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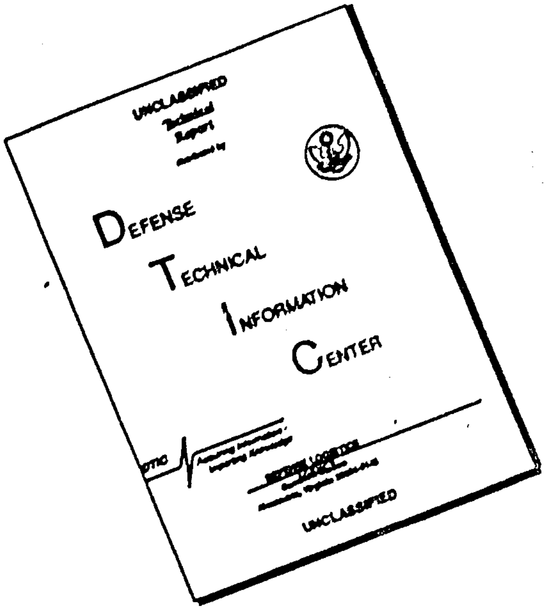

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SUMMARY REPORT

AIRBORNE PERSONNEL PLATFORM

CONTRACT NO. Nonr 1357(00)

FC

Report No. ARD-236

June 9, 1959

SUMMARY REPORT

AIRBORNE PERSONNEL PLATFORM
Contract No. Nonr 1357(00)

Wilbur J. Gill
Project Engineer

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ADVANCED RESEARCH
DIVISION OF HILLER AIRCRAFT CORPORATION

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1.0 SUMMARY

Under Phase IV of Contract No. Nonr 1357(00) a wind tunnel and static test program was conducted in which four duct shapes and three propeller configurations were tested in various combinations and an enlarged full scale flying platform was designed and tested.

The maximum figure of merit of all the ducted propeller models tested was 1.07 (based upon an ideal value of $\sqrt{2}$ for a non-diffusing duct). This value was obtained with a bell-mouth duct in combination with a set of twisted, 3-bladed, contra-rotating propellers. This same configuration showed the highest values of forward flight efficiency, lift coefficient and pitching moment coefficient for the range of speeds and propeller blade settings tested. The airfoil-profile ducts produced considerably lower figures of merit due to an indicated flow spearation at the duct inlet. The lower efficiencies and lift and pitching moment coefficients in forward equilibrium flight (where net propulsive force is zero) were evidently caused by the same duct inlet flow separation.

The original 5-foot diameter platform was underpowered. As the thrust produced by a given power increases with decreasing disk loading, the 5-foot diameter platform was modified to a 7-foot diameter platform. This platform, designated Model 1031-A-1, developed enough thrust to hover out of ground effect; but due to the increased moment of inertia and increased pitching moment of the platform, the pilot was unable to apply sufficient kinesthetic control for forward flight.

Theoretical studies conducted in platform stability and control indicated that the platform was unstable in hovering and forward flight without the automatic mechanical gyro-stabilizer. This stabilizing system made the platform dynamically stable in hovering, but would not stabilize the divergent motion of the platform in forward flight. A closed airfoil duct indicated some improvement in damping out this undesired motion. However, it did not produce stability but made it less unstable.

A theory was developed for predicting the pitching moment characteristics of a ducted propeller in equilibrium forward flight. It was indicated from a comparison of this theory and the simple momentum theory with the few experimental test data that much additional theoretical and experimental work is needed in order to give reliable predictions of ducted propeller aerodynamic characteristics.

2.0 INTRODUCTION

This contractor has been conducting a research and development program since early 1954 on airborne personnel platform under Contract No. Nonr 1357(00) awarded by the Office of Naval Research, Department of the Navy and funded in part by the Department of the Army. Work to date on this contract has been conducted in four phases.

The Office of Naval Research and Hiller Aircraft Corporation collaborated in designing the Phase I program for the purpose of extneding the work initiated by Mr. Charles Zimmerman and conducted by the National Advisory Committe for Aeronautics. According to Reference 1, the object of Phase I was to determine the feasibility, design and flight characteristics of this type of aircraft. The guiding philosophy of the vehicle design was that control in hovering and forward flight would be attained by kinesthetic control which utilizes the same human muscular reflexes in flight as are used by man to maintain the body upright when standing on a fixed surface. This principal was successfully demonstrated by the NACA in 1952 and 1953 with several test vehicles dependent on a ground power source (see References 2, 3 and 4). Phase I provided for the design, fabrication, and testing of a self-contained research platform capable of being stabilized and controlled by the pilot's instinctive reflex responses. The platform denoted as the Hiller Model 1031 employed a ducted, 5-foot diameter, contra-rotating, fixed pitch propellers driven independently by two Nelson H-59 engines of 40 horsepower each. The platform was found to be controllable by instinctive reflex response in hovering, but was difficult to control in translational flights and in gusty winds. It was recommended in Reference 1 that quantitative platform aerodynamic data be obtained and additional free flights be made to study the control problem in translational flight, including the effect of moment of inertia. In addition it was further recommended that the engine installation, cooling system and propeller drive system be redesigned in order that the engines could be operated at full power in summer weather and that safer single-engine descents could be achieved. The Phase I program has been presented in detail in Reference 1.

Phase II of Contract No. Nonr 1357(00) was initiated in March 1955 to accumulate further technical knowledge and to improve the flight characteristics and safety of the platform. A mobile test stand was designed and built to test the Model 1031 platform at low forward speeds to obtain quantitative data, including the lift, thrust, drag, and pitching moment characteristics of the platform as functions of forward speed, tilt angle, and power setting. The platform was then redesigned to incorporate a coaxial gear box drive system for greater flight safety in the event of a single-engine failure and for better cooling and reduced weight where possible for a lower total mass moment of inertia. The redesigned 5-foot platform was designated Model 1031-A.

It was concluded in Reference 5 that the redesigned powerplant system required much less maintenance because of the more rigid drive system and that the directional control was steadier because the coaxial gear box relieved the undesirable characteristics of the individually driven propellers. It was further concluded that the Model 1031-A required less pilot effort to control in forward flight in calm air than the Model 1031; however, the redesigned platform was still very difficult to handle in windy and gusty air. Thus, it was recommended in Reference 5 that the platform stability characteristics be studied and supported by a flight test program and that studies be made of methods of providing the pilot with a boost control system. It was also recommended that special vaned cylinder heads be installed on the engines to aid in the cooling problem and that further testing be done to obtain quantitative performance data, and that generalized performance methods be developed. Further details of the Phase II program have been presented in Reference 5.

Phase III of Contract No. Nonr 1357(00) was granted in February 1956 to provide, by means of further tests, more quantitative data relative to the characteristics of the airborne platform such as performance and stability and control characteristics. The Phase III program results shown in Reference 6 indicated that the Model 1031-A, 5-foot platform, was easily controlled in hovering and could be flown in forward flight up to a speed of 14 knots with the incorporation of a raised vertical center-of-gravity and an automatic mechanical gyro stabilizing system. Forward flight speed was limited by low power, large equilibrium tilt angles, and a random nose-up pitching moment. In addition the platform could not hover out-of-ground effect due the low power. Methods of reducing and controlling the pitching moment were studied. It was recommended in Reference 6 that additional research be conducted to quantitatively evaluate the thrust augmentation and pitching moment characteristics of various duct shapes and that further studies be conducted on stability and control of the platform. A detailed discussion of the Phase III program has been published in Reference 6.

This report presents the work done in Phase IV of Contract No. Nonr 1357(00).

3.0 PHASE IV PROGRAM

3.1 Scope and Objectives

Contract No. Nonr 1357(00) was extended by Annex B to the contract into a Phase IV program. The work authorized in this annex and proposed in Reference 7 was to design and fabricate a scale model of the flying platform to obtain basic data required for performance and stability calculations; assist in the wind tunnel testing of this model and reduce the test data; design and fabricate a full-scale ducted propeller platform, of the Model 1031-A type, suitably modified to incorporate advance design features; conduct additional theoretical studies to further explore the aerodynamic and stability and control characteristics of the ducted propeller platform; and conduct flight tests to evaluate performance, control response and dynamic stability over the whole practical speed range. The "TARD" gyro developed by the Altoscan Co. was to be developed and tested on the full scale platform.

3.1.1 Wind Tunnel Model and Tests

The ducted propeller model that was to be designed and fabricated incorporated:

(a) Four different interchangeable ducts.

(b) Three different types of contra-rotating propellers with adjustable pitch blades.

(c) Variable propeller tip clearance and axial positioning in the duct.

(d) Two types of centerbodies.

(e) Exit vanes.

(f) Strain gage sections for determining total normal and axial forces, total pitching moment and motor torque.

(g) Strain gage sections for determining duct normal and axial forces and duct pitching moment.

The model was to be tested with various combinations of Items (a) through (e) and ranges of advance ratio, tilt angle, propeller blade pitch setting, and propeller rpm. The measured force and moment data were to be reduced to coefficient form and plotted two ways: 1) against tilt angle and 2) against advance ratio (tunnel speed/tip speed).

3.1.2 Full-Scale Ducted Propeller Platform and Tests

The full-scale platform, Model 1031-A, was to be redesigned, utilizing as many of the Model 1031-A components as possible, so that it would hover and make forward flights out-of-ground effect. In order to accomplish this, the disk loading was to be decreased by increasing the duct diameter from 5 feet to 7 feet. As a result the following major components were to be redesigned:

a. duct

b. contra-rotating propellers

c. transmission gears

d. support structure

The full-scale platform was to be tested on the static test stand to determine the engine cooling and static thrust capabilities of the platform at various engine rpm, spark advance, and heights above the ground with one- and two-engine operation. Tethered flights were to be performed to investigate the time history of the pitching (or rolling) motion following an abrupt control input of an unstabilized platform and of a platform with an automatic mechanical gyro-stabilizing system and with the "TARD" gyro stabilizing system, employing various damping characteristics and linkage ratios. These tests were to be performed at various flight speeds and center-of-gravity heights with two different ducts.

3.1.3 Theoretical Studies

Stability derivatives were to be determined from the wind tunnel test data. With these derivatives, theoretical stability and control investigations were to be carried out for hovering and forward flight for various configurations of an unstabilized platform and for a platform with an automatic mechanical gyro-stabilizer. These studies were to be compared with flight test data.

3.2 Wind Tunnel Program

3.2.1 Design of Model

In Reference 7 it was proposed to design and build a wind tunnel model with which to determine basic data required for performance and stability calculations. A duct diameter of 2 feet was decided upon in predesign talks with the Aerodynamic Laboratory personnel at the David Taylor Model Basin. It was further decided that the model would be mounted on an existing mounting stand which could be remotely controlled and would be tested in the 17 by 20 foot return section of the "south" Subsonic Wind Tunnel at DTMB. In addition it was determined that the model would be powered by a 75 hp electric motor capable of developing the necessary torque and a method of supporting the model so that the total forces and moments of the model and of the duct could be independently measured was decided upon.

The wind tunnel model is shown in Figure 1. It consisted of four interchangeable duct shapes, three sets of alternate contra-rotating propellers, two types of centerbodies, and a set of slipstream vanes. The electric motor was housed in the model slipstream.

The four ducts had inside diameters of 2 feet (see Tables 1 - 5). Two of these had a length/diameter ratio of o.25, one of which had a total diffuser angle of about 17°. The third airfoil profile had a length/diameter ratio fo 0.15 and no diffuser. The fourth duct shape was a scale model of the full-scale duct which had a lemniscate profile and a length/diameter ratio of 0.25.

Two of the contra-rotating propellers (2-bladed and 3-bladed) used the same chord and twist distributions (see Table 6 Reference 8) with an RAF-6, 12 percent thick blade section. The blades of the third propeller were untwisted and had a constant chord, RAF-6, 12 percent thick section.

Two sets of hubs were designed for the 2-bladed and 3-bladed contra-rotating propellers. Provisions were incorporated in these hubs to permit variations in propeller tip clearance and propeller blade pitch setting.

Slipstream vanes with a 15 percent thick symmetrical airfoil section and 0.20 foot chord were designed for longitudinal control. These vanes were mounted in the slipstream as shown in Figure 1.

A scale model of the Nelson engines used on the platform were designed for the wind tunnel model to determine the effects of this type of blockage in the duct inlet. A dummy of the electric motor housing was designed in order that the aerodynamic interference might be determined due to the electric motor housing in the slipstream. These bodies are shown installed on the model in Figure 2.

The model was powered by a water-cooled, variable-frequency electric motor rated at 75 horsepower at 12,000 rpm and 32.9 foot pounds of torque. This power was transferred to a gear box of 1:1 gear ratio which converted the single rotation from the electric motor to contra-rotation for the propellers.

The model was mounted for testing as shown in Figures 3 and 4. The model was instrumented in such a way that, in addition to the total aerodynamic forces and moments acting on the model, the forces and moments acting on the duct itself could be obtained simultaneously. The electric motor was instrumented with a strain gage beam to measure the motor torque and with a tachometer to measure the propeller rotational speed.

A more complete description of the wind tunnel model has been given in Reference 8.

3.2.2 Static and Wind Tunnel Tests of Model

Static and wind tunnel tests were conducted on various combinations of the model described above. The model was tested statically at various rpm in a large rrom with an open 12 by 13.5 foot door to provide an unobstructed escape for the slipstream. Static tests were also conducted inside the wind tunnel at 3915 rpm.

The models were compared in the static or hovering condition on the basis of their static efficiencies commonly called the figure of merit, which is defined here as

$$M = \frac{T}{P}\sqrt{\frac{T/A}{2\rho}}$$

where T is the total thrust, P is the power supplied to the model, A is the minimum inside duct area, and ρ is the air mass density. The ideal value as given by simple momentum theory is $\sqrt{2}$ for a ducted propeller with no diffuser.

The highest figure of merit, 1.07, was obtained with the duct incorporating the lemniscate curve or bell-mouth inlet and a set of twisted, 3-bladed, contra-rotating propellers at a blade pitch angle of approximately 19 degrees at the 0.7 blade radius. A comparison is shown in Figure 5 of the performance characteristics of various ducted propeller models at a propeller rpm of 5600, incorporating two different sets of contra-rotating propellers. It can be seen that the airfoil-profile ducts developed considerably lower maximum figures of merit, at correspondingly lower propeller blade pitch settings than did the bell-mouth duct. It should be noted that the bell-mouth duct (lemniscate curve inlet) carried a higher percentage of the total thrust (46 percent) than did any of the other ducts tested. It was noticed from limited tuft studies during the tests that the three airfoil-profile ducts encountered separation of the airflow over the inlet lip, resulting in their comparatively low performance.

The twisted, 3-bladed, contra-rotating propellers produced slightly higher maximum figures of merit for each duct tested than did either the twisted, 2-bladed, contra-rotating propellers or the untwisted, constant chord, 3-bladed, contra-rotating propellers. It appears from these tests that duct shape and duct length/diameter ratio are more important parameters to consider in design than propeller blade planform, blade twist, and blade solidity. Detailed static test data have been presented in Reference 8.

The wind tunnel tests were conducted in the return section (17 by 20 foot) of DTMB's "south" Subsonic Wind Tunnel. The models were investigated through ranges of tilt angles, propeller blade pitch settings and model advance ratios (tunnel airspeed/tip speed) at one propeller rpm.

The various ducted propeller models were tested in most cases until a maximum forward flight efficiency was obtained at the condition of equilibrium (net propulsive force equal to zero) for each advance ratio. The efficiency of a ducted propeller in forward flight is expressed in the form of an "equivalent" lift/drag ratio defined by

$$\varepsilon = \frac{LV}{P-FV}$$

where L is the lift, V is the tunnel airspeed, P is the model power, and F is the net propulsive force. Thus, for the condition of equilibrium, where F is zero, the forward flight efficiency becomes

$$\varepsilon = \frac{LV}{P}$$

It was found from the tests that the bell-mouth duct in combination with the twisted, 3-bladed, contra-rotating propellers in general developed high forward flight efficiency and the highest lift and pitching moment coefficients at the condition of equilibrium (F = 0). Only the shorter chord duct showed smaller equilibrium tilt angles than the bell-mouth duct configuration. Summary plots of these four parameters at the point of maximum forward flight efficiency for each advance ratio tested are shown in Figure 6.

The models with the twisted, 2-bladed, contra-rotating propellers indicated higher forward flight efficiencies than the 3-bladed propellers with the same ducts, but tended to have lower lift and pitching moment coefficients at the same advance ratio.

Comparing the ducts combined with a set of untwisted, constant chord, 3-bladed, contra-rotating propellers with the same ducts combined with a set of twisted, 3-bladed, contra-rotating propellers, it was seen that the former developed greater lift and pitching moment coefficients but produced lower forward flight efficiencies than the latter.

The exit vanes showed little effectiveness in lowering either the tilt angle or the pitching moment coefficient at the condition of equilibrium (net propulsive force equal zero). Slipstream measurements of the local flow angularity and dynamic pressure were made to determine an effective exit vane location and to gain a better understanding of the exit conditions. Measurements were made at two axial locations for three advance ratios, with two propeller blade pitch settings, through a tilt angle range of 0 to 90 degrees.

