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FLIGHT TEST OF A HINGELESS FLEXBEAM  
ROTOR SYSTEM

Charles W. Hughes, et al

Bell Helicopter Company

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| Maneuvers                                                                                                                                                                                                                                                                                                                                                                                                                    | Rigidity              |                                                                                                                           |         |             |                                                                                                                           |           |          |        |           |                   |  |
| Struts                                                                                                                                                                                                                                                                                                                                                                                                                       | Vibration             |                                                                                                                           |         |             |                                                                                                                           |           |          |        |           |                   |  |
| Helicopter rotors                                                                                                                                                                                                                                                                                                                                                                                                            |                       |                                                                                                                           |         |             |                                                                                                                           |           |          |        |           |                   |  |
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| <p>This report presents the results of flight tests of a stiff-in-plane flexbeam hingeless four-bladed main rotor, hereafter referred to as the Model 609. The tests were conducted on a modified UH-1 at gross weights from 10,000 to 14,000 pounds and at level-flight speeds up to 150 knots to evaluate performance, handling qualities, maneuverability, and load levels. The</p> <p style="text-align: right;">214</p> |                       |                                                                                                                           |         |             |                                                                                                                           |           |          |        |           |                   |  |

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tests also evaluated a focused pylon system designed for isolating rotor vibrations.

The overall handling qualities of the test helicopter were good to excellent, with all forward flight modes statically and dynamically stable. The basic control was too sensitive at high speeds, but was manageable with the aid of an adjustable force-feel system. The handling qualities in hover were judged to be excellent.

The rotor structural loads in level flight were within endurance limits. In maneuvers, the oscillatory loads in the blades and yoke were limiting, with handling qualities and vibration levels remaining acceptable. One-per-rev Coriolis forces generated a large portion of the rotor loads observed in maneuvers.

Flight test results were correlated with analytical computer predictions using the C-81 computer program. Correlation of loads was good in level flight, but poor in maneuvers. Performance correlation was good in forward flight, but poor for hover.

The focused pylon evaluation established the focus point and spring rate which would allow the lowest fuselage vibration without compromising handling characteristics. The effects of changes in focus point and spring rate on rotor loads were negligible. The predominant vibration of the rotor was a low-amplitude four-per-rev. The vibration environment in the aircraft was comfortable.

A blade out-of-track condition encountered at high advancing blade tip Mach numbers (approximately 0.92) caused large one-per-rev vibrations which precluded the evaluation of the rotor at higher tip Mach numbers. No other pylon or rotor instabilities were observed during the flight evaluation.

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## PREFACE

The work reported here was performed by Bell Helicopter Company for the U. S. Army Air Mobility Research and Development Laboratory under Contract DAAJ02-72-C-0036 (DA Task 1F263211D15711).

Technical program direction was provided by Mr. D. Arents of USAAMRDL. Principal Bell Helicopter personnel associated with the program were Messrs. S. Blackman, K. Builta, D. Cannon, L. Dooley, D. Greenlee, L. Hartwig, C. Hughes, T. McLarty, V. Shami, W. Spivey, J. Van Gaasbeek, H. Vela, R. Wernicke, and W. Wilson.

A complete compilation of measured data is contained in Bell Helicopter Company Report 299-099-572, Flight Test Data Report. The computer flight simulation approach is discussed in Bell Helicopter Company Report 299-099-573, Computer Program Report. Both of these reports are on file at USAAMRDL.

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## INTRODUCTION

The class of helicopter rotors referred to as "rigid" rotors may be defined as that group of rotors in which the blades are not hinged or pinned to the hub or mast in such a way as to allow the blade to flap or lag freely. "Hingeless" is a better adjective to use in describing these rotors, since their blades are clamped to the mast, and move with respect to the mast only as the flexibility of the rotor structure allows. In early rotors, the high structural loads inherent in such a design were discouraging. In the past fifteen years, the science of materials has developed to the point where such a rotor has approached practicality.

The Model 609 hingeless flexbeam rotor is part of a continuing development of hingeless rotors started at Bell Helicopter in 1957. The rotor uses a direct control system without any gyro-stabilized inputs. It was designed for use with a stronger, shorter mast, and an upgraded transmission without the limitations of the standard UH-1 mast and power train designed for a two-bladed teetering rotor system. The rotor is mounted on the focused pylon vibration isolation system.

The purpose of this program was to obtain flight test data and perform analyses on the Model 609 in the areas of rotor structural loads, performance, handling qualities, maneuverability, and the focused pylon as an isolation mount for the transmission-rotor system. The analyses also included the determination of fatigue life, rotor-fuselage dynamic response, and stability and control. Flight test results were compared with theoretical predictions obtained from the C-81 computer program to validate the accuracy of this analysis for helicopters with hingeless rotors. Pilot observations were correlated with test records. The results of this test program are presented in this report.

## BACKGROUND

Bell Helicopter Company has been building and flight-testing experimental stiff in-plane hingeless rotors since 1957. The first designs were small three-bladed rotors which were flown on the Model 47 light helicopter. One, the Model 504, was flexible in flapping. It doubled the cg range of the helicopter and quadrupled the control power, but the resulting stress levels in the mast were unacceptable, even during modest flight maneuvers.

Another hingeless rotor had high flapwise as well as in-plane stiffness and was mounted on a tilting pylon. This configuration also gave the helicopter a greater allowable cg range than did the equivalent semirigid rotor, as well as better stability, faster response to cyclic control, and more precise maneuverability. It also subjected the mast to unacceptable stresses. Development continued, going to a more elaborate three-bladed hingeless rotor for the Model 47, then to a larger three-bladed hingeless rotor for the heavier UH-1B. This rotor, the Model 533, was flight-tested in two configurations before giving way to the first Bell four-bladed hingeless rotor, the Model 8065, in 1964. Five versions of the Model 8065 were tested on various UH-1 airframes (including the high performance compound helicopter). Results were promising, particularly with respect to vibrations, cg range, and maneuverability, but the value of the tests was limited by the shortcomings of the rotor mast, constrained in diameter by the transmission and hence in strength and rigidity. The testing of the Model 8065 hingeless rotor on the compound HPH is reported in Reference 1.

In 1969, the development of the Model 609 series of hingeless rotors began. The basic Model 609 rotor has a forged titanium hub for strength and fatigue resistance, and has some flapwise freedom because of the flexibility of the hub at shallow sections inboard of the pitch-change bearings. The test vehicle has a transmission able to take a mast of increased diameter, strength, and stiffness, and uses the T55-L-7B/C engine. The development and preliminary testing of the rotor and modifications of the test helicopter proceeded under IR&D funding.

The Model 609 rotor was first flown in 1971, which revealed some problems with the rotor and test vehicle. The vehicle experienced "tail wag" in hover and forward flight. The tail wag was alleviated by installing a stronger and stiffer tail boom as well as adding an enlarged fairing that enclosed the swashplate, thereby reducing the turbulence of the air impinging on the vertical fin.

During maneuvers, the chord loads in the rotor were much larger than expected, with the lowest strength area being the spindle and blade bolt hole. The original titanium spindles were replaced with increased diameter steel spindles, and the blades were strengthened by modifying the bolt hole area and adding doublers from the inboard end out to midspan. Also during the flights in 1971, an out-of-track condition was encountered. The swept tip portion of the blades was cut off and 10-pound leading edge tip weights were added to improve the mass balance of the blades. In 1972, Army Contract DAAJ02-72-C-0036 was awarded which extended flight testing of the Model 609 rotor. The program was concluded with a brief Government flight evaluation.

The benefits to be derived from hingeless rotors include simplicity and reliability by reducing the need for bearings. Multibladed rotors offer reductions in noise, vibrations, and control loads.

## CONFIGURATION

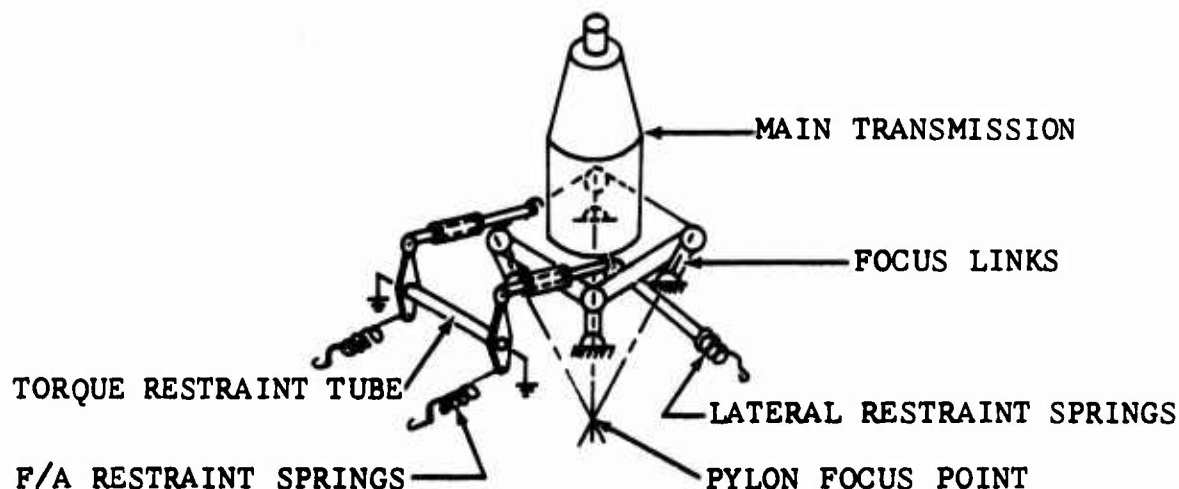
### MAIN ROTOR

The main rotor is a four-bladed, hingeless, flexbeam, stiff-in-plane rotor designated Bell Model 609. The rotor diameter is 48.3 feet, and the blades have a chord length of 21 inches. A detailed description of the rotor with all pertinent dimensional data is given in Appendix I.

### TEST VEHICLE

The test vehicle is a Bell Model 204B helicopter modified for greater strength and performance, using a 2000-shp main transmission and a T55-L-7B/7C engine. The fuselage structure, the landing gear, and the antitorque system are upgraded accordingly. Figure 1 is a photograph of the test vehicle in flight, and Figure 2 is a three-view sketch with notations of the salient features.

The test vehicle is equipped with a "focused pylon." This is a kinematic passive vibration isolation system shown schematically below.



A detailed description of the test vehicle is given in Appendix I, and a discussion of the focused pylon is given in the "Fuselage Vibration" section.

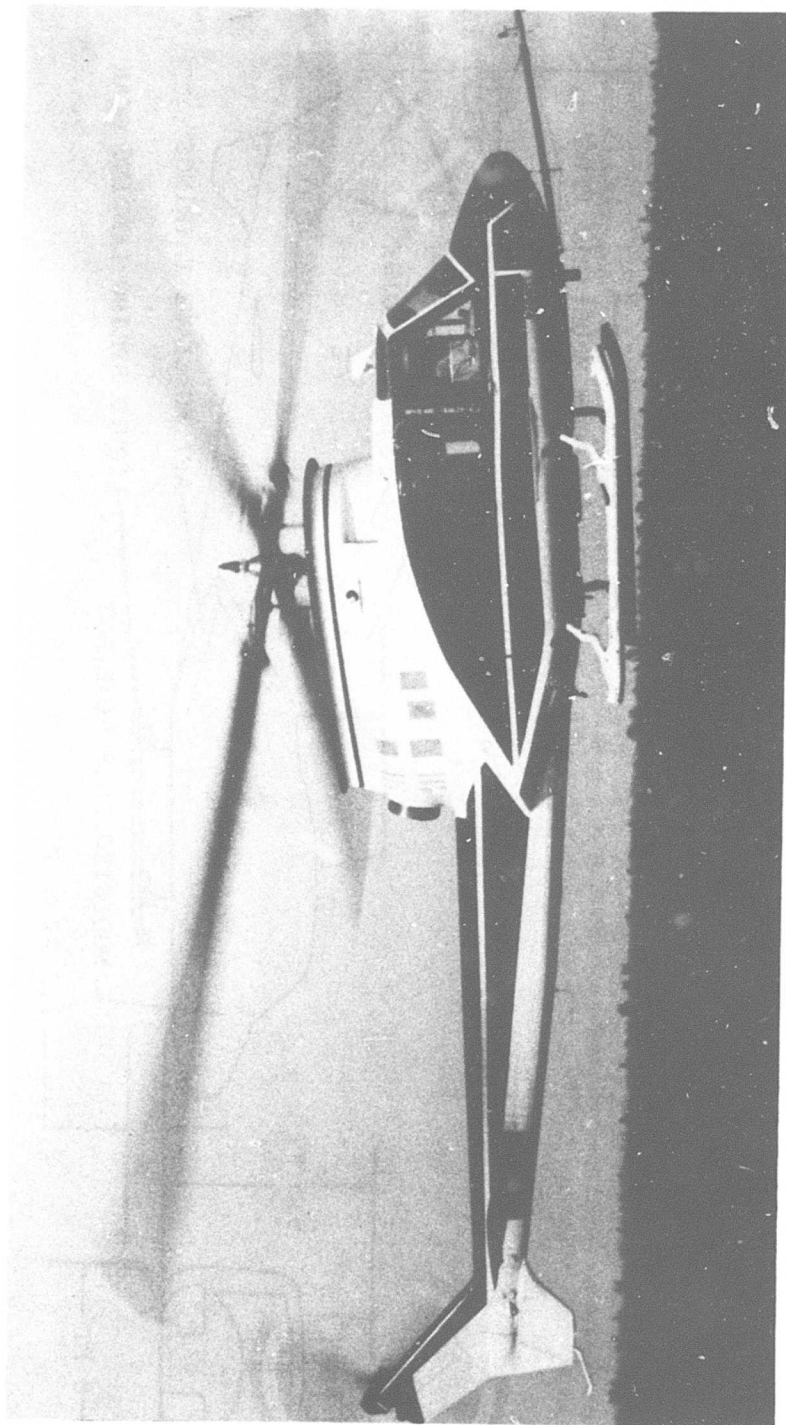


Figure 1. Test Vehicle.

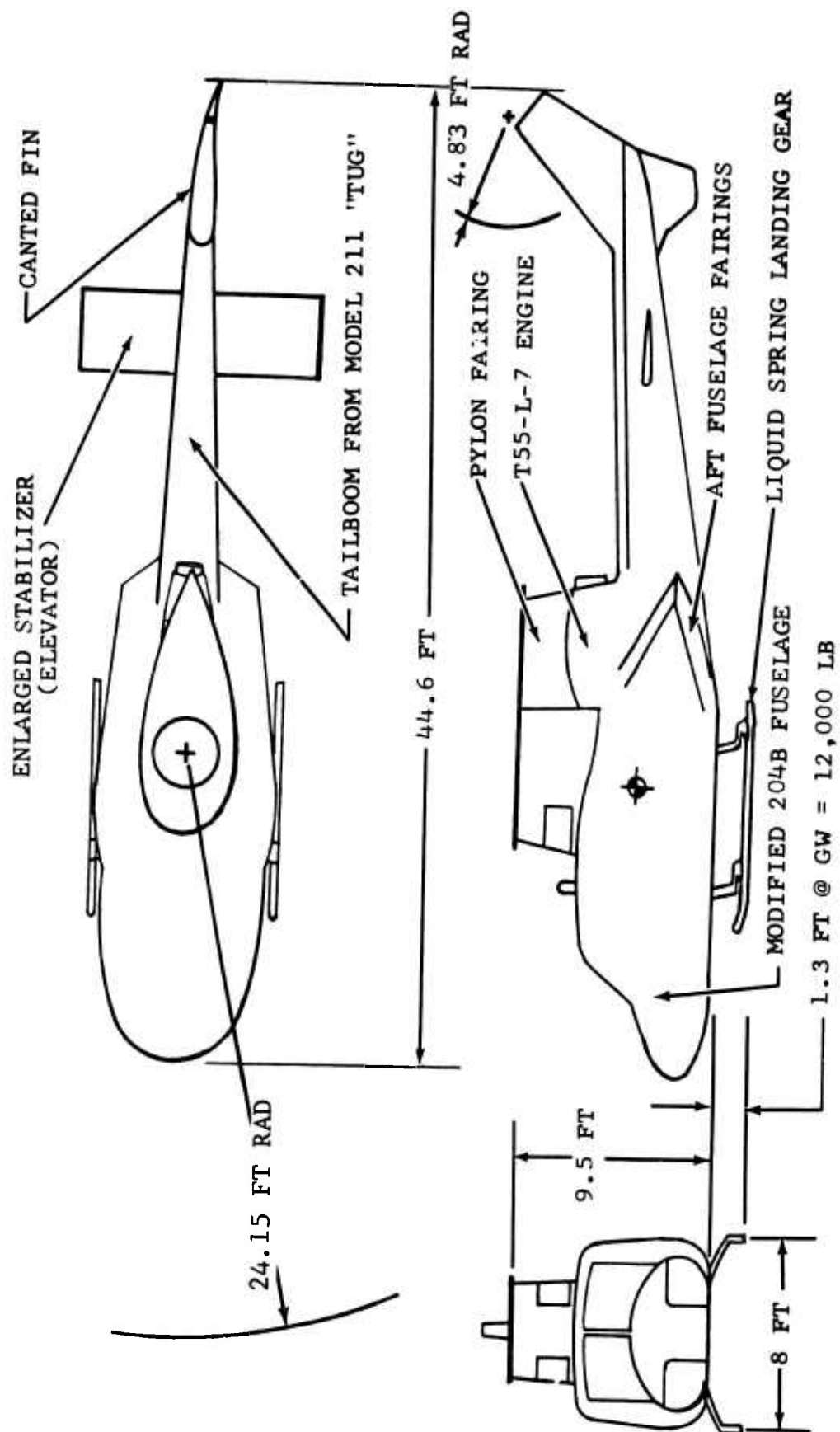


Figure 2. Three-View Sketch of Test Vehicle.

## METHODS

### FLIGHT TEST PROGRAM AND DATA ACQUISITION

The specific tasks to be accomplished by this program were:

1. Focused pylon evaluation
2. Rotor systems and airframe load level survey
3. Helicopter performance measurements
4. Helicopter handling qualities
5. Limit maneuver evaluation

The data acquisition system, which is also described in detail in Reference 1, consists of an airborne magnetic tape system, special pilot panel indicators, a photo panel, and air-to-ground telemetry. The magnetic tape system uses frequency multiplexing to record up to 104 channels. Thirteen of the channels recorded on the magnetic tape were also telemetered to a ground data center to permit real time assessment of the more critical parameters. The telemetry system assisted in rapid flight envelope expansion and contributed to safety of flight.

Several options are available for the reduction of data recorded on magnetic tape. These include analog stripouts, analog analysis using an x-y plotter, digitized tape compatible with BHC's IBM 360 computer, and several digital "quick-look" programs for an immediate analysis on an IBM 1800 computer. All of these methods were used to obtain the data presentations shown in this report. The quick-look routine was used extensively during the program to augment the telemetry information.

### COMPUTER SIMULATION

The purpose of the computer simulation was to establish the accuracy of the C-81 analysis (Reference 2) for predicting the aeroelastic and aerodynamic behavior of a hingeless rotor helicopter. The program simulates helicopter flight, and it can be used to analyze single-rotor, compound, tandem, or side-by-side helicopter configurations in hover, transition, cruise, or high-speed flight. The analysis, with a uniform level of complexity for its different phases, can calculate performance, stability and control, or rotor loads. Its inputs are organized to make the program easy to use, and the output format facilitates comparison of computed results with flight and tunnel test data.

Three major parts of the analysis are a mathematical model of an elastic rotor, rotor aerodynamics, and rigid-vehicle flight mechanics. The program is used in support of three phases of rotor system design and evaluation: wind tunnel simulation, steady-state flight simulation, and transient or maneuvering flight simulation.

The stability and control section calculates trim positions (including control positions), gradients, and stick margins--in level, climbing, diving, turning, or accelerated flight. It uses linear analysis to compute response characteristics and the locations of stability roots for coupled flight modes. It can also use fully coupled nonlinear equations to calculate and plot variables against time. Disturbances like gusts, sinusoidal control motions, and weapon recoil can be simulated.

The program includes a fully coupled, time-variant aeroelastic analysis of the rotor blades. This portion uses modal equations to calculate beam, chord, and torsional loads during either steady or maneuver flight, and prints out the results.

A detailed description of the methods and sources for preparing the C-81 input data for this project is given in Reference 3. The approach was to use the best initial estimates of the required input data and then adjust them to obtain level flight performance correlation. This procedure also produced satisfactory rotor loads agreement in level flight. In maneuvering flight, additional input parameter adjustments were required for correlation with measured blade loads. The rationale for this is given in the section entitled "Rotor Loads in Level Flight and Maneuvers - Results and Discussion."

## PILOT'S OBSERVATIONS AND QUALITATIVE ASSESSMENTS

Many of the specific or understood goals of any rotor development program have to do with the pilot--how easy or difficult it is for him to make the helicopter do what it must to carry out a mission, how long he can fly it without being worn down by excessive demands on his skills, and how much vibration he has to endure at his flight station. Therefore, it is appropriate to include a summary of the test pilot's observations about the test helicopter and the Model 609 rotor. Bell's Chief Experimental Test Pilot, with over 6,000 hours of helicopter flight time, flew all the test flights for this program. His comments will aid the reader in a better interpretation of the measured data.

In general, the pilot was pleased with the flight characteristics. Vibration levels at the pilot's seat were acceptable. High control response, sensitivity, and damping gave the helicopter excellent handling characteristics in hover, but the control sensitivity at high speed was excessive. The helicopter was equipped with an electric-hydraulic force-feel and trim system which increased the cyclic force-feel gradient with air-speed. This overcame the problem of high control sensitivity at high speeds. The pilot could also use this system to adjust the lateral and longitudinal stick-force gradient while airborne. Also, the stick position trim rate decreased with air-speed to help compensate for increasing control sensitivity.

The hingeless rotor hub generates high control moments per degree cyclic control. At high forward speeds, it is easy to get high pitching and rolling accelerations at the low and medium gross weights with acceptable blade loads. In high-speed maneuvers at high gross weight, however, the pilot could easily overstress the rotor by making too large a cyclic control input. The pilot had a critical-load meter (blade chord load at station 94) on the instrument panel, and his use of it helped to define the limit maneuver envelope. The pilot also received some warning from the buildup in fuselage vibration during high stress maneuvers, but vibration was not a reliable indication of excessive rotor stresses.

The range of center-of-gravity station locations from 122.0 to 136.0 inches was the widest range that allowed a good ride and the most reasonable rotor loads for maneuvering throughout the speed range. Controllability was satisfactory at the extremes.

Symmetrical pullups could exceed 2 G's at the low and medium gross weights tested without overstressing the rotor. Pushovers following symmetrical pullups resulted in accelerations as low

as 0.1 G. Neither high- nor low-G maneuvers generated significant roll tendencies (previous rigid rotor configurations always had an excessive amount of roll coupling with G's).

The directional axis had the weakest stability in both power-on and power-off flight. A ventral fin, added to improve the directional stability, did improve it considerably, but it was still considered to be weak. The ventral fin was canted to help counteract main rotor torque; in autorotation, it was too effective: it took almost full right pedal to hold heading during autorotation. The tail rotor control power required for maneuvering with power on prevented a change in tail rotor rigging to increase the right pedal margin.

An undesirable control coupling occurred during transition from hover to forward flight. The helicopter would roll right (page 24) as it went through the 15- to 20-knot speed range, and it took about 25 percent of left cyclic to correct the roll. After passing through 30 knots, the helicopter would rapidly roll back to level trim. Previous rigid rotors have exhibited this same rolling characteristic. The amount and rate of roll are influenced by the rate of acceleration through transition, with a slow acceleration through this range resulting in the largest migration of the cyclic stick to the left. Deceleration back to a hover from forward flight resulted in very little cyclic trim change in the roll axis. The use of the stability and control augmentation system (SCAS) during takeoff greatly reduced the roll tendency.

The SCAS was also effective in attenuating gust response. With stability augmentation off, the gust response was considered to be excessive at all speeds, including hover.

The helicopter could develop moderately high forward accelerations in the 0- to 30-knot speed range. The pilot developed an ability to use the load meter to anticipate how much control he could use without causing fatigue damage in the rotor. On the ground, motions of the helicopter on the skid gear were an adequate indication of high oscillatory rotor loads.

Landings in full autorotation also caused high rotor loads, but these loads occurred for only 2 to 3 rotor revolutions. The landings seemed normal, with no indication that loads were high.

