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EVALUATION OF AN ENERGY DISTRIBUTION SYSTEM FOR HELICOPTER LANDING GEARS DURING HARD LANDINGS

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APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

The findings of a laboratory tested landing gear energy distribution system having crashworthiness capabilities are presented in this report. A hydraulic system of conventional oleo dampers, accumulators, equalizers, etc., with interconnection of each landing gear strut, is used to minimize both pitch and roll moments that occur during hard landings. The resulting attenuation and redistribution of the landing impact energy enhances the pilot's control of the aircraft and reduces the possibility of aircraft damage and personnel injury. Both ground shake tests and drop tests were performed to evaluate the viability of the concept. A cost savings of greater than 2:1 is indicated from analysis by incorporating the interconnected landing gear system in new production aircraft.

Mr. William T. Alexander of the Aeronautical Technology Division served as project engineer for this effort.

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An experimental program was conducted to evaluate a landing gear concept that redistributes the impact energy of an autorotational landing. This landing gear concept redistributes the impact energy by providing an interconnection between the front and rear landing gears. Through the interconnection, as the rear landing gear moves from the flight position toward the full compressed position under landing impact, the front gear is impelled next page

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Cont to move from the flight position toward the fully extended position. When these motions have been accomplished, the skids remain on the ground surface throughout the landing, greatly reducing the pitching moments.

The landing gear was drop tested to demonstrate the effects of sink rate, gross weight, center-of-gravity (CG) location, touchdown attitude (both pitch and yaw), ground resonance, system damping, and spring rate. The testing included drop velocities up to 19.5 feet per second and simulated forward and lateral speed landings. For purpose of design and development, the OH-6A helicopter was used as the baseline aircraft, and the landing gear was designed to require minimum modification to the OH-6A. Although the gear was designed for the OH-6A, the basic design principles developed also apply to wheel-type landing gear.

The results of the testing showed that the interconnected landing gear reduces the nosedown pitching velocities and angles during autororation landings. In the particular case of a noseup landing with forward speeds, the interconnected landing gear reduced the pitching velocities 60 percent as compared to the basic OH-6A. As compared to MIL-STD-1290, the interconnected landing gear increased the OH-6A fuselage ground contact velocities to 19.5 feet per second. In addition, analysis showed that if the fuselage support structure were strengthened, an OH-6A equipped with the interconnected landing gear can absorb approximately a 33.7-foot-per-second impact without serious crew injury. The experimental landing gear was also interconnected in roll and demonstrated a 40-percent reduction in roll velocities. A cost analysis indicated that incorporation of the inter-connected landing gear in new production aircraft would result in a return on investment greater than 2:1.

PREFACE

This report was prepared by Hughes Helicopters, Division of Summa Corporation, under Contract DAAJ02-77-C-0019, funded by the Applied Technology Laboratory, U. S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia. The ATL technical monitor for this contract was Mr. William T. Alexander. The Hughes Helicopters project manager was Mr. Andrew H. Logan. Mr. C. A. Waldon conducted the drop test of the landing gear, and Mr. E. Fourt developed the cost/benefits analysis. The authors would like to acknowledge Mr. R. A. Wagner for his support and many helpful suggestions during the program.

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INTRODUCTION

Blade/tail boom strikes occur with an excessive frequency during emergency autorotations. Many of these strikes have resulted in substantial damage to the helicopter and in fatalities and injuries to personnel. In addition, current Army-size limitations require more compact helicopter designs which bring the tail boom and main rotor closer together, increasing the possibility of blade-boom contact.

The sequence of events which results in blade/tail boom strikes in emergency (or practice) autorotations predominately follow this pattern:

a. Ground contact is made with the helicopter in a noseup attitude.

b. The vertical reaction loads act to give a nosedown moment on the helicopter. This nosedown moment is increased due to drag loads if forward speed is present at contact.

c. This nosedown moment causes angular acceleration and nosedown angular velocity (<u>nosedown</u> angular velocity is also <u>tail boom-up</u> angular velocity).

d. Pilot reaction to nosedown velocity is to pull the cyclic stick back. This brings the rotor blades down in the rear while the tail boom is coming up. This combination aggravates main rotor blade and tail boom interference.

It should be evident that whatever reduces the nosedown pitching moment will reduce the tendency toward boom chops. This fact is widely recognized, and pilots are trained to level the helicopter prior to ground contact for the sole reason of reducing the nosedown moment.

Unfortunately, this maneuver requires considerable judgment and finesse in handling both the cyclic and collective controls. Additionally, the act of leveling the helicopter prior to touchdown reduces the angle of attack of the rotor; and, hence, reduces the lift on the rotor at the wrong time in the maneuver.

Recognizing these autorotation problems, a preliminary design study was conducted to define a landing gear concept which reduces the nosedown pitching moments by providing an interconnection between the front and rear landing gears.[1] Through the interconnection, as the rear landing gear moves from the flight position toward the full compressed position under landing impact, the front gear is impelled to move from the flight position to a more extended position. When these motions have been accomplished, the skids (or front and rear wheels) are on the ground surface, and the vertical reactions inherent in absorbing the autorotational landing do not produce a pitching moment.

The analysis showed that interconnection of the front and rear supports of a skid-type landing gear significantly reduces the maximum nosedown pitching angles and velocities that occur during autorotational landings. This results in a more controllable autorotational landing and increased blade/tail boom separation (Figure 1). The increase in separation is larger in a pure vertical landing than in a landing with forward speed. Although the increase in blade/tail boom separation is smaller, the contribution of the interconnected landing gear during forward speed autorotation landings is significant because it eliminates blade/tail boom contact in a landing where contact has been recorded.

The lateral interconnection of the landing gear produces the same increase in helicopter controllability during autorotation with roll as does the fore and aft interconnection in pitch.

To verify the predicted benefits, an experimental study was conducted. Utilizing the preliminary design findings,[1] a full-scale skid-type landing gear was designed and fabricated to be capable of alleviating the landing loads and moments associated with both normal and hard landings. The landing gear incorporated both pitch and roll hydraulic interconnect systems which distribute and attenuate the landing impact energy between landing gears to minimize both rolling and pitching moments. The landing gear was designed by Hughes Helicopters and fabricated by the Western Development Center of MOOG, Inc.

The landing gear was drop tested to demonstrate the effects of sink rate, gross weight, CG location, touchdown attitude (both pitch and roll), ground resonance, system damping and spring rate. The testing included drop velocities of 6.5, 8.2, and 19.5 feet per second; design (2550 pounds) and overload (2880 pounds) gross weights; simulated forward and lateral speed landings; maximum fore and aft CG locations; and noseup, level, and

1. LOGAN, A.H., "Analytical Investigation of an Improved Helicopter Landing Gear Concept," USAAMRDL-TR-76-19, August 1976, U.S. Army Air Mobility Research and Development Laboratory, Ft. Eustis, Va., AD A029372

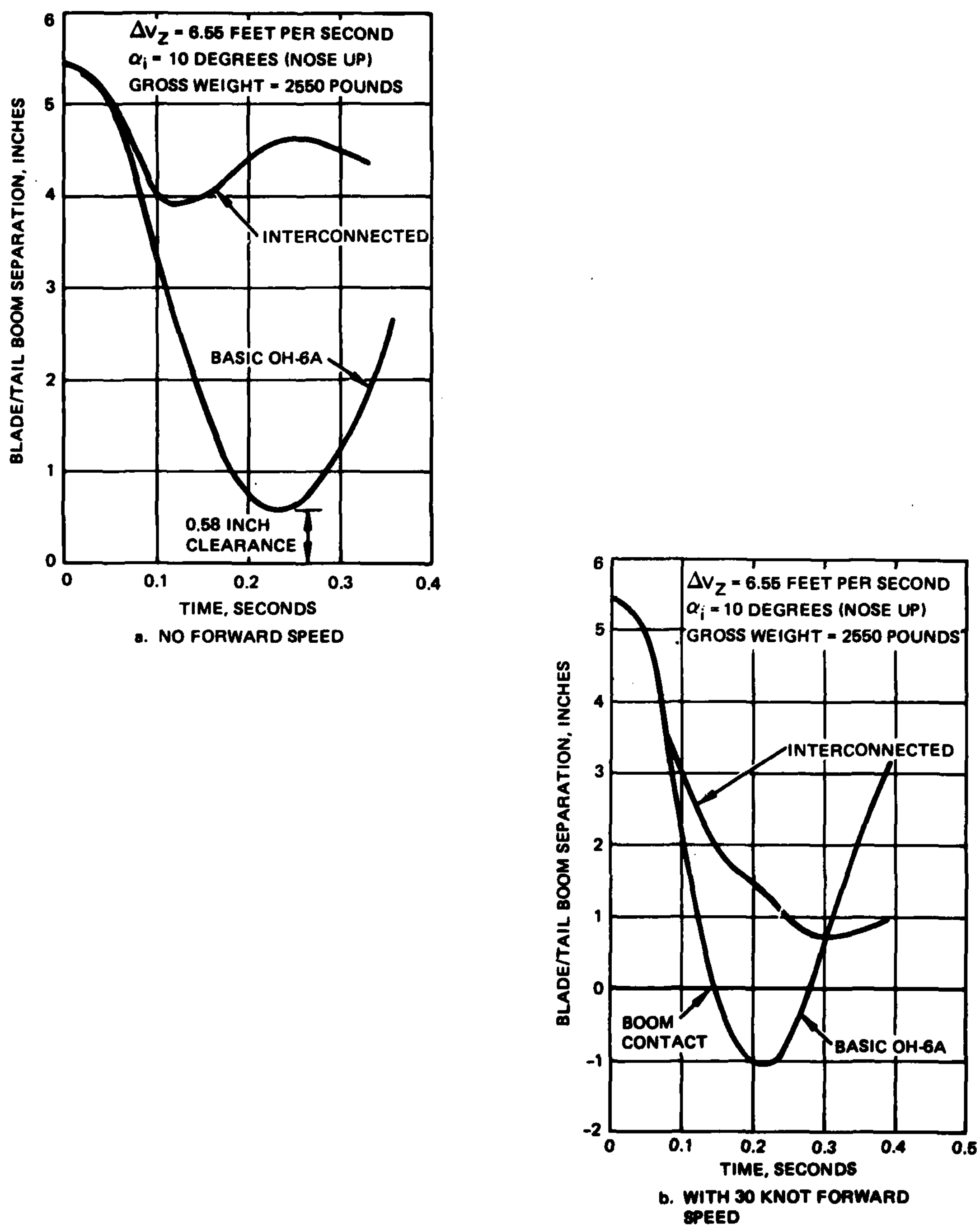


Figure 1. The interconnected landing gear increases blade/tail boom separation and eliminates contact.

nosedown, and roll landing attitudes. For purpose of design and development, the OH-6A helicopter was used as the baseline aircraft, and the landing gear was designed to require minimum modification to the OH-6A. An existing OH-6A landing gear drop test fixture was used for the tests. Although the gear was designed for the OH-6A, the basic design principles developed also apply to wheel-type landing gear. The difference is that, in wheel-type gear, the interconnected front and rear supports are attached to independent wheels and not a skid tube common to all supports.

The results of the testing were compared to the basic OH-6A helicopter test data, and landing gear performance improvements were determined. A cost/benefits study was then conducted to determine the impact of the interconnected landing gear on the OH-6A cost, reliability, and maintainability characteristics.

INTERCONNECTED LANDING GEAR DESIGN

The test configuration landing gear is a skid-type landing gear incorporating both pitch and roll hydraulic interconnect systems. The OH-6A is the baseline aircraft and the test landing gear is designed to require minimum modification to the OH-6A. The complete design development of the interconnect system is presented in Reference 1 and a description of the test configuration is presented in the following sections.

PITCH INTERCONNECTION

The pitch interconnected landing gear is essentially the OH-6A landing gear with modifications as shown schematically in Figure 2. The basic OH-6A fuselage pivot points, drag braces, and skids remain unchanged. The front and rear oleo dampers (369H92131) now fit into new sleeves which are attached to the cross tubes. Each new sleeve provides an additional 1.74 inches of travel both up and down from the neutral position. The oleo damper upper attachment points are relocated from the basic OH-6A position to accommodate this additional interconnect travel. For each sleeve,

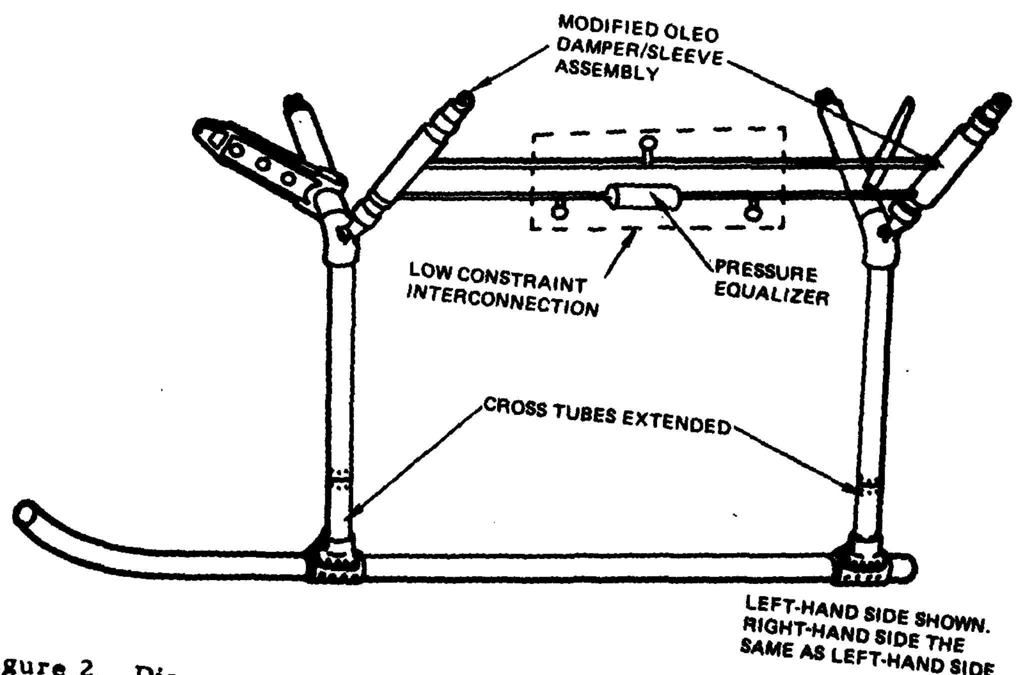


Figure 2. Diagram of pitch interconnected landing gear for the OH-6A.

two annular chambers filled with hydraulic fluid are formed by sealing the sleeve to the basic oleo damper (Figure 3). Matching hydraulic chambers on the front and rear damper/sleeve assemblies are connected through a low constraint interconnection system. The low constraint interconnection system is comprised of a pressure equalizer (Figure 4), and two surge reservoirs. The pressure equalizer is a spring/piston assembly which connects the lower hydraulic chambers on the front and rear damper/sleeve assembly. In a nose-high landing when the aft skid experiences high force and the forward skid little force, the aft skid hydraulic chamber is compressed, forcing hydraulic fluid out of the lower aft chamber, into the pressure equalizer. This creates unequal pressure in the pressure equalizer, moving the piston forward and forcing hydraulic fluid into the lower forward chamber. This causes the forward skid damper to extend down while the aft skid damper compresses upward.

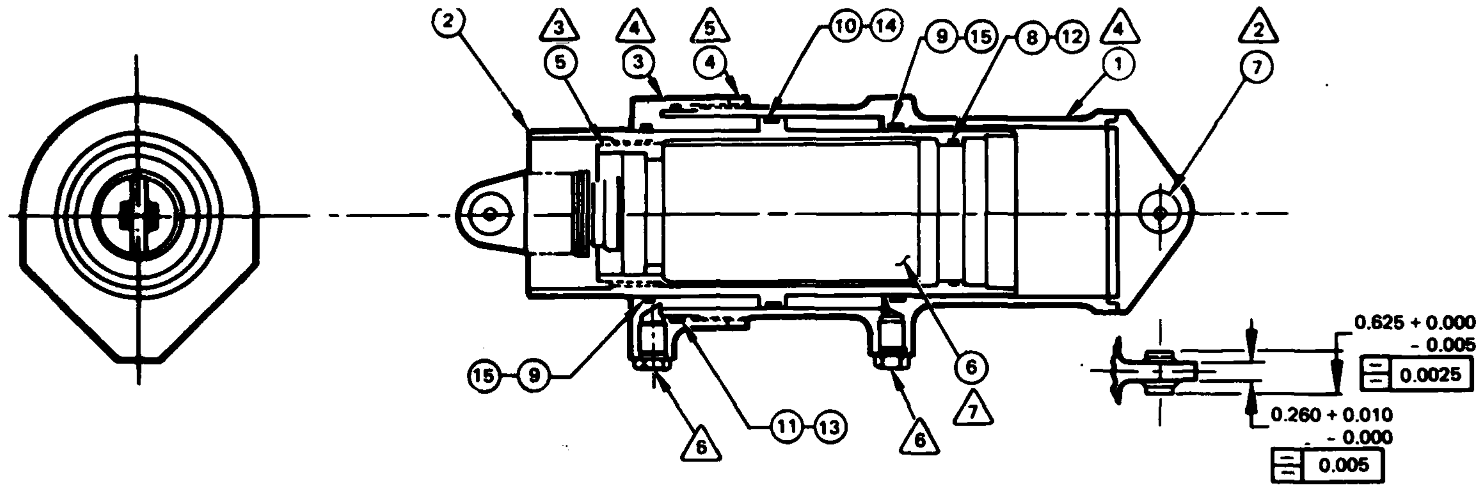
The interconnect system spring rate and damping characteristics were changed by modifications to the pressure equalizer. With reference to Figure 4, the spring rate was changed by installing different springs in the pressure equalizer. Two spring rates were tested: 17 pounds per inch and 11 pounds per inch, giving system spring rates of 34 and 22 pounds per inch, respectively. The damping was changed by installing a different diameter orifice in the piston face. Two orifice diameters were tested, 0.128 and 0.059 inch.

ROLL INTERCONNECTION

The roll interconnection of the landing gear is accomplished in a manner similar to the pitch interconnection shown in Figure 2. For roll interconnection, two additional pressure equalizers are needed: one interconnecting the front modified damper/sleeve assemblies and one between the rear damper/sleeve assemblies.

SYSTEM INSTALLATION

The complete pitch and roll interconnection system installation is shown in Figure 5. There are four pressure equalizers, four surge accumulators, and one reservoir. The surge accumulators are used to limit line pressure and are placed on each side of the pressure equalizers and are connected by a dual flow valve simulation using check and relief valves in parallel. The relief valve allows flow into the accumulators when the line pressure exceeds 1200 psi. The check valve allows flow out of the accumulator when the line pressure is below 100 psi. The relief valve pressure is set so that when the landing gear is on the ground, the damper/sleeve assembly

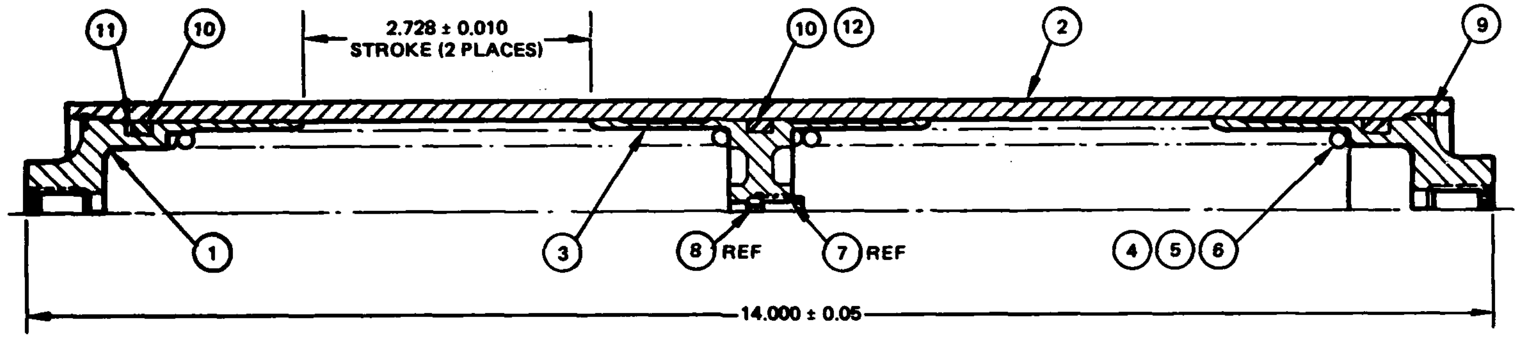


NOTES:

1. INSTALL ITEM 16 (NAMEPLATE) IN LOCATION SHOWN.
2. INSTALL ITEM 7 (BEARING) IN ITEM 1 (CYLINDER WELD ASSY) AND STAKE TO NOTED DIMENSION WITH TOOL NO. A10712 TO 50 FT-LBS MAX.
3. PROVIDE ONE DROP OF LOCTITE 242 ON ITEM 5 (JAM NUT) AND TORQUE TO IN-LBS.
4. TORQUE ITEM 1 (CYLINDER WELD ASSY INTO ITEM 3 (END CAP) TO 50 FT-LBS.
5. TORQUE ITEM 4 (LOCKING NUT) TO 50 FT-LBS.
6. INSTALL SHIPPING PLUG IN HYDRAULIC PORT ITEM 1 (CYLINDER WELD ASSY) AND ITEM 3 (END CAP).
7. THIS ITEM PROVIDED BY HUGHES TOOL COMP, AIRCRAFT DIVISION, CULVER CITY, CALIFORNIA.
8. LOCKWIRE PER SPEC MS33540 USING ITEM 17.
9. INSTALLATION DWG NO. 15 A10661

NO.	QTY.	PART NO.	NOMENCLATURE
1	1	A10651-1	CYLINDER ASSY
2	1	A10652-1	PISTON ASSY
3	1	A10653-1	END CAP
4	1	A10659-1	LOCKING NUT
5	1	A10654-1	JAM NUT
6	1	3691192131	DAMPER ASSY
7	1	ABYT-5	BEARING
8	1	MS-28775-142	O-RING
9	2	MS-28775-233	O-RING
10	1	MS-28775-235	O-RING
11	1	MS-28775-238	O-RING
12	1	MS-28774-142	BACKUP RING
13	1	MS-28774-238	BACKUP RING S-11248-
14	1	S30661-235N	DOUBLE DELTA
15	2	S30651-233N	DOUBLE DELTA
16	1	074-20082	NAMEPLATE
17	2	090-06204	DRIVE SCREW
18	A/R	MS209950-29	LOCKWIRE
		A10660-1	LANDING SKID DAMPER ASSY

Figure 3. Modified damper/sleeve assembly.

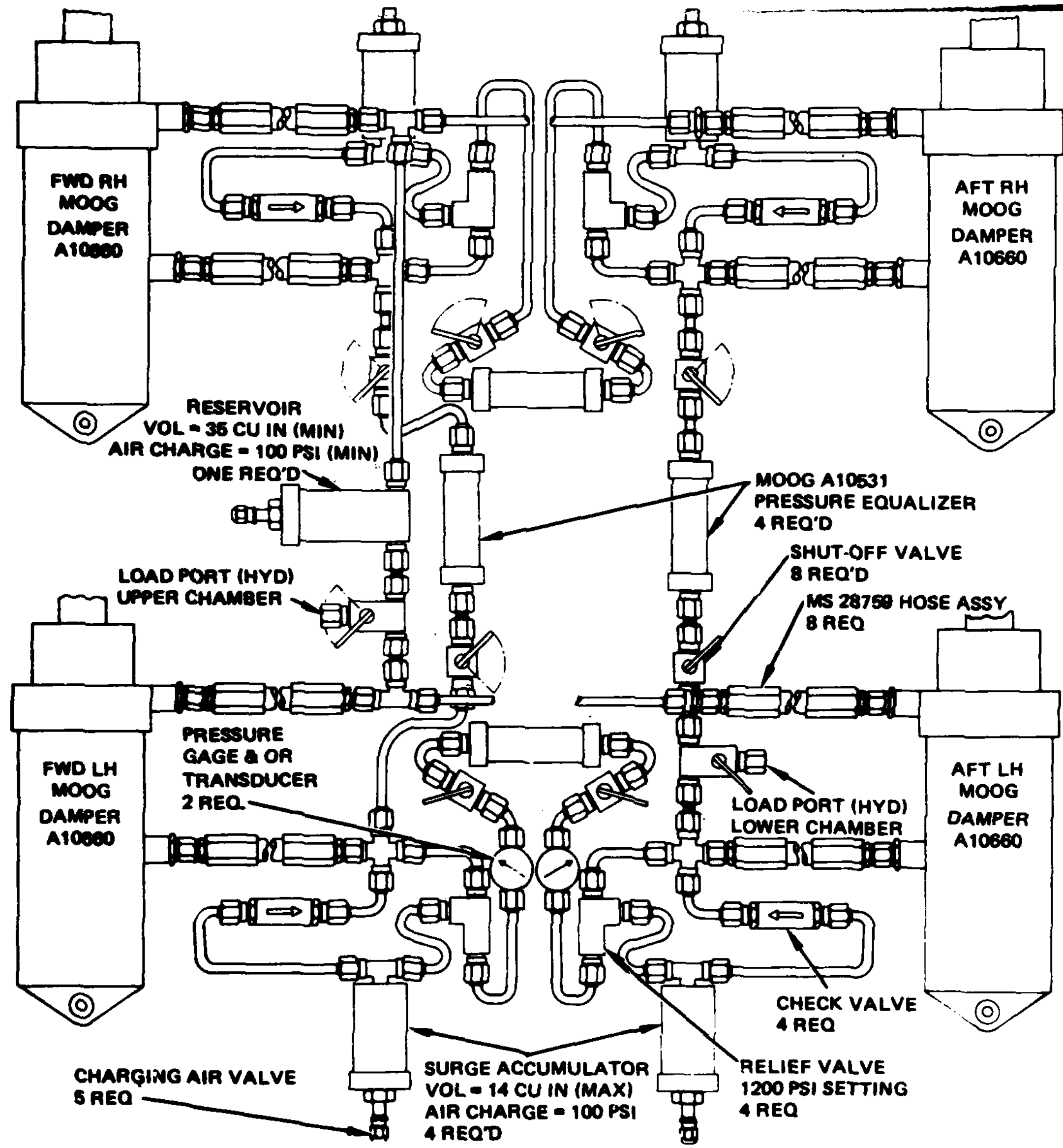


NOTES:

1. TOTAL VOLUME DISPLACEMENT = 13.0 IN^3
2. DISPLACEMENT = ± 2.728 IN
3. MEDIUM = HYDRAULIC OIL (MIL-H-5606 OR EQUIV)
4. PISTON AREA = 2.38 IN^2
5. SPRING RATE FOR -1 = 17.0 #/IN
   -2 = 11.3 #/IN
   -3 = 5.6 #/IN

NO.			QTY.	PART NO.	NOMENCLATURE
1	2	2	2	A10533-1	END CAP
2	1	1	1	A10534-1	TUBE
3	1	1	1	A10538-1	PISTON ASSY REF
4			2	A10532-1	SPRING
5		2		A10532-2	SPRING
6	2			A1053-3	SPRING
7	1	1	1	A10536-1	RETAINER
8	1	1	1	A10537-1	ORIFICE
9	2	2	2	RRT-181	RING - SPIROLOX
10	3	3	3	MS-28775-222	O-RING
11	2	2	2	MS-28774-222	BACKUP
12	1	1	1	530661-222	DOUBLE DELTA
				A10531-1	PRESS EQUALIZER ASSY
				A10531-2	PRESS EQUALIZER ASSY
				A10531-3	PRESS EQUALIZER ASSY

Figure 4. Pressure equalizer.



NOTE: UNLESS OTHERWISE SPECIFIED:

1. ALL HYD LINES TO BE ¼ HIGH PRESSURE MS FLARED TO MATCH MS33656-4 AND INSTALLED PER MS 21344-4
2. THE HYDRAULIC FLUID SHALL BE EITHER MIL-H 5606 OR MIL-H 6083
3. BLEED SYSTEM BY CRACKING NUT WITH HYD PRESSURE

Figure 5. Hydraulic schematic of interconnected landing gear installation.

would be in a neutral position, providing approximately 1.75 inches additional damper travel up and down. The reservoir is connected to the upper hydraulic chambers of the damper/sleeve assemblies, is pressurized to 100 psi, and is installed to prevent cavitation in the upper chambers.

