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Part I

(Unclassified)

PRELIMINARY DESIGN AND EXPERIMENTAL INVESTIGATION OF THE FDL-5A UNMANNED HIGH L/D SPACECRAFT

Part I Summary

J. T. Lloyd
Lockheed-California Company

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TECHNICAL REPORT AFFDL-TR-68-24, PART I

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(U) FOREWORD

(U) This is the final report of work performed under Contract No. AF33(615)-5241, "Preliminary Design of Two Volumetrically Efficient High L/D Unmanned Flight Test Vehicles". This report was prepared under Project 1366, "Aerodynamics and Flight Mechanics", Task 136616, "Synthesis of Hypersonic Vehicles".

(U) The work was sponsored by the Aerospace Vehicle Branch, Flight Mechanics Division Air Force Flight Dynamics Laboratory. The research investigation was performed under the direction of the Air Force Project Engineer Mr. Thomas R. Sieron. Mr. C. J. Cosenza and Mr. A. C. Draper of AFFDL provided overall technical guidance.

(U) The work was accomplished by the Lockheed-California Company, Burbank, California and the report is also identified as LR 21204.

(U) This is Part I of a five part report:

Part I	Summary
Part II	Parametric Configuration Development and Evolution
Part III	Aerodynamics
Part IV	Aerothermodynamics
Part V	Vehicle Design

(U) This manuscript was released by the authors for publication in January 1968.

(U) Mr. J. T. Lloyd of the Spacecraft and Hypersonics Division was the project engineer for the Lockheed-California Company. Special appreciation is given to Mr. G. L. Alexander for his valuable guidance and consultation in the conduct of this program.

(U) The assistance of Flight Dynamics Laboratory personnel including Messrs M. L. Buck. R. D. Neumann, V. Dahlem, P. Lane, and W. H. Goesch contributed significantly to the accomplishments of this program.

(U) This technical report has been reviewed and is approved.

Philip P. Antonatos
Chief, Flight Mechanics Division
Air Force Flight Dynamics Laboratory

(U) ABSTRACT

(U) Conceptual design and experimental wind tunnel testing of unmanned entry research vehicles having high hypersonic lift/drag ratio and high volume are described. Analytic parametric data are presented for two lifting body classes designated HLD-35 and FDL-5. The FDL-5 is a unique configuration which is aerodynamically stabilized without outboard fins. Experimental aerodynamic and heat transfer data from the Arnold Engineering Development Center Wind Tunnels A, B, C, and F are compared with analytic data for the FDL-5. Candidate structure and subsystems are selected for performing unmanned hypersonic research with the vehicle.

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SECTION 1

(U) INTRODUCTION

(U) This preliminary design study of two volumetrically efficient high L/D unmanned flight test vehicles is a part of the continuing USAF Flight Dynamics Laboratory program to conduct basic research on hypersonic maneuvering vehicle systems. Use of atmospheric maneuvering has been found to provide operational flexibility and versatility for performing a large variety of potential USAF missions. Technologies for high-performance entry systems have been gradually developing over the past six years. The study reported herein is concerned with unmanned free-flight research vehicles which would be used (1) to obtain broad free-flight hypersonic technology data in aerodynamics, thermodynamics, structures, and propulsion, (2) to demonstrate the maneuver potential of advanced entry vehicle concepts operating in the large-scale entry environment, (3) to demonstrate operational utility of such vehicles, and (4) to demonstrate reusable structure concepts and the adaptability of the airframe to man.

(U) This contract followed an earlier study entitled "Preliminary Design of Hypersonic High L/D Test Vehicles" (Ref. 1). In the earlier study, six high L/D entry vehicles were analyzed to establish the size, weight, and system requirements for conducting free flight research on high performance entry systems from orbital speed to landing.

(U) The present study was focused on improving the hypersonic geometry and properties of a high L/D research vehicle. Specifically, the objectives were to configure an unmanned entry research vehicle having a hypersonic L/D of 3.0 at 20,000 fps and 200,000 feet altitude; and to confirm vehicle aerodynamic and heat transfer performance through wind tunnel test. In addition to this requirement, the vehicle was to be designed for maximum volume with the relationship between volume and L/D to be identified. Horizontal landing was the primary recovery mode, but alternate recovery concepts were to be investigated. A structure concept and the vehicle subsystems were to be selected based on earlier work and the experience gained in other USAF programs including ASSET, ASCEP, and PRIME.

(U) The contract effort was divided into two phases: the first consisted of the development of the parameters affecting the selection of candidate configurations; the second included supersonic and hypersonic wind tunnel testing of one candidate configuration and selection of the structure and subsystems.

(U) In a parametric study, over 200 relationships among configuration geometry, volume, aerodynamic heating, and aerodynamic performance and stability were evolved. These data trends were based on hypersonic theories, results of ASSET flight data, and results of USAF AFFDL and Lockheed in-house wind tunnel tests of high performance lifting bodies. The sources for each of these data are documented in this final report. The purpose in developing these parameters was to provide the rationale for selecting the test geometry for the test and design phase.

(U) Two classes of configurations emerged from the configuration studies: (1) a dual finned geometry designated the HDL-35 series, and (2) a unique high volume geometry designated as the FDL-5 series.

(U) The FDL-5 was selected for wind tunnel testing and structure design in the test and design phase. Its size was varied during the study from 30 to 35 ft in length.

(U) The principal conclusions and results derived from the two study phases are:

1. (U) A new class of lifting entry vehicle designs (FDL-5 series) was defined and tested.

2. (U) The FDL-5 configuration has demonstrated through wind tunnel test that it is stable and controllable from supersonic to hypersonic speeds. Freedom exists to tailor the base geometry and control surfaces for subsonic and transonic control and performance. Variable geometry may be considered to improve landing performance.

3. (U) Heat transfer wind tunnel test data revealed no unusual or unpredictable heating phenomena.

4. (U) An insulated and cooled structure concept was selected for the vehicle design. The primary structure is made of aluminum and the heat shields are made of coated columbium on the lower surface and Inconel on the upper surface. Leading edges are made of coated tantalum.

5. (U) Candidate subsystems for conducting a three quarter orbit mission were selected.

6. (U) Launch weight of the 35-foot-long unmanned research vehicle is estimated to be 7700 pounds.

SECTION 2

(U) PARAMETRIC CONFIGURATION DEVELOPMENT AND EVALUATION

(U) Figure 1 depicts the status of high L/D configuration development at the initiation of this contract. The configurations designated by AF prefixes were conceptual designs developed by the USAF Flight Dynamics Laboratory and were provided as the starting point for an earlier study contract (Reference 1).

(U) Figure 2 shows the general arrangement of the F-5 configuration which served as the starting point and basic model about which the parametric configuration and structure trades were performed. The F-5 was chosen for this purpose, since it was in a more advanced state of definition than the other configurations.

(U) The first phase of this contract was concerned with development of the configuration geometry rationale. The interactions among geometry, aerodynamic performance, volume, stability and heating were achieved through an extensive series of parametric trades. Figure 3 illustrates the basic geometry elements that were systematically varied to accomplish the parametric trades.

(U) The following sections summarize the parametric trades that were conducted. The more significant trades are illustrated.

2.1 (U) AERODYNAMIC PARAMETRIC ANALYSES

(U) The scope of the aerodynamic trades which were developed for high L/D shapes is illustrated in Table 1. Variations in the geometry of each element of the vehicle have been analyzed, and the effects on the performance, stability and volume parameters shown across the top of the table have been determined. The designations within the table show the slopes of the trade about the nominal parameter values for a 30-foot F-5 vehicle, or they indicate the nature of the trade as coded by the table notes. For example, an increase of one degree in the body leading-edge sweep angle increases the hypersonic L/D_{max} by +0.007, and decreases vehicle volume by 19.7 cubic feet; effects on stability are negligible. Since most of the trades are nonlinear, the parametric trade slopes or derivatives in Table 1 are representative only at or near the F-5 parametric values. Large deviations from the F-5 values require consideration of the complete parametric trade.

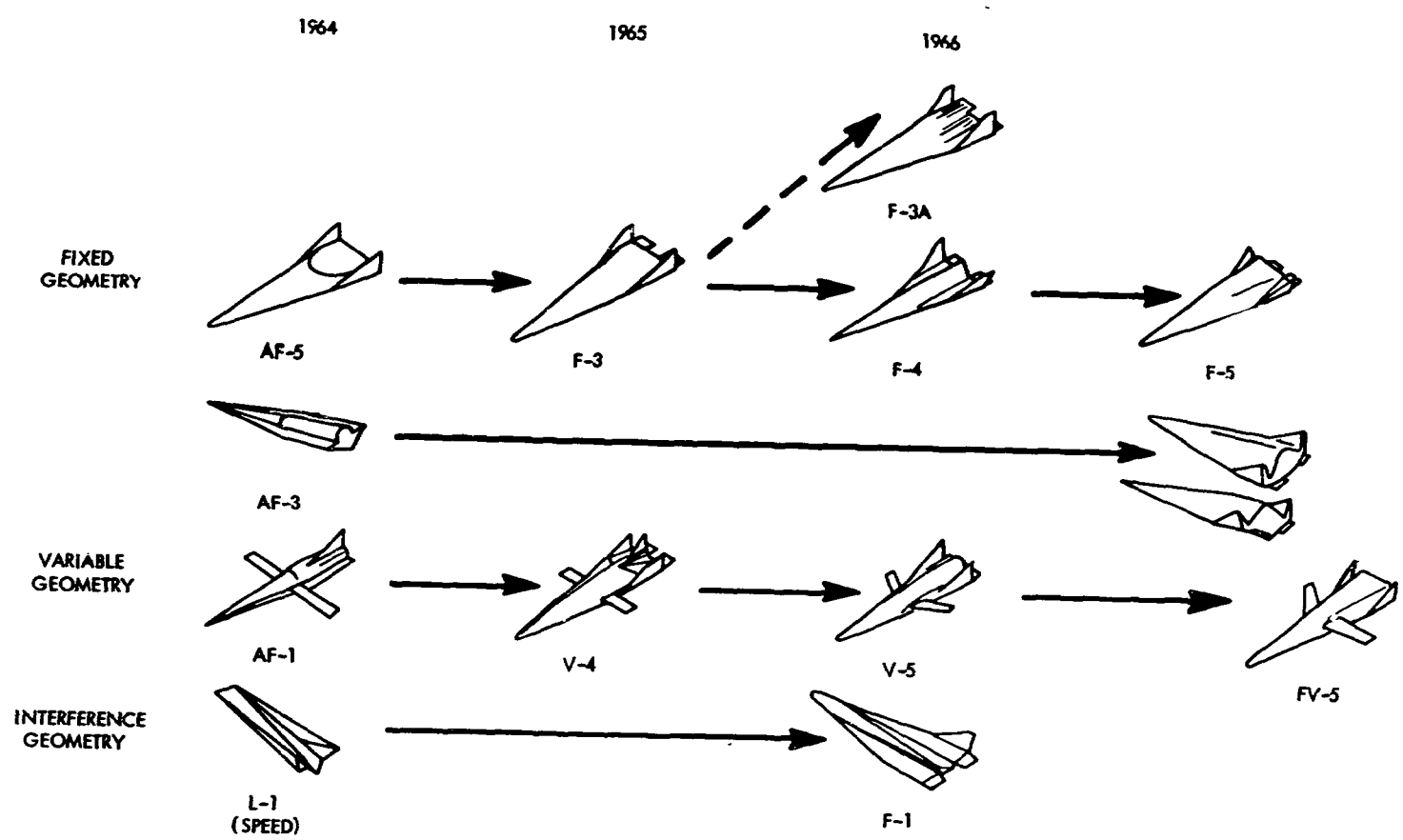

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FIGURE 1 (U) EVOLUTION OF HIGH L/D VEHICLE CONCEPTS

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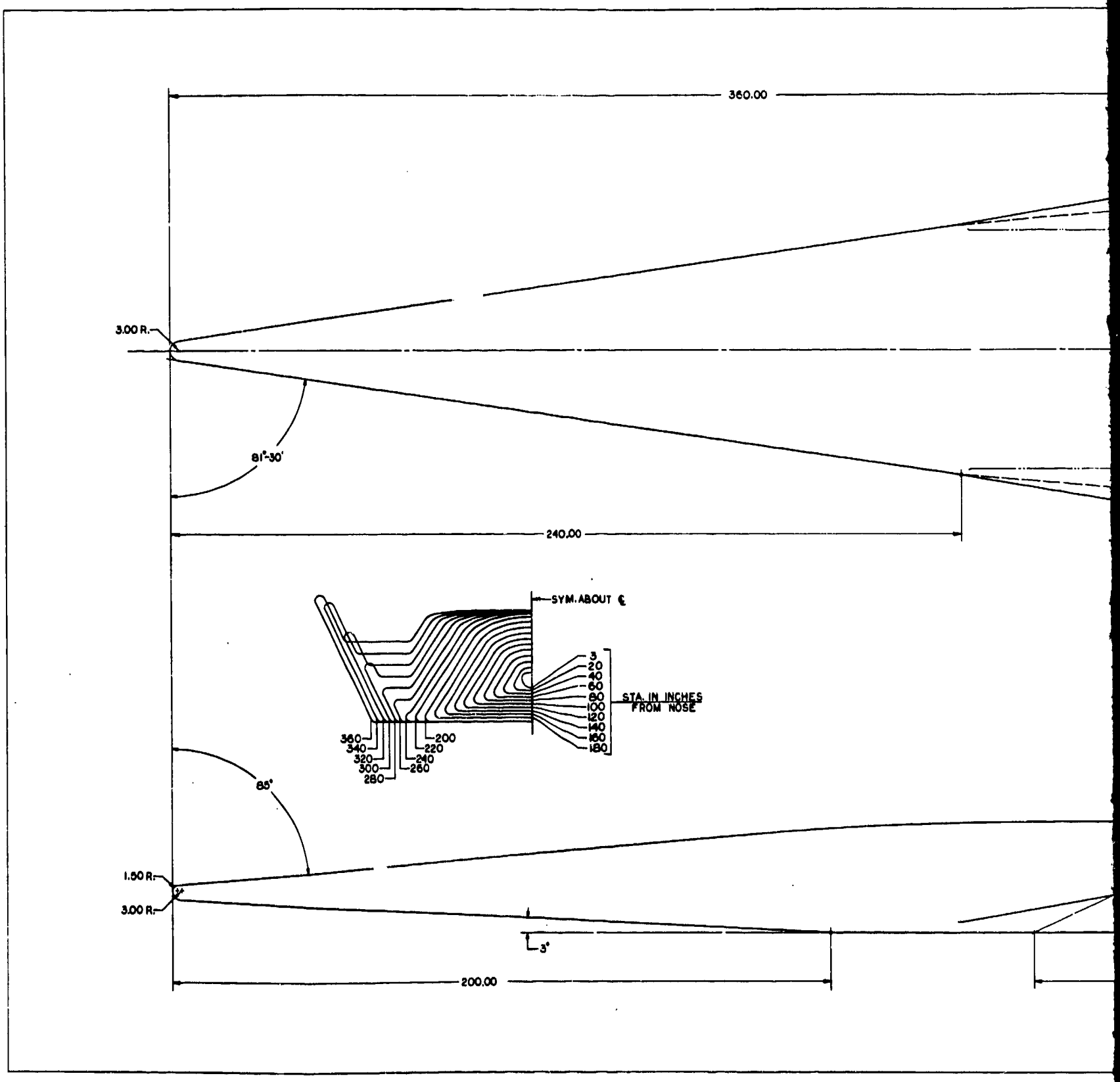
360.00
3.00 R.
81°-30'
240.00
SYM. ABOUT ℄
3
20
40
60
80
100
120
140
160
180
STA. IN INCHES FROM NOSE
360
340
320
300
280
200
220
240
260
85°
1.50 R.
3.00 R.
3°
200.00

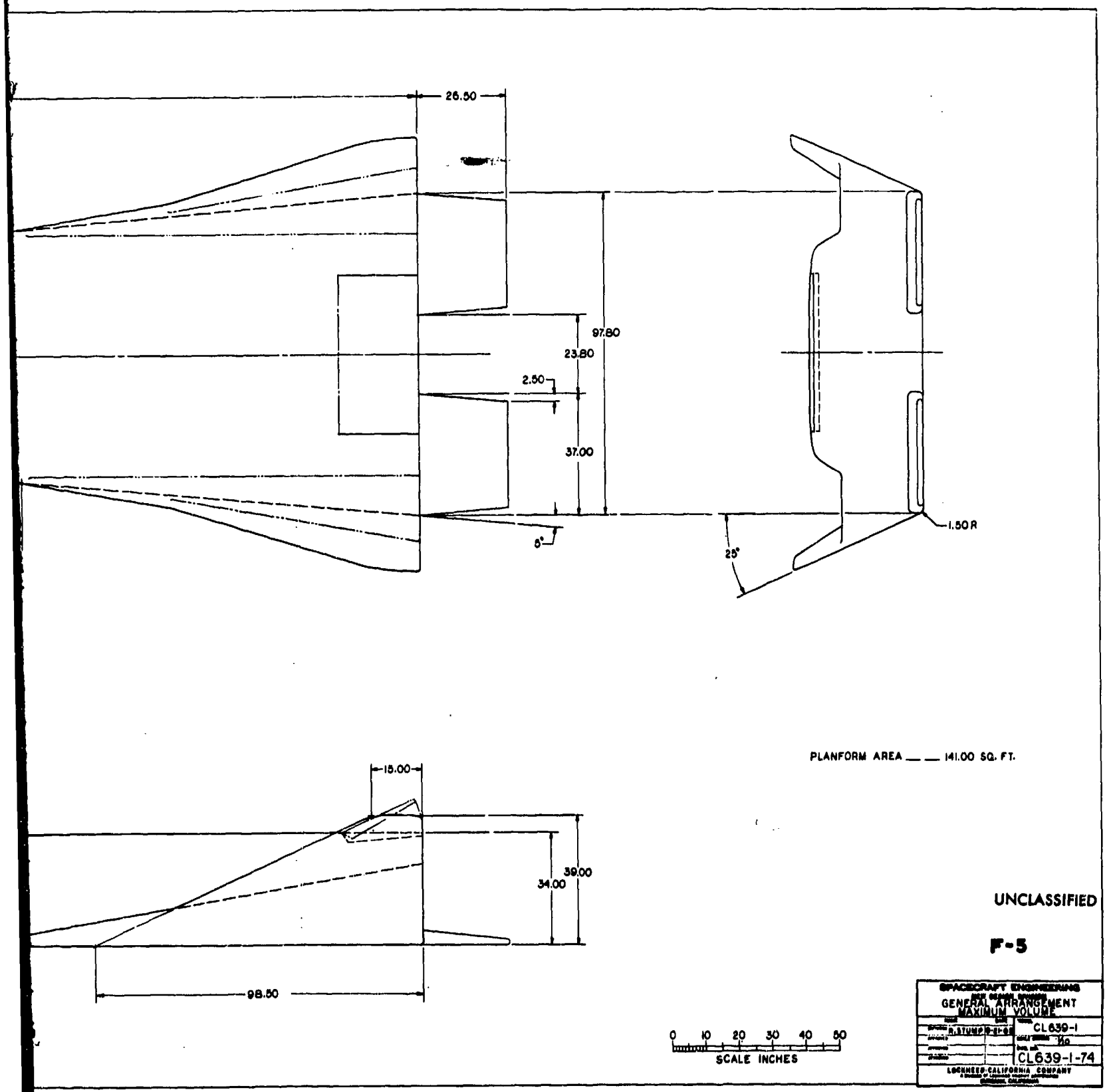

FIGURE 2 (U) F-5 GENERAL ARRANGEMENT

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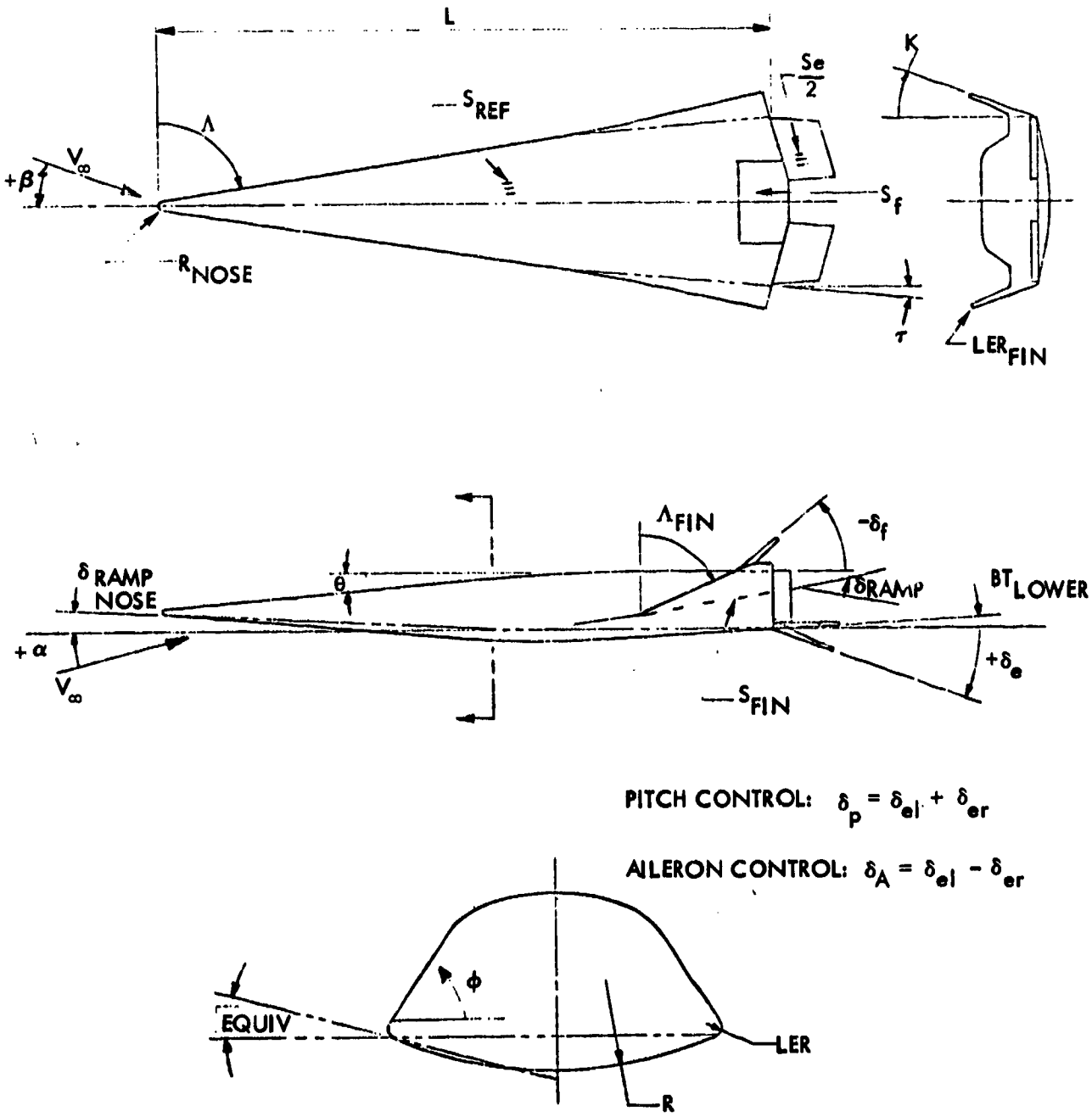

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FIGURE 3 (U) BASIC GEOMETRY

TABLE 1

(C) AERODYNAMIC TRADES

	L/D			C_m			C_{n_β}			C_{ℓ_β}			VOL
	Sub	Super	Hyp	Sub	Super	Hyp	Sub	Super	Hyp	Sub	Super	Hyp	Ft^3
FINS:													
Toe-in, τ (Deg.)	+.102	-.018	-.046	*	*	*	-.00006	+.00019	+.00019	-.00006	-.0001	-.0001	2.64
Roll-out, K (Deg.)	+.042	0	A	*	*	*	-.00006	+.00002	+.00002	-.00006	-.00002	-.00002	.333
Camber, (% Chord)	+.11	A	A	*	A	A	-.00031	A	A	+.00006	A	A	A
Area, $\bar{S}$ (% Planform)	0	C	-.014	*	*	*	+.0006	C	D	-.0008	C	D	A
LE Sweepback, Λ_{Fin} (Deg.)	A	C	+.01	A	*	*	A	A	A	A	A	A	A
LE Radius, LER_{Fin} (In.)	A	C	-.07	A	*	*	A	A	A	A	A	A	A
℄ Fin Area, $\bar{S}_{℄}$ (% Planform)	A	A	A	A	A	A	+.059	+.004	+.002	-.043	-.002	-.001	A
UPPER BODY:													
Length, L (Feet)	A	C	+.036	B	B	B	B	B	B	B	B	B	25.38
LE Sweepback, Λ_{Body} (Deg.)	A	C	+.007	A	A	A	A	A	A	A	A	A	-19.7
Side Roll-out, ϕ (Deg.)	A	0	0	A	*	*	A	C	*	A	C	+.00001	2.87
LE Radius, LER_{Body} (In.)	A	0	0	A	A	A	A	A	A	A	A	A	A
Profile Angle, θ (Deg.)	C	C	0	A	*	*	A	0	0	A	0	0	17.15
Base Area, $\bar{S}_{Base}$ (% Planform)	-.17	A	A	B	B	B	B	B	B	B	B	B	6.53
Flap Area, $\bar{S}_F$ (% Planform)	-.19	-.02	0	*	*	B	B	B	B	B	B	B	B
Flap Deflection, δ_F (Deg.)	-.033	-.006	0	*	*	B	B	B	B	B	B	B	B
Elevon Area, $\bar{S}_E$ (% Planform)	-.06	C	+.0055	*	C	*	B	B	B	B	B	B	B
Elevon Deflection, δ_E (Deg.)	+.041	0	0	*	*	*	B	B	B	B	B	B	B
Fin Ramps, δ_R (Deg.)	A	-.045	-.045	D	*	*	A	A	A	A	A	A	2.11
Ailerons, δ_A (Deg.)	B	B	B	B	B	B	B	B	B	*	*	*	B
Nose Cap Radius, R (In.)	A	-.036	-.036	A	A	A	A	A	A	A	A	A	A
LOWER SURFACE:													
Nose Ramp Area, $\bar{S}$ (% Planform)	A	C	D	A	*	*	A	A	A	A	A	A	A
Nose Ramp Angle, δ_N (Deg.)	A	C	-.07	A	*	*	A	C	+.00008	A	C	-.000008	A
Dihedral Bottom, Γ (Deg.)	-.016	C	-.018	A	*	*	A	C	-.000036	A	C	-.00003	3.33
Curved Bottom, $\Gamma_{Vol.\ Equiv.}$ (Deg.)	-.016	C	-.018	A	*	*	A	C	-.000024	A	C	-.000026	3.33
Boat Tail	-.016	C	-.045	*	*	*	D	A	A	A	A	A	*

(*) Complex Trade

NOTE

A. Negligible
B. Not Applicable
C. Hypersonic and Supersonic Trends Similar
D. Not Determined

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(U) Figure 4 shows the impact of equivalent lower surface dihedral angle, Γ, side rollout angle, ϕ, body sweep angle, Λ, and vehicle length on hypersonic L/D_{max} and volume. It is noted that all of these geometric parameters (excepting length) produce a loss in L/D with an increase in volume. Furthermore, for a fixed vehicle length, volume can be obtained with least penalty to L/D_{max} by decreasing sweep angle. Increasing the side rollout angle is seen to be the least desirable approach to increasing volume. Variations in these parameters are ultimately limited by aerodynamic heating and stability considerations.

(U) Volume and L/D_{max} are also shown in Figure 4 for the earlier F and V series configurations. The trend of reduced L/D_{max} with increased volume is consistent with the observations made from the parametric analyses.

(U) A separate series of parametric trades was performed on various arrangements of finned and finless aft body geometry elements. These trades, which led to the evolution of the "compression-sharing" concept and the FDL-5 geometry, are described in Part II.

2.2 (U) AEROTHERMODYNAMIC PARAMETRIC ANALYSES

(U) The heat transfer parameter trades that were conducted during the study are indexed in Table 2. As in the aerodynamic analyses, variations of the F-5 geometry parameters were analyzed. The effect on the surface temperature of the various configuration elements were then determined. In addition to the basic geometry parameters, two attitude parameters, α and β were investigated. Two of the more significant heat transfer trades are illustrated in Figures 5 and 6.

(U) Figure 5 combines the aerodynamic and heat transfer trades at the stagnation point to illustrate the change in hypersonic L/D with stagnation temperature for various nose radii. The selection of an equivalent nose radius of three inches is based on a maximum temperature of 4500°F and a low penalty in hypersonic L/D. Table 2 indicates the rate of change of nose stagnation temperature with change in nose radius to be -200°F per inch increase in radius.

(U) Figure 6 shows that increasing the body side rollout angle, ϕ, results in a significant increase in upper surface temperatures. Furthermore, the effects of yaw are such that, for a fixed temperature limit, body side angle must be reduced by 2-1/2 degrees for every degree of yaw that will be tolerated during peak heating.

2.3 (U) DESIGN CONSIDERATIONS

(U) The alternate recovery modes shown in Figure 7 were considered during the study to estimate their effects on weight and vehicle geometry. Recovery weight (in fraction of unassisted landing weight) determined for each of the alternates is tabulated in Table 3. All the modes considered can be

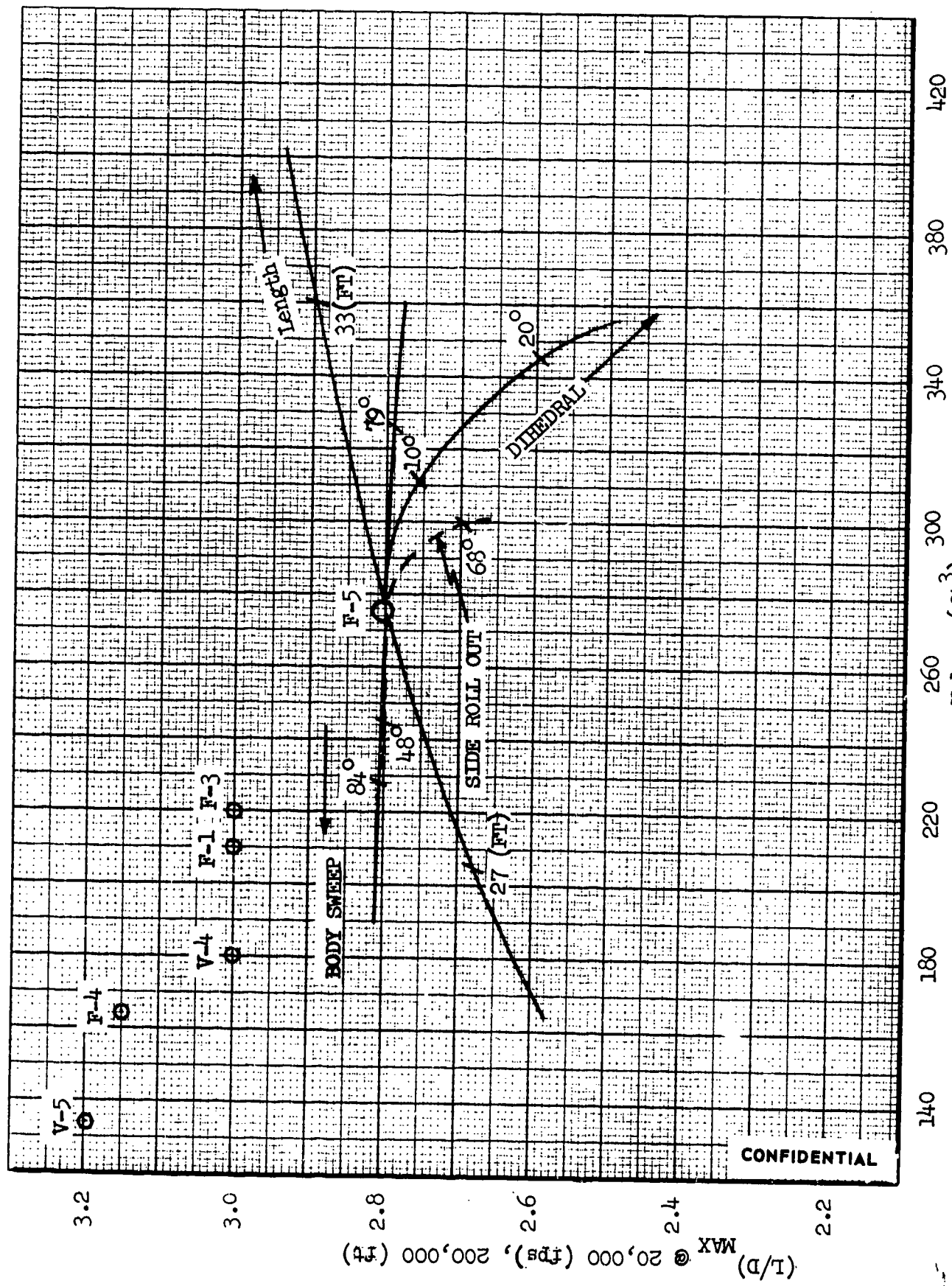

FIGURE 4 (U) VARIATION OF L/D_{MAX} WITH VOLUME

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TABLE 2

(U) AEROTHERMODYNAMIC SENSITIVITY SUMMARY

Parameter	F-5 Design Value	Predicted F-5 Temperatures (°F)						
		Fin Stagnation Line 3230	Fin Outboard Panel (X=3 ft) 1830	Wing Stagnation Line 2870	Body Upper Surface 1300(a) 780(b) 1400(c)	Lower Surface Centerline (X=10 ft) 1780	Elevons 2200	Nose Stagnation Point 4300
		ΔT/Δ Parameter (°F/degree or °F/in.)						
Toe-in Angle	5 deg	25	41					
Roll-out	25 deg	80	5					
Leading-edge Sweepback Angle	63 deg	-35	0					
Leading-edge Radius	1.5 in.	-300	0					
Leading-edge Sweepback Angle	81.5 deg			-37	0	0		
Leading-edge Radius	1.5 in.			-280				
Body Side Angle	57 deg				38(a)			
Profile Angle	6 deg				0			
Fin Ramp Angle	10 deg				100(c)			
Elevon Deflection Angle	5 deg						200(d)	
Nose Radius	1.5 in.							-200
Forward Ramp Angle	3 deg			55		50		
Lower Surface Curvature						0		
Dihedral Angle						0		
Boattail Angle	0 deg					0		
Angle of Attack	10 deg	-32	22	52	38(a)	42(e)		
Yaw Angle	0	40	35	40	170(a)	30		

(a) Side Panel, X = 1 ft
(b) Upper Forebody Centerline, X = 5 ft
(c) Fin Ramp, X = 1 ft
(d) Assuming Separated Flow
(e) Laminar Flow

