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RESULTS OF EXPERIMENTAL INVESTIGATIONS TO DETERMINE EXTERNAL TANK PROTUBERANCE LOADS USING A 0.03-SCALE MODEL OF THE SPACE SHUTTLE LAUNCH CONFIGURATION (MODEL 47-OTS) IN THE NASA/ARC UNITARY PLAN WIND TUNNEL (IA190A/B)

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by

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JOHNSON SPACE CENTER
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HOUSTON, TEXAS

WIND TUNNEL TEST SPECIFICS:

TEST NUMBER:	411-1,2,3-11,	411-1,2,3-97
NASA SERIES NUMBER:	IA190A	IA190B
MODEL NUMBER:	47-OTS	
TEST DATES:	7 FEB-19 FEB.80	17 MAR-30 MAY 80
OCCUPANCY HOURS:	167 + 128	

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ABSTRACT

Data were obtained on a 3-percent model of the Space Shuttle launch vehicle in the NASA/Ames Research Center 11x11-foot and 9x7-foot Unitary Plan Wind Tunnels. This test series has been identified as IA190A/B and was conducted from 7 Feb. 1980 to 19 Feb. 1980 (IA190A) and from 17 March 1980 to 19 March 1980 and from 8 May 1980 to 30 May 1980 (IA190B). The primary test objective was to obtain structural loads on the following external tank protuberances:

1) LO_2 feedline
2) GO_2 pressure line
3) LO_2 antigeyser line
4) GH_2 pressure line
5) LH_2 tank cable tray
6) LO_2 tank cable tray
7) Bipod
8) ET/SRB cable tray
9) Crossbeam/Orbiter cable tray

To fulfill these objectives the following steps were taken:

a) Eight 3-component balances were used to measure forces on various sections of 1 thru 6 above.

b) 315 pressure orifices were distributed over all 9 above items. The LO_2 feedline was instrumented with 96 pressure taps and was rotated to four positions to yield 384 pressure measurements. The LO_2 antigeyser line was instrumented with 64 pressure taps and was rotated to two positions to yield 128 pressure measurements.

c) Three Chrysler miniature flow direction probes were mounted on a traversing mechanism on the tank upper surface centerline to obtain flow field data between the forward and aft attach structures.

d) Schlieren photographs and ultraviolet flow photographs were taken at all test conditions.

Data from each of the four test phases are presented.

TABLE OF CONTENTS

INDEX OF MODEL FIGURES

INDEX OF MODEL FIGURES - (Concluded)

INDEX OF DATA FIGURES

INDEX OF DATA FIGURES

SCHEDULE	COEFFICIENTS PLOTTED	SCHEDULE	COEFFICIENTS PLOTTED	SCHEDULE	COEFFICIENTS PLOTTED
A	$C_{A_{B1}}$ VS α	E	$C_{A_{B5}}$ VS α	I	C_{p_L} VS X_T
	$C_{Y_{B1}}$ VS α		$C_{Y_{B5}}$ VS α		M_L VS X_T
	$C_{N_{B1}}$ VS α		$C_{N_{B5}}$ VS α	J	σ_{xz} VS X_T
B	$C_{A_{B2}}$ VS α	F	$C_{A_{B6}}$ VS α		ϕ_{xy} VS X_T
	$C_{Y_{B2}}$ VS α		$C_{Y_{B6}}$ VS α	K	C_p VS θ
	$C_{N_{B2}}$ VS α		$C_{N_{B6}}$ VS α	L	C_p VS X_T
C	$C_{A_{B3}}$ VS α	G	$C_{A_{B7}}$ VS α	M	C_p VS θ_T
	$C_{Y_{B3}}$ VS α		$C_{Y_{B7}}$ VS α		
	$C_{N_{B3}}$ VS α		$C_{N_{B7}}$ VS α		
D	$C_{A_{B4}}$ VS α	H	$C_{A_{B8}}$ VS α		
	$C_{Y_{B4}}$ VS α		$C_{Y_{B8}}$ VS α		
	$C_{N_{B4}}$ VS α		$C_{N_{B8}}$ VS α		

INTRODUCTION

This report presents data obtained from a 3 percent model of the Space Shuttle launch vehicle (Model 47-OTS) in the NASA/Ames Research Center Unitary Plan Wind Tunnels. Testing at Mach numbers from 0.4 to 1.4 was conducted in the 11x11-foot tunnel (IA190A) and testing at Mach numbers from 1.55 to 2.5 was conducted in the 9x7-foot tunnel (IA190B).

The primary purpose of this test was to obtain loads information on the External Tank protuberances. A secondary purpose was to obtain flow field data between the external tank and the orbiter for ice debris analysis. To accomplish these objectives the test was run in four distinct phases. These phases were:

1) Force balance data: Eight 3-component balances were installed in the external tank to measure loads on four sections of the GO_2 pressure line/LO_2 antigeyser line/LH_2 tank cable tray array, three sections of the GH_2 pressure line, and one section of the GO_2 pressure line/LO_2 tank cable tray array. Figure 2c shows the exact limits of each metric section and the numbering sequence of the balances

2) Pressure data: 315 pressure taps were used to obtain distributed pressure data on the ET protuberances. The pressure taps were located on the model as follows:

Location	Sequence	Cum.Total
LO_2 feedline	1-96	96
LO_2 antigeyser line	101-164	160
LH_2 tank cable tray	201-268	228
GH_2 pressure line	301-332	260
LO_2 tank cable tray	401-420	280
Orbiter/ET attach	501-516	296
ET/SRB cable tray	601-612	308
GO_2 pressure line	701-704	312
ET/SRB cable tray rake	901-903	315

Pressure taps were located at 16 stations on the LO_2 feedline with 6 taps at each station spaced 60° apart. The LO_2 feedline was mounted on the model in such a way as to allow indexing about its longitudinal axis in 15° increments. By indexing the LO_2 feedline 4 times the effective density of pressure measurements was increased to 24 taps at each station. This indexing was done manually so four runs were necessary to get all the data.

The LO_2 antigeyser line had four taps 90° apart at 16° stations. It was indexed once to 45° to give an effective pressure measurement density of 8 taps per station. All pressure tap locations are listed in table III. These data are presented in the Appendix.

The data were combined and interpolated after the test to get section coefficient data and distributed pressure data. (These data are documented under Chrysler special requests SPRT8R and SPRT8T.)

3) Probe data: Three miniature flow direction probes were mounted on a traversing carriage at the top centerline of the ET. The tip of the probes could move from $X_T = 1180.7$ to $X_T = 1926.3$. The three probes were located at $\theta_T =$ 165°, 180° and 195° and were .25 inches (model scale) above the tank surface. The probes measured local flow direction and velocity as well as local pressure. These data are also presented in the Appendix.

4) Oil flow: Oil was released from a manifold at $X_T = 731$ and allowed to flow down the tank surface and around the protuberances. Photographs of the resulting fluorescent oil patterns were taken at each α/β combination using ultraviolet lighting. Samples of these photographs are shown in Figures 31 thru 3p. Schlieren photographs were taken during the test to help analyze the flow field between the ET and orbiter but these were not successful and are not presented. All tank protuberances were updated to the latest lines prior to this test. The exterior moldline of the SOFI was modeled around all protuberances. Figures 2e and 2f show the details of the protuberance attachments and Figures 3a thru 3k show the entire model in detail.

NOMENCLATURE

Symbol	Mnemonic	Description
A_{Bi}		Axial force measured by balance i (1→8), pounds
a_L	AL	Local speed of sound, ft/sec
	BREF	Span of vehicle, inches
C_{p_i}	CPi	Pressure coefficient at orifice i -(Pi - P_∞)/q_∞
$C_{A_{B_i}}$	CABi	Axial force coefficient for balance i (1→8)
$C_{N_{Bi}}$	CNBi	Normal force coefficient for balance i (1→8)
$C_{Y_{B_i}}$	CYBi	Side force coefficient for balance i (1→8)
D		Reference diameter of protuberance, inches
ET		External Tank
	GAP	Change in relative spacing from scale between orbiter and E.T., inches.
GH_2	GH2	Gaseous hydrogen
GO_2	GO2	Gaseous oxygen
K		A complex function relating local flow conditions at the probe tip to local pressure, determined during calibration of the probes and applied during data reduction.
LH_2	LH2	Liquid hydrogen
LO_2	LO2	Liquid oxygen
	LREF	Reference length of vehicle, inches
ℓ		Reference length of metric protuberances, inches
M_L	ML	Local Mach number
M_∞	MACH	Freestream Mach number

NOMENCLATURE (Continued)

Symbol	Mnemonic	Description
N_{Bi}		Normal force measured by balance i(1→8), pounds
OMS	OMS	Orbital Maneuvering System
P_i	Pi	Pressure at orifice i, psia
P_T	PT	Freestream total pressure, psia
P_{T_L}	PTL	Local total pressure, psia
P_L	PL	Local static pressure, psia
$\overline{P}$	PBAR	Average probe tip measured pressure, psia
P_{1-5}		Individual probe measured pressures, psia
P_1/P_{T_L}	P1OPTL	Ratio of measured probe total pressure to actual local total pressure, from calibration.
P_∞	P	Freestream static pressure, psia
	POSTN	Position (1→4) identifying on which face of cable tray pressure tap is located. 1 = bottom, 2 = outbd, 3 = top, 4 = inboard.
q_∞	Q(PSF)	Freestream dynamic pressure, psf
q_L	QL	Local dynamic pressure, psf
R		Gas constant
Rn	RN/L	Reynolds number per unit length
SRB		Solid Rocket Booster
SSME		Space Shuttle Main Engines
	SREF	Reference area, $in.^2$
	SCALE	Model scale (0.03)
SOFI		Spray On Foam Insulation
T_L	TL	Local static temperature, °R

NOMENCLATURE (Continued)

Symbol	Mnemonic	Description
T_{T_∞}	TTF	Freestream total temperature, °R
V_{X_p}	VXP	Velocity component measured by a probe parallel to ET X-axis, ft/sec.
V_{R_p}	VRP	Radial velocity component measured by a probe perpendicular to local ET surface, ft/sec.
V_{θ_p}	VTP	Tangential velocity component measured by a probe perpendicular to VXP and VRP, ft/sec.
V_{X_T}	VXT	Velocity component measured by a probe parallel to ET x-axis, equal to VXP, ft/sec.
V_{Y_T}	VYT	Velocity component measured by a probe parallel to Y-axis, ft/sec.
V_{Z_T}	VZT	Velocity component measured by a probe parallel to Z-axis, ft/sec.
V_{L_p}	VLP	Magnitude of total velocity vector measured by a probe, ft/sec.
X_p	XP	Probe axial location, inches
X_T	XT	External Tank station, full scale, inches
X/L_s	XLS	Percent of total length of bipod strut
	XMRP	Location of model reference point along x-axis, inches
Y_{B_i}		Side force measured by balance i (1→8), pounds
	YMRP	Location of model reference point along Y-axis, inches
	ZMRP	Location of model reference point along Z-axis, inches

NOMENCLATURE (Continued)

Symbol	Mnemonic	Description
α	ALPHA	Model pitch angle, degrees
α_L	ALPHAL	Local angle of attack of velocity vector at a probe tip relative to probe centerline, degrees
α_{XZ}	ALFAXZ	Angle of attack of velocity vector at a probe tip when projected onto the X-Z plane, degrees
β	BETA	Model angle of sideslip, degrees
β_L	BETAL	Angle of sideslip of velocity vector at a probe tip when projected onto the X-Y plane, degrees
BXY	BETAXY	(same as above)
δ	DELTA	Probe crossflow direction relative to the radial line perpendicular to local ET surface, deg., $\delta = \delta_c + 45°$ for IA190A; $\delta = \delta_c -45°$ for IA190B.
δ_c	DELTAC	Probe crossflow direction relative to the probe reference line, deg. (0→360°)
δ_{ei}	IB-ELV	Deflection angle of inboard elevons, degrees
δ_{eo}	OB-ELV	Deflection angle of outboard elevons, degrees
γ		Ratio of specific heat at a constant pressure to specific heat at a constant volume, 1.4 for air
ρ	RHO	Probe pitch angle pressure parameter, function of P1→P5, used in calibration table lookup, degrees
ϵ	EPSLON	Probe directional pressure parameter, function of P1→P5, used in calibration table lookup, degrees
ϕ	PHI	Angle of rotation of the probe about the local radial direction, degrees
θ	THETA	General angular location on ET or protuberances, degrees

NOMENCLATURE (Concluded)

Symbol	Mnemonic	Description
θ_{AG}		Angular location of pressure taps on the LO_2 antigeyser line, degrees
θ_{GP}		Angular location of pressure taps on the GO_2 pressure line, degrees
θ_{HP}		Angular location of pressure taps on the GH_2 pressure line, degrees
θ_{OF}		Angular location of pressure taps on the LO_2 feedline, degrees
θ_p		Angular location of a probe, degrees
θ_s		Angular location of pressure taps on the bipod strut, degrees
θ_T		Angular location on the ET, degrees

CONFIGURATIONS INVESTIGATED

The model provided for this test was a 0.030 scale replica of the Rockwell International Space Shuttle Vehicle in the launch configuration. The launch configuration consists of the assembly of a payload carrying Orbiter, an expendable External Oxygen/Hydrogen Tank (ET) which provides fuel for the Orbiter main engines (SSME) and two expendable Solid Rocket Boosters (SRB). See figure 2a.

The Orbiter is of blended wing/body design with a double delta plan form (81°/45° leading edge), 12% thick wing with full span elevons incorporating a six-inch interpanel gap between the independently deflectable inboard and outboard panels. A single swept (45°) centerline vertical tail with rudder/speed brake capability is mounted on the top of the orbiter behind the cargo bay and between the two Orbital Maneuvering System (OMS) pods. At the lower aft end of the fuselage is a body flap to aid in trim control when the speed brakes are used. Three engines (SSME) are mounted on the blunt base of the orbiter.

The External Tank is of cylindrical cross section with a nominal diameter of 333 inches and a maximum diameter of 336.2 inches. The forward section of the ET has a tangent ogive nose which terminates in a biconic nose cap over the LO_2 vent valve. The forward third of the tank is filled with liquid oxygen and the rest with liquid hydrogen. Covering the entire tank is up to two inches of Spray On Foam Insulation (SOFI) to prevent ice formation. There are a number of external protuberances which consist of fluid lines, electrical conduits and attach hardware. The fluid lines modeled are the LO_2 feedline, LO_2 antigeyser line, GO_2 pressure line, GH_2 pressure line and the LH_2 feedline. Conduits modeled were the LO_2 tank cable tray, the LH_2 tank cable tray, the ET/SRB cable tray (on both sides) and all the brackets, fittings and fairings associated with each of these. Removable load reducing ramps were provided for each of these cable trays.

The two Solid Rocket Boosters are 146 inch nominal diameter cylinders with 18° half angle nose cones and a 13.27" spherical tip.

The SRB's and Orbiter were built to conform to ICD-2-0001, Revision C lines while the ET was updated to Revision E details.

The LH_2 pressure line was intentionally constructed at double scale diameter for the pressure phase of the test to allow room for instrumentation inside the line. This increased the diameter from 0.060 inches to 0.120 inches model scale. A scaled diameter line was used for the force, probe and oil flow phases of the test.

The aft Orbiter/ET attach structure was modified for structural reasons. The LH_2 feedline and LO_2 feedline extensions were used to support the orbiter. This caused slight deformities in each of these lines.

The forward Orbiter/ET (bipod) attach structure was modified for a small portion of the pressure test. The diameter of the support posts was doubled to allow room for instrumentation. The majority of the pressure test and all the remaining testing was done with the scaled bipod.

During the same runs that the enlarged bipod was used, and for a few runs thereafter (see run schedule), the left hand SRB/ET cable tray and its load reduction ramp were removed and replaced with a three-tube rake.

Several runs were made during the "A" portion of the pressure test with the Orbiter raised 0.2 inches model scale from its normal position relative to the ET. These runs are indicated in the run schedule.

The following nomenclature was used during the test to identify model components.

B62	-140 A/B Body
C9	-140 A/B Canopy
E64	OV102 Elevon
W131	OV102 Wing
M16	-140C Short OMS pods
N112	SSME Nozzles

R5	146A Rudder
V8	146A Vertical Tail
FD3	Flipper doors
T39	External Tank with "E" protuberances
S27	Solid Rocket Boosters

INSTRUMENTATION

The instrumentation used during each of the four phases of the test were distinctly different from one another and required a complete disassembly of the model and reinstallation in the tunnel.

Force Balances

Eight separate 3-component balances were used to obtain protuberance force data. Each balance was mounted inside the tank and supported a length of one of the fluid lines or cable trays by small posts projecting through the tank surface. The exact location and size of the metric protuberances can be found in figure 2c.

The rated loads of each balance are listed below:

Balance Position	Rated Load ~ lbs N	Y	A
1	3	3	1.5
2	12	12	6
3	12	12	6
4	12	12	6
5	12	12	6
6	3	3	1.5
7	3	3	1.5
8	3	3	1.5

Each balance was calibrated prior to the test to determine its basic calibration matrix and was check-loaded after installation to insure proper clearances and function.

Pressures

There were 315 pressure taps on the tank protuberances. These were recorded on 10 scanivalve modules driven by two drive/stepper motors mounted inside the ET. The location of the pressure taps is listed in Table III.

A completely different set of protuberances were used for the pressure measurements than those used for force data. The pressure lines were routed through the parts and were carried into the tank through or just behind a mounting structure to minimize flow disturbance. The only exception to this was at the aft end of the LO_2 feedline where 48 pressure tubes crossed from the LO_2 feedline to the tank. The resulting bundle of tubes was approximately the same diameter as the LO_2 feedline.

The diameter of the bipod and of the GH_2 pressure line were doubled from scale to allow room inside these parts for pressure tubing. Pressure taps 257 thru 268 listed with an asterisk in Table III are located on the crossbeam/ET cable tray that can be seen in Figure 3b as a small curved rectangular cross-section part near the top of the aft right-hand support strut. The taps are located, one on each face, at the forward end of the curved section (257→260), in the middle of the curved section (261→264) and at the upper tangent point (265→268) of the curved section. These are labeled in the data as being at X_T 4001, 2 or 3 for convenience only. These numbers do not reflect the actual location of the taps.

Probes

The probes used were constructed by the Chrysler/Slidell Engineering Office specifically for this test program. The probes are 0.050 inches in diameter with a 25° half angle conical tip. Five pressure orifices with an inside diameter of 0.005 inches are on the tip of each probe. Figure 2j shows the probes in detail. Each probe was calibrated by Chrysler for flow angle, Mach number and local pressure in the NASA/MSFC 14" TWT prior to the test. Figures 2k and 2l show the calibration fixture and installation.

Three probes were used simultaneously during the test. The resulting 15 pressures were read on 5 scanivalve modules using one drive mounted in the ET. The pressures were plumbed to the scanivalve such that all five pressures on one probe were read simultaneously.

Oil Flow

The oil flow phase of the test was conducted with the force balances in place on the tank. All pressure instrumented parts of the model that remain during this configuration were sealed at the orifice and disconnected at the scanivalve to prevent oil from damaging the transducers or plugging the tubing.

The oil was delivered to the model under pressure through a 1/4" copper line. A solenoid valve was mounted in the tank nose to control oil flow onto the tank surface.

Photographs were taken under ultraviolet light only from both sides of the model. An observer determined when the proper amount of fluorescent oil was present on the ET surface and triggered the camera. A sampling of these photographs are presented in Figures 31 thru 3p.

TEST FACILITIES DESCRIPTION

Ames 11 x 11-Foot Transonic

The Ames 11 x 11-Foot Transonic Wind Tunnel is a variable density, closed return, continuous flow type. This tunnel has an adjustable nozzle (two flexible walls) and a slotted test section to permit transonic testing over a Mach number range continuously variable from 0.4 to 1.4.

Ames 9 x 7-Foot Supersonic

The Ames 9 x 7-Foot Supersonic Wind Tunnel is a variable density, continuous flow type with an adjustable nozzle to permit supersonic testing over a Mach number range continuously variable from 1.5 to 2.5. The nozzle is of the asymmetric, sliding-block type in which the variation of the test section Mach number is achieved by translating, in the stream-wise direction, the fixed-contour block that forms the floor of the nozzle.

DATA REDUCTION

All pressure data recorded were reduced to standard pressure coefficients of the form.

$$Cp_i = \frac{P_i - P_\infty}{q_\infty}$$

These data are listed by geometric location for each $\alpha/\beta/M$ combination in the Appendix.