Each pressure equalizer was connected to the system by valves so that the removal of the pressure equalizers did not require replumbing the entire system. Hydraulic fluid was fed into the system by two valves, one for the upper hydraulic chambers and one for the lower hydraulic chambers.

SYSTEM WEIGHT

The experimental prototype interconnect system was designed to be simple and low in cost while retaining the dynamic characteristics of a more complex flightworthy installation. Consequently, no effort was made to design small, lightweight components. The weights of the prototype interconnect system's major elements are presented in Table 1. Comparisons to the weights of a basic OH-6A and a production version of the interconnect system are also presented. Only the major elements of the system

TABLE 1. SYSTEM WEIGHT

Item	Basic OH-6A Weights, lb	Interconnect Landing Gear weights, lb	
		Production*	Prototype
Dampers (4)	6.4	17.2	56
Surge Accumulators (4)	0	4.0	20.9
Reservoir (1)	0	1.5	7.0
Pressure Equalizers (4)	0	10.8	15.0
		+27.1	+92.5

*From Reference 1

are shown due to the difficulty of obtaining an accurate weight of the prototype plumbing. As shown in Table 1, the prototype interconnect system developed for this test weighed 92.5 pounds more than a basic OH-6A landing gear. In production, however, where more efficient and compatible components would be designed, the system elements would add no more than 27.1 pounds to the aircraft basic weight. As an example of where component weight could be reduced by more efficient design, the four surge accumulators and one reservoir used in the prototype system were off-the-shelf items. These items were made of cast iron, had more capacity than needed, and were developed for industrial applications. The dampers and pressure equalizers were designed similarly. There was no machining of excess material to reduce weight and a complex analysis was not conducted to determine minimum wall thicknesses. A production version would incorporate both additional machining and detailed analysis resulting in reduced weight.

TEST EQUIPMENT AND INSTRUMENTATION

A complete description of the test equipment and instrumentation is presented in the test report (Appendix A). This section contains a summary of the test equipment and instrumentation.

TEST EQUIPMENT

The experimental landing gear consisted of the interconnected landing gear system, described previously, mounted on an OH-6A extended length landing gear. The experimental landing gear was mounted on the test fixture as shown schematically in Figure A-3.

With the landing gear installed, the test fixture simulates the helicopter weights, moments of inertia, and CG locations by relocating ballast attached to the fixture at designated weight pan positions. Simulated rotor lift is applied through the CG of the drop test fixture by the use of test linkage connected to a special air cylinder – tank absorbing system mounted on the test gantry as shown in Figure A-3. The downward drop velocity is controlled by changing the free drop height. The required drop height is obtained by a second hoisting mechanism (other than the simulated rotor lift hoist) located between the test fixture and the overhead electric hoist on the gantry as shown in Figure A-3. This mechanism, which supports the test specimen until drop time, provides for remote air actuation of the safety pin and release hook.

The landing attitude, forward speed, and lateral speed are simulated by the orientation and composition of the impact surfaces. A typical test setup for a forward speed landing with a pitchup attitude is shown in Figure 6. Forward speed is simulated through the use of an inclined landing platform with a rusty steel surface (coefficient of friction equals 0.5), as shown in Figure 6. Reaction components are normal and parallel to the surface as with drag induced by forward velocity. Landing attitude is measured relative to the landing platform with a pitchup attitude relative to the inclined surface being shown in Figure 6. To simulate a landing with lateral speed, a plywood platform and side ramp (Figure 7) were used to produce a vertical right skid reaction and a left skid outboard reaction equal to approximately 50 percent of the vertical reaction.

INSTRUMENTATION

The instrumentation was installed to substantiate the landing gear design and functional behavior. The data collected included the axial and vertical forces for forward and aft struts and drag braces. All four oleos were

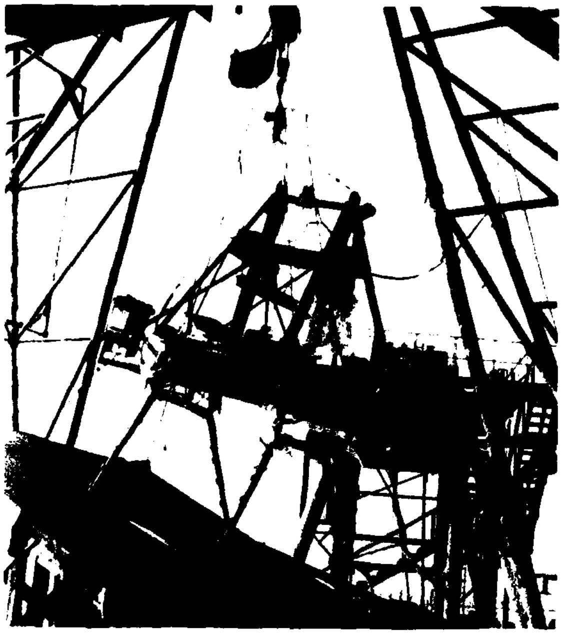


Figure 6. Typical test setup to simulate a forward speed landing with pitchup attitude.

instrumented for position and loads. All four modified oleo sleeves were also instrumented for position to determine interconnect movement. Pitch and roll attitudes and rates as well as lateral and vertical accelerations were measured. Also, lift, contact velocity, and interconnect system pressure were measured. The exact parameters to be measured are identified by an "X" in Table 2 of the Engineering Test Request found in Appendix A, and the frequency response is listed next to each parameter.

The strut and drag brace forces were recorded by 120Ω strain gage bridges that were applied at the locations shown in Figure 8. The left-hand landing gear was fully instrumented. In addition, the right forward drag brace was instrumented for axial and vertical loads to measure differences with respect to the left side caused by the 6-degree offset of the left upper forward oleo attach position relative to the right upper forward oleo attach position. The right and left rear oleo attach positions are identical.

All four oleo loads were recorded by load cells installed between the oleos and the upper attachment fitting on the test fixture.

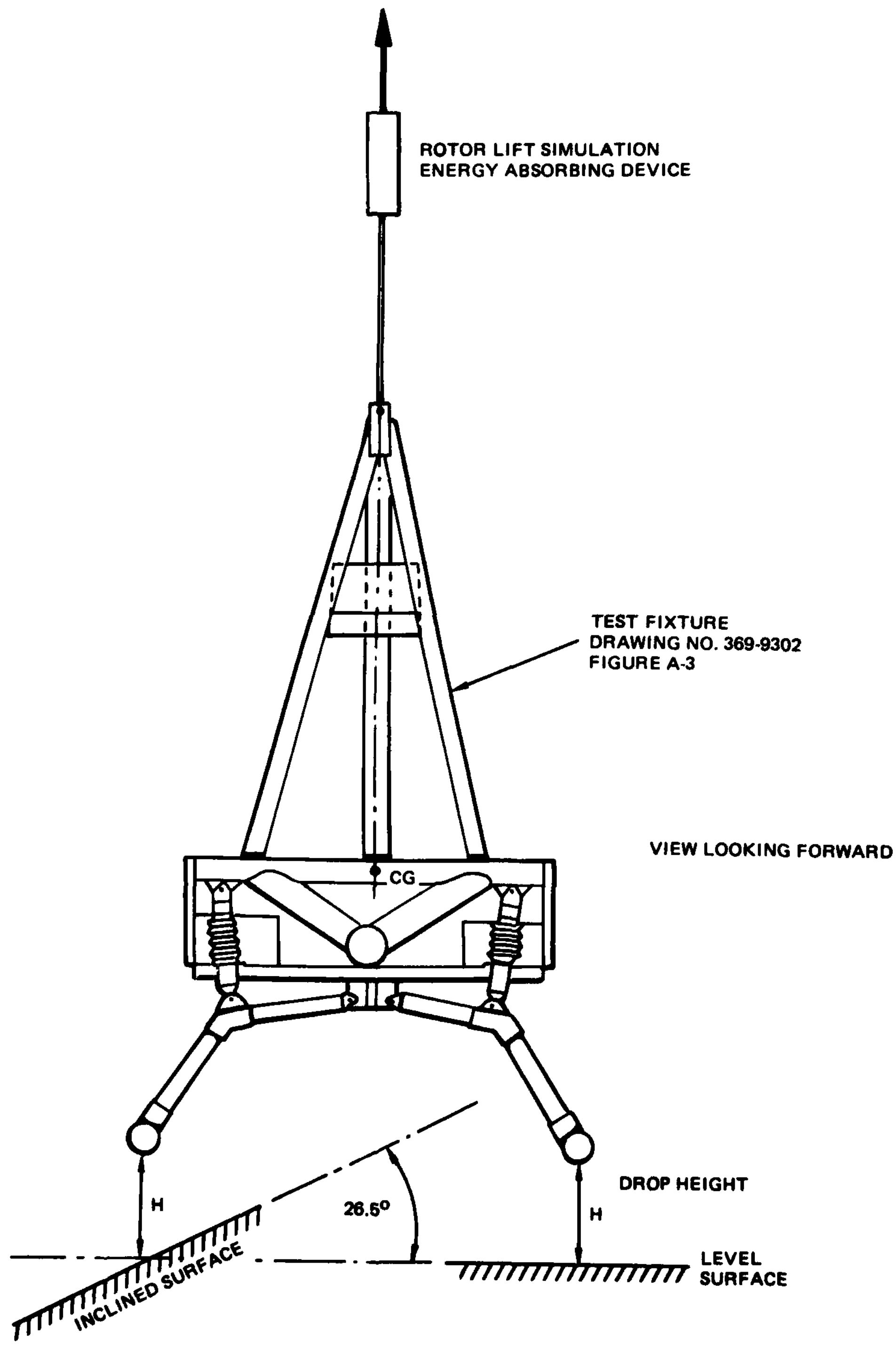


Figure 7. Test setup to simulate a level autorotational landing with lateral velocity.

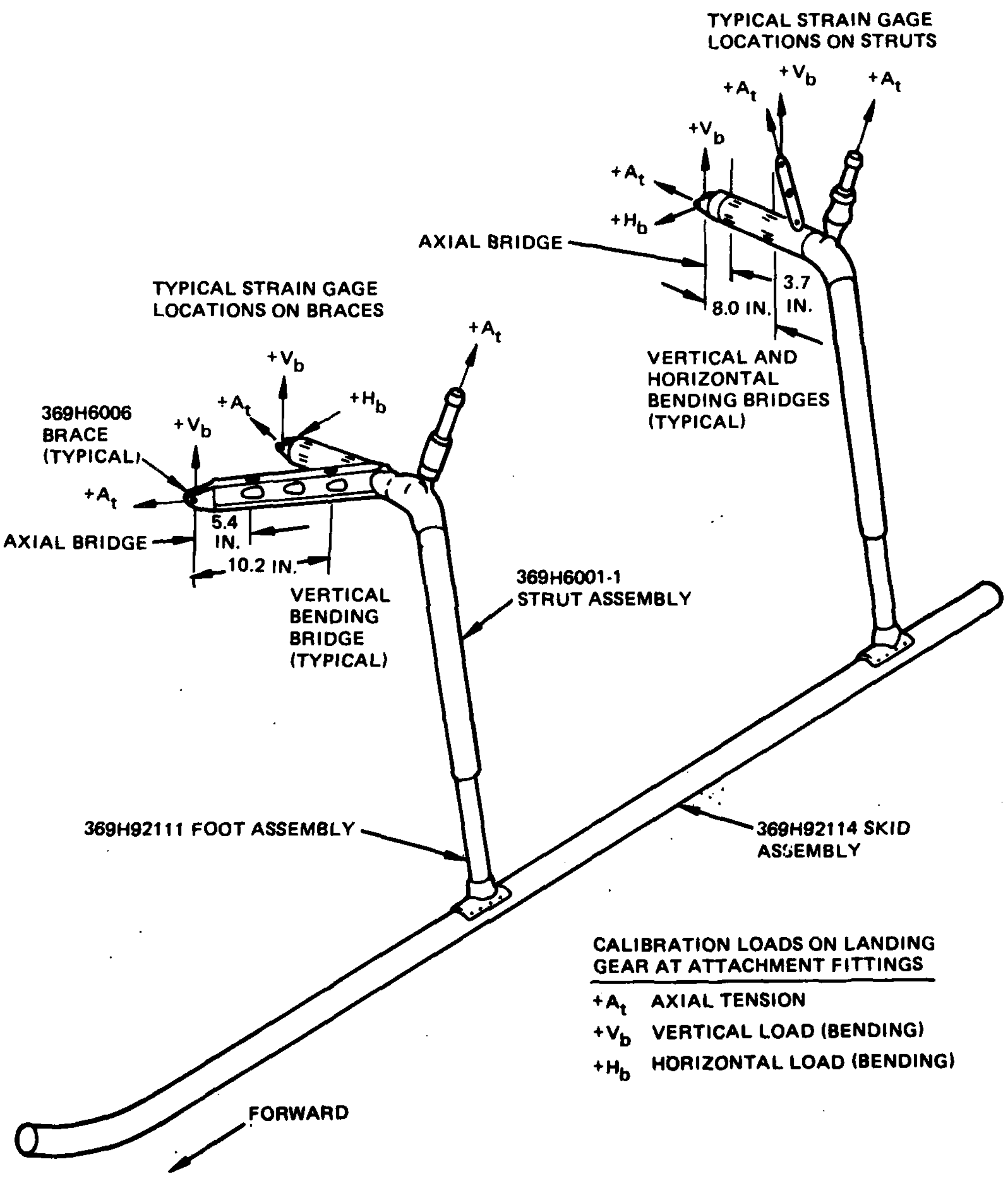


Figure 8. Strain gage locations.

The interconnect system is designed to move the landing gear relative to the fuselage. This relative motion allows the landing gear to be on the ground, reacting the landing force, without requiring corresponding motion of the fuselage. The motion of the landing gear relative to the fuselage was measured directly at all four damper/sleeve assemblies. The relative landing gear motion is comprised of two movements: the basic oleo piston stroke and the interconnect system movement. These two motions were measured by linear position transducers installed as shown schematically in Figure 9 and on the test fixture in Figures A-1 and A-2. The basic oleo piston stroke, Δ_1, was measured between the oleo upper attachment point and the inner barrel of the damper/sleeve assembly. The interconnect system movement, Δ_2, was measured between the inner and outer barrels of the oleo/damper assembly. By comparing the Δ_1 and Δ_2 motions of the four damper/sleeve assemblies, the motion of the landing gear relative to the fuselage was determined.

In addition, the complete interconnect system performance can be determined by combining the Δ_2 motion measurement with the line pressure measurements. The pressure measurements monitor the action of the accumulators. The surge accumulators were controlled by a pressure sensitive valve which opened when the line pressure exceeded the valve pressure setting, thus stabilizing the line pressure near the valve pressure setting. If the surge accumulators are closed, a compressive Δ_2 motion in the rear oleo/damper assembly is transmitted through the pressure equalizer and results in a Δ_2 extension in the forward oleo/damper assembly. If the accumulators are open, the compressive Δ_2 motion results in fluid flowing into the accumulators and does not result in Δ_2 extension in the front oleo/damper.

The interconnect system pressure was measured by two sensors, one on each side of the pitch interconnect pressure equalizers on the left-hand gear as shown in Figure 5. These pressure sensors monitored the operation of the dual flow valves and surge accumulators.

Both lateral and vertical accelerations were measured by standard linear accelerometers (55 mV/G approximately) installed at the CG of the test fixture.

Pitch and roll rate gyros were mounted near the test fixture CG to measure pitch and roll attitudes and rates.

The drop velocity was measured by the device depicted in Figure 10.

Simulated lift was measured by a load transducer situated near the test fixture CG as shown in Figure A-3.

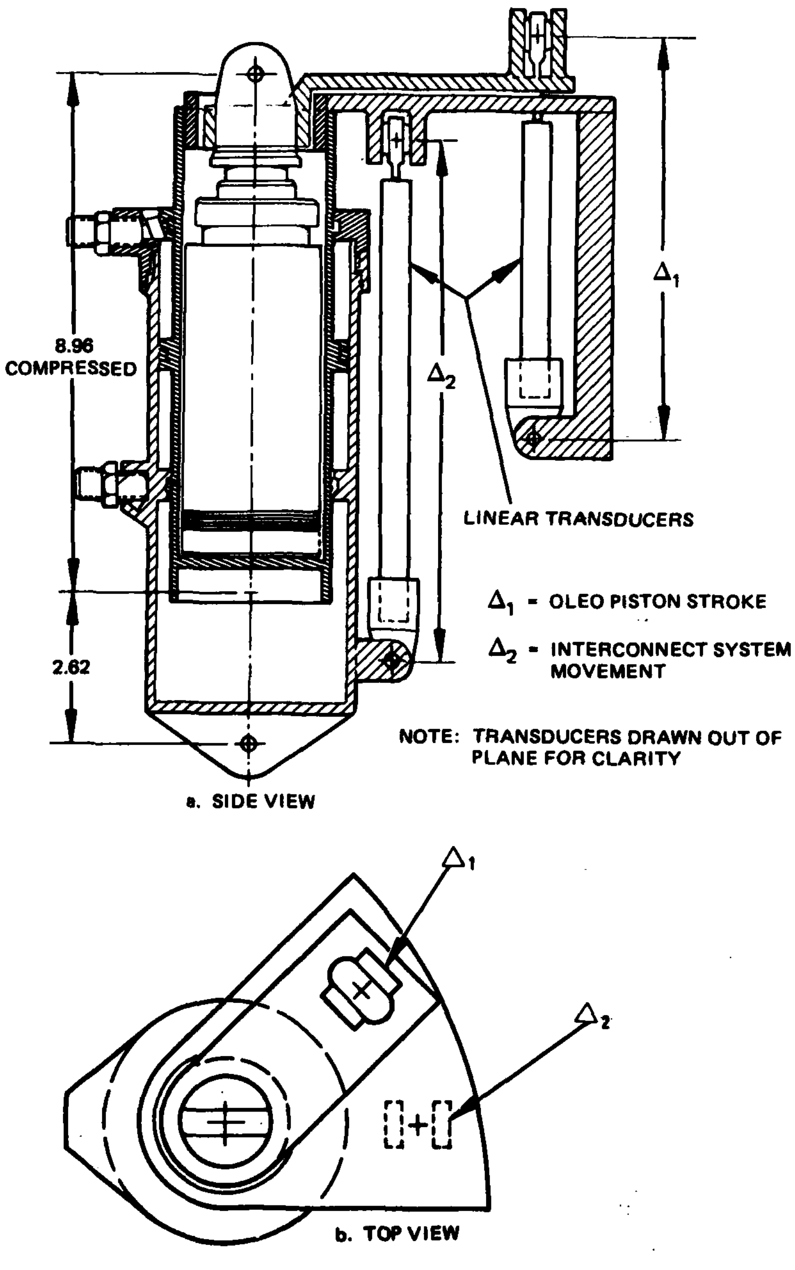


Figure 9. Schematic of modified damper/sleeve assembly instrumentation.

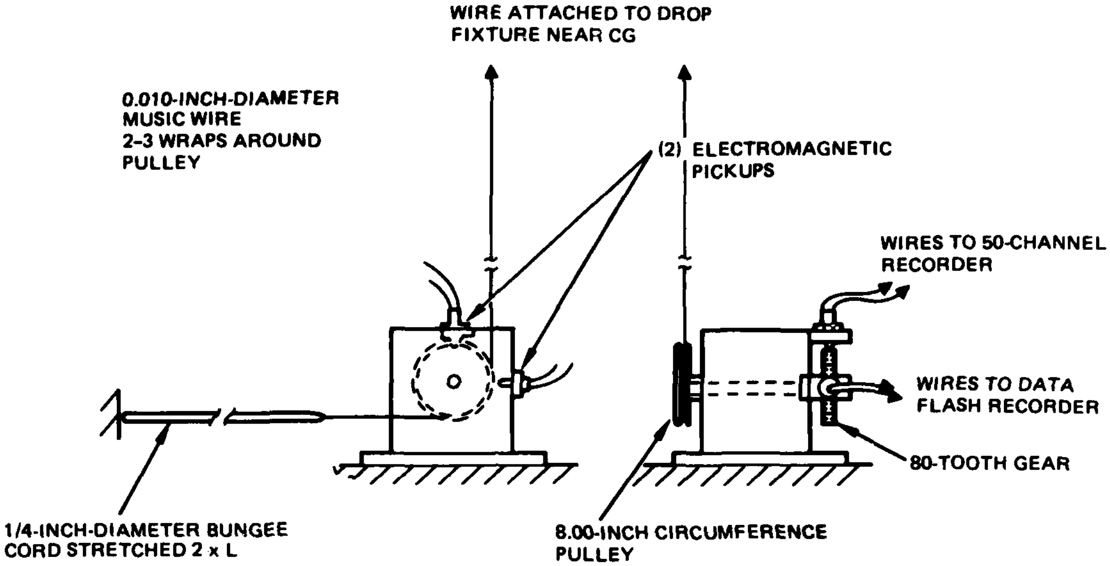


Figure 10. Velocity pickup operation.

A 50-channel visicorder with associated support equipment was used to record the output of the instrumentation during the test drops. The trace was made at 40 inches per second, allowing a resolution of at least 0.01 second. For each drop condition, the landing action was accomplished within one-half second.

The vertical impact velocity was recorded as shown in Figure 10. As the landing gear specimen fixture fell, the preloaded bungee cord reeled in the wire which rotated the pulley-gear combination. Since the pulley circumference equaled 8.00 inches and the gear has 80 teeth, the magnetic pickup(s) indicated one blip on the oscillograph record as 0.1 inch of drop height. The frequency of blips per unit of time (i.e., 1/200 second from 200 cycle AC signal) indicated a velocity at any instant of the drop. Two electromagnetic pickups were used for permanent and quick-look records of the contact velocities measured. The exact instant of contact was indicated by the accelerometers or the damper response.

Photographic coverage was made of all drop test conditions. The photographic coverage consisted of two 16mm motion picture cameras set up to record landing gear motion in two orthogonal planes. One camera was positioned in front of the test setup to record motion in the roll plane while the other camera was positioned to the right side of the test setup to record the motion in the pitch plane. Photographic coverage included a minimum of 100 feet of 400 frames per second coverage of each drop test condition.

TESTS

The testing was conducted in two phases: shake test and drop test. The shake test phase was conducted to explore the ground resonance characteristics of the interconnected landing gear. The drop test phase was conducted to explore the operation of the interconnected landing gear and its effect on the aircraft landing characteristics. A complete description of the tests is presented in Appendix A. This section is a summary of the tests conducted.

SHAKE TEST

The shake test was conducted at one gross weight, 2550 pounds, for no lift and 90-percent lift conditions. The interconnected landing gear was mounted on the drop test fixture which was, in turn, in ground contact through greased Teflon pads sitting on four steel plates. This simulated a friction-free contact. The shake test rig was oscillated through a range of frequencies (1 to 10 hertz) for a range of amplitudes (1 to 2 inches). The frequency range included the predicted[1] critical frequency of 1.3 hertz.

DROP TEST

The drop test was conducted over a range of conditions selected to represent the full range of operating conditions. The test conditions included the following:

a. Drop velocities of 6.5, 8.2 and 19.5 feet per second. These velocities represent the current OH-6A helicopter limit energy drop velocities, the reserve energy drop velocity, and the analytically determined maximum allowable drop velocity for the new landing gear, respectively.

b. Design and overload gross weights of 2550 and 2800 pounds, respectively.

c. Simulated forward and lateral speeds to OH-6A limit conditions.

d. Maximum fore and aft CG locations.

e. Level ground contact.

f. ±10 degrees pitch slope and ±10 degrees slope.

RESULTS AND DISCUSSION

The complete results of the shake test and drop test are presented in Appendix A, Structural Test Report. The results are presented in both tabular form and as time histories of all data recorded during the drop test. In this section, salient results of the testing are presented and discussed.

SHAKE TEST

No ground resonance point could be identified over the amplitude and frequency range tested. Possible ground resonance frequencies were identified in the range from 1.38 to 2.15 hertz. However, there was no consistency as test conditions were changed.

The ground shake testing did reveal the problem of putting the orifice in the pressure equalizer piston face. Prior to each test, the landing gear had to be centered manually. No attempt was made to correct the problem because it was felt that it would not affect the drop test results and because of schedule and budget constraints.

Due to the limited scope of the test program, the pressure equalizer was designed to be simple and inexpensive, yet retain the basic features of a more sophisticated system. Consequently, system damping characteristics were achieved by a simple orifice in the piston face. This design worked well in the dynamic mode but in static situations and during very slow movement, the orifice design compromised the interconnected landing gear concept. Since the fore and aft chambers were connected, during static conditions there was no counteracting centering moment. Consequently, if a static moment was applied (such as a man standing offset from the center of CG), one hydraulic chamber would eventually compress and the other extend without restoration to a neutral position when the moment was removed. In a more sophisticated production system, this characteristic would be eliminated by a more complex damping arrangement. One way of achieving damping, yet having static centering, is to have a movement sensitive orifice in the piston face. At low piston speeds, the orifice would be closed and at high speeds it would be open. Another method would be to have piston damping achieved by a system separate from the hydraulic interconnect system. Both of these concepts require further design effort.

Another ground resonance shake test would be required for this refined design of the interconnected landing gear.

DROP TEST

The primary drop test objective was to demonstrate that a hydraulically interconnected landing gear would reduce pitching and rolling velocities during autorotational landings. The data indicate that the interconnected landing gear does reduce pitching and rolling velocities resulting in more controllable autorotational landings.

The test results for both pitch and roll landing conditions were compared to predicted behavior from Reference 1. A comparison between predicted and measured pitch angle and velocities is shown in Figure 11. Due to instrumentation problems, the variation of the interconnected landing gear experimental pitch angle is calculated by integrating the measured pitch rate trace. The test data were recorded during a 6.25-foot-per-second drop with the test rig angled 10 degrees noseup relative to a 26.5-degree inclined surface. This condition simulates a noseup autorotation landing with forward speed. The test data indicate lower pitch rates than were predicted for the interconnected landing gear. This occurred due to two factors: First, based on other comparisons, the computer simulation is conservative in that it predicts slightly higher loads and rates than are measured. Second, the interconnect spring rate used in the test landing gear is lower than the spring rate used in the computer simulation which predicted the landing gear behavior. The lower spring rate was used in the experimental gear due to fabrication difficulties and size limitations associated with using the simulation spring rate.

In addition to predicted interconnected landing gear behavior, the predicted behavior for the basic OH-6A landing gear is presented in Figure 11. A comparison shows that the interconnected landing gear reduces the nose-down pitch rate by approximately 60 percent when compared to pitch rates predicted for the basic OH-6A landing gear. The basic OH-6A landing gear has not been tested for these conditions. However, during development of the computer simulation, which predicted the basic OH-6A landing gear pitch rates, good correlation was demonstrated between predicted and experimental behavior for other drop conditions. This is shown in Figure 12, which is taken from Reference 1. Consequently, it is felt that the experimental data for the OH-6A would be close to the predicted values if it was tested under the proper conditions. Consequently, the comparison of experimental and predicted pitching behavior results is a valid determination of the benefits of the interconnected landing gear.

