NASA Technical Paper 1473

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National Aeronautics
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SUMMARY

NASA and the Naval Air Systems Command entered into an agreement to conduct tethered hover testing of the U.S. Navy XFV-12A Thrust Augmented Wing V/STOL Technology Demonstrator Aircraft in the Langley impact dynamics research facility (IDRF). The IDRF was modified for the testing. This paper describes these modifications and operation of the facility during static and dynamic tests.

A joint test team conducted the tests during the first half of 1978. Tethered hover testing of the XFV-12A in the IDRF has indicated that valid force and moment data can be obtained from static testing and that dynamic tethered hover flying qualities can be evaluated.

INTRODUCTION

From the beginning of the U.S. Navy XFV-12A Thrust Augmented Wing V/STOL Technology Demonstrator Aircraft Program, there was considerable discussion as to the best method to investigate the hover capabilities of the total aircraft in a realistic, and yet safe, environment. The consensus of those who had previously tested V/STOL aircraft was that tether rigs or pedestals provided unrealistic inputs to aircraft handling qualities and, in some cases, created erroneous impressions of aircraft control responses. Testing devices constructed to remove ground effect, such as grids, provided no safety for investigation of aircraft response to large control inputs during hover flight.

For the XFV-12A program, a facility was desired with the capability to address the following test objectives:

1. To statically test the aircraft in the hover mode by rigidly positioning it at a desired altitude and attitude to obtain
   - Force and moment data both in and out of ground effect
   - Aircraft lift and balance characteristics both in and out of ground effect
   - Final VTOL system adjustments

2. To dynamically test the aircraft in a limited hover envelope to obtain
   - Correlation with static test results
   - Aircraft control response data, including large control inputs, both in and out of ground effect
   - Effects of the stability augmentation system both in and out of ground effect
   - Effects of ambient wind and gusts

3. To provide a realistic environment in which pilots can train and maintain proficiency in VTOL flight.

4. To define the external environment (flow field, velocity, pressure, temperature, and noise) around the aircraft for various aircraft attitudes and altitudes and wind conditions.

It was determined that the Langley impact dynamics research facility (IDRF) could be modified to achieve these test objectives and minimize the problems with previous hover test facilities.

NASA and the Naval Air Systems Command entered into an agreement in late 1976 to conduct tethered hover testing of the XFV-12A in the IDRF. The facility was modified for the program in 1977, and during the first half of 1978, tethered hover testing of the XFV-12A was carried out by a joint test team from NASA, U.S. Navy, and North American Aircraft Division of Rockwell International Corp. Static force and moment data were obtained and limited dynamic tethered hover testing was accomplished.

SYMBOLS

Measurements and calculations were made in U.S. Customary Units. They are presented herein in the International System of Units (SI) and U.S. Customary Units.

δ_D	diffuser half-angle, deg
$\delta_{D,c}$	canard diffuser half-angle, deg
$\delta_{D,w}$	wing diffuser half-angle, deg
δ_{LL}	lift lever position, cm (in.)
δ_{Lat}	lateral stick position (positive for right wing down), cm (in.)
δ_{Long}	longitudinal stick position (positive for nose up), cm (in.)
δ_R	rudder pedal position (positive for nose right), cm (in.)
ΔP	pressure differential
$\dot{\theta}$	pitch rate (positive for nose up), deg/s
ϕ	augmentation ratio, $\dfrac{\text{Measured lift}}{\text{Isentropic thrust}}$
$\dot{\phi}$	roll rate (positive for right wing down), deg/s
$\dot{\psi}$	yaw rate (positive for nose right), deg/s

ABBREVIATIONS

A/C	aircraft
ac	alternating current
AUTO	automatic
BAT	battery
COM	command
DET	detector
EMERG	emergency
HI	high
ICOM	intercommunications
IDRF	impact dynamics research facility
IWRC	independent wire rope center
LLRF	lunar landing research facility
LTS	lights
MAN	manual
pot.	potentiometer
PWR	power
REL	release
STOL	short takeoff and landing
UHF	ultrahigh frequency
VEL	velocity
V/STOL	vertical/short takeoff and landing
VTOL	vertical takeoff and landing

DESCRIPTION OF TEST AIRCRAFT

The XFV-12A, shown in figure 1, is a unique V/STOL aircraft being developed by the U.S. Navy. This V/STOL technology demonstrator aircraft program is

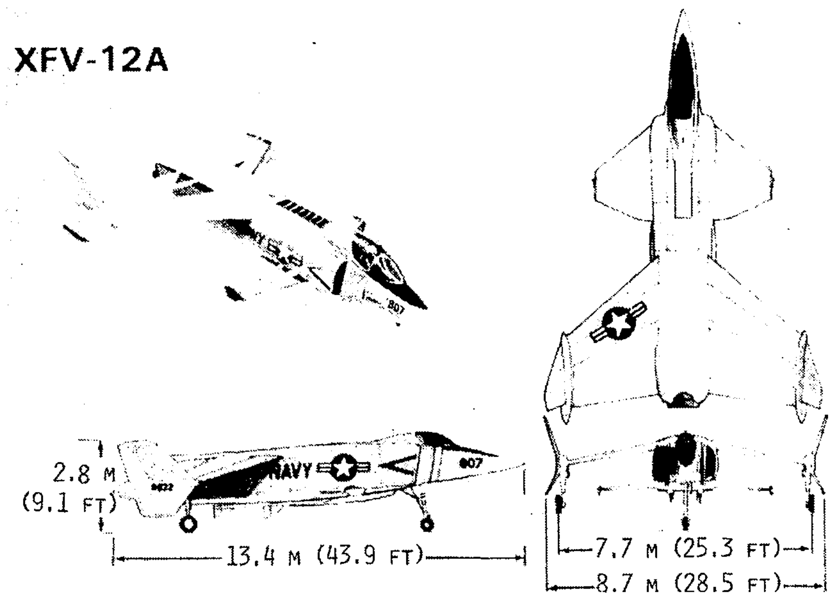

Figure 1.- General arrangement of XFV-12A.

intended to explore the suitability of applying a thrust-augmented wing/canard ejector concept to an air-superiority fighter-type aircraft with V/STOL capability. It is not intended that the XFV-12A program produce an operational production aircraft, but rather that the aircraft serve as a research tool to explore ejector thrust-augmentation technology. It is anticipated that the aircraft will eventually develop into a flight-worthy vehicle to investigate and develop aircraft characteristics in vertical and conversion flight modes at typical fighter takeoff and landing weights. The physical characteristics of the aircraft are given in table I.

TABLE I.- PHYSICAL CHARACTERISTICS OF THE XFV-12A

Takeoff gross weight in STOL mode, kN (lb)	107.9 (24 250)
Takeoff gross weight in VTOL mode, kN (lb)	85.1 (19 130)
Length, m (ft)	13.4 (43.9)
Span, m (ft)	8.7 (28.5)
Height, m (ft)	2.8 (9.1)
Engine (one YF-401):	
Sea-level static thrust, kN (lb)	73.4 (16 500)
Maximum fuel capacity, kN (lb):	
Wing	9.1 (2040)
Fuselage	12.3 (2774)
Moment of inertia, kg-m^2 (slug-ft^2):	
Pitch	69 400 (51 200)
Roll	18 300 (13 500)
Yaw	85 100 (62 800)

Configuration Features

The XFV-12A is a V/STOL fighter design featuring a high wing and low canard arrangement and is powered by a single YF-401 engine. Figure 2 is a cutaway illustration of the aircraft. The air induction system for the YF-401 engine

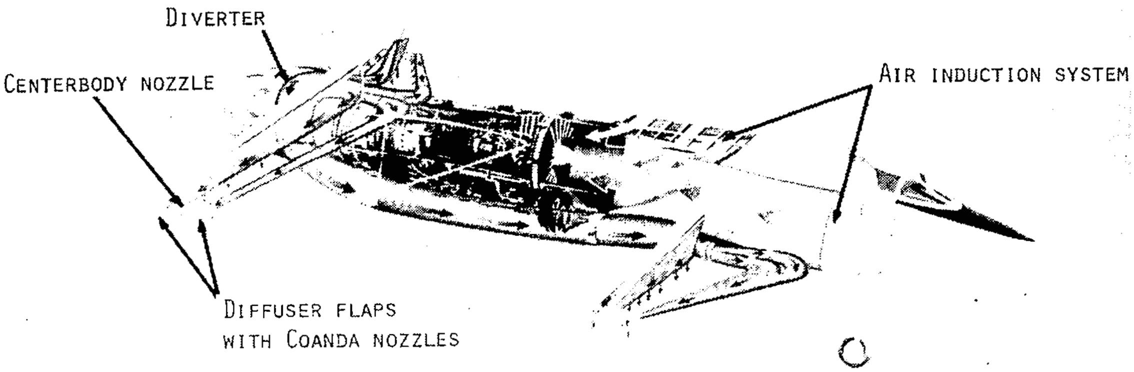

Figure 2.- Cutaway of XFV-12A illustrating airflow for V/STOL operation.

is comprised of two external compression inlets located along the sides of the fuselage and an auxiliary inlet located on top of the fuselage. Flow from the engine exits into the diverter which directs the engine exhaust flow aft through the plug nozzle for conventional flight or forward to the wing and canard ducting and augmenter systems for V/STOL operation.

For V/STOL operation the engine exhaust is directed through the augmenter, that is, between diffuser flaps by means of a centerbody nozzle and Coanda nozzles located on the diffuser flaps. This arrangement causes ambient air to be entrained in quantities several times the mass flow of the engine exhaust. Thrust from the augmenter is increased above the basic nozzle thrust because of the transfer of kinetic energy of the engine exhaust to the entrained secondary air.

During conversion from hover to conventional flight (fig. 3), this secondary air is accelerated over the aerodynamic surfaces by the pumping action of the augmenters to create a rapid buildup of aerodynamic circulation lift on the wing and canard. As the flaps are retracted to mean augmenter flap angles less than 30°, the engine flow converts to normal tail-pipe operation, and the flaps and ejector centerbody fold into a high-performance airfoil, with the trailing-edge flap on both the wing and canard used for aerodynamic control.

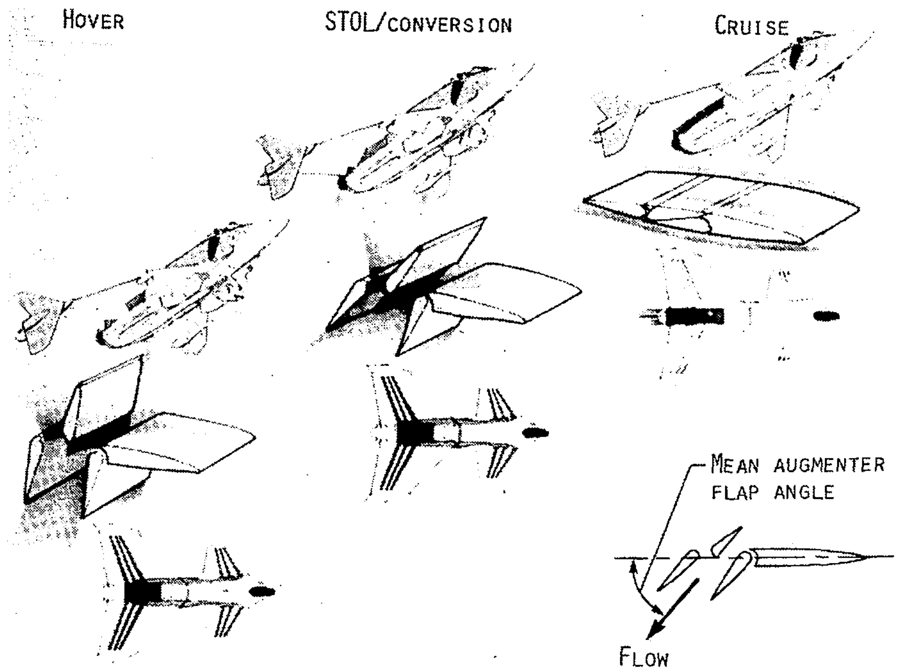

Figure 3.- XFV-12A transition from hover to cruise.

Hover Control System

Hover height and attitude control are also achieved through the augmenter flap system (fig. 4). Variation of the diffuser half-angle modulates the amount of secondary airflow, and thereby the lift created on each augmenter surface. With no change of engine thrust, height control is obtained by variation of the diffuser half-angles on all four augmenters simultaneously. This

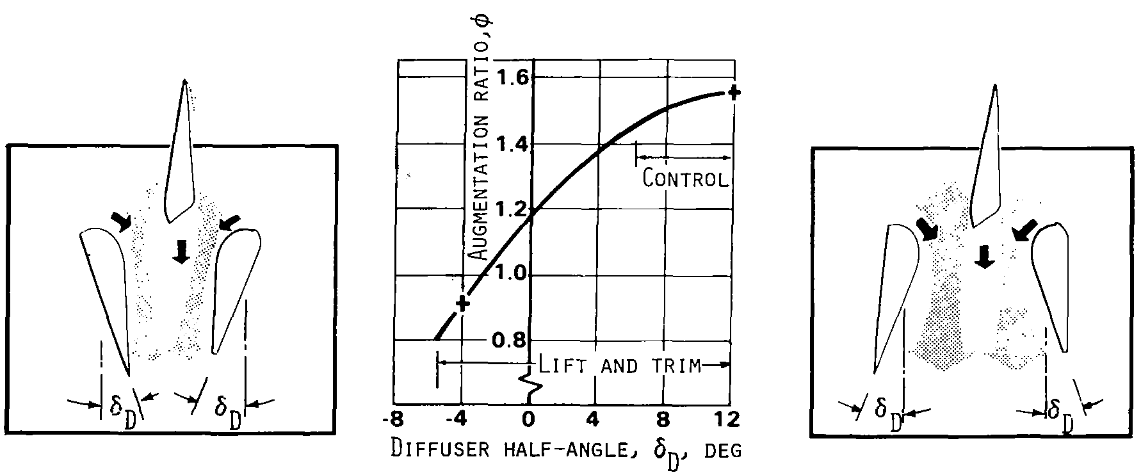

Figure 4.- Hover control concept of XFV-12A.

collective change in diffuser half-angles is accomplished by the pilot moving the aircraft lift lever which is located beside the throttle in the throttle quadrant. At the designed augmenter performance level, the neutral position of the lift lever produces zero rate of climb. A forward or positive movement of the lift lever from neutral produces a positive rate of climb and an aft or negative movement produces a negative rate of climb. Attitude control is achieved by differential variation of the diffuser half-angles on the wing and canard for pitch, differential variation of the diffuser half-angles on the right and left wings for roll, and differential variation of the mean augmenter flap angles on the left and right wings for yaw.

DESCRIPTION OF TEST FACILITY

Langley Lunar Landing Research Facility (LLRF)

The LLRF was built in the early 1960's in support of the Apollo Program. The LLRF gantry (see fig. 5), oriented in the east-west direction, is composed of truss elements arranged with four sets of inclined legs. Access to overhead areas and equipment is provided by an elevator enclosed in a shaft at the south-east corner and by various catwalks. The gantry is approximately 73 m (240 ft) high, 122 m (400 ft) long, and 61 m (200 ft) across at ground level.

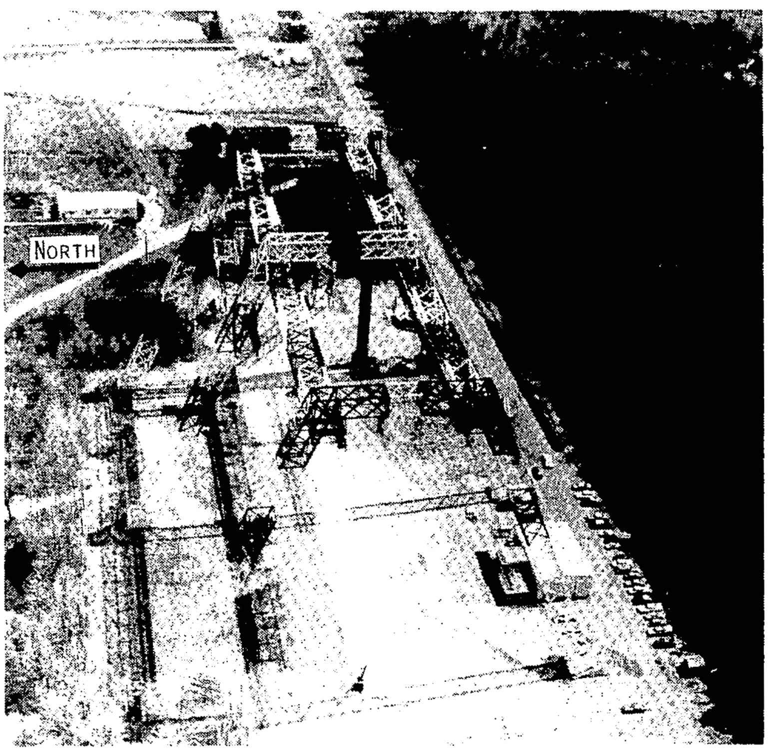

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Figure 5.- Aerial view of LLRF.

The LLRF provided pilots and astronauts the opportunity to maneuver the lunar landing research vehicle (fig. 6) through the final 46 m (150 ft) before

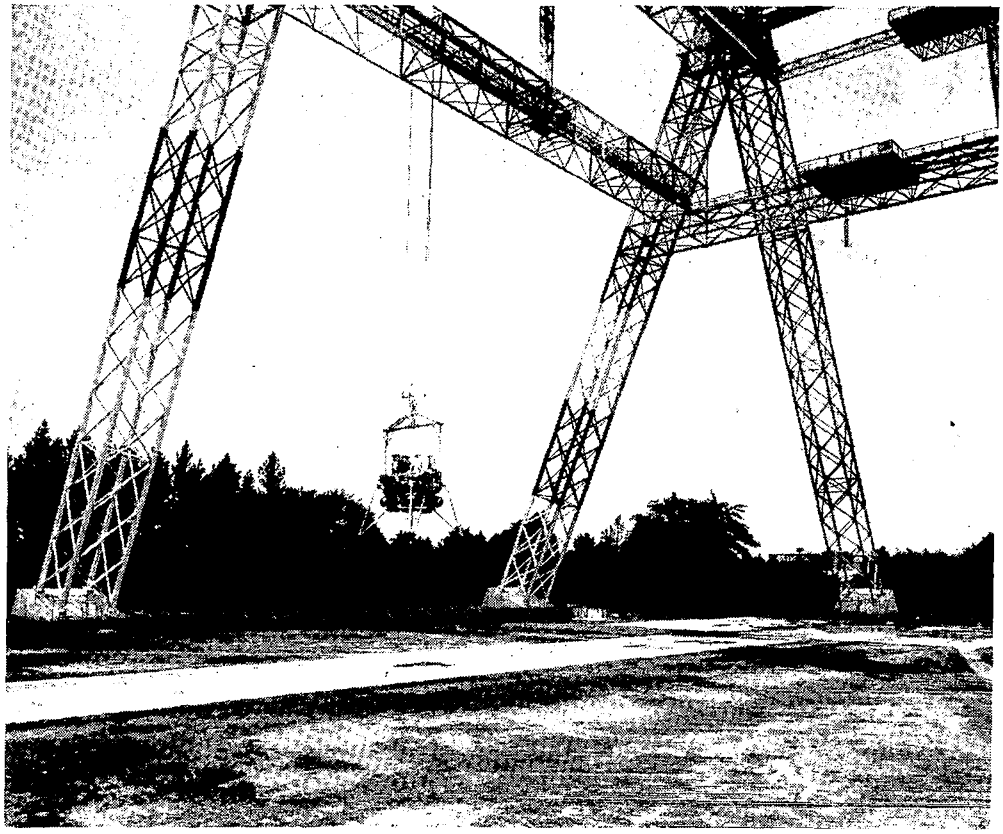

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Figure 6.- Lunar landing research vehicle suspended in LLRF.

landing while under the influence of a simulated lunar gravitational field. Simulation of the lunar gravitational field was achieved by using an overhead suspension system which provided a vertical lifting force equal to five-sixths of the vehicle weight. The suspension cables were attached to the vehicle through a gimbal system which acted through the vehicle center of gravity and allowed freedom of motion in the pitch, roll, and yaw axes. The cables were attached to a winch on the LLRF traveling bridge at the 67 m (220 ft) level, as shown in figure 7. The winch employed a servo-controlled hydraulic-drive system which automatically moved the cables up and down in response to vertical motions of the vehicle generated by pilot input. To control the servodrive unit, load cells in the suspension system provided signals proportional to the tension in the cables.