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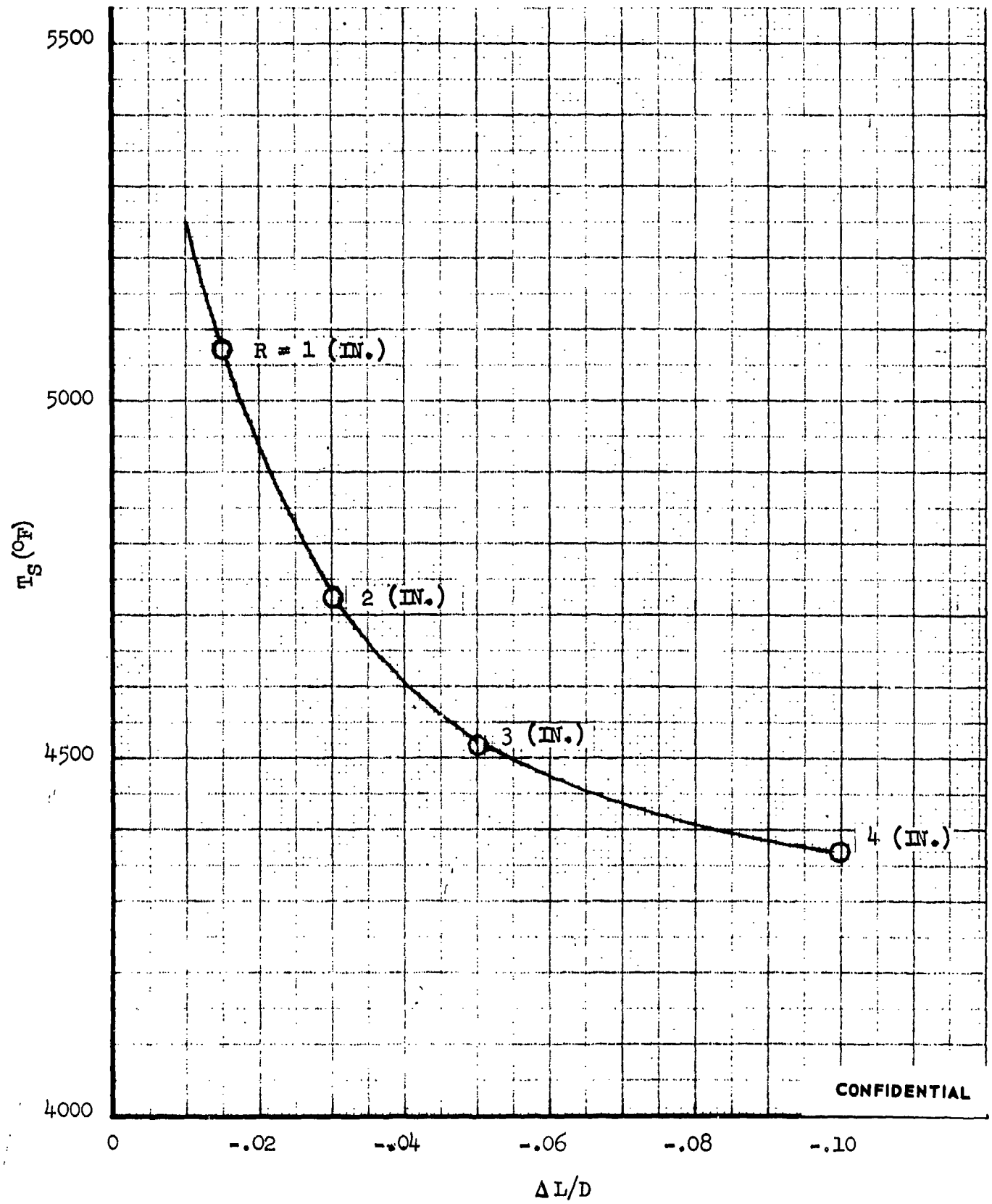

FIGURE 5 (U) NOSE RADIUS TRADE

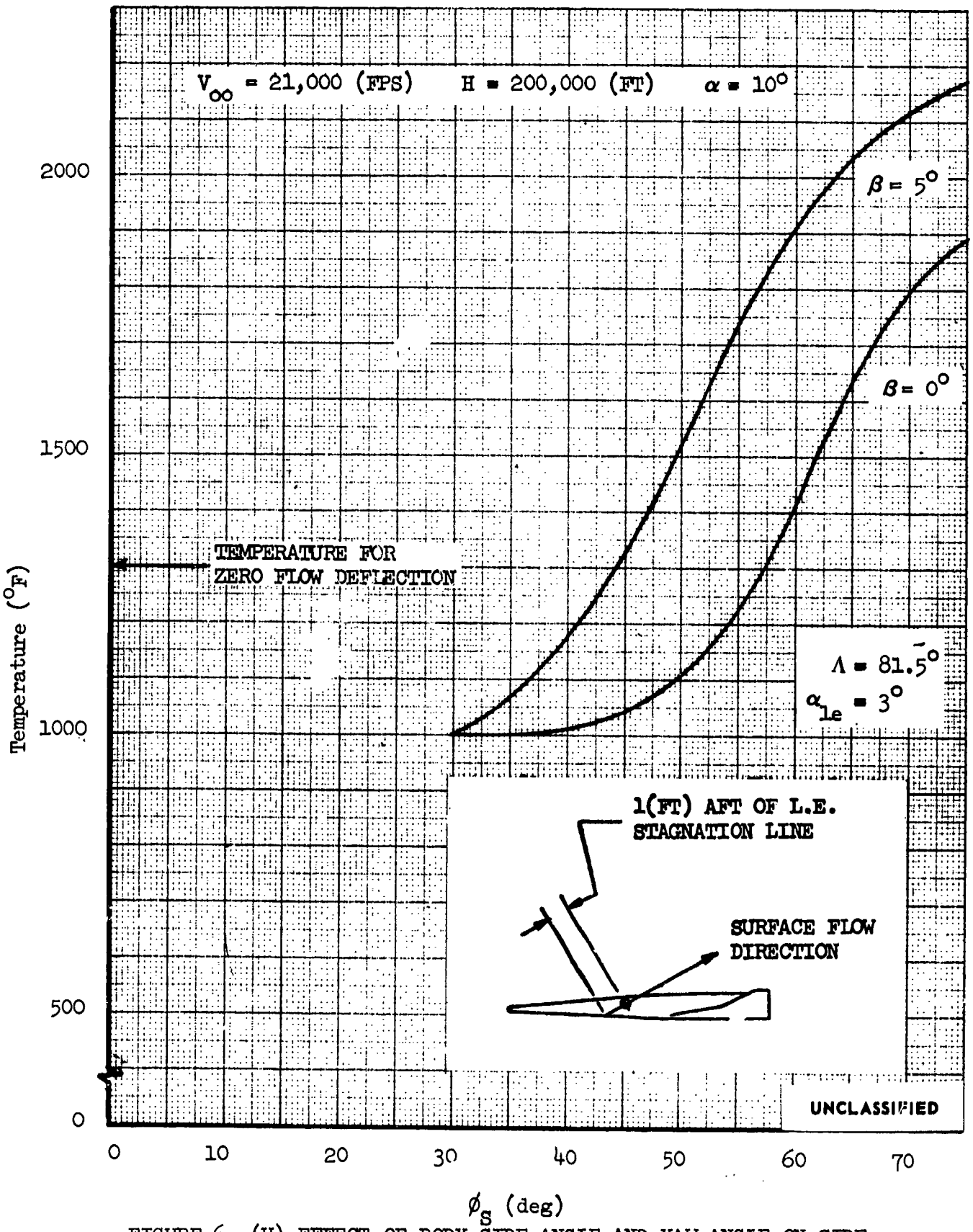

FIGURE 6 (U) EFFECT OF BODY SIDE ANGLE AND YAW ANGLE ON SIDE PANEL SURFACE TEMPERATURES

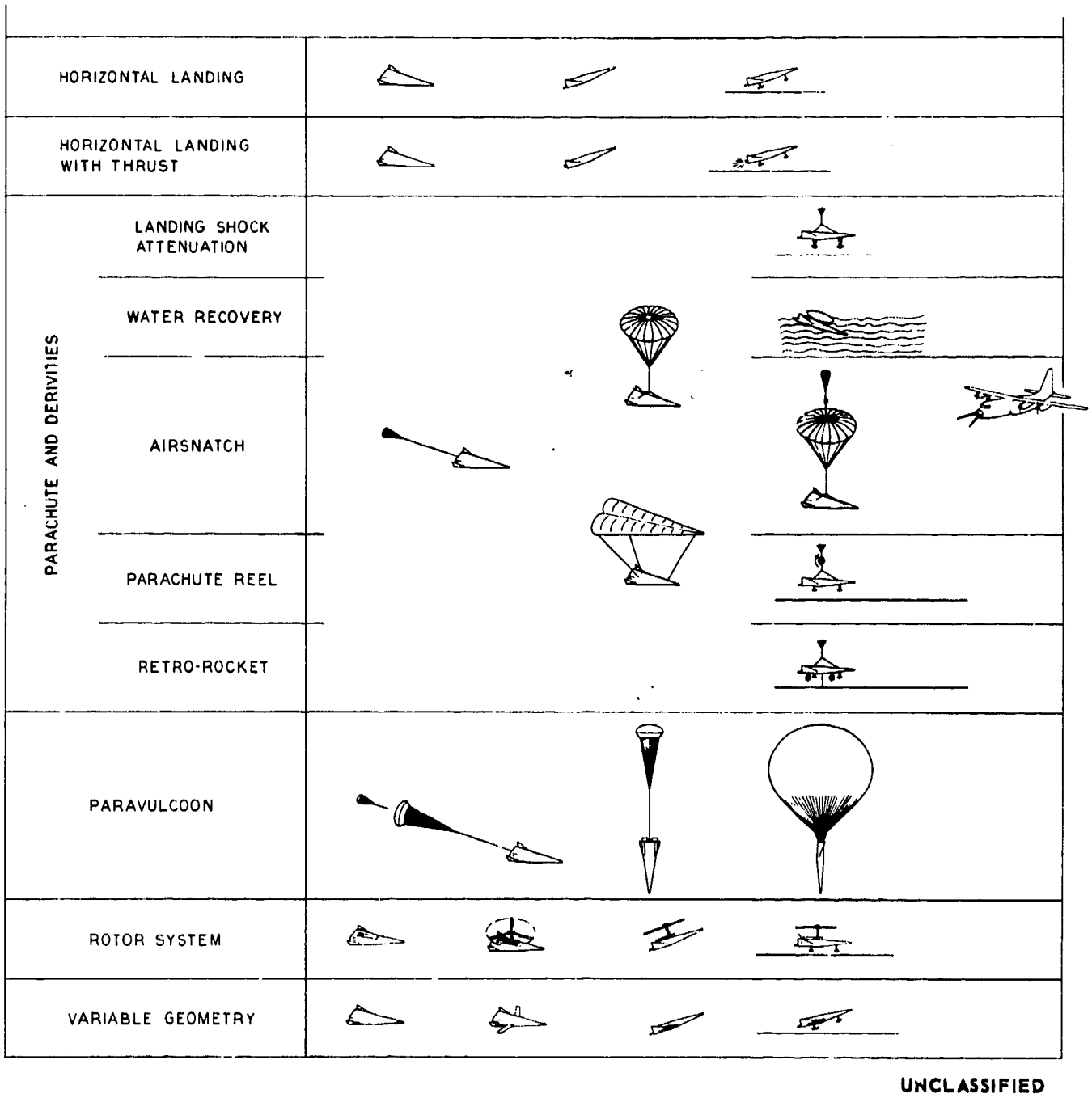

FIGURE 7 (U) ALTERNATE RECOVERY TECHNIQUES

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TABLE 3

(U) ALTERNATE LANDING SYSTEMS

System	Weight/Horizontal Landing Weight*	Comments
Horizontal Landing	1.00	Lowest weight. However, with no thrust available to offset the high base drag, the sink speed may be too high for reasonable landing gear design.
Horizontal Landing W/Thrust	1.05	This system is based on ground contact at V_v = 10 ft/sec and thrust time of approximately 20 sec.
Vertical Descent Recovery (All)		Landing thrust and horizontal-type landing gear not required.
Parachute + honeycomb shock strut	1.09	The lightest weight of this combination occurs when parachute decelerates vehicle to 25 fps. Honeycomb shock strut then decelerates vehicle to zero fps.
Parachute (water recovery)	1.05	This system may operate with high vertical descent, 30 fps, if vehicle is allowed to enter water nose first.
Parachute (air snatch)	1.01	This system is sized with a parachute system to decelerate vehicle to 25 fps.
Parachute (reel)	1.04	Reel system to wind parachute lines rapidly just before touchdown can be rocket-powered.
Parachute + retrorockets	1.07	The lowest weight of this combination occurs when parachute decelerates vehicle to 26 fps. Retrorockets are fired just before touchdown.
Paravulcoon	1.11	This system was sized to hover at an assumed altitude of 5000 ft.
Rotor	1.13	System sized for vehicle simulating horizontal landing at an altitude, then deploying rotors to obtain an average descent of 25 fps and adding collective pitch just before impact to reduce descent rate to 8 fps.
Paraglider	1.17	Paraglider system weight for this vehicle was scaled from other data.
Horizontal Landing (Variable Geometry)	1.20	Weight based on 4g load factor and use of wing flaps, ailerons, and slots.

*Based on 5000-lb vehicle

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configured and packaged in a manner which will not significantly change the hypersonic configuration.

(U) A trade study was made between the weight of the vehicle-booster adapter and the weight of a solid rocket motor used to overcome base drag during landing. This trade arises from the fact that a reduction in vehicle base area to improve landing L/D leads to the requirement for a larger, heavier adapter. The use of a rocket engine precludes the need for base area reduction and the associated larger adapter section. The trade is summarized in Figure 8, and includes consideration of adapter weight, rocket weight, and subsonic base drag.

2.4 (U) GEOMETRY SELECTION

(U) Tables 4 and 5 summarize the geometry parameters that resulted from the parametric trades. The columns headed "Effect of Decrease" and "Effect of Increase" define the competing considerations that result in the recommended geometry elements. Table 4 is concerned with the geometry, performance and volume trades; and Table 5 is concerned with stability requirements.

(U) The resulting geometry is similar to that for the original F-5 configuration except for the contoured lower surface. The general arrangement is shown in Figure 9 and incorporates the recommended geometry elements of Table 4 and 5. This system was designated the HLD-35-1.

2.5 (U) CONFIGURATION EVOLUTION

(U) The HLD-35-1 has two unattractive features. These are (1) the large base area which requires thrust-augmented landing or some other landing mode and (2) the use of heavy, high temperature fins for stabilization. Several alternate aft vehicle geometries were considered in attempting to overcome these deficiencies.

(U) The first aft vehicle geometry variation is described in Figure 10 and was given the designation HLD-35-2. Its geometry elements are similar to those of the HLD-35-1 except that the base area has been reduced by boattailing and elimination of the fin/body ramps. This geometry has satisfactory performance, stability and control and satisfies the requirement for minimizing base area; but it retains the discrete high temperature fins.

(U) A second excursion was identified as HLD-35-3 and is shown in Figure 11. This geometry was the first attempt to remove the outboard fins by substituting slab body sides. It was found to have adequate directional stability at high angle of attack but only marginal stability at low angle of attack. A center fin is provided for low-speed directional stability. The base area is greater than that of the HLD-35-2.

(U) Figure 12 illustrates the approach suggested by AFFDL to minimize the fin and accomplish base fairing simultaneously. This initial geometry

results in large reductions of the hypersonic L/D due to the aft upper surface contours that produce large down and drag loads. It achieves more than adequate directional stability, however, and suggested that hypersonic directional stability could be obtained without fins.

(U) The geometry that was ultimately selected for the test phase is shown in Figure 13. It is designated FDL-5. This configuration resulted from parametric analyses of the effects on stability and performance of the aft contouring suggested by the geometries of Figures 5 and 6. The large increase in directional stability with increase in angle of attack observed on the HLD-35-3 and the large value of directional stability observed on the AFFDL configuration suggested a compromise geometry might accomplish a nearly uniform value of directional stability with various angles of attack while minimizing the penalties in hypersonic L/D. This compromise contouring philosophy was found to provide the desired stability and is the basis for the "Compression-sharing" concept defined in detail in Part II.

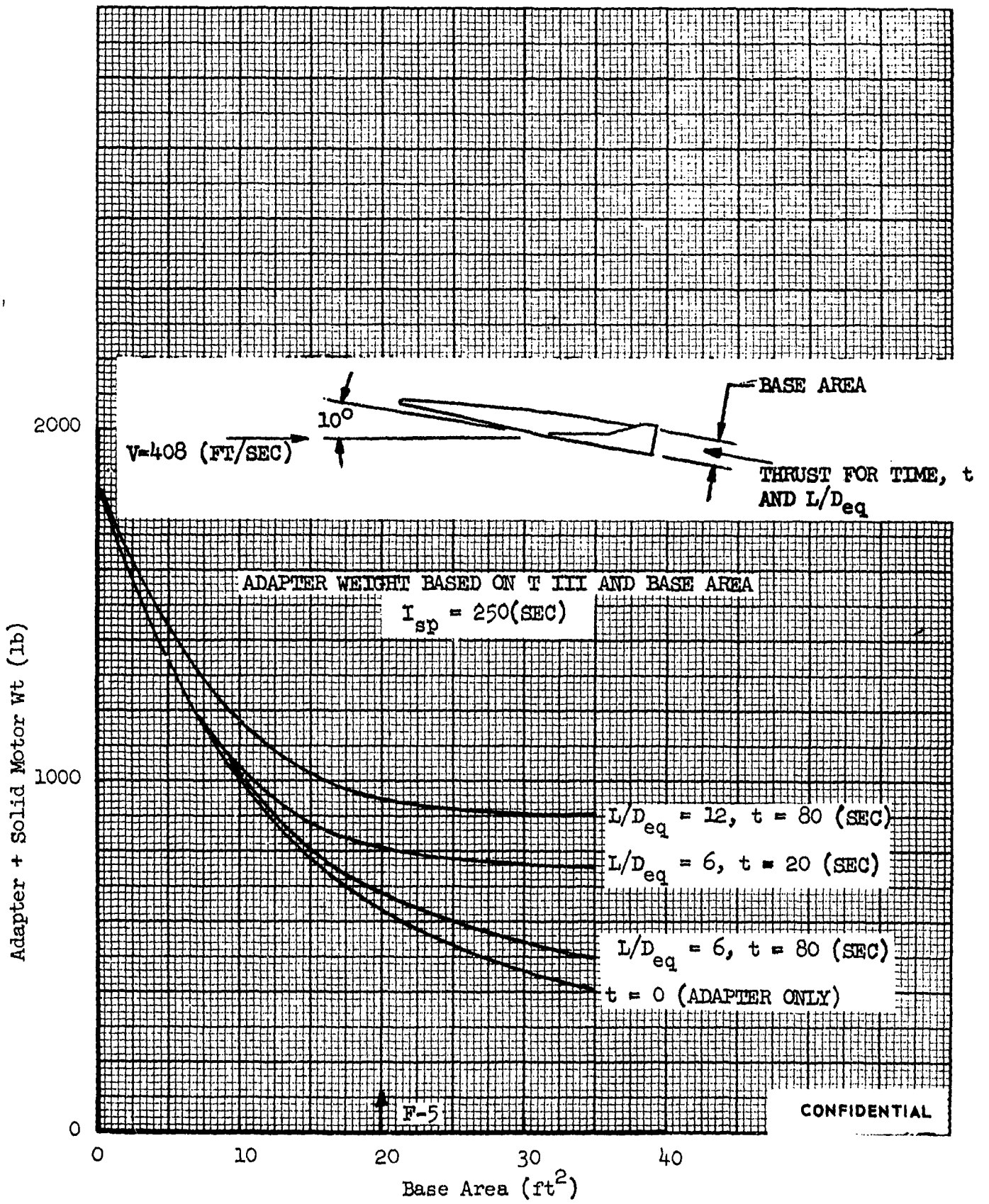

FIGURE 8 (U) LANDING WEIGHT PENALTY

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TABLE 4

(U) GEOMETRY TRADES

Geometry	Effect of Increase	Recommended Values	Effect of Decrease
Equivalent Nose Radius	Decreased Heating	3 in.	Increased Hypersonic L/D
Leading Edge Radius	Decreased Heating	1.5 in.	--
Leading Edge Sweep	Decreased Fin Toe-in/CP Movement Side Surface Heating	81-1/2°	Increased Volume Decreased Side Surface Heating & Volume Sensitivity to Yaw
Side Angle	Increased Volume	58°	Increased Yaw Stability Increased Hypersonic L/D Decreased Heating
Profile Angle	Increased Volume	5°	Increased Hypersonic L/D Increased Yaw Stability
Equivalent Dihedral Angle	Increased Volume Increased Depth	10°	Increased Hypersonic L/D Increased Yaw Stability
Base Area	Increased Hypersonic L/D (Lwr. Surf.) Decreased Adapter Weight	24 ft^2	Increased Subsonic L/D
Length	Increased Volume Increased Hypersonic L/D	30 ft	Decreased Weight

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TABLE 5

(U) STABILITY TRADES

Geometry	Effect of Decrease	Recommended Value	Effect of Increase
Fins:			
Toe-in	$\ell_o{}^{\alpha}$ pitch-up (sub)	5 deg.	excessive heating (hyp)
Roll-out	pos Δ C_m (hyp)	25 deg.	exc. heating (hyp); loss $C_{n\beta}$ $C_{\ell\beta}$ (sub)
LE Sweep	Neg Δ L/D, incr. temp (hyp)	73 deg.	effectiveness loss (sub)
LE Radius	excessive heating (hyp)	1 in.	neg. Δ L/D (hyp)
Camber	Neg Δ C_m, Δ L/D (sub)	2%	neg. Δ $C_{n\beta}$ (sub)
Area	Pos Δ C_m, loss $C_{n\beta}$, $C_{\ell\beta}$	12.5%	excessive static margin (all speeds)
Height	N/A	low	$C_{n\beta}$, $C_{\ell\beta}$ loss (hyp)
Elevons:			
Area	destabilizing (hyp)	9%	neg Δ C_m (sub)
Nose Ramp:			
Deflection	Neg Δ C_{m_o} (sub)	3 deg.	destabilizing (hyp)
Area	Neg Δ C_m (hyp)	40%	neg Δ C_m (hyp)
Lower Surface:			
Eq. Dihedral	small vol increase	10 deg.	excessive hyp L/D loss

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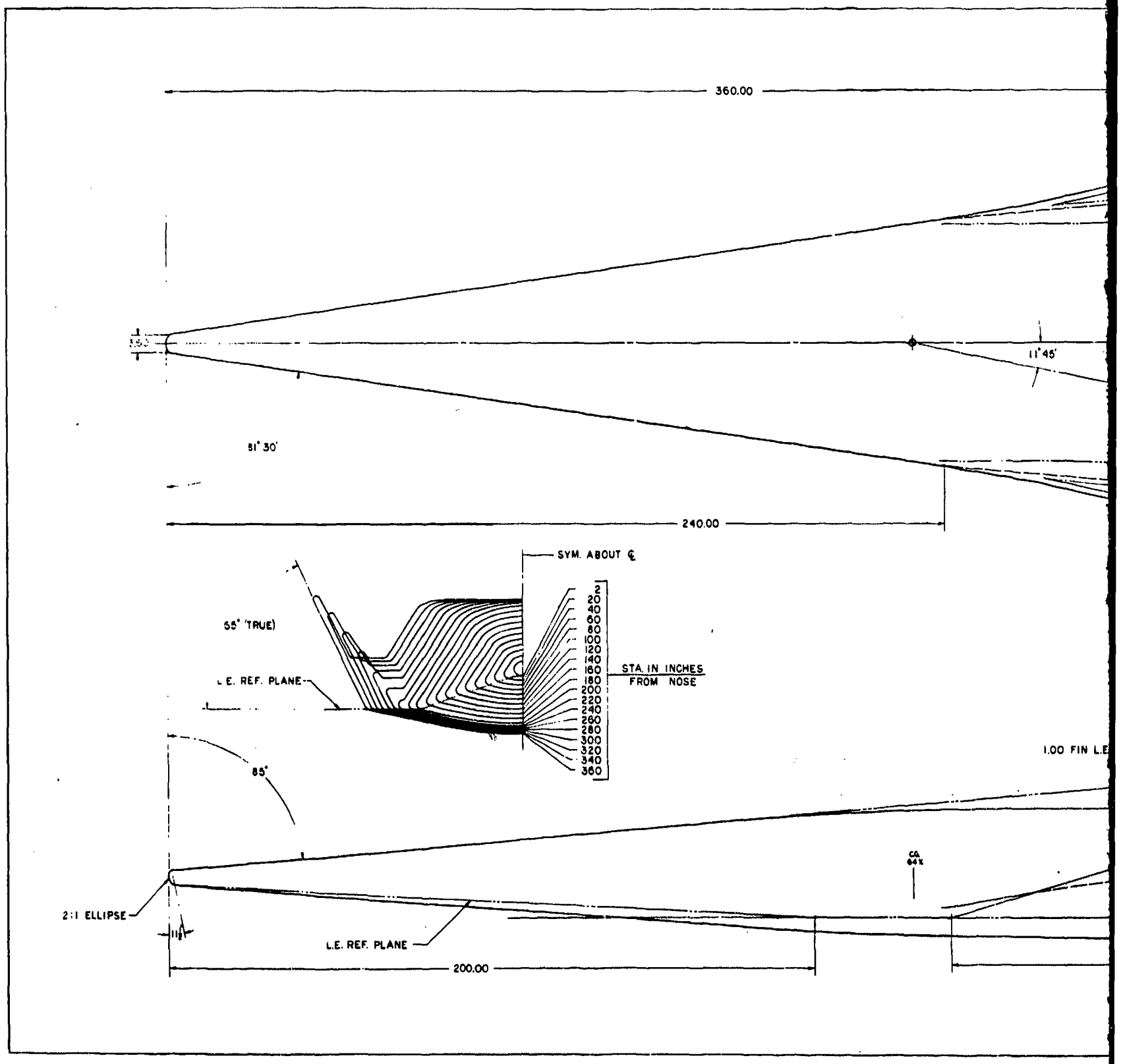

360.00
11°45'
81°30'
240.00
SYM. ABOUT ℄
55° (TRUE)
L.E. REF. PLANE
2
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
STA. IN INCHES FROM NOSE
85°
1.00 FIN L.E
CA 64%
2:1 ELLIPSE
L.E. REF. PLANE
200.00

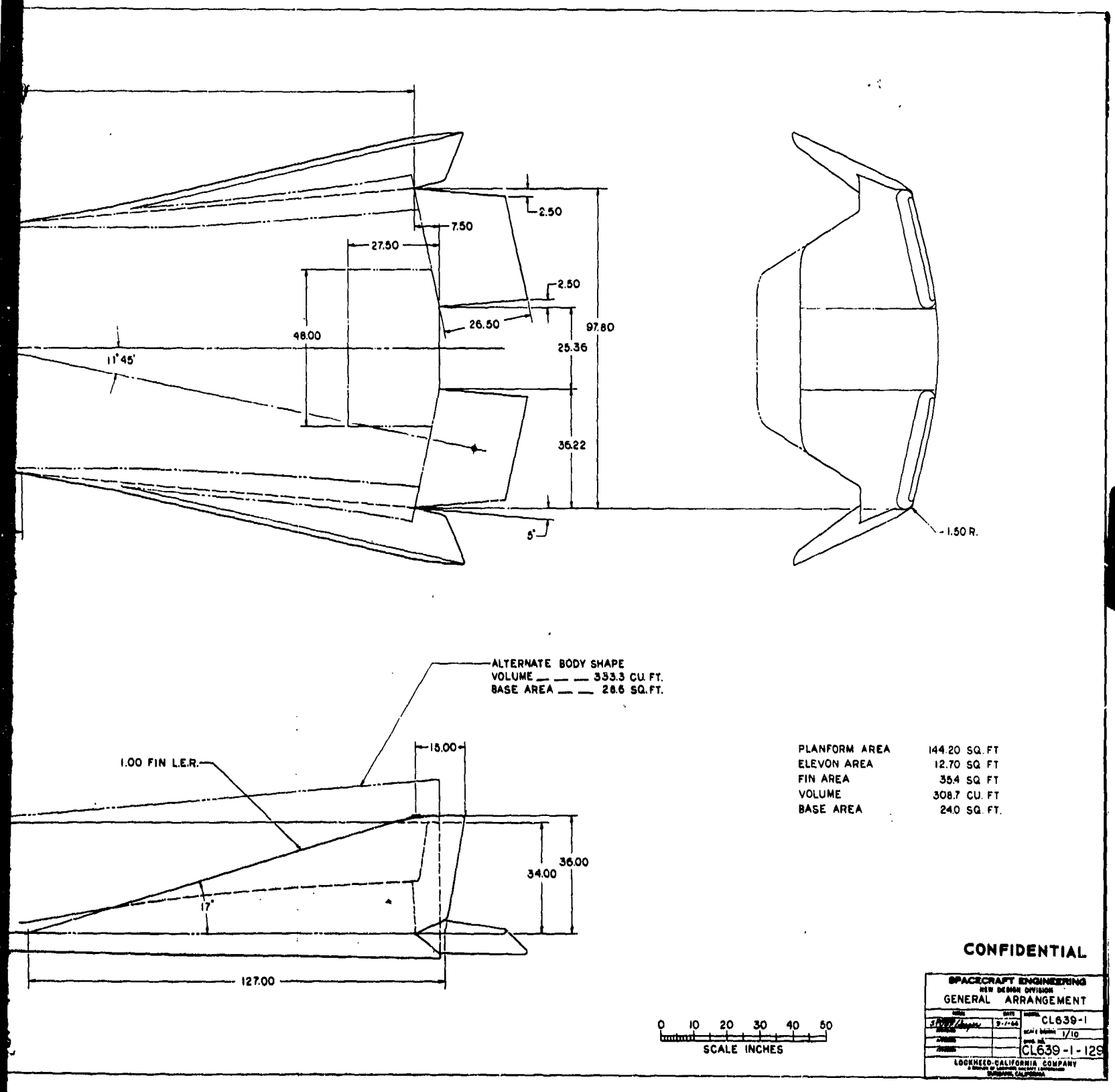
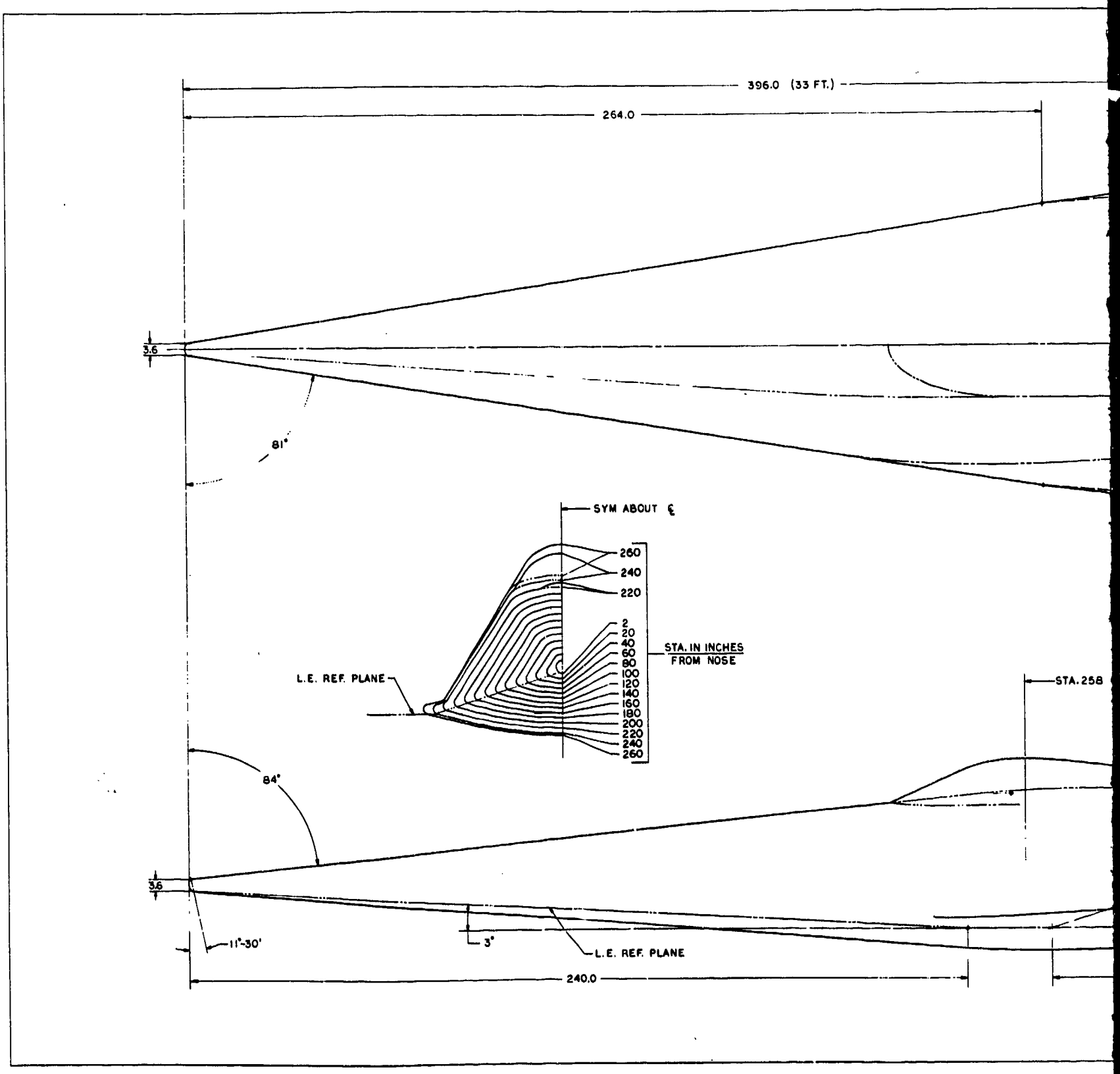


FIGURE 9 (U) HLD-35-1 GENERAL ARRANGEMENT

(REVERSE SIDE IS BLANK)


396.0 (33 FT.)
264.0
3.6
81°
SYM ABOUT ℄
260
240
220
2
20
40
60
80
100
120
140
160
180
200
220
240
260
STA. IN INCHES FROM NOSE
L.E. REF. PLANE
STA. 258
84°
3.6
11°-30'
3°
L.E. REF. PLANE
240.0