At the highest gross weight tested, the maximum level-flight speed (limited by the transmission takeoff power limit) was 150 knots. The maximum dive speed was 160 knots. This was limited by a "popping-out-of-track" phenomenon which occurred at high advancing tip Mach numbers. The onset of the out-of-track could be observed visually, and was accompanied by a

buildup in one-per-rev vibration. The problem is believed to be associated with changes in the shape of the hollow thin-wall blade section near the tip of the blade caused by changes in the chordwise pressure distribution at high Mach numbers.

Other hardware problems also affected vibration levels. It was impossible to keep the one per rev out of the rotor because of a relatively soft clampup between the upper and lower blade sets which necessitated frequent retorquing of the clamping bolts.

Vibrations at higher frequencies were very low until midway in the evaluation, when there was a sudden increase in the four-per-rev level. The bearing staking in one of the pylon focus links had become loose. The link was replaced, greatly reducing the four per rev, but the level of this vibration was never as low as on the previous flights.

## PERFORMANCE - RESULTS AND DISCUSSION

Performance was measured in both hover and stabilized level flight. The power required was based on main rotor mast torque and rpm measurements.

For C-81 computer correlation, the aerodynamic characteristics of the fuselage had to be extrapolated from full-scale wind-tunnel tests of a standard UH-1 helicopter (Reference 4). The equivalent fuselage flat plate drag area was increased over the initial estimates to match flight test performance. The main rotor blade airfoil section tapers linearly from an NACA 64X18 Mod inboard to an NACA 0008 Drooped Mod at the tip. The average blade airfoil section characteristics were obtained by interpolation of section data from wind-tunnel tests of the inboard and tip airfoil (Reference 5). These average aerodynamic values were used in C-81 which was limited to the use of one set of aerodynamic section characteristics to represent all blade stations. The estimated aerodynamic characteristics (drag coefficient and drag divergence Mach number) were then modified to match flight test performance results.

### FORWARD FLIGHT PERFORMANCE

Level flight performance measurements were obtained for three gross weights: 10,500 pounds, 12,000 pounds, and 14,000 pounds. At 12,000 pounds, measurements were obtained at two referred rotor speeds ( $N_R/\sqrt{\theta}$ ) to isolate Mach number effects from advance ratio ( $\mu$ ) effects. These results are shown in Figure 3, and good correlation with computed values is apparent.

The measurements at 10,500 pounds and 14,000 pounds were obtained at only one rotor speed and were used primarily in conjunction with rotor loads correlation, but they were obtained in sufficiently smooth air to yield valid performance data. These performance data are shown in Figure 4, and are presented as main rotor horsepower versus advance ratio ( $\mu$ ) and true airspeed. Again, good correlation with computed values is apparent.

Data from these two flights were also used to compare measured and computed rotor thrust levels. Although the resultant force of the main rotor could not be measured directly in flight, the sum of the gross weight and the elevator download can be measured and is approximately equal to the rotor lift. The lift derived in this way is shown in Figure 5, and reasonable correlation with computed values is indicated.

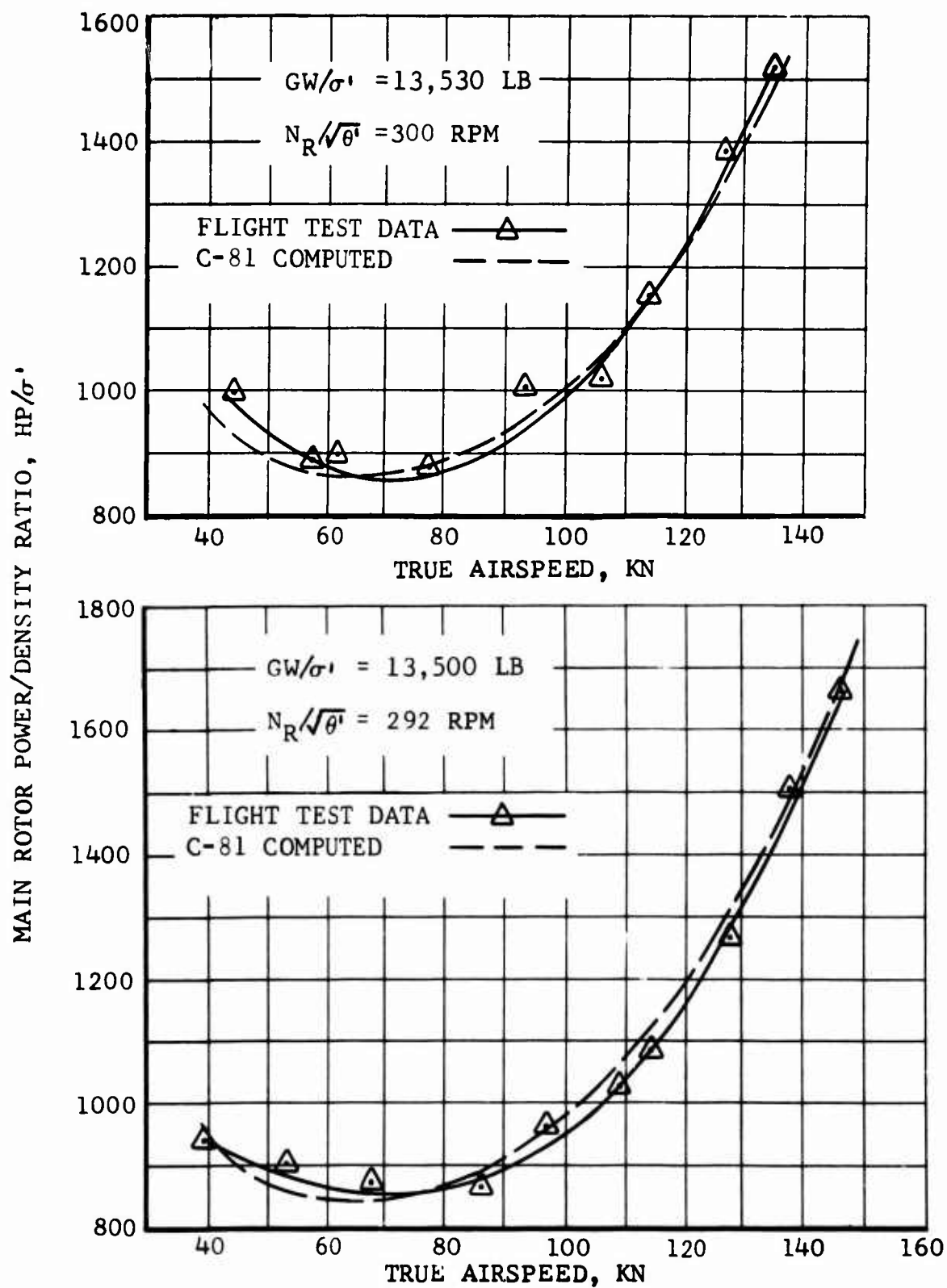


Figure 3. Forward Flight Performance.

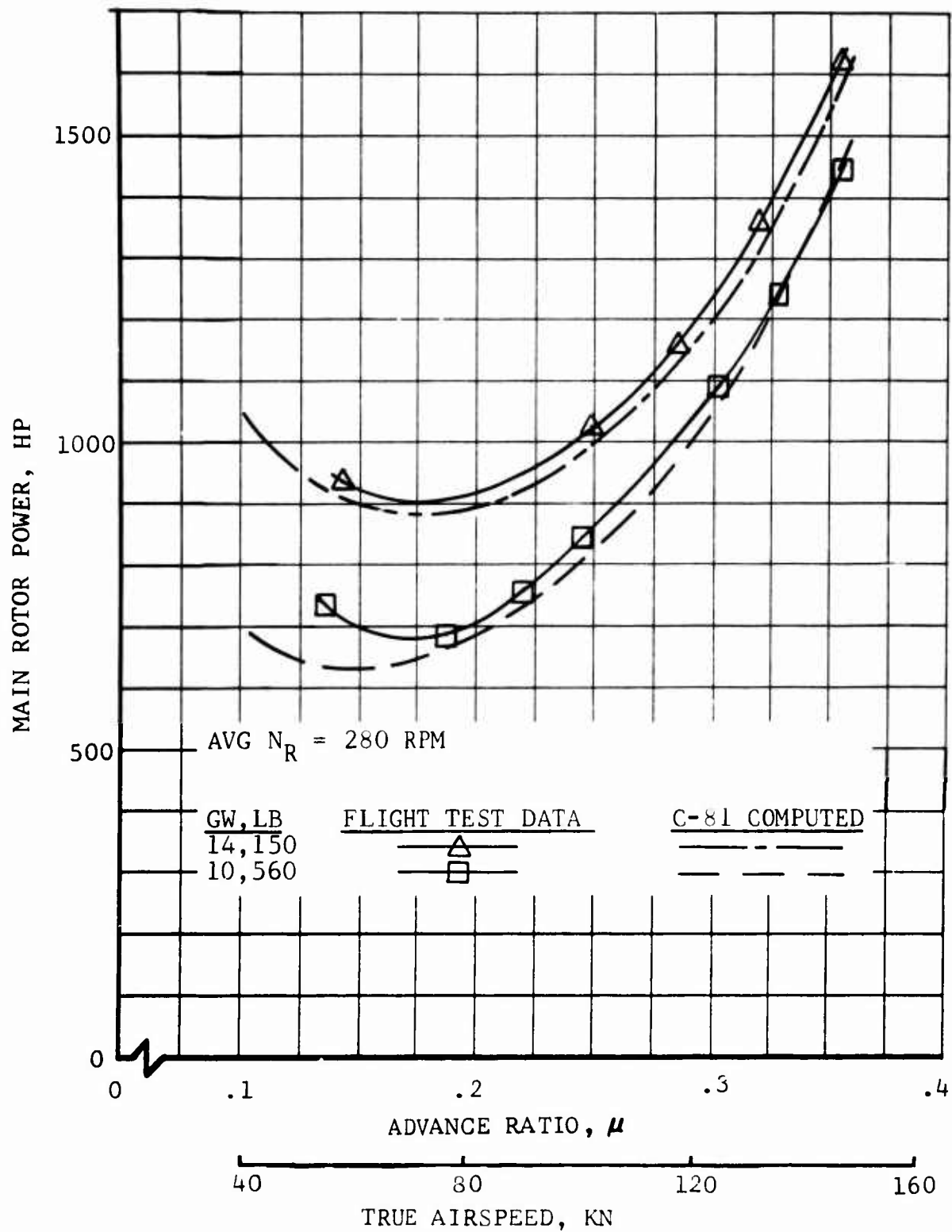


Figure 4. Measured and Computed Main Rotor Horsepower in Forward Flight at Two Gross Weights.

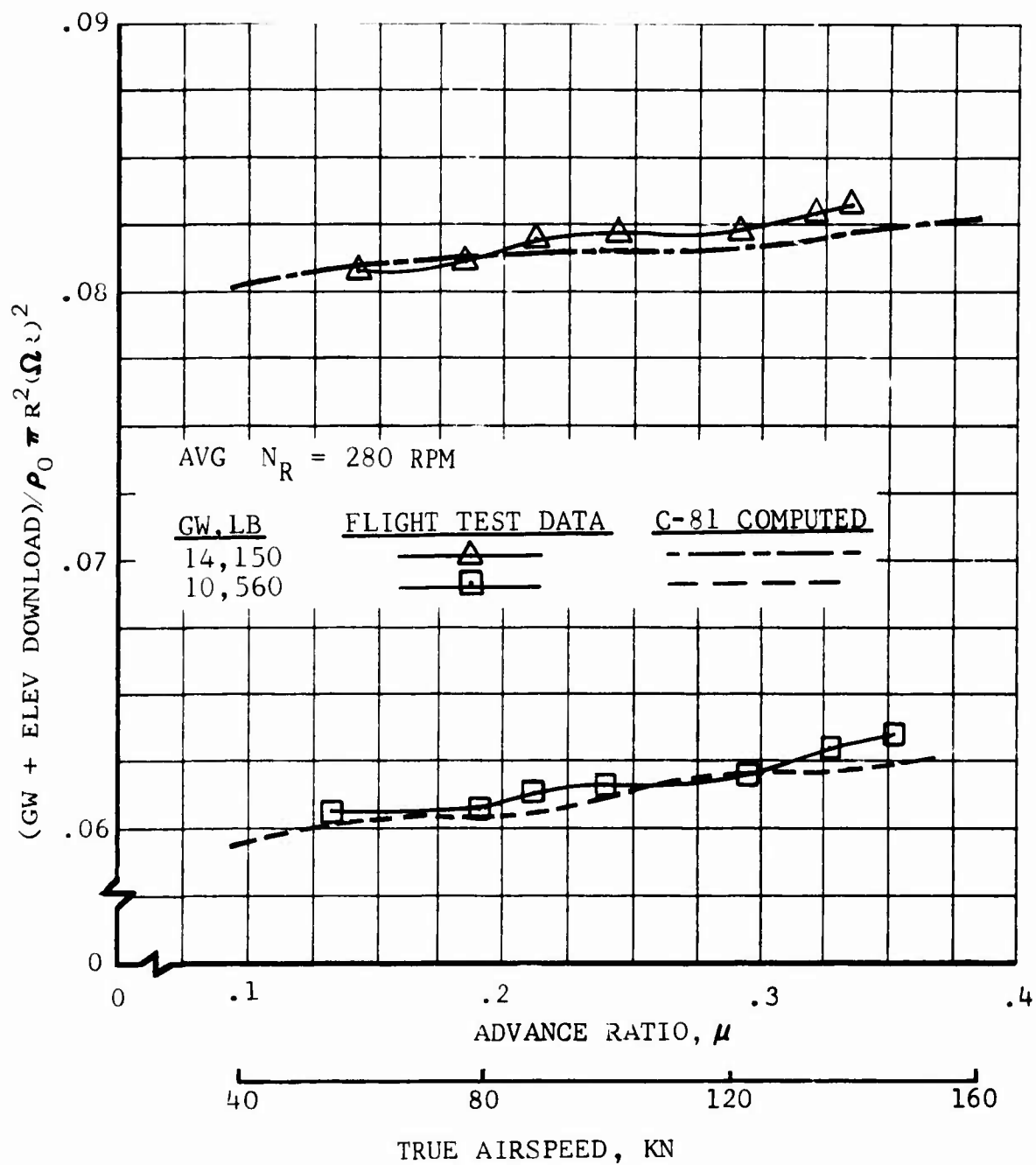


Figure 5. Measured and Computed Nondimensional Thrust Parameter in Forward Flight at Two Gross Weights.

In all the above computer correlation work, an average minimum blade profile drag coefficient  $C_{d0}$  of 0.009 was used, and a value of 22 square feet was used for the equivalent (flat plate) drag area of the fuselage at zero angle of attack.

#### HOVER PERFORMANCE

Hover performance OGE was obtained at one loading condition and four rotor speeds. These data are presented nondimensionally in Figure 6 together with computed values. Using the "level flight"  $C_{d0}$  value of 0.009, correlation is poor. To indicate the magnitude of this difference, a change in  $C_{d0}$  of over 40 percent ( $C_{d0} = 0.013$ ) would be required to match test results.

This discrepancy between "hover" and "level flight" values of  $C_{d0}$  probably results from two factors. One is aerodynamic interference, an effect which causes power required as calculated by blade-element methods to be increasingly optimistic as the number of blades increases. The other factor -- substantiated by mean yoke-beam bending data -- could be a difference in thrust produced by the upper and lower blade pairs possibly reducing rotor efficiency.

#### CALCULATED BLADE STALL LIMITS

Performance calculations were made to determine the steady-state rotor thrust limits. For these calculations, the C-81 computer program was used in the "wind-tunnel" mode, in which the fuselage and tail rotor are deleted from the computations. (C-81 correlation with all the complexities of a total flight simulation are presented in a later section.) Lift, propulsive force, and horsepower were calculated as if the rotor were operated in a wind tunnel at various blade collective pitch settings and shaft angles from 50 degrees forward to 30 degrees aft, with cyclic blade feathering manipulated to zero-out flapping. These calculations were made using steady aerodynamics and a rigid blade pinned at the root.

Figure 7 shows the calculated rotor lift and drag for constant collective pitch angles at airspeeds of 80 and 160 knots. The maximum lift obtainable before encountering deep stall is indicated on the figure by the "STALL" line. This figure also shows that the collective setting establishes the rotor propulsive force.

These computed values of maximum steady-state rotor lift are also presented on Figure 8 in terms of lift coefficients versus advance ratio for three values of fuselage equivalent drag area,  $f$ , of +25, 0 and -25 square feet. The first value of drag is representative of the test vehicle drag. The latter two values

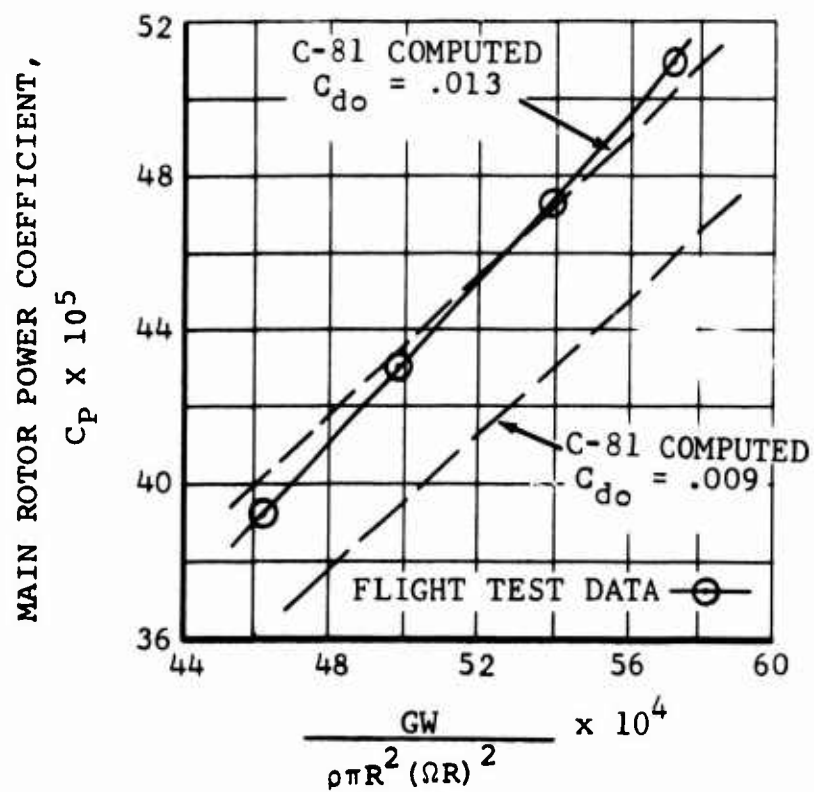


Figure 6. Measured and Computed Nondimensional OGE Hover Performance.

# COLLECTIVE PITCH ANGLE, DEG

| $\theta_0$ |       |
|------------|-------|
| 8          | 0.75  |
| 12         | 1.25  |
| 16         | 4.25  |
| 20         | 9.25  |
| 24         | 13.25 |
|            | 17.25 |

NOTE: C-81 RIGID BLADE ANALYSIS  
STEADY AERODYNAMICS

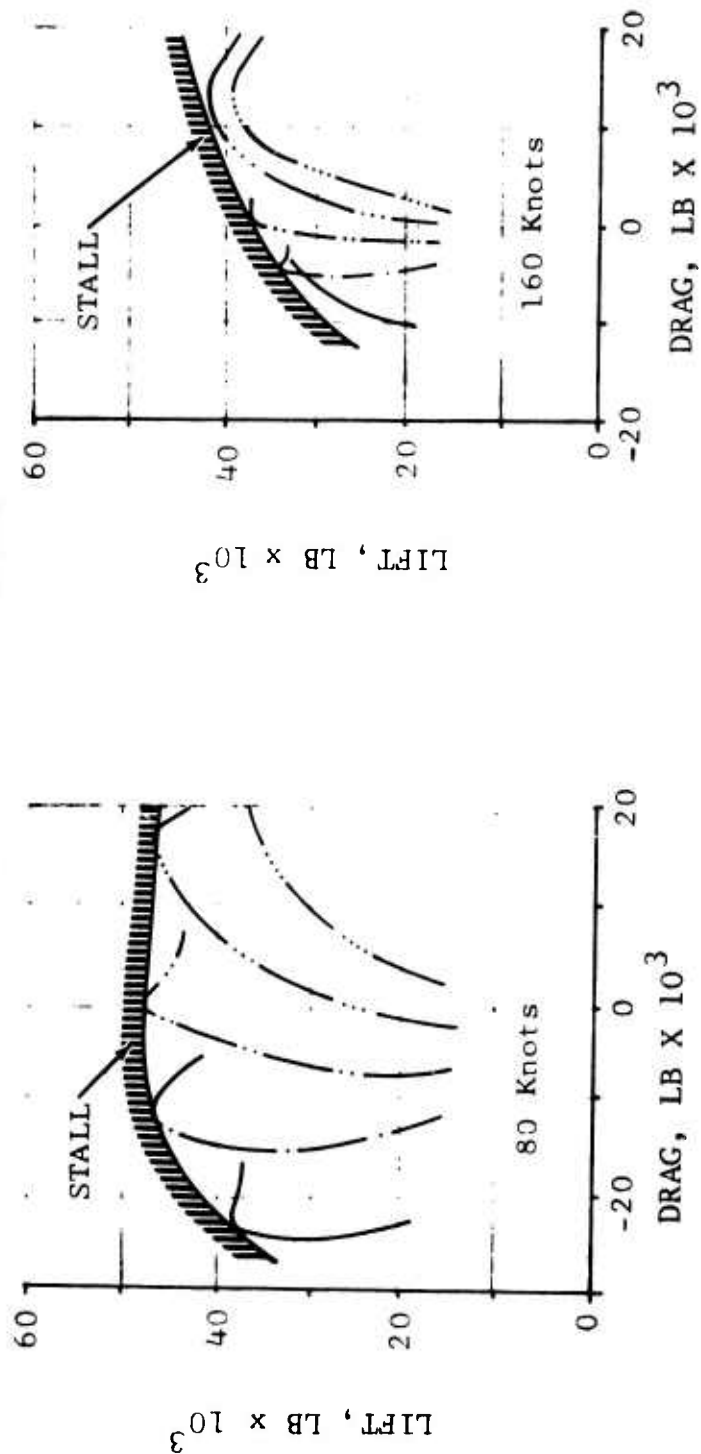


Figure 7. Computed C-81 Rotor Lift and Drag at Constant Collective Pitch Settings.



are arbitrary choices which could be achieved with a compound helicopter, or may be considered quasi-static simulations of conditions encountered during maneuvers. An incipient stall boundary from Reference 6 calculated at  $f = 0$  is shown for comparison. An envelope of the measured level flight data is also shown and reaches the calculated thrust limit. The maximum thrust was then recalculated for a selected point of  $f = 0$ , velocity = 120 knots, using elastic blade modes, unsteady aerodynamics, and allowing large radial flow angles. This recalculated value is included in Figure 8 and is believed to be more nearly representative of the true lift limit.

## HANDLING QUALITIES - RESULTS AND DISCUSSION

This section contains a discussion of stability and control characteristics of the helicopter in various flight regimes. The discussion covers flight records, pilot interpretations, and computations. The method of computation is discussed in Reference 3.

The helicopter exhibits handling qualities peculiar to hingeless rotors and this particular configuration. In general, they are judged acceptable in all flight test conditions.

The control positions in this section are presented from 0 to 100 percent. The sign conventions at 100 percent are as follows:

F/A cyclic stick position - full forward

Lat cyclic stick position - full right

Pedal position - full right

Collective stick position - full up

Positive angular rates are determined as follows: pitch - nose-up; roll - right; and yaw - nose right.

For this section of the report, the following cg locations were tested: forward - 122.6; mid - 128.9; and aft - 136.0.

### HOVER

The high control response, sensitivity, and damping of this rotor system give the pilot precise control in hovering flight. Figure 9 shows the pitch rate and response of the helicopter to a step input of forward cyclic. The small amount of lateral cyclic and pedal input required to stabilize rates about the roll and yaw axes shows that there is little control coupling.

Figure 10 shows how the helicopter responds to a right lateral cyclic pulse input. The response is stable, and all rates are well damped with no short-period divergent tendencies.

The flexbeam rotor with its high hub moment per degree flapping contributes to excessive gust sensitivity in hover, as well as at all other flight speeds. The Stability and Control Augmentation System (SCAS) reduces this gust sensitivity to an acceptable level.