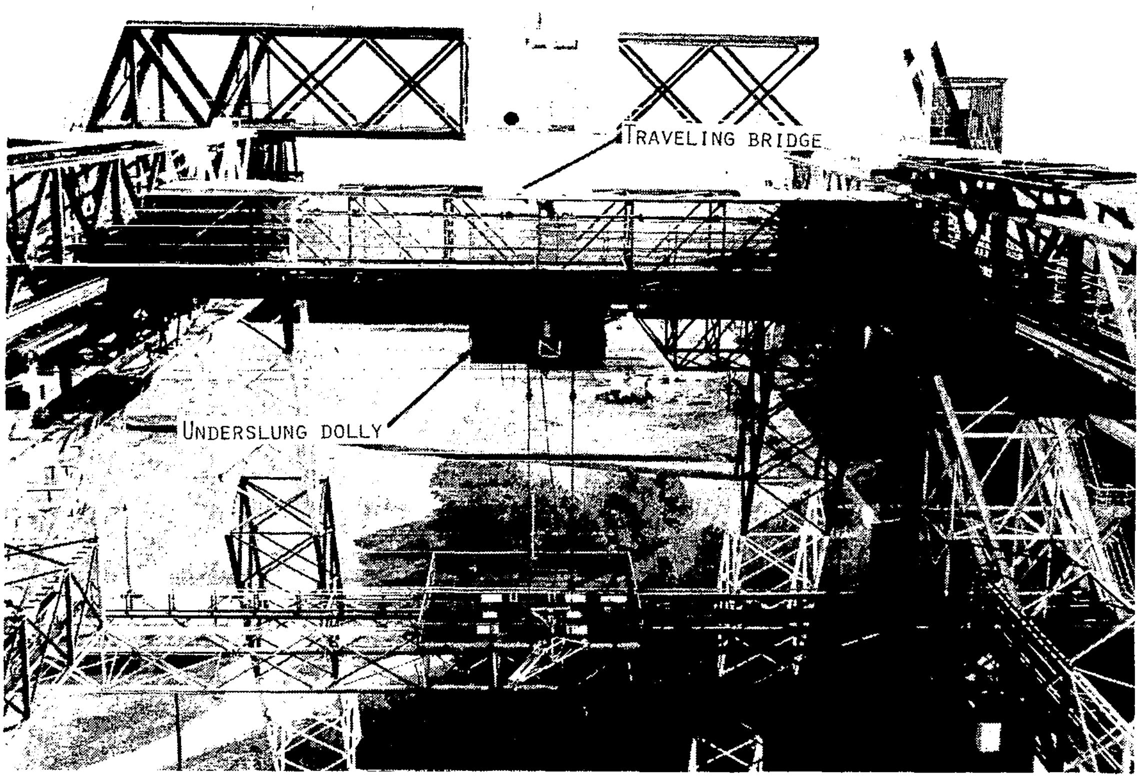

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Figure 7.- LLRF traveling bridge and underslung dolly.

In order for the research vehicle to have freedom to translate fore and aft as well as laterally without cable interference, the support cables were maintained in vertical alignment with the vehicle at all times. To accomplish this, the traveling bridge and underslung dolly housing the winch followed the vehicle automatically and stayed directly over it. The fore, aft, and lateral motions of the traveling bridge and underslung dolly were controlled by dolly-mounted cable-angle sensors that detected angular deviations of the cable from vertical and separated these deviations into components in the fore, aft, and lateral directions.

Additional information on the LLRF can be found in reference 1.

Langley Impact Dynamics Research Facility (IDRF)

After completion of the Apollo Program, the LLRF was converted into a facility to conduct research on aircraft crash safety. The facility name was changed to impact dynamics research facility which reflects this redirection of effort. Conversion of the facility from the LLRF to the IDRF consisted of the following:

1. The system that controlled the traveling bridge and underslung dolly was removed.

2. A fixed winch platform was installed under the center of the bridge.

3. Three additional winches and controls were installed to pull back the aircraft and control it during the flight portion of the crash test.

4. Additional winches were installed on the center and west legs of the gantry to handle umbilical cables for data transmission.

5. The concrete pad area was enlarged.

6. The control room was equipped with new data recorders and a pyrotechnic control system.

7. A collision protection fence was installed in front of the control building.

8. Woods at the west end of gantry were cleared to provide approximately a 107 m (350 ft) run for the aircraft after crash impact.

Development of the Tethered Test Facility

The IDRF as developed for the tethered hover testing of the XFV-12A, shown in figure 8, provides a facility which allows both static and dynamic tethered

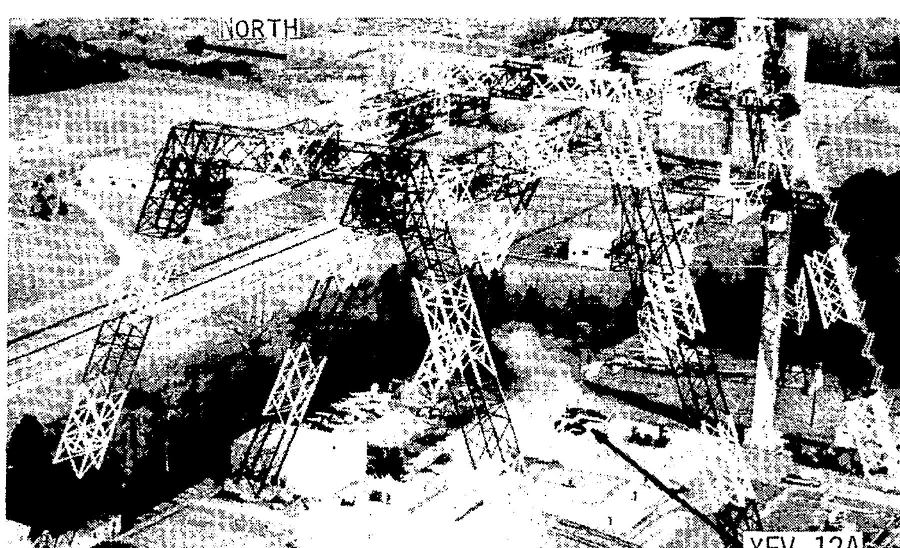

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Figure 8.- Aerial view of IDRF configured for tethered hover testing of XFV-12A.

hover tests to be undertaken with utmost safety. This development consisted of the following:

1. The "Z" system which is used as the overhead suspension system for the aircraft was installed.

2. The fixed winch platform under the center of the bridge, installed for the aircraft crash safety program, was removed.

3. An enlarged winch platform was installed under the center of the bridge to house the "Z" system winch and IDRF pullback winch.

4. An umbilical cable was installed for data transmission.

5. A mechanical restraint system was installed to limit lateral and longitudinal translations of the aircraft.

6. The test pad area was enlarged.

7. Static tiedown anchors were installed to secure the aircraft in the desired position for static tests.

8. Pilot visual cues were installed.

9. A hangar to house the aircraft was built and office trailers for test personnel were added.

10. The control room was modified.

11. The communication system was modified.

12. Video cameras and recorders were installed to monitor testing.

<u>"Z" system</u>.- The tether or "Z" system includes all components from the winch to the structural attach unit on the aircraft, namely, the winch, "Z" cable, shock absorber, position sensor, slack sensor, load cell, and structural attach unit. The "Z" system is illustrated in figure 9 and a more detailed view of the lower portion is shown in figure 10. The initial dynamic test operating restrictions are given in table II.

Winch: A modified Navy highline shipboard underway replenish winch (fig. 11) was installed in a new winch platform under the gantry bridge approximately 61 m (200 ft) above the ground. (See fig. 12.)

There are two modes of winch operation, manual and automatic, which are selected by the Console Operator. In the manual mode, the winch serves as a hoist to raise or lower the aircraft. It receives command signals from the winch manual control handle located on the control console in the control room. In the automatic mode, the winch operates through a feedback system to track the aircraft vertical motion using signals from the potentiometer in the position sensor.

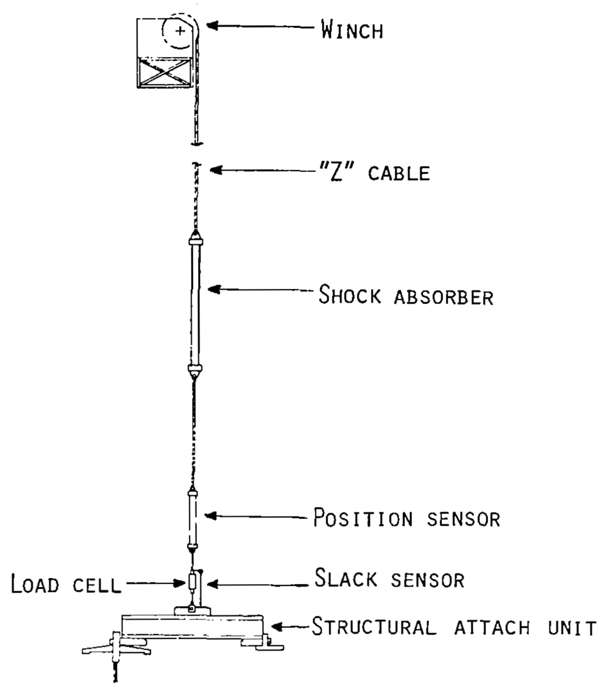

Figure 9.- "Z" system components.

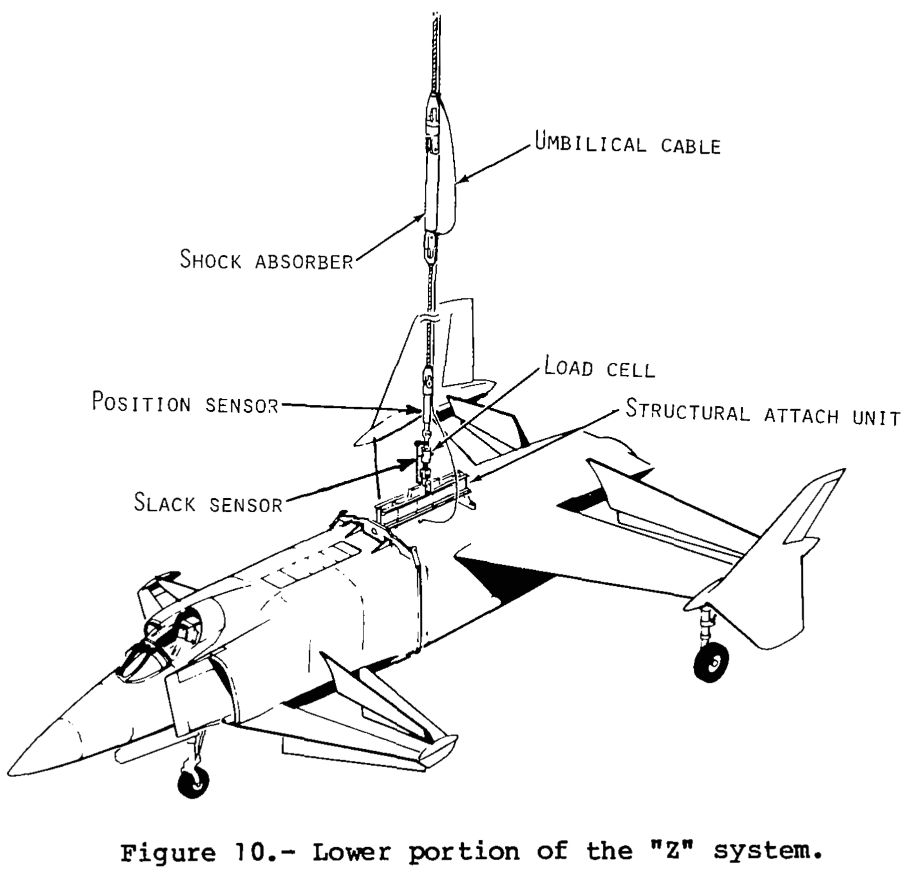

Figure 10.- Lower portion of the "Z" system.

TABLE II.- INITIAL DYNAMIC TEST OPERATING RESTRICTIONS

Horizontal displacement, m (ft)	±7.6 (±25)
Height, m (ft)	0 to 15.2 (0 to 50)
Horizontal velocity, m/s (ft/s)	±0.9 (±3)
Vertical velocity, m/s (ft/s)	±0.9 (±3)
Horizontal acceleration, m/s^2 (ft/s^2)	±0.9 (±3)
Vertical acceleration, m/s^2 (ft/s^2)	±0.6 (±2)
Pitch and roll, deg	±5
Heading, deg	0 to 360

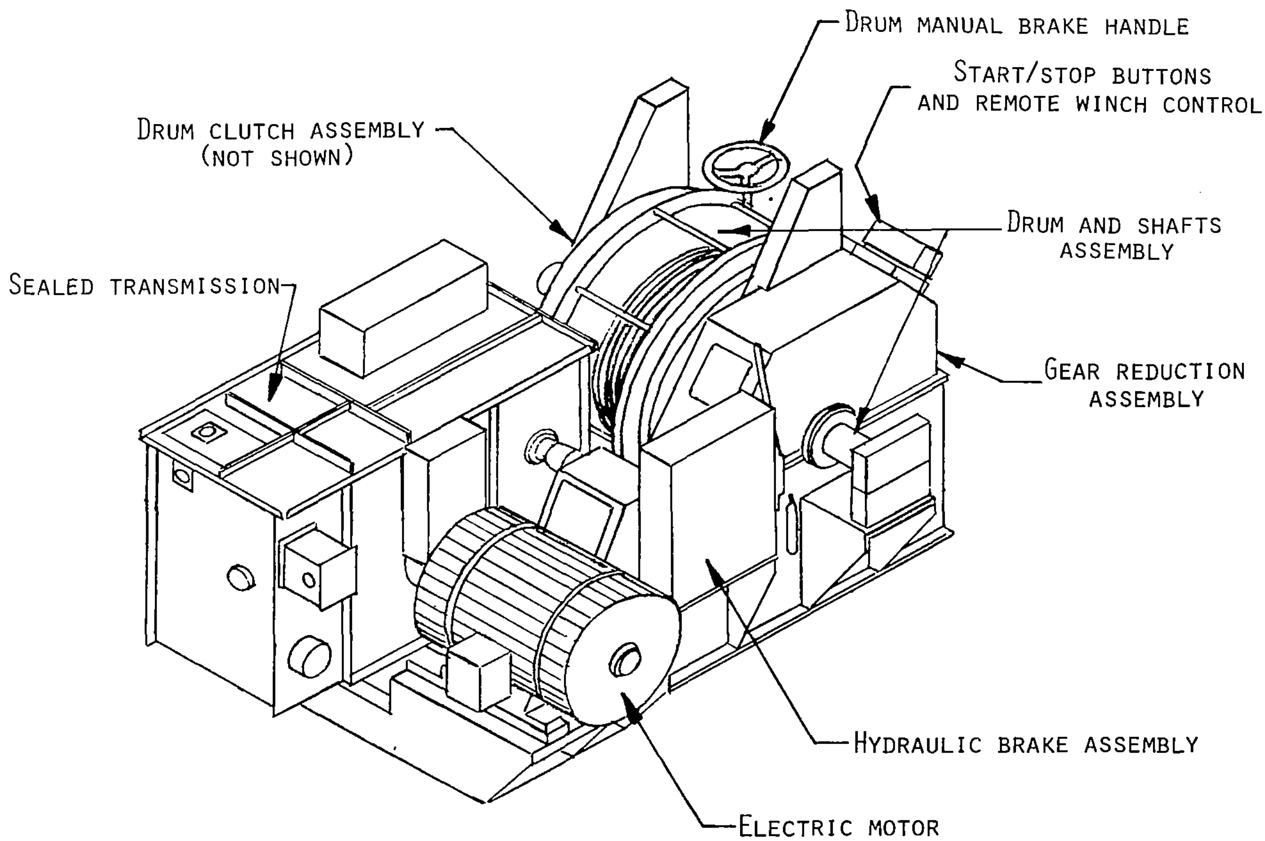

Figure 11.- Highline winch assembly.

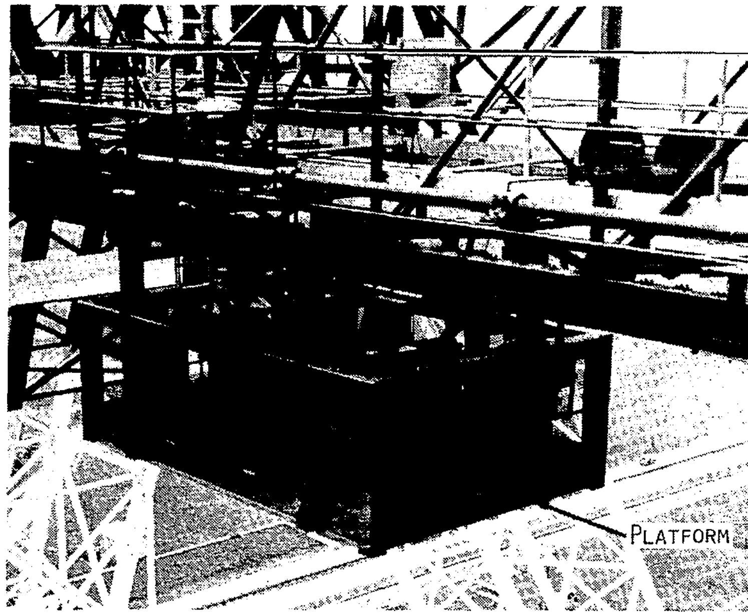

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Figure 12.- New winch platform installed under gantry bridge.

The single drum of the winch is driven by a variable-speed, bidirectional hydraulic motor through a gear reduction assembly. Hydraulic flow for powering the motor is provided by a variable-displacement pump mounted with the hydraulic motor inside a sealed transmission. The pump is driven by a 111.9 kW (150 hp) electric motor. A servovalve in the sealed transmission controls hydraulic pump flow to the hydraulic motor. The servovalve is controlled by signals from the winch electronic controls. The winch system in block diagram is shown in figure 13. The winch system includes a shoe-type brake that acts on the input shaft of the gear reduction assembly. The brake is set by a mechanical spring and is held in the released position by hydraulic pressure when the winch is operating. The brake is controlled by the brake and bypass solenoid.

"Z" cable: The "Z" cable is made up of three lengths of wire rope as shown in figure 14. Wound on the winch drum is 175 m (575 ft) of 2.5 cm (1 in.) diameter, IWRC, extra improved plow steel wire rope made of six 37-wire strands. The breaking strength of this rope is 459.9 kN (103 400 lb). The end fitting is a MacWhyte[1] SA-163-32 open socket to which is attached a 133.4 kN (15 ton) Timken[1] bearing swivel no. 15-S-4. Attached to this swivel is 29 m (95 ft) of 2.9 cm (1 1/8 in.) diameter 18-strand (7 wires to the strand) nonrotating wire rope constructed from extra improved plow steel with a breaking strength of 472.4 kN (106 200 lb). Both ends have a MacWhyte SA-163-36 open socket fitting. A 133.4 kN (15 ton) Timken bearing swivel no. 15-S-2 is between the lower

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[1]Names of manufacturers are identified in this paper to adequately describe the apparatus. Identification of these manufacturers does not constitute official endorsement, either expressed or implied, by NASA.