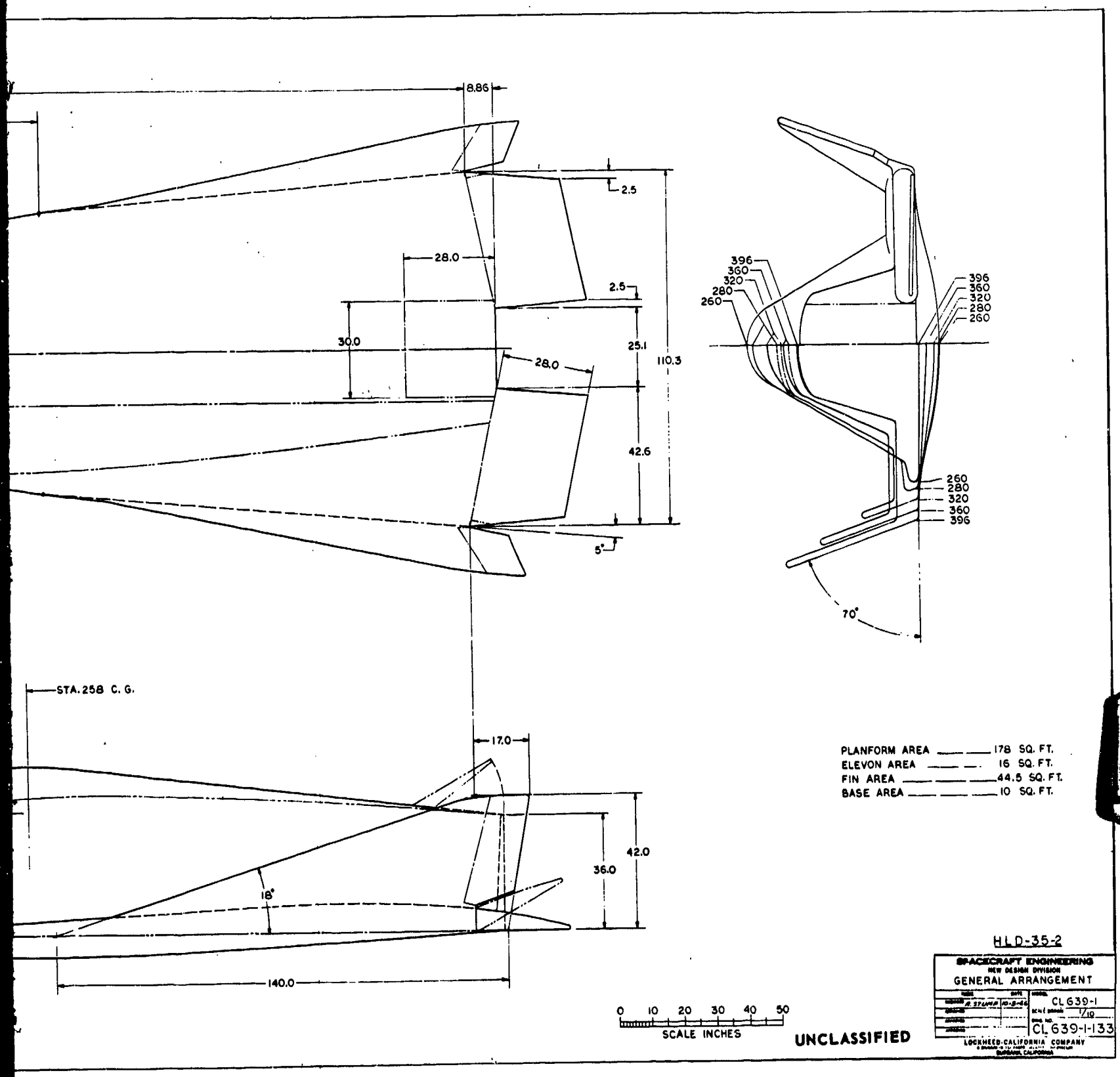
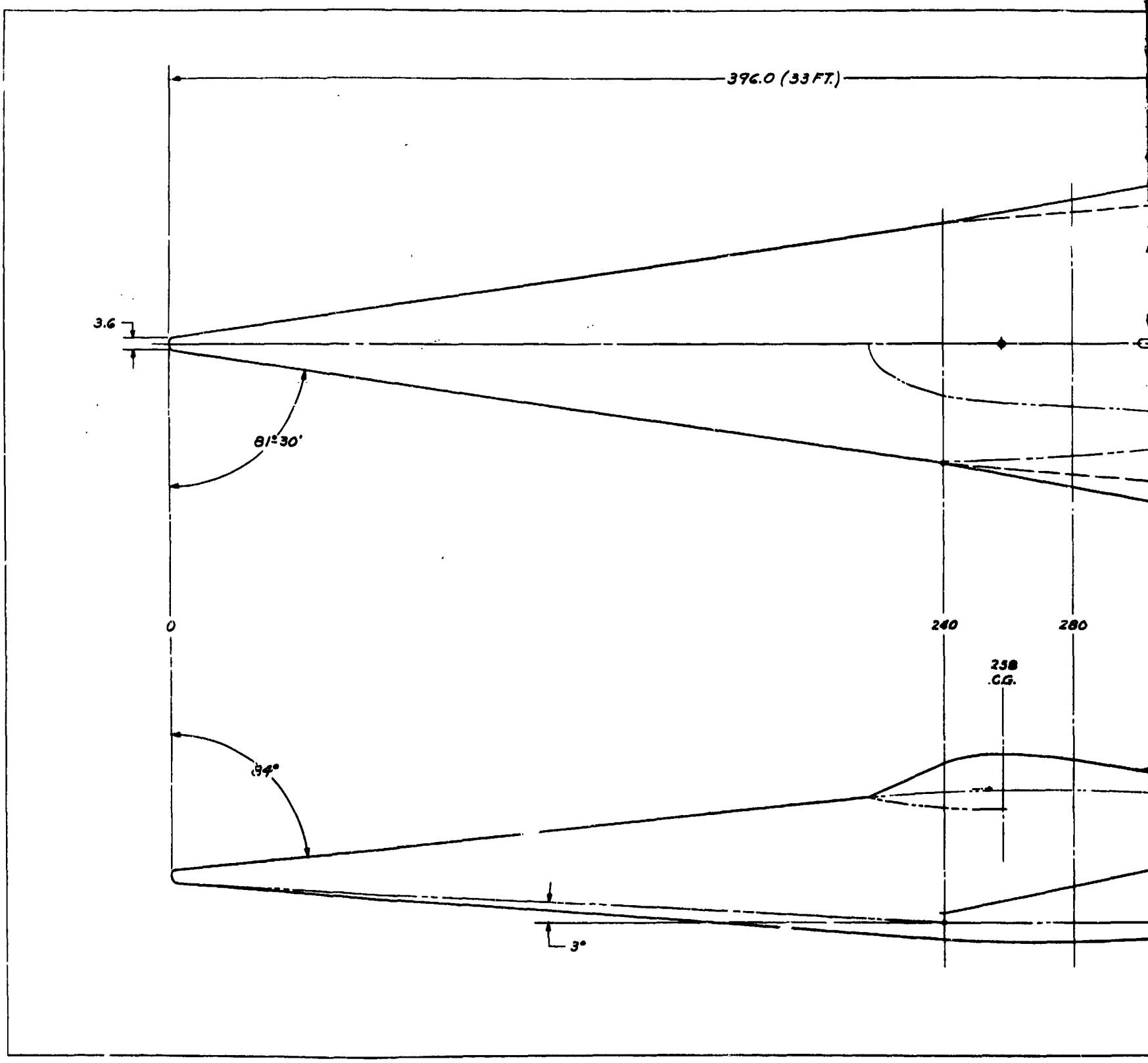
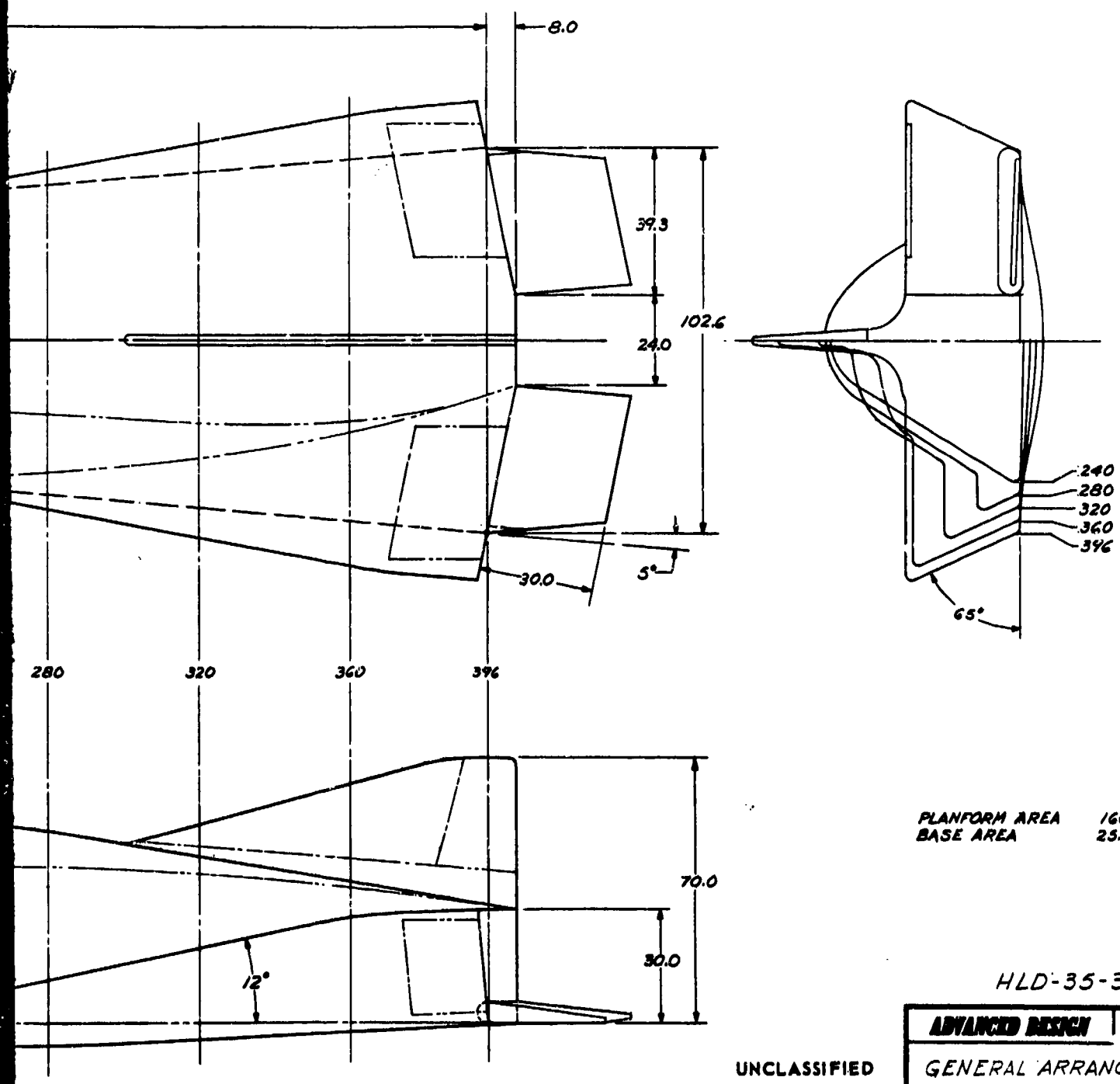


FIGURE 10 (U) HLD-35-2 GENERAL ARRANGEMENT

(REVERSE SIDE IS BLANK)


396.0 (33 FT.)
3.6
81°30'
0
240
280
238
C.G.
94°
3°



PLANFORM AREA 166 SQ.FT.
BASE AREA 25.6 SQ.FT.

HLD-35-3

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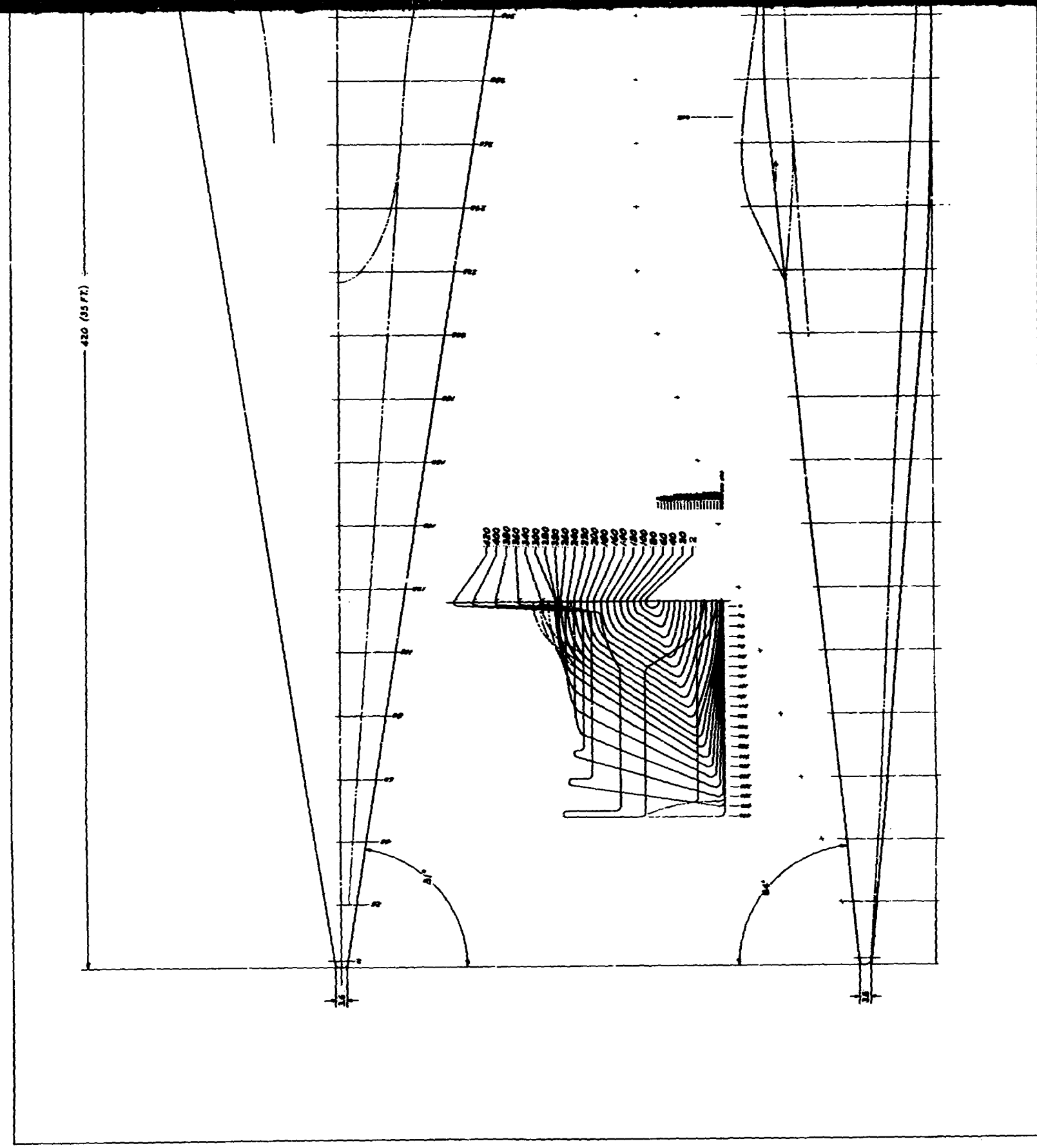
ADVANCED DESIGN
LOCKHEED-CALIFORNIA CO. BURBANK, CALIFORNIA

GENERAL ARRANGEMENT

R. STUMP
1/40 10-14
CL639-1-134

FIGURE 11 (U) HLD-35-3 GENERAL ARRANGEMENT

(REVERSE SIDE IS BLANK)


420 (95 FT.)

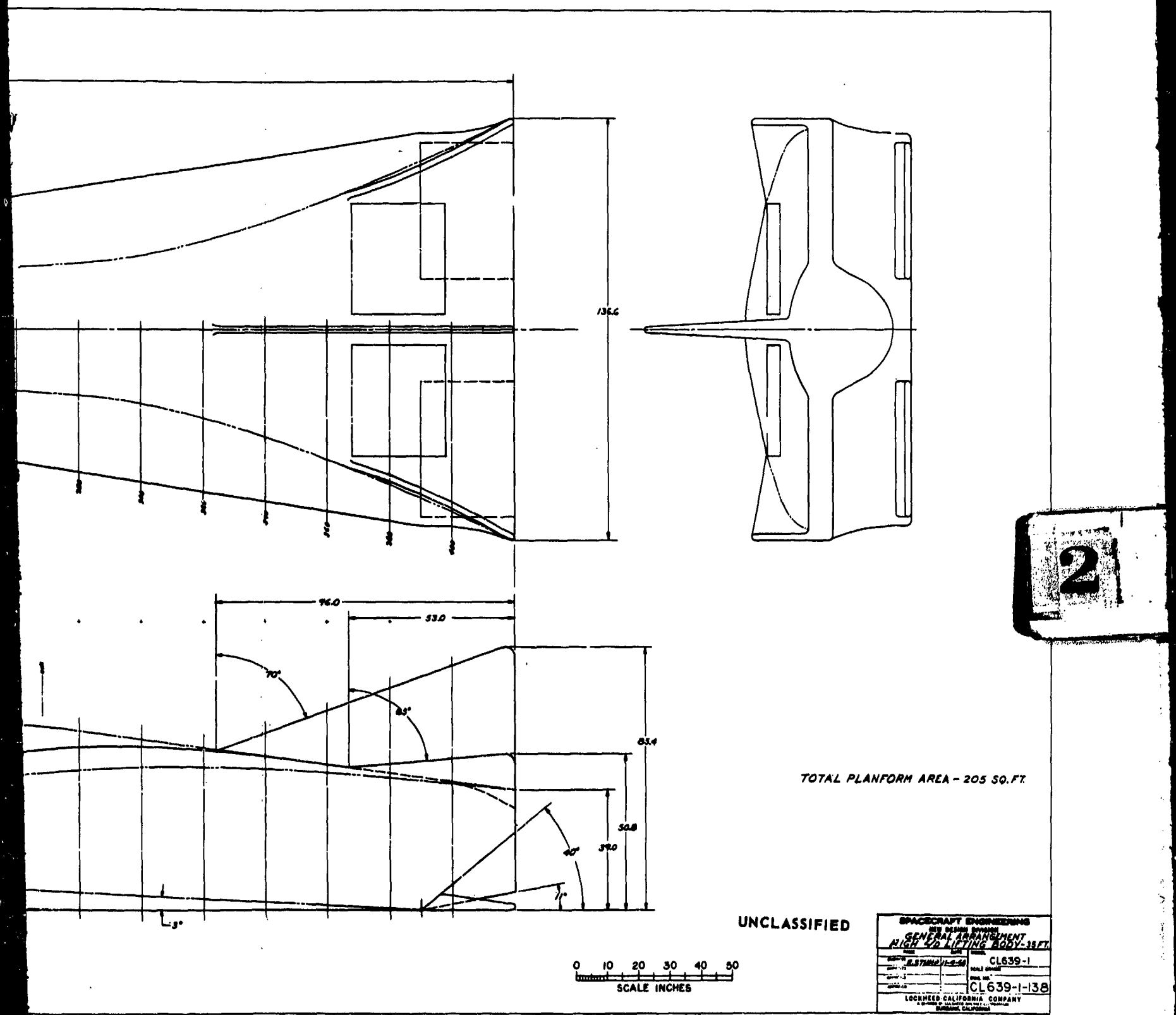
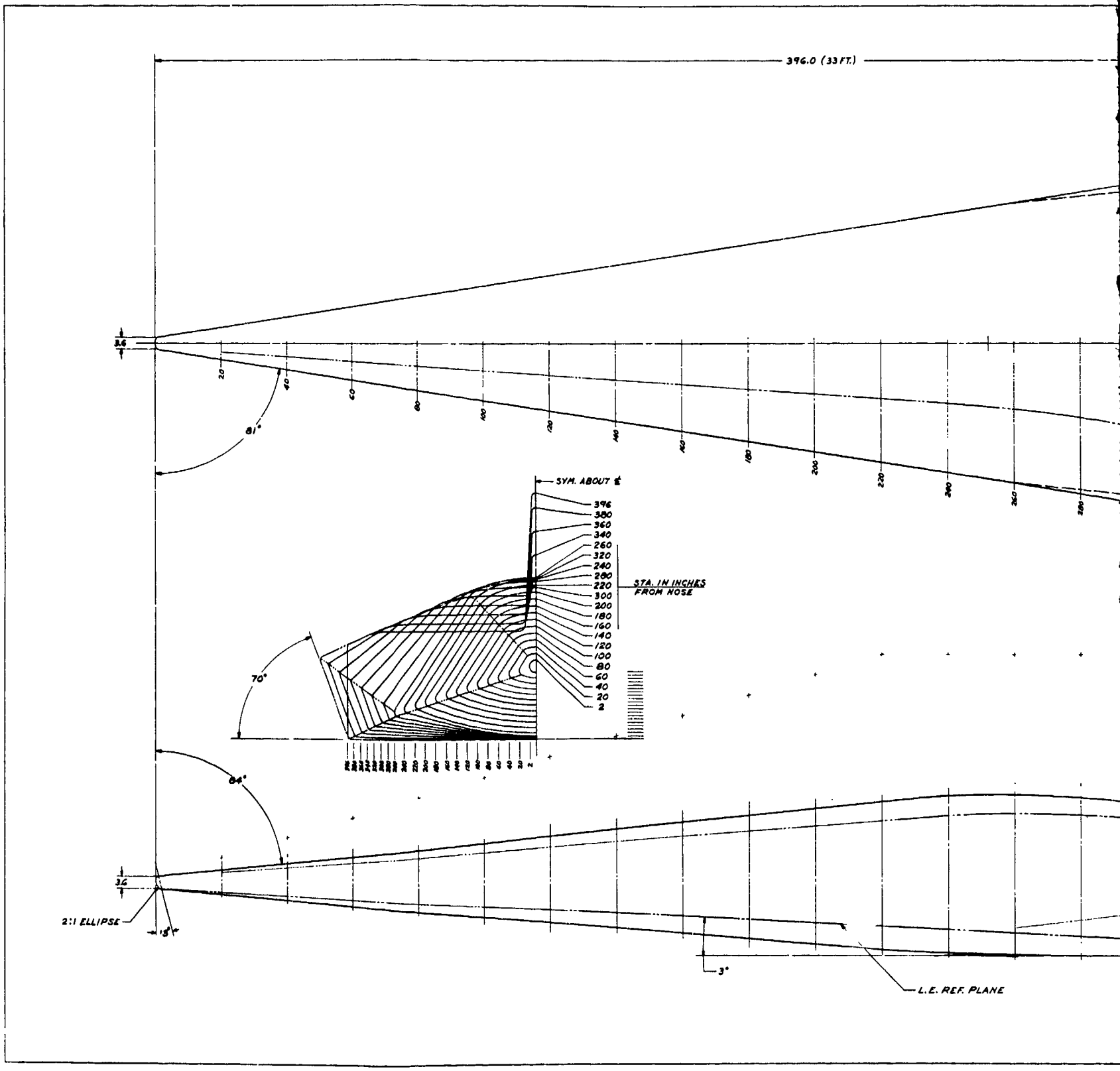


FIGURE 12 (U) GENERAL ARRANGEMENT - HIGH L/D LIFTING BODY - 35 FT

(REVERSE SIDE IS BLANK)


396.0 (33 FT.)
3.6
81°
20
40
60
80
100
120
140
160
180
200
220
240
260
280
SYM. ABOUT ℄
396
380
360
340
260
320
240
280
220
300
200
180
160
140
120
100
80
60
40
20
2
STA. IN INCHES FROM NOSE
70°
84°
3.6
2:1 ELLIPSE
15°
3°
L.E. REF. PLANE

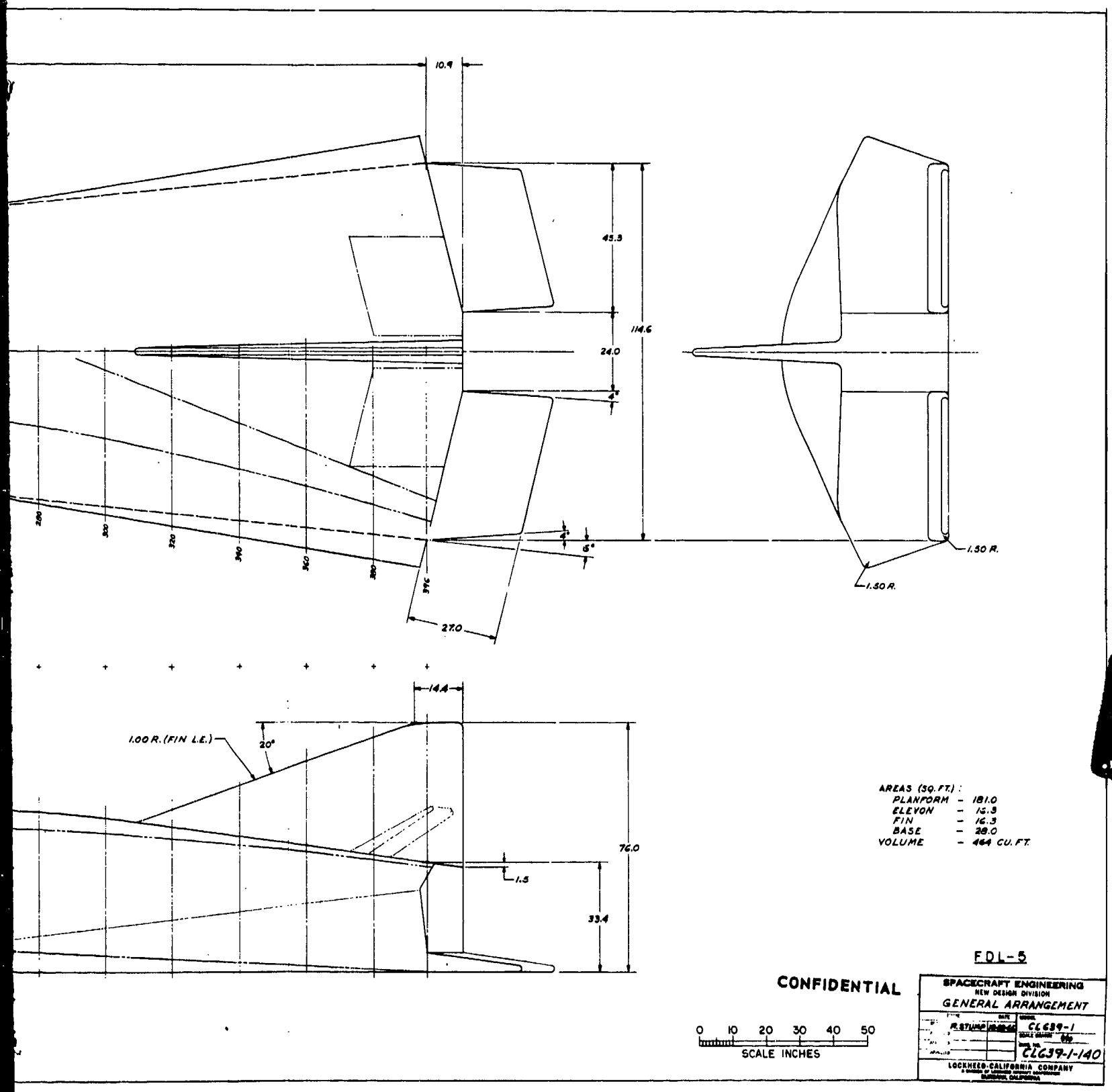


FIGURE 13 (U) FDL-5 GENERAL ARRANGEMENT

(REVERSE SIDE IS BLANK)

SECTION 3

TEST PROGRAM

(U) The wind tunnel test program was conducted in the AEDC wind tunnels A, B, C and F. Table 6 summarizes the test runs and test conditions. Approximately 25,000 separate data points were obtained during this test series. The FDL-5 configuration was exercised through the complete range of test attitudes and test conditions that could be expected of the test vehicle. The wind tunnel models used in the test series are described in Table 7 and shown in Figures 14, 15, 16, 17, and 18.

TABLE 7

(U) MODEL SUMMARY

Model Size	Construction	AEDC Facility
20-inch	Steel force	A, B, C
15-inch	Fiber glass force	F
20-inch	Aluminum pressure/ht transfer	F
20-inch	Steel pressure	C
20-inch	Steel thin skin ht transfer	C

(U) Details of the aerodynamic force, pressure, and heat transfer test program are contained in Parts III and IV of this report.

TABLE 6

(U) TEST SUMMARY

AEDC Facility	Test Data	Number or Groups of Runs	Angle of Attack - Deg	Yaw - Deg	Mach Number	Reynold Number Per Foot
A	Force and moment	135	-5 to 22	-2 to 8	1.5, 2.0, 2.5, 3.5, 5.0	1.2 to 6.4 x 10^6
B	Force and moment	19	-4.5 to 25	-2 to 8	8	2.35 x 10^6
C	Force and moment	45	-4 to 47	-2 to 8	10	0.4 to 2.1 x 10^6
F	Force	64	0 to 21	0 to 8	14 to 19	0.11 to 2.1 x 10^6
A	Pressure	122	0 to 20	0 to 8	1.5, 2.0, 2.5, 3.5, 5.0	2.4 to 6.3 x 10^6
C	Pressure	49	0 to 35	-2 to 6	10	0.5 to 2.1 x 10^6
F	Pressure	25	0 to 30	-2 to 6	19	5.6 to 6.2 x 10^5
C	Heat transfer	75	0 to 35	-2 to 6	10	0.4 to 2.1 x 10^6
F	Heat transfer	22	0 to 25	-2 to 6	19	5.0 to 5.8 x 10^5

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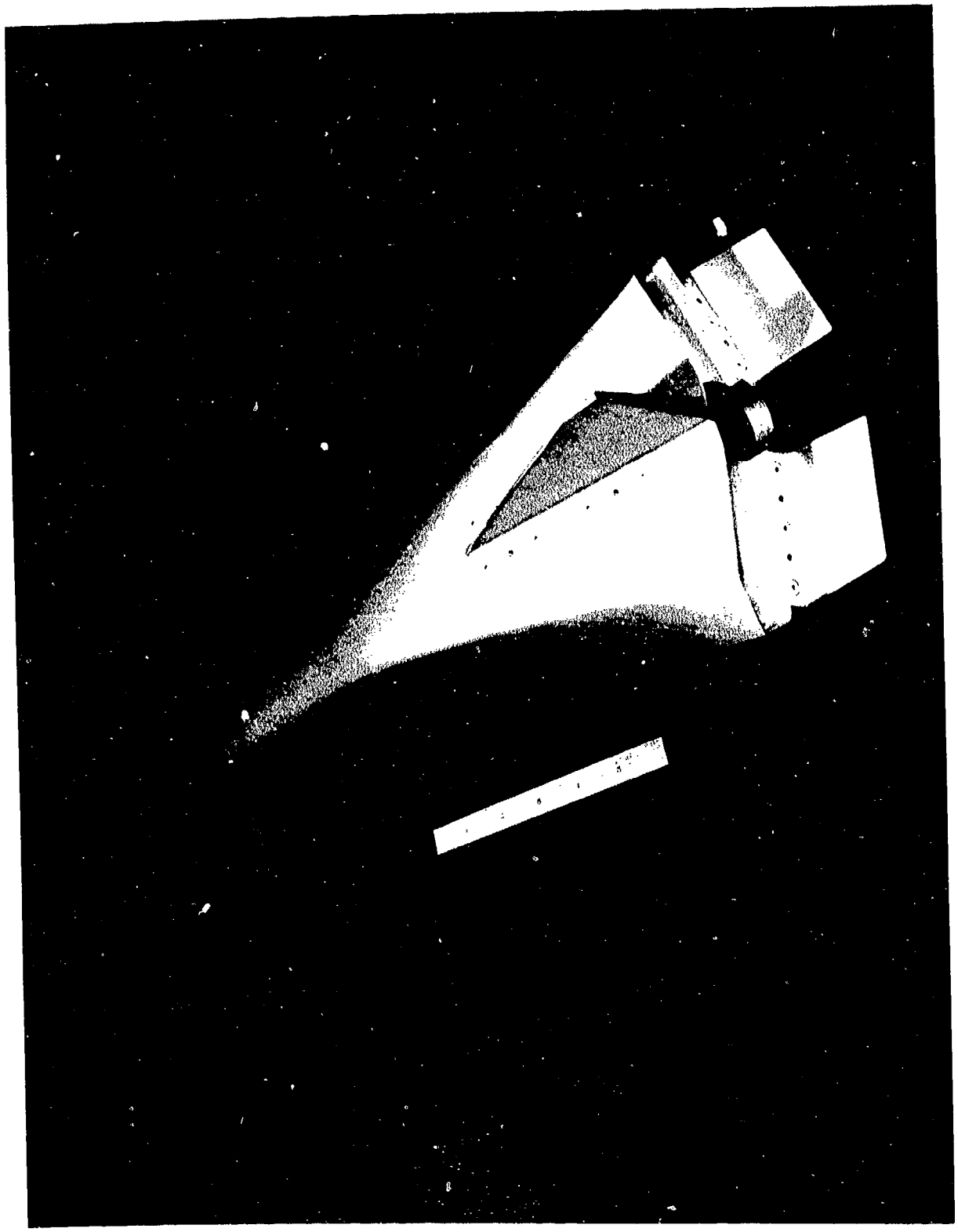

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FIGURE 14 (U) 20-INCH STEEL FORCE MODEL FOR TUNNELS A, B, C

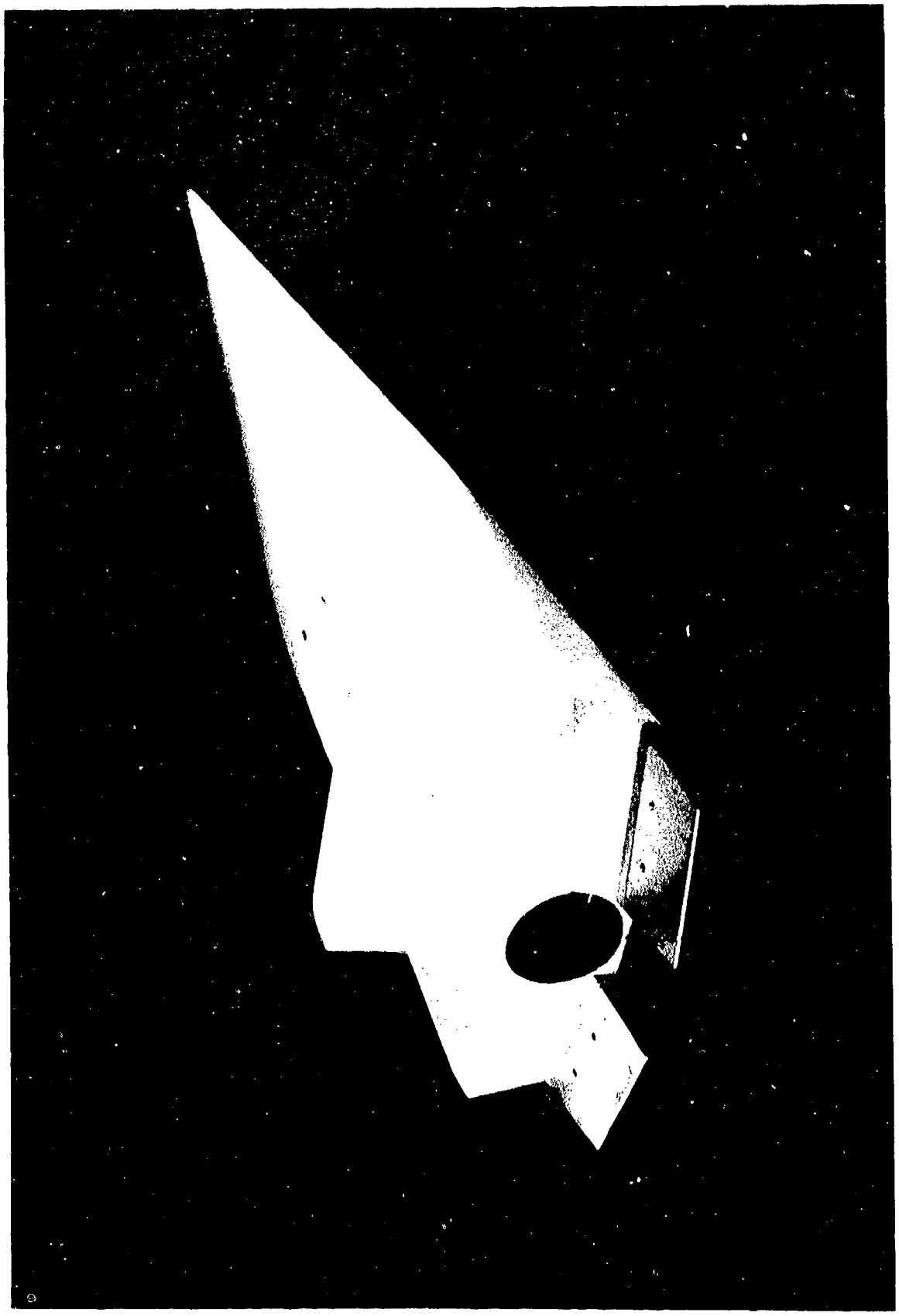

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FIGURE 15 (U) 15-INCH FIBER GLASS FORCE MODEL FOR TUNNEL F

FIGURE 16 (U) 20-INCH ALUMINUM PRESSURE/HEAT TRANSFER MODEL FOR TUNNEL F (PRESSURE PLUGS INSTALLED)