Collective step inputs were performed both in- and out-of-ground effect. Figure 11, the record of a typical case, shows an

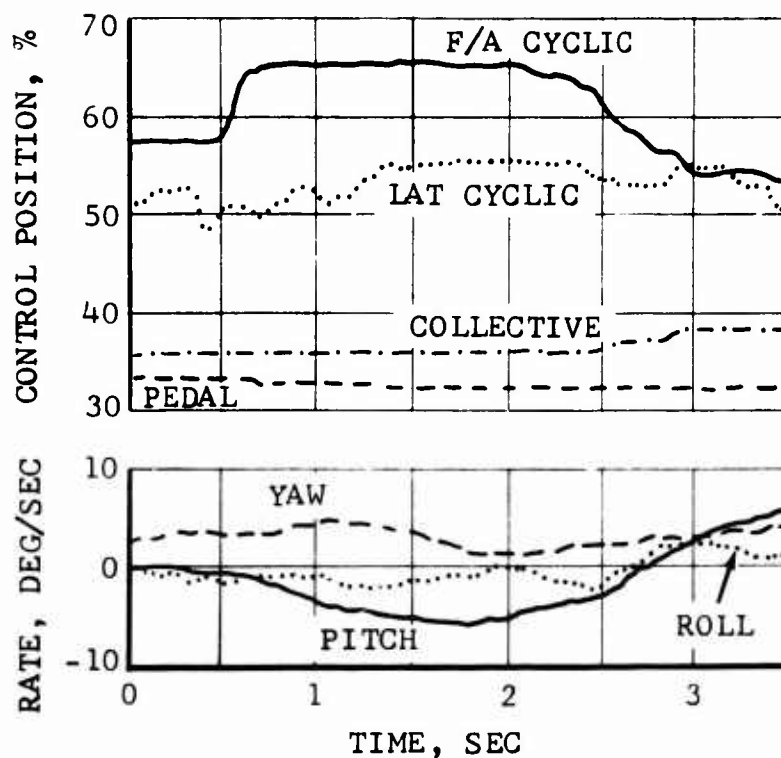


Figure 9. Longitudinal Cyclic Step in IGE Hover, Flight Test Data, 12,000 Pounds GW, Aft CG.

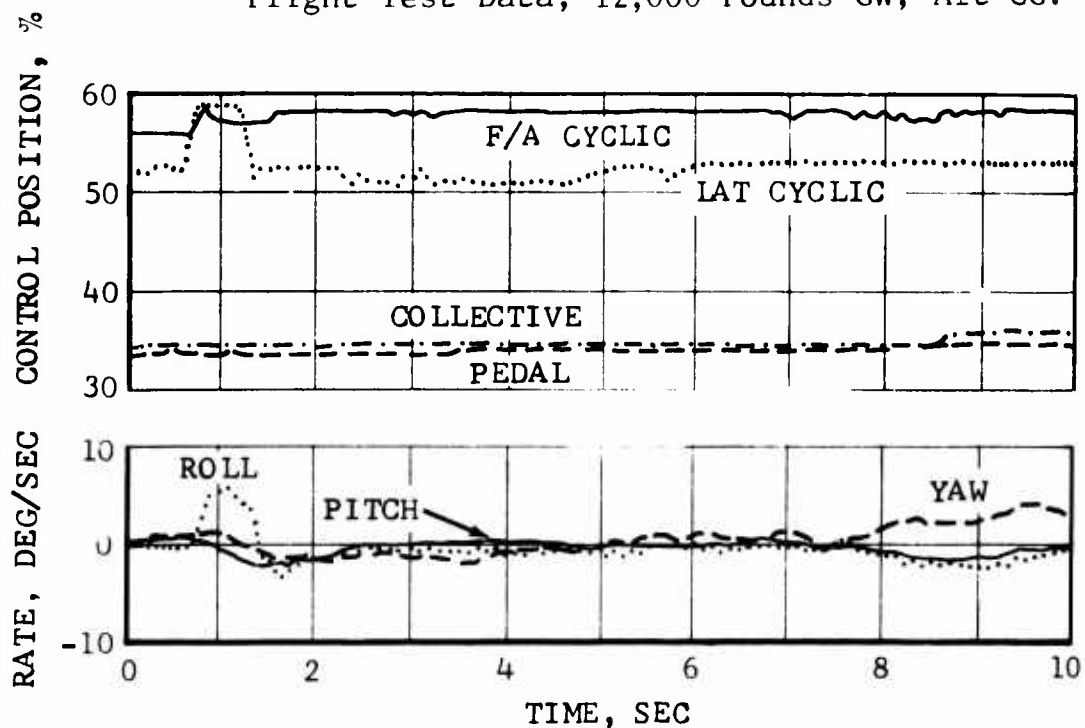


Figure 10. Lateral Cyclic Pulse in IGE Hover, Flight Test Data, 12,000 Pounds GW, Aft CG.

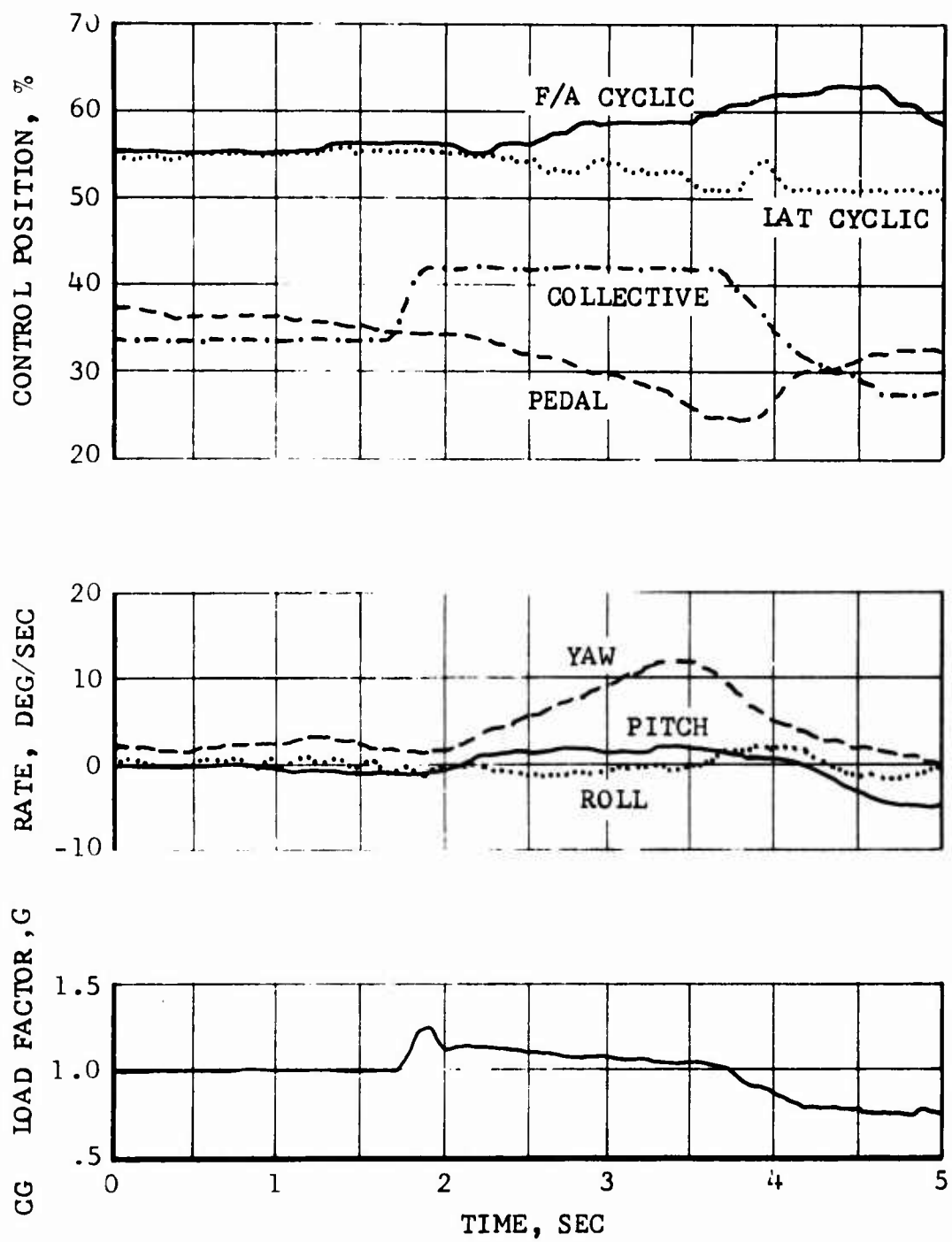


Figure 11. Collective Step in IGE Hover, Flight Test Data, 12,000 Pounds GW, Aft CG.

immediate (delay less than 0.05 second) normal acceleration in response to the collective input, with the acceleration peaking as the full step is reached. The normal acceleration has a damped oscillation.

#### TRANSITION

During transition from hover to forward flight, the helicopter rolls right in the 15- to 30-knot speed range. A variation in induced velocity over the main rotor disk combines with rotor coning to give the blades a higher blade angle of attack at the forward azimuth than the aft azimuth. The resulting right rotor flapping rolls the fuselage to the right. (This characteristic has been noted in other rigid rotor configurations tested at BHC previously.) The high control power was not reduced throughout the transitional flight regime, as cyclic stick inputs still resulted in high pitch and roll accelerations in the 0- to 30-knot speed range.

No unusual control inputs were required for the transition from forward flight to hover. There was no roll comparable to that in the transition from hover to forward flight.

#### SIDEWARD AND REARWARD FLIGHT

Sideward and rearward flight was investigated for four combinations of gross weight and center-of-gravity location, and no unusual characteristics were noted. In sideward flight, variations in control positions and fuselage attitude with velocity are smooth (Figures 12 and 13) at speeds up to 30 knots. In sideward flight to the left, there is a sharp increase in the right pedal at 30 knots. This is probably a result of the tail rotor going into the vortex ring state at this speed (induced velocity for the tail rotor is about 30 knots to the left in the hover).

Figure 14 presents attitudes and control positions during rearward flight. The control positions vary consistently for the different gross weights and cg's, but the pitch attitude variation with airspeed is different for the 12,000-pound, aft cg case. The elevator download was examined for these areas. Due to the large moment arm of the elevator (22 feet), small variations of download can cause measurable differences in pitch attitude. The elevator download for the 20-knot flight cases was less than 50 pounds except for the 12,000-pound, aft cg flight which had a download of approximately 100 pounds, causing the higher noseup pitch attitude.

The lack of fuselage data ruled out any attempt at the simulation of sideward or rearward flight with the C-81 computer program.

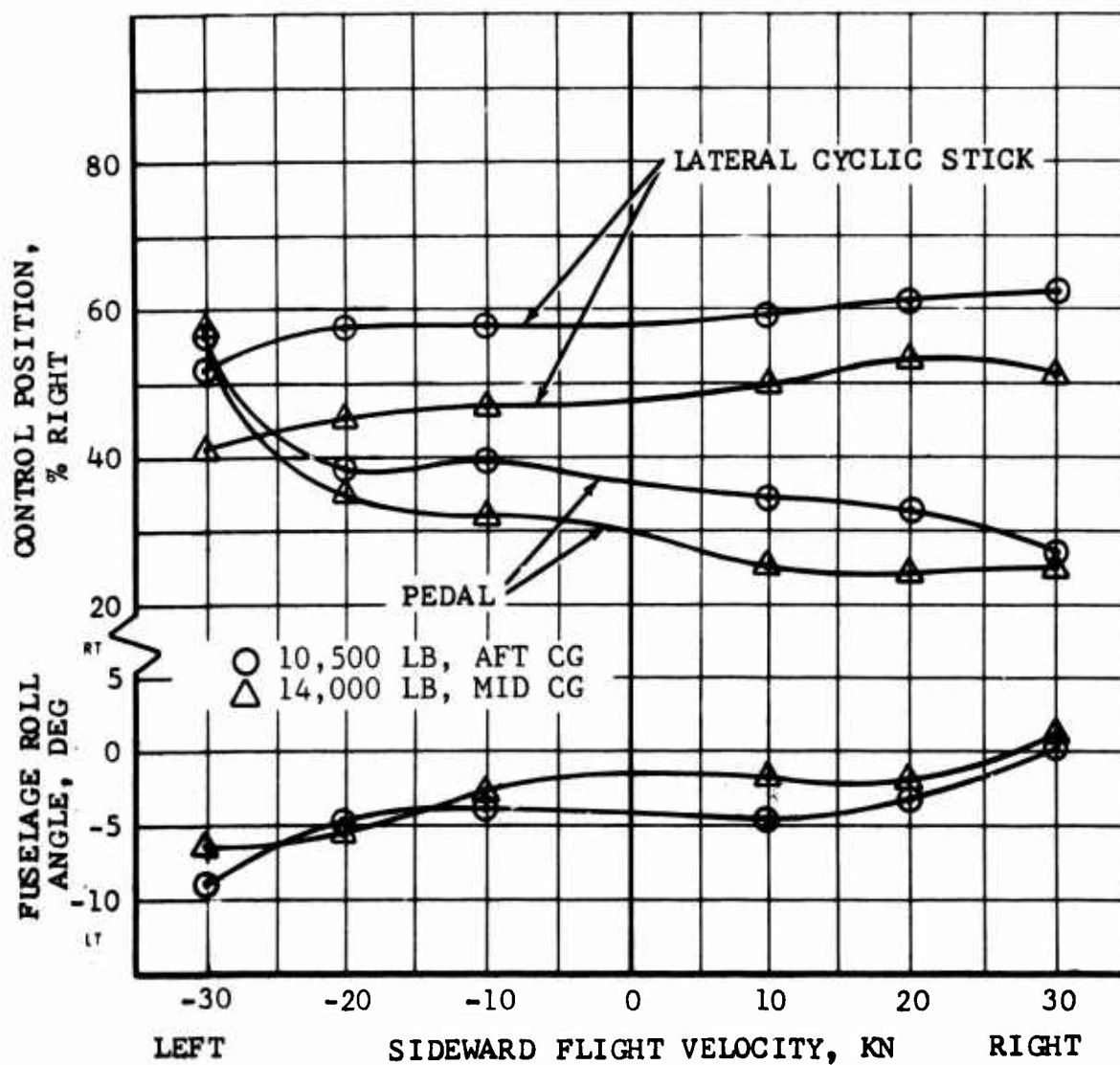


Figure 12. Sideward Flight Characteristics, Flight Test Data, 10,500 Pounds and 14,000 Pounds GW.

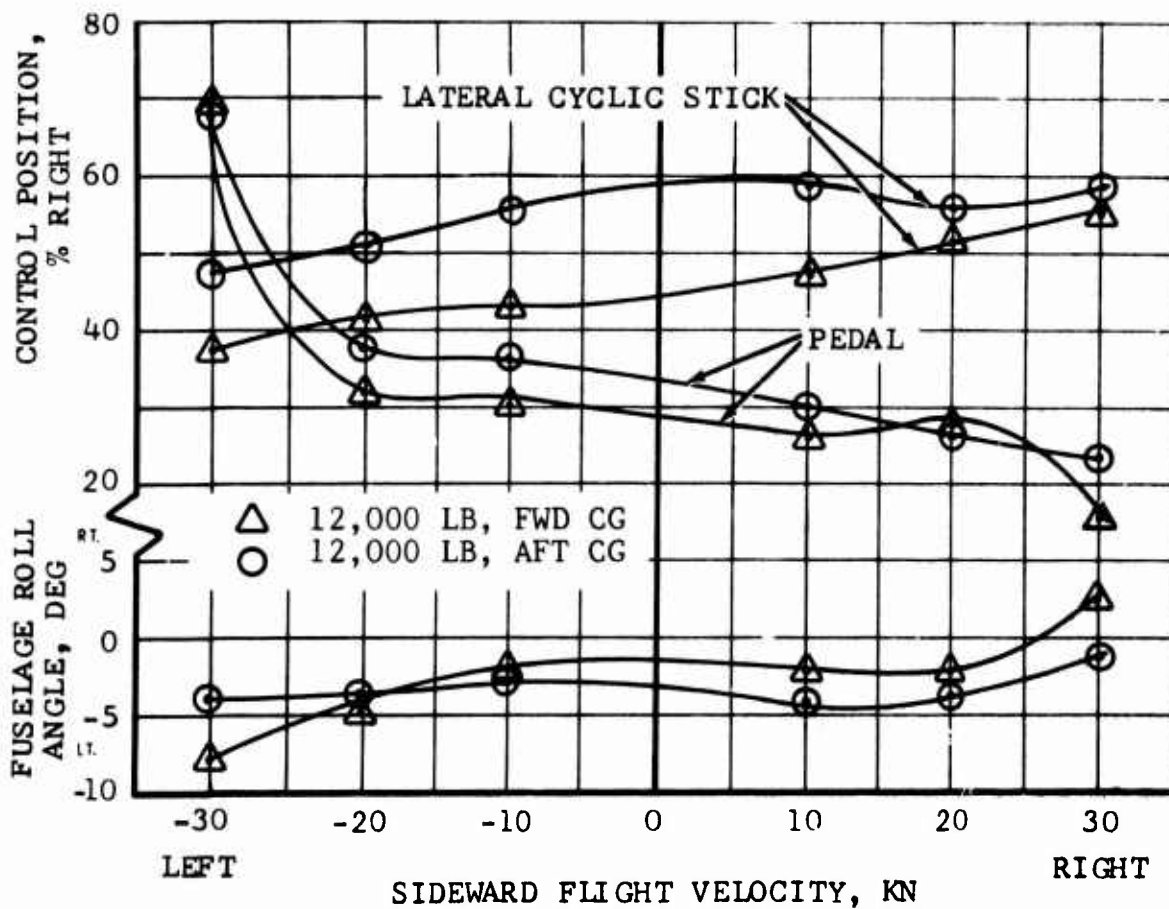
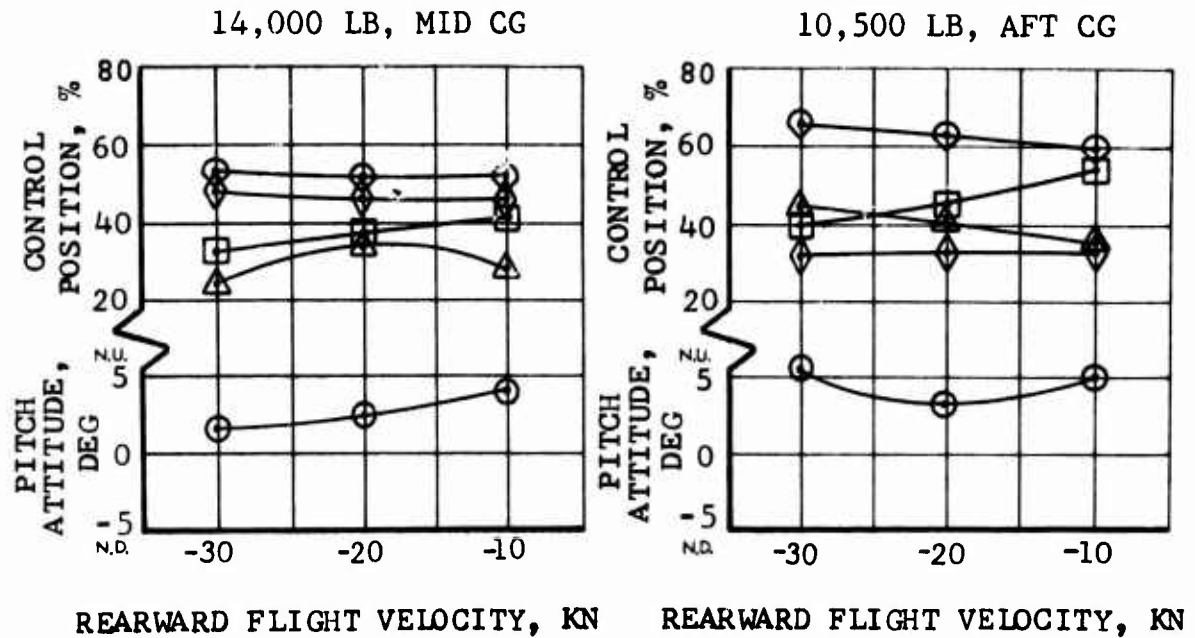


Figure 13. Sideward Flight Characteristics, Flight Test Data, 12,000 Pounds GW.



□ F/A CYCLIC STICK      △ PEDAL      ◇ COLLECTIVE STICK  
 ○ LATERAL CYCLIC STICK      ○ PITCH ATTITUDE

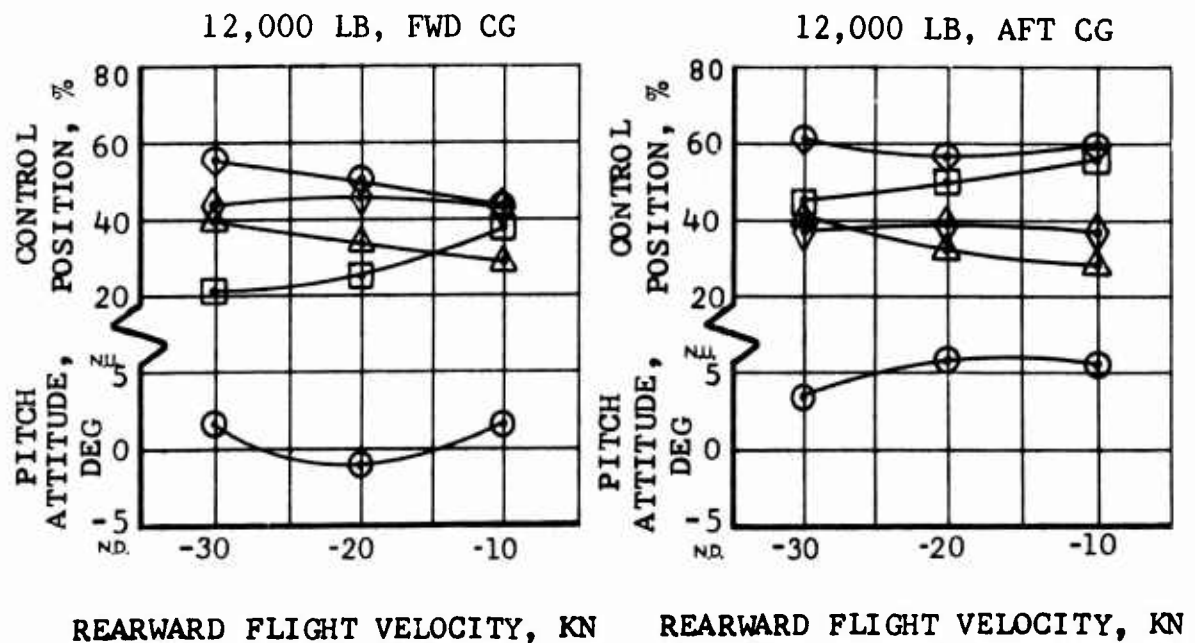


Figure 14. Rearward Flight Characteristics, Flight Test Data.

## AUTOROTATION

The helicopter entered autorotation easily at all speeds and loading conditions tested. A large amount of right pedal was needed to balance the effect of the canted ventral fin, which was very effective with the fuselage at the positive angles of attack of autorotation. A record of an autorotational entry and subsequent descent is presented in Figure 15. The variations in roll attitude represent turns the pilot made during the descent.

Table I compares measured and C-81 computed characteristics. The flight test data were obtained in steady-state autorotations and are not comparable to the entry conditions shown in Figure 15.

| TABLE I. MEASURED AND PREDICTED TRIM PARAMETERS<br>IN AUTOROTATION |                |                       |                |                       |
|--------------------------------------------------------------------|----------------|-----------------------|----------------|-----------------------|
|                                                                    | Forward cg     |                       | Aft cg         |                       |
|                                                                    | Flight<br>Test | C-81<br>Com-<br>puted | Flight<br>Test | C-81<br>Com-<br>puted |
| F/A Cyclic Stick Position                                          | 42%            | 41%                   | 59%            | 53%                   |
| Lat Cyclic Stick Position                                          | 44%            | 51%                   | 48%            | 59%                   |
| Pedal Position                                                     | 98%            | 89%                   | 90%            | 88%                   |
| Fuselage Pitch Attitude                                            | -1.3 deg       | -3.5 deg              | -              | -1.6 deg              |
| Elevator Lift (+ Up)                                               | -100 lb        | +160 lb               | +254 lb        | +260 lb               |
| Gross weight:                                                      | 12,000 lb      | Airspeed:             | 100 kn         |                       |

This comparison shows roughly the same trend as that for level flight at the same speed--good agreement for fore-and-aft stick position at forward cg, but a higher predicted elevator upload. The fuselage pitch attitude, however, does not agree as well as in the level flight case.