Force data for each of the eight balances were reduced to force coefficients per unit length of the form:

$$C_{N_{Bi}} = \frac{N_{Bi}}{q_\infty D\ell} \quad (Normal\ force)$$

$$C_{Y_{Bi}} = \frac{Y_{Bi}}{q_\infty D\ell} \quad (Side\ force)$$

$$C_{A_{Bi}} = \frac{A_{Bi}}{q_\infty D\ell} \quad (Axial\ force)$$

where Bi = balance position number (1→8)

D = protuberance reference diameter 0.0171 inches

ℓ = length of metric section

The reference axis system for each balance consists of three mutually perpendicular axes with the normal force axis perpendicular to the local ET surface, axial force perpendicular to normal force and parallel to the ET centerline and side force parallel to the local ET surface and perpendicular to normal force and axial force. Forces were resolved at a point .116 inches above the local ET surface for the GH_2 pressure line and .147 inches above the local ET surface for the cable tray/antigeyser line/GO_2 pressure line array.

Probe data were reduced using calibration tables supplied by Chrysler/DATAMAN. These tables consisted of a three parameter table lookup and interpolation routine. The five probe pressures (figure 2j) were used to obtain the following three parameters:

$$\rho = \frac{\sqrt{(P_3-P_5)^2+(P_2-P_4)^2}}{P_1}$$

$$\varepsilon = 57.2958\tan^{-1}\left[\frac{P_3-P_5}{P_4-P_2}\right]$$

$$P_1 = \frac{P_2+P_3+P_4+P_5}{4P_1}$$

These parameters where used to obtain δ_c, M_L and α from the tables

δ_c = probe crossflow direction with respect to the probe reference line, deg

M_L = Local Mach number

α_L = angle of the flow relative to the probe centerline

For Test IA190A, $\delta = \delta_c + 45°$

For Test IA190B, $\delta = \delta_c - 45°$

Local total pressure, P_{TL}, was determined from the above parameters

$$P_{TL} = P_1/K$$

where $K = f(\delta_c, M_L, \alpha_L)$

Other local conditions were determined using standard perfect adiabatic flow relationships:

$$P_L = P_{T_L}\left(1+\frac{M_L^2}{5}\right)^{-3.5}$$

$$q_L = \frac{\gamma}{2} P_L M_L^2$$

$$a_L = \sqrt{\gamma R T_L}$$

$$T_L = \frac{5 T_{T_\infty}}{5+M_L^2}$$

$$V_{L_p} = M_L a_L$$

Having determined all of the local flow conditions relative to the probe reference line the local velocity components were determined in the probe reference system.

$$V_{X_p} = M_L a_L \cos\alpha_L$$

$$V_{R_p} = \frac{\sin\alpha_L M_L a_L}{\sqrt{1+\tan^2\delta}} = (\sin\alpha_L \cos\delta) M_L a_L$$

$$V_{\theta_p} = -\frac{\sin\alpha_L \tan\delta M_L a_L}{\sqrt{1+\tan^2\delta}} = -M_L a_L \sin\alpha_L \sin\delta$$

The velocity components were then rotated into the standard aircraft rectangular coordinate system

$$V_{X_T} = V_{X_P}$$

$$V_{Y_T} = V_{Rp} \sin\theta_p - V_{\theta p} \cos\theta_p$$

$$V_{Z_T} = - V_{Rp} \cos\theta_p - V_{\theta p} \sin\theta_p$$

Finally pitch and yaw angles of the velocity vector were determined

$$\alpha_{XZ} = \tan^{-1}\left[\frac{V_{Z_T}}{V_{X_T}}\right]$$

$$\beta_{XY} = -\tan^{-1}\left[\frac{V_{Y_T}}{V_{X_T}}\right]$$

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TABLE 1 TEST CONDITIONS

TEST : IA190A/B

DATE :

TEST CONDITIONS

MACH NUMBER	REYNOLDS NUMBER (per unit length)	DYNAMIC PRESSURE ~~(pounds/sq. inch)~~	STAGNATION TEMPERATURE (degrees Fahrenheit)
0.60	5.00×10^6	600 psf	100
0.90	3.69×10^6	↓	↓
1.10	3.23×10^6	↓	↓
1.25	3.03×10^6	↓	↓
1.40	2.93×10^6	↓	↓
1.55	2.85×10^6	↓	↓
2.00	2.86×10^6	↓	↓
2.50	3.07×10^6	↓	↓

BALANCE UTILIZED: See Instrumentation Section

	CAPACITY:	ACCURACY:	COEFFICIENT TOLERANCE:
NF			
SF			
AF			
PM			
RM			
YM			

COMMENTS:

TABLE II – EXTERNAL TANK PROTUBERANCE LOADS TEST (IA190A) RUN SCHEDULE
FORCE

TEST: IA190A (ARC 411–2–11) — DATA SET/RUN NUMBER COLLATION SUMMARY — DATE: MARCH 1980

DATA SET IDENTIFIER	CONFIGURATION	SCHD. Alpha	SCHD. Mach	PARAMETERS Q	PARAMETERS ELVI	PARAMETERS ELV0	BETA −4	BETA 0	BETA +4
R3U$01	OTS (RAMPS ON)	A	0.60	600	10	9		27	
R3U$02		A	0.60	600	10	9	14	13	15
R3U$03		A	0.90	600	10	9	24	25	26
R3U$04		A	1.10	600	10	9	20	21	22
R3U$05		A	1.25	600	10	0	49	50	51
R3U$06		A	1.40	600	10	0	52	53	54
R3U$07	OTS (RAMPS OFF)	A	0.60	600	10	9	36	37	38
R3U$08		A	0.90	600	10	9	33	34	35
R3U$09		A	1.10	600	10	9	30	31	32
R3U$10		A	1.25	600	10	0	45	46	47
R3U$11		A	1.40	600	10	0	42	43	44
R3U$76	OIL FLOW (RAMPS ON)	A	0.60	600	10	0	55	56	57
R3U$77		A	0.90	600	10	0	59	60	61
R3U$78		A	1.10	600	10	0	68	69	70
R3U$79		A	1.25	600	10	0	65	66	67
R3U$80		A	1.40	600	10	0	62	63	64

TEST RUN NUMBERS

alpha or beta SCHEDULES

A: ALPHA = −4, 0, +4 DEG.

$: A – BALANCE #1
$: B – BALANCES #2, #3, & #4
$: C – BALANCE #5
$: D – BALANCES #6, #7, & #8

TABLE II – EXTERNAL TANK PROTUBERANCE LOADS TEST (IA190A) RUN SCHEDULE
PRESSURE

TEST: IA190A (ARC 411–1–11) | DATA SET/RUN NUMBER COLLATION SUMMARY | DATE: MARCH 1980

DATA SET IDENTIFIER	CONFIGURATION	SCHD. Beta	SCHD. Mach	PARAMETERS Q	ELVI	ELVO	LO2	A–G	GAP	ALPHA –4	0	+4
R3U$12	OTS BIPOD / RAKE /	A	0.60	600	10	0	0	0	0	119	120	121
R3U$13	RAMPS ON	A	0.90	600	10	0	0	0	0	116	117	118
R3U$14		A	1.10	600	10	0	0	0	0	113	114	115
R3U$15		B	1.25	600	10	0	0	0	0	110	111	112
R3U$16		A	1.40	600	10	0	0	0	0	107	108	109
R3U$17	OTS RAMPS ON / RAKE	A	0.60	600	10	9	0	0	0	138	139	140
R3U$18		A	0.90	600	10	9	0	0	0	135	136	137
R3U$19		A	1.10	600	10	9	0	0	0	131	132	133
R3U$20		B	1.25	600	10	0	0	0	0	129	128	127
R3U$21		A	1.40	600	10	0	0	0	0	124	125	126
R3U$22	OTS RAMPS ON	B	0.60	600	10	9	15	45	0	238	239	240
R3U$23		B	0.90	600	10	9	15	45	0	235	236	237
R3U$24		B	1.10	600	10	9	15	45	0	232	233	234
R3U$25		B	1.25	600	10	0	15	45	0	245	246	247
R3U$26		B	1.40	600	10	0	15	45	0	242	243	244
R3U$27		A	0.60	600	10	9	30	0	0	203	204	205
R3U$28		A	0.90	600	10	9	30	0	0	200	201	202
R3U$29		A	1.10	600	10	9	30	0	0	197	198	199
R3U$30		B	1.25	600	10	0	30	0	0	210	211	212
R3U$31		A	1.40	600	10	0	30	0	0	207	208	209

TEST RUN NUMBERS

alpha or beta SCHEDULES
A: BETA = –4, 0, +4, DEG.
B: BETA = –4,–2,0,+2,+4, DEG.

$: A – TANK CABLE TRAYS
$: B – LO2 ANTIGEYSER LINE
$: C – GO2 PRESSURE LINE
$: D – LO2 FEEDLINE
$: E – FWD ATTACH STRUTS
$: F – GH2 PRESSURE LINE
$: G – ET / SRB CABLE TRAY
$: H – PRESSURE RAKE

NOTE : WHEN RAKE IS INSTALLED, THE L. H. ET / SRB CABLE TRAY RAMP IS REMOVED

TABLE II – EXTERNAL TANK PROTUBERANCE LOADS TEST (IA190A) RUN SCHEDULE PRESSURE (CONT'D)

TEST: IA190A (ARC 411–1–11)		DATA SET/RUN NUMBER COLLATION SUMMARY																DATE : MARCH 1980	
DATA SET		SCHD.		PARAMETERS						ALPHA									
IDENTIFIER	CONFIGURATION	Beta	Mach	Q	ELVI	ELVO	LO2	A–G	GAP		–4		0		+4				
R3U$32	OTS RAMPS ON	B	0.60	600	10	9	45	45	0		228		229		230				
R3U$33		B	0.90	600	10	9	45	45	0		225		226		227				
R3U$34		B	1.10	600	10	9	45	45	0		222		223		224				T
R3U$35		B	1.25	600	10	0	45	45	0		218		219		220				E
R3U$36		B	1.40	600	10	0	45	45	0		215		216		217				S
R3U$37		A	0.60	600	10	0	15	45	0.20		262		263		264				T
R3U$38		A	0.90	600	10	0	15	45	0.20		259		260		261				
R3U$39		A	1.10	600	10	0	15	45	0.20		256		257		258				R
R3U$40		B	1.25	600	10	0	15	45	0.20		253		254		255				U
R3U$41		A	1.40	600	10	0	15	45	0.20		250		251		252				N
R3U$42	OTS RAMPS OFF	A	0.60	600	10	9	0	0	0		157		158		159				
R3U$43		A	0.90	600	10	9	0	0	0		154		155		156				N
R3U$44		A	1.10	600	10	9	0	0	0		151		152		153				U
R3U$45		A	1.25	600	10	0	0	0	0		174		175		176				M
R3U$46		A	1.40	600	10	0	0	0	0		171		172		173				B
R3U$47		A	0.60	600	10	9	30	0	0		193		194		195				E
R3U$48		A	0.90	600	10	9	30	0	0		190		191		192				R
R3U$49		A	1.10	600	10	9	30	0	0		187		188		189				S
R3U$50		B	1.25	600	10	0	30	0	0		183		184		185				
R3U$51		A	1.40	600	10	0	30	0	0		180		181		182				

alpha or beta SCHEDULES

A: BETA = –4, 0, +4 DEG.
B: BETA = –4, –2, 0, +2, +4, DEG.
$: A – TANK CABLE TRAYS
$: B – LO2 ANTIGEYSER LINE
$: C – GO2 PRESSURE LINE
$: D – LO2 FEEDLINE
$: E – FWD ATTACH STRUTS
$: F – GH2 PRESSURE LINE
$: G – ET/SRB CABLE TRAY
$: H – PRESSURE RAKE

TABLE II – EXTERNAL TANK PROTUBERANCE LOADS TEST (IA190A) RUN SCHEDULE
TRAVERSING PROBES

TEST: IA190A (ARC 411–3–11)		DATA SET/RUN NUMBER COLLATION SUMMARY																DATE: MARCH 1980	
DATA SET		SCHEDULES					PROBE LONGITUDINAL POSITION – COUNTS												
IDENTIFIER	CONFIGURATION	beta	alpha	Mach	ELVI	ELVO	0	347	694	1041	1735	2429	3470	4511	5552	6593	7287	7634	7762
R3U$52	OTS (TRAVERSING PROBE)	A	–4	0.60	10	0	104	107	110	113	116	119	122	125	128	131	134	137	140
R3U$53		A	0	0.60	10	0	105	108	111	114	117	120	123	126	129	132	135	138	141
R3U$54		A	4	0.60	10	0	106	109	112	115	118	121	124	127	130	133	136	139	142
R3U$55		A	–4	0.90	10	0	189	186	183	180	177	174	171	168	165	162	159	156	144
R3U$56		A	0	0.90	10	0	190	187	184	181	178	175	172	169	166	163	160	157	145
R3U$57		A	4	0.90	10	0	191	188	185	182	179	176	173	170	167	164	161	158	146
R3U$58		A	–4	1.10	10	0	269	272	---	275	278	---	281	---	284	287	290	293	296
R3U$59		A	0	1.10	10	0	270	273	---	276	279	---	282	---	285	288	291	294	297
R3U$60		A	4	1.10	10	0	271	274	---	277	280	---	283	---	286	289	292	295	298
R3U$61		A	–4	1.25	10	0	266	263	---	260	257	254	251	248	245	242	239	236	233
R3U$62		A	0	1.25	10	0	267	264	---	261	258	255	252	249	246	243	240	237	234
R3U$63		A	4	1.25	10	0	268	265	---	262	259	256	253	250	247	244	241	238	235
R3U$64		A	–4	1.40	10	0	194	197	200	203	206	209	212	215	218	221	224	227	230
R3U$65		A	0	1.40	10	0	195	198	201	204	207	219	213	216	219	222	225	228	231
R3U$66		A	4	1.40	10	0	196	199	202	205	208	211	214	217	220	223	226	229	232

TEST RUN NUMBERS

alpha or beta — A: BETA = –4, 0, +4 DEG.

SCHEDULES — $: 1 – LEFT TRAVERSING PROBE (PROBE #31)
$: 2 – MID TRAVERSING PROBE (PROBE #46)
$: 3 – RIGHT TRAVERSING PROBE (PROBE #43)

TABLE II – EXTERNAL TANK PROTUBERANCE LOADS TEST (IA190A) RUN SCHEDULE
STATIONARY PROBE

TEST: IA190A (ARC 411–3–11)		DATA SET/RUN NUMBER COLLATION SUMMARY							DATE: MARCH 1980
DATA SET		SCHD.		PRAMETERS			MACH NUMBER		
IDENTIFIER	CONFIGURATION	BETA	ALPHA	P. POS.	ELVI	ELVO	0.90	1.10	1.25
R3U467	OTS (STATIONARY PROBE)	A	–4	1	10	0	309	306	303
R3U468		A	0	1	10	0	310	307	304
R3U469		A	4	1	10	0	311	308	305
R3U470		A	–4	2	10	0	319	316	313
R3U471		A	0	2	10	0	320	317	314
R3U472		A	4	2	10	0	321	318	315
R3U473		A	–4	3	10	0	---	328	325
R3U474		A	0	3	10	0	---	329	326
R3U475		A	4	3	10	0	---	330	327

TEST RUN NUMBERS

alpha or beta SCHEDULES

A: BETA = –4, 0, +4 DEG.

NOTE : P. POS. = PROBE POSITION

TABLE II – EXTERNAL TANK PROTUBERANCE LOADS TEST (IA190B) RUN SCHEDULE
PRESSURE

TEST: IA190B (ARC 411–1–97)		DATA SET/RUN NUMBER COLLATION SUMMARY											DATE: JUNE 1980	
DATA SET		SCHD.		PARAMETERS					BETA					
IDENTIFIER	CONFIGURATION	Alpha	Mach	Q	ELVI	ELVO	LO2	A–G	–6	–4	0	+4	+6	
R3V$01	OTS BIPOD / RAKE /	A	1.55	600	8	–5	30	0	354	355	356	357	358	
R3V$02	RAMPS (1)	D	2.00	600	8	–5	30	0	359	360	361	362	363	
R3V$03		D	2.50	600	8	–5	30	0	364	365	366	367	368	T
R3V$04	OTS (RAMPS (1)	B	1.55	600	8	–5	0	45		327	328	329		E
R3V$05		B	2.00	600	8	–5	0	45		331	332	333		S
R3V$06		B	2.50	600	8	–5	0	45		335	336	337		T
R3V$07		C	1.55	600	8	–5	15	45		319	320	321		
R3V$08		C	2.00	600	8	–5	15	45		322	323	324		R
R3V$09		B	1.55	600	8	–5	30	0	370	371	372	373	374	U
R3V$10		D	2.00	600	8	–5	30	0	375	376	377	378	379	N
R3V$11		D	2.50	600	8	–5	30	0	380	381	382	383	384	
R3V$12		B	1.55	600	8	–5	45	0		340	341	342		N
R3V$13		B	2.00	600	8	–5	45	0		344	345	346		U
R3V$14		B	2.50	600	8	–5	45	0		348	349	350		M
R3V$15		C	1.55	600	10	–5	15	45		300	301	302		B
R3V$16		C	2.00	600	10	–5	15	45		303	304	305		E
R3V$17		C	2.50	600	10	–5	15	45		306	307	308		R
R3V$18		C	1.55	600	0	–2	15	45		310	311	312		S
R3V$19		C	2.00	600	0	–2	15	45		313	314	315		
R3V$20		C	2.50	600	0	–2	15	45		316	317	318		

alpha or beta SCHEDULES

A: ALPHA = –4, 0, +4, +6, DEG.
B: ALPHA = –6, –4, 0, +4, DEG.
C: ALPHA = –4, 0, +4, DEG.
D: ALPHA = –6, –4, 0, +4, +6, DEG.

$: A – TANK CABLE TRAYS
$: B – LO2 ANTIGEYSER LINE
$: C – GO2 PRESSURE LINE
$: D – LO2 FEEDLINE
$: E – FWD ATTACH STRUTS
$: F – GH2 PRESSURE LINE
$: G – ET / SRB CABLE TRAY
$: H – PRESSURE RAKE

NOTE : RAMPS (1) INCLUDES LH2 TANK CABLE TRAY RAMP AND ET / SRB CABLE TRAY RAMPS
(EXCEPT WHEN RAKE IS INSTALLED, THE L.H. ET / SRB CABLE TRAY IS REMOVED)

TABLE II – EXTERNAL TANK PROTUBERANCE LOADS TEST (IA190B) RUN SCHEDULE PRESSURE (CONT'D)

TEST: IA190B (ARC 411–1–97) | DATA SET/RUN NUMBER COLLATION SUMMARY | DATE : JUNE 1980

DATA SET IDENTIFIER	CONFIGURATION	SCHD. Alpha	SCHD. Beta	PARAMETERS Mach	Q	ELVI	ELVO	LO2	A–G	BETA –6 (TEST RUN NUMBERS)	–4	0	+4	+6
R3V$21	OTS RAMPS (2)	B	---	1.55	600	8	–5	30	0	386	387	388	389	390
R3V$22		D	---	2.00	600	8	–5	30	0	391	392	393	394	395
R3V$23		D	---	2.50	600	8	–5	30	0	396	397	398	399	400
R3V&24	OTS RAMPS OFF	B	---	1.55	600	8	–5	30	0	402	403	404	405	406
R3V$25		D	---	2.00	600	8	–5	30	0	407	408	409	410	411
R3V$26		D	---	2.50	600	8	–5	30	0	412	413	414	415	416
										ALPHA				
R3V$27	OTS RAMPS (1)	0	C	1.55	600	8	–5	0	45			330		
R3V$28		0	C	2.00	600	8	–5	0	45			334		
R3V$29		0	C	2.50	600	8	–5	0	45			338		
R3V$30		0	C	1.55	600	8	–5	45	0			343		
R3V$31		0	C	2.00	600	8	–5	45	0			347		
R3V$32		0	C	2.50	600	8	–5	45	0			351		

alpha or beta SCHEDULES

A: ALPHA = –4, 0, +4, +6, DEG.
B: ALPHA = –6, –4, 0, +4, DEG.
C: ALPHA & BETA = –4, 0, +4, DEG
D: ALPHA = –6, –4, 0, +4, +6, DEG

$: A – TANK CABLE TRAYS
$: B – LO2 ANTIGEYSER LINE
$: C – GO2 PRESSURE LINE
$: D – LO2 FEEDLINE
$: E – FWD ATTACH STRUTS
$: F – GH2 PRESSURE LINE
$: G – ET / SRB CABLE TRAY
$: H – PRESSURE RAKE

NOTE : RAMPS (2) = RAMPS (1) + LO2 TANK CABLE TRAY RAMPS

TABLE II – EXTERNAL TANK PROTUBERANCE LOADS TEST (IA190B) RUN SCHEDULE
FORCE

TEST: IA190B (ARC 411–2–97)		DATA SET/RUN NUMBER COLLATION SUMMARY									DATE: JUNE 1980	
DATA SET IDENTIFIER	CONFIGURATION	SCHD. Alpha	SCHD. Beta	PARAMETERS Mach	Q	ELVI	ELVO	BETA –6	–4	0	+4	+6
R3V$43	OTS (RAMPS ON)	A	– – –	1.55	600	8	–5	517	518	519	520	521
R3V$44		A	– – –	2.00	600	8	–5	522	523	524	525	526
R3V$45		A	– – –	2.50	600	8	–5	527	528	529	530	531
R3V$46	OTS (RAMPS OFF)	A	– – –	1.55	600	8	–5	533	534	535	536	537
R3V$47		A	– – –	2.00	600	8	–5	539	540	541	542	543
R3V$48		A	– – –	2.50	600	8	–5	545	546	547	548	549
								ALPHA				
R3V$49	OTS (RAMPS OFF)	0	B	1.55	600	8	–5			538		
R3V$50		0	B	2.00	600	8	–5			544		
R3V$51		0	B	2.50	600	8	–5			550		
								BETA				
R3V$52	OIL FLOW /	A	– – –	1.55	600	8	–5	552	553	554	555	556
R3V$53	OTS (RAMPS ON)	A	– – –	2.00	600	8	–5	557	558	559	560	561
R3V$54		A	– – –	2.50	600	8	–5	562	563	564	565	566

TEST RUN NUMBERS

alpha or beta SCHEDULES

A: ALPHA = –6, –4, 0, +4, +6, DEG.
B: BETA = –6, –4, 0, +4, +6, DEG.