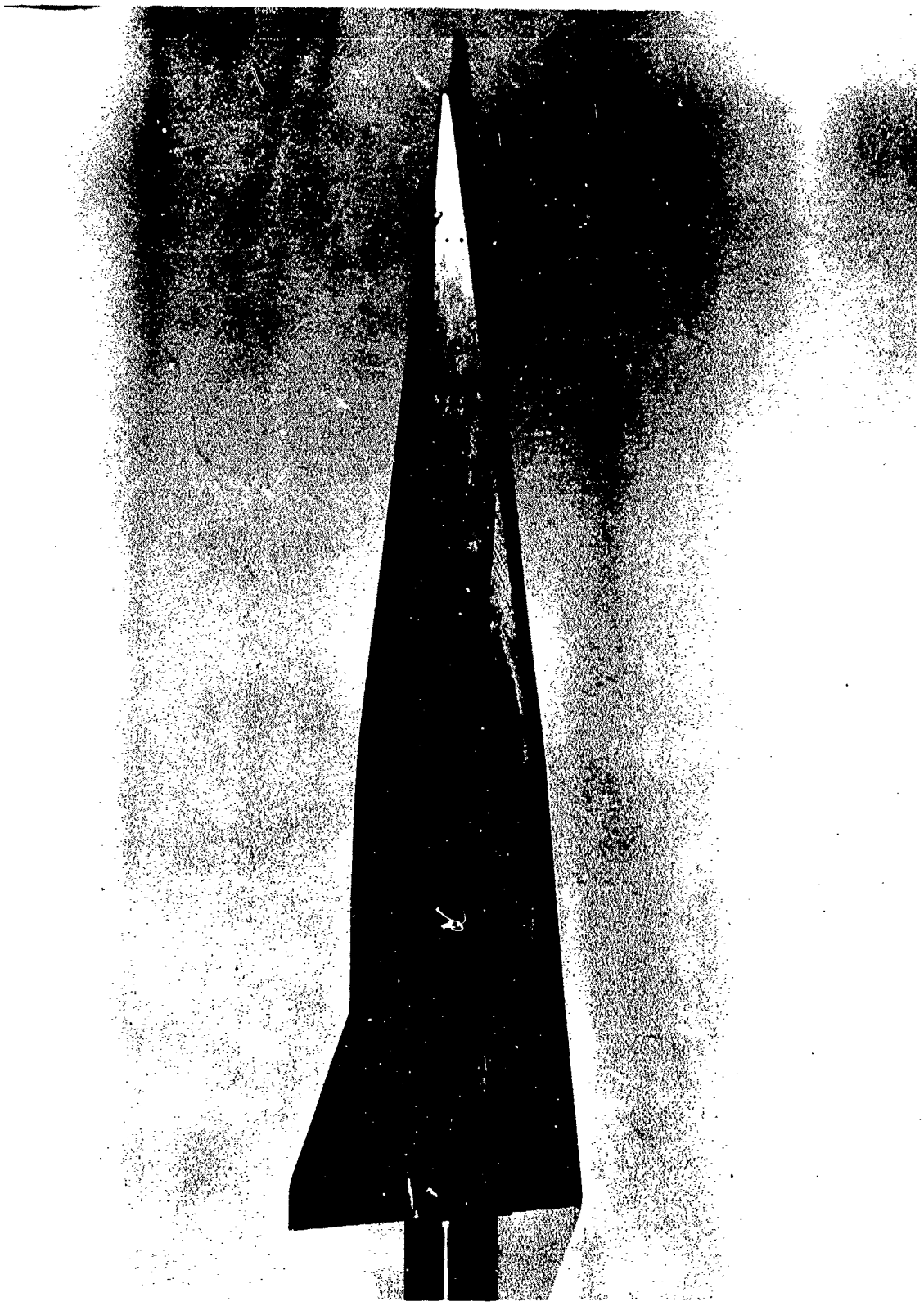

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FIGURE 17 (U) 20-INCH STEEL PRESSURE MODEL FOR TUNNELS A AND C

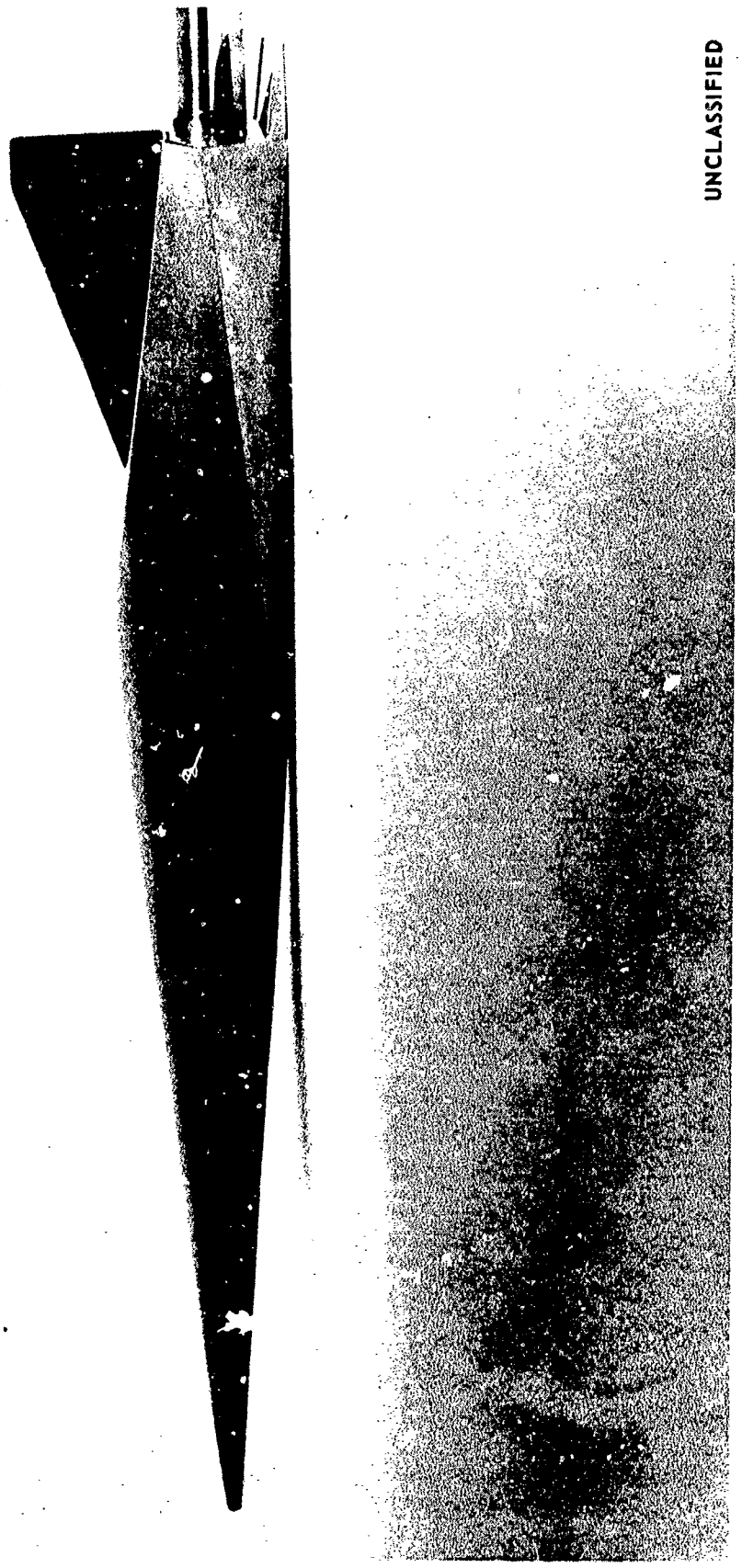

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FIGURE 18 (U) 20-INCH THIN SKIN HEAT TRANSFER MODEL FOR TUNNEL C

SECTION 4

(U) FDL-5 AERODYNAMIC PERFORMANCE SUMMARY

(U) Predicted and measured aerodynamic performance of the FDL-5 is summarized in Figures 19 through 32. The basic geometry achieves high aerodynamic performance and is stable and controllable in pitch, roll and yaw at all Mach numbers at a center of gravity location of 62%.

(C) Figure 19 correlates measured L/D_{max} obtained from force tests in AEDC tunnels B, C and F with the rarefaction parameter

$$\frac{M_\infty \sqrt{C^*}}{\sqrt{R_{e_{L_\infty}}}}$$

A line faired through the data intersects the design condition of 20,000 fps and 200,000 feet altitude at L/D_{max} (trimmed) of 2.84. The design condition shown on the figure is based on a vehicle length of 35 feet.

(C) Figure 20 summarizes the trimmed L/D_{max} of the FDL-5 from M = 0 to M = 20. The curve is compiled from the wind tunnel test data. The maximum value of L/D_{max} is 3.3 and occurs near M = 12. Measured L/D_{max} values at supersonic speeds are sensitive to base geometry and area. With additional modification of aft body contours, it is expected that the potential L/D values shown by the upper faired curve could be achieved.

(U) Figures 21 and 22 are typical comparisons of analytical and experimental values of axial and normal force coefficients at M = 19. Predictions are based on wind tunnel test conditions and show excellent agreement with the data.

(C) Figure 23 shows the experimental variation of L/D with angle of attack and elevon deflection at M = 19. Maximum measured L/D (trimmed) at M = 19, $R_e = 0.800 \times 10^6$ is 2.4.

(U) Typical experimental pitching moment data at M = 19 are compared with analytical values in Figure 24.

(C) Longitudinal stability and control characteristics at M = 19 are shown in Figure 25. Satisfactory trim at L/D_{max} ($C_N = 0.12$) occurs with approximately 10 degrees of up elevon and with a center of gravity of 62%.

(C) Figure 26 shows the typical longitudinal trim and stability variations with maximum elevon and flap deflection for M = 1.5 to 5.0. Maximum elevon and flap deflection provide positive values of C_{M_0} and stable trim throughout the Mach number range tested. Center-of-gravity positions of 62, 64 and 66 percent of the body reference length are shown. Trim through the angle of attack range of 5 to 30 degrees can be accomplished throughout the supersonic regime with a suitable combination of center of gravity and control surface geometry.

(C) Yaw and roll stability of the FDL-5 are summarized in Figures 27, 28, 29 and 30. The configuration has satisfactory directional stability and dihedral effect over the entire speed range tested as shown in Figures 29 and 30. It is particularly noteworthy that the compression-sharing concept provided stability over the entire range of Mach number and angle of attack tested.

(C) Typical pressure data at two positions on the vehicle lower surface (Figures 31 and 32) show that maximum pressure coefficients occur at low supersonic speeds. These data, considered with the typical launch trajectory, lead to the conclusion that maximum design loads occur during boost, at low supersonic speeds in the peak wind shear environment. Detail pressure distributions are contained in Parts III and IV.

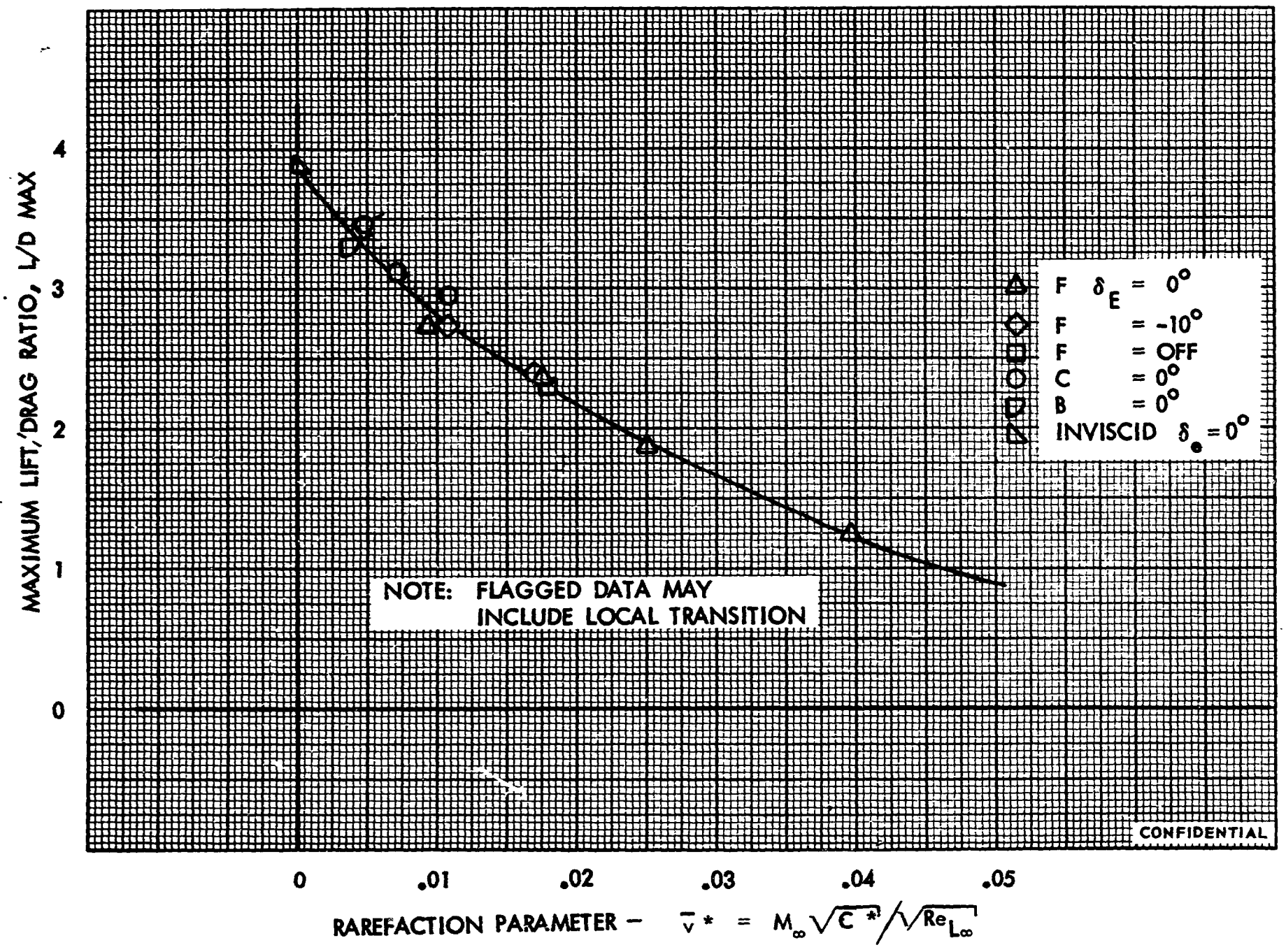

FIGURE 19 (U) FDL-5 VARIATION OF MAXIMUM L/D WITH $\bar{V}^*$

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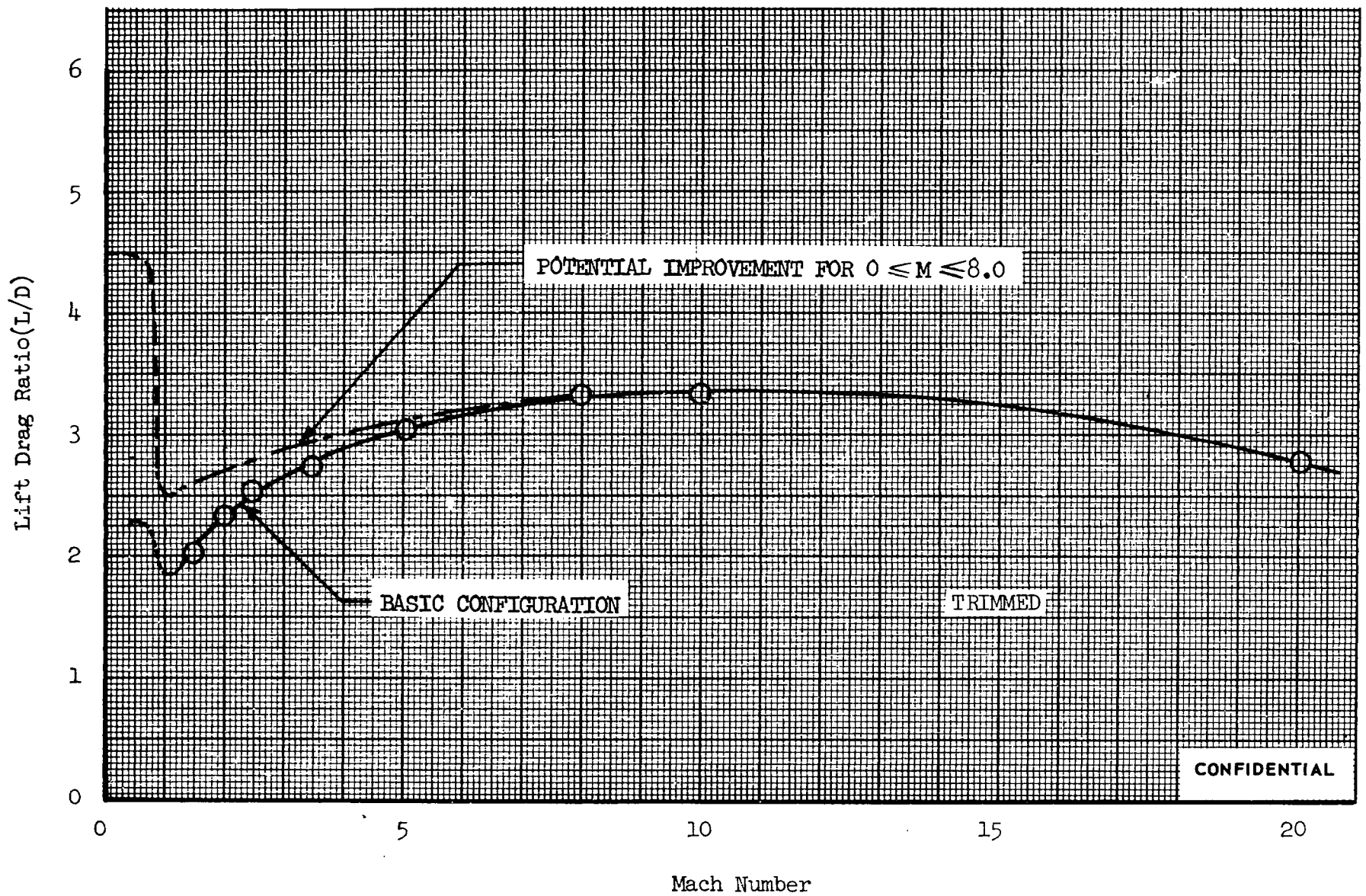

FIGURE 20 (U) FDL-5 VARIATION OF MAXIMUM L/D

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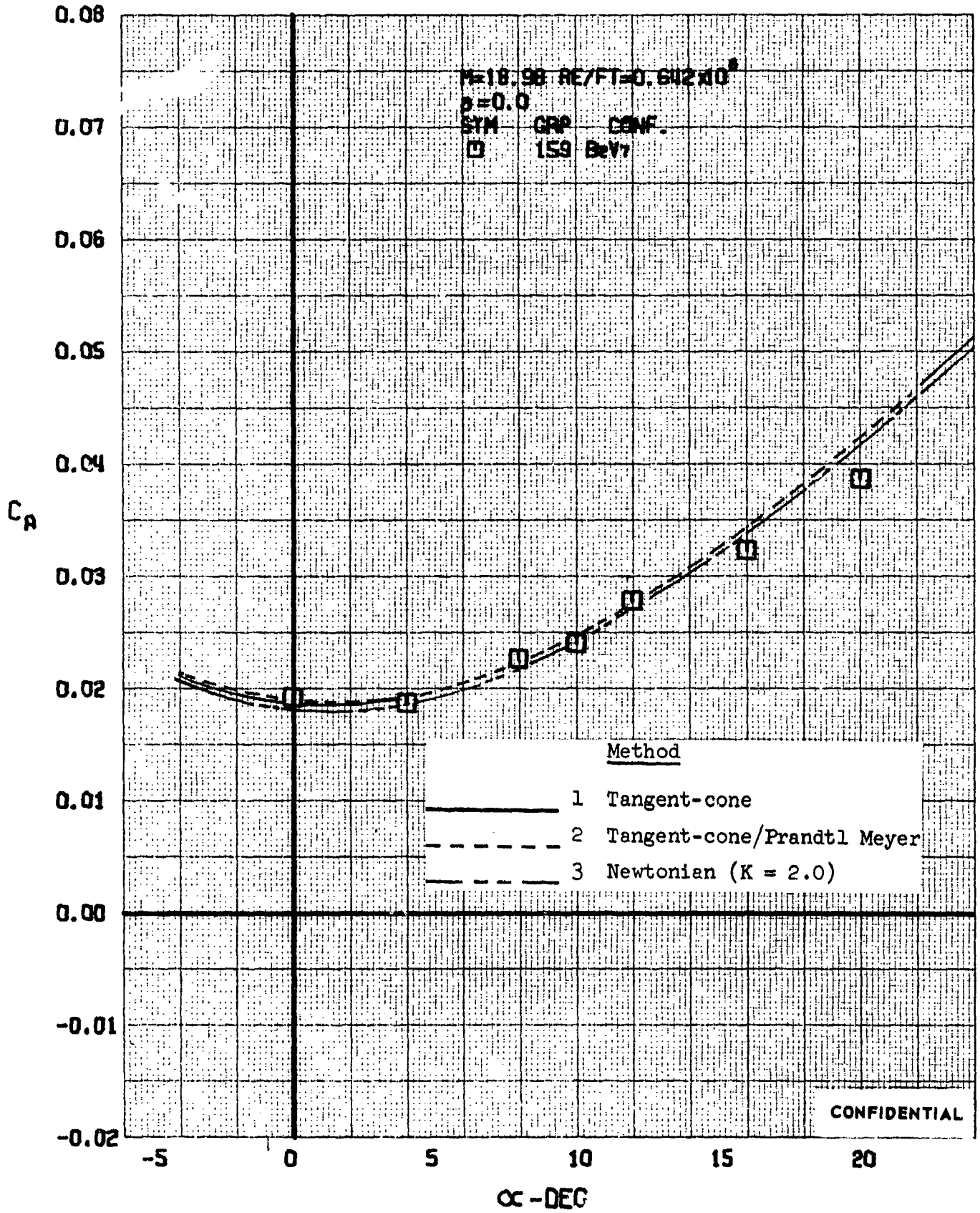

FIGURE 21 (U) COMPARISON OF ESTIMATED AND EXPERIMENTAL COEFFICIENTS - AXIAL FORCE COEFFICIENT VARIATION WITH ANGLE OF ATTACK (M = 18.98)

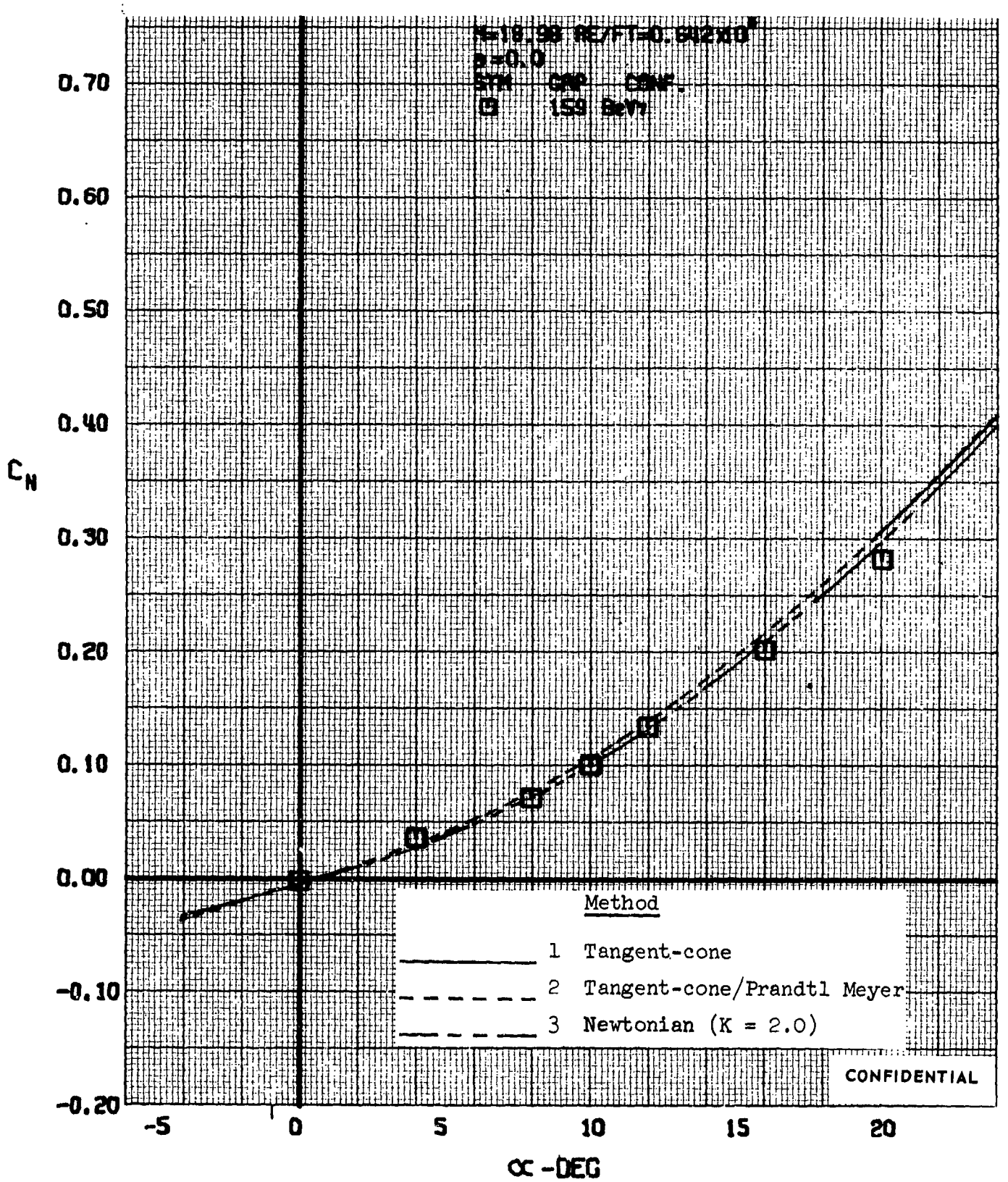

FIGURE 22 (U) COMPARISON OF ESTIMATED AND EXPERIMENTAL COEFFICIENTS - NORMAL FORCE COEFFICIENT VARIATION WITH ANGLE OF ATTACK (M = 18.98)

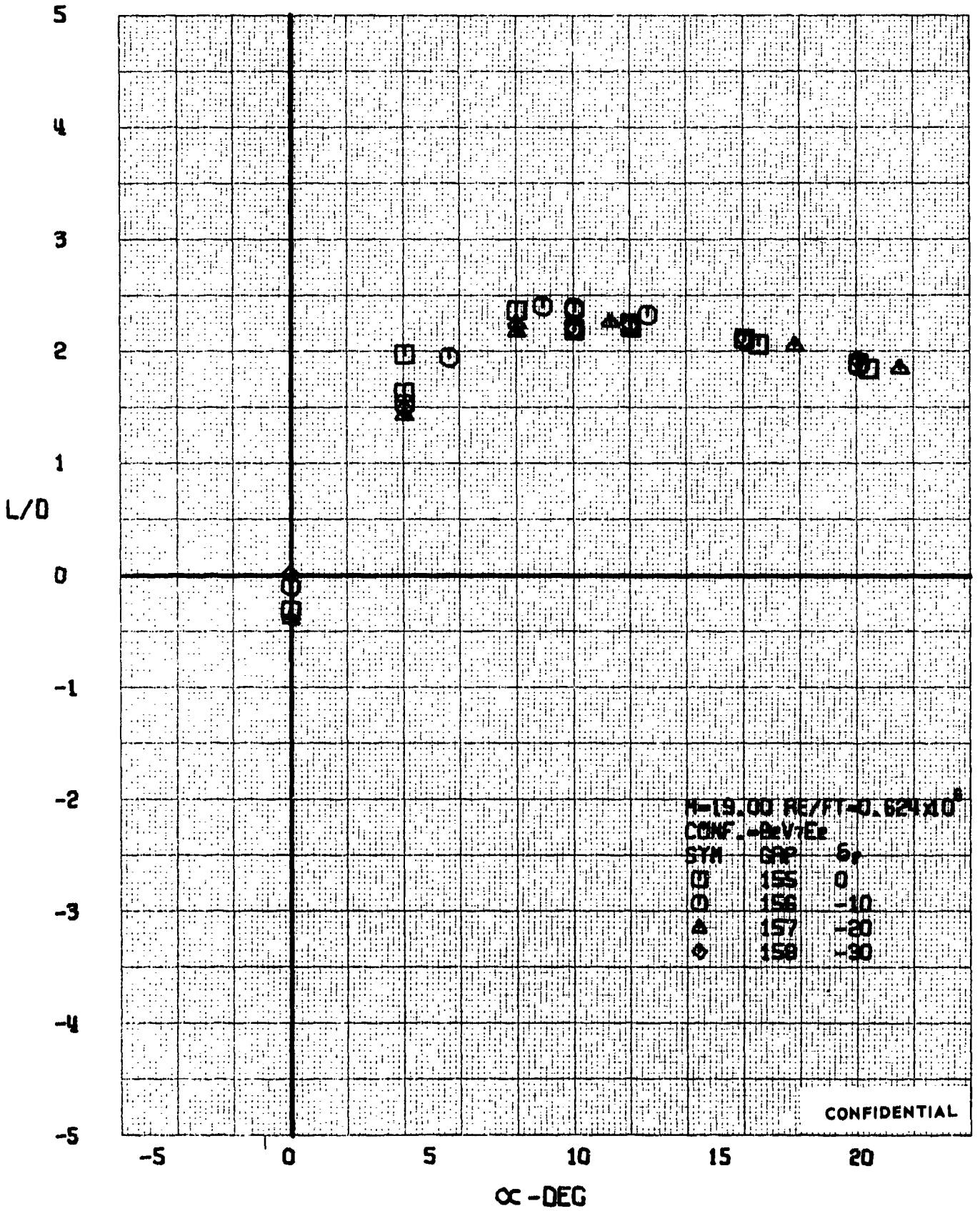

FIGURE 23 (U) ELEVON EFFECTS - LIFT/DRAG RATIO VARIATION WITH ANGLE OF ATTACK (M = 19.00)

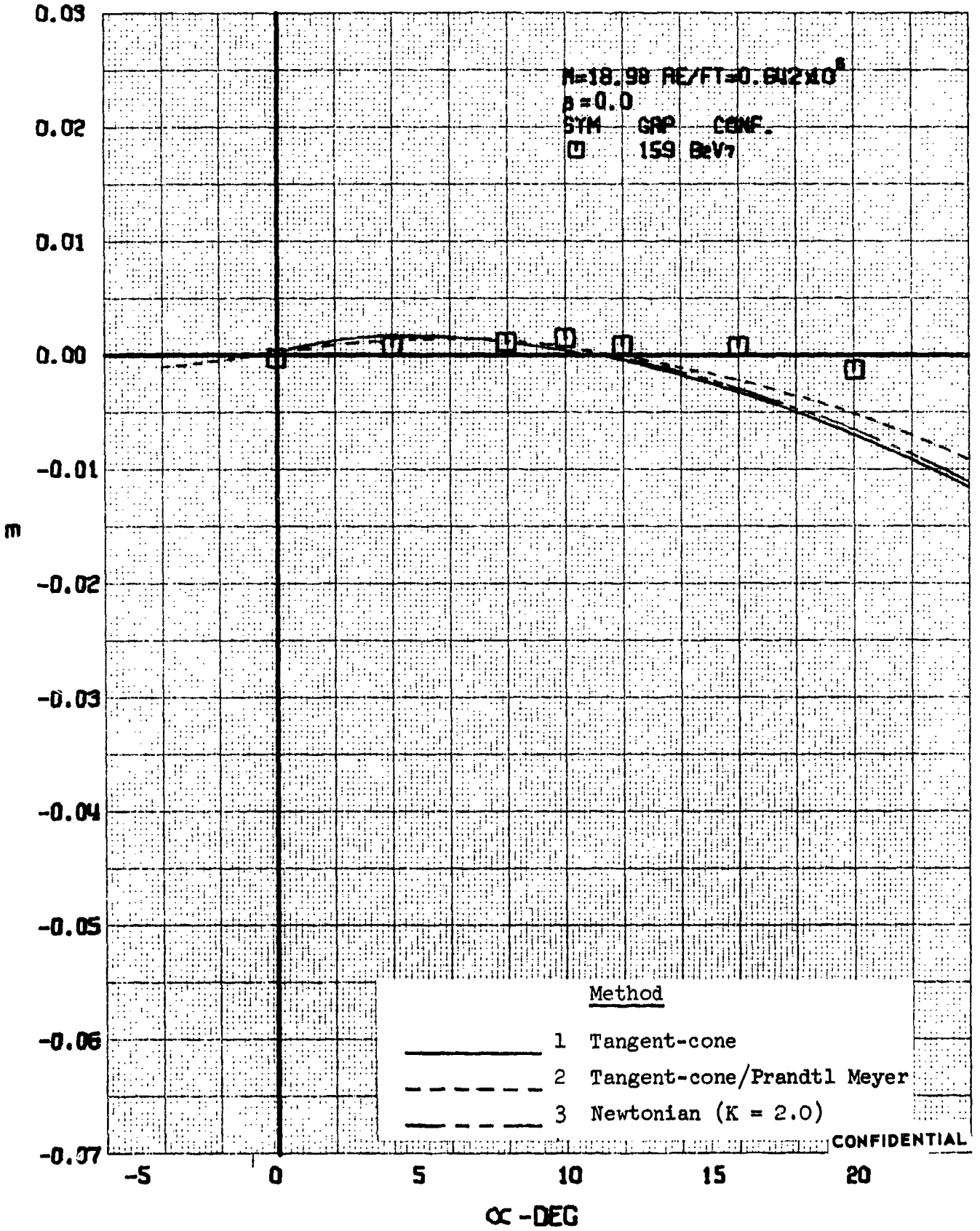

FIGURE 24 (U) COMPARISON OF ESTIMATED AND EXPERIMENTAL COEFFICIENTS - PITCHING MOMENT COEFFICIENT VARIATION WITH ANGLE OF ATTACK (M = 18.98)

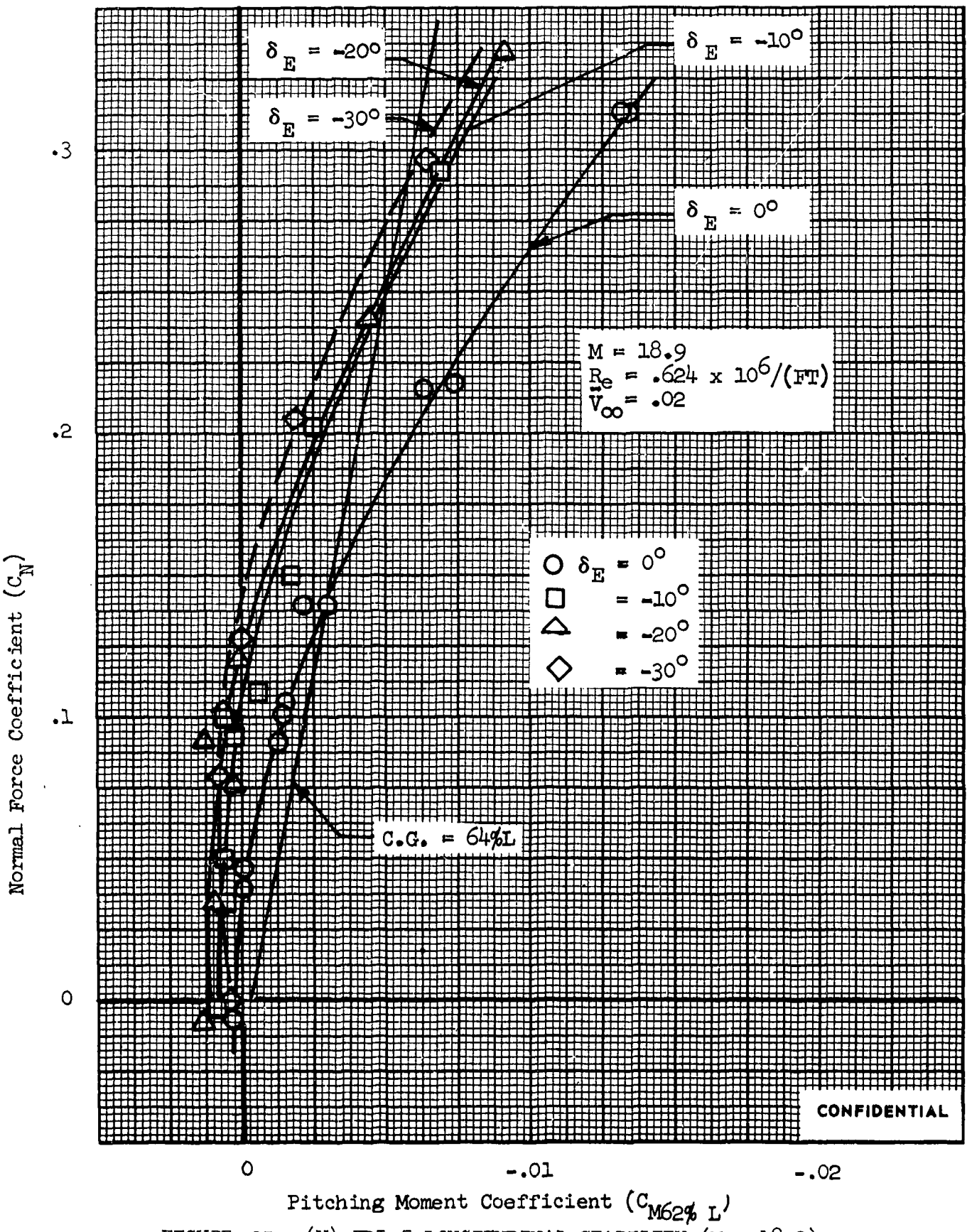

FIGURE 25 (U) FDL-5 LONGITUDINAL STABILITY (M = 18.9)