## CONTROL RESPONSE AND AIRCRAFT STABILITY

A large number of test records were taken to define the flight dynamic characteristics of the aircraft. The results are presented below.

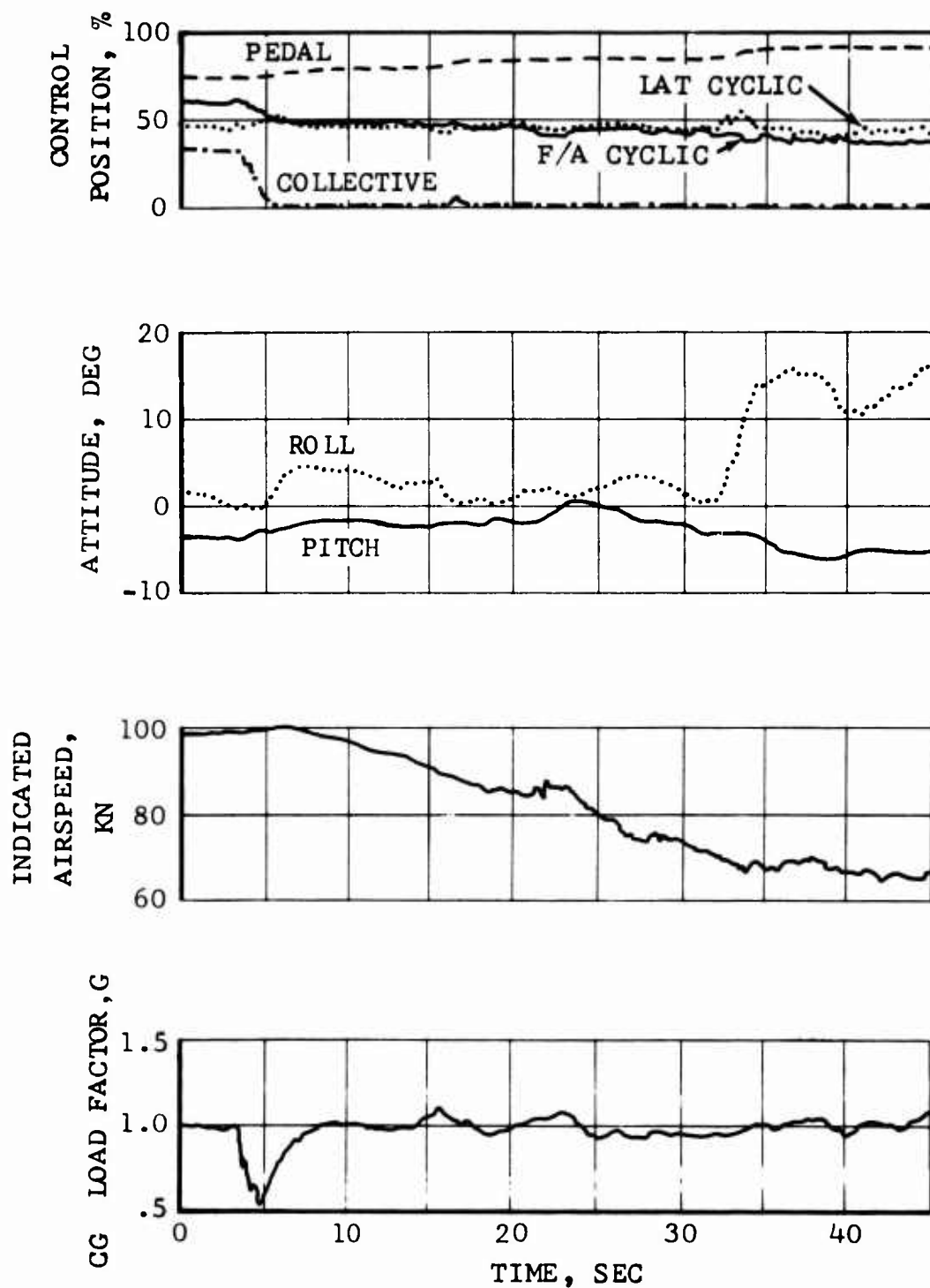


Figure 15. Autorotation Entry and Subsequent Descent, Flight Test Data, 12,000 Pounds GW, Forward CG.

### Apparent Speed Stability

The helicopter has positive apparent speed stability and adequate control margin in level flight, climb, and autorotation for all combinations of gross weight, center of gravity, and main rotor speed tested. Positive apparent speed stability is defined as increasing fore and aft cyclic stick position with increasing airspeed, and the collective stick position is allowed to vary. The flight test data and computed values in Figures 16 and 17 verify the accuracy of the computer simulation over a range of level flight conditions. Figure 18 shows stick position versus airspeed for climb and autorotative flight conditions.

At forward and mid center-of-gravity test conditions and at low speed, the predicted fuselage pitch attitude is more noseup than measured in flight test. The computer simulation shows the elevator angle of attack at 60 knots for these loadings to be very near the stall, making it difficult to predict lift accurately in this speed range. With an aft center of gravity, the elevator is not near stall and the predicted fuselage attitude agrees more closely with flight test.

### Static Longitudinal Stability

The helicopter has positive static longitudinal stability between 70 and 140 knots at 12,000 pounds gross weight with the center of gravity forward. Positive static longitudinal stability is defined as increasing fore and aft cyclic stick position with increasing airspeed and the collective stick held fixed. With the center of gravity aft, the longitudinal cyclic stick gradient was slightly negative (-1 percent in 20 knots) at 140 knots and positive for all speeds less than 140 knots. The gradient was positive for the same speed with a forward center of gravity. Stability was positive in climb and autorotation at 100 knots. The flight test data are presented in Figure 19.

Analysis predicted the decrease in static longitudinal stability at high speed and aft center of gravity. The increasing noseup attitude of the elevator with increasing speed generates adequate control margin but decreases speed stability (pitching moment change with speed). The rigid hub also reduces angle-of-attack stability. The combination of these two effects tends to reduce the longitudinal cyclic stick gradient with speed. A comparison of predicted and measured values of this gradient is presented in Figure 20.

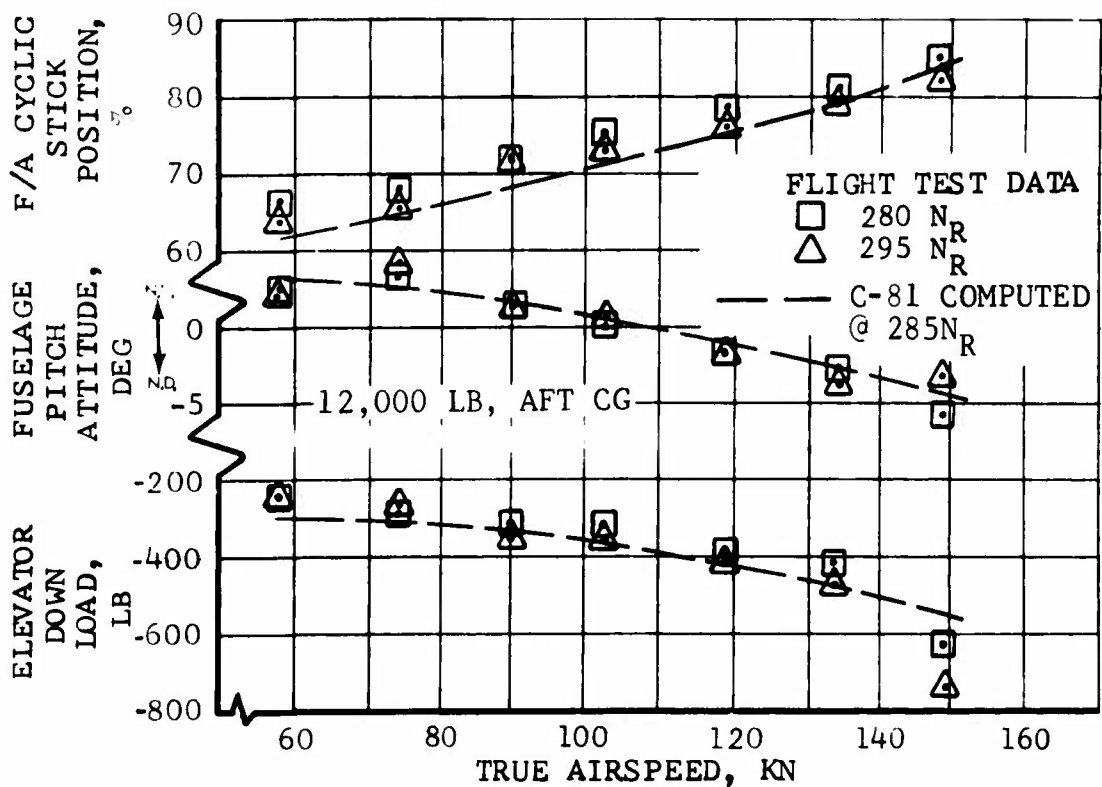
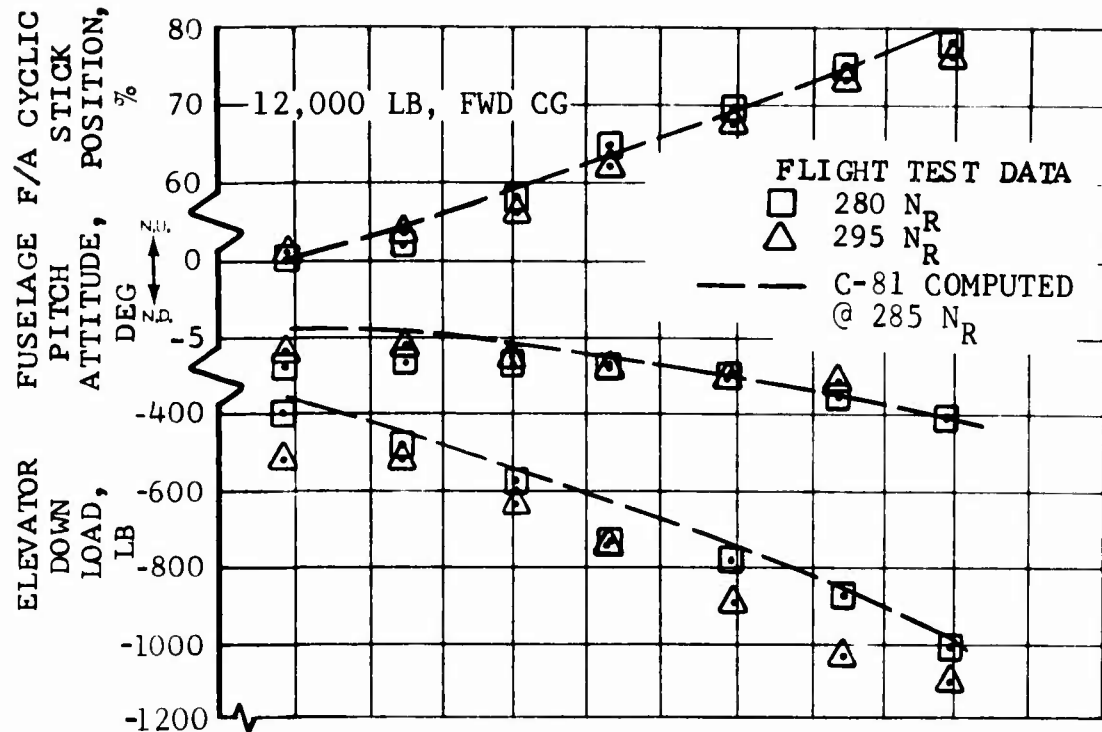


Figure 16. Measured and Computed Forward Flight Trim Values, 12,000 Pounds GW.

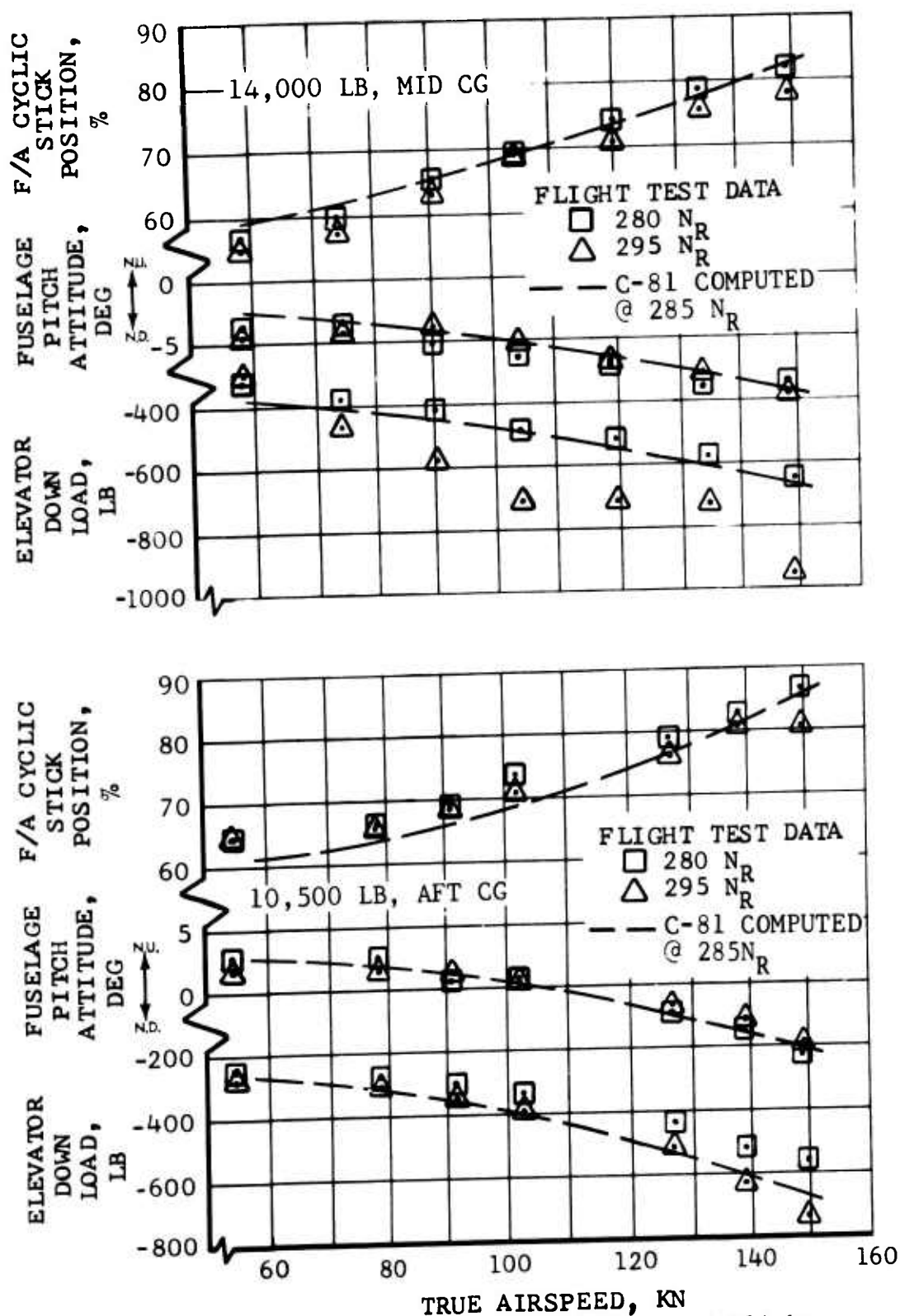


Figure 17. Measured and Computed Forward Flight Trim Values, 10,500 Pounds and 14,000 Pounds GW.

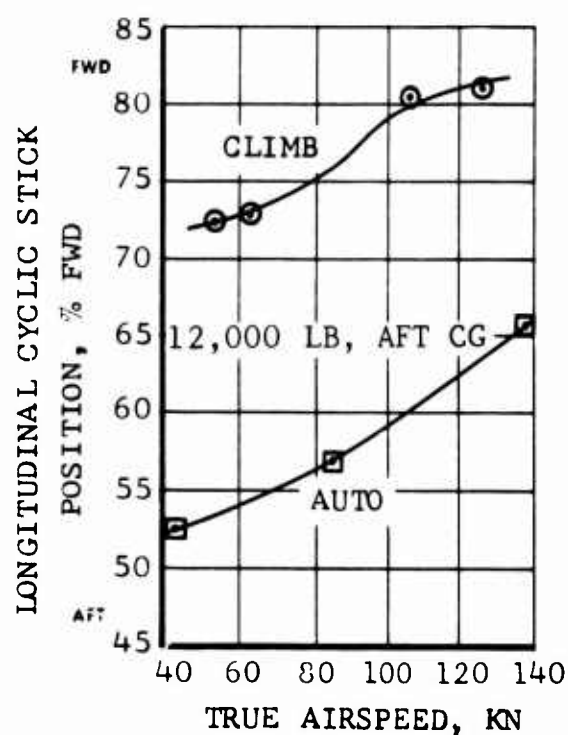
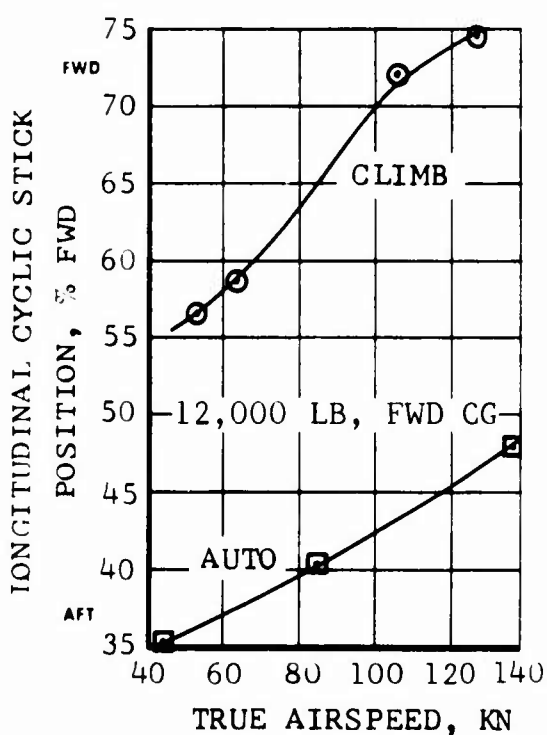
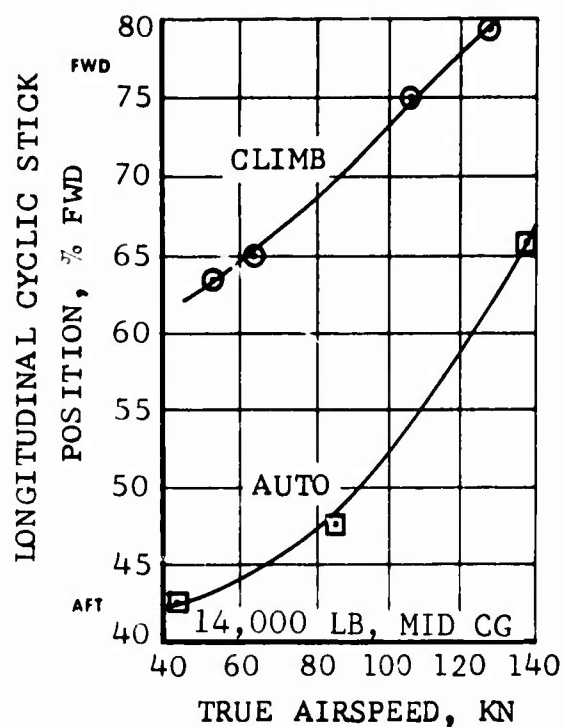
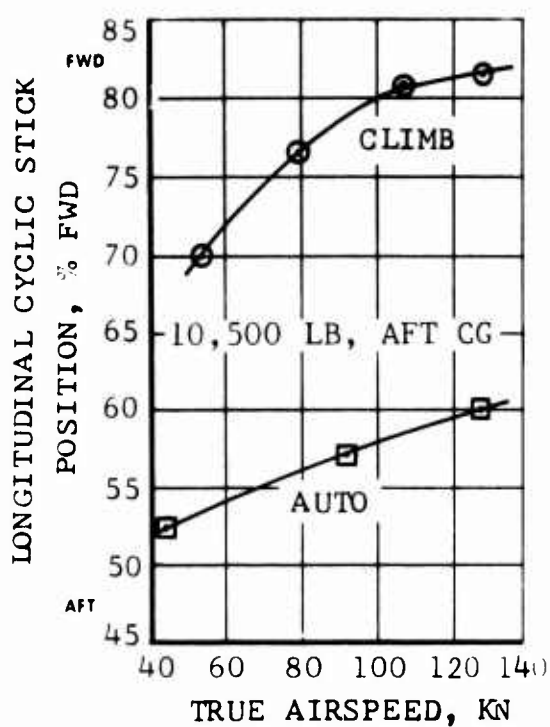


Figure 18. Apparent Speed Stability in Autorotation and Climb, Flight Test Data.

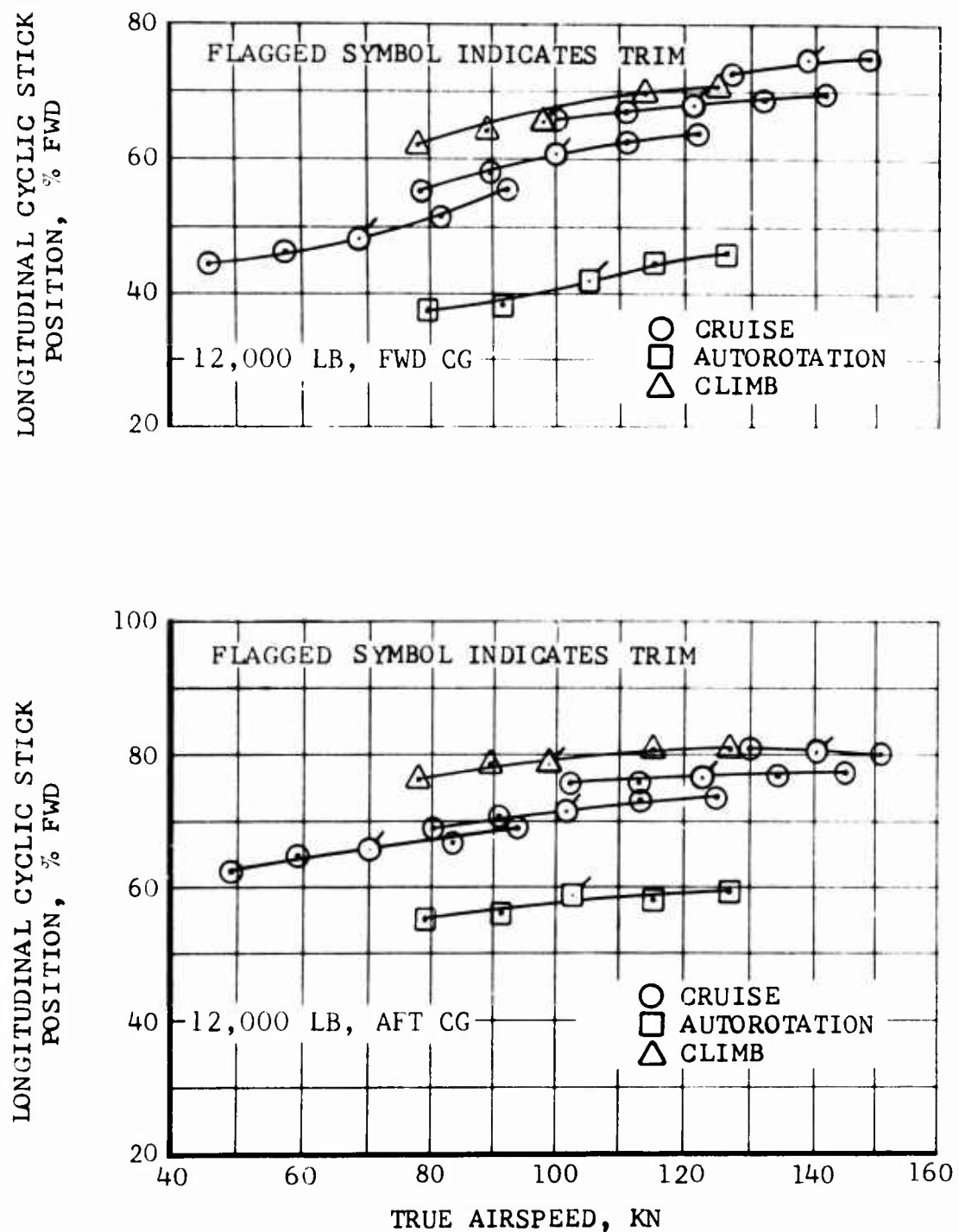


Figure 19. Static Longitudinal Stability, Flight Test Data.

