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GENERAL DESCRIPTION OF THE PRINCETON DYNAMIC MODEL TRACK

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November 1966

U. S. ARMY AVIATION MATERIEL LABORATORIES FORT EUSTIS, VIRGINIA

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PRINCETON UNIVERSITY
PRINCETON, NEW JERSEY

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GENERAL DESCRIPTION OF THE PRINCETON DYNAMIC MODEL TRACK

Report No. 738

by
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Prepared by
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Princeton, New Jersey

for
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FORT EUSTIS, VIRGINIA

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ABSTRACT

The Princeton Dynamic Model Track is a facility which consists of a servo-controlled hydraulically powered model carriage mounted on a monorail track. The track is housed inside a 30-by-30-foot building 750 feet long. The carriage contains a model mount designed to allow the carriage to follow the powered model without imposing restraints on the model motions being studied. From one to five degrees of freedom motions can be examined, both longitudinal and lateral-directional, in or out of ground effect. The Dynamic Model Track can provide static and dynamic derivative data (e.g., velocity and rate-dependent aerodynamic stability and control derivatives) on V/STOL aircraft models or components in and near hover, slow speed flight, and during transition. In addition, it can provide an experimental simulation of the expected full-scale vehicle control-fixed dynamic motions.

Models are usually dynamically scaled (mass and inertias) from full-scale. The maximum model weight is presently about 60 pounds. The maximum span or diameter is generally 8 feet. Constant- or variable-frequency electric power up to 75KVA is available for model drive motors. Power supplies other than electric may be adapted for use. Telemetering equipment and analog or digital readout are available to record quantities measured on the model. The maximum carriage acceleration and deceleration capability along the track is 0.6g; the maximum carriage speed is approximately 40 feet per second, which corresponds to $40\sqrt{\lambda}$ feet per second full-scale, where λ is the model to full-scale linear scaling factor. The maximum model mount angular excursions are $\pm 30^\circ$; the maximum vertical velocities are $\pm$ 10 feet per second, and the lateral carriage velocities are $\pm$ 10 feet per second.

Although many projects are run in connection with Government contracts, private industry is invited to use the facility. The scaling requirements and weight limitation on the model can lead to a cost of $35,000 or higher and to a model design/fabrication time of 6 months or greater, depending strongly on the level of sophistication of the model. Construction of the models is not undertaken directly by Princeton.

FOREWORD

The Princeton Dynamic Model Track is a Government-owned facility. Research conducted in this facility is performed under contracts issued by the United States Army Aviation Materiel Laboratories (USAAVLABS). Government-sponsored research is currently funded jointly by USAAVLABS, the United States Navy (Airframe Division of the Naval Air Systems Command), and the Air Force Flight-Dynamics Laboratory of the Research and Technology Division.

Industrial firms may also arrange to sponsor model tests on the facility and should request information about administrative procedures, schedules, and other details by contacting the Director of the facility, who is currently:

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INTRODUCTION

The Princeton Dynamic Model Track is a unique facility designed expressly for the study of the dynamic stability and control of helicopters and V/STOL aircraft for the speed regime ranging from hover through transition. Basic components of the facility include a test section building with a cross section of 30 by 30 feet, a servo-controlled powered carriage that rides on a 750-foot-long monorail track, various model mounts, measuring transducers and data recording equipment.

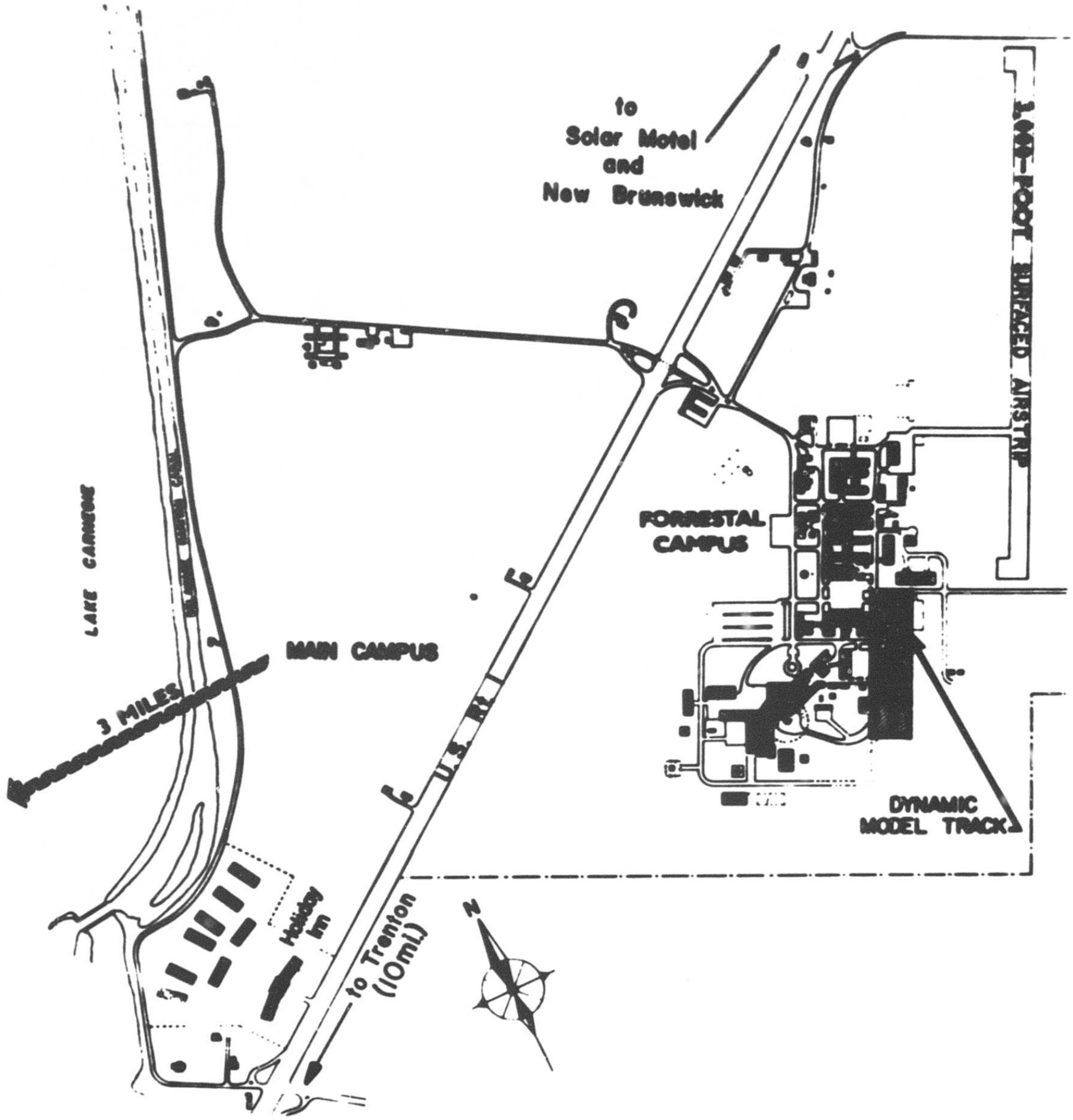
The various mounts permit unique methods of attaching the models to the carriage so that the classical longitudinal and lateral-directional degrees of dynamic motion may be studied. In addition to these freedoms, other experiments such as transition characteristics and "ground effect" research may be conducted.

