2	BOOSTER CERTIFICATION	2	4	ALSO ENGINE WATER DEVELOPMENT	3	6	SAME AS F-1	4	8	EXPENDABLE	1	2
TESTING AND DEVELOPMENT	2		3	6		3	6		3	6	LESS TESTING	1	2
DEPTH OF ANALYSIS	1	SUBSTANTIAL	1.5	1.5	LOWER	3	3	LOWEST	4	4	SUBSTANTIAL	1.5	1.5
TOTAL			34	52.5		34.5	54		39	61		22.5	32.5

MCDONNELL DOUGLAS CORPORATION
TRW

DEPTH OF ANALYSIS SURVEY

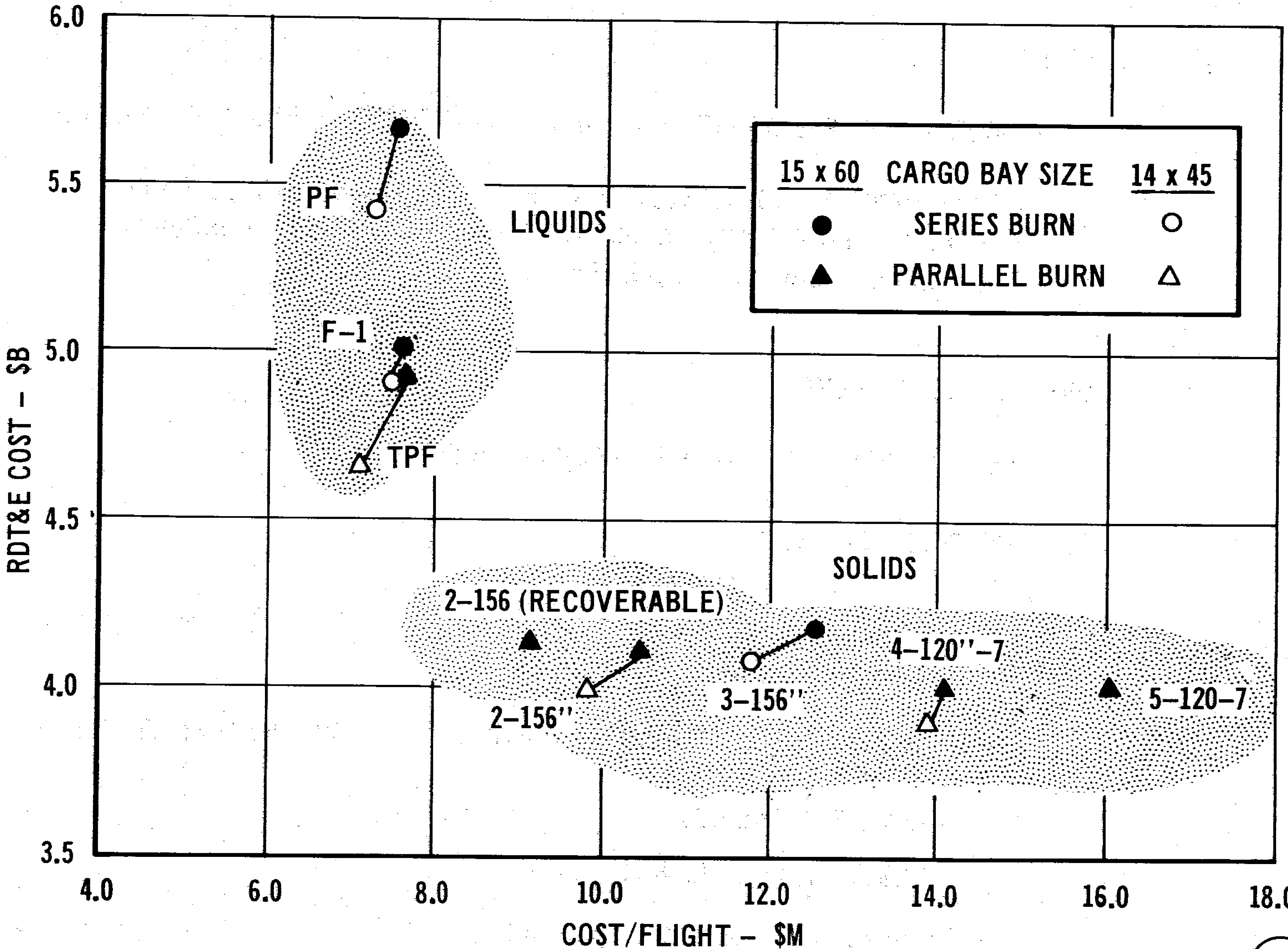
- (hatched) SUBSTANTIAL
- (stippled) MODERATE
- (blank) SHALLOW
- NA NOT APPLICABLE