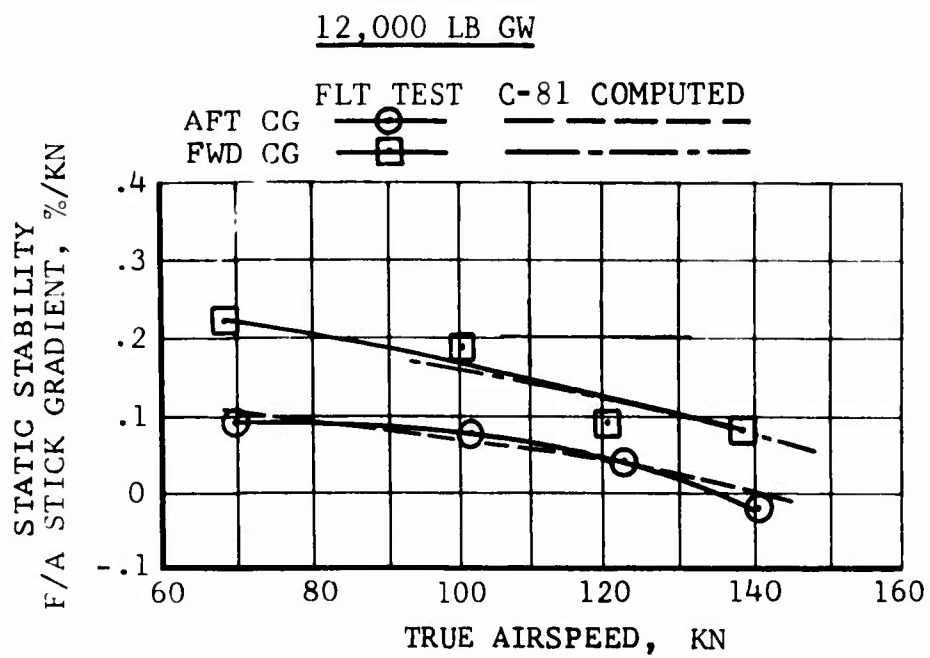


Figure 20. Measured and Computed Level Flight Static Longitudinal Stability.

### Static Lateral-Directional Stability

The helicopter has positive static directional stability and dihedral effect for all conditions tested. Dihedral effect, indicated by the change of the lateral cyclic stick position with sideslip angle, is positive for all flight conditions and increases with forward speed (Figure 21).

Static directional stability is positive but varies with flight conditions and with airspeed. The directional stability of the fuselage and fin changes with fuselage angle of attack. Negative angles of attack (forward flight and climb) reduce the sweepback of the fin and make it more effective. At positive angles of attack (autorotation), tailboom interference and the increase in fin sweepback reduce directional stability. This appears in Figure 21 as a more negative gradient of the pedal with sideslip angle as power increases. At high speed, the angle of attack changes less between level flight and climb than it does at low speed, and the pedal gradients for these two flight conditions approach each other.

The contribution of the vertical stabilizer to yawing moment due to sideslip increases with forward speed. Yawing moment produced by a unit pedal deflection increases with forward speed, but it does not increase as much as the vertical stabilizer contribution. These factors combine to increase pedal gradient linearly with freestream dynamic pressure, as shown in Figure 21.

### Dynamic Stability

The dynamic stability of the helicopter at a gross weight of 12,000 pounds was investigated with the center of gravity at both forward and aft locations. Longitudinal modes were excited with cyclic stick pulses and lateral-directional modes with cyclic stick or pedal inputs. All modes exhibited coupling between longitudinal and lateral-directional parameters.

The longitudinal short period mode is characterized by a pitch rate oscillation which is shown in Figure 22. This mode has a period of 2 to 4 seconds, and damps after no more than 1-1/2 cycles. The presence of a roll and yaw oscillation indicates lateral-directional coupling. Computer analysis agrees with the test predicting a period between 2 and 4 seconds, a damping ratio between 0.35 and 0.7, and strong coupling between longitudinal and lateral-directional motion.

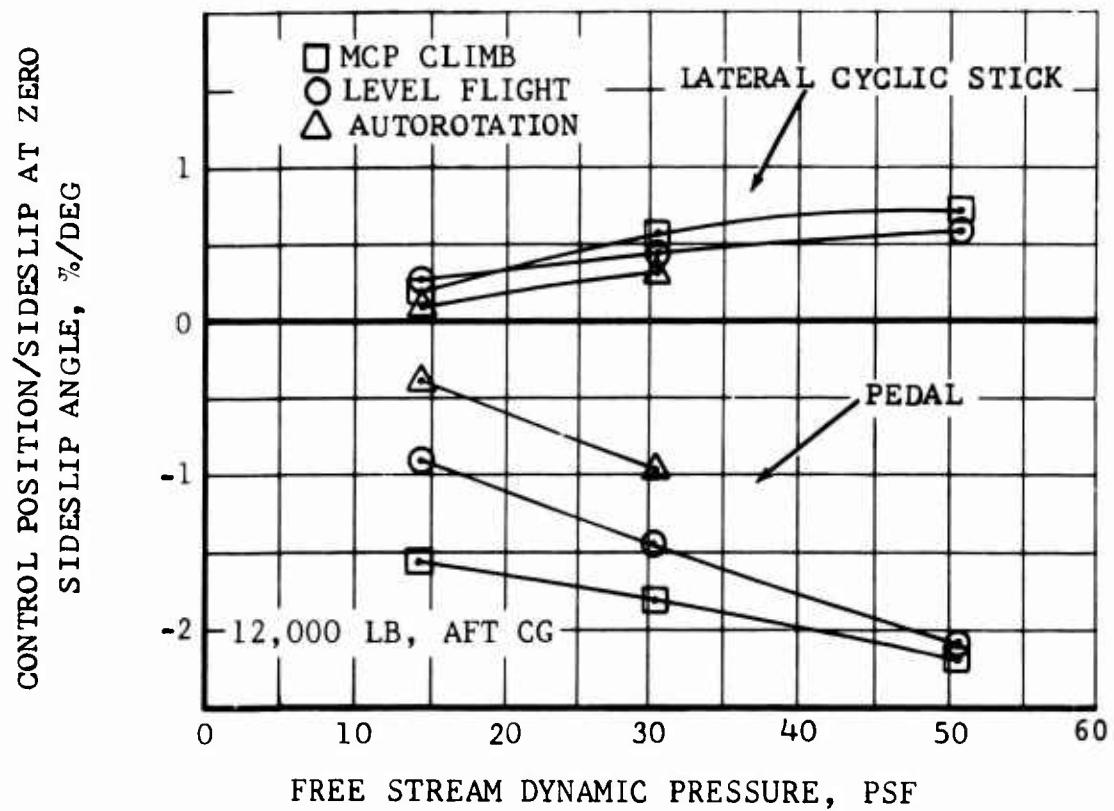


Figure 21. Static Lateral-Directional Control Gradients, Flight Test Data.

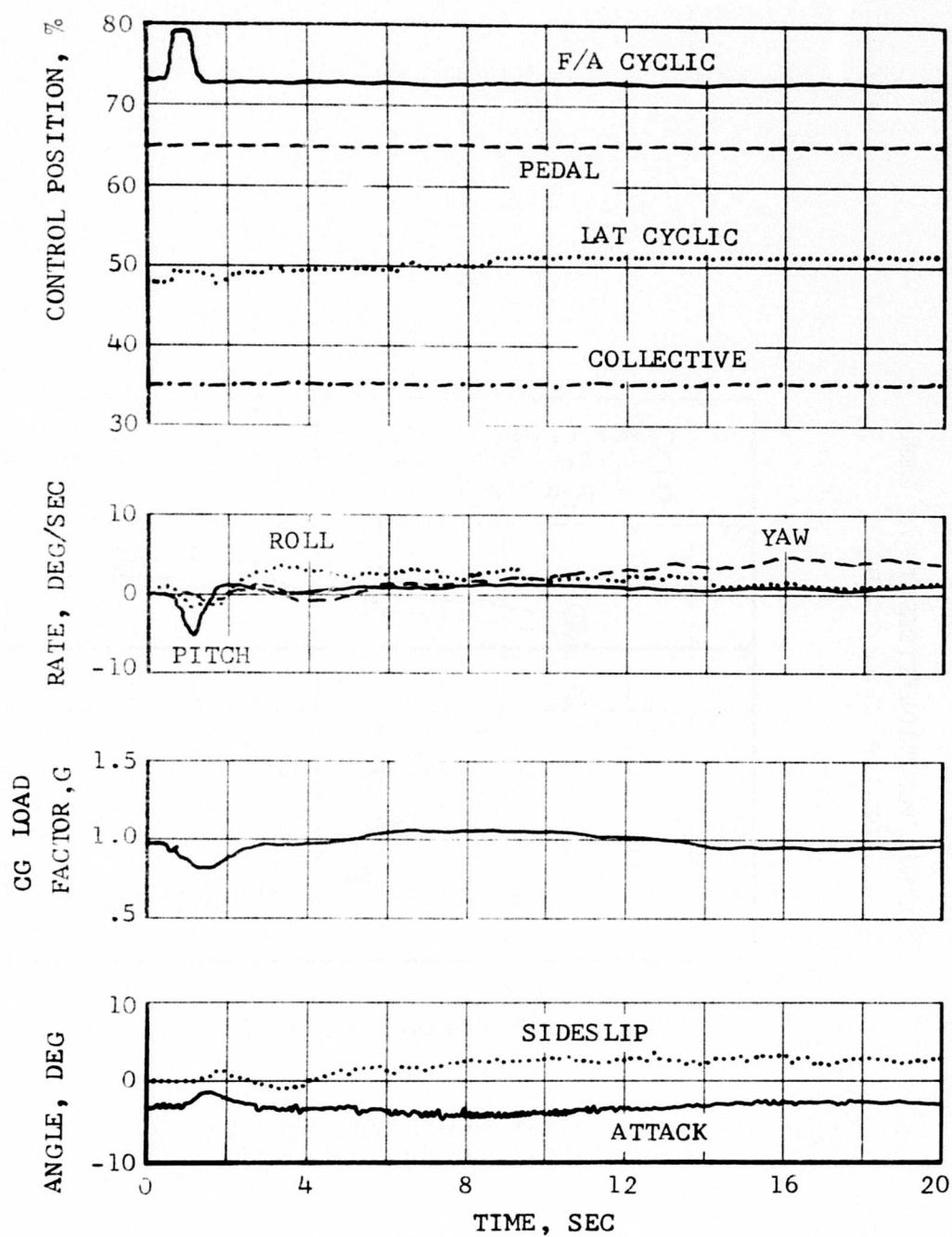


Figure 22. Forward Cyclic Pulse at 100 Knots, Flight Test Data, 12,000 Pounds GW, Aft CG.

Dutch roll motion can be induced with a lateral cyclic stick pulse, as is shown in Figure 23, or with a pedal step as shown in Figure 24. The period of this mode is between 2 and 3 seconds and damps in less than 2 cycles. Coupling is apparent in that the pitch rate is almost half the magnitude of roll and yaw rates, which are approximately equal.

Computed dutch roll period and damping agree with test data. The predicted magnitude of the pitch to yaw rate is similar to flight test results, but the roll rate is one-half the yaw rate.

The long-period longitudinal response (phugoid), shown in Figure 25, has a pitch attitude oscillation with a period of 25 seconds and neutral to slightly negative damping. Some roll coupling is present which induces a right roll, which was left uncorrected and caused a gradual right turn.

Table II shows the measured and computed phugoid mode characteristics. The predicted periods agree well, but the damping is overestimated.

| TABLE II. MEASURED AND PREDICTED PHUGOID CHARACTERISTICS |                 |                  |                 |                  |
|----------------------------------------------------------|-----------------|------------------|-----------------|------------------|
| True Airspeed<br>(kn)                                    | Flight Test     |                  | Calculated      |                  |
|                                                          | Period<br>(sec) | Damping<br>Ratio | Period<br>(sec) | Damping<br>Ratio |
| 70                                                       | 25              | ~ 0              | 22              | .008             |
| 99                                                       | 25              | ~ 0              | 27              | .031             |
| 145                                                      | 43              | ~ 0              | 49              | .096             |
| 150                                                      | -               | -                | 90              | .046             |
| Gross weight: 12,000 lb cg aft                           |                 |                  |                 |                  |

Although the spiral mode is computed to be stable, with a time-to-half amplitude between 6 and 8 seconds, the flight tests showed it to be nearly neutral. Right and left banked turns at 130 knots with controls fixed had a time-to-double of 30 seconds for the bank angle, after which the bank angle started to return slowly toward zero. This difference between computed and flight-test results is probably due either to a high estimate of dihedral stability or a low estimate of directional stability. Since few

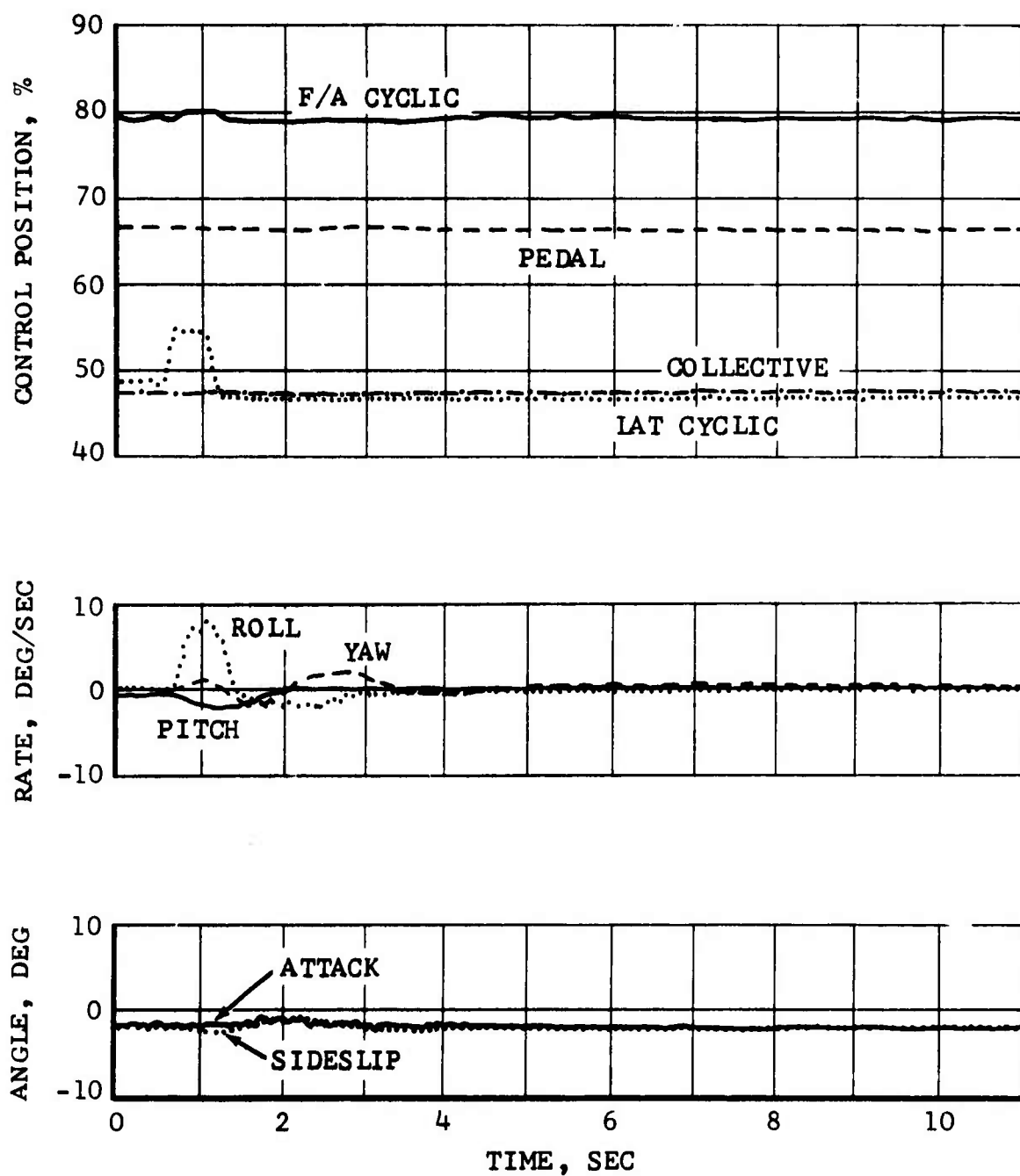


Figure 23. Lateral Cyclic Pulse at 130 Knots, Flight Test Data, 12,000 Pounds GW, Aft CG.

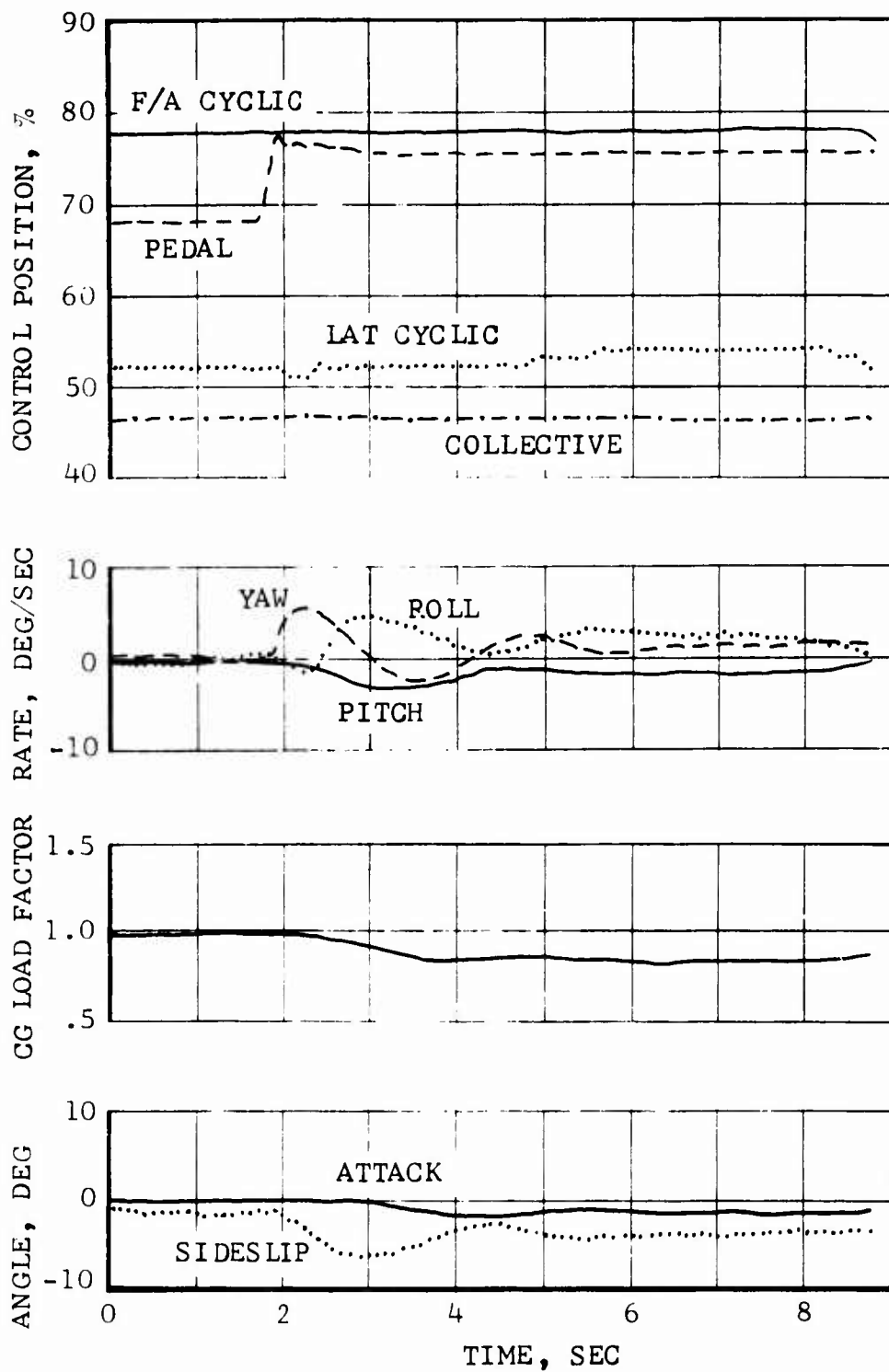


Figure 24. Pedal Step at 130 Knots, Flight Test Data, 12,000 Pounds GW, Aft CG.

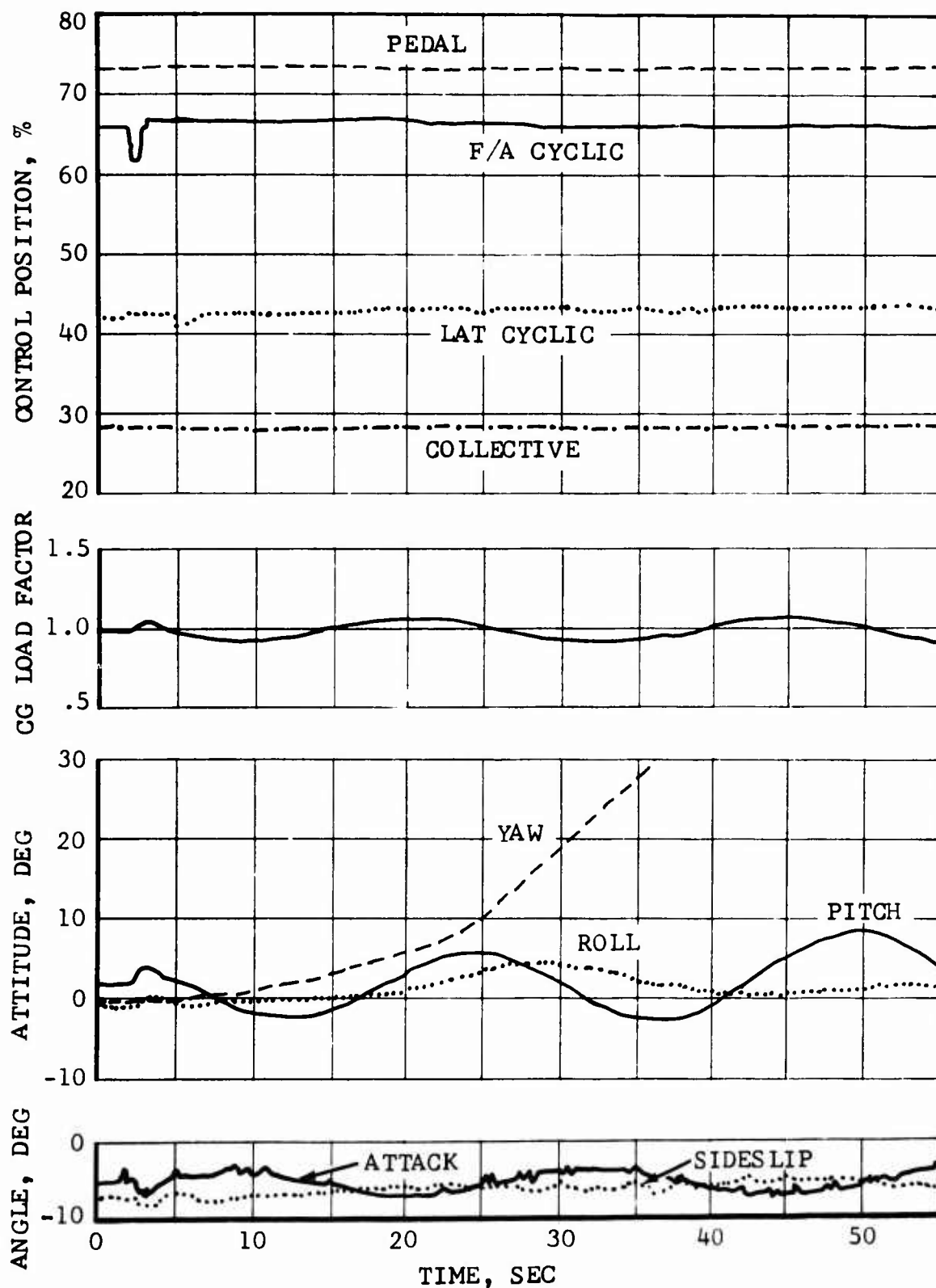


Figure 25. Longitudinal Cyclic Pulse at 100 Knots,  
Flight Test Data, 12,000 Pounds GW, Aft CG.

wind-tunnel data were available for fuselage sideslip derivatives, the exact cause could not be determined.