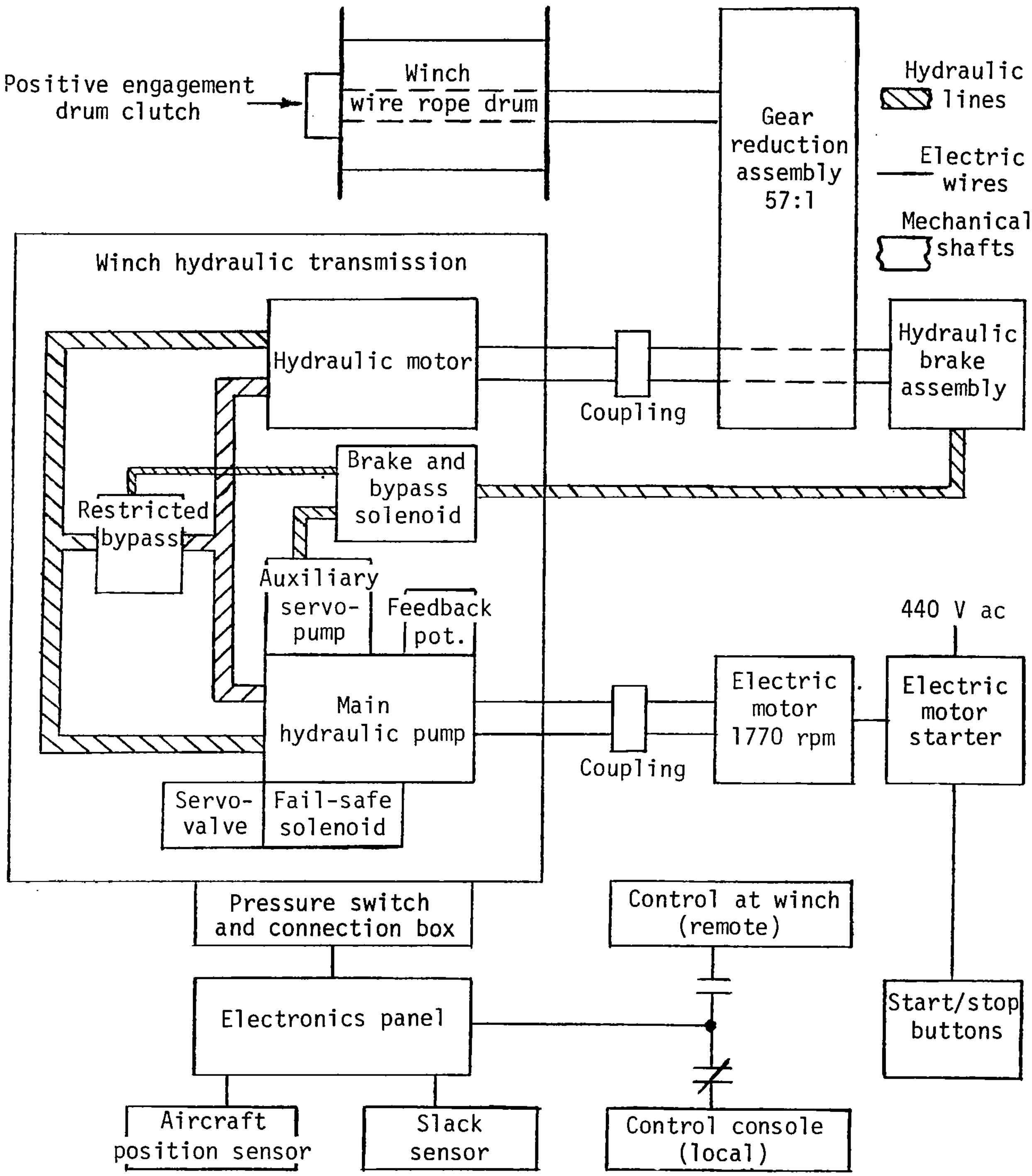


Figure 13.- Block diagram of winch system.

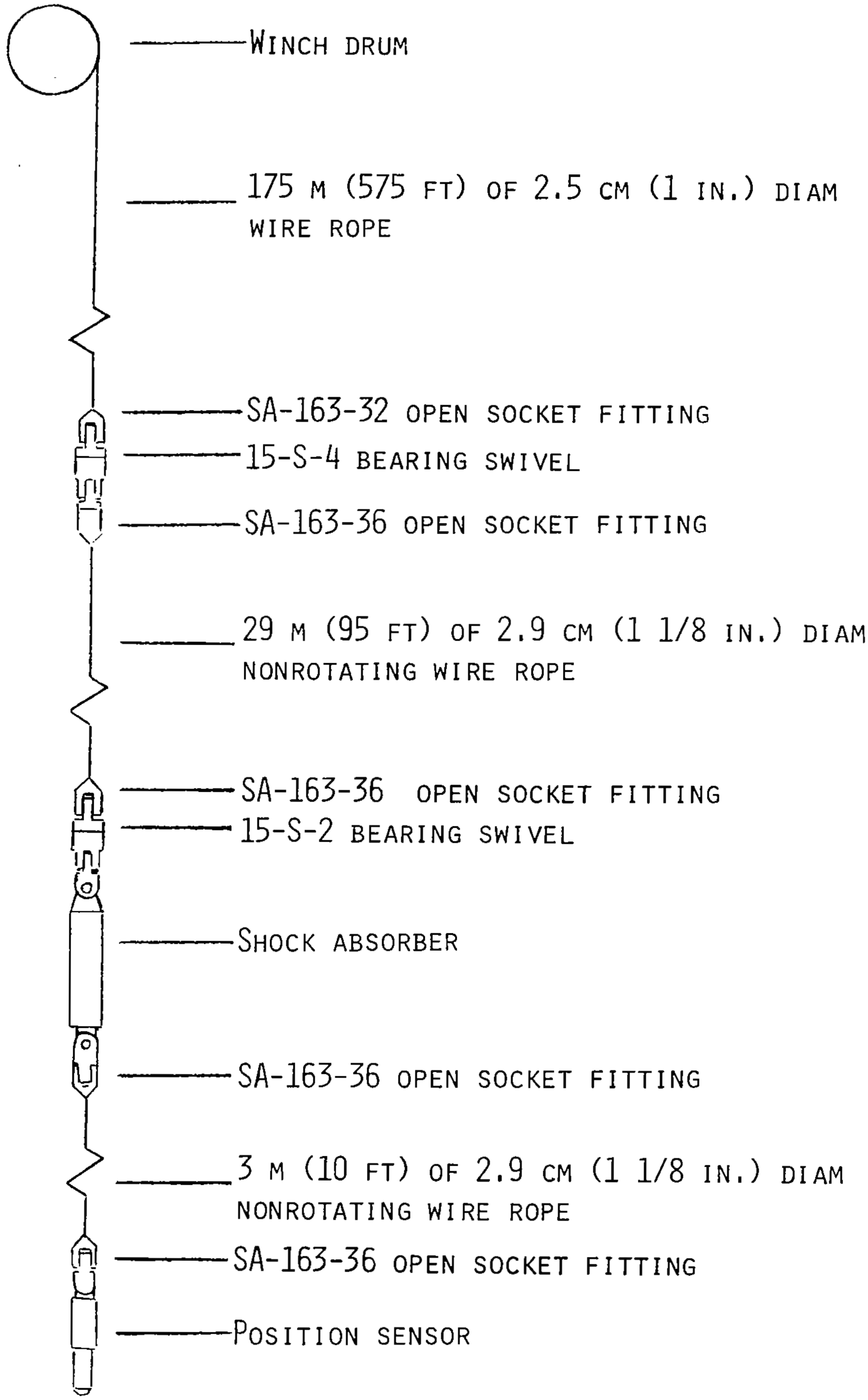


Figure 14.- Schematic of "Z" cable.

fitting and the shock absorber. Between the shock absorber and the position sensor is 3 m (10 ft) of the same 2.9 cm (1 1/8 in.) diameter nonrotating wire rope with a MacWhyte SA-163-36 open socket fitting on both ends.

Shock absorber: The pneumatic-hydraulic shock absorber shown in schematic form in figure 15 was included in the "Z" system to limit shock loads to the

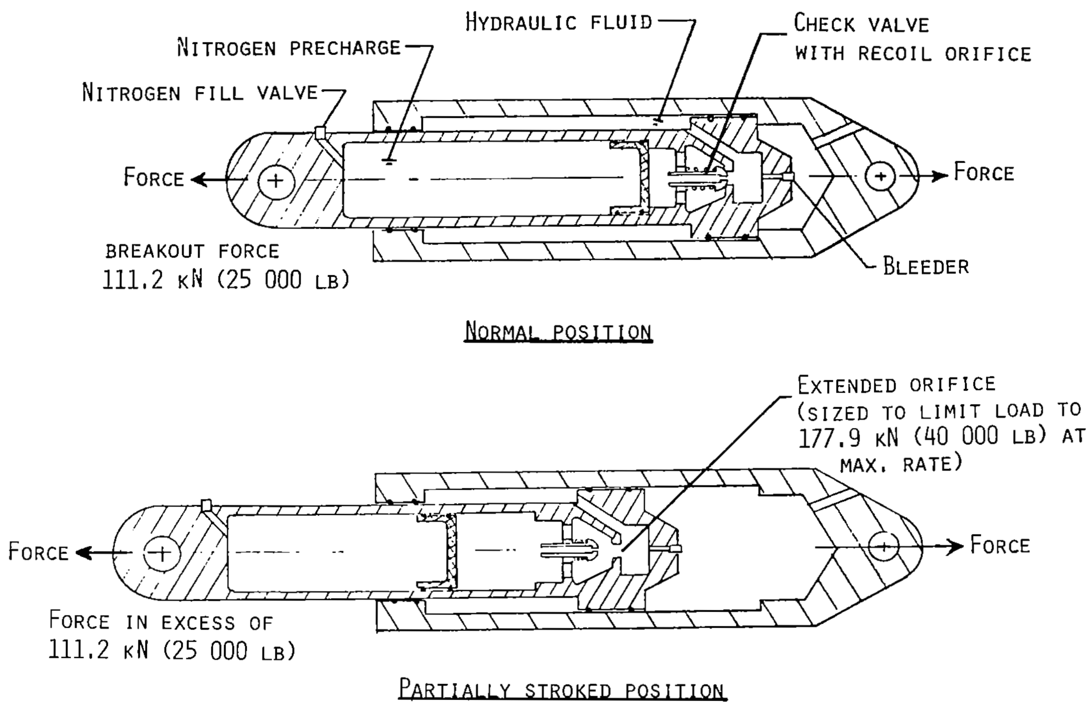


Figure 15.- Schematic of shock absorber.

aircraft to less than 177.9 kN (40 000 lb). The outer cylinder is filled with hydraulic fluid, while the inner cylinder is pressurized with nitrogen to a nominal 22.8 MN/m^2 (3300 psi). The nitrogen precharge resists loads up to 111.2 kN (25 000 lb). Stroking the shock absorber forces the hydraulic fluid through the extended orifice which compresses the nitrogen and results in a load of 164.6 kN (37 000 lb) at maximum stroke of 150 cm (60 in.). Under abrupt load applications, the load rises towards 177.9 kN (40 000 lb) earlier in the stroke. Design characteristics of this shock absorber are given in figure 16 for several typical loading conditions. When the load is removed, the recoil orifice controls the rate of return to the unloaded condition.

Curve	Initial slack, m (ft)	Velocity, m/s (ft/s)	Aircraft lift, kN (lb)	Weight on cable, kN (lb)
A	2.1 (7)	5.6 (18.4)	22.2 (5 000)	66.8 (15 000)
B	1.2 (4)	4.2 (13.9)	22.2 (5 000)	66.8 (15 000)
C	1.2 (4)	3.2 (10.4)	51.6 (11 600)	37.4 (8 400)

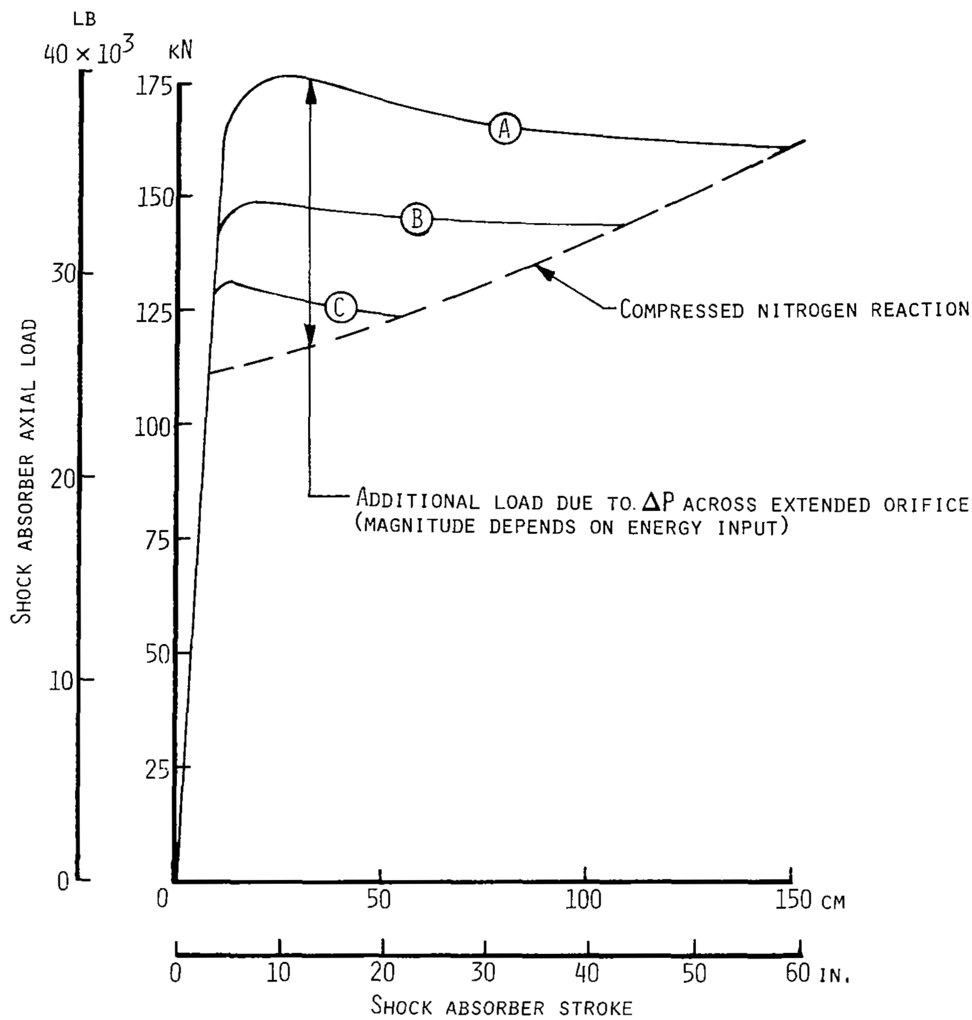


Figure 16.- Shock absorber design characteristics. Aircraft weight, 89 kN (20 000 lb); effective orifice area, 1.47 cm^2 (0.228 in^2); nitrogen precharge, 22.8 MN/m^2 (3300 psi).

Position sensor: The position sensor is an electromechanical device, shown schematically in figure 17, which provides the feedback signal that enables the

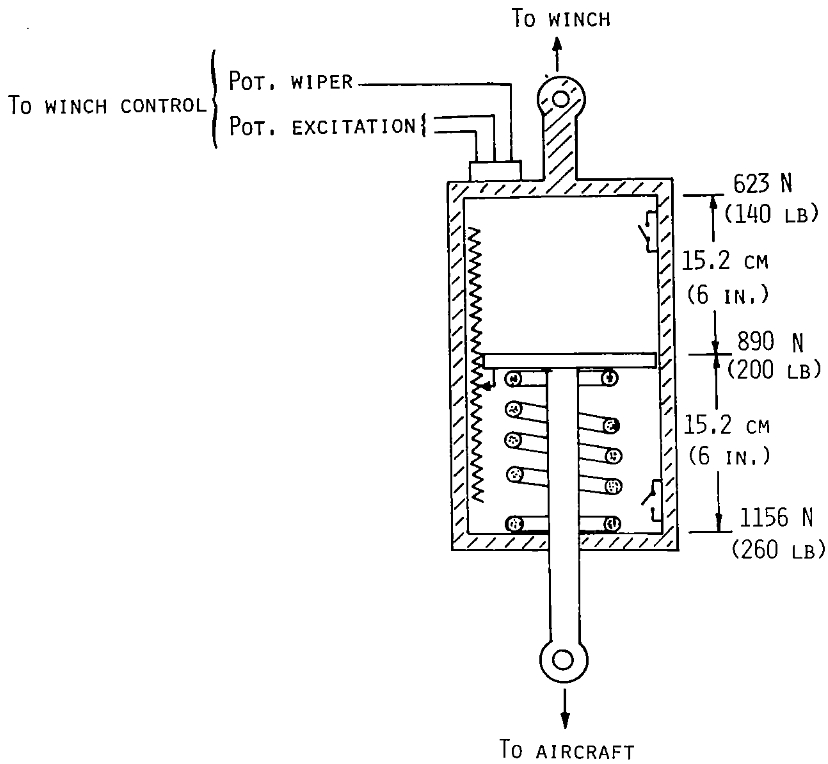


Figure 17.- Schematic of position sensor.

"Z" system to automatically track vertical aircraft motion during dynamic tethered tests. The feedback signal is furnished by the wiper of a linear potentiometer (pot.) that is mechanically linked to the position sensor piston. When the piston is centered within its range of travel, the potentiometer has zero output. As the aircraft ascends or descends, the piston translates from the center or neutral position and the resulting potentiometer output commands the winch to reel in or pay out cable to recenter the piston. At the neutral position the unit is maintaining approximately 890 N (200 lb) of tension in the "Z" cable. This level of tension was chosen to minimize the "Z" system effects on aircraft dynamic hover characteristics. When the aircraft vertical velocity exceeds the winch maximum vertical rate of approximately ±1.5 m/s (±5 ft/s), the piston activates either the "up" or "down" warning switch. These switches activate warning lights for the Pilot in the cockpit which indicate that the aircraft vertical velocity is exceeding the winch capability. If the aircraft is ascending faster than the winch capability, the up switch also activates an aural warning on the test intercommunications (ICOM) network.

Slack sensor: A slack sensing device is included in the "Z" system during dynamic operations with lift-to-weight ratios greater than 1 to detect any slack in the linkages between the load cell and the structural attach unit. The sensor for the "Z" system is a 10-turn, 10 000-ohm-resistance linear-displacement transducer with a 216.9 cm (85 3/8 in.) extension. It converts mechanical motion into an electrical output. The output from this sensor triggers an additional aural warning on the test ICOM network and drives an indicator on the control console.

Load cell: A dual-bridge load cell serves as a continuous monitor of the load in the "Z" system. The output of one bridge is transmitted via the aircraft telemetry system and recorded on the data tape; the other bridge is hardwired to the control console for monitoring by the Test Director and Console Operator.

Structural attach unit: The structural attach unit for the XFV-12A, shown in figure 18, provides the interface between the "Z" system and the aircraft load-pickup points. In addition it provides freedom for the aircraft to roll and pitch.