For investigation of the dynamic stability and control characteristics, the position type servo operation of the carriage allows the model to fly "free" in the desired degrees of freedom to be analyzed for that flight condition. Servo error links are used to sense the model movement with respect to the mounts and to command the carriage to follow without imposing restraints on the model motion being studied. Because of the complexity of the dynamic motions of these types of aircraft, limited degree-of-freedom tests are most frequently conducted; however, as needs dictate, additional degrees of freedom (up to five) can be provided. Most model support mounts will permit up to three angular freedoms and combinations of two translational freedoms simultaneously. The mounting structures for longitudinal, lateral-directional and ground effect studies are shown in Figures 1, 2, and 3.

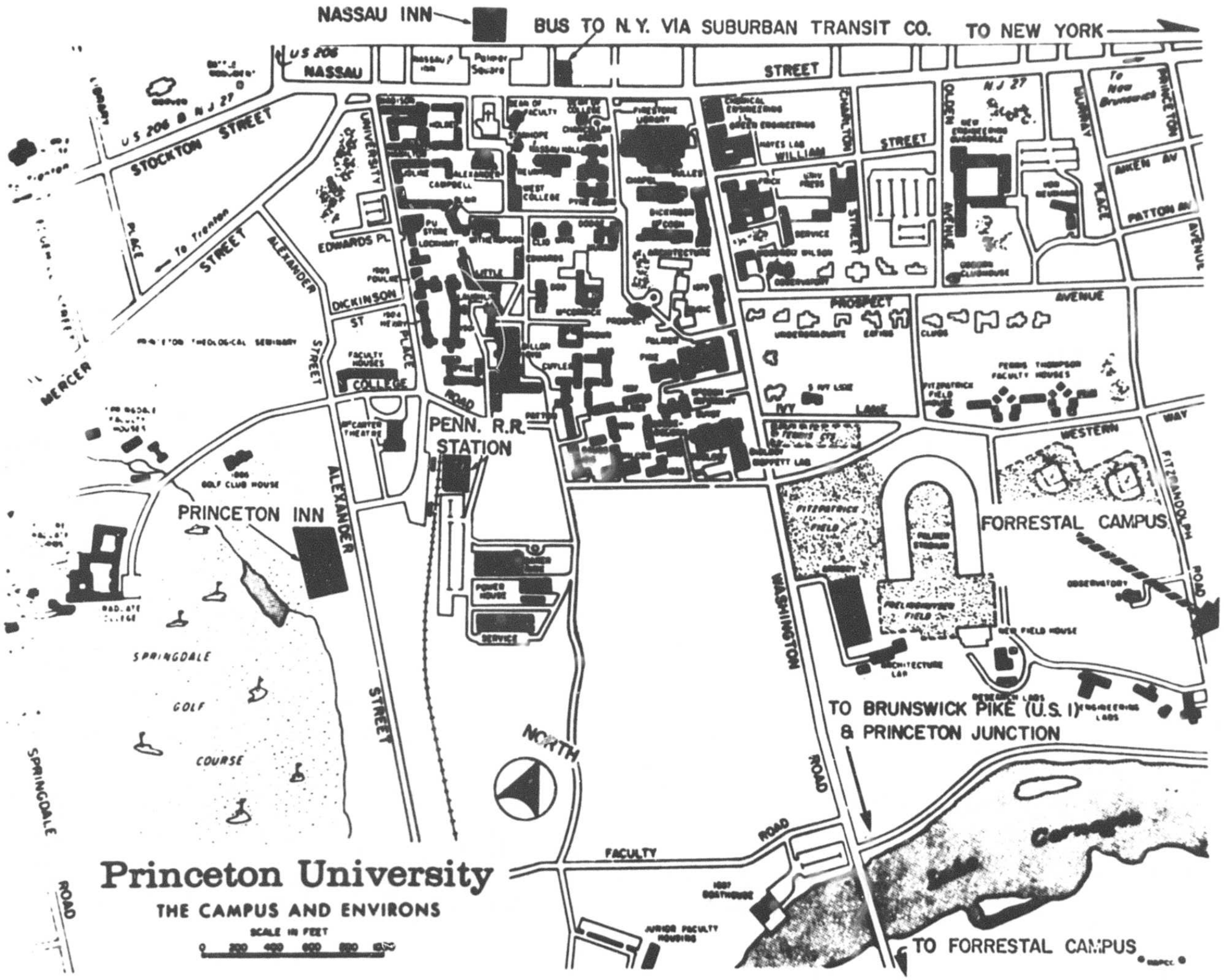
Although the facility was designed primarily to conduct dynamic testing, certain features make it well suited for static stability research of V/STOL vehicles for the hover to transition speed range. This form of testing is similar to conventional wind tunnel testing (though perhaps not as efficient) but with the advantages of a 30-by-30-foot test section, precise airspeed measurement, and a uniform flow condition free from turbulence (still air).

Additional details on the capabilities and features of the Princeton Dynamic Model Track are contained in References 1, 2, and 3.

The following maps show the location of Princeton University — the Main Campus and the Forrestal Campus. The Dynamic Model Track is located at the southeast corner of the Forrestal Campus. Commercial accommodations are available near the Forrestal Campus or near the Main Campus and are shown on the maps (pages 2 and 3).



MAP I PRINCETON UNIVERSITY - FORRESTAL CAMPUS



MAP II PRINCETON UNIVERSITY - MAIN CAMPUS

EXPERIMENTAL APPLICATIONS

SUMMARY

The Princeton Dynamic Model Track is used primarily for making direct measurements of the time histories of the motion of dynamically similar models in response to control inputs and other disturbances. In these experiments, the carriage movement is commanded by the motion of the model through positioning servomechanisms. The response of a suitably scaled model may then be directly interpreted in terms of full-scale aircraft characteristics, and analyzed for the stability derivatives of the vehicle. This application of the device is referred to in the following pages as dynamic testing. The dynamic stability and control data obtained by this technique are similar to those obtained by full-scale testing but with higher safety, better experiment control, and reduced cost.

In addition, the apparatus may be used for what is called static testing, where the model motion is determined by programming the motion of the carriage, and the forces and moments acting on the model are measured. These programmed carriage motions may be at constant velocities, in which case the experiments are similar to conventional wind tunnel tests, or the velocity of the carriage may be programmed in some desired variation with time.

DESCRIPTION OF MODEL SUPPORT APPARATUS

Apparatus Capability

1. Carriage speed range: 0 to 40 feet per second, forward or backward. A model speed of 40 feet per second is equivalent to a full-scale speed of approximately 86 miles per hour for a one-tenth scale model ($\lambda = 10$ in Table I).