### Forward Flight Control Response and Sensitivity

A series of control steps in the longitudinal and lateral directions were performed at 12,000 pounds gross weight and forward and aft center-of-gravity locations. Control response and sensitivity were measured from records of the resulting pitch and roll rates and normalized for 1-inch control displacements. Because the control inputs were small, it was not possible to check the linearity of control response. Sample records are shown in Figures 26 and 27, and a summary of all test data is presented in Figures 28 and 29.

The near-zero lag between the insertion of the full step cyclic input and the peak angular acceleration shows the rotor responsiveness to the cyclic controls. Since angular accelerations are measured from the slope of the angular rate plot, the time of peak angular accelerations was difficult to determine (in general, the peak acceleration occurred less than 0.1 second after the control motion stopped).

Some difficulty was encountered in measuring the control inputs used in these tests of response and sensitivity. The pilot's cyclic stick used for the step input was instrumented for displacement measurements, but the fixture which acted as a positive stop was on the copilot's stick. Deflections between these two sticks and the swash-plate washed out some of the control input. The control inputs were restricted to 1/2 inch or less above 100 knots; therefore, a small amount of lost motion was a significant percentage of the step size and consequently of control response and sensitivity. As much as 25 percent of the stick input has been lost in some measured cases.

#### 1. Lateral Control

At high speed, the test helicopter has higher lateral sensitivity for left steps than for right steps, as shown in Figure 29. A left step causes the rotor to tilt aft (indicated by the initial noseup pitch rate in Figure 27), increasing the rotor angle of attack. This produces an increase in rotor thrust and thus an increased rolling moment. A right step produces the opposite effect (Figure 23), reducing thrust and thus reducing the right rolling moment. The rotor thrust versus angle-of-attack gradient increases with speed, and

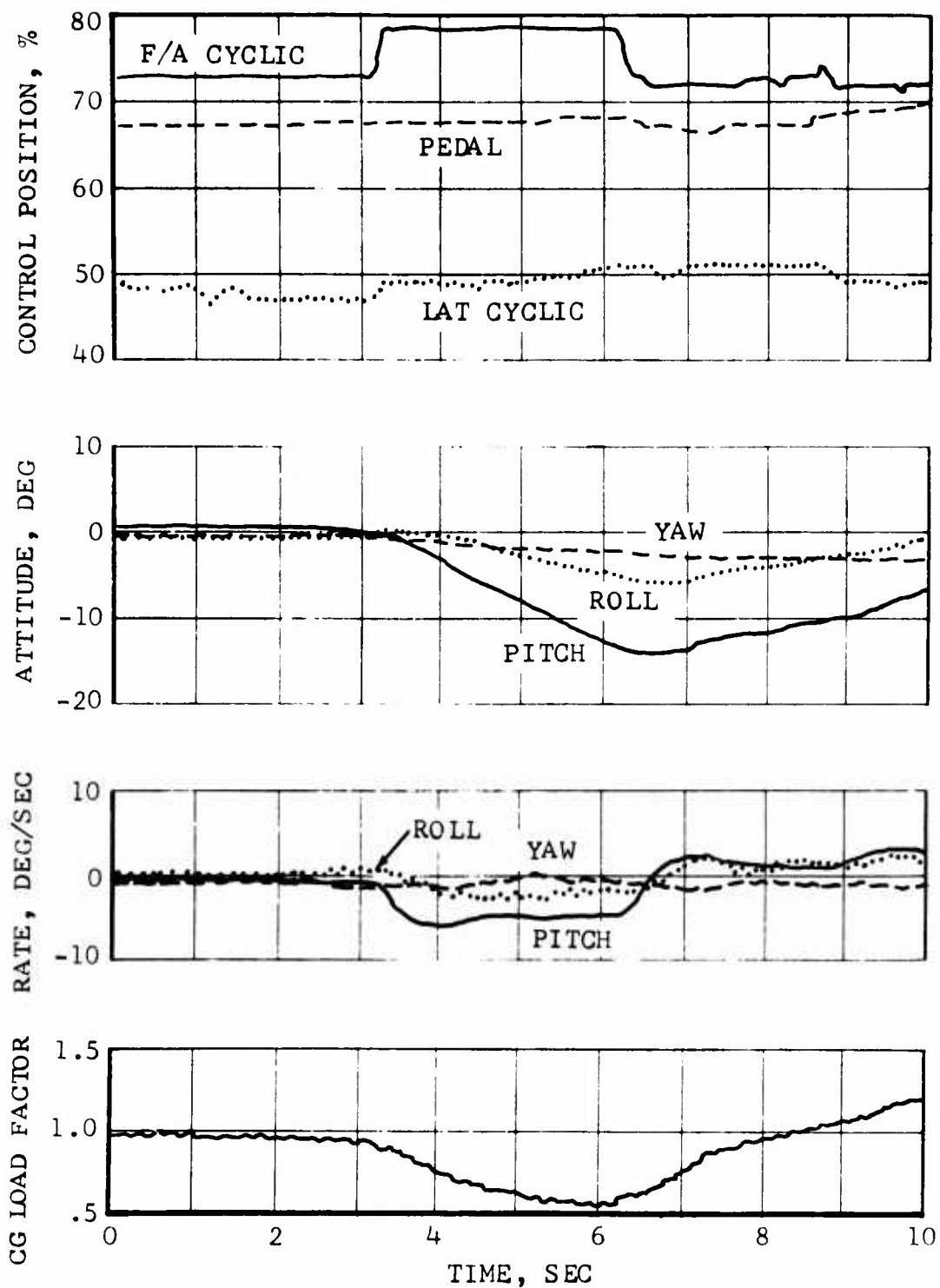


Figure 26. Longitudinal Cyclic Step at 100 Knots, Flight Test Data, 12,000 Pounds GW, Aft CG.

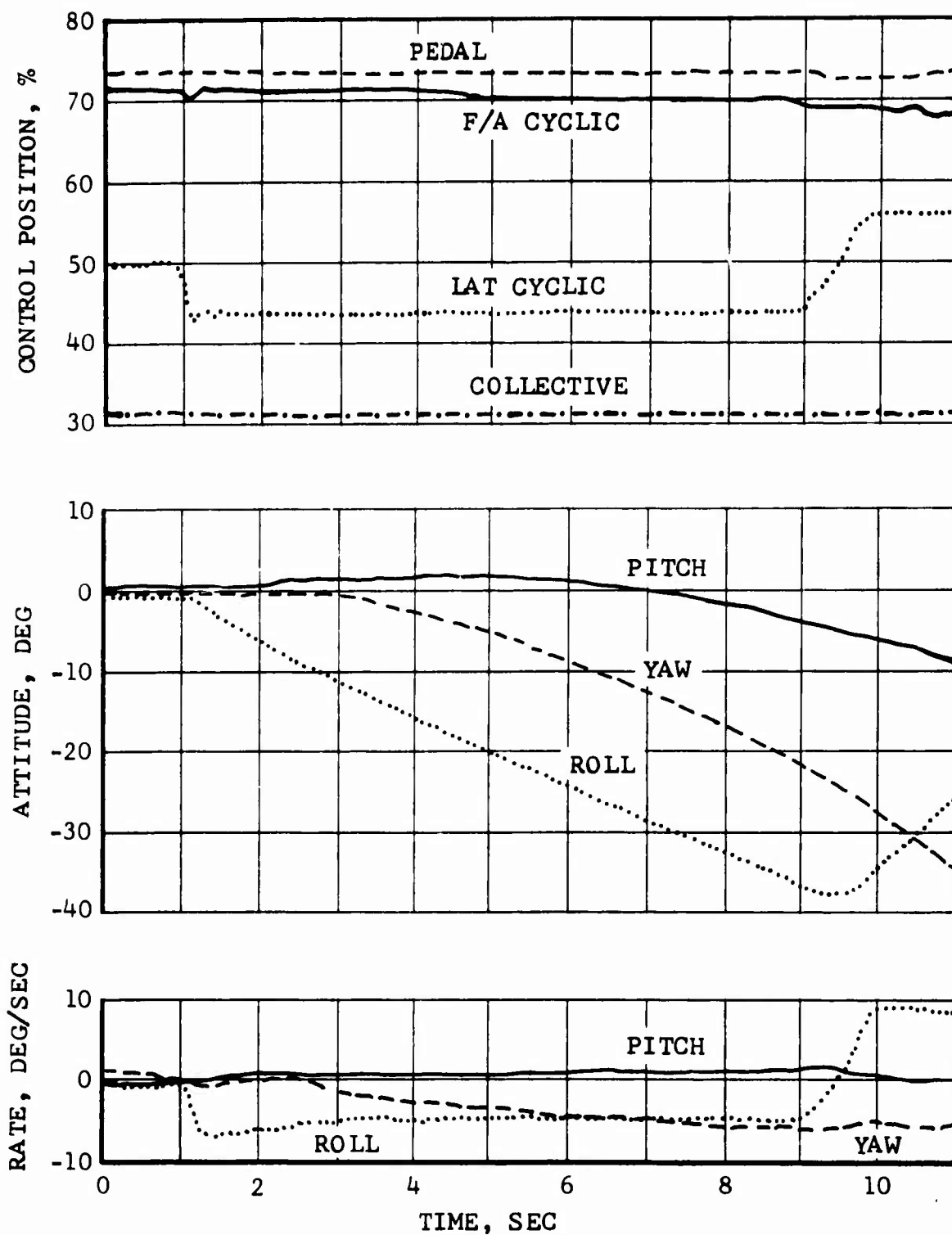


Figure 27. Lateral Cyclic Step at 100 Knots, Flight Test Data, 12,000 Pounds GW, Aft CG.

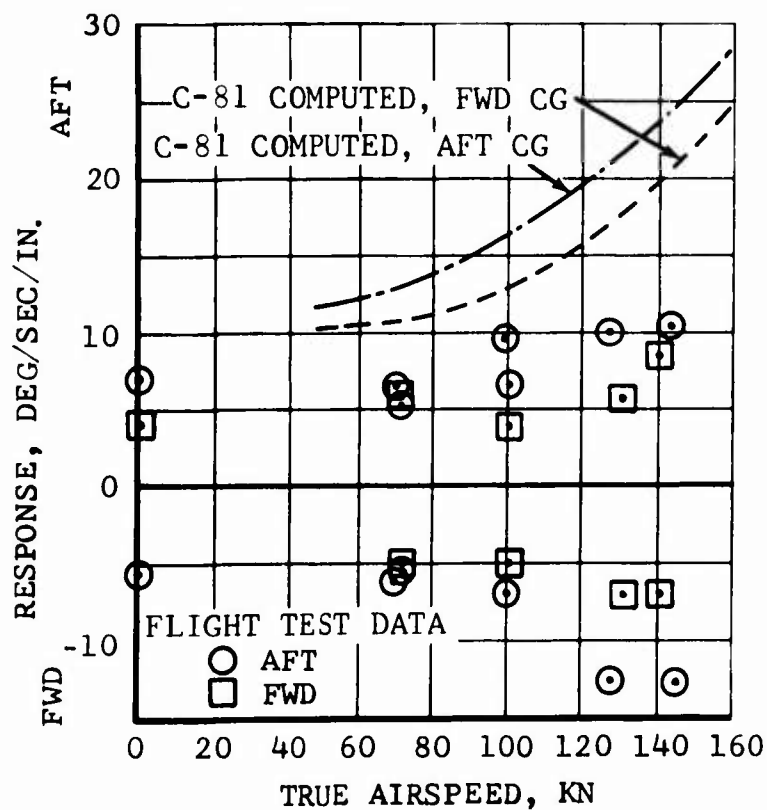
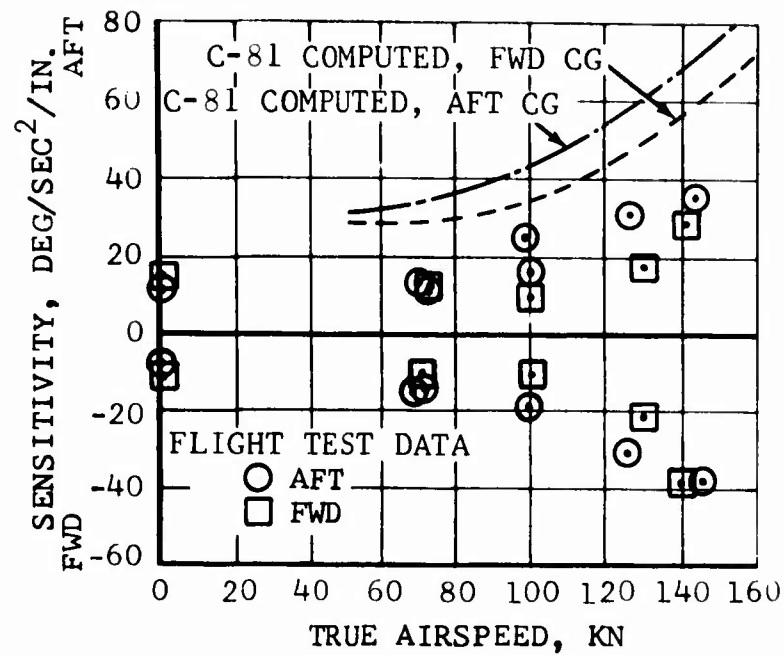


Figure 28. Measured and Computed Longitudinal Cyclic Control Characteristics.

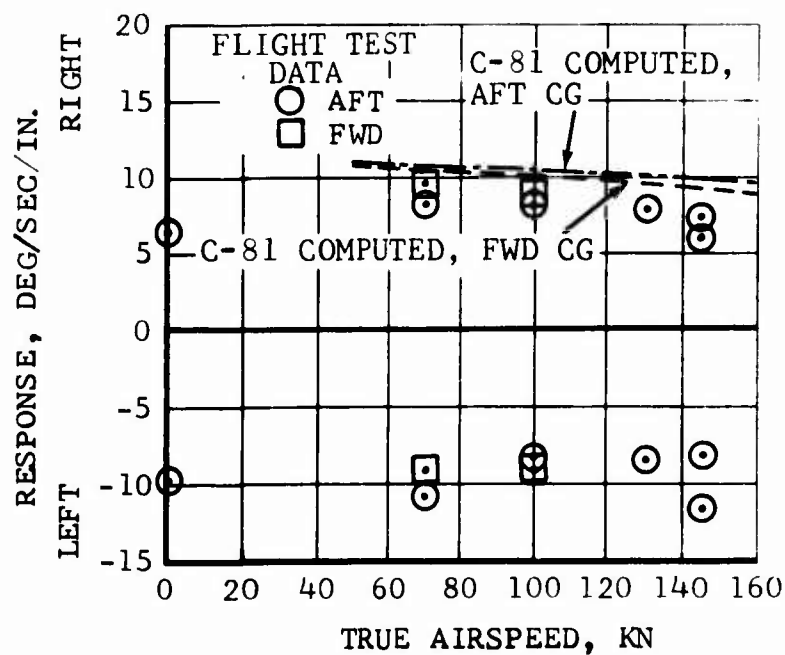
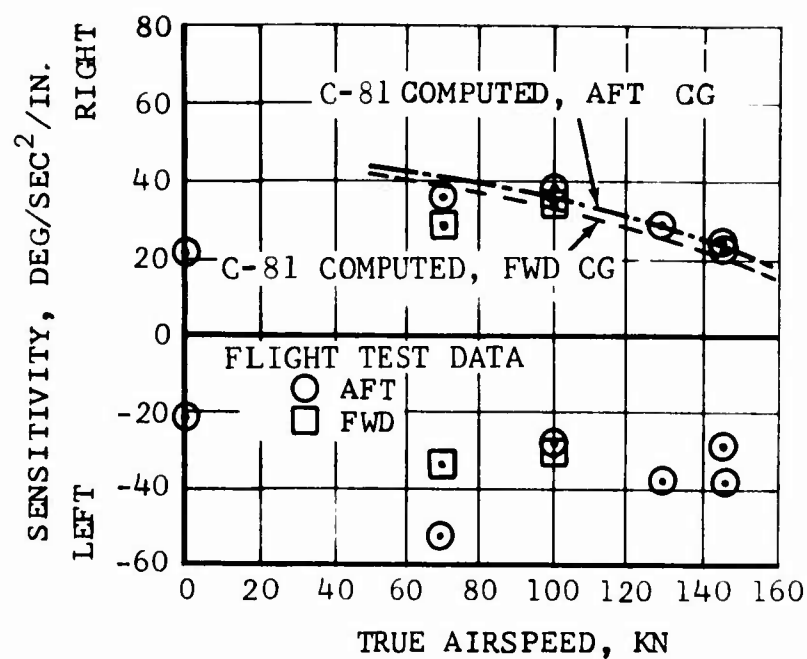


Figure 29. Measured and Computed Lateral Cyclic Control Characteristics.

therefore, the difference between the response to a left step and that to a right step is greatest at high speed.

This effect also applies to longitudinal steps and generates left roll with forward steps (Figure 26) and right roll with aft steps. Motions in this plane, however, have no mechanism similar to the rotor angle-of-attack change described above to magnify this effect.

## 2. Longitudinal Control

Control sensitivity in the test helicopter increases with airspeed, and at 150 knots it is approximately four times its value at hover. This increase is primarily due to the horizontal stabilizer, which is geared to move with the longitudinal cyclic stick as shown in Figure 83. This gearing provides adequate control margins and reduces rotor flapping loads in maneuvers. At high speed, the stick is forward--in the region where elevator incidence changes significantly with stick displacement. This, combined with the high dynamic pressure, acts to markedly increase the pitching moment contribution of the elevator. This acts with the increased moment response of the rigid hub with speed to produce the high control sensitivity seen in the flight test data. At high forward speeds, step inputs had to be limited to one-quarter inch.

The force feel system (described in Appendix I) increases the cyclic force-feel gradient with airspeed, thereby avoiding excessive control responses at high speed. Longitudinal cyclic stick inputs were normally applied by means of the beeper trim system at high forward speeds, giving a slower trim rate.

Longitudinal control response also increases with speed, as does pitch damping. The latter tendency is countered by increasing pitch control sensitivity to make the response at high speed approximately twice that in the hover.

## Control Sensitivity and Response Estimation

Longitudinal and lateral control sensitivity and response predictions agree with flight-test trends, although the magnitudes of longitudinal response and sensitivity are

overestimated (Figure 28). The washout of control inputs noted previously is not modeled in the computer; therefore, the computer predicts higher control sensitivities than were actually measured. This difference is accentuated when both rotor and elevator contribute to the response and sensitivity about the pitch axis.

### Maneuverability

Maneuverability was investigated for the test helicopter at a gross weight of 12,000 pounds with the center of gravity in the forward and aft locations, and at a gross weight of 14,000 pounds with the center of gravity at its mid location. The purpose of these tests was primarily to define the maximum maneuverability of the helicopter for these loading conditions throughout the forward flight speed range.

A series of left and right turns was performed at constant airspeed to define the variations of normal acceleration with longitudinal cyclic stick position. The results are shown in Figure 30 for two airspeeds and two center-of-gravity locations. Aft stick motion is required for increasing load factor at all conditions tested, but the gradient is lower when the center of gravity is aft.

The pilot reported a tendency for the main rotor to "dig in" (the load factor increases when the cyclic stick is held fixed after a step input) during maneuvers at positive load factors with the center of gravity aft. This tendency was not present when the center of gravity was forward. High-speed flight with the center of gravity aft produces a low gradient of stick position with load factor. This combines with high longitudinal control power to make the helicopter very sensitive in pitch. Although the "digging in" phenomenon did not show up on flight records, the high pitch sensitivity could give the pilot cues which would convince him that the phenomenon was present. This condition did not receive a thorough computer investigation because it was not possible to model the helicopter precisely under these maneuvering conditions.

Figure 31 shows the record of a symmetrical pullup and pushover flown during the flight tests. Entry speed was 148 knots, with the aircraft at a gross weight of 12,000 pounds and its center of gravity aft. At this speed, small control inputs resulted in over 1.7G. A right roll tendency was countered with a small amount of left cyclic stick to hold a level roll attitude. (Rotor load variation will be considered later.)

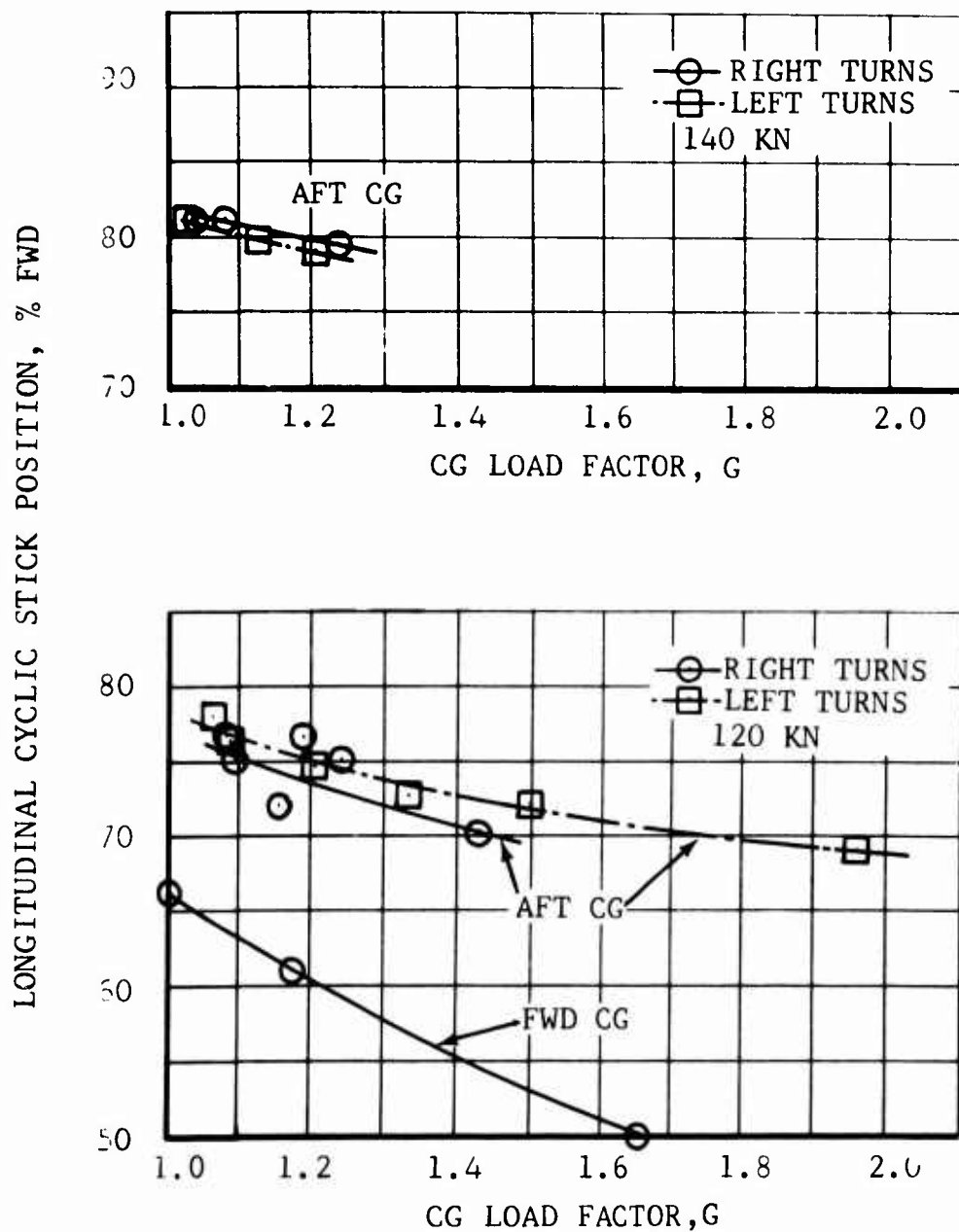


Figure 30. Longitudinal Cyclic Stick Position Variation With Normal Acceleration, Flight Test Data, 12,000 Pounds GW.