Axial movement of the propellers in the duct caused variations in the model aerodynamic characteristics which depended on the propeller blade pitch setting. Increasing the propeller tip clearance tended to decrease all aerodynamic coefficients. Simultaneously moving the propeller toward the duct leading edge and increasing the tip clearance lowered all the model aerodynamic coefficients. However, due to mechanical limitations, sufficient variations in these two parameters were not made to determine with any degree of certainty the extent of these effects. The force and moment coefficients of the duct in the presence of the propellers and electric motor housing varied in much the same manner as the total force and moment coefficients. A complete report of the forward flight test data has been presented in Reference 8.

3.3 Full-Scale Platform

3.3.1 Design and Fabrication of Full-Scale Platform

It was evident from the flight test program in Phase III of this contract that the 5-foot diameter platform was underpowered for its gross weight and would not hover or fly out-of-ground effect. Therefore, the platform had to be redesigned to correct this situation. At the same time use was to be made of as many of the Model 1031-A components as possible. As suggested in Reference 7, to retain the Nelson engines it would be necessary to lower the disk loading by increasing the duct diameter. After an analysis of the platform hovering performance, it was decided that a duct diameter of 7 feet would be adequate.

Duct

A new duct was designed of fiber glass, using the knowledge gained on the 5-foot diameter fiber glass duct and on the U.S. Army Model VZ-1E 8-foot diameter fiber glass duct. The profile for the inside surface of the 7-foot diameter duct incorporated a modified lemniscate curve in the inlet and a straight cylindrical section to the exit, with a total length to diameter ratio of 0.25. The duct was constructed of laminated fiber glass.

The cylindrical portion of the duct in the area of the propellers was reinforced on the outside with a ring of aluminum honeycomb which was enclosed and retained with fiber glass. The duct inlet was reinforced on the outside with molded fiber glass ribs which were spaced 30 degrees apart and extended from the duct inlet to the honeycomb ring. Double ribs were installed at the four attachment points. The completed duct is shown in Figure 7. The duct was attached to the basic structure at four points by means of self aligning rod end bearings mounted on each of the radial beams. A shear bolt with spacers and the rod end bearing at each point of attachment provided the means by which the duct could be centered around the propellers.

Propellers and Drive System

The contra-rotating propellers for the redesigned 7-foot diameter platform had twisted, fixed pitch blades and were mounted on coaxial transmission shafts. The blade section had an RAF-6 profile which varied in thickness chord ratio from 24 percent at the 30 percent radius station to 9.9 percent at the blade tip. The propellers were made of laminated mahogany with a fiber glass covering 0.30 inches thick. The relatively high blade thickness inboard on the propeller blades was used to improve resistance to flutter. The average tip clearance was 0.18 inches or 0.22% diameter.

Transmission

In the aerodynamic analysis of the propellers, it was found that the propellers would develop maximum thrust at 1600 rpm, but the minimum allowable rpm dictated by the transmission was 2200. As shown in Reference 9, the excess thrust at this rpm was marginal, making flights out-of-ground effect questionable. Therefore, it was decided to fabricate a new set of transmission gears with as high a gear reduction as possible, with sufficient strength to take the increased torque, and of a size to fit into the existing transmission housing. The new gears gave a speed reduction of 1.68:1 and were of the ground spiral bevel type. However, this gear reduction was not sufficient

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to slow the propellers down to the desired 1600 rpm, so two sets of larger input sheaves on the transmission were designed and fabricated to give speed reductions of 1.47 and 1.36.

Main Support Structure

The main support structure had to be redesigned to accommodate the larger duct diameter and the associated larger loads and bending moments. The same type of structural design used in Model 1031-A was maintained in the Model 1031-A-1 support system, except that the radial beams were constructed from preformed oval tubing instead of a built up streamlined beam. In addition, two of the beams had to be offset to accommodate the larger input transmission sheaves. (see Figure 8).

Landing Gear

The landing gear struts were redesigned to accommodate the increased platform gross weight, bending moments, duct length, and exit control vane chord. The landing gear brackets that support the sliding landing gear struts were found to be structurally sound after minor rework. These brackets were bolted to the ends of each radial beam with the landing loads being taken by two bungee rings mounted on each strut-bracket combination.

Pilot Enclosure

The pilot stand and rail enclosure from Model 1031-A were used on Model 1031-A-1 except that the shoe tie down harness was discarded for a plain circular non-skid deck, and separate tubular extensions were utilized for changing the center of gravity height instead of the adjustable telescoping tubes used previously.

Power Plant

The propellers were powered by two Nelson H-59A two-stroke cycle, horizontal, opposed aircooled engines which developed 42 hp at 4000 rpm. These engines were placed deep into the duct for additional cooling and used the same mounting technique as was used on Model 1031-A described in detail in Reference 5 (also see Figure 9).

Electrical System

A lightweight, rechargeable, 12 volt D.C. battery supplied power to the two ignition coils. All three of these components were mounted under the pilot deck. The condensers and points were in the engine.

Fuel System

The 2-1/2 gallon fuel tank from Model 1031-A was used for the redesigned platform. It was mounted midway up on the pilot stand with a gravity feed system to each carburetor. A new fuel shut-off switch and new fuel lines replaced these worn components of Model 1031-A. The standard fuel used was a mixture of four parts by volume of aviation gasoline, 80-87 octane, regular, non-leaded and one part aviation motor oil, SAE 30.

Starting System

The two Nelson engines were started by manual pull chords from each engine. Both engines were started at one time.

Controls

Attached to the left hand side of the pilot hand rail was a twist grip throttle control which actuated a push-pull cable to each carburetor. This control was used to vary power and hence altitude. A friction knob was attached to the control so that the throttle could be retained at a desired setting to free the pilot's left hand. A yaw control lever was attached to the right hand side of the pilot hand rail which actuated push-pull cables to the two yaw control vanes in the duct inlet. A friction knob was also attached to the yaw control lever so that the vanes could be held in a desired location to free the pilot's right hand. Yaw control was accomplished by differential deflection of the two control surfaces in the duct inlet. Two electrical switches were provided for separate engine ignition control, and a master ignition switch was provided for emergency use. All three switches were installed close to the hand throttle. Pitch and roll control were obtained by shifting the pilot's weight in the direction of desired control.

Automatic Mechanical Gyro Stabilizer

The Model 1031-A automatic mechanical stabilizing system which has been described in detail in Reference 6 was used in the Model 1031-A-1 redesign by scaling up its total mass polar moment of inertia. The radius at which the aerodynamic center of the gyro damping paddles acted was fixed at 0.30 of the propeller radius. The redesigned automatic mechanical gyro stabilizer is shown in Figure 10.

The "TARD" gyro which had previously been developed by the Altoscan Co. of Lansdowne, Pa. and demonstrated on a model is a stabilizing device based upon the same principles as the Hiller gyro-stabilizer; that is, it senses both the attitude and rate of change of the attitude caused by a disturbance and signals for a correction. The displacement of the "TARD" gyro is picked up electrically and the controls actuated by a servo-mechanism. As work is not performed by the gyro itself, feed-back and other coupling effects are avoided.

A subcontract was given the Altoscan Co. to refine the "TARD" gyro stabilizing system and develop a special unit for the platform. However, near the completion date of the subcontract a review of the project was made at Altoscan by a Hiller representative. It was evident from what had been built and demonstrated that the unit would not give the required damping characteristics and minimize the pitch and roll cross coupling contrary to the Altoscan Progress Reports. A Stop Order was subsequently issued and after Altoscan had proceeded further at their own expense and still could not eliminate the cross coupling effect in the pitch and roll damping characteristics, the subcontract with Altoscan was terminated.

Instrumentation

An engine tachometer connected to one of the coils was installed on the middle portion of the pilot hand rail. A temperature indicator connected to the hottest cylinder (determined from static tests) was also installed on the middle portion of the same rail.

Stress Analysis and Weights

A stress analysis was performed for all components of the platform which were redesigned as well as for those components that were to be re-used and were considered to be in a critical area.

All components of the platform were weighed as they were assembled. A summary of the weight, center-of-gravity and moment of inertia is presented in Appendix I.

3.3.2 Static and Tethered Tests of Full-Scale Platform

Static tests were performed to determine the functional adequacy of all moving and rotating components of the platform; to determine the carburetor outlet pressure and the temperature characteristics of transmission, Sprag clutches, all engine exhaust ports, all cylinder heads, and carburetor air. In addition the total thrust of the platform was to be determined as a function of engine rpm, manifold pressure, one-and two-engine operation, and height above the ground.

The full scale platform was installed on the static test stand as shown in Figure 11. Thermocouples were attached to all components considered to be critical. The leads from these thermocouples were connected to rotary switches and indicators on the instrument panel. Tachometers were attached to each engine and to one of the transmission input shafts to determine propeller speed and the slippage of the "V" belt drive. The static thrust was determined by suspending the platform in an overloaded condition from a line in which a dynamometer was installed. Figure 11 shows the general set-up of the platform, the thrust line going off to the right with the installed dynamometer, and the location of the instrument panel and control area.

After the running-in period for the new transmission gears and reworked Nelson engines and after the shakedown tests, it was found that all components operated at a safe and satisfactory level. The static thrust and temperature measurements were then taken simultaneously. A plot of the static thrust against propeller rpm at two heights above the ground is shown in Figure 12.

It can be seen from these curves that a ten percent loss in thrust was experienced when the platform (duct trailing edge) was raised from a 30 inch height above the ground to a 60 inch height. A limited inlet and exit velocity survey was made on the static stand by means of a static and total pressure rake installed alternately above and below the propellers as shown in Figure 13. The results of this velocity survey are shown in Figure 14.

It can be seen from this figure that the axial velocity is not constant across the radius as considered in the propeller design but is trapezoidal in shape. From this data, the propellers could have been redesigned to utilize more effectively the actual measured velocity distribution and thereby increase the thrust. However, the possible gains in thrust at this point did not seem to justify a redesign since there was already enough thrust available to hover out-of-ground effect.

The thrust of the propellers was calculated from the measured pressure difference across the propellers and is shown in Figure 15. With the total thrust and propeller thrust known, the duct thrust was determined and is also shown in Figure 15. It will be noticed that as the duct approaches the ground it loses thrust while the propellers gain thrust. The result in this particular case was an increase in total thrust as indicated before in Figure 13.

A detailed description of the static tests and their results was submitted in Reference 10. The static test program began on October 17, 1957 and was concluded on November 15, 1957. The total operating time of the engines was 7 hours and 15 minutes.

The platform was next rigged for tethered flight testing. The purpose of the early flights was to familiarize the pilots with the new platform and to obtain their opinion and evaluation of its flying qualities. If it was though that the platform showed promise of being kinesthetically controlled in steady and gusty flight conditions, it would be instrumented and a complete test program conducted on this duct configuration as well as on a second duct configuration to be chosen after the completion of the wind tunnel test program.

A number of tethered flights were made at various platform heights above the ground, with and without forward ballast, with and without the mechanical gyro stabilizing system, with the center-of-gravity at various heights, and with an enlarged pilot's deck and rail. Each flight ended with much the same comment from the pilots: that there was not sufficient control moment available. The pilots were not able to apply sufficient kinesthetic control for forward flight in other than still air. Even then, the pitch-up tendency was disturbing to the pilot. The high inertia of the vehicle and the increased pitching moment associated with the increased duct diameter made it extremely difficult to handle and fly in windy or gusty weather. However, there was sufficient power at all times for altitude and speed control. The enlarged pilot deck was intended to give the pilot more room to move his center-of-gravity or control moment; but due to the limited length of the tether line, the pilots could not move sufficiently far forward before they had to stop the flight to avoid hitting the tether support frame. To evaluate this means of control properly, the vehicle would have to be flown on a much longer tether rig.

There was a tendency for the platform to yaw one way or the other during any windy condition. As a means of trying to eliminate this tendency, fabric was applied to the outside surface of the duct from the inlet to the stiffening ring at the bottom of the duct (see Figure 16). This formed a smooth closed duct profile except for the discontinuities at the edge of the duct lip and stiffening ring, covering up all the corners and wind-catching ribs that were present on the outside of the duct. This treatment was to no avail as the platform still yawed inconsistently and was quite sensitive to gusts. A more detailed account of the tethered flights may be found in Reference 11.

Since the platform flying qualities apparently could not be sufficiently improved to permit kinesthetic control with the various methods tried, it was decided to halt any further flight testing of the platform.

There was little or no mechanical difficulty during these tests. The engines did not overheat and ample thrust was available at all times with partial throttle at a 25 degree spark advance. The duct was very rigid and gave no trouble. The fiberglass-covered propellers performed very well and showed no signs of wear, erosion, or flutter.

The automatic mechanical gyro stabilizing system worked very well and was free of feed-back. The pilots felt that this component was a definite aid in controlling the platform as they experienced much more difficulty in flying with it removed.

The tethered flights began on November 20 and continued through December 13, 1957. A total of 3 hours and 34 minutes flight time was accumulated during this period.

3.4 Theoretical Studies

3.4.1 Stability and Control Analysis

A detailed longitudinal stability and control analysis of the Model 1031-A-1 flying platform was made in Reference 12 for various conditions of hovering and forward flight. Among those things that were considered in the analysis were changes in duct profile shape duct length, propeller solidity, propeller blade pitch setting, propeller-duct clearance, gross weight, center-of-gravity location, automatic gyro stabilizing system, gusts and forward speed. Equations of motion in the longitudinal plane of symmetry were developed for the flying platform, and these equations were solved by utilizing an analog computer and using the stability derivatives obtained from the wind tunnel test data of Reference 8.

The conclusions indicated by this analysis were that the present platform configuration (lemniscate duct inlet and a set of twisted, 2-bladed, contra-rotating propellers at a blade pitch setting of 12.8 degrees) has undesirable stability characteristics in that it has an unstable oscillation in hovering flight and a divergent motion in forward flight. It was found that the automatic mechanical gyro stabilizing system provided sufficient damping in hovering but would not stabilize the divergent motion in forward flight.

Slight improvement in damping out the undesired platform motion was obtained with the closed duct profiles in hovering and in low-speed forward flight conditions.

3.4.2 Pitching Moment Analysis

The problem of predicting the equilibrium pitching moment for a ducted propeller was considered in Reference 13. As a first approximation to the problem, the ducted propeller was replaced by a single ring vortex and the pitching moment exerted on the ring was calculated for equilibrium forward flight in terms of the total lift, the duct length to radius ratio and the center of gravity height above the plane of the vortex ring. Also considered in this reference was the determination of the tilt angle or angle of attack for equilibrium (where the net propulsive force is zero) by use of the simple momentum theory. This parameter was found to be related to the total lift and drag of the platform and the ratio of the exit velocity to the free stream speed. Comparison of both the existing momentum theory and the new vortex ring theory with the few available experimental data for these two parameters (pitching moment and tilt angle) at various lift coefficients (Figures 11 and 12 of Reference 13) indicates that there is much need for additional work in theory and experiment before a unified theory can be obtained.

4.0 CONCLUSIONS

Programs were carried on in Phase IV of Contract No. Nonr 1357(00) to obtain basic aerodynamic data for performance and stability analyses from scaled models tested in a wind tunnel, to conduct theoretical studies of aerodynamic and stability and control characteristics for a ducted propeller platform and to conduct flight tests to evaluate performance and flying qualities of a ducted propeller platform.

4.1 Wind Tunnel Tests

Wind tunnel and static tests were conducted on various 2-foot diameter ducted propeller models at the David Taylor Model Basin. Total force and moment measurements were made as well as duct forces and moments. Model power was also measured. The models were tested at various tunnel airspeed/propeller tip speed ratios, tilt angles and propeller blade pitch settings. The following conclusions are drawn from this program:

1. Of all the configurations tested, the bell-mouth duct in combination with a set of twisted, 3-bladed, contra-rotating propellers yielded the highest figure of merit, 1.07, which was approximately 57% higher than the maximum figure of merit obtained with the same propeller without a duct. This duct also carried the highest percentage of total thrust, namely 46%.

2. The airfoil-type ducts produced maximum figures of merit considerably lower than the bell-mouth duct and carried a smaller portion of the total thrust. This low performance was considered to be caused by inlet flow separation.

3. It appeared from the static model tests that duct shape and duct length/diameter ratio were more important design parameters to consider than the physical propeller characteristics.

4. Of all the ducts tested in nonaxial flow in combination with the twisted, 3-bladed, contra-rotating propellers, the bell-mouth duct configuration produce the highest forward flight efficiency (equivalent lift/drag ratio) and the highest lift and pitching moment coefficients at the condition of equilibrium (net propulsive force equal to zero).

5. The bell-mouth duct in combination with a set of twisted, 2-bladed, contra-rotating propellers produced the highest forward flight efficiency of all configurations for the propeller blade settings and advance ratios tested, but developed lower lift and pitching moment coefficients.

6. The exit vanes showed little effectiveness in lowering either the tilt angle or the pitching moment at the condition of equilibrium (net propulsive force equal to zero) for the vane location tested.