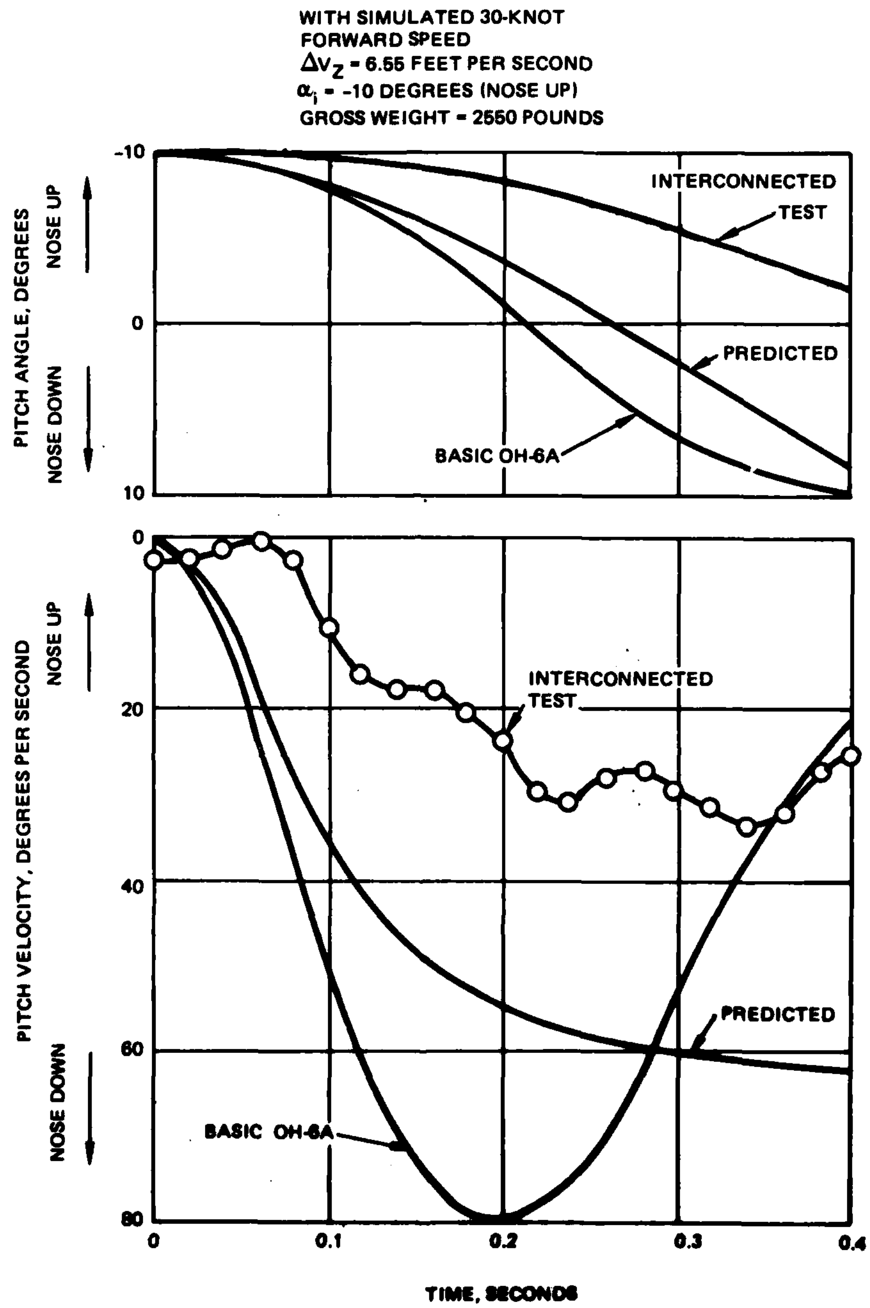


Figure 11. Effect of interconnected landing gear on pitch angle and velocity for a 6.55-foot-per-second vertical drop with simulated 30-knot forward speed.

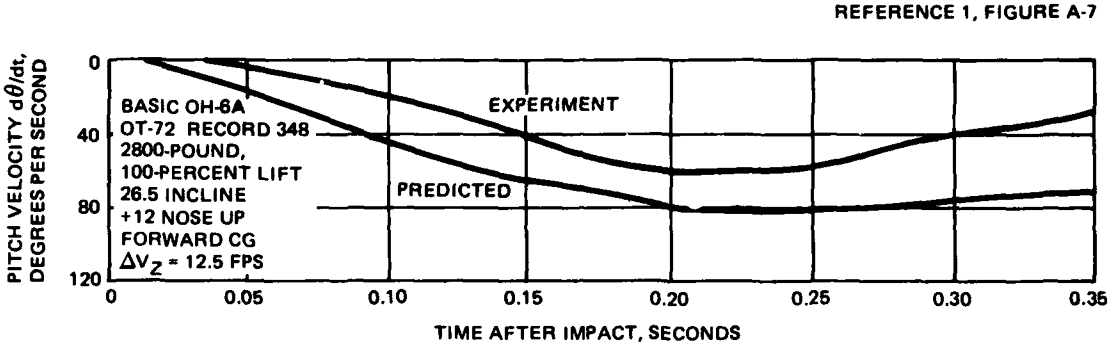


Figure 12. Comparison of theoretical and experimental pitch velocities for the basic OH-6A.

The benefits of the interconnected landing gear are also demonstrated during a level autorotation landing. A comparison of experimental data for the interconnected and basic OH-6A landing gear[2] is shown in Figure 13. The comparison shows that the standard gear pitches over sharply to approximately 5 degrees while the interconnected landing gear resulted in less than a 2-degree noseup attitude following the drop.

A further comparison to experimental landing gear data indicates that for a forward CG location the effect of interconnection is minimized. A comparison is shown in Figure 14 for the interconnected landing gear, the extended length landing gear,[3] and an improved OH-6A landing gear[4].

2. MAGULA, A. W., "369A6000B Production Landing Gear Drop Tests 2800 lb Gross Weight, using 369A6300 Dampers with 369A340-601 Bladders and 369ASK 150 Double Acting Dampers," Hughes Tool Company — Aircraft Division Report 369-BT-3609.

3. MAGULA, A. W., "369H90006 Regular Production Extended Landing Gear Drop Tests (2550 lb Gross Weight)" Hughes Tool Company — Aircraft Division Report 369-BT-3033, 1969.

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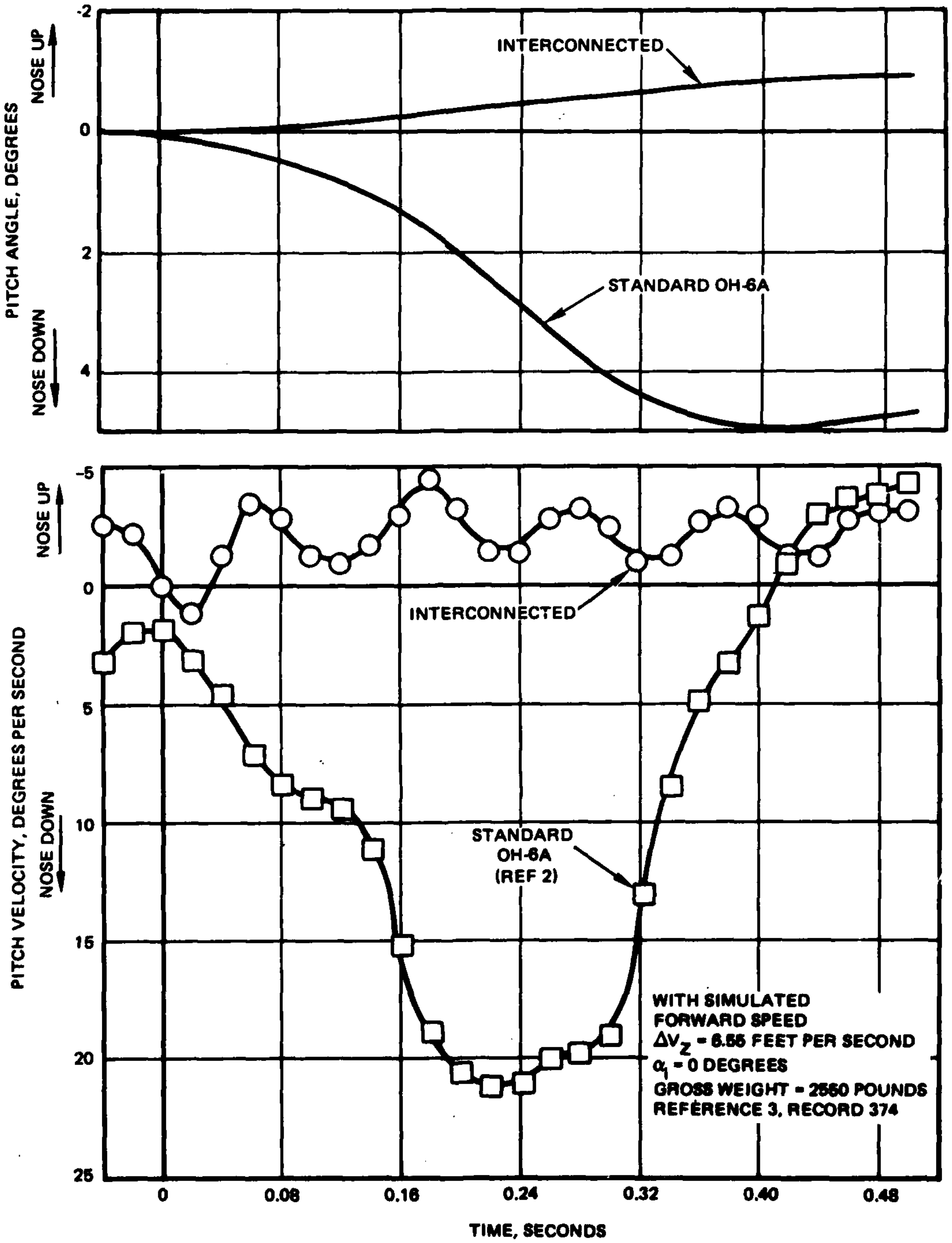

Figure 13. Comparison of pitch angles and velocities for the interconnected and basic OH-6A landing gear during a level autorotational landing.

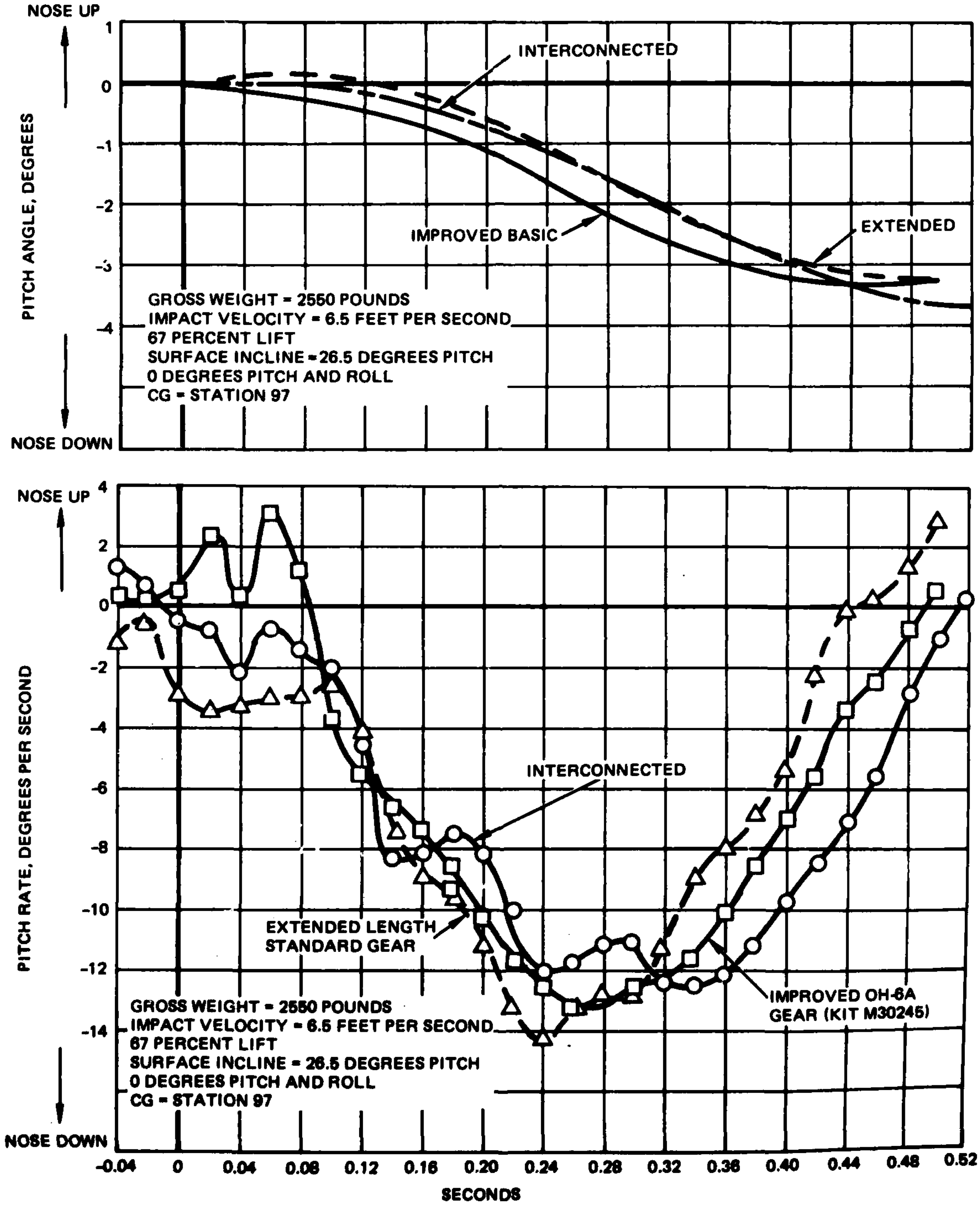

Figure 14. Comparison of experimental pitch velocities for extended length standard gear and interconnected gear during a level autorotational landing with forward CG.

The geometry of the extended length landing gear is essentially the interconnected landing gear without interconnection. The other difference is that the interconnected gear uses four 369H92131 dampers, while the extended gear uses 369H6340 dampers in the front and 369H92131 dampers in the aft struts. As compared to the basic OH-6A landing gear, the improved OH-6A landing gear (kit M30245) has a swivel joint at the aft cross tube-to-skid attachment and aft cross tubes with increased yielding capability. The comparison shows that for this drop condition, the performance is approximately equal for all three landing gears. The interconnected landing gear, however, did have the lowest pitching rate, approximately 12 percent less than the improved OH-6A landing gear.

In the roll mode, the drop test data indicate that increases in autorotational landing controllability are shown for the interconnected landing gear. As shown in Figure 15, for test condition 8 (6.5 foot-per-second impact velocity and 10-degree roll attitude), the roll interconnection reduces maximum roll velocities by 40 percent as compared to calculated maximum values for the basic OH-6A.

The dynamics of the interconnected landing gear system also result in the helicopter seeking a level attitude without overshooting, as shown in the top part of Figure 15. Due to instrumentation malfunction, the experimental roll angles are calculated using the measured roll velocities.

A comparison between experimental and calculated rolling velocities for the interconnected landing gear is also shown in Figure 15. The comparison shows that the experimental values are less than calculated primarily due to the lower interconnected spring and damping rates used in the experimental hardware. The reasons for this have been discussed previously during the discussion of landing gear pitching behavior.

Generally, the interconnected landing gear reacted dynamically as expected. The geometric action of the interconnected landing gear can be determined by examining the interconnected displacements shown in Table A-4. In the longitudinal axis for nose-high landings, both the rear right and left interconnect chambers compressed and the forward right and left interconnect chambers extended. The reverse was true for the nosedown landing. In level landings, all four interconnect chambers compressed. The compressions were generally unequal due to the aft CG location and slight roll and pitch angles at contact.

In the lateral axis for left skid down landings (condition 8), both the left fore and aft interconnect chambers compressed and the right fore and aft interconnect chambers extended. The interconnect action was also

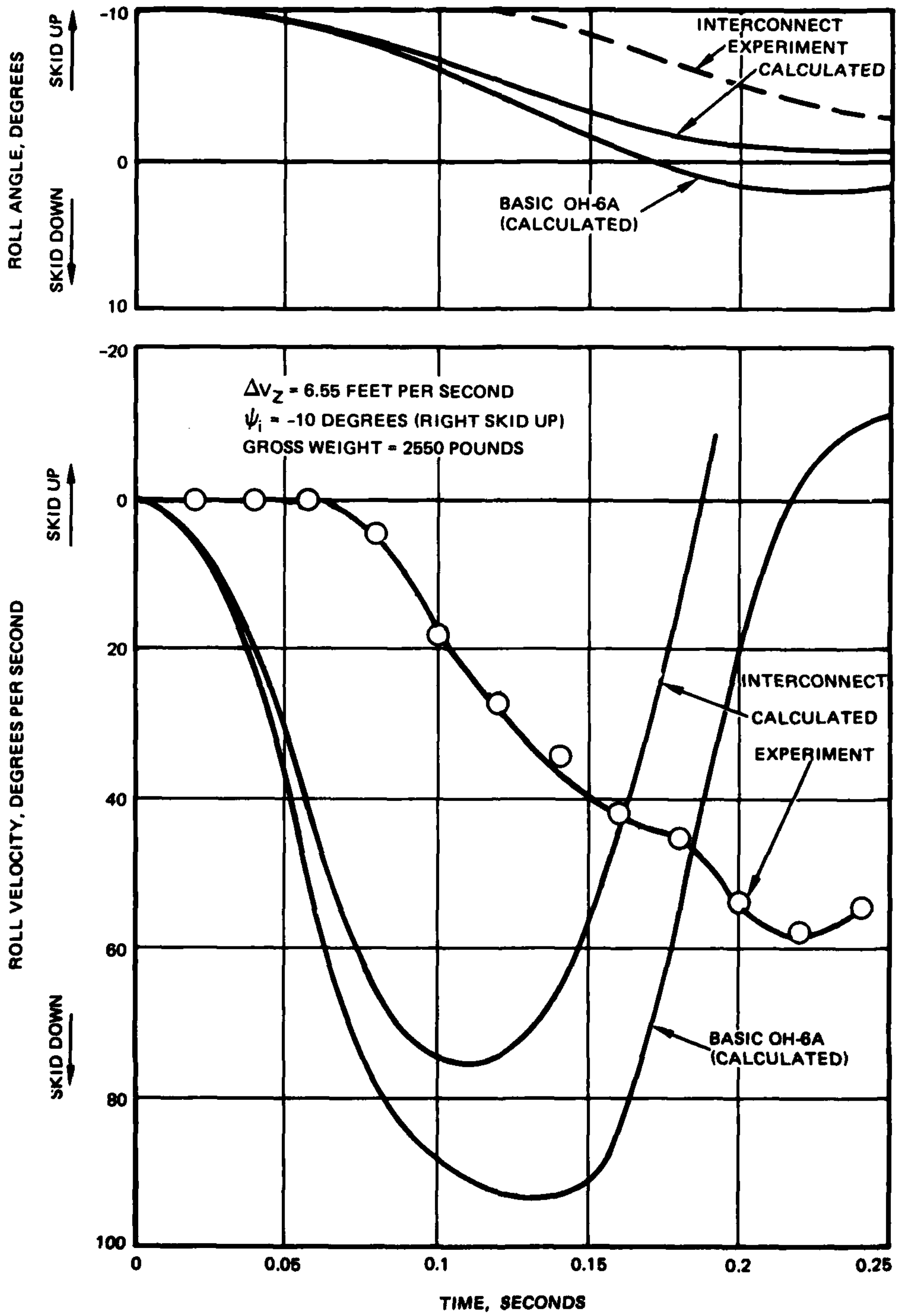

Figure 15. Effect of landing gear interconnection on roll angle and velocity for a 6.55-foot-per-second vertical drop.

evident in the simulated lateral speed landing (condition 6). In this mode, as shown in Figure 7, the right skid contacts first on a horizontal platform while the left skid contacts an inclined surface. For this condition, the right fore and aft interconnect chambers compressed and the left fore and aft interconnect chambers extended.

A detailed comparison of the interconnect action indicates that the extension was generally unequal and less than the compression interconnect movement. This is independent of landing attitude or test condition. Even in level landings with compression of all four interconnect chambers, the aft interconnect chamber compressed more than the forward chamber due to the aft CG location. The inequality of interconnect compression and extension was due to a combination of hydraulic fluid leakage and air trapped within the system. The sources of hydraulic fluid leakage were the pressure relief valve which was shown to have a slow leak during the shake tests. Another source of leakage may have been the seal between the upper and lower interconnect chambers. During some drop tests, a hydraulic mist was observed being expelled from the modified oleo dampers. In addition, the damping orifice in the face of the pressure equalizer piston also contributed to the unequal compression and extension. This design deficiency and the corrections have been discussed earlier.

The landing gear did not fail until the final drop condition, which was designed to evaluate the MIL-STD-1290 criterion of 20-foot-per-second contact velocity without fuselage impact. For this drop condition, the landing gear was dropped from a skid height of 6 feet, impacting at 19.2 feet per second in a level attitude. The lift load was approximately 75 percent of the desired level of 2550 pounds because the increase in drop energy exceeded the lift simulation capability of the system.

The results of the MIL-STD-1290 evaluation are shown in Figure 16 and in Figure A-12, A-13, and A-14. Three landing gear cross tubes yielded and the fourth fractured. Three of the four oleo dampers bottomed and the right forward oleo attach lug fractured.

The fractured cross tube was the right aft cross tube and it may have fractured for reasons other than the forces experienced during this drop. The data indicate that the maximum right aft oleo load was the smallest of the four oleo loads. The oleo load is a qualitative indication of the loads in the individual cross tubes. This implies that the fractured cross tube may have been affected by previous testing and cause it to fracture before the other cross tubes. If the drop test was repeated with fresh cross tubes, it is probable that all four cross tubes would have yielded but not fractured.

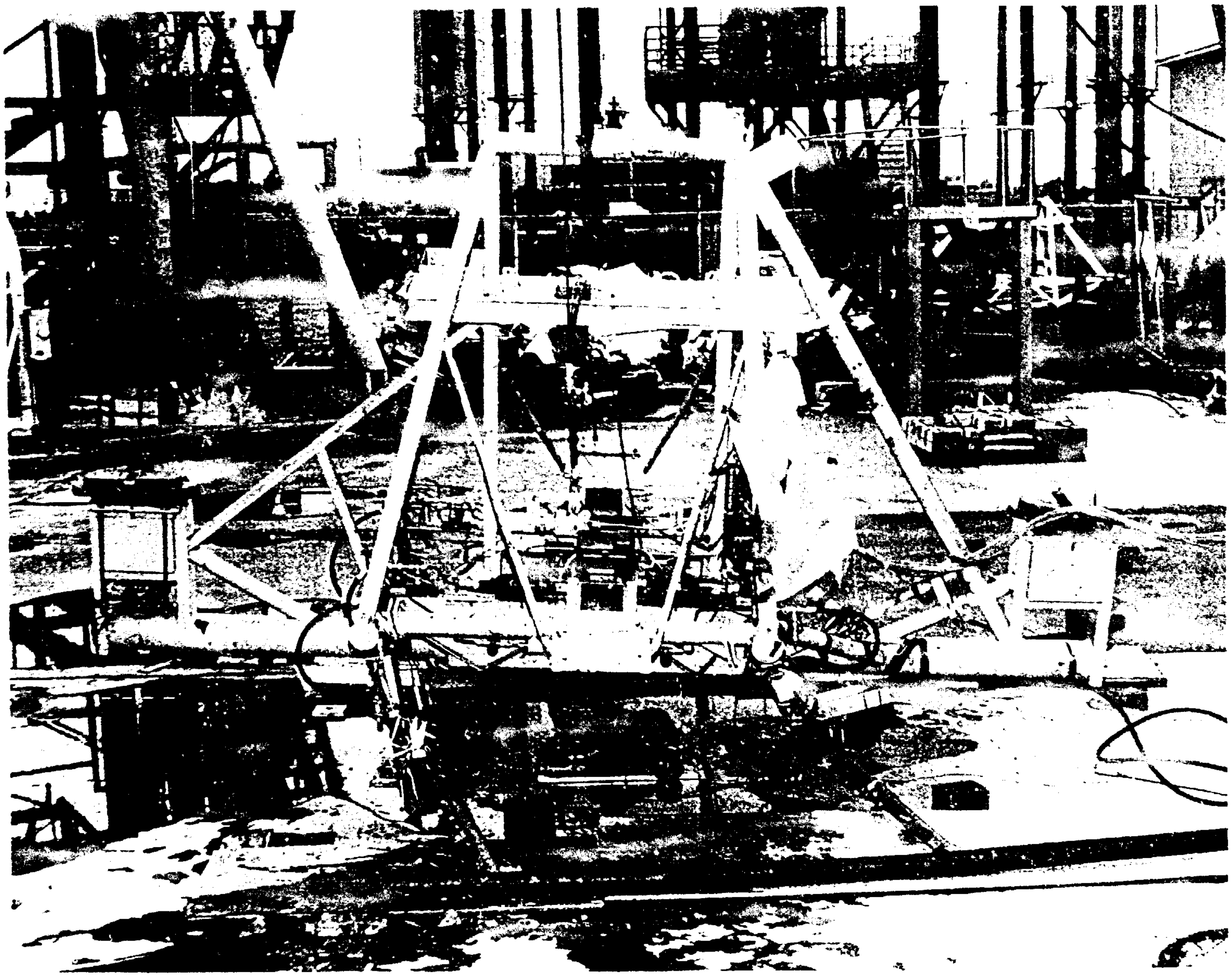

Figure 16. Interconnected landing gear after a 19.2-foot-per-second vertical impact.

The level of the oleo damper load is a strong indicator of the severity of the loads in the landing gear and its supporting fuselage structure. The data from Test Condition 12 indicate that the right front oleo maximum load was 10,002 pounds and the left front oleo maximum load was 6202 pounds. The present OH-6A is designed for a 6750-pound ultimate load in the front oleo. This value reflects a minimum ultimate margin of safety of 6 percent. As can be seen by comparison, the interconnect oleo damper loads exceeded or approximately equaled the OH-6A fuselage structural strength. In the case of the right front oleo, the oleo attachment lug was fractured during testing.

A comparison of front oleo loads indicates that the right front oleo was 3252 pounds overloaded with reference to the design ultimate load. This was caused by the fracture of the right aft cross tube and subsequent tilting of the helicopter. With reference to Figure A-26, the right front oleo experiences a sharp 3000 pounds overload in the hundredth of a second following the right aft cross tube fracture. The overload condition is terminated by the fracture of the oleo attachment lug. Consequently, it appears that the landing gear structural elements such as the oleo attachment lug and the cross tube are the limiting elements.

It is difficult to predict the probable performance of the interconnected landing gear in satisfying the 42-foot-per-second vertical impact requirements of MIL-STD-1290. Specifically, MIL-STD-1290 requires that the landing gear must be capable of decelerating the aircraft at normal gross weights from 20-foot-per-second downward vertical velocity without allowing the fuselage to contact the ground. The aircraft structure except the rotor blades and the landing gear shall be flightworthy after this impact.

The interconnect landing gear was predicted to have an energy-absorbing capability of 19.5 feet per second based on ground contact and predicted loads. The results of Test Condition 12 indicate that the interconnected landing gear would provide that capability based on ground contact. However, the loads exceeded the OH-6A fuselage design loads. The OH-6A landing gear was designed to absorb a 12-foot-per-second impact and the supporting structure designed accordingly. Consequently, the interconnected landing gear is limited to approximately 14 feet per second based on fuselage structural limits. (The 14-foot-per-second value is derived by interpolating between the maximum oleo loads measured at Test Condition 12, ΔV_2 = 19.2 feet-per-second, and Test Condition 7, ΔV_2 = 6.25 feet-per-second.) If the OH-6A structure is strengthened to accept the higher loads, the interconnected landing gear raises the OH-6A maximum energy absorption capability to 33.7 feet-per-second. If the structure is not strengthened, the capability is 30.9 feet-per-second, which is approximately the present design value for the OH-6A.

The maximum energy absorption for the OH-6A with the interconnected landing gear is determined using data and an analysis outlined in Reference 5. In brief, the analysis adds the increase in landing gear capability in the following manner.

$$(\Delta V_z)_{\substack{\text{OH-6A} \\ \text{with Int. L.G.}}} = \sqrt{(\Delta V_z)^2_{\text{OH-6A}} + (\Delta V_z)^2_{\substack{\text{Int.} \\ \text{L.G.}}} - (\Delta V_z)^2_{\substack{\text{OH-6A} \\ \text{L.G.}}}}$$

$$= \sqrt{(30 \text{ fps})^2 + (19.5 \text{ fps})^2 - (12 \text{ fps})^2}$$

$$(\Delta V_z)_{\text{OH-6A}} = 33.7 \text{ fps}$$

The load factors experienced during the final drop indicate that if the fuselage structure had been reinforced, a survivable landing with minor or no injury could have resulted. The peak load factor experienced at the CG was 5.49G. This peak value was a spike value superimposed on a mean load factor of 4.23G for approximately 0.20 second duration. Using the data on the limits of human tolerance to vertical deceleration as defined in Reference 6, it is seen that the mean load factor and its duration are within the boundary of minor injury (Figure 17).

LIFE-CYCLE COSTS

A detailed cost estimate was conducted for the interconnected landing gear to determine the benefits for both retrofit and forward production (initial installation) in the OH-6A. This section presents a summary of the analysis used, assumptions, and results. The detailed calculations can be found in Appendix B.