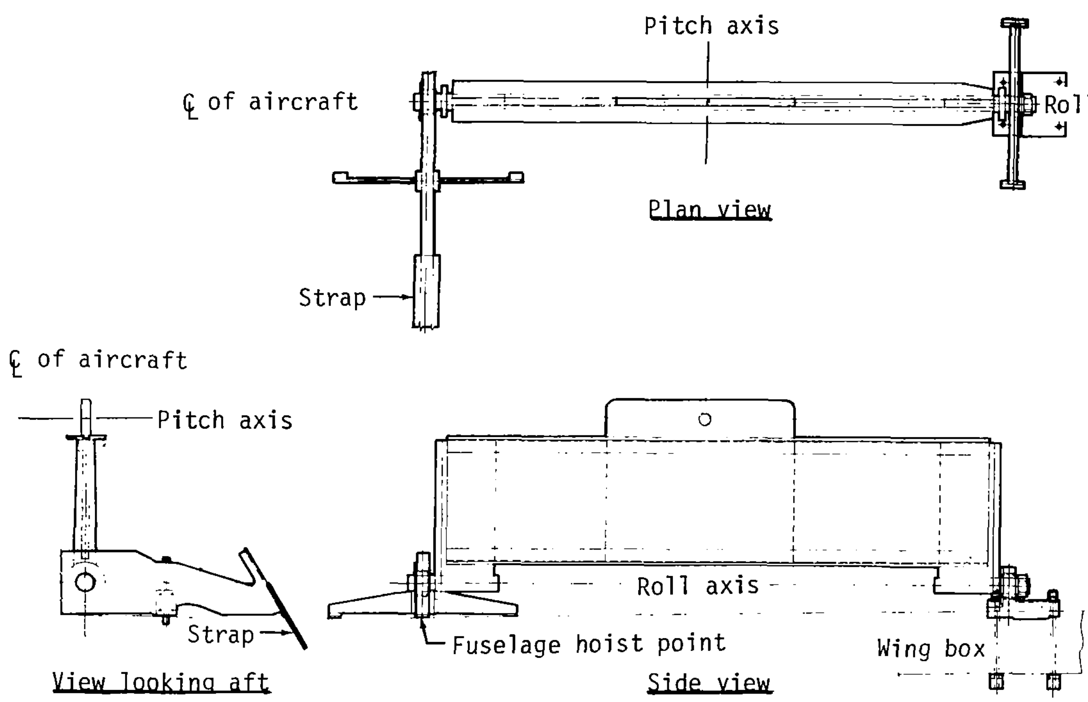
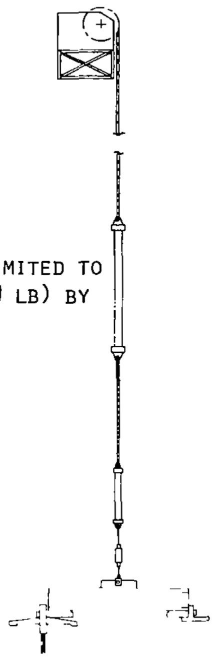


Figure 18.- Structural attach unit.

Qualification of the "Z" system: To qualify for operation, all components of the "Z" system were designed to a minimum yield strength and static proof-loaded to a minimum of 177.9 kN (40 000 lb). Figure 19 itemizes the design



RECOVERY LOAD LIMITED TO 177.9 kN (40 000 LB) BY SHOCK ABSORBER

	DESIGN MINIMUM YIELD STRENGTH, kN (LB)	STATIC PROOF LOADING, kN (LB)
WINCH	371.7 (83 571)	177.9 (40 000)
GANTRY		224.4 (50 000)
"Z" CABLE	459.9 (103 400)	224.4 (50 000)
SHOCK ABSORBER	400.3 (90 000)	266.9 (60 000)
FITTINGS	≥400.3 (≥90 000)	266.9 (60 000)
POSITION SENSOR	400.3 (90 000)	266.9 (60 000)
LOAD CELL	444.8 (100 000)	
STRUCTURAL ATTACH UNIT	533.8 (120 000)	195.7 (44 000) (ON AIRCRAFT)

Figure 19.- "Z" system design yield strengths and static proof loadings.

minimum yield strengths and proof loadings of the components. In addition, dynamic proof loadings were conducted and are discussed in the section "Dynamic Analysis and Hardware Proof Testing."

Modifications to IDRF.- In order to utilize the IDRF as a tethered hover facility, the basic facility required other modifications in addition to incorporating the "Z" system. These modifications are discussed in the following paragraphs.

Winch platform: The winch platform added to the bridge structure when the IDRF was established was removed and replaced with an enlarged platform to house both the "Z" system winch and the IDRF pullback winch for the aircraft crash safety program. To prevent objects from falling through the floor grating, a plexiglass floor covering with antiskid pads was installed over the grating.

Umbilical cable: The umbilical cable electrically connects the aircraft, load cell, position sensor, slack sensor, and winch to the control room (see fig. 10). It is composed of four separate electrical cables which are mechanically fastened to a 0.64 cm (1/4 in.) diameter steel carrier wire rope. Two of the four electrical cables are 12-pair conductors, one is a 6-pair conductor, and one is a 1-pair conductor, as required by the XFV-12A test program. The carrier wire rope is attached to the gantry through an umbilical winch on the bridge to allow the umbilical length to be preset consistent with the test being performed.

Restraint system: The restraint system is a mechanical cable and ring arrangement suspended from the gantry around the "Z" cable, as shown in figure 20. This system limits the lateral and longitudinal translations of

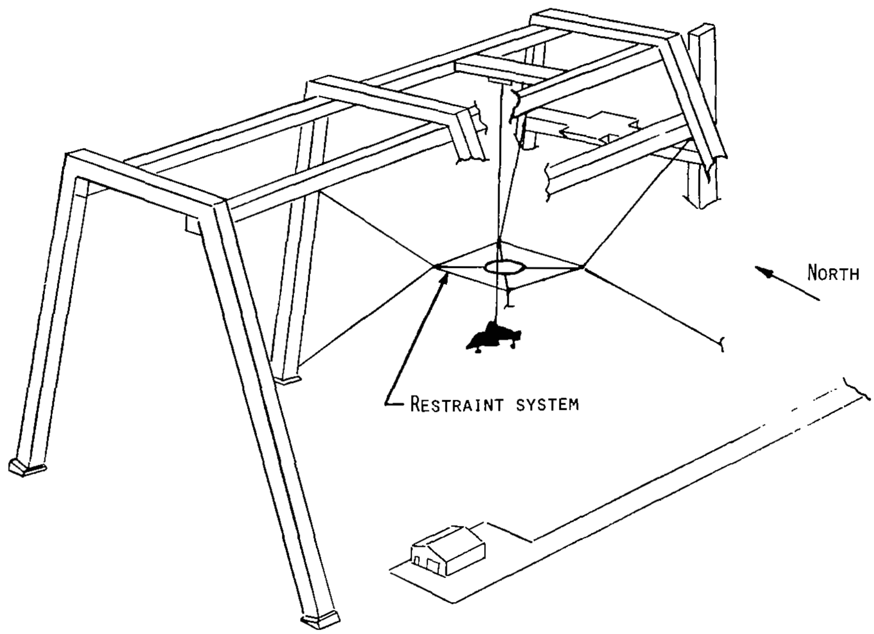


Figure 20.- Restraint system.

the "Z" cable and hence the translations of the aircraft. Two limits were provided in the system by inclusion of a small ring within the larger cable

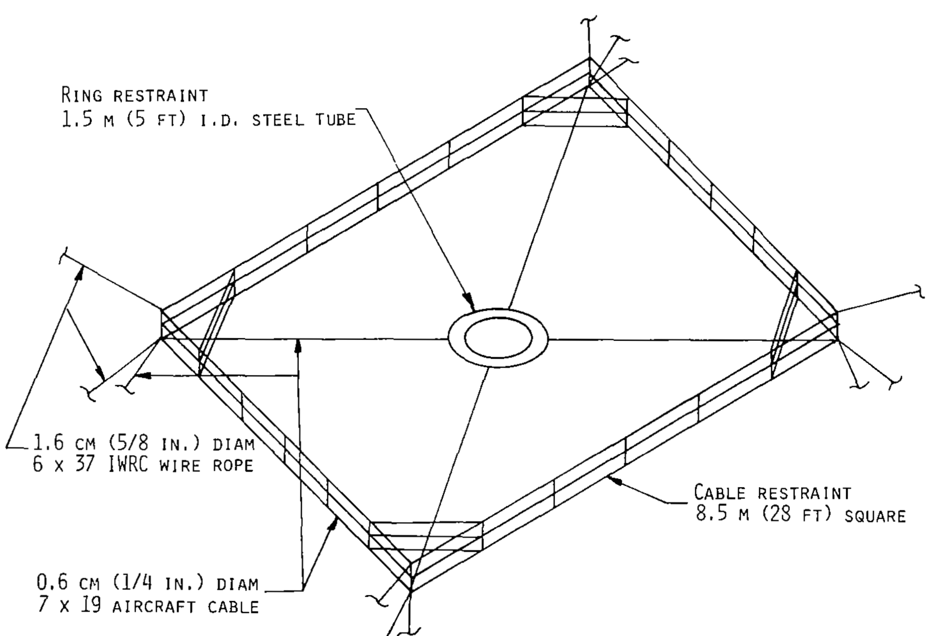


Figure 21.- Details of restraint system.

restraint as shown in figure 21. The elasticity of the wire rope suspension holding the restraint in the gantry reduces the harshness of the impact of "Z" system against the restraint during overtravel. The 30.5 m (100 ft) height of

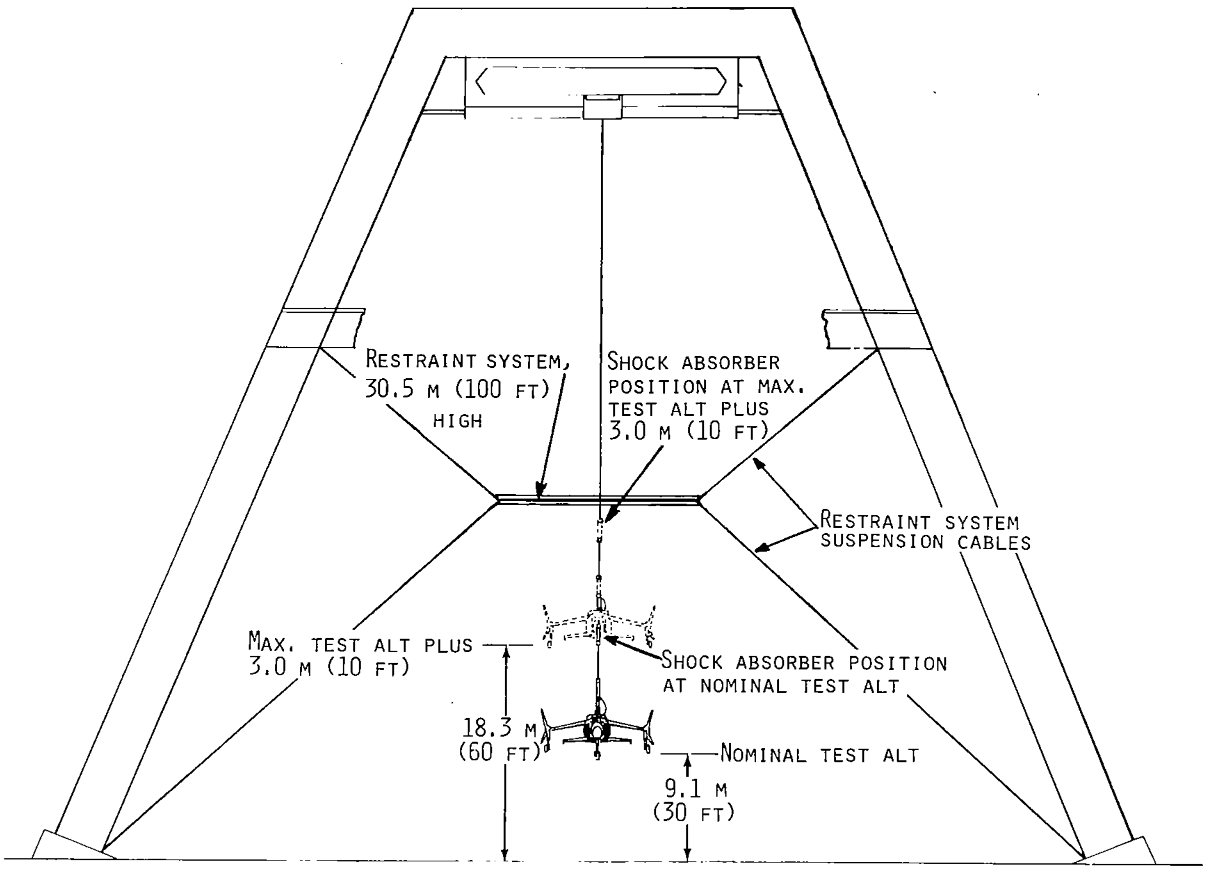


Figure 22.- Vertical profile of restraint system.

the restraint, as shown in figure 22, was chosen so that the aircraft could operate at a maximum altitude of 15.2 m (50 ft) without the shock absorber coming in contact with the restraint with a 20-percent altitude overshoot.

Test pad improvements: The concrete test pad area of the IDRF was increased nearly 1000 m^2 (10 760 ft^2), as shown in figure 23, to prevent foreign object damage (FOD) to the aircraft engine during tests. In addition to the increased concrete pad, an extensive area under the gantry was covered with aircraft landing matting to provide easier access to the test area.

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Figure 23.- Improvements to test pad.

Static tiedowns: To secure the aircraft in the desired position for the static tests, 16 ground tiedown anchors were placed in the concrete test pad. These anchors were standard aircraft mooring eyes capable of retaining a 44.8 kN (10 000 lb) pullout force. For the XFV-12A testing, the anchors are arranged in the pad as shown in figure 24.

Pilot cues: Various visual aids, as shown in figure 25, were added to the gantry to provide the Pilot with orientation cues during dynamic testing. Along the centerline of the gantry, four sets of 0.9 m (3 ft) diameter balls were hung in groups of four with a yellow ball at 3.8 m (12.5 ft) and 11.4 m (37.5 ft) and a red ball at 7.6 m (25 ft) and 15.2 m (50 ft). To the north side of the test pad, two 1.2 m by 1.2 m (4 ft by 4 ft) black and white targets were hung at 7.6 m (25 ft) and 15.2 m (50 ft).

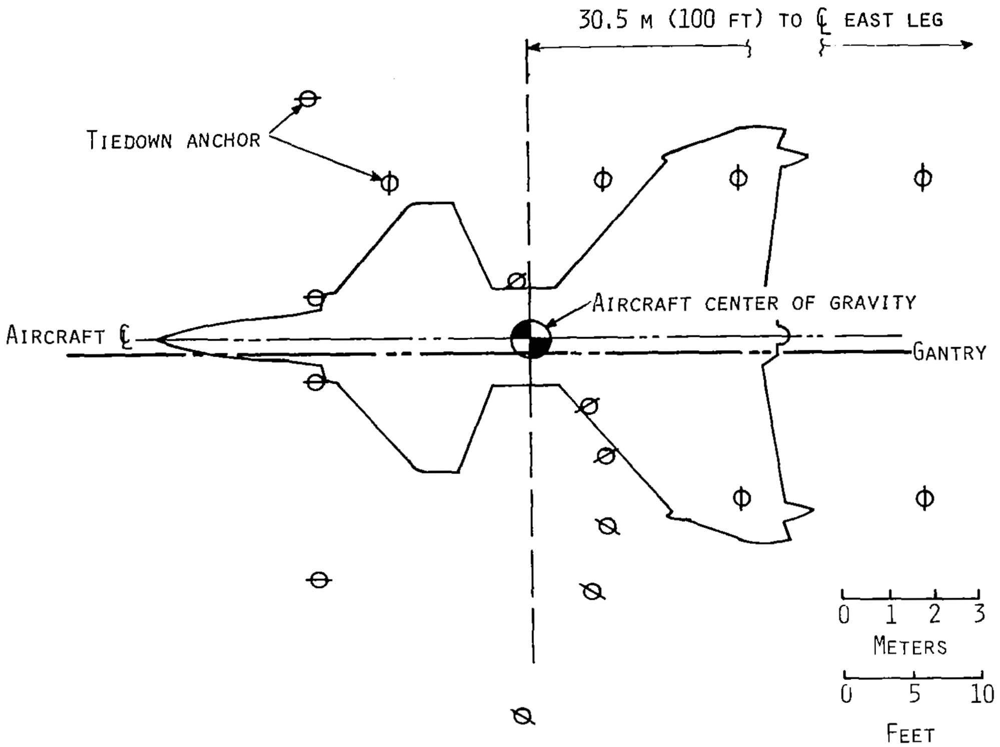

Figure 24.- Arrangement of static tiedown anchors.

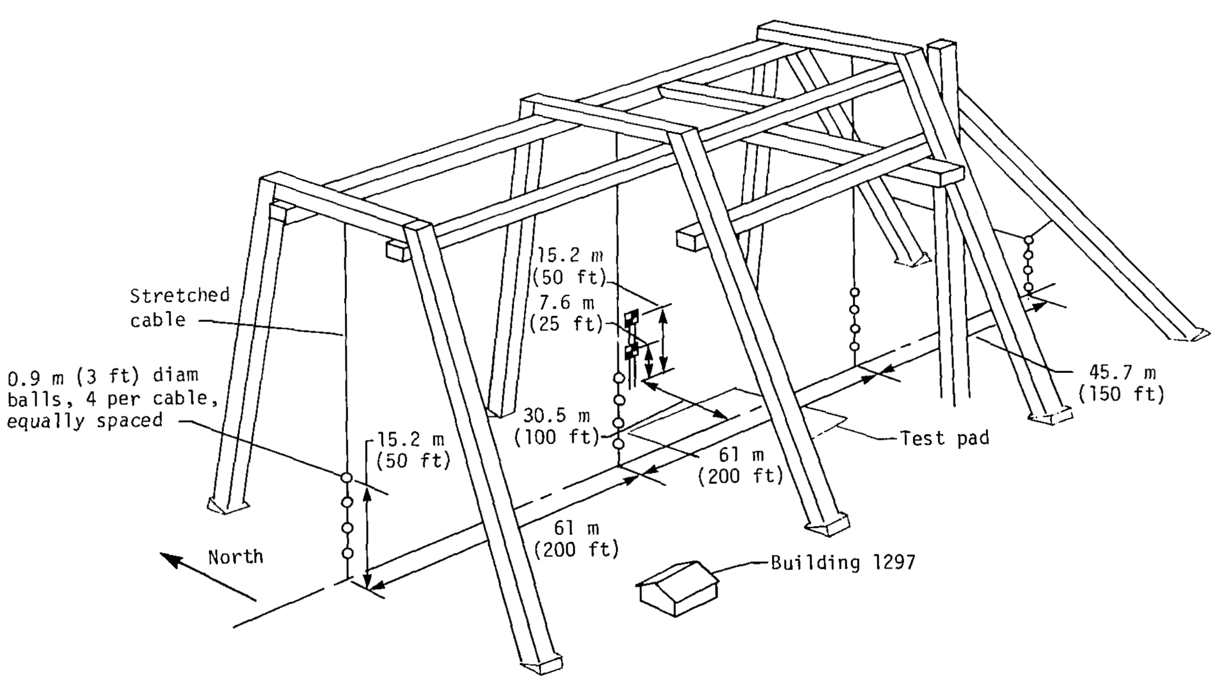

Figure 25.- Arrangement of pilot cues.

Aircraft hangar and personnel trailers: A 12.2 m by 18.3 m (40 ft by 60 ft) hangar with a main door opening of 9.8 m by 3.7 m (32 ft by 12 ft) was constructed on the east side of the north center leg to house the aircraft. The hangar is equipped with 110 V ac electrical power and a carbon dioxide fire extinguishing system. In addition, the hangar is plumbed for compressed air and wired for 440 V ac, both of which were supplied by portable equipment. Heating in the winter months was also provided by portable equipment.

Three office trailers were provided to house the engineering, instrumentation, and maintenance personnel during the testing.

