ORBITER OMS AND RCS TECHNOLOGY

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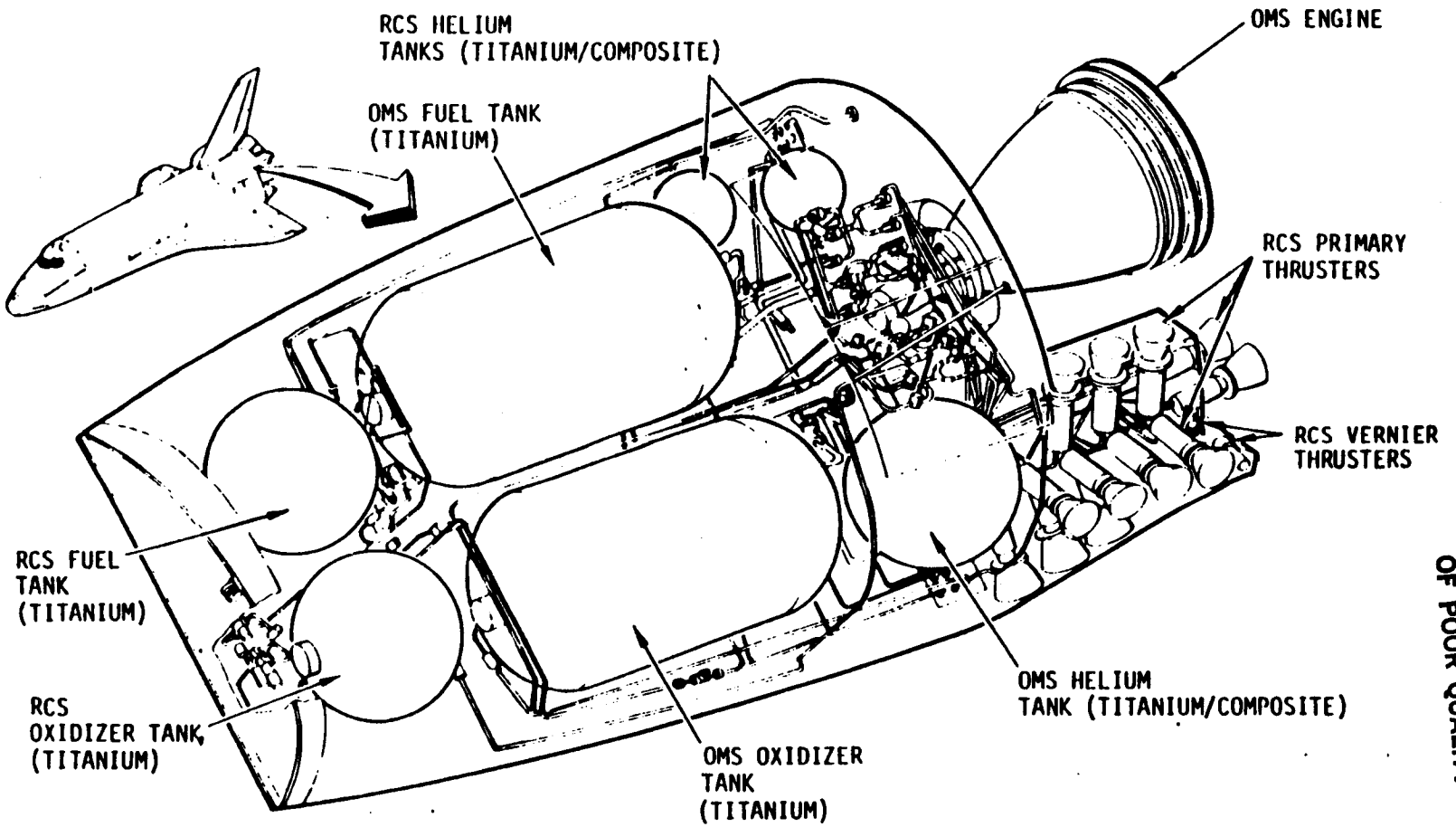
ORBITAL MANEUVER SUBSYSTEM



INTRODUCTION

- ORBITER OMS AND RCS TANKAGE HAS BEEN HIGHLY SUCCESSFUL IN SHUTTLE FLIGHTS AS OF THIS WRITING (STS-1, 2, AND 3)
- OMS AND RCS TECHNOLOGY HAS PROVIDED A SUBSTANTIAL BASIS FOR FUTURE USES OF STORABLE PROPELLANTS
  - UNDERSTANDING OF FLUID MECHANICS AND SCREEN FUNCTION
  - SYNTHESIS OF LIGHT WEIGHT SUPPORT AND SCREEN STRUCTURES
  - TANK QUALIFICATION IN HOSTILE ENVIRONMENTS
  - SUCCESSFUL FLIGHT DEMONSTRATION OF FUNDAMENTAL MODES OF OPERATION -- TRANSLATION MANEUVERS AND REACTION CONTROL
- REMAINING TECHNOLOGY UNEXPLORED BY OMS AND RCS APPLICATIONS IS CENTERED ON ON-ORBIT PROPELLANT TRANSFER

OMS PROPELLANT TANKS

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OMS PROPELLANT ACQUISITION SYSTEM

PURPOSE

- TO MAINTAIN PROPELLANT AT TANK OUTLET UNDER ZERO G CONDITIONS AND THEREBY ALLOW INITIAL FLOW TO START THE ENGINE; ALLOW PROPELLANT USAGE BY RCS UNDER LOW G

CHARACTERISTICS

- PROVIDE PROPELLANTS, FREE OF UNDISSOLVED PRESSURANT GAS/PROPELLANT VAPOR, TO THE OMS/RCS ENGINES
- PROVIDE CAPABILITY OF 10 OMS STARTS WITHOUT PROPELLANT SETTLING
- PROVIDE 454 KG (1000 LBS) OF PROPELLANT TO THE RCS PER TANK SET
- MAXIMUM STARTUP FLOW RATES KG/SEC (LBS/SEC)

	NTO	MMH
• OMS POD (1 ENGINE/FEED)	5.41 KG/SEC (11.93 LBS/SEC)	3.28 KG/SEC (7.23 LBS/SEC)
• RCS POD (7 THRUSTER/FEED)	5.87 KG/SEC (12.95 LBS/SEC)	3.68 KG/SEC (8.12 LBS/SEC)
• MINIMUM PROPELLANT (START WITHOUT RCS ULLAGE BURN)	377 KG (831 LBS)	289 KG (504 LBS)