$: A – BALANCE #1
$: B – BALANCES #2, #3, & #4
$: C – BALANCE #5
$: D – BALANCES #6, #7, & #8

TABLE II – EXTERNAL TANK PROTUBERANCE LOADS TEST (IA190B) RUN SCHEDULE
TRAVERSING PROBES

TEST: IA190B (ARC 411–3–97)		DATA SET/RUN NUMBER COLLATION SUMMARY																	DATE: JUNE 1980
DATA SET		SCHD.		PARAMETERS			PROBE POSITION												
IDENTIFIER	CONFIGURATION	alpha	beta	Mach	ELVI	ELVO	1181.7	1214.0	1247.33	1280.66	1347.33	1414.0	1514.0	1614.3	1714.0	1814.0	1880.7	1914.0	1926.3
R3V$60	OTS (TRAVERSING PROBE)	A	–4	1.55	10	–5	166	163	160	157	154	151	148	145	142	139	136	133	130
R3V$61		A	0	1.55	10	–5	167	164	161	158	155	152	149	146	143	140	137	134	131
R3V$62		A	4	1.55	10	–5	168	165	162	159	156	153	150	147	144	141	138	135	132
R3V$63		A	–4	2.00	10	–5	170	173	176	179	182	185	204	213	210	207	222	219	216
R3V$64		A	0	2.00	10	–5	171	174	177	180	183	186	205	214	211	208	223	220	217
R3V$65		A	4	2.00	10	–5	172	175	178	181	184	187	206	215	212	209	224	221	218
R3V$66		A	–4	2.50	10	–5	261	258	255	252	249	246	243	240	237	234	231	228	225
R3V$67		A	0	2.50	10	–5	262	259	256	253	250	247	244	241	238	235	232	229	226
R3V$68		A	4	2.50	10	–5	263	260	257	254	251	248	245	242	239	236	233	230	227
R3V$69		A	–4	2.00	10	–5	264					201							
R3V$70		A	0	2.00	10	–5	265					202							
R3V$71		A	4	2.00	10	–5	266					203							

TEST RUN NUMBERS

alpha or beta SCHEDULES

A: ALPHA = –4, 0, +4 DEG.
$: 1 – LEFT TRAVERSING PROBE (PROBE #31)
$: 2 – MID TRAVERSING PROBE (PROBE #46)
$: 3 – RIGHT TRAVERSING PROBE (PROBE #43)

PROBE POSITION : 198 COUNTS/INCH MODEL SCALE STARTING AT XT = 1180.7
PROBES LOCATED AT TANK THETA = 165, 180, & 195 DEGREES AT .25 INCHES ABOVE SURFACE

Table III. PRESSURE TAP LOCATIONS

LO_2 FEEDLINE

X_T	Θ_{OF} (Nominal Position)					
	0°	60°	120°	180°	240°	300°
1050	1	2	3	4	5	6
1100	7	8	9	10	11	12
1150	13	14	15	16	17	18
1200	19	20	21	22	23	24
1250	25	26	27	28	29	30
1300	31	32	33	34	35	36
1350	37	38	39	40	41	42
1400	43	44	45	46	47	58
1450	49	50	51	52	53	54
1500	55	56	57	58	59	60
1600	61	62	63	64	65	66
1700	67	68	69	70	71	72
1800	73	74	75	76	77	78
1900	79	80	81	82	83	84
1950	85	86	87	88	89	90
2000	91	92	93	94	95	96

Table III. PRESSURE TAP LOCATIONS (Continued)

LO_2 ANTIGEYSER LINE

X_T	Θ_{AG} (Nominal Position)			
	0^o	90^o	180^o	270^o
1050	101	102	103	104
1100	105	106	107	108
1130	109	110	111	112
1180	113	114	115	116
1240	117	118	119	120
1300	121	122	123	124
1370	125	126	127	128
1420	129	130	131	132
1450	133	134	135	136
1500	137	138	139	140
1625	141	142	143	144
1690	145	146	147	148
1820	149	150	151	152
1930	153	154	155	156
1965	157	158	159	160
2000	161	162	163	164

GH_2 PRESSURE LINE (0.06 SCALE)

X_T	Θ_{HP}			
	0^o	90^o	180^o	270^o
1120	301	302	303	304
1180	305	306	307	308
1300	309	310	311	312
1500	313	314	315	316
1690	317	318	319	320
1950	321	322	323	324
2000	325	326	327	328
2030	329	330	331	332

GO_2 PRESSURE LINE

X_T	Θ_{OP}			
	0^o	90^o	180^o	270^o
950	701	702	703	704

Table III. PRESSURE TAP LOCATIONS (Continued)

LH_2 TANK CABLE TRAY

X_T	POSITION			
	BOTT	OUTBD	TOP	INBD
1130	201	202	203	204
1180	205	206	207	208
1240	209	210	211	212
1300	213	214	215	216
1370	217	218	219	220
1420	221	222	223	224
1450	225	226	227	228
1500	229	230	231	232
1625	233	234	235	236
1690	237	238	239	240
1820	241	242	243	244
1930	245	246	247	248
1965	249	250	251	252
2000	253	254	255	256
*4001	257	258	259	260
*4002	261	262	263	264
*4003	265	266	267	268

LO_2 TANK CABLE TRAY (OGIVE)

X_T	POSITION			
	BOTT	OUTBD	TOP	INBD
800	401	402	403	404
820	405	406	407	408
835	409	410	411	412
850	413	414	415	416
880	417	418	419	420

ET/SRB CABLE TRAY (R. H. SIDE)

Θ_T	POSITION			
	BOTT	OUTBD	TOP	INBD
116°	601	602	603	604
120°	605	606	607	608
124°	609	610	611	612

TABLE III STATIC PRESSURE TAP LOCATIONS - CONCLUDED

ORBITER/ET FORWARD ATTACH STRUT (BIPOD)

x/ℓ_S	θ_S							
	0	45°	90°	135°	180°	225°	270°	315°
.25		(501)		502		503		(504)
.50	(505)	(506)	507	508	509	510	(511)	(512)
.75		(513)		514		515		(516)

NOTE: NUMBERS IN PARENTHESIS ARE ON THE LEFT-HAND LEG OF THE BIPOD. OTHERS ARE ON THE RIGHT-HAND LEG.

ET/SRB CABLE TRAY RAKE

θ_T	RAKE
	TAP NO.
116°	901
120°	902
124°	903

NOTE: THIS RAKE REPLACES THE ET/SRB CABLE TRAY AND RAMP ON THE LEFT-HAND SIDE OF THE ET

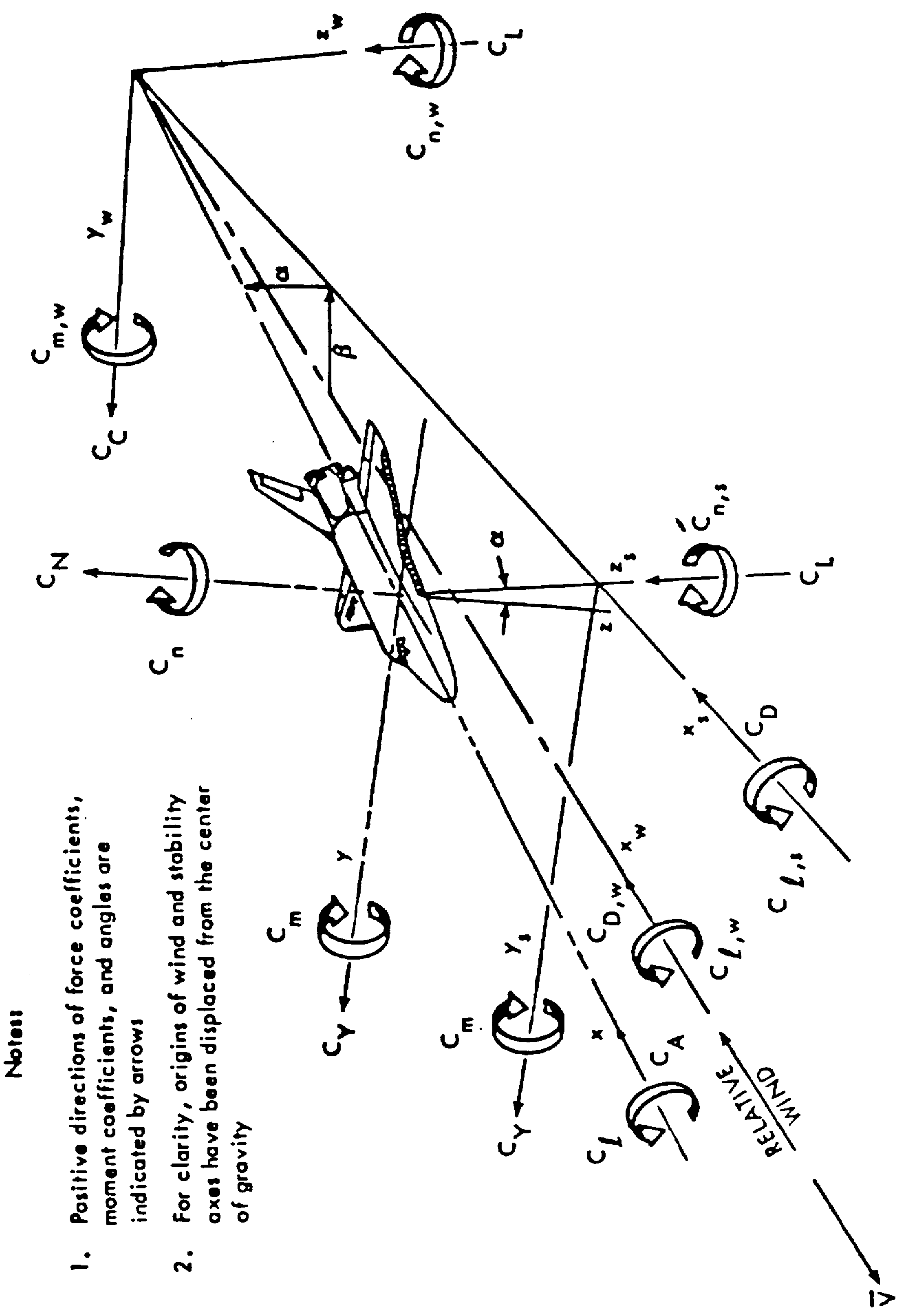

Figure 1. Model Axis Systems and Sign Conventions

a. Orbiter Axis System

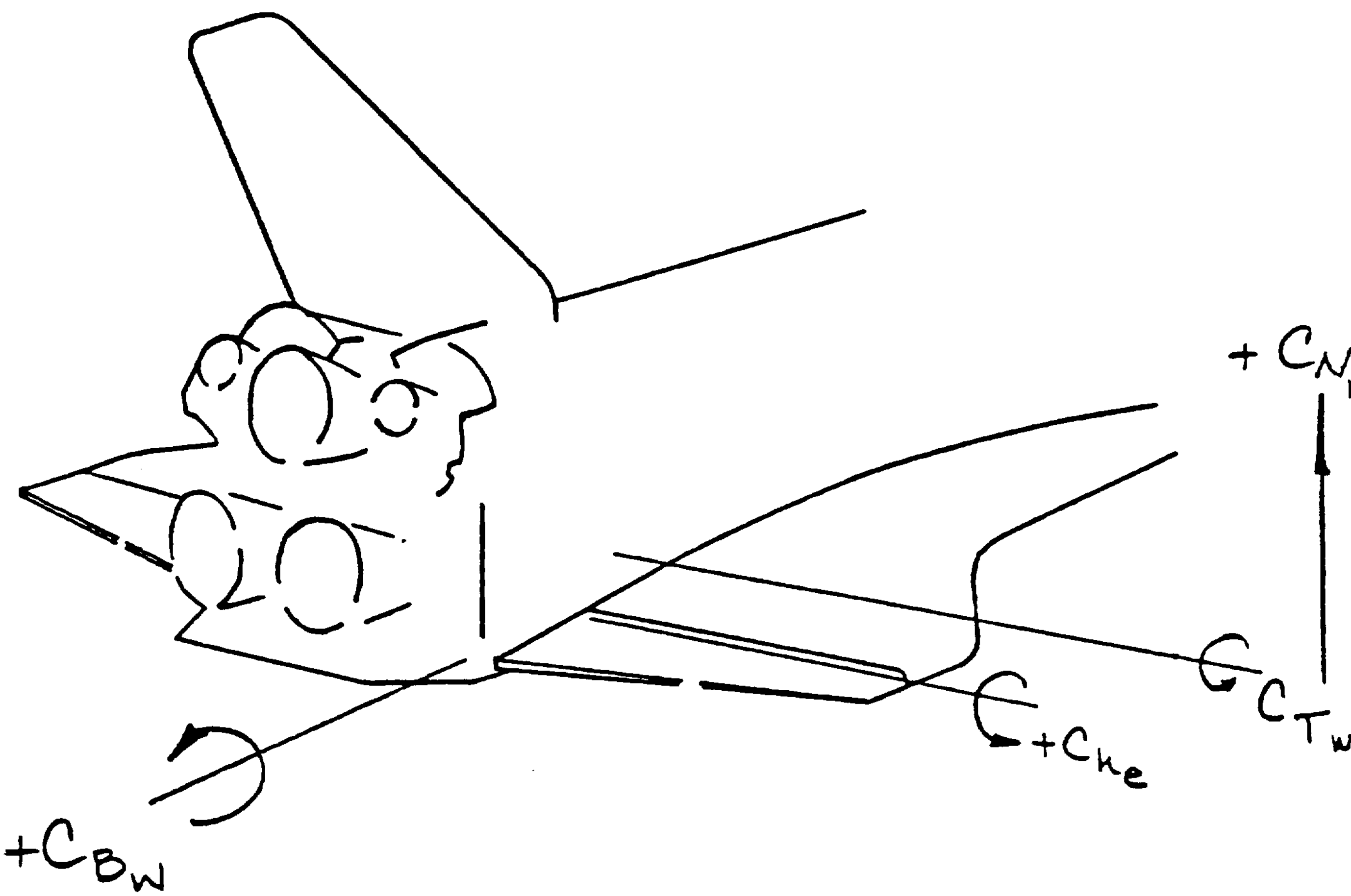

Figure 1. Model Axis Systems and Sign Conventions
b. Moment Sign Conventions

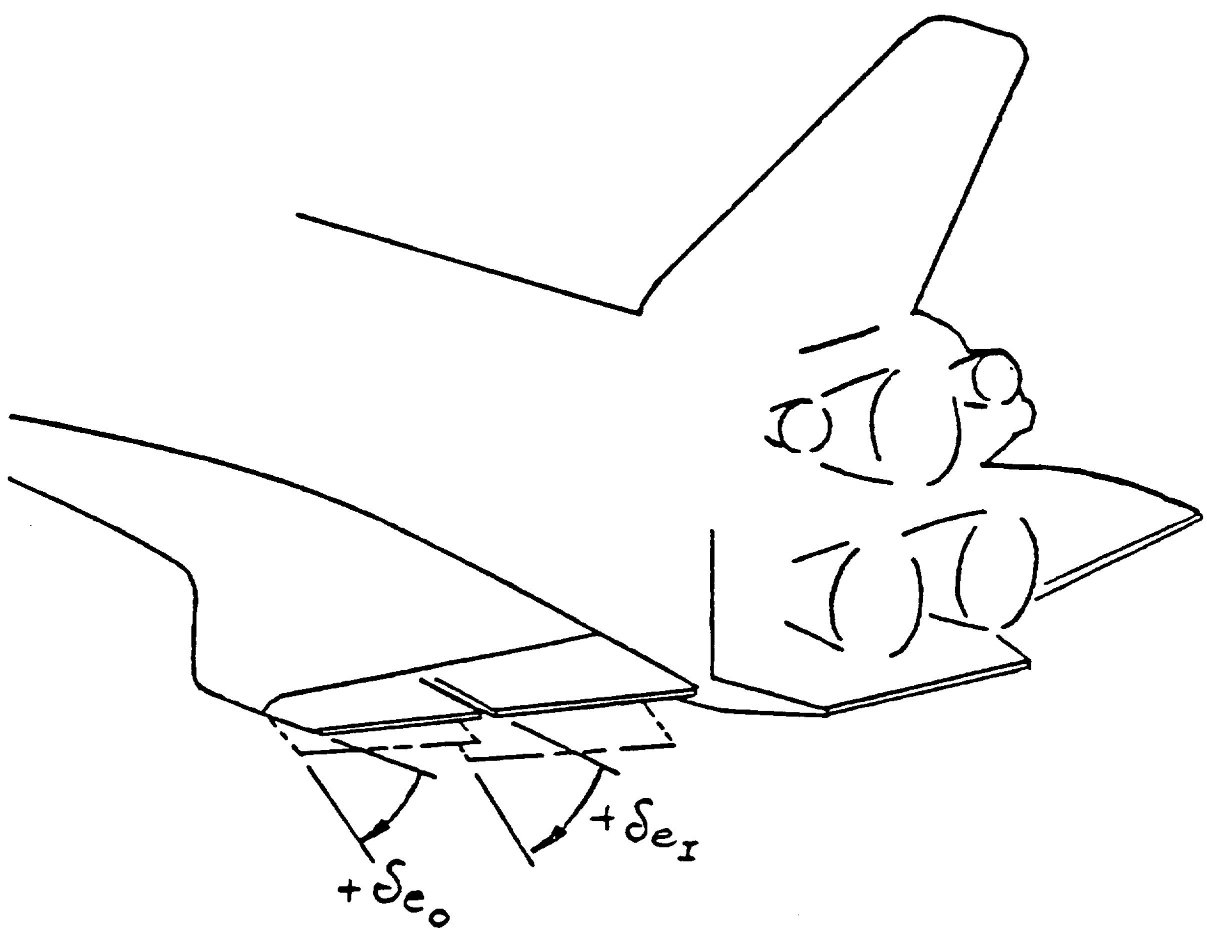

Figure 1. Model Axis Systems and Sign Conventions

c. Elevon Sign Conventions

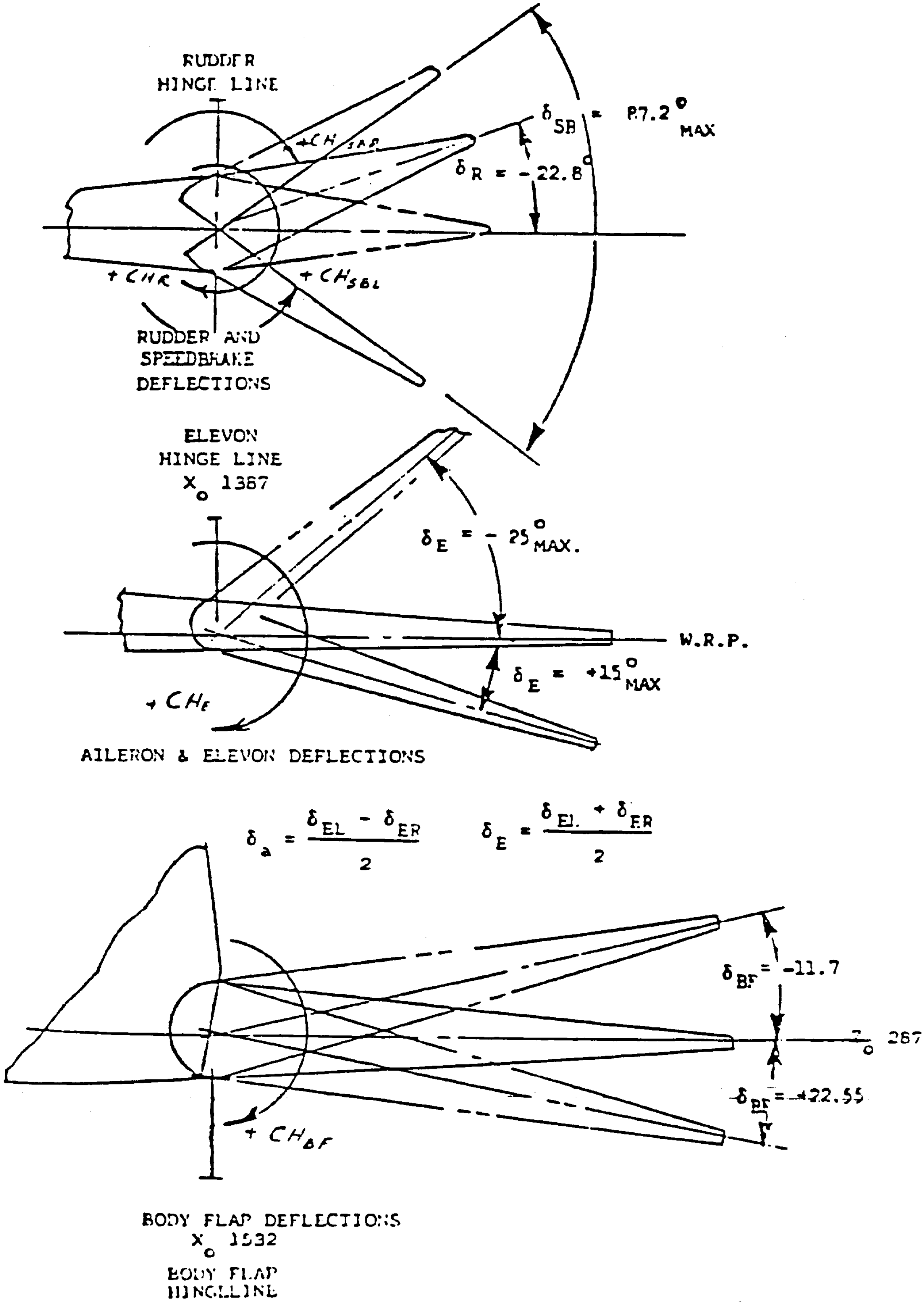

Figure 1. Model Axis Systems and Sign Conventions
d. Definition of Angular Measurements

