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PRETEST INFORMATION FOR A TEST TO VALIDATE PLUME SIMULATION PROCEDURES (FA-17)

Final Technical Report
for
Contract NAS8-32128

January 1978

By

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Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Contract NAS8-32128

FOREWORD

This memorandum presents information acquired in preparation for conducting a test to validate plume simulation procedures for Shuttle (Test FA-17). This work was performed for the Systems Dynamics Laboratory of MSFC under Contract NAS8-32128. The NASA Technical Coordinator for this work is Mr. Kenneth L. Blackwell of ED32. Appreciation is extended to Dr. W. A. Foster, Jr., of Auburn University, for the elevon balance design and analysis efforts.

CONTENTS

NOMENCLATURE

a	Absolute
AP	Ammonium perchlorate
b	Wing span
B.P.	Butt plane (corresponds to Y direction)
c.g.	Center of gravity
c.p.	Center of pressure
C_{BM}	Bending moment coefficient
C_{HM}	Hinge moment coefficient
C_N	Normal force coefficient
C_{TM}	Root torque coefficient
CTPB	Carboxyl-terminated polybutadiene
d	Differential
F_N	Normal force
F.S.	Fuselage station (corresponds to X direction)
H	Hinge line
I_X, I_Y	Moment of inertia
ICC	Interstate Commerce Commission
Id.	Identification
IML	Inner mold line
L	Left
M	Mach number
M.A.C.	Mean aerodynamic chord
O	Orbiter
O/F	Oxidizer-to-fuel flowrate ratio
OML	Outer mold line
OMS	Orbital Maneuvering System
P	Pressure
psf	Pounds per square foot
psi	Pounds per square inch
q	Dynamic pressure
r	Radius
R	Right
Re	Reynolds number
RI	Rockwell International
T	Temperature
U_{XY}	Product of inertia
W.P.	Water plane (corresponds to Z direction)
X, Y, Z	Orthogonal directions
α	Angle of attack
γ	Ratio of specific heats
δ_e	Elevon deflection angle
δ_j	Plume initial expansion angle (see Fig. 1)

Subscripts

b	Base
c	Chamber
e	Elevon
i	Inboard
o, O	Orbiter, Outboard
p	OMS pod
t	Total
T	Tank
∞	Freestream
*	Throat

1. INTRODUCTION

The Space Shuttle Launch Vehicle (SSLV) configuration exhibits significant interaction between the main propulsion plumes and the vehicle aerodynamics. Exhaust plumes from the Space Shuttle Main Engines (SSME) and Solid Rocket Boosters (SRB) interact among themselves and with the external flowfield. This interaction establishes the base environment on the Orbiter, SRB, and External Tank (ET); affects aerodynamic stability and control (via flow separation); and affects the aerodynamic control surface effectiveness.

A comprehensive study keyed to analysis of well-chosen experiments has been in progress for some time, Ref. 1. The ultimate goal is to base the SSLV aerodynamics upon measured values from a subscale model test in a wind tunnel, while using proper simulation of the propulsion plumes. To meet that goal requires validation of this simulation procedure.

Simulation of a model to a prototype plume has been considered by many (Refs. 2-13), and it appears sufficient to match shape and edge viscous effects, Fig. 1. A simple concept to achieve this match would use a geometrically scaled nozzle flowing the prototype plume gas. However, matching of γ and temperature is not available at this time by means other than use of subscale rockets. It would have been very complicated and expensive to base the complete SSLV development program on such subscale rockets. Therefore, a simpler technique was sought; use air jets and match some appropriate simulation criteria. Review of prior work indicated that matching Herron's parameters (Ref. 10) might be adequate simulation.

An investigatory test (MA-10F) initiated the experimental effort in mid 1973. Subsequently, an extensive program has been performed. The bulk of testing has involved a simple ogive-cylinder body, with limited investigations of the SRB flare effect and the SRB+ET combination. Parallel to the experiments has been analytical effort aimed at verifying the applicability of Herron's parameters (Ref. 10), especially δ_j, or finding other adequate correlators (Refs. 14, 15).

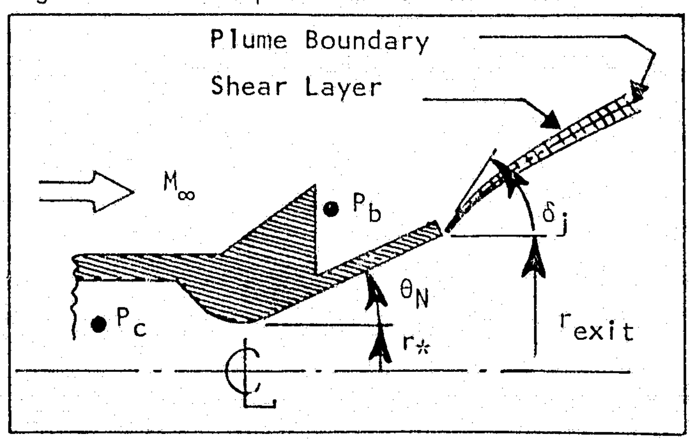


Fig. 1 Plume Geometry

More recently the parameter $\delta_j \gamma^{\xi}$ (where ξ is a function of M_∞) has been recommended to provide adequate correlation between gas-only and solid-propellant exhaust (Ref. 16).

This memo presents the results of an effort to plan a final verification wind tunnel test (FA17) to validate the recommended correlation parameters and application techniques. The test planning effort is complete except for test site finalization and the associated coordination. Two suitable test sites are identified. Desired test conditions are shown in Table 1. Subsequent sections of this memo present the selected model and test site, instrumentation of this model, planned test operations, and some concluding remarks.

TABLE 1. DESIRED TEST CONDITIONS

α	M_∞			
	0.9	1.0	1.2	1.4
-4°	Nom. + Add'l.	Nom.	Nom. + Add'l.	Nom.
0°	Nom.		Nom.	
+4°	Nom.		Nom.	

where

"Nom." = nominal value of δ_e, probably to be consistent with Test IA 119A and
"Add'l."= an additional value of δ_e.

2. MODEL DESCRIPTION

For this test program, the model must simulate all SSLV ascent propulsion plumes while maintaining geometric similitude to the SSLV vehicle shape. The effect of these ambitious constraints upon model selection are detailed in the first section below, followed by description of the physical and operational aspects of the selected model.

2.1 Selection - There are two basic approaches generally available: either adapt existing hardware to the specific needs of the contemplated test, or build new test-specific hardware. Both approaches were considered. The desired model features were:

1. Match external mold lines of SSLV ascent configuration.
2. Simulate hot, reacting exhausts of SSLV ascent configuration:
    a. SSME - O_2/H_2 at $P_C \approx 3000$ psia, $T_C \approx$ XXXX°R
    b. SRB - 16% Aℓ solid propellant @ $P_C \approx 600$ psia, $T_C \approx$ XXXX°R
3. Match P_C/P_∞ in transonic range.

The existing models that might be considered are of three general categories. First are those built under MSFC initiative for the plume technology program. Those described in Refs. 17 - 19 feature plume simulation via cold or warm (1000 °R) gas, and model shapes that are only generally similar to SSLV. Those described in Refs. 20 and 21 have solid propellant rocket motors for either a single body (Ref. 20) or for the SRB+ET combination (Ref. 21). Second are the Rockwell International (RI) models built for vehicle aerodynamic test which match the SSLV configuration and use cold air plume simulation, Refs. 22 and 23. Third is a single model built for RI and used for base heating tests, Refs. 24 and 25. This model, denoted 19-OTS, generally matches SSLV shape and features near duplication of SSLV plumes via O_2-H_2 combustion products for SSME and solid propellants for SRB.

Most of the models in the first two categories are designed for the plume simulation gas to be supplied from a source outside the model. It was judged impractical to attempt to pipe gases at 5000° R. Moreover these models would not have adequate structural integrity for such gases. The rocket models (Refs. 20 and 21) are akin to the SRB but quite different from the SSME. Furthermore, neither is very representative of the SSLV mold lines. Therefore, all models in the first two categories were eliminated. However, the 19-OTS model appeared very attractive for this application and was selected for adaption.

This model is 2.25% scale, and is very close to the current SSLV configuration except that the ET is one diameter longer and the O/ET attachment structure is not to scale; it has about 0.6 sq. ft. of frontal area. The plume simulation operates at 50% of nominal flight P_c values, for 30 - 60 msec. For this size model to present only 0.5% blockage requires a tunnel of 120 sq. ft. cross-section. A 0.5% blockage value is suggested as appropriate for transonic testing, especially when considering that the plumes increase the effective blockage. The available model P_c level would require a variable-density tunnel to match flight values of P_c/P_∞. The impact of the short duration of plume simulation upon instrumentation is detailed in Section 4, below. The impact of the overlong ET is discussed in Section 6, below.

Consideration was also given to building new test-specific hardware. Three features of such a new model could be more attractive than the 19-OTS model:

1. Smaller size so that a smaller, less expensive tunnel could be used.
2. Higher P_c so that a variable density tunnel would not be needed.
3. A simpler SSME simulation might be devised - probably a solid propellant rocket.

Investigation of these ideas did not indicate that a new model would be justified. First, it was assumed that any new model would cost at least as much as duplicating the current 19-OTS model. Although the new smaller model would use less material, considerable engineering effort would be required to design any smaller O_2/H_2 valving or alternate SSME simulation technique. Such a cost would probably not be recovered from tunnel costs savings for any foreseeable test program even if the new model were small enough to be tested in 4x4 or 6x6 foot tunnels. Moreover a 50% reduction (which might fit a 6x6 foot tunnel) would likely result in a significant reduction of plume simulation duration, probably as much as 50%. Although a duration of 30 msec is probably acceptable, 15 msec is probably not - see Section 4 below. Therefore, a smaller model was eliminated from further consideration.

Second, the provision of higher P_c was investigated. If such could be incorporated into the extant 19-OTS then a real savings could be realized. However, it was evident that this model was designed for the current pressure levels, and a factor of 2 increase could not be applied without complete redesign. Thus higher P_C would mean a new model. As above, the cost of a new model could not be expected to be recovered from tunnel cost savings. Third, a simpler (i.e., solid propellant) SSME simulation would not be worthwhile by itself, but only in combination with either a smaller model and/or higher P_C capabilities. The high P_C capability would be for 3000 psia, and satisfactory current solid propellant model technology is not known. Therefore, further consideration of any new model was terminated.

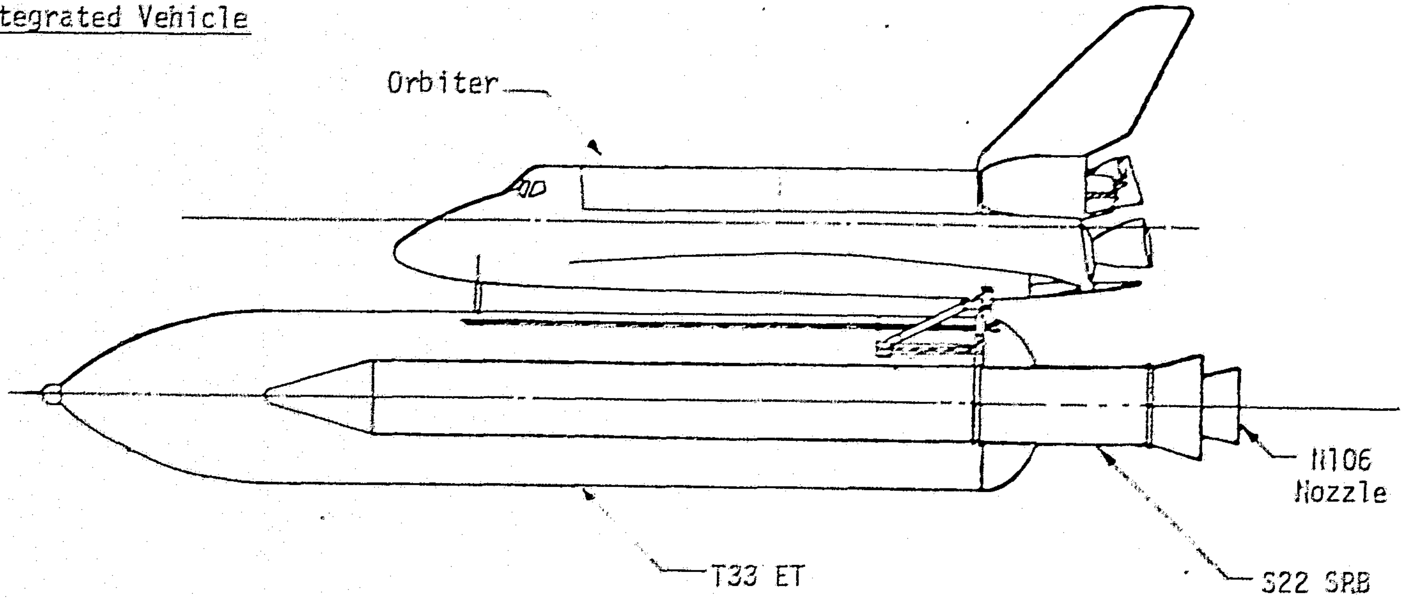
Thus the 19-OTS model was selected for this program with certain instrumentation additions described in Section 4 below.

2.2 Description - The 19-OTS model was developed by Calspan Corporation during 1972-73, Refs. 24 and 25. Two test programs - IH5 and IH34 - were performed during 1974-75; the model was refurbished, improved and updated for the 1976-77 IH39 test (Refs. 26 and 27); and is now in use on IH75A. Thus this model represents mature design for which a considerable amount of experience is available. Fig. 2 depicts the model. Table 2 gives detailed dimensional data and Table 3 lists the associated drawings. The model ET mounts to a thin blade strut which attaches to a sting, and all instrumentation, control, and pneumatic lines are routed internally through them.

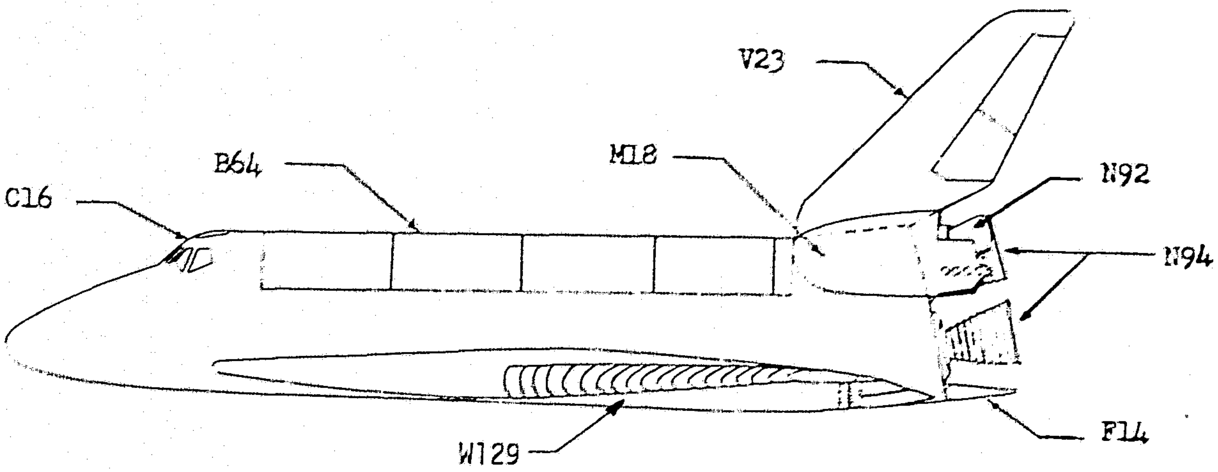
Model - This model operates on short-duration firing principles. Combustion products of H_2 and O_2 are provided to the three SSME nozzles, and 15% aluminum solid propellant combustion products to the two SRB nozzles, for near duplication of the SSLV. SSME and SRB nozzle internal surfaces are geometrically duplicated; external surfaces are smooth. These nozzle walls are structurally thickened to withstand heating. The skirt curtain between the SRB shroud and nozzle is simulated. The OMS nozzles are simulated externally and internally, although there are no flow provisions, and are positioned in their "stowed" ascent position (6° pitch down and 7° yaw outboard from null). A non-scale adapter connects the orbiter to the ET, containing propulsion supply lines, autovalve control lines, charge tube thermocouples, and cooling lines. It also provides a mounting surface for the orbiter wing. Flanges and a small strut connect the SRB's to the ET. The ET is one diameter longer than correct scale.