- WEIGHT: 17.7 KG (38.9 LBS)
- TOTAL PER VEHICLE: 4

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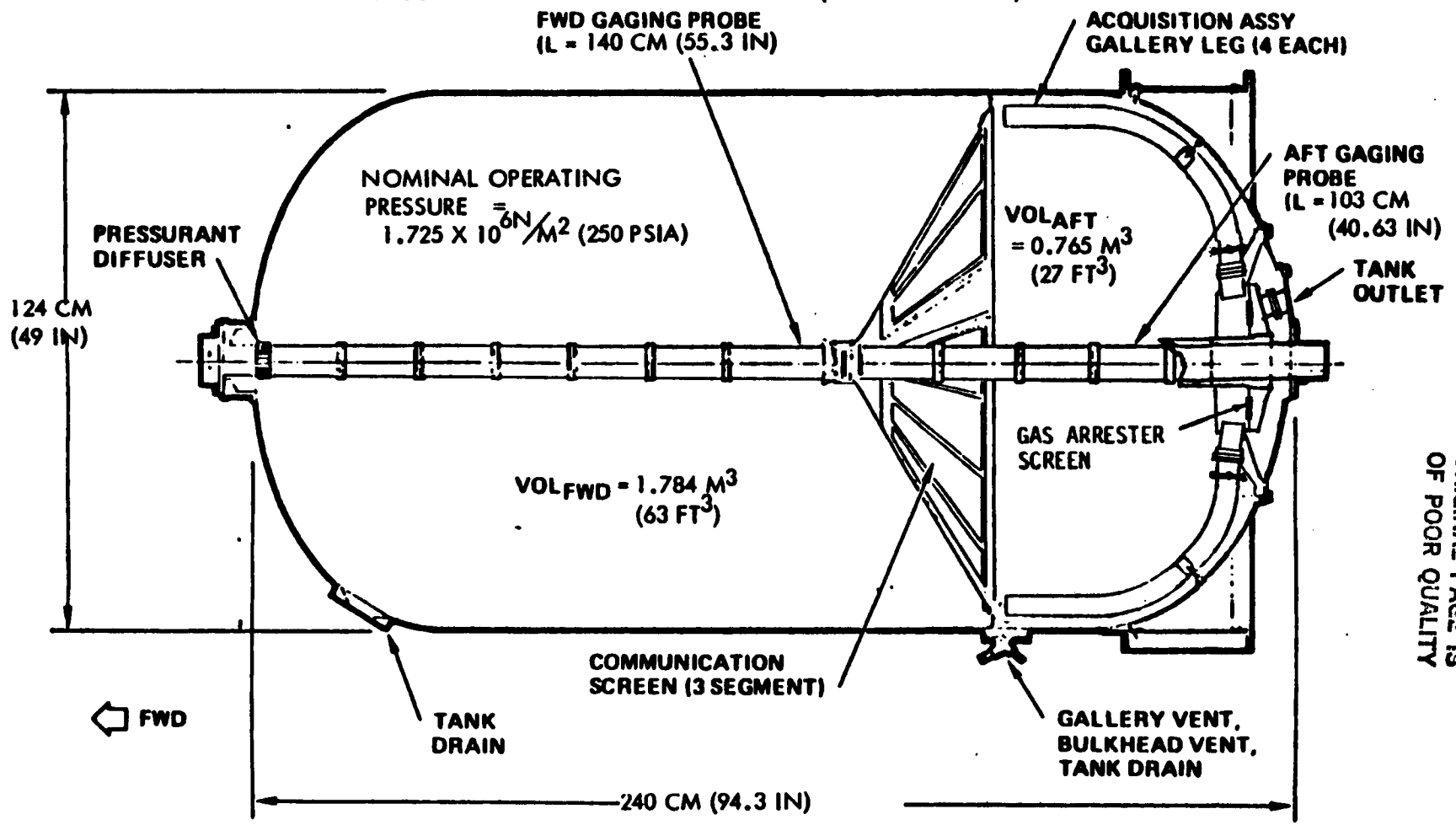
LAUNCH MINUS 2 DAY REVIEW
OMS PROPELLANT TANK CONFIGURATION

SUPPLIER: MCDONNELL ASTRONAUTICS COMPANY, EAST (TANK ASSEMBLY)
AEROJET MANUFACTURING COMPANY (PRESSURE VESSEL)