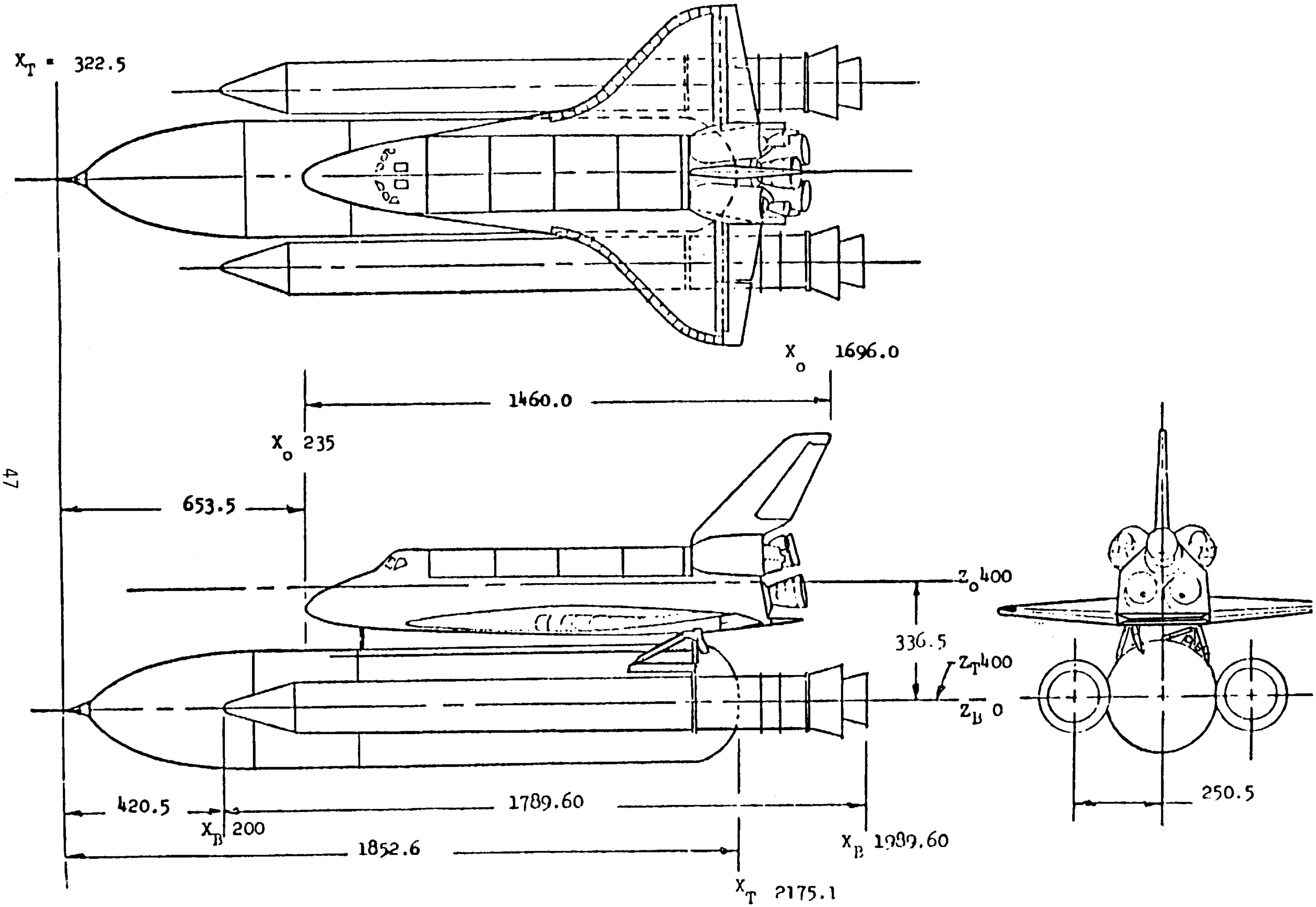

Figure 2. Model Sketches
a. Launch Vehicle Configuration

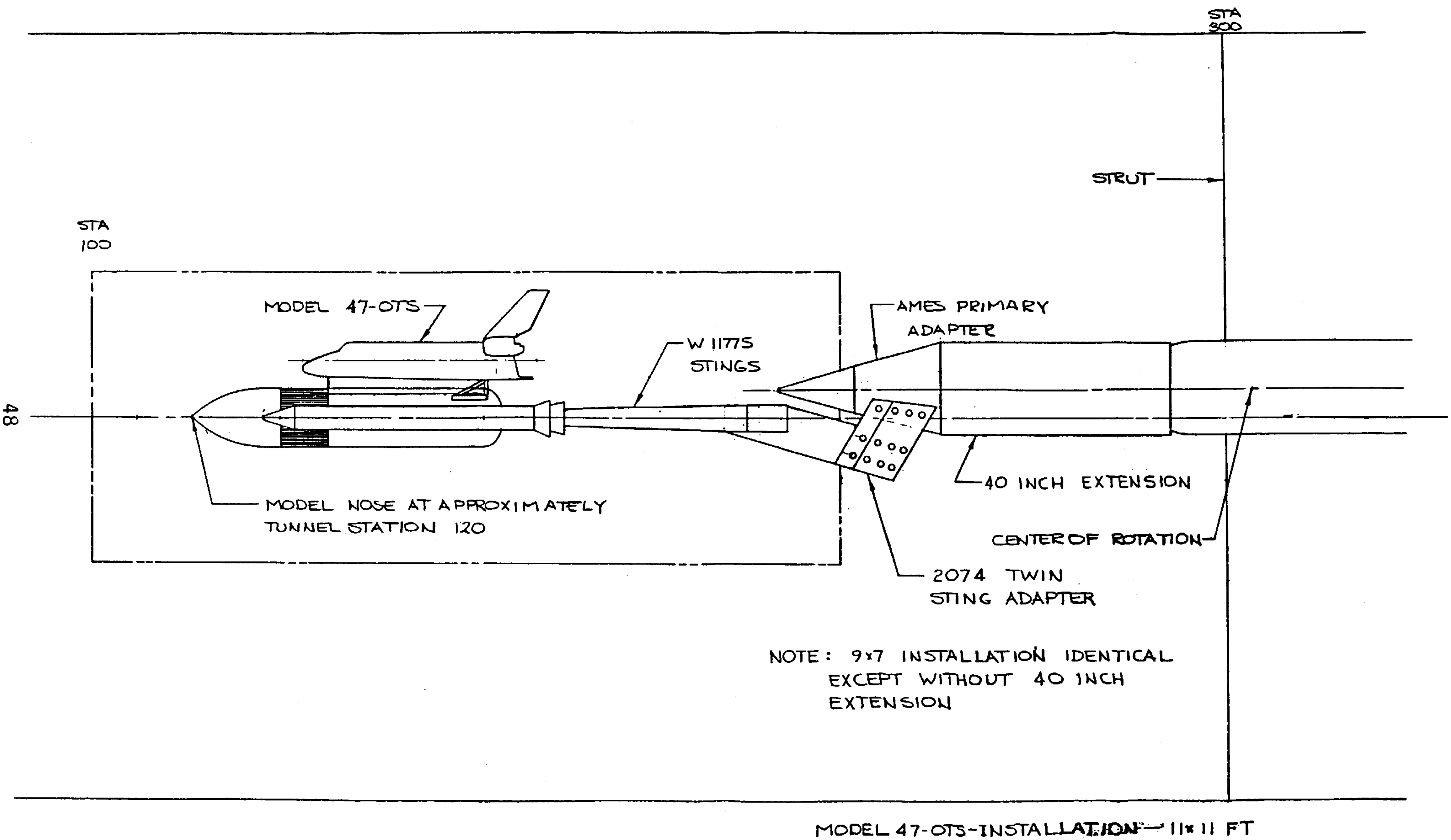

Figure 2. Model Sketches

b. Tunnel Installation

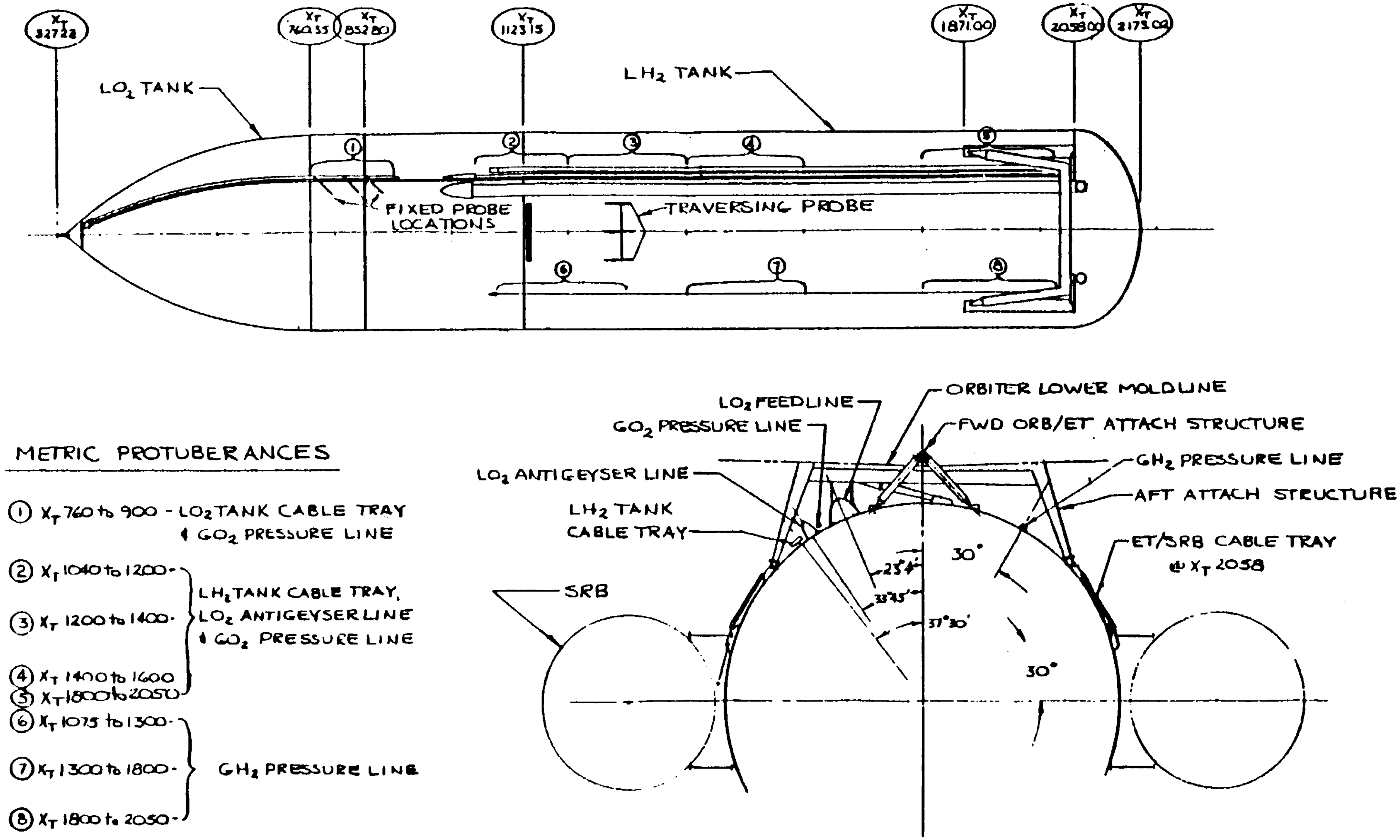

Figure 2. Model Sketches
c. ET Angular Definitions and Balance Locations

VIEW LOOKING AFT

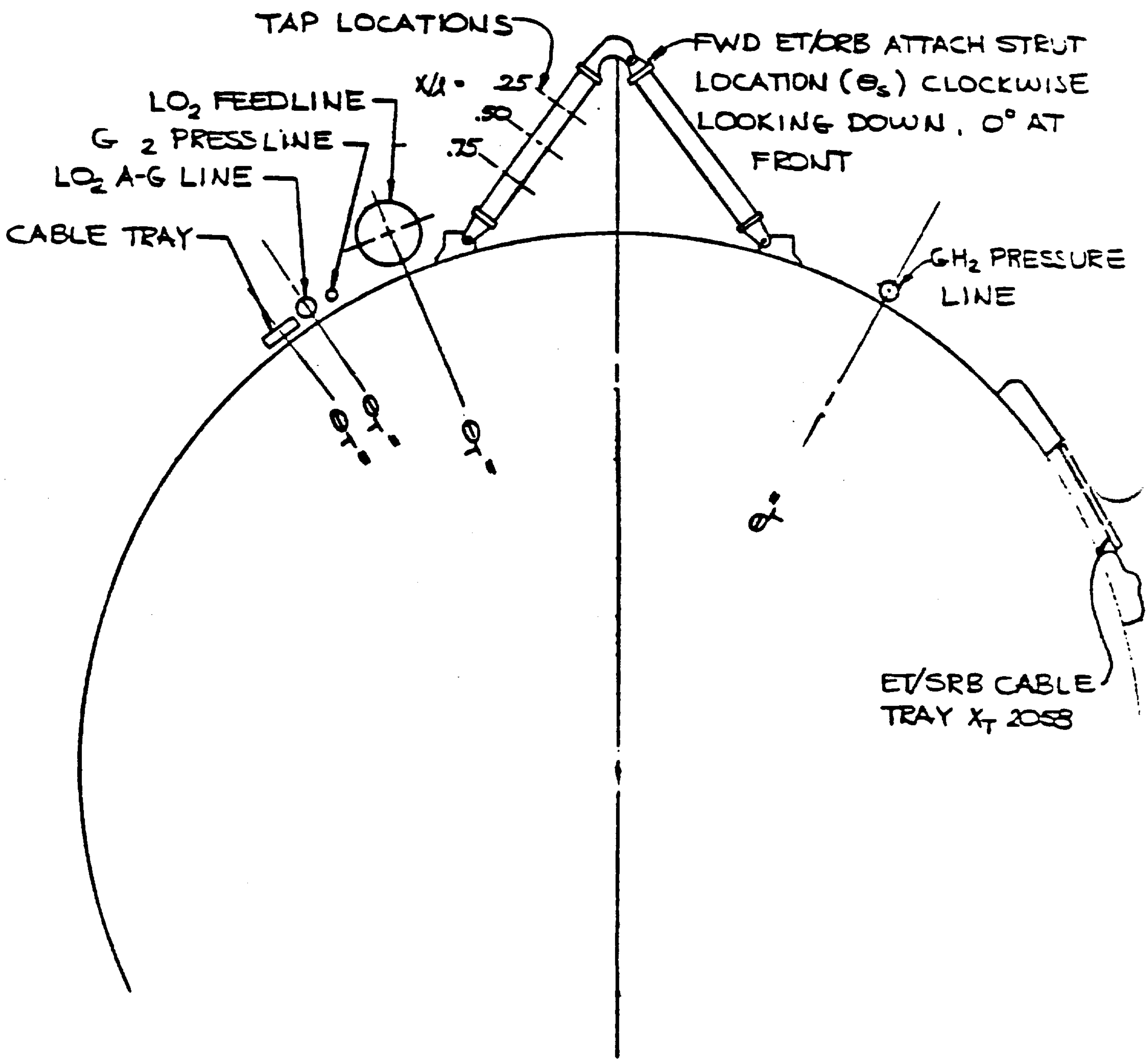

Figure 2. Model Sketches
d. ET Protuberance Locations

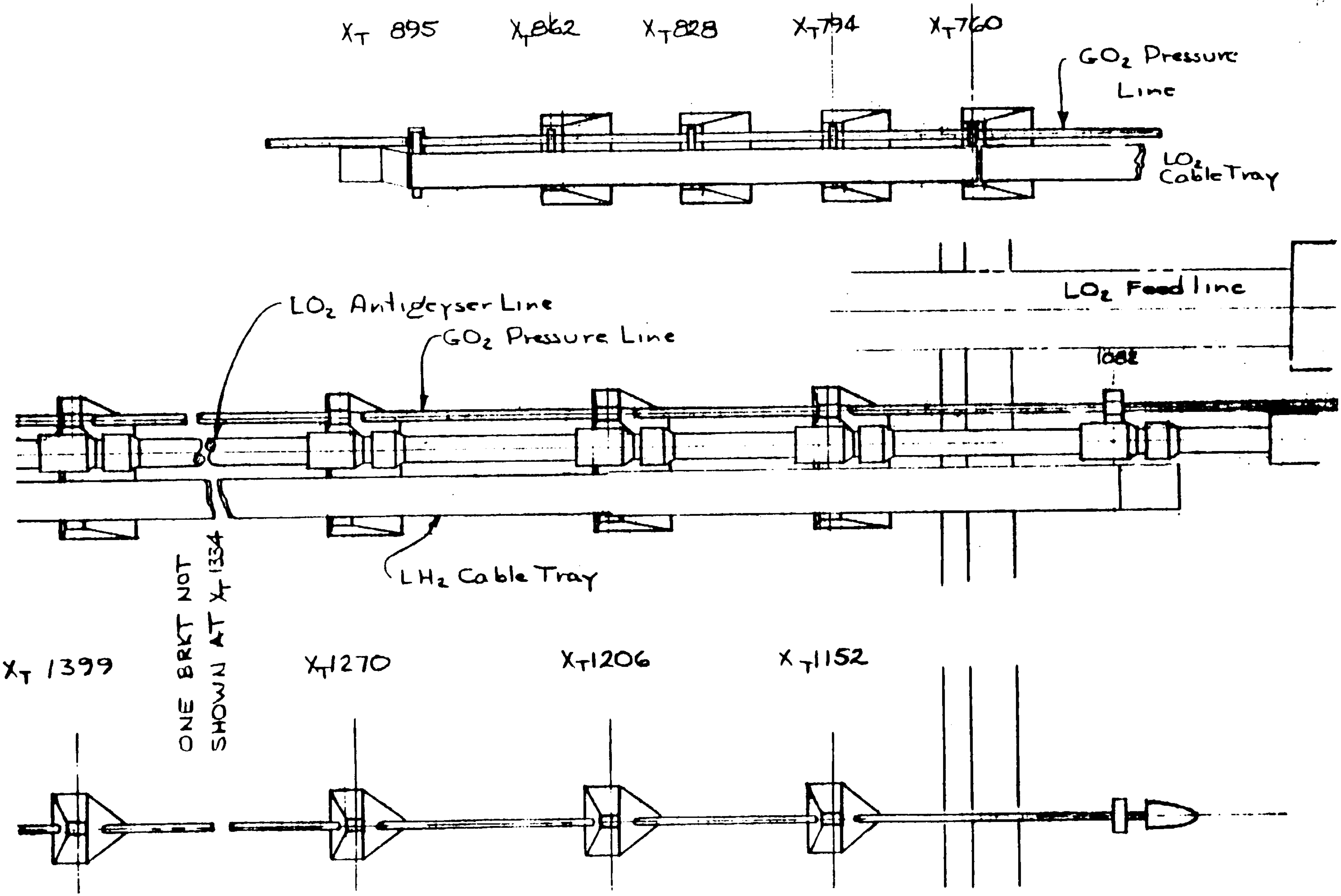

Figure 2. Model Sketches

c. Metric Protuberance Details

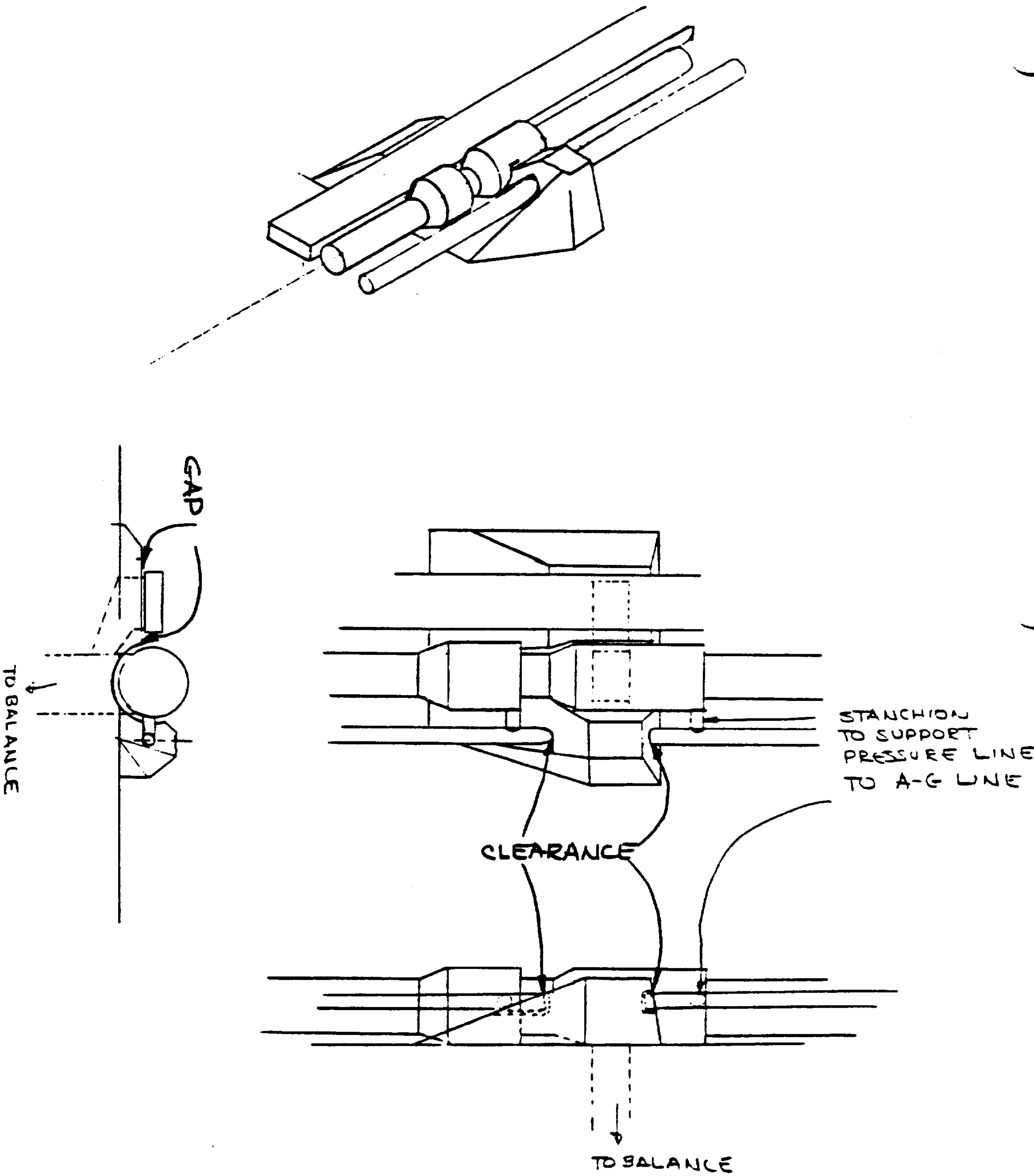

Figure 2. Model Sketches