Control room and control console: The control room is located on the second floor of Building 1297, shown in figure 25. It is equipped with an ICOM system to all parts of the facility, a public address system, walkie-talkie sets, and the control console for the tether tests. A layout of the control room is shown in figure 26. During test operations, the control room is

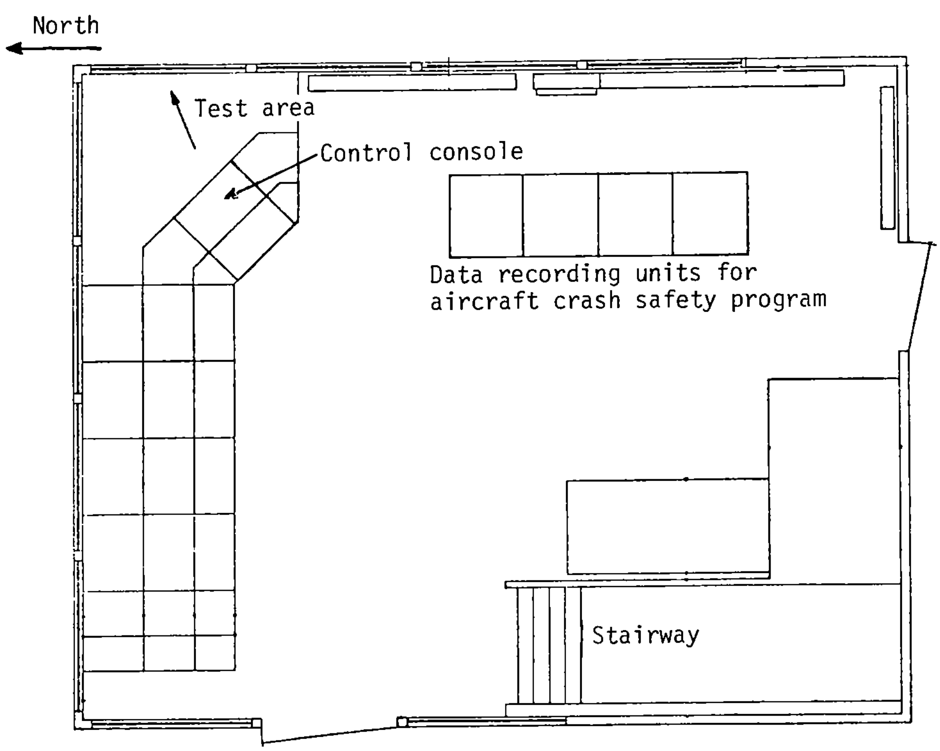

Figure 26.- Layout of control room.

manned by the Test Director, Console Operator, Test Coordinator, NASA Safety Observer, and NASA Facility Coordinator, as shown in figure 27. Other personnel are kept to a minimum during tests to prevent distraction of the control room personnel.

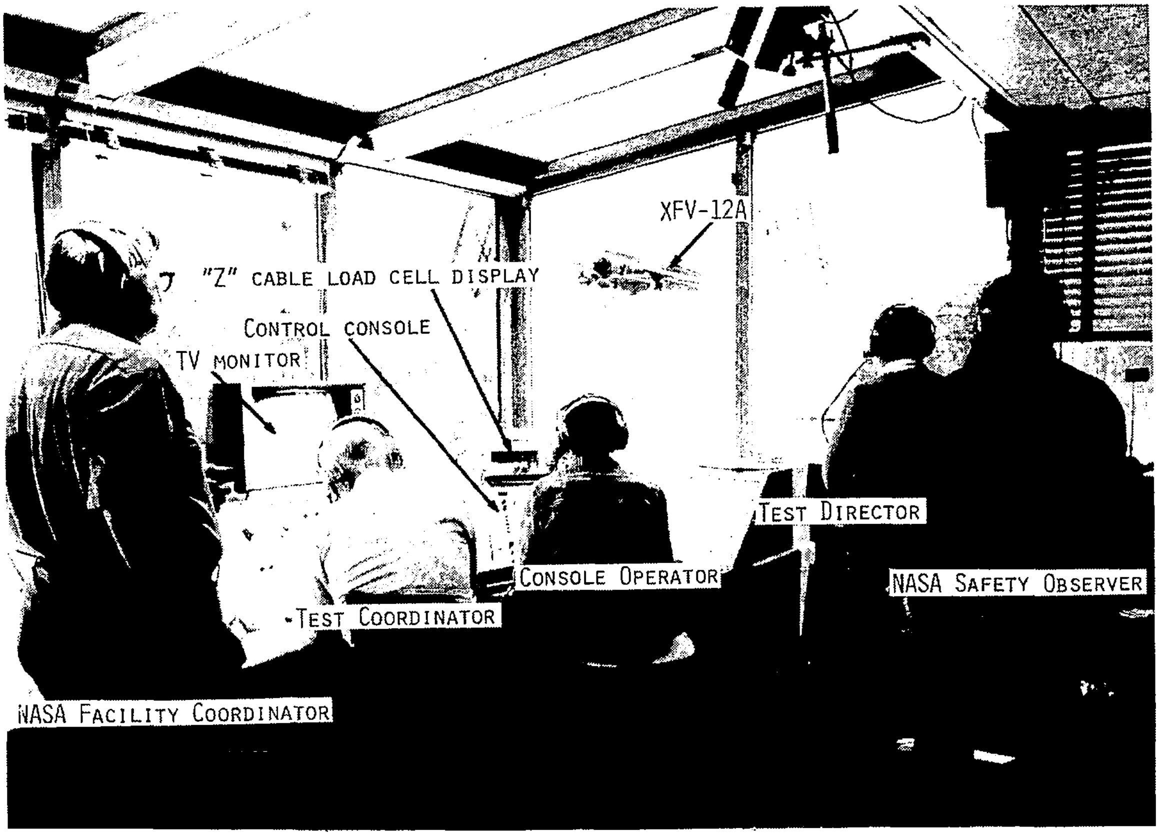

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Figure 27.- View from control room.

The control console shown in figure 28 is equipped to enable both normal and emergency control of the tethered tests. The equipment includes controls and indication for

1. Winch operation

2. Aircraft emergency fuel shutoff

3. Aircraft fire warning

4. Voice communication

When the START push button switch is depressed on the console, 440 V ac is supplied to the winch electric motor and 115 V ac is supplied to the winch electronics panel. The SYSTEM ON light illuminates. The WINCH AUTO/MAN switch gives control of the winch to the Console Operator in MAN and to the "Z" system position sensor in AUTO. The WINCH MANUAL CONTROL allows the console operator to use the winch as a conventional hoist system by moving the handle in the UP or DOWN direction. The winch BRAKE switch has three positions:

RELEASE . . . . . Brake off at all times

SET . . . . Brake on at all times

AUTO REL . . . . Brake on automatically when WINCH MANUAL CONTROL is near neutral and off automatically when UP or DOWN commands are given

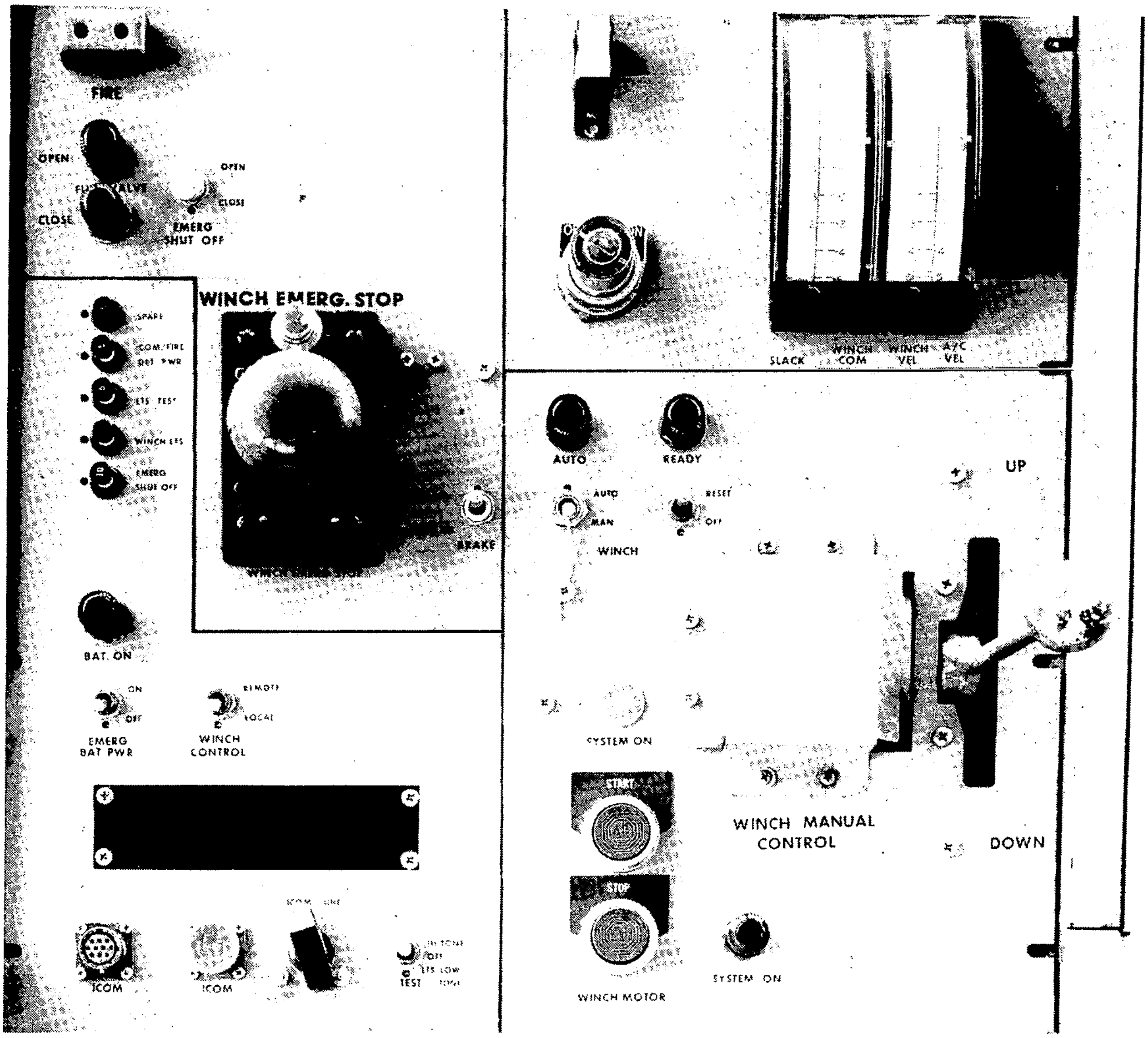

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Figure 28.- Control console.

Pressing the WINCH EMERG STOP switch removes power to the winch and sets the brake. Indicators of winch and aircraft vertical velocity, winch command input, and "Z" system slack are located in the upper right corner. The readout from the "Z" system load cell is located above the control console.

Communications: The primary means of communication for controlling test operations is the hard-wired ICOM system. The ICOM system consists of two networks, the test network and the facility network. The test network ties together the aircraft, control room, data observers, and ground observers. The facility network ties together the NASA facility personnel with the control room.

The personnel on the test network are the Test Director, Pilot, Console Operator, Test Coordinator, Ground Observers, and Data Observers. The NASA Safety Observer and Facility Coordinator have split headsets so that they can monitor both networks and can select either one to talk over. NASA facility personnel can use only the facility network.

In case of commercial electrical power failure, the ICOM system amplifiers have a battery backup power supply. If the ICOM system amplifiers fail, the Test Director, Console Operator, and Pilot have a battery-powered UHF radio for backup.

Video system: Four video cameras and video recorders were utilized during testing to monitor and record the spooling of the wire rope on the winch, operation of the control console, and movements of the aircraft from the bridge overhead and from the control room building roof. The overhead view with local time superimposed was displayed in the control room so that the Test Director could monitor the position of the aircraft in the test area during dynamic testing and the Test Coordinator could note the start and stop time for each test point. These cameras proved to be useful for postflight review.

QUALIFICATION OF THE FACILITY FOR MANNED TESTING

Modification of the facility as described in the previous sections and operation of the modified facility had to be approved in accordance with Langley Management Instruction (LMI) 7000.2 entitled "Reviews of Major Construction or Facility Modification Projects." In addition, since the XFV-12A is a manned aircraft, the modified facility had to be man-rated in accordance with LMI 1710.1 entitled "Human Factors Research, Man-Rating Requirements, and Committee Review Procedures."

In order to comply with these management instructions, the following reviews were held: Critical Design Review (CDR), Man-Rating Committee (MRC) Review, Integrated Systems Review (ISR), and Operational Readiness Review (ORR).

Critical Design Review

The CDR is a review of the project by an independent NASA committee with primary emphasis on modifications being made to the test facility. If this committee identifies problem areas that have been overlooked in the design or need additional work, it charges the project management to present a solution to the problem to the chairman of the CDR.

Man-Rating Committee

The MRC is appointed by the chairman of the Langley Research Center Executive Safety Board. The MRC is responsible for reviewing the entire program to determine whether the program meets the safety requirements for manned operation or not. They then recommend to the chairman of the Executive Safety Board that the program be approved, or disapproved, for manned operation.

The MRC requires in-depth documentation of the safety aspects of the program. This documentation for the XFV-12A tethered hover test program included a Safety Analysis Report, Sneak Circuit Analysis, Failure Mode and Effects Analysis, Dynamic Analysis of the Aircraft/"Z" System, and Operational Test Procedures.

Safety Analysis Report (SAR).- The SAR identifies and classifies potential system and operational hazards or undesired events. This enables corrective actions to be taken so as not to expose personnel or equipment to unacceptable risks. The classifications include an evaluation of the consequence of the undesired event if it happens (hazard category) and an evaluation of the risk with the selected hazard control implemented (risk classification). The hazard categories and risk classifications are

I. Possible serious or fatal injury to public or test subject

II. Possible serious or fatal injury to test facility personnel

III. Possible damage to major equipment

IV. Terminated or delayed operation

V. Nuisance failure

VI. Acceptable risk due to adequate controls, procedures, and/or safety factors

Undesired events with hazard categories of I, II, or III must have design or procedure controls to reduce their risk classification to IV, V, or VI. The hazard control priority is as follows:

1. Eliminate the hazard through design.

2. Minimize the probability of the hazard occurring through design safety factors.

3. Provide safety devices to control the hazard.

4. Provide a warning device to alert crew members to the hazard.

5. Develop procedures to minimize the hazard.

An example of typical undesired events is shown in table III.

TABLE III.- TYPICAL UNDESIRED EVENTS LIST

Subsystem: "Z" system, winch

Date: 7-22-77

Item no.	Undesired event	Remarks, recommendation, or conclusion	Hazard category	Risk classification
30	Winch drum clutch disengages	The drum clutch consists of a sliding clutch jaw, a yoke, and a clutch handle. The sliding clutch jaw moves along a feather key in the drive shaft. The jaw contains four teeth that engage notches in the winch drum hub. Once the teeth are engaged, procedures are to pin the mechanically engaged clutch in the engaged position. Inspection of the clutch is part of the winch preflight check. Due to the clutch design and preflight check, it is improbable that it would become disengaged. Recommendations: none	I	VI
31	Winch hydraulic transmission fails	Winch hydraulic transmission failures will normally result in the loss of replenishment pressure in the transmission. In this case, the replenishment pressure switch opens, causing the fail-safe (pump centering) solenoid and the brake and bypass solenoid valves to deenergize, stopping the winch. This failure is not a hazard in the MAN mode of winch operation. It is not a hazard in the AUTO mode provided that the Pilot reduces lift immediately upon recognizing the winch condition, either by aural tone and red position sensor light or by direction from Test Director. If the failure is such that replenishment pressure is not lost or the pressure switch fails to open, the winch would not track in AUTO, a condition that would be observed in sufficient time to recover the aircraft safely. If the winch was supporting the aircraft with this condition, the winch could overspeed. This overspeed condition would have to be detected through visual observation of the aircraft descending faster than commanded by the Console Operator. The winch could then be stopped by (1) returning the WINCH MANUAL CONTROL to neutral with the BRAKE switch in AUTO, or (2) pressing the WINCH EMERG. STOP switch with the brake switch in RELEASE. Recommendations: none	III	VI

Sneak Circuit Analysis.- A sneak circuit analysis for the XFV-12A tethered hover test program was performed on the "Z" system electronic control circuitry to confirm that no sneak circuits existed in the system which could cause undemanded electrical inputs to the "Z" system electronics.

Failure Mode and Effects Analysis (FMEA). The FMEA for the XFV-12A tethered hover test program was performed on the "Z" system winch and control electronics to identify possible failure modes and their effects on the system. This analysis was used to identify undesired events in the winch and its electronics for the SAR. It was useful in identifying possible failures that could have caused severe hazard or time delays.

Dynamic Analysis and Hardware Proof Testing.- A dynamic analysis of the aircraft/"Z" system was performed by using a man-in-the-loop computer simulation. This analysis was to determine that with the Pilot and Console Operator in-the-loop a recovery of the aircraft from an undesired condition could be performed without exceeding the "Z" system capability. The most severe undesired conditions defined by the analysis were verified by dropping dead weights attached to the "Z" system with various amounts of slack in the system between the aircraft attach unit and the shock absorber. These drop test results are shown in table IV and indicate that the dynamic analysis provided a conservative estimate of the effects of the undesired conditions.

TABLE IV.- VERIFICATION OF DYNAMIC ANALYSIS

Drop weight		Drop distance		Actual shock absorber stroke		Calculated shock absorber stroke	
kN	lb	cm	in.	cm	in.	cm	in.
66.7	15 000	76.2	30	56.4	22.2	81.3	32.0
66.7	15 000	127.0	50	88.4	34.8	114.3	45.0
88.9	20 000	76.2	30	92.7	36.5	92.7	36.5

Operational Test Procedures.- Operational test procedures for the XFV-12A tethered hover test program were established for all test conditions. These include preflight,[2] flight, postflight, and abort procedures. The procedures were developed by the test team and approved by the MRC. After the testing was underway, the procedures were modified to reflect the experience gained during testing. To modify the procedures, the Test Director, Pilot, Console Operator, and NASA Safety Observer would propose the modification to the program managers of the three participating agencies, and if they concurred with the proposed modification, the procedures were changed and issued to the test team.

Integrated Systems Review/Operational Readiness Review

The ISR and ORR are senior level reviews of a project which grant final approval for testing to begin. For this project, the ISR and ORR were combined. All unresolved items from the CDR and MRC must be resolved to obtain an ISR/ORR approval for testing. The ISR/ORR reviews the project as a whole. In the case of this interagency program, such things as public information, visitor control, and accident investigation procedures were addressed.

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[2]The word flight here refers to the powered portion of static or dynamic testing.

OPERATION OF FACILITY

The test operations for both static and dynamic testing were conducted by the test team in three phases: preflight,[3] flight, and postflight. The preflight activities were primarily performed by the facility and aircraft maintenance crews who ensured that all facility and aircraft systems operated correctly. During the flight phase the Pilot, Test Director, and ground personnel performed their specific tasks to accomplish the test plan in a safe manner. The postflight phase involved debriefing the test team and preparing the aircraft and facility for another test or securing the aircraft and facility for the day. The responsibilities of the principal test team members and more details of the test activities are discussed in the following sections.

Principal Test Team Personnel

Test Director.- The Test Director is responsible for the overall conduct of the test program with emphasis on the safety of all personnel, equipment, and facility. He resolves problems and ensures familiarity with program objectives by all personnel. He reviews, in detail, the test requirements with the Pilot and test team to ensure compliance with the established schedule of tests and maintains a close liaison with facility officials to ensure compliance with NASA regulations and procedures.

During tethered hover tests, the Test Director's physical location is in the control room. He directs the tests, including starting, lifting, flight, lowering, and shutdown. He is the primary communications link with the Pilot and, as required, advises him of flight conditions, trends, attitudes, and other external conditions that the Pilot may not be able to monitor.

Pilot.- The Pilot is responsible for actual control of the aircraft, subject to the authority of the Test Director. He participates in the briefing of the test plan before the test and the debriefing following the test.

Console Operator.- The Console Operator operates the control console. He is responsible for informing the Test Director of any anomalies in the system operation and performance and is ready to take appropriate action. The Console Operator is also responsible for performing the preflight and postflight checkouts of facility and aircraft systems.

Test Coordinator.- The Test Coordinator is located in the control room during testing to coordinate the activities of the test team. He is responsible for calling out the test conditions, recording all test times, and making notes of any unusual happenings.

Safety observers.- Two safety observers who are highly familiar with the aircraft are stationed in the vicinity of the test pad to supplement the Test Director's visual observation of the aircraft. Their primary responsibility is to closely monitor the airplane and its systems at all times for evidence of malfunctions, such as hydraulic leaks, fuel leaks, erratic control surface

[3]See footnote 2 on p. 32.

operation, damaged surfaces, smoke, overheat conditions, and fire. They report any abnormalities over the ICOM to the Test Director.

Data observers.- Observers monitor selected parameters recorded on the real-time instrumentation strip charts and report to the Test Director any parameters that exceed specified limits. Their primary responsibility is to monitor the selected parameters to determine that the engine and aircraft systems are operating normally and to report to the Test Director over the ICOM system any unanticipated or potentially dangerous trends.