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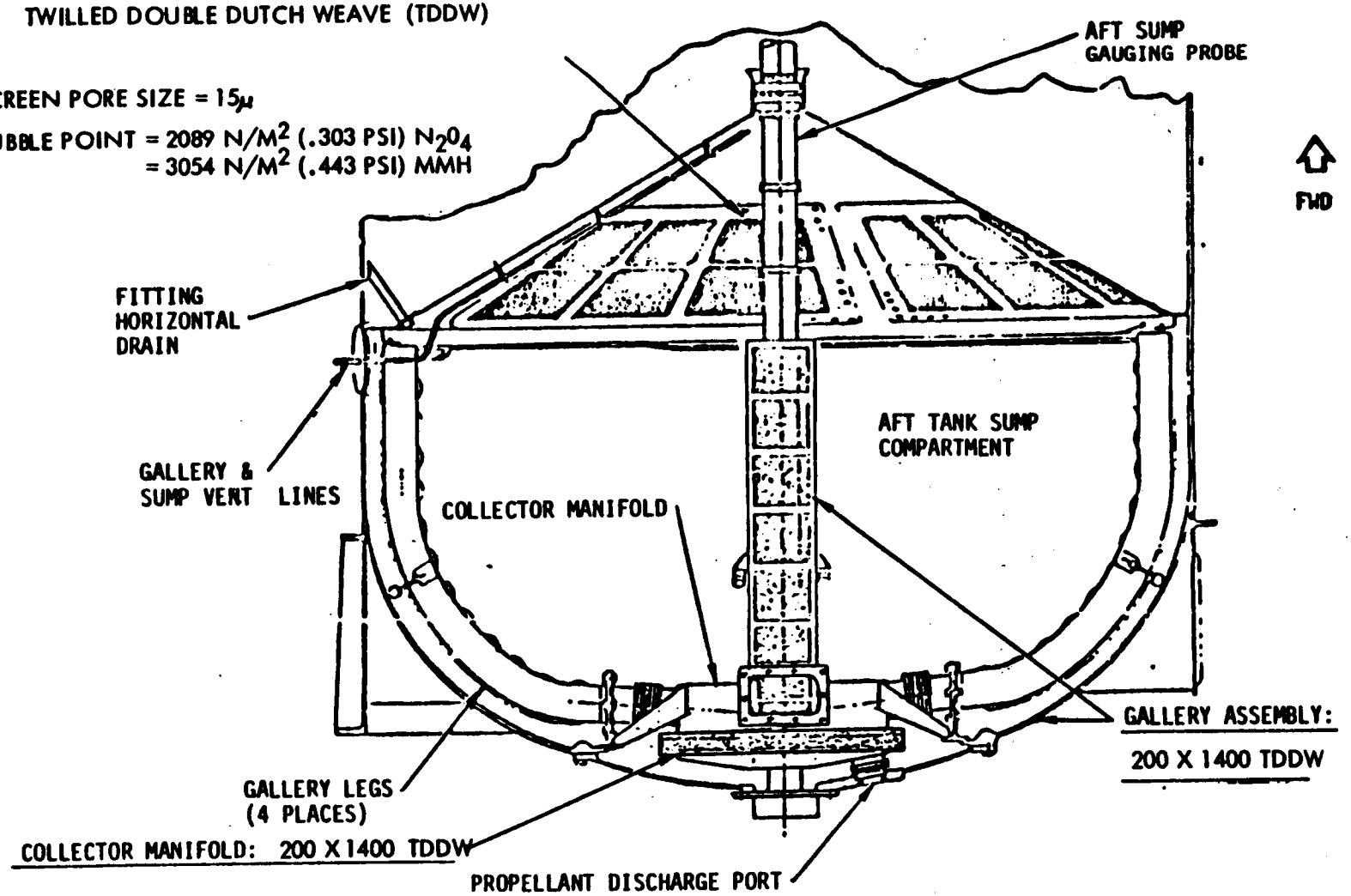
PROPELLANT ACQUISITION SYSTEM

COMMUNICATION SCREEN: 200 X 1400
TWILLED DOUBLE DUTCH WEAVE (TDDW)

SCREEN PORE SIZE = 15μ

BUBBLE POINT = 2089 N/M^2 (.303 PSI) N_2O_4
= 3054 N/M^2 (.443 PSI) MMH



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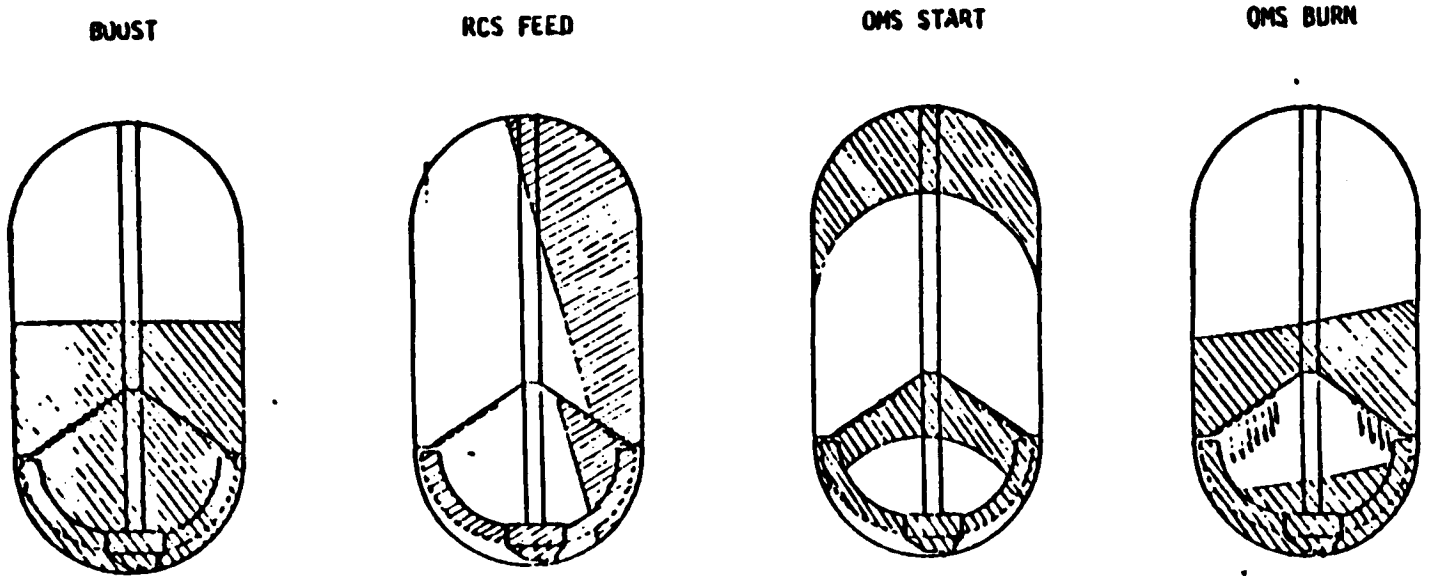
OMS PROPELLANT ACQUISITION SYSTEM OPERATING MODES



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OMS PROPELLANT TANKS
ACQUISITION SYSTEM DEVELOPMENT

- KEY PROBLEMS ENCOUNTERED
  - FAILURE OF PLAIN DUTCH SQUARE WEAVE SCREEN DURING VIBRATION TESTING
    - COINING AT EDGE OF SCREEN PANEL REDUCED WIRE CROSS-SECTION AND THEREFORE FATIGUE LIFE
  - EXCESSIVE NUMBER OF IN PROCESS REPAIRS
    - STRESS RELIEF OF TI WELDS OVER-STRESSED SCREENS
- SOLUTIONS
  - ELIMINATED COINING AND EMPLOYED STRONGER TDDW
  - REVISED FABRICATION PROCESS TO ELIMINATE STRESS RELIEF AFTER SCREEN PANEL INSTALLATION

