Report No. NADC-77265-30

FEASIBILITY DESIGN STUDY FOR SCALE MODEL OF ZPG-X AIRSHIP

Contract N62269-77-M-4260

Jun[redacted]978

74p.

Prepared For

NAVAL AIR DEVELOPMENT CENTER

Warminster, Pennsylvania

GER-16558

By

GOODYEAR AEROSPACE CORPORATION

AKRON, OHIO

Final rept.

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J. W. Lancaster

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 77265-30	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Feasibility Design Study for Scale Model of ZPG-X Airship		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER GER-16558
7. AUTHOR(s) J. W. Lancaster		8. CONTRACT OR GRANT NUMBER(s) N62269-77-M-4260
9. PERFORMING ORGANIZATION NAME AND ADDRESS Goodyear Aerospace Corporation 1210 Massillon Rd Akron, Ohio 44315		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AIRTASK A03P/001B/7WF41-411-000 Work Unit No. DH816
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Air Development Center Code 30P3 Warminster, Pa. 18974		12. REPORT DATE June 1978
		13. NUMBER OF PAGES 74
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Air Development Center Code 30P3 Warminster, Pa. 18974		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Lighter-Than-Air
VTOL
Flight Test Model

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents a Feasibility Design Study of a scale model of the ZPG-X airship which would demonstrate the VTOL and hover capability of this vehicle concept.

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FOREWORD

Goodyear Aerospace Corporation, under contract to the U.S. Navy, Naval Air Development Center (NADC), recently conducted a study of a modernized version of the U.S. Navy ZPG-3W non-rigid airship utilized as an AEW platform during the early 1960's. The configuration resulting from that study designated the ZPG-X is a VTOL/Hover capable modern airship vehicle.

Evaluation of this vehicle as a part of the Advanced Navy Venicle Concept Evaluation (ANVCE) study indicated substantial improvements in the performance and operational capabilities of the ZPG-X and identified several promising Naval mission applications. Complete results are documented in GER-16456. This potential resulted in the feasibility design study, documented in this report, of a scale model of the ZPG-X which would demonstrate the VTOL and hover capability of this vehicle concept.

The objectives of the study were to analyze small scale models of the ZPG-X, select a preferred concept, and estimate the program cost. Two scale sizes were analyzed; one-half and one-twelfth. The preferred/selected concept is in the one-twelfth to one-tenth scale range based on a qualitative assessment of cost effectiveness.

Messrs John Eney and Dave Bailey of the NADC LTA project office provided valuable guidance during the study effort. Mr. N. D. Brown was the principal designer on the one-half scale model and Mr. J. Killion was the principal designer on the one-twelfth scale model. Total contract value for the work reported herein was $9,958.

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References

1) GER 16456 Rev. A, "Advanced Navy Vehicle Concept Evaluation - ZPG-X Point Design - Goodyear Aerospace Corporation, March 1978

1.0 INTRODUCTION AND SUMMARY

1.1 Introduction

The feasibility design effort was focused on two different design concepts with substantially different objectives.

1.2 One-Half Scale Model

The objective of the large scale model (one-half) design effort was to define characteristics of a ZPG-X type vehicle which would be a modification to the Goodyear Advertising Blimps. Northrup 0-100-B, 4 cylinder, 2 cycle engines developing about 90 HP at 4100 RPM were selected for both the forward and aft propulsors. Thrust output of the propulsors is a critical factor in the success of the concept.

Consequently a two phase program was defined. Phase I would consist of a ground test program to determine the thrust of the forward propulsors, and the thrust and control moments of the stern propulsor and ruddervator control surfaces. Approximate costs of the ground test phase is $340,000.

The second phase of the program would consist of actually modifying an advertising airship to include the foreward and aft propulsors. Three options, involving different utilizations of Goodyear airship assets, were examined: 1) Constructing a "new" airship out of existing spare components, 2) retiring an existing operational vehicle "early" and making the necessary additions, and 3) waiting until the normal retirement of an existing vehicle. Approximate cost estimates for these options range from $1,000,000 to $1,600,000.

The one-half scale model would provide a man-rated test and demonstration platform which could provide valuable insights into the flight dynamics and handling characteristics of a ZPG-X type vehicle.

1.3 One-Twelfth Scale Model

The second design concept pursued, the one-twelfth scale model, had an entirely different objective guiding the study effort. No flight dynamics, or man-rated handling quality data would be expected to result from this vehicle. Rather, the objective was to identify a low-cost concept demonstration vehicle which could provide a visual, in-flight demonstration of a VTOL/hover capable modern airship such as the ZPG-X. The value of this type of a vehicle has been aptly described in the June issue of Aeronautics and Astronautics ("Grumman's Radio-Controlled Experimental Air Force by Bruce Frisch). In this article, Robert Kress, Assistant Director of Advanced Concepts is quoted as follows (referring to the value of small-scale, radio-controlled V/STOL aircraft):

> "Though he shrinks from developing his models into mini-RPVs, Kress rates them high for selling a concept. He rates them fairly low as a design aid, but adds, "In the technical area they are regarded as valid for certain tasks in the airplane-design business. For example, they provide a good indication of the airplane's static stability and control, providing you stay out of the stall regime. In the hovering case, they are dynamically dissimilar from a rotational point of view. On the other hand, in the initial stages of airplane design, most of the key issues pertaining to V/STOL concepts are static issues rather than dynamic. Also, because of the 3:1 speed-up in model response rates, if you can fly it in model scale with the

crude equipment we have to work with, then your chances of operation at full scale are probably excellent."

Two designs evolved from the one-twelfth scale study, one gasoline engine powered, and a second, electric motor powered. Both designs assumed utilization of fabric and miscellaneous material available inhouse at GAC, and motors, propellers, and radio control equipment readily available through local suppliers.

Electric motor propulsors were selected on the basis of potential problems with vibration of the "glow plug" gasoline engines. A remote, 110V AC power supply connected via umbilical to a DC converter on board the vehicle was the final design resulting from the current effort. This arrangement results in an umbilical which is much lighter and more flexible than the alternative of placing the DC converter at the ground end of the umbilical. Since the thrust output is a critical design factor, a two-phase program was defined similar to that for the one-half scale program described above. The ground test phase (thrust and stern control surface force and moment calibration) could be completed in about 2 months for approximately $10,000.

The second phase of the program would include construction of the envelope and fins and assembly of the propulsors and control surface. This phase of the program would take about 4 months at an approximate cost of $40,000. No Engineering analysis or flight testing is included in these approximate costs. Effort would be required to analyze the expected flight characteristics and to identify control system logic for the VTOL/transition flight demonstration program.

An overall design feasibility assessment of the umbilical powered, one-twelfth scale model indicates that a slightly larger model scale (about one-tenth) and/or an on-board battery power approach would be a more feasible design alternative. Further analysis of these options is recommended.

On the basis of a qualitative judgement of budgetary constraints, the virtues of serial development, and overall concept cost effectiveness for the current state of the ZPG-X concept development, the small scale model concept (one-twelfth to one-tenth scale) is recommended for further program evaluation. Upon successful completion of the flight demonstration of this vehicle concept, the one-half scale size vehicle should be pursued, at least through the ground test phase.

2.0 ONE-HALF SCALE MODEL

2.1 Discussion

The complete list of design data and drawings produced for the one-half scale model concept is contained in Table I. A program overview of the preliminary one-half scale model test program are shown in Table II. Preliminary, budgetary planning, approximations of material costs, and labor hours are also shown in the table. Note: These costs do not include costs associated with making the GZ20 vehicle ready and available for the program.

Further definition of the tasks associated with each phase of the one-half scale model test program are contained in Table III. This task effort is possibly incomplete and should be reanalyzed prior to commencement of the one-half scale model test program. Its inclusion is solely for the purpose of identifying the scope of the task efforts required for the one-half scale model test program.

TABLE I - ONE-HALF SCALE MODEL DRAWINGS

Figure No.	GAC Drawing No.	Description
1	77-244	GZ20, Half-Scale Model of ZPG-X Hover Demonstration Vehicle
2	--	Forward Power Plant Installation: GZ20 Half-Scale Model
3	--	Aft Power Plant: GZ20 Half-Scale Model
4	77-256 Sht. 4	Half-Scale Model Ruddevator and Control Surface
5	77-256 Sht. 3	Control Surface Design Detail
6	77-433 Sht. 1	Stern Control Surface Hydraulic Actuator
7	77-436	Stern Engine Mounting, Cushioning, and Hydraulic System Design Details
8	77-433 Sht. 2	Stern Engine Hydraulic Details
9	77-300	Ground Test Stand Assembly: Rear View
10	77-300	Ground Test Stand Assembly: Side View
11	77-256 Sht. 2	Ground Test Stand Engine Mount: Top View
12	77-256 Sht. 1	Ground Test Engine Mount: Gear Box and Engine Assembly