Model 19-OTS was built to the Space Shuttle Vehicle 5 lines and conforms to the following Rockwell International Space Division Drawings:

a. Integrated Vehicle



b. Orbiter



c. Plume Simulation Items

(after Ref. 24)

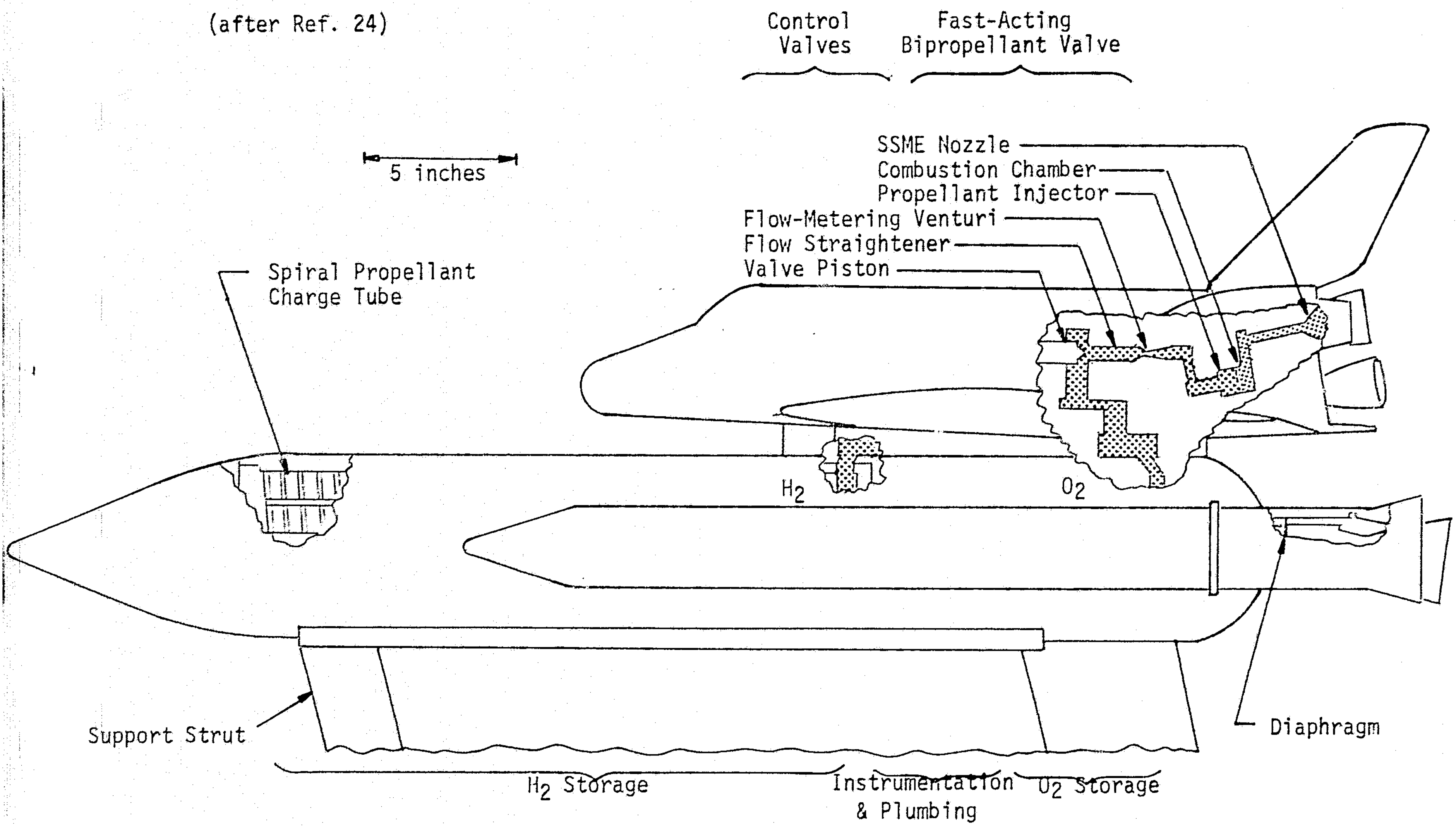


Fig. 2 19-OTS Model

TABLE 2. 19-OTS MODEL DIMENSIONS

a. Bodies and Nozzles

Dimension	Units	ORBITER BODY (B64) Full Scale	ORBITER BODY (B64) Model Scale	ORBITER CANOPY (C16) Full Scale	ORBITER CANOPY (C16) Model Scale	OMS POD (M18) Full Scale	OMS POD (M18) Model Scale
Length OML	in.	1293.3 (1)	29.099	236.9207 (6)	5.331	200.00 (10)	4.500
Length OML Ref.		1290.3 (2)	29.032				
Length IML		1288.8 (3)	28.998				
Max. Width OML		262.718 (4)	5.911	194.4394 (7)	4.375	135.75 (11)	3.054
Max. Width IML		260.718 (4)	5.866				
Max. Depth OML		248.575 (5)	5.593	58.8007 (8)	1.323	74.50 (11)	1.676
Max. Depth IML		246.575 (5)	5.548				
Fineness Ratio OML	↓	5.203				1.937	
Fineness Ratio IML		5.227					
Max. Cross-sectional Area	$ft.^2$	340.82 (5)		45.6558 (9)	0.0231	58.169 (12)	0.029
Drawing Number		VC70-000002, #MDV-70 Baseline IML		VC70-000002A, MDV-70		VC70-000002, VL70-008410, MDV-70	
		Ref. Vehicle 5, MCR 200, Rev. 7 10/17/74		Ref. Orbiter 102, MCR 175		Ref. Vehicle 5 MCR 200, Rev. 7 10/17/74	
		(1) X_0 = 235-1528.3 (2) X_0 = 238-1528.3 (3) X_0 = 239.5-1528.3 (4) At X_0 = 1516.801 (5) At X_0 = 1463.316		(6) X_0 = 433.0793-670 (7) At X_0 = 594 (8) At X_0 = 492 (9) At X_0 = 520		(10) X_0 = 1311-1511 (11) X_0 = 1511, X_p = 304 (12) X_p = 304	

Dimension	Units	EXTERNAL TANK (T33) Full Scale	EXTERNAL TANK (T33) Model Scale	SRB (S22) Full Scale	SRB (S22) Model Scale	
Length	in.	1852.486	41.681	1789.60	40.266	
Max. Diameter	↓	333.000	7.493	146.00	3.285	(Tank)
				208.20	4.685	(Aft Shroud)
Fineness Ratio		5.563		8.596		
Max. Cross-sectional Area	$ft.^2$	604.807	0.306	236.423	0.120	
W. P. of centerline	(Z_T)			400.0	9.000	
F. S. of nose	(X_T)			743.0	16.718	
B. P. of centerline	(Y_T)			250.5	5.636	
Drawing Number		VC78-000002B, 82600203049 for spike nose		VC77-000002C, VC70-000002A, VC72-000002C		

Dimension	Units	MAIN NOZZLES (N94) Full Scale	MAIN NOZZLES (N94) Model Scale	OMS NOZZLES (N92) Full Scale	OMS NOZZLES (N92) Model Scale	SRB NOZZLES (N106) Full Scale	SRB NOZZLES (N106) Model Scale
Length (Gimbal Pt. to Exit Pl.)	in.	156.69	3.526	56.00	1.260		
Diameters	in.						
Exit		93.75	2.109	50.00	1.125	(15) 145.640	3.277
Throat				27.778	0.625		
Areas	$ft.^2$						
Exit		47.937	.0243	13.634	.0069	(15) 115.688	0.059
Throat				4.205	.0021		
Gimbal Point (Sta.)	in.						
X_0		(13) 1445.000	32.513	158.00	34.155	(16) 1863.458	41.928
Y_0		0.000	0.000	+88.00	+1.980	±250.500	±5.636
Z_0		443.000	9.968	∓92.00	∓1.070	‾400.000	‾9.000
X_0		(14) 1468.170	33.034				
Y_0		53.000	±1.193				
Z_0		34.264	‾0.771				
Null Position	deg.						
Pitch		(13) 16.0° Up		15°49' Up		0°	
Yaw		3.0°		6°30' Outboard		0°	
Pitch		(14) 10.0° Up					
Yaw		3.5° Outboard					
Drawing Number		VC70-000002, VL70-008144, RS09189, SS-A01216		VD70-000002, SS-A01240		VC77-000002D	
		(13) Upper Nozzle (14) Lower Nozzle				(15) I.D.; O.D. = 147.64 3.322 (16) Cold; hot = 1875.358 42.196	

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TABLE 2. (Concluded)

b. Wings, etc.

Dimension	Units	TOTAL WING (W129) Full Scale	TOTAL WING (W129) Model Scale	EXPOSED WING Full Scale	EXPOSED WING Model Scale	ELEVON Full Scale	ELEVON Model Scale	VERTICAL TAIL (V23) Full Scale	VERTICAL TAIL (V23) Model Scale	BODY FLAP (F14) Full Scale	BODY FLAP (F14) Model Scale
Planform Area (Theo.)	$ft.^2$	2690.00	1.362	1751.50	0.887	206.57	0.105	413.253	0.209	134.125	0.068
Span (Theo.)	in.	936.68	21.075	720.68	16.215	346.44	7.795	315.720	7.104	238.000	5.355
Aspect Ratio		2.265		2.060				1.675			
Rate of Taper		1.177						0.507			
Taper Ratio		0.200		0.245				0.404			
Dihedral Angle	deg.	3.500°									
Incidence Angle	deg.	0.500°									
Sweep Angles	deg.										
L.E.		45.000°				0.000°		45.00°		0°	
T.E.		-10.056°				-10.056°		26.25°		0°	
.25 Element Line		35.209°						41.13°			
Hingeline						0.000°				0°	
Chords	in.										
Root (Theo.)		689.243 (17)	15.508	562.090 (18)	12.640			268.50	6.041	81.00	1.823
Tip (Theo.)		137.849	3.102	137.849 (19)	3.102			108.47	2.441	81.00	1.823
M.A.C.		474.812	10.683	392.826	8.839	89.50	2.014	199.81	4.496	81.00	1.823
.25 M.A.C. Fus. Sta.		1136.834	25.579	1186.500	26.696			1463.50	32.929		
.25 M.A.C. W.P.		290.857	6.544	293.683	6.608			635.52	14.299		
.25 M.A.C. B.L.		182.132	4.098	251.769	5.665			0.0	0.0		
Airfoil		RI mod. of NASA XXXX-64; Root b/2 = .1136 Tip b/2 = .1200						Double Wedge; Leading Wedge = 10.00° Trailing Wedge = 14.92°			
L.E. Radius								2.00	0.045		
L.E. Cuff (data for 1 of 2 sides)											
Planform Area	$ft.^2$			145.4	0.074						
L.E. Intersects Fus. M.L. at Sta.	in.			500.0	11.250						
L.E. Intersects Wing at Sta.	in.			1084.0	24.390						
Inboard Equivalent Chord	in.					116.500	2.621				
Outboard Equivalent Chord	in.					55.219	1.242				
Ratio of moveable/total chord											
At Inbd. Equiv. chord						.2137					
At Otbd. Equiv. chord						.3999					
Area Moment (Area x M.A.C.)	$ft.^3$					1540.74	0.0175			905.344	0.0103
Area used in C_{HM_e} Computation	$ft.^2$					210.00	0.106				
Void Area	$ft.^2$							13.17	0.007		
Drawing Number						VC70-000002A Hingeline at X_O=1387, Splitline at Y_O=312.5 6.0" gap, beveled edges. Ref. MCR 200, Rev.7 10/17/74		VC70-000002; Blanketed area=0 Ref. Vehicle 5, MCR 200, Rev.7, 10/17/74		VC70-000002, MDV-70 Y_O=-1280 HL at X_O=1532 Ref.Vehicle 5, MCR 200,Rev.7, 10/17/74	

(17) At B.P. 0

(18) At B.P. 108

(19) At 100% b/2

TABLE 3

19-OTS MODEL DRAWING LIST

DRAWING NUMBER	REVISION	TITLE	DATE
		a. Test IH-39 Original Drawings	
SS-H-00404	-	Hydrogen Charge Tube - Outer	03-15-73
405	-	Hydrogen Charge Tube - Inner	03-15-73
407	-	Oxygen Charge Tube - Outer	03-18-73
408	-	Oxygen Charge Tube - Inner	03-18-73
413	C	Autovalve Assembly	02-27-76
414	A	Autovalve Body Detail	01-20-75
415	E	Autovalve Details	06-18-74
418	J	External Tank Body Detail	04-30-76
419	A	Plug Cover -ET	11-08-73
420	B	End Plug - ET	05-17-76
423	K	Nozzle SSME Firing	05-05-76
424	E	Nozzle SSME Non-Firing	05-06-76
425	F	Gimbal Blocks - SSME	03-09-76
426	A	Detail - Nozzle Clamps	03-28-74
428	-	Transducer Cover - ET	04-06-73
439	A	Model Strut Details & Weldment	06-11-73
444	B	OMS Nozzle Detail	03-04-76
447	B	Autovalve Details	07-14-76
450	-	Orbiter Details	05-10-73
451	B	Shock Absorber - Autovalve	05-29-74
455	C	Detail Brackets - Autovalve	06-10-74
SS-H-01506	D	Installation - Model 19-OTS Test IH-39 in NASA Lewis 10' x 10' Supersonic Wind Tunnel	04-26-76
SS-H-01535	A	Model Strut & Fairing Rework	02-17-75
SS-H-01536	F	Sting Detail & Weldment	03-30-76
		b. Test IH-39 New Drawings	
SS-H-01620	3	Wing & Elevons	04-12-76
21	3	Nose Assy - Orbiter	03-11-76
22	4	OMS/RCS Pods	04-15-76
23	7	Venturi Housing & Venturi Inserts	05-19-76
24	6	Injector Housing & Injector Insert	05-19-76
25	8	Combustor Housing & Nozzle Adapters	07-12-76
26	3	Autovalve Revision & Details	03-11-76
27	6	Adapter - Orbiter/ET	07-12-76
28	3	Base Section	05-11-76
29	3	Outer Frame Section (Cold Base)	05-14-76
30	5	Heat Shield - Orbiter & Nozzle	05-18-76
31	1	Venturi Test Fixture	03-12-76
32	2	Vertical Tail	03-04-76
33	4	Body Flap & Closeout Plate	04-08-76
34	3	Outer Frame Section (Hot Base)	05-14-76
35	7	Heat Shield Assy (Hot Base)	05-06-76
36	1	Orbiter Assy	04-28-76
37	2	OTS Model Assy	04-30-76
38	7	External Tank Assy & Details	05-17-76
39	1	Autovalve Body Detail	06-25-76
40	1	Hyrdrogen Charge Tube Assy	11-12-75
41	11	SRB Assy & Details	07-09-76
42	3	Alternate Propellant Holder & Details	07-08-76
43	1	Model Strut Revision	03-12-76

VC72-000002D	Design Geometry - Shuttle
VC70-000002A	Design Geometry - Orbiter
VC78-000002B	Design Geometry - External Tank
VC77-000002D	Design Geometry - Solid Rocket Booster
VC70-355101C (sheets 1-10)	Orbiter Heat Shield
VL70-008401	OMS/RCS Pod (Plus an unnumbered attachment showing the modified "doghouse")

plus these McDonnell Douglas Astronautics Company drawings:

73J311006	OMS Pod Base Bulge
73J311007 (2 sheets)	OMS Pod Base Bulge

Considerable complexity is associated with H_2/O_2 combustion process. This system consists of H_2 and O_2 charge tubes, a fast-acting bi-propellant valve (autovalve), H_2 and O_2 metering venturis, an injector, a combustion chamber, and the three SSME nozzle assemblies. The charge tubes are arranged spirally in the ET; all other items are in the orbiter. These charge tubes supply gases at approximately 3000 psia through the autovalve to the venturis. When the autovalve opens, the gases are supplied to the venturis at constant conditions for the expansion wave time of the charge tubes. The autovalve is a pneumatically operated piston-type valve, Fig. 3. Two electrical solenoid (Valcor) valves, when energized, permit high pressure N_2 (approximately 3000 psia) to enter chambers within the autovalve and move the piston to open or close the O_2 and H_2 ports. The autovalve is probably the most complex item associated with this model, initiating then terminating the SSME nozzle flows

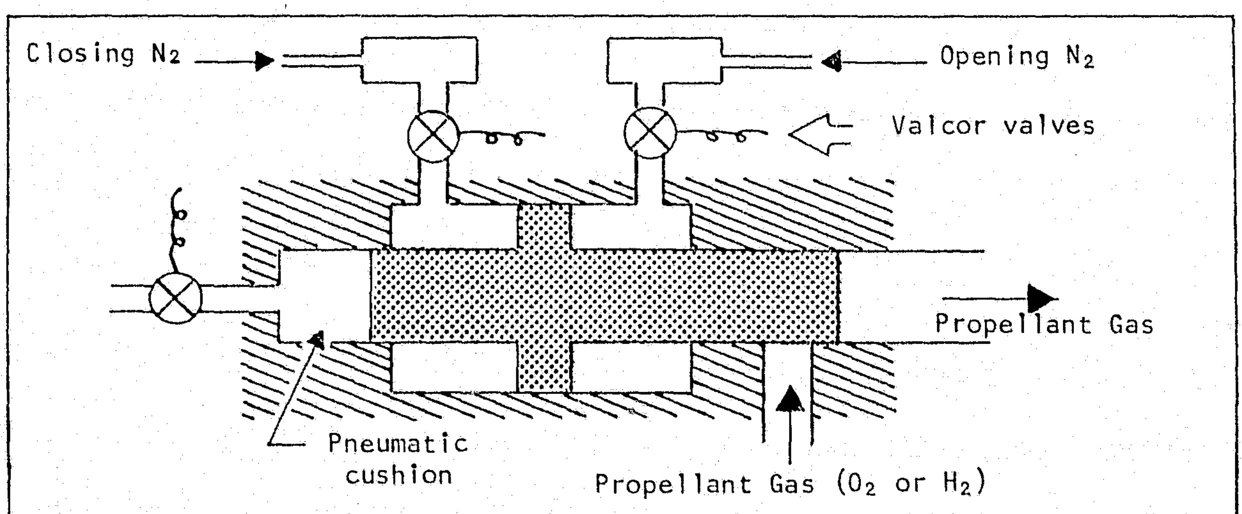


Fig. 3 Autovalve Concept

within controllable periods as brief as 30 msec. The venturis operate under choked flow conditions, and are designed for an O/F ratio of 6.0. The single injector is composed of twelve doublets designed to impinge on a diameter equivalent to the combustion chamber area mean diameter. Doublet holes are equal in size, angled to balance the radial momentum of H_2 and O_2 streams. The single combustion chamber provides the necessary volume for the gases to mix and burn, and is common to all three SSME nozzles. A pyrotechnic ignition source is located in the chamber. Nominal P_c is 1500 psia and is controlled by charge tube pressure and losses in the autovalve, venturi, and injector. Nominal run time is 30 msec. Up to 60 msec can be readily obtained but leads to some hardware deterioration (one inadvertant 150 msec run resulted in a hole being burned in the combustion chamber wall).

In effect, the SSME exhaust simulation involves all of the aspects of the NASA/MSFC Impulse Base Flow Facility except for the IBFF's vacuum cell feature.

In addition, this model has solid propellant charges for the SRB simulation. These items are similar to the Calspan-developed motors used on the MA11F, FA7, and FA22 tests, (Refs. 28-30), and are essentially identical to those used on the FA23 test (Ref. 21). Each consists of a propellant holder, ignition gas system, diaphragm, and nozzle assembly. SRB flow is controlled by the amount of solid propellant used. The propellant holder is a cylindrical casing which fits inside the SRB. Solid propellant is glued to a thin aluminum sheet (0.011 in. thick) and rolled to fit inside the holder. GN_2 coolant is flowed through the propellant holder to maintain the propellant at a constant temperature during the wind tunnel run before ignition. To insure rapid and simultaneous ignition of the two SRB's, both are filled with a mixture of ethylene (C_2H_6) and oxygen immediately before the desired firing time. A pyrotechnic source ignites this gas mixture which in turn ignites the propellant. A single igniter is used for both SRB's. The diaphragm is contained in the aft propellant holder and cap. It is made of thin sheets of Mylar sized to burst slightly above the desired P_c. An 0.063 in. diameter hole is at the center of the diaphragm to permit the N_2 coolant flow to exit. The solid propellant is ANB-3066B, a 15% Aℓ/AP/CTPB composition which is an ICC Class B explosive that functions by rapid combustion rather than detonation. Burning rate is a function of pressure, temperature, and humidity. Nominal P_c is 290 psia and nominal duration is 100 msec.

Data typical of model operation is shown in Fig. 4.