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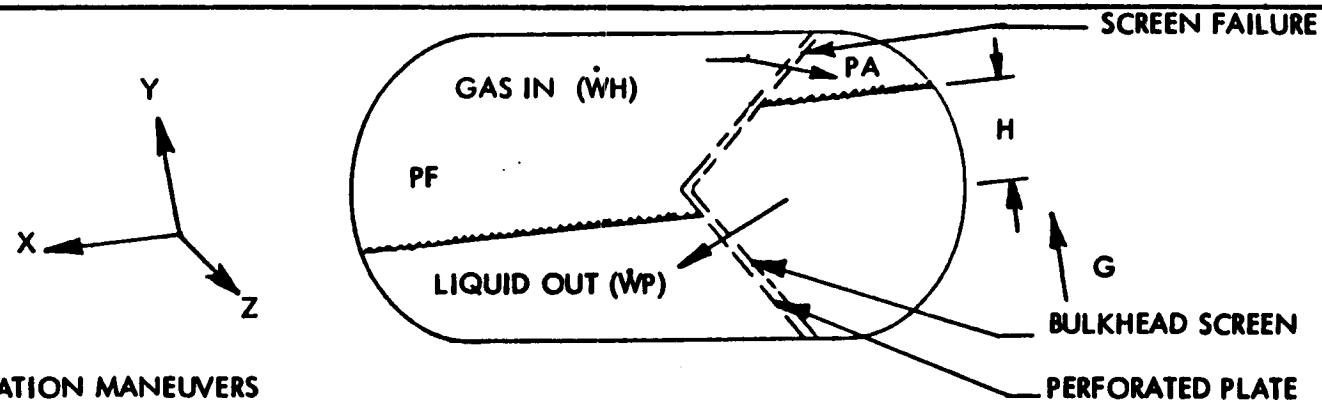
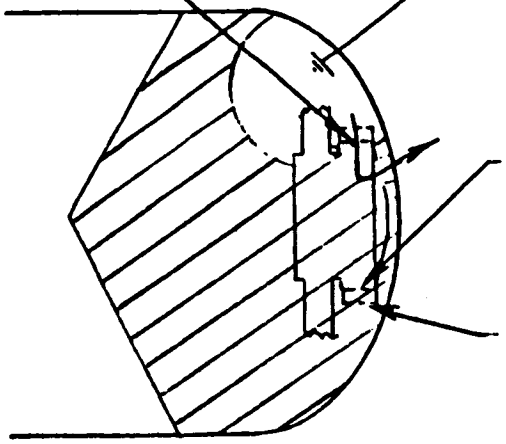
EFFECT OF BULKHEAD SCREEN FAILURE
TRANSLATION MANEUVERS



- Y, Z TRANSLATION MANEUVERS
  - A HEAD DIFFERENCE (H) IS ESTABLISHED BETWEEN THE FORWARD AND AFT TANK COMPARTMENTS DEPENDING ON THE RELATIVE QUANTITIES
  - LIQUID CAN FLOW OUT OF THE AFT COMPARTMENT ONLY AS FAST AS ITS VOLUME IS REPLACED BY IN FLOW OF HELIUM
  - HELIUM IN FLOW IS A FUNCTION OF THE EFFECTIVE FLOW AREA AND PRESSURE DIFFERENTIAL
  - MAXIMUM ΔP IS 2068 N/M^2 (0.3 PSI) AND DECREASES AS THE PROPELLANT IS TRANSFERRED. THEREFORE, PROPELLANT IS TRANSFERRED AT A RELATIVELY SLOW RATE, EVEN WITH SIGNIFICANT SCREEN FAILURES
- -X TRANSLATION MANEUVERS
  - HEAD EFFECTS EVEN LESS SEVERE
- RESULTING EFFECTS
  - CREDIBLE SCREEN FAILURES WILL RESULT IN LITTLE PROPELLANT TRANSFER
  - ENGINE RESTARTS NOT AFFECTED

- FAILURE



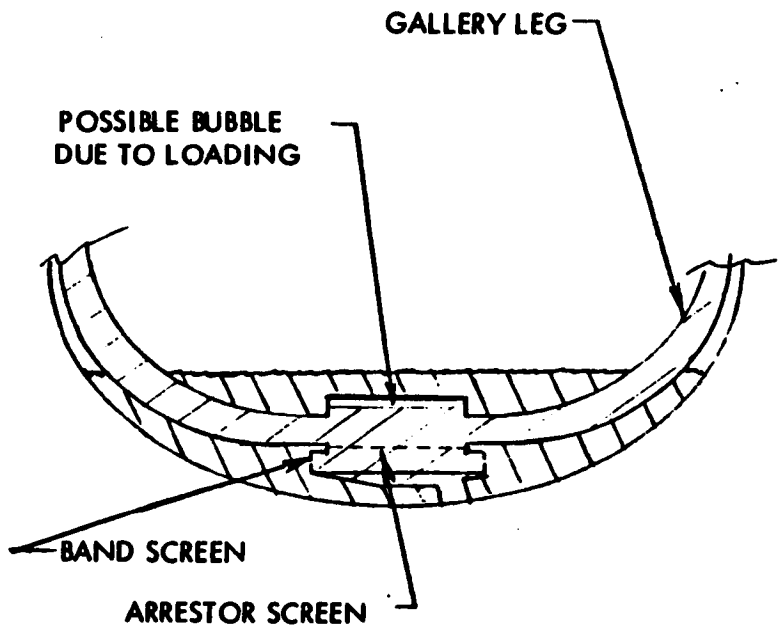
MAXIMUM BUBBLE DUE TO 4 OME STARTS (WITH PROPELLANT AT FAR END OF TANK) AND 99.8 KG (220 LBS) OMS/RCS USAGE IS 0.156 M^3 (5.5 FT^3) AFT COMPARTMENT IS 0.765 M^3 (27 FT^3)

BAND SCREEN - PROTECTS AGAINST START DYNAMICS AND STEADY STATE G LEVELS

PERFORATED PLATE - PROTECTS AGAINST STEADY STATE G LEVELS

- EFFECT OF FAILURE - MINOR
  - IF BUBBLE IS ADJACENT TO FAILED AREA DURING PROPELLANT SLOSH, SOME BUBBLES WILL BE PULLED IN TO FEED SYSTEM DURING INITIAL START TRANSIENTS
  - MAY RESULT IN A SHORT PERIOD ($\approx$ 0.5 SEC) OF 2 PHASE FLOW ACCEPTABLE TO OMS ENGINE