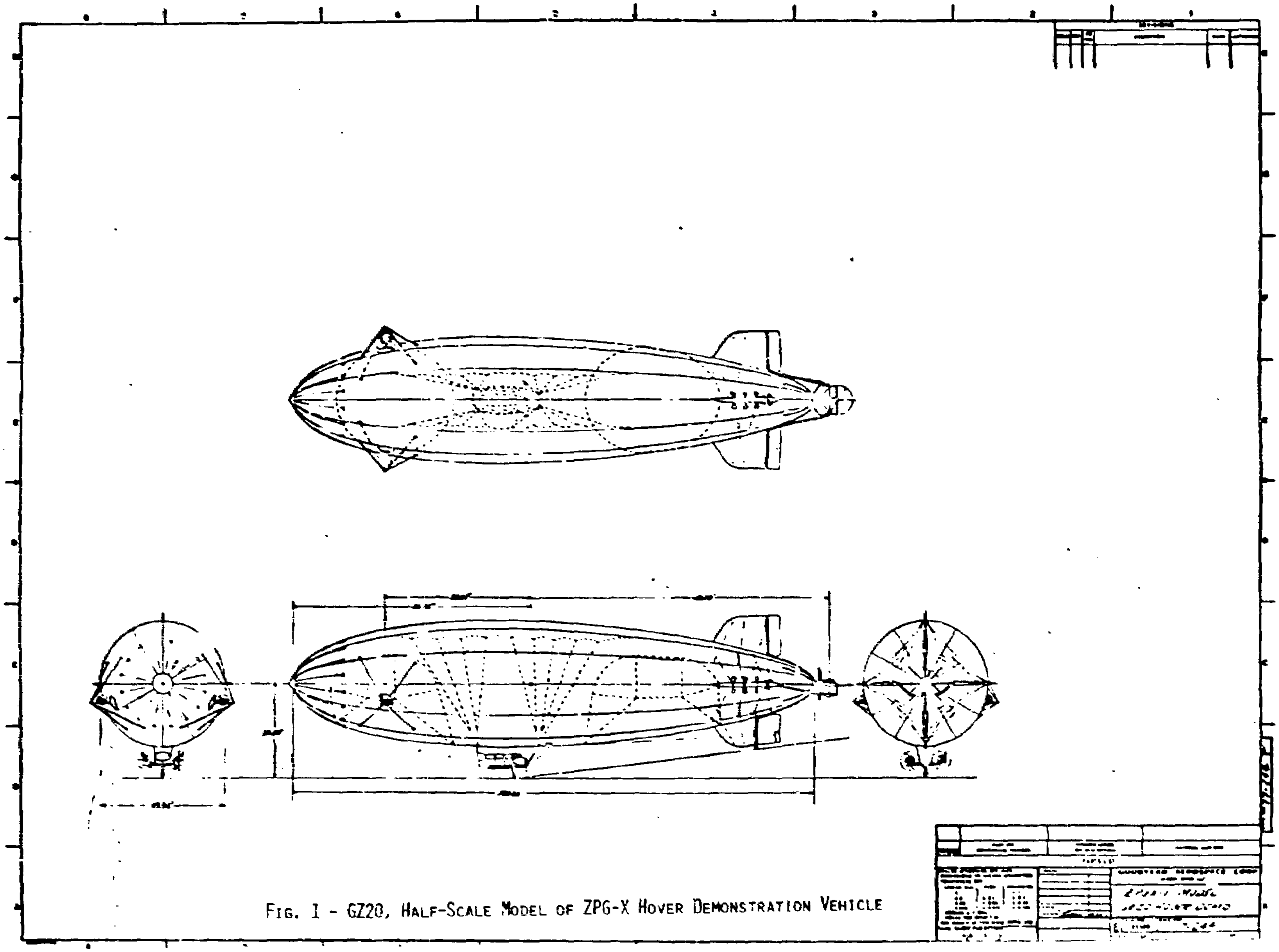


Fig. 1 - GZ20, Half-Scale Model of ZPG-X Hover Demonstration Vehicle

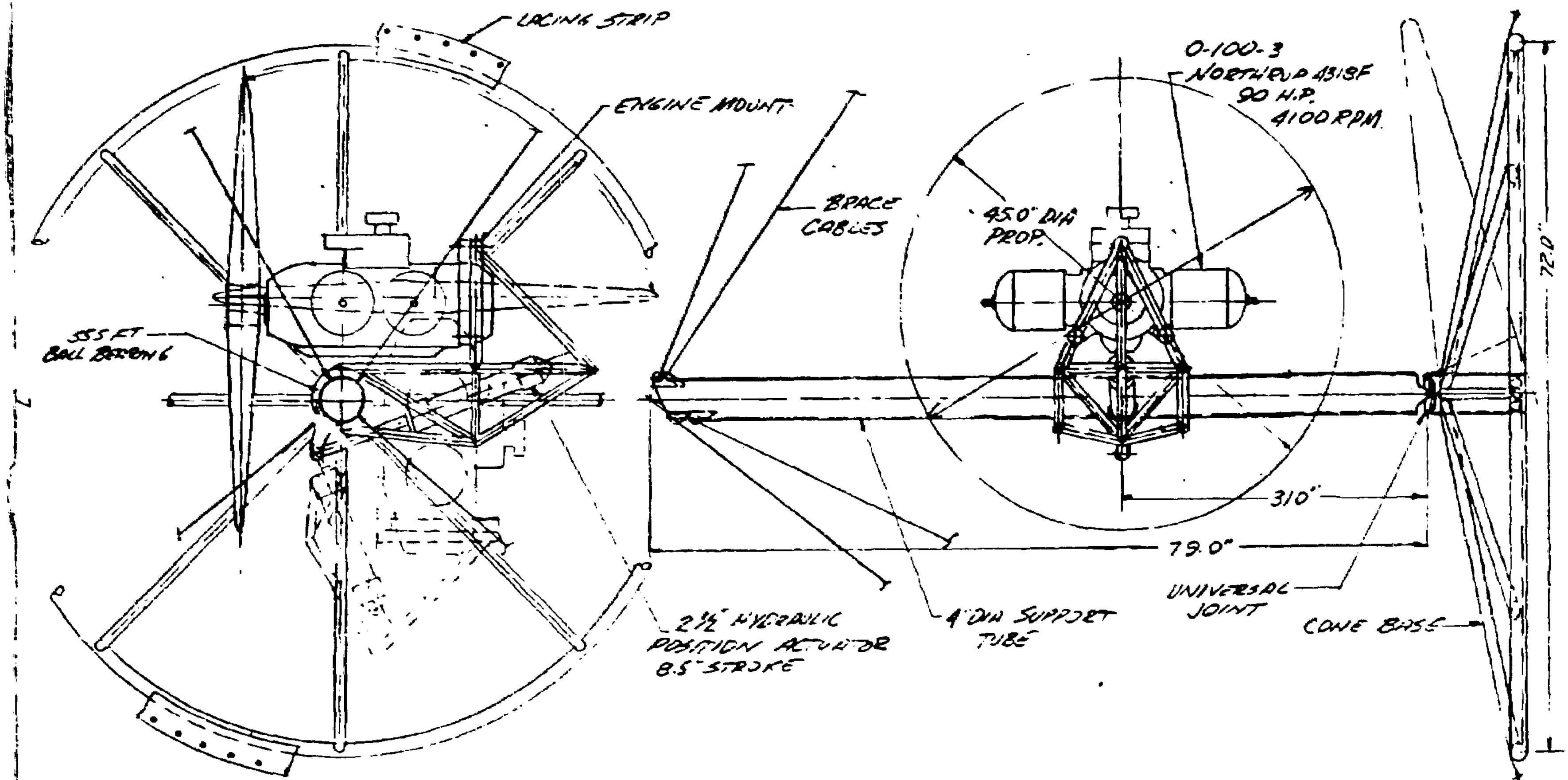


Fig. 2 - Forward Power Plant Installation: Half-Scale Model

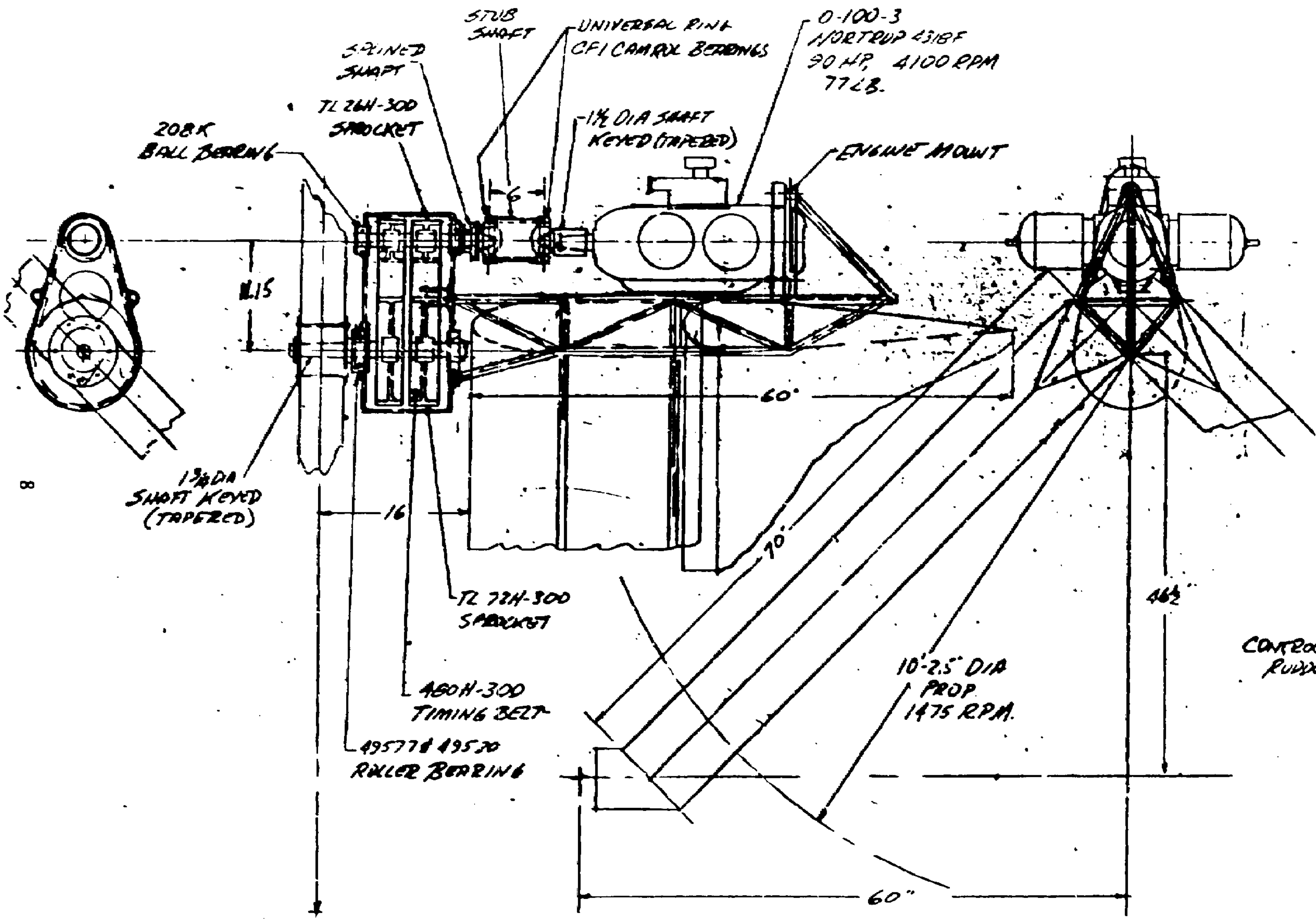


FIG. 3 - AFT POWER PLANT: GZ20 HALF-SCALE MODEL

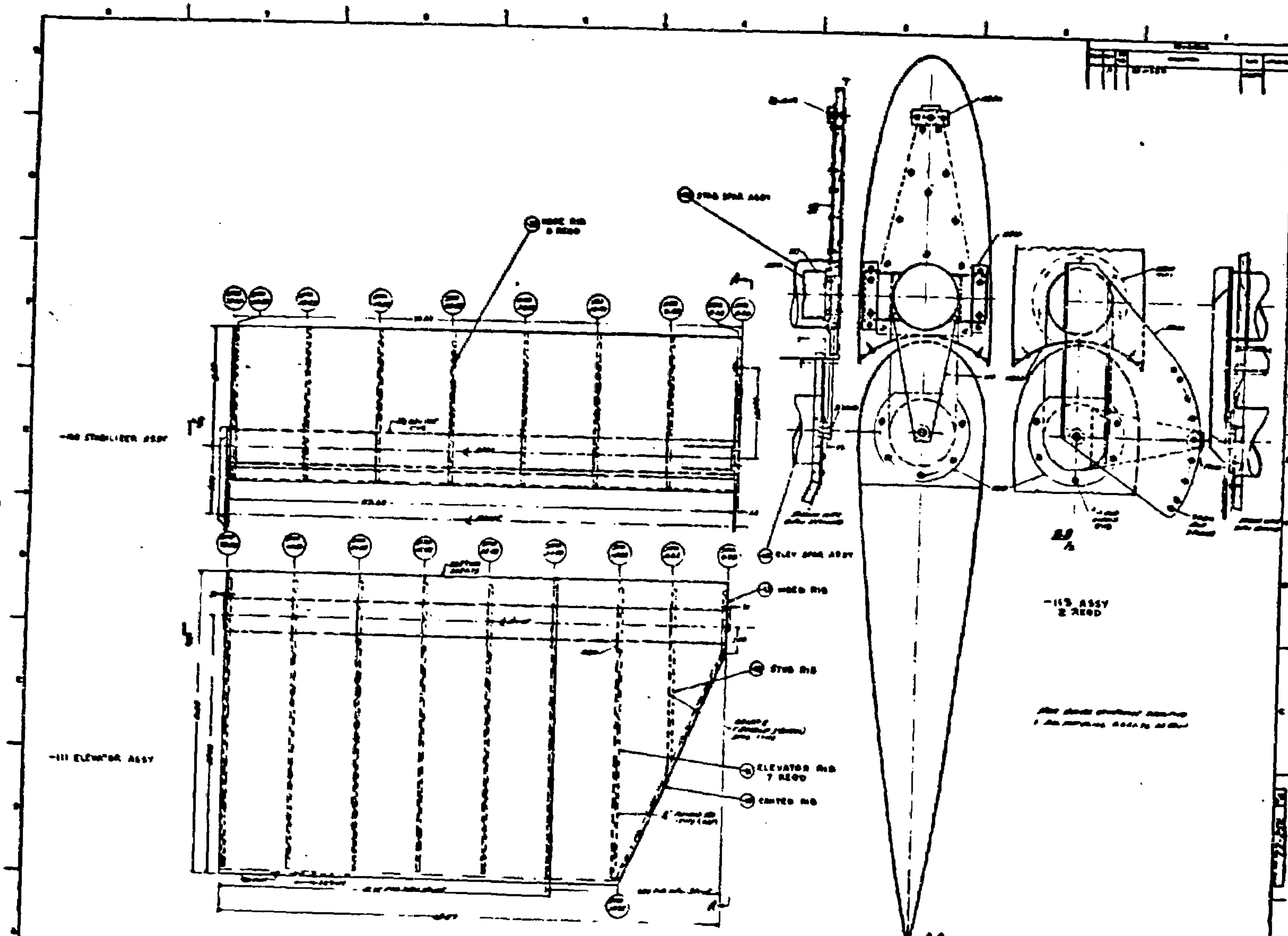


FIG. 4 - HALF SCALE MODEL RUDDEVATOR AND CONTROL SURFACE

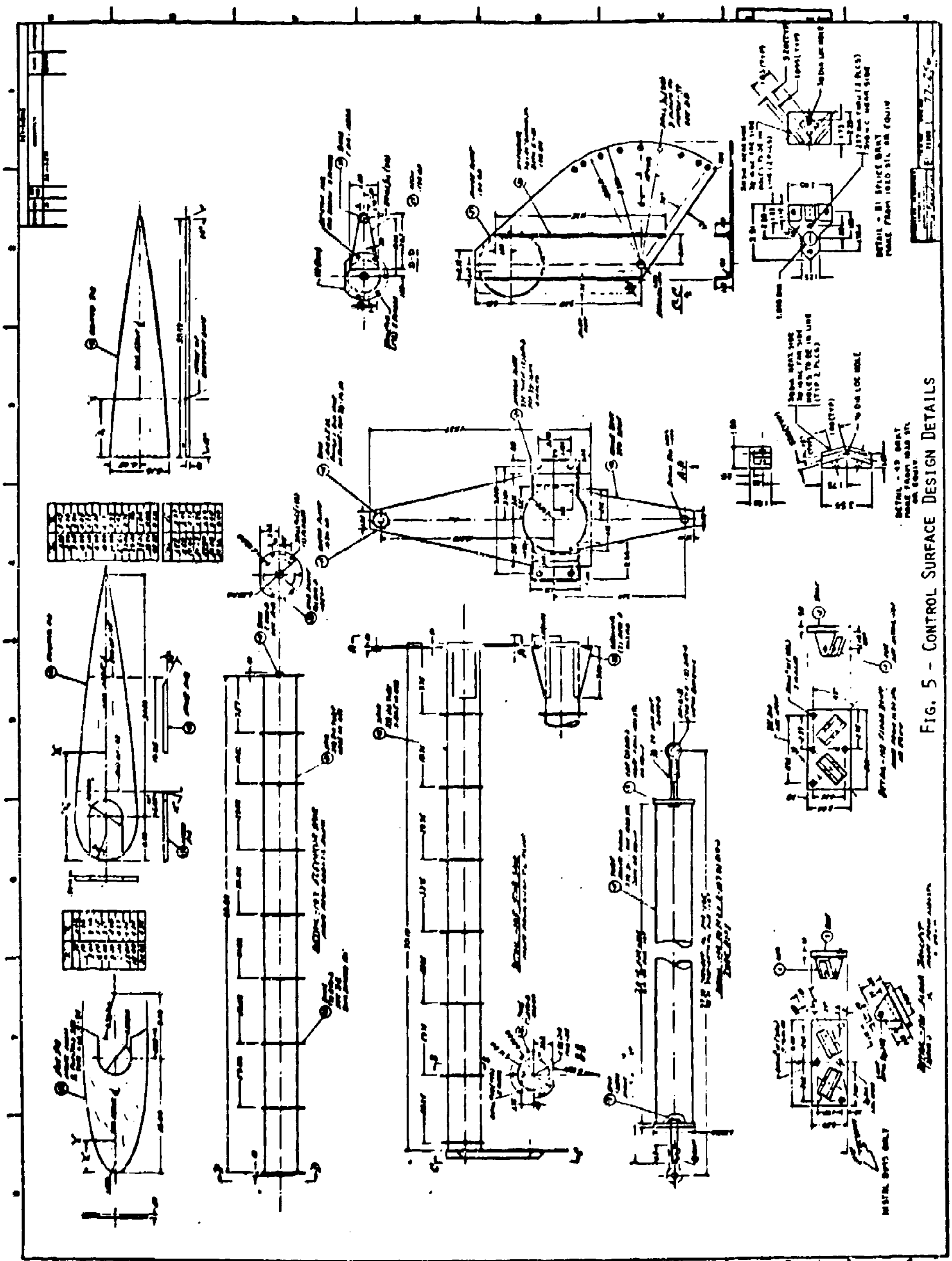


Fig. 5 - Control Surface Design Details

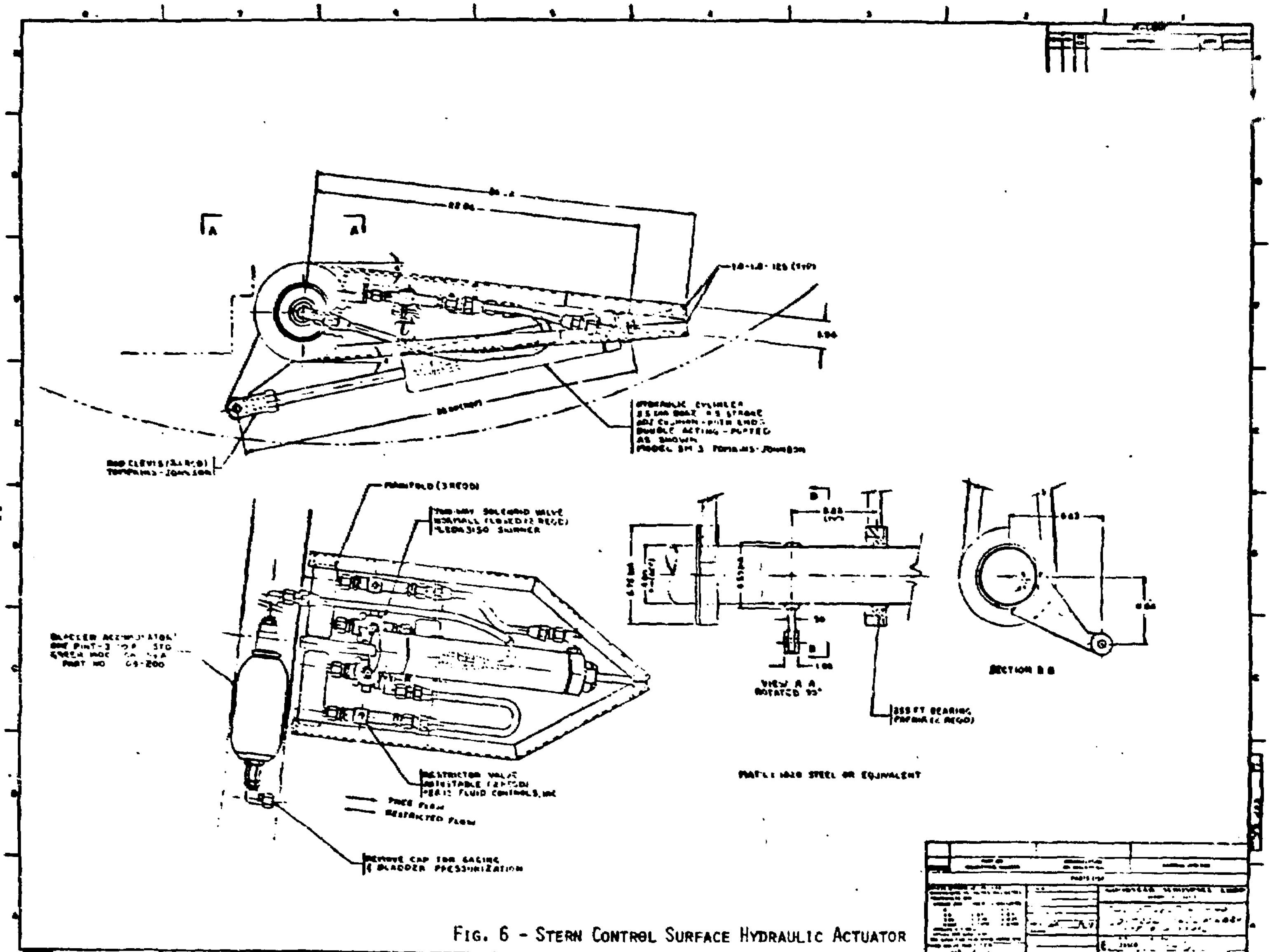


Fig. 6 - Stern Control Surface Hydraulic Actuator

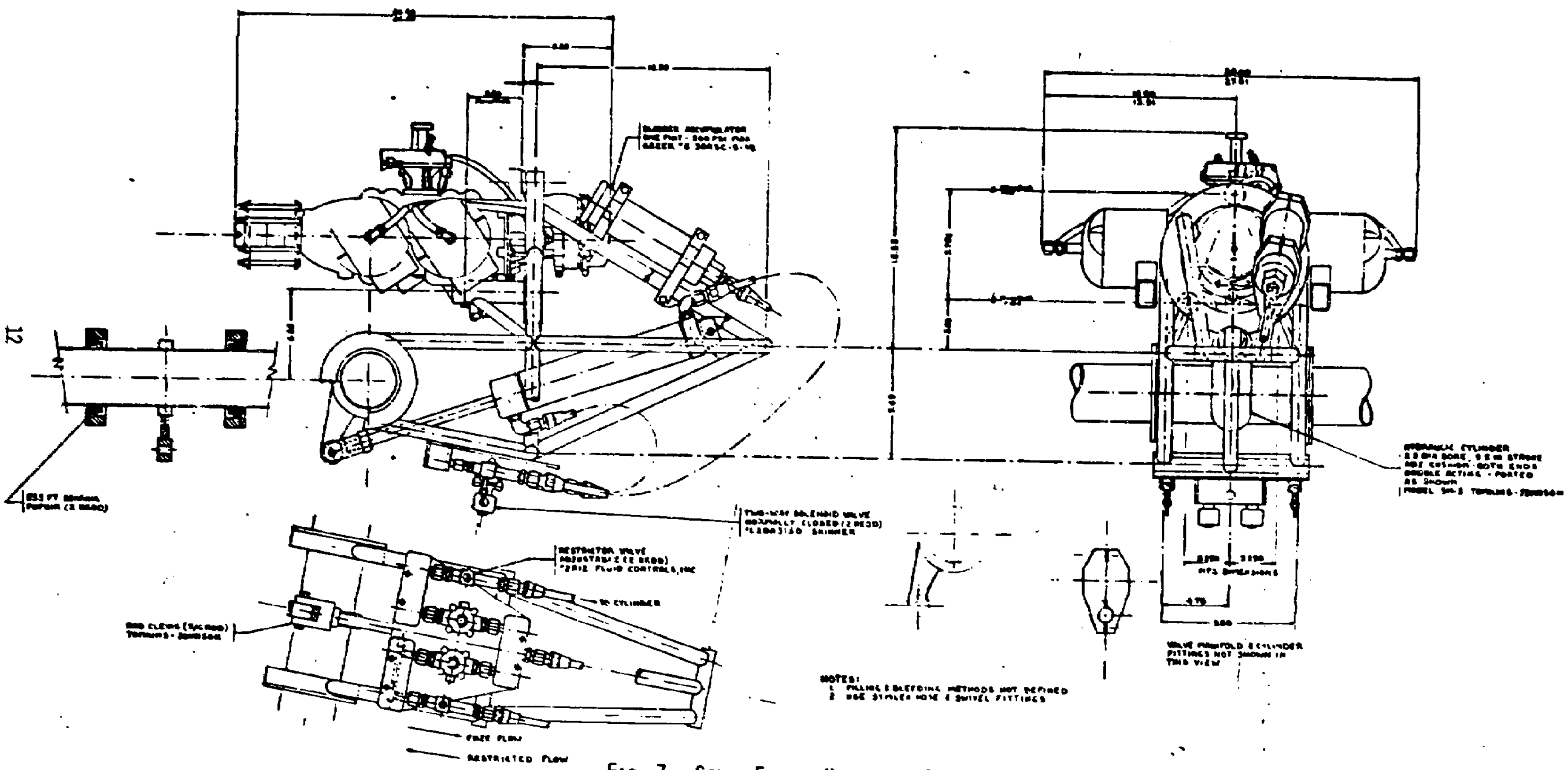


FIG. 7 - STERN ENGINE MOUNTING, CUSHIONING, AND HYDRAULIC DESIGN DETAILS

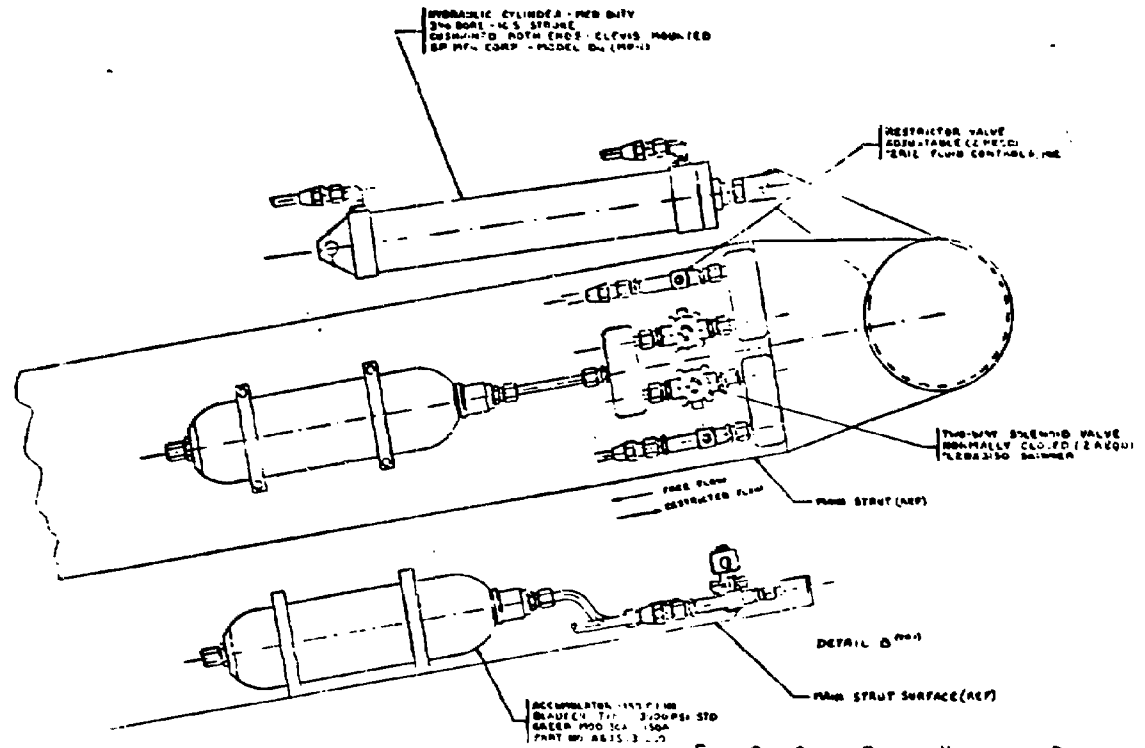


FIG. 8 - STERN ENGINE HYDRAULIC DETAILS

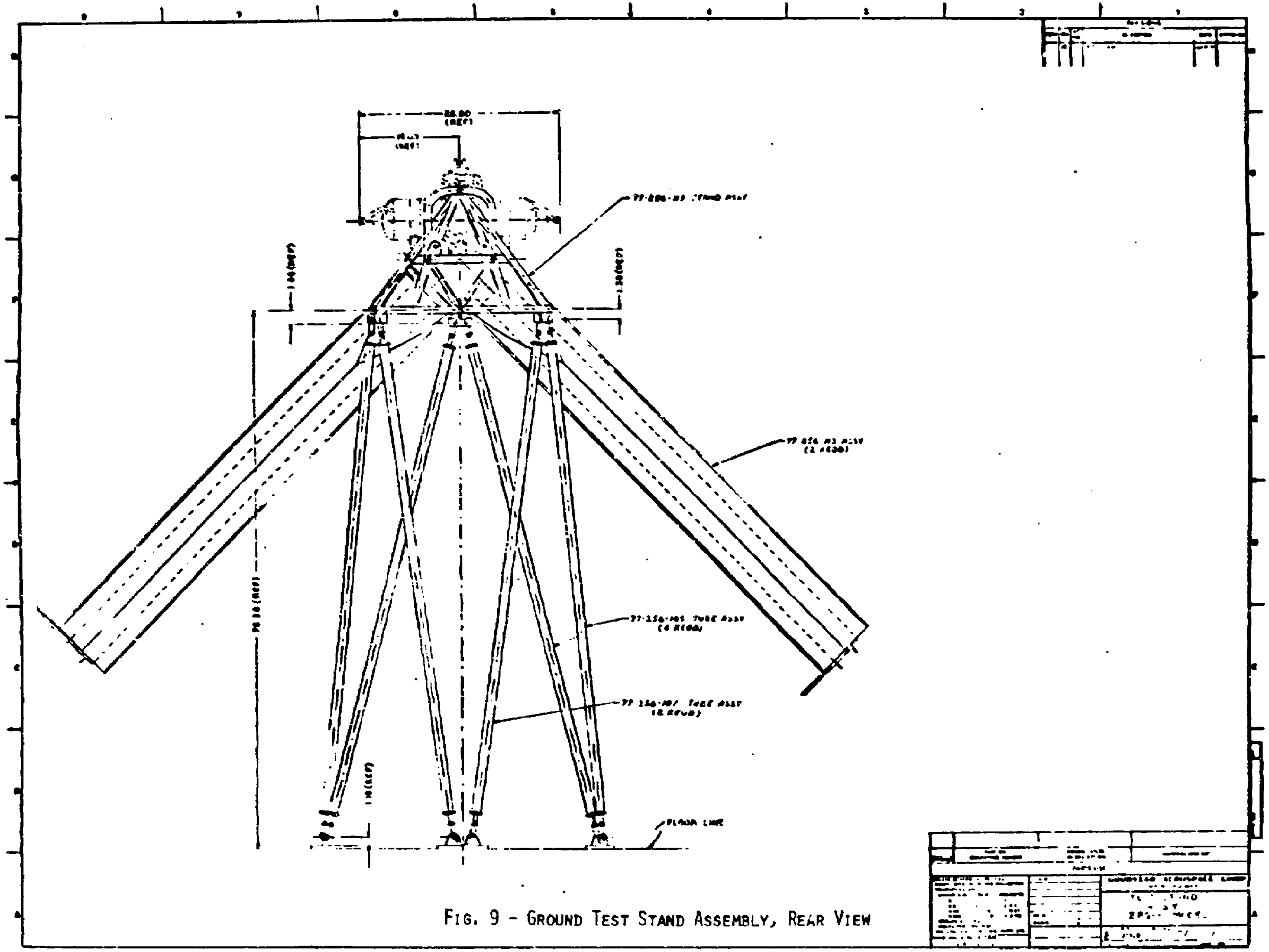


Fig. 9 - Ground Test Stand Assembly, Rear View

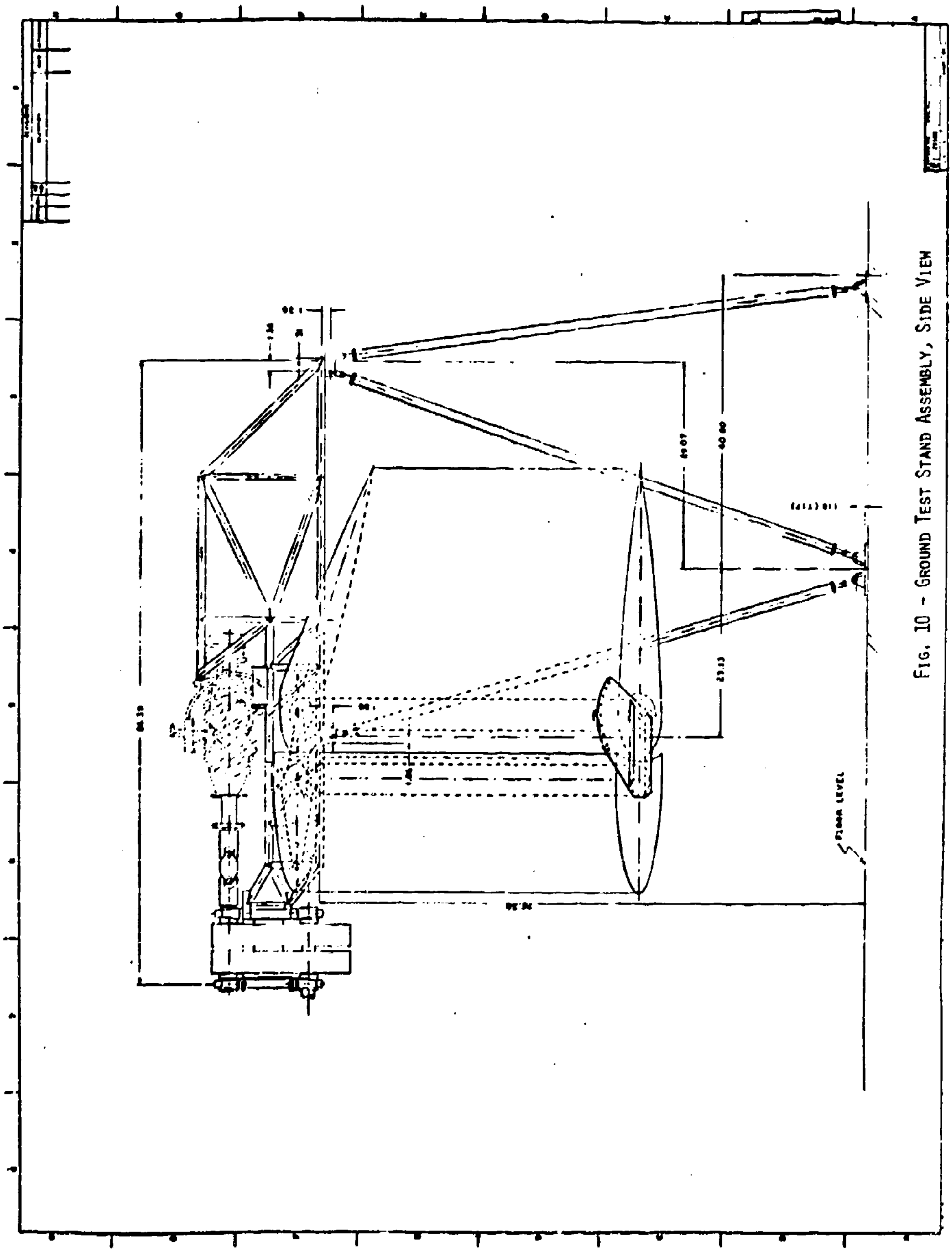


Fig. 10 - Ground Test Stand Assembly, Side View

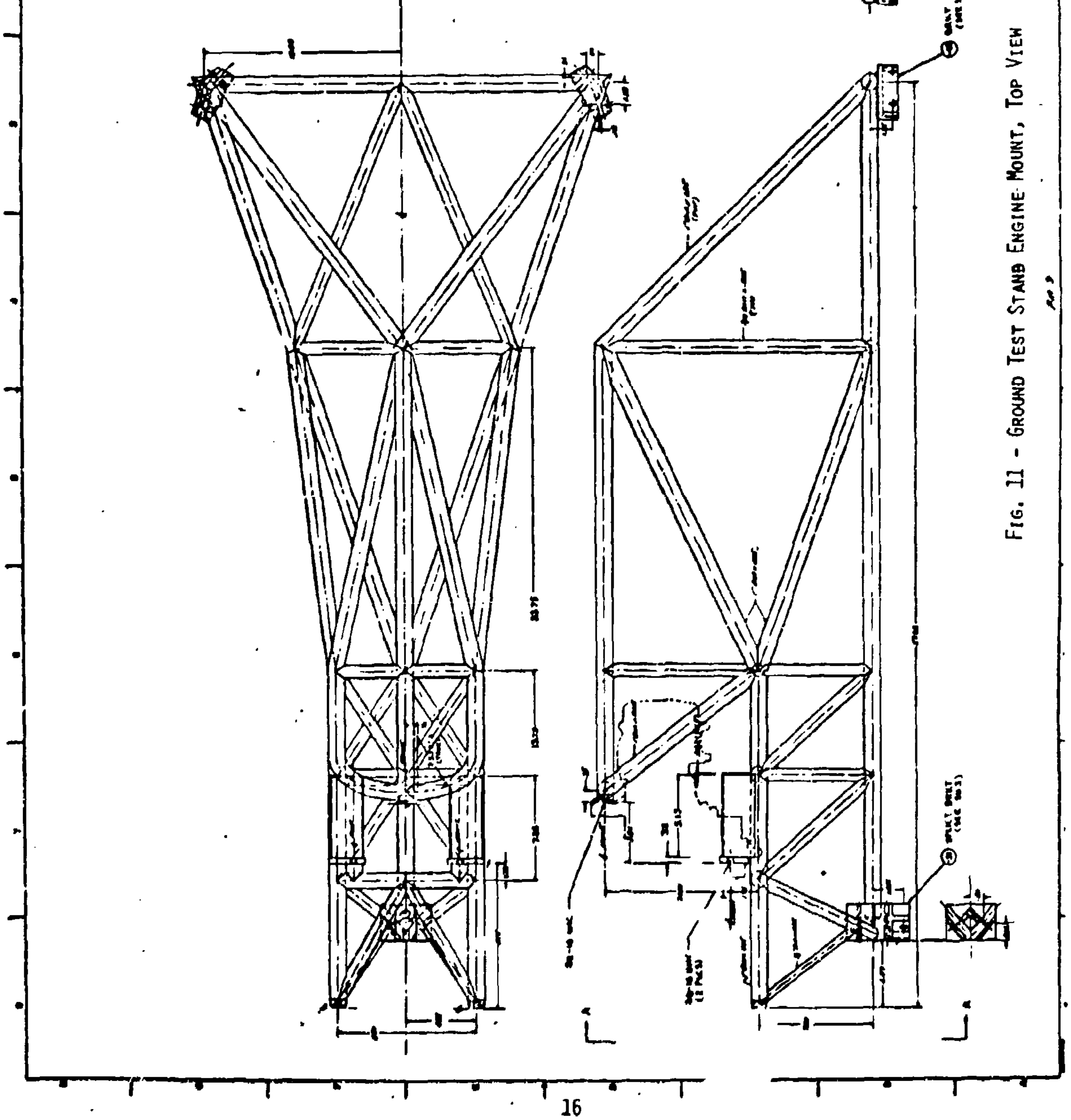


FIG. 11 - GROUND TEST STAND ENGINE MOUNT, TOP VIEW

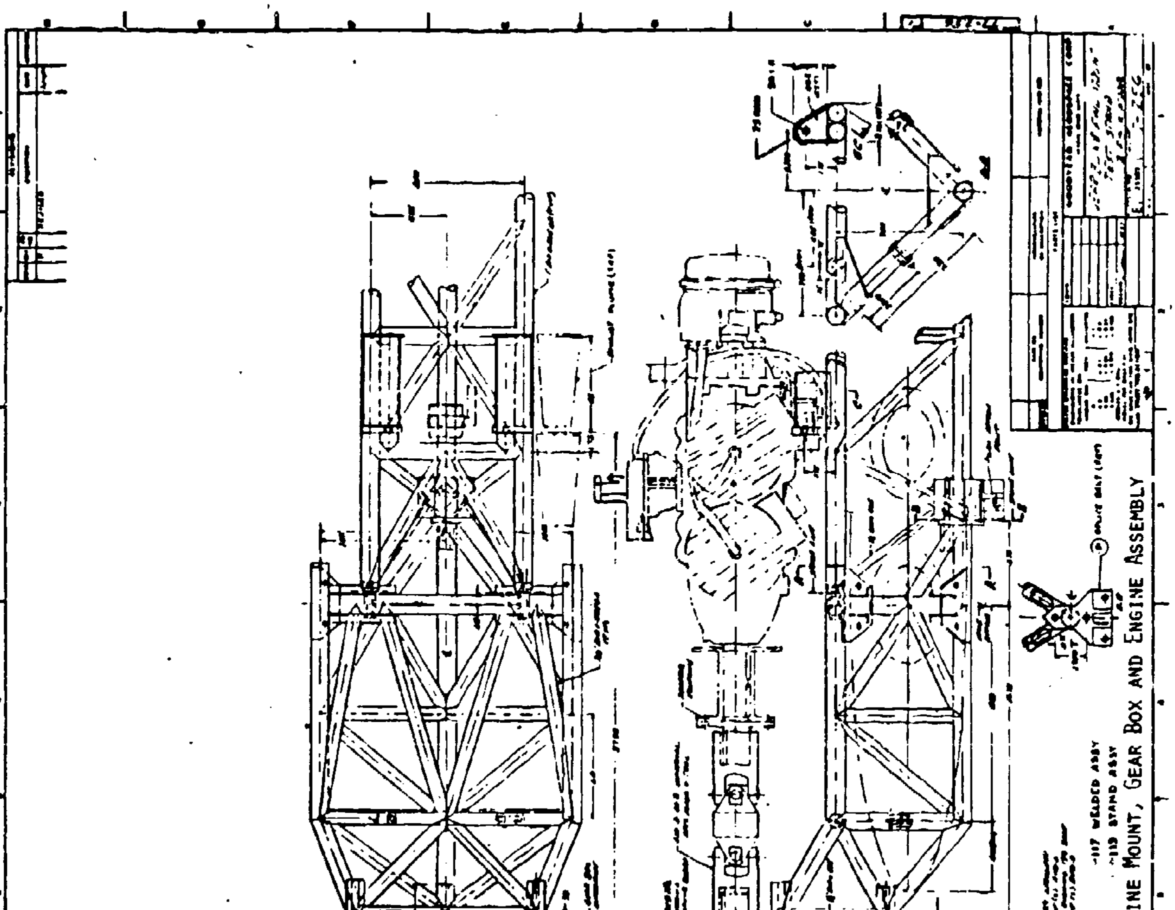


FIG. 12 - GROUND TEST STAND ENGINE MOUNT, GEAR BOX AND ENGINE ASSEMBLY

TABLE II - PRELIMINARY HALF-SCALE MODEL TEST PROGRAM

	MONTHS AFTER GO AHEAD (1–14)	ESTIMATED MATL $	ESTIMATED HOURS
PHASE I			
R&D Assoc. Kickoff (Northrop Engine Supplier)			
Ordering		5	
Receive			
Design Test Stand			300
Build Test Stand		2.5	1200
ASBL Engine & Stand			300
Test Stern			1600
Test Main			1000
PHASE II			
Chk Loads on A/S Envelope			200
FAA Certification Check	("X" Certification)		
Design Envelope Attachment Hardware			1600
Fabricate Envelope Attach Hdwr		15.0 5.7	3000
ASBL			1600
PHASE III			
Initiate Flight Test Program			
Total		28.2K* Matl	10800* Labor Hours

*NOTE: Costs and hours estimated are Preliminary, Budgetary estimates only and do not include costs associated with providing the GZ-20 vehicle.

TABLE III - PRELIMINARY ONE-HALF SCALE MODEL TEST PROGRAM TASK EFFORT DETAILS

Phase I

- Coordinate engine acquisition and performance with R&D Assoc.
- Select prop supplier and initiate prop design (Fwd and Stern)
- Purchase (lease?) engine (90 day lead time)
- Purchase propeller(s) (30-60 day lead time (Fritzen Propeller Co., Carson, Ca. (Both forward and stern)
- Estimate propeller performance
- Design engine test stand including main propulsor, stern propulsor and deflectable control surface and load measuring systems
- Obtain cost estimate for test stand
- Instrument/calibrate test stand
- Fabricate test stand
- Write test plan report
- Assemble engine and test stand and forward propulsor
- Test forward propulsor
- Assemble stern prop and gear box
- Recalibrate instruments
- Test stern propulsor (no control surface)
- Install control surface
- Recalibrate instruments
- Test stern propulsor with control surface
- Analyze test results
- Compare experimental results with analytical predictions
- Prepare test report
- Develop flight dynamic simulation inputs based on test results, analyze the controllability of the GZ20 (ZPG-X) configuration, and develop required control laws

TABLE III (Continued)

<u>Phase II</u>

- <u>Design and Planning</u>
- Design flightweight hardware for forward propulsor
- Design flightweight hardware for stern propulsor and control surface
- Verify envelope loads capability and define design modifications required