2. Approximately level flight - Climb or descent conditions may be simulated by application of a horizontal force to the model (Reference 4).

3. Test section design and testing techniques permit realistic test conditions for studies in or out of ground effect.

4. Sufficient acceleration capabilities and adequate frequency response characteristics of all carriage servo drive systems provide accurate driving and following of all model motions being measured. The horizontal servo drive system has a maximum acceleration capability of 0.6g and a response frequency of 2 cycles per second. The vertical servo drive system has an acceleration capability of about 0.3g.

Degrees of Freedom

Longitudinal Mount (Figure 1) - The three classical longitudinal degrees of freedom (θ, u, w) and each two-degree-of-freedom combination or each single degree of freedom may be investigated. Note that, while it is simple to restrict the degrees of freedom with respect to a space-fixed axis as desired, it is more difficult to restrict other variables. That is, investigation of constant angle of attack motion would be considerably more complex than the case where pitch angle equals angle of attack.

Lateral-Directional Mount (Figure 2) - The three lateral degrees of freedom (φ, Ψ, v) and each two-degree-of-freedom combination and each single degree of freedom may be investigated. Only one of these, roll, is a classical, body-axis degree of freedom; yaw and lateral velocity are with respect to space axes. It is not possible, at present, to conduct lateral response measurements with lateral velocity in ground effect. The longitudinal ground effect mount described below may be used to study roll-sideslip motions ($\Psi = -\beta$).

It is possible to conduct five-degree-of-freedom experiments on either the longitudinal or the lateral-directional mounts. The model may be mounted so as to have all three angular freedoms in combination with horizontal velocity and vertical velocity on the longitudinal mount (Figure 1) or in combination with lateral velocity and horizontal velocity using the lateral mount (Figure 2). Figures 1, 2, and 3 show the mounts and summarize the maximum excursions and capabilities:

1. Longitudinal Mount (Figure 1) - Three angular freedoms available plus horizontal and vertical translational freedom, or three angular freedoms available plus lateral and vertical translational freedom (near hover).

2. Lateral-Directional Mount (Figure 2) - Three angular freedoms plus lateral and horizontal translational freedoms.

3. Ground Proximity Mount (Figure 3) - Three angular freedoms available plus horizontal and vertical translational freedoms.

DYNAMIC TEST (Response time histories)

Test Procedure

Prior to making measurements, the proper model trim settings are determined experimentally. In the first part of the run, the model is fixed with respect to the carriage, and the carriage is programmed to accelerate rapidly to the desired speed. Following a time interval sufficient to achieve stabilized flow conditions, the model is released with respect to the carriage, and the position servo mode of operation of the carriage is turned on and the carriage follows the model motions (Figure 4). After a preprogrammed time, a control input is applied and the transient ensues. Time histories of vehicle motions are recorded.

Analysis of Data

The resulting time history measurements are analyzed in the following ways:

1. The response of the model can be interpreted directly in terms of full-scale control-fixed characteristics, with appropriate time and distance scaling. Also, in addition to studying these responses for the stick-fixed, open-loop motions, appropriate feedback loops may be closed with the model control system in order to investigate the closed-loop response. For example, variable rate and attitude feedback loops have been investigated in this way to determine the performance of automatic stabilization systems.

2. The static and dynamic stability derivatives of the vehicle are determined by analysis of the measured response in terms of the vehicle equations of motion. The extraction of derivatives in this manner can be greatly simplified by eliminating derivatives from the equations through use of the various limited degree-of-freedom tests.

STATIC DERIVATIVE TESTS (Force and moment measurement)

Test Procedure

Measurements can be made of the forces and moments acting on a model over the speed range of the apparatus. At present, the balances are tailored to the specific model under investigation and no "standard" balance system is available on which any model may be mounted.

In order to minimize the time required for a static test, the variable of interest is programmed to vary slowly during the time interval of interest. If the force and moment variations with horizontal velocity are of interest, the carriage is programmed to change velocity slowly about the equilibrium condition. This type of quasi-steady-state run has indicated that rates may be selected that are slow enough that steady-state data are obtained with a considerable saving of testing time. All the recorded data (e.g., lift, drag, and pitching moment recorded as a function of time) may be easily cross plotted with velocity by using X-Y plotters to present directly the static derivative functional relationships of interest (e.g., plots of lift, drag, and pitching moment versus velocity).

OTHER TESTS

It is also possible to conduct tests that are various combinations of static and dynamic testing, such as transition experiments with a tilt-wing VTOL model where a motor-driven wing-tilt mechanism drives the wing down from vertical and then back to the hover position. In this instance, the model is free horizontally, and the carriage tracks the resulting horizontal velocity of the model in "position-servo" operation.

The Princeton Dynamic Model Track characteristics are summarized in Table II.

MODEL CONSIDERATIONS

SIZE, WEIGHT, AND POWER LIMITATIONS

1. Maximum Linear Dimension - approximately 8 feet
2. Maximum Weight - approximately 60 pounds
3. Model Propulsive Power Source - large-capacity, multiphase, electric power; constant frequency or variable frequency up to approximately 75KVA limit.
4. Model Drive Motors - various induction type, variable rpm, electric motors for powering model rotors and propellers. A typical intermittent duty cycle model motor measuring 4 inches in diameter and 8 inches long, weighs about 9 pounds and delivers approximately 6 horsepower.
5. Auxiliary Electric Power - various special-purpose power supplies are available for model control systems and other auxiliary drives as needed.

SCALING

Scaling places a requirement on the weight and moments of inertia of the model in dynamic testing. The laws by which a model is designed to study the behavior of a real system are developed formally through dimensional analysis (Reference 5). Physically, the result may be considered as a requirement that the polygon of forces acting on the model is similar to that on the real system (Reference 2). In studying the dynamic motions of aircraft, three kinds of forces are important: gravitational, inertial, and aerodynamic. (The possible interaction of elastic forces, i.e., structural deformations, is not considered here. This interaction can be included, however, by suitable model design, as has been done in the case of a helicopter, Reference 6.) The requirement for force similarity between the model and full-scale places two conditions on the scaling: both the Froude number and the aerodynamic force coefficients must be maintained the same on the model and full-scale vehicle. These two requirements lead to three conditions that determine the ratios of mass, length, and time between the model and full-scale. (These are the only conditions that may be placed on the model, since force is related to mass, length and time through Newton's second law.) Thus, the Reynolds number and Mach number will be different on the model, as indicated in Table I. Also shown is the manner in which various other physical quantities vary with the model scale factor. Reynolds number and Mach number have a direct influence on the aerodynamic force coefficients. That is, even though the model and its full-scale counterpart are geometrically similar, there may be differences in the aerodynamic force coefficients. To date, comparisons of model and full-scale responses indicate that the Reynolds number apparently does not have a strong influence on the stability characteristics (Reference 7). While propeller tip Mach number may influence power required, it would not be expected that the inability to match Mach number would influence the stability characteristics of vehicles at the flight speeds of interest here.