EFFECT OF GAS ARRESTOR SCREEN FAILURE



- FUNCTION
  - KEEPS BUBBLE IN GALLERY LEG SECTION
  - GALLERY SCREENS BREAK DOWN AS TANK EMPTIES
  - ARRESTOR SCREEN PREVENTS GAS FROM ENTERING SYSTEM UNTIL BAND SCREEN UNCOVERED

- EFFECT OF FAILURE - MINOR
  - SYSTEM HAS BEEN QUALIFIED FOR BUBBLE SIZES LARGER THAN THOSE EXPECTED FROM LOADING
  - EXPULSION EFFICIENCY DEGRADED BY 1%

OMS ACQUISITION SYSTEM VERIFICATION HISTORY

SCREEN PANEL TESTS BUBBLE PT., WICKING/DEWICKING, FLOW ΔP, COMPATIBILITY STAINLESS STEEL SCREEN/TI FOIL WELD, REDUCED B.P. WITH N_2O_4 SCREEN REPAIR TECHNIQUE	4/74 - 7/76
ACQUISITION ASSEMBLY, REDUCED SCALE SETTLING DYN., FLUID CONTAINMENT W/OUTFLOW	8/75 - 4/76
ACQUISITION ASSEMBLY, FULL SCALE, SIM TANK SYSTEM PERFORMANCE, SCREEN CONTAINMENT WITH VIB. FLOW TRANSIENT GAS INGESTION	10/75 - 4/77 (GRD)
KC-135 LOW-G TESTS	4/77 - 8/77 (FLT)
ONE-HALF SCALE TANK, KC-135 LOW-G TESTS	3/76 - 7/76
TANK QUAL (TANK #2) ACCEL, SHOCK, TRANSIENT, RANDOM VIB.	4/78 - 7/79
6 MISSION SHOCK/VIB TANK TESTS	7/79 - 10/79
100 MISSION SHOCK/VIB TANK TESTS	10/79 - 5/80
AFA 26 ACOUSTIC FATIGUE TESTS	4/80 - 7/81

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FLIGHT USAGE OF OMS PROPELLANT

	PROPELLANT QUANTITY (OX + FU)											
	STS-1				STS-2				STS-3			
	L POD		R POD		L POD		R POD		L POD		R POD	
	KG	LB	KG	LB	KG	LB	KG	LB	KG	LB	KG	LB
PROPELLANT LOADED (IN TANKS)	3876	8546	4258	9388	3911	8622	4201	9263	4018	8858	3999	8818
PROPELLANT USED BY OMS												
OMS-1 BURN	759	1674	751	1655	681	1501	680	1499	742	1635	745	1643
OMS-2 BURN	660	1455	649	1431	611	1346	611	1346	767	1692	771	1700
OMS-3 BURN	240	530	-	-	-	-	-	-	-	-	-	-
OMS-3A BURN	-	-	-	-	108	238	-	-	135	298	-	-
OMS-3B BURN	-	-	-	-	216	476	-	-				
OMS-4 BURN	-	-	281	619	186	410	152	335	-	-	-	-
DEORBIT	1362	3002	1338	2950	1507	3322	1508	3326	1280	2822	1287	2838
OMS PROPELLANT USED BY RCS	328	723	231	510	19	42	79	174	539	1188	507	1117
TOTAL USED	3349	7384	3250	7165	3328	7335	3030	6690	3463	7635	3310	7298
RESIDUAL	527	1162	1008	2223	583	1287	1171	2573	555	1223	689	1520

TOTAL PROPELLANT USED FROM

LEFT POD TANKS	10,140 Kg (22,354 LB)
RIGHT POD TANKS	9,595 Kg (21,153 LB)

OMS PROPELLANT TANK CERTIFICATION STATUS

- DEVELOPMENT AND QUALIFICATION PROGRAMS HAVE BEEN SUCCESSFULLY COMPLETED
  - CERTIFICATION COMPLETED FOR PERFORMANCE, STRUCTURAL INTEGRITY, LIFE, AND SERVICABILITY FOR ACQUISITION SYSTEM AND PRESSURE VESSEL
  - FURTHER ANALYSIS REQUIRED FOR TANK SKIRT FATIGUE LIFE PENDING DEFINITION OF LOAD SPECTRUM

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RCS PROPELLANT TANKS

RCS TANK FUNCTION AND OPERATIONAL REQUIREMENTS

SERVICING

- FILL TANKS WHILE INSTALLED IN ORBITER ON LAUNCH PAD
  - PROVIDE GAS ULLAGE FOR THERMAL EXCURSIONS
- PROVIDE CAPABILITY TO LAUNCH OFF LOADED
  - FRCS TO 59% OF CAPACITY
  - ARCS TO 65% OF CAPACITY

BOOST REQUIREMENT

- WITHSTAND 100 MISSIONS OF BOOST RANDOM VIBRATION AND LIFTOFF TWANG
- ARCS TANK PROPELLANT BURN-OFF TO 65% DURING POWERED BOOST PHASE

RCS CONTROL OPERATION

- PROVIDE GAS FREE PROPELLANT DURING ANY COMBINATION OF THRUSTER STEADY STATE OR PULSE OPERATION DURING EXPOSURE TO OMNIDIRECTIONAL ACCELERATION FIELDS
- MATED COAST/EXTERNAL TANK SEPARATION
  - NORMAL MISSION 2.8 L/SEC (45 GPM)
  - RETURN TO LAUNCH SITE - 3.4 L/SEC (54 GPM) FRCS AND 4.0 L/SEC (63 GPM) ARCS
- ON-ORBIT
  - FRCS - 2.8 L/SEC (45 GPM) - 92% EXPULSION EFFICIENCY
  - ARCS - 4.0 L/SEC (63 GPM) - 68% EXPULSION EFFICIENCY
- ENTRY - ARCS ONLY
  - LOW G - 2.8 L/SEC (45 GPM) TO 72% EXPULSION
  - LOW G - 2.3 L/SEC (36 GPM) TO 76% EXPULSION
  - HIGH G - 2.3 L/SEC (36 GPM) TO 98% EXPULSION EFFICIENCY