- Apply for/investigate "X" category FAA certification
- Prepare an assembly plan and cost estimate for GZ20 modification
- <u>Fabricate, Assemble and Checkout</u>
- Fabricate hardware (forward
- Fabricate hardware (stern propulsor)
- Assemble and checkout main and stern propulsors on GZ-20

  Option 1) ASBL to existing GZ20

  Option 2) ASBL an A/S from existing assets

- Perform on ground checkout

<u>Phase III</u>

- Conduct preliminary flight tests
- Modify control laws for improved flight characteristics
- Conduct final flight tests
- Conduct customer demonstration flights

3.0 ONE-TWELFTH SCALE MODEL

3.1 Discussion

This design study was made to determine the feasibility of building a one-twelfth scale model of an airship to demonstrate the capability of hovering and transitioning into forward flight. The design was based on the ZPG-X Advanced Naval Vehicle, (Ref. 1) Arrangement. The overall list of drawings produced for the one-twelfth scale model is presented in Table IV.

Originally, propulsion was to be provided by model airplane engines of 0.60 cubic inch displacement (CID) with a power output on the order of one horsepower at 12 to 14,000 rpm. The aft engine was to drive a 22-inch propeller through a Du Bro 2.5 to 1 or a Master Climb 2.0 to 1 speed reduction propeller drive unit. The forward propellers were to be eleven-inch in diameter driven directly by 0.60 CID engines. Control surfaces and engine pitch were to be operated by model airplane servos with control signals transmitted through model airplane transmitter/receiver equipment. The engines use a little less than one pint of fuel each in fifteen minutes at rated speed. The transmitter operates on 9.8 VDC and the receiver/servos operate on 4.8 VDC. For extraneous signal rejection, a Kraft transmitter/receiver appears desirable.

Two transmitter/receivers operating on two different carrier frequencies were to be used to provide two-man control of the vehicle. For vehicle control, nine control channels and thirteen servos were required as follows:

		Channels	Servos
1.	Forward engine pitch (Engines pitching together)	1	2
2.	Forward engine throttle (Engine speeds controlled separately)	2	2
3.	Aft engine pitch (One servo each side, common signal)	1	2
4.	Aft engine throttle	1	1
5.	Aft engine ruddevator surfaces (Electronic mixer reqd - Model Dynamics)	2	2
6.	Main ruddevator surfaces (Electronic mixer reqd - Model Dynamics)	2	2
	Total	9	13

The envelope was to be made of 3.4 oz/yd^2 laminated Dacron material available at GAC. Size and shape were to be determined by dimensionally scaling the ZPG-3W airship assembly drawing No. 17Z100-001 modified by rounding off the aft end per the ZPG-X configuration.

The large control surfaces (fin assembly including ruddevator, aft engine mount, airfoil, and ruddevator) were to be of clear white pine (estimated density 25 lbs/ft^3) covered by a lightweight nylon cloth. Leading edges of airfoils not lending themselves to being covered by cloth (concaving between ribs) were to be covered with 0.022 inch thick polystrene by heating with a blower and draping over the structure to the shape required. The polystyrene is heat formable, and leading edge test samples were produced in the GAC Engineering Shop quickly and successfully. Forward and aft engine support structure was to be aluminum tubing and engine mounting plates fabricated of aluminum.