If only static testing is contemplated, then it is not necessary to scale the model weight and inertias; nevertheless, the maximum allowable weight of the model is approximately 60 pounds due to structural limitations of the carriage and supporting structures. Since force measurements are being made on the moving carriage, track irregularities cause inputs to the model support which are reflected in the strain gauge measurements. To minimize the influence of these irregularities and the resulting noise input, it is desirable to keep the model weight as low as possible.

MODEL DESIGN

Some design considerations relating to the models, particularly with respect to dynamic tests, are discussed briefly.

Experience has shown that the major design problem is usually meeting the weight requirement and moments of inertia. Generally, stress levels are not a particularly difficult problem since the stresses on the model are reduced by the scale factor (see Table I). While some experiments can be conducted and analyzed even if the mass and inertia properties are not scaled, it is necessary to scale these quantities accurately in order to interpret response measurements directly in terms of full-scale characteristics.

The model must have essentially the same controls that the full-scale aircraft has since it is actually flying during the experiments (though generally "stick-fixed"); it must be possible to trim the model. For efficient operation, these controls should be remotely powered. Light, compact positioning servomechanisms have been developed at Princeton that permit accurate positioning of model controls. Also, these closed-loop servomechanisms maintain precise control positions and deflections throughout the entire test run independent of the external loads imposed on the controls.

The model should be designed so that the angular freedom axis may be located at its center of gravity. For longitudinal and lateral experiments, out of ground effect, the mounting link enters the model from the bottom (Figures 1 and 2). For ground effect, the mounting link enters from the top (Figure 3). The model center of gravity should be in the position corresponding to that of the full-scale vehicle.

Center of gravity mounting is always desirable in order to minimize the effect of small mass violations in scaling. These are incurred by the mass of some portions of the supporting "error links and mounts" that are installed with the model and whose mass must also be accelerated during the dynamic tests. These effects may be easily accounted for and are usually not very significant unless the model is not mounted at its center of gravity.

The main structural members of the model have generally been fabricated of aluminum, and the aerodynamic surfaces are Fiberglas, formed in molds. Fuselages have been made of a sandwich construction of styrofoam and Fiberglas. Propellers generally have controllable pitch, so that the proper blade angle/advance ratio may be simulated.

The power drive trains of the models must be carefully engineered for light weight with satisfactory running life. Usually, weight requirements have imposed a short running life on the power transmission components. The life of transmission components on previous models tested in this facility has averaged 50 to 100 hours of running time.

Typical models that have been tested in the facility are a 0.10 scale XC-142 tri-service tilt-wing transport, a 0.15 scale H-19 helicopter, a 0.10 scale twin rotor tilt-wing aircraft, and a 0.192 scale VZ-2 experimental tilt-wing aircraft.

A small machine shop is located in the facility and is available when immediate model repairs or minor modifications are required.

TEST INSTRUMENTATION

All data such as static forces and moments, angles, control positions, velocities, accelerations, displacements, etc., are telemetered from the moving carriage to a control room located adjacent to the test section building. The transmitted data are received and channeled to various data recording and conditioning equipment located in the control room. All raw data are permanently recorded on an Ampex model 303 tape recorder with a pulse-width recording electronics chassis designed to operate with the standard Ampex tape transport system. The recorder is dual track, which provides for recording voice test identification information on the upper track and the pulse-width modulated raw data on the lower track. An ASCOP 43-channel telemetry station is used to receive and condition the raw data. All 43 channels have visual readout on meters and oscilloscope presentations permitting continuous monitoring of the data channels during the test runs. Also, all data may be graphically displayed on Sanborn type direct-writing recorders. In addition to the Ampex model 303 pulse-width tape recorder, any 20 channels of information may be conditioned, filtered, and simultaneously recorded on a seven-track Ampex TM-7 tape recorder in natural binary coded decimal (BCD) system (IBM compatible format). In this form, the data may be fed directly to digital computers with appropriate programming for any desired manipulations, axis transfers and graph printing (Figure 7).

The use of the moving carriage as a reference eliminates the necessity of making direct aerodynamic measurements (such as angle of attack, sideslip angle and airspeed) to determine response time histories. The accurate measurement of these quantities presents no problem with this testing facility. For example, angle of attack is precisely determined by measuring the pitch attitude with a potentiometer and vertical and horizontal velocities of the model with tachometers.

Basic accuracy of measurement is limited by the one to two percent of full-scale accuracy of the telemetering system. Extensive use of gain adjustment, biasing, and signal clipping is made to keep the measurements as sensitive as possible. For example, it is frequently necessary to measure small changes in a quantity about some larger steady-state value, such as the velocity variation about a trim speed. Solid-state diodes are used to clip the lower portion of the signal and thus permit measurement with any desired sensitivity about a steady-state value, once the usable cutoff point of the diode has been established through calibration.

Some of the transducers employed for the various measurements are:

1. Horizontal, vertical and lateral velocities - measured by DC tachometers and automatic electric timing clocks. For horizontal velocity, a tachometer mounted on the carriage with a drive wheel riding on the monorail generates a voltage that may be read directly on the recording equipment. In addition, a series of

special automatic electric timing clocks, activated by photocells, are mounted at known distances along the track. Both systems yield accurate flight velocity information.

2. Pitch, roll and yaw rates - measured by DC tachometers and rate gyros. For very high performance, rate gyros are preferable, but tachometers with high gear ratios have been used on certain applications with good results.

3. Distances, angles or positions - measured with potentiometers (low-friction potentiometers where necessary). Error link position, altitude or model vertical position on climbs or descents, fuselage attitude, wing or tail incidence, flap or control positions, propeller pitch, etc., are quantities measured by potentiometers. This is usually a simple measurement, since most model systems already contain feedback potentiometers that may be monitored and relayed by the telemeter to the ground recorder.

4. Forces and moments - measured with strain gauges and differential transformers with AC carrier amplifiers. The facility will obtain a universal-use, six-component, strain gauge balance system to facilitate the acquisition of static data in place of the custom-mounted single strain gauges presently used.

TABLE I
SCALE FACTORS FOR MODEL PROPERTIES

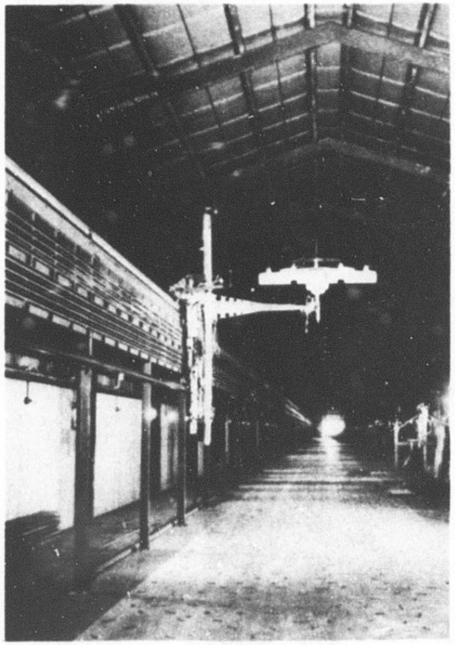
Model properties are obtained by multiplying full-scale properties by the given scale factors.