7. Increasing the propeller tip clearance lowered all the model aerodynamic coefficients. Moving the propellers toward the duct leading edge caused different variations in the aerodynamic coefficients, depending upon the propeller pitch setting. The model aerodynamic coefficients were lowered when the propeller tip clearance was widened at the same time the propellers were moved axially toward the duct leading edge.

4.2 Full Scale Tests

The original 5-foot diameter flying platform was redesigned into a 7-foot diameter platform, in order that the platform could hover and fly out of ground effect, using the same power supply. The following are the conclusions drawn from the program.

1. The static tests indicated that the platform functioned mechanically very well and that the engines and gear box were cooled satisfactorily by the duct inflow stream.

2. The static tests indicated that sufficient static thrust was available to hover out-of-ground effect as a result of the increased duct diameter.

3. Limited velocity surveys were made on the static stand in front of and behind the propellers, indicating that the velocity distribution is near trapezoidal in shape with the lowest velocities near the center. A constant velocity distribution had been assumed in the propeller design. It was found that as the height above the ground was decreased, the propeller thrust increased and the duct thrust decreased.

4. The pilot was unable to apply sufficient kinesthetic control to overcome the high moment of inertia and high pitching moment of the platform.

5. The automatic mechanical gyro stabilizing system made the platform dynamically stable in hovering but would not stabilize the divergent motion in forward flight.

6. The stability and control study indicated that the present platform configuration has undesirable stability characteristics in hovering and forward flight. Slight improvement was obtained in damping out the undesired platform motion by use of a closed duct profile.

7. A simplified theory, using a single ring vortex model, was developed for predicting the ducted propeller pitching moments in forward flight equilibrium. However, it was concluded that much additional work in theory and experiment are needed before a unified ducted propeller theory can be obtained.

5.0 REFERENCES

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13. Sacks, A. H.: The Flying Platform as a Research Vehicle for Ducted Propellers; Institute of the Aeronautical Sciences Preprint No. 832, dated January 27 - 30, 1958.

6.0 APPENDIX I

WEIGHT, CENTER-OF-GRAVITY, AND MOMENT OF INERTIA
DATA FOR 7-FOOT PLATFORM

FIGURE I-1: ORIENTATION OF REFERENCE AXES FOR 7-FOOT PLATFORM

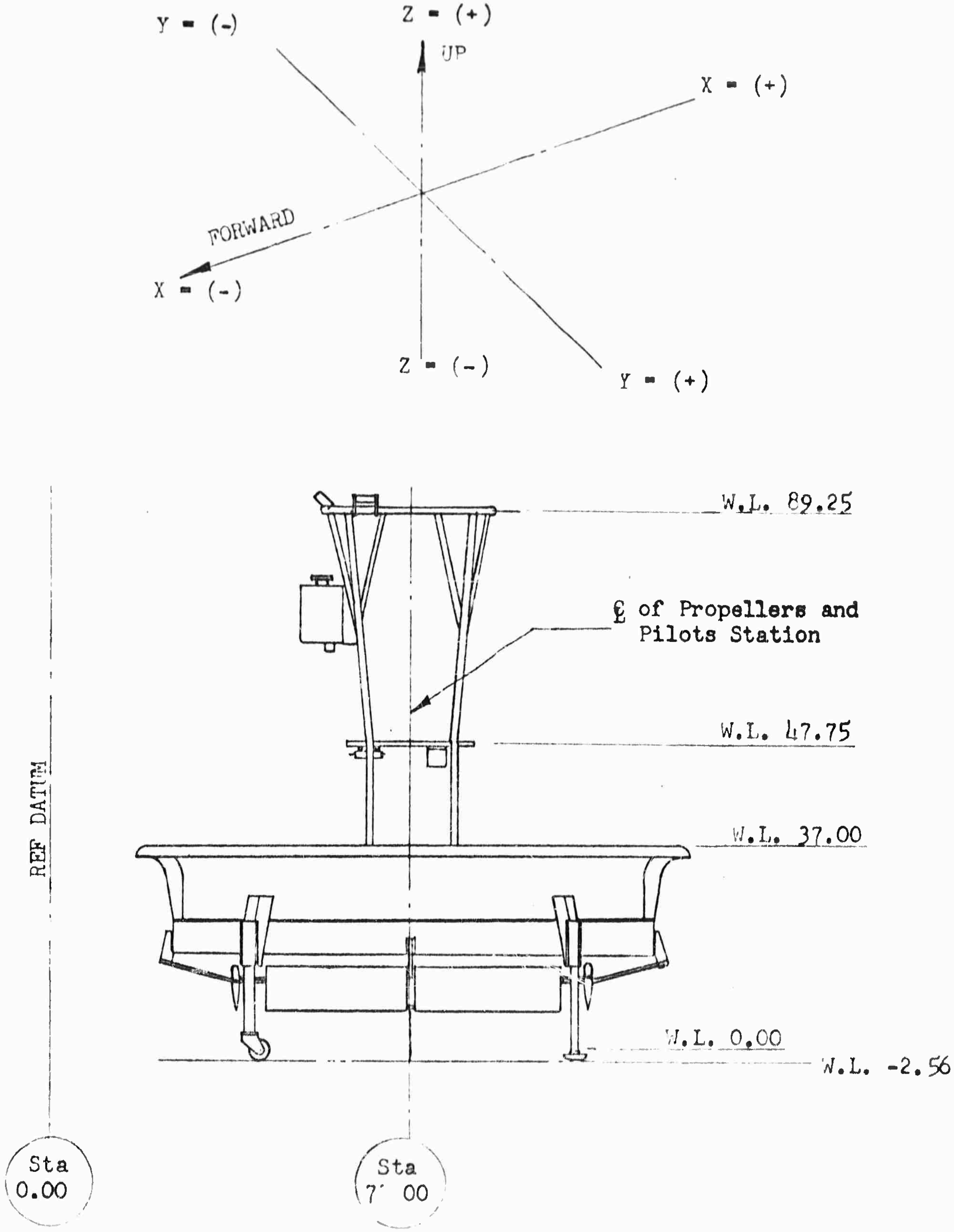


TABLE I-1

SUMMARY OF MODEL 1031-A-1 WEIGHT, CENTER-OF-GRAVITY AND MOMENT OF INERTIA

	Weight lbs	Pitch Arm, X in	M_X in-lbs	Lateral Arm, Y in	M_Y in-lbs	Vertical Arm, Z in	M_Z in-lbs
Empty Weight	370	69.55	25,722	.035	12.82	28.13	10,406
Fuel	15	54.50	818	0	0	73.00	1095
Crew	170	70.00	11,900	0	0	82.00	13,940
Gross Weight	555	69.28	38,440	.023	12.83	45.85	25,441

$I_{Pitch} = 123$ slug-ft^2

7.0 TABLES AND FIGURES

TABLE 1

DUCT 1 ORDINATES AND ORIENTATION
MODIFIED NACA 6421 SECTION

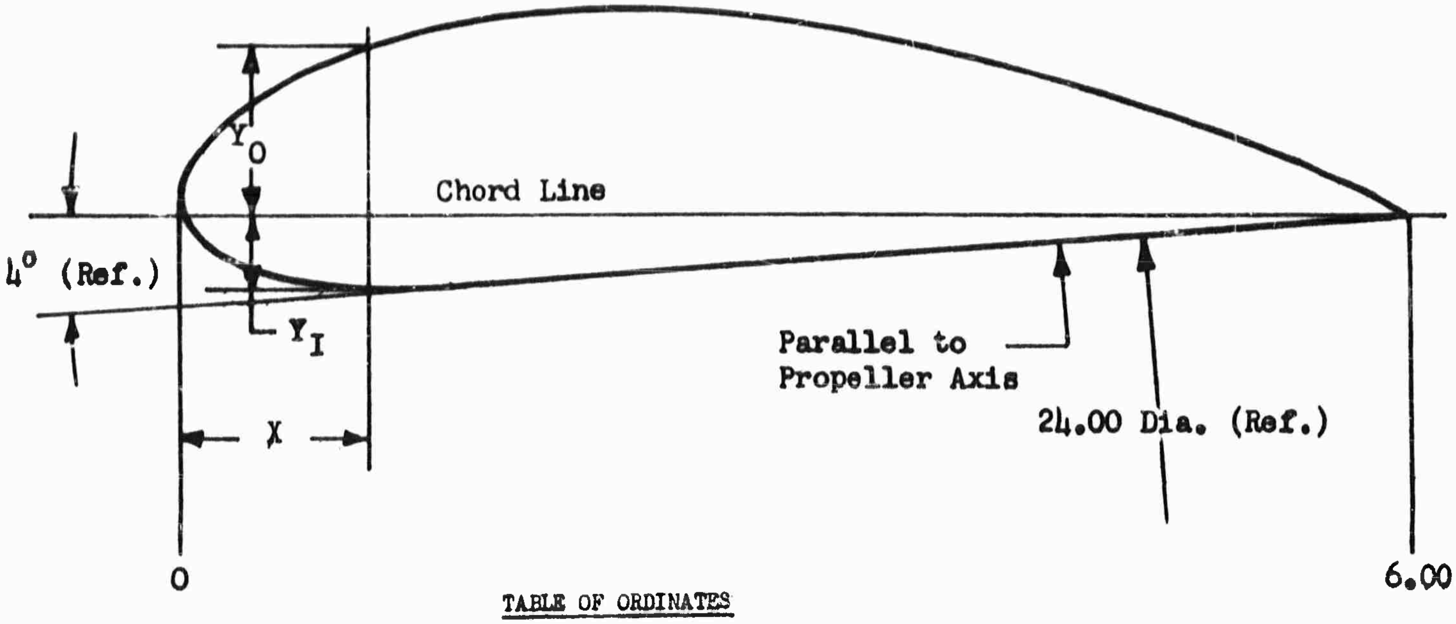


TABLE OF ORDINATES

L.E. Radius = .291
Slope of Radius Thru
End of Chord = 3/10

CHORD X (in.)	OUTER ORDINATE Y_O (in.)	INNER ORDINATE Y_I (in.)
0		0
.075	.308	-.125
.15	.396	-.182
.30	.518	-.250
.45	.615	-.289
.60	.692	-.311
.90	.806	-.331
1.20	.886	-.329
1.50	.938	-.314
1.80	.970	
2.40	.970	
3.00	.910	
3.60	.806	
4.20	.664	
4.80	.485	
5.40	.272	
5.70	.148	
6.00		0

Straight Line Between these Points

TABLE 2

DUCT 2 ORDINATES AND ORIENTATION
NACA 0018 SECTION

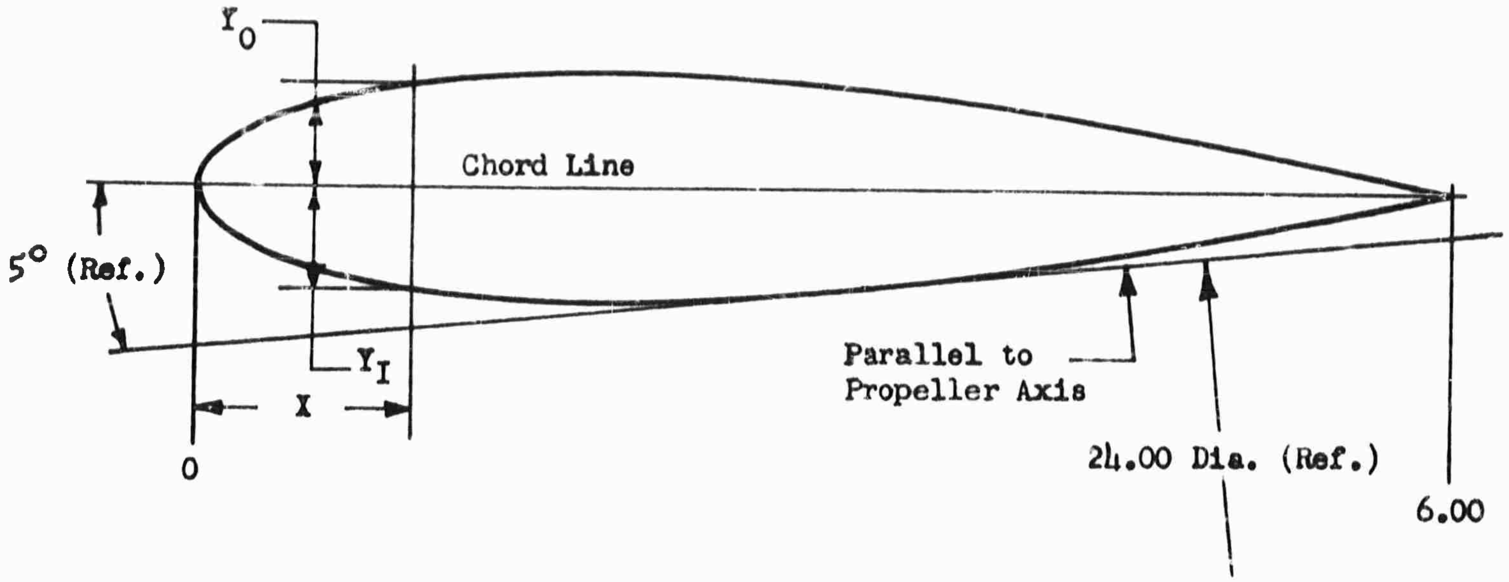


TABLE OF ORDINATES

L.E. Radius = .214

CHORD X (in.)	OUTER ORDINATE Y_O (in.)	INNER ORDINATE Y_I (in.)
0	0	0
.075	.170	-.170
.15	.237	-.237
.30	.320	-.320
.45	.378	-.378
.60	.422	-.422
.90	.481	-.481
1.20	.516	-.516
1.50	.535	-.535
1.80	.540	-.540
2.40	.523	-.523
3.00	.477	-.477
3.60	.411	-.411
4.20	.330	-.330
4.80	.236	-.236
5.40	.132	-.132
5.70	.073	-.073
6.00	0	0

TABLE 3

DUCT 3 ORDINATES AND ORIENTATION MODIFIED LEMNISCATE CURVE

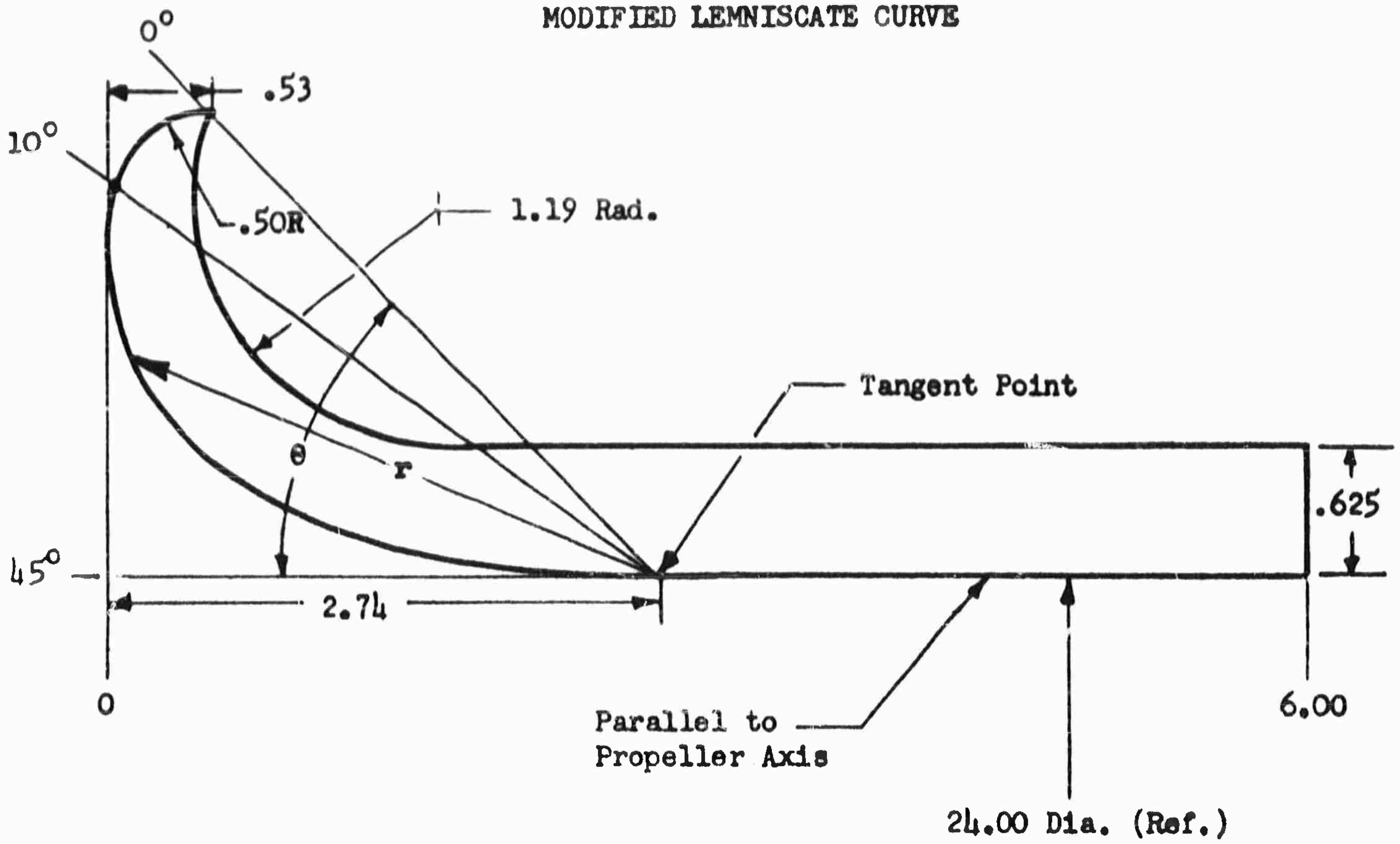


TABLE OF ORDINATES

θ DEGREES	r INCHES
0	3.39
3	3.38
6	3.36
10	3.27
15	3.16
20	2.99
25	2.72
30	2.40
33	2.16
36	1.89
38	1.67
40	1.41
41	1.27
42	1.10
43	0.90
43.5	0.78
44	0.63
44.5	0.45
44.75	0.31
45	0

The radii between θ of 0° and 10° modified by an arc of a circle whose radius is 0.50 as shown above.