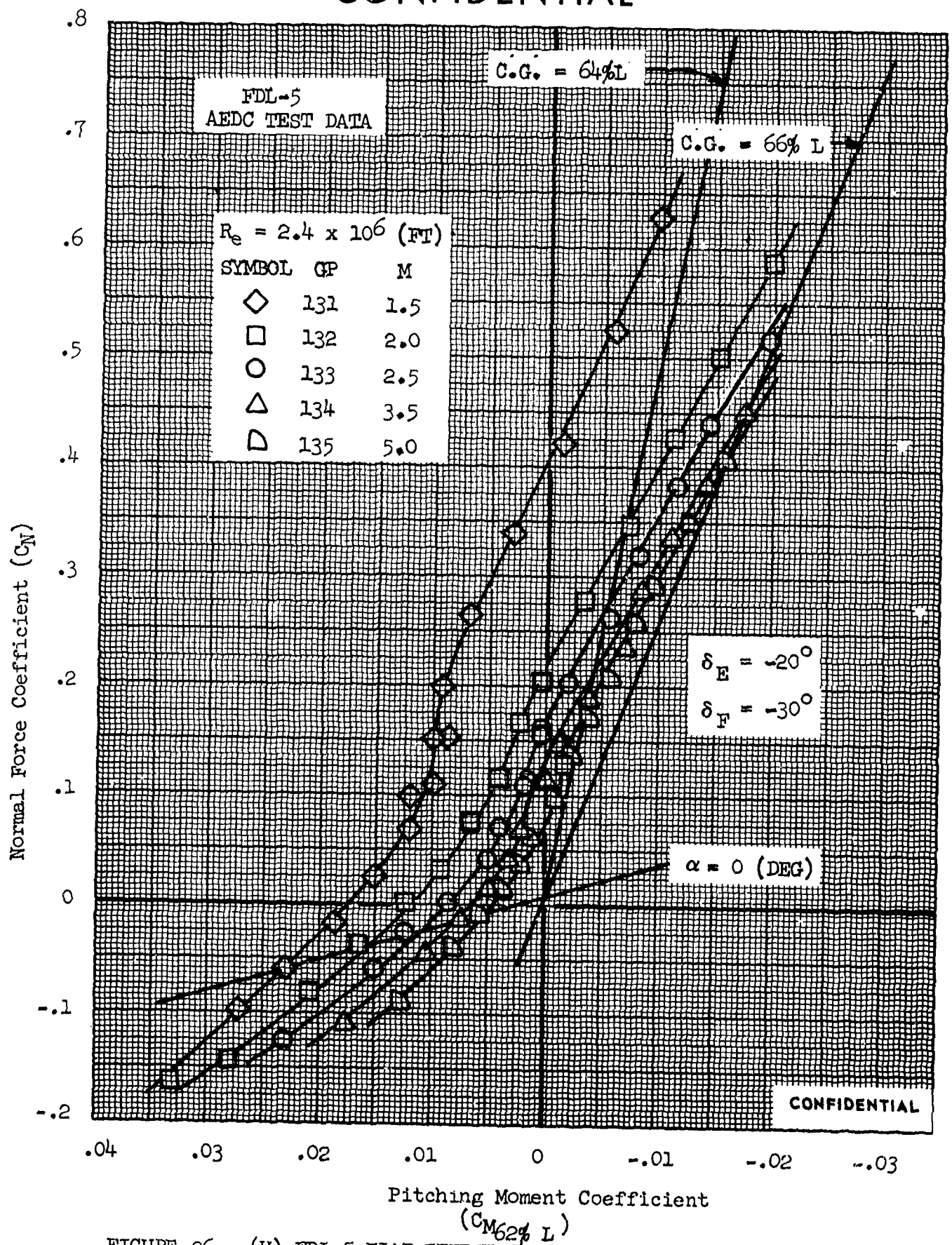

FIGURE 26 (U) FDL-5 FLAP EFFECT ON LONGITUDINAL STABILITY AT VARIOUS MACH NUMBERS

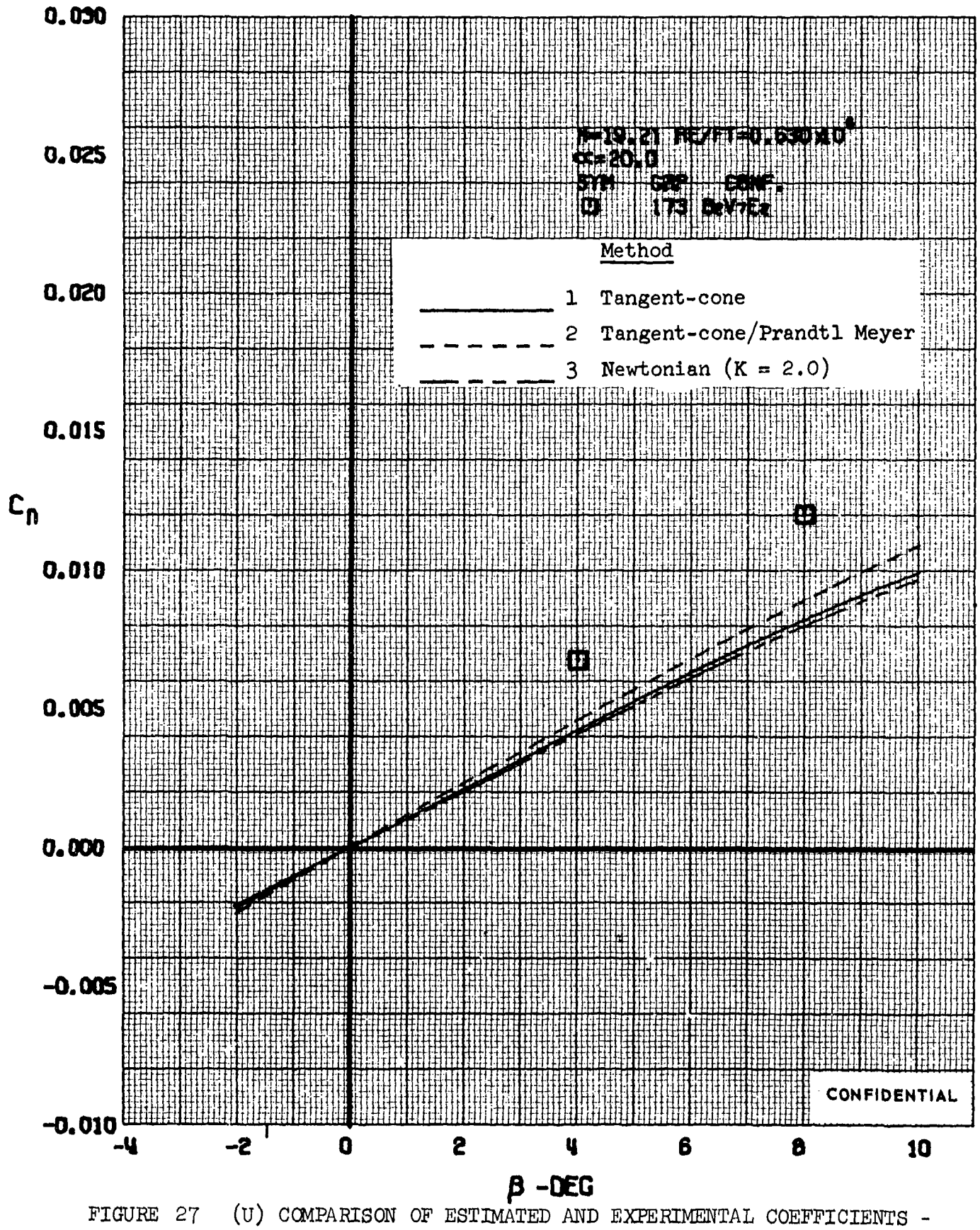

FIGURE 27 (U) COMPARISON OF ESTIMATED AND EXPERIMENTAL COEFFICIENTS - YAWING MOMENT COEFFICIENT VARIATION WITH ANGLE OF YAW (M = 19.21)

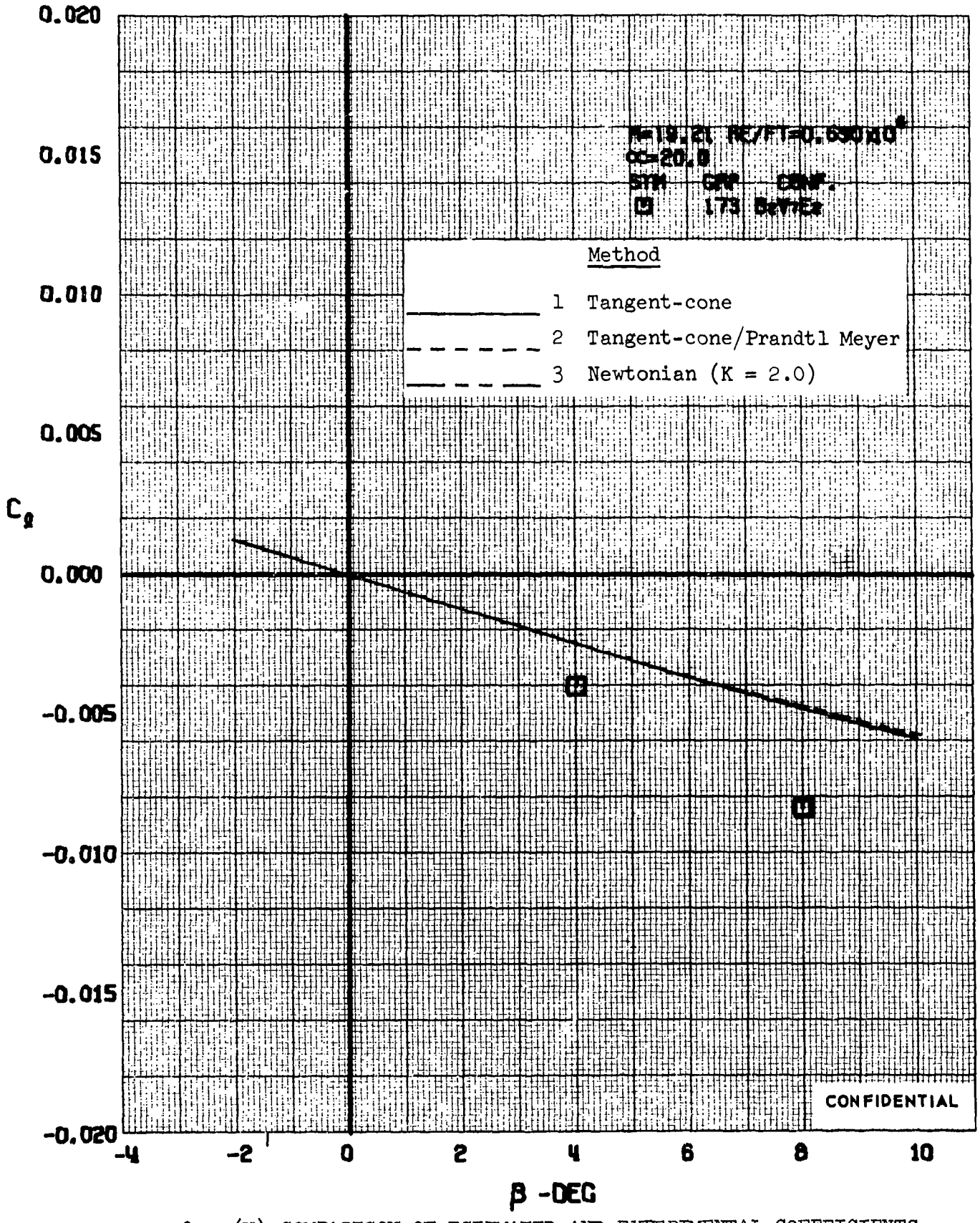

FIGURE 28 (U) COMPARISON OF ESTIMATED AND EXPERIMENTAL COEFFICIENTS - ROLLING MOMENT COEFFICIENT VARIATION WITH ANGLE OF YAW (M = 19.21)

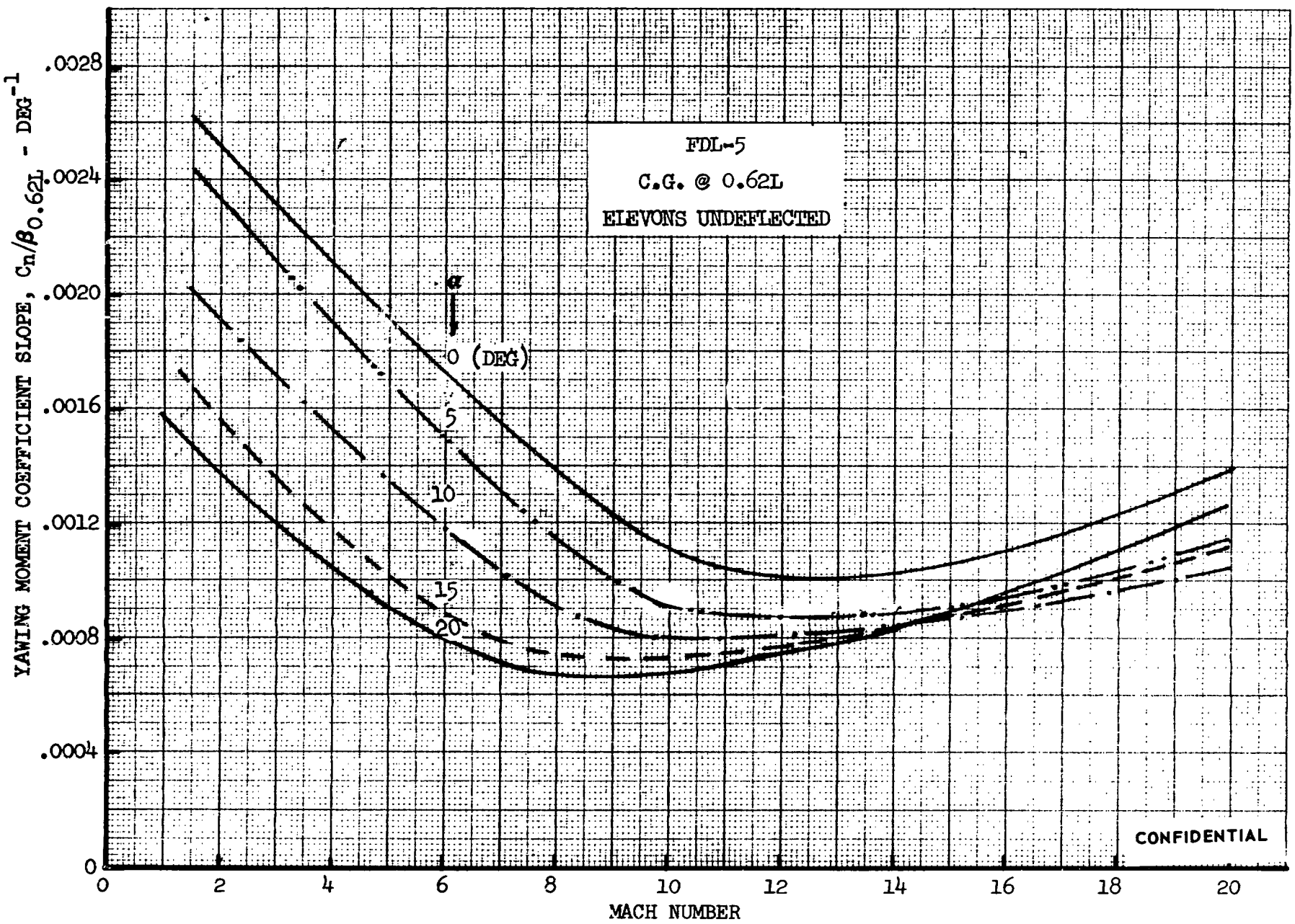

FIGURE 29 (U) FDL-5 YAWING MOMENT COEFFICIENT SLOPE VARIATION WITH MACH NUMBER

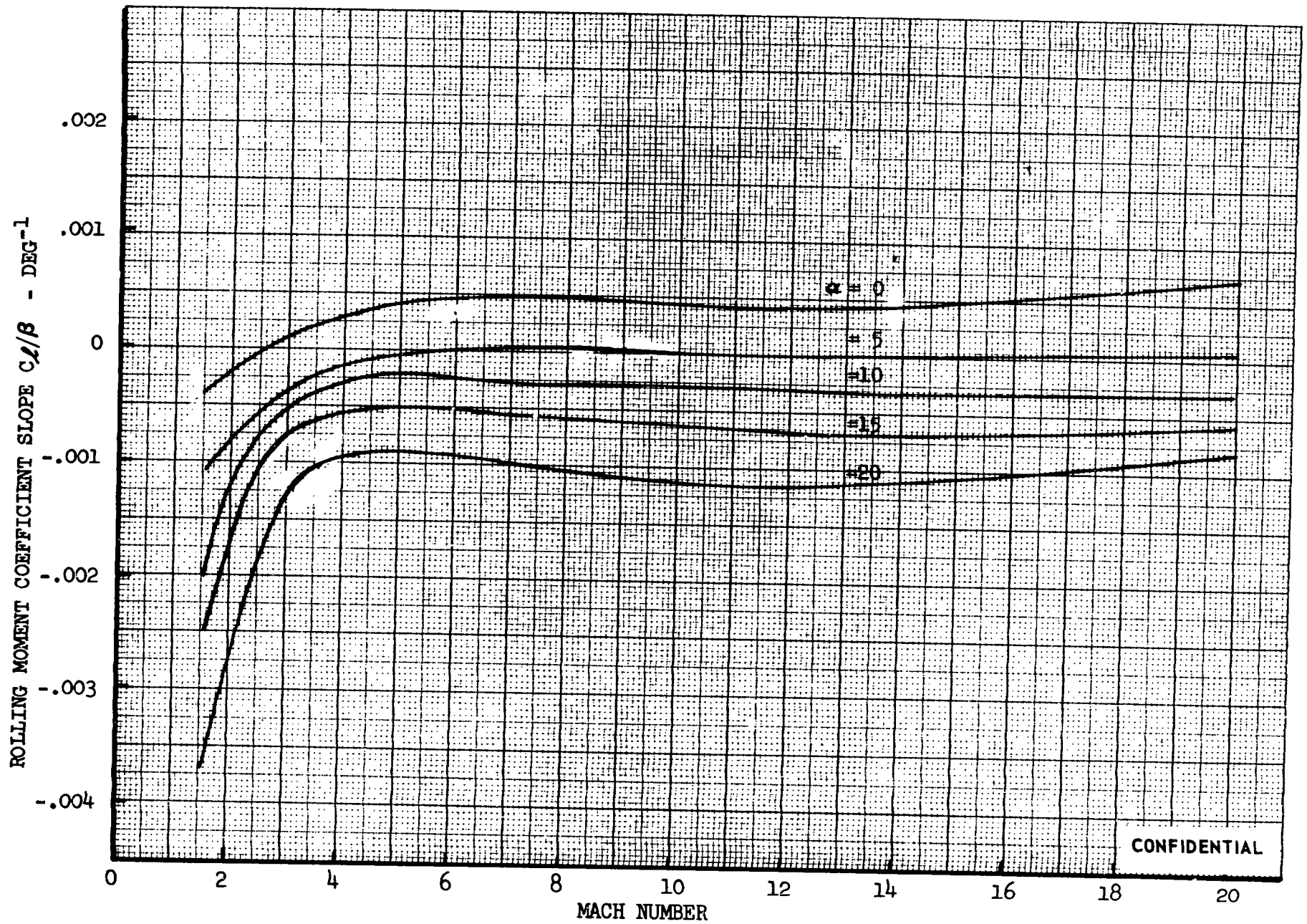

FIGURE 30 (U) FDL-5 ROLLING MOMENT COEFFICIENT SLOPE VARIATION WITH MACH NUMBER

CONFIDENTIAL

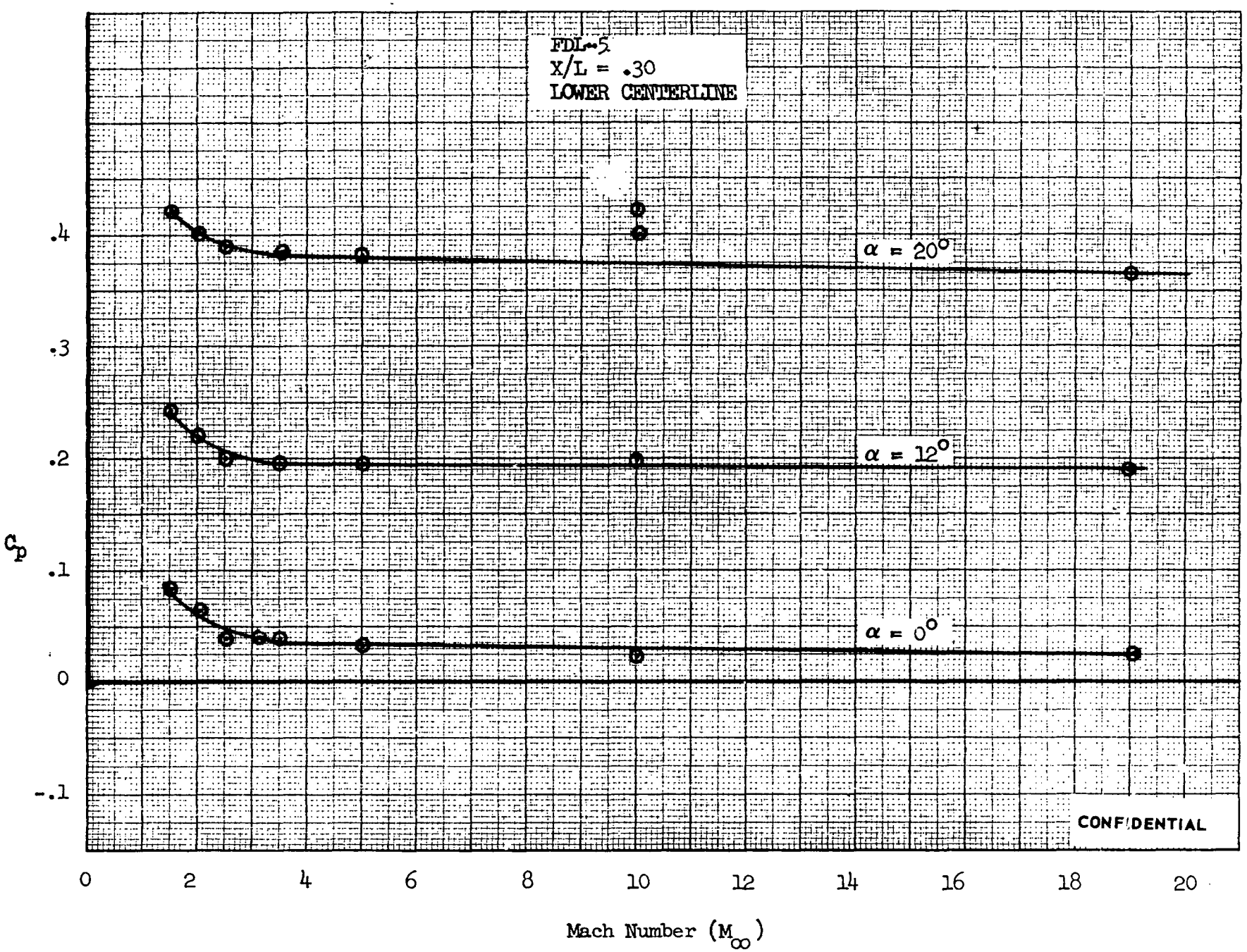

FIGURE 31 (U) VARIATION OF A LOWER SURFACE CENTERLINE PRESSURE COEFFICIENT WITH MACH NUMBER (X/L = .30)

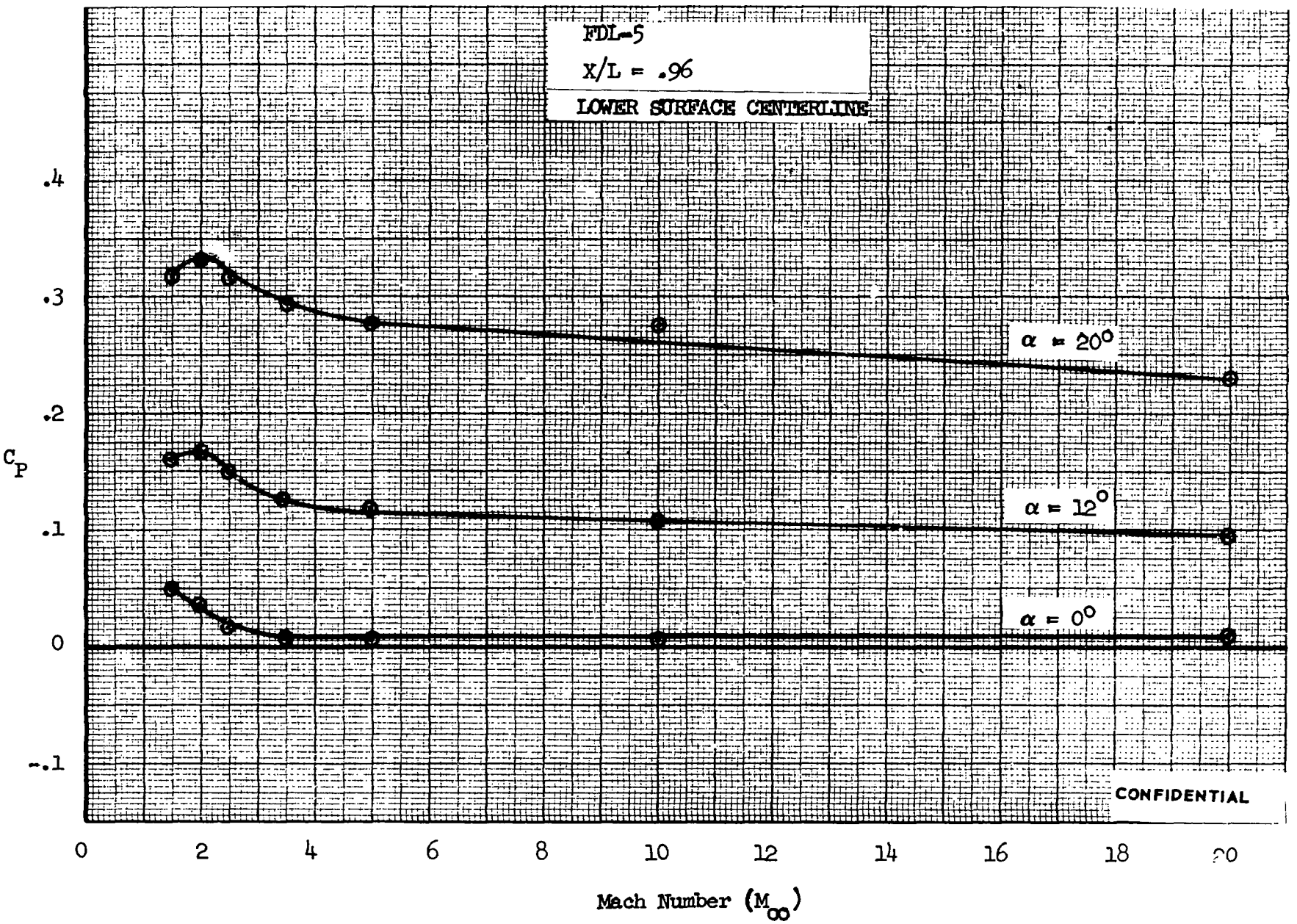

FIGURE 32 (U) VARIATION OF A LOWER SURFACE CENTERLINE PRESSURE COEFFICIENT WITH MACH NUMBER (X/L = .96)

CONFIDENTIAL

SECTION 5

(U) FDL-5 HEAT TRANSFER SUMMARY

(U) Heat transfer and structure design data are based on the reference trajectory shown in Figure 33 and the reference design condition of 11 degrees angle of attack, 20,000 fps and 200,000 feet altitude. The trajectory and the reference design point are based on the work reported in Reference 1 for a typical high angle of attack history and a typical banked history. The banked low-altitude trajectory results in higher surface temperatures and is based on an angle of attack of 11 degrees and bank angle of 34 degrees. Launch injection conditions are conservatively based on accomplishing the ETR to EAFB glide with these flight attitudes.

(U) Predicted temperature histories on the FDL-5 vehicle are shown in Figure 34 for the stagnation point, leading edge and lower surface. Surface emittance is assumed to be 0.7 on all surfaces. Boundary-layer transition is accounted for in the figure and causes the step increase in temperature late in the flight. Maximum temperatures are 4400 and 2900°F at the stagnation point and leading edge, respectively.

(C) Composite peak temperatures (occurring at different times during the low reference trajectory flight) are shown in Figure 35 for the lower surface centerline. Maximum temperature is 2450°F at station 140 and is the result of turbulent heating.

(C) The effect of transition criterion on peak lower surface temperature is shown in Figure 36. The recommended criterion of $Re_\theta/M_e = 150$ is seen to result in highest design temperature aft of station 180. It is believed that this criterion is conservative and flight temperatures may be lower.

(C) The effect of wing loading on peak temperature is depicted in Figure 37. Increasing the wing loading from 30 to 40 psf would increase the maximum lower surface temperature to 2500°F based on the 34-degree, banked, low-altitude trajectory.

(C) Typical correlation of experimental and theoretical heat transfer data is shown in Figure 38. Lower surface heating is seen to correlate most satisfactorily with swept cylinder theory. Strip (flat plate) theory underpredicts the heating at high angles of attack while cone theory overpredicts the heating at low angle of attack.

(C) A typical comparison of predicted and measured temperatures at vehicle stations 210 and 403 (X/L = 0.50 and 0.96) is shown in Figure 39. The inside temperatures are based on predicted heating at 200,000 feet altitude.

20,000 ft/sec and 11 degrees angle of attack. The outer temperatures are based on extrapolation of measured heat transfer rates to the same conditions. Comparison of the data shows good agreement (within 200°F) between predicted and measured temperatures. Detail heat transfer and pressure correlations are contained in Part IV.

(U) Figures 40 and 41 summarize the laminar peak temperature distributions occurring at the design point of 20,000 fps, 200,000 feet altitude and angle of attack of 11 degrees. The data are based on the tunnels C and F heat transfer tests and were computed based on a surface emittance of 0.7.