(model value) = (full-scale value) x (scale factor)

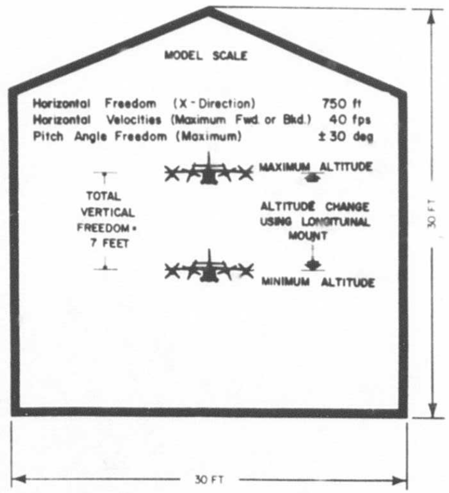
PARAMETER	SCALE FACTOR
Dimensional Quantities	
Linear dimensions	λ^{-1}
Area	λ^{-2}
Volume, mass, force	λ^{-3}
Moment	λ^{-4}
Moment of inertia	λ^{-5}
Linear velocity	$\lambda^{-0.5}$
Linear acceleration	λ^{0}
Angular velocity	$\lambda^{0.5}$
Angular acceleration	λ^{1}
Time	$\lambda^{-0.5}$
Frequency	$\lambda^{0.5}$
Stiffness (EI and GJ)	$\lambda^{-0.5}$
R.P.M.	$\lambda^{0.5}$
Disc loading, stresses	λ^{-1}
Power loading (thrust/horsepower)	$\lambda^{0.5}$
Power	$\lambda^{-3.5}$
Nondimensional Quantities	
Aerodynamic force coefficient $\frac{F}{\frac{1}{2}\rho V^2 \ell^2}$	λ^{0}
Froude number $\frac{V^2}{\ell g}$	λ^{0}
Reynolds number $\frac{\rho V \ell}{\mu}$	$\lambda^{-1.5}$
Mach number $\frac{V}{a}$	$\lambda^{-0.5}$

TABLE II
PRINCETON DYNAMIC MODEL TRACK CHARACTERISTICS

FLIGHT CONDITIONS	
Velocity Range	Hover to ± 40 fps model velocity
Flight Path	Steady or accelerated level flight, climbs or descents (in or out of ground effect)
Carriage Acceleration and Frequency Response	Horizontal acceleration—capability—0.6g Frequency response—2 cps Vertical acceleration—capability—0.3g
Building Test Section Dimensions	30 feet high by 30 feet wide by 750 feet long
GENERAL MODEL CHARACTERISTICS	
Characteristic Length (max)	Approximately 8 feet
Model Power (max)	75KVA capacity, variable frequency electric power
Weight (max)	Approximately 60 pounds
DEGREES OF FREEDOM	
Longitudinal	θ_B , u_s , w_s subscript $_B$ denotes body-axis reference
Lateral-Directional	φ_B , Ψ_s , v_s subscript $_s$ denotes space-axis reference
Multi Degree of Freedom including Transitions	θ_B , φ_B , Ψ_s , u_s , w_s or θ_B , φ_B , Ψ_s , u_s , v_s
STATIC TESTS	Six component, forces and moments measured
INSTRUMENTATION AND DATA RECORDING	Appropriate transducers and telemeter system with 43 data channels IBM compatible digital tape data Sanborn time history data recording



A. GENERAL ARRANGEMENT OF LONGITUDINAL MOUNT FOR HOVER AND FORWARD FLIGHT

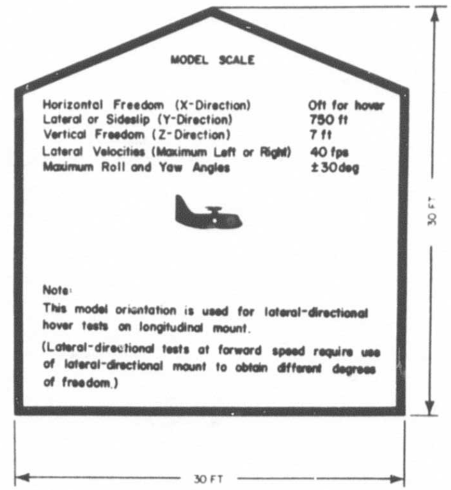


EXAMPLE OF EQUIVALENT FULL SCALE VALUES OF FREEDOM

(Assuming a 0.1 Scale Dynamically Similar Model and a Carriage Speed of 40 feet per second)

Horizontal Freedom (X-Direction)	7500 ft.
Horizontal Velocities (Max. Forward or Backward)	75kts(86 mph)
Vertical Freedom (Z-Direction)	70 ft
Pitch Angle Freedom (Maximum)	±30 Deg.

B. DISPLACEMENT FREEDOMS AVAILABLE WITH LONGITUDINAL MOUNT



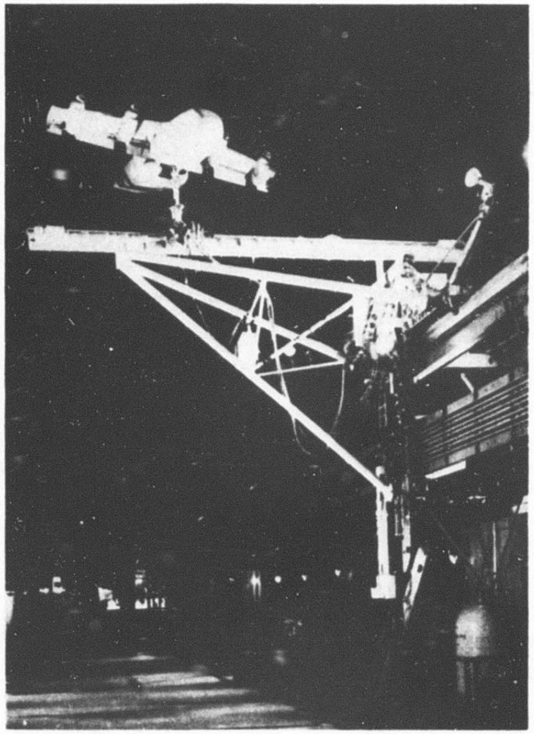
EXAMPLE OF EQUIVALENT FULL SCALE VALUES OF FREEDOM

(Assuming a 0.1 Scale Dynamically Similar Model and a Carriage Speed of 40 feet per second.)