TABLE IV - ONE-TWELFTH SCALE MODEL DRAWINGS LIST

Figure No.	GAC Drawing No.	Description
13	77-251	One-Twelfth Scale Models General Arrangement
14	77-252	Fwd Engine Instl - Glow Plug Engine Concept
15	77-253	Aft Engine Instl - Glow Plug Engine Concept
16	78-211	Engine Support Structure - Aft Engine Glow Plug Concept
17	78-210	Aft Ruddevator - Glow Plug Engine Concept
18	77-264	Fin Assembly
19	77-265	Fin Structure
20	77-267	Fin Root Chord
21	77-263	Fin Ruddevator
22	78-236	Fwd Electric Motor Propulsor Concept
23	78-238	Fwd Motor Mount
24	78-241	Fwd Motor Pivot
25	78-235	Aft Electric Motor Instl
26	78-237	Aft Electric Motor Mount
27	78-239	Aft Electric Motor Support Structure
28	78-242	Aft Electric Motor Ruddevator
29	78-212	Tail Cone Structure

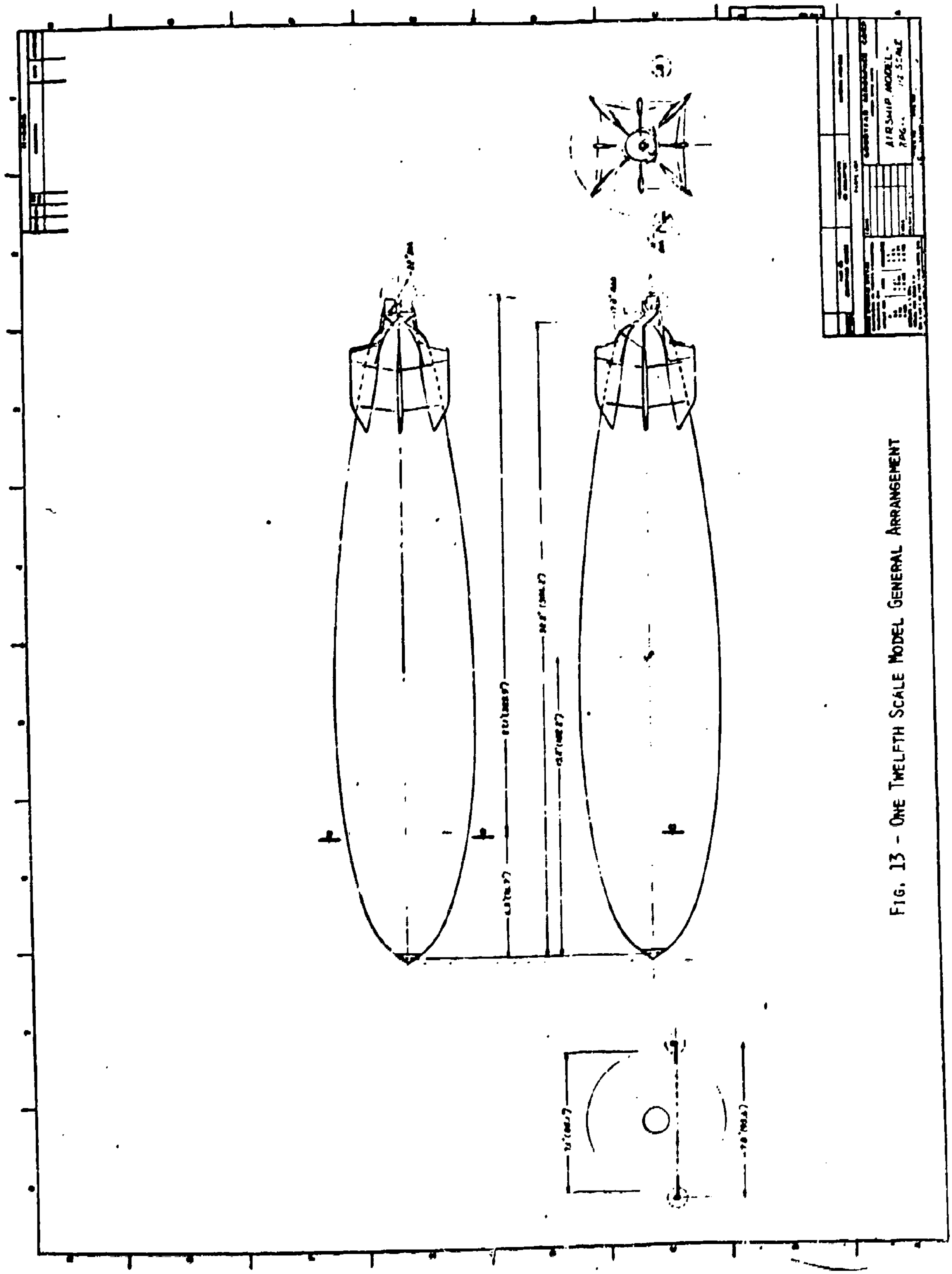


FIG. 13 - ONE TWELFTH SCALE MODEL GENERAL ARRANGEMENT

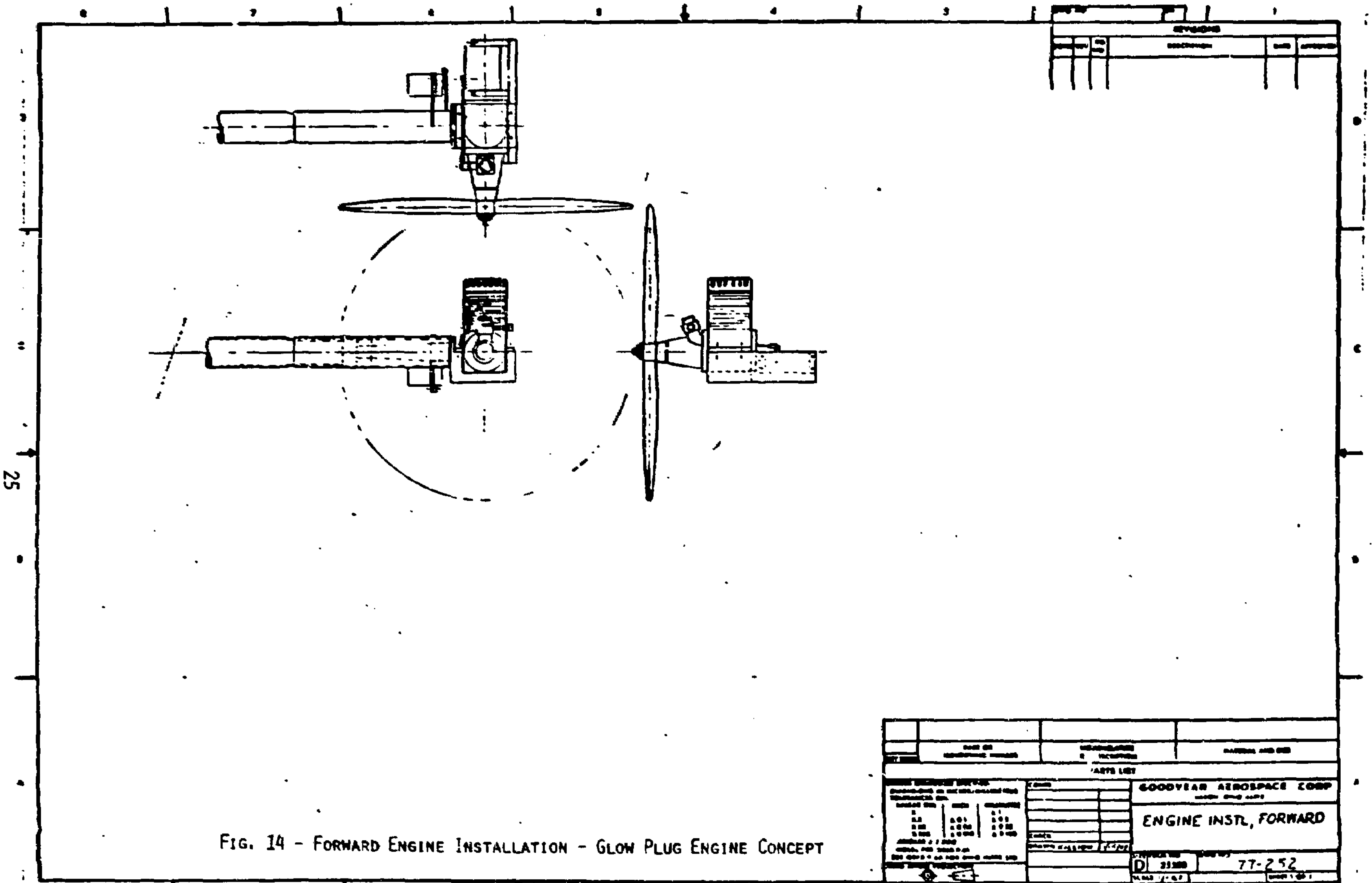
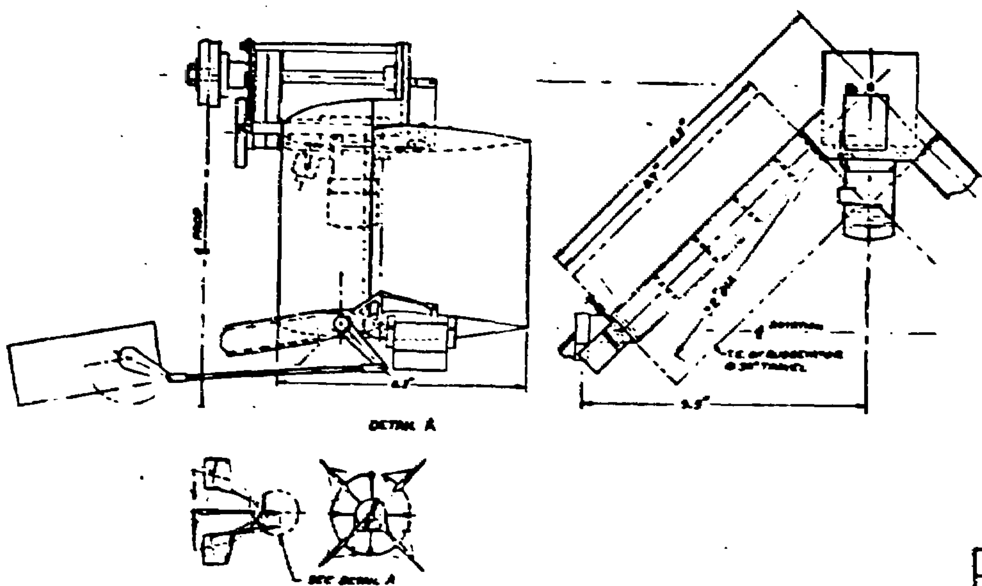


Fig. 14 - Forward Engine Installation - Glow Plug Engine Concept



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ENGINE INSTL, AFT

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Fig. 15 - Aft Engine Installation - Glow Plug Engine Concept