TABLE 4

DUCT 4 ORDINATES AND ORIENTATION
MODIFIED NACA 6421 SECTION

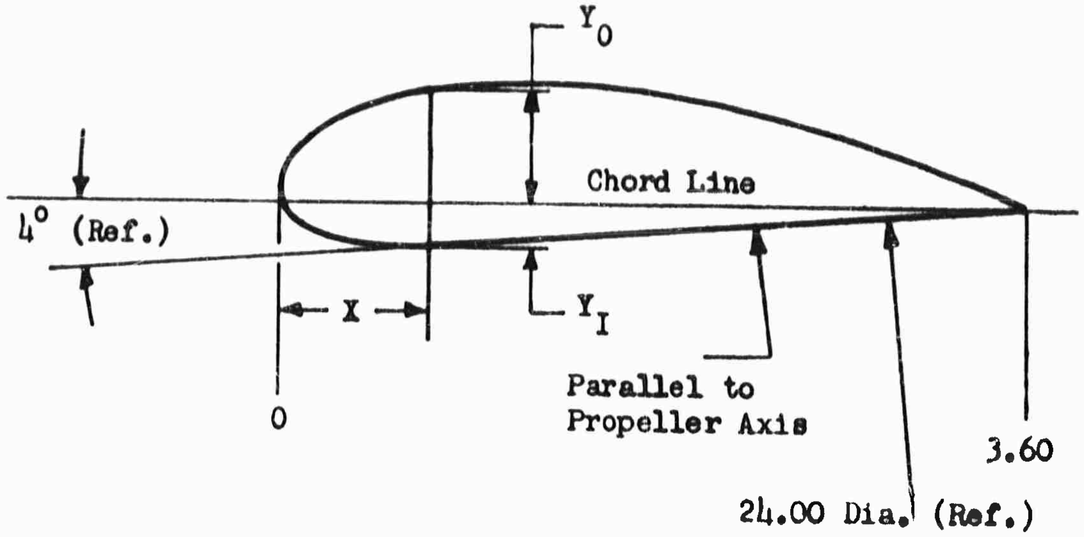


TABLE OF ORDINATES

L.E. Radius = .175
Slope of Radius Thru
End of Chord = 3/10

CHORD X (in.)	OUTER ORDINATE Y_0 (in.)	INNER ORDINATE Y_I (in.)
0		0
.045	.185	-.075
.090	.238	-.109
.180	.311	-.150
.270	.369	-.173
.360	.415	-.186
.540	.484	-.199
.720	.532	-.198
.900	.563	-.188
1.080	.581	
1.437	.582	
1.800	.545	
2.156	.484	
2.520	.398	
2.875	.291	
3.240	.162	
3.420	.089	
3.600		0

Straight Line Between these Points

FIGURE 1a: MODEL GENERAL ARRANGEMENT - SIDE VIEW

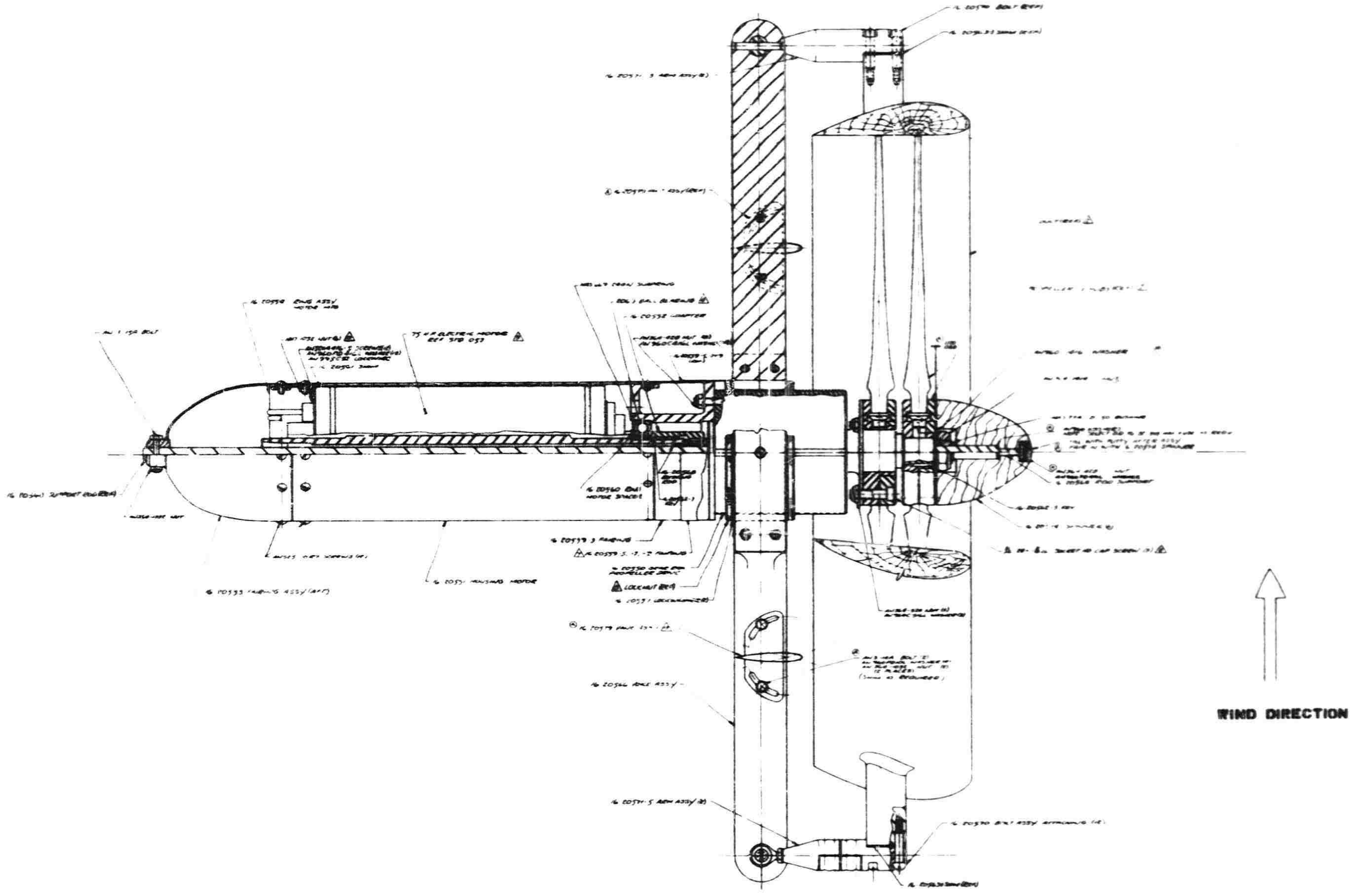


FIGURE 1b: MODEL GENERAL ARRANGEMENT - INLET VIEW

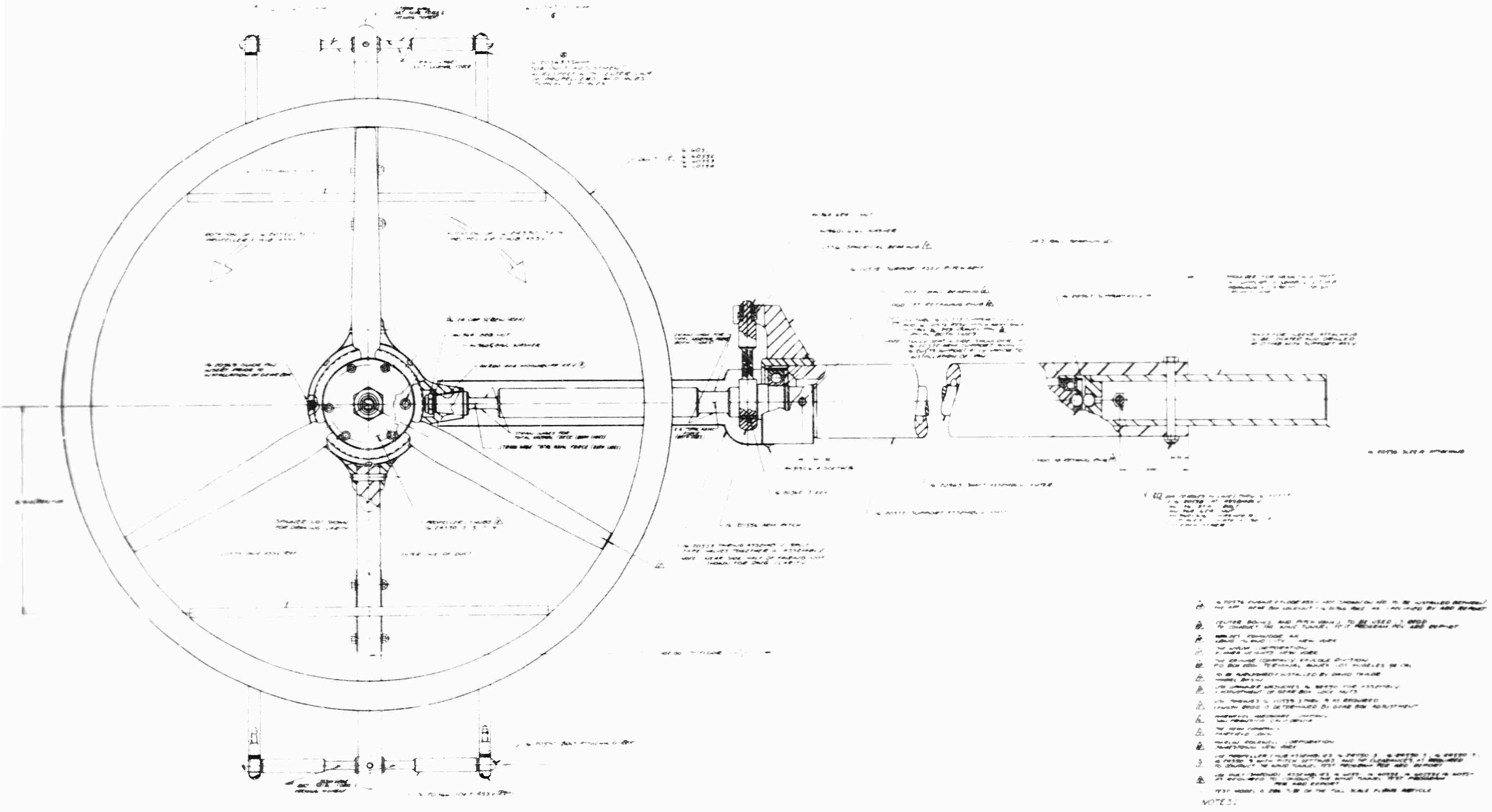


FIGURE 2a: MODEL IN TUNNEL SHOWING DUMMY ELECTRIC MOTOR HOUSING IN DUCT INLET

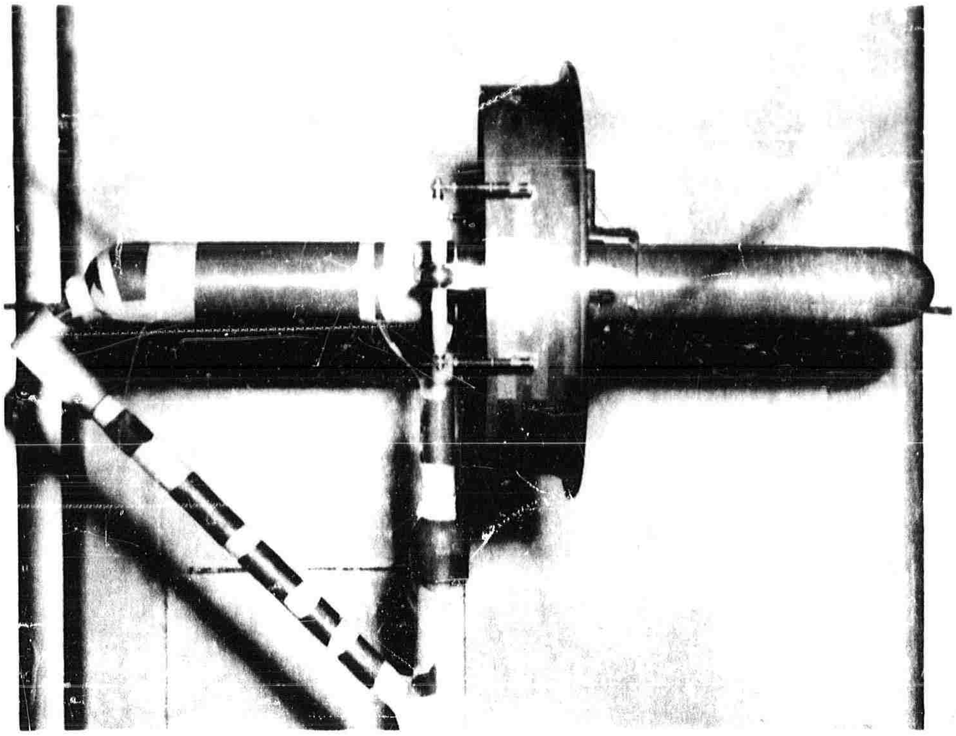


FIGURE 2b: MODEL IN TUNNEL SHOWING SIMULATED PLATFORM ENGINES

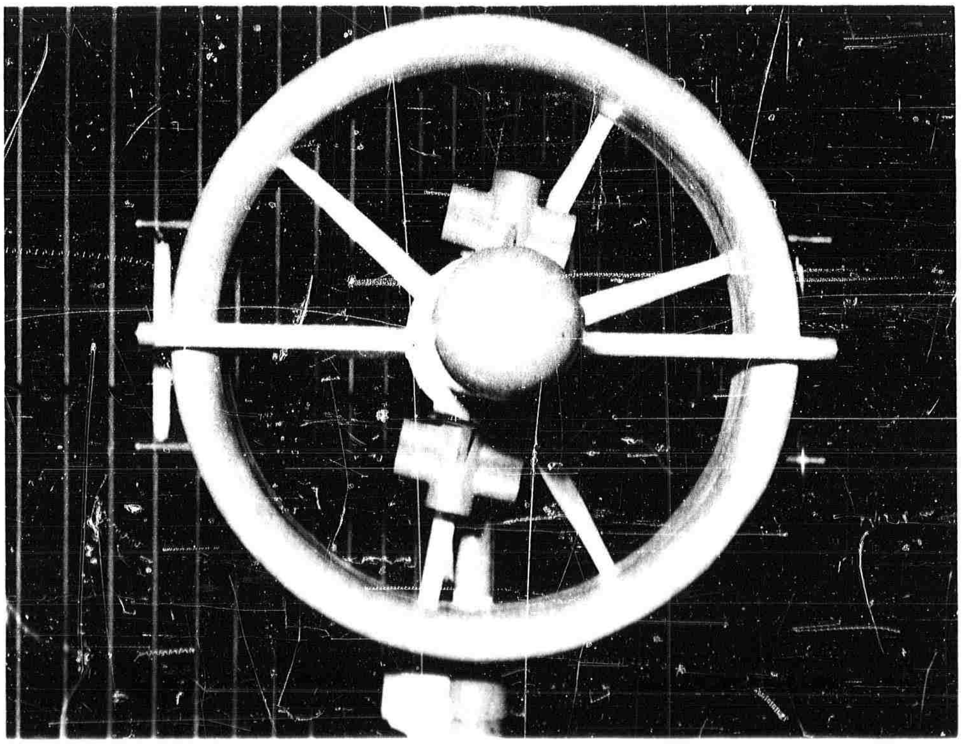


FIGURE 3: MODEL MOUNTED ON STATIC TEST STAND (Viewed from rear)