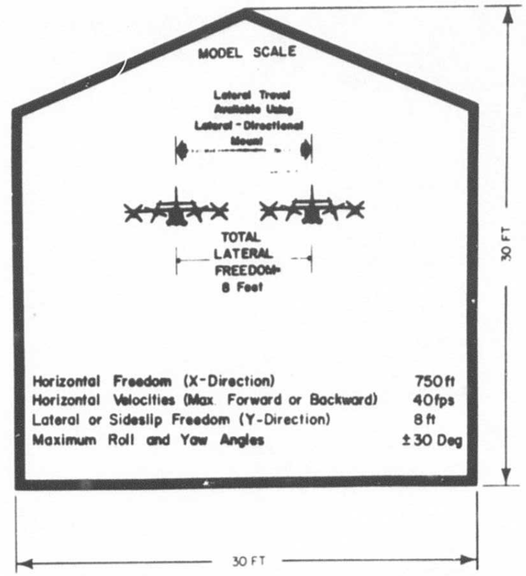
Horizontal Freedom (X-Direction)	0 ft for hover
Lateral or Sideslip Freedom (Y-Direction)	7500 ft
Vertical Freedom (Z-Direction)	70 ft
Lateral Velocities (Max. Left or Right Sideslip)	75 knots(86mph)
Yaw Angle Freedom (Maximum)	±30 Degrees
Roll Angle Freedom (Maximum)	±30 Degrees

C. FREEDOMS AVAILABLE USING SPECIAL ROLL-YAW LINK ON LONGITUDINAL MOUNT

FIGURE I TYPICAL UTILITY AND SCALED FREEDOMS AVAILABLE WITH LONGITUDINAL MOUNT



A. GENERAL ARRANGEMENT OF LATERAL – DIRECTIONAL
MOUNT FOR FORWARD FLIGHT

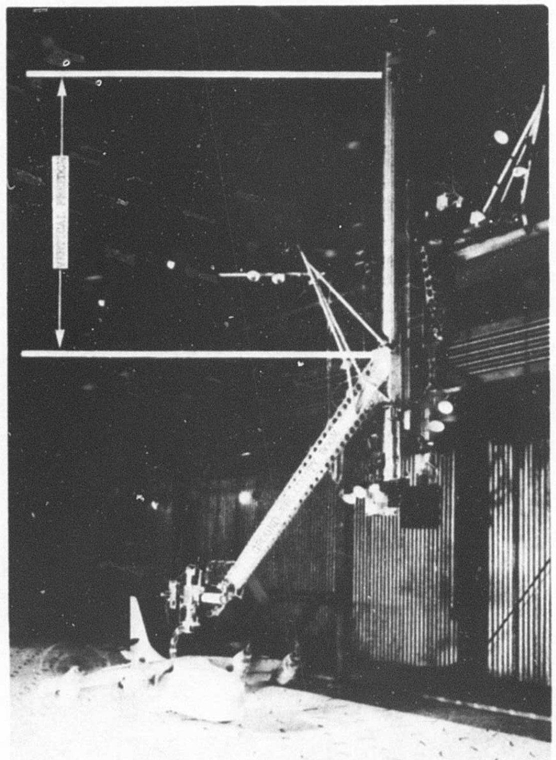


Example of Equivalent Full Scale Values of Freedom
(Assuming a 0.1 Scale Dynamically Similar Model and a Carriage Speed of 40 feet per second)

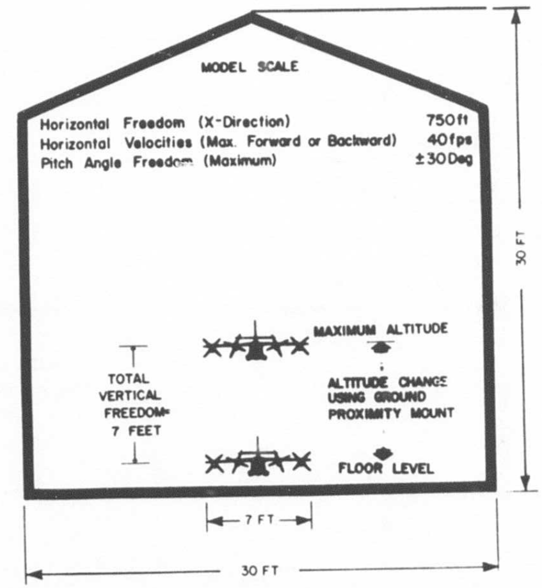
Horizontal Freedom (X-Direction)	7500 ft
Horizontal Velocities (Max. Fwd. or Bkd.)	75 knots (86 mph)
Lateral or Sideslip Freedom (Y-Direction)	80 ft
Yaw Angle Freedom (Maximum)	±30 Deg
Roll Angle Freedom (Maximum)	±30 Deg

B. DISPLACEMENT FREEDOMS AVAILABLE
WITH LATERAL-DIRECTIONAL MOUNT

FIGURE 2 TYPICAL UTILITY AND SCALED FREEDOMS
AVAILABLE WITH LATERAL-DIRECTIONAL MOUNT



A. GENERAL ARRANGEMENT OF GROUND PROXIMITY MOUNT FOR CONSTANT ALTITUDE FLIGHTS AND PROGRAMMED CLIMB-OUTS OR DESCENTS



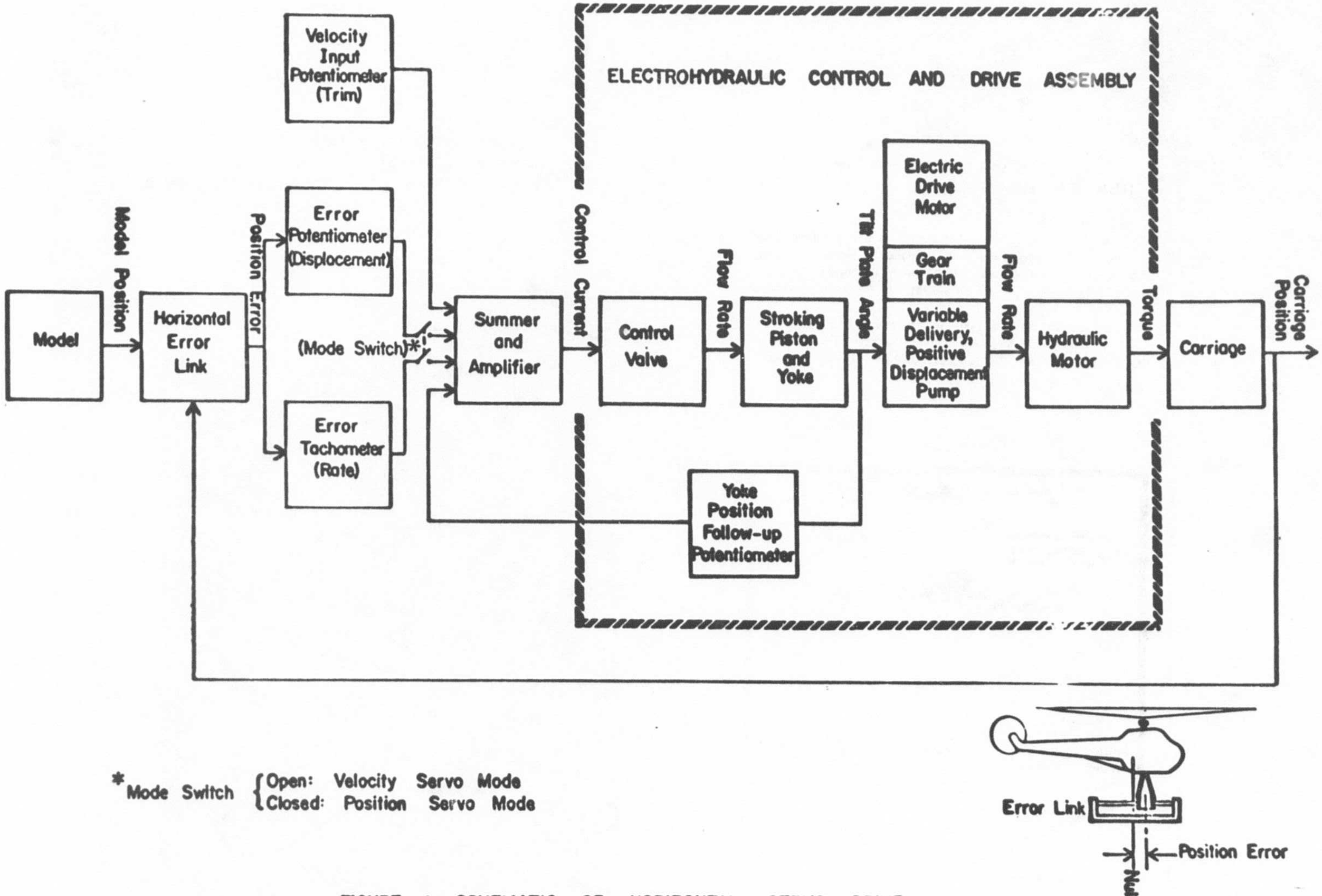
<u>EXAMPLE OF EQUIVALENT FULL SCALE VALUES OF FREEDOM</u>