NASA Safety Observer.- The NASA Safety Observer is present in the control room during all manned tests. He attends all test briefings and debriefings and ensures that tests are conducted within agreed guidelines. He monitors all radio and ICOM communications. He has authority to order the Test Director to terminate testing whenever he deems safety to be compromised. He impounds and secures test data, records, equipment, and accident site in case of accident with assistance of the NASA Security Guard Force and notifies the Head of the Langley Research Center Systems Safety, Quality and Reliability Office.

NASA Facility Coordinator.- The NASA Facility Coordinator is present in the control room during preflight and postflight facility checkouts and during tests. He is in charge of NASA facility personnel and certifies to the Test Director that the facility is ready for test. He monitors all radio and ICOM communications and coordinates Langley Air Force Base assistance.

Static Testing

For static testing, the aircraft is suspended at the desired altitude and attitude by being attached to the "Z" system cable and to seven ground tiedown cables as shown in figures 29 and 30.

Preflight activities.- Preflight activities consist of two main items, aircraft preflight checkout by the aircraft maintenance crew and daily inspection of the tether system ("Z" system and gantry) by facility and control room personnel in accordance with the XFV-12A Tether Test Program Operating Procedures.

The aircraft preflight checkout is similar to that done on any test aircraft. The tether system checkout consists of visually inspecting the "Z" system cable or wire rope, ensuring that the shock absorber pressure is within pressure limits for its temperature, conducting a winch functional check, and finally adjusting the load cell for any drift that occurred since the last test day.

After the aircraft and tether system checkouts are complete, the aircraft is rolled out and the "Z" cable, the ground tiedown cables, the umbilical cable, the engine start hose, and ground electrical power are connected.

Flight activities.- The flight phase activities begin with a briefing of the test team by the flight test engineer. This briefing reviews details of the test to be conducted, significant aircraft configuration changes, and the

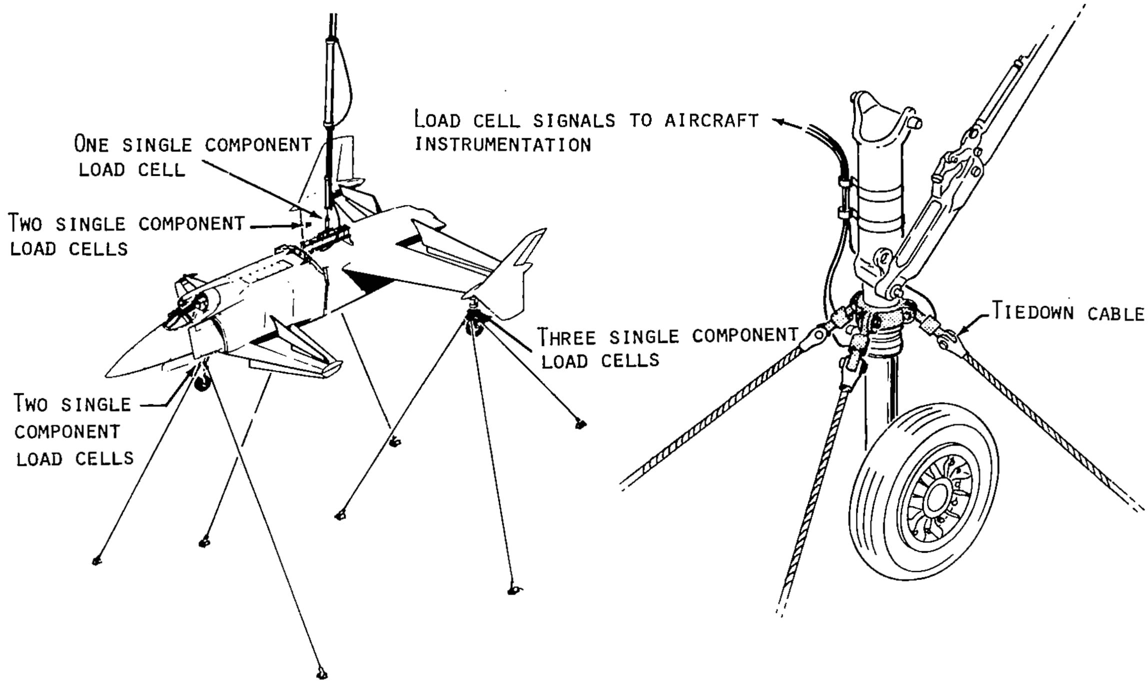

Figure 29.- Static test tiedown arrangement for XFV-12A.

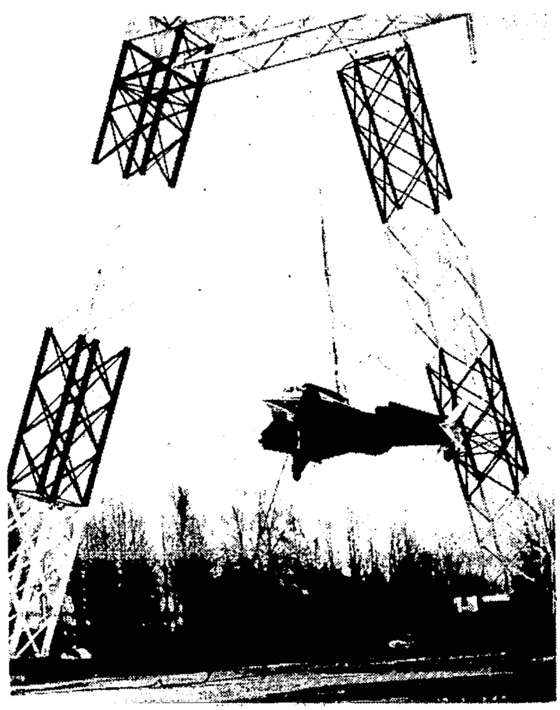

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Figure 30.- XFV-12A suspended in IDRF for static testing.

disposition of problems or malfunctions (squawks) that occurred during the last test. The briefing is completed with the key personnel signing the XFV-12A Tether Test Operational Readiness Report (fig. 31).

XFV-12A Tether Test Operational Readiness Report

Test No. __________ Date __________

"Z" System/Aircraft Maintenance: (Corrections of previous Squawks of significance to test and any outstanding Squawks)

Pretest Checkout:

"Z" System ____________________ Aircraft ____________________
Console Operator Crew Chief

Facility ____________________ ____________________
NASA Facility Coordinator Quality Control

Data Station ____________________
Instrumentation

Accepted for Test ____________________ Approved for Test ____________________
Pilot Test Director

Released for Test ____________________
NAVY Representative

Figure 31.- XFV-12A Tether Test Operational Readiness Report.

Once fire and rescue personnel and equipment are in position and the gantry area is secured by the NASA Security Guard Force, the Pilot mans the aircraft and begins cockpit preflight checks with the control room. Access to the gantry area is restricted to test personnel and invited visitors because of the high noise environment which requires hearing protection in the vicinity of the gantry area and because of the need to keep the only access road to the gantry open in case of emergency. After the cockpit and control room checks are completed, the aircraft is hoisted to approximately 0.3 m (1 ft) for weighing; then it is hoisted up against the tiedown cables with a tension in the "Z" cable equal to the weight of the aircraft plus 11.1 ± 2.2 kN (2500 ± 500 lb). The attitude of the aircraft is controlled by adjusting the turnbuckles in the tie-down cables. This process can be very time consuming because adjusting the turnbuckles also affects the tiedown cable loads which must be such that all cables are in tension before engine start to ensure accurate load measurement. It should be noted that once the cable lengths have been adjusted for a given altitude and attitude, only loads and angles are checked. Tare readings are then taken, and the engine started using an extra long (30.5 m (100 ft)) starter hose, as shown in figure 32. After engine start the starter hose is removed.

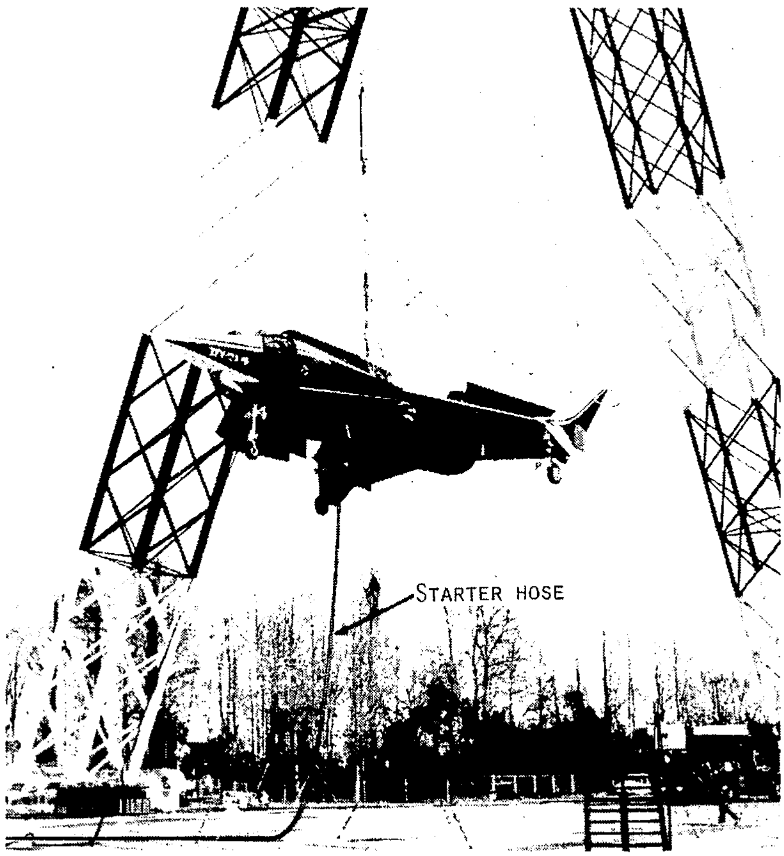

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Figure 32.- XFV-12A with engine starter hose connected.

After engine operation has stabilized, the flight is conducted in accordance with the test plan. At the completion of the flight, the engine is shut down with the aircraft still in the hoisted and tensioned position. After engine rundown, a postflight tare is taken and the aircraft is lowered to the ground.

Postflight activities.- After the flight, a postflight debriefing is held to discuss the preliminary test results and any anomalies that occurred during the flight. The aircraft maintenance crew refuels the aircraft and conducts a postflight inspection in order to prepare the aircraft for the next test. If no further testing is planned for the day, the aircraft is disconnected from the "Z" system and ground tiedown cables and returned to the hangar. The "Z" system is then secured by the facility and control room personnel.

Dynamic Testing

For dynamic testing, the aircraft is attached to only the "Z" system cable as shown in figure 33. The test envelope for dynamic testing, shown in

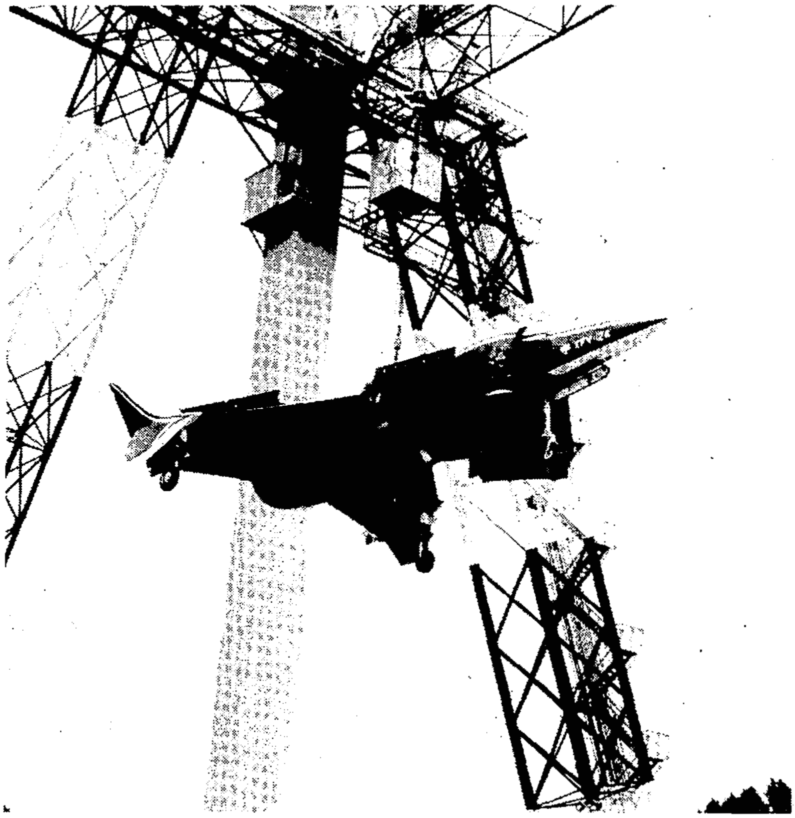

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Figure 33.- XFV-12A during dynamic tethered hover testing.

figure 34, is 15.2 m by 15.2 m (50 ft by 50 ft) at ground level decreasing to 11.6 m by 11.6 m (38 ft by 38 ft) at 15.2 m (50 ft). The facility can be quickly converted from dynamic to static modes to resolve any anomalies encountered.

Preflight activities.- Preflight activities for dynamic testing are essentially the same as for static testing. The major difference is in the daily checkout of the "Z" system. Checkout of the automatic mode of winch operation is added to the "Z" system checkout. This test determines whether the "Z" system will follow the aircraft vertical motion.

For a dynamic test, the aircraft is connected to only the "Z" system cable, the umbilical cable, the engine start hose, and ground electrical power.

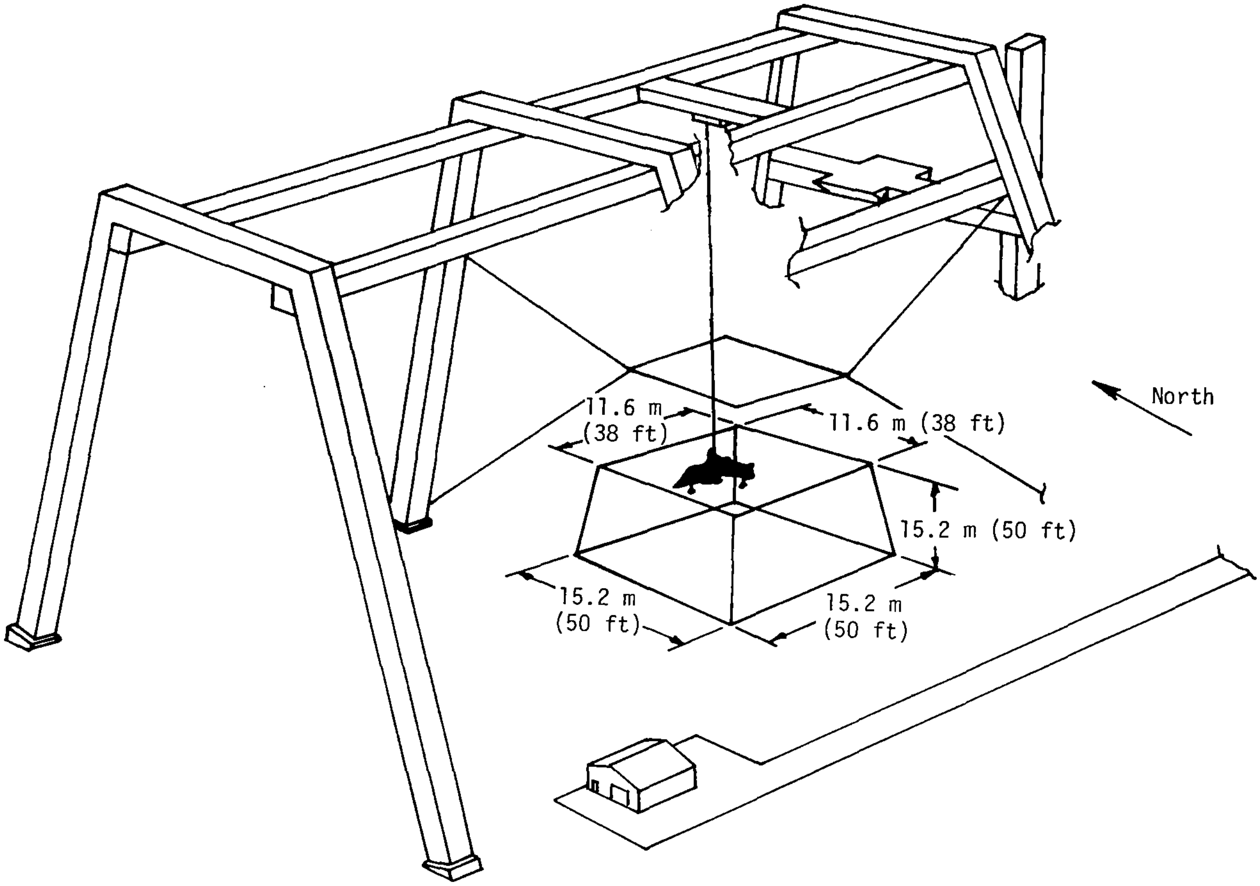


Figure 34.- Test envelope for dynamic tethered hover testing.

Flight activities.- As with preflight activities, dynamic and static operations are similar. The difference between the two operations begins after the aircraft is manned by the Pilot. As with static testing, the aircraft is lifted approximately 0.3 m (1 ft) off the ground for weighing. After lowering the aircraft and starting the engine, the starter hose and ground electrical power are removed with the aircraft on the ground.

For tests in which the initial altitude of the aircraft is above ground level, the aircraft is lifted to test height with the engine at idle power setting. The throttle is advanced to the desired level and the flight is conducted in accordance with the test plan. For tests in which the aircraft is to make a vertical takeoff, the aircraft lifts off and climbs to test altitude. The aircraft is then either flown down to the ground or the engine power is reduced to idle and the aircraft lowered back to the ground.

Postflight activities.- Postflight activities for both dynamic and static testing are the same.

Safety Aspects

The overall responsibility for conducting the testing in a safe manner to protect all personnel, equipment, and facilities lies with the Test Director.

The Government's interests with respect to safety lie with the NASA Safety Observer. He is the only person during a test who has authority, whenever he deems that safety is being compromised, to order the Test Director to stop the test.

Tables V and VI are matrices of emergency conditions and the actions required for static and dynamic testing, respectively. Note that each call for stopping the test begins with the word "recover" followed generally by a descriptive word or words.

TABLE V.- STATIC TEST RECOVERY MATRIX

Event	Call	Pilot action	Console Operator action	Test Director action
Fire	Recover, fire	1. Reduce lift 2. Throttle back to idle 3. Shut off engine 4. Shut off fuel	1. Switch winch BRAKE to AUTO REL 2. Switch EMERG SHUT OFF to OFF 3. Lower aircraft to ground	Request crash and rescue equipment
Winch malfunction	Recover, winch	1. Reduce lift 2. Throttle back to idle	Push WINCH EMERG STOP	Instruct winch platform technicians to set manual brake on winch
Primary communication failure	Recover, com	1. Reduce lift 2. Throttle back to idle	Switch to UHF	1. Inform test team of communications failure with bull horn 2. Take appropriate actions as required
Test complete	Recover, test complete	1. Reduce lift 2. Throttle back to idle	As directed	Take appropriate actions as required
All other reasons for delaying or stopping test	Recover	1. Reduce lift 2. Throttle back to idle	As directed	Take appropriate actions as required

TEST RESULTS

Typical results of both static and dynamic tests of the XFV-12A are presented in this section. These results illustrate the type of data that can be acquired through utilization of the IDRF as a tethered test facility for V/STOL aircraft.

TABLE VI.- DYNAMIC TEST RECOVERY MATRIX

Event	Call	Pilot action	Console Operator action	Test Director action
Fire	Recover, fire	1. Reduce lift 2. Throttle back to idle 3. Shut off engine 4. Shut off fuel	1. Switch WINCH AUTO/MAN to MAN 2. Switch EMERG SHUT OFF to OFF 3. Lower aircraft to ground	Request crash and rescue equipment
Winch malfunction	Recover, winch	1. Reduce lift 2. Throttle back to idle	Push WINCH EMERG STOP	Instruct winch platform technicians to set manual brake on winch
Primary communication failure	Recover, com	1. Reduce lift 2. Throttle back to idle	1. Switch to UHF 2. Switch WINCH AUTO/MAN to MAN	1. Inform test team of communications failure with bull horn 2. Take appropriate actions as required
Test complete	Recover, test complete	1. Reduce lift 2. Throttle back to idle	Switch WINCH AUTO/MAN to MAN	Take appropriate actions as required
All other reasons for delaying or stopping test	Recover	1. Reduce lift 2. Throttle back to idle	Switch WINCH AUTO/MAN to MAN	Take appropriate actions as required

Static Test Results

For XFV-12A static testing, the tiedown cables were constructed to give test altitudes of 0, 0.9, 3.0, and 9.1 m (0, 3, 10, and 30 ft). These altitudes are adequate to generate aircraft force and moment data both in and out of ground effect. During the static testing, considerable attention was given to improving the augmenter performance.