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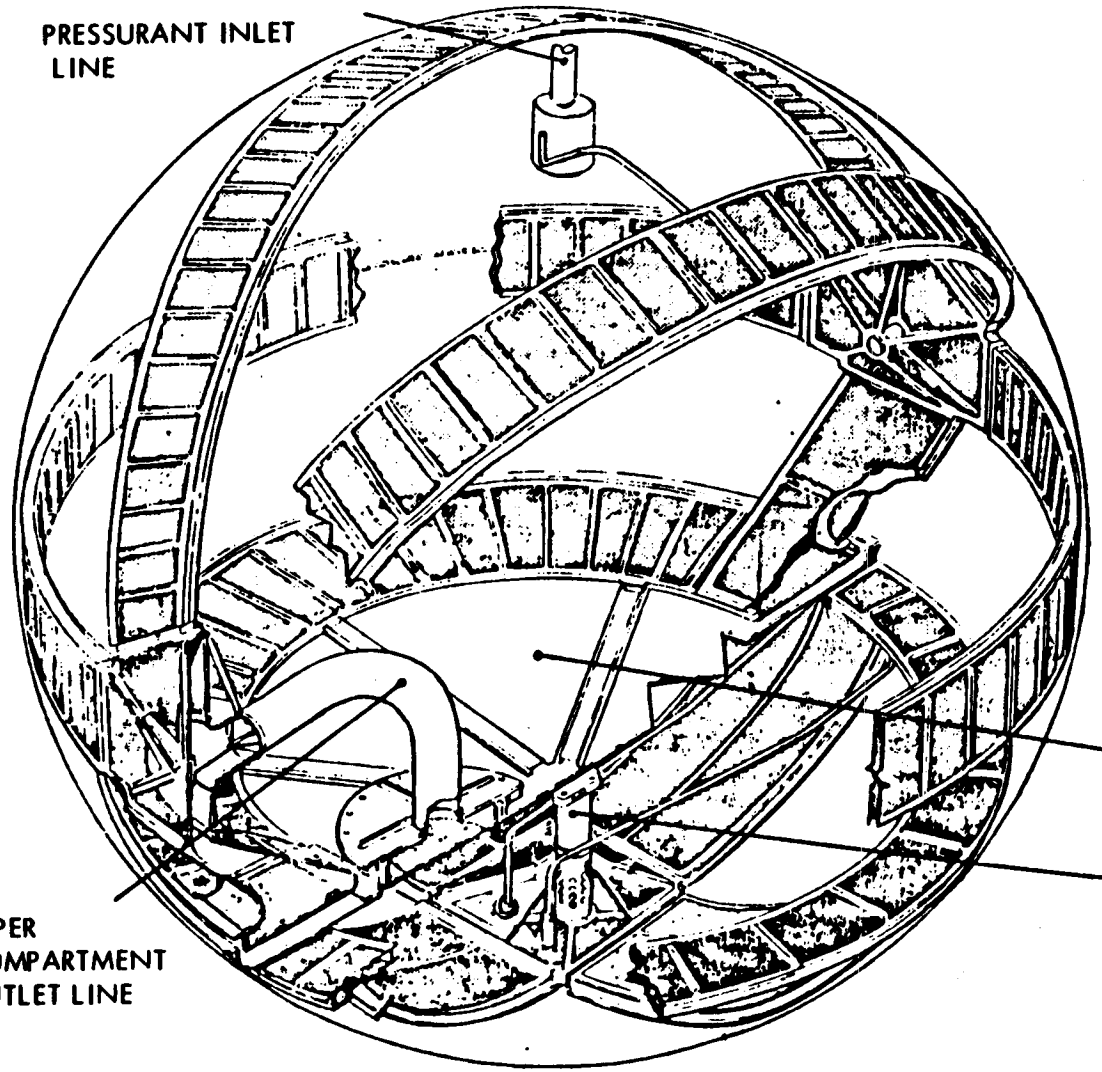
FORWARD REACTION CONTROL SYSTEM PROPELLANT TANK



.99M (39 IN) SPHERICAL DIAMETER 6AL-4V TITANIUM SHELL

- OPERATING PRESSURE
  - 1.675×10^6 N/M^2 (243 PSIA) NOM.
  - 2.413×10^6 N/M^2 (350 PSIA) MAX.
  - 200 PRESSURE CYCLE LIFE
- CAPACITY
  - N_2O_4 - 675 KG (1488 LBS)
  - MMH - 422 KG (930 LBS)
  - N_2H_4 - 491 KG (1082 LBS)

STAINLESS STEEL PAD DRY WEIGHT - 32.6 KG (72 LBS)