Assuming a 0.1 Scale Dynamically Similar Model and a Carriage Speed of 40 feet per second

Horizontal Freedom (X-Direction)	7500 ft
Horizontal Velocities (Max. Forward or Backward)	75kts(86mph)
Vertical Freedom (Z-Direction; Climb-out or Descent)	70ft
Pitch Angle Freedom (Maximum)	± 30 Deg

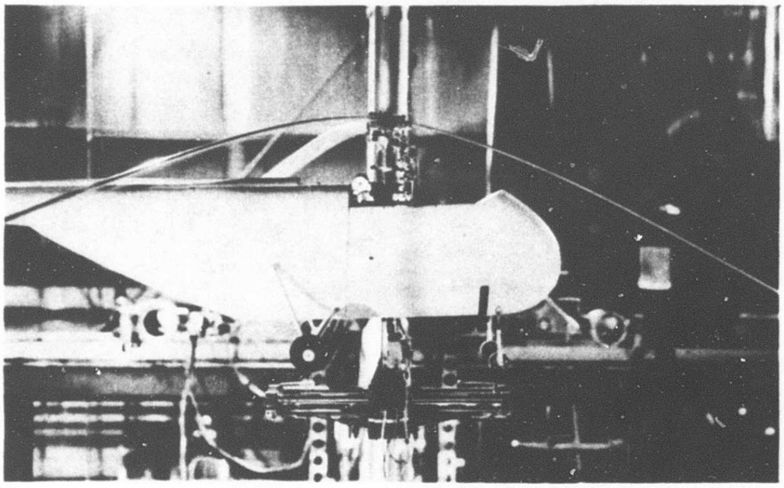
B. DISPLACEMENT FREEDOMS AVAILABLE WITH GROUND PROXIMITY MOUNT