	ORBITERS		HO TANKS		BOOSTER SYSTEMS (LARGE ORBITERS*)						
					SERIES BURN				PARALLEL BURN		
	LARGE 15 x 60	SMALL 14 x 45	SERIES	PARA	PR.FD.	F–1	HiPc	SRM 156"	PR. FD.	SRM'S 120"	SRM'S 156"
DESIGN/LAYOUTS	Substantial	Moderate	Substantial	Substantial	Substantial	Moderate	Moderate	Moderate	Substantial	Shallow	Substantial
WEIGHTS	Substantial	Moderate	Substantial	Substantial	Substantial	Moderate	Moderate	Moderate	Substantial	Moderate	Substantial
SIZING/SENSITIVITIES	Substantial	Moderate	Substantial	Substantial	Substantial	Moderate	Moderate	Moderate	Substantial	Shallow	Substantial
AERODYNAMICS	Substantial	Moderate	Moderate	Substantial	Substantial	Substantial	Moderate	Moderate	Substantial	Shallow	Substantial
THERMODYNAMICS	Substantial	Moderate	Moderate	Moderate	Substantial	Moderate	Moderate	Substantial	Substantial	Shallow	Substantial
PROPULSION	Substantial	Moderate	Substantial	Substantial	Substantial	Substantial	Substantial	Moderate	Substantial	Moderate	Substantial
STRUCTURES	Substantial	Moderate	Substantial	Substantial	Substantial	Moderate	Moderate	Moderate	Substantial	Shallow	Substantial
TRAJECTORIES	Substantial	Shallow	Moderate	Moderate	Substantial	Substantial	Moderate	Substantial	Substantial	Substantial	Substantial
RECOVERY	Substantial	Moderate	NA	NA	Substantial	Shallow	Shallow	Shallow	Substantial	Shallow	Shallow
SEPARATION	Substantial	Moderate	Moderate	Moderate	Substantial	Shallow	Shallow	Substantial	Substantial	Shallow	Substantial
ABORT	Substantial	Shallow	Moderate	Moderate	Substantial	Shallow	Shallow	Moderate	Substantial	Shallow	Substantial
OPERATIONS	Substantial	Moderate	Moderate	Moderate	Substantial	Substantial	Substantial	Substantial	Substantial	Moderate	Substantial
COSTS	Substantial	Moderate	Substantial	Substantial	Substantial	Moderate	Shallow	Substantial	Substantial	Substantial	Substantial

*SMALL ORBITER BOOSTER SYSTEMS EXTRAPOLATED EXCEPT FOR SOME TRAJECTORY ANALYSIS

MCDONNELL DOUGLAS CORPORATION
TRW

SYSTEM COST COMPARISON



MCDONNELL DOUGLAS CORPORATION
TRW

RECOMMENDATIONS

ABORT

- INCORPORATE PAD ABORT AND HIGH q SEPARATION CAPABILITY IN BASELINE
- COMPREHENSIVE GROUND TEST OF ABORT SYSTEMS – NO MANNED ABORT VERTICAL FLIGHT TESTS – IF UNMANNED FLIGHT TESTING INCORPORATED, THEN INCLUDE LIMITED DEMONSTRATION

ORBITER THRUST LEVEL

- RETAIN 3 ENGINES AT 470 K LB VACUUM THRUST

PAYLOAD SIZE & WEIGHT

- RETAIN 15' x 60' AND 65K EAST

BOOSTER SYSTEM SELECTION

- TWIN SRM WITH THRUST TERMINATION AND WATER RECOVERY IS FIRST CHOICE
  - LOWEST RDT&E COST
  - LOWEST TECHNICAL RISK
- F-1 PUMP FED SYSTEM NEXT BEST CHOICE