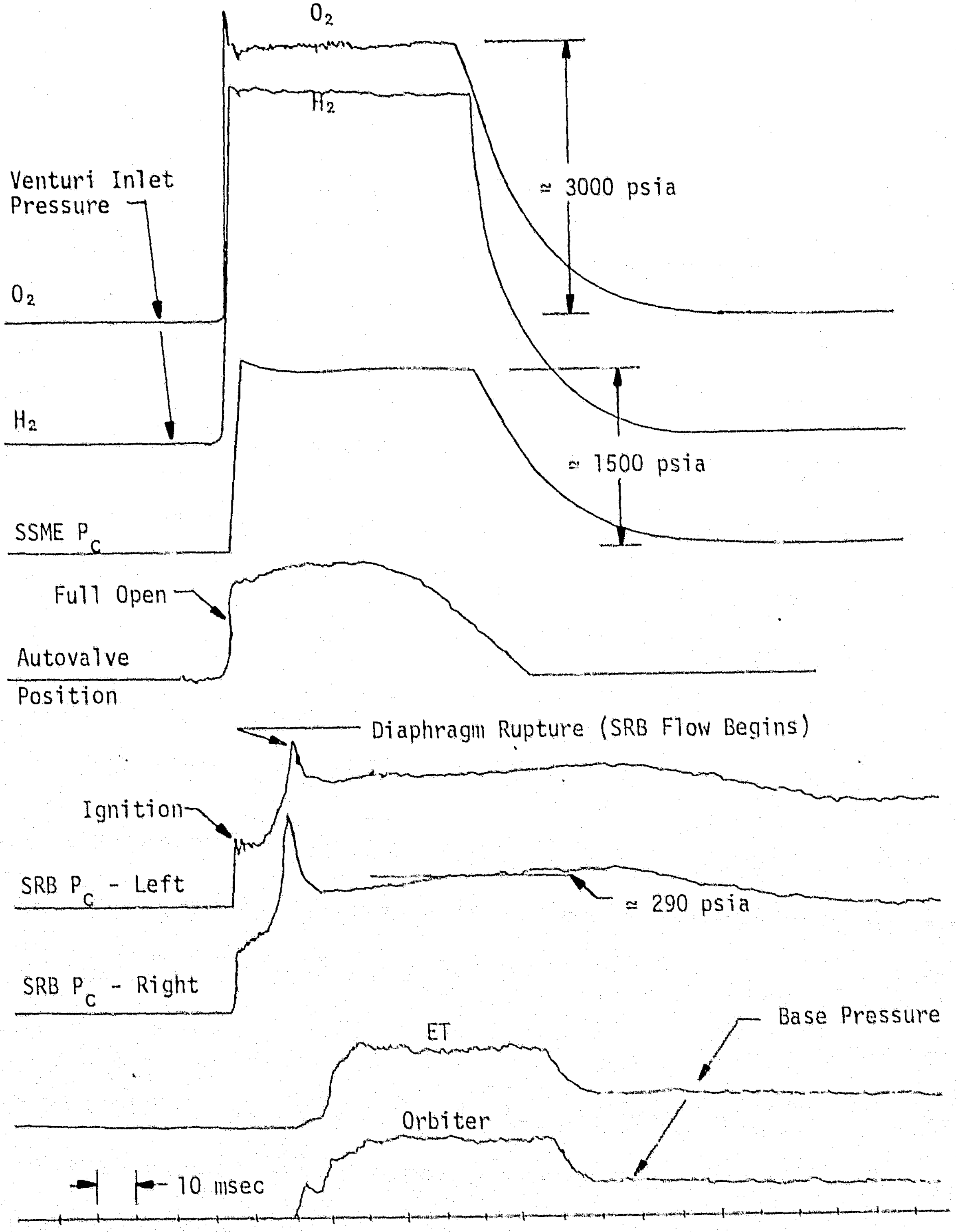


Fig. 4 Typical 19-OTS Model Operation

Gas Supply and Control - Considerable effort was expended by NASA-Lewis to design and build gas supply and control systems for the IH-39 test. The concept is sketched in Fig. 5. The detailed schematics are presented in NASA-Lewis drawings MDS-945 Revision K and MDS-945A, Revision G (Fig. 6). Five plumbing panels were built: one each for SSME O_2, H_2, 6000 psi N_2, cooling/purge N_2, and ethylene/oxygen for SRB ignition. These panels and all supply bottles were mounted atop the tunnel test section, except for the cooling N_2 which came from a trailer parked outside the tunnel building. In the control room, an extensive console was used to monitor and control these gas systems.

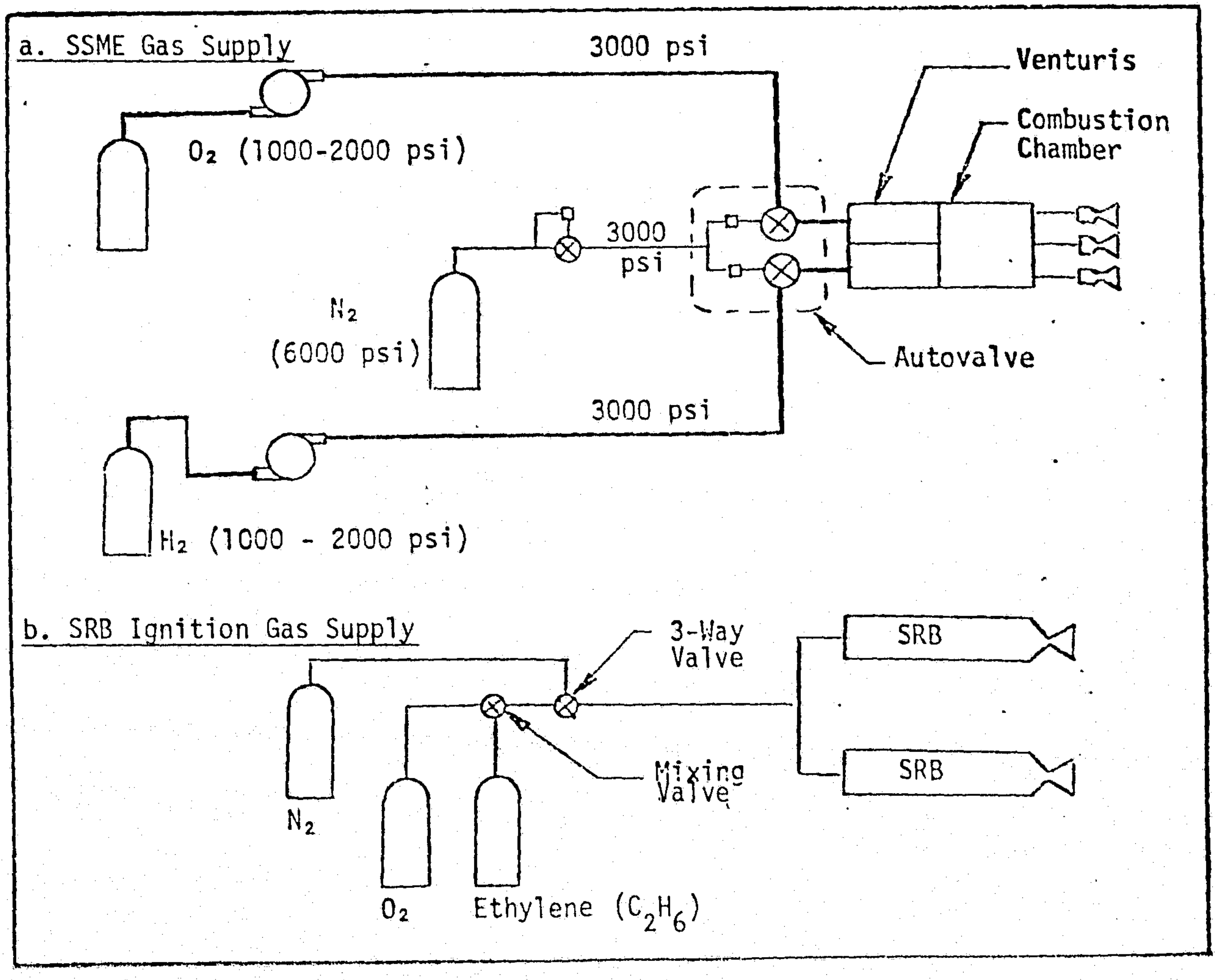


Fig. 5 Gas Supply Schematic

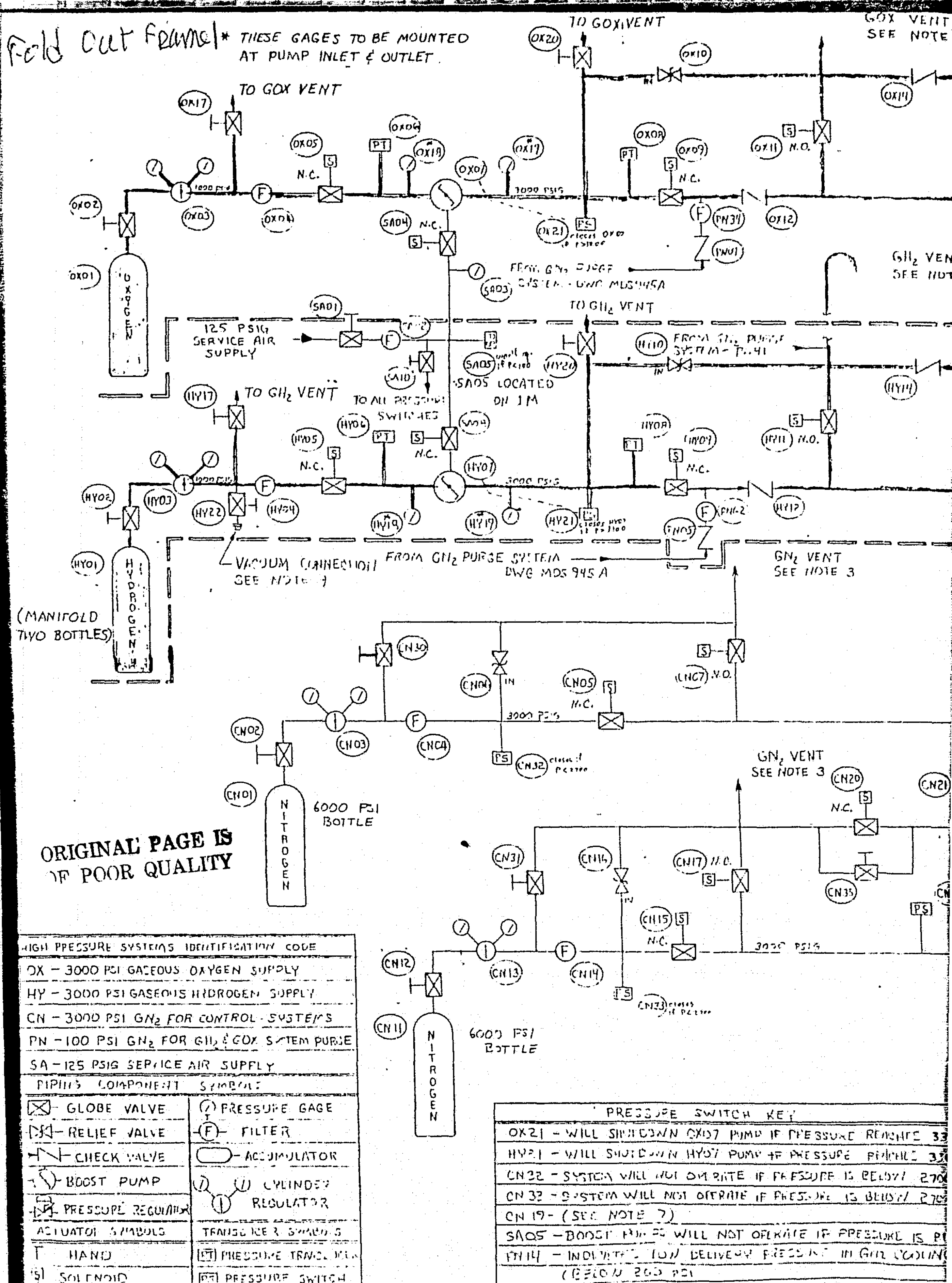
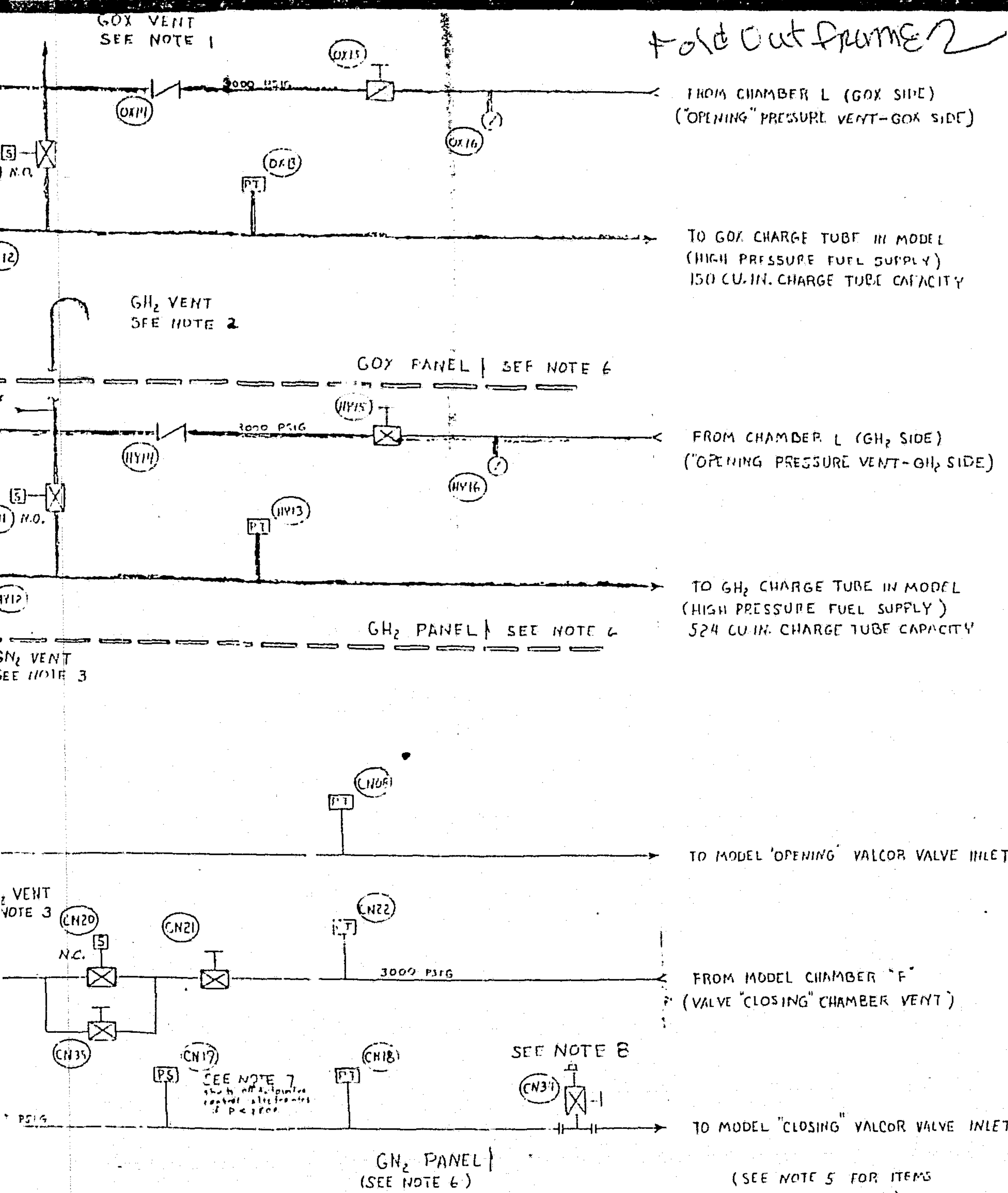


Fig. 6 IH39 Plumbing Schematic

Fold Out Frame 2



GENERAL NOTES:

1. GASEOUS OXYGEN (GOX) TO BE VENTED INTO TUNNEL CIRCUIT JUST DOWNSTREAM OF THE TEST SECTION.
2. GASEOUS HYDROGEN (GH_2) TO BE VENTED TO 3 IN. DIA COPPER VENT STACK WHICH EXTENDS 12 FT OVER REAR OF 10x10 SWT BUILDING
3. GASEOUS NITROGEN (GN_2) TO BE VENTED INTO AREA ABOVE TEST SECTION AT LEAST 10 FT. ABOVE ANY WORKING AREA.
4. ALL GAS LINES TO BE 1/4" O.D. x .035 WALL STAINLESS STEEL TUBING UNLESS OTHERWISE SPECIFIED.
5. REF. CALSPAN CORP. DWG. SS-H-00413 "ASSEMBLY - AUTOVALVE GAS-SHUTTLE 17-OTS MODEL (2.25%)
6. GAS SYSTEM PANEL MOUNTS AS SHOWN WITH GOX & GH_2 ON SEPARATE PANELS ON TOP OF TEST SECTION WITH SERVICE AIR ITEMS MOUNTED WITH ASSOCIATED SYSTEMS. CHAMBER "L" & "L" VENTS TO BE MOUNTED WITH ASSOC. SYSTEMS. GN_2 CONTROL & PURGE ALONG WITH CHAMBER "F" & "B" VENTS TO BE ON GN_2 PANEL.
7. PRESSURE SWITCH SET TO INTERUPT AUTOVALVE CONTROL ELECTRONICS IF 'CLOSING' PRESSURE IS BELOW 2800 PSI
8. TEE USED TO APPLY LOW PRESSURE GN_2 TO CLOSE AUTOVALVE IF REQ'D PRIOR TO APPLICATION OF HIGH PRESSURE GN_2.
9. TEE USED TO CONNECT VACUUM PUMP TO EVACUATE AREA AFTER GH_2 BOTTLE CHANGE.
10. TWO TEES SEPARATED BY 6" MIN. OF REMOVEABLE LINE FOR POSSIBLE ADDITIONAL GN_2 COOLING
11. BURST ~~DISCS LOCATED IN BOTTLE VALVE ASS'YS~~; GOX & GH_2
12. SEE DWG. 945A FOR GOX-ETHYLENE BSRM IGNITING GAS SYSTEM & GN_2 TIE IN

CHANGE	NO	REVISION	DATE	CK APP
C 5-15-75		ADDED TUBE TRAILER; ADDED ITEM (HY22), DELETE NOTE 9; CORRECTED COOLING GN_2 END POINTS		
B 3-17-75		4. ADDED BURST DISC ASS'YS (NOTE 11) & VENTS FROM THESE (GH_2 & GOX)		
		3. ADDED 3 TEES; SEE NOTES 9 & 10		
		2. REARRANGED PN26, PN04 & PN27, PN11		
A		1. ADDED ITEMS (CN35), (PN25), (PN24), (PN27), (PN26)	2-28-75	

CHANGE	REVISION
K 7-15-75	ADDED SAV & PRESSURE SWITCH PURGE; DELETED [illegible]
J 6-5-75	ADDED (FN6) & NOTE "FROM GN_2 PURGE SYSTEM - PN41"; REMOVED GH_2 & GOX BOTTLE OVERPRESSURE VENTS; DELETED NOTE 11
I 5-29-75	APPROX. WORKING PRESSURES NOTED ON SYSTEMS
H 5-22-75	FILTER JUST DOWNSTREAM OF PN07 WAS PN28 (UPDATED) WAS CHANGED TO PN24
G 5-7-75	ADDED NOTE 4 & (N34)
F 5-14-75	ADDED PRESSURE SWITCH KEY
E 5-6-75	REMOVED NITROGEN PURGE & COOLING ITEMS TO MDS 945A DWG. REMOVED LINE FROM MODEL CHAMBER 'B' INC. CN09 & CN10
D 4-17-75	ADDED NOTE 12 & (PN28)