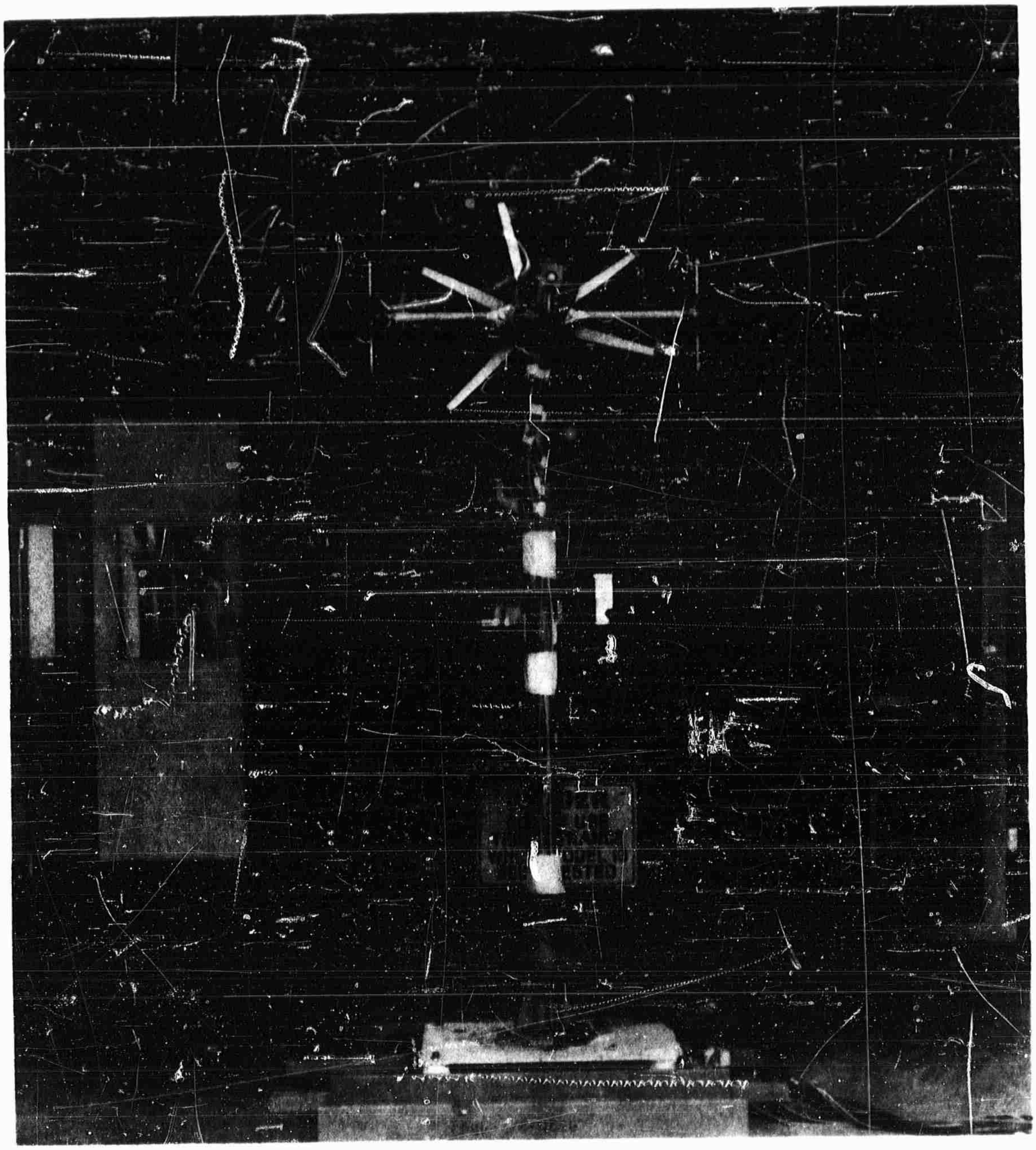
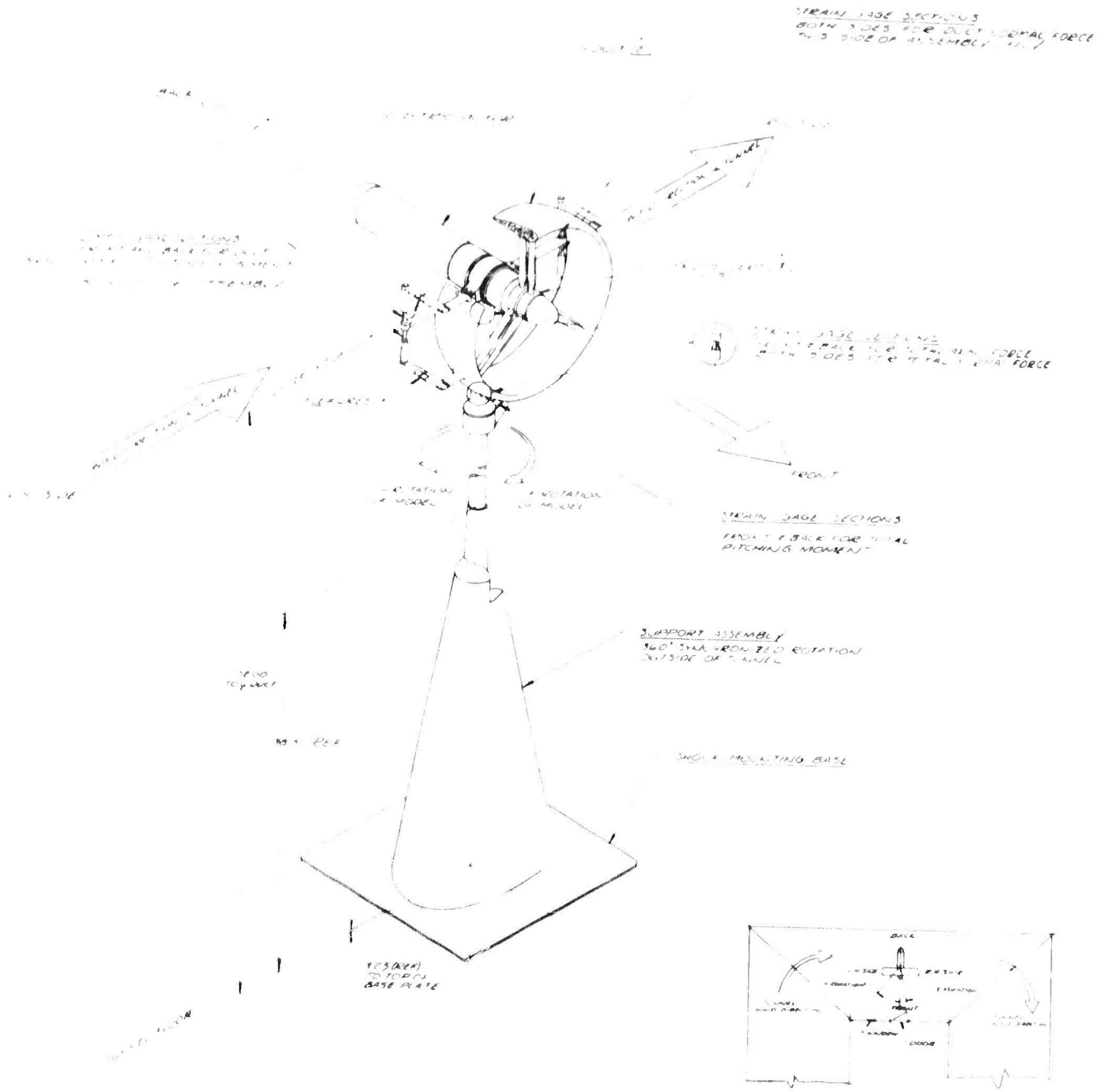


FIGURE 4: MODEL ORIENTATION IN WIND TUNNEL TEST SECTION



TEST ASSEMBLY

PLAN VIEW
of TUNNEL

FIGURE 5a: STATIC PERFORMANCE CHARACTERISTICS OF DUCTED PROPELLERS MODELS AT 5600 PROPELLER RPM

Note: All models with set of twisted, 3-bladed contra-rotating propellers

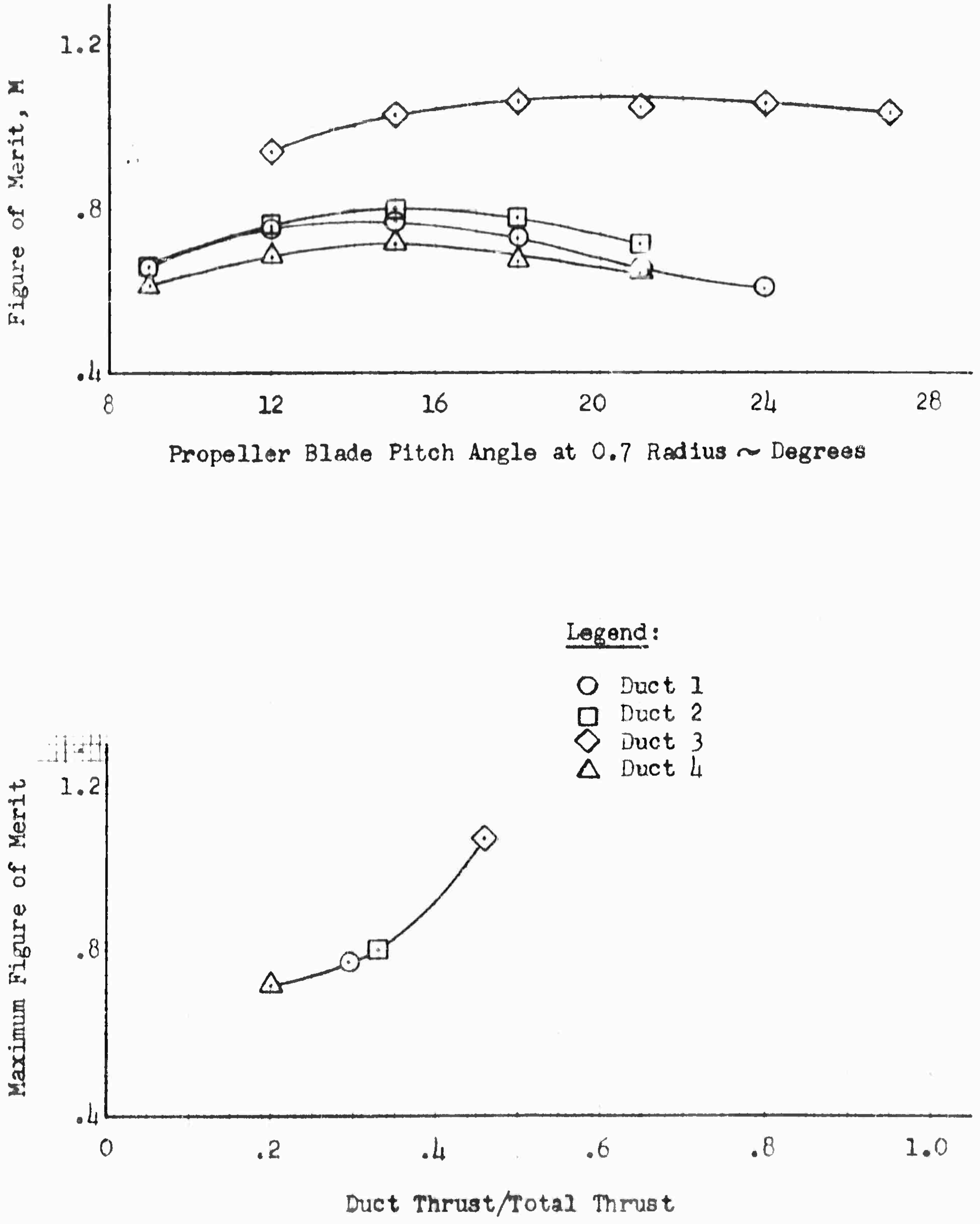


FIGURE 5b: STATIC PERFORMANCE CHARACTERISTICS OF DUCTED PROPELLER MODELS AT 5600 PROPELLER RPM

Note: All models with set of twisted, 2-bladed contra-rotating propellers

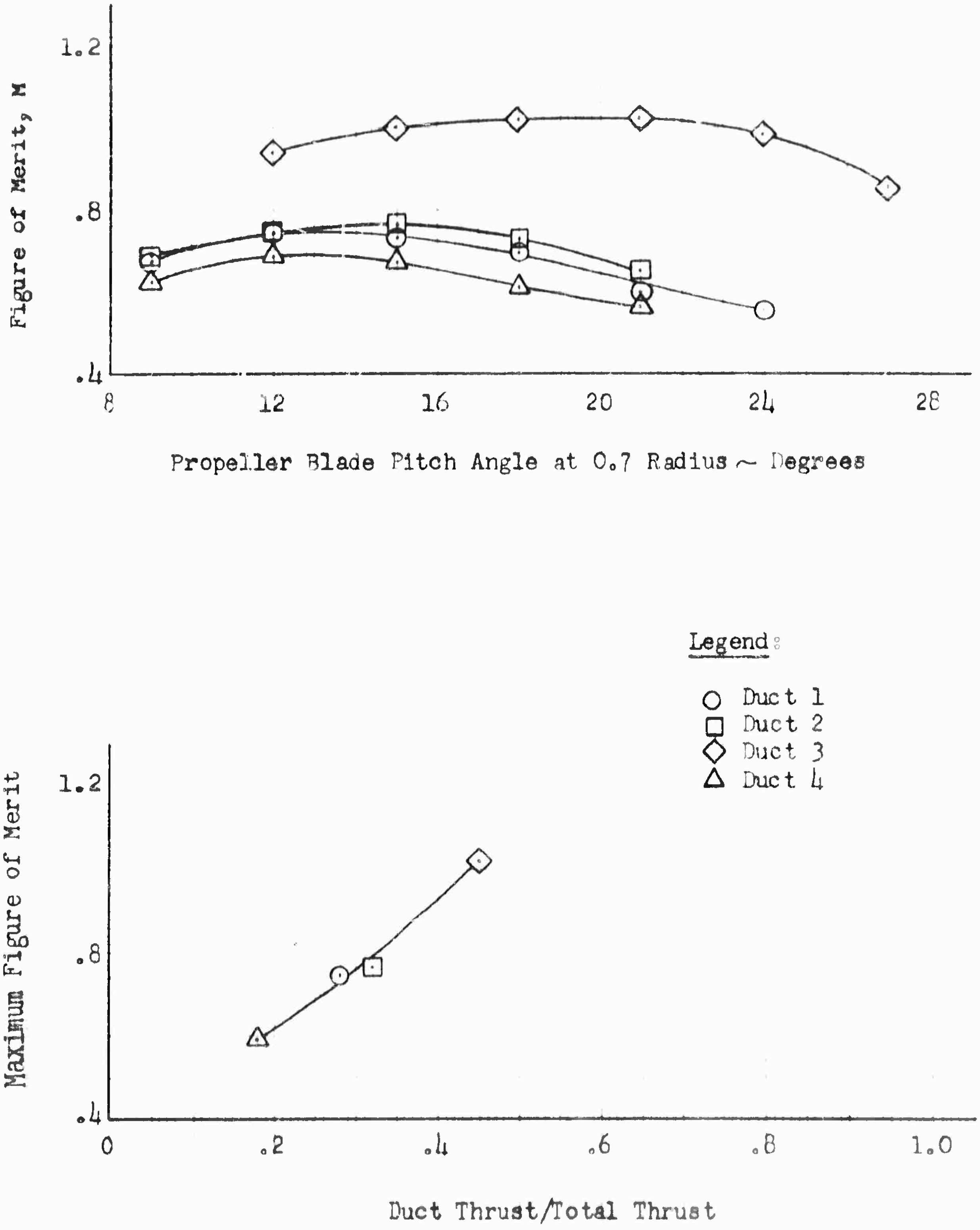
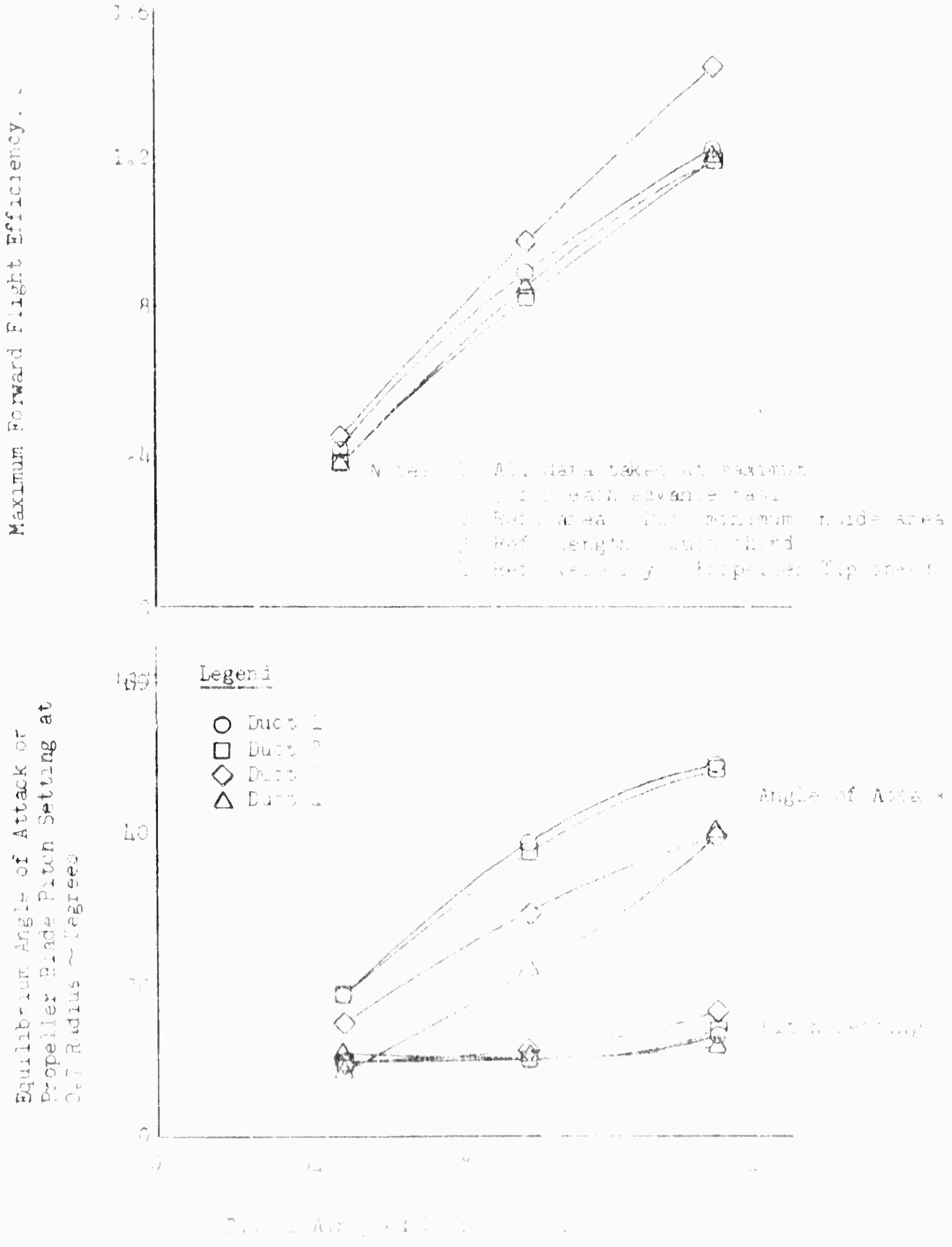