MCDONNELL DOUGLAS CORPORATION
TRW SYSTEMS GROUP

MAIN CONTENDERS WITH UPDATED CAPABILITIES

1-423A

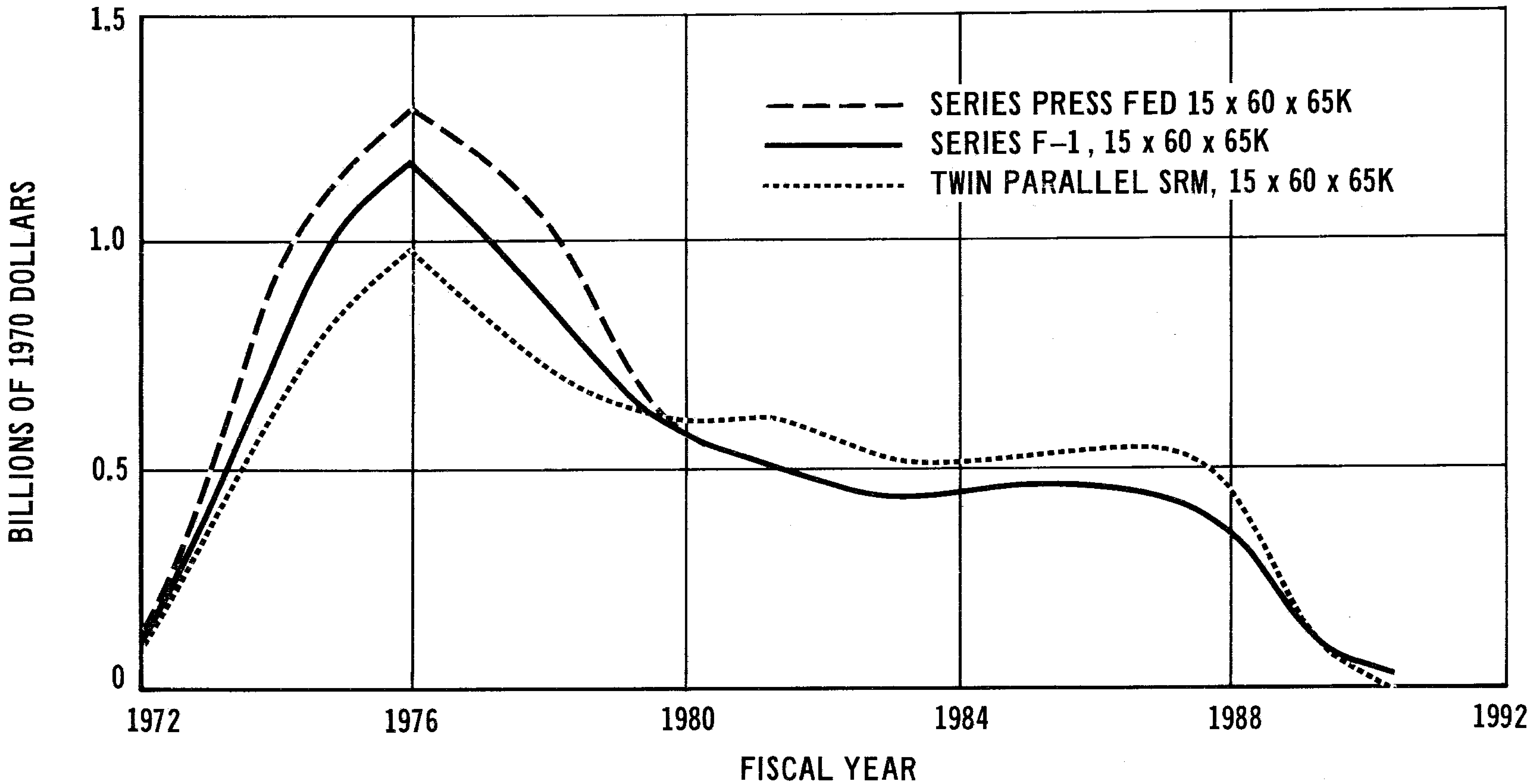
- OFF-THE-PAD ABORT CAPABILITY
- RECOVERABLE BOOSTERS
- LARGE ORBITER, 15 x 60 BAY
- ORBITER ENGINES: 3-470 K LB

	SERIES BURN		PARALLEL BURN
	PRESSURE FED	PUMP FED F-1	TWIN 156 IN SRM
WEIGHTS (K LB)			
PAYLOAD (EAST)	65.0	65.0	65.0
GLOW	5930.9	4573.4	4617.1
OLOW	1578.3	1401.7	1967.7
USABLE PROP	1224.2	1052.6	1608.1
ORBITER DRY	153.4	153.4	153.5
TANK DRY	59.3	54.7	66.0
BLOW	4352.6	3171.8	2649.4
USABLE PROP	3512.9	2740.7	2 x 1148.5
BOOSTER DRY	744.5	374.0	2 x 176.2
REL STAGING VEL (FPS)	4000.0	5000.0	4000.0
(T/W)1 / (T / W)2	1.35/0.913	1.35/1.031	1.405/0.905
COSTS ($ M)			
TOTAL PROGRAM	11,048	10,230	9,816
RDT&E	5,803	5,135	4,313
PEAK FUNDING (YR)	1,299 (76)	1,165 (76)	988 (76)
PER FLIGHT (TOTAL)	7.53	7.58	9.49
OPERATIONS	4.65	5.17	3.80
TANKS	1.39	1.30	1.51
EXPN'D BOOSTER HDWRE	1.49	1.11	4.18

MCDONNELL DOUGLAS
TRW SYSTEMS GROUP
CORPORATION

FUNDING COMPARISONS

New Baselines



MCDONNELL DOUGLAS
TRW
CORPORATION

EFFECTS OF INFLATION AND FEE ON COSTS

1–410 B

Millions of Dollars

		BASELINE $(1970) W/O FEE	$(1971) INCLUDING FEE	ESCALATED AT 3%/YR INCLUDING FEE	ESCALATED AT 6%/YR INCLUDING FEE
TWIN PARALLEL SRM	RDT&E	4313	4894	5638	6593
	PAF (76)	988	1121	1301	1501
SERIES P.F.	RDTE	5803	6582	7612	8784
	PAF (76)	1299	1474	1708	1973
SERIES F–1	RDT&E	5135	5825	6720	7736
	PAF (76)	1165	1322	1532	1770

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