The analysis followed the procedures of a bottom-up approach rather than the technique of parametric relationships, such as changes in weight or piece part count. In support of the bottom-up approach, a document search and review was conducted to determine landing damper (or oleo) performance in the past in terms that would have bearing on operating and support costs. Failure modes, failure rates, remove and replace rates, and average time for maintenance action were included in the available information. This information along with an analysis of the

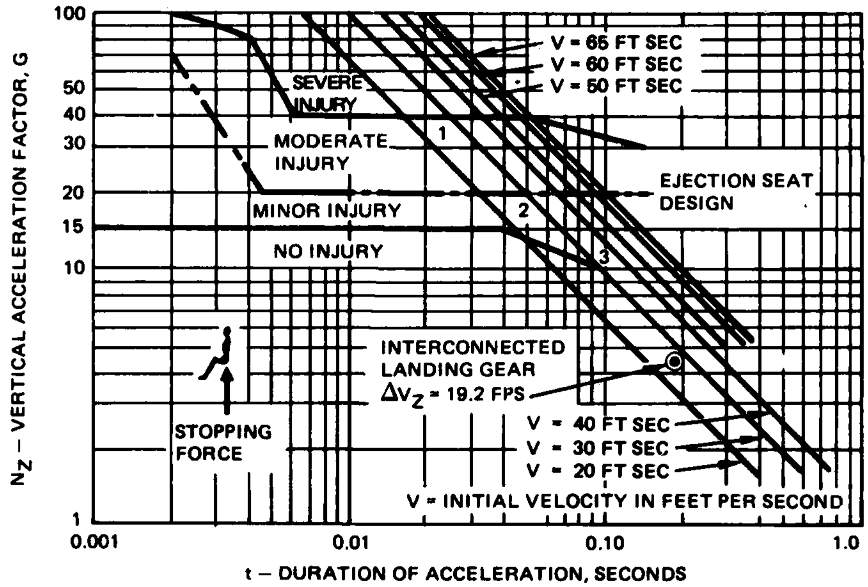

Figure 17. Limits of human tolerance to vertical deceleration (derived from Reference 6).

components and functional design, enabled prediction of the MTBF for the new configuration damper and an average MTBF for the other components of the interconnected landing gear system.

The cost of retrofit and forward production used in this analysis was generated by the HH DTUPC (Design to Unit Production Cost) group and represents an average unit production cost. Learning curve correlations were used with retrofit quantities of 100, 200, and 400 shipsets and with the forward production of 100, 200, and 500 shipsets.

The assumptions used in the analysis are generally conservative in that only blade/tail boom strike benefits were included. Increases in autorotational landing controllability due to pitch and roll interconnection were not included due to uncertainty in quantifying the benefits. All the assumptions are presented below.

- The increase in operating and support cost for the interconnected landing gear is due to an increase in unscheduled removals and replacements.

- The distribution of repair time for "On" aircraft and "Off" aircraft repairs is identical.
- The old-style damper replacement rate of 3.4/1000 hours is superseded by a projected new style damper replacement rate of 3.635/1000 hours.
- The additional hydraulic elements of the interconnecting design will have a combined replacement rate of 1.280/1000 hours.
- The mean MMH/UMA (Maintenance Man-hour per Unscheduled Maintenance Action) for each of the hydraulic elements of the landing gear is 3.5 hours.
- The inventory of OH-6As for retrofit consideration is 400 aircraft.
- The utilization of OH-6As after retrofit varies from 8 through 30 flight-hours per month.
- The service life of the OH-6As after retrofit is projected to be from 10 to 13 years.
- The maintenance float is 14.2 percent of the year-end inventory of aircraft. For flight utilization less than 20 hours/month the maintenance float is reduced proportionally.
- The mean retrofit and production rates for the OH-6A will be 100 aircraft per year (8.3 per month).
- The service life of new production OH-6As will be 20 years.
- Tail boom chops of OH-6A aircraft of the current configuration occur at a rate of once every 5600 flight-hours.
- Tail boom chop repair requires an expenditure of $30,968 (1972 dollars).
- Downtime for retrofit causes a loss of 24 flight-hours.
- Replacement part supply utilizes 20 percent new parts and 80 percent rebuilt parts.

- Increase in maintenance man-hour requirement is considered to be so small that it does not require additional numbers of maintenance personnel.

- The interconnected landing gear is effective in eliminating at least 80 percent of tail boom chops.

- All monetary calculations are based on 1972 dollar values.

The results of the analysis are summarized in Figure 18 and Table 2 for retrofit costs and in Table 3 for forward (initial) production. The analysis shows that the cost of the integrated landing gear is lower in forward production than in retrofit. This is because the expected life of the aircraft is longer (20 years versus 13 years), making greater cost benefits possible. The analysis shows that the cost of the interconnected landing gear adds $3, 000 (1972 dollars) to the cost of an OH-6A landing gear, but the reduction in tail boom chops and elimination of the associated repair costs offset the initial cost of forward production aircraft.

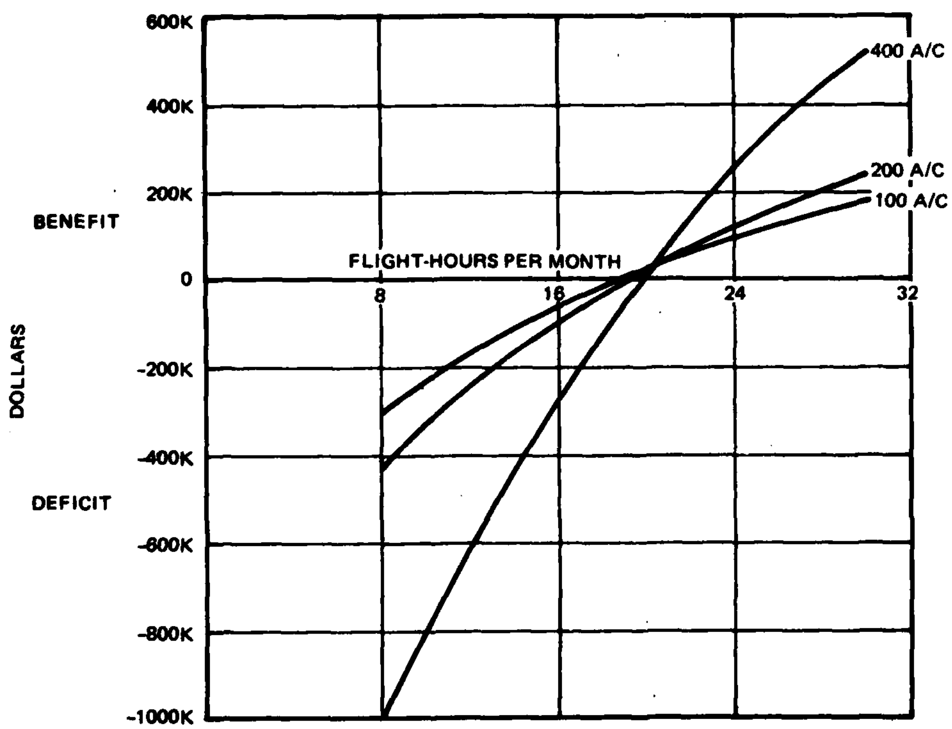

Figure 18. Cost savings of interconnected landing gear - retrofit aircraft.

TABLE 2. COST SAVINGS OF INTERCONNECTED LANDING GEAR FOR RETROFIT (1972 DOLLARS)

	100 A/C		200 A/C		400 A/C	
	10 years	13 years	10 years	13 years	10 years	13 years
8 hours/ month	-392,156	-298,826	-584,703	-423,208	-1,333,295	-993,077
20 hours/ month	-69,338	30,071		26,363		22,654
30 hours/ month	85,894	182,298		244,284		528,278

TABLE 3. COST SAVINGS OF INTERCONNECTED LANDING GEAR FOR FORWARD PRODUCTION (1972 DOLLARS)

Utilization Rate	100 A/C 20 years	200 A/C 20 years	500 A/C 20 years
20 hours/month	$784,658	$1,568,965	$4,312,039
Investment	336,700	673,400	1,683,500
Return on Investment (RDI)	2:1	2.3:1	2.6:1

The cost benefits of retrofitting the interconnected landing gear are dependent on the number of flight-hours. As shown in Figure 18, the cost reductions due to elimination of tail boom chops offset the cost of the interconnected landing gear when flight-hours exceed approximately 20 hours per month. The present OH-6A fleet are operated primarily in the National Guard, and monthly flight-hours are difficult to accurately estimate. Present estimates are approximately 8 hours a month, but there are indications that this will rise to 20 hours a month due to a greater military reliance on the National Guard. The effect on retrofit costs of a reduction in aircraft service life is shown in Table 1. When service life is reduced to 10 years from the assumed 13 years, the cost benefits are reduced. Again, service life is difficult to estimate due to uncertainty in National Guard usage.

The cost benefits of incorporating the interconnected landing gear in new production are shown in Table 3. In new production aircraft, use of the interconnected landing gear results in cost savings of up to $4,312,039 for a fleet of 500 aircraft. These savings represent a return on investment of from 2:3 to 2.6:1 in constant 1972 dollars relative to the initial cost of the interconnected landing gear.

CONCLUSIONS

1. The interconnected landing gear reduces the nosedown pitching velocities and angles during autorotation landings. In the particular case of a noseup landing with forward speed, the interconnected landing gear reduced the pitching velocities approximately 60 percent as compared to predicted values for the standard OH-6A landing gear.

2. The benefits of the interconnected landing gear are also found in the roll mode. In one case, the roll velocities were reduced 40 percent and attenuated over a longer time.

3. The landing gear was shaken over a wide range of frequencies and no resonance was identified.

4. As compared to MIL-STD-1290, the interconnected landing gear increases the landing gear absorption capabilities as compared to the standard OH-6A landing gear. An OH-6A equipped with the interconnected landing gear could absorb approximately a 33.7-foot-per-second impact without serious injury to the crew if the fuselage support structure was strengthened.

5. A cost analysis indicates that the incorporation of the interconnected landing gear in new production aircraft would result in savings more than twice the costs. Retrofitting the current OH-6A fleet with the interconnect landing gear would save money if the flight hours per aircraft exceeds 20 hours per month.

RECOMMENDATIONS

Based on the results of this effort, it is recommended that:

1. A wheel-type interconnected landing gear be designed and tested.

2. An interconnected landing gear be designed and tested for a Scout-type helicopter, such as the OH-58, with cross tube-skid landing gear.

3. A flight test version of the interconnected landing gear be designed, manufactured, and flown.

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APPENDIX A

INTERCONNECTED OH-6A LANDING GEAR DROP TESTS OF AN ENERGY DISTRIBUTION SYSTEM FOR HELICOPTER LANDING GEARS DURING HARD LANDINGS

1.0 INTRODUCTION

This appendix presents the results of drop tests to determine the structural integrity and functional response for the interconnected landing gear. All testing was accomplished within the Hughes Helicopters Complex. The ground resonant portion of the tests was discontinued after failure to obtain any resonant data. The drop tests were performed from 20 January 1977 to 27 February 1977 at Hughes Helicopters, Culver City, California.

2.0 TEST OBJECTIVE

The objective of these tests was to experimentally determine the structural integrity and functional response of the interconnected landing gear in the landing modes established in Reference 1.

3.0 DESCRIPTION AND LOCATION OF HARDWARE

An existing OH-6A drop test fixture was modified by lowering the brace and cross tube attachment points 1.72 inches. This allowed the installation of the four modified oleo dampers. The interconnect system also required four pressure equalizers, five surge accumulators, and four dual flow valves, which were installed per Drawings 369-ASK-2060 and 369-ASK-2058. Figures A-1 and A-2 show this system installed on the test vehicle.

The ground resonant test was conducted for the baseline configuration per the conditions in Table A-1. The interconnect spring constant was approximately 34 pounds per inch and the damping orifice diameter was 0.128 inch.

The drop tests were conducted according to the configurations defined in Table A-2.

Changes to the interconnect system included spring and damping variations. The center of gravity (CG) for the vehicle was FS 104 for all tests except Test Condition 5, which was FS 97. All gross weights were 2550 pounds except Test Condition 9, which was 2800 pounds to simulate overload.

3.1 Conformity

The simulated OH-6A test vehicle conformed to the test plan. The applicable drawings for the test configuration are as follows:

OH-6A Drop Vehicle	369-9302 SH-2
Shake Test Setup	999-0490
Hydraulic Schematic, Damper Interconnect Assembly	369 ASK 2058
Interconnected Landing Gear Installation	369 ASK 2060
Displacement Transducer Installation	999-0489

4.0 METHOD OF TEST

4.1 Shake Test

Input shake amplitudes, measured by a built-in linear variable differential transformer (LVDT), were used to control a hydraulic actuator installed between a test structure and the drop vehicle. A load cell in series with the actuator allowed simultaneous load monitoring. The capacity of this hardware was ±1000 pounds and a ±3-inch stroke.

A spectral dynamics sweep oscillator was used to input the stroke frequency. An MTS servo controller was used to monitor input and feedback from the actuator. Load and frequency were monitored on an X-Y plotter. An oscilloscope was used to obtain load-deflection Lissajous figures. The interconnect deflections, pressures, landing gear strain gages, accelerometers, lift load, and gyros were monitored on a 50-channel visicorder. Teflon rings were fastened to the skids at the aft and middle pad locations. The vehicle was placed on four greased steel plates. The lift load was applied through a torsion bar attached by a cable.

4.2 Drop Test

Drop tests were configured per the test plan. The vehicle was hoisted above the landing surfaces by a gantry located at remote Test Site 2. Figure A-3 shows a schematic view of a typical drop setup. The vehicle was released from an air-release hook mechanism, and free fall developed the required drop velocity. At a preset position, the lift beam begins to apply the lift load. An air cylinder, pressurized to a preset pressure, provides the simulated rotor lift while allowing the test vehicle to continue its descent. A hydraulic actuator attached between the lift beam and load cell is used to help dampen any oscillatory loadings that may occur during the sudden lift loading. The lift load cell attaches to the vehicle at the CG specified in the test plan.

The drop velocity is measured by a magnetic pickup that senses the rotating gear teeth. The gear is driven by a wire attached to the vehicle. This wire wraps around the gear's drive pulley and then attaches to a bungee cord which maintains tension. Table A-3 presents the ballast and locations to obtain the required CG for each configuration.

5.0 DATA ACQUISITION AND REDUCTION

5.1 Shake Test

Load versus frequency data was recorded on an X-Y plotter and load versus deflection data on an oscilloscope. A Polaroid camera was used to obtain a permanent record of the load-deflection Lissajous figures. The requested parameters pertinent to the interconnect system response were recorded on a 50-channel visicorder.

5.2 Drop Test

All parameters listed in the test plan were recorded on a 50-channel visicorder. High-speed photography was used on each drop condition. This was accomplished using two cameras positioned to view the most critical motions of the gear. Generally, the cameras were positioned to view the side and front of the landing gear.

The drop velocity was calculated using 0.01-second increments.

6.0 TEST RESULTS

6.1 Shake Test

Input shake amplitudes of 0.25, 1.0, and 2.0 inches peak-to-peak were run for a lift condition of 90 percent. The gross weight of 2550 pounds was used for all shake tests. Frequency scans were run per Table A-1 and the load versus frequency plots are presented in Figures A-4, A-5, and A-6. It did not seem clear where any resonant points were for the 0.25-inch amplitude run. For the 1.0-inch P-P run, the Lissajous at 1.38 Hz is shown in Figure A-7. It may be noted that the corresponding frequency in Figure A-5 does not indicate a resonant point. For the 2.0-inch P-P run, the Lissajous at 2.15 Hz is shown in Figure A-8. It may also be noted that the corresponding frequency point in Figure A-6 does not indicate a resonant point.

The lift load was removed and frequency scans were run for 0.25-inch and 2.0-inch P-P amplitudes. The load versus frequency plots are presented in Figures A-9 and A-10. Again, nautral frequency response was undefinable, and when the input rod failed, testing was discontinued. It appeared that the data presented may have been affected by hydraulic leakage past the seals and the pressure relief valve. No usable data were obtained on the visicorder trace of the other requested instrumentation.

6.2 Drop Tests

The drop test vehicle was configured to the parameters given in Table A-2 for each drop. The vehicle was hoisted into position and ropes were tied to the skids to prevent vehicle rotation. The interconnect system was set so that approximately 1.9 inches of extension were showing on the aft oleos and 1.6 inches of extension on the forward oleos. Figure A-11 shows the deflection transducers used to measure interconnect and damper motions. It can be noted in the photograph that the interconnect is fully retracted due to leakage in the pressure relief valve. When the weight of the vehicle was removed, the interconnects would extend toward their normal positions, but not equally at each oleo due to differences in internal friction and the ability of the oil to flow around the system. The drop test data are summarized in Table A-4 and the complete visicorder traces of all data for all test conditions are presented in Figures A-15 through A-26.

Test Conditions 1 through 5 used a 26.5-degree ramp as the landing surface. The ramp was covered with a steel plate and is the same type of surface as used for previous drop testing. The forward end of the landing gear was pitched up 10 degrees to the surface prior to the first drop. The gross weight was 2550 pounds with the CG at Sta 104. Rotor lift was set at 67 percent and application began approximately 1.5 inches above ground contact. As the landing gear made contact, the aft interconnects contracted and the forward interconnects extended. The amounts are given in Table A-4 along with the other recorded data. Oil mist was seen blowing off the dampers during initial contact. This was attributed to oil film buildup on the inner piston or seal blowby. This, along with the leakage in the pressure relief valves, and trapped air in the system are possible reasons why the deflection in the interconnect system does not add up (i.e., compression = extension). It was noted that the pitch and roll attitude traces showed little or no motion even though pitch and roll rate traces did show motion. This indicated that the gyros were probably not functioning properly. Since no replacements were available, no changes were made. A calibration trace, taken prior to each drop, indicated the proper response, but during each test little or no response was obtained.

For Test Condition 2, the pressure equalizers were removed and sent to MOOG, and the pressure equalizer piston was exchanged for one with a smaller orifice. The Test Condition 1 orifice was 0.128 inch in diameter and Test Conditions 2 through 12 used an orifice of 0.0595 inch in diameter. The results of the drop test are presented in Table A-4. Similar results to Test Condition 1 were obtained except the pitch rate was noticeably reduced by approximately 16 percent.

For Test Condition 3, the pressure equalizers were again removed and sent to MOOG, and the springs were replaced with softer ones. The new spring constant was approximately 22 pounds per inch and remained so throughout the rest of the tests.

The results for Test Condition 3 show similar values to Test Conditions 1 and 2, except for pitch rate, which was about 4 percent greater than Condition 2 (12 percent less than Condition 1).

Test Condition 4 was conducted with the skids parallel to the 26.5-degree slope. This condition simulated forward speed with an aft CG. The test results presented in Table A-4 show a low positive pitch rate, 3.58 degees per second.

Test Condition 5 was configured similar to Test Condition 4, except the CG was forward at Sta. 97. The drop test results (see Table A-4) showed that an initial pitch rate was -12.45 degrees per second, pitching down in front.

Lateral speed was simulated by dropping the test vehicle on a plywood platform with one side sloped at 26.5 degrees. The left skid was placed over the slope and was parallel to the fore and aft surface. This drop, Test Condition 6, was completed and the results are presented in Table A-4. The right interconnects compressed significantly and the left extended. The vehicle was noticeably more level than it normally would have been without interconnects. The roll rate of -27.31 degrees per second seems high, but the final position of the vehicle indicates little motion, even though there are no previous roll drop data with which to compare these data.

Test Condition 7 was conducted on plywood sheets placed on level ground and the skids were parallel to the plywood. The drop test results are presented in Table A-4 and do not indicate any excessive or reduced values. The pitch rate was noted to have increased from approximately 4 degrees per second (Report 369-BT-3033 Record 896) to approximately 15 degrees per second.

It was decided to conduct Test Condition 10 next, as the only change required was to elevate the vehicle enough for an increase in free fall velocity to a maximum of 8.02 feet per second. Also, the lift pressure was increased so 100 percent lift would be obtained. A peak lift of 2503 pounds was measured at contact, but it had reduced to 2115 pounds by 0.25 second, giving the reported average of 2309 pounds. The results given in Table A-4 are noticeably similar to Test Condition 7. The pitch rate made the only significant change, and it was in the positive direction to 17.50 degrees per second.

Test Condition 8 was conducted similar to Condition 7, except the right skid was raised 10 degrees for a roll attitude. As the skids made contact, the left interconnects compressed and the right extended. The roll rate was 57.56 degrees per second maximum. The drop vehicle appeared to roll right until reaching the level position then it continued to descend at this attitude with no further roll motion. The lateral acceleration reached a maximum of 2.23 G with the ground load factor.

Test Condition 11 was the next drop to be run. The flat wood was used as a landing surface. The drop vehicle was pitched forward (nosedown) so that the base of the skids was inclined -10 degrees to the landing surface. As expected, the forward interconnects compressed and the aft extended. Table A-4 gives the recorded amounts. The pitch rate, 45.0 degrees per second, was in the desirable direction. The trace indicated little or no negative pitch motion. The positive pitch motion continued until the forward tips of the skids had raised off the landing surface to approximately +10 degrees. Due to instrument problems, this drop was made three times. It was noted that after the first drop the front pads on the skids no longer contacted the landing surface when the vehicle was sitting at rest. Both pads appeared to be approximately 1/8 to 1/4 inch above the surface. There did not appear to be any change after the second and third drops.

The overload configuration, Test Condition 9, required that the total drop weight be increased to 2800 pounds. The CG (FS 104), drop velocity (6.5 feet per second), and rotor lift (67 percent) were the same as previous tests. The results in Table A-4 indicate that the vehicle pitched forward (nosedown) and rolled left. The motion picture data show the aft descent stopping and the front continuing downward, which gave the forward pitching data results.

The final test condition, number 12, is the maximum drop condition. In order to obtain the 19.5-foot-per-second drop velocity, the vehicle was raised 72 inches above the wood landing surface. This height resulted in a 19.2-foot-per-second fall. The lift pressure was increased to obtain 100 percent lift at impact. The lift came up very strong and overshot, which may have been caused by the hydraulic damping system. The lift immediately dropped and oscillated with an average from 1943 to 1899 pounds, which was well below the desired 2550 pounds. At impact the load measured 2734 pounds. It appears that the increase in energy was too much for the hydraulic damper on the lift bar to sustain.

As shown in Table A-4, three of the four oleo dampers bottomed; one of those, the left aft, was loaded to only 2989 pounds, which was less than the oleo proof and some other test condition loadings on the forward dampers. The results in Test Condition 9 did not give any indication of oleo damper problems. Failure of the right aft strut occurred approximately 0.17 second after impact. The pitch rate of -66 degrees per second was caused by the forward end continuing to descend just prior to failure. This may have been due to the dampers that had bottomed approximately 0.12 second after impact. The peak of negative pitch rate was reached at 0.24 second. The pitch rate immediately became positive and by roughly 0.32 second, it had peaked at 93 (estimated) degrees per second. This was observed in the movies showing the flat descent stop as the aft end bottomed and the forward end continued to descend. At failure, the aft end again descended until contact with the ground was made with the stub strut. Total fracture of the strut was incurred, as was failure to the right forward oleo attach lug. The failures are shown in Figures A-12, A-13, and A-14. Figure A-12 shows the total fracture of the rear right strut, below the elbow. Other items of interest in the picture include the hydraulic hose broken away from both rear oleo interconnects (arrows 2 and 3). These lines attach to the reservoir. Also, note a failure of the fixture at the forward center attach point of the cross tubes (arrow 4). Figure A-13 shows the same details as Figure A-12, but it also shows the rear left damper almost fully compressed. The front right damper was even more compressed, as can be seen in Figure A-14 (arrow 2). The lug failure can also be seen (arrow 1) along with damage to the damper deflection transducer.

The right and left forward brace vertical bending bridges appear to have failed shortly after the strut failure. The values in Table A-4 are taken before or near the failure time.

The high roll rate was caused by the strut failure and occurred after fracture.

7.0 CONCLUSIONS

The interconnect landing gear system was able to perform responsively to reduce many of the undesirable characteristics involved with an autorotational-type landing. This functional capability was obvious in Test Conditions 6 and 8, where expected pitching did not occur. The flat surface landings were all showing level descent and virtually no forward pitching.

The structural integrity of the oleo damper was more than sufficient and the hose failure incurred on the final drop did not affect the functioning of the system for that landing, as it was part of the upper system which extends the interconnects to their middle position after lift-off.

8.0 RECOMMENDATIONS

Based on the testing, it is recommended that the following changes be incorporated in the design. First, better seals with wipers be installed in the charging and pressure relief system to eliminate leakage. Second, a self-centering ability be incorporated in the system. These changes could be accomplished by eliminating the orifice in the pressure equalizer piston face, and by a motion sensitive orifice or a separate damping system.

TABLE A-1. GROUND RESONANCE TEST

GW (lb)	CG (Station)	Lift (%)	P-P Input Amplitude (in.)	Frequency Sweep Range (Hz)
2550	104.0	90	0.25	1.0 - 10.0 - 1.0
			1.00	1.0 - 5.0 - 1.0
			2.00	1.0 - 4.0 - 1.0
		0	0.25	1.0 - 10.0 - 1.0
			1.00	1.0 - 5.0 - 1.0
			2.00	1.0 - 4.0 - 1.0

TABLE A-2. LANDING GEAR DROP TEST CONDITIONS.