PRESSURE REACHES 3300 PSI	
PRESSURE REACHES 3300 PSI	
PRESSURE IS BELOW 2700 PSI	
PRESSURE IS BELOW 2700 PSI	
... IF PRESSURE IS BELOW 100 PSI	
... IN GH_2 COOLING SYSTEM	

SCALE —
UNLESS OTHERWISE SPECIFIED

REFERENCE: SEC MDS 945A

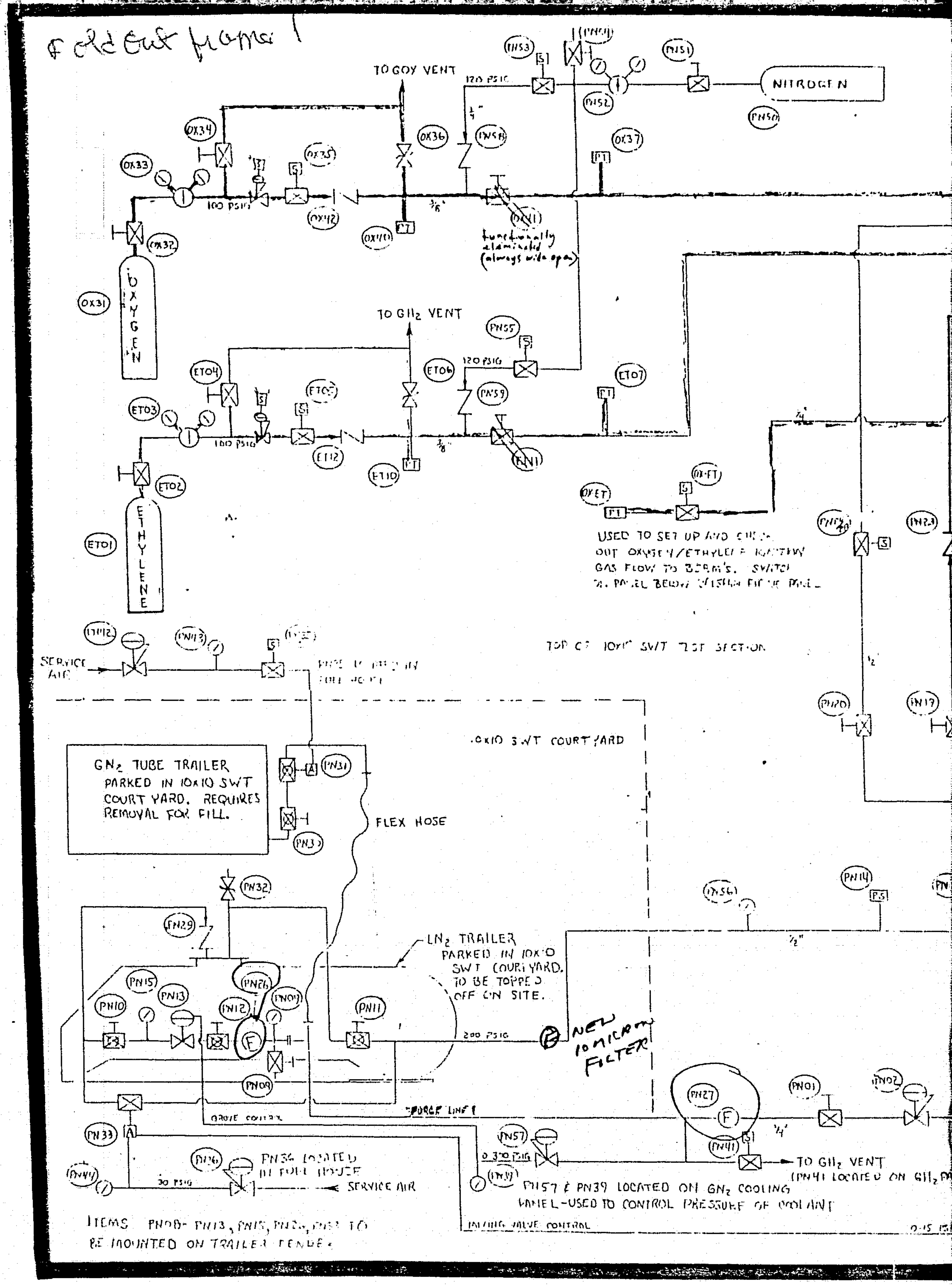
SPACE SHUTTLE TEST - 10x10 SWT

HIGH PRESSURE FUEL & CONTROL SYSTEMS FOR ... 17-OTS SSV MODEL

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
CLEVELAND, OHIO

CD MDS 945

ORIGINAL PAGE IS
OF POOR QUALITY


Fold Out Frame 1
TO GOX VENT
NITROGEN
120 PSIG
100 PSIG
OXYGEN
functionally eliminated (always wide open)
TO GH2 VENT
120 PSIG
100 PSIG
ETHYLENE
SERVICE AIR
FLEX HOSE
GN2 TUBE TRAILER PARKED IN 10x10 SWT COURT YARD. REQUIRES REMOVAL FOR FILL.
LN2 TRAILER PARKED IN 10x10 SWT COURTYARD. TO BE TOPPED OFF ON SITE.
NEW 10 MICRON FILTER
200 PSIG
PURGE LINE
DRIVE CONTROL
30 PSIG
SERVICE AIR
TO GH2 VENT
PN57 & PN39 LOCATED ON GN2 COOLING PANEL-USED TO CONTROL PRESSURE OF COOLANT
ITEMS PN08-PN13, PN15, PN26, PN33 TO BE MOUNTED ON TRAILER FENDER

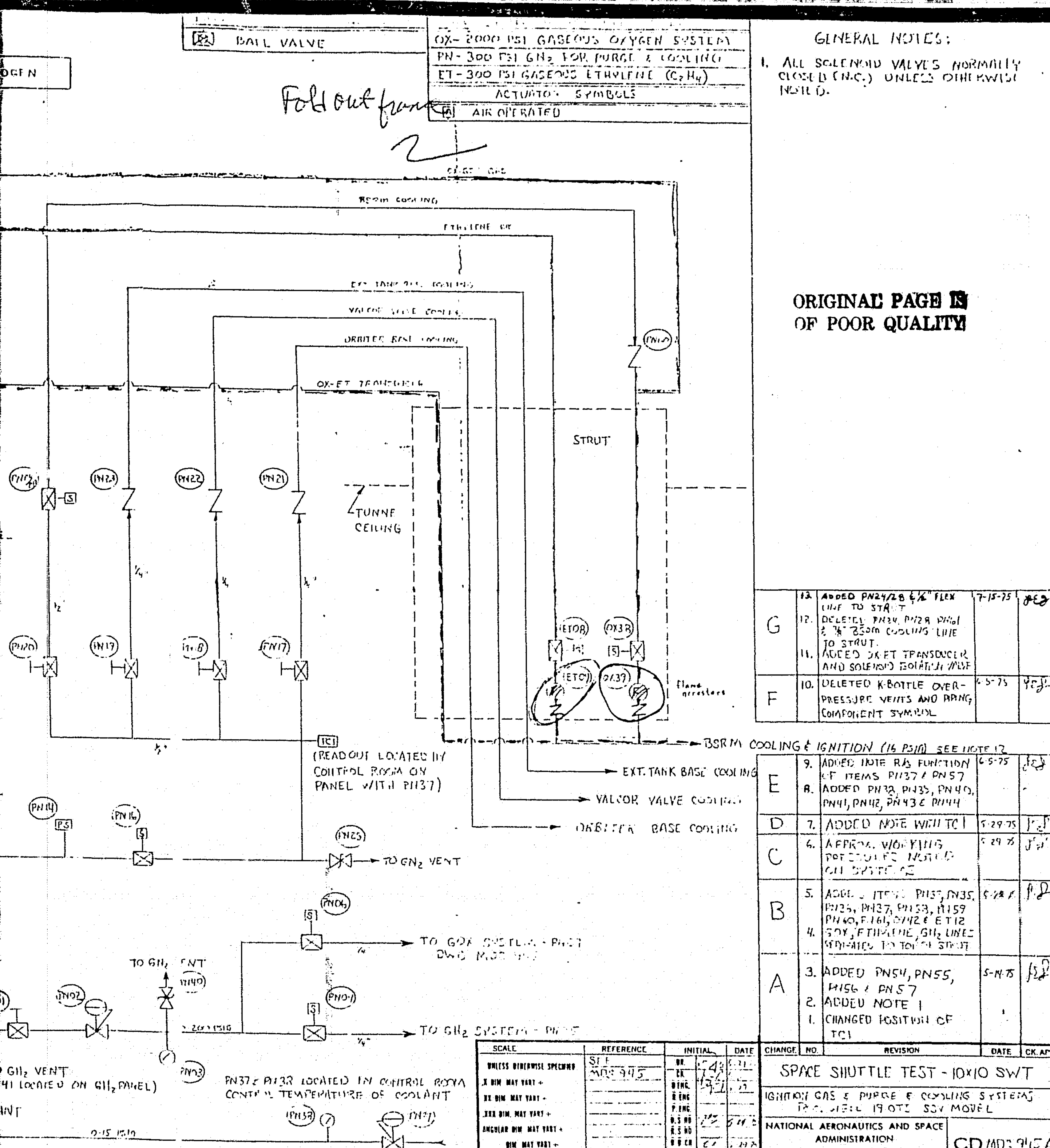


Fig. 6 (Concluded)

3. TEST SITE

The selection of the 19-OTS model has a significant impact on wind tunnel selection. The size of this model combined with the need to keep blockage at or below 0.5% requires a tunnel test section of 120 sq. ft. The model P_c levels combined with the need to match P_c/P_∞ requires a variable density facility able to provide $q_{test} = 0.5 \times q_{flight}$. For these constraints combined with the desired Mach range of Table 1, there are only two candidates:

NAME	SIZE	MACH RANGE
NASA Ames UPWT 11x11	121 sq. ft.	0.5 - 1.4
USAF AEDC 16T	256 sq. ft.	0.6 - 1.6

Both operate in continuous, as opposed to blowdown, mode. The capabilities of these candidates are compared to the requirements (using the Ref. 31 flight profiles) in Fig. 7. Either facility could meet the primary test needs. There are secondary technical items which favor AEDC 16T: (1) propulsion testing is commonplace there so that provisions for propellant handling, exhaust gas scavenging, etc., are already available; and (2) the larger size minimizes any wall effects on the model. These items alone would not compel the selection of AEDC 16T. Rather, cost and schedule (availability) considerations could be the deciding factors. Final selection and scheduling is beyond the scope of this effort.

4. INSTRUMENTATION

The 19-OTS model was built for base heating studies, and has been provided with extensive instrumentation in the base region of each component. This instrumentation measures surface pressures, temperatures, and heat transfer. Only the pressure instrumentation would be of use for FA-17 needs. However, base pressure alone would not fully satisfy the goal of validating that the recommended plume simulation parameters adequately account for all of the important plume-induced aerodynamics. For this goal it would be necessary to measure pressures or forces on the wing, elevons, body flap, vertical tail, and nozzles. To thoroughly quantify the complex aerodynamics on these complex geometries via surface pressure measurements would require a very large number of taps. A simpler approach is to incorporate force balances

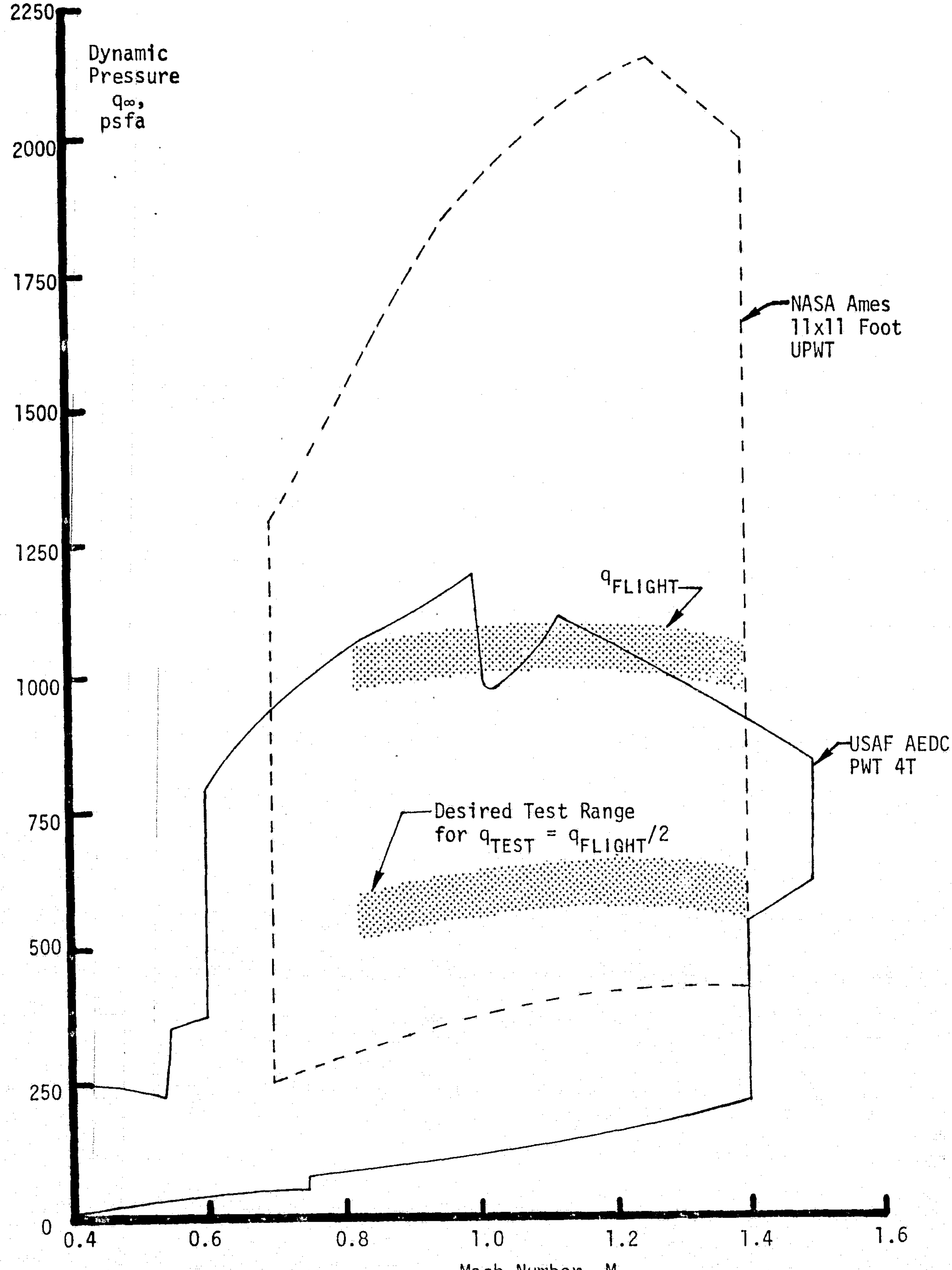


Fig. 7 Comparison of Test Facilities

into these components. Such balances must withstand the most critical of either power-off or power-on steady loads, and measure the power-on loads with precision adequate to satisfy the validation goal. Also, because metal balances would not damp out to steady state in the short duration of plume simulation (without providing mechanical dampers which would be complex beyond practicality of this test), special data reduction techniques will be needed. The design of balances to meet these criteria was undertaken. To date the wing balance and elevon flexures have been completed, as described below.

Loads were taken from earlier wind tunnel test programs. To establish the loads it was necessary to define the desired range of elevon deflection angles as these deflections cause significant effects on both wing and elevon loads. The flight values of deflection angles and angle of attack are not precisely known because in flight they will be controlled so as to minimize total wing loads. Estimated elevon angles are shown in Fig. 8; anticipated excursions about this nominal schedule are ± 3-4°. The FA-17 wing and elevon balances were designed for this envelope of elevon deflections.