FIGURE 22 EQUILIBRIUM FORWARD FLIGHT CHARACTERISTICS OF DUCTED PROPELLER MODEL



Notes: 1. All data taken at maximum L/D for each advance ratio
2. Ref. area = Duct minimum inside area
3. Ref. length = Duct chord
4. Ref. velocity = Propeller Tip speed

FIGURE 6b. EQUILIBRIUM FORWARD FLIGHT CHARACTERISTICS OF DUCTED PROPELLER MODELS

Notes: 1. All data taken at maximum ε for each advance ratio
2. Ref. area = Duct minimum inside area
3. Ref. length = Duct radius
4. Ref. velocity = Propeller Tip speed

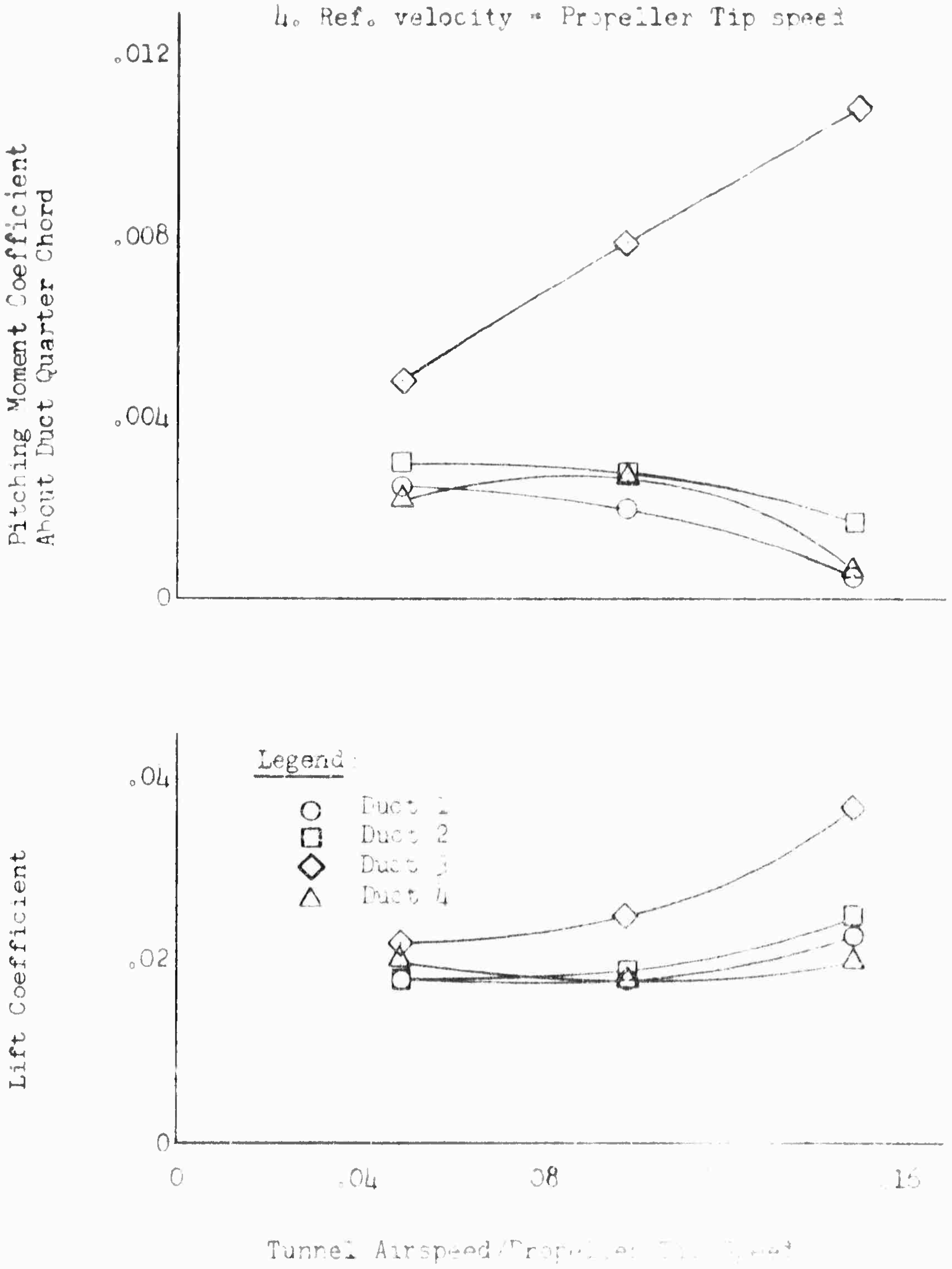
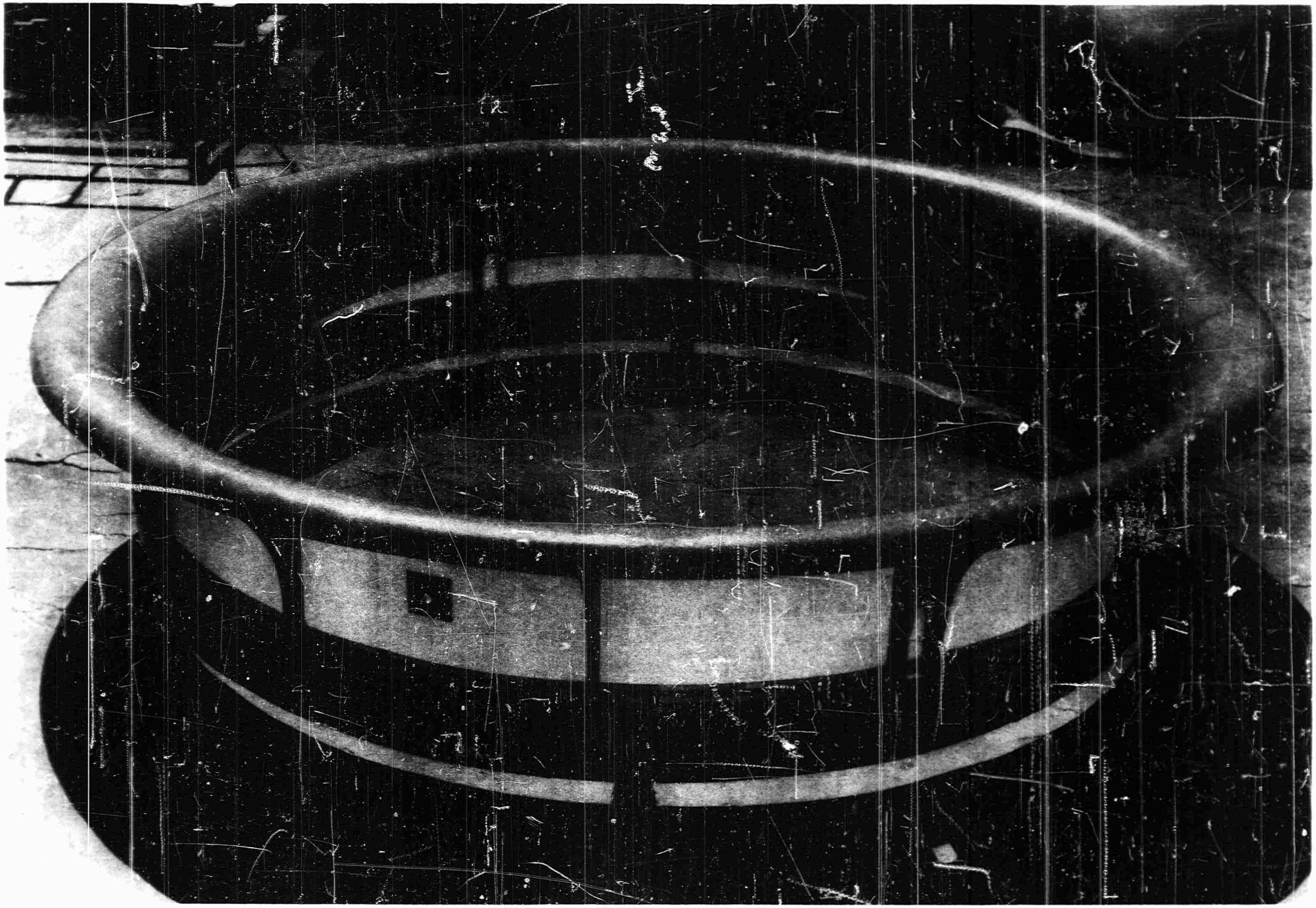


FIGURE 7: 7-FOOT DUCT ASSEMBLY



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In reply refer to:
ARD-59-M53 GJS:as 18

September 2, 1959

To: Office of Naval Research
Department of the Navy
Washington 25, D. C.

Attention: Air Branch, Code 461
Major J. L. Wosser

Via: Bureau of Aeronautics Representative
Palo Alto, California

Subject: Final Report, Contract No. Nonr 1357(00)

Enclosures: 4 copies of "Summary Report - Airborne Personnel Platform", Contract No. Nonr 1357(00), Advanced Research Division of Hiller Aircraft Corporation Report No. ARD-236.

1. In compliance with the provisions of the subject contract, the contractor is submitting herewith its final report, Advanced Research Division Report No. ARD-236, "Summary Report - Airborne Personnel Platform".

HILLER AIRCRAFT CORPORATION

G. J. Sissingh
Technical Director
Advanced Research Division

Distribution per list
in enclosure

5213/Nonr 1357(00)
GLS:ena
Ser 2063
8 Sep 1959

FIRST ENDORSEMENT on HILLER AIRCRAFT CORPORATION ltr ARD-59-M53 GJS:as of 2 Sep 1959

From: Bureau of Aeronautics Representative, Palo Alto, California
To: Office of Naval Research (Code 461), Department of the Navy, Washington 25, D. C.
Attn: Major J. L. Wosser, Air Branch

Subj: Final Report, Contract No. Nonr 1357(00)

1. Forwarded for review and action as may be considered necessary.

J Caldwell
J. CALDWELL
Acting

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Distribution list (in enclosure)
Hiller Aircraft Corporation