f. Metric Protuberance Attachment Details

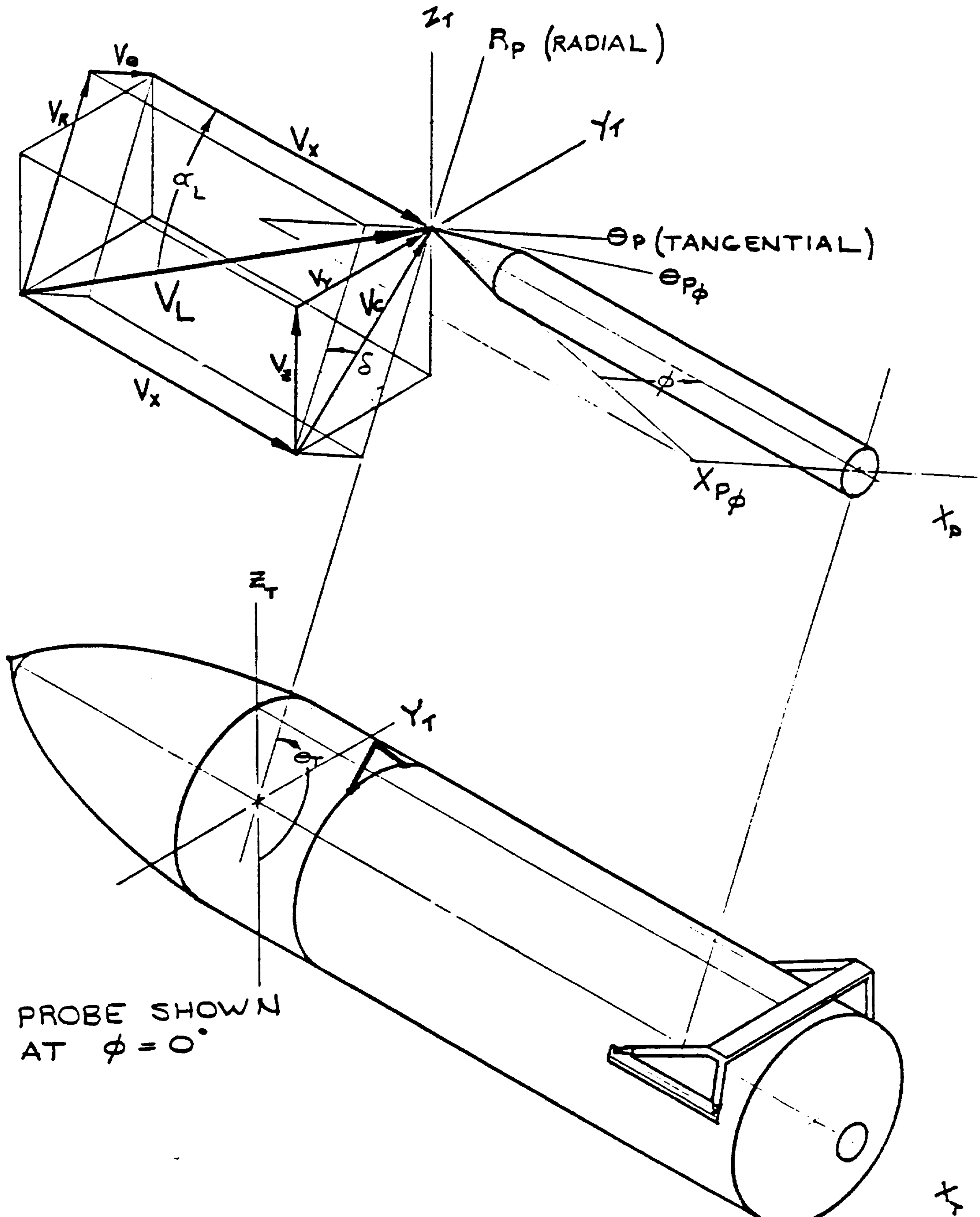

Figure 2. Model Sketches
g. Probe Axis Definition

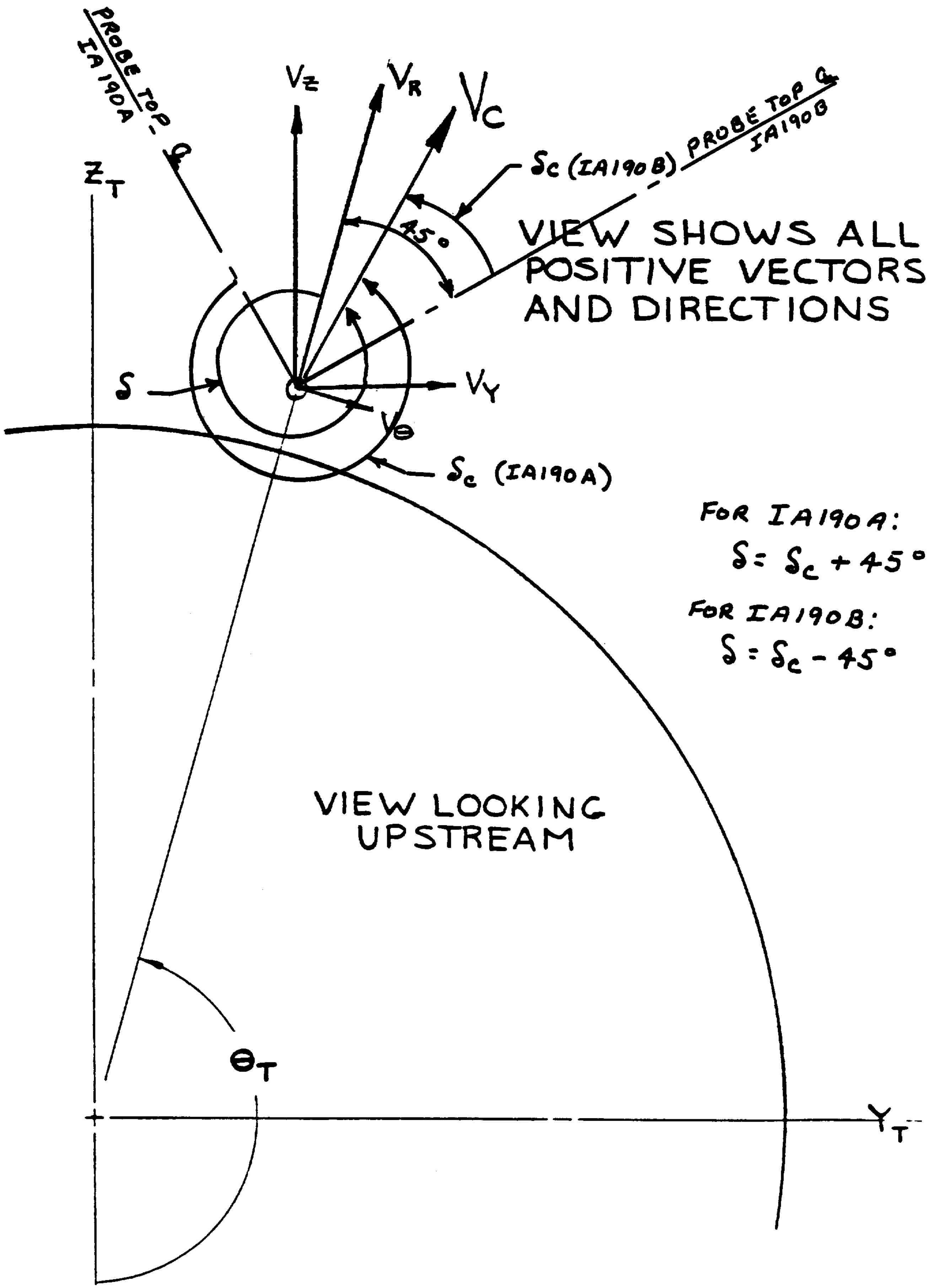

Figure 2. Model Sketches
h. Probe Axis Details

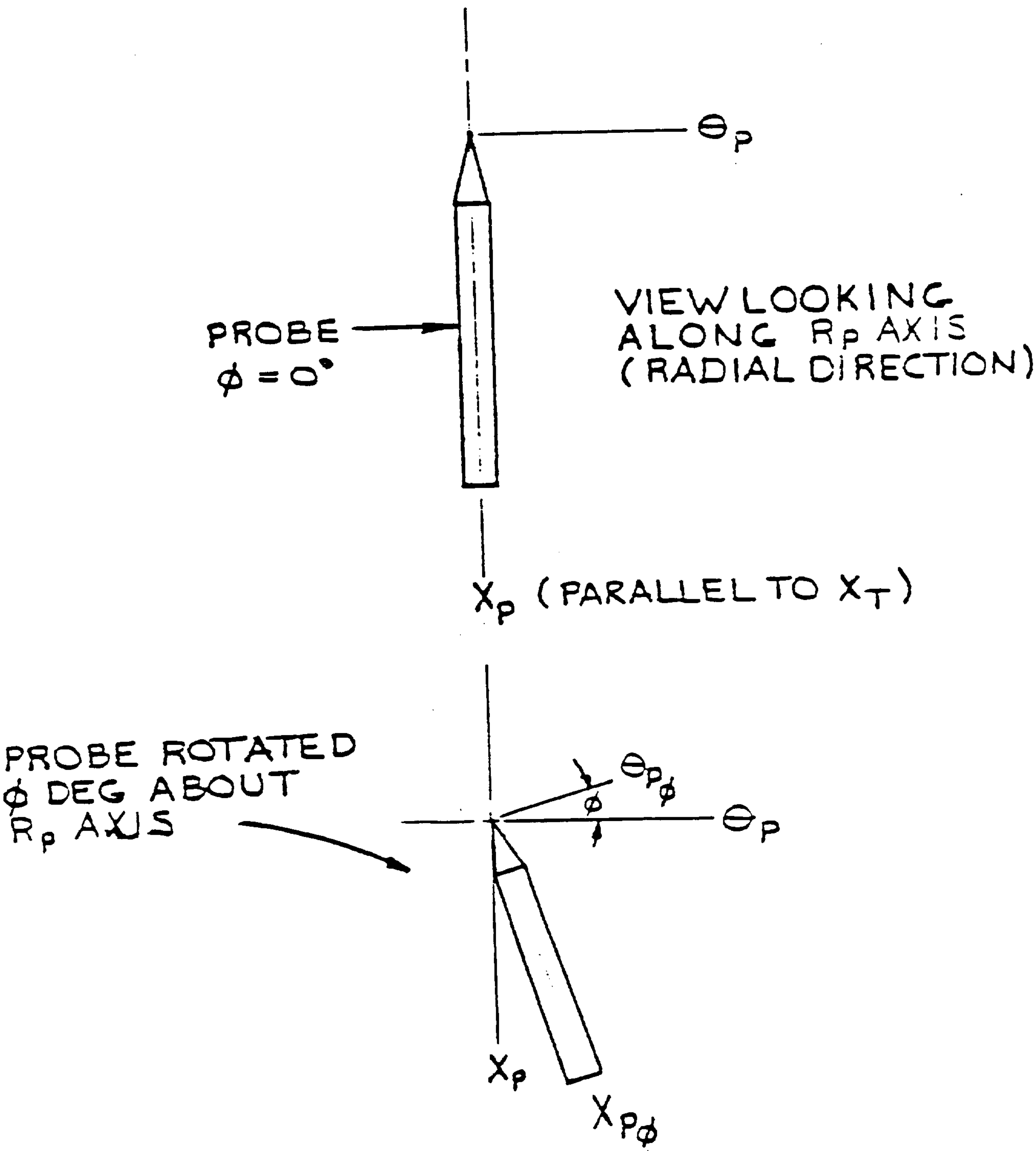

Figure 2. Model Sketches

i. Probe Axis Details

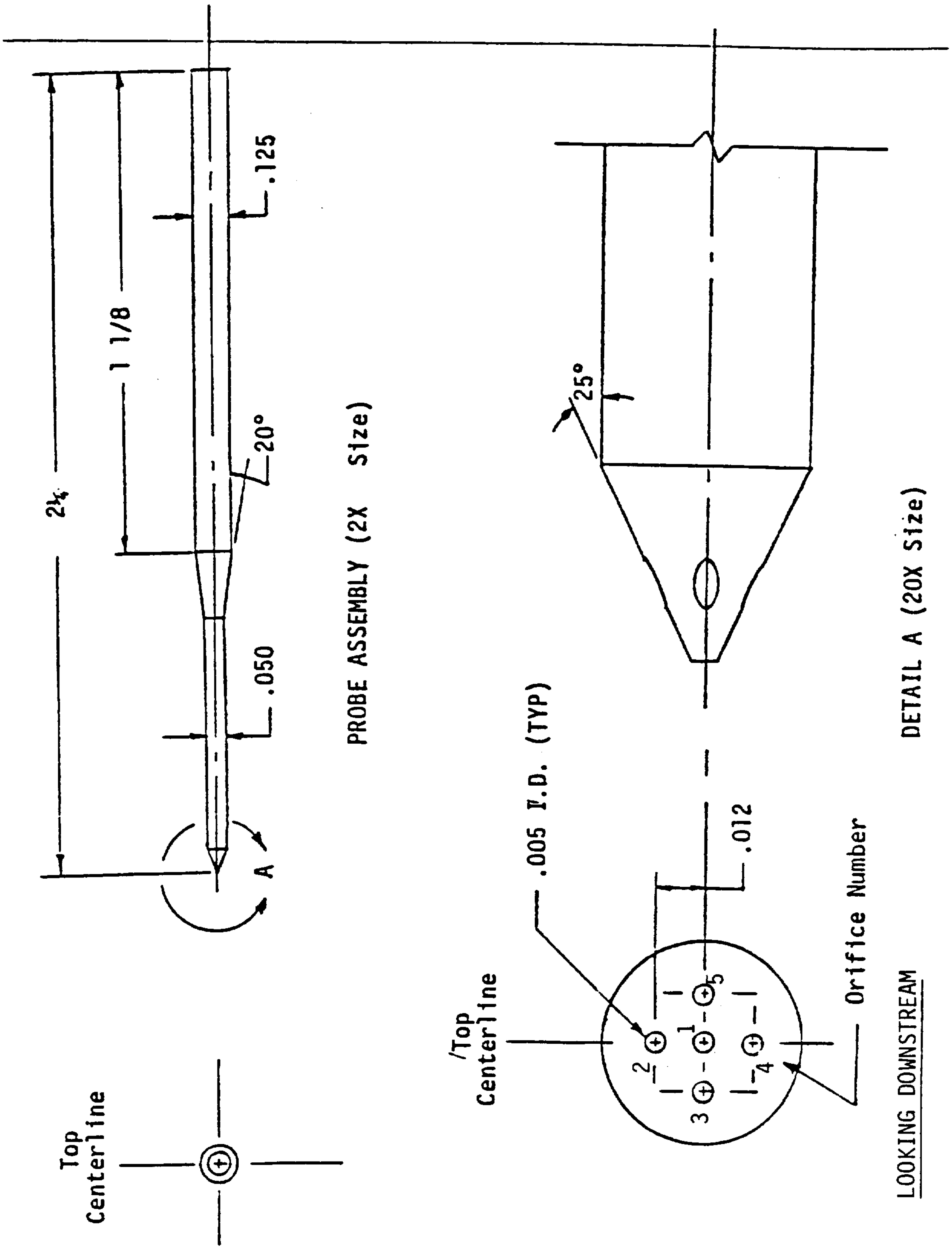

Figure 2. Model Sketches
j. Probe Details

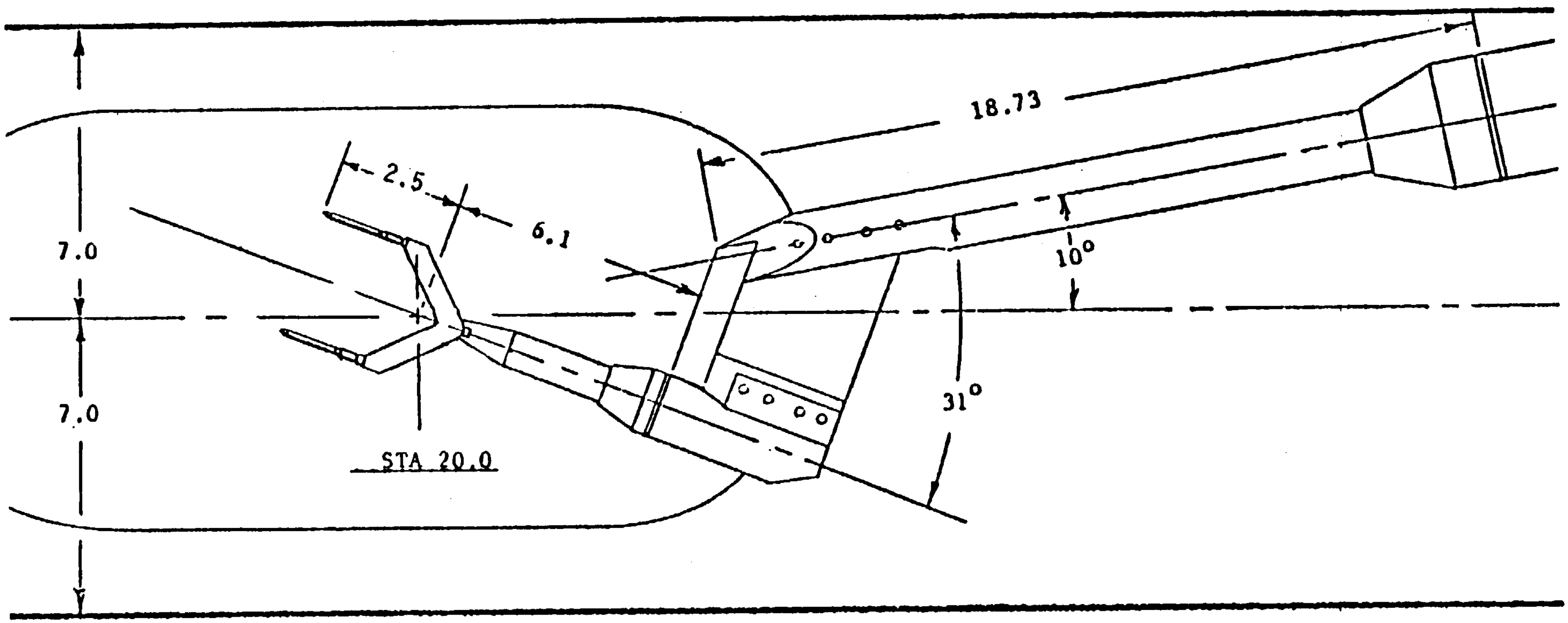

Figure 2. Model Sketches

K. Probe Calibration Installation in MSFC 14' TWT

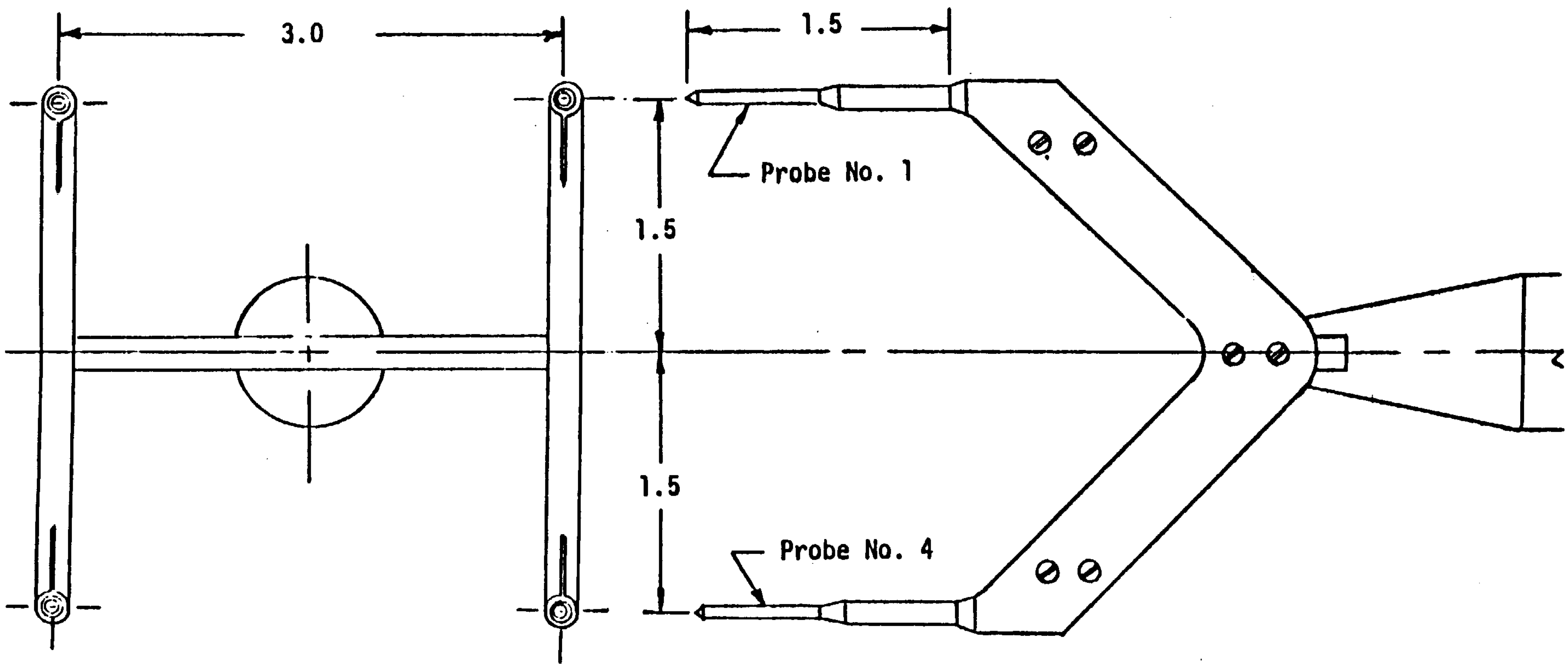

Figure 2. Model Sketches

1. Probe Calibration Fixture Details