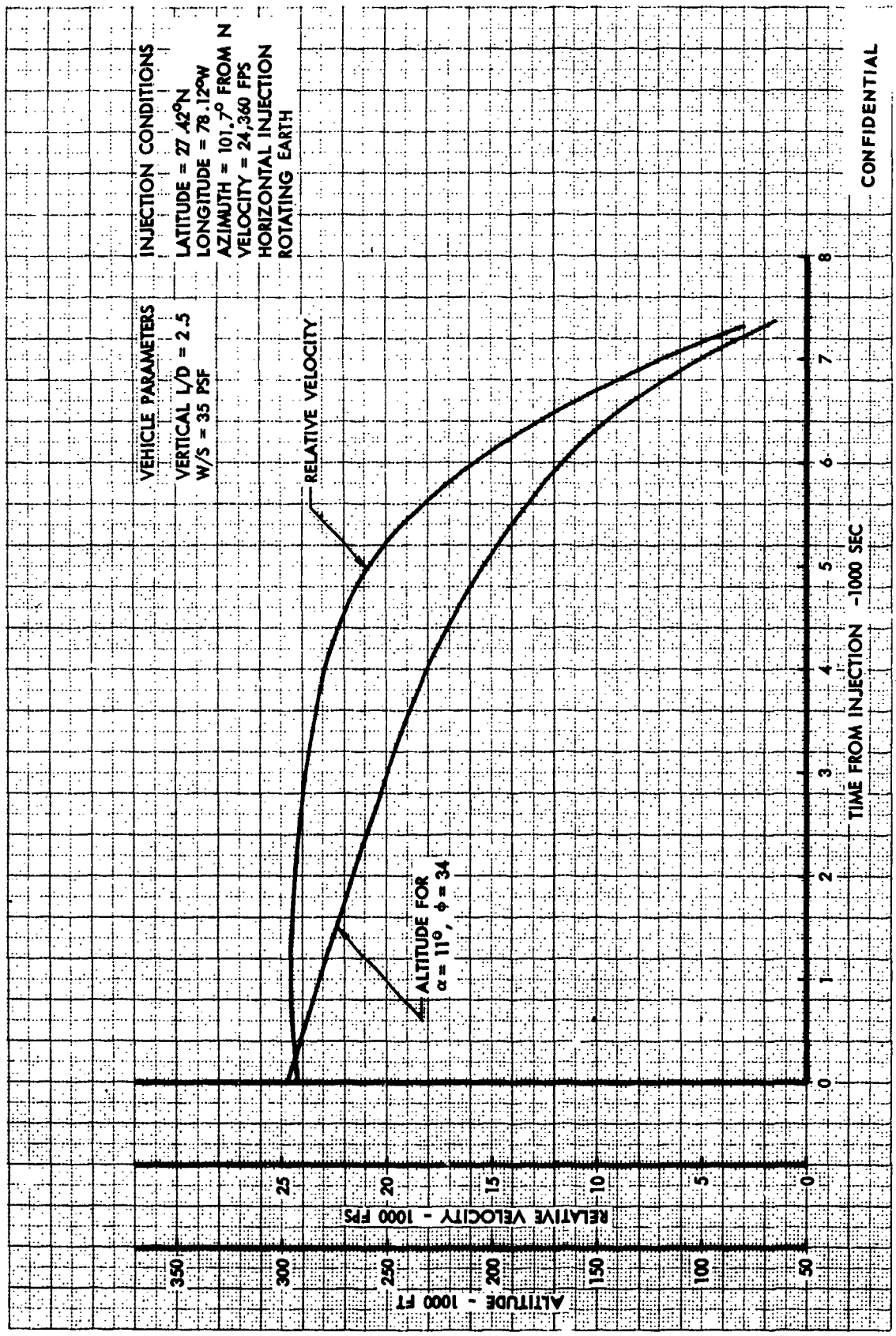

FIGURE 33 (U) REFERENCE TRAJECTORY

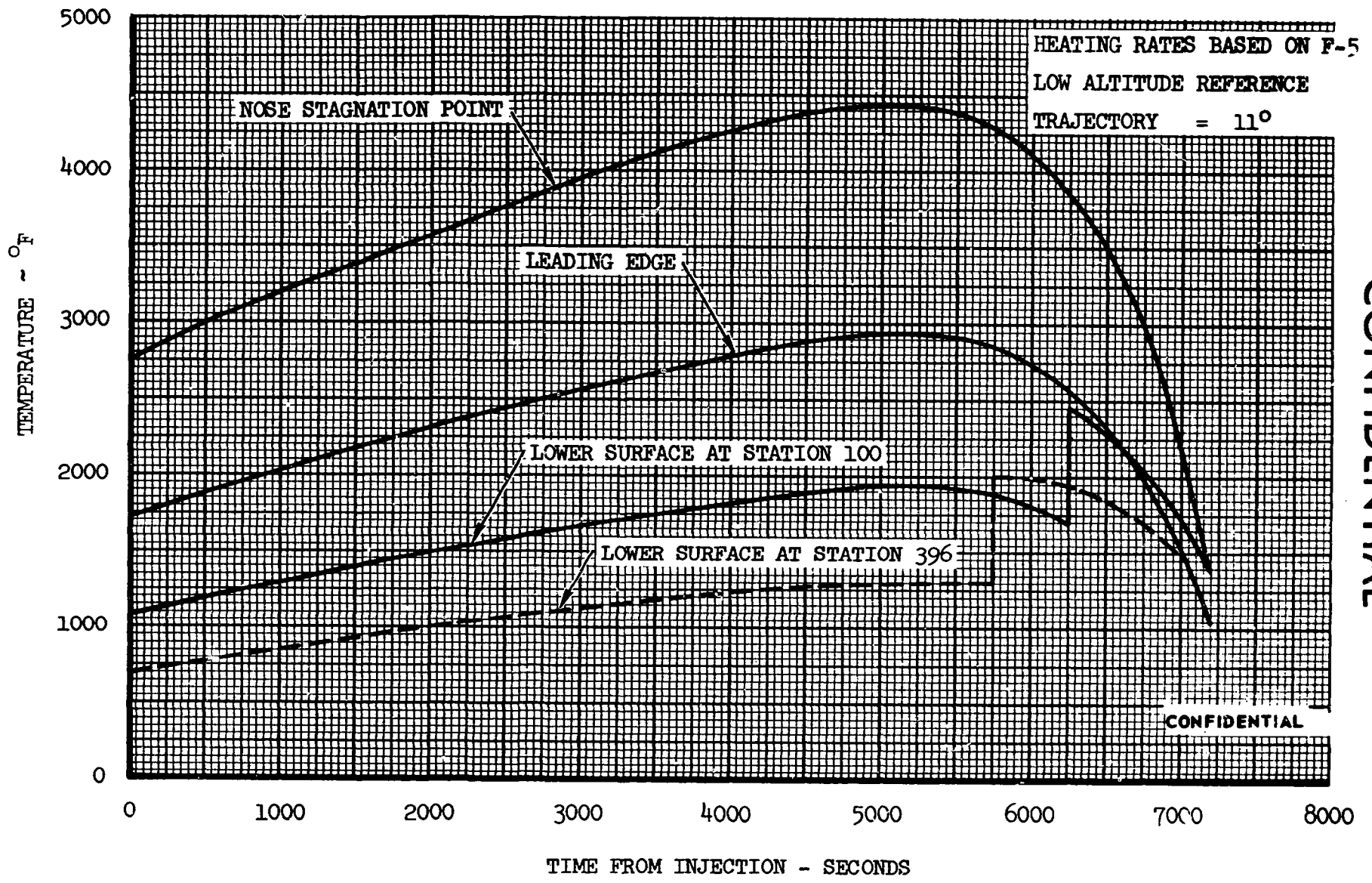

FIGURE 34 (U) TEMPERATURE HISTORIES AT VARIOUS VEHICLE LOCATIONS

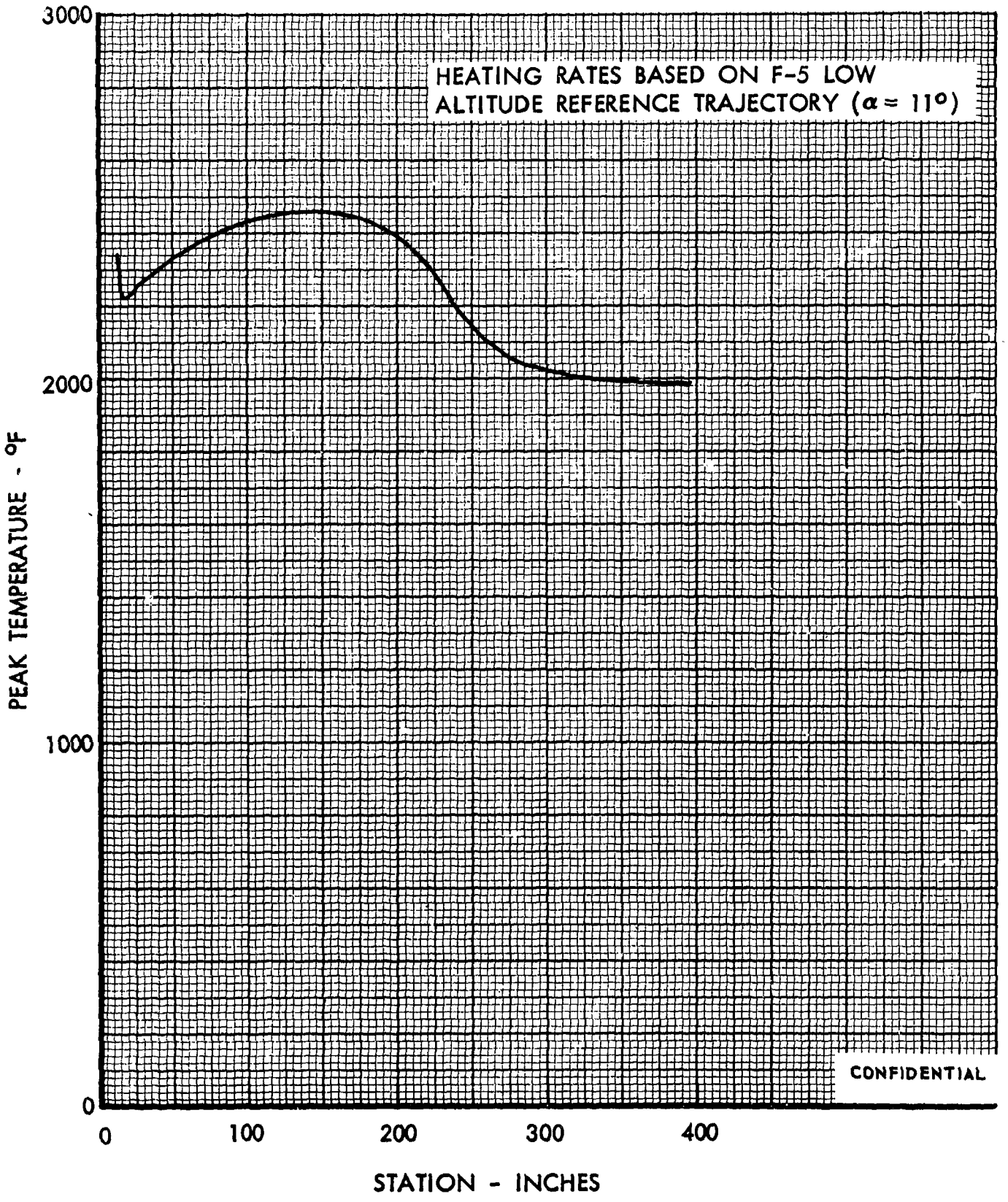

FIGURE 35 (U) PEAK LOWER SURFACE CENTERLINE TEMPERATURES

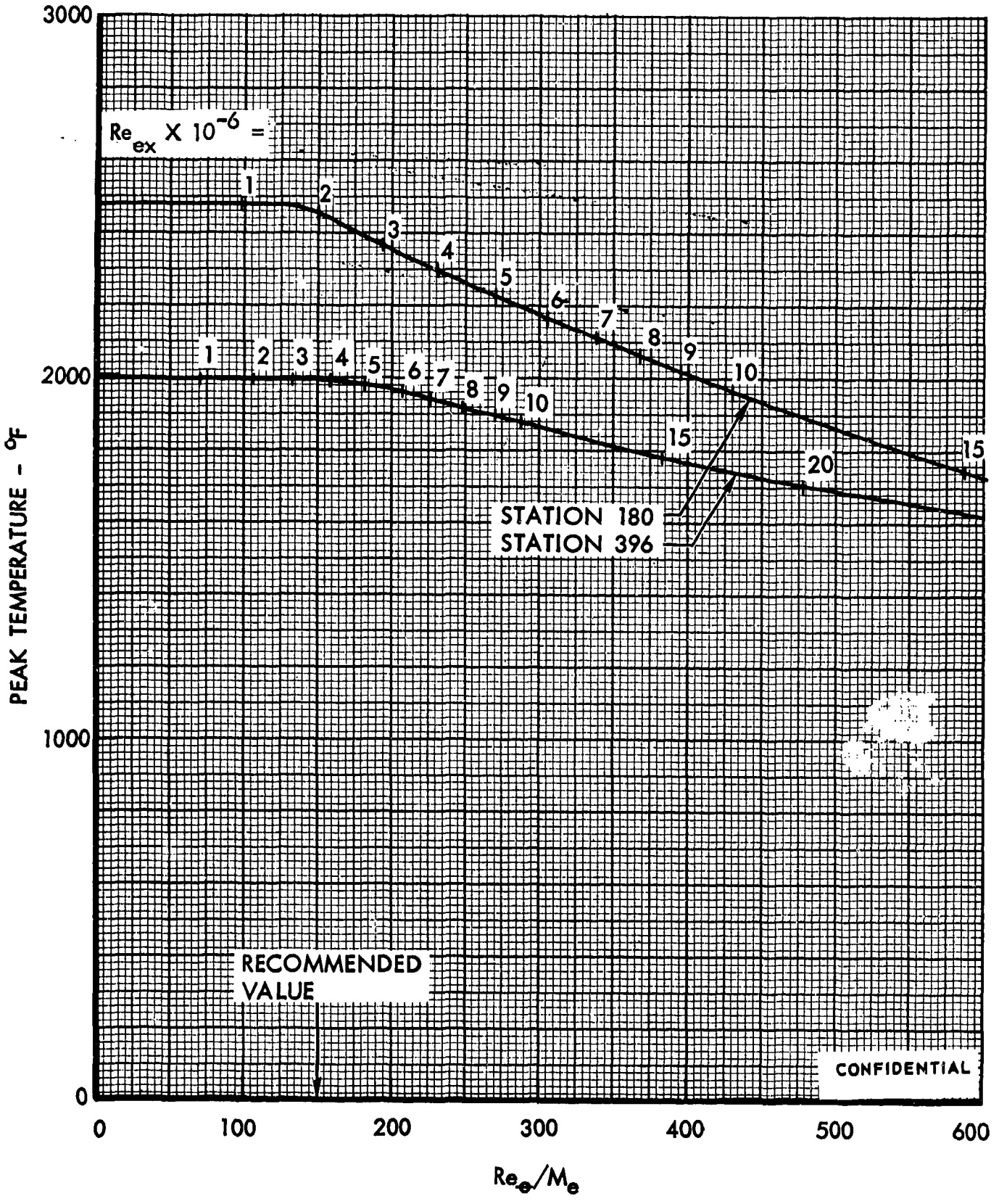

FIGURE 36 (U) EFFECT OF TRANSITION CRITERION ON PEAK LOWER SURFACE CENTERLINE TEMPERATURES

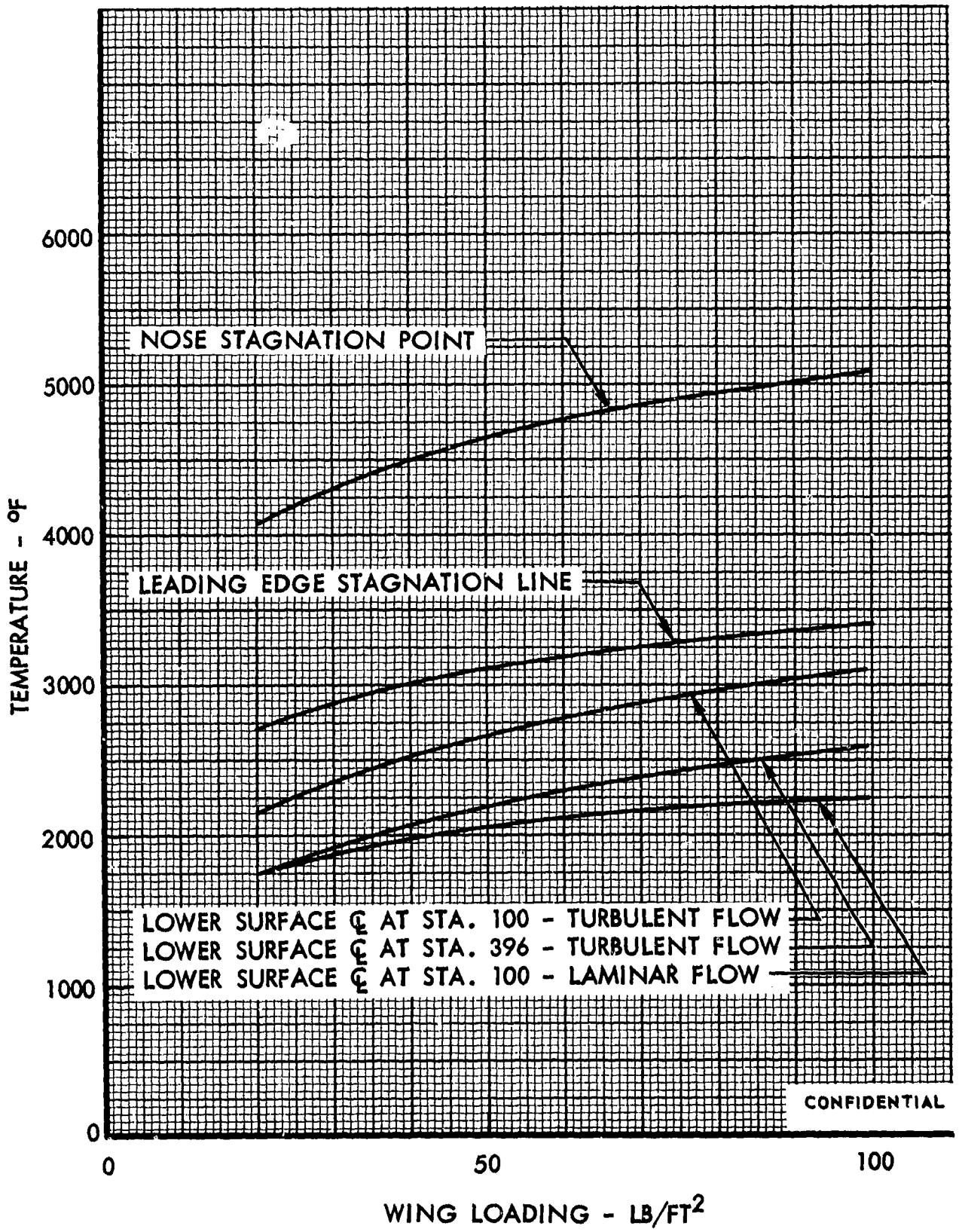

FIGURE 37 (U) EFFECT OF WING LOADING ON PEAK TEMPERATURES

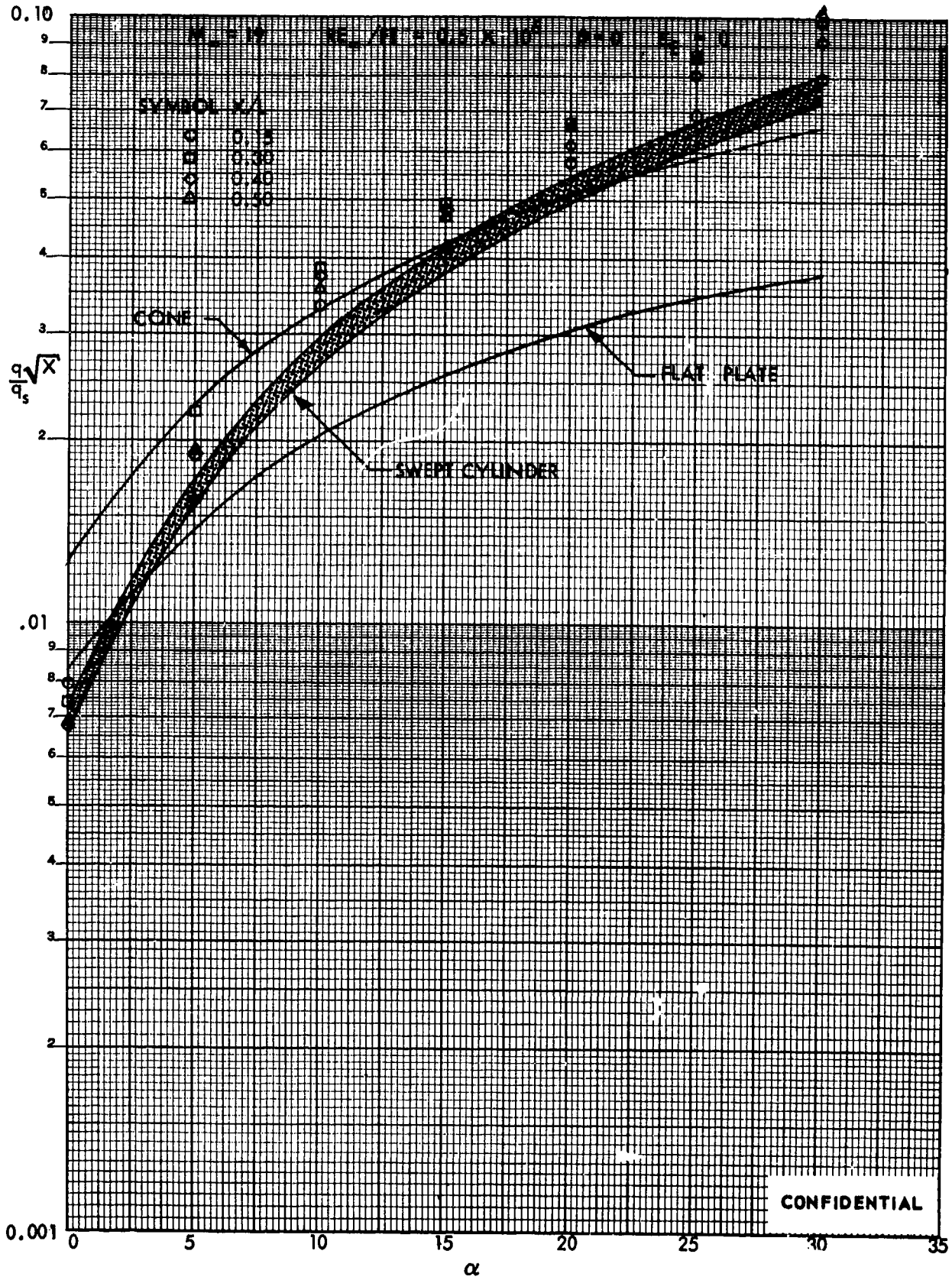

FIGURE 38 (U) CORRELATION OF TUNNEL F FORWARD RAMP CENTERLINE HEATING DATA

TEMPERATURES IN °F

INNER TEMPERATURES - ORIGINAL PREDICTIONS

OUTER TEMPERATURES - BASED ON WIND TUNNEL DATA

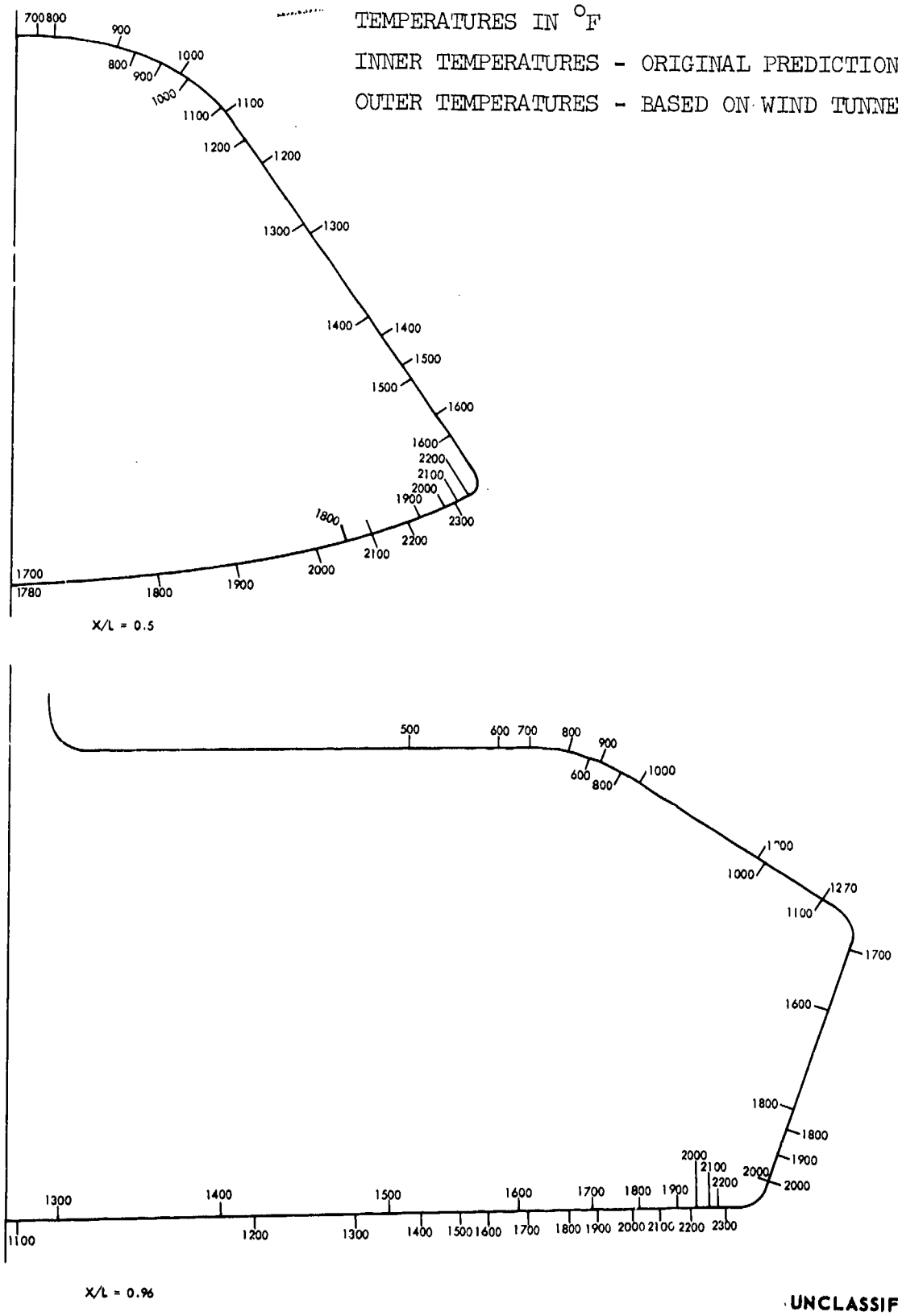

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FIGURE 39 (U) COMPARISON OF PREDICTED AND REVISED DESIGN POINT RADIATION EQUILIBRIUM TEMPERATURE - AT 50 AND 96 PERCENT CHORD

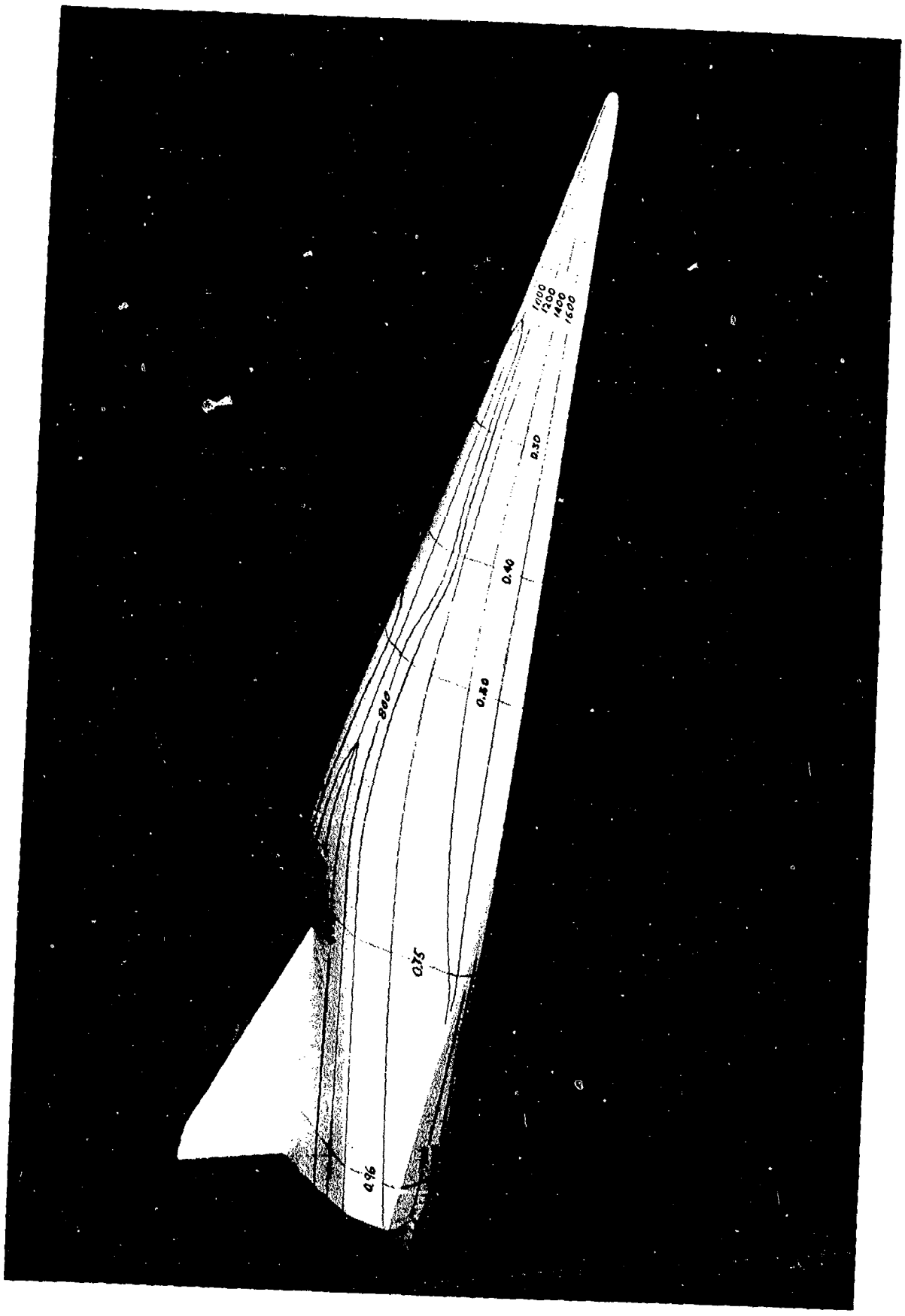

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FIGURE 40 (U) UPPER SURFACE ISOTHERMS

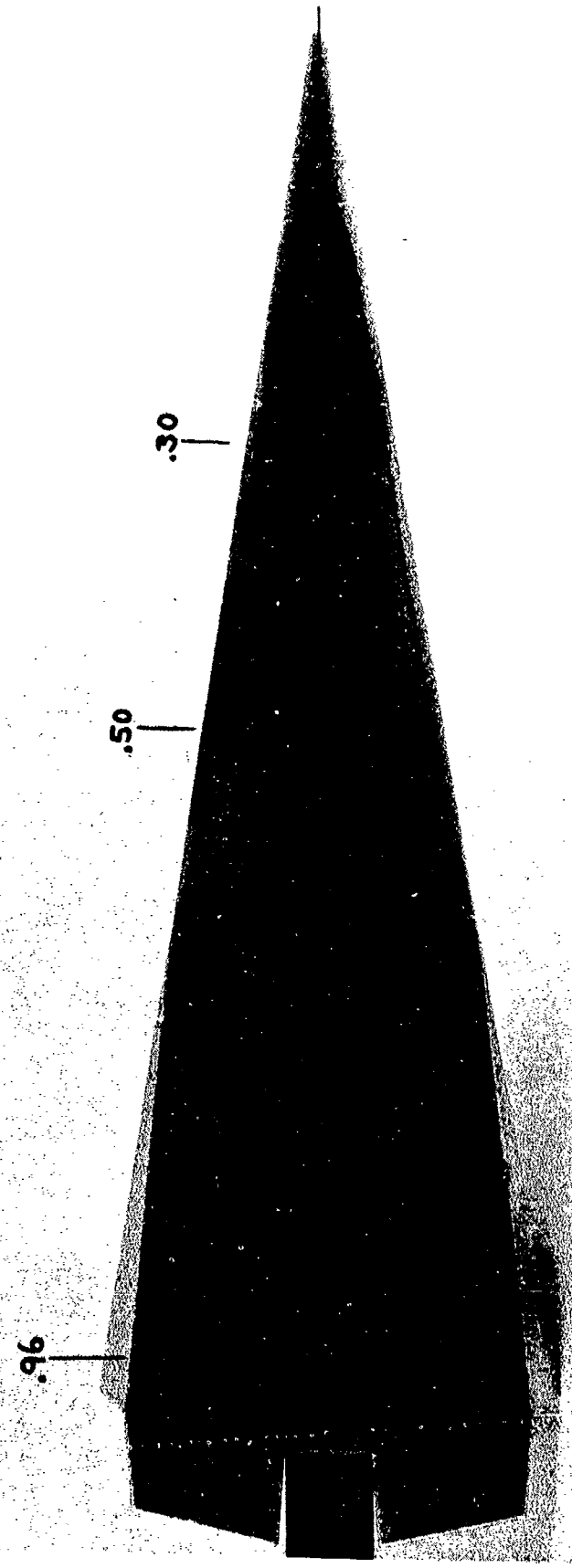

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FIGURE 41 (U) LOWER SURFACE ISOTHERMS

SECTION 6

(U) FDL-5 DESIGN

(U) Structure parametric trades, systems selections and vehicle weight estimates of the unmanned free flight research vehicle were accomplished during the study. Initially, these selections were based upon the early 30-foot-long F-5 configuration derived from Reference 1.

6.1 (U) STRUCTURES

(U) A Lockheed-sponsored structure parametric analysis provides the basic data for selection and design of a candidate vehicle structure concept. The parametric analysis is based on the 30-foot F-5 configuration with the general structure arrangement shown in Figure 42.

(U) Design loads are based on estimated pressures occurring during the Titan IIIB launch (Figure 43).

(C) Payload capability of the T-II or T-III core for the ETR flight is from 8000 to 9000 pounds and is marginally adequate to launch the 35-foot FDL-5 vehicle (7,391 pounds) and adapter (approximately 800 pounds). Strength of the T-IIIB is compared to the loads induced by the 30- and 35-foot F-5 configurations in Figure 44. The data are based on a dynamic response factor of 1.33 and a factor of safety of 1.5. It can be seen that the loads for the 30-foot vehicle do not exceed the booster strength, while the loads for the 35-foot vehicle do exceed the booster strength. With a dynamic response factor of approximately 1.27, the 35-foot vehicle is compatible with the booster capability. Reduction of the dynamic response factor would require limiting the test launches to days with low wind shears.

(U) Table 8 shows the materials and design minimum gages considered during the parametric analysis. Minimum gage is based on practical manufacturing and application problems. The importance of minimum gage to the vehicle design and weight is shown in Figure 45, which compares the equivalent panel and skin thickness required to support loads with the minimum gage. Minimum gage is seen to prevail in the design requirements for the front 30 feet of the vehicle length.

(U) Figures 46 and 47 summarize the effects on weight of many variations of material, panel design, and insulated, insulated-and-cooled, and hot-structure concepts for upper and lower surfaces of the vehicle. Lowest vehicle weight is realized if no internal thermal conditioning is required, as shown by the high back-face temperature part of the curves. If the inside of the vehicle is to be maintained at room temperature, the hot-load-carrying concept with internal insulation and cooling, or the insulated-and-cooled structure

concept is required. The insulated-and-cooled structure then is somewhat lighter than the hot-load-carrying concept with internal vehicle cooling. The unit weights shown in the figures include panel, longeron, and frame weights, but do not include weight provisions for fins, control surfaces, landing gear, or structure cutouts.

(U) Figure 48 shows the structural arrangement created for the 35-foot vehicle. The drawing illustrates typical panel concepts, and the location of primary load bearing longerons and frames. Materials are identified on the drawing, as are access panels, attachment details and landing gear support structure.

(U) A complete description of the structure concept is contained in Part V.

6.2 (U) SYSTEMS

(U) Figure 49 is a candidate systems general arrangement drawing which describes the location and preliminary selection of the vehicle systems. The systems have been positioned with consideration for geometry requirements, balance, and ease of access and servicing.

(U) The landing gear is a tricycle system using dual metal nose wheels and main gear metal brush skids. Shock attenuation is accomplished with crushable honeycomb cylinder inserts.

(U) Antenna placements assure satisfactory command and telemetry contact.

(U) The guidance and navigation system consists of an inertial platform and a general-purpose digital computer. Both are available as modified off-the-shelf or easily developed hardware. The inertial navigator was selected on the basis that an autonomous continuous means of determining the vehicle state vectors is necessary. An altitude-sensing system may be required to suppress the accumulation of altitude errors during the flight. A modified off-the-shelf radar altimeter could be used for this purpose, if further analysis indicates that this is warranted.

(U) The flight control system is comprised of an autopilot, a reaction control system, an aerodynamic control system and a landing propulsion system. Signals from the guidance and navigation systems are fed to the autopilot. Output from the autopilot controls the reaction control system and the aerodynamic control system.

(U) Aerodynamic controls are driven by hydraulic actuators in a cooled hydraulic power system; and the reaction control and landing rocket systems use monopropellant hydrogen peroxide fuel. The fuel for the reaction motors and landing motors is contained in common tanks located at the vehicle center of gravity.

(U) Eight reaction control motors are required to provide complete three-axis pure moment vehicle control. Pitch and roll motors are used during low dynamic pressure flight only while yaw motors are used throughout the flight to augment aerodynamic stability and control during maneuvering flight.

(U) Four 500-pound-thrust, off-the-shelf hydrogen peroxide landing motors are provided to augment landing. The maximum equivalent L/D of the basic vehicle with all engines thrusting is approximately 6. The use of thrust from zero to 4 of the engines allows the equivalent L/D to be varied from 2 to 6. The fuel provided for landing is adequate for 20 seconds of thrust from all four engines.

(U) The data management system includes all aspects of data acquisition, transmission, and post-flight data handling and processing. The functions of the system are to obtain basic research information and provide diagnostic performance data for the vehicle and supporting systems.

(U) Sensor data are fed into the PCM multiplexer encoder and RF transmitters. The PCM serial wavetrain is fed simultaneously to the VHF transmitter, microwave transmitter, and on-board tape recorders. VHF transmission is the main data link with microwave transmission providing data during the blackout period. Compressed time transmission of recorded data is provided over both VHF and microwave link during vehicle flight over ground stations.

(U) A total of 315 sensor measurements will be made during a typical research mission. All of the data management system equipments are available off the shelf or with minimum development.

(U) Vehicle tracking is accomplished with a C band transponder and skin track. The approach and landing is accomplished using the ground control system developed for the X-20 program. This system provides for eight channels of data on X band and uses a small onboard transponder. An X band tracking antenna is provided in the nose of the vehicle for the automatic landing system.

(U) The destruct system is an autonomous and ground-controlled system designed to induce ballistic flight of the test vehicle upon actuation. The ground control is provided on the standard 400 MHz frequency, while the autonomous control is based on use of a bank angle/time allowance similar to that employed on ASSET. Ballistic flight is achieved by pyrotechnic separation of the left elevon to obtain roll to the left. Separation of part of the vehicle structure cannot be achieved without larger weight for the destruct explosive and a more complex design of the destruct system installation.