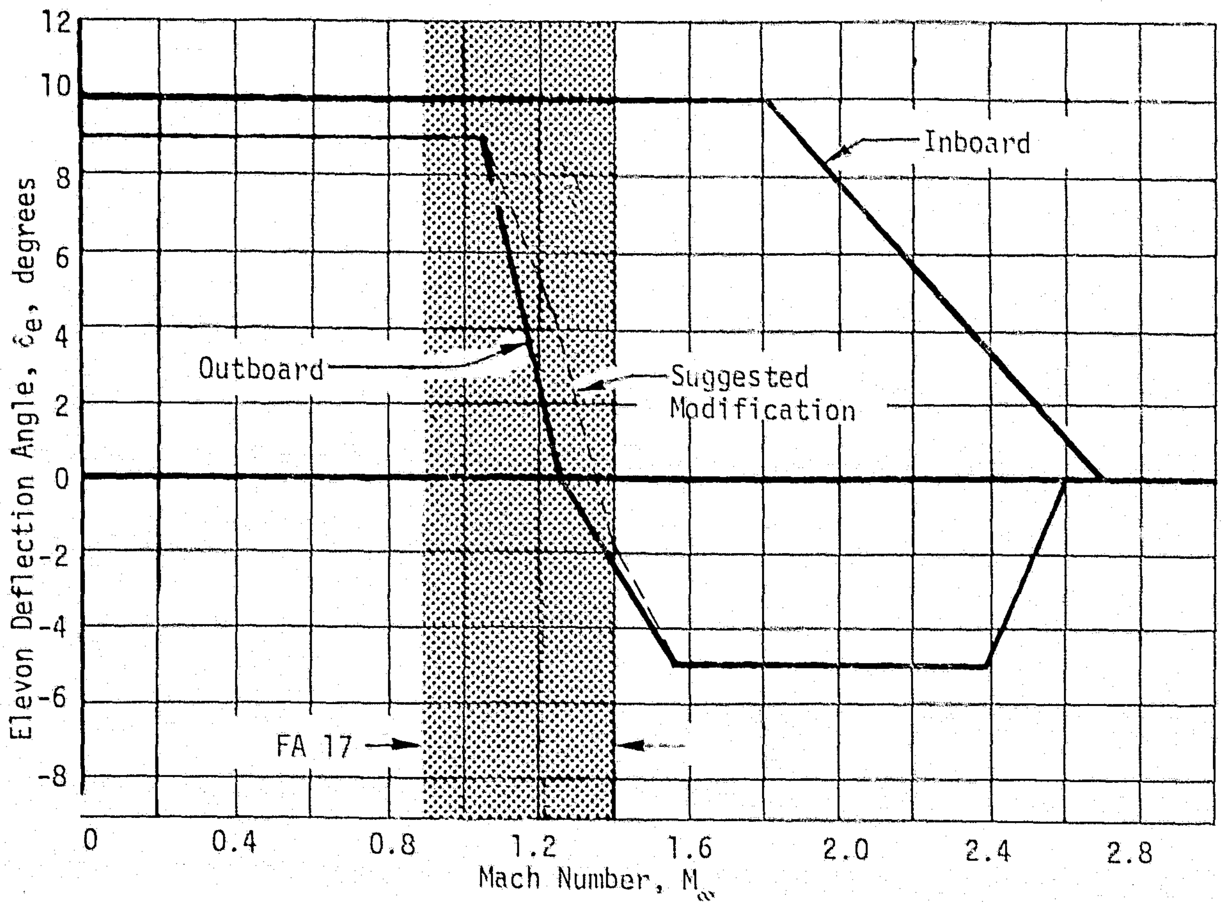


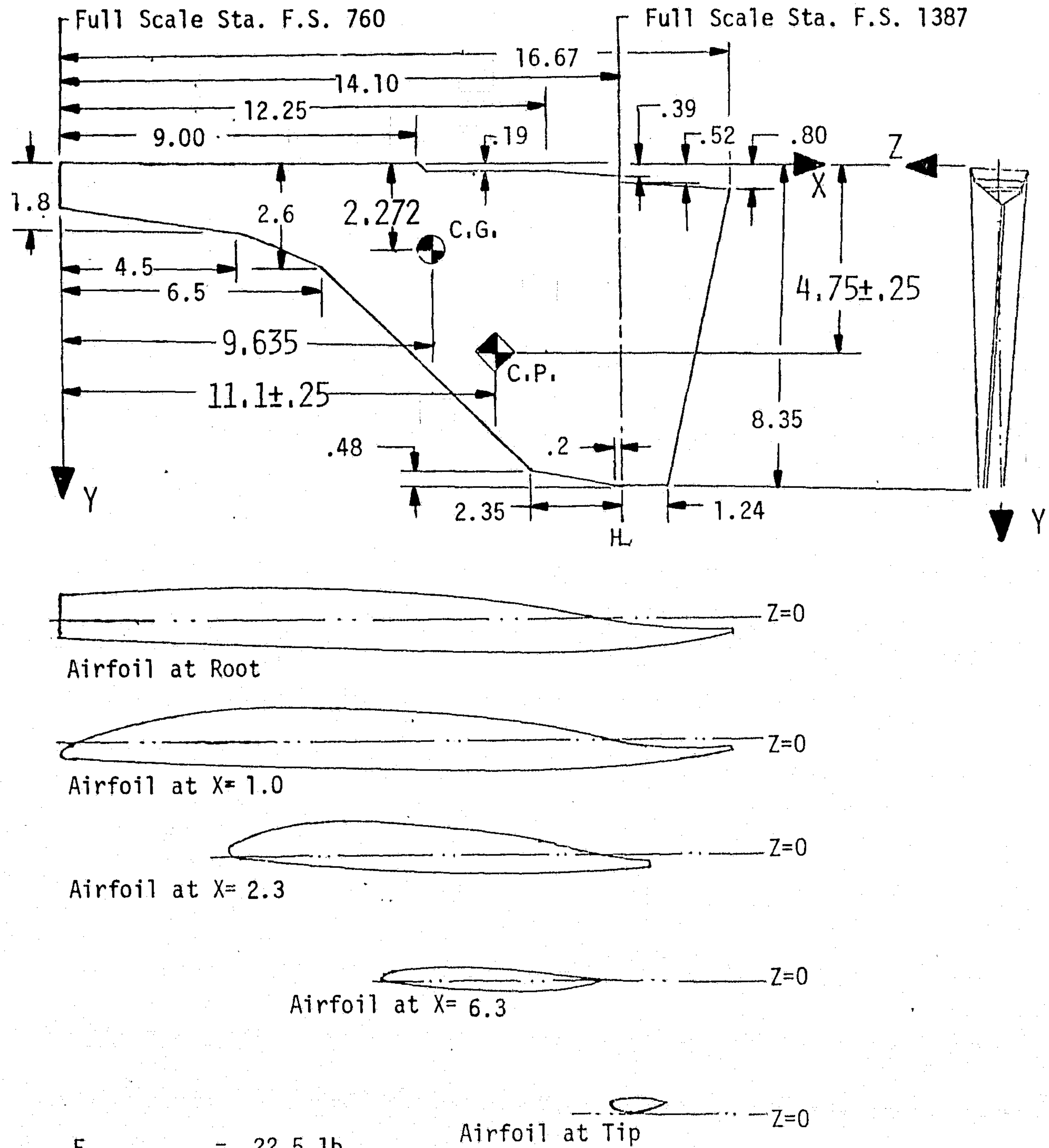
Fig. 8 Elevon Deflection Schedule 6 (July 28, 1976)

4.1 Wing Balance - The wing balance is intended to measure normal force and its location. For the FA-17 test it would be important to precisely measure the difference in plume on and plume off normal force; this difference was estimated to generally be no more than 10% of the likely plume off design level.

For wing balance design loads, data from Test IA80 were used. That test covered the range $M = 0.9 \rightarrow 1.4$ and $\alpha = -4° \rightarrow +4°$, both with and without plume simulation. These data showed that normal force at the nominal flight value of $\alpha = 2°$ would be no larger than about 22.5 lb., but this value would increase 4-6 lb. for each increase in α of 1°. Thus a balance designed to accommodate $\alpha = 4°$ would be operating at half or less of maximum capacity at the most important condition ($\alpha = -2°$), with correspondingly reduced accuracy, especially considering the need to quantify plume-on to plume-off differences. This type of problem frequently arises, and can be handled by several techniques: different capacity balances for differing load ranges, lowering tunnel dynamic pressure to maintain constant force levels as nondimensional force coefficients increase, or limiting the test matrix. For this program it was decided that providing several balances would be too expensive, and that the change in Reynolds number accompanying a change in tunnel dynamic pressure would be unacceptable. Instead, it was decided to design the wing balances for $\alpha = -2°$ and limit testing with this wing balance to $\alpha \lesssim -2°$, while planning to test at $\alpha > -2°$ with other instrumentation (elevon balances, base pressures, etc.). Thus, design wing loads were $F_N = 22.5$ lb., $dF_N/d\alpha = 6$ lb./deg.

Wing center of pressure was relatively constant, generally being within $\pm$ 0.25 in. of a point 3.0 in. forward of the elevon hinge line and 4.7 in. outboard of the wing root, Fig. 9. Wing mass properties were obtained by approximating the wing defined on RI Drawing SS-H01620, 4/12/76, by 41 trapezoidal prisms. These mass properties and loads were used to design a wing balance which could meet both static and dynamic conditions. Maximum stress at the gages of 10,000 psi was the design criteria. Location of this balance was severely constrained by the 19-OTS model fuselage design which was utilized for valving, metering, and combusting O_2 and H_2. The only practical approach was to locate the balance in the volume originally used for wing attachment. A single point mass was used to represent the wing, and the balance was analyzed as a simple cantilever. The resulting design is sketched in Fig. 10. A prototype balance was built, gaged, and calibrated at MSFC. An aluminum wing approximating the 19-OTS wing was also built. The combined prototype balance

REMTECH INC.



$F_{N_{DESIGN}}$ = 22.5 lb.

$\left(\frac{dF_N}{d\alpha}\right)_{DESIGN}$ = 6.0 lb./deg.

Volume = 45.65 cu. in.

Weight = 4.61 lb. (for Aℓ)

Through c.g.:

I_x = 0.0353 in.-lb.-sec²

I_Y = 0.0780 in.-lb.-sec²

U_{XY} = 0.0276 in.-lb.-sec²

Fig. 9 Wing Properties and Loads

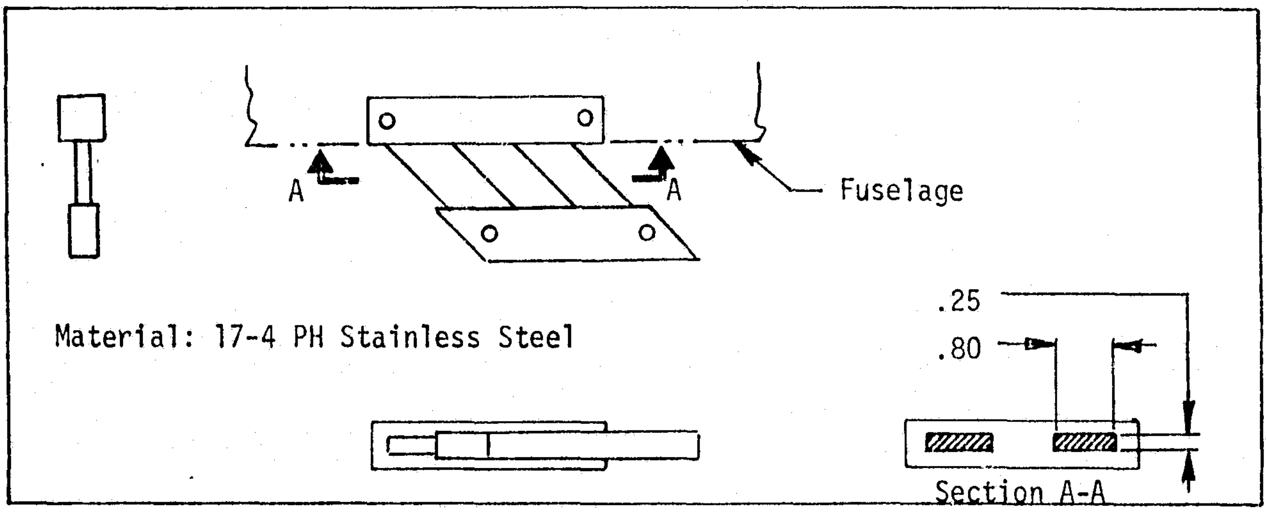


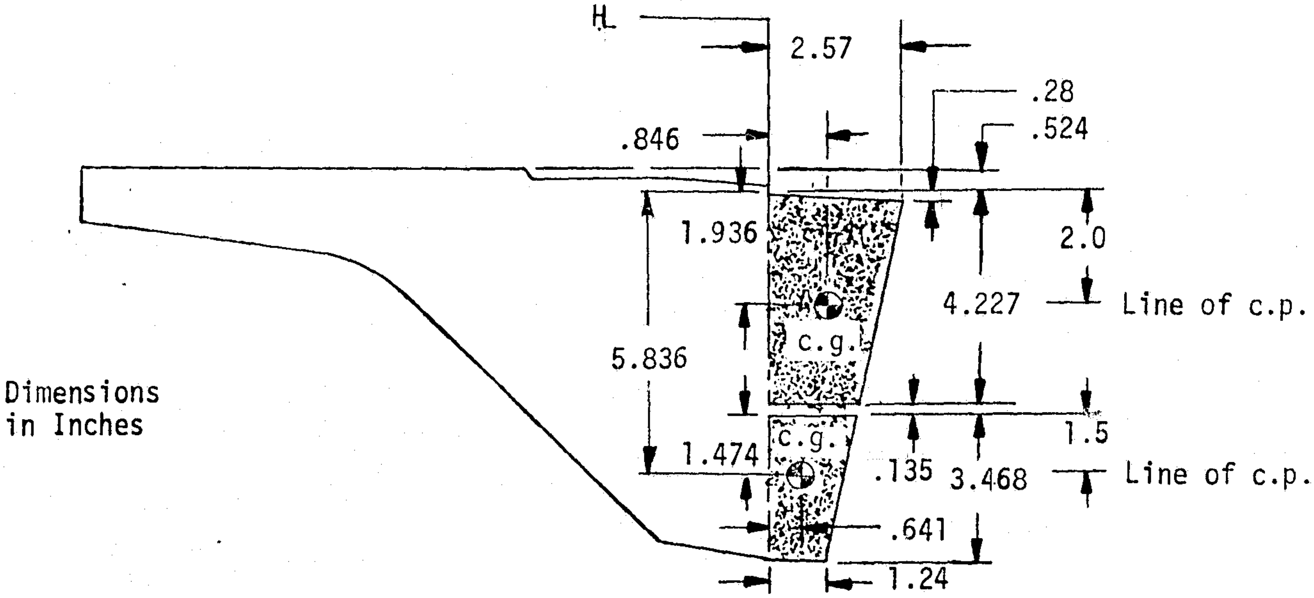
Fig. 10 Wing Balance

and simulated wing were tested for dynamic response, by hanging a weight at the estimated c.p. and then suddenly removing it. Response was satisfactory. Thus, the wing balance design capabilities have been demonstrated.

A deflection analysis of this balance indicates an angular deflection less than 0.1°. Such motion would mean about 0.015 in. tip deflection.

4.2 Elevon Flexures - The elevon flexures are intended to measure hinge moments. As with the wing balance, it would be important to precisely measure the difference in plume-on and plume-off hinge moments; these differences were estimated to be as much as 30% of maximum expected plume-off levels.

For elevon flexure design loads, data were used from Tests IA93 and IA135 as developed in Ref. 32. Inspection of these data did not clearly indicate which conditions might be critical. The main reason was that high confidence could not be placed in the elevon c.p. locations. To define the design loads, an envelope of loading cases was developed for all conditions of M = 0.9 - 1.25, $\alpha = -4° \rightarrow 0°$ at Schedule 6 deflection angles (Fig. 8) for each elevon: inboard and outboard. The hinge moments in these envelopes were taken from Test IA93 data, increased by 30% to account for expected differences in plume-on to plume-off. The longitudinal c.p. locations were taken from Ref. 32. From inspection of these envelopes, three extreme cases were selected for each elevon. To estimate the lateral c.p. location, the Test IA135 data were integrated for the same conditions. The resulting locations were close to the respective c.g. locations. These selected cases are shown in Fig. 11.



Physical Properties

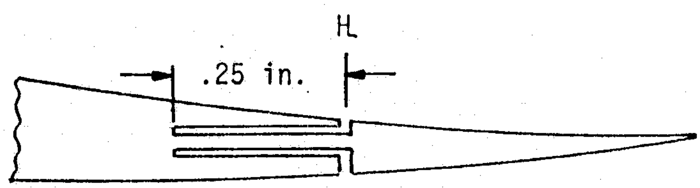
	Inboard	Outboard
Volume (cu. in.) Weight (lb)	2.33 0.89	0.24 0.09
Through c.g.: I_x (in.-lb-sec^2) I_y (in.-lb-sec^2) U_{xy} (in.-lb-sec^2)	 0.00083 0.00023 -0.000036	 0.00023 0.000048 -0.000056

Selected Critical Loads

Inboard		Outboard	
M_∞ $\delta_{e_i}/\delta_{e_o}$	Load	M_∞ $\delta_{e_i}/\delta_{e_o}$	Load
.975 12°/10°	0.4; 3.0 lb	1.15 10°/14°	6.1 lb; 0.6
1.05 10°/10°	0.6 lb; 3.0	1.25 10°/-2°	1.0; 2.6 lb
1.25 8°/4°	1.7; 3.3 lb	1.25 8°/4°	0.07; 11.7 lb

Fig. 11 Elevon Properties and Loads

Elevon mass properties were obtained as for the wing by approximating the elevons defined on RI Drawing SS-H01620, 4/12/76, by trapezoidal prisms. These mass properties and loads were used to design elevon flexures which could meet both static and dynamic conditions. It was desired to have each flexure be full span for the respective elevon to obviate any gap sealing problem, while achieving approximately 10,000 psi stress in the flexure to ensure adequate strain gage output. It was found that thickness of .030 - .032 in. were satisfactory for the static load situation. A dynamic analysis was then performed for a limited number of candidate designs for the Fig. 11 loading cases using the NASTRAN code. The dynamic analysis used a 2 msec ramp function (based on Ref. 24), and a structural damping coefficient of 1% of critical. The response characteristics were acceptable and the resulting flexure designs are sketched in Fig. 12.



Material: Stainless Steel

	Inboard	Outboard
Thickness, inches	.032	.030
Max. Bending Deflection, deg.	0.5	0.4
Max. Torsional Deflection, deg.	2×10^{-4}	7×10^{-4}

Fig. 12 Elevon Flexures

4.3 Other Instrumentation - The 19-OTS model has several surface pressure ports which might be of some interest to the FA17 test, plus instrumentation to monitor the plume simulation equipment. Sixteen thermocouples are provided to monitor the temperature of the piezoelectric pressure transducers, Valcor valve cavity, charge tube gases, and SRB propellants, Table 4.

Piezoelectric pressure transducers are connected to the 33 surface pressure ports used for plume-on test data plus the 7 plume simulation monitoring ports. These transducers are mounted inside the model. Each transducer is compensated for acceleration and has a heat shield to minimize temperature and radiation effects. These piezoelectric transducers operate in a differential mode as opposed to an absolute pressure mode, and thus require a reference (plume-off, steady-state) pressure. For the 33 model surface pressure ports there are 17 reference surface pressure ports, which are connected by 0.095 in. i.d. tubing to a single, conventional stain-gage diaphragm pressure transducer through a scanning valve, located outside the wind tunnel. The two transducers monitoring SRB P_c are referenced to the pre-fire pressure of the ethylene-oxygen ignition gas mixture. For the other five monitoring transducers, the pre-fire reference pressures are so small relative to operational plume-on pressures that they may be neglected. The pressure transducers are summarized in Table 5, and their locations are sketched in Fig. 13.