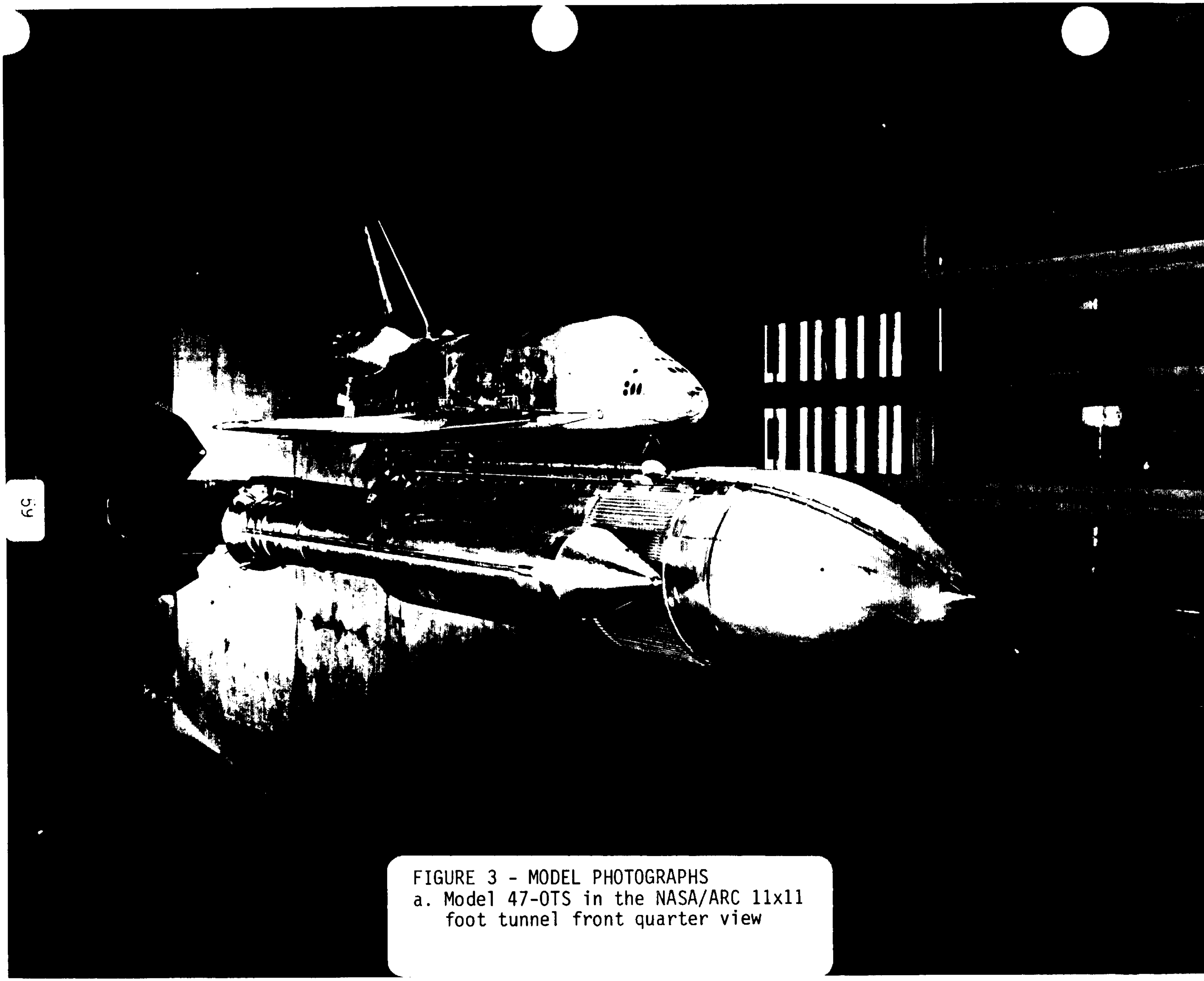

FIGURE 3 - MODEL PHOTOGRAPHS
a. Model 47-OTS in the NASA/ARC 11x11 foot tunnel front quarter view

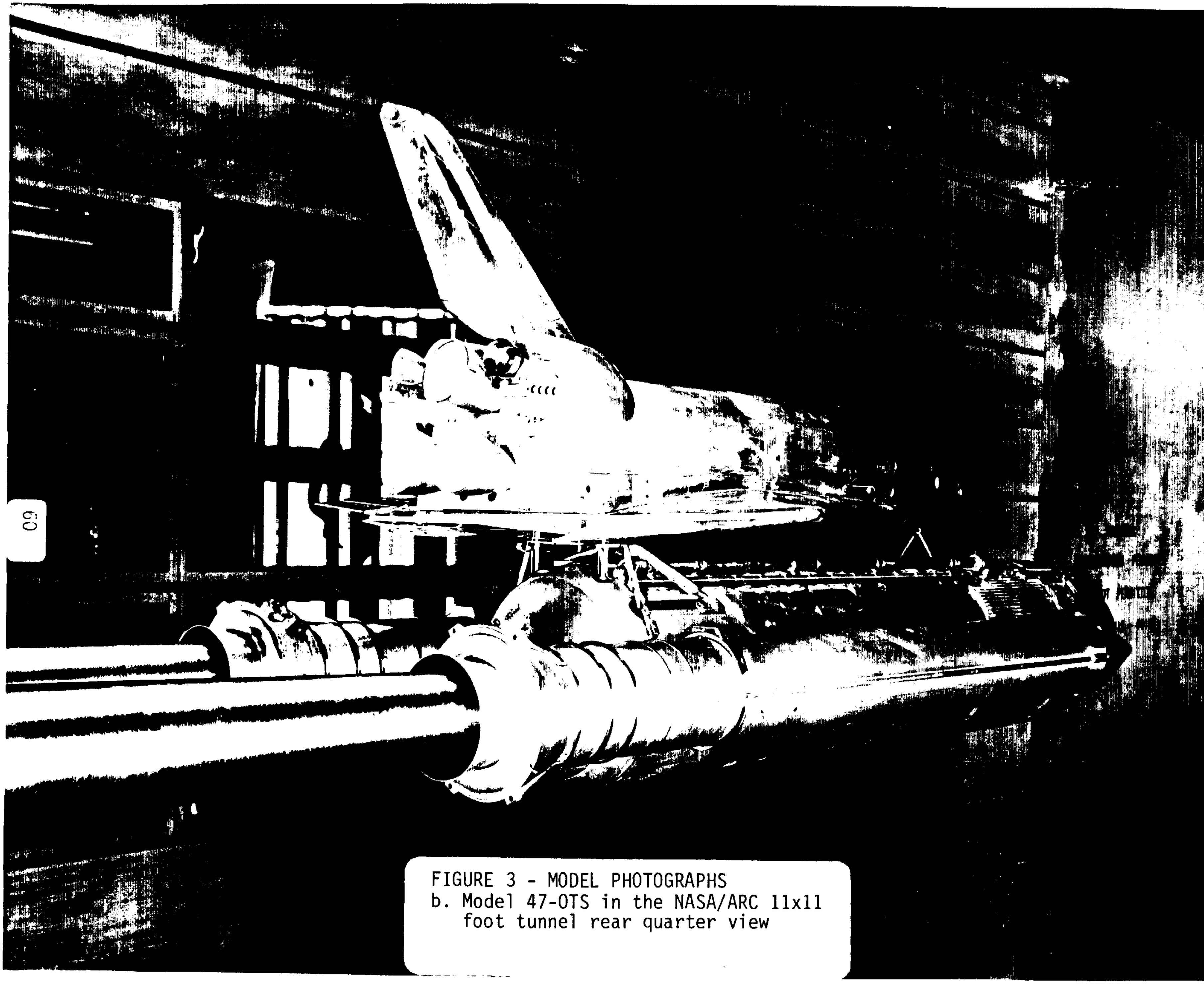

FIGURE 3 - MODEL PHOTOGRAPHS
b. Model 47-OTS in the NASA/ARC 11x11 foot tunnel rear quarter view

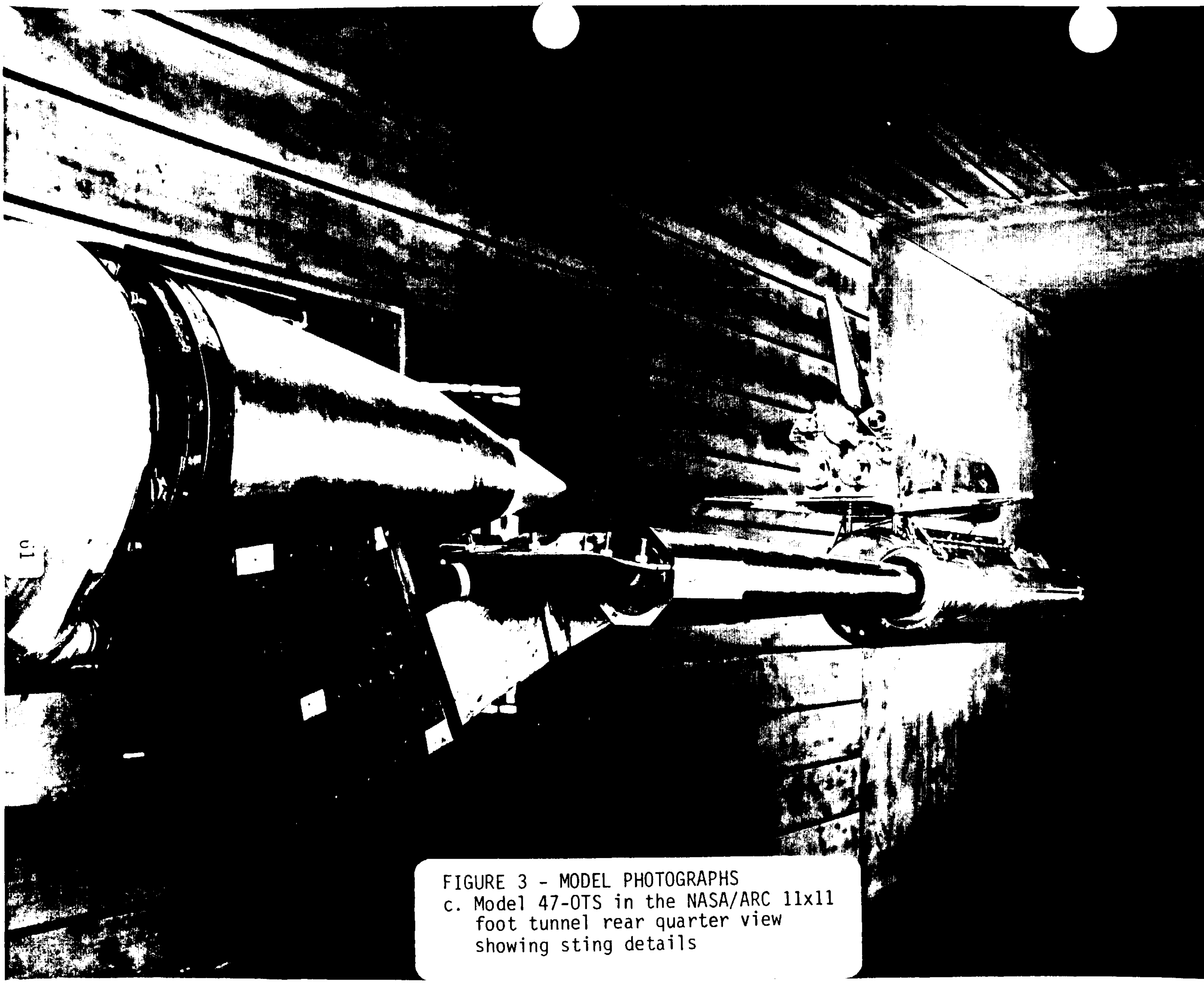

FIGURE 3 - MODEL PHOTOGRAPHS
c. Model 47-OTS in the NASA/ARC 11x11 foot tunnel rear quarter view showing sting details

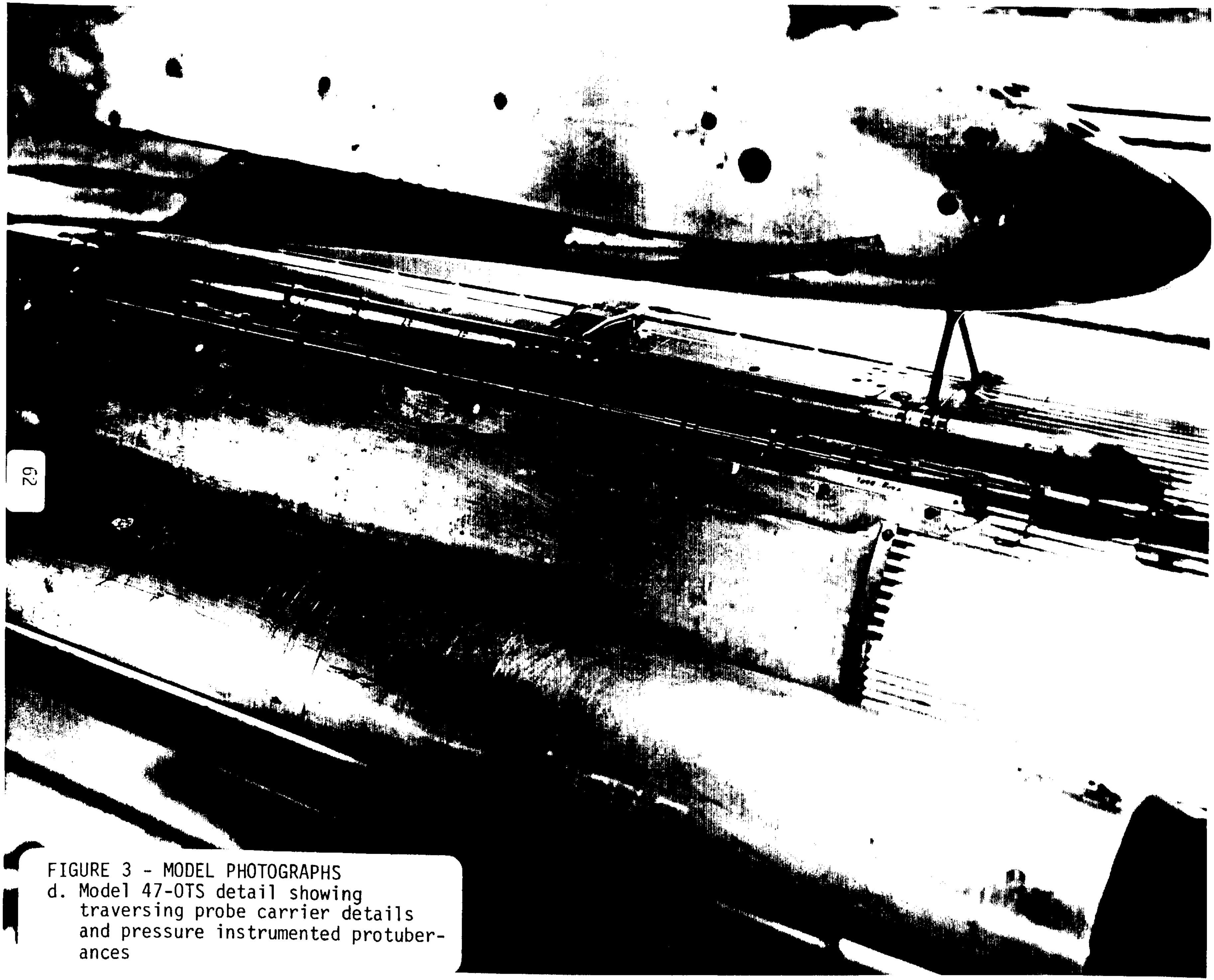

FIGURE 3 - MODEL PHOTOGRAPHS
d. Model 47-OTS detail showing traversing probe carrier details and pressure instrumented protuberances