Initially, only single-axis control inputs were evaluated. Typical results are given in figures 35 to 37. These plots show the primary moment variations and the effects of cross coupling with control input for pitch, roll, and yaw. Substantial cross-coupling effects of yaw with roll input (fig. 36) were observed. Later dynamic tests proved this cross coupling to be acceptable. In addition to these moment plots, variations of lift and drag were generated for various lift lever positions, longitudinal stick positions, and wing mean augmenter flap angles. Parametric tests of these variations were accomplished both in and out of ground effect.

Control hysteresis was another problem investigated during the static tests. Single-axis roll and yaw inputs generated up to 2° hysteresis on the wing diffuser flap angles and 1° for the canard. Moment variations generated for these conditions are shown in figures 36 and 37. Multiple-axis inputs were evaluated in various combinations and resulted in no serious problems with either moment values or control reversal.

Another area of investigation within the IDRF facility could be the effect of mean augmenter flap angle, power setting, and lift lever position on reingestion at ground level. These parameters would allow the development of an operational lift-off technique which would minimize reingestion and maximize the aircraft V/STOL takeoff gross weight.

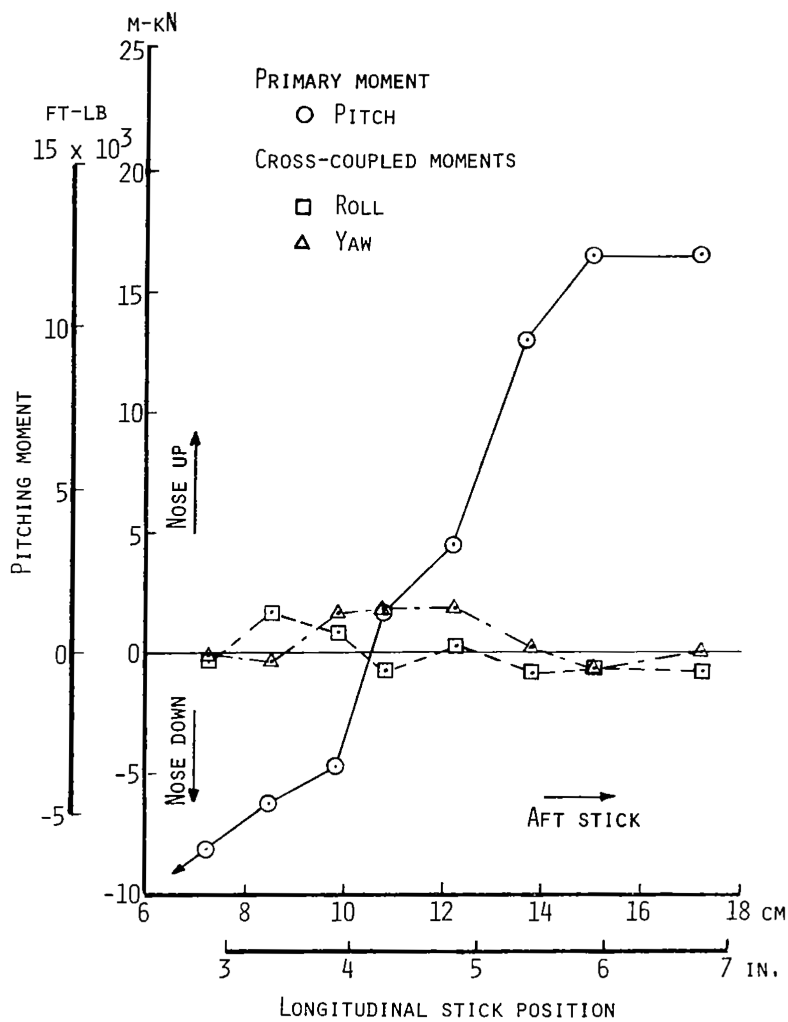


Figure 35.- Variation of pitching moment with longitudinal stick position for the XFV-12A with yaw and roll controls fixed.

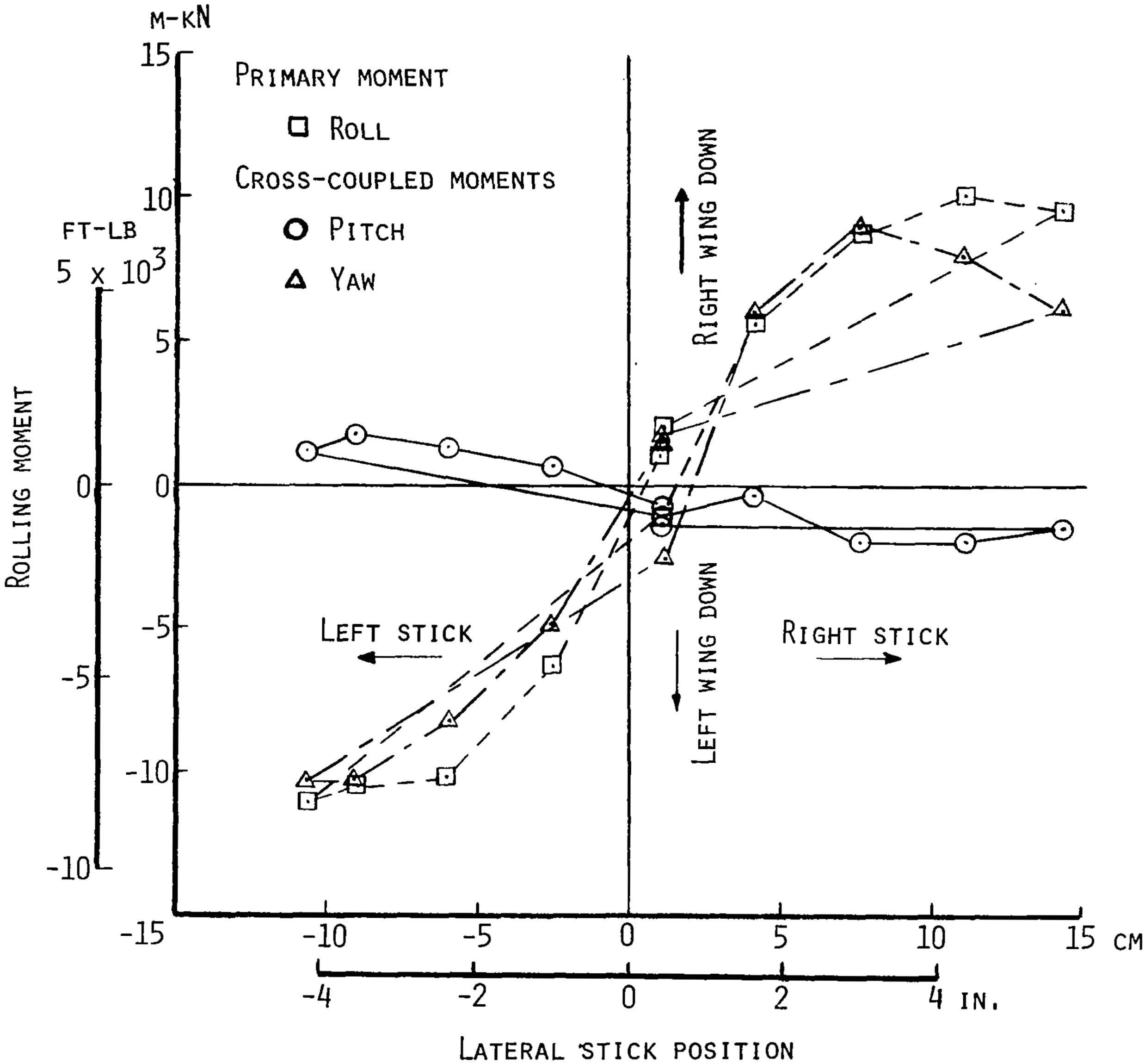


Figure 36.- Variation of rolling moment with lateral stick position for the XFV-12A with pitch and yaw controls fixed.

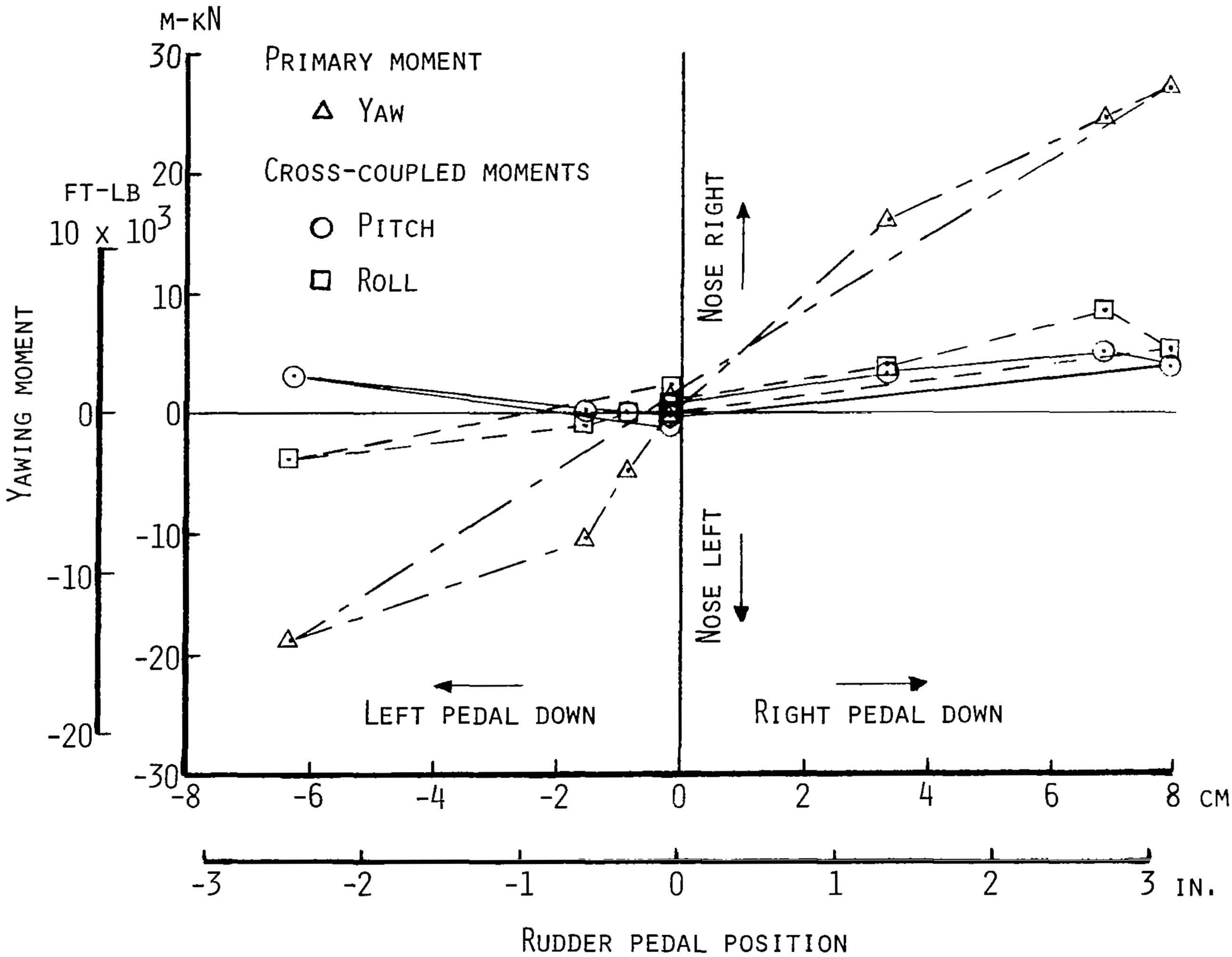


Figure 37.- Variation of yawing moment with rudder pedal position for the XFV-12A with pitch and roll controls fixed.

Dynamic Test Results

At the conclusion of static testing, dynamic testing to assess aircraft controllability with lift-to-weight ratios less than 1 was initiated. Most of the XFV-12A dynamic test were conducted at a lift-to-weight ratio of approximately 0.75 for a trimmed configuration with adequate controllability. Since significant tension still remained in the "Z" cable, which was attached above the aircraft center of gravity, the aircraft control was not totally representative of a free-air hover. However, a good qualitative evaluation of the aircraft handling qualities was possible when the "Z" cable was nearly vertical and the pitch and roll angles were small.

The XFV-12A has a three-axis rate damper augmentation system with 10-percent authority. This system was evaluated for all three axes with the aircraft out of ground effect at 9.1 m (30 ft) altitude and maximum engine thrust. Figure 38 shows the variation of control input with dampers off and on and figure 39 shows the corresponding aircraft response rates. The damper system in general has little effect in the pitch axis, a slightly greater effect in the yaw axis, and a significant effect in the roll axis.

Pilot work load was evaluated for two tasks. The first task was to stabilize the aircraft at 9.1 to 12.2 m (30 to 40 ft) altitude and then lower the aircraft into ground effect to approximately 3 m (10 ft). The second task was to stabilize the aircraft at 9.1 m (30 ft) with an aft lift lever position (δ_{LL} = -2.8 cm (-1.1 in.)) and then advance the lift lever forward to the neutral position (δ_{LL} = 0). Because the augmenters were not performing as designed, this procedure caused all diffuser half-angles to move from the linear portion of the augmenter lift-curve slope to the flatter portion just before stall (fig. 4), resulting in a significant reduction in control margins. Figures 40, 41, and 42 show the traces of pilot input for pitch and the corresponding diffuser half-angles for the wing and canard. As shown, the pilot work load increased substantially as the lift lever approached the neutral position. This particular series of tests also helped to understand the amount of control margin required and the desired slope of the augmentation ratio curves.

During the ground-effect investigations, lift values were recorded from free air through ground effect. This variation is plotted in figure 43.

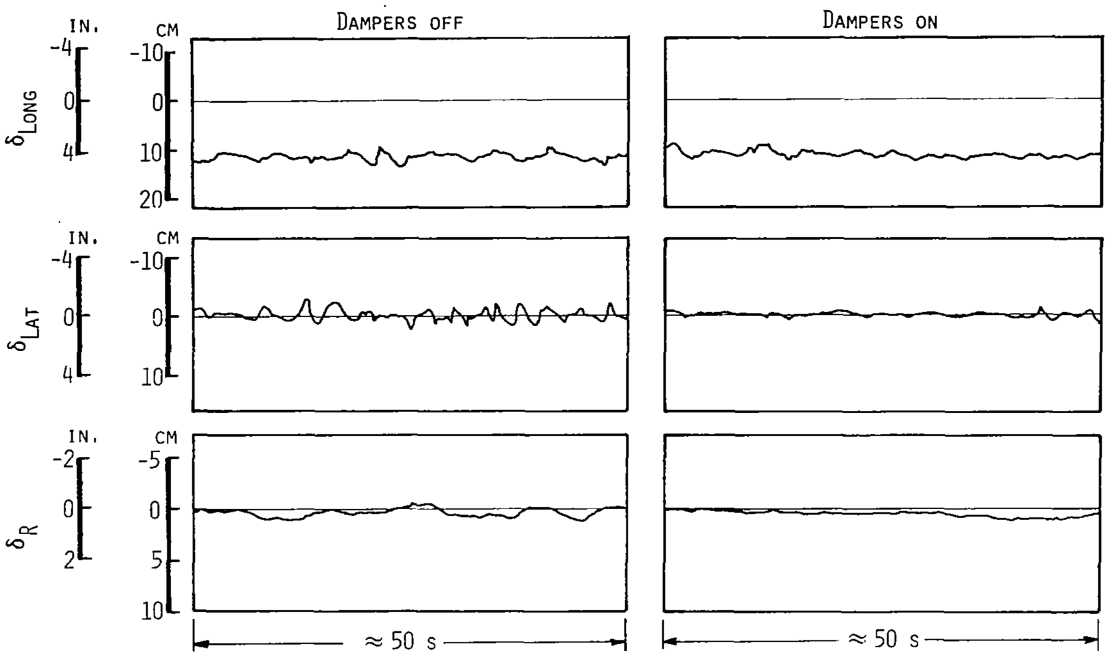


Figure 38.- Comparison of pilot control input required to maintain constant attitude of the XFV-12A during dynamic tethered hover with dampers off and on.

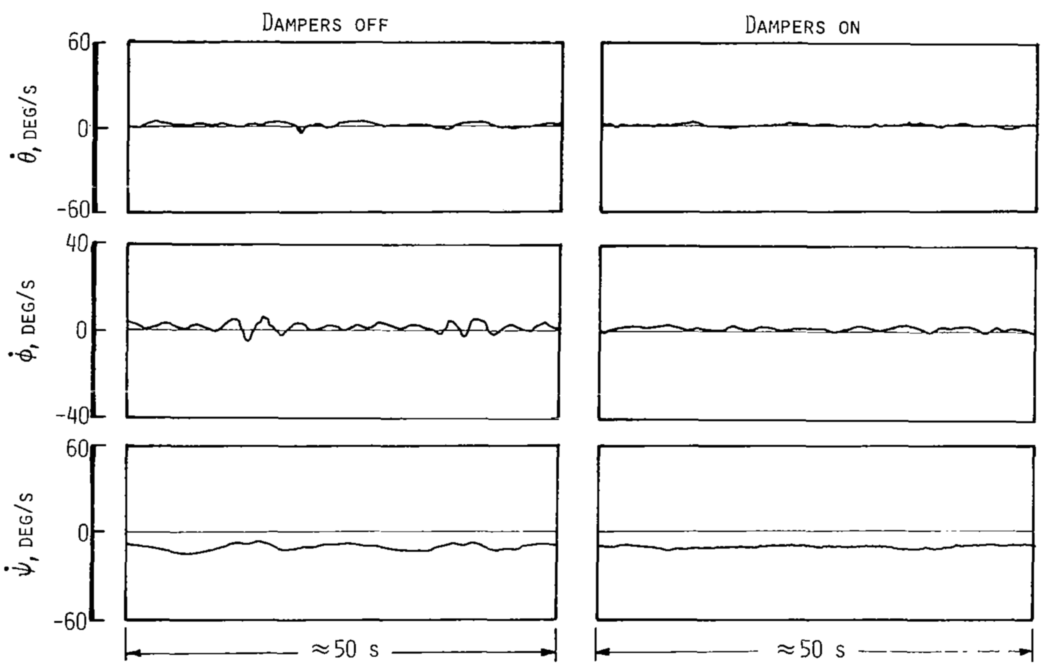
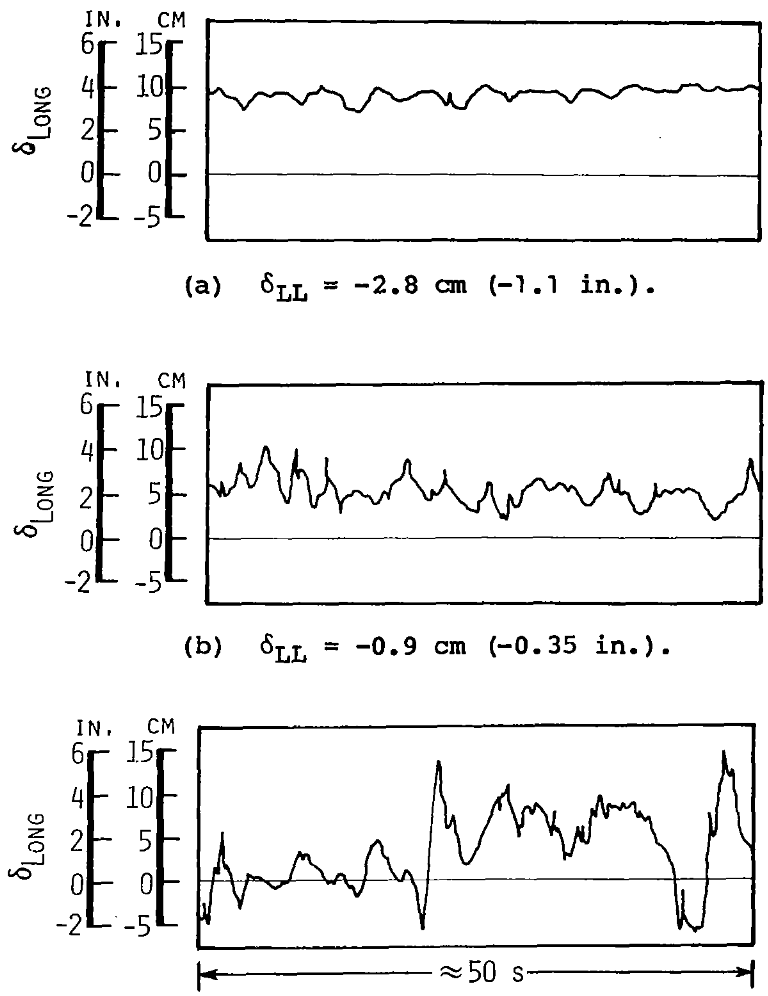


Figure 39.- Comparison of XFV-12A response rates while maintaining constant attitude during dynamic tethered hover with dampers off and on.