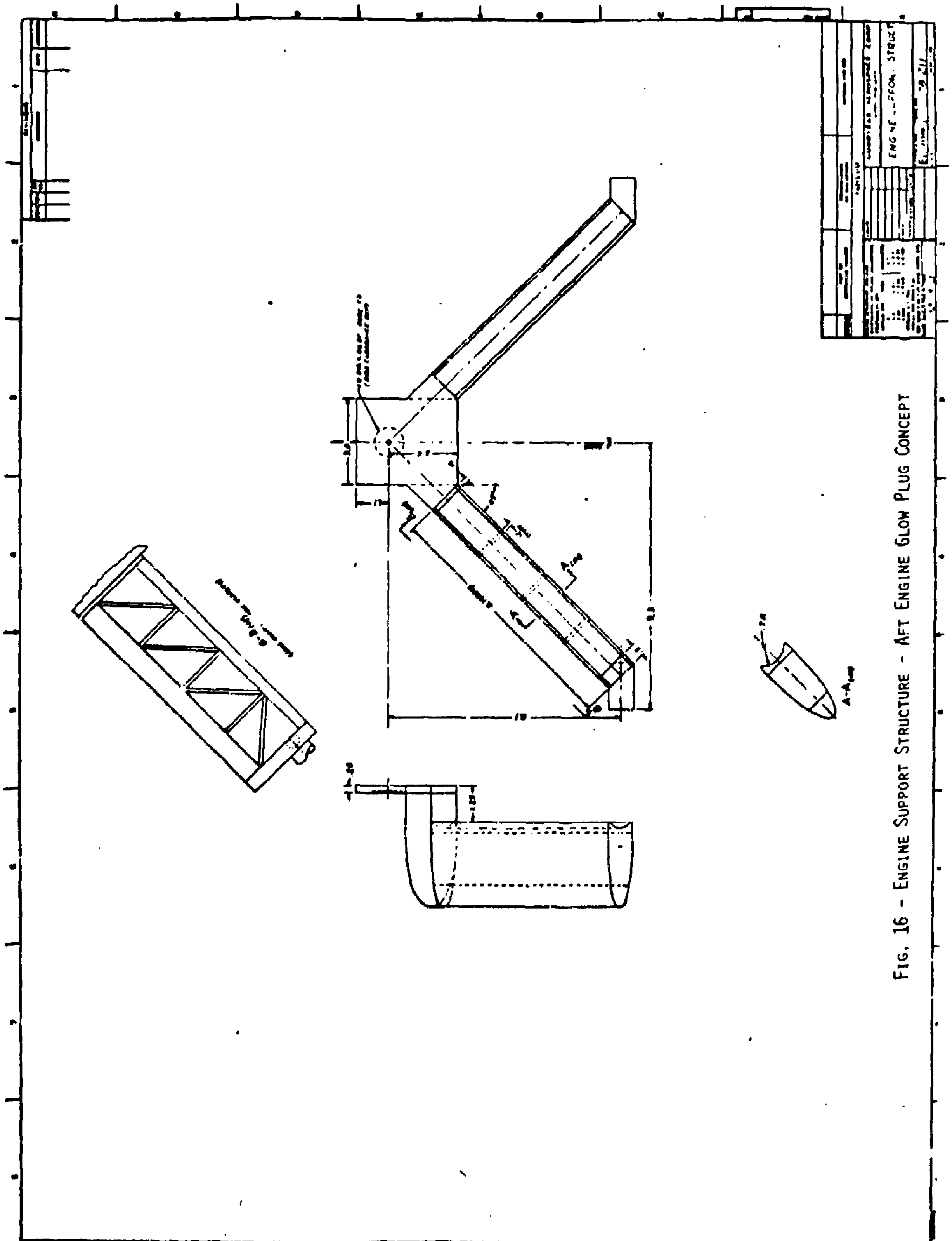

FIG. 16 - ENGINE SUPPORT STRUCTURE - AFT ENGINE GLOW PLUG CONCEPT

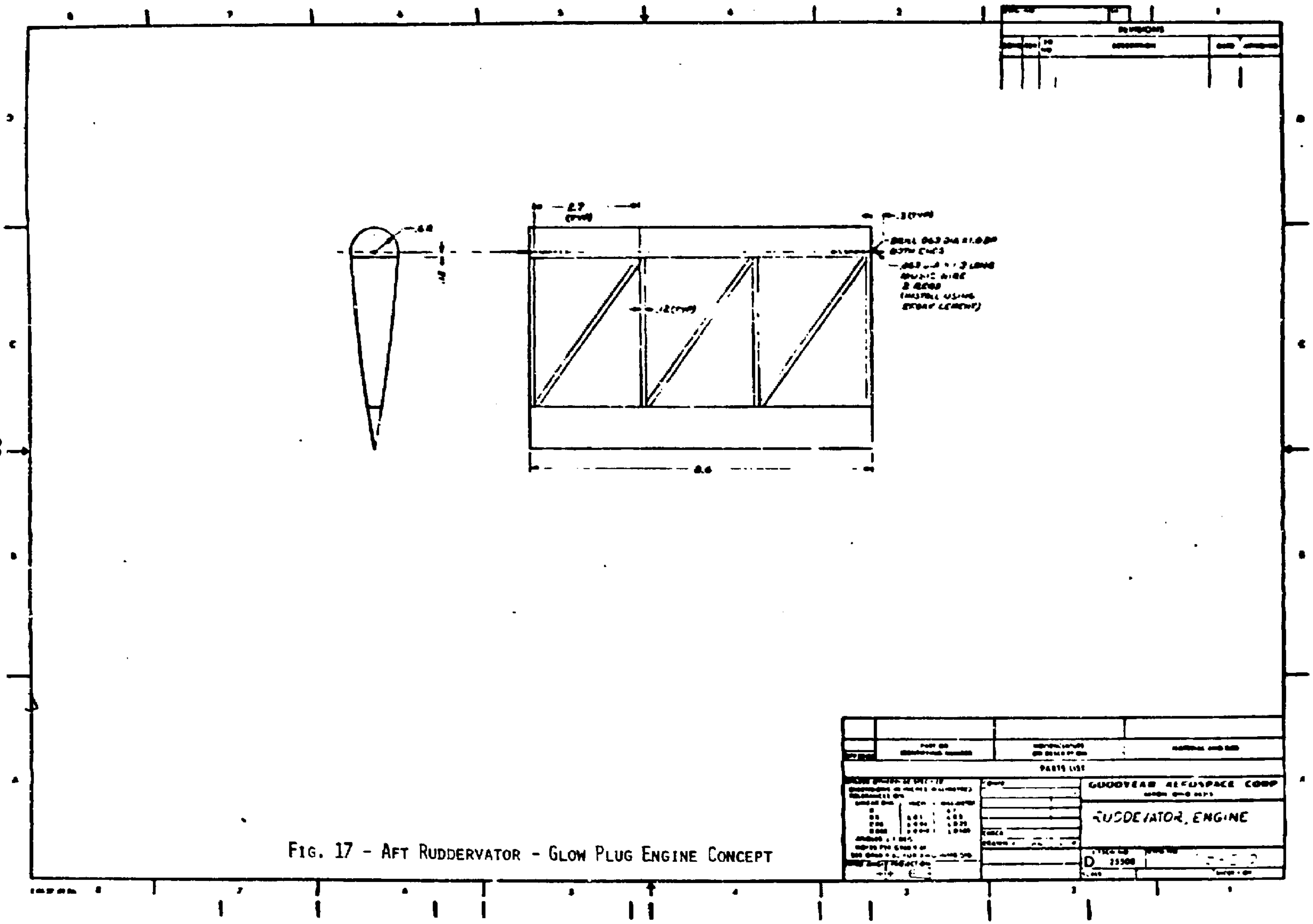

Fig. 17 - Aft Ruddervator - Glow Plug Engine Concept

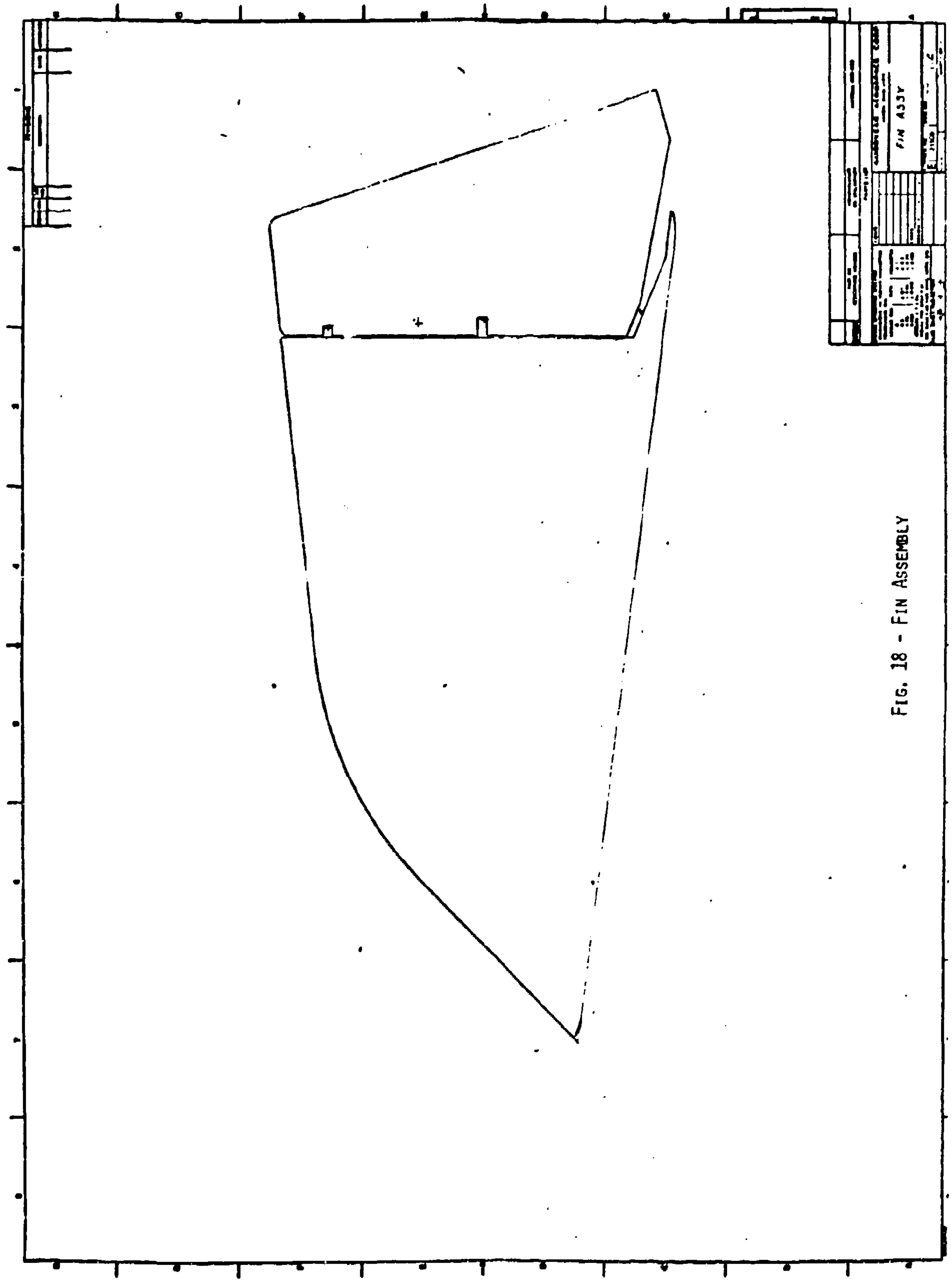

FIG. 18 - FIN ASSEMBLY

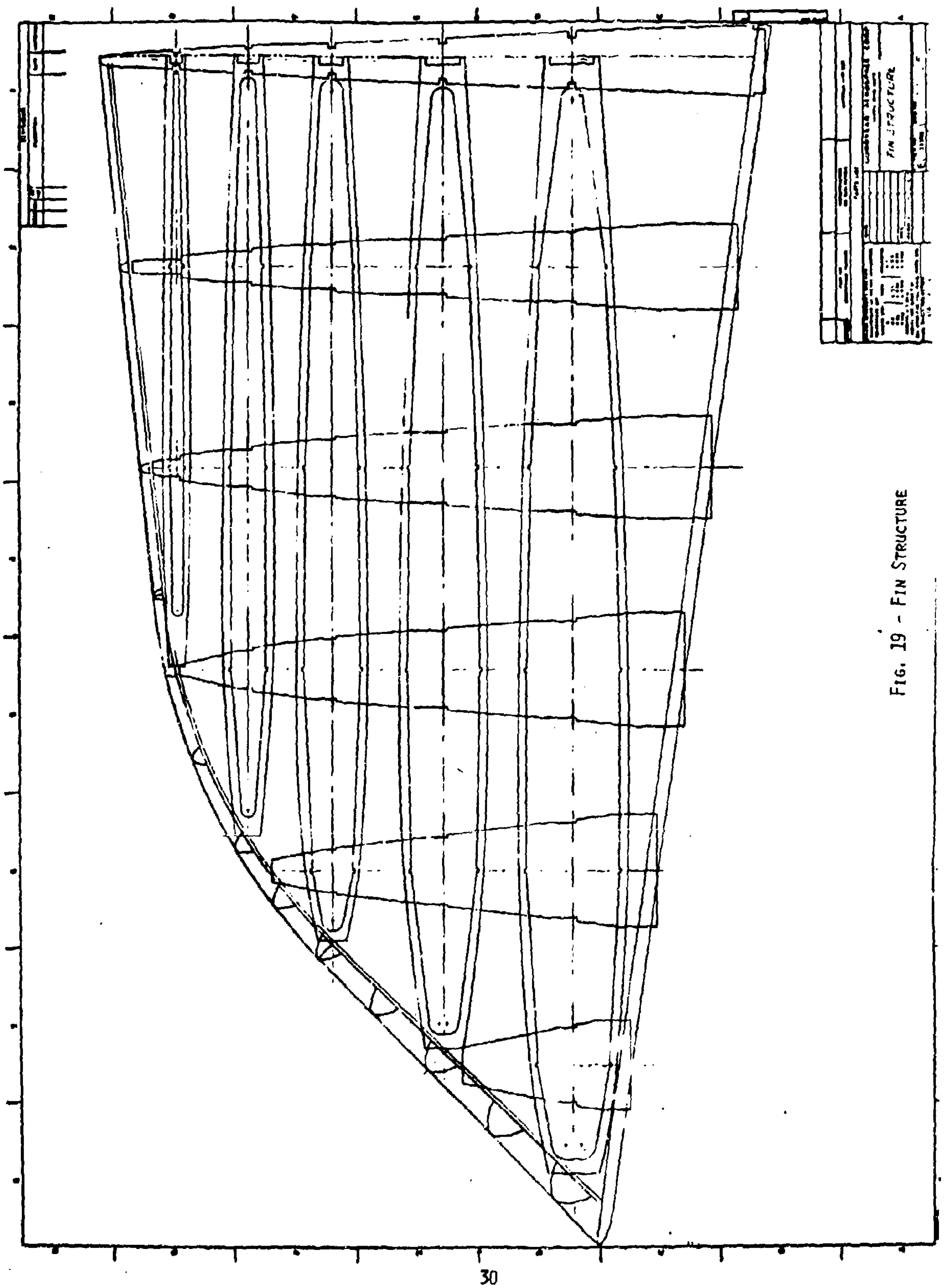

FIG. 19 - FIN STRUCTURE

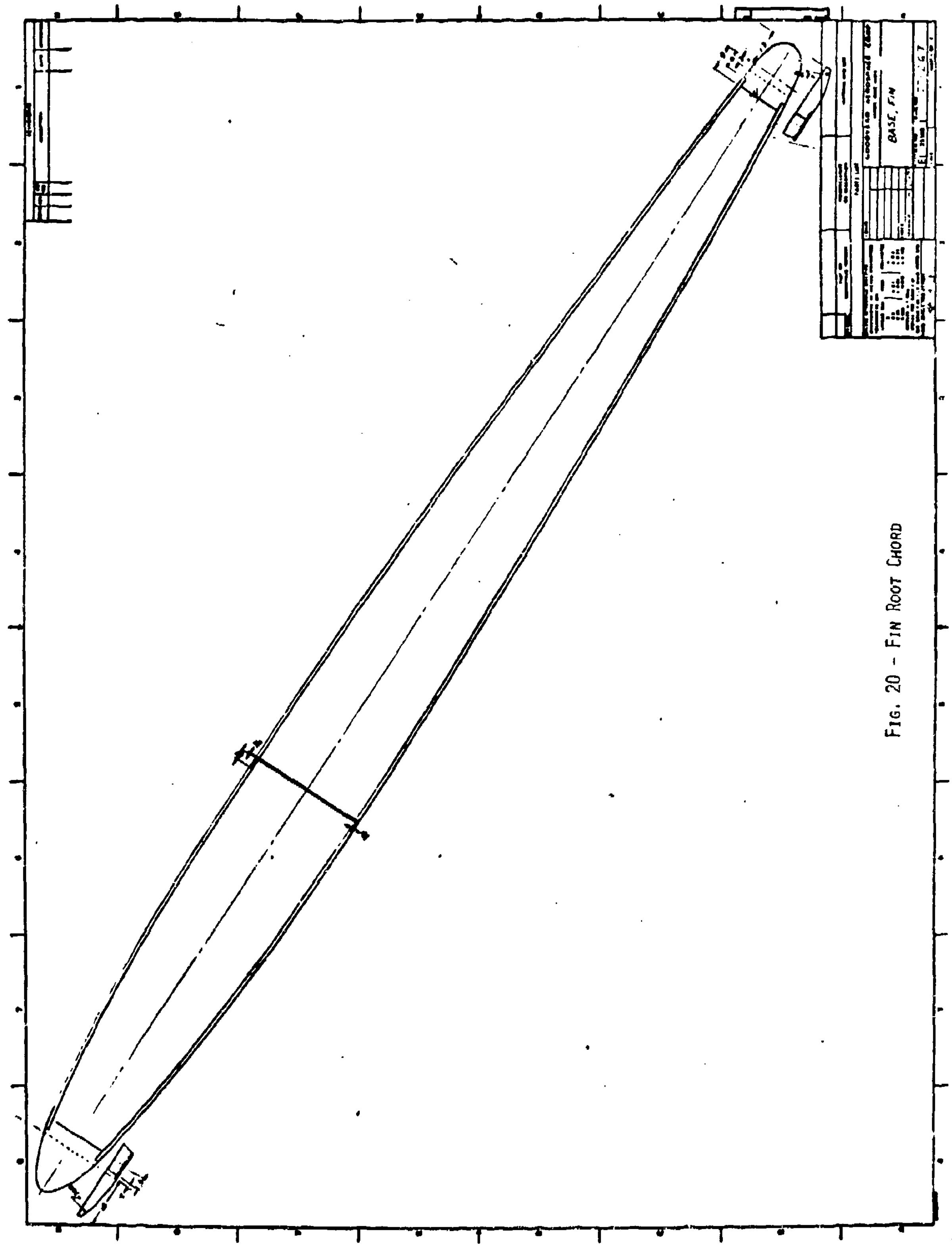

FIG. 20 - FIN ROOT CHORD

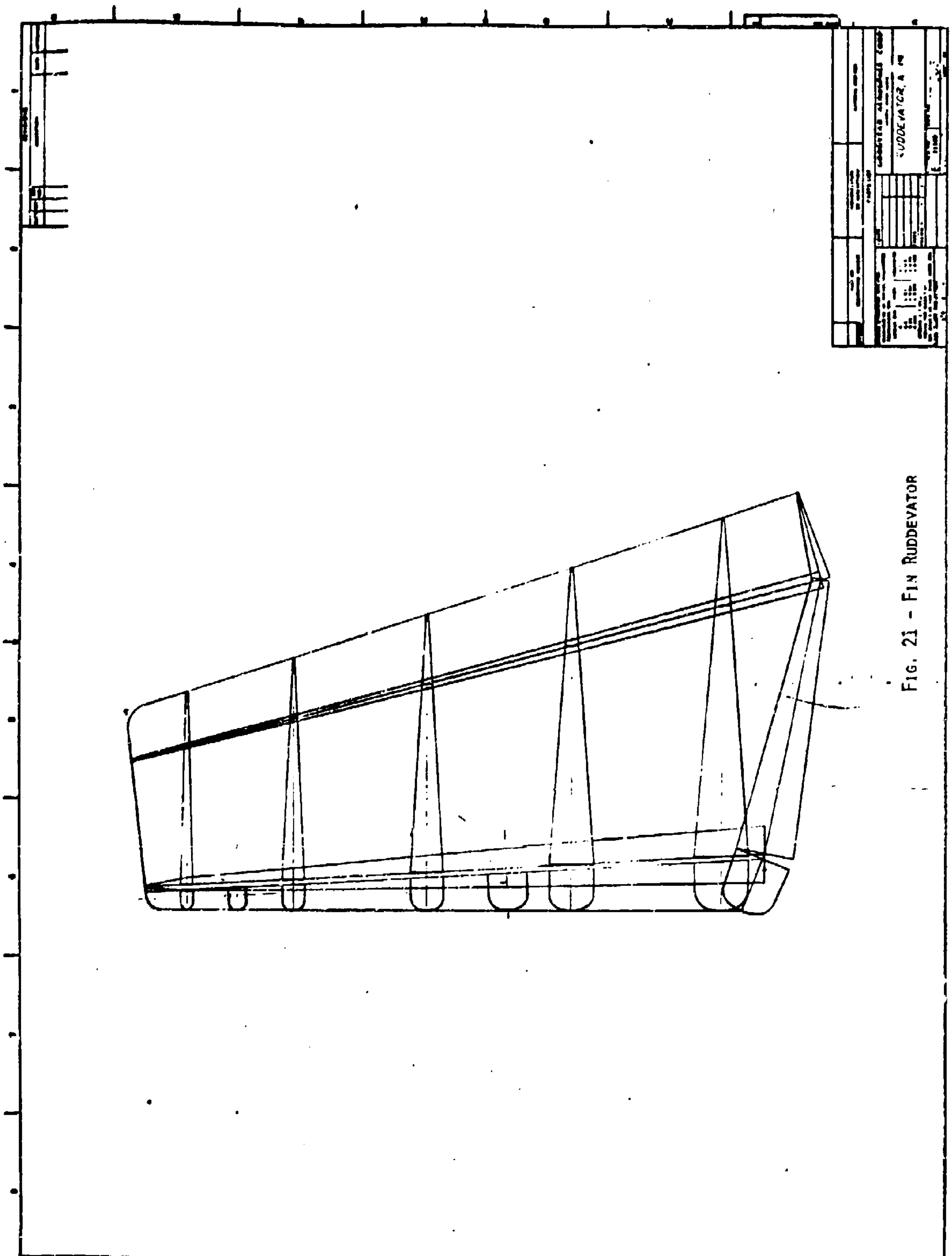

FIG. 21 - FIN RUDDEVATOR

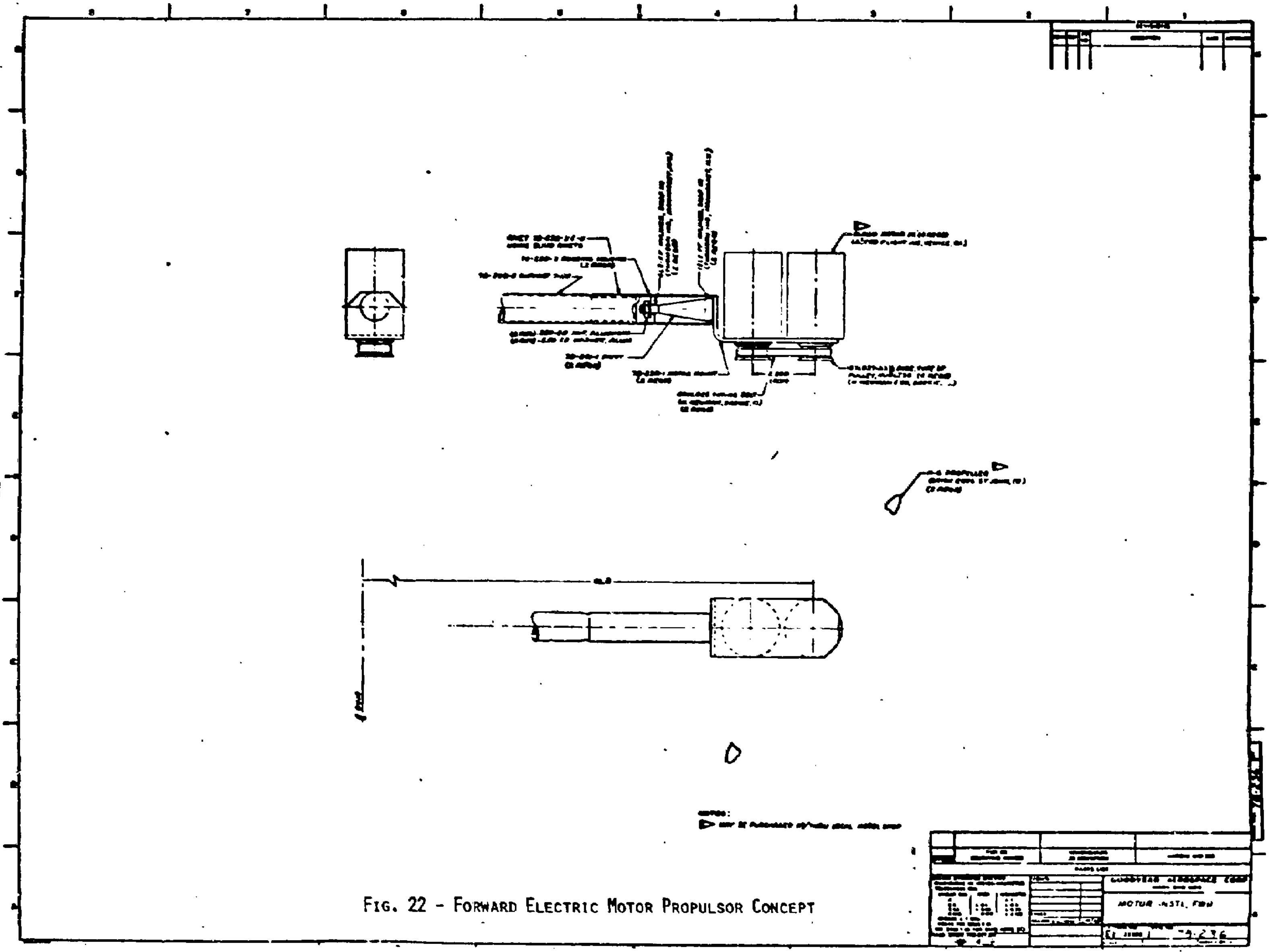

Fig. 22 - Forward Electric Motor Propulsor Concept

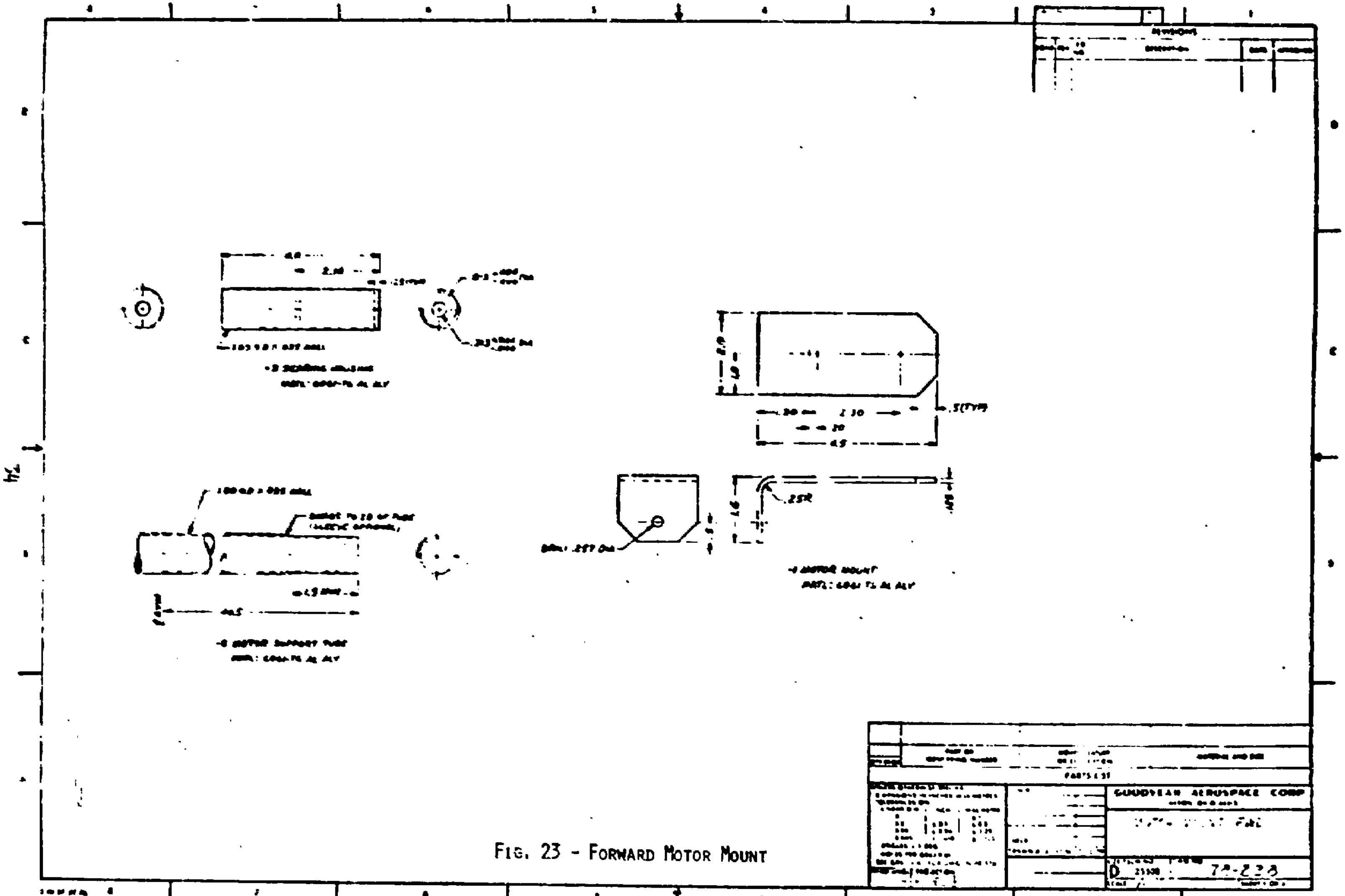

Fig. 23 - Forward Motor Mount

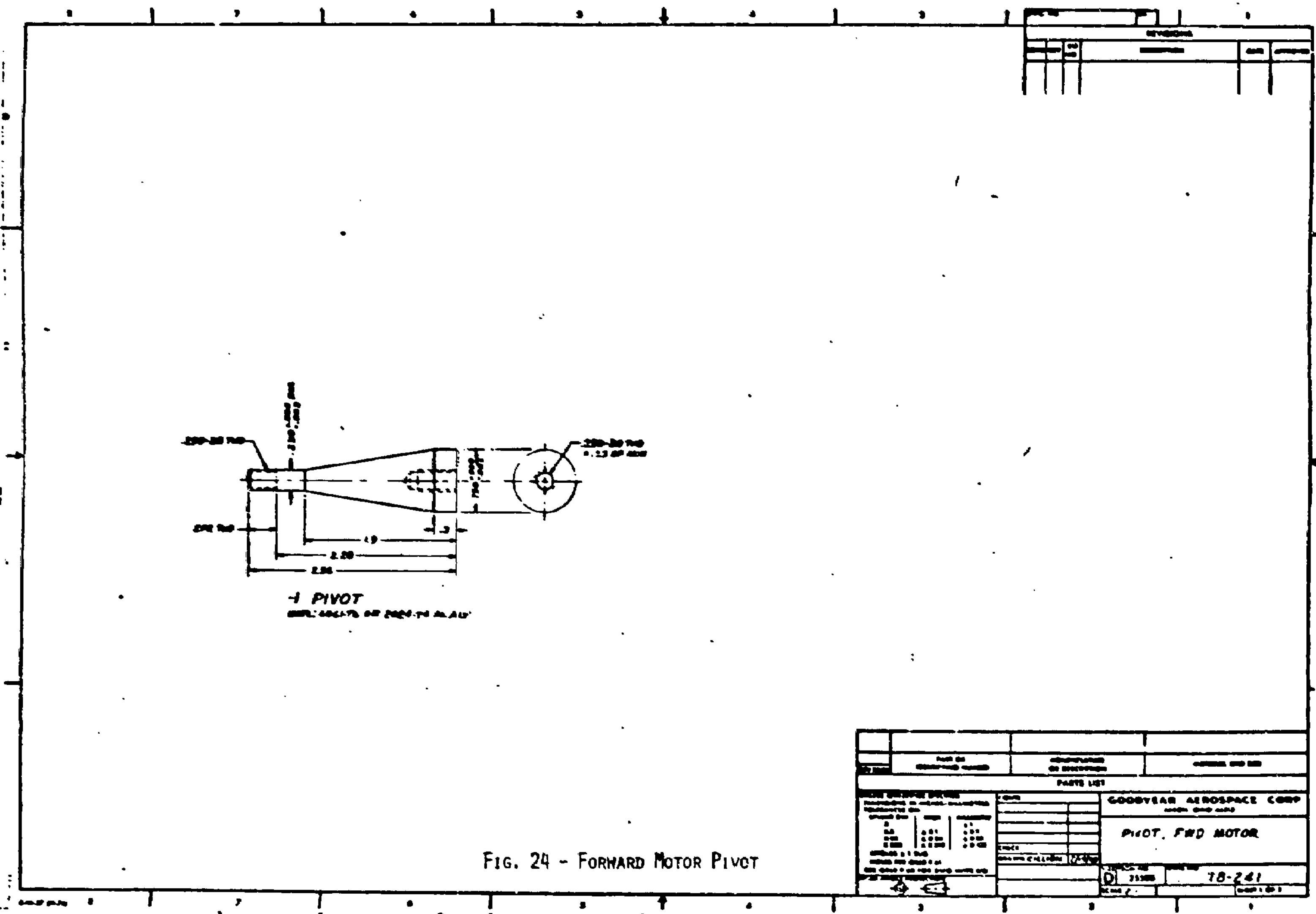

FIG. 24 - FORWARD MOTOR PIVOT

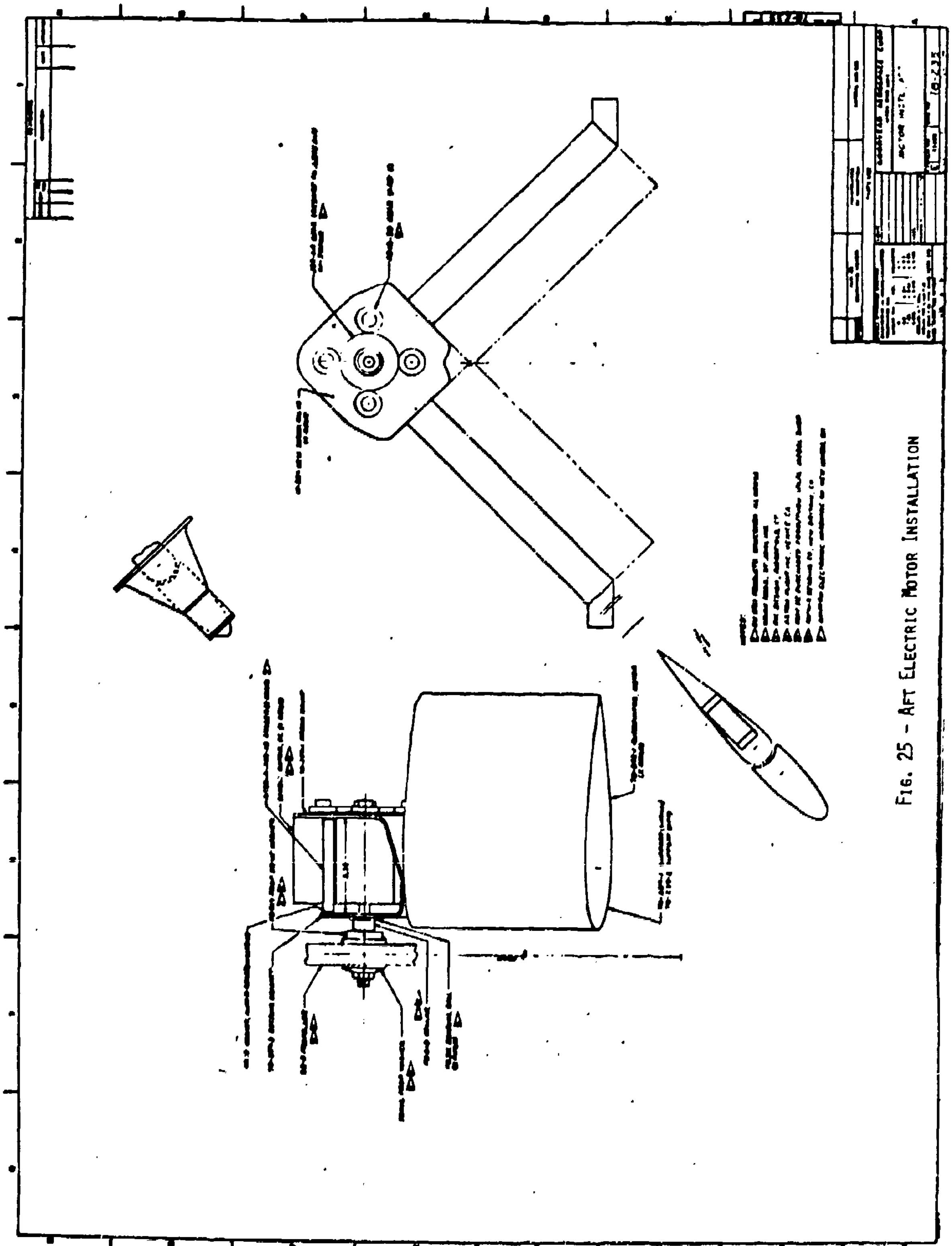

FIG. 25 - AFT ELECTRIC MOTOR INSTALLATION

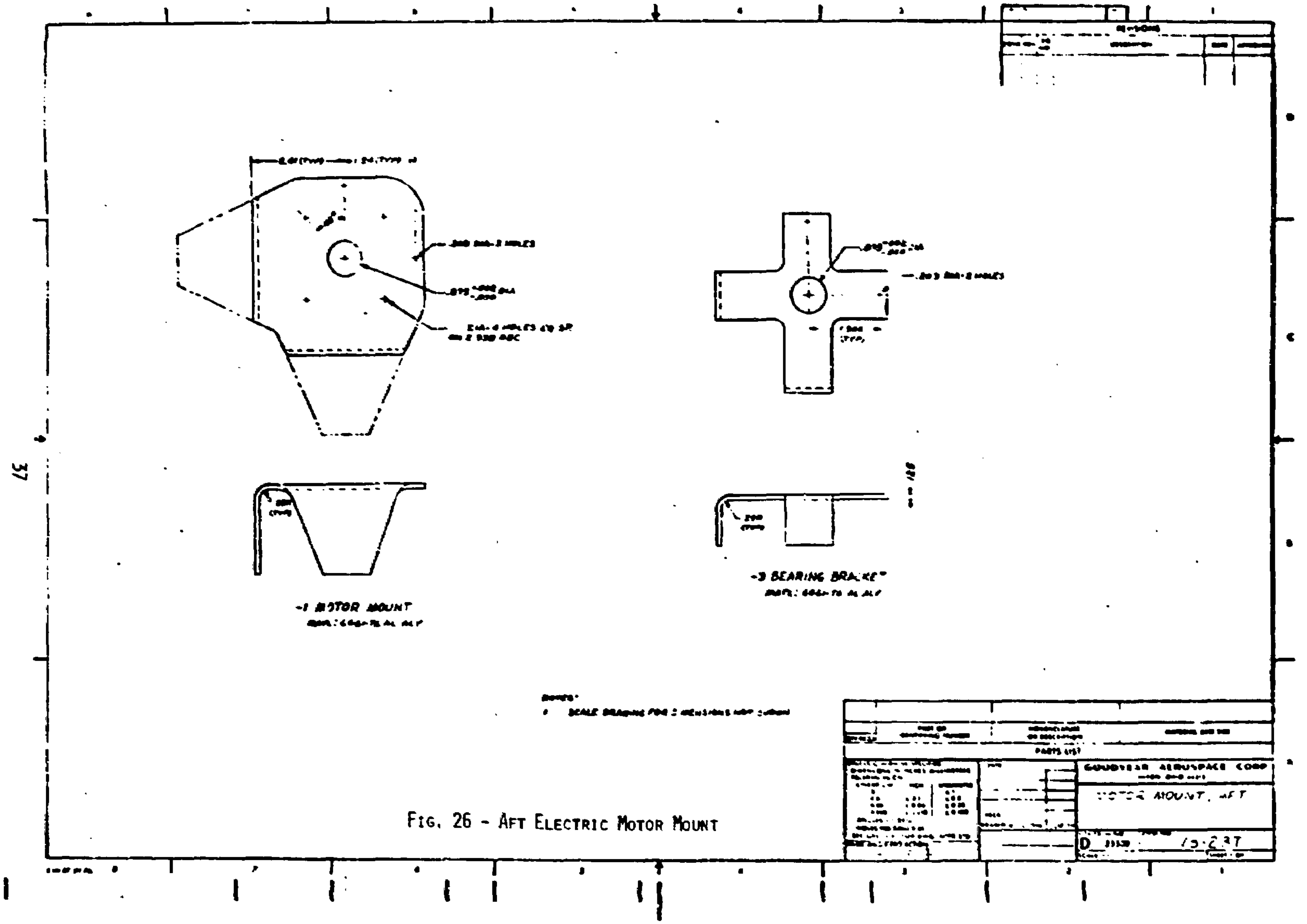

FIG. 26 - AFT ELECTRIC MOTOR MOUNT

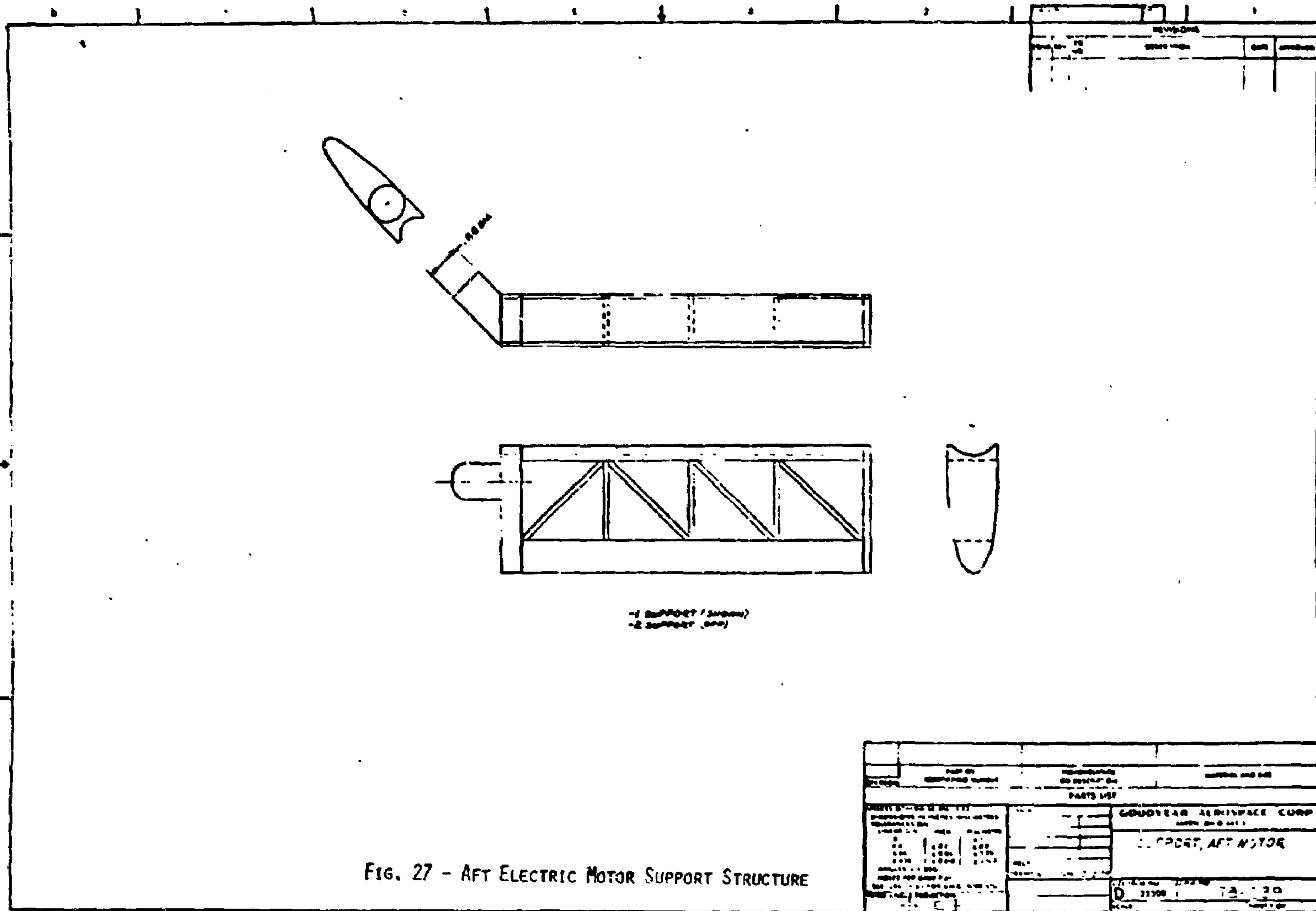

FIG. 27 - AFT ELECTRIC MOTOR SUPPORT STRUCTURE

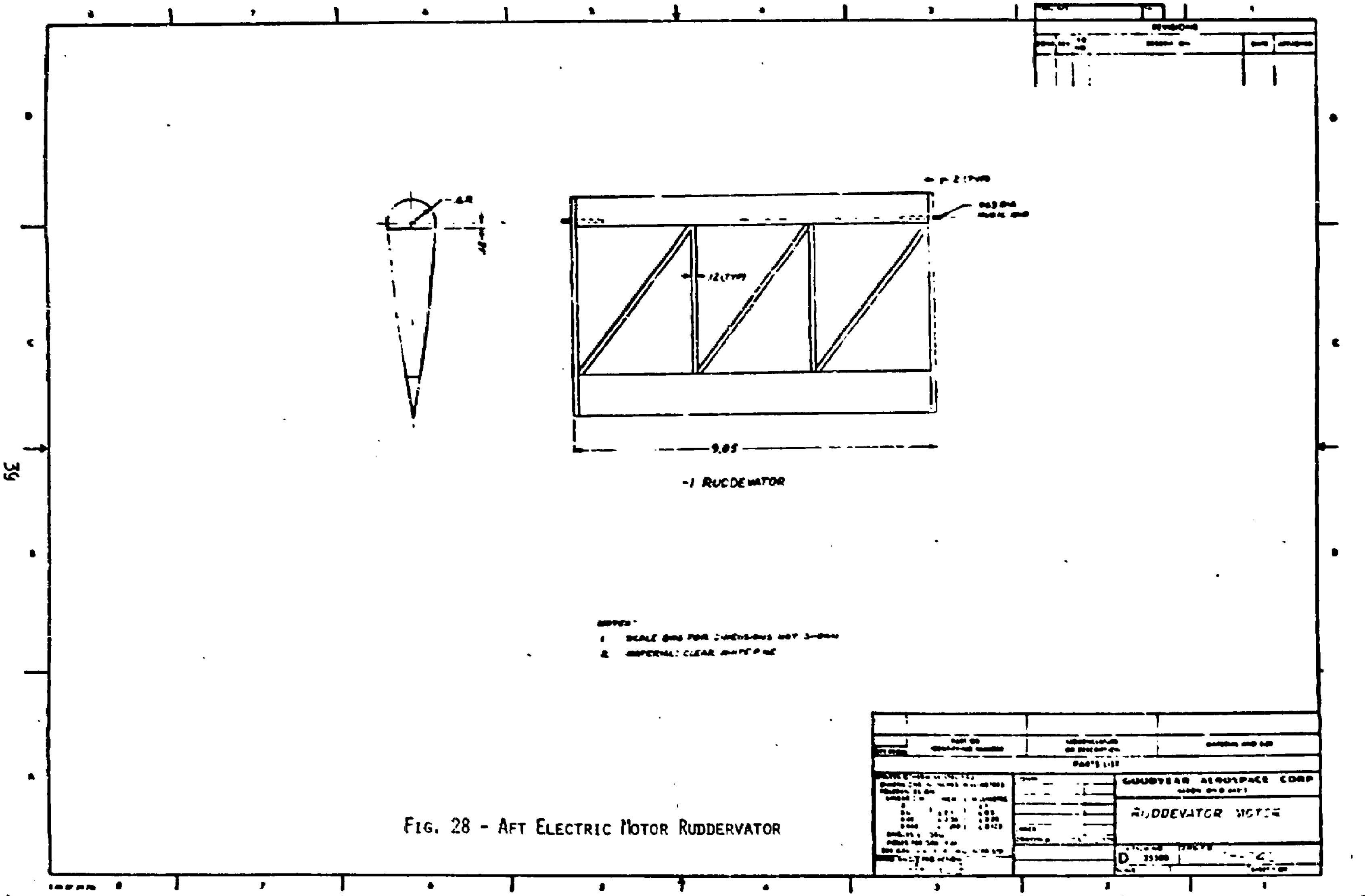

FIG. 28 - AFT ELECTRIC MOTOR RUDDERVATOR

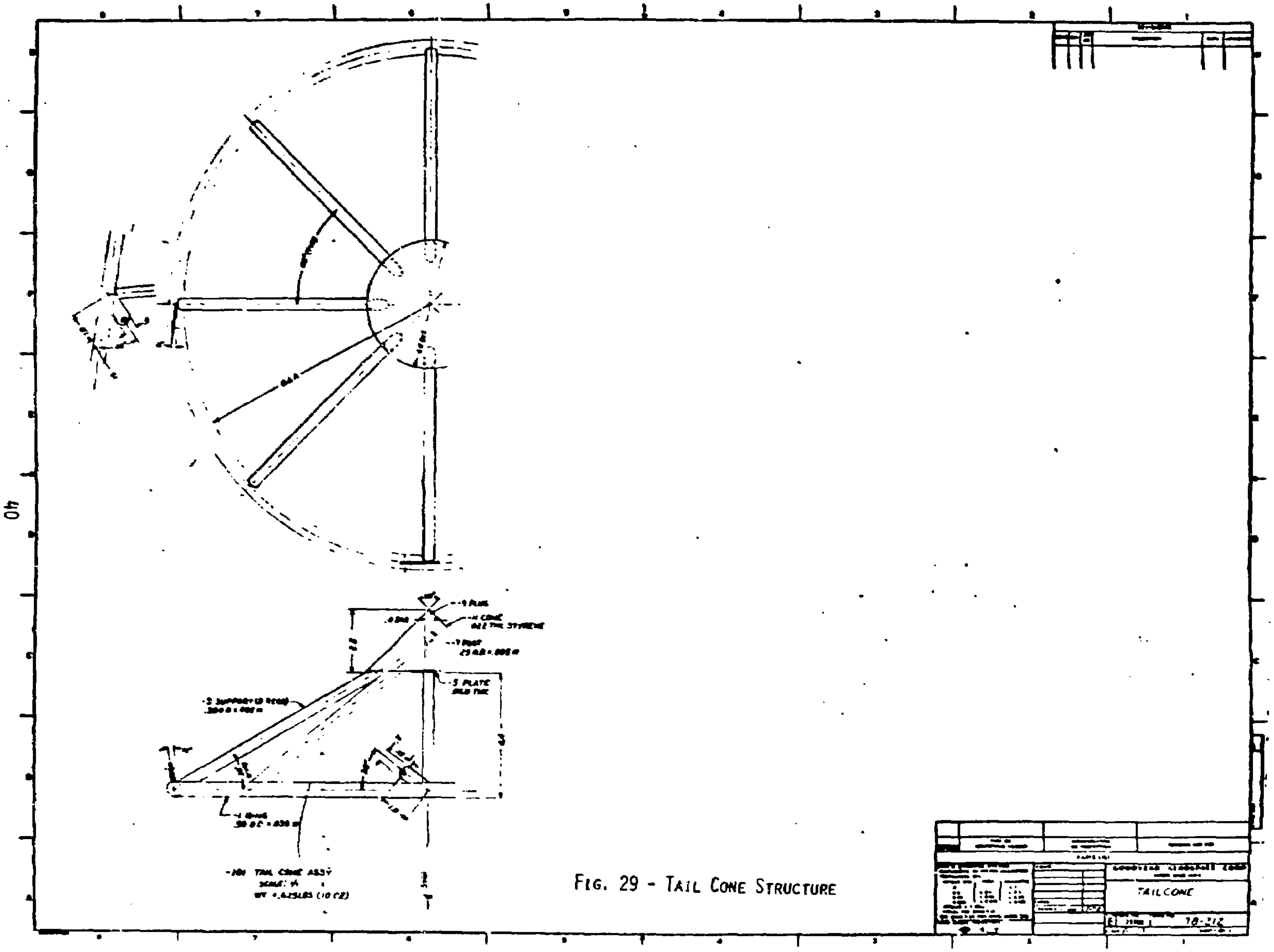

FIG. 29 - TAIL CONE STRUCTURE

To improve reliability and reduce noise and vibration, electric motors were substituted for the model airplane (glow plug) engines. Astro Flight 0.25 HP permanent magnet 24VDC model airplane motors were selected. The size (0.25 HP) is comparable in power to a glow engine of equivalent displacement (.25 CID) and horsepower. The aft propulsion unit consists of four motors geared to a 22-inch propeller with a 64/30 speed reduction (propeller RPM = 4450). The forward units are comprised of two motors driving an 11-inch propeller direct through a toothed timing belt. Electric power would be controlled on the ground and transmitted to the model through an umbilical cable consisting of three pairs of #18 stranded wire fused for 14 amps. 115 V, 60 Hz power was to be controlled by Variacs (one for each propulsion unit), full wave rectified, and transmitted to the motors. The four aft motors were to be wired in series requiring 96 VDC. The two motors in each of the forward propulsion units were to be wired in series requiring 48 VDC. Ten amps maximum would be required for each propulsion unit.