Test Condition	Run No.	Rotor Lift (%)	Downward Drop Velocity ΔV_Z (fps)	Pitch* Angle (deg)	Roll** Angle (deg)	CG Location (STA)	Gross Weight (lb)	Landing Surface Angle θ (deg)	Comments
1	1-9	67	6.5	+10	0	104	2550	26.5°P	Baseline Design Condition
2	10-12	67	6.5	+10	0	104	2550	26.5°P	Damping Variation
3	13-15	67	6.5	+10	0	104	2550	26.5°P	Spring Variation
4	16	67	6.5	0	0	104	2550	26.5°P	Simulated Forward Speed
5	17	67	6.5	0	0	97	2550	26.5°P	Forward CG
6	18	67	6.5	0	0	104	2550	26.5°R	Simulated Lateral Speed
7	19-20	67	6.5	0	0	104	2550	0	Level Drop
8	21-22	67	6.5	0	-10	104	2550	0	Roll
9	26	67	6.5	0	0	104	2800	0	Overload
10	21	100	8.2	0	0	104	2550	0	Reserve Energy
11	23-25	67	6.5	-10	0	104	2550	0	Nose Down
12	27	100	19.5	0	0	104	2550	0	Maximum Drop (MIL-STD-1200 Evaluation)

*Noseup, positive
**Right skid up, negative

TABLE A-3. DROP TEST BALLAST SUMMARY FOR THE MODEL 369A INTERCONNECTED LANDING GEAR CONFIGURATION*

Load Condition	Gross Weight (lb)	Horizontal CG FS (in.)	Vertical CG WL (in.)	Moment of Inertia (slug-ft^2)		
				Roll	Pitch	Yaw
1	2550	104.0	28.9	318	868	751
2	2550	97.0	29.9	318	872	755
3	2800	104.0	28.9	328	888	768

Ballast Box	Ballast Locations (in.)			Ballast Weight (lb) Load Conditions		
	H-Arm (FS)	L-Arm (BL)	V-Arm (WL)	No. 1	No. 2	No. 3
A	35	0	26.8	260	400	260
B	165	0	26.8	444	301	444
C	79	0	63.8	133	128	133
D	121	0	63.8	83	88	83
E	100	-35	29.3	0	0	0
F	100	135	29.3	0	0	0
GL	84	- 8	18.3	0	0	50
GR	84	8	18.3	0	0	50
HL	116	- 8	18.3	0	0	75
HR	116	8	18.3	0	0	75

*Using drop test fixture, P/N 369-9302

TABLE A-4. SUMMARY OF DROP TEST DATA

Ch. No.	Description and/or Location	Test Condition 1	2	3	4	5	6	7	8	9	10	11	12	Units
1	Strut Fwd Left Axial	-902	-1110	-1055	369	-361	-416	-625	-444	-638	-527	1624	-2476	lb
2	Vert. Bend	14823	15232	15414	14278	16142	12959	13459	11640	16187	14914	14368	38650	in-lb
3	Long. Bend	-3161	-3464	-3334	2425	4330	2555	1039	-2338	-1948	1039	7621	-8554	in-lb
4	Aft Left Axial	-1151	-1188	-1151	-448	-315	-654	-970	-1248	-1139	-970	679	-2693	lb
5	Vert. Bend	8870	9846	10644	10422	16310	13106	11941	9902	18873	12000	12290	29662	in-lb
6	Long. Bend	4634	4929	4761	843	1138	2359	2022	3707	3750	2191	-5013	5334	in-lb
7	Brace Fwd Left Axial	-1292	-1292	-1333	-820	-738	-984	-1128	-1491	-1825	-1231	1477	-3750	lb
8	Vert. Bend	3179	2914	2892	-3138	-4372	-3924	-4977	-6501	-4036	-5403	-5650	-9204 (F)	in-lb
9	Aft Left Axial	1559	1687	1632	954	807	1265	1155	1284	2531	1229	-807	1596	lb
10	Vert. Bend	4676	5379	5161	6469	7414	6905	8044	8141	11388	8674	8141	18184	in-lb
11	Fwd Right Axial	-1444	-1299	-1396	288	568	-621	-781	-1082	-1633	-710	5535	-1715	lb
12	Vert. Bend	3565	3434	3925	-2944	-4366	-4170	-4734	-4808	-7702	-5053	-6378	-10450(F)	in-lb
13	Oleo Load Rt Fwd	-2908	-3276	-3301	-2945	-3153	-2760	-2601	-2601	-2920	-2601	-2699	-10002	lb
14	Lt Fwd	-2649	-2788	-2766	-2383	-2639	-2128	-2213	-2713	-2511	-2405	-2277	-6202	lb
15	Rt Aft	-867	-753	-776	-776	-1095	-821	-890	-776	-798	-1049	-890	-2463	lb
16	Lt Aft	-1004	-817	-864	-911	-887	-1004	-957	-844	-934	-981	-1027	-2989	lb
17	Acceleration(2) Vertical	1.50	1.44	1.44	1.34	1.48	1.45	1.79	1.22	1.60	1.79(1)	1.71	5.49(1)	g
18	Lateral	–	–	–	–	–	1.68	–	2.23	–	–	–	–	g
19	Lift Load (Avg)	1720	1683	1727	1654	1741	1683	1677	1669	1640	2309	1777	1921	lb
20	Interconnect Press. Fwd	994	1056	1056	1097	1097	994	1035	828	1076	1076	1118	2194	psi
21	Aft	1014	1056	1159	1056	1118	1014	1117	828	1076	1097	–	2360	psi
23	Interconnect Displ. Rt Fwd	0.40	0.39	0.45	-0.14	-0.15	-0.45	-0.31	0.62	-1.05	-0.34	-1.00	-1.65	in.
24	Lt Fwd	0.28	0.33	–	-0.24	-0.16	0.29	-0.33	-1.14	-1.08	-0.33	-1.04	-1.47	in.
25	Rt Aft	-0.52	-0.71	-0.77	-0.35	-0.26	-0.92	-0.49	0.52	-1.11	-0.49	0.18	-1.93	in.
26	Lt Aft	-0.76	-0.67	-0.72	-0.43	-0.27	0.06	-0.67	-1.46	-1.51	-0.65	0.27	-1.99(B)	in.
27	Oleo Displ. Rt Fwd	-2.43	-2.51	-2.49	-2.43	-2.56	-2.33	-2.18	-2.15	-2.56	-2.26	-2.26	-3.01(B)	in.
28	Lt Fwd	-2.30	-2.51	-2.50	-2.41	-2.58	-2.18	-2.18	-1.77	-2.62	-2.23	-2.30	-3.22(B)	in.
29	Rt Aft	-2.30	-2.35	-1.99	-1.94	-2.06	-2.14	-2.28	-2.21	-2.21	-2.31	-2.55	-2.97	in.
30	Lt Aft	-2.21	-2.28	-1.96	-2.19	-2.04	-2.35	-2.31	-1.80	-2.45	-2.35	-2.55	-3.09(B)	in.
31	Pitch Attitude	0.65	–	0.74	0.74	0.56	–	0.74	1.30	3.35	–	0.74	3.26	deg
32	Pitch Rate	-33.4	-28.16	-29.3	3.58	-12.45	11.07	14.98	7.33	-8.10	17.50	45.0	-66/98(E)	deg/sec
35	Drop Velocity	6.25	6.46	6.46	6.46	6.67	6.46	6.25	6.46	6.25	7.92	6.46	19.2	ft/sec
36	Roll Rate	1.33	-9.96	-7.38	9.59	–	-27.31	10.33	57.56	-19.93	8.12	7.33	103.3	deg/sec
22	Roll Attitude	–	–	–	–	–	–	–	–	–	–	–	–	deg

(Neg) – comp. loads, comp. defl, pitch down fwd and left, neg bending

(1) No ground load factor

(2) $N_t G \times \Delta g + \left(1 - \frac{L}{W}\right); g$

(F) Gage failure

(B) Pot hot honed

(E) Curve estimate

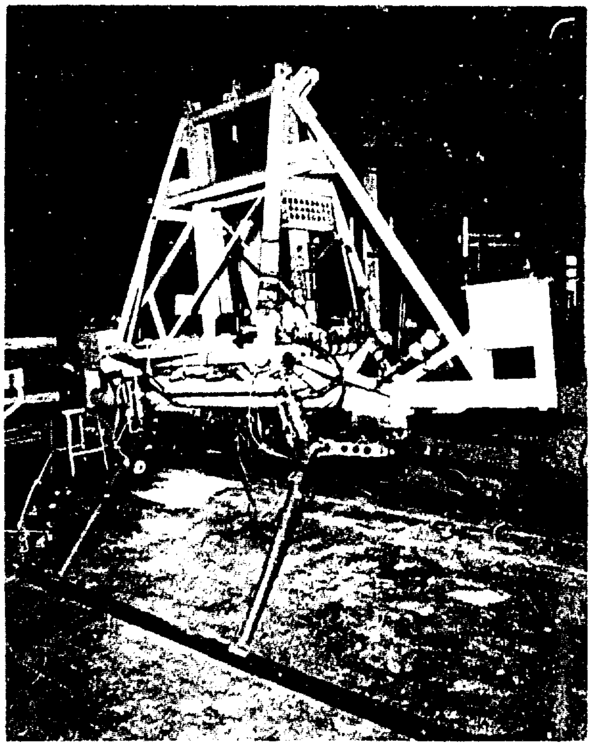

Figure A-1. View of modified oleo damper interconnect installation.

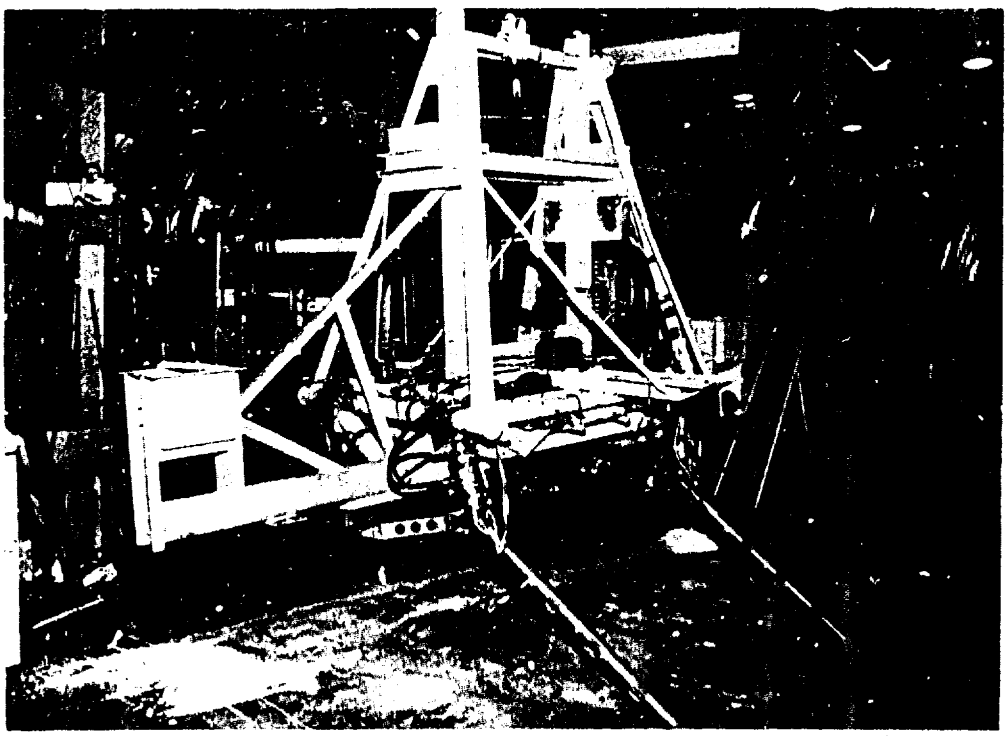

Figure A-2. View of modified oleo damper interconnect installation.

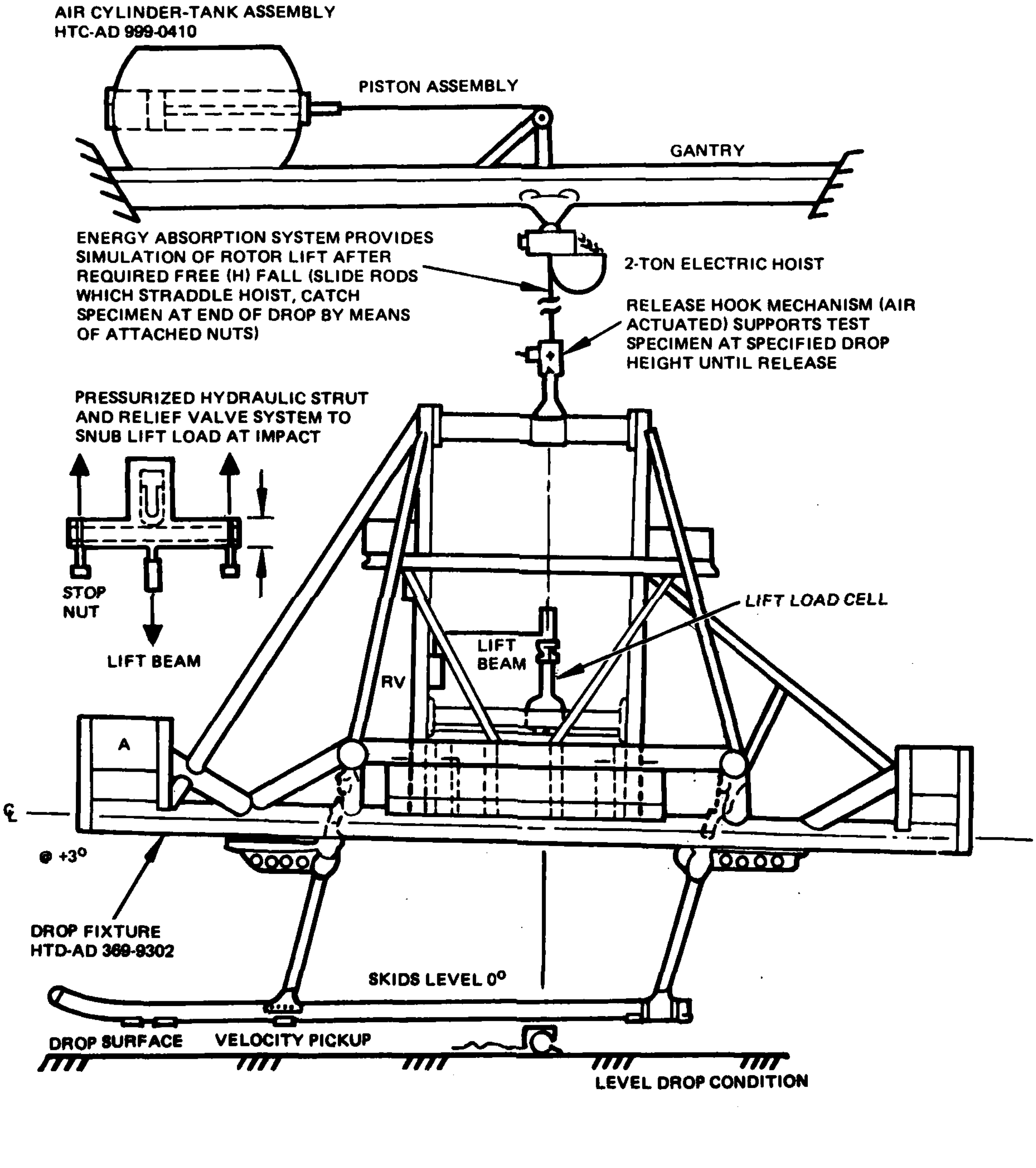

Figure A-3. Landing gear drop test fixture used for the interconnected landing gear tests.

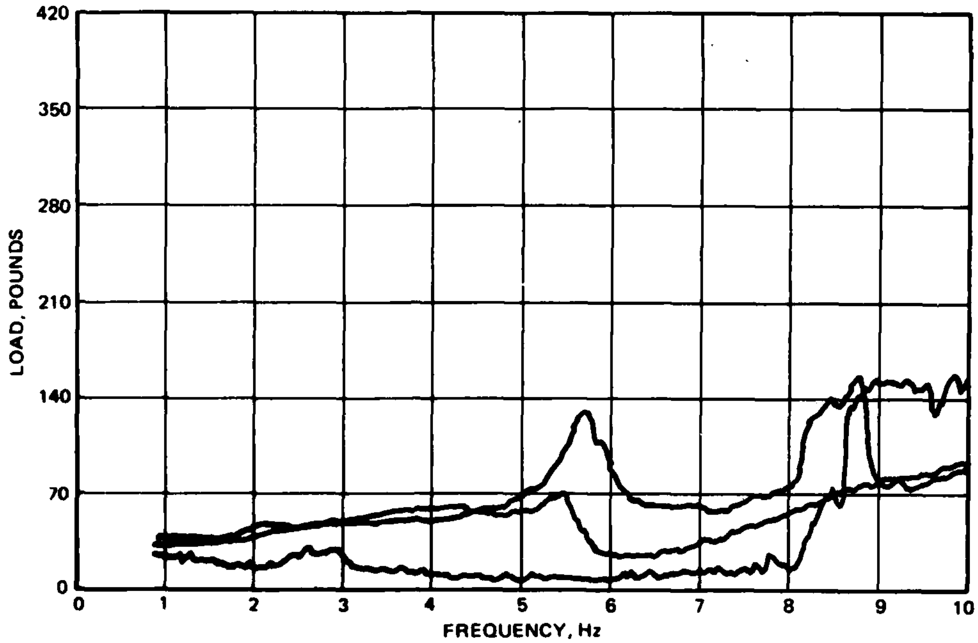

Figure A-4. Plot of load versus frequency at input 0.25 inch P-P, 90 percent lift.

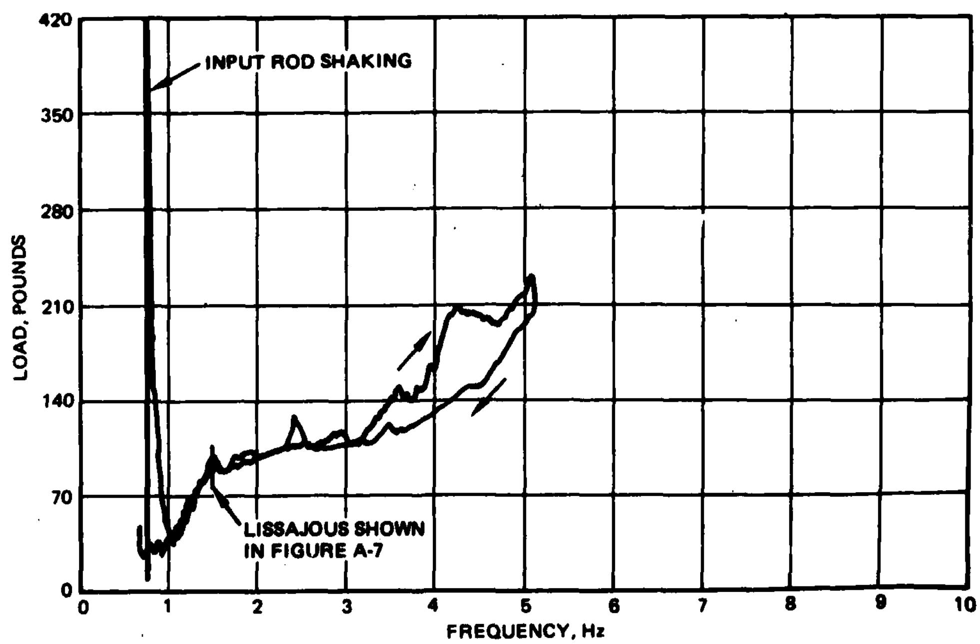

Figure A-5. Plot of load versus frequency at input 1 inch P-P, 90 percent lift.

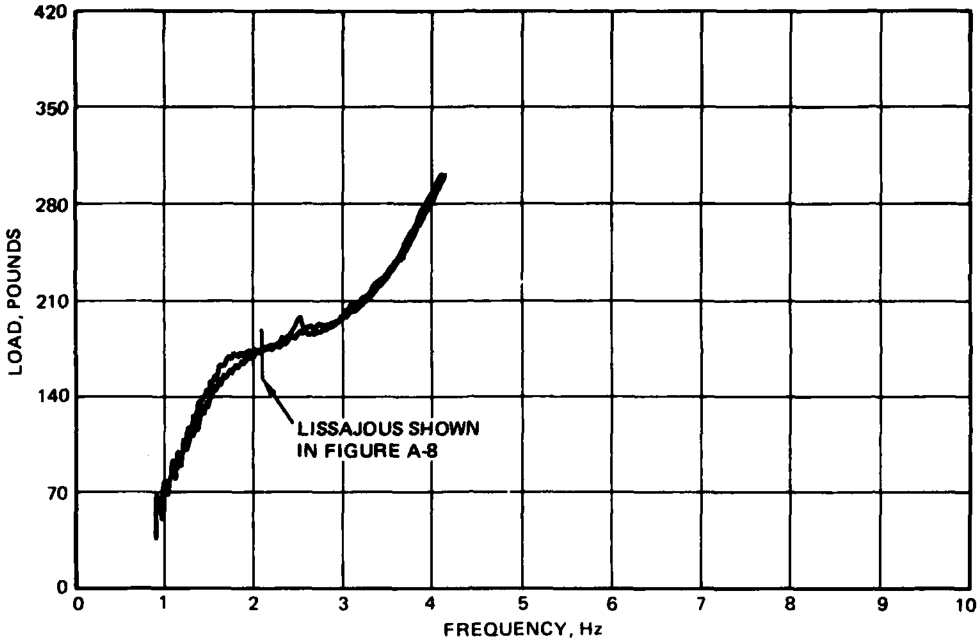

Figure A-6. Plot of load versus frequency at input 2 inches P-P, 90 percent lift.

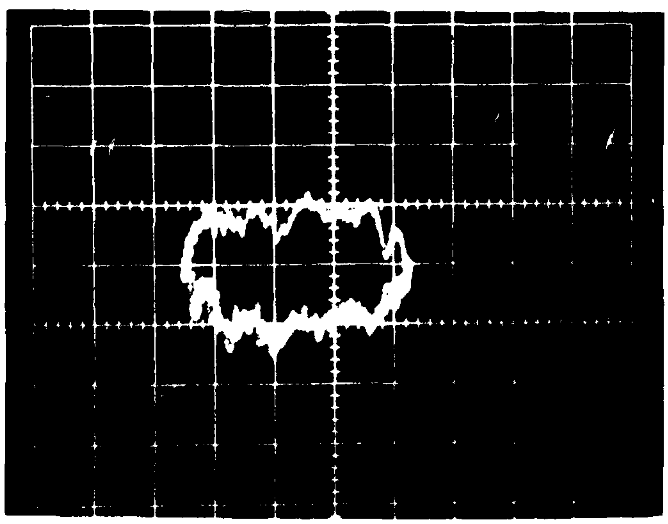

Figure A-7. Lissajous of 1-inch P-P at 1.38 Hz, ±77 pounds.

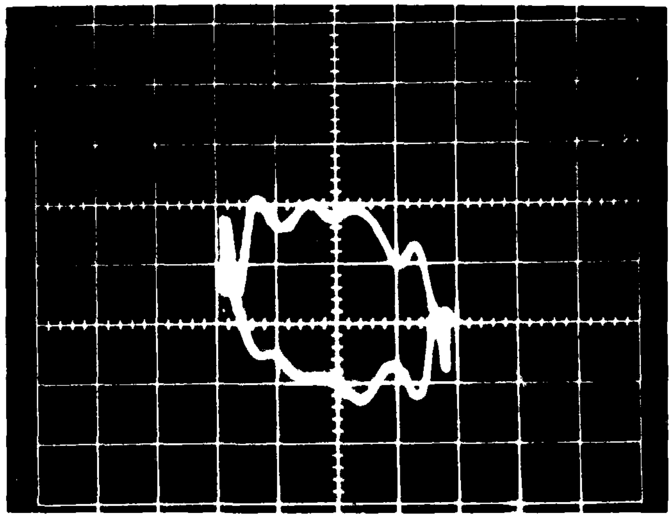

Figure A-8. Lissajous of 2-inch P-P at 2.15 Hz, ±175 pounds.

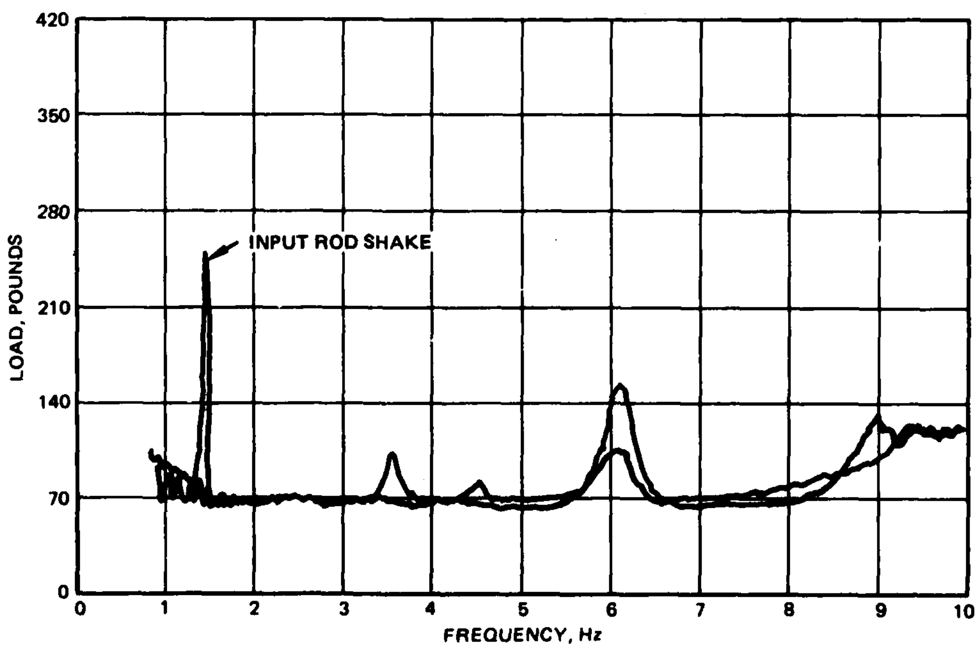

Figure A-9. Plot of load versus frequency at input 0.25 inch P-P, 0 percent lift.

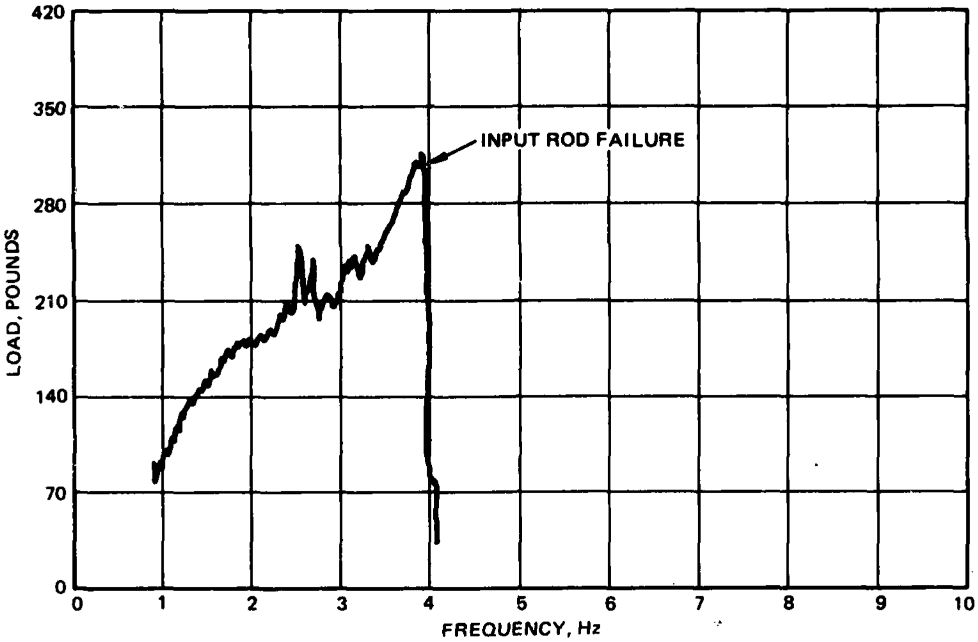

Figure A-10. Plot of load versus frequency at input 2 inches P-P 0 percent lift.

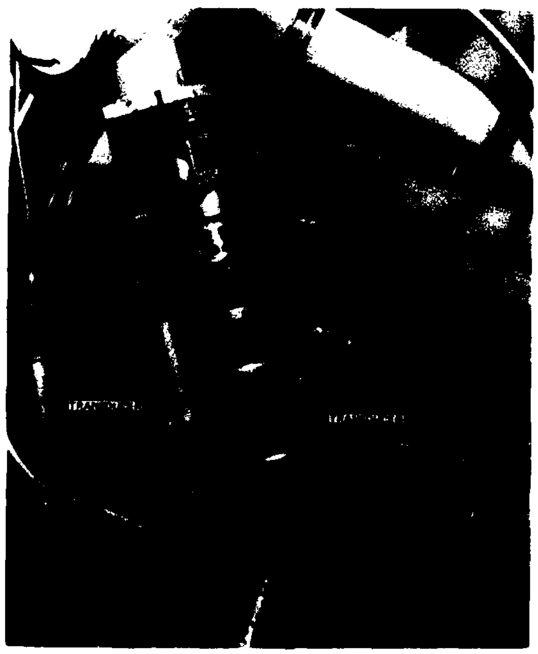

Figure A-11. View of deflection transducers used to measure interconnect and damper motions.

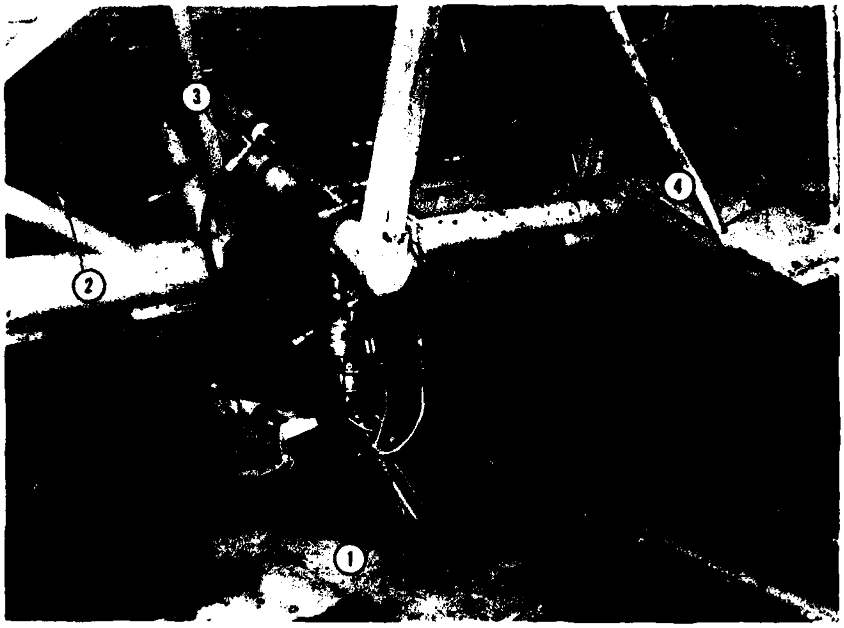

Figure A-12. View of aft right strut failure, Test Condition 12.

Figure A-13. View looking forward at failed landing gear, Test Condition 12.