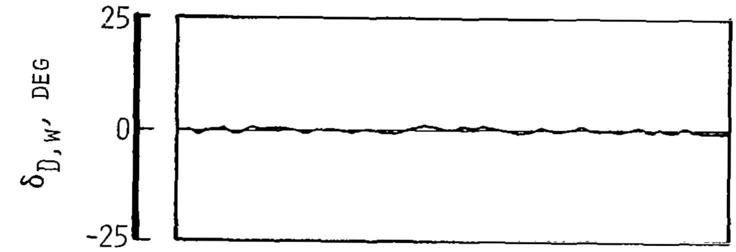


(a) δ_{LL} = -2.8 cm (-1.1 in.).

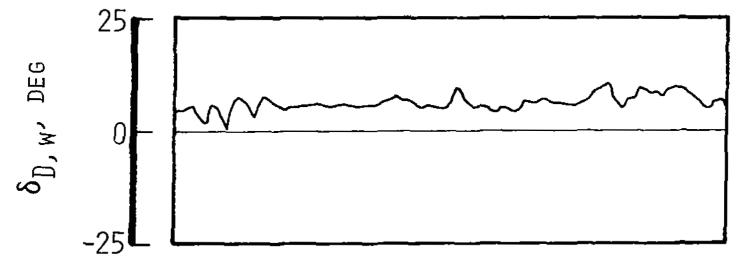
(b) δ_{LL} = -0.9 cm (-0.35 in.).

(c) δ_{LL} = 0 cm (0 in.).

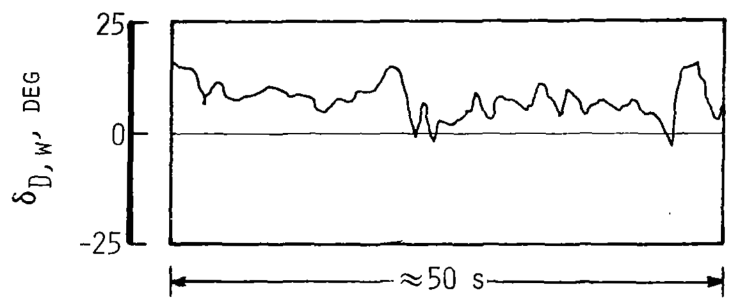
Figure 40.- Longitudinal control input required to maintain constant attitude for various lift lever positions of XFV-12A during dynamic tethered hover.



(a) δ_{LL} = -2.8 cm (-1.1 in.).

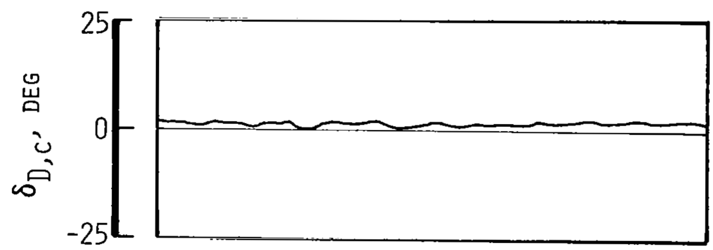


(b) δ_{LL} = -0.9 cm (-0.35 in.).

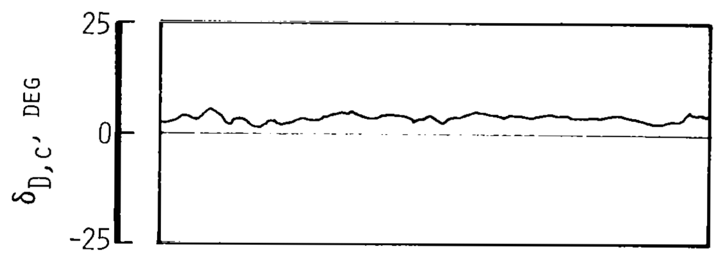


(c) δ_{LL} = 0 cm (0 in.).

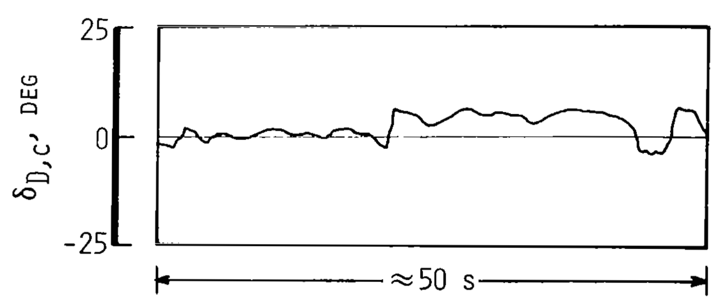
Figure 41.- Variation of wing diffuser half-angle required to maintain constant attitude for various lift lever positions for XFV-12A during dynamic tethered hover.



(a) δ_{LL} = -2.8 cm (-1.1 in.).



(b) δ_{LL} = -0.9 cm (-0.35 in.).



(c) δ_{LL} = 0 cm (0 in.).

Figure 42.- Variation of canard diffuser half-angle required to maintain constant attitude for various lift lever positions for XFV-12A during dynamic tethered hover.

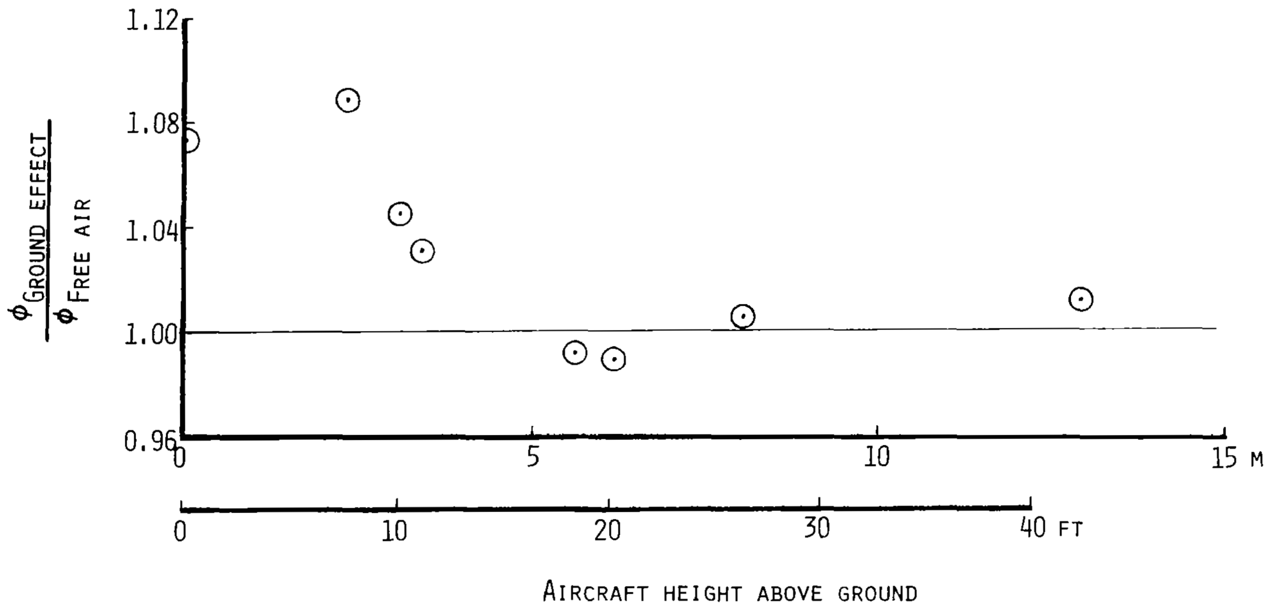


Figure 43.- Variation of normalized augmentation ratio with altitude for the XFV-12A.

Comparison of Static and Dynamic Results

Since most of the dynamic test results are either qualitative or dynamic parameters that do not exist from static testing, only the total aircraft lift is available for comparing static and dynamic tests. Nine data points were compared at various conditions, as shown in table VII. These points represent a "slice of time" from stabilized dynamic runs. The ratio of dynamic lift to static lift varied between 0.99 and 1.01 which indicates an extremely good correlation between the static and dynamic tests.

TABLE VII.- COMPARISON OF DYNAMIC AND STATIC LIFT FOR XFV-12A

$\delta_{D,w}$, deg	$\delta_{D,c}$, deg	$\frac{\text{Dynamic lift}}{\text{Static lift}}$
-3.0	6.0	1.00
0	1.0	1.00
1.5	0	1.00
5.5	3.0	1.00
4.0	4.0	.99
-1.0	2.0	1.00
-.4	1.4	1.01
.2	.3	.99
.2	1.1	1.00

PILOT OBSERVATIONS

Piloting tasks for both static and dynamic operations were dissimilar in that the Pilot was essentially a cockpit controls operator for the static runs, whereas for the dynamic runs, his task was similar to hovering an aircraft. In the static case, the Pilot was almost completely "head down" inside the cockpit, whereas in the dynamic case, he was almost completely "head up" outside the cockpit in order to observe and control the aircraft dynamic motions.

Static Operations

From the Pilot's viewpoint, the static testing involved little or no piloting tasks since the aircraft was rigidly restrained by the tiedown cables. High power runs were limited to 5 to 8 minutes, or slightly longer if some data were obtained at less than full power. Initially, 20 seconds of data were obtained at each point, but as the program progressed, it was determined that stabilized data could be obtained with points as short as 10 seconds. Early testing indicated that the Pilot was fully occupied with the stick, rudder, lift lever, and throttle movements; therefore, the Test Coordinator position was established in the control room to time the test and to confirm Pilot control position movements. With this additional test team member on the ICOM system, coordination of all the members of the test team was improved, and delays between data points were eliminated.

Although the pilots were physically comfortable during static tensioning and tests, it was not a particularly comfortable experience, at least not as comfortable as it might appear to the outside observer. The Pilot had no immediate escape route available in case of fire. The ejection seat was disabled and the canopy rail was about 11.9 m (39 ft) above the ground, too high to jump safely. The Air Force emergency tree lowering device carried by the Pilot would be difficult to use quickly in an emergency. It took a significant amount of time to carefully climb over the side of the cockpit and some care had to be taken to avoid twisting the nylon tape. The IDRF bucket truck was available but required a few minutes to move into position and set up. The quickest way down was the Console Operator lowering the aircraft with the winch. Emergency lowering was practiced and it was determined that the aircraft could be brought down from 9.1 m (30 ft) to the ground in about 7 to 10 seconds. The compensating factor in fire considerations was the fact that it would take a double failure, that is, a fire plus a winch failure, for the pilot to be unable to evacuate expeditiously. Also, the Air Force crash truck had the capability to saturate the aircraft with light water all the way up to maximum operating height. However, the Pilot depended most on the Console Operator, since he not only directly controlled the winch but also was the first to know of any winch malfunction. Therefore, he also had the responsibility for "catching" the aircraft if any failure of the winch system occurred which would allow the aircraft to descend at an uncontrolled rate. On one occasion when this occurred, due to the failure of the drive coupling between the winch transmission and the gear box just as the aircraft was lifted clear of the ground, the Console Operator did set the emergency brake after the airplane had dropped only about 0.3 m (1 ft). It is worthy to note that this undesired event was identified in the FMEA and the procedures established for the event were satisfactory.

The majority of the static test operations were performed with the wheel height at 9.1 m (30 ft) which corresponded to the Pilot's eye level at about 12.2 m (40 ft). After tensioning the tiedown cables, the airplane was usually very solid with little movement except for intermittent small abrupt lurches, apparently due to slight hangups in the individual tiedown cable swivels, shackles, etc. This phenomenon was initially disconcerting until it became obvious that it was a common characteristic of the system. It did provide an indication of variations in lift and control moments as these lurches usually occurred when lift was varied due to power changes or control movements. The exception to this occurred during ground height static tests when the aircraft experienced buffeting due to ground effect. This buffeting was more noticeable in the IDRF than in previous ground height tests because the tiedown system was not as rigid.

The fire warning system was triggered several times during the static test program. These warnings were always due to either a hot air leak from the ducting system (usually the lower plenum) or, in one instance, a sensing element which malfunctioned. Discrete warning lights in the cockpit which indicated individual sensing elements were a great help in evaluating the situation in each case. With experience, it was possible to confirm with telemetered data that actuation of a sensing element was due to a marginal overheat condition rather than to an actual fire. In these situations, it was possible, providing that all indications were consistent (i.e., telemetric indication of overheat, fire warning extinguished with reduction of power, and absence of visible fire indications), to cool down at idle for a period of 4 to 5 minutes and then go back up to power and complete the data run prior to reactivation of the warning system. It should be noted that tethered testing subjects the aircraft to a much longer period of high temperature operation than would normally exist in an operational V/STOL situation and therefore places more stringent requirements on the fire and overheat warning system in the test aircraft. Preferably, a real-time data system could be utilized to monitor all engine bay temperature instrumentation automatically, but that was not available for this program.

Visual Aids

Although the visual aids were not required for static operations, it became obvious that the aids would be inadequate for full dynamic testing. The large number of multicolored spheres fore and aft of the airplane on the gantry centerline were visually confusing, which rendered them useless for height reference and poor for lateral lineup. For further testing, the spheres should be removed and the east-west painted centerline lengthened and darkened, as this is an excellent lineup reference. Offset lines parallel to the centerline should be provided at about 3 m (10 ft) intervals; these should not be as wide, and possibly not be the same color, as the centerline stripe. Painted radius circles should also be provided around the tethered area at 30.5 m (100 ft) and 61 m (200 ft) from the center for longitudinal reference. The black and white checkerboard to the north of the test area was ineffective and should be discarded. The least confusing height reference can be provided by marking the gantry legs and the elevator tower with horizontal lines as height markers corresponding to the Pilot's eye height at 3.0, 6.1, 9.1, and 12.2 m (10, 20, 30, and 40 ft).

Dynamic Operations

Initial free tethered flights were conducted at 9.1 m (30 ft) with the 1.5 m (5 ft) restraint ring. Since one of the primary purposes of these initial tests was to obtain a precise reading of the "Z" system load cell with minimum extraneous interference, the Pilot attempted to stabilize the aircraft clear of the small restraint ring. Laterally, this was possible by reference to the gantry centerline. But the Test Director, by observing the cable position within the restraint ring, had to coach the Pilot to center longitudinally. The overhead TV monitor on the winch platform was not a satisfactory reference for this due to the parallax caused by the necessity for mounting the camera too far from the "Z" cable. In any case, it was possible to stabilize clear of the restraint ring long enough to ensure valid data.

When proficiency in attitude control had been demonstrated, the ring restraint was removed and dynamic flights were executed with only the cable restraint at heights from 12.2 m (40 ft) to 3.0 m (10 ft). Some concern existed about the ability to position the aircraft longitudinally due to the poor longitudinal visual references. However, when deliberate mild longitudinal maneuvers were attempted, the "Z" cable load of about 22.2 kN (5000 lb) provided a centering effect sufficient to prevent the aircraft from making contact with the cable restraint. Lateral maneuvers of ±3 m (±10 ft) were found to be relatively easy to execute with some precision. The centering effect of the cable was felt when the aircraft was displaced laterally 3 m (10 ft), but position could be held by maintaining a small bank angle. The "Z" cable tension also exerted a pitching and/or rolling moment when the load was not vertical because of the pendulum effect of the aircraft vertical center of gravity being below the hoist point. Therefore, a good qualitative evaluation of the aircraft longitudinal and lateral handling characteristics was only possible when the "Z" cable was nearly vertical and pitch and roll angle changes were small.

In an early dynamic test, when a loss of attitude control occurred during a flight with reduced control margins, the flight was aborted and the aircraft was recovered safely without incident in accordance with the Operating Procedures.

CONCLUSIONS

Modifications to the Langley impact dynamics research facility (IDRF) to support the XFV-12A Tethered Hover Test Program were accomplished and procedures to utilize the facility for tethered hover testing were established. From the 6 months of static and dynamic testing, the following conclusions were drawn:

1. The IDRF offers several unique capabilities for hover testing of V/STOL aircraft:

   a. The aircraft can be "caught" and recovered at any time during the test.

   b. Control limits can be rapidly and safely defined, and operation in regions of reduced control margins can be investigated.

   c. Ground effect boundaries and variations of aircraft characteristics within these boundaries can be rapidly defined, and dynamic hover flight can be safely demonstrated in a realistic ground effect environment.

   d. Quick conversion from dynamic to static test modes allows rapid definition and resolution of any anomalies incurred.

   e. The external environment (flow field velocity, pressure, temperature, and noise) around the aircraft can be defined for various aircraft attitudes and altitudes and wind conditions.

   f. The facility provides a realistic environment in which pilots can train and maintain proficiency in VTOL flight.

2. XFV-12A tethered hover testing within the IDRF has indicated that valid force and moment data can be obtained from static testing and that dynamic tethered hover flying qualities can be evaluated.

RECOMMENDATIONS

On the basis of experience gained during the tethered hover testing of the XFV-12A at the Langley impact dynamics research facility (IDRF), the following recommendations are made:

1. Validate the facility for dynamic tethered hover testing at lift-to-weight ratios greater than 1 by performing dynamic tethered hovers with an aircraft having known hover characteristics, such as the AV-8A Harrier aircraft using several experienced AV-8A pilots.

2. Modify the IDRF so that the facility can be used for both the aircraft crash safety program and tethered hover testing with minimum interference.

3. Upgrade the IDRF for tethered hover testing based on experience from XFV-12A testing; that is, improve the control room, intercommunication system, video system, pilot cues, and aircraft maintenance work areas.

4. Incorporate tethered hover testing as an integral part of the developmental process for future V/STOL aircraft; that is, after wind-tunnel and simulation tests, conduct tethered testing before flight tests.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
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15. Supplementary Notes
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Edward A. Gillespie and Archie G. Lane: North American Aircraft Division, Rockwell International Corp., Columbus, Ohio.

16. Abstract

From the beginning of the U.S. Navy XFV-12A V/STOL Technology Demonstrator Aircraft Program, there was considerable discussion as to the most appropriate method to investigate the hover capabilities of the total aircraft in a realistic, and yet safe, environment. The consensus of those who had previously tested V/STOL aircraft was that VTOL test devices (tether rigs, pedestals, or grids) provided unrealistic inputs to the aircraft and sometimes created erroneous impressions of the aircraft characteristics. It was desired that the test facility for the XFV-12A have the capability to obtain static force and moment data and to allow assessment of aircraft handling qualities during dynamic tethered hover "flight." It was determined that the Langley impact dynamics research facility (IDRF) could be modified to achieve these objectives and minimize the objections to previous hover test facilities. The modifications were accomplished and procedures for testing established. Static lift and control measurements were obtained and limited dynamic tethered hover "flight" was conducted during the first half of 1978 in the IDRF.

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