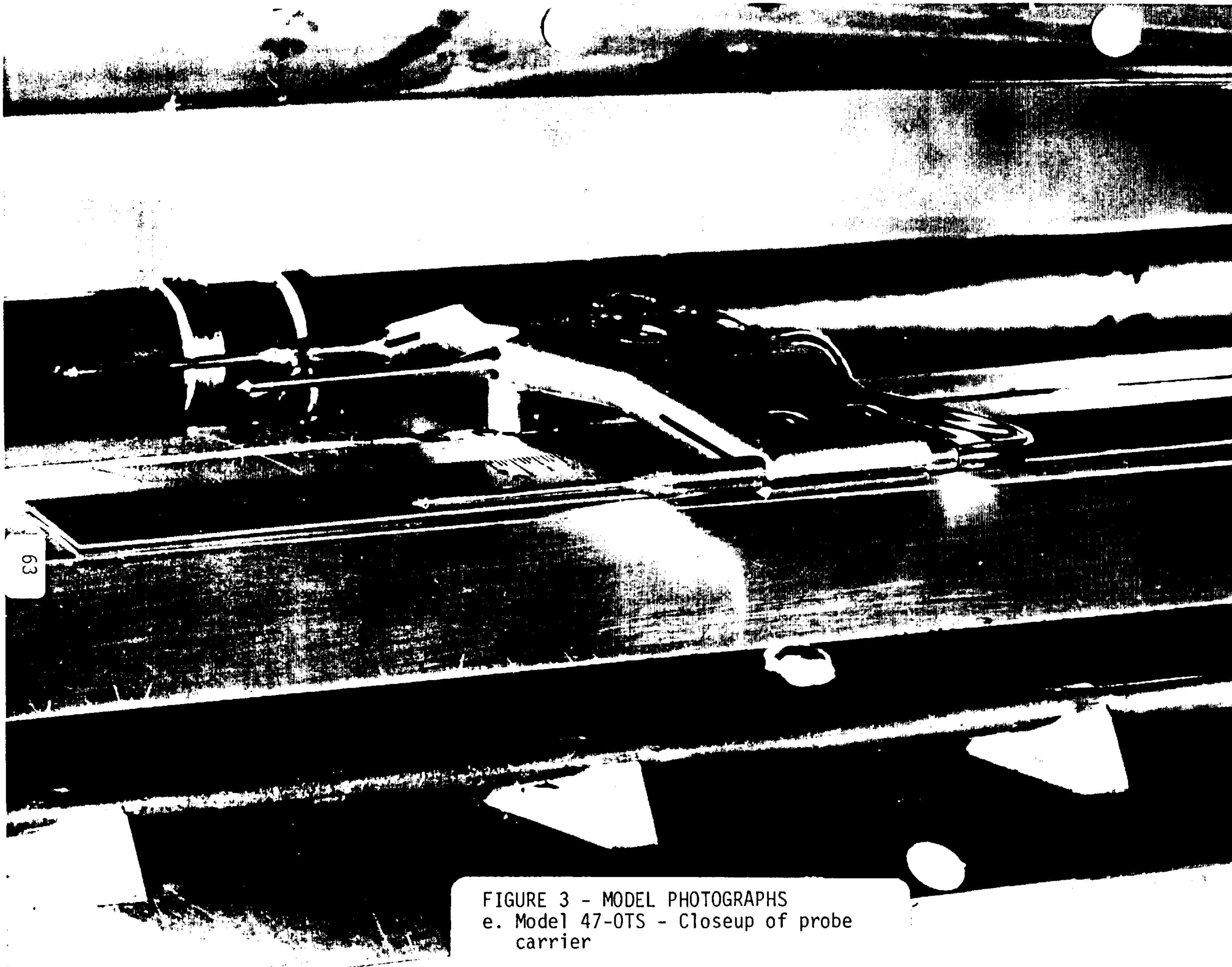

FIGURE 3 - MODEL PHOTOGRAPHS
e. Model 47-OTS - Closeup of probe carrier

FIGURE 3 - MODEL PHOTOGRAPHS
f. Model 47-OTS - Closeup of Rear Attach Structure

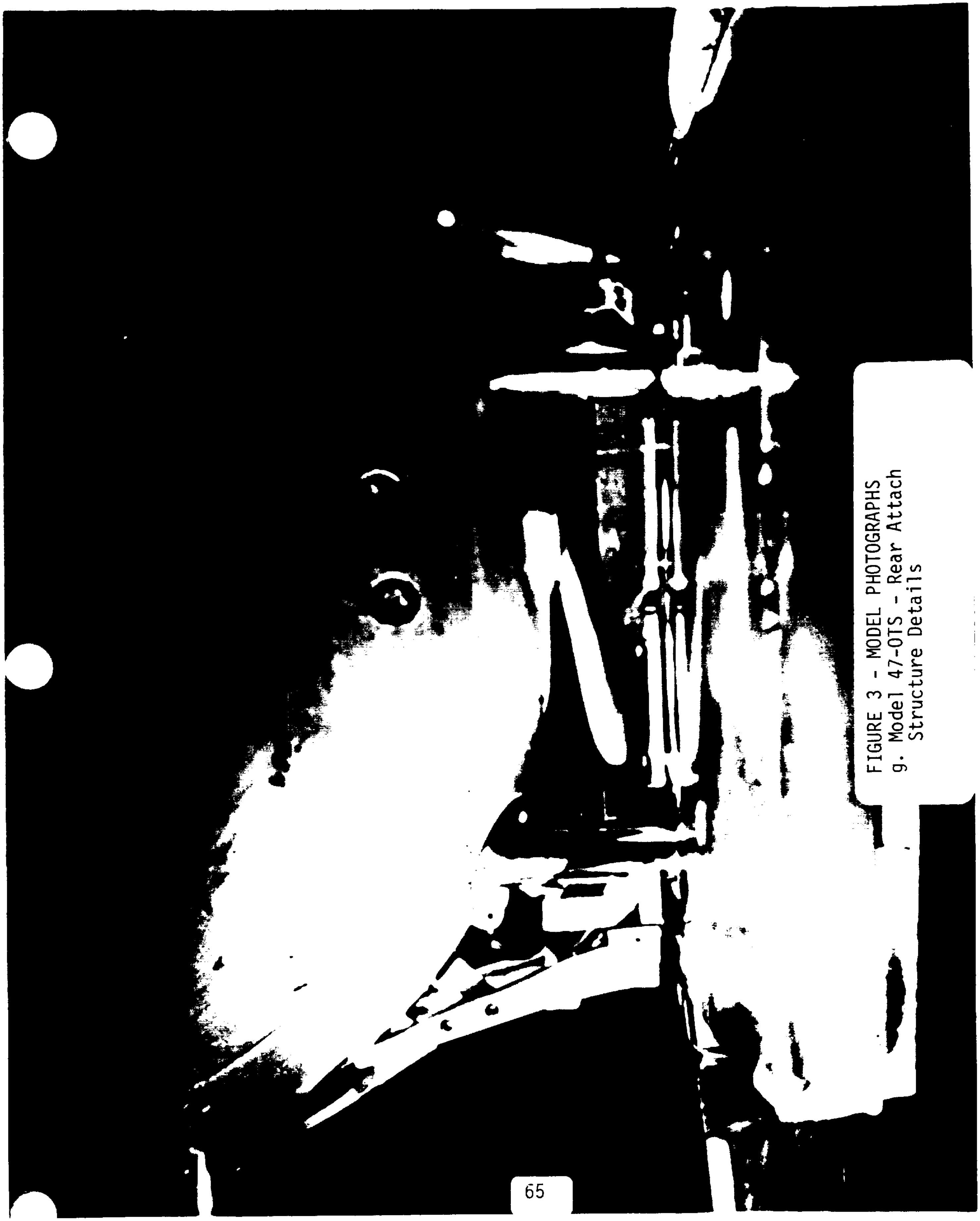

FIGURE 3 - MODEL PHOTOGRAPHS
g. Model 47-OTS - Rear Attach Structure Details

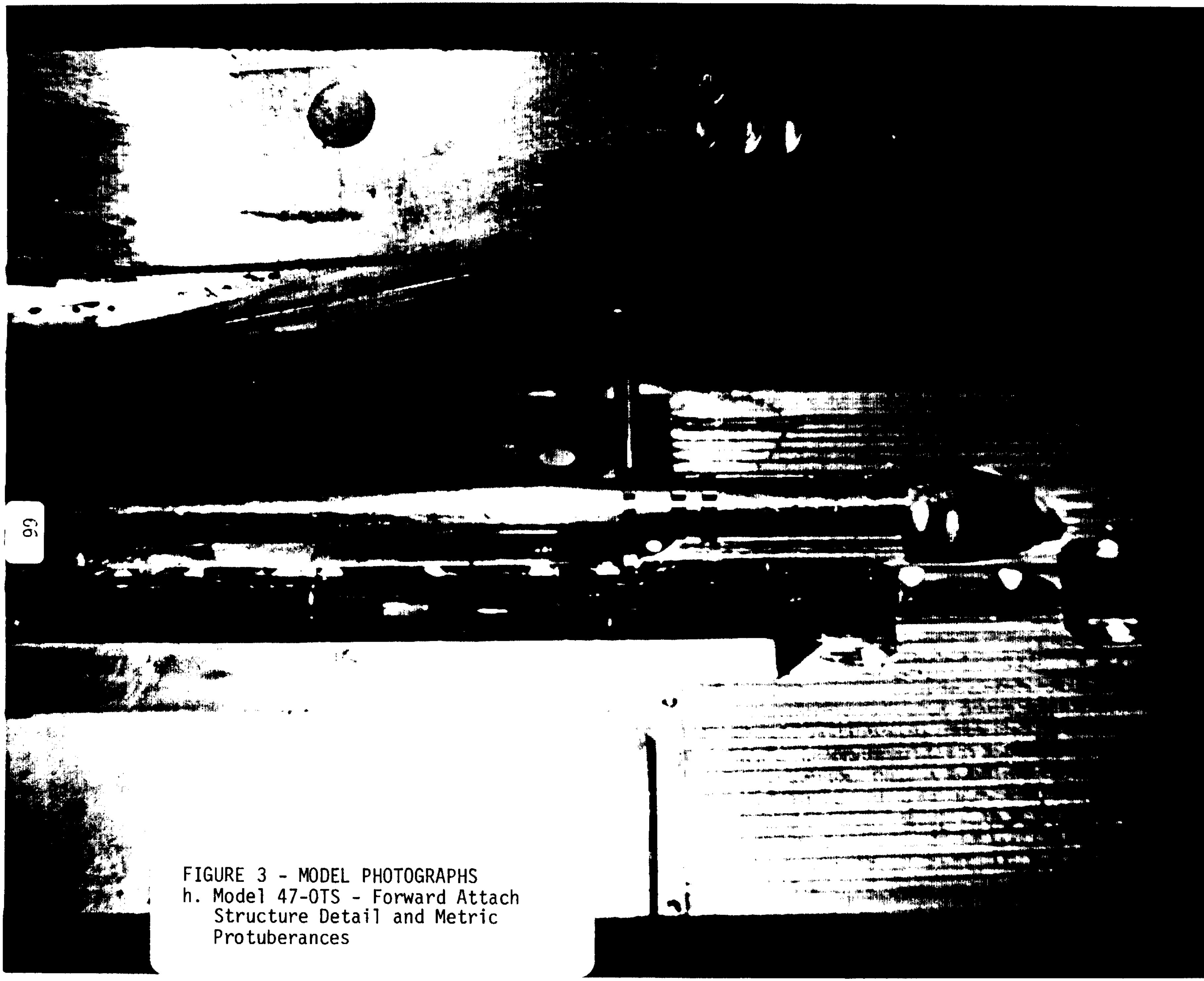

FIGURE 3 - MODEL PHOTOGRAPHS
h. Model 47-OTS - Forward Attach Structure Detail and Metric Protuberances

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BLACK AND WHITE PHOTOGRAPH

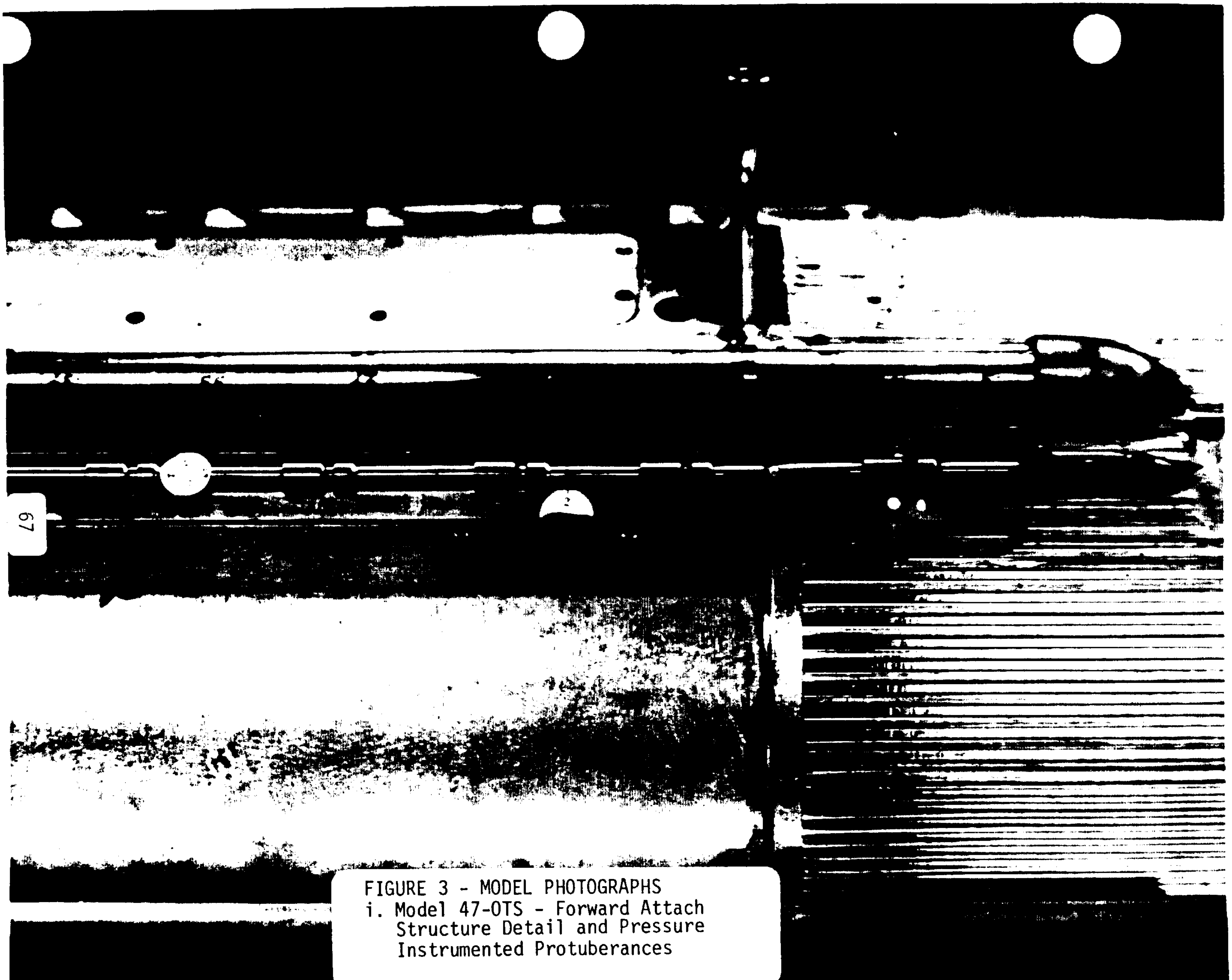

FIGURE 3 - MODEL PHOTOGRAPHS
i. Model 47-OTS - Forward Attach Structure Detail and Pressure Instrumented Protuberances