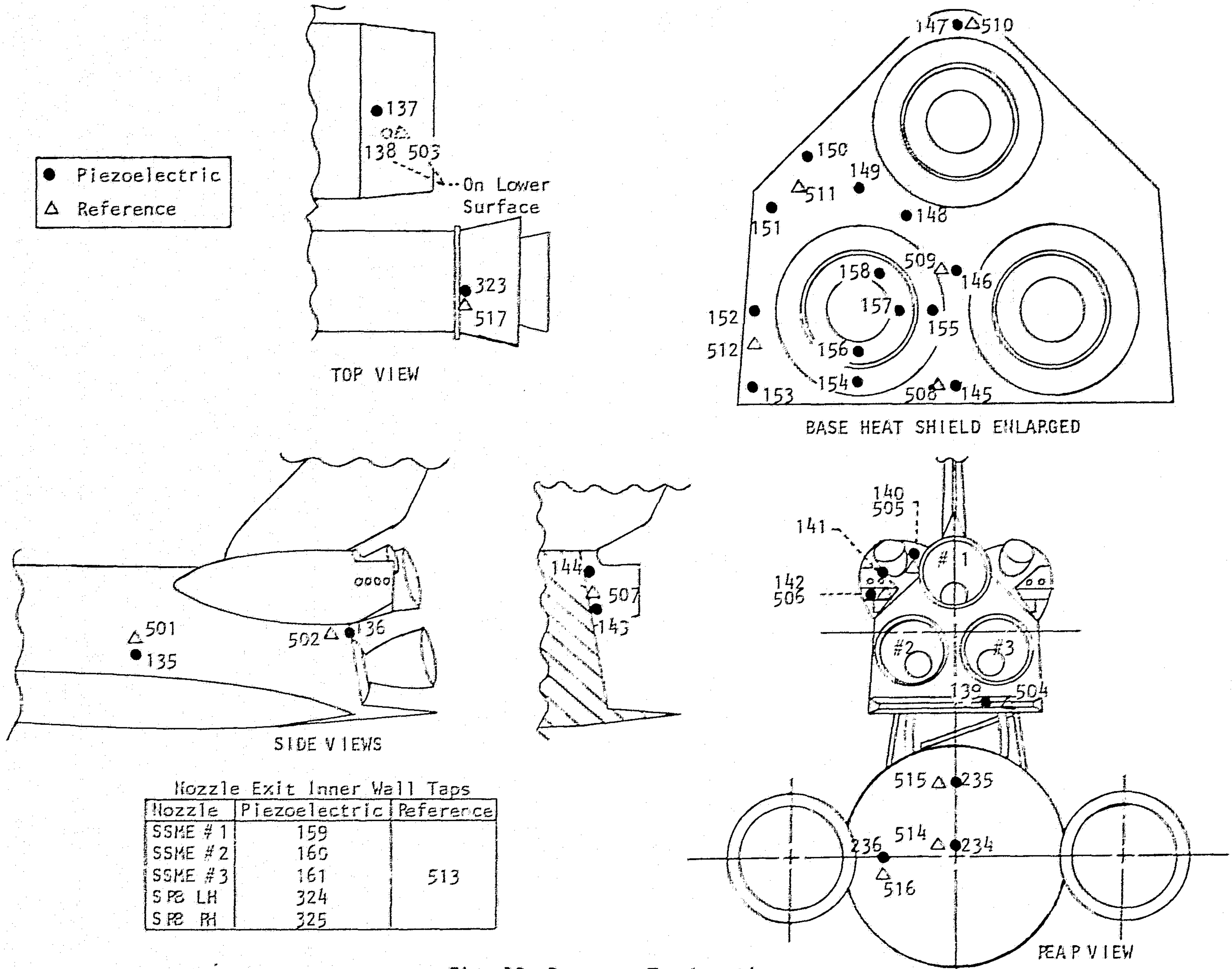
TABLE 4 THERMOCOUPLES

No.	Location	Type
601	Orbiter base heat shield (attached)	Chromel-Alumel
602	Orbiter base heat shield	
603	Orbiter base heat shield	
604	ET base cavity	
605	ET base cavity	
606	Left OMS pod	
607	Right OMS pod	
608	Valcor valve cavity	
609	Valcor valve cavity	
610	Hydrogen charge tube	Iron Constantan, "Type J"
611	Oxygen charge tube	
612	Left SRB shroud	Chromel-Alumel
613	Right SRB shroud	
614	Left-hand SRB Propellant	Chromel-Alumel*
615	Right-hand SRB Propellant	
616	Venturi Housing	Chromel-Alumel

* Iron Constantan "Type J" if the CRUCIFORM propellant holders are used.

TABLE 5 PRESSURE TRANSDUCERS

Item	Piezoelectric Pressure Transducer Location	Range (psid)	Id. No.	Reference Pressure Id. No.	Thermocouple Id. No. For Determining Transducer Temperature (See Table 4)
1	Orbiter Fuselage (L)	2	135	501	616
2			136	502	Avg. of 601 - 603
3	Body Flap - Top		137	508	
4	Body Flap - Bottom		138	503	
5	Body Flap - T. E.		139	504	
6	OMS Pod Base (L)		140	505	606
7			141		
8			142	506	
9	OMS Pod Side (R)		143	507	607
10			144		
11	Orbiter Base Heat Shield		145	508	Avg. of 601 - 603
12			146	509	
13			147	510	
14			148	509	
15			149	511	
16			150		
17			151		
18			152	512	
19			153		
20			154	508	
21			155	509	
22			156	508	
23			157	509	
24			158		
25	SSME Nozzle (#1)	10	159	513	
26	(#2)		160		
27	(#3)		161		
28	ET Base	2	234	514	Avg. of 604, 605
29			235	515	
30			236	516	
31	SRB L. Shroud	10	323	517	612
32	L. Nozzle		324	Not Req'd.	
33	R. Nozzle		325		613
34	SRB P_C (L)	1000	701	Ignition Gas Pressure	
35	(R)		702		
36	Venturi O_2	5000	703	Negligible	
37	H_2		704		
38	Injector O_2		705		
39	H_2		706		
40	SSME P_C		700		



Nozzle Exit Inner Wall Taps

Nozzle	Piezoelectric	Reference
SSME #1	159	
SSME #2	160	
SSME #3	161	513
SRB LH	324	
SRB RH	325	

Fig. 13 Pressure Tap Locations

5. TEST OPERATIONS

There are a variety of operations associated with this test whose needs sometimes conflict: safety in handling the various potentially hazardous materials used in plume simulation; quality of data especially in precise synchronization of the five exhausts and in well-calibrated instrumentation, and productivity in conducting the program with a minimum amount of test site occupancy. The ability to achieve the first two items has been demonstrated on each previous test using the 19-OTS model, but high productivity has not been shown. Operational details of the IH-39 test are presented in Ref. 33.

Pending final negotiations with a suitable wind tunnel, it is expected that equipment for this test will be supplied as follows. NASA-MSFC (either directly or through a contractor) will furnish the required number of piezo-electric pressure transducers with power supplies, thermocouples, and all wiring within the model. The wind tunnel will furnish scanning valves and transducers for the reference static pressures, an angle of attack indicator, and wiring from the model sting to the control room.

5.1 Test Conditions - Values of the various test parameters have been selected to cover a limited parametric investigation of the flight regime critical to plume simulation for power-on aerodynamic considerations. The transonic Mach number range for ascent along a nominal KSC ascent flight profile was selected, Table 6. The 19-OTS model is limited in SSME P_c to approximately one-half

TABLE 6 SSLV FLIGHT CONDITIONS

Per Ref. 32 - Mission 1 (Launch from KSC at 28.5°)

Flight Condition	M_∞			
	0.9	1.0	1.2	1.4
Altitude (ft.)	19,018	23,073	31,243	38,059
P_∞ (psfa)	1047.3	893.4	631.7	462.1
Pt_∞ ↓	1771.2	1691.1	1531.8	1470.7
q_∞ ↓	593.8	625.4	636.8	634.0
Re_∞ (10^6/ft.)	4.6	4.8	5.0	5.1
$P_{c_{SSME}}$ (psia)	3000 →	→	→	→
$P_{c_{SRB}}$ ↓	≈560	≈540	≈540	≈560

of flight values, so to maintain P_c/P_∞ in test equal to the flight ratio, tunnel pressures were selected to be one-half of flight, Table 7. Values of angle of attack were selected to cover the expected flight range, but use of the wing balance must be limited, as discussed above, Section 4.1. To encompass the desired range of Mach number and angle of attack, while keeping the total program to a practical level, elevon deflection angles were generally limited to nominal values. Both SSME and SRB P_c were absolutely limited to nominal values. The total program is summarized in Table 7.

5.2 Procedures - There are several categories of procedures involved: instrumentation calibration, plume simulation equipment activities, data acquisition, normal run sequence, and abort/malfunction sequence. The latest integration of these functional procedures into a comprehensive sequence of steps is shown in the Appendix, Test IH-39 Checklist.

The piezoelectric pressure transducers will need to be calibrated at a series of discrete operating temperatures before installation in the model, to define the change of millivolt output with pressure, at each specified temperature. Low range transducers used for model surface pressure measurement should be calibrated at 75°F, 100°F, and 125°F. High range transducers used to monitor the propulsion simulation equipment should be calibrated at 100°F and 200°F. The electronic output of these piezoelectric transducers vanish under a continuous pressure, so it is necessary to use a device which applies a step pressure load and use the resulting instantaneous output values in the calibration. The conventional strain-gage pressure transducer used for plume-off steady-state reference pressures can be calibrated for room temperature operation. The wing and elevon balances will need to be calibrated before installation on the model. Additionally, frequent checks should be made during the test to verify that the primary calibration has not shifted for any reason. Special jigs/fixtures will need to be provided to facilitate these check calibrations.

To preclude damage from exposure to the elevated temperature of the continuous tunnel airstream, the piezoelectric transducers should be cooled to approximately 80°F and the SRB propellant and Valcor valve cavity to approximately 100°F, using GN_2 as coolant. Cooling lines for the piezoelectric transducers are routed to the SRB shrouds, the ET base cavity, the orbiter base, and the OMS pods. Cooling to these areas should be used while the tunnel is operating except when the test data are being recorded during model firing.

TABLE 7. TEST CONDITIONS

		M_∞ 0.9	1.0	1.2	1.4
P_∞	(psfa)	523.6	446.7	315.9	231.0
Pt_∞	(psfa)	885.6	845.6	765.9	735.4
q_∞	(psfa)	296.9	312.7	318.4	317.0
Re_∞	(10^6/ft)	2.3	2.4	2.5	2.5
Pc_{SSME}	(psia)	1500 →	→	→	→
Pc_{SRB}	(psia)	≈280	≈270	≈270	≈280
α	-4°	Nom. δ_e Addl. δ_e	Nom. δ_e	Nom. δ_e Addl. δ_e	Nom. δ_e
α	-2°	Nom. δ_e	Nom. δ_e	Nom. δ_e	Nom. δ_e
α	0° (3)	Nom. δ_e	Nom. δ_e	Nom. δ_e	Nom. δ_e
α	2° (3),(4)	Nom. δ_e		Nom. δ_e	
α	4° (3),(4)	Nom. δ_e		Nom. δ_e	

\+ one repeat point (to be determined)
\+ allowance for one misfire

NOTE: 1. Nom. δ_e = nominal value of elevon deflection angle, either:
- Schedule 6, or
- Any update to Schedule 6, or
- Value selected from resulted of Test IA119.

2. Addl. δ_e = an additional value of $\delta_{e_i}/\delta_{e_o}$
3. Without wing balance.
4. Without elevon balances.

Activities related to the plume simulation equipment begin with loading solid propellant into the SRB's. Pyrotechnic igniters for SRB's and SSME are installed. Completion of the pre-run checklist will verify readiness of model fuel and control systems, model configuration, and instrumentation. Then the tunnel may be closed and pumped down with the model at $\alpha = 0°$ and GN_2 model instrumentation cooling initiated. Start the tunnel and obtain desired conditions; during this time, pressurize the autovalve charge tubes, and make any needed timing ajustments to the firing sequence control panel. If the charge tube gas temperatures vary significantly during this period, the charge tube pressures must be adjusted so that the fixed-geometry venturis will maintain the desired O/F = 6.0. Adjust model angle of attack as required. Verify that fuel, control, and recording systems are correctly adjusted and operating. When affirmative, cease cooling to the model and charge the SRB's with ethylene and oxygen. Operate the firing button. The firing sequence control panel will be used to control the SSME and SRB flows. The steady plume-on SSME flow will be limited to about 55 msec maximum to preclude deleterious nozzle heating. (This setting will produce a total SSME flow time of approximately 65 msec.). The steady plume-on SRB flow time will nominally be 100 msec for a nominal propellant thickness of 0.050 in. Due to the time required to reach steady plume-on conditions, the SRB flow will always be initiated before the SSME flow. All of these times are preset into the control panel, so operating the firing button activates each item at the proper time, including recording data. After the firing, resume model cooling, shut off recording equipment as appropriate, and set the model to $\alpha = 0°$ for tunnel shutdown.

In the event of an aborted run or a malfunction in the plume simulation equipment, detailed procedures of the Appendix should be followed.

Data acquisition will be performed at five time periods:

1. Just before closing the tunnel (ambient pre-fire call)
2. Just before firing the motors (tunnel pre-fire call)
3. During the motor firing - plume on
4. Just after firing the motors (tunnel post-fire call)
5. Just after opening the tunnel (ambient post-fire call)

Four of these periods are for plume-off conditions, and all channels will be recorded. For the plume-on condition, only the wing balance, elevon balances, base surface pressures and plume simulation monitoring ports (measured by piezoelectric transducers), plus events, will be recorded. The plume-off data will be recorded on digital encoding equipment, and the plume-on data onto an analog type system as a function of time. Table 8 summarizes the data acquisition process.

There are some photographic procedures involved. Installation photographs of each test setup are required. Photographs of the model assembly, components, instrumentation, etc., will be taken upon request of the responsible test engineer. Close-up photographs of the model instrumentation are required. High speed Schlieren movies are required for each run. The primary interest is the flow field generated by the model plumes and boundary layer separation induced by the model plumes.

TABLE 8. DATA ACQUISITION SUMMARY

Id.	Recording Device	Data	Quantity of channels
1	Analog Tape System	Model Surface Pressures (Piezoelectric)	33
2		Propulsion Simulation Operating Pressure	7
3		Autovalve Potentiometer Position	1
4		Events (4)	18
5	Digital Encoder	Model Reference Pressures	17
6		Thermocouples	16
7		Fuel System Pressures	13
8		Tunnel Configuration Parameters	To be determined
9	Visicorders	Propulsion Simulation Operating Pressures (same as Id. No. 2 above)	7
10		Propulsion Simulation Operating Events: Ignite SRB's Autovalve Opening Autovalve Closing - Primary Autovalve Closing - Redundant	8

5.3 Data Reduction and Presentation - Data from the wing and elevon balances will need special handling because these devices will not reach steady state operation during the time of plume simulation. Instead, their output data history will be a lightly-damped sinusoidal function, Fig. 14. The elevon balance is expected to require approximately 400 msec for oscillations to damp to about 5%, and approximately 600 msec to damp to about 1%, while plume simulation will be limited to about 55 msec. However, the balance dynamics are predicted to cover several cycles during plume simulation. A suitable approximation to the steady state value that would result if the plume simulation could be maintained for a long duration can be obtained from:

$$E_{\text{steady state}_i} = \frac{1}{2}\left[\frac{1}{2}\left(E_{\max_i} + E_{\max_{i+1}}\right) + E_{\min_i}\right] \quad (1)$$

where E is the individual balance output term. Per the methods of Ref. 34 for damping equal to 1% of critical, the result given by Equation 1 differs

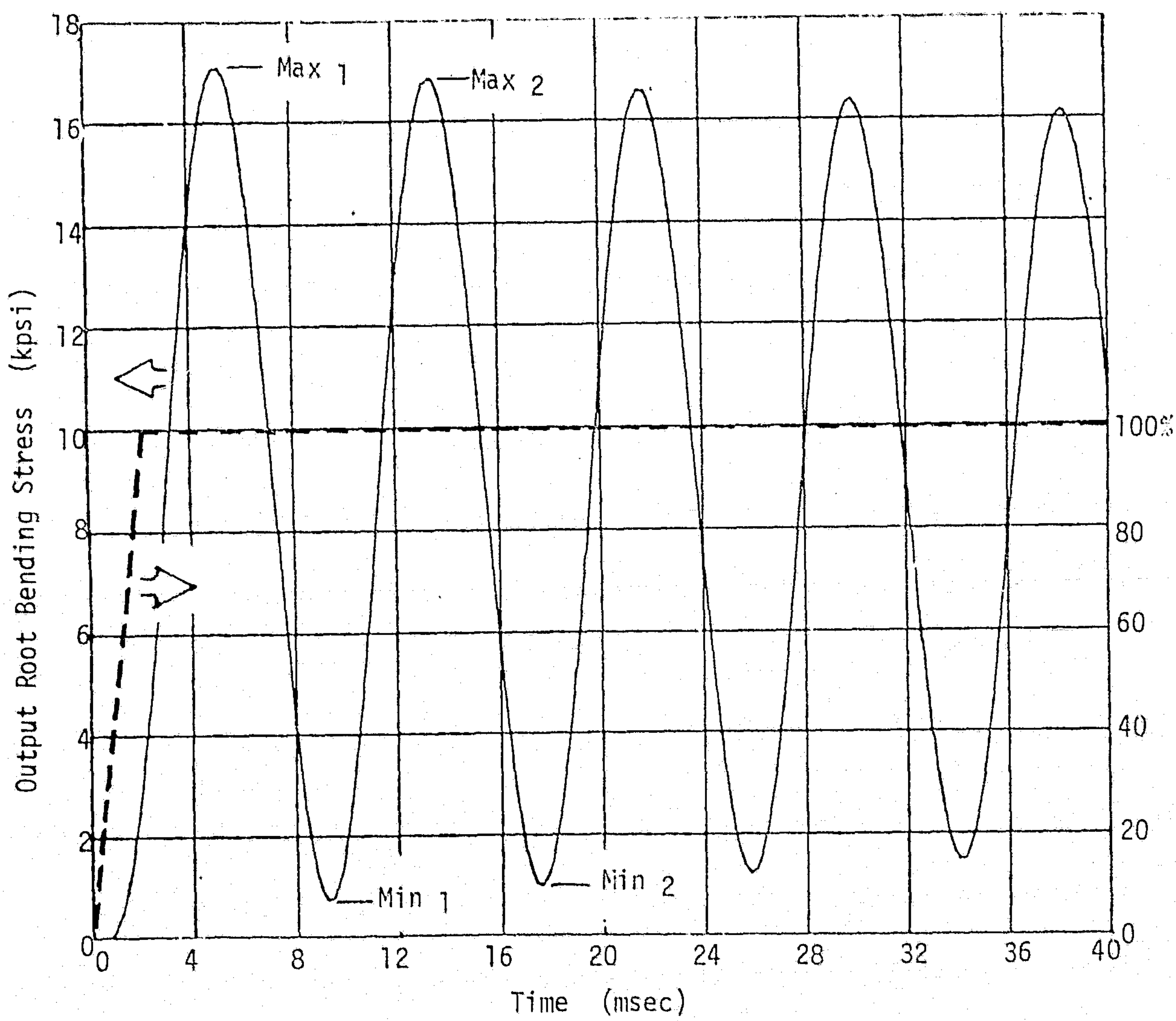


Fig. 14 Balance Data Output

from the exact solution by only about 0.02%. To minimize random experimental effects, the several values obtained at different i's would be averaged for either the entire plume duration or for a time interval to be decided for each run by the test engineer after inspection of the Visicorder output.

Data from the model pressure instrumentation recorded as functions of time will be reduced to a single value (per parameter), as averaged over a specified time interval. This interval will be decided for each run by the test engineer after inspection of the Visicorder output. Operations for the pressures are detailed below.

The 7 propulsion simulation operating pressures and the 33 model surface pressures recorded as functions of time on analog tape are to be reduced using Equation 2:

$$P(t) = \left(\frac{\Delta E(t)}{GAIN}\right) \times \left(\frac{1}{S}\right) + P_R \qquad (2)$$

where $\Delta E(t)$ = Voltage drop measured by the recording system at time, t;

GAIN = net gain of the electronic system between the sensor and recording system;

S = transducer sensitivity;

P_R = steady state plume-off reference pressure.