Figure 8a: 7-FOOT PLATFORM GENERAL ARRANGEMENT - SIDE VIEW

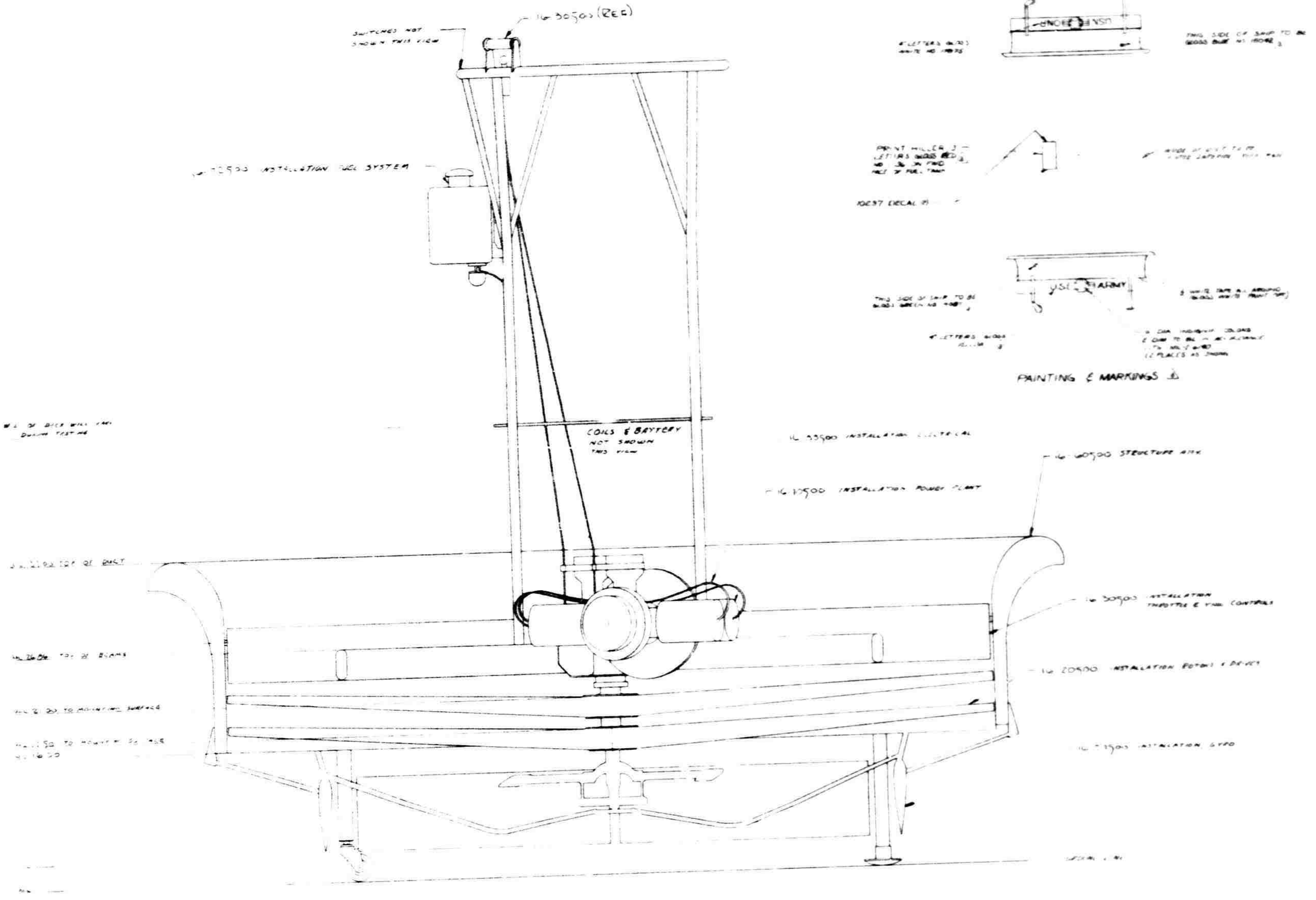


Figure 8b: 7-FOOT PLATFORM GENERAL ARRANGEMENT - PLAN VIEW

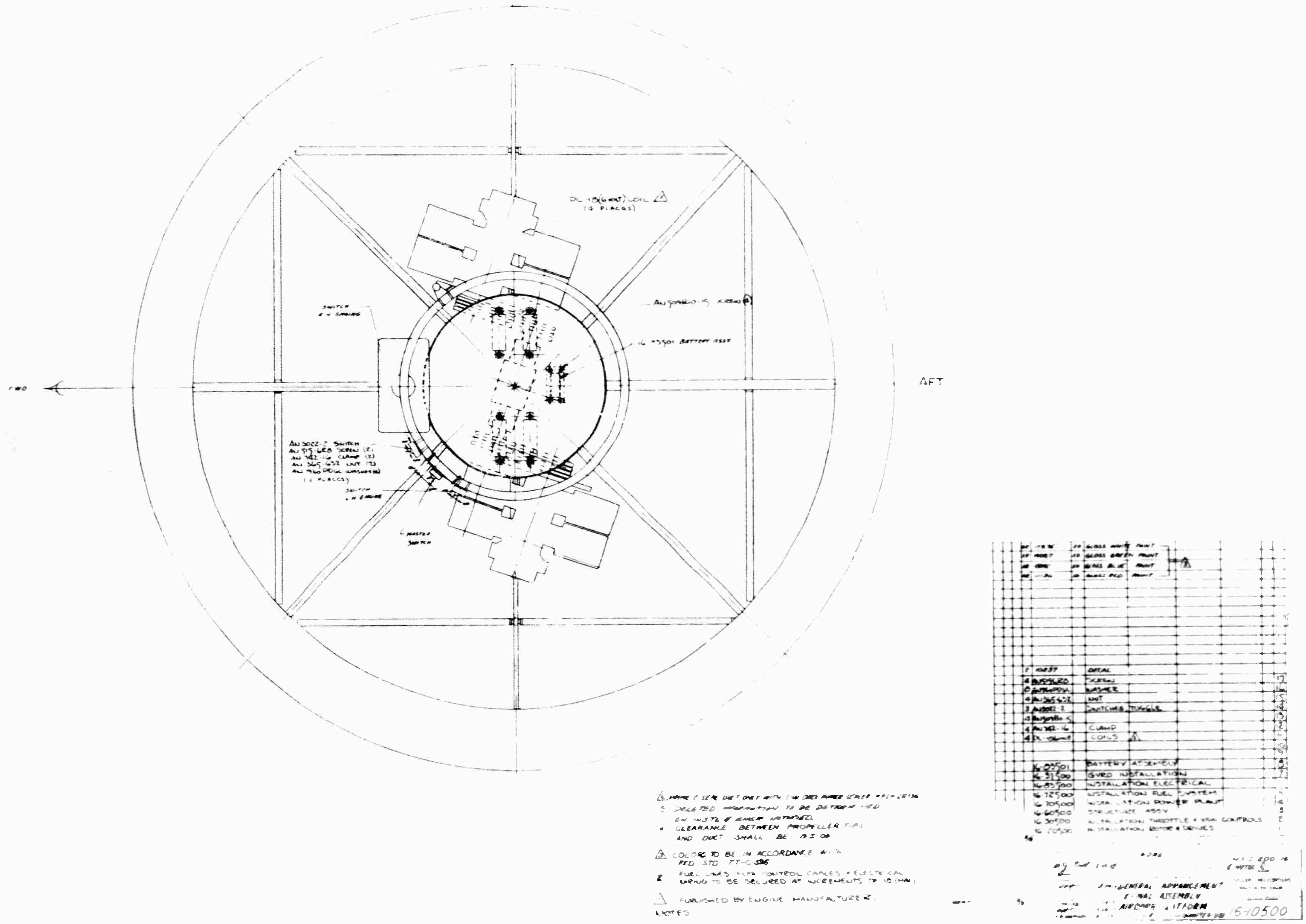


Figure 9: DUCT INLET INTERNAL ARRANGEMENT OF 7-FOOT PLATFORM

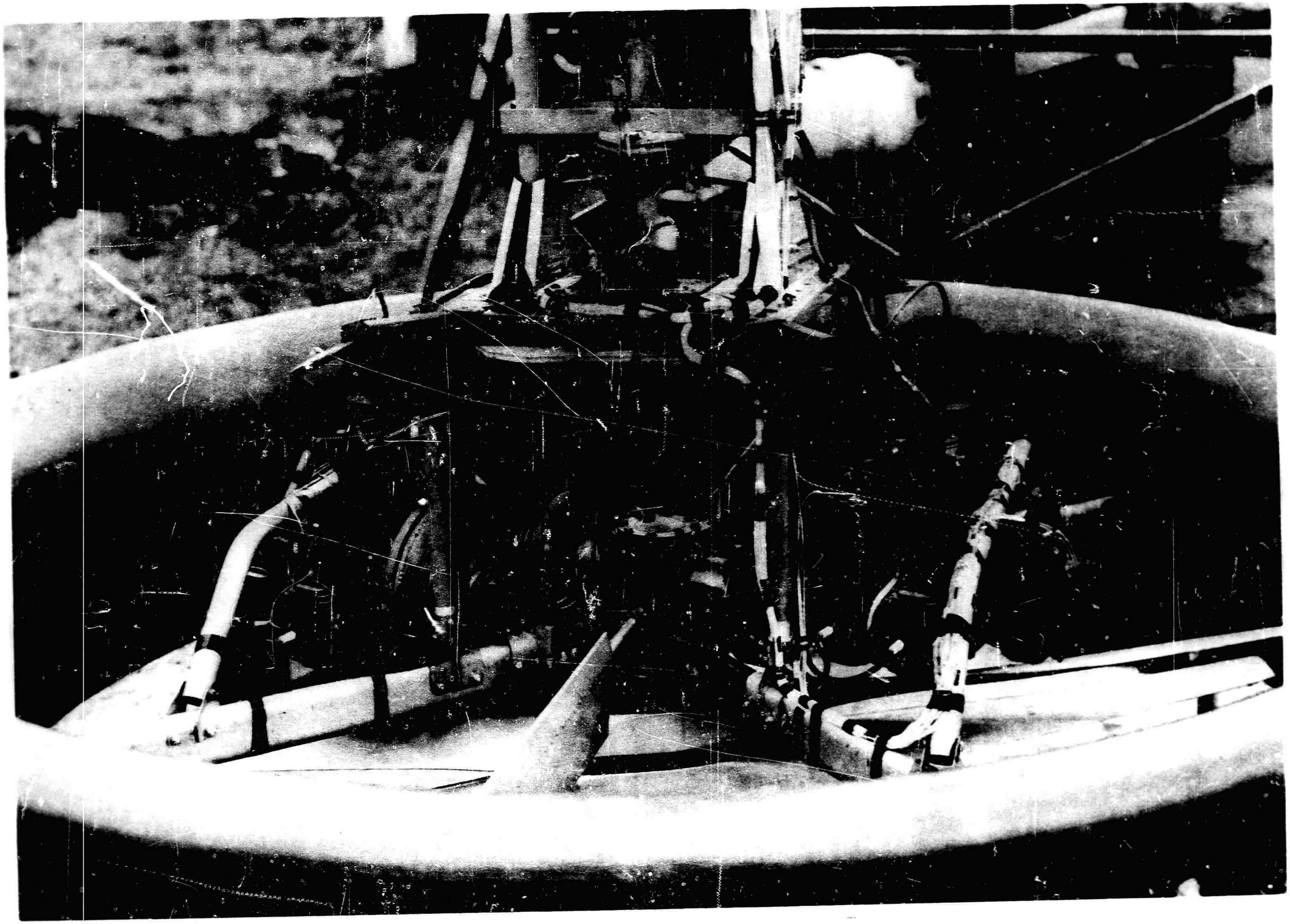


Figure 10: AUTOMATIC MECHANICAL GYRO STABILIZER OF 7-FOOT PLATFORM

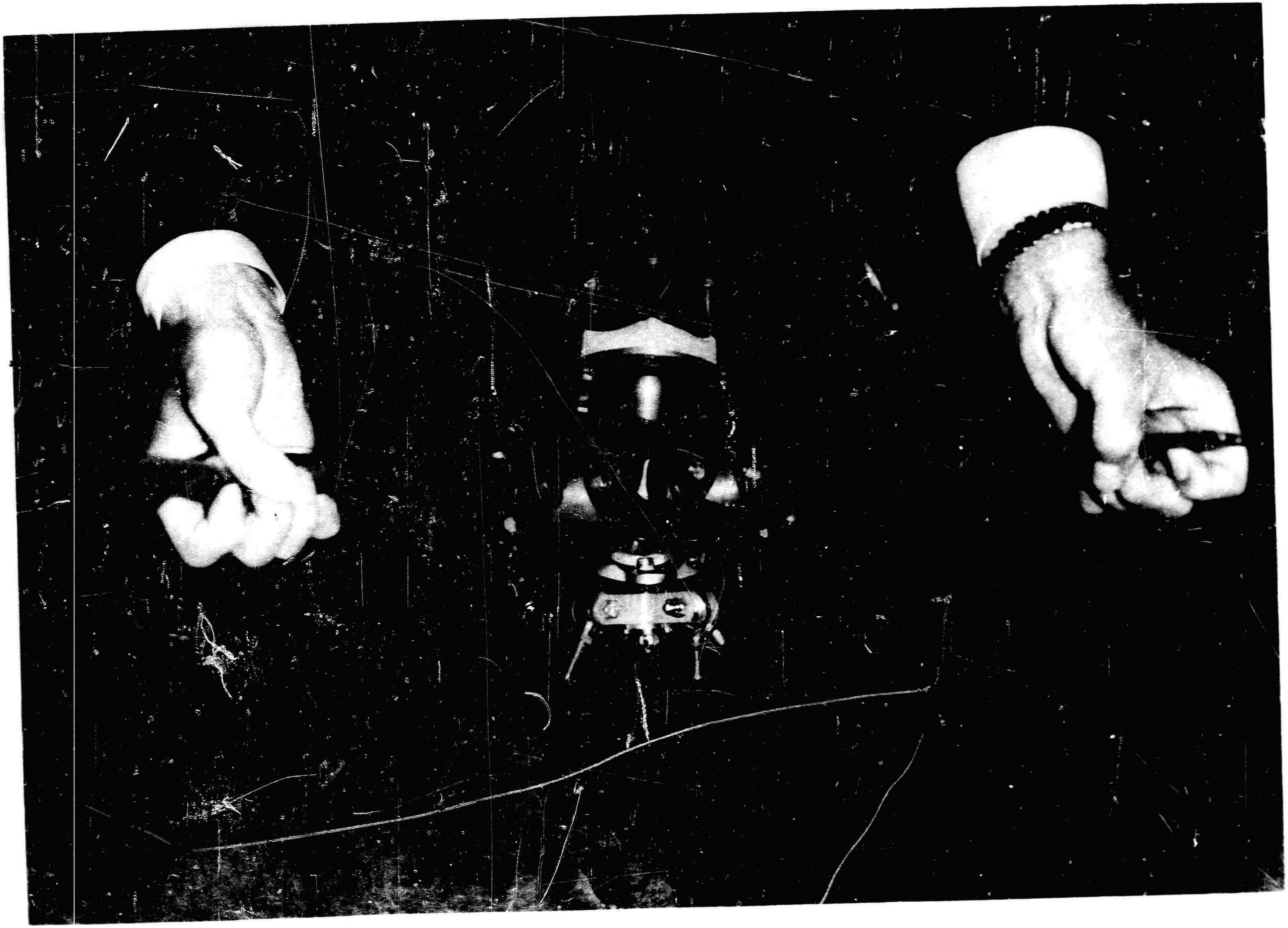


Figure 11: 7-FOOT PLATFORM MOUNTED ON STATIC TEST STAND

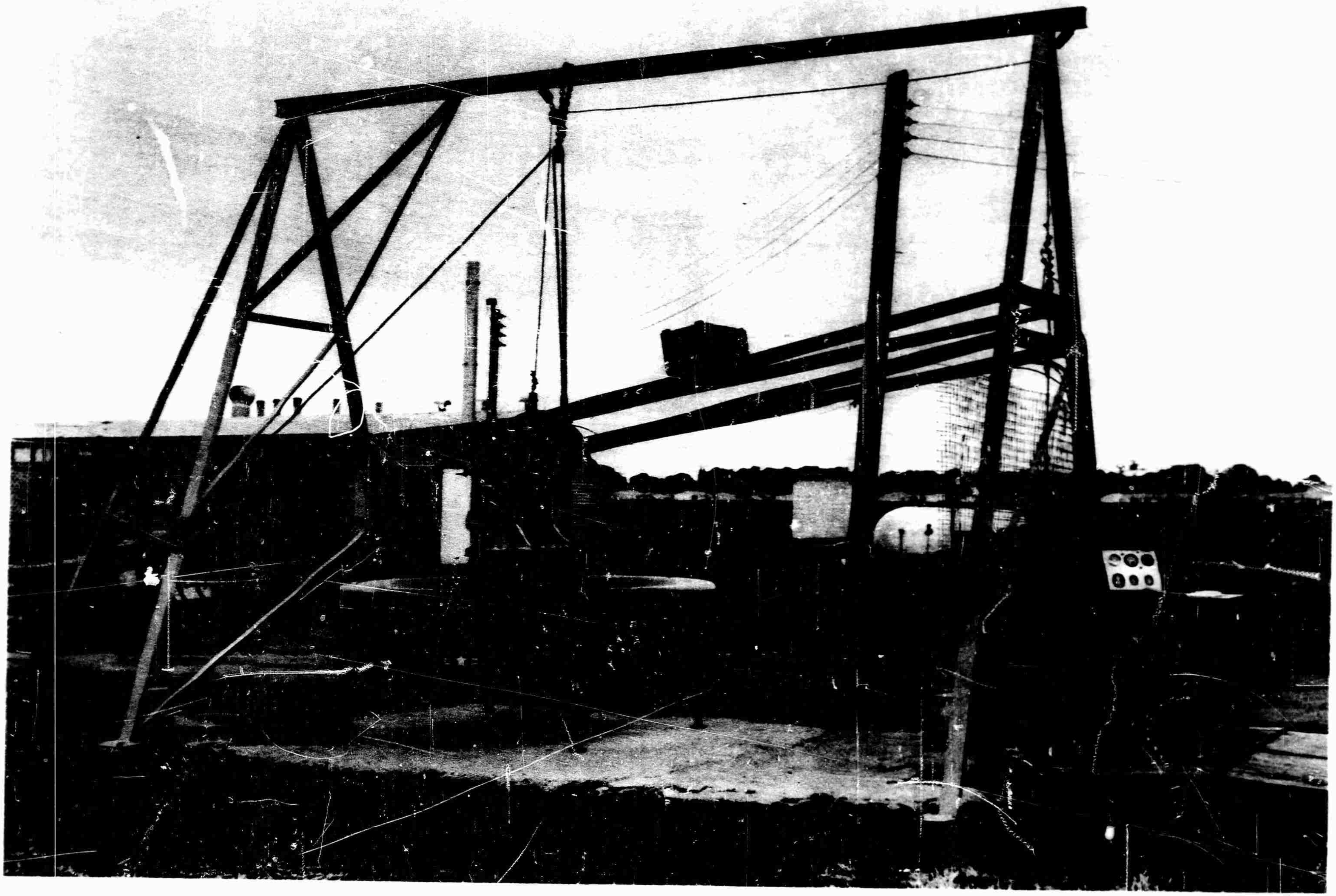


FIGURE 12: MEASURED NET STATIC THRUST OF 7-FOOT PLATFORM

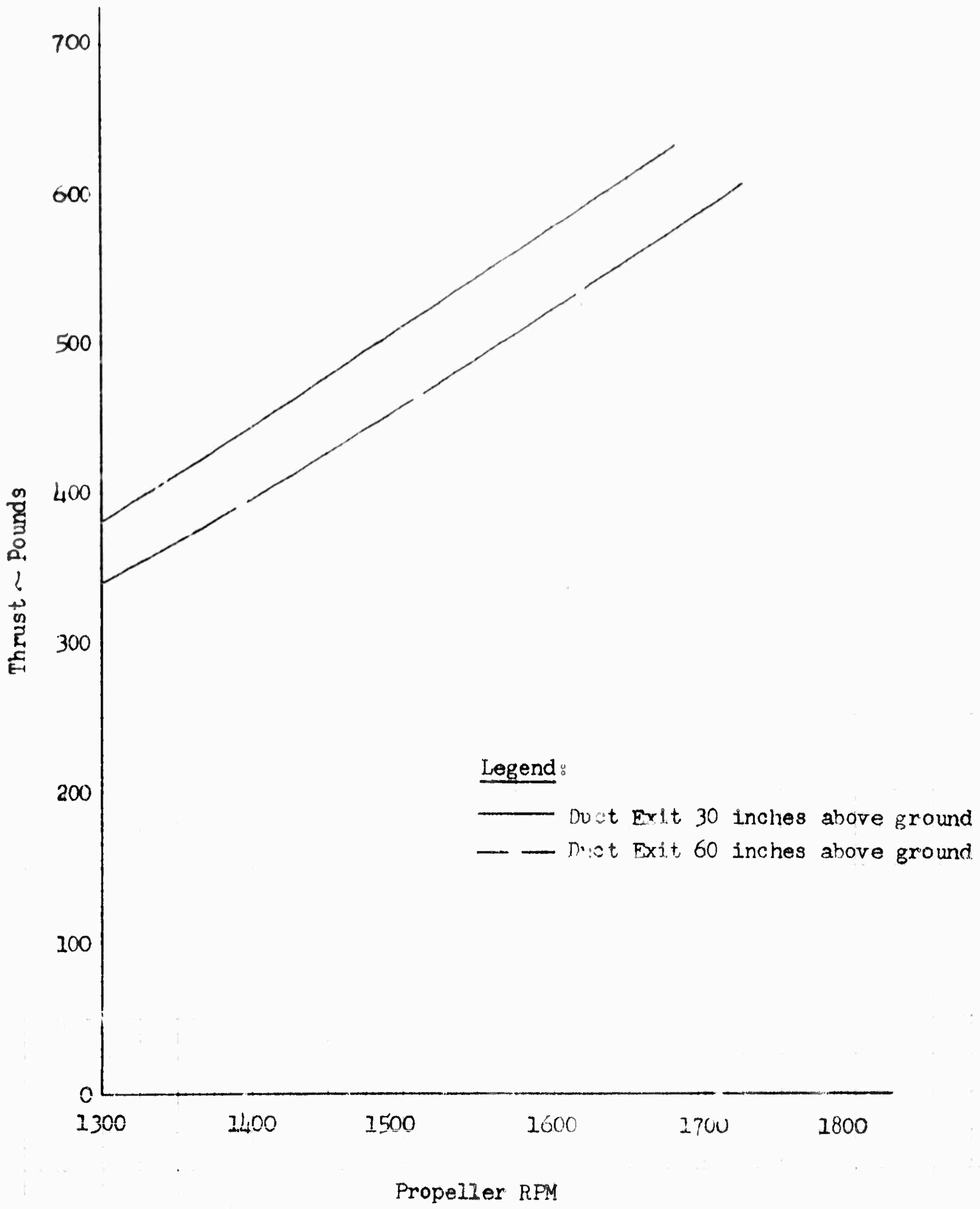


FIGURE 13: ORIENTATION OF VELOCITY SURVEY RAKE

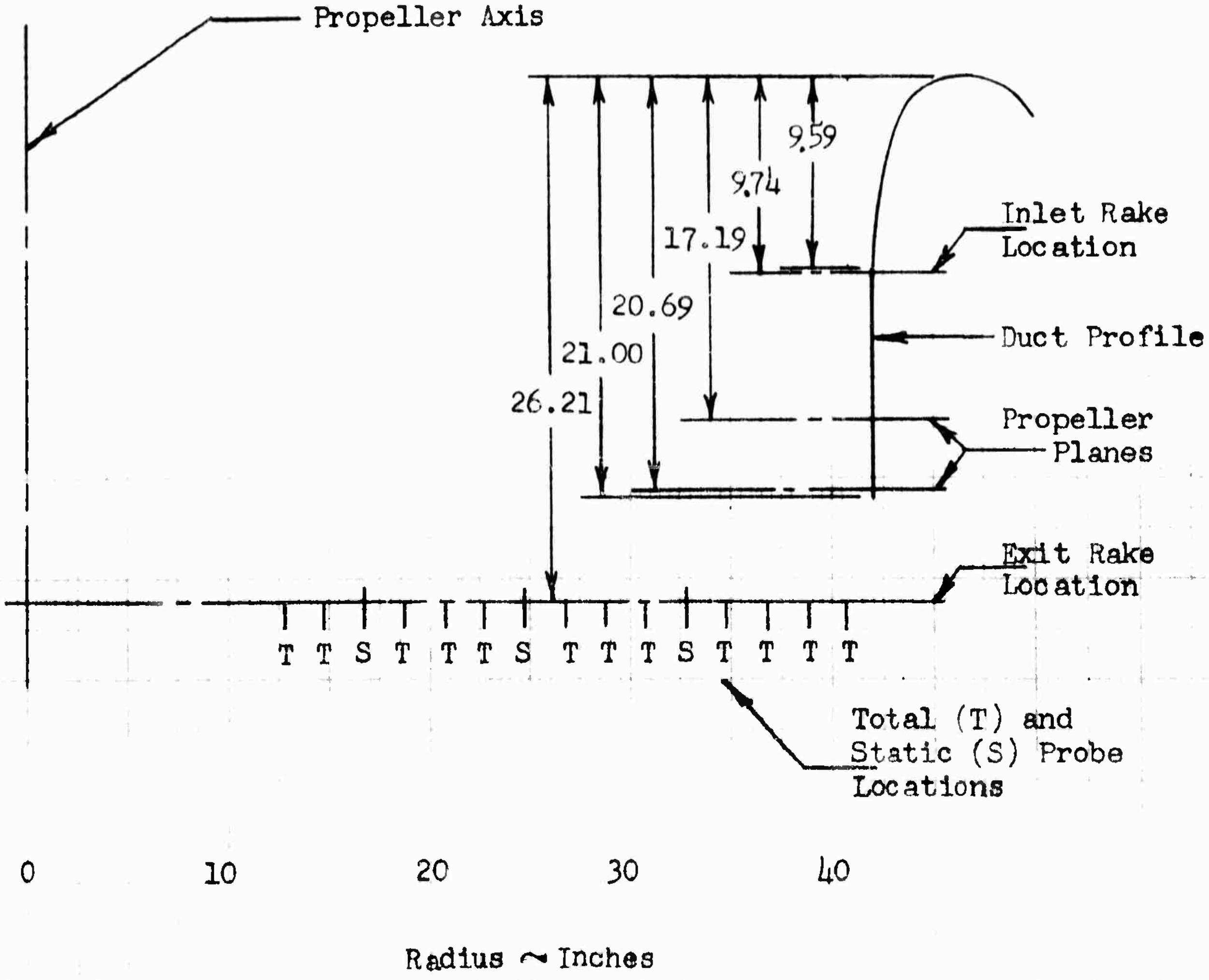