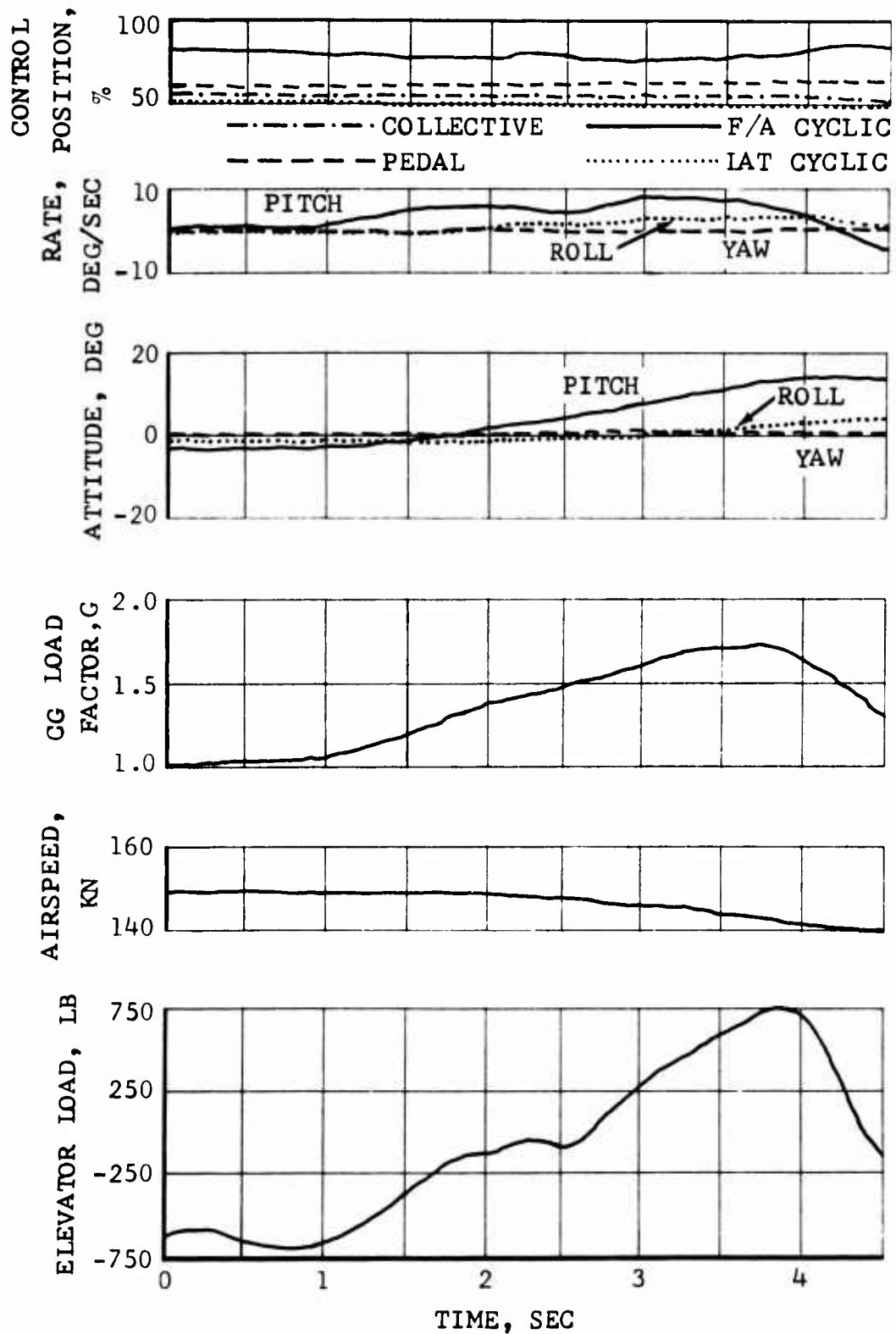


Figure 31. Symmetric Pullup and Pushover, Flight Test Data, 12,000 Pounds GW, Aft CG.

This maneuver was simulated on the computer for comparison with flight test results. A series of control inputs devised for the simulation matched normal load factor and fuselage attitudes. This simulation is compared with the test results in Figure 32. Control motions required to duplicate this maneuver were smaller than those recorded in flight. This is attributed primarily to control washout mentioned earlier in the discussion of control response.

#### FORCE-FEEL SYSTEM

The test helicopter had a force-feel system which incorporated a trim feature. The system furnished longitudinal and lateral cyclic stick force gradients which increased with forward airspeed. The force gradient counteracted the increasing sensitivity of the cyclic controls with increasing speed. It was variable between 1-1/2 and 7 pounds per inch longitudinally and between 1/2 and 4-1/2 pounds per inch laterally. The pilot could select different gradients as shown in Figure 86, Appendix I.

The cyclic stick trim rate varied automatically with airspeed--from 1.2 inches per second in hover to 0.2 inch per second at high speed. This gives the pilot fast control response for precise hovering and protection against overcontrolling at high speeds. The pilot used this trim to perform normal flight tasks, such as turns and changes in airspeed or altitude.

The flight tests also included a limited evaluation of a longitudinal stick force gradient which increased with pitch rate. Increased gradient due to pitch rate was detectable in forward flight, but the force applied at the stick was limited to a maximum of 10 pounds, and this proved to be too low to warn the pilot of potentially dangerous maneuvering loads. The system would probably be a useful warning device if the stick forces developed were higher.

#### STABILITY AND CONTROL AUGMENTATION SYSTEM (SCAS)

Although the basic test helicopter was not considered excessively hard to fly, the gust sensitivity and control power of the hingeless main rotor demanded a relatively high level of pilot proficiency and attention. The SCAS reduced pilot work load, and was especially helpful during IGE maneuvering and cruise flight in rough air. It was also helpful in alleviating the right rolling tendency noted in transition from hover to forward flight. (Approximately 75 percent of the required left cyclic stick correction was applied by the SCAS unit.) The three-axis SCAS installed in the test vehicle had been used previously with other two- and four-bladed experimental main rotors and was found to work well during the Model 609 rotor program without modification.

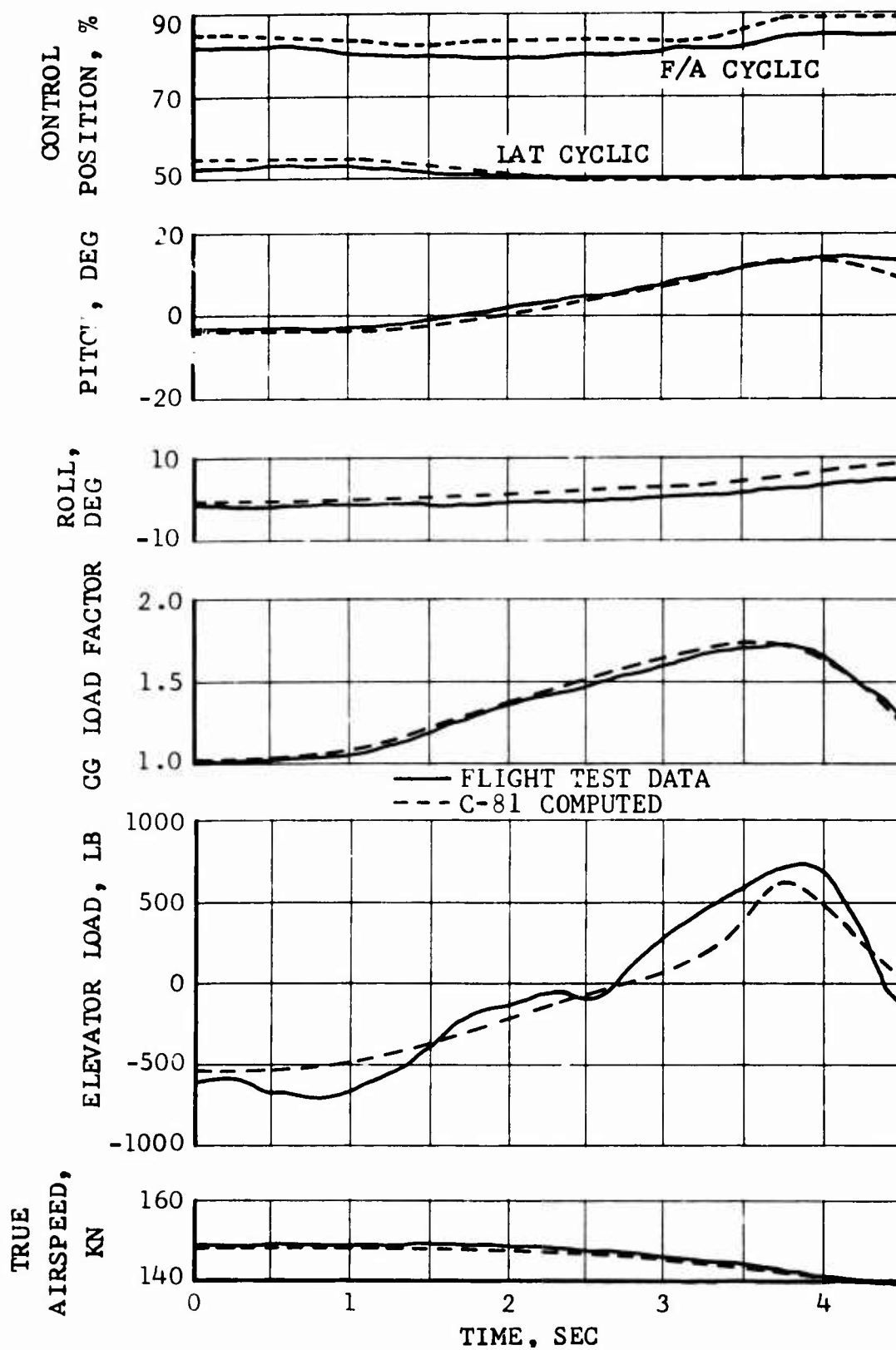


Figure 32. Measured and Computed Maneuver Comparison, 12,000 Pounds GW, Aft CG.

## ROTOR LOADS IN LEVEL FLIGHT AND MANEUVERS - RESULTS AND DISCUSSION

### LEVEL-FLIGHT AND MANEUVER ENVELOPE

The maneuver envelope investigated during the evaluation is presented in Figure 33. This figure presents load factors and delineates the types of maneuvers flown at each gross weight. The level-flight and maneuver envelope is presented nondimensionally in terms of rotor thrust coefficients in Figure 34. The high-speed, high "G" maneuvers were used to define the maneuver envelope in Figure 34. The maneuver rotor thrust coefficients are calculated from the measured airspeed and main rotor rpm at the instant of maximum or minimum G. Also shown for comparison are the maximum maneuver thrust coefficients achieved in an earlier investigation of two- and four-bladed rotors on the Bell High Performance Helicopter (HPH).

### LEVEL FLIGHT

Measured level-flight rotor loads are functions of thrust coefficient and advance ratio. For example, the lines of constant chordwise oscillatory moments shown in Figure 35 for the critical blade station (94.0) plot in an orderly manner. This map was constructed from 280-rpm level-flight data for the three gross weights flown (inset Figure 35).

### MANEUVER FLIGHT

The orderly plots of loads generated during level flight suggest that simple extrapolation would predict loads during maneuvers, but a comparison (Figure 36) of peak loads encountered during maneuvers with the level-flight loads shown in Figure 35 makes it apparent that simple extrapolation will not work. Consistency even seems to be lacking within the maneuver data themselves. For example, in the level  $V_L$  turn at the 14,000-pound gross weight, loads were much higher than at comparable rotor lift coefficients in other maneuvers.

Since most maneuvers were transient, the nondimensional maneuver data in Figure 36 are based on the actual rpm's and airspeeds occurring when the maximum vertical load factors were developed. Maneuvers were entered at 285 rpm. Rotor speed in maneuvers did not exceed 295 rpm significantly. The figure includes level-flight data obtained at 295 rpm to show that the differences between maneuver and level-flight loads cannot be explained simply by rpm overspeeding.

The maneuver data are analyzed to quantify those factors having first-order effects on loads generated during maneuvers. Factors which can increase maneuver loads significantly in any type of rotor are (see Reference 7):

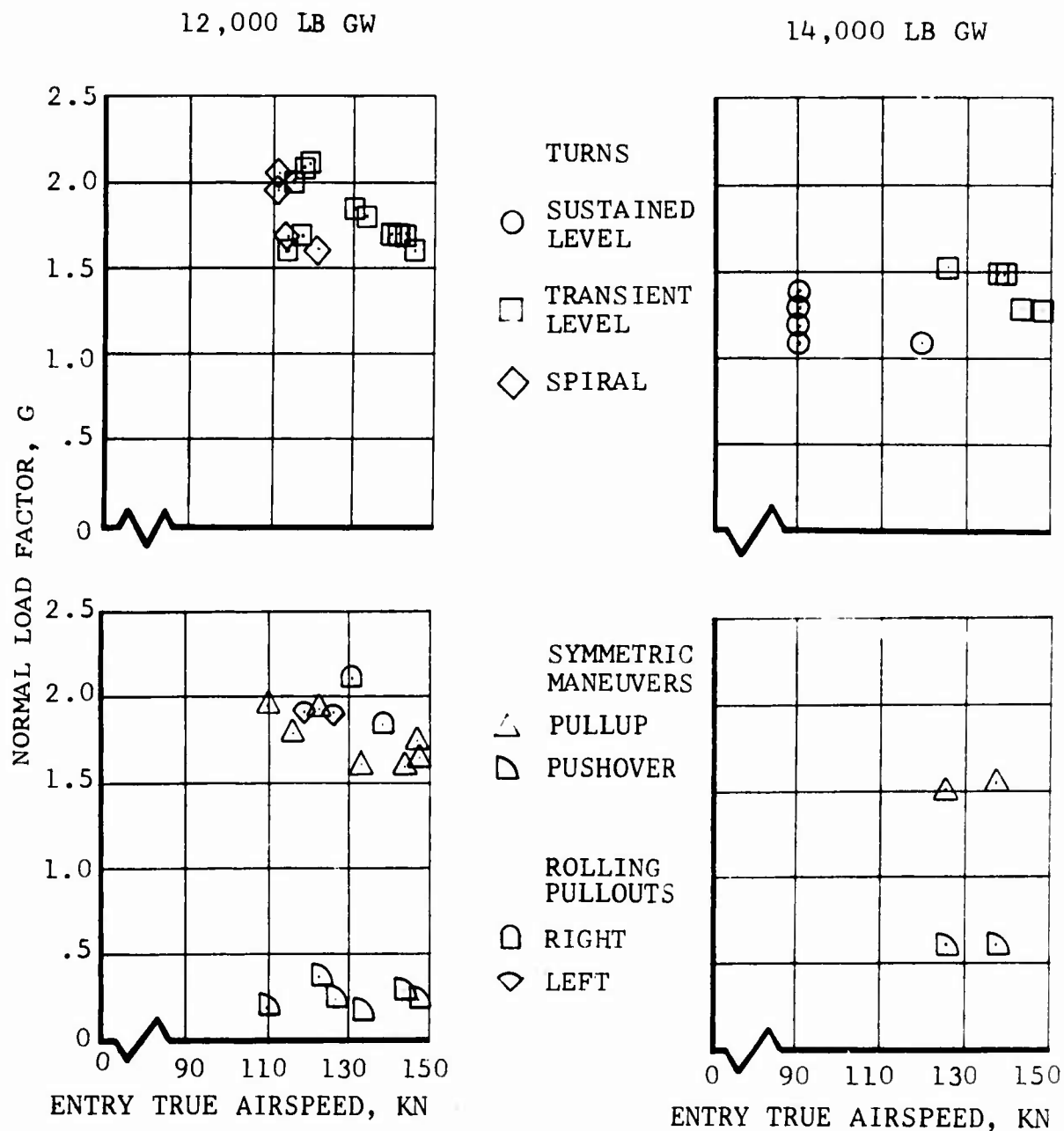


Figure 33. Maneuver Investigation Dimensional Envelope, Flight Test Data.

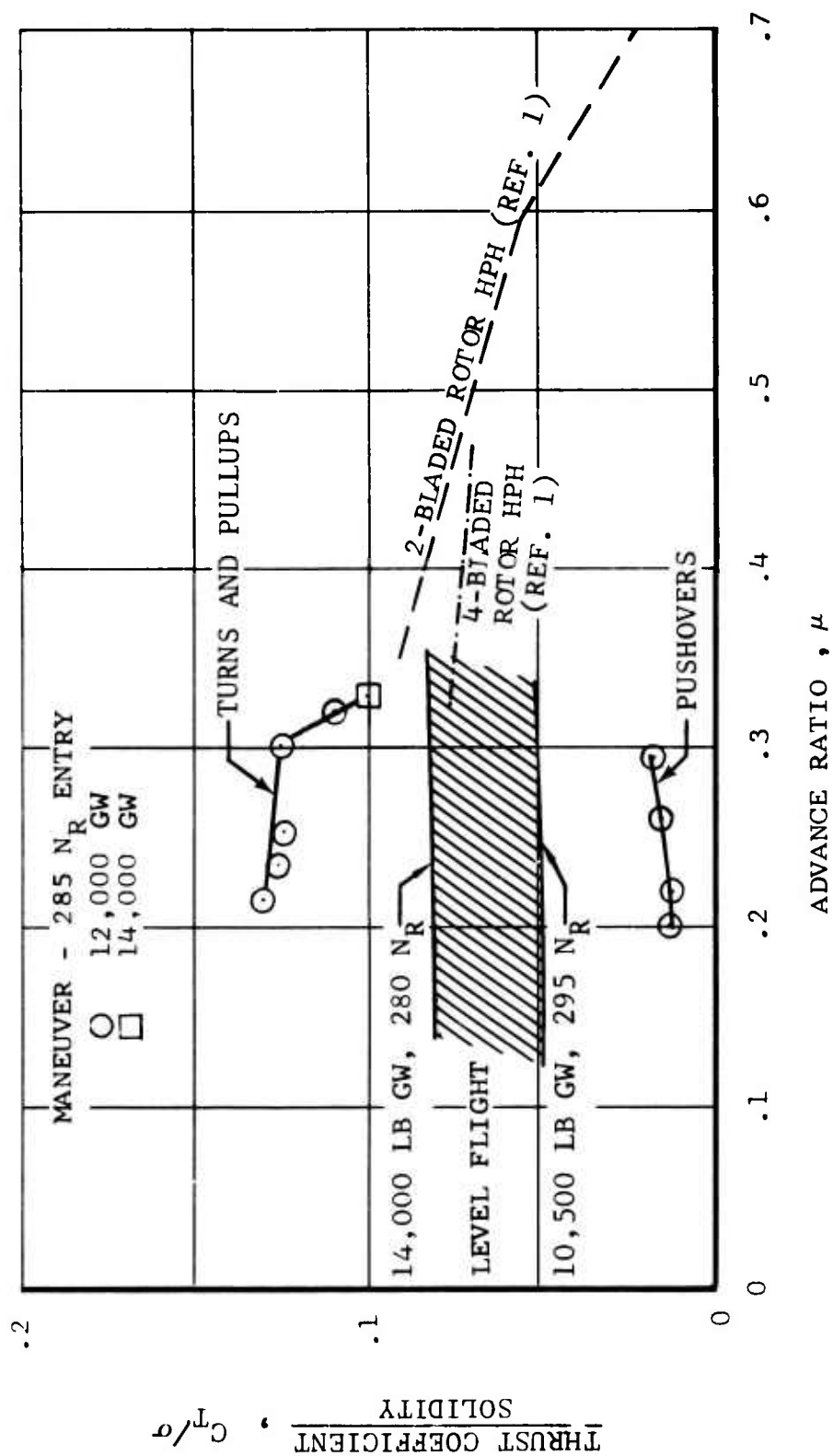


Figure 34. Nondimensional Maneuver Envelope,  
Fig. Test Da'

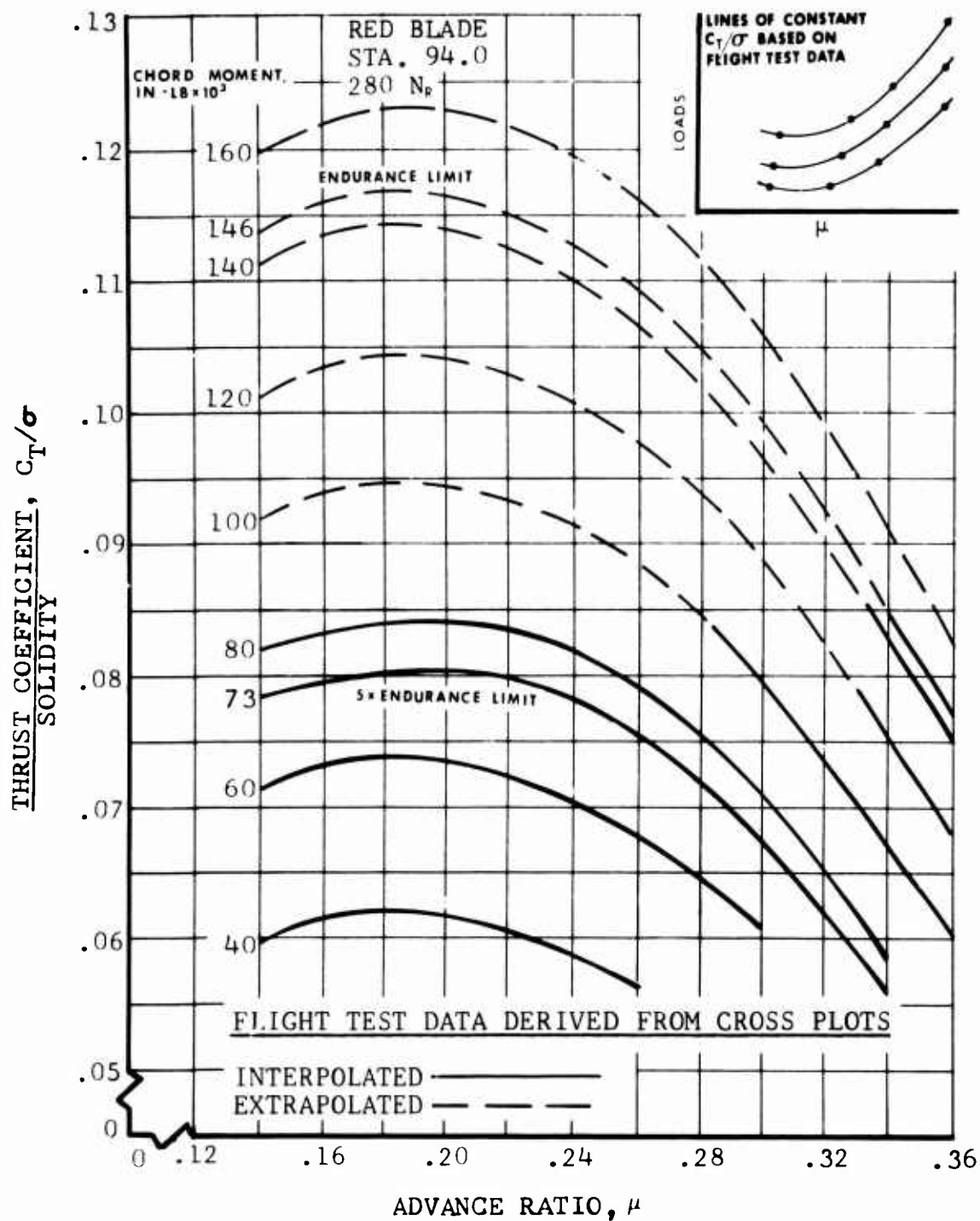


Figure 35. Constant Chordwise Moments Versus  $C_T/\sigma$  and  $\mu$ , Flight Test Data.