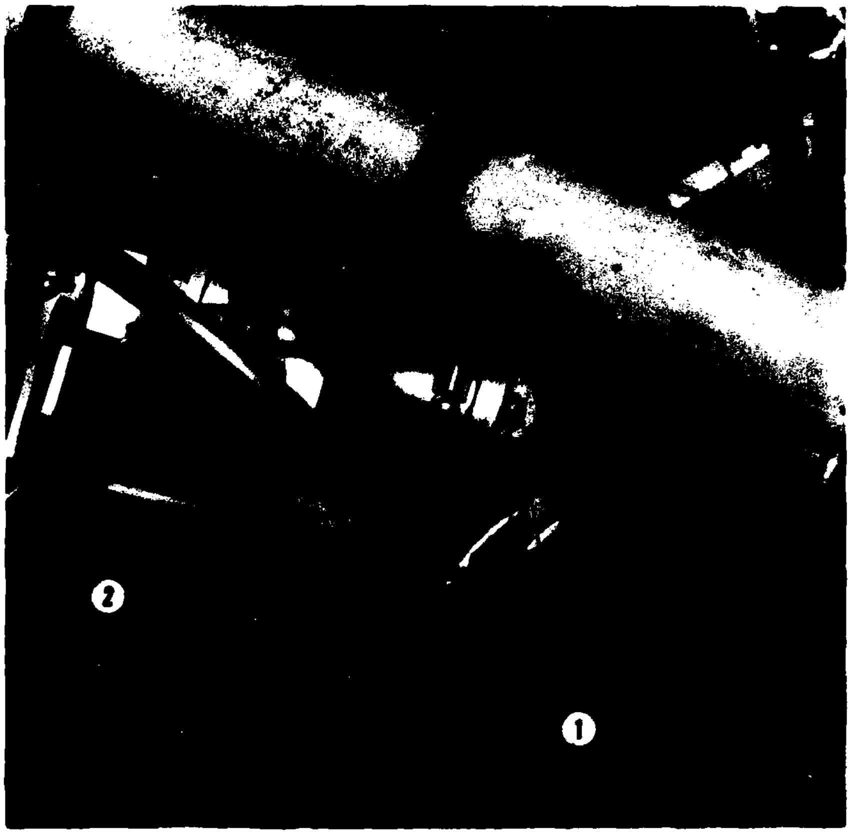

Figure A-14. View of failed lug on front right strut.

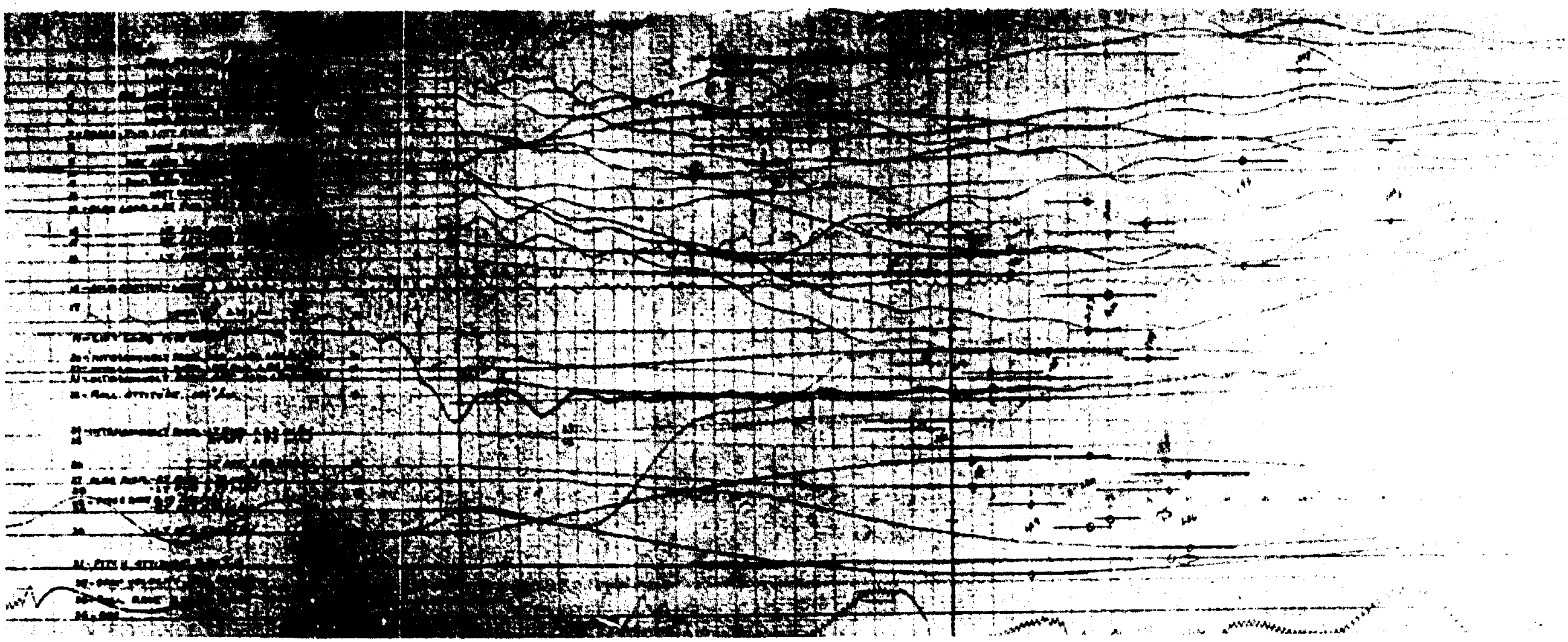

Figure A-15. Record 9, Baseline Design Condition, Test Condition 1

Gross Weight = 2550 lb	Drop Velocity = 6.25 fps
Aft CG, Sta 104	Surface Angle 26.5° P
Rotor Lift = 67%	Pitch Angle = +10°

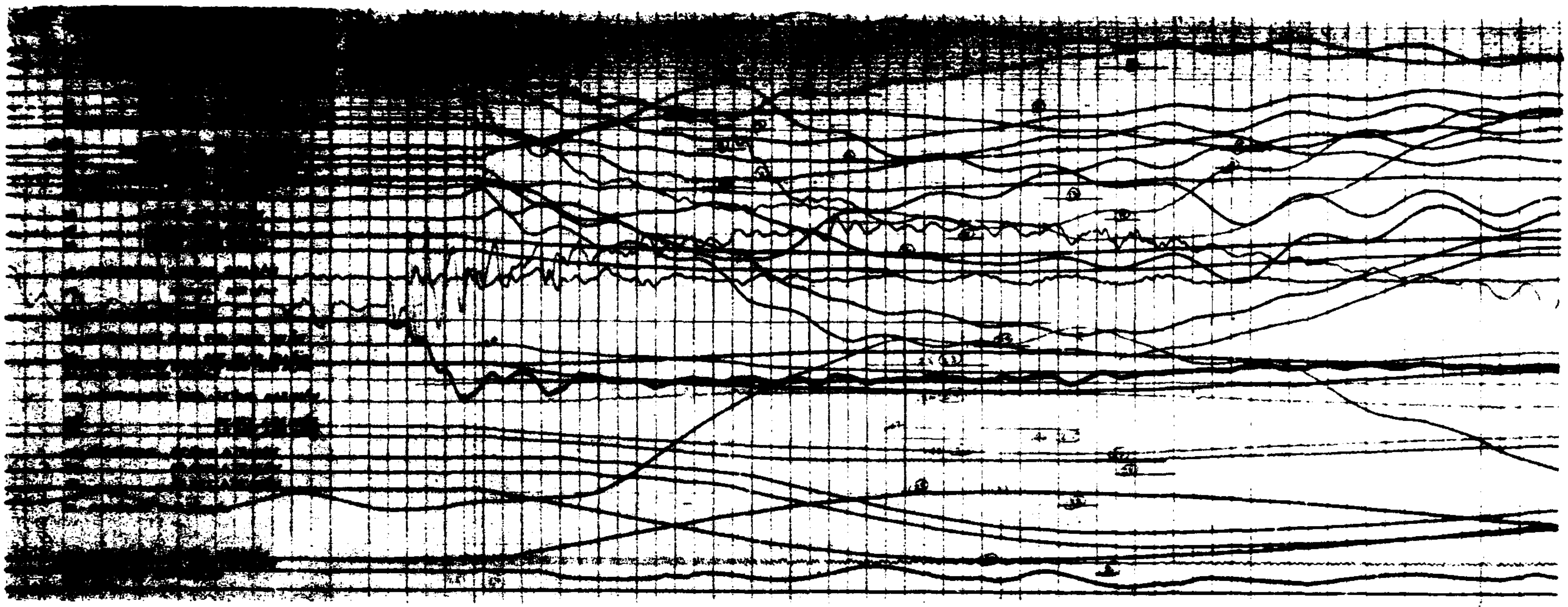

Figure A-16. Record 12, Damping Variation, Test Condition 2

Gross Weight = 2550 lb	Drop Velocity = 6.46 fps
Aft CG, Sta 104	Surface Angle = 26.5° P
Rotor Lift = 67%	Pitch Angle = +10°

Figure A-17. Record 15, Spring Variation, Test Condition 3

Gross Weight = 2550 lb	Drop Velocity = 6.46 fps
Aft CG, Sta 104	Surface Angle = 26.5° P
Rotor Lift = 67%	Pitch Angle = +10°

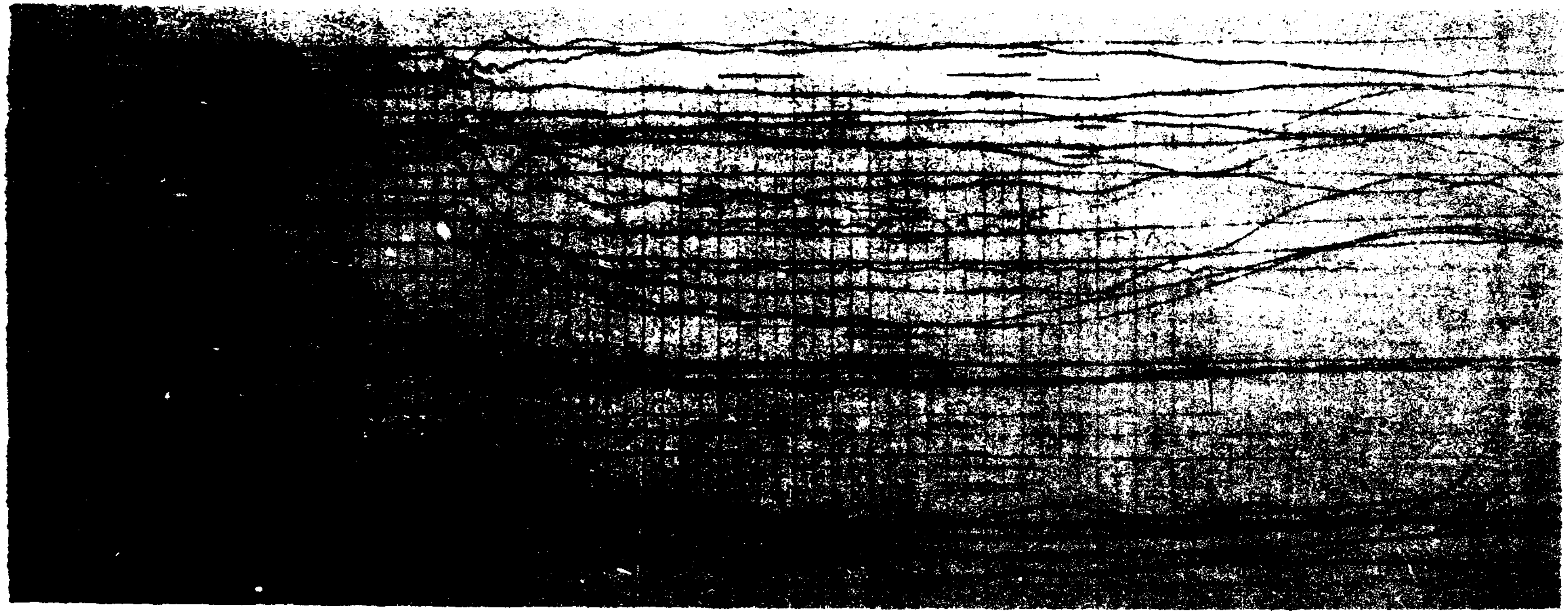

Figure A-18. Record 16, Simulated Forward Speed, Test Condition 4

Gross Weight = 2550 lb	Drop Velocity = 6.46 fps
Aft CG, Sta 104	Surface Angle = 26.5° P
Rotor Lift = 67%	Pitch Angle = 0°

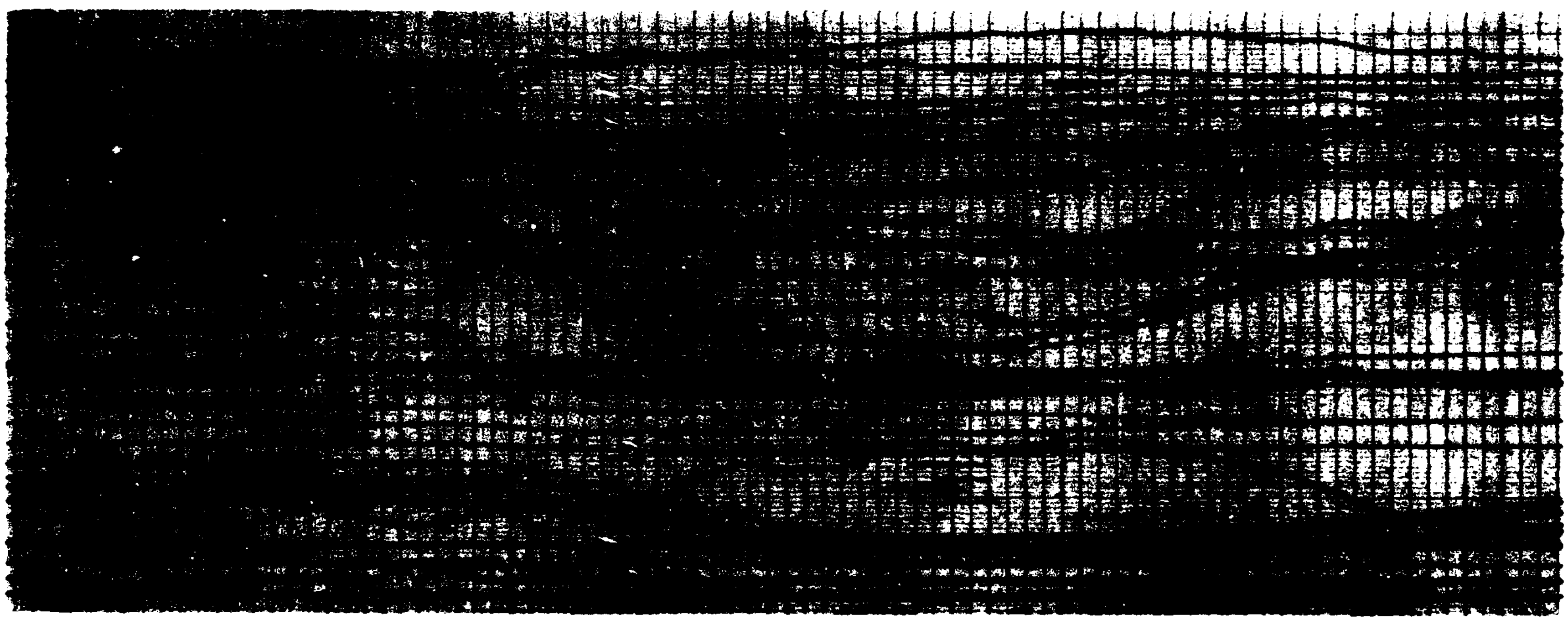

Figure A-19. Record 17, Forward CG, Test Condition 5

Gross Weight = 2550 lb	Drop Velocity = 6.67 fps
Forward CG, Sta 97	Surface Angle = 26.5°P
Rotor Lift = 67%	Pitch Angle = 0°

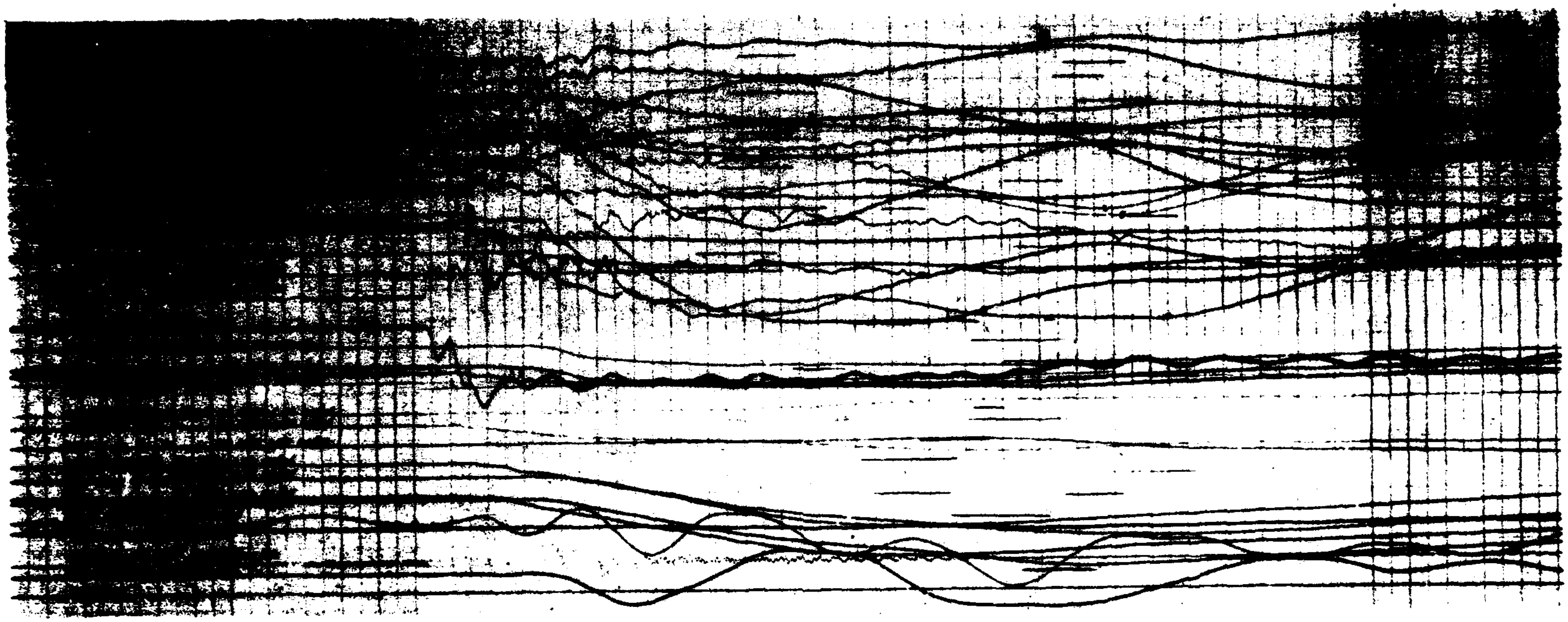

Figure A-20. Record 18, Simulated Lateral Speed, Test Condition 6

Gross Weight = 2550 lb	Drop Velocity = 6.46 fps
Aft CG, Sta 104	Surface Angle = 26.5°R
Rotor Lift = 67%	Roll Angle = 0°

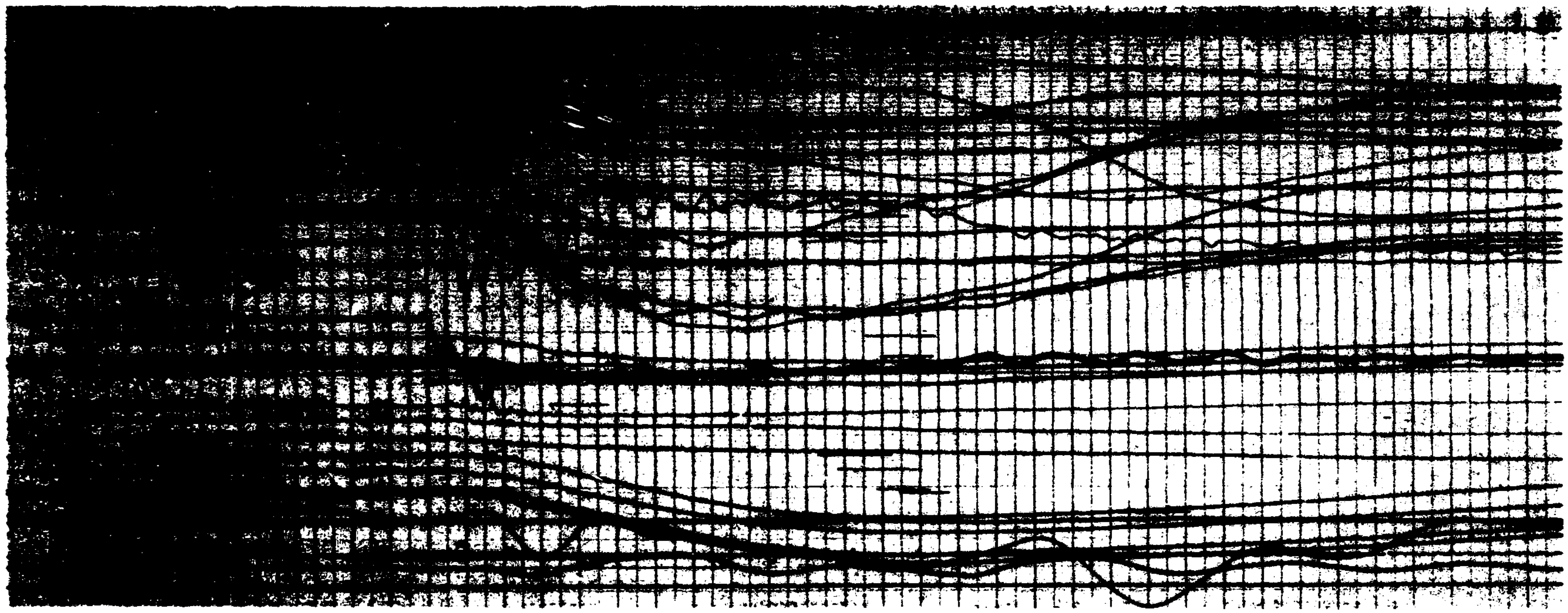

Figure A-21. Record 20, Level Drop, Test Condition 7

Gross Weight = 2550 lb
Aft CG, Sta 104
Rotor Lift = 67%

Drop Velocity = 6.25 fps
Surface Angle = 0°
Roll Angle = 0°

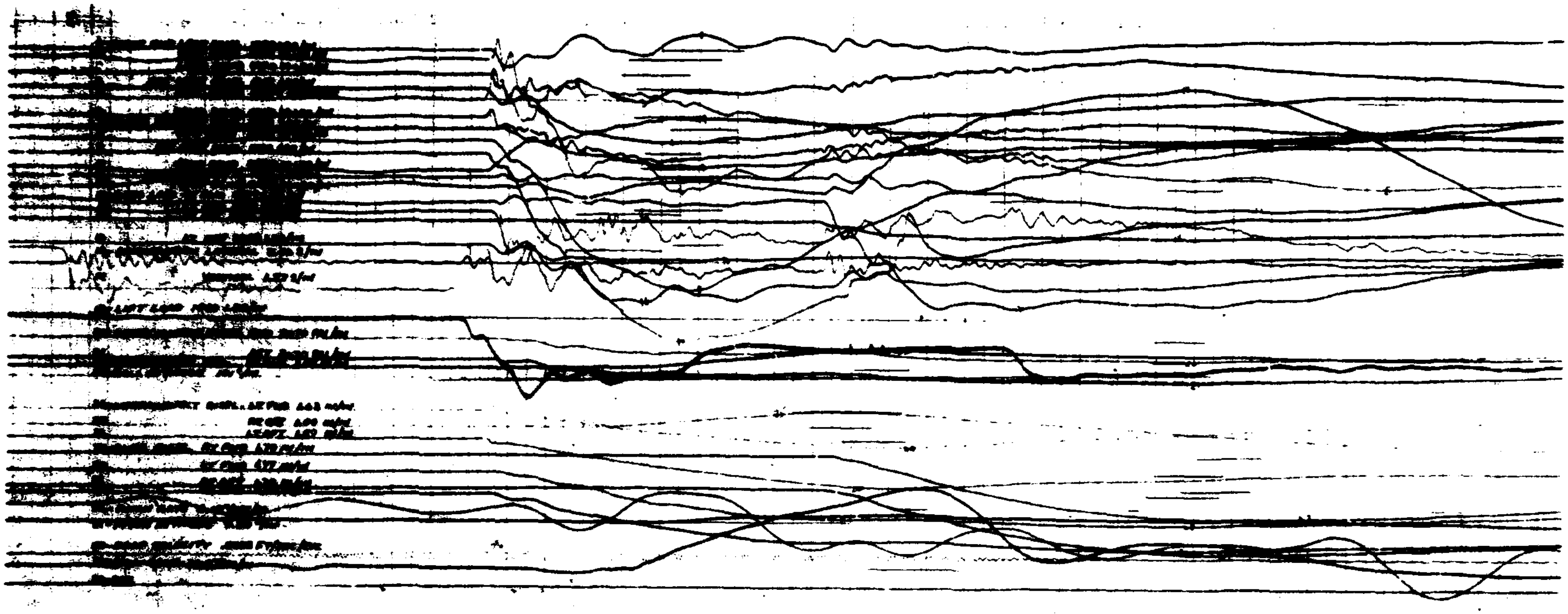

Figure A-22. Record 22, Roll, Test Condition 8

Gross Weight = 2550 lb   Drop Velocity = 6.46 fps
Aft CG, Sta 104   Surface Angle = 0°
Rotor Lift = 67%   Roll Angle = -10°