(U) The environmental control system maintains room temperature conditions in the entire vehicle for the benefit of both structure and systems. Heat is rejected with a water/ammonia boiler/heat-exchanger system pressurized to maintain initial coolant temperature at 40°F. Water-glycol circulating in a

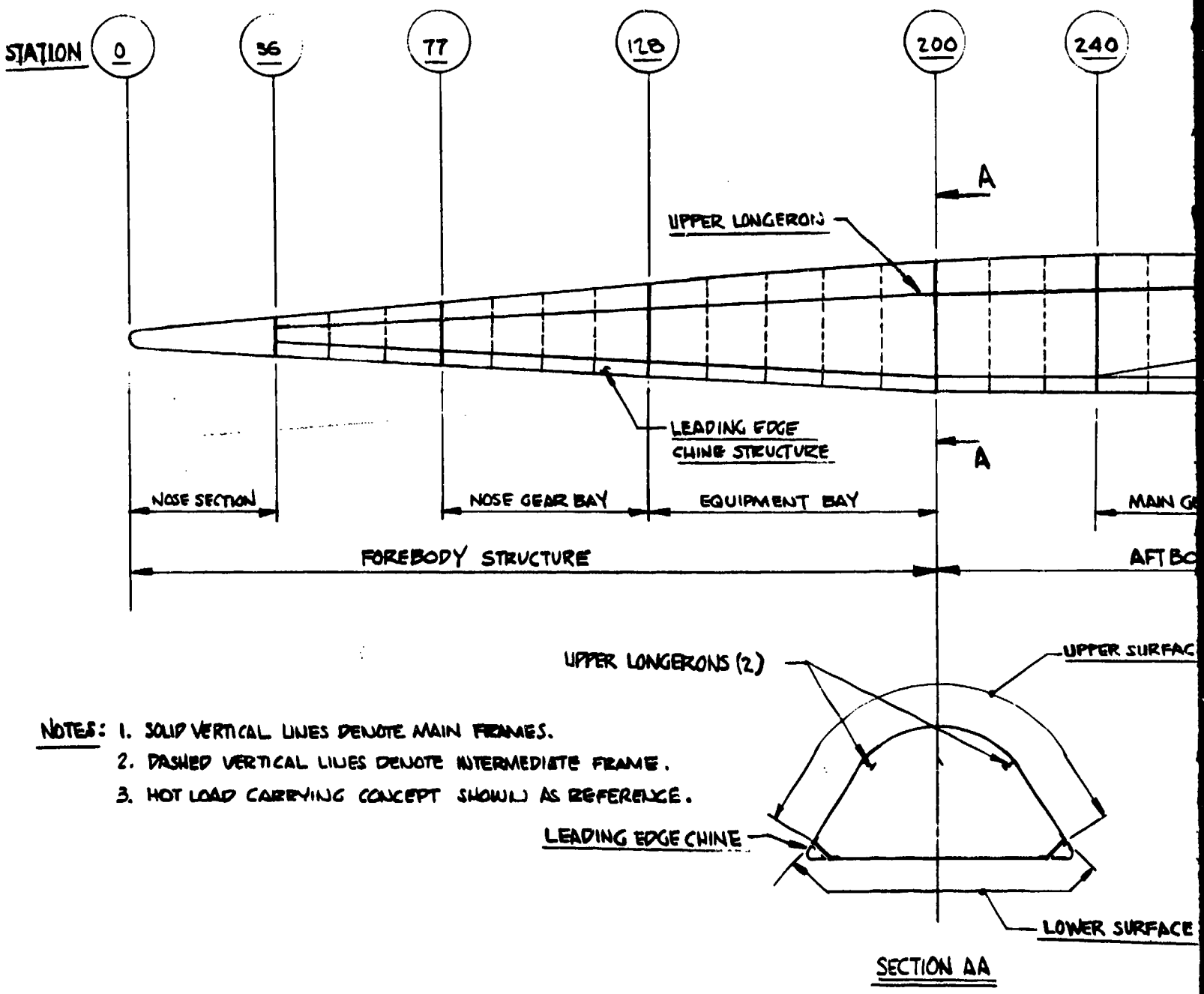
closed loop carries heat from the cooled structure and internal equipment to the water/ammonia boiler/heat-exchanger system. Water and ammonia tanks are located near the vehicle center of gravity.

(U) The electrical power system provides all onboard power from silver-zinc batteries. The system includes the batteries, inverters, regulators and distribution system. Total power capacity is 200 ampere-hours with a 250-ampere peak load.

6.3 (U) WEIGHT

(U) Vehicle and systems summary weight statements are shown in Tables 9 and 10. Total launch weight is 7666 pounds, including contingency and ballast. The structure is 59 percent, systems (including expendables) are 38 percent of the launch weight and the contingency is approximately 3 percent. Landing weight is 6790 pounds and landing wing loading is 33.5 psf. The expendable items weigh 876 pounds and include water, ammonia, and hydrogen peroxide.

(U) The largest subsystem weights are the expendable items associated with the environmental control system and reaction control system. Other equipment items weight 1829 pounds.



NOTES:
1. SOLID VERTICAL LINES DENOTE MAIN FRAMES.
2. DASHED VERTICAL LINES DENOTE INTERMEDIATE FRAME.
3. HOT LOAD CARRYING CONCEPT SHOWN AS REFERENCE.

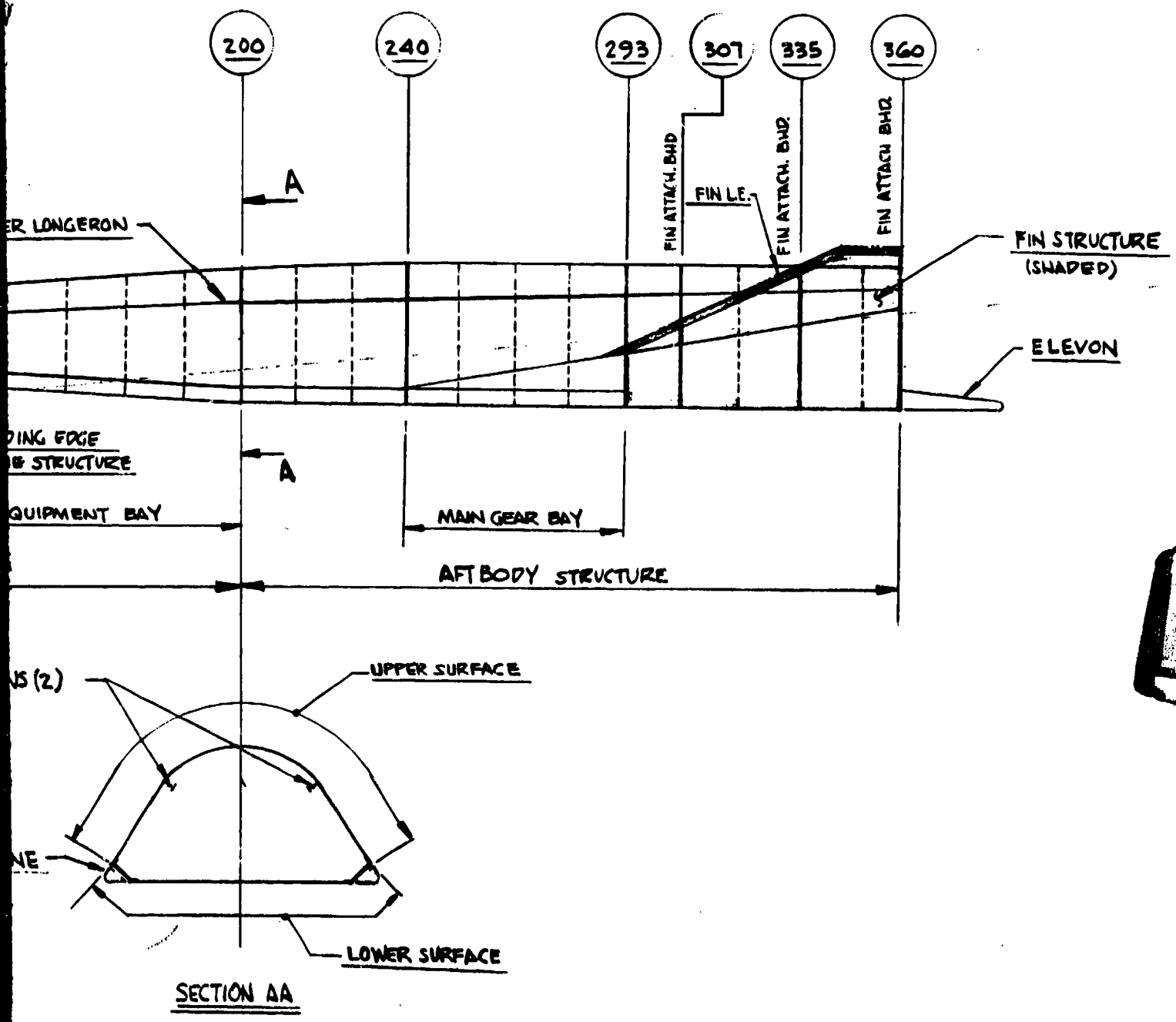


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FIGURE 42 (U) STUDY VEHICLE (F-5) STRUCTURAL ARRANGEMENT FOR DESIGN CONCEPT EVALUATION

(REVERSE SIDE IS BLANK)

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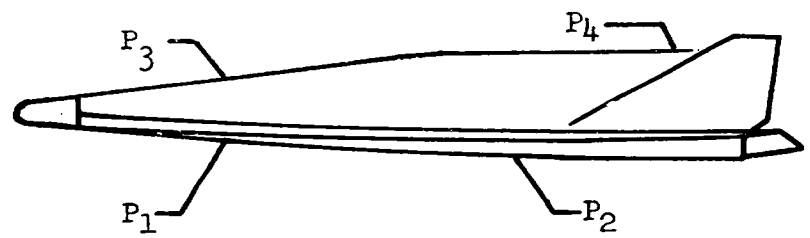
F-5/TITAN IIIB DESIGN PRESSURES - EXIT PHASE

F-5



LOCATION	LIMIT PRESSURE (PSI)
NOSE	12.7
LEADING EDGE	2.6
P_1	1.73;- 0.31
P_2	1.21;- 0.81
P_3	1.64
P_4	0.81; - 1.21

NOTE: + COMPRESSION;- SUCTION

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FIGURE 43 (U) DESIGN PRESSURES FLIGHT TEST VEHICLE

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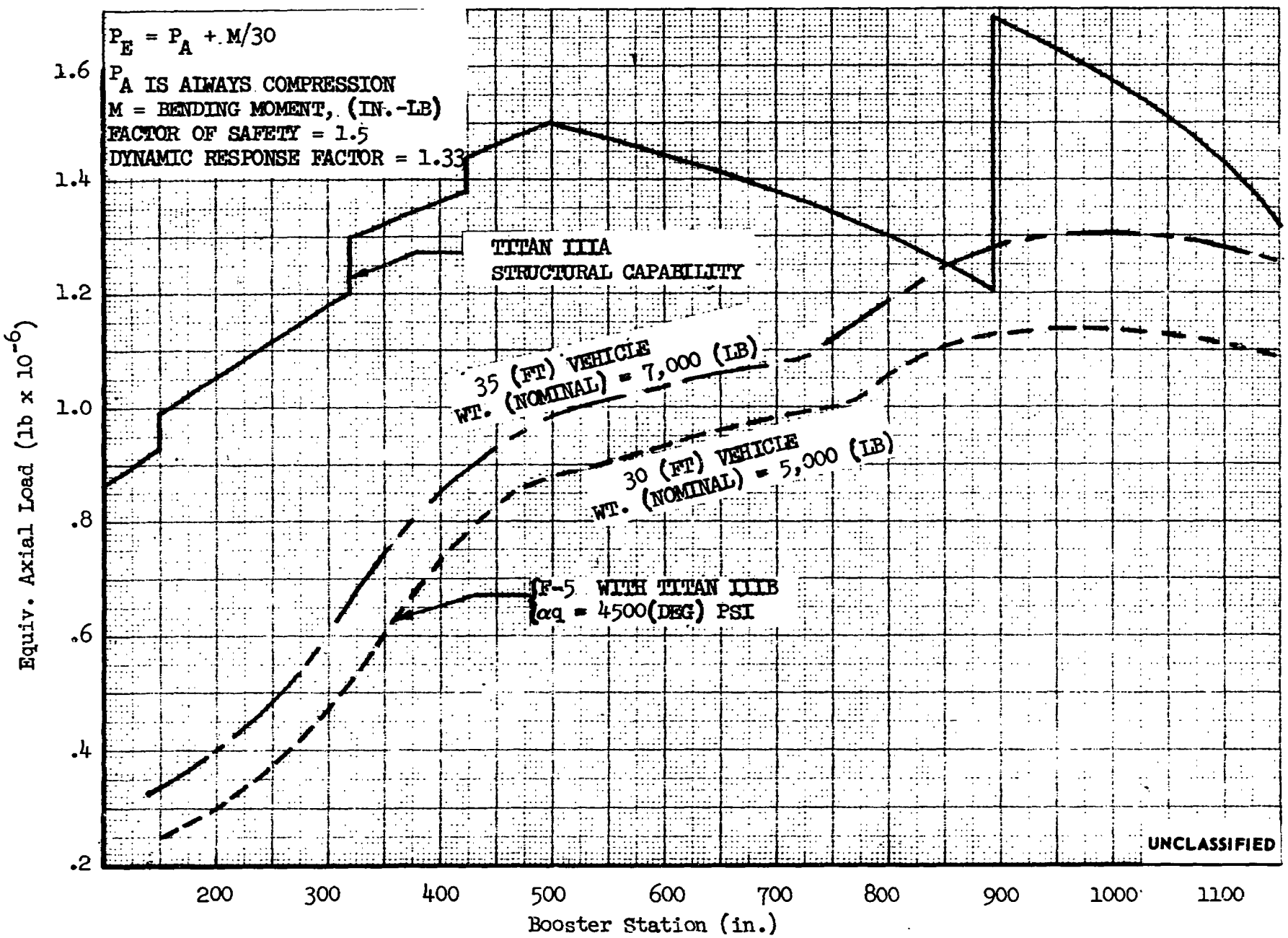

FIGURE 44 (U) COMPARISON OF MAXIMUM FLIGHT STRUCTURAL LOAD CAPABILITIES

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TABLE 8

(U) MINIMUM GAGE FOR METALLIC MATERIALS (INCHES)

MATERIAL ALLOY DESIGNATION	STRUCTURAL CONFIGURATION						FRAME BULKHEAD APPLICATION
	SINGLE CORRUGATION	CORRUGATION-STIFFENED		INTEGRALLY STIFFENED	HONEYCOMB SANDWICH		
		SKIN	CORRUG.		SKIN	CORE	
Aluminum 2219T81	.016	.016	.012	.016(1)	-	-	.020
Beryllium Be-38Al	.016	-	-	.016	-	-	.020
Beryllium AMS7902	.016	-	-	.016	-	-	.020
Titanium Ti 8Al-1Mo-1V	.016	.016	.012	.016	-	-	.020
Nickel base Inconel 718	.016(3)	.016(3)	.012(3)	(2)	.012(3)	.002	.020
Nickel base Inconel 625	.010	.010	.010	(2)	.008	.002	.012
Cobalt base Haynes 25	.010	.010	.010	(2)	.008	.002	.012
Columbium Cb 752-R512B	-	.012(4)	.012(4)	.012	.010(.008)(5)	.002(6)	.016
Tantalum 90Ta-10W(7)	-	-	-	.012	-	-	.016

NOTES
(1) Minimum selected based on manufacturing consideration.
(2) Not considered because of serious mfg. problems (warpage, distortion, extremely difficult chemically to mill).
(3) Gages selected because of distortion due to heat treatment of thinner gages.
(4) Poor structural resistant welds: projected application of solid state roll diffusion bonded technique.
(5) ( ) value indicates heat shield application.
(6) Core material: Columbium alloy D-36 (ρ = .286 lb/in.^{3}).
(7) For strength requirements consider tantalum alloy T-222.

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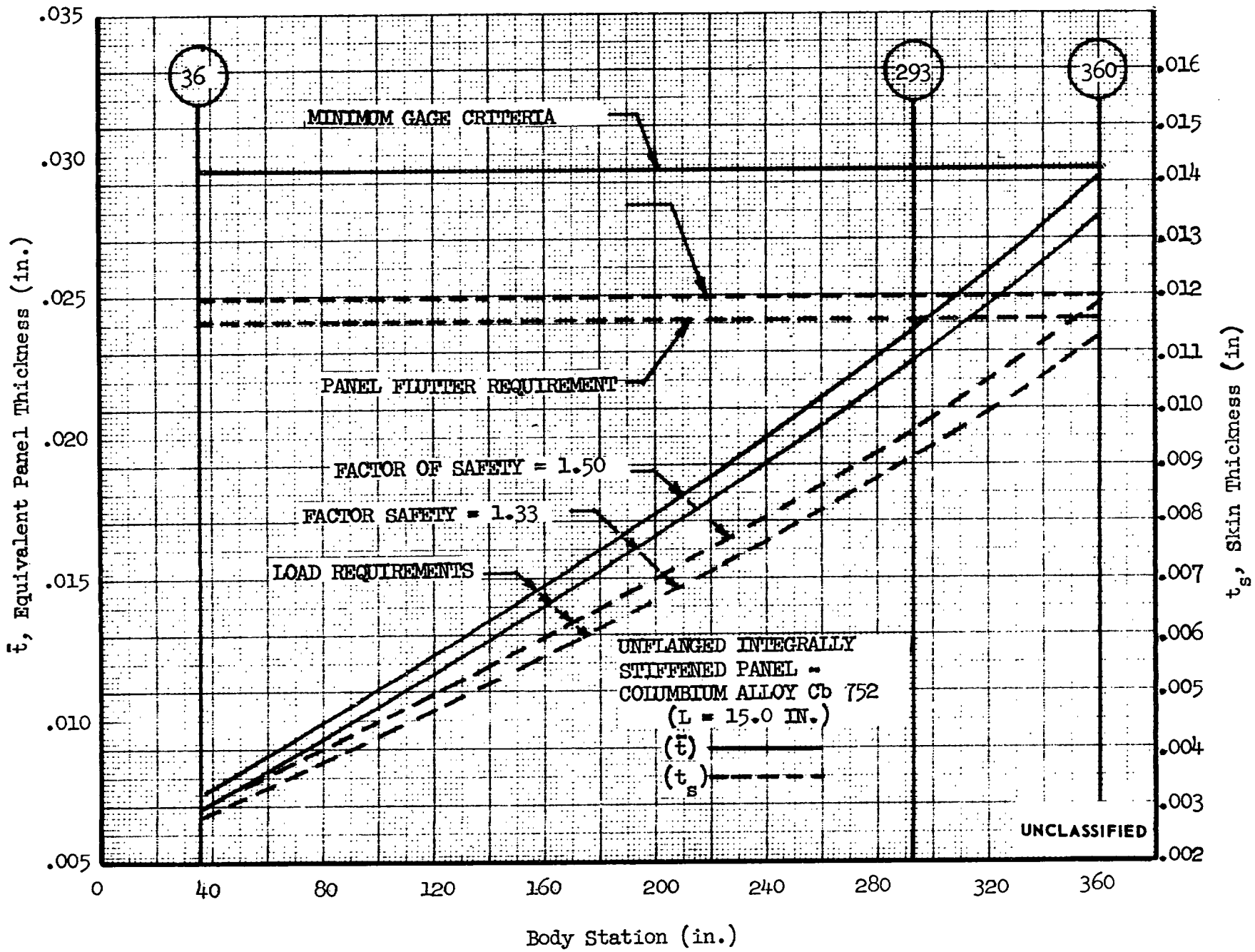

FIGURE 45 THICKNESS REQUIREMENTS FOR LOWER SURFACE PANELS (L = 15.0 INCHES)

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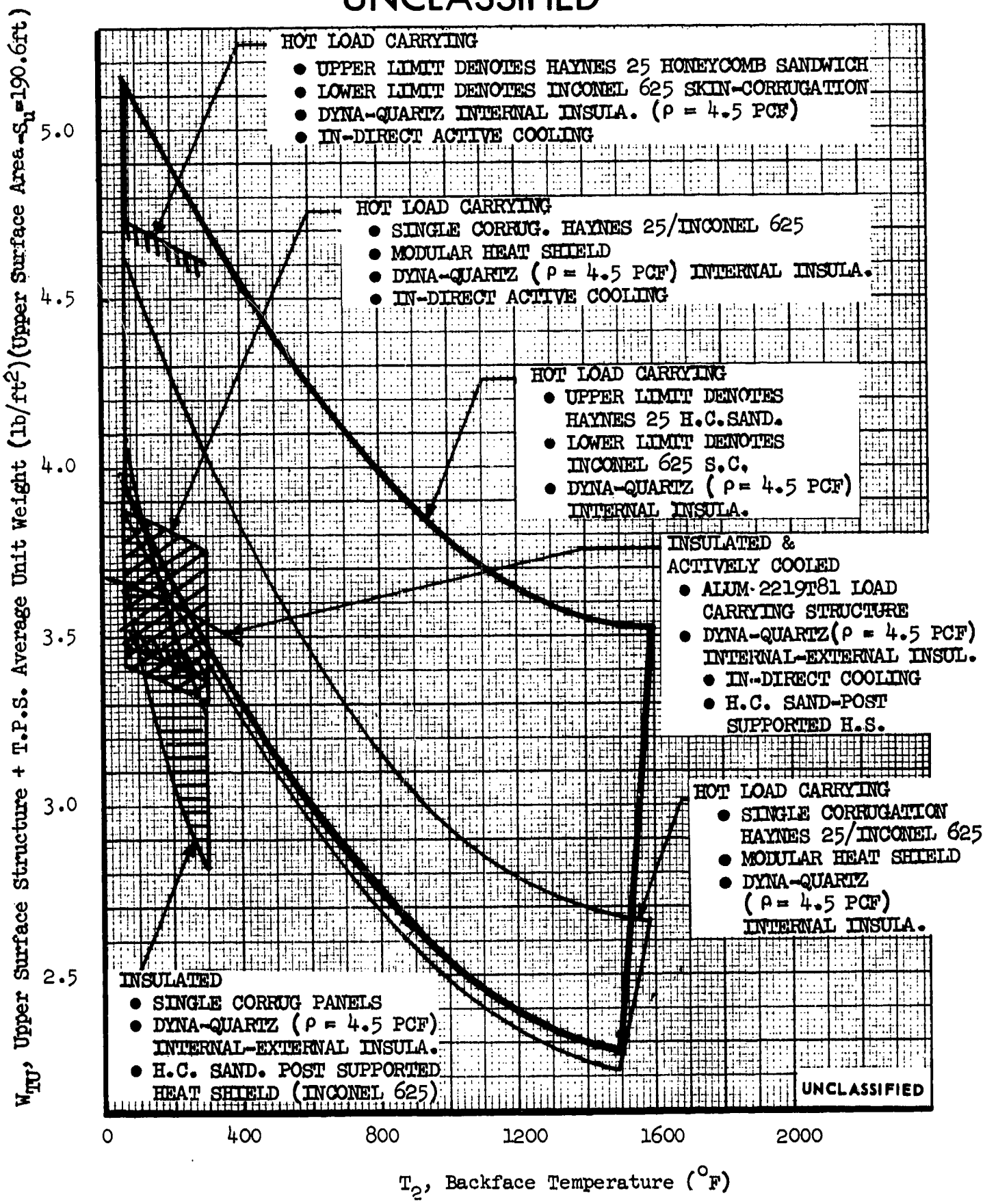


FIGURE 46 (U) UPPER SURFACE WEIGHT COMPARISON - STRUCTURE AND THERMAL PROTECTION SYSTEM FOR VARIOUS THERMO-STRUCTURAL CONCEPTS

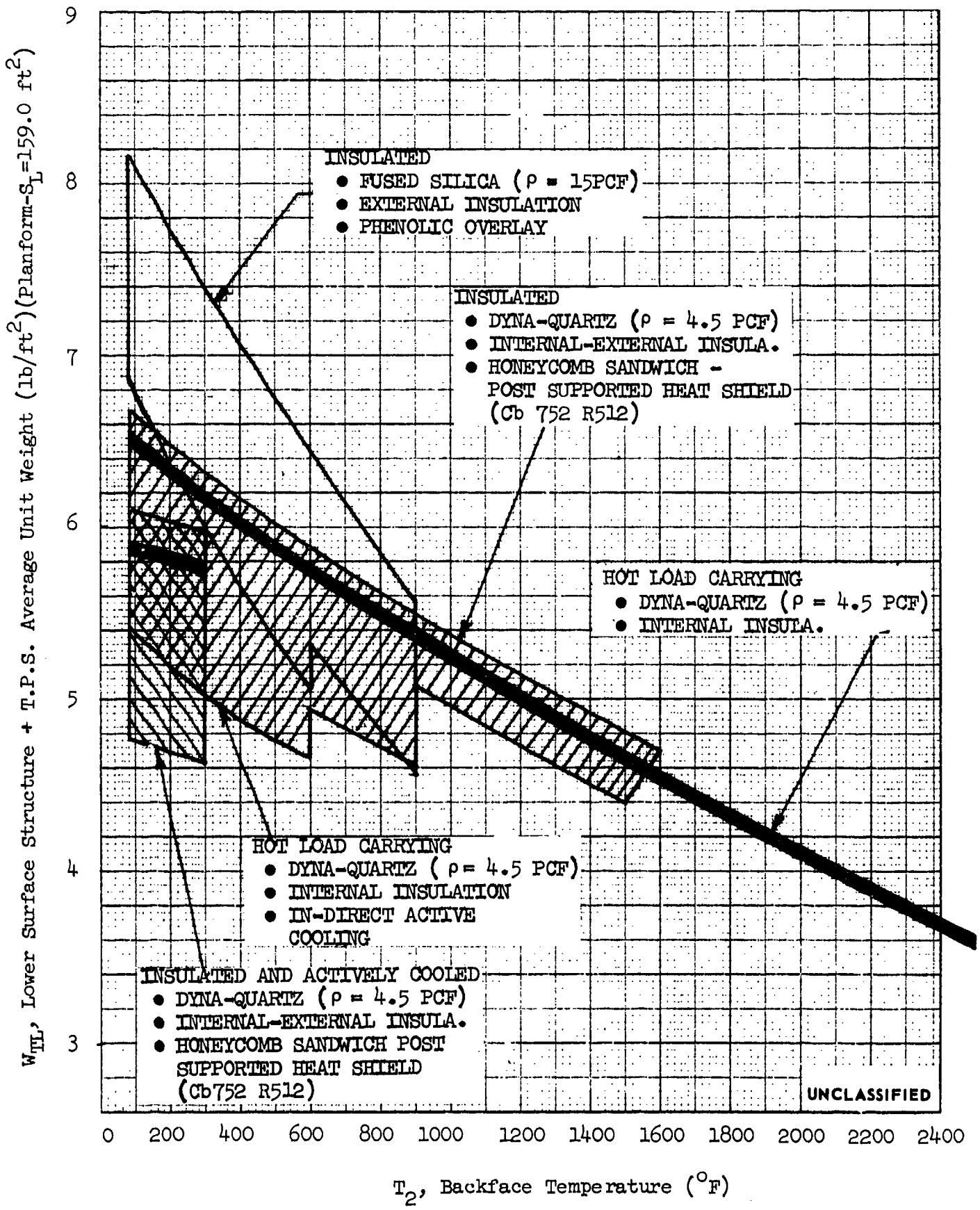
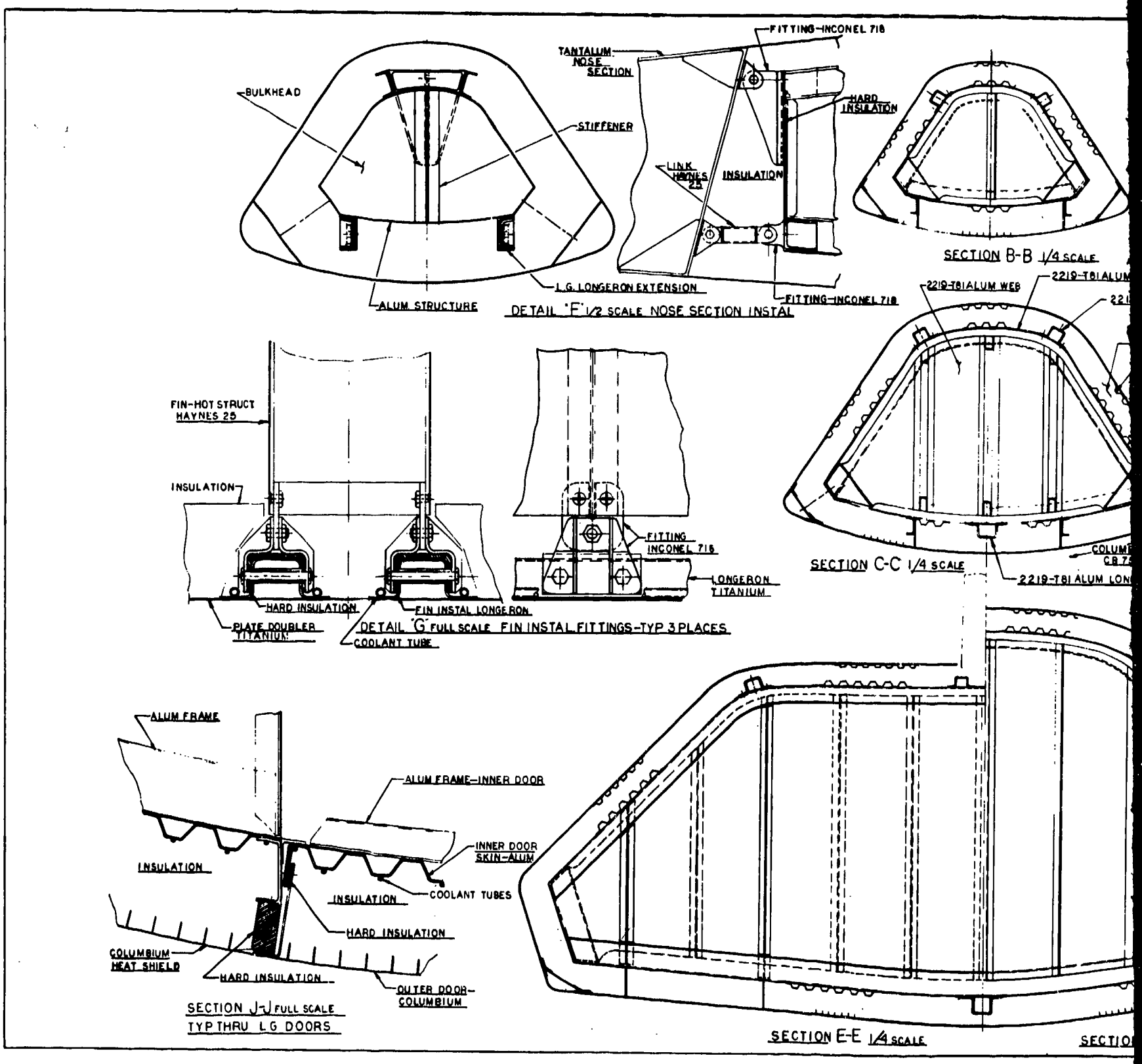
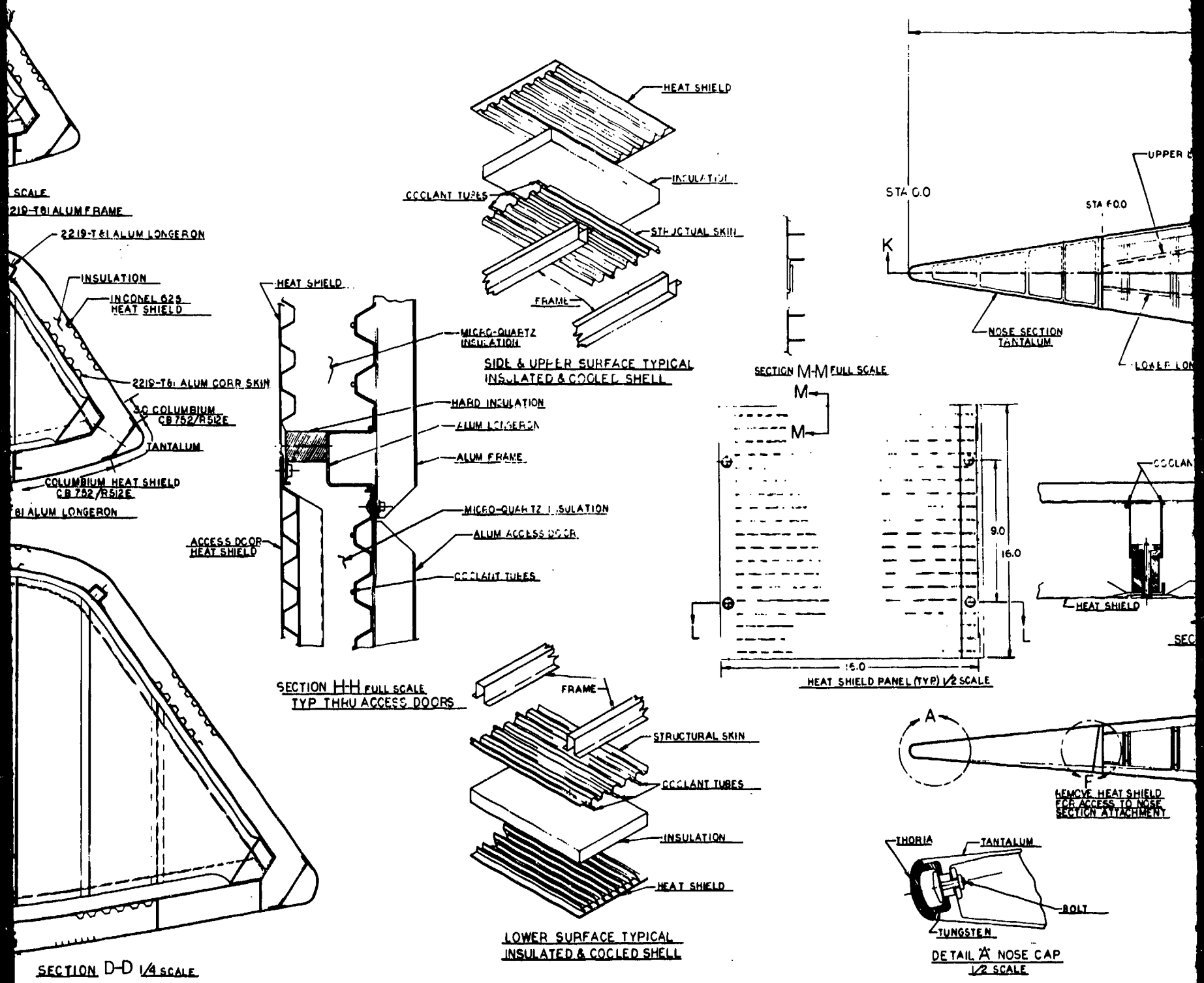
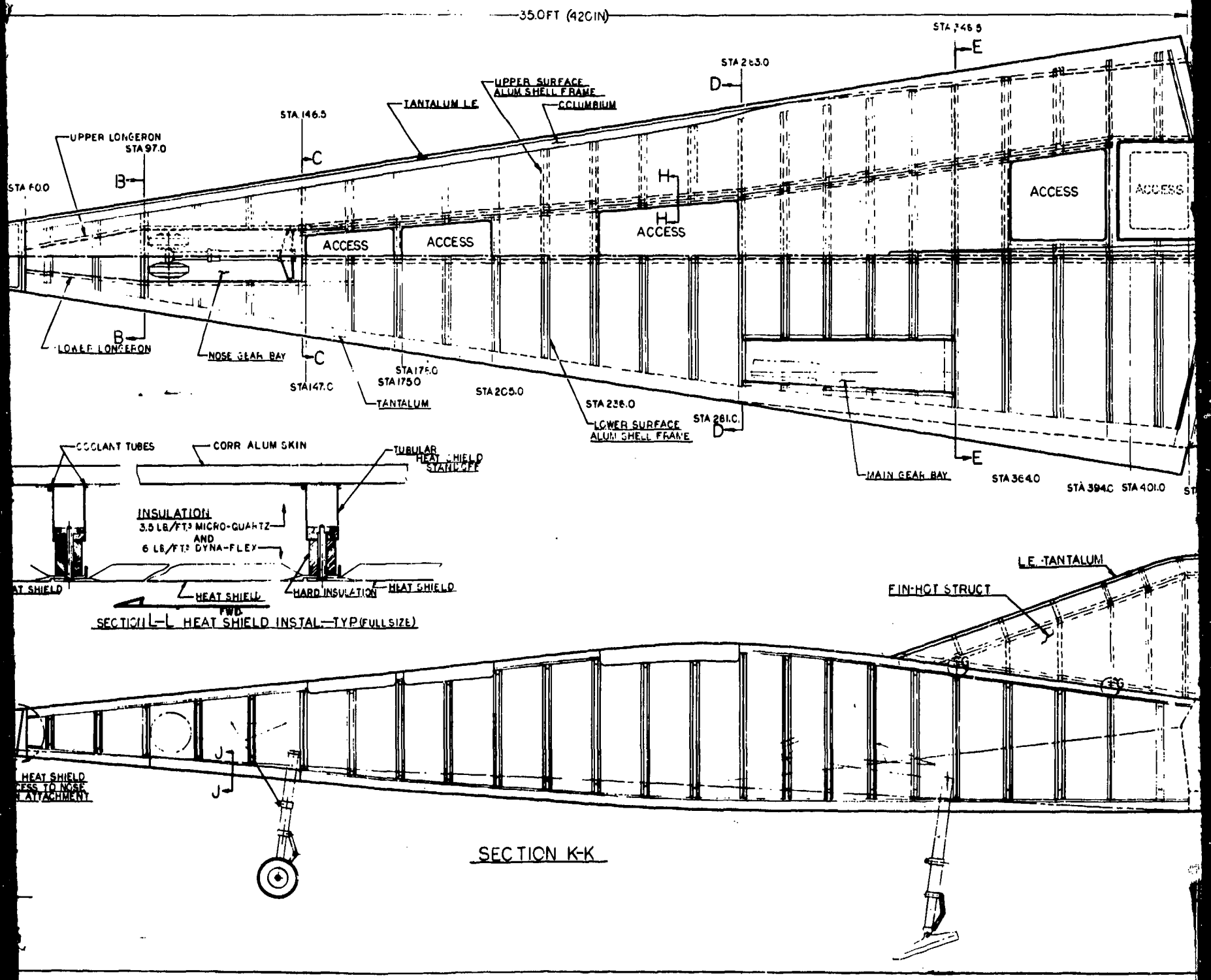