The steady state plume-off reference pressure, P_R, is to be reduced using standard test site methods and presented in engineering units. Table 5 listed the reference pressure to be used with each piezoelectric transducer. The piezoelectric transducer sensitivity to temperature, S, used in Equation 2 will be determined by the transducer temperature. The temperature of the high range transducers monitoring propulsion simulation operation will be assumed identical to the tunnel freestream total temperature. Calibration sensitivities will be available at 100°F and 200°F. The temperature of the low range transducers measuring base pressures will be determined by surrounding thermocouples. A transducer/thermocouple correlation was given in Table 5. Calibration sensitivities will be available at 75°F, 100°F, and 125°F. To select a sensitivity for Equation 2, assume a linear variation between calibration temperatures.

There will be a variety of different types of electronic circuitry used to link the model instrumentation (piezoelectric transducers) to the analog tape recording system. To obtain a true response from each model sensor, the output voltage signals must be corrected to account for the different time constant of each sensor electronic circuit. Voltage output signals are to be corrected using Equation 3:

$$\Delta E_c(t_n) = \Delta E(t_n)\left(1 + \frac{\Delta t}{\tau}\right) + \Delta E_c(t_{n-1})\left[1 - e^{\left(-\frac{t_n - 1}{\tau}\right)}\right] \quad (3)$$

where ΔE_c = corrected voltage;

ΔE = actual voltage output at time, t;

t = time at which the voltage is being corrected;

n = the number of time intervals from 0 to t;

Δt = t/n = time interval at which voltages are recorded (Δt = 0.4 msec);

τ = circuit time constant.

From Equation 3, the corrected voltage at any time, t_n, is a function of the voltage output at that time, t_n, and the corrected voltage at the previous data point, t_{n-1}.

The presentation of reduced data shall be in three categories: header data, raw dynamic data, and reduced data. Header data shall be listed with the reduced dynamic data for each run and shall consist of tunnel operating conditions evaluated just before model firing, model configuration data, and facility data. Raw dynamic data will be primarily be Visicorder traces but may also include tabulated data. Reduced data will include tabulated steady state data plus both tabulated and plotted dynamic data. Table 9 summarizes the data presentation. It is desired to be able to tabulate any of the dynamic data vs. time at any point during the test as required.

The availability of data should be as follows. Visicorder data should be provided immediately after the run. Digital encoded data should be provided for immediate playback in the control room. Selected analog tape channels shall be played back on Visicorders immediately after the run. Data on the analog tape should be reduced and provided in tabulated form 24 hours after the run. All header data should be listed with tabulated data 24 hours after the run. Plotted data should be provided one week after the run. There need not be a data tape for DATAMAN for this test. Two complete copies of the data will be required: one for the test engineer and one for NASA-MSFC. One extra copy of the summarized data will also be required for the test engineer.

TABLE 9 DATA PRESENTATION SUMMARY

HEADER DATA

Tunnel operating conditions	1. stagnation pressure (psfa) 2. static pressure (psfa) 3. dynamic pressure (psf) 4. model altitude (ft.) 5. Reynolds number ($ft.^{-1}$) 6. stagnation temperature (°R) 7. static temperature (°R) 8. density (slugs/ft.) 9. Mach number
Model configuration	1. angle of attack (deg.) 2. elevon deflection (deg.)
Facility	1. facility 2. facility test number 3. model number (19-OTS) 4. Shuttle test number (FA17) 5. run number 6. date

RAW DYNAMIC DATA

Propulsion simulation operating transducers	mV vs. time (Visicorder)
Propulsion simulation operating events	(Visicorder)
Selected model surface transducers	(Analog tape)
Wing and elevon balances	(Analog tape)
Selected piezoelectric transducers } △1	mV vs. time (tabulated)
Wing and elevon balances } △1	mV vs. time (tabulated)

△1 At the request of the test project engineer

REDUCED DATA

Steady State	Tabulated	Thermocouples (°F and °C) Reference pressures (psia)
Dynamic	Tabulated △2	Propul. sim. op. pressures (psia) Model surface pressures (psia) Balance loads (C_N, C_{BM}, C_{TM}, C_{HM})
Dynamic	Plotted vs. time	Propul. sim. op. pressures (psia) Model surface pressures (psia) Balance loads (C_N, C_{BM}, C_{TM}, C_{HM}) Temperatures (°F)

△2 Corresponding to the specified time interval.

6. CONCLUDING REMARKS

Test FA17 would most favorably be conducted with a modified 19-OTS model in the AEDC 16T facility, but could probably meet program goals if performed in the 11 x 11 leg of NASA-Ames UPWT. Final test site selection and scheduling is beyond the scope of this effort.

To achieve program goals the 19-OTS model should be modified to include at least wing and elevon balances, and it may be desired to consider body flap, vertical tail, and/or SSME nozzle balances. That is, use of the extant base pressure instrumentation alone is not likely to provide adequate verification of the candidate plume simulation/correlation parameters and application techniques. Use of the 19-OTS model with its short-duration firing principles will require competent (and preferably experienced) staff because of the associated complexities. However, this model has been successfully used for several years so that no conceptual difficulties are envisioned. A suitable wing balance design was devised and a prototype built and successfully demonstrated. Elevon balances were designed in a similar fashion. No other balances have yet been investigated in any detail.

The FA17 model would not exactly match that of IA119. To provide for direct comparison, it would be desireable to add a limited set of runs to IA119 with a modified model. This modification would involve increasing the ET length by one diameter, and replacing the scale truss ET-to-Orbiter attachment with a large solid strut. It is anticipated that only a limited test matrix matching Table 7 would be required.

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SPACE

SHUTTLE

****

10X10 SWT SPACE SHUTTLE CHECK LIST

****

(1) SPACE SHUTTLE PRE-RUN CHECK LIST

(2) POST RUN PROCEDURE

****

RUN NO.______.______.______ DATE / /

****

LATEST REVISION DATE

****

REVISION (T)	10-26-76
REVISION (U)	11-1-76
REVISION (V)	11-23-76

****

NOTE: IN CASE ANY MALFUNCTION OCCURS, SEE 'ABORT PROCEDURES' ON PAGE 22

APPENDIX
TEST IH39 CHECKLIST

RM 024-1

ORIGINAL PAGE IS OF POOR QUALITY

SPACE SHUTTLE PRE-RUN CHECK LIST

RUN NO. (*TO BE DEFINED BY RESEARCH ENGINEER, SEE MODEL SET-UP SHEET)

___ ____ ____ CONTRACTOR PERSONNEL TO COMPLETE THIS PORTION OF THE CHECK LIST

... . MODEL SET-UP SHEET COMPLETE

... . PERMISSIVE KEYS FOR FIRING PANEL AND GAS SYSTEMS TO BE IN POCESSION OF MECHANIC COMPLETING CHECK LIST

.... CALSPAN FIRING PANEL KEY

.... SOLENOID MASTER POWER KEY

.... TUNNEL DOOR SHORTING KEY

... . ENTER TEST SECTION AND INSTALL GAS TEMPERATURE PROBE COVERS (IF APPLICABLE)

... . USING CAMEL HAIR ARTIST BRUSH, CAREFULLY CLEAN HEAT TRANSFER GAGES WITH COBEHN

... . INSPECT TEST SECTION (REMOVE DEBRIS AND WASTE MATERIALS, SERVICE EQUIPMENT AND TOOLS EXCEPT THOSE NEEDED TO LOAD IGNITERS AND BSRM SOLID PROPELLANT)

... . FINAL CONFIRMATION OF MODEL CONFIGURATION

.... SSME ENGINE TYPE AND GIMBAL ANGLES

.... BSRM ENGINE GIMBAL ANGLES

.... ELEVON ANGLE

.... GAS TEMPERATURE PROBES

.... HEAT TRANSFER GAGE CLEANLINESS

MECHANICS DOING THIS PORTION OF CHECK (WHERE PROPELLANT AND IGNITERS ARE INSTALLED) MUST WEAR LEG STATS AND FACE SHIELDS

... . INSTALL SOLID PROPELLANT WITHIN BSRM HOUSING AND CONNECT T/C'S

... . REMOVE GAS TEMPERATURE PROBE COVERS (IF APPLICABLE)

... . CONDUCT STRAY VOLTAGE CHECK ON IGNITER CONNECTING WIRES

... . TRIM IGNITER LEADS

... . INSTALL IGNITER INTO ORBITER COMBUSTION CHAMBER AND BSRM IGNITERS INTO END OF PROPELLANT HOLDER INSERT

... . REMOVE IGNITER SHORT FROM IGNITER LEADS

... . INSTALL IGNITION WIRE LEADS ON IGNITORS

... . INSTALL ORBITER IGNITOR COVER AND BSRM NOSE PIECES

... . EXIT TEST SECTION WITH REMAINING TOOLS AND SERVICE EQUIPMENT

... . CONFIRM GAS TEMPERATURE PROBE CONTINUITY FROM OUTSIDE OF TEST SECTION (IF APPLICABLE)

NASA PERSONNEL TO COMPLETE THE REMAINDER OF THE CHECK LIST

... . VERIFY TEST SECTION SCHLIEREN WINDOWS ARE CLEAN

... . TEST SECTION TO BE CLEARED AND LOCKED BEFORE PROCEEDING WITH CHECK LIST

... . AFTER LOCKING TEST SECTION, INSERT TUNNEL DOOR SHORTING KEY AND TURN 'ON'

... . CONFIRM CARDOX SYSTEM 'ON' IN CONTROL ROOM (KEY SWITCH)

.... CHECK CARDOX SYSTEM SUPPLY TANK LEVEL

SET UP GN2 COOLING SYSTEM

.... GO TO AREA OF GN2 AND LN2 TRAILERS AND VERIFY FLEX HOSE CONNECTING LN2 AND GN2 TRAILERS IS IN PLACE AND THAT PIPING CONNECTING THE LN2 TRAILER TO THE BUILDING IS PROPERLY CONNECTED

.... CONFIRM PN43 READS APPROX. 60 PSI(FUEL HOUSE)

.... CONFIRM PN44 READS APPROX. 30 PSI(FUEL HOUSE)

.... 'OPEN' PN31 BY ENERGIZING PN35 FROM CONTROL ROOM

.... 'OPEN' VALVE PN30 ON TUBE TRAILER TO 'BLEED' POSITION

.... LEAVE AREA FOR AT LEAST TWO MINUTES TO ALLOW SYSTEM TO COME TO FULL PRESSURE

.... RECORD TUBE TRAILER SUPPLY PRESSURE (PN09) (SHOULD BE 300 PSI MIN.)

PN09=______________PSI

.... 'OPEN' PN30 FULLY

.... 'OPEN' PN10 AND PN12

.... 'OPEN' PN11 TO 45 DEGREE POSITION (HALF OPEN)

.... RECORD COOLING SYSTEM PRESSURE (PN15)

PN15=______________PSI

.... IF PN15 IS NOT 150 PSI, ADJUST FROM PN57 ON TOP OF TEST SECTION

.... CONFIRM OPERATION OF PN33 BY CYCLING VALVE WITH PN37 AND VISUAL INSPECTION AT TRAILER

.... TURN 'ON' FOUR ROOF VENT FANS

WHEN SETTING UP SYSTEMS ON TOP OF TEST SECTION FACE SHIELDS ARE TO BE WORN

.... CONFIRM GROUNDING CLIPS ON BOTTLE REGULATORS

.... CONFIRM ALL BLEED VALVES 'CLOSED' (OX17, OX20, ET04, OX34, PN54, HY17, HY20, HY22, CN30, CN31, CN35)

.... TURN 'ON' PANEL FAN ON 2M

TO SET UP GOX AND GH2 BOTTLES (OX01 AND HY01)

.... 'OPEN' HAND VALVES OX02 AND HY02 ON BOTTLES AND NOTE REGULATOR INLET PRESSURE (OX03 AND HY03)

GOX=______________PSI

GH2=______________PSI

IF ANY BOTTLE PRESSURE IS LESS THAN 1000 PSI REPLACE WITH NEW BOTTLE USING STANDARD PROCEDURES. IF GH2 BOTTLE CHANGE IS REQUIRED, CONDUCT THE FOLLOWING PROCEDURE AFTER GH2 BOTTLE IS IN PLACE

WITH NEW BOTTLES IN PLACE:

... CONFIRM HY05 AND HY17 'CLOSED'

... CONFIRM VACUUM SOURCE CONNECTED TO HY22

... TURN 'ON' VACUUM PUMP

... 'OPEN' HY22

... LEAVE VACUUM SOURCE ON FOR 2 MINUTES

... 'CLOSE' HY22

... TURN 'OFF' VACUUM PUMP

RECORD NEW BOTTLE PRESSURES:

GOX=_______________PSI

GH2=_______________PSI

PROCEED WITH CHECK LIST

.... CONFIRM REGULATOR OX03 SET TO MAX. OUTLET PRESSURE AND HY03 SET TO 500 PSI MIN. OUTLET PRESSURE

.... CONFIRM SOLENOID COOLING WATER 'ON'

.... VERIFY SA01 'OPEN'

.... CONFIRM BOOSTER PUMP DRIVE PRESSURE SA03. (NEAR BRIDGE)

SA03=(_______________)PSIG

.... 'OPEN' SA10 - PRESSURE SWITCH PURGE

.... VERIFY PN01 'OPEN' - NITROGEN PURGE

.... CONFIRM PRESSURE ON PN03 (GN2 PURGE) GAGE = 150 PSIG MINIMUM

TO SET UP HIGH PRESSURE GN2 BOTTLES CN01 AND CN11
(USE GLOVES FOR THIS OPERATION)

.... 'OPEN' CN02 AND CN12 AND NOTE REGULATOR INLET PRESSURE

CN03=____________________PSI

CN13=____________________PSI

(IF PRESSURE IN GN2 BOTTLES IS LESS THAN 3500 PSI, REPLACE WITH NEW BOTTLE)

.... RECORD OUTLET PRESSURES OF REGULATORS CN03 AND CN13

CN03 = __________PSI CN13 = __________PSI.

SET UP IGNITION GAS SYSTEM

(ALL REGULATORS ARE PRE-SET: 'DO NOT' ADJUST)

.... 'OPEN' FT02 AND OX32 - BOTTLE HAND VALVES

.... RECORD FT03 AND OX33 INLET AND VERIFY OUTLET PRESSURES.

FT03(IN)__________PSI OX33(IN)__________PSI

FT03(OUT)__________PSI OX33(OUT)__________PSI

INLET PRESSURE TO BE 300 PSI MINIMUM

SET UP IGNITION GAS BUFFER SYSTEM
(REGULATOR PRE-SET: 'DO NOT' ADJUST)

.... 'OPEN' PN51 -- BOTTLE HAND VALVE

.... RECORD PN52 INLET AND VERIFY OUTLET PRESSURE

PN52(IN)__________PSI PN52(OUT)__________PSI
(INLET PRESSURE TO BE 200 PSI MINIMUM)

... . LOAD HIGH SPEED FILM (PREPARE CAMERA AND SCHLIEREN SYSTEM FOR RUN)

... . INSTALL BARRICADES ON ALL FOUR STEPS LEADING TO TUNNEL. TURN 'OFF'ELEVATOR SWITCH AND TAG OUT.

END OF ACTIVITIES ON TOP OF TEST SECTION

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BEGINNING OF MULTIPLE RUN SEQUENCE

.... ASSURE THAT CN02 AND CN12 ARE OPEN

ACTIVITIES IN CONTROL ROOM
TO SET UP HIGH PRESSURE CONTROL GAS SYSTEM

.... VERIFY AUTOVALVE IN 'CLOSED' POSITION. IF AUTOVALVE IS 'NOT CLOSED' ,SEE RESEARCH ENGR. (THERE IS A TEE IN THE 'CLOSING' CONTROL LINE DOWNSTREAM OF CN15. A GN2 K-BOTTLE WITH PRESSURE REGULATED TO ABOUT 500 PSI TO BE CONNECTED HERE AND PRESSURE APPLIED UNTIL AUTOVALVE CLOSES.)

.... CONFIRM ALL SWITCHES TO LEFT EXCEPT PN35

.... TURN ON SOLENOID POWER (KEY SWITCH)

.... 'OPEN' CN15 TO SUPPLY 3000 PSI GN2 TO CLOSING VALCOR MODEL FIRING VALVE

.... VERIFY FULL GN2 PRESSURE AT CN18
(SEE MODEL SET-UP SHEET AND RE-ADJUST AS REQUIRED)

.... CONFIRM ARM SWITCHES 'OFF' ON CALSPAN FIRING PANEL (DOWN)

.... ENERGIZE FIRING PANEL

.... ''PUSH'' MANUAL 'CLOSE' BUTTON ON FIRING PANEL

.... DE-ENERGIZE FIRING PANEL

.... 'CLOSE' CN15

.... VERIFY PRESSURE AT CN22 = (1)____________

(2)____________ (3)____________ PSI

.... 'OPEN' CN05 -- SOLENOID VALVE

.... VERIFY AND RECORD CN08 PRESSURE (AND TIME)=

(1)________(________) (2)________(________)

(3)________(________)
(SEE MODEL SET-UP SHEET AND READJUST AS REQUIRED)

.... 'CLOSE' CN05

.... 'OPEN' OX05 AND HY05

.... VERIFY PRESSURE AT OX06 AND HY06

... . VERIFY 2Y IS CLEAR (USE P.A.)

... . VERIFY 'TIME CODE' IS WORKING

... . 'OPEN' SA04 AND OX09 (SAME SWITCH)
(THIS ACTION STARTS THE GOX PUMP)

... . 'OPEN' SA08 AND HY09 (SAME SWITCH)
(THIS ACTION STARTS THE GH2 PUMP)

MONITOR HY13 AND OX13 AND SHUT OFF PUMPS WHEN REQUIRED

.... ELECTRONICS CHECK LIST TO BE COMPLETE
BEFORE PUMP DOWN STARTS

... . START TUNNEL PUMPDOWN

... . CADDE SYSTEM 'ON' TO RECORD HT GAGE
RESISTANCES AFTER BEGINNING PUMP DOWN

... . CONFIRM SCANIVALVES HOME

... . WHEN THE TUNNEL IS DOWN TO ABOUT 1000 PSFA,
TAKE A DATA CALL AND RECORD THE NUMBER

1._____, 2._____, 3._____

CONTINUE WITH CHECK LIST

... . NOTIFY MULTIPLEX PEOPLE (PAX 6133) THAT RUN
WILL START IN APPROXIMATELY ONE HOUR

TO SET UP GN2 COOLING SYSTEM

... . CONFIRM OX-ET TRANSDUCER ISOLATION VALVE
'CLOSED'

... . CONFIRM CALSPAN FIRING PANEL 'OFF'

... . SOLENOID POWER 'ON' IN CONTROL ROOM

... . CONFIRM C.A. T/C SCANNER READOUT UNIT 'ON'
AND VERIFY AMBIENT TEMPERATURES

... . VERIFY TC-1 READOUT 'ON'

... . 'OPEN' PN16 - NITROGEN PANEL

... . 'OPEN' PN24/28, AND OX38 - IGNITION PANEL

... . SET REGULATOR PN37 TO ABOUT 10 PSI
ON GAUGE PN38. ADJUST AS REQUIRED TO KEEP
MODEL T/C'S BETWEEN +40 F AND +100 F

IGNITION GAS SYSTEM CHECK OUT

NOTE: TUNNEL MUST BE PUMPED DOWN TO 700 PSFA BEFORE DOING THIS CHECK.