Since motor speed would be controlled from the ground through the umbilical rather than by means of servos, the radio channels required would decrease by three (to six) and the servos by three (to ten).

The umbilical cable, consisting of three pairs of #18 wire at 21 lbs/1000 ft/pair (Essex Parallel "POT") for motor power and one pair of #22 wire at 8 lbs/1000 ft/pair (Essex thermoplastic appliance wire, single conductor at 4 lbs) for receiver/servo power. The added weight of cable which must be lifted by the model is 7.1 lbs/100 ft. As a point of interest, an Aerocrane model tested by NADC is reported to have an umbilical weight of 0.63 lbs/ft (63 lbs/100 ft). The umbilical would exit from a point vertically in line with the center of bouyancy and provide a metacentric moment proportional to the length of the cable.

With the aft propulsion installed, the model is inherently tail heavy. An approximation of its weights and distribution (neglecting miscellaneous hardware and the weight of a car) shows that the one-twelfth scale model has a marginal flight capability. If a required ballast of fifteen pounds is placed entirely in the nose cone, the airship is three pounds heavy. Tolerances on the measurements and calculations used make it possible that the model would not get off the ground in level flight. However, the bouyancy estimate used herein should be on the conservative (low) side due to the volume calculated 818 ft^3 vs 1,490,000/1728 or 868 ft^3 for a true one-twelfth scale model. Furthermore, helium lift was also conservatively taken as 0.06 lbs/ft^3 for a calculated gross static lift of 49 lbs rather than a scaled value of 54.2 lbs. Thus, the one-twelfth scale model may be marginally feasible.

A comparison was made using one-eleventh and one-tenth scale. Comparable figures (disregarding hardware, car, and umbilical) were used with sizes and weights scaled up. The same propulsion units as on the one-twelfth scale were used. The one-eleventh scale would attain vertical buoyancy with a 22 lb ballast located 142 inches forward of the center of buoyancy (with the nose 194 inches forward of the center of buoyancy). Again considering tolerances, such a model should fly and perform as intended.

The one-tenth model was calculated to have a neutral buoyancy with a 37-lb ballast located 103 inches forward of the center of buoyancy (with the nose at 213 inches). This is a further improvement over the one-eleventh scale model.

The above weights were based on an envelope size scaled from a drawing made from a reduced print of the ZPG-3W airship. The envelope area was calculated to be 61.8 yd^2 and the volume at 818.1 ft^3 for the one-twelfth scale model. The center of buoyancy was estimated to be 177.5 inches from the envelope nose rather than 182.2 inches shown on Dwg. 76-432. The center of gravity of the envelope was scaled at 2.1 inches aft of the center of buoyancy. The envelope area, volume, center of gravity, and center of buoyancy were used as scaled since any error introduced was on the conservative side. Envelope material weight was conservatively taken as 4 ounces/yd^2 to allow for lapping and gluing the seams of the 3.4 ounce/yd^2 material. Helium was assumed to have 0.06 lb/ft^3 buoyancy.

Normal sources of vendor information at GAC provide no information on products, suppliers, or manufacturers of model airplane components. Most of the components selected were found in the Radio Control Buyer's Guide, 3rd edition. Additionally, some companies were contacted for specific information. These are listed in Table V.

Envelope material stress was calculated based on a pressurization of 1-1/2 inches of water and a 93.6 inch maximum diameter. Total stress was found to be 2.57 lb/in. Barometric pressure and temperature changes resulted in a fraction of a pound per inch stress change which was deemed insignificant.

Rotation of the model due to motor torque was calculated to be 13.1° with the propellers rotating all in the same direction and 4.7° with the forward propellers rotating opposite to the aft propellers.

The possibility of redistributing the weight of the vehicle by relocating the aft motors to a point further forward and driving the propeller through a flexible shaft was considered. Analysis showed that the overall weight problem worsened due to the weight (.192 lbs/ft) and its CG of the flexible shaft.

The weight distribution problem is not improved radically by using a glow engine in place of the electric motors for the aft propul-

TABLE V - ONE-TWELFTH SCALE MODEL STUDY SOURCES OF INFORMATION

1.	Kraft Great Lakes, Inc. 6787 Wales Avenue, NW Canton, Ohio 44720	Mr. Jack Yarger (216) 499-8310
	All Kraft Systems, Inc. components - engines, transmitters/receivers, servos. Catalog data was received.	
2.	Du Bro Products, Inc. 480 Bonner Road Wauconda, Ill. 60084	Mr. Bentley (312) 526-2136
	Propeller drive unit, control linkages, miscellaneous parts/materials. Catalog data was received.	
3.	Futaba Industries 630 W. Carob Street Compton, California 90220	Mr. Glen Toma (213) 537-9610
	Transmitters/receivers, servos. Data was received.	
4.	World Engines, Inc. 8960 Rossash Avenue Cincinnati, Ohio 45236	Mr. Gene Steinkamp, Sales (513) 793-5900
	General engine information. No written data received.	
5.	Irish Brothers St. John, Ind.	Mr. Tony Irish (219) 365-4061
	Information on propellers. Unable to contact him as he was out of town on the times called.	
6.	Airport Hobby Shop 1889 Triplet Blvd. Akron, Ohio 44312	Mr. Al Brown, Co-Owner (216) 784-8800
	General information on models and controls. No written data received.	

TABLE V (Continued)

7. Probar Design — Unable to get a phone no.
P. O. Box 639
Escondido, California 92025

Information on a 40-inch pound torque sail control winch servo. A letter was sent to them (LTA-PM-103) asking for information but no response was received.

8. James E. Cline
564 Smith Avenue — (513) 372-1383
Xenia, Ohio 45385

Data on Master Climb prop drive unit. He was not contacted since the data was obtained from Kraft Great Lakes above.

9. Astro Flight, Inc. — Mr. Bob Boucher (Boo-shay')
13377 Beach Avenue — (213) 821-6242
Venice, California 90291 — (-0291 direct to Boucher)

Information on model airplane electric motors. Catalog data was received.

10. Bill Putman
Princeton University — (609) 452-5151

Information on electric motors used on model Aerocrane. Co-author of All American Engineering Co. Report 05-137, Navy Contract N00019-75-C-0418.

11. Bob Ovendorff
GAC - Dept. 181-G (Procurement — (216) 794-2753

General information on models, engines, controls sion unit. The glow engine and propeller drive unit are ε mated to weigh approximately three pounds. A glow engine problem that was not resolved concerned the fuel system. If the fuel is located near the engine then weight is being added at the rear. If it is located remotely forward then a small pitch of the vehicle results in a large vertical displacement of the fuel supply. Engine driven fuel pumps and fuel pressurization by the use of exhaust gas pressure are used but result in a pressure increase of only a few inches of fuel. Pressurization of the fuel system would be practical if a small, light pressure regulator can be found to install adjacent to each engine.

No good engine/propellor thrust data has been acquired. Du Bro data says twelve pounds of thrust can be developed with their 2.5 to 1.0 speed reduction propeller drive unit and that 27 pound models have been flown successfully with greater than 24 oz/ft^2 wing loading. Jack Yarger of Kraft Great Lakes Inc., after talking to the manufacturer, reported that the 2/1 speed reduction Master Climb propeller drive unit developed twelve pounds of thrust with a 16-1/2 inch propeller. He estimates that a 22-inch propeller would develop a little more thrust, probably about 14 or 15 pounds total. Twelve pounds of thrust appears higher than could be expected. Independent estimates of thrust output indicate something on the order of 4-1/2 pounds of thrust with a one horsepower driving unit. This would agree with the Du Bro 27-pound airplane if an L/D of 6 is assumed.

The flight performance capability of the model airship obviously is dependent significantly on the propulsion unit thrust characteristics. Thus, a test program was defined to calibrate the thrust and control forces and moments of the stern propulsion and control surface.

3.2 One-Twelfth Scale Model Test Plan and Cost Estimate

Propulsion is supplied by a series of model airplane permanent magnet DC motors of approximately 1/4 horsepower each at their rated speed of 9,500 RPM. The aft propulsion unit will have a cluster of four motors geared to a 22-inch propeller. Each of the two forward units will consist of two motors connected with a toothed timing belt driving an eleven-inch propeller. Each cluster of motors will be wired in series with power transmitted from the ground through an umbilical cable. Electrical power will be 60 Hz full wave rectified and controlled by Variacs for motor speed control.

Motor inclination and control surface deflections will be operated by model airplane servos with signals transmitted through a radio transmitter on the ground to a receiver in the vehicle. The forward motors will be rotatable through 90 degrees (straight ahead to straight up) with the motors rotating together. The aft motor unit will rotate through 90 degrees independently of the forward motors.

A total of six radio channels and ten servos will be required. The radio channels required are (1) forward motor inclination, (2) aft motor inclination, (3) main ruddevators (2 channels required), and (4) aft motor ruddevators (2 channels required). The servos required are (1) forward motor inclination (2 servos required), (2) aft motor inclination (2 servos required), (3) main ruddevators (4 servos required), and (4) aft motor ruddevators (2 servos required). Additionally, two electronic mixers will be mounted in the vehicle to provide controls mixing of the main ruddevators and the aft motor ruddevators. DC power (5 volts) will be supplied from the ground through the umbilical for operation of the servos, mixers, and radio receiver. The bag will be fabricated of 3.5 oz/sq. yd. coated Dacron material. Airfoils will be cloth-covered wood structure using kiln dried clear white pine. Motor unit supports will be of aluminum.

Testing will consist of two phases. Phase I will consist of testing the aft and forward motor/propeller combinations for speed/-

current/voltage/thrust/torque characteristics. The aft motor unit will be installed on its mount and additionally tested for longitudinal, lateral, and vertical forces developed by the ruddevators at various angles and motor speeds. Phase II will consist of construction and testing of the lifting/hover/forward flight transition characteristics of the complete model.

The Phase I and Phase II test plans, component requirements and fabrication estimates are described below.

Phase I - Test Details

1. Test motor/propeller combination for thrust/speed/torque/current/volts for both forward and aft motor assemblies. Aft motor assembly is less control (ruddevator) surfaces.
   - A. Purchase parts listed in Table VI.
   - B. Fabricate parts listed in Table VII.
   - C. Assemble for test as shown in Figure 30 (fwd. motors) and Figure 31 (aft motors). (Motors are common. Assemble fwd motors for test first.)
   - D. Wire per Figure 32.
   - E. Test per Table VIII (aft motors) and Table IX (fwd. motors).

2. Test mount/propeller/control surfaces combination for speed/control surface deflection/lateral, longitudinal, vertical thrust - rear motors only.
   - A. Assemble per Figure 33.
   - B. Test per Table X except for vertical force. Test with ruddevators set at angles listed in Table XI.
   - C. Assemble per Figure 34.
   - D. Test per Table X, vertical force only with ruddevators set at angles of item 2B above.

Phase II

Fabricate complete airship per drawings (Figures 13, 18 through 29). Table XII summarizes the fabricated parts and purchased parts lists and estimated material and labor costs. Table XIII presents the estimated overall one-twelfth scale model fabrication and ground test program cost summary.

TABLE VI - ONE-TWELFTH SCALE MODEL PARTS LIST AND COST ESTIMATE

Motor/Propeller Test - Purchased Parts

1.	Motor (Astro Flight Cat. #2003M) (4 req.)	$200
2.	Sprocket, timing belt (Neuman P/N 18XL025 (2 req.)	5
3.	Timing belt (Morse P/N 80XL025) (10/pkg)	20
4.	Gear, 30 tooth Delrin (PIC P/N AB18-30) (4 req.)	32
5.	Gear, 64T, Al. Aly, hubless (PIC P/N J24-64) (Bore to .6875)	6
6.	Hub, 3/8 shaft, Cres (PIC P/N K1-51)	8
7.	Propeller, 11 x 6 and 11 x 8 (Grish Bros.) ($1 ea.)	2
8.	Propeller, 22 x 8 (Grish Bros.) (add 1 hr. for finishing)	10
9.	Propeller washer (Du Bro P/N PD016)	2
10.	Propeller drive washer (Du Bro P/N PD017)	4
11.	Variac, 14 amp (10 amp is avail in Engrg. Shop)	65
12.	Diode, 200 PIV, 14 amp (4 req.)	15
13.	Bearing, Ball, 3/8 bore (Fafnir F 3K) (2 req.)	5
14.	Collar, 3/8 shaft (Du Bro P/N PD019)	1
15.	Propeller balancer + 3/8 shaft adapter (H.B. Huebl Custom 76)	15
16.	Miscellaneous hardware and material	21
	Total parts and material	$410

Additionally, the following is assumed to be available in house:

Voltmeter, DC, 0-50V
Voltmeter, DC, 0-100V
Ammeter, DC, 0-15A
Stroboscope
Force Scales (approx. 0-5 lbs. 2 req.)

TABLE VII - ONE-TWELFTH SCALE MODEL PHASE I TESTING - FABRICATION REQUIREMENTS & LABOR ESTIMATE

Motor/Propeller Test - Shop Fab - Ph. 1

Fwd. Motors		Hrs.
*1.	Mounting Plate	4
*2.	Propeller/Shaft Adapter	4
3.	Support Tube	8
4.	Support Bracket	2
5.	Assembly	2
	Sub Total	20

Aft. Motors		Hrs.
*1.	Mounting Plate, Motor	8
*2.	Mounting Plate, fwd. bearing	6
3.	Hanger Plate	4
*4.	Spacer (2 req.)	2
5.	Support Tube	2
*6.	Rebore Gear and Assemble	2
*7.	Prop Shaft	4
8.	Assembly	8
	Sub Total	36
*9.	Motor Mount	39
*10.	Ruddevator (2 req.)	25
	Sub Total	64
	Total	120