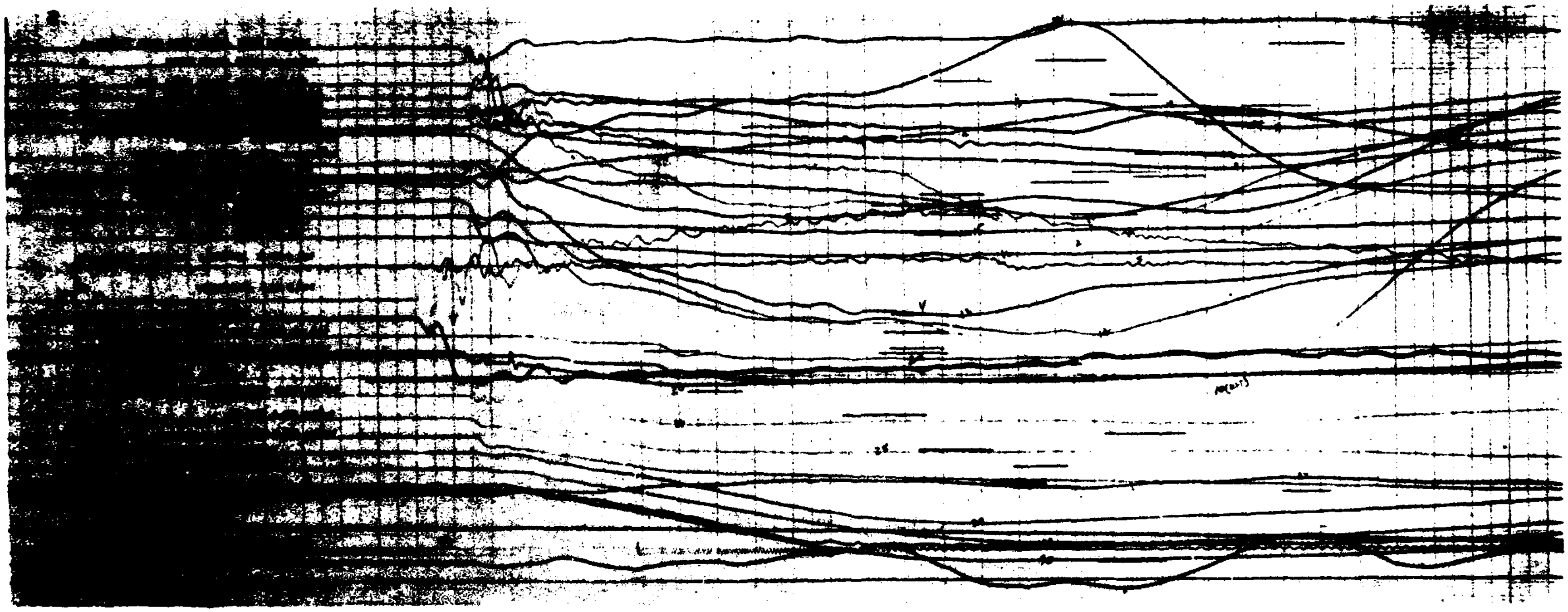

Figure A-23. Record 26, Overload, Test Condition 9

Gross Weight = 2800 lb
Aft CG, Sta 104
Rotor Lift = 67%

Drop Velocity = 6.25 fps
Surface Angle = 0°
Roll Angle = 0°

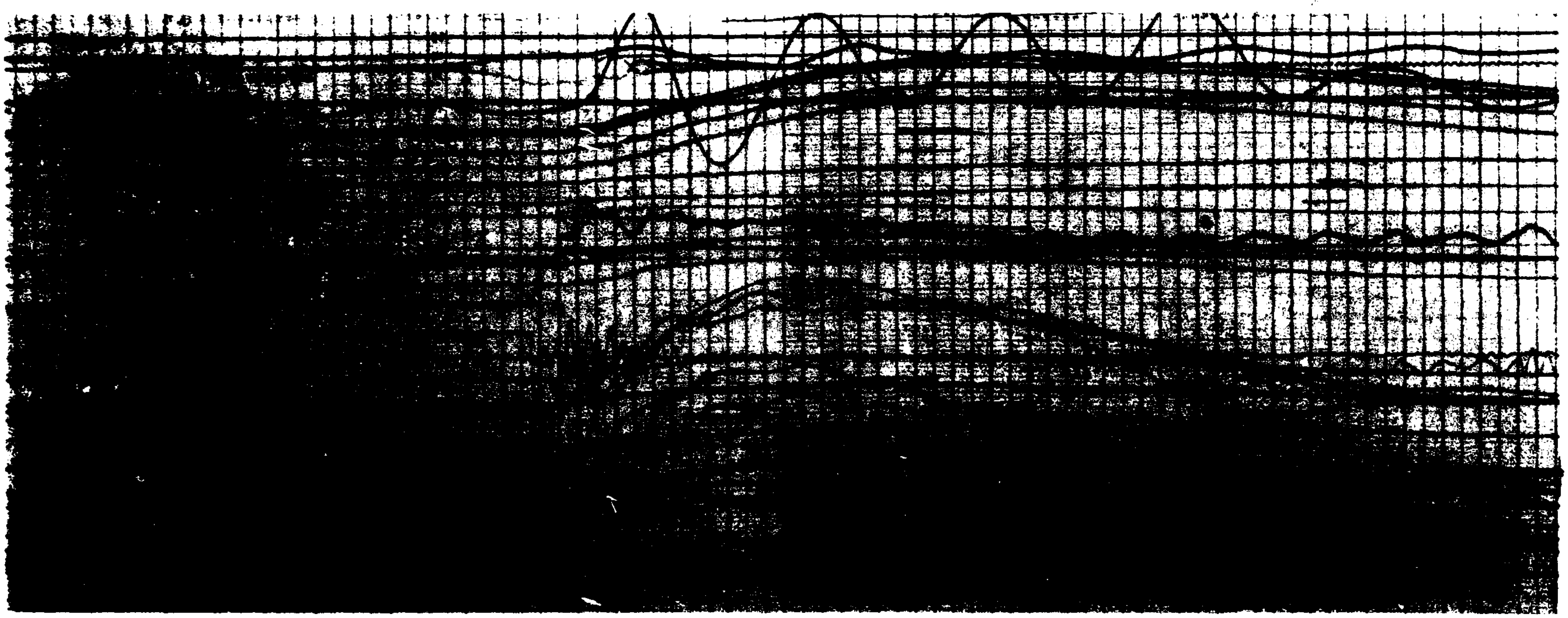

Figure A-24. Record 21, Reserve Energy, Test Condition 10

Gross Weight = 2550 lb	Drop Velocity = 7.92 fps
Aft CG, Sta 104	Surface Angle = 0°
Rotor Lift = 100%	Roll Angle = 0°

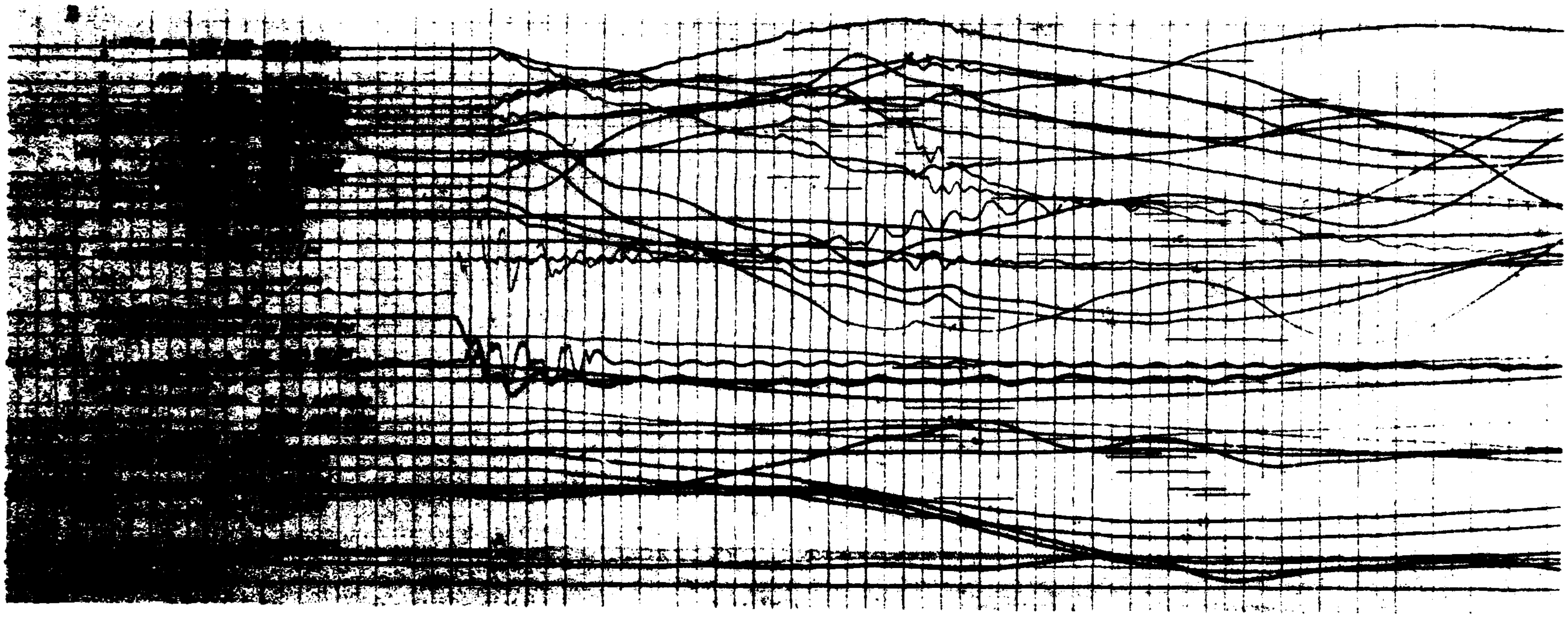

Figure A-25. Record 25, Nose Down, Test Condition 11

Gross Weight = 2550 lb	Drop Velocity = 6.46 fps
Aft CG, Sta 104	Surface Angle = 0°
Rotor Lift = 67%	Pitch Angle = -10°

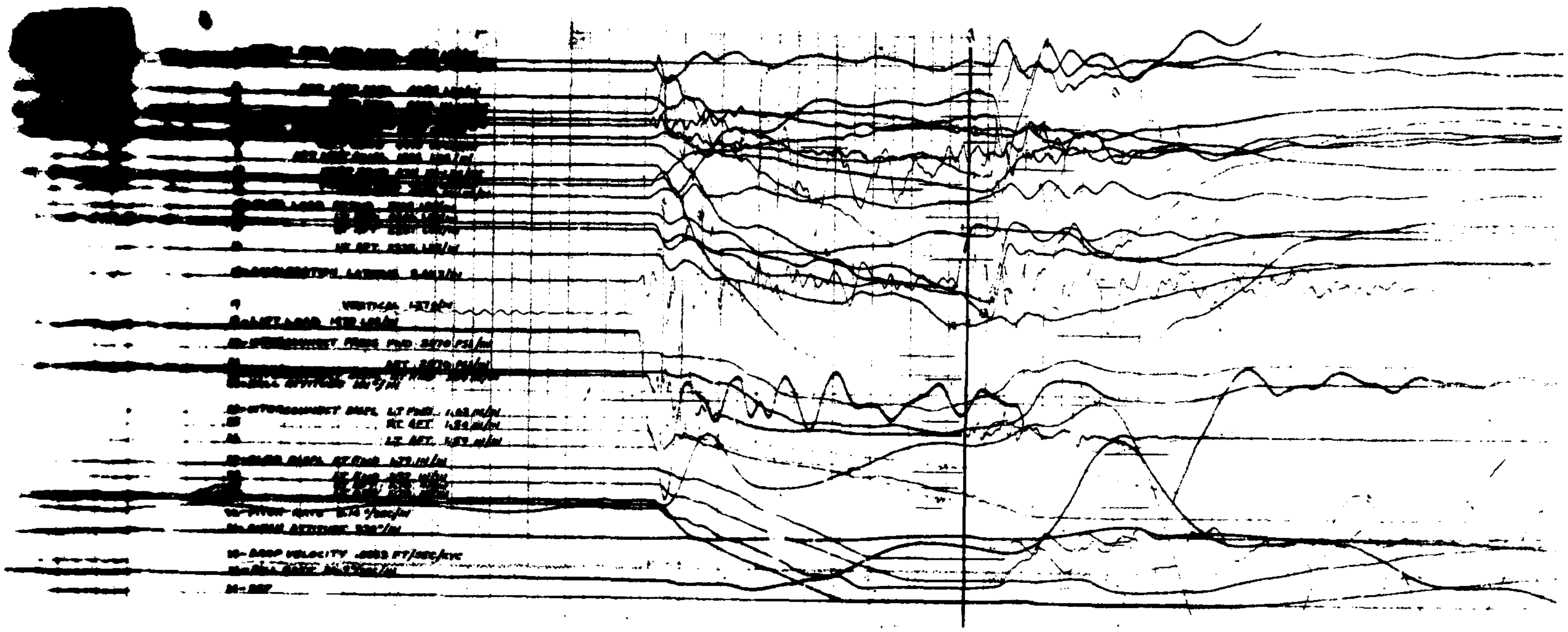

Figure A-26. Record 27, Maximum Drop, Test Condition 12

Gross Weight = 2550 lb
Aft CG, Sta 104
Rotor Lift = 100%

Drop Velocity = 19.2 fps
Surface Angle = 0°
Pitch Angle = 0°

APPENDIX B

COST ANALYSIS CALCULATIONS

LIST OF CALCULATIONS

*Maintenance Float Increased in Proportion to Flight Hour. Increase from 20 to 30 hours per month.

LIST OF CALCULATIONS (CONT)

LIST OF CALCULATIONS (CONT)

Retrofit of 100   Standing Inventory 400 A/C   6/8/78

Retrofit Rate of 8.3/month (100 per year)   .05×16×12 = (9.6

Year's End Inventory: Retrofitted A/C (R) ; Non-Retrofitted A/C (NR)

Year	TOT A/C	5.68% Maint Plant	2.3% (Accum) Cum	Ave # Flying A/C	ORG Flying Hours (96/yr)	5% A/C @ 16 Hrs/mo Δ Time Flying Hours
1 R	100	5.68	0	70	664 6720	65 672
1 NR	293.1	16.84	6.90	276.3	26525	2652
2 NR+R	384.1	21.8	(9.04) 15.94	362.3	34781	3478
3	376.2	21.3	(8.83) 24.77	353.9	33979	3397
4	366.6	20.8	(8.63) 33.40	345.8	33197	3320
5	358.2	20.3	(8.43) 41.83	337.9	32438	3244
6	349.9	19.9	(8.24) 50.07	330.0	31680	3168
7	341.9	19.4	(8.04) 58.11	322.5	30960	3096
8	334.0	19.0	(7.86) 65.97	315.0	30240	3024
9	326.4	18.5	(7.68) 73.65	307.9	29558	2956
10	318.8	18.1	(7.51) 81.16	300.7	28867	2887
					318,940	31,894

Total Flying Hours $\boxed{350,834}$

Flying Hours of retrofitted A/C:

1st year: ½ (6720 + 672) = 3696 (year of retrofit action)

Other years [350,837 − (3696 + 26525)] ¼ = 72186

Total Flying Hours on Retrofitted A/C = 72,186 + 3696 = $\boxed{75,882}$

Retrofit of 200 — 5/8/78

Year's End Inventory: Retrofitted (R) & Non-Retrofitted (NR) A/C

Year	Tot A/C	5.68% Mount Pilot	2.3% (Attrit) Cum	Ave # Flying A/C	ORG Flying Hours (96/year)	Δ Trng Flying Hours
1R	100	5.68	0	70	6720	672
1NR	293.1	16.84	6.90	276.3	26525	2652
2R	100	5.68	0	70	6720	672
2NR	286.4	16.27	(6.74) 13.64	270.1	25932	2593
3(R+NR)	377.5	21.4	(8.89) 22.53	356.1	34186	3419
4	368.8	20.9	(8.68) 31.21	347.9	33398	3340
5	360.4	20.5	(8.41) 39.62	339.9	32630	3263
6	352.1	20.0	(8.29) 47.91	332.1	31882	3188
7	344.0	19.5	(8.10) 56.01	324.5	31152	3115
8	336.1	19.1	(7.91) 63.92	317.0	30432	3043
9	328.4	18.7	(7.73) 71.65	309.7	29731	2973
10	320.8	18.2	(7.55) 79.20	302.6	29050	2905
					318,358	31835

Total = $\boxed{350,213}$

Flying Hours of retrofitted A/C:

1st year: $\frac{1}{2}(6720+672) = 3696$ (year of retrofit action)

2nd year: $\frac{1}{2}(6720+672) = 3696$ (" " ")

$\frac{1}{4}(25932+2593) = \underline{7131}$

10,827

Other years: $\left[350,213 - (2 \times 3697 + 10,827)\right]\frac{1}{2} = 165,996$

Total Hours in Retrofitted A/C = 165,996 + 10,990

= $\boxed{176,986}$

Retrofit of 400 | 6/8/78

Flying 8 hrs/month

Year's End Inventory: Retrofitted (R) & Non-Retrofitted (NR)

Year	TOT A/C	5.68% Mount Fleet	2.3% (Accum.) Cum	Ave # Flying A/C	ORG Flying Hours	6% Δ Trng Flying Hours
1R	100	5.68	0	70	866 6720	75 672
1NR	292.1	16.84	6.9	276.3	26525	2652
2R	100	5.68	0	70	6720	672
2NR	286.4	16.27	(6.76) 13.64	270.1	25932	2593
3R	100	5.68	0	70	6720	672
3NR	279.8	15.9	(6.59) 20.23	263.9	25334	2533
4R	100	5.68	0	70	6720	672
4NR	273.3	15.53	(6.43) 26.66	257.8	24749	2575
5	367.1	20.8	(6.29) 32.95	346.3	33245	3325
6	358.6	20.4	(8.44) 41.39	338.2	32467	3247
7	350.4	19.9	(8.25) 49.64	330.5	31728	3173
8	342.3	19.4	(8.06) 57.70	322.9	30998	3100
9	334.4	19.0	(7.87) 65.57	315.4	30278	3028
10	326.7	18.6	(7.69) 73.26	308.1	29578	2958
11	319.2	18.1	(7.51) 80.77	301.1	28906	2891
12	311.9	17.7	(7.34) 88.11	294.2	28243	2824
13	304.7	17.3	(7.17) 95.28	287.4	27590	2759
					403,443	40,346

Total Flying Hours = $\boxed{443,789}$

Flying Hours of Retrofitted A/C

1st year: $\frac{1}{2}(6720 + 672) = 3696$

2nd year: $\frac{1}{2}(6720 + 672) = 3696$

$\frac{1}{4}(25932 + 2593) = 7131$

3rd year: $\frac{1}{2}(6720 + 672) = 3696$

$\frac{1}{2}(25334 + 2533) = 13,934$

4th year: $\frac{1}{2}(6720 + 672) = 3,696$

$\frac{3}{4}(24749 + 2575) = 20493$

Total during Retrofit Period of 4 years 56,342

Total During 13 year Period

Total years 5 → 13 = 273,033 + 27,305

= 300,338

Total years 1 → 4 = 56,342

Total of Retrofitted Aircraft = $\boxed{356,680}$

Forward Prod. at 100

Year's End Inventory of A/C

Year	TOT A/C	Maint. Float	5.76% Cum Attrit.	Ave # Flying A/C	Line Org. Flying Hours	3 A/C @ 40 mo. ↓ Δ Trng. Flying Hours
1	100	14.2	0	85.8	@ 1010 9078	2400
2	94.24	13.4	5.76	84.85	" 19,406	
3	88.81	12.6	11.19	76.21	18,290	
4	83.69	11.88	(5.12) 16.31	71.81	17,234	
5	79.87	11.34	(4.82) 21.13	67.53	16,207	
6	75.27	10.69	(4.6) 25.7	64.58	15,499	
7	69.96	9.93	(4.34) 30.04	60.03	14,407	
8	65.93	9.36	(4.03) 34.07	56.57	13,577	
9	62.13	8.82	(3.80) 37.87	53.31	12,794	
10	58.55	8.31	(3.58) 41.45	50.24	12,058	
11	55.18	7.83	(3.37) 44.82	47.35	11,364	
12	52.00	7.38	(3.18) 48.00	44.62	10,709	
13	49.00	6.96	(3.0) 51.00	42.04	10,090	
14	46.18	6.56	(2.82) 53.82	39.62	9509	
15	43.52	6.18	(2.66) 56.48	37.34	8962	
16	41.01	5.82	(2.51) 58.99	35.19	8446	
17	38.65	5.49	(2.36) 61.35	33.16	7958	
18	36.42	5.17	(2.23) 63.58	31.25	7500	
19	34.32	4.87	(2.10) 65.68	29.45	7068	
20	32.34	4.59	(1.98) 67.66	27.75	6660	2400
21					239,816	48,0[illegible]

Total Hrs = $\boxed{287,8[illegible]}$

Forward Based of 200 — 6/7/78

Year's End Inventory of A/C

Year	Tot A/C	Maint Float	5.76% (Attrit) Cum.	Ave # Flying A/C	ORG Flying Hours	10 A/C @ 40 Hrs/Mo ΔTng Flying Hours
1	100	14.2	0	85.8	9,078	4800
2	194.24	27.58	5.76 (11.19)	166.66	28,484	
3	183.05	25.99	16.95 (10.54)	157.06	37,694	
4	172.51	24.50	27.49 (9.94)	148.01	35,522	
5	162.57	23.08	37.43 (9.36)	139.49	33,478	
6	153.21	21.76	46.79 (8.82)	131.45	31,548	
7	144.39	20.50	55.61 (8.32)	123.89	29,734	
8	136.17	19.32	63.93 (7.84)	116.75	28,020	
9	128.23	18.21	71.77 (7.39)	110.02	26,405	
10	120.84	17.16	79.16 (6.96)	103.68	24,883	
11	113.88	16.17	86.12 (6.56)	97.71	23,450	
12	107.32	15.24	92.68 (6.18)	92.08	22,099	
13	101.14	14.36	98.86 (5.83)	86.78	20,827	
14	95.31	13.53	104.69 (5.48)	82.78	19867	
15	89.83	12.76	110.17 (5.17)	77.07	18,497	
16	84.66	12.02	115.34 (4.88)	72.64	17,434	
17	79.78	11.33	120.22 (4.64)	68.45	16,428	
18	75.18	10.68	124.82 (4.33)	64.50	15480	
19	70.85	10.06	129.15 (4.08)	60.79	14590	
20	66.77	9.48	133.23 (3.85)	57.29	13750	
21	62.92	8.93	137.08 (3.62)	53.49	12958	
22	59.30	8.42	140.70	50.88	12211	4800
					472,437	105,600

Total = $\boxed{578{,}037}$

Forward Pad at 500 16/7/78

Year's End Inventory of A/C

Year	TOT A/C	Maint Float	5.76% (Attrit) Cum	Ave # Flying A/C	ORG Flying Hours	25 A/C @ 40 Hrs/Mo Δ Trng Flying Hours
1	100	14.2	0	85.8	12 14 13 9,078	12,000
2	194.24	27.58	5.76 (11.19)	166.66	12 28,484	
3	283.05	40.19	16.95 (16.30)	242.86	58,286	
4	366.75	52.08	33.25 (21.12)	314.67	75,521	
5	445.63	63.28	54.37 (25.67)	383.35	91,764	
6	419.96	59.63	80.04 (24.19)	360.33	86,479	
7	395.77	56.20	104.23 (22.80)	339.57	81497	
8	372.97	52.96	127.03 (21.48)	320.01	76802	
9	351.49	49.91	148.51 (20.25)	301.58	72379	
10	331.24	47.04	168.76 (19.08)	284.20	68208	
11	312.16	44.33	187.84 (17.98)	267.83	64279	
12	294.18	41.77	205.82 (16.94)	252.41	60,578	
13	278.24	39.51	221.76 (16.27)	238.73	57,295	
14	261.97	37.20	238.03 (15.07)	224.57	53,897	
15	246.90	35.06	253.10 (14.22)	211.84	50842	
16	232.68	33.04	267.32 (13.40)	199.64	47914	
17	219.28	31.14	280.72 (12.63)	188.14	45154	
18	206.65	29.34	293.35 (11.90)	177.31	42554	
19	194.75	27.65	305.25 (11.22)	167.10	40,104	
20	183.53	26.06	316.47 (10.57)	157.47	37,793	
21	172.96	24.56	327.04 (9.96)	148.40	35,616	
22	163.00	23.15	337.00 (9.39)	139.85	33564	
23	153.61	21.81	346.39 (8.85)	131.80	31632	
24	144.76	20.56	355.24 (8.34)	124.20	29808	
25	136.42	19.37	363.58	117.65	28,092	12,000
					1,277,620	300,000

Total = $\boxed{1,577,620}$

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Retrofit of 100   Starting Inventory: 400 A/C   6/8/78

Retrofit Rate of 8.3/month (100 per year)   .05×16×12 = 9.6

Year's End Inventory: Retrofitted A/C (R)
Non-Retrofitted A/C (NR)

Year	TOT A/C	5.68% Maint Float	2.3% (Attrit) Cum	Ave # Flying A/C	ORG Flying Hours (96/mo)	5% A/C @ No Modify Δ Time Flying Hours
1 R	100	5.68	0	70	664 6720	65 672
1 NR	293.1	16.84	6.90	276.3	26525	2652
2 NR+R	384.1	21.8	(9.04) 15.94	362.3	34781	3478
3	375.2	21.3	(8.83) 24.77	353.9	33974	3397
4	366.6	20.8	(8.63) 33.40	345.8	33197	3320
5	358.2	20.3	(8.43) 41.83	337.9	32438	3244
6	349.9	19.9	(8.24) 50.07	330.0	31680	3168
7	341.9	19.4	(8.04) 58.11	322.5	30960	3096
8	334.0	19.0	(7.86) 65.97	315.0	30240	3024
9	326.4	18.5	(7.68) 73.65	307.9	29558	2956
10	318.8	18.1	(7.51) 81.16	300.7	28867	2887
11	311.5	17.7	(7.33) 88.49	294.8	28301	2830
12	304.3	17.3	(7.16) 95.65	287.0	27552	2755
13	297.4	16.9	(6.99) 102.64	280.5	26928	2693
					401,721	40,172

Total Flying Hours = $\boxed{441,893}$

Flying Hours of Retrofitted A/C

1^{st} year: $\frac{1}{2}(6720 + 672) = 3696$

Other years: $[441,893 - (3696 + 26525)] \cdot \frac{1}{4} = 102,918$

Total Flying Hours in Retrofitted A/C =

$= 102,918 + 3696 = \boxed{106,614}$

Retrofit of 200 | 5/8/78

Flying Hours

Year's End Inventory: Retrofitted (R) & Non-Retrofitted (NR) A/C

Year	Tot A/C	5.68% Mound Flying	2.3% (Attrition) Cum	Avg # Flying A/C	ORG Flying Hours (96/yr)	10% Trng Flying Hours
1R	100	5.68	0	70	6720	672
1NR	298.1	16.84	6.90	276.3	26525	2652
2R	100	5.68	0	70	6720	672
2NR	286.4	16.27	(6.74) 13.64	270.1	25932	2593
3(R+NR)	377.5	21.4	(8.89) 22.53	356.1	34186	3419
4	368.8	20.9	(8.68) 31.21	347.9	33398	3340
5	360.4	20.5	(8.41) 39.62	339.9	32630	3263
6	352.1	20.0	(8.29) 47.91	332.1	31882	3188
7	344.0	19.5	(8.10) 56.01	324.5	31152	3115
8	336.1	19.1	(7.91) 63.92	317.0	30432	3043
9	328.4	18.7	(7.73) 71.65	309.7	29731	2973
10	320.8	18.2	(7.55) 79.20	302.6	29050	2905
11	313.4	17.8	(7.38) 86.58	295.6	28378	2838
12	306.2	17.4	(7.21) 93.79	288.8	27725	2773
13	299.2	17.0	(7.04) 100.83	282.2	27091	2709
					401,552	4016

Total Flying Hours = $\boxed{405568}$

Flying Hours of Retrofitted A/C

1st year: $\frac{1}{2}(6720+672) = 3696$

2nd year: $\frac{1}{2}(6720+672) = 3696$

$\frac{1}{4}(25932+2593) = 7131$

$10,827$

Total Flying During 13-year period

Total/years 2 → 13 =

$= [405,568 - (2 \times 3696 + 10,827)] \cdot \frac{1}{2} = 211894$

Total of retrofitted aircraft = $\boxed{222,721}$

Retrofit of 400 | 6/8/78

Year's End Inventory: Retrofitted (R) & Non-Retrofitted (NR) A/C

Year	TOT A/C	5.68% Maint Float	2.3% (Attrit) Cum	Ave # Flying A/C	ORG Flying Hours per year	5% @ Attrit Δ Trng Flying Hours
1R	100	5.68	0	70	6720	672
1NR	293.1	16.84	6.9	276.3	26525	2652
2R	100	5.68	0	70	6720	672
2NR	286.4	16.27	(6.74) 13.64	270.1	25932	2593
3R	100	5.68	0	70	6720	672
3NR	279.8	15.9	(6.59) 20.23	263.9	25334	2533
4R	100	5.68	0	70	6720	672
4NR	273.3	15.53	(6.43) 26.66	257.8	24749	2575
5	367.1	20.8	(6.29) 32.95	346.3	33245	3325
6	358.6	20.4	(8.44) 41.39	338.2	32467	3247
7	350.4	19.9	(8.25) 49.64	330.5	31728	3173
8	342.3	19.4	(8.06) 57.70	322.9	30998	3100
9	334.4	19.0	(7.87) 65.57	315.4	30278	3028
10	326.7	18.6	(7.69) 73.26	308.1	29578	2958
					318,704	31,872

Total (All A/C) $\boxed{350,576}$

Flying Hours of retrofitted A/C:

1st year : $\frac{1}{2}(6720 + 672) = 3696$

2nd year : $\frac{1}{2}(6720 + 672) = 3696$

$\frac{1}{4}(25932 + 2593) = 7131$

3rd year : $\frac{1}{2}(6720 + 672) = 3696$

$\frac{1}{2}(25334 + 2533) = 13934$

4th year : $\frac{1}{2}(6720 + 672) = 3696$

$\frac{3}{4}(24749 + 2575) = \underline{20493}$ (+)

Total during retrofit period of 4 years 56,842

Total during 10 year Period:

Total years 5 → 10 = 188,294 + 18,831

= 207,125

Total years 1 → 4 = $\underline{56,842}$

Total of Retrofitted Aircraft = $\boxed{263,467}$

Retrofit of 100 — 6/14/78

Flight Hours increased to 20hrs/month (240hrs/year)
Maintenance float increased to 14.2%
Attrition increased to 5.76%/year.