- .... TURN 'ON' CALSPAN FIRING PANEL
- ____ ____ CONFIRM PN16, PN 24/28 'CLOSED'
- ____ ____ 'OPEN' OX-ET TRANSDUCER ISOLATION VALVE (SWITCH LOCATED BELOW CALSPAN FIRING PANEL)
- ____ ____ 'OPEN' ET05 AND OX35
- .... 'OPEN' OX38
- .... CONFIRM OX-ET TRANSDUCER PRESSURE = ... PS. ADJUST OX41 VALVE AS REQUIRED TO OBTAIN THIS VALUE (SEE SETUP SHEET FOR CORRECT PRESSURE)
- .... 'OPEN' ET08
- .... CONFIRM OX-ET TRANSDUCER PRESSURE = ... PS ADJUST ET11 VALVE AS REQUIRED TO OBTAIN THIS VALUE (SEE SETUP SHEET FOR CORRECT PRESSURE)
- .... 'CLOSE' ET05 AND OX35 (ALLOW ET10 AND OX40 TO BLEED DOWN TO TUNNEL STATIC)
- .... 'CLOSE' ET08 AND OX38
- .... TURN 'OFF' CALSPAN FIRING PANEL
- .... 'CLOSE' OX-ET TRANSDUCER ISOLATION VALVE
- .... OPEN PN16,PN24-28 AND OX18 TO CONTINUE MODEL COOLING
- .... INSURE MODEL ANGLE OF ATTACK IS ZERO

************** TUNNEL MAY NOW BE STARTED *****************

- ... . AS TUNNEL IS COMING ON TO CONDITION, GO TO SCHLIEREN SYSTEM AND SIGHT IN HIGH SPEED MOVIE CAMERA.

WHEN TUNNEL IS ON 'CONDITION', PROCEED WITH MODEL FIRING PROCEDURE

- ... . SET MODEL TO REQUIRED ANGLE OF ATTACK
- ... . CHECK GNOP PRESSURE. IF PRESSURE HAS NOT DROPPED MORE THAN 300 PSI, 'PROCEED'- IF PRESSURE HAS DROPPED MORE THAN 300 PSI NOTIFY P.E. FOR DECISION
- ... . FASTEX CAMERA 'ON' AND MIRROR IN POSITION
- ... . T.V. LIGHTS 'OFF' FOR DATA RUN.
- ... . TERMINATE ALL COOLING BY CLOSING PN16

  ALLOW ......SEC. FOR GN2 TO BLEED DOWN IN RSRM COOLING LINES BEFORE TAKING DATA CALL)
- ... . CLOSE PN24 / PN28
- ... . SET CONFIGURATION POTS
- ... . CHECK AMPLIFIER GAINS

ORIGINAL PAGE IS OF POOR QUALITY

... . 'OPEN' OX-ET TRANSDUCER ISOLATION VALVE

... . VERIFY READINESS OF ALL TUNNEL AND DATA RECORDING SYSTEMS

... . 'OPEN' CN20 AND ALLOW CHAMBER 'F' TO VENT USE CN22 TO SET PRESSURE (SEE MODEL SET UP SHEET FOR PRESSURES)

... . FIRING PANEL 'ON'

... . AUTOVALVE ARM 'ON' (FIRING PANEL)

... . ARM IGNITERS (FIRING PANEL)

... . VERIFY ET08 AND OX38 'OPEN' -- IGNITION PANEL

... . 'OPEN' ET05 AND OX35 TO ESTABLISH IGNITION GAS FLOW.

... . CONFIRM OX-ET TRANSDUCER READS ...... PSIA SEE SETUP SHEET FOR REQUIRED PRESSURE ADJUST OX41 OR ET11 IF REQUIRED

... . 'CLOSE' OX-ET TRANSDUCER ISOLATION VALVE

... . CONFIRM SCANIVALVES 'HOME'

... . TAKE CADDE DATA CALL (TO RECORD PRE-RUN HT GAGE RESISTANCES) AND RECORD NUMBER

1.________, 2.________, 3.________

... . FILTER SWITCHES IN

... . RECORD FINAL VALUES OF CN08,CN18,CN22,HY13, AND OX13 ON MODEL SET UP SHEET.
ADJUST AS REQUIRED WITH ENGINEER APPROVAL

... . VERIFY FIRING VOLTAGES OK

... . WHEN ANALOG RECORDING TIME COUNTS DOWN TO

<u>15 THEN DEPRESS THE IGNITION BUTTON ON THE FIRING PANEL</u>

... . ACTIVATE CN19 JUMPER PERMISSIVE SWITCH

... . WITHIN ONE MINUTE AFTER 'IGNITION' BUTTON IS DEPRESSED, CONTINUE COOLING BY OPENING PN16 (NITROGEN PANEL) AND PN24/28 (IG GAS PANEL)

... . 'CLOSE' ET05 AND OX35

... . CONFIRM PN24/28 'CLOSED'

... . CYCLE FIRING PANEL 'OFF', THEN BACK 'ON'

... . PUSH PN53/55 BUTTON AND ALLOW ET07 AND OX37 TO SETTLE OUT TO PURGE PRESSURE (IGNITION GAS PANEL)

... . AFTER ET07 AND OX 37 HAVE SETTLED OUT TO TUNNEL STATIC, PUSH PN53/55 BUTTON AGAIN TO RECYCLE PURGE

... . TURN POWER 'OFF' ON CALSPAN FIRING PANEL AND VERIFY ARM SWITCHES DOWN (SAFE)

... . 'CLOSE' ET08

... . 'OPEN' PN24/28 FOR ADDITIONAL COOLING FLOW

... . VERIFY OX38 'OPEN' -- IGNITION PANEL

... . FILTER SWITCHES OUT

... . CONFIRM SCANIVALVES 'HOME'

... . TAKE DATA CALL AND RECORD NUMBER

1.________, 2.________, 3.________

... . RETURN MODEL TO ZERO DEGREES ANGLE OF ATTACK (STRUT ANGLE - 3 DEGREES)

... . <u>TUNNEL SHUTDOWN PROCEDURE MAY BE INITIATED</u>

POST RUN PROCEDURE

(THIS PROCEDURE MAY BE INITIATED DURING TUNNEL SHUTDOWN)

NOTE: THE MODEL GH2 AND GOX CHARGE TUBES MUST BE PURGED AND THE HIGH PRESSURE CONTROL GN2 PRESSURE MUST BE RELIEVED PRIOR TO OPENING TUNNEL TEST SECTION.

THE FOLLOWING STEPS WILL PURGE THE MODEL CHARGE TUBES:

... . PURGE GH2 VENT STACK 3 - 5 SEC. BY OPENING PN41 -- COOLING CONTROL PANEL

... . VENT GH2 AND GOX CHARGE TUBES BY OPENING OX11 AND HY11

----PURGE CYCLE BEGINS HERE----

... . WHEN PRESSURE AT HY13 AND OX13 STABILIZES NEAR ZERO PRESSURE, 'CLOSE' OX11 AND HY11

... . 'OPEN' PN06 (O2 PANEL) AND PN04 (H2 PANEL) TO PRESSURIZE CHARGE TUBES WITH GN2

... . WHEN OX13 AND HY13 STABILIZE AT GN2 PURGE SYSTEM PRESSURE (150 PSI) 'CLOSE' PN06 (GOX PANEL) AND PN04 (GH2 PANEL)

... . 'OPEN' OX11 AND HY11 TO VENT MIXTURE IN CHARGE TUBES

REPEAT THIS PURGE CYCLE THREE TIMES MINIMUM FOR COMPLETE MODEL PURGE

... . FOLLOWING PURGE, 'CLOSE' OX11 AND HY11 WHEN PRESSURE AT HY13 AND OX13 HAS STABILIZED AT NEAR ATMOSPHERIC PRESSURE

THE FOLLOWING STEPS WILL RELIEVE THE HIGH PRESSURE CONTROL GN2 PRESSURE:

... . 'CLOSE' BOTTLE HAND VALVES CN02 AND CN12

CN03=________PSI CN13=________PSI

... . VERIFY CN05 AND CN15 'CLOSED'

... . 'OPEN' (DE-ENERGIZE) CN07

... . 'OPEN' CN21 AT LEAST TWO FULL TURNS (IF REQUIRED)

... . PUSH CN20 (ENERGIZE) AND HOLD OPEN UNTIL PRESSURE AT CN22 GOES TO ZERO

... . 'OPEN' CN21 ONE QUARTER (1/4) TURN (IF REQUIRED)

... . 'OPEN' (DE-ENERGIZE) CN17

... . WHEN PRESSURE AT CN08, CN18, AND CN22 HAVE STABILIZED AT ATMOSPHERIC PRESSURE, 'CLOSE' CN07 AND CN17

... . SHUT 'OFF' MODEL COOLING (PN16, PN24/28) WHEN TUNNEL IS DOWN TO M = 2.5

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WHEN TUNNEL SHUTDOWN IS COMPLETED

... . CONFIRM SCANIVALVES 'HOME'

... . TAKE DATA CALL AND RECORD NUMBER

1.________, 2.________, 3.________

... . CONFIRM ALL ARROWS TO LEFT EXCEPT PN35 SWITCH AND OX05 AND HY05

... . INITIATE TUNNEL VENT FANS FOR 5 MINUTES BEFORE ALLOWING ENTRY INTO TEST SECTION. (PURGE OF TUNNEL AFTER SOLID ROCKET FIRING REQUIRES THREE MIN. OF TUNNEL COOLING.)

... . POWER 'OFF' TO ALL SOLENOIDS.

... . OBTAIN APPROVAL TO ENTER TEST SECTION AFTER TUNNEL SHUTDOWN

... . PERMISSIVE KEYS FOR 'FIRING PANEL', AND SOLENOID MASTER KEY AND TUNNEL DOOR SHORTING KEY IN POSSESION OF MECHANIC COMPLETING CHECK LIST

50

... . VISUALLY INSPECT CONDITION OF MODEL AND INSTRUMENTATION FROM PREVIOUS RUN:(NOTE IRREGULARITIES ON RUN LOG)

... . REMOVE SPENT IGNITERS AND BSRM PROPELLANT HOLDER INSERT ASSEMBLIES

... . REFURBISH MODEL AND SET UP MODEL CONFIGURATIONS FOR NEXT RUN (SEE MODEL SET-UP SHEET) IF ANOTHER RUN IS PLANNED FOR THIS NIGHT, CONTINUE ON PAGE 9 FOR NEXT RUN. IF THIS WAS THE FINAL RUN OF THE NIGHT, PROCEED WITH SHUTDOWN

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SYSTEM SHUT DOWN

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..... GO TO TOP OF TEST SECTION AND NOTE BOTTLE PRESSURE OF EACH SYSTEM

--- GOX =........PSI(OX03) GH2 =........PSI(HY03)

IF ANY GOX OR GH2 BOTTLE IS BELOW 1000 PSI, LEAVE ORDERS FOR FIRST SHIFT TO REPLACE AS REQUIRED

--- GN2 =........PSI(CN03) GN2 =........PSI(CN13)
(OPENING SYSTEM) (CLOSING SYSTEM)

IF ANY GN2 BOTTLE IS BELOW 3500 PSI, LEAVE ORDERS FOR FIRST SHIFT TO REPLACE AS REQUIRED

--- CHECK OX31 AND ET01 BOTTLES
REPLACE IF BELOW 200 PSI

--- CHECK GN2 BOTTLE(PN50)
REPLACE IF BELOW 200 PSI

..... 'CLOSE' ALL BOTTLE SHUT-OFF VALVES (OX02, HY02, CN02, CN12, OX32, ET02, AND PN51)

..... VENT ALL BOTTLE REGULATOR-FILTER SECTIONS BY OPENING HAND BLEED VALVES OX17, HY17, CN30, CN31, ET04, OX34, AND PN54

..... BLEED PUMP SECTIONS BY OPENING HAND BLEED VALVES OX20 AND HY20

..... 'CLOSE' SA10 (PRESSURE SWITCH PURGE)

..... TURN 'ON' SOLENOID POWER

..... WHEN OX06 AND HY06 SHOW ATMOSPHERIC PRESSURE 'CLOSE' OX05 AND HY05

..... TURN 'OFF' SOLENOID POWER

..... 'CLOSE' BLEED VALVES OX17, HY17, CN30, CN31, ET04, OX34, OX20, HY20, AND PN54 WHEN SECTION HAS BLED DOWN

..... 'CLOSE' HAND VALVE PN30 AT TUBE TRAILER

..... 'CLOSE' PN10, PN11, AND PN12

..... BLEED PRESSURE IN LINE BY OPENING PN08

..... 'CLOSE' PN08 WHEN PN09 INDICATES ATMOSPHERIC PRESSURE

..... 'CLOSE' PN31 BY DE-ENERGIZING PN35 FROM CONTROL ROOM

..... SHUT 'OFF' CARDOX SYSTEM (KEY SWITCH IN CONTROL ROOM)

..... VERIFY ELECTRONICS SHUTDOWN COMPLETE

..... RETURN ALL UNUSED IGNITERS AND PROPELLANT TO EXPLOSIVES STORAGE TRAILER

*************** END OF POST RUN PROCEDURE ***************

**************** ABORT PROCEDURES ****************

ABORT NO.1

IF A MALFUNCTION OCCURS PRIOR TO LEAVING TEST SECTION AREA, USE THE FOLLOWING PROCEDURES:

REMOVE TUNNEL DOOR SHORTING KEY, CLOSE OFF ALL GAS SOURCES AND VENT ALL DELIVERY LINES TO ATMOSPHERE

(A) IF THIS ACTION CAUSES NIGHT'S OPERATION TO BE ABORTED, REMOVE IGNITERS AND BSRM PROPELLANT HOLDERS AND RETURN ALL UNUSED IGNITERS AND PROPELLANT TO EXPLOSIVE TRAILER STORAGE.

(B) IF RUN IS TO BE CONTINUED, RETURN TO FIRST STEP OF 'PRE-RUN CHECK LIST' AND VERIFY COMPLETION OF ALL STEPS

ABORT NO.2

IF A MALFUNCTION OCCURS AFTER LEAVING THE TEST SECTION AREA AND PRIOR TO PUSHING THE 'FIRE' BUTTON, USE THE FOLLOWING PROCEDURE:

VERIFY MODEL COOLING 'ON'

VERIFY FT05 AND OX35 'CLOSED'

VERIFY FIRING PANEL POWER 'OFF'

IF TUNNEL ENTRY IS REQUIRED AND TUNNEL HAS BEEN STARTED, THE STANDARD TUNNEL SHUT-DOWN PROCEDURE MAY BE INITIATED

PROCEED WITH 'POST RUN PROCEDURE' ON PAGE 17 TO POINT ON PAGE 19 OF OBTAINING PERMISSIVE KEYS TO ENTER TEST SECTION

(A) IF THIS ACTION CAUSES NIGHT'S OPERATION TO BE ABORTED, REMOVE IGNITERS AND BSRM PROPELLANT HOLDERS AND CONTINUE WITH 'POST RUN PROCEDURE'.

(B) IF RUN IS TO BE CONTINUED, RETURN TO FIRST STEP OF 'PRE-RUN CHECK LIST' AND VERIFY COMPLETION OF ALL STEPS

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********************   ABORT NO.3   ********************
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IF PUSHING THE 'FIRE' BUTTON CAUSES NO RESPONSE IN THE MODEL, REQUEST AN ELECTRICAL SYSTEM CHECK BY ELECTRICAL ENGINEER AND 'CLOSE' FT05 AND OX35. AFTER SYSTEM CHECK IS COMPLETE, GO TO PAGE 15 TO STEP WHERE FT05 AND OX35 ARE OPENED TO ESTABLISH IGNITION GAS FLOW. IF NO RESPONSE IS INDICATED AGAIN, PROCEED WITH CHECK LIST EXCEPT WHEN TUNNEL SHUT-DOWN IS COMPLETE, TUNNEL VENT FANS TO BE LEFT ON FOR ONE HOUR BEFORE ALLOWING ENTRY INTO TEST SECTION.

PERSONNEL ENTERING THE TUNNEL SHALL DON PLASTIC FACE SHIELD, PROCEED TO THE FRONT OF THE MODEL AND DISASSEMBLE PARTS TO EXPOSE THE IGNITER WIRE LEADS. THE IGNITION WIRES ARE TO BE DISCONNECTED AFTER SHORT CIRCUITING THE BRIDGE WIRE BY INSTALLING A CLAMP ON THE IGNITER WIRES, THE IGNITER SHALL BE REMOVED AND PLACED INTO A BUCKET OF WATER.

THE MALFUNCTIONED IGNITERS SHALL BE DISPOSED OF PER PROCEDURES SET FORTH IN CALSPAN ARD-75-001.

REMOVE BSRM PROPELLANT HOLDERS AND RETURN TO TEMPORARY STORAGE AREA.

(A) IF THIS ACTION CAUSES NIGHT'S OPERATION TO BE ABORTED, CONTINUE WITH 'POST RUN PROCEDURE'

(B) IF RUN IS TO BE CONTINUED, RETURN TO FIRST STEP OF 'PRE-RUN CHECK LIST' AND VERIFY COMPLETION OF ALL STEPS

53

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********************   ABORT NO.4   ********************
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IF ONE OR TWO OF THE IGNITERS FAIL TO IGNITE, THE RUN IS ABORTED. PROCEED WITH CHECK LIST EXCEPT WHEN TUNNEL SHUT-DOWN IS COMPLETE, TUNNEL VENT FANS TO BE LEFT ON FOR ONE HOUR BEFORE ALLOWING ENTRY INTO TEST SECTION.

TEST SECTION ENTRY PROCEDURES WILL BE THE SAME AS FOR ABORT NO.3

'ALL' IGNITERS INCLUDING UNFIRED ONES WILL BE REMOVED (AS PER ABORT NO.3) AND PLACED INTO A BUCKET OF WATER AND DISPOSED OF AS PER ABORT NO.3.

REMOVE UNFIRED BSRM PROPELLANT HOLDERS AND RETURN TO TEMPORARY STORAGE AREA.

(A) IF THIS ACTION CAUSES NIGHT'S OPERATION TO BE ABORTED, CONTINUE WITH 'POST RUN PROCEDURE'

(B) IF RUN IS TO BE CONTINUED, RETURN TO FIRST STEP OF 'PRE-RUN CHECK LIST' AND VERIFY COMPLETION OF ALL STEPS.