FIGURE 47 (U) LOWER SURFACE WEIGHT COMPARISON - STRUCTURE AND THERMAL PROTECTION SYSTEM FOR VARIOUS THERMO-STRUCTURAL CONCEPTS


BULKHEAD
STIFFENER
ALUM STRUCTURE
TANTALUM NOSE SECTION
FITTING-INCONEL 718
HARD INSULATION
LINK HAYNES 25
INSULATION
I.G. LONGERON EXTENSION
FITTING-INCONEL 718
DETAIL 'F' 1/2 SCALE NOSE SECTION INSTAL
SECTION B-B 1/4 SCALE
2219-T81 ALUM WEB
2219-T81 ALUM
SECTION C-C 1/4 SCALE
2219-T81 ALUM LON
FIN-HOT STRUCT HAYNES 25
INSULATION
HARD INSULATION
PLATE DOUBLER TITANIUM
FIN INSTAL LONGERON
COOLANT TUBE
FITTING INCONEL 718
LONGERON TITANIUM
DETAIL 'G' FULL SCALE FIN INSTAL FITTINGS-TYP 3 PLACES
ALUM FRAME
ALUM FRAME-INNER DOOR
INNER DOOR SKIN-ALUM
INSULATION
INSULATION
COOLANT TUBES
HARD INSULATION
COLUMBIUM HEAT SHIELD
HARD INSULATION
OUTER DOOR-COLUMBIUM
SECTION J-J FULL SCALE
TYP THRU LG DOORS
SECTION E-E 1/4 SCALE


SCALE
2219-T81 ALUM FRAME
2219-T81 ALUM LONGERON
INSULATION
INCONEL 625 HEAT SHIELD
2219-T81 ALUM CORR SKIN
30 COLUMBIUM CB752/R512E
TANTALUM
COLUMBIUM HEAT SHIELD CB 752/R512E
T81 ALUM LONGERON
SECTION D-D 1/4 SCALE
HEAT SHIELD
ACCESS DOOR HEAT SHIELD
MICRO-QUARTZ INSULATION
HARD INSULATION
ALUM LONGERON
ALUM FRAME
MICRO-QUARTZ INSULATION
ALUM ACCESS DOOR
COOLANT TUBES
SECTION H-H FULL SCALE
TYP THRU ACCESS DOORS
HEAT SHIELD
INSULATION
COOLANT TUBES
STRUCTURAL SKIN
FRAME
SIDE & UPPER SURFACE TYPICAL
INSULATED & COOLED SHELL
FRAME
STRUCTURAL SKIN
COOLANT TUBES
INSULATION
HEAT SHIELD
LOWER SURFACE TYPICAL
INSULATED & COOLED SHELL
SECTION M-M FULL SCALE
M
M
9.0
16.0
16.0
HEAT SHIELD PANEL (TYP) 1/2 SCALE
STA 0.0
STA 60.0
K
NOSE SECTION TANTALUM
A
F
REMOVE HEAT SHIELD FOR ACCESS TO NOSE SECTION ATTACHMENT
THORIA
TANTALUM
BOLT
TUNGSTEN
DETAIL "A" NOSE CAP
1/2 SCALE


35.0 FT (420 IN)
STA 346.5
E
STA 263.0
D
UPPER SURFACE
ALUM SHELL FRAME
TANTALUM L.E.
COLUMBIUM
STA 146.5
C
UPPER LONGERON
STA 97.0
B
STA 60.0
H
ACCESS
ACCESS
ACCESS
ACCESS
ACCESS
B
LOWER LONGERON
NOSE GEAR BAY
C
STA 147.0
STA 175.0
STA 175.0
TANTALUM
STA 205.0
STA 236.0
LOWER SURFACE
ALUM SHELL FRAME
STA 281.0
D
E
MAIN GEAR BAY
STA 364.0
STA 394.0
STA 401.0
COOLANT TUBES
CORR ALUM SKIN
TUBULAR
HEAT SHIELD
STANDOFF
INSULATION
3.5 LB/FT.³ MICRO-QUARTZ
AND
6 LB/FT.³ DYNA-FLEX
HEAT SHIELD
HEAT SHIELD
HARD INSULATION
HEAT SHIELD
FWD.
SECTION L-L HEAT SHIELD INSTAL.—TYP. (FULL SIZE)
L.E. TANTALUM
FIN-HOT STRUCT
J
J
SECTION K-K

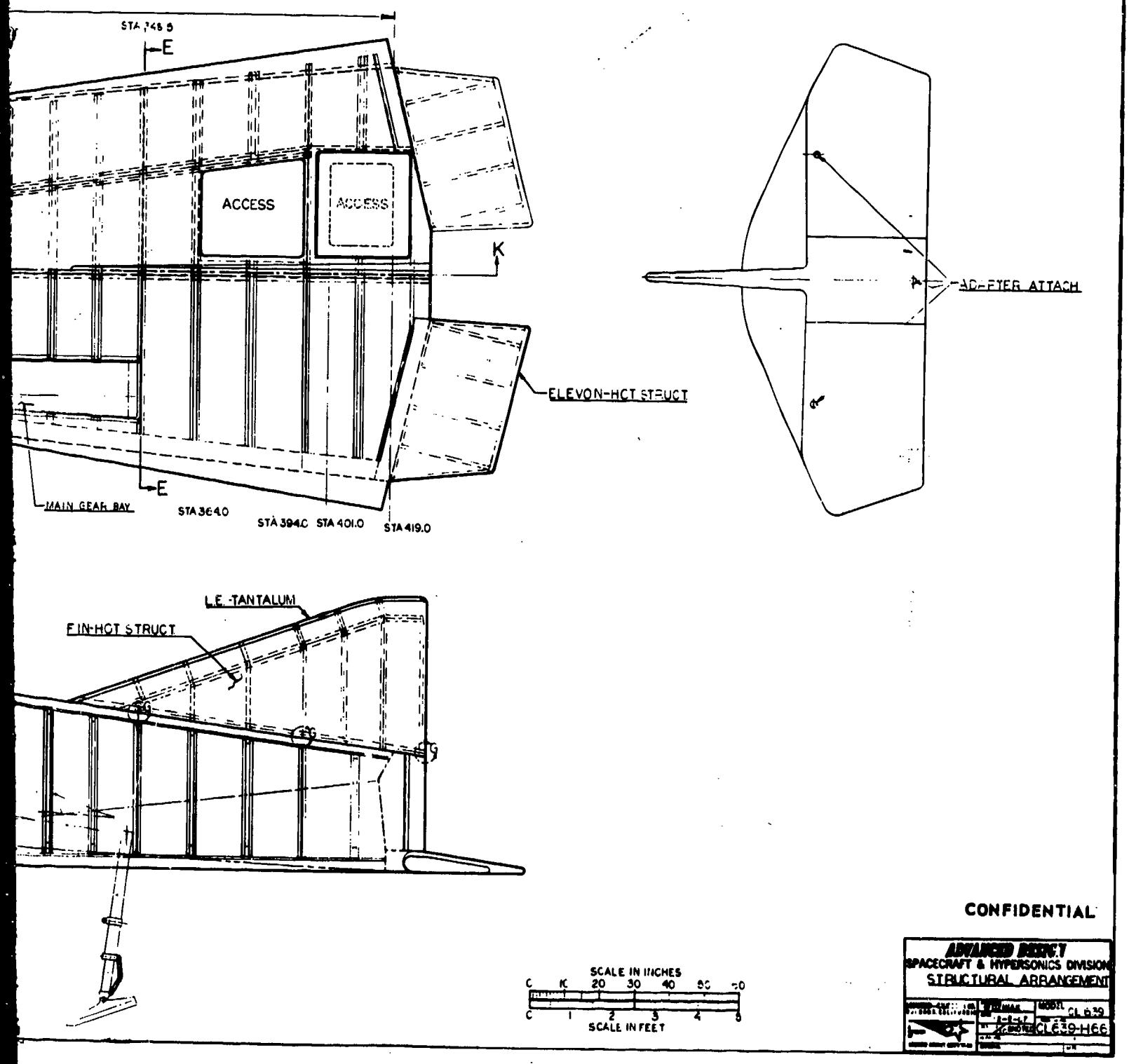
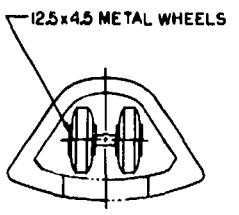
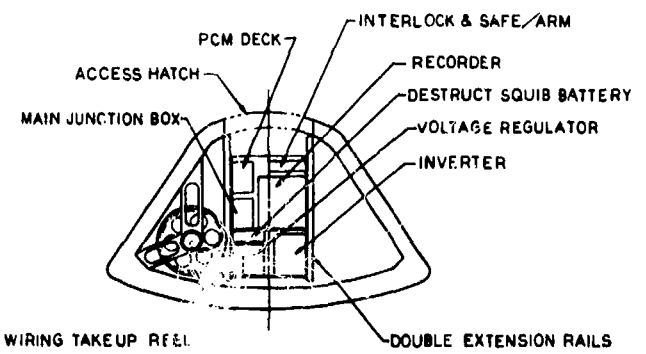


FIGURE 48 (U) MV-37 FLIGHT TEST VEHICLE STRUCTURAL ARRANGEMENT

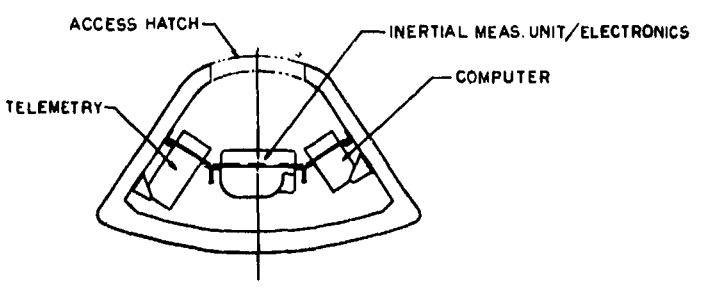
(REVERSE SIDE IS BLANK)



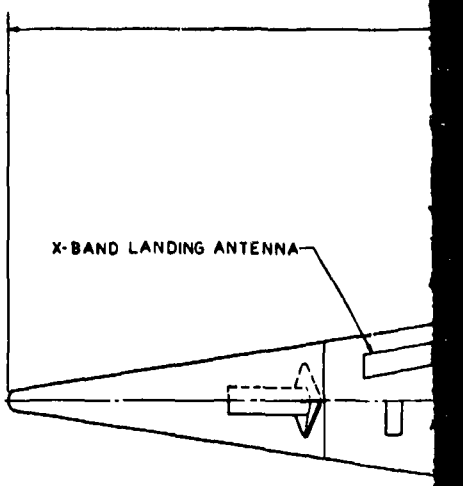
SECTION A-A
STA 105

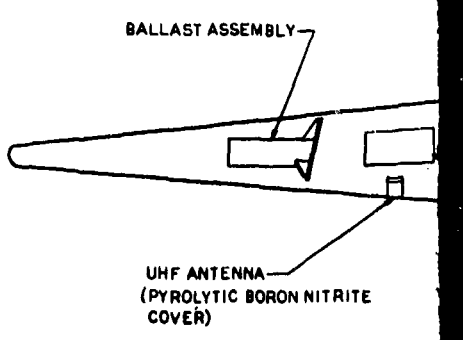


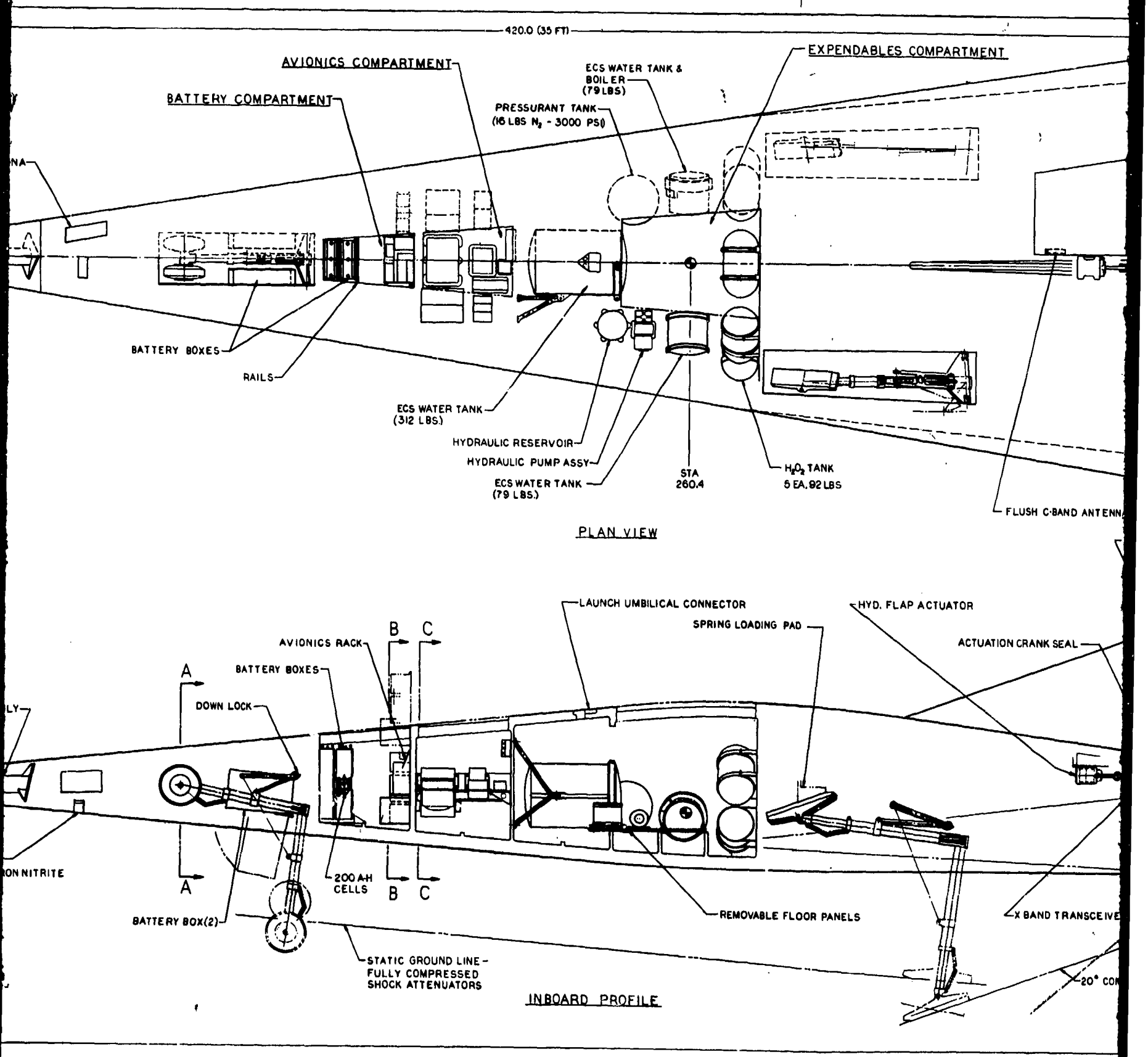
SECTION B-B
STA 176
AVIONICS RACK-SLIDE
OUT FOR ACCESS



SECTION C-C
STA 180
PANEL MOUNTED AVIONICS
EQUIPMENT






420.0 (35 FT)
AVIONICS COMPARTMENT
BATTERY COMPARTMENT
ECS WATER TANK & BOILER (79 LBS)
PRESSURANT TANK (16 LBS N_2 - 3000 PSI)
EXPENDABLES COMPARTMENT
BATTERY BOXES
RAILS
ECS WATER TANK (312 LBS.)
HYDRAULIC RESERVOIR
HYDRAULIC PUMP ASSY
ECS WATER TANK (79 LBS.)
STA 260.4
H_2O_2 TANK 5 EA. 92 LBS
FLUSH C-BAND ANTENN
PLAN VIEW
LAUNCH UMBILICAL CONNECTOR
HYD. FLAP ACTUATOR
SPRING LOADING PAD
ACTUATION CRANK SEAL
AVIONICS RACK
BATTERY BOXES
DOWN LOCK
A
B C
200 A-H CELLS
BATTERY BOX(2)
REMOVABLE FLOOR PANELS
X BAND TRANSCEIVE
STATIC GROUND LINE - FULLY COMPRESSED SHOCK ATTENUATORS
20° CO
INBOARD PROFILE

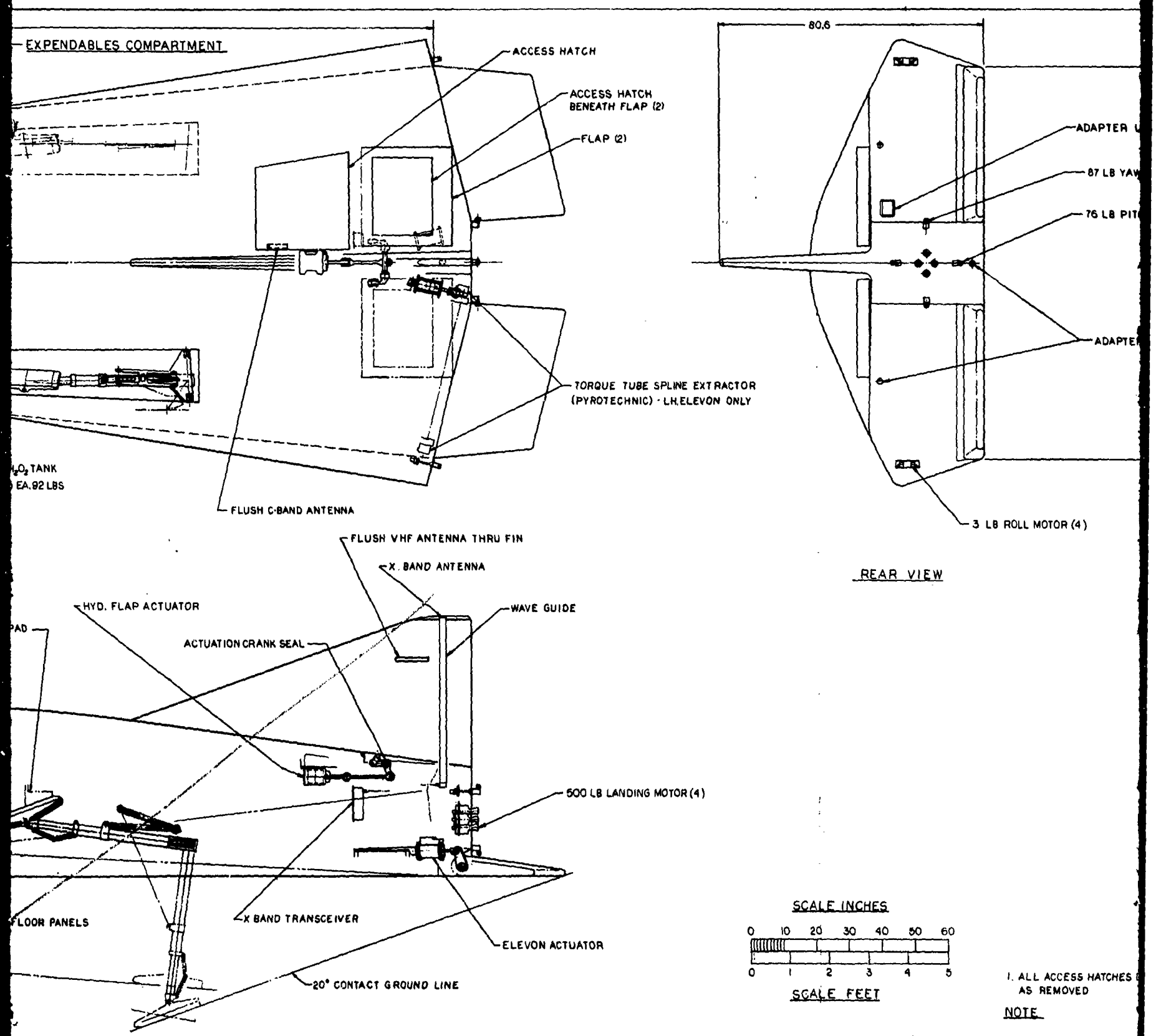


FIGURE 49 (U) BE

(REVERSE SIDE IS

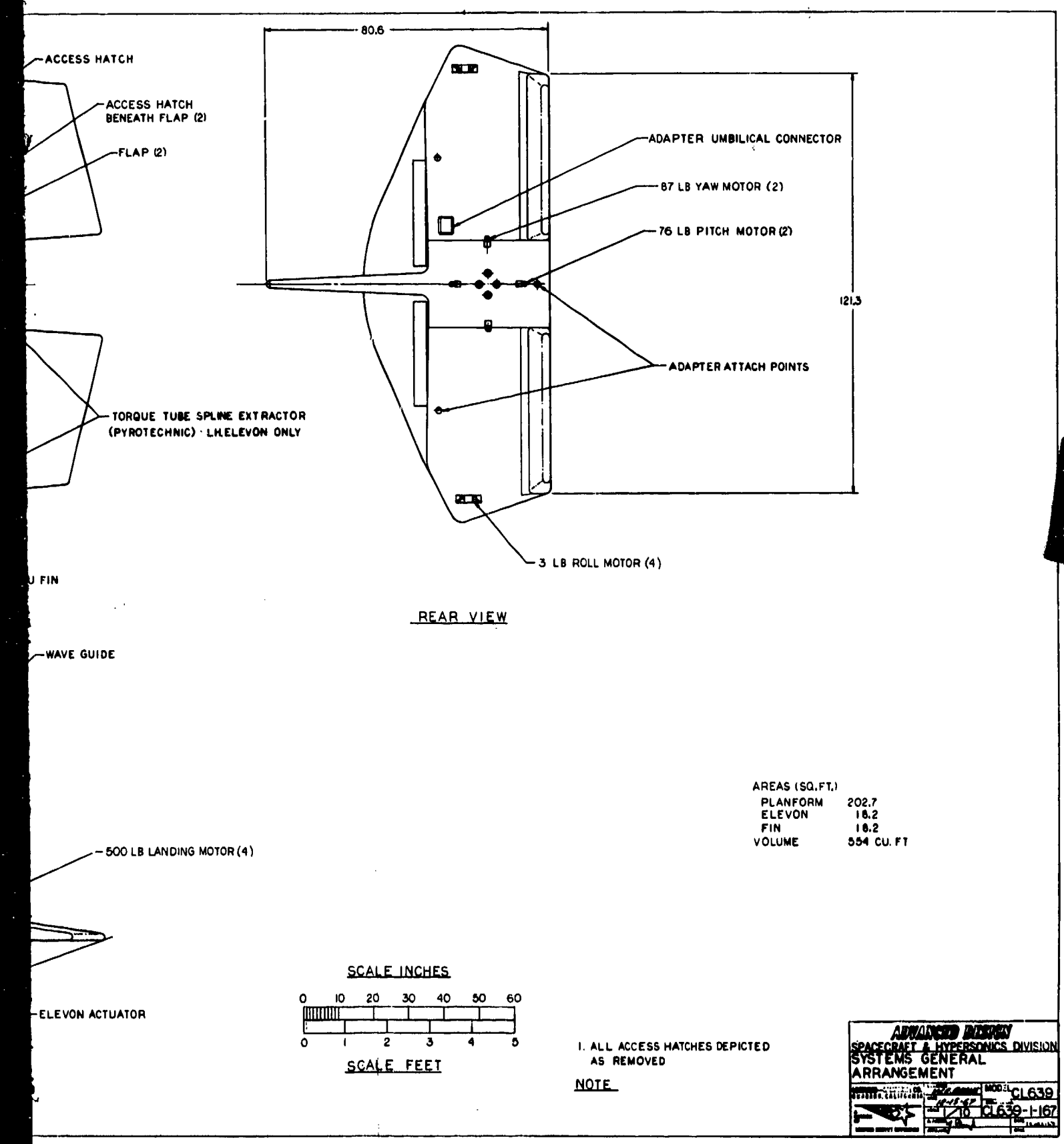


FIGURE 49 (U) BE-1 SYSTEMS GENERAL ARRANGEMENT

(REVERSE SIDE IS BLANK)

TABLE 9

(U) WEIGHT STATEMENT

	Weight (Lb)		C.G. (Sta)*	
STRUCTURE:				
Thermal Protection		1973		258.05
Heat Shield (212 sq ft, Cb 752)	458		281	
Heat Shield (343 sq ft, Inco 625)	693		287	
Leading Edge (64 ft, Ta)	256		240	
Nose Section (Sta 60, Ta)	160		36	
Lwr Surf. Insulation (212 sq ft)	217		277	
Upr Surf. Insulation (343 sq ft)	189		287	
Internal Structure (2219-T81)		1018		284.90
Skins, Single Corrugation	204		285	
Longerons	239		285	
Frames	203		285	
Nose Gear Bay and Doors	48		122	
Main Gear Bay and Doors	109		316	
Penalities for Access Doors (7)	40		281	
Fittings - Elevons	37		419	
Fittings - Body Flaps	11		394	
Fittings - Vertical Fins	11		389	
Gussetts and Attachments	60		285	
Equipment Supports	56		235	
Elevons (17.2 sq ft)		241		441.00
Elevon Seals		25		419.00
Body Flaps (11.6 sq ft)		93		412.00
Vertical Fin (34.3 sq ft) -		274		397.00
Separation Ring (incl Hard Points)		65		430.00
Nose and Main Landing Gears		270		275.00
Contingency		395		294.00
EQUIPMENT: (See Table 10)		2787		247.14
BALLAST: (To 62 percent)		525		50.00
Gross Weight		7666		260.42
Less:				
Water		-418		249.00
Ammonia		- 20		226.00
Hydrogen Peroxide		-438		276.00
Minimum Landing Weight		6790		260.22
*Nose of vehicle = 0 Body reference length = 420 in.				UNCLASSIFIED

TABLE 10

(U) EQUIPMENT BREAKDOWN

	Weight (Lb)		C.G. (Sta)	
GUIDANCE AND NAVIGATION SYSTEM:		69		184.00
IMU and Electronics	40		184	
Computer and Rate Gyros (3)	19		184	
Cabling and Connectors	10		184	
FLIGHT CONTROL SYSTEM				
AERODYNAMIC CONTROL SYSTEM:		270		306.07
Hydraulic Pump, Accumulator, Reservoir	140		250	
Hydraulic Actuators	70		402	
Plumbing and Valves	60		325	
LANDING PROPULSION SYSTEM:		50		411.80
Thrust Motors (4)	40		427	
Plumbing and Valves	10		351	
Propellant included in RCS	--			
AUTOPILOT SYSTEM:		50		198.00
REACTION CONTROL SYSTEM:		686		287.30
Thrust Motors	54		425	
Tanks (H_2O_2)	113		276	
Tank (N_2)	28		246	
Hydrogen Peroxide	460		276	
Nitrogen	16		246	
Plumbing and Valves	15		350	
DATA MANAGEMENT SYSTEM:		190		184.87
Real-Time Microwave Transmitter	14		184	
Microwave Power Divider	3		184	
Real Time VHF Transmitter	3		184	
Delayed Time VHF Transmitter	4		184	
VHF Multiplexer	2		184	
PCM Deck	20		172	
Subcarrier Oscillator, Sampler, and Translator	2		184	
Telemetry Tape Recorder	13		172	
Microwave Antenna	1		184	UNCLASSIFIED

TABLE 10

(U) EQUIPMENT BREAKDOWN (Concluded)

	Weight (Lb)		C.G. (Sta)	
VHF Antenna	3		184	
Instrumentation	100		184	
Cabling and Connectors	25		178	
TRACKING AND COMMAND SYSTEM:		86		161.20
C-Band Transponder	7		396	
C-Band Diplexer	4		396	
C-Band Power Divider	3		396	
C-Band Antenna	1		396	
Transponder - Landing	18		78	
Diplexer - Landing	4		78	
Power Divider - Landing	3		78	
Antenna and Corner	8		78	
Receiver Decoder	20		78	
Antenna	1		78	
Cabling, Connector, etc	17		237	
ENVIRONMENTAL CONTROL SYSTEM:		748		253.86
Water	460		249	
Ammonia	22		226	
Ethylene - Glycol	67		285	
Loop Distribution	83		285	
Pump and Motor	10		226	
Tanks and Supports	53		252	
Heat Exchanger	53		226	
ELECTRIC POWER SYSTEM:		300		147.56
Batteries	208		138	
Inverter and Regulator	30		172	
Umbilical and J Box	27		172	
Wiring	35		155	
DESTRUCT SYSTEM:		24		172.00
LANDING GEAR SYSTEM:		60		275.00
Landing Gear (included in structure)				
Controls	60			
CONTINGENCY		254		247.00
TOTAL		2787		247.14

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SECTION 7

(U) CONCLUSIONS

(U) A new lifting entry vehicle concept has been defined and tested through

- Parametric configuration analyses
- Parametric structural analyses
- Wind tunnel testing at M = 1.5 to 20
- Preliminary design

(U) The configuration has been designated FDL-5 to identify it as one of a series undergoing concurrent development by the Air Force Flight Dynamics Laboratory.

(U) The FDL-5 configuration design provides a high degree of useful volume, while maintaining high hypersonic lift-to-drag ratio. The configuration has been derived through a series of design trades involving the consideration of:

- Aerodynamic performance
- Aerodynamic stability and control
- Aerodynamic heating
- Material temperature limitations
- Usable volume
- Booster compatibility

(U) Modification of controls, base geometry and/or addition of variable geometry may be required to obtain satisfactory subsonic performance.

(U) A preliminary candidate structural concept has been defined for an unmanned hypersonic test vehicle using the FDL-5 configuration. The concept provides maximum internal volume. An insulated-and-cooled aluminum primary structure is employed, while the vehicle surface is composed mostly of radiation-cooled, coated, refractory metal and superalloy heat shields.

(U) Candidate subsystems to perform the research mission have been reviewed and a tentative selection is described.

(U) Specific conclusions related to the various technical disciplines are as follows:

7.1 (U) AERODYNAMICS

1. (C) The configuration is stable in all three axes over the Mach range from 1.5 to 20.

2. (C) Trimmed hypersonic L/D_{max} extrapolated to reference conditions (200,000 feet altitude, 20,000 fps, 35 feet length) is 2.84 at 11 degrees angle of attack. Maximum trimmed L/D_{max} during entry is 3.3 at Mach 12.

3. (U) Test data correlate in general with analytical predictions using tangent-cone theory on compression surfaces and Prandtl-Meyer theory on expansion surfaces at hypersonic speeds.

4. (C) Modification to the aft upper surface, base and elevon geometry will be required as a result of subsonic and transonic wind tunnel tests. Modification of these surfaces of the FDL-5 system are not expected to affect hypersonic performance.

7.2 (U) AEROTHERMODYNAMICS

1. (U) For the low-altitude reference trajectory, predicted surface temperatures are compatible with the proposed structural materials: tungsten-thoria for the nose cap, coated tantalum for leading edges, coated columbium for the lower surface, and Inconel for the upper surface. The leading-edge material must be extended approximately 4 inches beyond the leading-edge/side-panel tangency line, and portions of the forward upper surface must be fabricated from a material, such as coated columbium, which has a temperature capability exceeding that of superalloys.

2. (C) From a heating standpoint, the lower surface is the most critical. Peak centerline temperatures on this surface range from about 2000°F at station 396 to 2450°F at station 120 for the banked low altitude reference trajectory.

3. (C) For the low-altitude reference trajectory, predicted maximum temperatures on essentially the entire lower surface result from turbulent flow. For a practical range of transition Reynolds numbers, peak temperatures on the aft lower surface are not sensitive to transition criterion. Forward ramp peak temperatures, however, decrease significantly with increasing transition Reynolds number. Results of wind tunnel transition data on the FDL-5 and basic geometries indicate that heating rates based on the assumption of an instantaneous shift from laminar to turbulent flow at $Re_\theta/M_e = 150$ may be overly conservative.

4. (C) At the design point flight conditions, radiation equilibrium temperatures based on the AEDC heat transfer data generally agree with analytically predicted temperatures within ±200°F on the lower surface, and within ±100°F on the body side panels and aft lower compression surface.

5. (U) Increasing the vehicle wing loading from the assumed value of 35 psf results in an increase in lower surface temperature of approximately 18°F/psf.

7.3 (U) STRUCTURES

1. (U) The parametric structural analysis indicates that:

- Minimum gage criteria establish structural weight requirements over most of the body shell.
- The radiation-cooled, hot-load-carrying structural concept, without internal temperature constraint, is minimum weight.
- The vehicle weight for a hot-load-carrying structure concept, with internal insulation and active cooling, is 2 percent more than with the use of an insulated and cooled primary load carrying aluminum alloy structure.
- The passive insulated concept weight is competitive with that of the other concepts; however, this concept has a lower volumetric efficiency.

2. (U) Structural concept and material selections were made, and the following is recommended for the flight test vehicle:

- Insulated and actively cooled concept, using 2219-T81 aluminum alloy for the internal primary load carrying structure (skin, frames, longerons).
- Edge-supported heat shield panels. The lower surface uses integrally stiffened panels, made of Cb-752/R512E coated columbium alloy. The upper surface uses skin-corrugation panels, made of Inconel-625 nickel alloy. (The more commercially available and more oxidation-resistant cobalt alloy Haynes-25 may be used at a weight increase of approximately 60 lbs.)
- Dyna-Flex (6 lb/ft^3) and Micro-Quartz (3.5 lb/ft^3) insulation.

7.4 (U) WEIGHT

1. (U) The estimated unmanned free flight vehicle launch weight is 7666 pounds.

2. (U) Estimated landing weight is 6790 lb, and the landing wing loading is 33.5 psf.

REFERENCES

1 Lockheed-California Company, Preliminary Design of Hypersonic High L/D Test Vehicles, AFFDL-TR-66-12, J. T. Lloyd et al, May 1966.

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4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Final Report (1 July 1966 through 31 March 1968)

5. AUTHOR(S) *(Last name, first name, initial)*

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13. ABSTRACT

(U) Conceptual design and experimental wind tunnel testing of unmanned entry research vehicles having high hypersonic lift/drag ratio and high volume are described. Analytic parametric data are presented for two lifting body classes designated HLD-35 and FDL-5. The FDL-5 is a unique configuration which is aerodynamically stabilized without outboard fins. Experimental aerodynamic and heat transfer data from the Arnold Engineering Development Center Wind Tunnels A, B, C, and F are compared with analytic data for the FDL-5. Candidate structure and subsystems are selected for performing unmanned hypersonic research with the vehicle.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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* High Hypersonic L/D and High Volume Research Vehicles						
* HLD-35 Configurations						
* FDL-5 Configurations						

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