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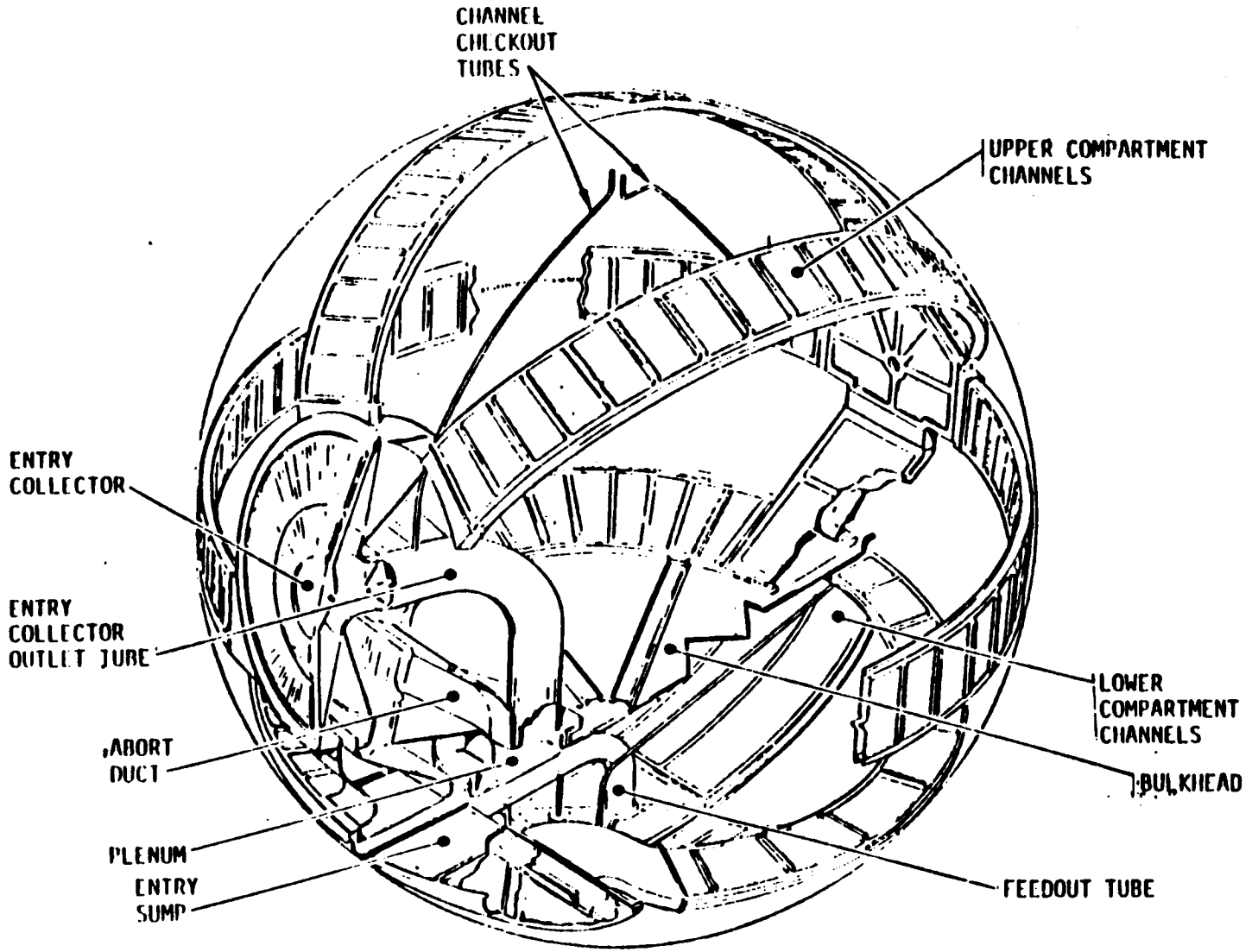
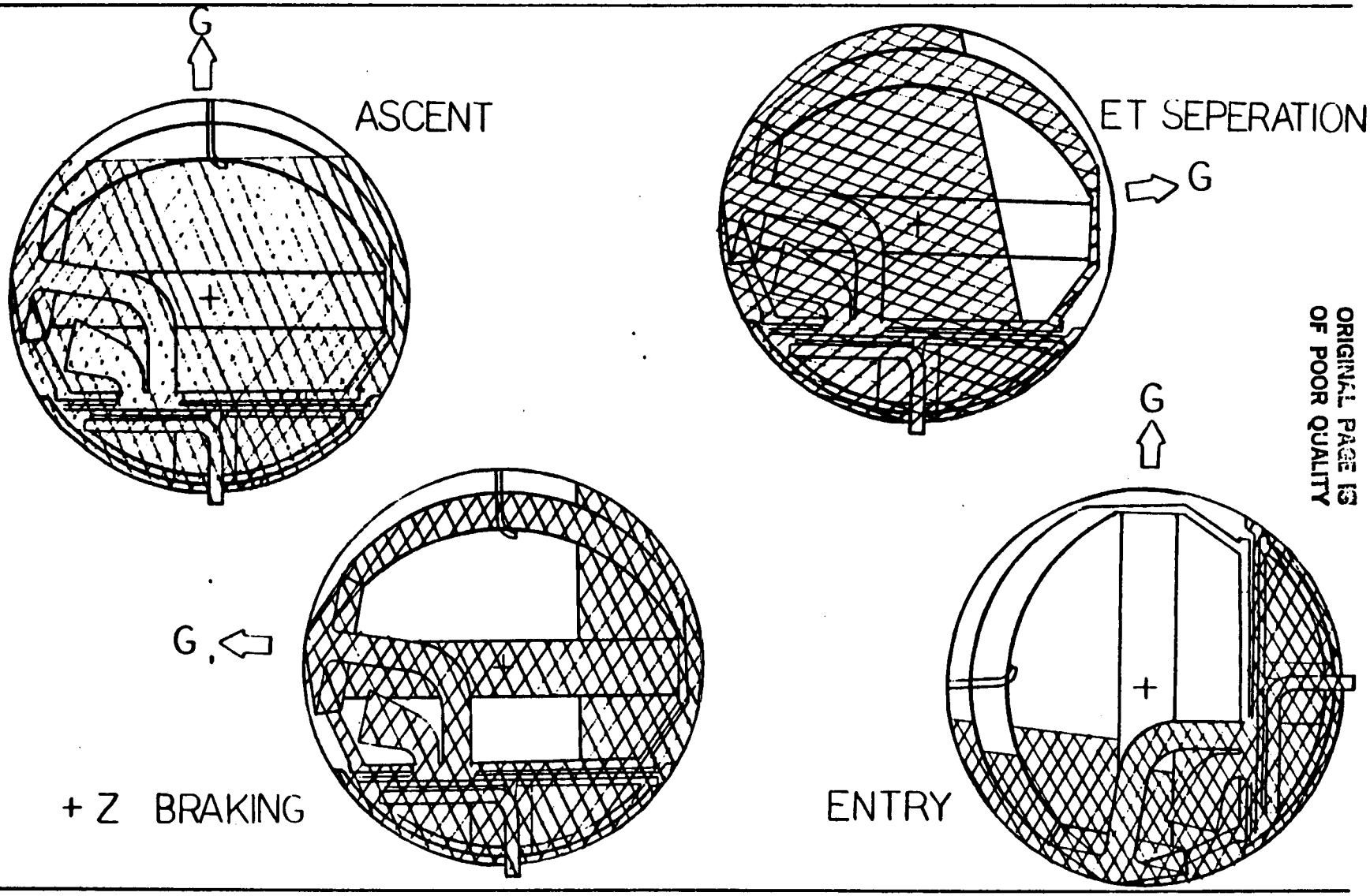
AFT REACTION CONTROL SYSTEM PROPELLANT TANK