.05×40×12=24

Year	Tot A/C	Maint Float	.0576 (Attrit) Cum	Ave. # Flying A/C	(240) ORG Flying Hours	5% A/C @ 40 hrs/mo △ Flying Hours
1R	100	14.2	0	70	16800	1680
1NR	293.3	41.6	6.74 (22.65)	251.7	60408	6041
2N+NR	370.6	52.6	29.39 (21.35)	318.0	76320	7632
3	349.3	49.6	50.74 (20.12)	299.7	71928	7193
4	329.1	46.7	70.86 (18.96)	282.4	67776	6778
5	310.2	44.0	89.82 (17.87)	266.2	63888	6389
6	292.3	41.5	107.69 (16.84)	250.8	60192	6019
7	275.5	39.1	124.53 (15.87)	236.4	56736	5674
8	259.6	36.9	140.40 (14.95)	222.7	53448	5345
9	244.7	34.7	155.35 (14.09)	210.0	50400	5040
10	230.6	32.7	169.44 (13.28)	197.9	47496	4750
11	217.3	30.9	182.72 (12.52)	186.4	44736	4474
12	204.8	29.1	195.24 (11.80)	175.7	42168	4217
13	193.0	27.4	207.04	165.6	39,744	3974
					752,040	75,206

Total Flying Hours = 827,246

Flying Hours of retrofitted A/C

1st year, $\frac{1}{2}(16,800 + 1680) = 9240$

Other years; $[827,246 - (9240 + 60408)]\frac{1}{4} = 189,400$

Total flying Hours in retrofitted A/C =
$= 189,400 + 9240 = \boxed{198,639}$

Retrofit of 400 | 6/19/78

Flying 20 hrs/month

Year's End Inventory

Year	TOT A/C	[illegible]	5% (Attrit) Cum	AVR # Flying A/C	[illegible]	5% A/C [illegible] Flying Hours
1R	100	14.2	0	70	16,800	1680
1NR	282.7	40.1	17.28	242.6	58,224	5822
2R	100	14.2	0	70	16,800	1680
2NR	266.4	37.8	(16.28) 33.56	228.6	54,864	5486
3R	100	14.2	0	70	16,800	1680
3NR	251.1	35.7	(15.34) 48.90	215.4	51,696	5170
4R	100	14.2	0	70	16,800	1680
4NR	236.6	33.6	(14.46) 63.36	203	48,720	4872
5	317.2	45.0	(19.39) 82.75	272.2	65,328	6533
6	299.0	42.6	(18.27) 101.02	256.4	61,536	6154
7	281.8	40.0	(17.22) 118.24	241.8	58,032	5803
8	265.5	37.7	(16.23) 134.47	227.8	54,672	5467
9	250.2	35.5	(15.29) 149.76	215.7	51,768	5177
10	235.8	33.5	(14.41) 164.17	202.3	48,552	4855
11	222.3	31.6	(13.58) 177.75	190.7	45,768	4577
12	209.4	29.7	(12.80) 190.55	179.7	43,128	4313
13	197.4	28.0	(12.06) 202.61	169.4	40,656	4066
					750,144	75,015

Total Flying Hours = $\boxed{825,159}$

Flying Hours of Retrofitted A/C

1st year: ½(16,800 + 1680) = 9240
2nd year: ½(16,800 + 1680) = 9240
¼(54,864 + 5486) = 14136
3rd year: ½(16,800 + 1680) = 9240
½(51,696 + 5170) = 28433
4th year: ½(16,800 + 1680) = 9240
¾(48,720 + 4872) = 40194
Total Flying During Retrofit Period = 119,723

Total Flying During 13 Year Period

Total years 5→13 = 469,440 + 46,945
= 516,385
Total years 1→4 = 119,723
Total Flying of Retrofitted A/C = $\boxed{636,108}$

Retrofit of 100

Flight Hours increased to 30 hrs/month (360 hrs/year)
Maintenance Float 14.2% (Same as for 20 hrs/mo)
Attrition increased to $\frac{360}{240} \times .0576 = .0864$

Year	TOT A/C	Maint Float	(Attrit) Cum	Ave Flying A/C	ORG Flying Hours	5% A/C @ 40 hrs/mo Δ Flying Hours
1 R	100	14.2	0	70	2365 25,200	555 1680
1 N.R.	274.1	38.9	25.92 (32.32)	235.2	84,672	5695
2 N+NR	341.8	48.5	58.24 (29.53)	293.3	105,588	7039
3	312.2	44.3	87.77 (26.97)	267.9	96,444	6430
4	285.3	40.5	114.74 (24.65)	244.8	88,128	5875
5	260.6	37.0	139.39 (22.52)	223.6	80,496	5366
6	238.1	33.8	161.91 (20.57)	204.3	73,548	4903
7	217.5	30.9	182.48 (18.79)	186.6	67,176	4478
8	198.7	28.2	201.27 (17.17)	170.5	61,380	4092
9	181.6	25.8	218.44 (15.69)	156.8	56,088	3739
10	165.9	23.6	234.13 (14.33)	142.3	51,228	3415
11	151.5	21.5	248.46 (13.01)	130.0	46,800	3120
12	138.5	19.7	261.47 (11.97)	118.8	42,768	2851
13	126.5	18.0	273.54	108.5	39,060	2604
					918,574	61237

Total Flying Hours = $\boxed{979,811}$

Flying Hours of Retrofitted A/c

1st year; $\frac{1}{2}(25,200 + 1680) = 13,440$

Other years; $[979,811 - (13,440 + 84672)] \cdot \frac{1}{4} = 227,145$

Total Flying Hours in Retrofitted A/c =

$= 227,145 + 13,440 = \boxed{240,585}$

Retrofit of 400 — 6/15/78

Flying 30 hrs/month

Year's End Inventory

Year	Tot A/C	14.2% Maint Float	9.64% (Attrit) Cum	AUE = Flying A/C	ORG Flying Hours /yr	5% A/C @ in hangar △ Flying Hours
1R	100	14.2	0	70	25200	1680
1NR	274.1	38.9	2592	235.2	84672	5645
2R	100	14.2	0	70	25200	1680
2NR	250.4	35.6	(23.68) 49.60	214.8	77,328	5155
3R	100	14.2	0	70	25,200	1680
3NR	228.8	32.5	(21.63) 71.23	196.3	70,668	4711
4R	100	14.2	0	70	25,200	1680
4NR	209.0	29.7	(19.77) 91.00	169.3	60,948	4063
5	290.9	41.3	(18.06) 109.06	249.6	89,856	5990
6	265.8	37.7	(25.13) 134.19	228.1	82,116	5474
7	242.8	34.5	(22.97) 157.16	208.3	74,988	4999
8	221.9	31.5	(20.98) 178.14	190.4	68,544	4570
9	202.7	28.8	(19.17) 197.31	173.9	62,604	4174
10	185.2	26.3	(17.51) 214.82	158.9	57,204	3814
11	169.2	24.0	(16.00) 230.82	145.2	52,272	3485
12	154.6	22.0	(14.62) 245.44	132.6	47,736	3182
13	141.2	20.0	(13.36) 258.80	121.2	43,632	2909
					963,368	64,891

Total Flying Hours = $\boxed{1,028,259}$

Flying Hours of Retrofitted A/c

1st year : ½(25200 + 1680) = 13,440

2nd year : ½(25,200 + 1680) = 13,440

¼(77,328 + 5155) = 20,621

3rd year : ½(25,200 + 1680) = 13,440

½(70,668 + 4711) = 37,690

4th year : ½(25,200 + 1680) = 13,440

¾(60,948 + 4063) = 48,758

Total Flying During Retrofit Period = 160,829

Total During 13 year Period

Total Years 5 → 13 = 578,952 + 38,597

= 617,549

Total years 1 → 4 = 160,829

Total of Retrofitted Aircraft = $\boxed{778,378}$

<u>Retrofit of 100</u> | 6/14/78

Flight Hours increased to 20 hrs/month (240 hrs/year)
Maintenance float increased to 14.2%
Attrition increased to 5.76%/year

.05×40 × 12 = 24

Year	Tot A/C	Maint Float	.0576 (Attrit) Cum	Ave # Flying A/C	(240) [illegible] Flying Hours	[illegible] A/C @ 40 hrs/mo Δ Flying Hours
1R	100	14.2	0	70	4646 / 16800	269 / 1680
1NR	293.3	41.6	6.74 (22.65)	251.7	60408	6041
2N+NR	370.6	52.6	29.39 (21.35)	318.0	76320	7632
3	349.3	49.6	50.74 (20.12)	299.7	71928	7193
4	329.1	46.7	70.86 (18.96)	282.4	67776	6778
5	310.2	44.0	89.82 (17.87)	266.2	63888	6389
6	292.3	41.5	107.69 (16.84)	250.8	60192	6019
7	275.5	39.1	124.53 (15.87)	236.4	56736	5674
8	259.6	36.9	140.40 (14.95)	222.7	53448	5345
9	244.7	34.7	155.35 (14.09)	210.0	50400	5040
10	230.6	32.7	169.44	197.9	47496	4750
					625,392	62,541

Total Flying Hours = $\boxed{687,933}$

<u>Flying Hours of retrofitted A/C:</u>

1st year: $\frac{1}{2}(16800 + 1680) = 9240$

Other years: $[687,933 - (9240 + 60408)] \cdot \frac{1}{4} = 159,191$

Total flying Hours in retrofitted A/C =
$= 159,191 + 9240 = \boxed{168,431}$

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Retrofit of 100 — 6/14/78

Flight Hours increased to 30 hrs/month (360 hrs/year)
Maintenance Float 14.2% (Same as for 20 hrs/mo)
Attrition increased to $\frac{360}{240} \times .0576 = .0864$

Year	TOT A/C	Maint Float	(Attrit) Cum	Ave # Flying A/C	ORG Flying Hours	5% A/C @ 40 hrs/mo Δ Flying Hours
1R	100	14.2	0	70	25,200	1670
1 N.R.	274.1	38.9	25.92 (32.32)	235.2	84,672	5645
2N+NR	341.8	48.5	58.24 (29.53)	293.3	105,588	7039
3	312.2	44.3	87.77 (26.97)	267.9	96,444	6430
4	285.3	40.5	114.74 (24.65)	244.8	88,128	5875
5	260.6	37.0	139.39 (22.52)	223.6	80,496	5366
6	238.1	33.8	161.91 (20.57)	204.3	73,548	4903
7	217.5	30.9	182.48 18.79	186.6	67,176	4478
8	198.7	28.2	201.27 17.17	170.5	61,380	4092
9	181.6	25.8	218.44 (15.64)	156.8	56,088	3739
10	165.9	23.6	234.13	142.3	51,228	3415
					789,946	52,662

Total Flying Hours = $\boxed{842608}$

Flying Hours of Retrofitted A/C

1st year: $\frac{1}{2}(25{,}200 + 1680) = 13{,}440$

Other years: $[842{,}608 - (13{,}440 + 84{,}672)] \cdot \frac{1}{4} = 192{,}844$

Total Flying Hours in retrofitted A/C =

$= 192{,}844 + 13{,}440 = \boxed{206{,}284}$

Retrofit of 100 $\boxed{6/14/78}$

Flight Hours Increased to 30 hrs/mo (360 hrs/yr)

Maintenance Phot increased to $\frac{360}{240} \times .142 = .213$

Attrition increased to $\frac{360}{240} \times .0576 = .0864$

Year	Tot A/C	Maint Phot	(Attrit) Cum	Ave # Flying A/C	Org Flying Hours	5% A/C @ 40 hr/mo Δ Flying Hours
1R	100	21.3	0	63	466. 22,680	555 1512
1NR	274.1	58.4	25.92 (32.32)	215.7	77,652	5177
2N+NR	341.7	72.8	58.24 (29.52)	283.5	102,046	6806
3	312.3	66.5	87.76 (26.98)	245.8	88,488	5899
4	285.3	60.8	114.74 (24.65)	224.5	80,820	5388
5	260.6	55.1	139.39 (22.52)	205.5	73,980	4932
6	238.1	50.7	161.91 (20.57)	187.4	67,464	4498
7	217.5	46.3	182.48 (18.79)	171.2	61,632	4109
8	198.7	42.3	201.27 (17.17)	156.4	56,160	3754
9	181.6	38.7	218.44 (15.69)	142.9	51,444	3430
10	165.9	35.4	234.13	130.5	46,980	3132
					729,326	48,627

Total Flying Hours = $\boxed{777,953}$

Flying Hours of Retrofitted A/C:

1st year: $\frac{1}{2}(22,680 + 1512) = 12096$

Other Years: $[777,953 - (12096 + 77,652)] \cdot \frac{1}{4} = 172,051$

Total Flying Hours in retrofitted A/C =

$= 172,051 + 12096 = \boxed{184,147}$

6/7/78
Page 1

Number of Tail boom Chips in New Procurement A/c

	100 A/c	200 A/c	500 A/c
Flight Hours in 20 Yrs	287,816	578,037	1,577,620
No. Tailboom Chips @5600 Hours between chips	52	104	282
If I.C. landing gear eliminates 80% chips, the number of chips saved =	41.6	83.2	225.6
Savings at $30,968 per Chip incident ('72 $)	$1,300,656	2,601,312	$6,998,768
Increased Investment due to I.C. Gear from Page 2	285,176	570,352	$1,425,880
NET Direct Dollar Savings	$1,014,480	$2,030,960	$5,572,888

6/9/75

Page 3

Number of Tailboom Chops in Retrofitted Fleet of A/C; Retrofitted Portion - Non-Retrofitted Portion

	100 A/C		200 A/C		400 A/C	
	R.	N.R	R.	N.R	R.	N.R.
Flight Hours in 10 year life starting at time of Initial A/C into inventory	75832	274,352	176,986	173,227	263467	87,109
No. Tailboom Chops @ 5600 Hrs between chops	14	49	32	31	47	16
If I.C. Landing Gear eliminates 80% Chops; Number of chop saves =	11.2		25.6		37.6	
Savings at $30,968 per chop incident ('72 $)	346,842		792,781		1,164,397	
Increased investment due to Retrofit from Page 4	678,200		1,236,000		2,287,200	
NET Direct Dollar Savings	-331,358		-443,219		-1,122,803	
Number of Additional Chops to break even	14		18		45	
Number of Additional Flight Hours To break even	78,400		100,800		252,000	

6/14/78

Page 3, Rev. 1

Number of Tailboom Chops in Retrofitted Fleet of A/c flying 20 hours/month.

	100 A/c		200 A/c		400 A/c	
	R	N.R	R.	N.R	R.	N.R.
Flight Hours in 10-year life	168,431					
No. Tailboom chops @ 5600 Hrs between chops	30					
If I.C. Landing Gear eliminates 80% chops; Number of chop saves	24					
Savings at 30,968 Per chop	743,232					
Increased investment due to retrofit from Page 4	678,200					
NET Direct Dollar Savings	65,032					

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6/14/78
Page 3
2nd Rev.

Number of Tailboom Chops in Retrofitted Fleet of A/C Flying 30 hours/month
(Maint. Float @ 14.2%) (Attrit at 8.64%)

	100 A/C		200 A/C		400 A/C	
	R	N.R	R.	N.R.	R.	N.R
Flight Hours in 10-yr. life	206,284					
No. Tailboom Chops @ 5600 Hours between Chops	37					
If I.C Landing Gear eliminates 80% Chops; Number of chops saved	30					
Savings at $30,968 Per chop	929,040					
Increased Investment due to retrofit from Page 4	678,200					
Net Direct Dollar Savings	250,840					

6/14/78

Page 3
2nd Rev.

Number of Tailboom Chops in Retrofitted Fleet at A/C flying 30 hours/month
(Maint Float @ 21.3%) (Attnt at .0864)

	100 A/C		200 A/C		400 A/C	
	R.	N.R.	R.	N.R.	R.	N.R.
Flight Hours in 10-yr. life	184,147					
No. Tailboom Chops @ 5600 Hours between Chops	33					
If I.C. Landing Gear eliminates 80% Chops; Number of chops saves	26					
Savings at $39,961 Per chop.	805,168					
Increased Investment due to ~~retrofit~~ from Page 4	678,200					
NET Direct Dollar Savings	126,968					

6/15/78
Page 3
4th Rev.

No. of Tailboom Chops in Retrofitted Fleet of A/C Flying 30 hrs/month (13-yrs) (Maint Float @ 14.2%) (Attrit at 8.64%)

	100 A/c R.	100 A/c N.R.	400 A/c R.
Flight Hours in 13-yr life	240,585		778,378
No. Tailboom chops @ 5600 Hours between chops	43		139
If I.C. Landing Gear eliminates 80% of chops; No. of chop saves	34		111
Savings at 30,968 per chop	1,052,912		3,437,448
Increased Investment due to retrofit from Page 4	678,200		2,287,200
Net Direct Dollar Savings	374,712		1,150,248

6/15/78

Page 3
5th Rev

No. of Tailboom Chops in Retrofitted Fleet of A/c Flying 20 hrs/month (12-year) (Maint. Float @ 14.2%) (Attrit of 5.67%)

	100 A/c	200 A/c	400 A/c
Flight Hours in 12yr Life	R. 198,639		R. 636,108
No. of Tailboom chops @ 5600 Hours between Chops	35		114
If. I.C. Landing gear eliminates 80% of chops; No. of chop saves	28		91
Savings @ 30,968 Per Chop	867,104		2,818,088
Increased Investment Cost to Retrofit from Page 4	678,200		2,287,200
Net Direct Dollar Savings	188,904		530,888

6/15/78

Page 3
6th Rev

No. of Tailboom Chops in Retrofitted Fleet of A/C Flying 8 hrs/month (13-years)
(Maint Float 5.68%) (Attrition of 2.3%)

	100 A/C	200 A/C	400 A/C
Flight Hours in 13 yr. Life	106,614	222,721	356,680
No. of Tailboom Chops @ 5600 Hours between Chops	19	40	64
If I.C. Landing gear eliminates 80% of chops; No of chops saved	15	32	51
Savings @ 30,968 Per chop	464,520	990,976	1,579,368
Increased Investment Due To Retrofit from PAGE 4	678,200	1,236,000	2,287,200
NET Direct Dollar Savings	−213,680	−245,024	−707,832

9/7/78

Page 2

Cost to Army of Buying OH-6A's with Interconnected landing Gear.

	100 A/c	200 A/c	500 A/c
Cost To Army/Shipset for I.C. gear	336,700	673,400	1,683,500
Cost To Army of NON I.C. gear	51,524	103,048	257,620
Increase in cost due to Army's investment in I.C gear	$285,176	$570,352	$1,425,880

6/9/78

Page 4.

Cost To Army of Buying Retrofit of OH-6A

	100 A/C	200 A/C	400 A/C
Cost To Army For Retrofit	678,200	1,236,000	2,287,200

6/12/78

Page 6

Cost To Army for Additional Spare Parts (Retrofitted A/C) — Assumes all replacements are with new spares

	100 A/C	200 A/C	400 A/C
Flight hours in 10 year life of retrofitted A/C	75,882	176,936	262,467
No. of damper replacements at a rate of 3.625/1000 hrs	276	643	958
Cost of spare dampers @ $432.60 each	119,398	278,162	414,431
No. of other hydraulic components replacements @ rate of 1.28/1000	97	227	337
Cost of other components @ $216.34 each	20,981	49,100	72,893
No. of old style dampers that would need replacing if not retrofitted @ rate of 3.4/1000	257	601	896
Cost of old style dampers	55,589	129,996	193,805
Total cost of new equip spares	140,379	327,262	487,324
NET increase in spares cost	84,790	197,266	293,519
From Page 3 NET Direct Dollar Savings	-331,358	-443,219	-1,122,803
OVERALL Savings attributable to I.C. Landing Gear	-416,148	-640,485	-1,416,322

6/12/78
Page 6

Cost To Army for Additional Spare Parts For New Production A/C - Assumes all replacements are with new spares

	100 A/C	200 A/C	500 A/C
Flight Hours in 20-yr Life	287,816	578,027	1,577,620
No. of Damper Replacements at rate of 3.635/1000 hr	1046	2101	5735
Cost of spare dampers at 432.60 each	452,500	908,893	2,480,961
No. of OTHER Hydraulic Component Replacements at Rate of 1.28/1000	368	740	2019
Cost of OTHER Components at 216.30 each	79,598	160,062	436,710
No. of old style Dampers that would need replacing if still on A/C. Rate of 3.4/1000	979	1965	5364
Cost of old style Dampers @ 216.30	211,758	425,030	1,160,233
Total Cost of New Equip Spares	532,098	1,067,955	2,916,671
Net Increase in Spares Cost	320,340	643,925	1,756,438
From Page 7 NET Direct Dollar Savings	1,014,480	2,030,960	5,572,888
Overall Savings Attributable to I.C. Landing Gear Config.	694,140	1,387,035	3,816,450

Comments / (369A)

$$\frac{\text{Rebuilt Spare}}{\text{New Spare}} = \frac{\$255\ ('79)}{\$481} = .53$$

Cost To Army for Additional Spare Parts and Damper Overhaul - Retrofitted A/C
Assumes 80% of replacements with rebuilt spares & 20% with new spares. - 8 hrs/mo

	100 A/C	200 A/C	400 A/C
Flight Hours in ?? year life of retrofitted A/C	75,882	176,986	263,467
No. of damper replacements at a rate of 3.625/1000 hrs	276	643	958
Cost of new spares @ $432.60 each	23,793	55,622	82,886
Cost of rebuilt spares @ 229.26 each	50,671	117,850	175,628
No. of OTHER hydraulic component replacements @ rate of 1.28/1000	97	227	337
Cost of OTHER components @ $216.30 each	20,981	49,110	72,898
No. of old style Dampers that would need replacing if A/C retrofitted @ rate of 3.4/1000	257	601	896
Cost of "New" old style spares @ $216.30	11,031	25,956	38,718
Cost of "Rebuilt" old style spares	23,616	55,142	82,197
Total Cost of old configuration "New" & "Rebuilt" Spares	34,647	81,098	120,915
Total Cost of new configuration "New" and "Rebuilt" spares	95,445	222,582	331,407
NET Increase in spares Cost	60,798	141,484	210,492
From Page 3 Net Direct Dollar Savings	-331,358	-443,219	-1,122,808
Overall Savings Attributable to I.C. Landing Gear	-392,156	-584,703	-1,333,296

6/13/78

Page 8

Cost To Army for Additional Spare Parts and Damper Overhaul for New Production A/C assumes 80% of damper replacements with rebuilt spares & 20% with new spares.

	100 A/C	200 A/C	500 A/C
Flight Hours in 20-yr. Life	287,816	578,037	1,577,620
No. of Damper Replacements at rate of 3.65/1000 hrs	1046	2101	5785
Cost of new Spares @ 430.60 each	90,500	181,779	496,172
Cost of Rebuilt Spares @ 229.28 each	191,862	385,374	1,051,987
No. of OTHER Hydraulic Component Replacements at 1.28/1000 hrs	368	740	2019
Cost of OTHER Components at 216.30 each	79,598	160,062	436,710
No. of old style Dampers that would need replacing if not superseded by I.C. design Rate of 3.4/1000 hrs	979	1965	5364
Cost of "New" old style spares at 216.20 each	42,352	85,006	232,047
Cost of "Rebuilt" old style spares at 114.64 each	89,786	180,214	491,943
Total Cost of old Configuration "New" & "Rebuilt" Spares	132,138	265,220	723,990
Total Cost of new Configuration "New" & "Rebuilt" Spares	361,960	727,215	1,984,839
Net Increase in Spares Cost	229,822	461,995	1,260,849
From Page 7 Net Direct Dollar Savings	1,014,480	2,030,960	5,572,888
Overall Savings Attributable to I.C. Landing gear config.	784,658	1,568,965	4,312,039

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6/14/78
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Rev I

Cost To Army for Additional Spare Parts and Damper Overhaul – Retrofitted A/C (10 yrs) Assumes 80% of replacement with rebuilt spares & 20% with new spares. - flying 30 hrs/mo

	(30 hrs/mo) 100 A/C	(20 hrs/mo) 100 A/C
Flight Hours in 10 years life of retrofitted A/C (Page 3, Rev II)	206,284	168,481
No. of damper replacements at a rate of 3.635/1000 Hrs	750	612
Cost of new spares @ $432.60	64,890	52,950
Cost of Rebuilt spares @ $229.28	137,568	112,255
No. of OTHER hydraulic comp. replacements @ 1.28/1000	264	215
Cost of OTHER Components @ 216.30 each	57,103	46,504
No. of old style dampers that would need [illegible] @ 3.4/1000	701	573
Cost of "New" old style spares @ 216.30	30,325	24,788
Cost of "Rebuilt" old style spares @ 114.60	64,290	52,551
Total Cost of old Configuration "New" & "Rebuilt" Spares	94,615	77,339
Total Cost of new configuration "New" & "Rebuilt" spares	259,561	211,709
Net Increase in Spares Cost	164,946	134,370
From Page 3, Net Direct Dollar Savings	Rev II 260,840	REV I 65,032
Overall Saving Attributable to I.C. Landing Gear	95,894	-69,338

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Rev 2

Cost To Army for Additional Spare Parts and Damper Overhaul - Retrofitted A/C (13 yrs) Assumes 80% of replacements with rebuilt Spares & 20% with new spares - (Flying 30 hrs/mo, 20 hrs/mo., & 8 hrs/mo.)

	(30 hrs/mo) 100 A/C	(20 hrs/mo) 100 A/C	(8 hrs/mo) 100 A/C
Flight Hours in 13 Years life of retrofitted A/c	240,585	198,639	106,614
No. of Damper replacements at a rate of 3.635/1000 Hrs	876	722	387
Cost of new Spares @ $432.60	75,705	62,467	33,526
Cost of rebuilt Spares @ $229.25	160,496	132,432	70,985
No. of OTHER hydraulic Comp. replacements @ 1.28/1000	308	254	136
Cost of OTHER Components @ $216.30 each	66,620	54,940	29,514
No. of old style dampers that would need replacing if not retrofitted @ 3.4/1000	818	675	362
Cost of "New" old style spares @ $216.30	35,387	29,200	15,679
Cost of "Rebuilt" old style spares @ 114.69	75,020	61,906	33,200
Total cost of old configuration "New" & "Rebuilt" Spares	110,407	91,106	48,879
Total Cost of new Configuration "New" & "Rebuilt" spares	302,821	249,939	134,025
Net Increase in Spares Cost	192,414	158,833	85,146
From Page 3 Net Direct Dollar Savings	[illegible] 374,712	Rev 6 188,909	REV 6 -213,680
Overall Saving Attributable to I.C. Landing Gear	182,298	30,071	-298,826

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Rev 3

Cost To Army for Additional Spare Parts and Damper Overhaul - Retrofitted A/C (13 yrs)
Assumes 80% of replacements with rebuilt spares and 20% with new spares
(Flying 30hrs/mo, 8hrs/mo)

	(30hrs/mo) 400 A/C	(20hrs/mo) 400 A/C	(8hrs/mo) 400 A/C
Flight hours in 13 year life of retrofitted A/C	778,378	636,108	356,680
No. of damper replacements at a rate of 3.635/1000 Hrs.	2829	2312	1297
Cost of new Spares @ $432.60	244,765	200,034	112,216
Cost of rebuilt spares @ $229.28	518,906	424,076	237,901
No. of OTHER hydraulic comp. replacements @ 1.28/1000	996	814	457
Cost of OTHER components @ $216.30	215,425	176,068	98,849
No. of old style dampers that would need replacement if not retrofitted at 3.4/1000	2646	2163	1213
Cost of "New" old style spares @ $216.30	114,466	93,571	52,474
Cost of "Rebuilt" old style spares @ $114.64	242,670	198,373	111,247
Total Cost of old configuration "New" & "Rebuilt" Spares	357,136	291,944	163,721
Total cost of new configuration "New" & "Rebuilt" Spares	979,106	800,178	448,966
NET Increase in Spares Cost	621,970	508,234	285,245
From Page 3 Net Direct Dollar Savings	Rev 4 1,150,248	Rev 5 530,888	Rev 6 -707,832
Overall Savings attributable to I.C. Landing Gear	528,278	22,654	-993,077

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Rev 4

Cost To Avoid for Additional Spare Parts and Damper Overhaul - Retrofitted A/C (13-yrs)
Assumes 80% of replacements with rebuilt Spares and 20% with New Spares.

	hrs/mo 200 A/C
Flight hours in 13 year life of Retrofitted A/C	222,721
No. of damper replacements at a rate of 3.635/1000 Hrs.	810
Cost of new spares @ $420.60	70,081
Cost of Rebuilt Spares @ $229.38	148,573
No. of OTHER hydraulic component replacements @ 1.28/1000 hrs	285
Cost of OTHER Components at $216.30	61,663
No. of old style dampers that would need replacement at 3.4/1000 if not retrofitted	757
Cost of "New" old style spares @ $216.30	32,[illegible]
Cost of "Rebuilt" old style spares @ $114.69	69,472
Total Cost of old configuration "New" & "Rebuilt" spares	102,133
Total Cost of new configuration "New" & "Rebuilt" spares	280,317
NET Decrease in Spares Cost	178,184
From Page 2 Net Direct Dollar Savings	REV 6 − 245,024
Overall Saving Attributable to E.C. Landing Gear	− 423,208

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