FIGURE 3 TYPICAL UTILITY AND SCALED FREEDOMS AVAILABLE WITH GROUND PROXIMITY MOUNT

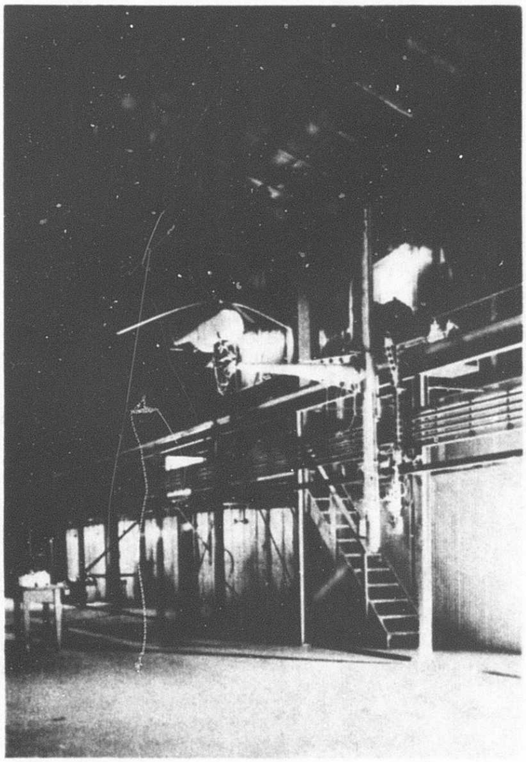


*Mode Switch {Open: Velocity Servo Mode; Closed: Position Servo Mode}

FIGURE 4 SCHEMATIC OF HORIZONTAL SERVO DRIVE

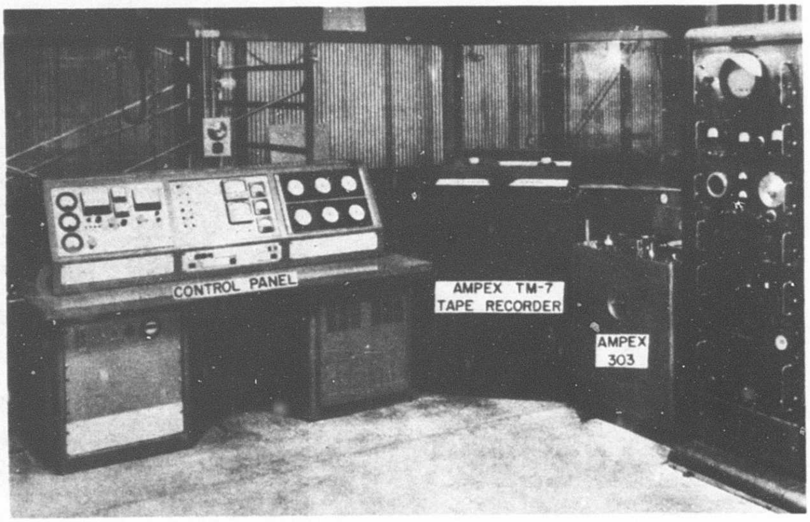


A. CLOSE-UP VIEW OF H-19 (S-55) AND SERVO ERROR LINKAGES

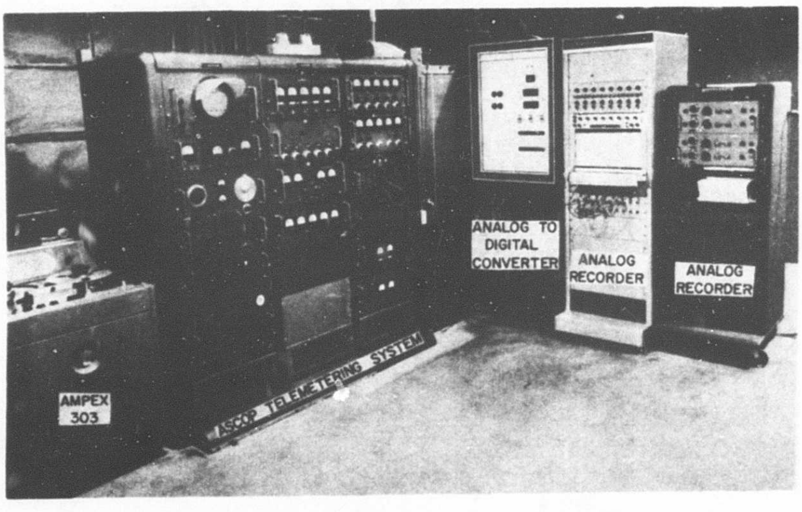


B. FRONT QUARTER VIEW OF H-19 (S-55) ATTACHED TO LONGITUDINAL MOUNT

FIGURE 5 H-19 (S-55) HELICOPTER ON LONGITUDINAL MOUNT



A. CONTROL CONSOLE AND TAPE RECORDERS



B. TELEMETERING SYSTEM, DATA CONVERTER AND RECORDERS

FIGURE 6 CONTROL ROOM SHOWING CONTROL CONSOLE AND DATA RECORDING EQUIPMENT

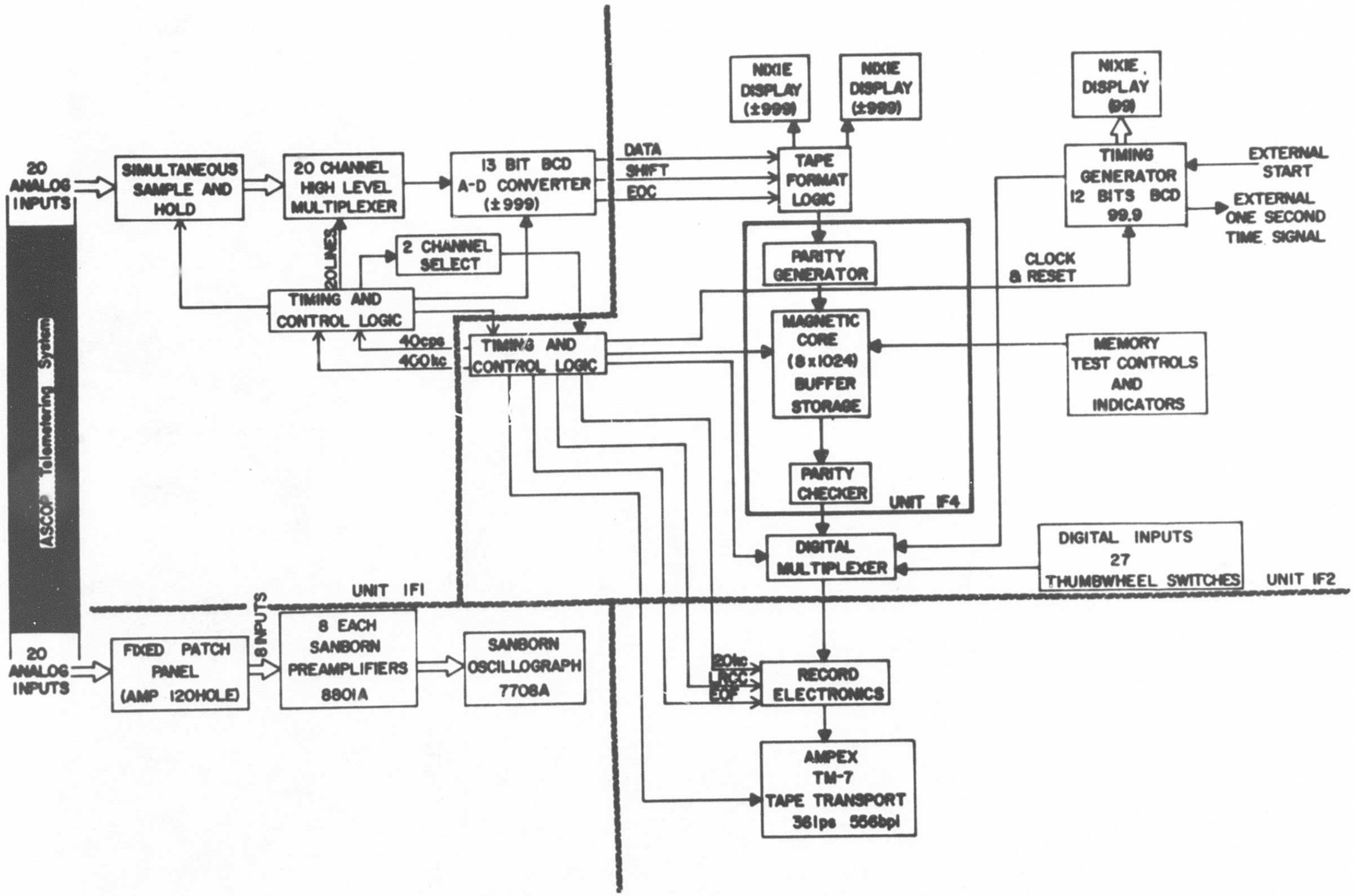


FIGURE 7 ANALOG AND DIGITAL READ-OUT SYSTEM

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13. ABSTRACT

The Princeton Dynamic Model Track is a facility which consists of a servo-controlled hydraulically powered model carriage mounted on a monorail track. The track is housed inside a 30-by-30-foot building 750 feet long. The carriage contains a model mount designed to allow the carriage to follow the powered model without imposing restraints on the model motions being studied. From one to five degrees of freedom motions can be examined, both longitudinal and lateral-directional, in or out of ground effect. The Dynamic Model Track can provide static and dynamic derivative data (e.g., velocity and rate-dependent aerodynamic stability and control derivatives) on V/STOL aircraft models or components in and near hover, slow speed flight, and during transition. In addition, it can provide an experimental simulation of the expected full-scale vehicle control-fixed dynamic motions.

Models are usually dynamically scaled (mass and inertias) from full-scale. The maximum model weight is presently about 60 pounds. The maximum span or diameter is generally 8 feet. Constant- or variable-frequency electric power up to 75KVA is available for model drive motors. Power supplies other than electric may be adapted for use. Telemetering equipment and analog or digital readout are available to record quantities measured on the model. The maximum carriage acceleration and deceleration capability along the track is 0.6g; the maximum carriage speed is approximately 40 feet per second, which corresponds to $40/\sqrt{\lambda}$ feet per second full-scale where λ is the model to full-scale linear scaling factor. The maximum model mount angular excursions are $\pm 30^{\circ}$; the maximum vertical velocities are ± 10 feet per second, and the lateral carriage velocities are ± 10 feet per second.

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