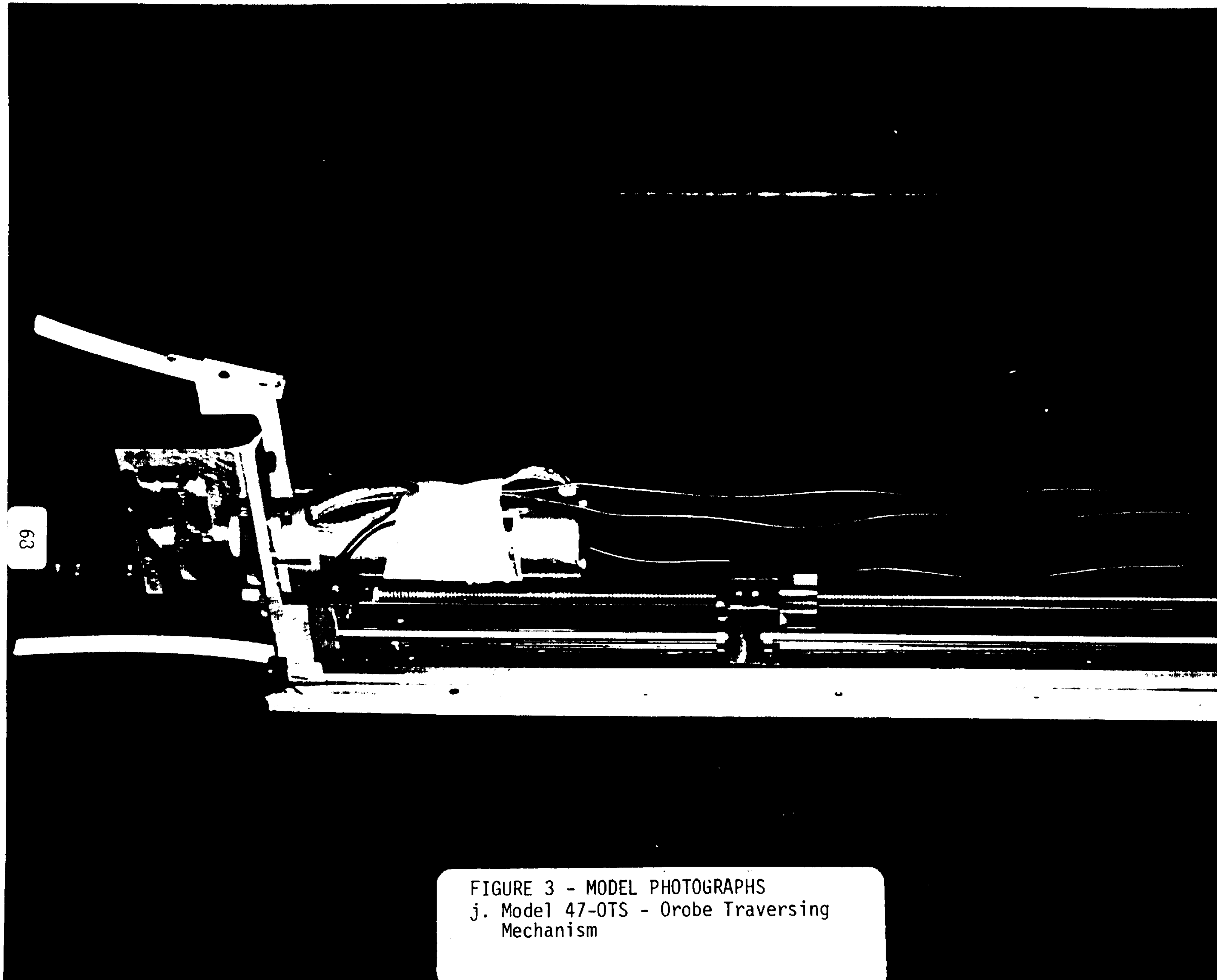

FIGURE 3 - MODEL PHOTOGRAPHS
j. Model 47-OTS - Orobe Traversing Mechanism

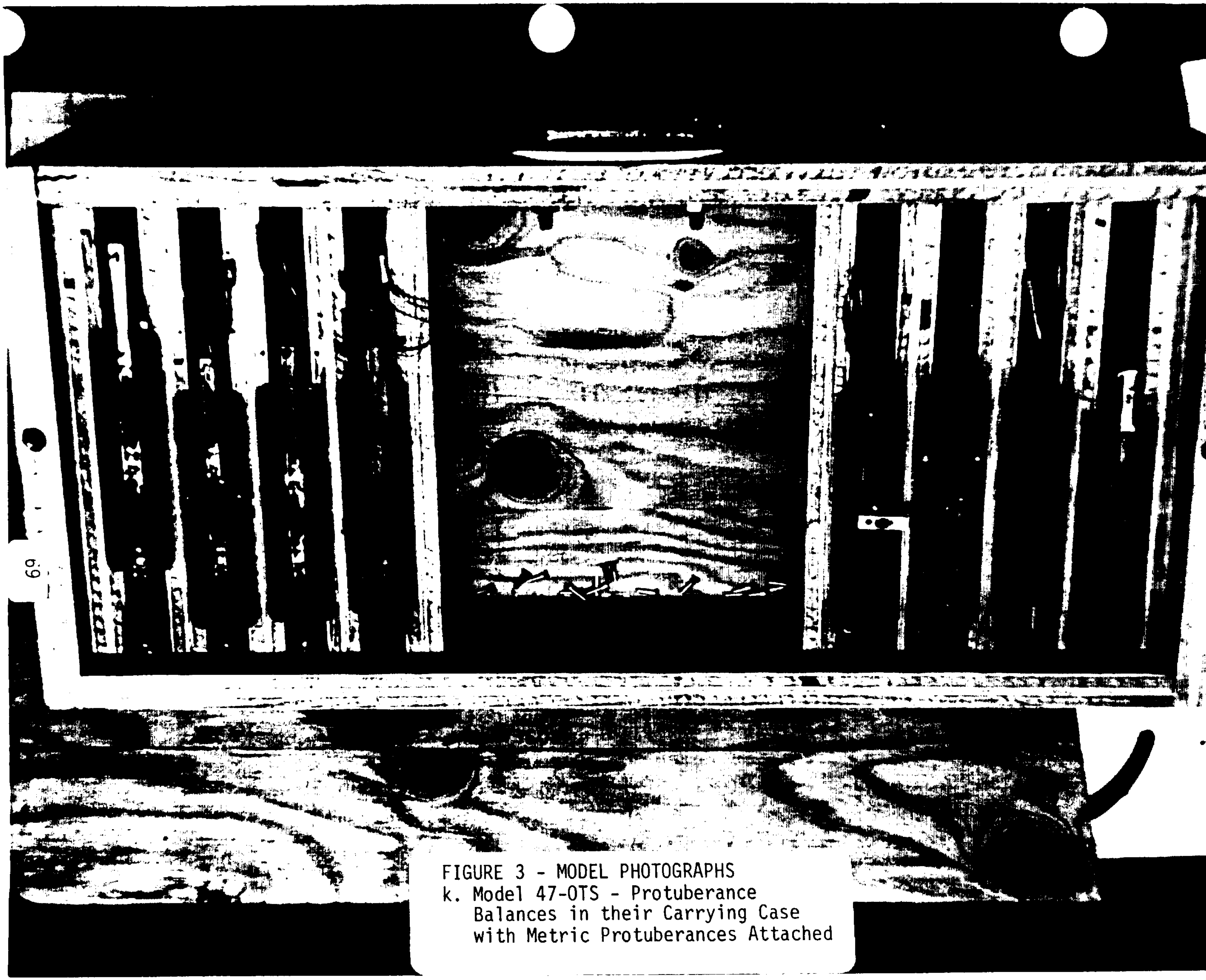

FIGURE 3 - MODEL PHOTOGRAPHS
k. Model 47-OTS - Protuberance Balances in their Carrying Case with Metric Protuberances Attached

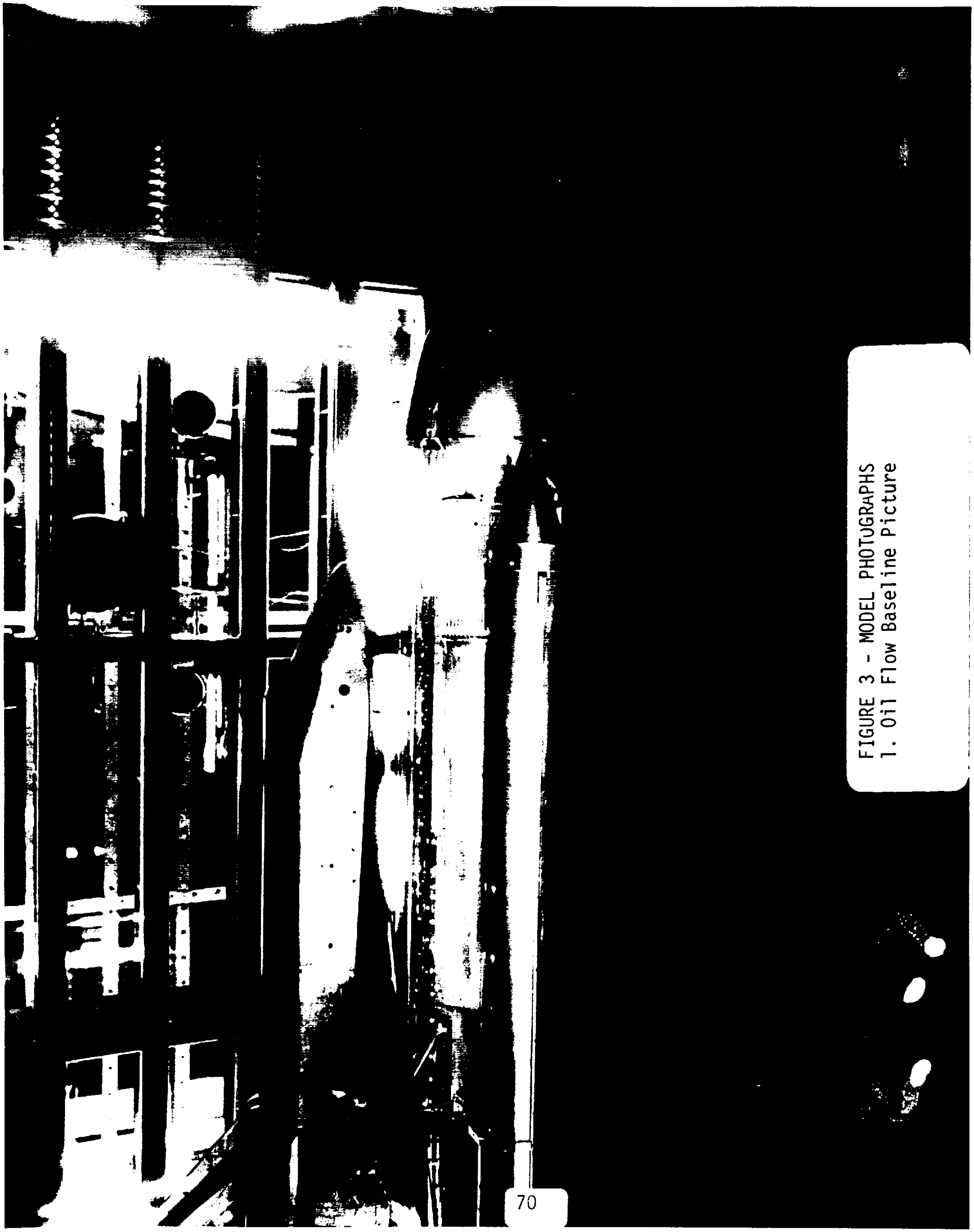

FIGURE 3 - MODEL PHOTOGRAPHS
1. Oil Flow Baseline Picture

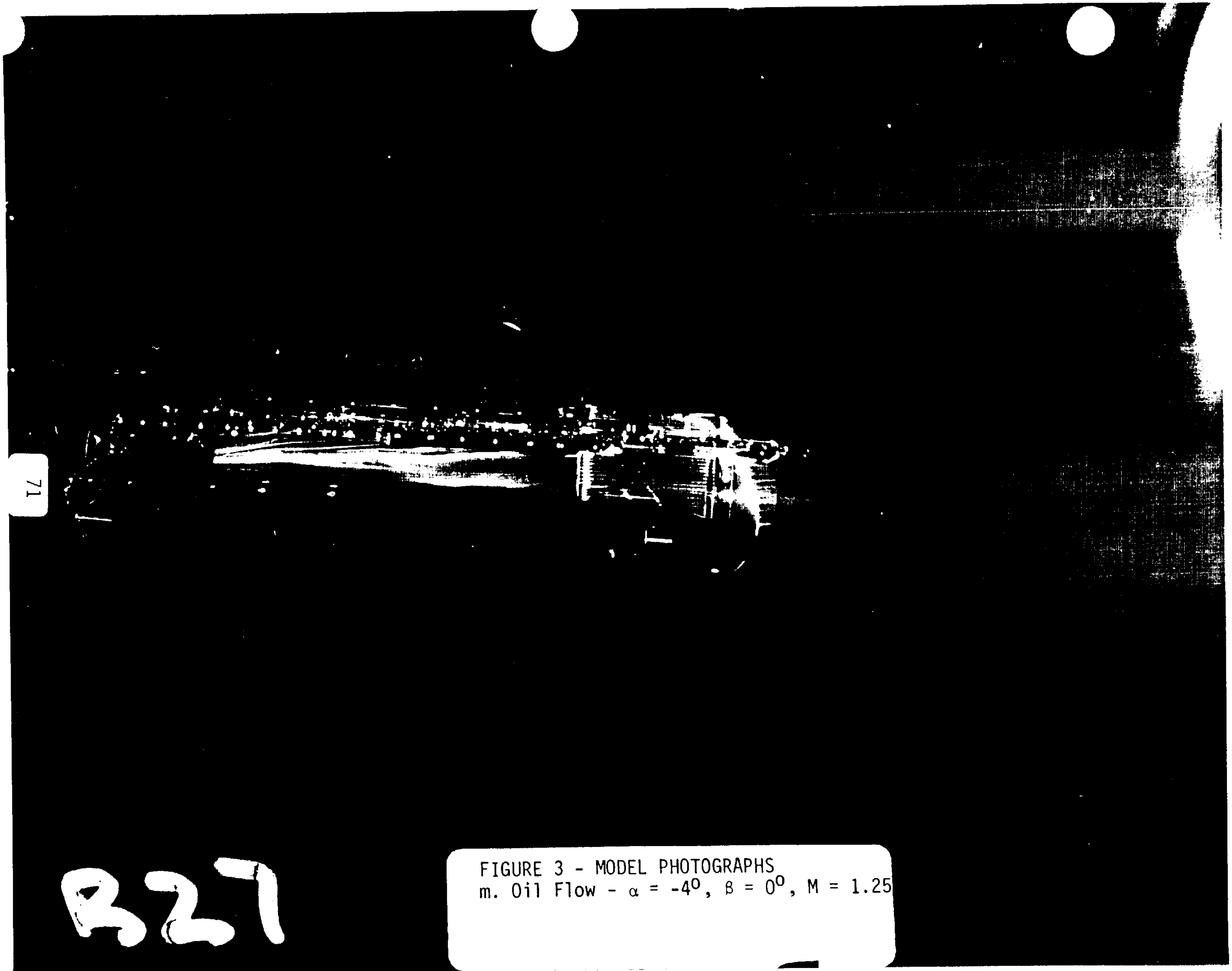

FIGURE 3 - MODEL PHOTOGRAPHS
m. Oil Flow - $\alpha = -4^{0}$, $\beta = 0^{0}$, M = 1.25

66-1 M=1.25 α=-4 β=0

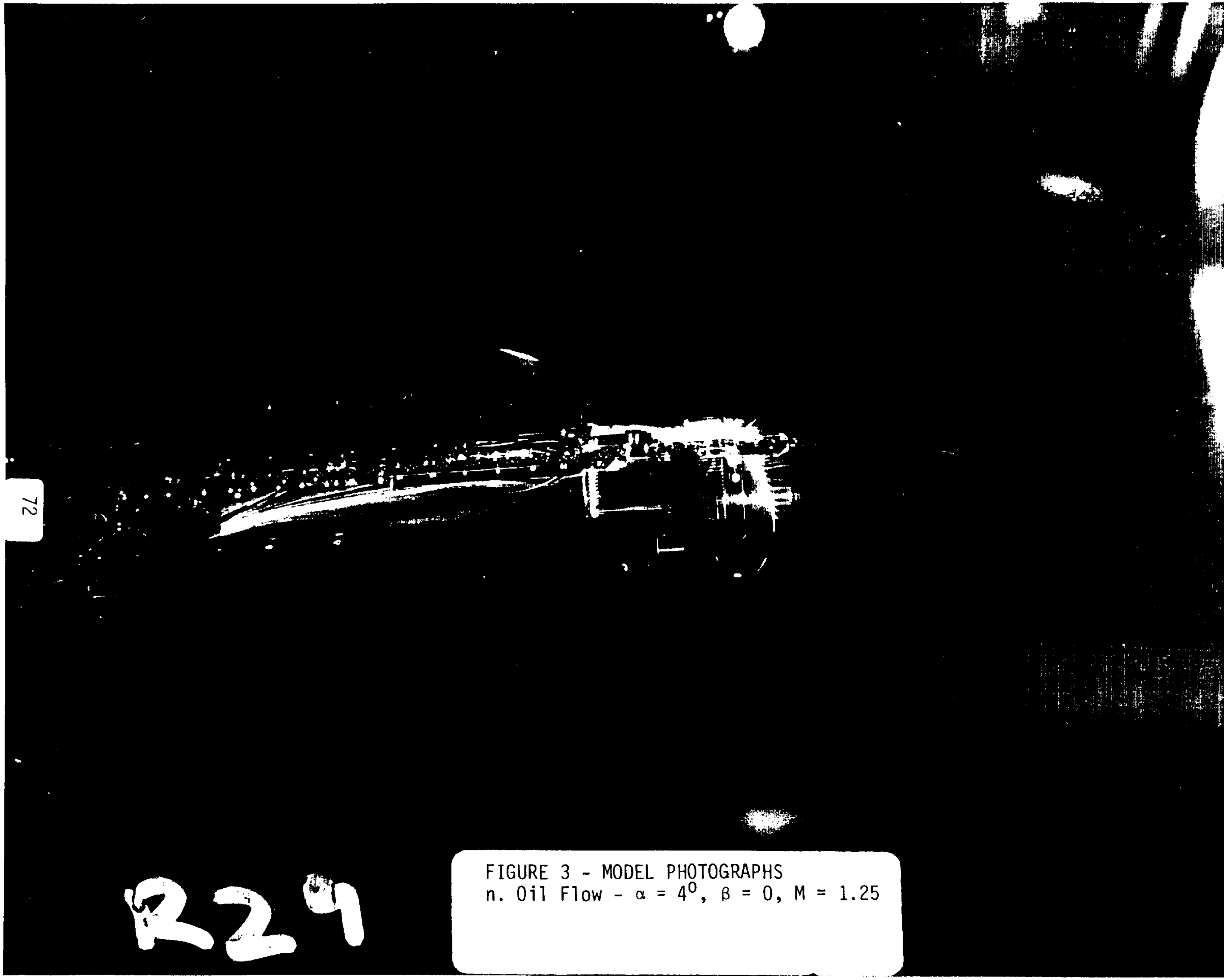

FIGURE 3 - MODEL PHOTOGRAPHS
n. Oil Flow - $\alpha = 4^0$, $\beta = 0$, $M = 1.25$

66-3 M=1.25 α=4 β=0

FIGURE 3. - MODEL PHOTOGRAPHS
o. Oil Flow - α = 0, β = -4^{o}, M = 1.25

65-2 M = 1.25 α=0 β = -4

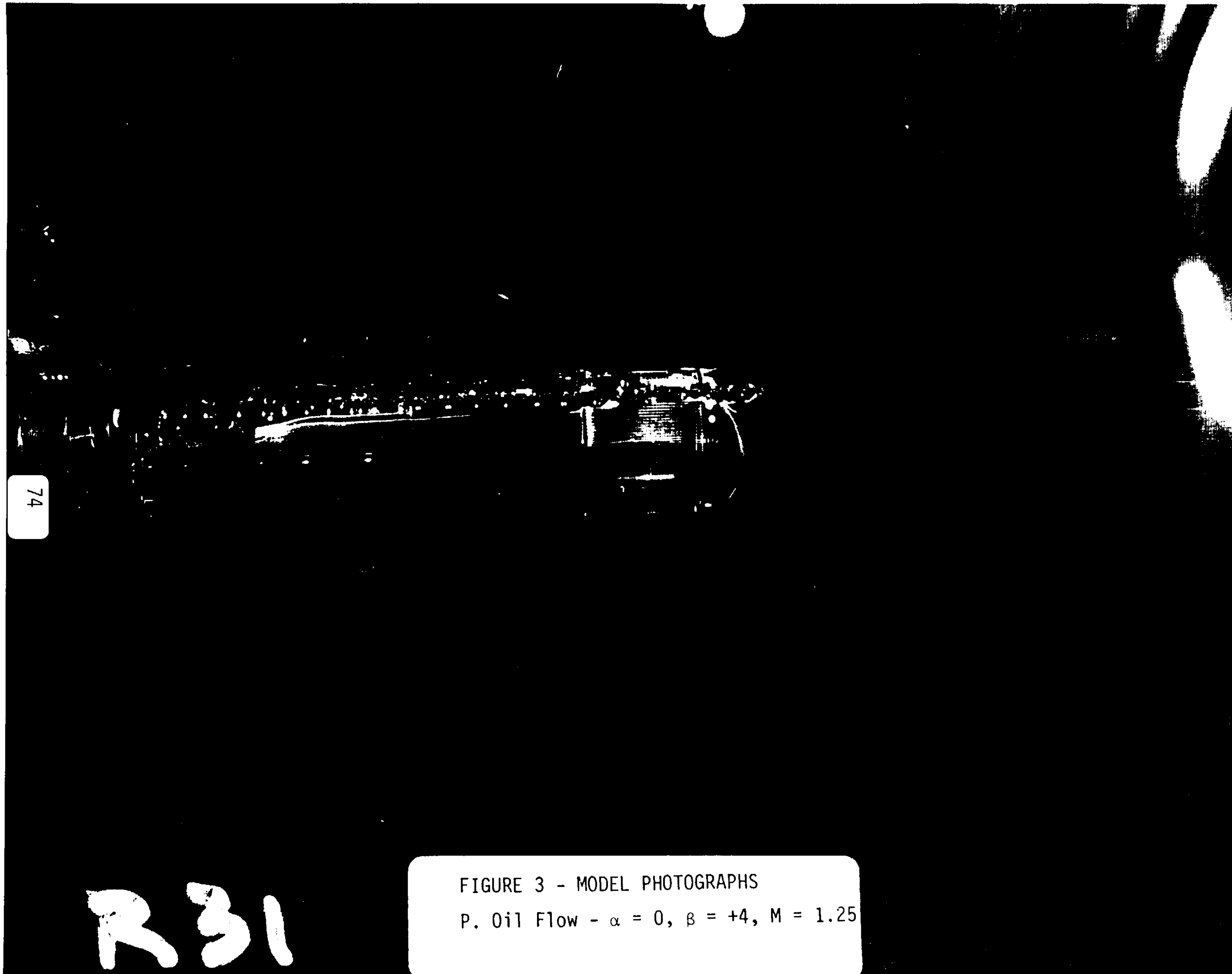

FIGURE 3 - MODEL PHOTOGRAPHS

P. Oil Flow - $\alpha = 0$, $\beta = +4$, $M = 1.25$

67-2 M=1.25 α=0 β=4

APPENDIX - VOLUME II

PRESSURE DATA - MICROFICHE

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