AFT RCS TANK
PROPELLANT ORIENTATIONS



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LOW G PERFORMANCE CERTIFICATION BY ANALYSIS

- DIRECT TEST NOT FEASIBILE WITHOUT ZERO G PROPELLANT LABORATORY
- GAS FREE EXPULSION ASSURED WHEN B.P. $\geq$ (ΔP_{START} + $\Delta P_{S.S.}$) X SF
  - ΔP_{START} f(NUMBER OF THRUSTERS STARTING)
  - $\Delta P_{S.S.} = \Delta P_E + \Delta P_V + \Delta P_H + \Delta P_{VIS}$
- LIMITED OPERATION WITH GAS INGESTION PERMITTED WHEN $\Delta P_{REHEAL} > (\Delta P_{S.S.})$ X SF
- INITIAL PERFORMANCE CERTIFIED TO STEADY STATE REQUIREMENTS WITH 1.15 SF
  - MATH MODELS VALIDATED BY 1-G ELEMENT AND SUB ASSEMBLY TESTS
  - LOW-G EXPULSIONS SIMULATED BY 1-G MASKED SCREEN TESTS
- UNEXPECTED EFFECTS OF START TRANSIENT ON TANK OPERATION CAUSED CAUTION
  - SF RAISED TO 1.5
  - TOTAL GAS INGESTION LIMITED TO 164 CC (10 IN^3) PER MISSION
- MISSION REQUIREMENTS REDUCED TO ACCOMMODATE START TRANSIENT CAPABILITIES
  - LIMITED FRCS THRUSTER USAGE TO 3 (WAS) 5
  - LIMITED ARCS THRUSTER USAGE TO 5 (WAS) 7
    - REQUIRES OVERFILL OF ARCS TANKS TO KEEP GAS OUT OF LOWER COMPARTMENT

ON-ORBIT SCREEN DRYOUT

- CAUSED BY CONVECTIVE MASS TRANSFER (PRESSURANT FLOW OVER SCREENS)
- RESOLVED BY SWIRL DIFFUSER

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DEVELOPMENT OF PAD BUBBLE POINT VERIFICATION TECHNIQUE INHIBITED BY N_2O_4 SCREEN DRYOUT

- SPECIAL CONTROLS AND TECHNIQUES DEVELOPED

SCREEN REPAIR TECHNIQUES REQUIRED TO SEAL PORE OPENINGS CREATED DURING MANUFACTURING

- SILVER/TIN SOLDER USED
- MMH CONTAMINATED WITH FREON CORRODES SILVER SOLDER
- PRESENCE OF FREON CONTAMINATION QUALITATIVELY SCREENED WITH SOLDER REPAIR DOTS

PAD SENSITIVITY TO SHOCK AND VIBRATION ENVIRONMENT UNKNOWN

- UNCERTAIN DURING HANDLING, TRANSPORTATION, AND BOOST ENVIRONMENTS
- PAD STRAIN GAGED AND SUBJECTED TO QUALIFICATION TEST ENVIRONMENTS
- STRESS AND FATIGUE ANALYTICAL MODELS UPDATED BASED ON RESPONSE DATA DURING ENVIRONMENTAL TESTS

TANK GIRTH WELD AND REPAIR

- SPECIAL TESTS WERE CONDUCTED TO VERIFY WELD STRESS/STRAIN CHARACTERISTICS OF MISMATCHED WELD LANDS
- TECHNIQUES WERE DEVELOPED TO REPAIR OR REPLACE INTERNAL PAD BY CUTTING TANK APART AND REPLACEMENT OF UPPER HEMISPHERE

FLIGHT USAGE OF RCS PROPELLANT

PROPELLANT QUANTITY (OX + FU)

		STS-1			STS-2			STS-3		
		F	L	R	F	L	R	F	L	R
LOADED	KG	888	999	999	892	1001	1001	881	1000	999
	LB	(1957)	(2203)	(2203)	(1967)	(2208)	(2208)	(1943)	(2205)	(2202)
ASCENT	KG	68	68.5	40	47	65	68	58	85	83
	LB	(150)	(151)	(89)	(103)	(143)	(151)	(128)	(188)	(183)
ON-ORBIT	KG	186	102	128	202	236	209	771	333	359
	LB	(410)	(225)	(283)	(446)	(522)	(460)	(1700)	(735)	(791)
DE-ORBIT	KG	16	5.5	1.5	-	40	38	-	39	37
	LB	(36)	(12)	(3)	-	(88)	(84)	-	(85)	(81)
FRCS DUMP	KG	-	-	-	517	-	-	78	-	-
	LB	-	-	-	(1141)	-	-	(172)	-	-
ENTRY	KG	-	243	228.5	-	413	418	-	261	260
	LB	-	(535)	(503)	-	(910)	(922)	-	(575)	(574)
TOTAL	KG	270	419	398	766	754	733	907	718	739
	LB	(596)	(923)	(878)	(1690)	(1663)	(1617)	(2000)	(1583)	(1629)
BUDGETED	KG	218	312	316	445	516	561	779	958	950
	LB	(480)	(689)	(697)	(982)	(1137)	(1237)	(1718)	(2112)	(2095)

RCS PROPELLANT TANK
CERTIFICATION STATUS

STRUCTURAL QUALIFICATION

- TANK SHELLS QUALIFIED FOR 100 MISSION LIFE
- OV-102 PAD QUALIFIED FOR 17 MISSION LIFE
- OV-099 AND SUBS PAD BEING QUALIFIED TO 100 MISSION LIFE
  - ARCS - JULY 1982
  - FRCS - JULY 1983

PERFORMANCE CERTIFICATION

- OV-102 TANKS CERTIFIED FOR LIMITED THRUSTER USAGE
  - FRCS 2SS + 3P
  - ARCS 1SS + 3P
    - CAN BE RECERTIFIED TO 2SS + 4P
- OV-099 AND SUBS TO BE CERTIFIED
  - FRCS - SAME AS OV-102
  - ARCS - 1SS + 5P
    - WSTF TEST - NOVEMBER 1982
    - CERTIFICATION ANALYSES - MARCH 1983

CONCLUSIONS

- SUCCESSFUL FLIGHTS OF ORBITER HAVE PROVEN THE VIABILITY OF SURFACE TENSION DEVICES FOR SHUTTLE APPLICATION

- EXTRAPOLATION TO OTHER APPLICATIONS INVOLVING STORABLE PROPELLANTS SHOULD BE A SUBSTANTIALLY EASIER TASK BECAUSE OF OMS AND RCS TECHNOLOGY

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