FIGURE 14: MEASURED RADIAL VELOCITY DISTRIBUTION OF 7-FOOT PLATFORM (Static Condition)

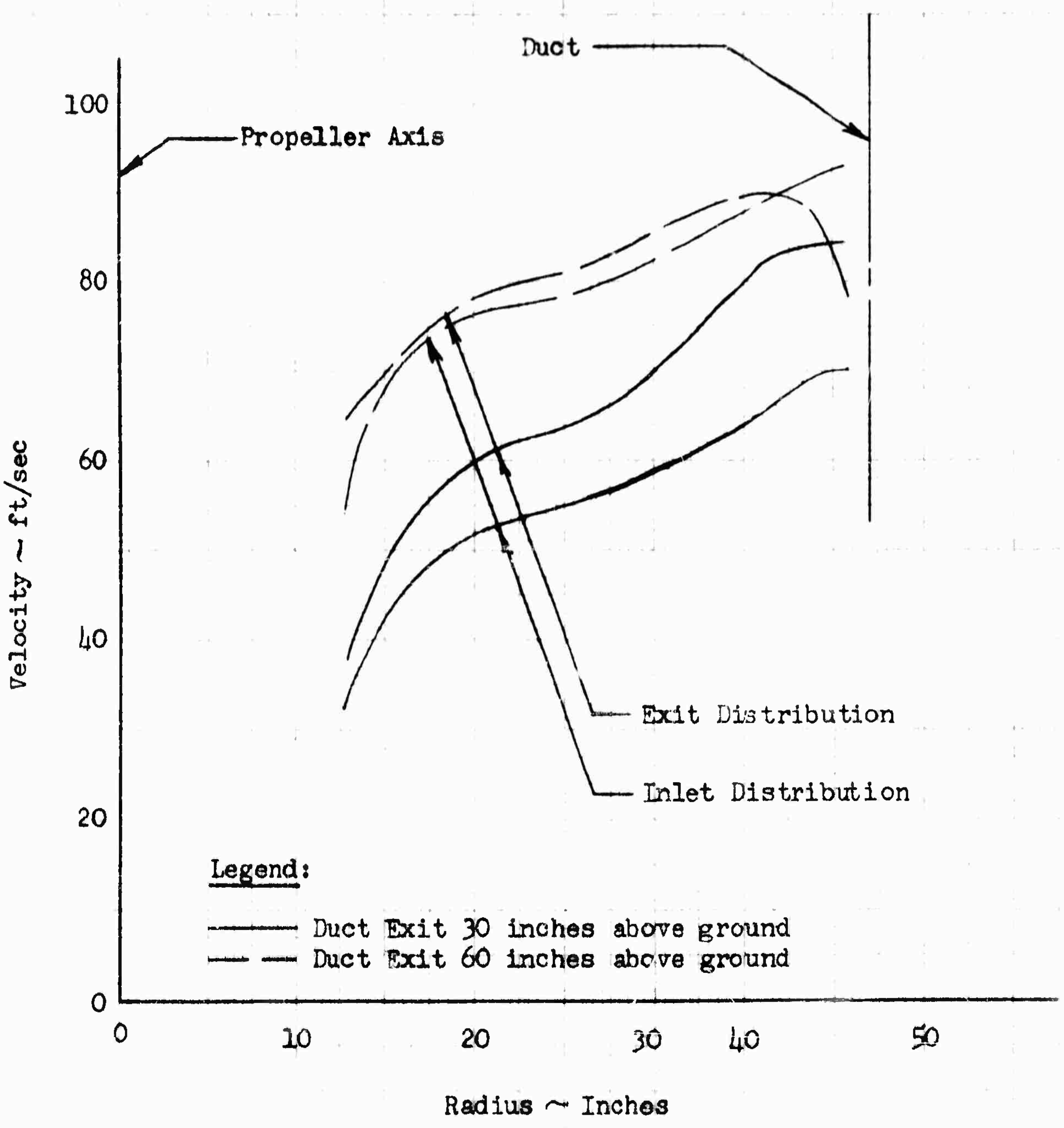


FIGURE 15: MEASURED PROPELLER AND DUCT STATIC THRUST OF 7-FOOT PLATFORM

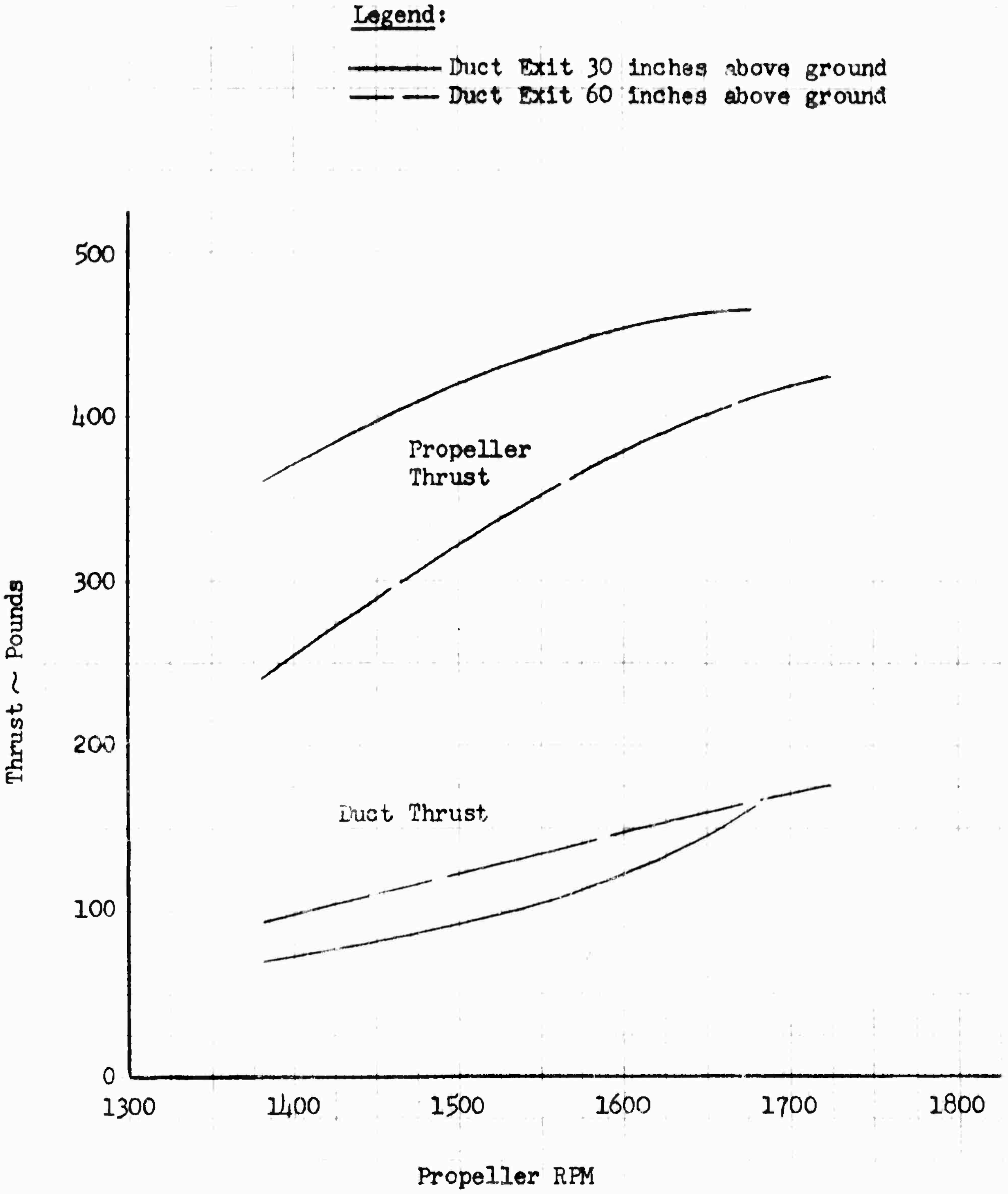
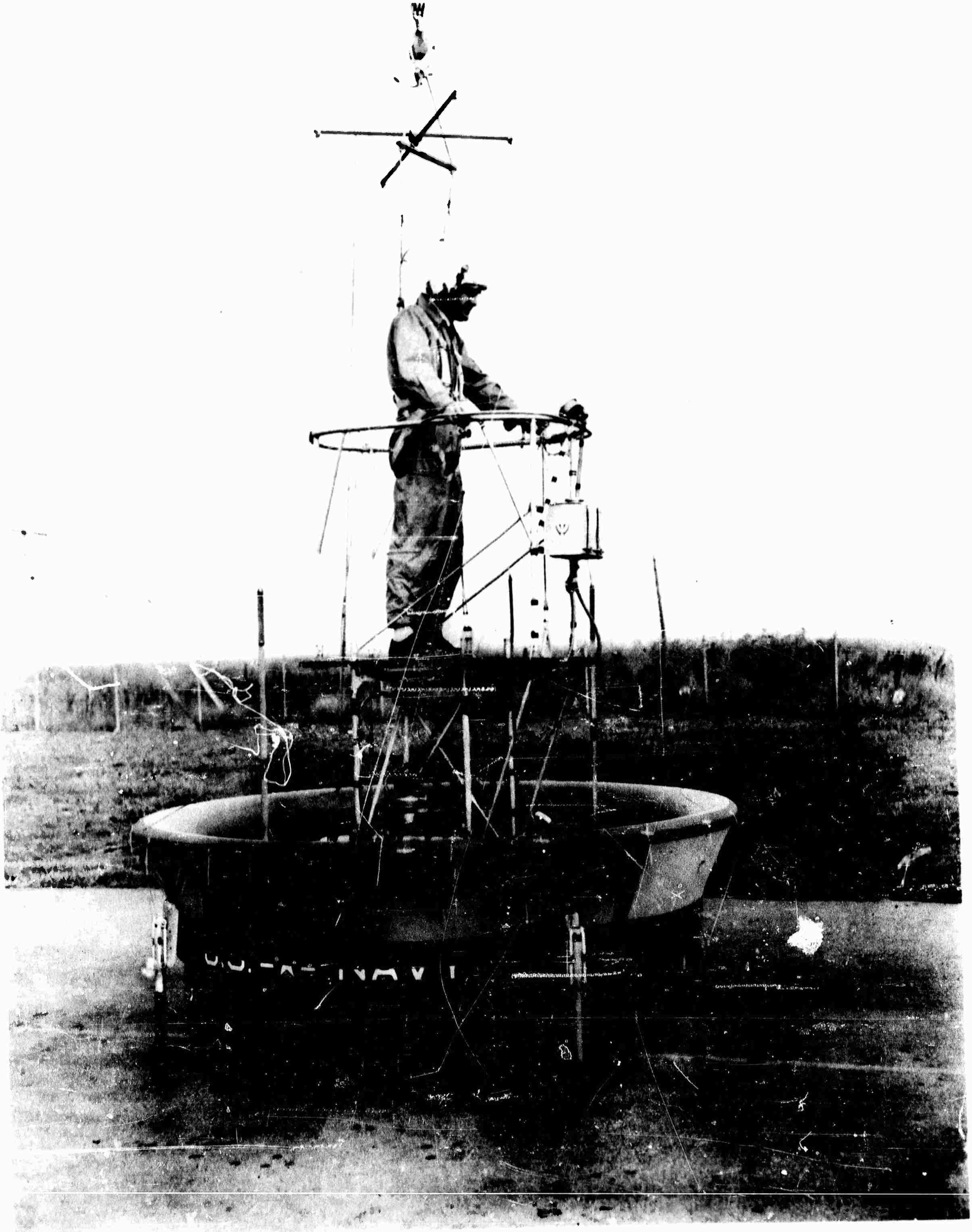


FIGURE 16: 7-FOOT PLATFORM WITH ENCLOSED DUCT AND ENLARGED PILOT ENCLOSURE



BIBLIOGRAPHICAL CONTROL SHEET

1. Originating Agency and/or Monitoring Agency:

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12. Abstract:

Summary report of wind tunnel and flight test programs and theoretical studies performed in Phase IV of Contract No. Nonr 1357(00). Brief summaries of the first three phases of this contract are also included.