*Usable on finished model

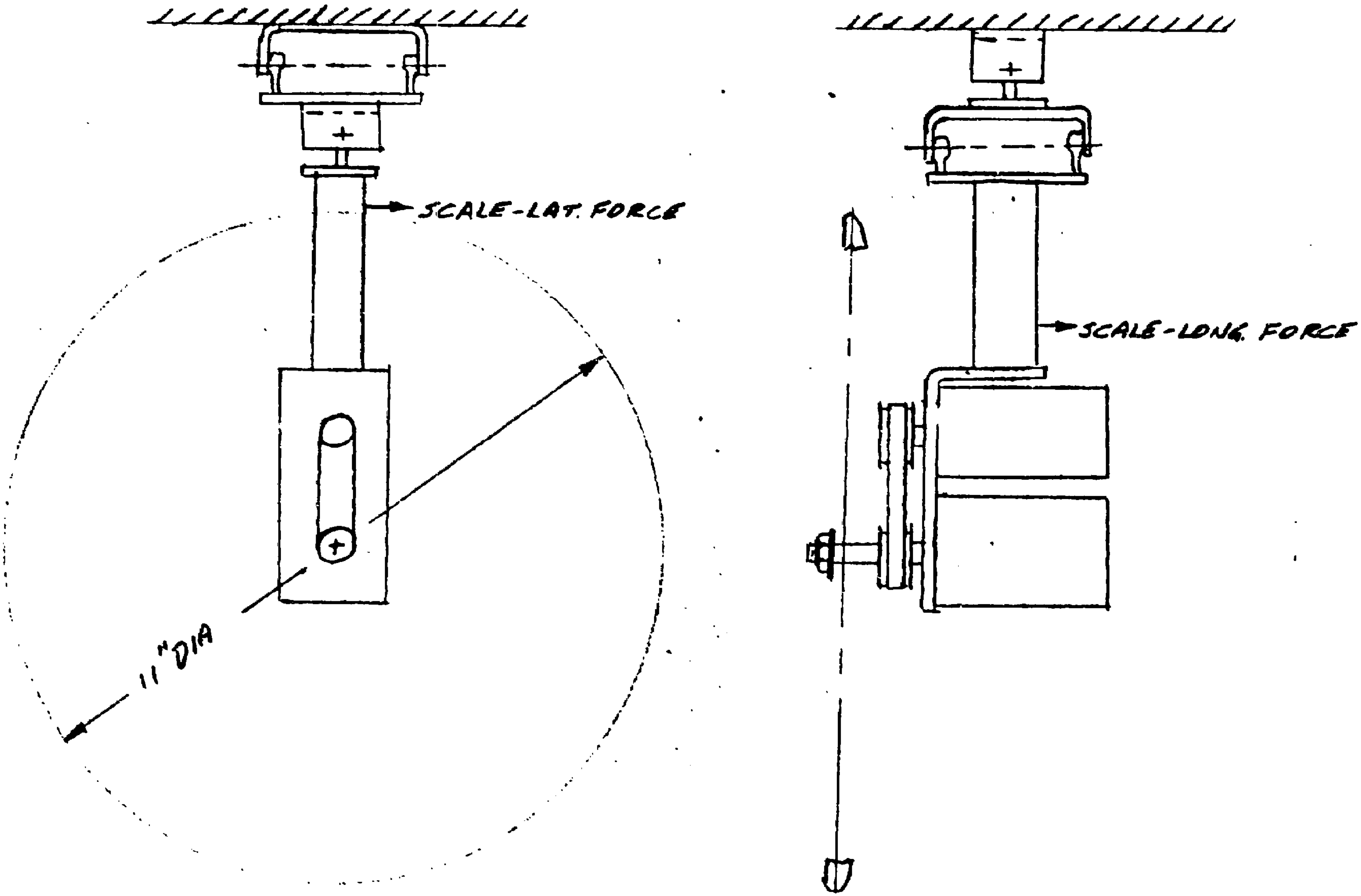

FIG. 30 - FORWARD MOTOR TEST ASSEMBLY

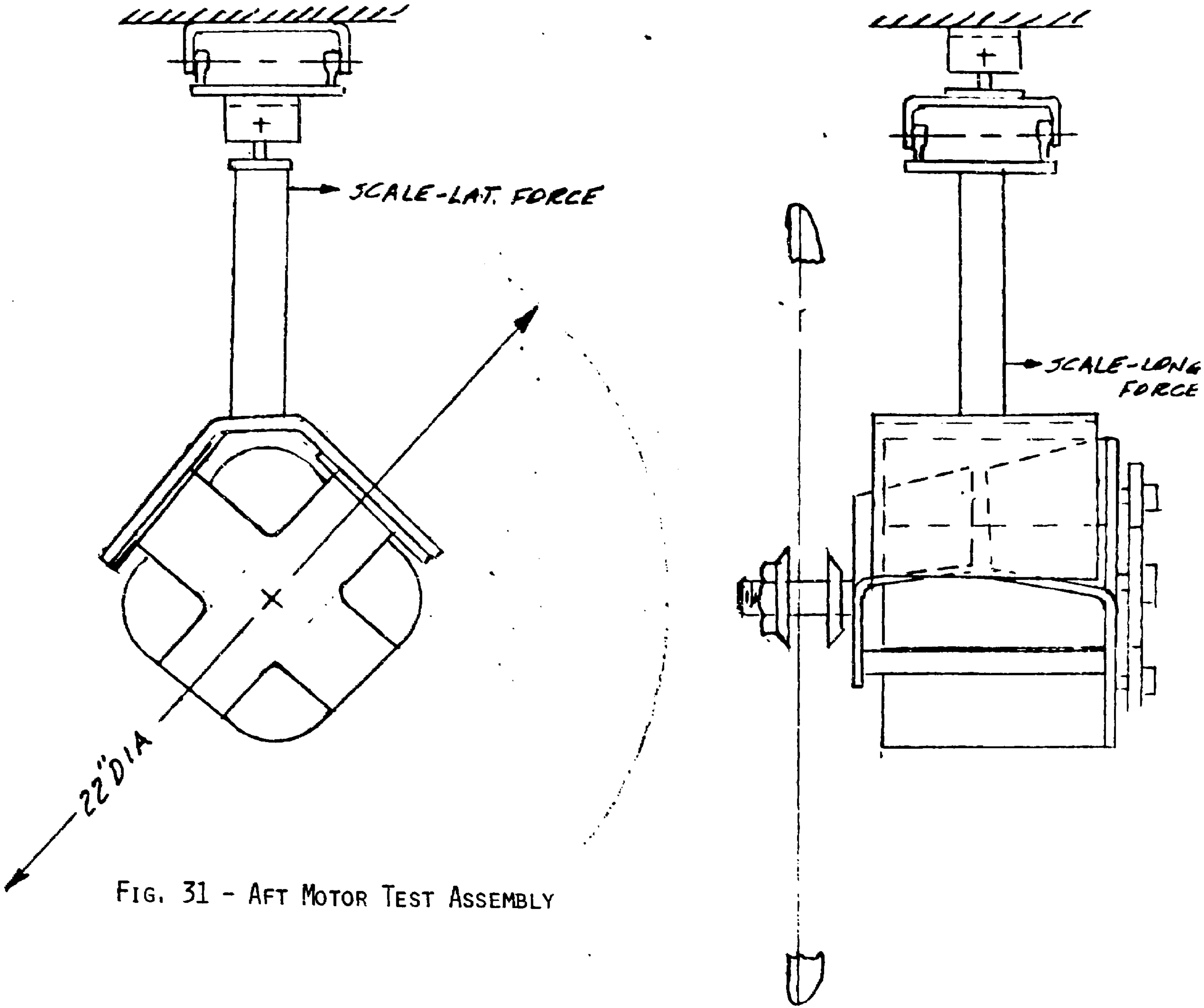

FIG. 31 - AFT MOTOR TEST ASSEMBLY

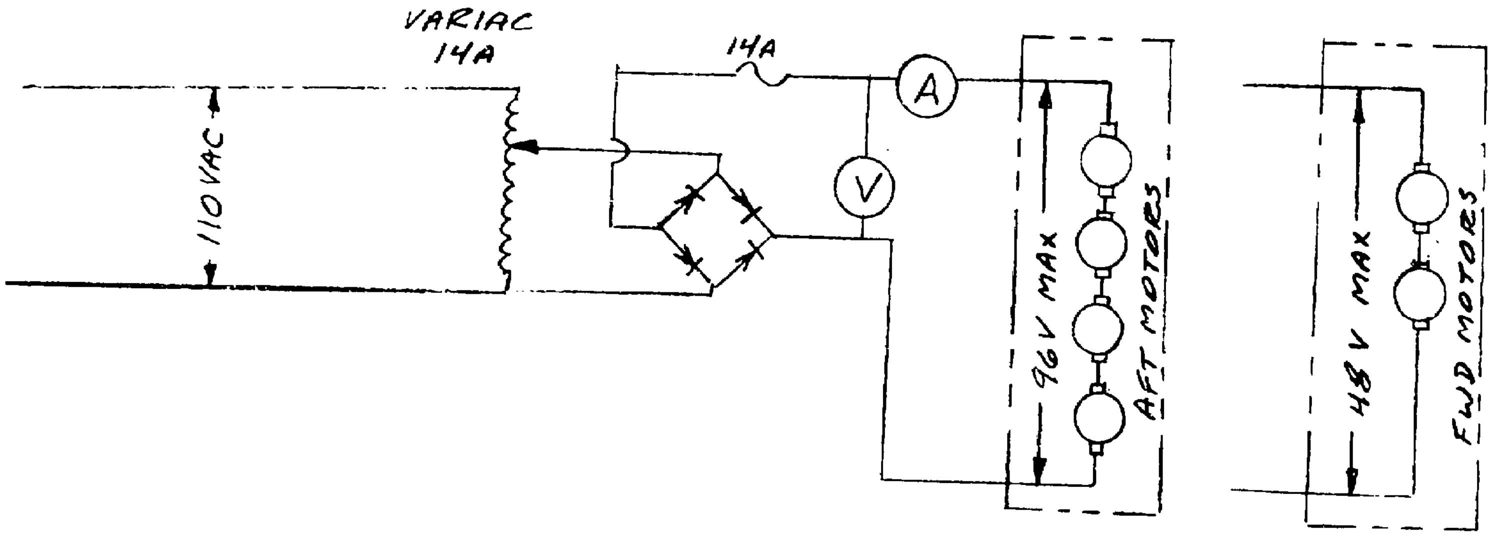

FIG. 32 - WIRING DIAGRAM - ONE-TWELFTH SCALE
MODEL PHASE I: FWD & AFT MOTORS TEST

TABLE VIII - ONE-TWELFTH SCALE MODEL - PHASE I AFT MOTOR TEST PLAN

S	I	V	LONG. FORCE, SCALED	LONG. FORCE (MULT. X)	LAT. FORCE, SCALED	LAT. FORCE (MULT. X)				
0										
.5K										
1K										
1.5K										
2K										
2.5K										
3K										
3.5K										
4K										
4.5K										
5K										

TABLE IX - ONE-TWELFTH SCALE MODEL - PHASE I FORWARD MOTOR TEST PLAN

S	I	V	LONG. FORCE, SCALED	LONG. FORCE, (MULT. X)	LAT. FORCE, SCALED	LAT. FORCE (MULT. X)				
0										
1K										
2K										
3K										
4K										
5K										
6K										
7K										
8K										
9K										
10K										

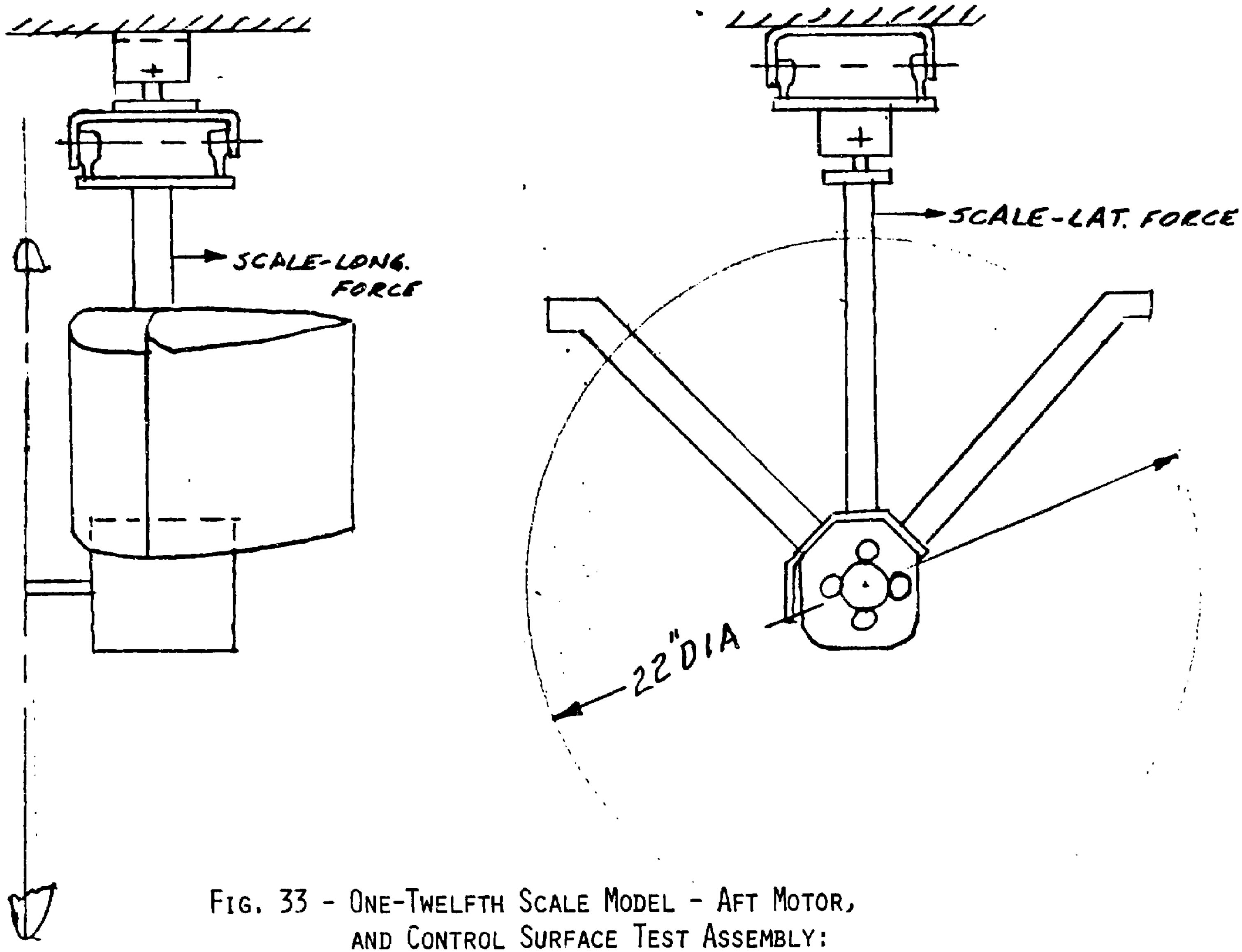

FIG. 33 - ONE-TWELFTH SCALE MODEL - AFT MOTOR, AND CONTROL SURFACE TEST ASSEMBLY: LATERAL & LOGITUDINAL FORCES

TABLE X - ONE-TWELFTH SCALE MODEL - AFT MOTOR & CONTROL SURFACE TEST

L. RUDDEVATOR L =
R. RUDDEVATOR L =

S	I	V	LAT. FORCE, SCALED	LAT. TORQUE (FXL-MOT. TORQ)	LAT. FORCE (LAT. TORQ ÷ L)	LONG. FORCE SCALED	LONG. FORCE (MULT. X)	VERT. FORCE SCALED	VERT. TORQUE (FXL-MOT. TORQ)	VERT. FORCE (VERT. TORQ ÷ L)
0										
.5K										
1K										
1.5K										
2K										
2.5K										
3K										
3.5K										
4K										
4.5K										
5K										

TABLE XI - AFT MOTOR/RUDDEVATOR TEST PLAN

Ruddevator Positions to be Tested - Ph. I

L. Rud.	R. Rud.
-30°	0°
-20	-10
	0
	+10
-10	-20
	-10
	0
	+10
	+20
0	-30
	-20
	-10
	0
	+10
	+20
	+30
+10	-20
	-10
	0
	+10
	+20
+20	-10
	0
	+10
+30	0

Difference between ruddevator surface angles ≤ 30°

Average of ruddevator surface angles $\frac{\text{L. Rud.} + \text{R. Rud.}}{2} \leq 15°$

Positions	=	25
Axes	=	(x)3
No. runs (shts)	=	75
Speeds	=	(x)11
Total Readings	=	825

(Readings @ 5° increments = 2805 total readings)

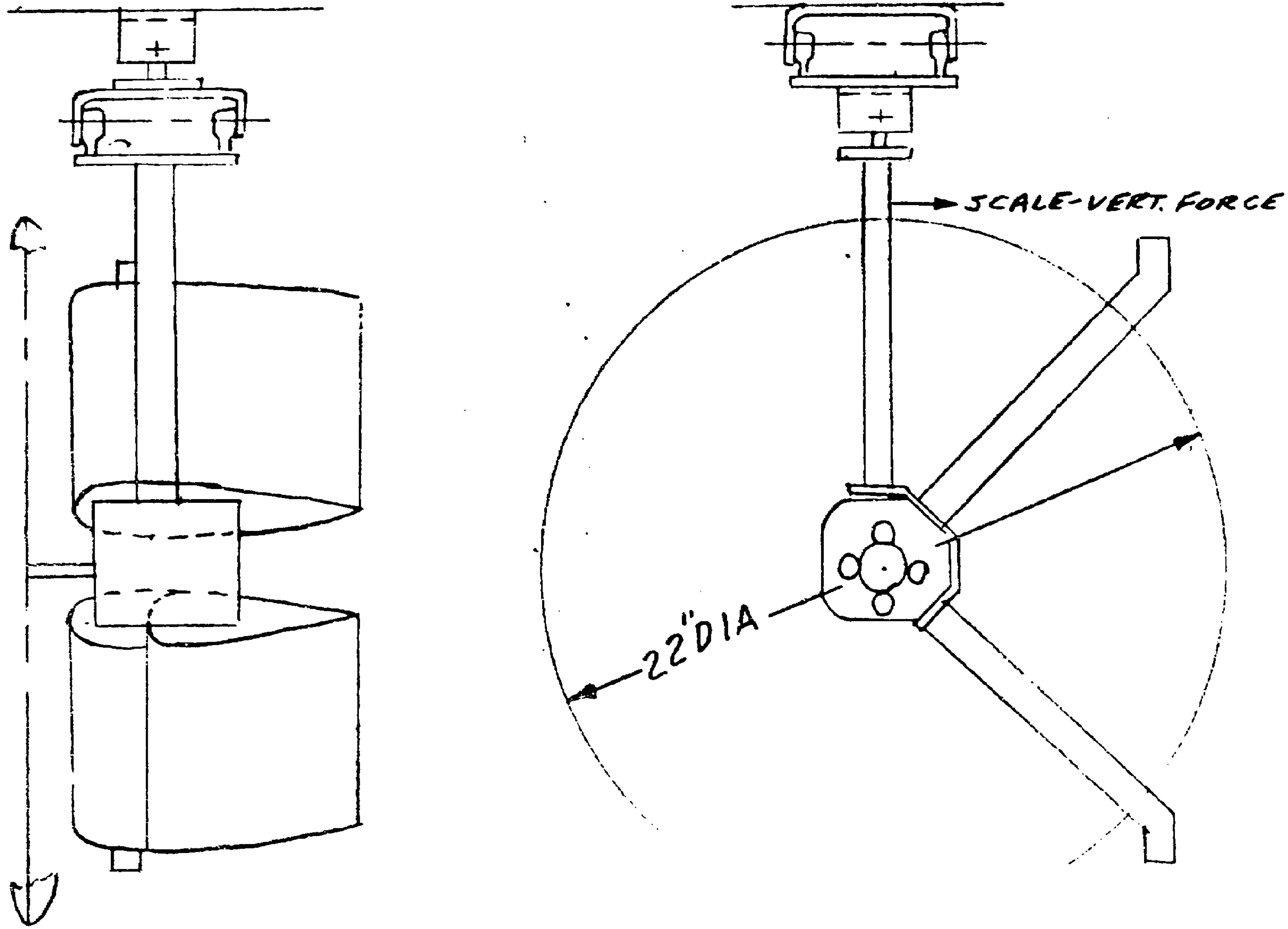

FIG. 34 - ONE-TWELFTH SCALE MODEL - AFT MOTOR AND CONTROL SURFACE TEST ASSEMBLY: VERTICAL FORCES

TABLE XII - PARTS LIST SUMMARY & ESTIMATED LABOR & MATERIAL COSTS

Ph. II - Fab Parts	Hrs.
1. Aft Engine ruddevators (2) (done Ph. I)	--
2. Aft Engine mount (done Ph. I)	--
3. Tailcone assembly	44
4. Fwd. engine mount (partially done Ph. I)	24
5. Aft engine mtg. & controls	40
6. Aft engine assy. (done Ph. I) 40	
7. Ruddevators (& trim tabs) (for 4)	140
8. Assemble fin & ruddevator (incl. rigging - for 4)	100
9. Fin (for 4) (incl. 4 extra bases)	198
10. Bag	275
	821

- Purch. Parts	Cost
Transmitter (Kraft) (2 reqd.)	200
Receiver (Kraft) 2 reqd.)	280
Motors (4 additional)	200
Servo, 40 in lb torque (2 reqd.)	200
Servo, 50 in oz torque (11 reqd.)	550
Mixer, ruddevator (2 reqd.)	90
Variacs (3 reqd. @ 65 ea.)	195
Meters (3 ea voltmeter & ammeter)	120
Misc. hdwr.	65
	$1900

TABLE XIII - ONE-TWELFTH SCALE MODEL FABRICATION & TEST PROGRAM ESTIMATED COST SUMMARY

Cost Summary*

Ph. I - Assemble & Test Motors & Ruddevators

1.	Purchased parts & material	$410	
2.	Shop fab		120 hrs
3.	Test time - Ph. 1 (2 men 1-1/2 days)		24 hrs
	Ph. 2 (2 men 4-1/2 days)		72 hrs

Ph. II - Assemble & Test Complete Airship Model

1.	Purchased parts & material	$1900	
2.	Shop fab		821 hrs

Ph. III - Conduct Flight Tests — T.B.D.

*NOTE: Cost estimates are budgetary approximations only. No Engineering analysis or design support costs are included.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

On the basis of the limited study reported herein the following conclusions are suggested:

1) A one-twelfth scale model of the ZPG-X appears marginally feasible using an umbilical powered, electric motor propulsion arrangement. A critical design factor is the thrust output of the motor/propeller combinations. Ground test calibration of thrust and control surface forces is mandatory to finally confirm the feasibility of the one-twelfth scale model. A slightly larger one-tenth scale model would appear to be a more promising, lower risk approach. This model would probably utilize the same engine design characteristics developed and described herein. Costs should be very close to those estimated for the one-twelfth scale model.

2) A one-half scale model of the ZPG-X which could be constructed by modifying a GZ20 Goodyear Advertising Airship is a very attractive, but much more expensive alternative. Virtues of this approach include:

a) Piloted vehicle performance testing

b) Better flight dynamics, V/STOL and hover dynamics testing capability.

c) Capability to utilize existing GZ20 propulsion for backup and non-hover performance demonstrations.

The high costs expected of this approach suggest further examination of its cost effectiveness is warranted prior to pursuing this approach.

The primary objective of this limited effort was to establish Zeroth order design feasibility assessments and associated costs. While this objective has been satisfied, several items and areas of analysis have not been considered due to the limited program scope.

4.2 Recommendations

A serial development and test plan is recommended for the ZPG-X flight demonstration program. The recommended program phases are listed in Table XIV. Go-No-Go program decision points could logically be utilized between each program phase.

TABLE XIV - RECOMMENDED ZPG-X MODEL TEST PROGRAM

Phase	Description
I	Calibrate electric motor/propeller/control surface force and moment capabilities
II	Select preferred "small" model scale (1/12th to 1/10th).
III	Fabricate and flight test "small" scale model
IV	Calibrate Northrop 0-100B motor/propeller/control surface force and moment capabilities via static test program
V	Complete Engineering design and analysis of GZ20 scale vehicle and selected preferred Goodyear asset utilization approach
VI	Fabricate and assemble GZ20 - ZPG-X flight demonstration vehicle
VII	Conduct VTOL/hover and flight dynamics testing

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