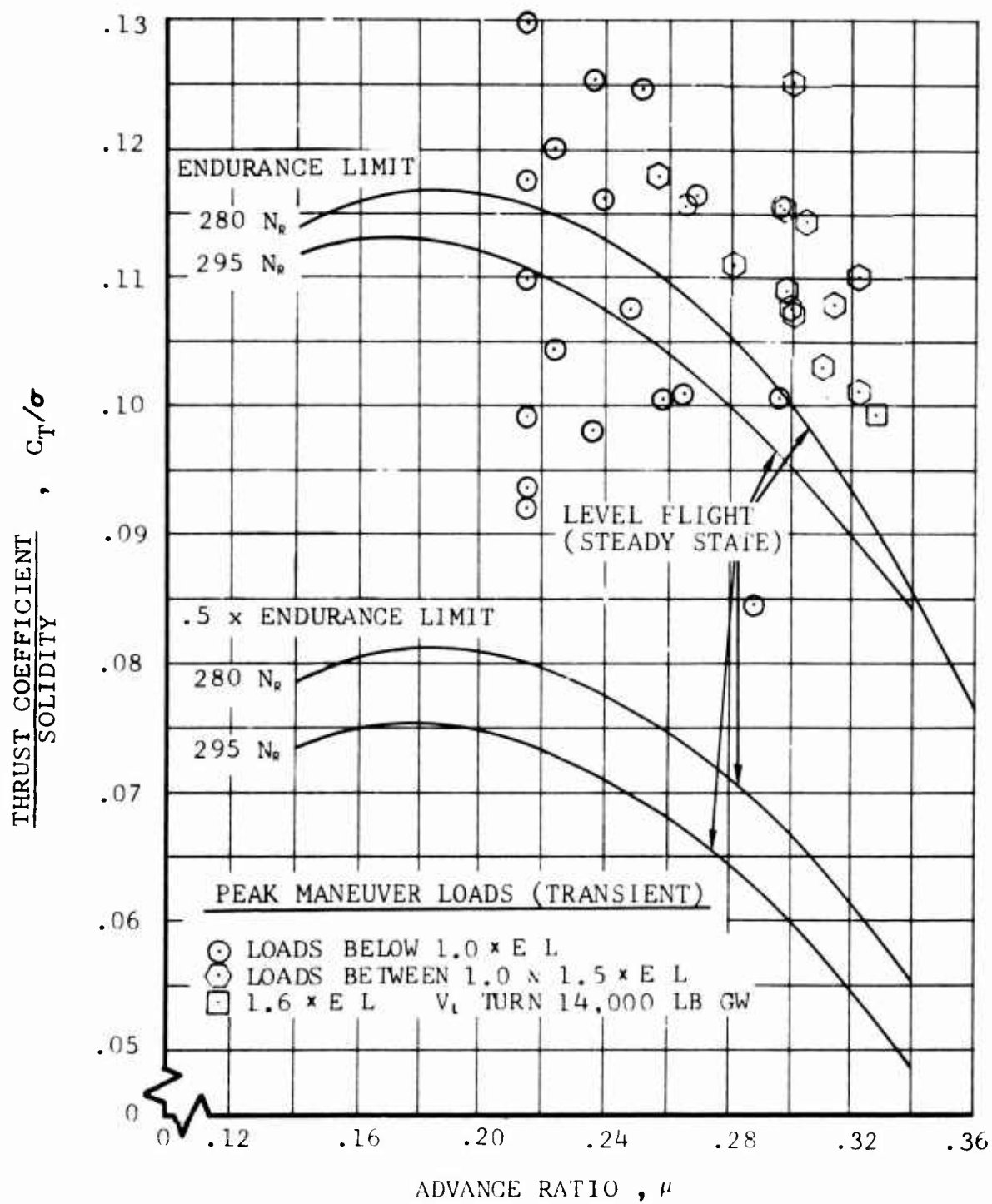


Figure 36. Comparison Between Maneuver and Level Flight Loads, Flight Test Data.

- Retreating blade stall (thrust coefficient and advance ratio)
- Rotor propulsive force
- Collective pitch (entry power)
- Rotor speed changes during maneuvers
- Pitch and roll velocities
- Rotor flapping (hub restraint)

In a hingeless rotor, flapping amplitude has a particularly strong influence on both beamwise and chordwise loads.

#### Collective Pitch and Advance Ratio

The aerodynamic effects of collective pitch settings at various advance ratios have been discussed in the section entitled "Performance". It was shown that the collective pitch controls the propulsive force and the rotor stall conditions. As can be seen from Figure 7, higher lifts can be obtained at the lower collective pitch angles before stall is encountered. Since oscillatory rotor loads in maneuvers are primarily stall induced, higher load factors can be achieved at similar rotor structural loads when lower collective pitch values are used for the maneuver.

Flight test values of collective blade pitch at the 0.75 radius during maneuvers are plotted in Figure 37. All maneuvers were performed with collective fixed (the rotor also had zero pitch cone coupling). The lower collective settings were for either low gross weights, low-speed entries, low-power diving pullouts, or combinations thereof. Values are plotted for the instant at which the oscillatory chord moment at Station 94 reached or passed through the endurance limit of  $\pm 146,000$  inch-pounds. The plot shows the trend toward higher obtainable thrust coefficients with lower collective angles for a given oscillatory load level.

Blade loads data from wind-tunnel tests of a full-scale two-bladed semirigid rotor (previously published in part in Reference 1) are also presented in Figure 37 to show that this trend also exists in a different kind of rotor system and at higher advance ratios. This figure is a plot of the loci of rotor lift coefficients for a selected oscillatory chordwise blade moment and shows clearly the increase in lift at a given load level when lower collective settings were used. (See also Appendix II.)

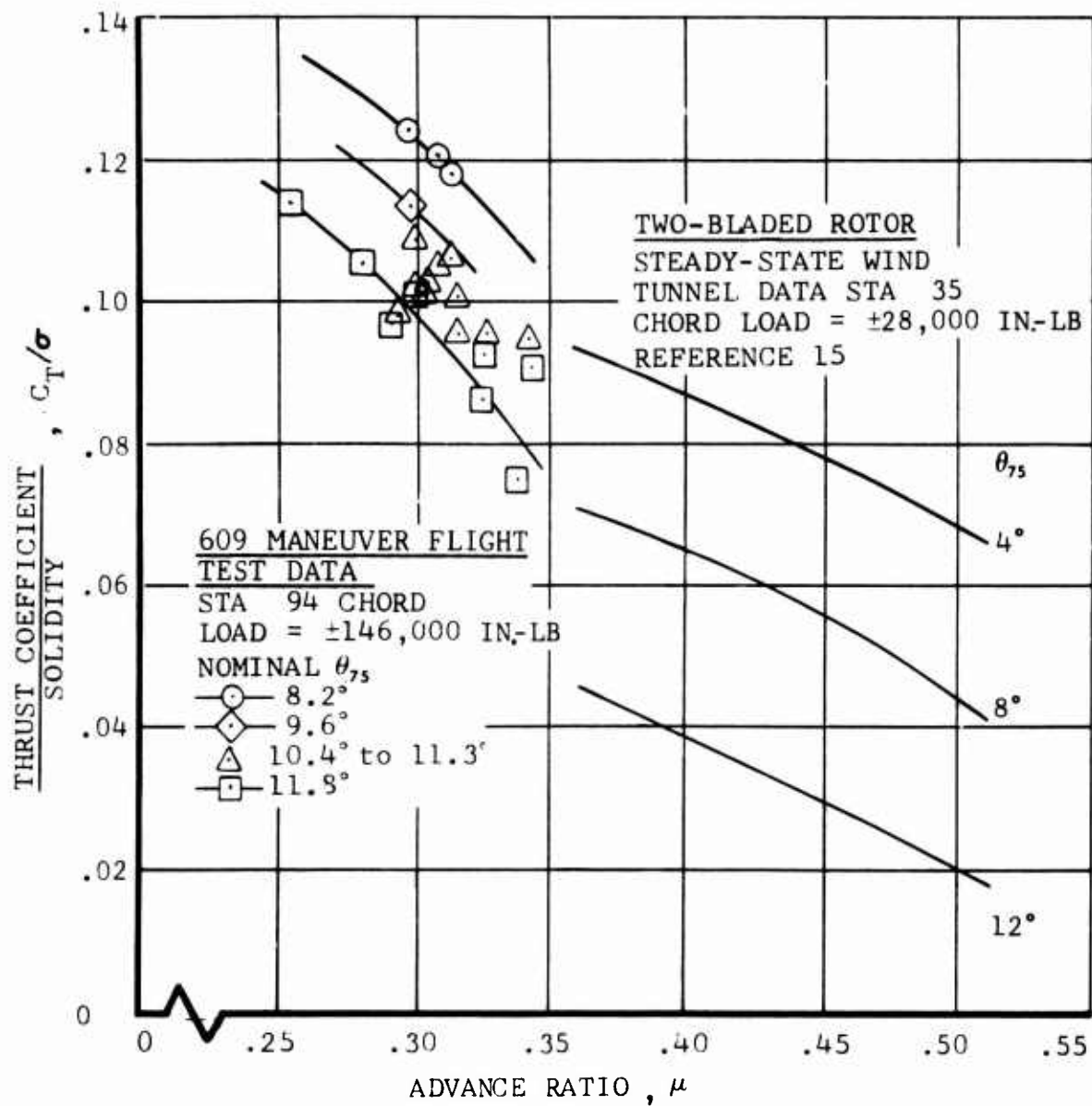


Figure 37. Maximum Nondimensional Lift (at a Constant Oscillatory Blade Moment) Versus Advance Ratio and Collective Pitch.

The collective pitch setting at entry into a maneuver is a measure of the entry power, and the severity of load generated during a maneuver can be related to this power. As shown in the "Performance - Results and Discussion" section, the collective setting also established the variation in rotor propulsive force (drag coefficient) as a function of rotor lift. Consequently, propulsive force was not examined as an independent factor.

#### Rotor Speed Changes During Maneuvers

The overspeed and decay characteristics of the main rotor during maneuvers are a function of the type of maneuver, how it is flown, and the response characteristics of the engine governor. Reference 8 reported significant increases in the speed of a hingeless rotor on the XH-51A during maneuvers, with the rotor frequently going into autorotation. Maneuvers with the 609 rotor were performed with the collective fixed in the middle of the pitch range. Consequently, changes in rpm were functions of only the changing rotor torque requirements and the response of the power turbine governor.

During maneuvers, the main rotor speed stayed fairly constant and never increased by more than 12 rpm. The maneuvers that generated the highest blade loads (because of stall effects) were at high speed and were either pullups where peak G occurred soon after the control inputs were made or steady turns with a sustained G level. For both these types of maneuver, the largest increase in rotor speed was only 4 rpm. Figure 38 presents the increase in rpm (normalized by the peak load factor) versus entry airspeed for the maneuvers investigated.

#### Pitch and Roll Velocity

Rapid roll reversals were performed to demonstrate the performance of the rotor in this type of maneuver and to determine the effects of roll accelerations and velocities on rotor loads. Measured quantities plotted in Figure 39 are for the maximum maneuver that the pilot could perform comfortably at each airspeed. High accelerations and rates were developed without exceeding the endurance limit at Blade Station 94, the critical station. In turns and rolling pullouts, rolling accelerations and velocities are of little consequence, since rolling velocities and accelerations in those maneuvers were only a fraction of those developed in the rapid roll reversals.

Pitch rates developed in maneuvers entered at high speeds were on the order of 9 to 12 degrees per second. The

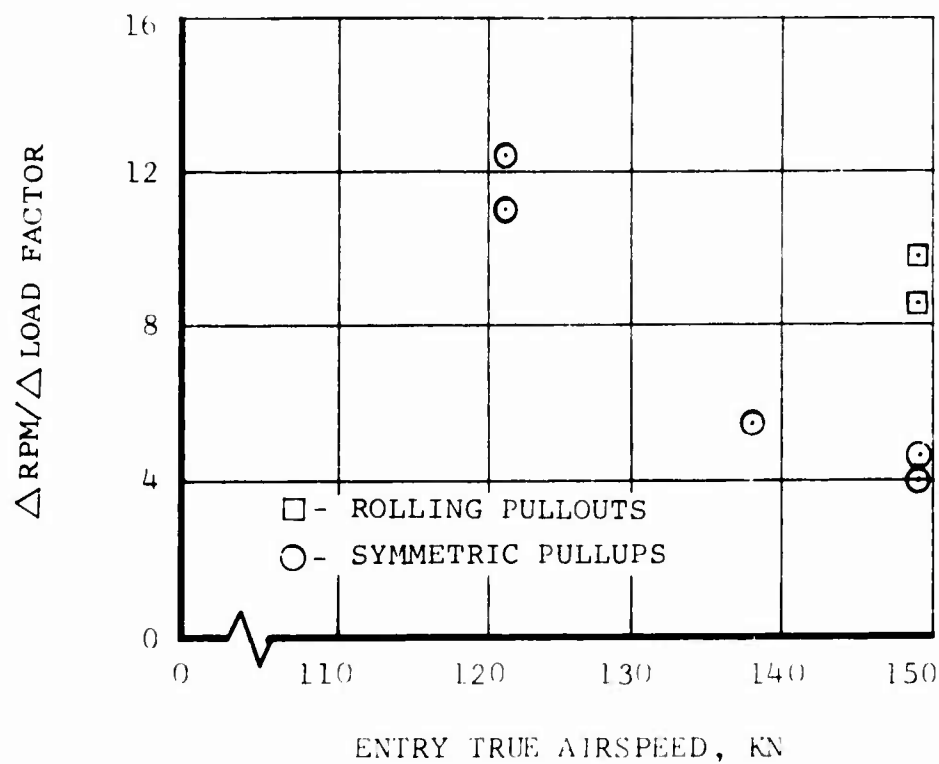
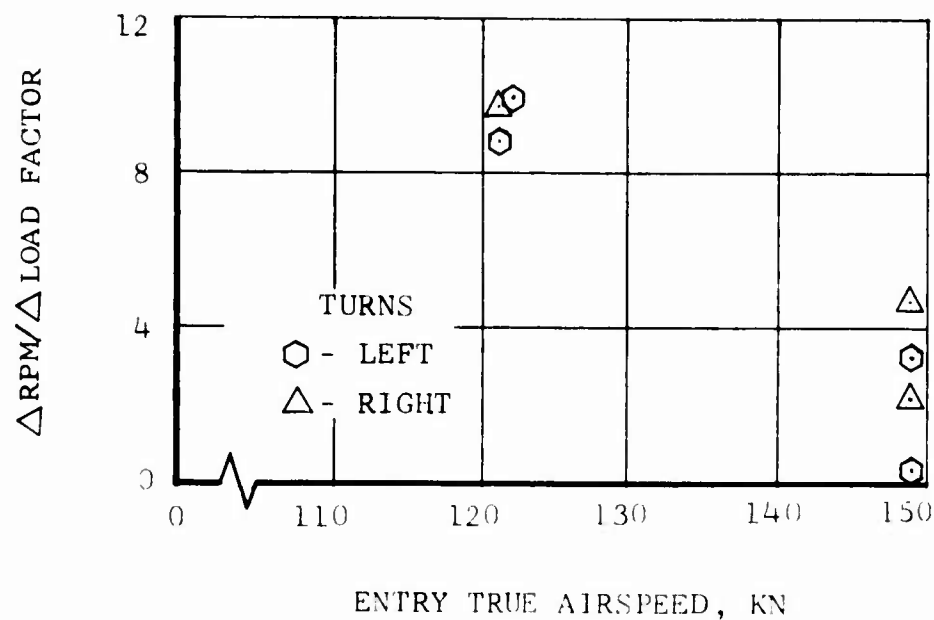


Figure 38. Main Rotor Overspeed Characteristics in Maneuvers, Flight Test Data.

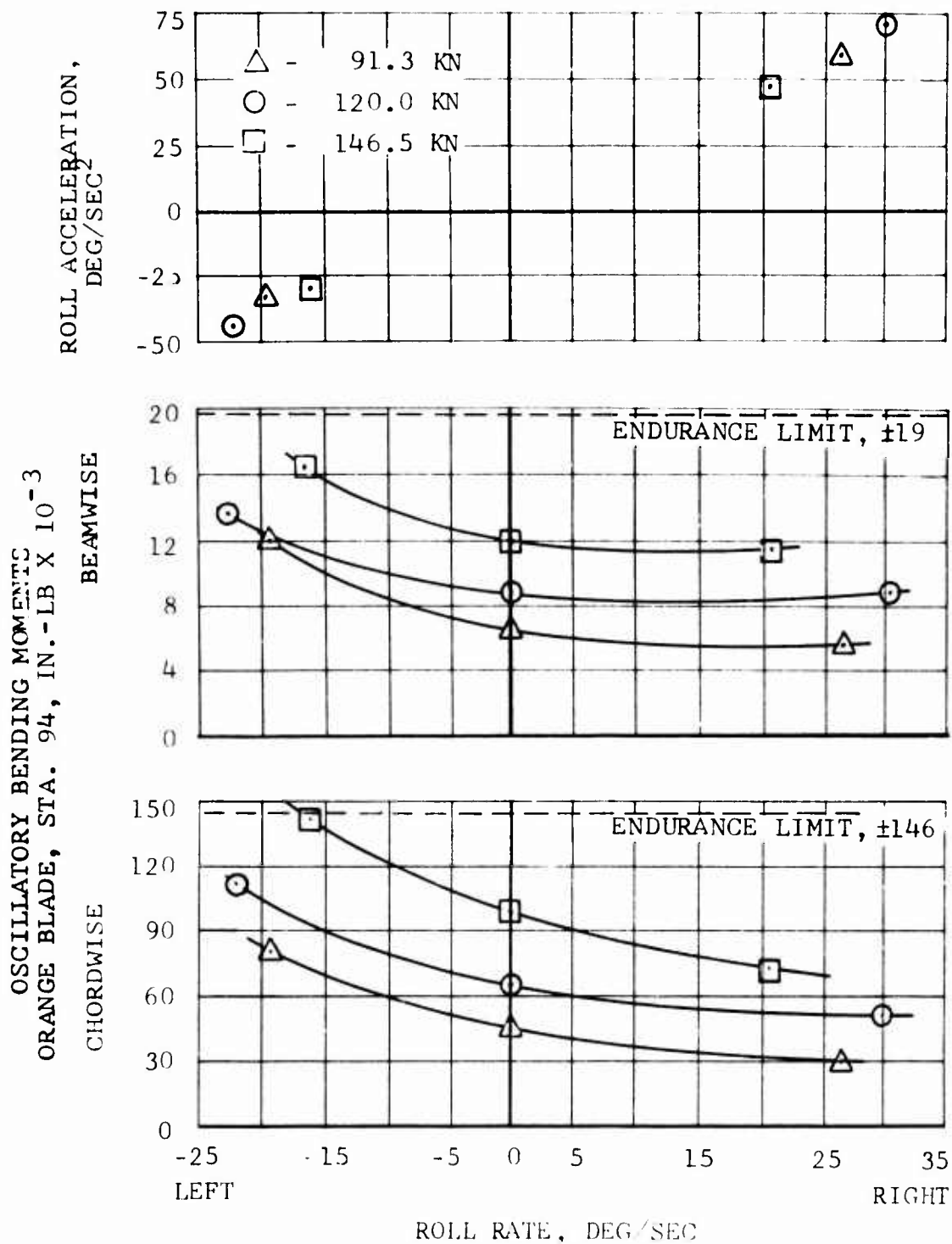


Figure 39. Rapid Roll Reversal Characteristics, Flight Test Data.

limit maneuver investigation was not designed to permit identification of pitching rate effects; therefore, these effects are not discussed here.

### Rotor Flapping in Maneuvers

One-per-rev beamwise moments develop in the hub flexure in proportion to rotor flapping. (The magnitudes of beamwise moments at higher harmonics were insignificant from a stress standpoint.) One-per-rev chordwise moments develop in the blade and flexure in response to air loads and in proportion to Coriolis forces generated by rotor flapping and coning. Coning varies as a function of rotor thrust. Figure 40 presents the maximum allowable rotor flapping and thrust (coning) before the rotor endurance limits are reached (no aerodynamic excitations and assuming that no high harmonics are present). A 21,300 inch-pound moment is indicative of one degree of rotor flapping at the 3/4 blade radius station. The rotor flapping limits were determined from this flapping "spring rate."

The elevator control system was designed to minimize fore-and-aft rotor flapping in level flight, and a plot of one-per-rev beamwise moments (Figure 41) shows that the flapping was low in forward flight. In Figure 41, the measured moments have been resolved into lateral and fore-and-aft flapping components. This shows that most of the flapping was to the left, implying that the elevator control was very effective in minimizing fore-and-aft flapping.

Figure 42 shows how flapping varied in maneuvers entered at high speed. Flapping approaches the structural limits of the rotor at 12,000 pounds for the forward center-of-gravity cases and, at 14,000 pounds, for the neutral center-of-gravity case.

The highest loads encountered during the evaluation were in a 1.3-G left turn at 14,000 pounds. This maneuver was therefore selected for closer examination. The flapping contribution to loads is shown in Figure 43. This figure indicates that the elimination of flapping in maneuvers would increase maneuverability at forward and neutral centers-of-gravity. Feedback of the flapping moments to the elevator control system could be used to alleviate the flapping.

### CORRELATION OF COMPUTED AND MEASURED ROTOR LOADS

Blade loads on the Model 609 rotor have been computed for comparison with loads measured in flight. The computation used

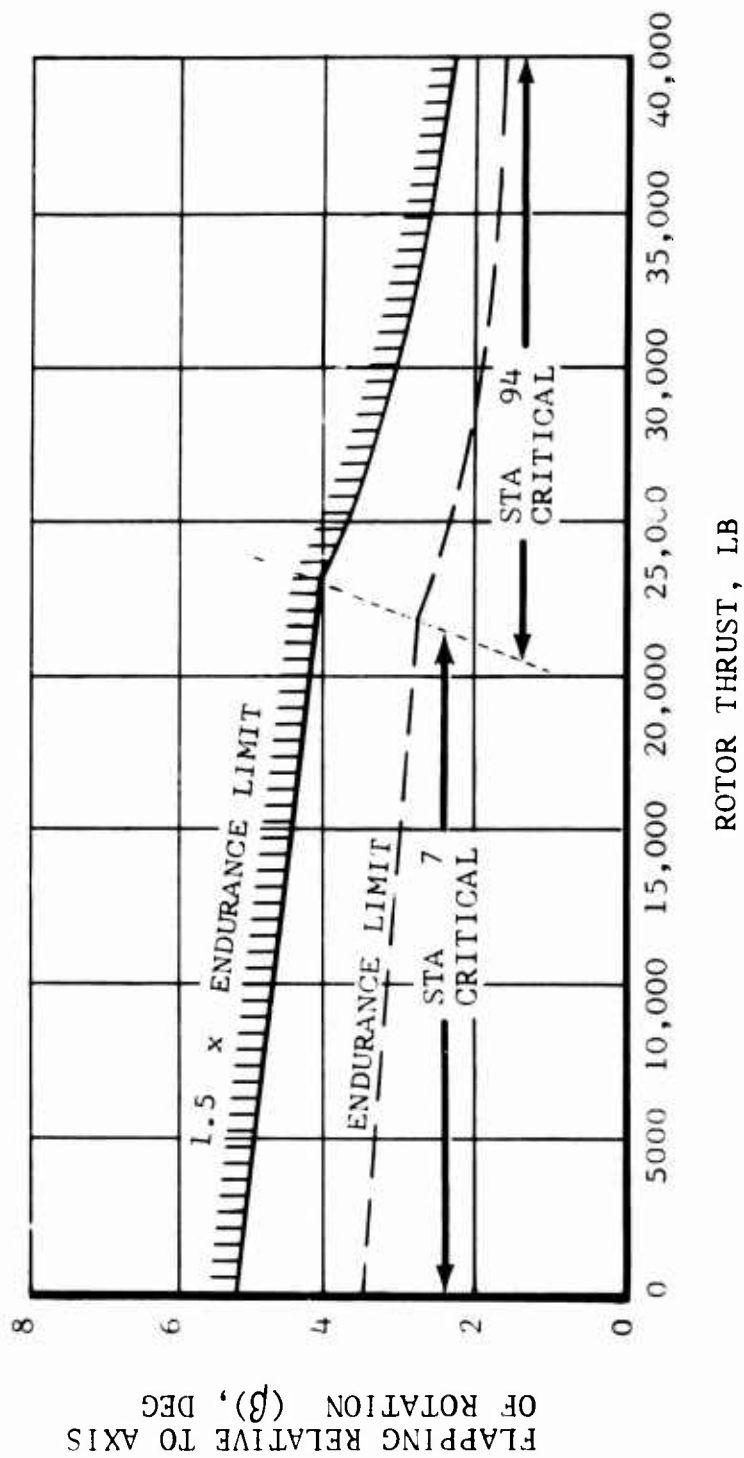


Figure 40. Flapping and Coriolis 1/Rev Limitation.

M/R RED YOKE BEAM BEND. MOM.,  
STA 7.0 1/REV, IN.-LB X 10<sup>3</sup>

LATERAL FLAPPING,  
DEG

F/A FLAPPING,  
DEG

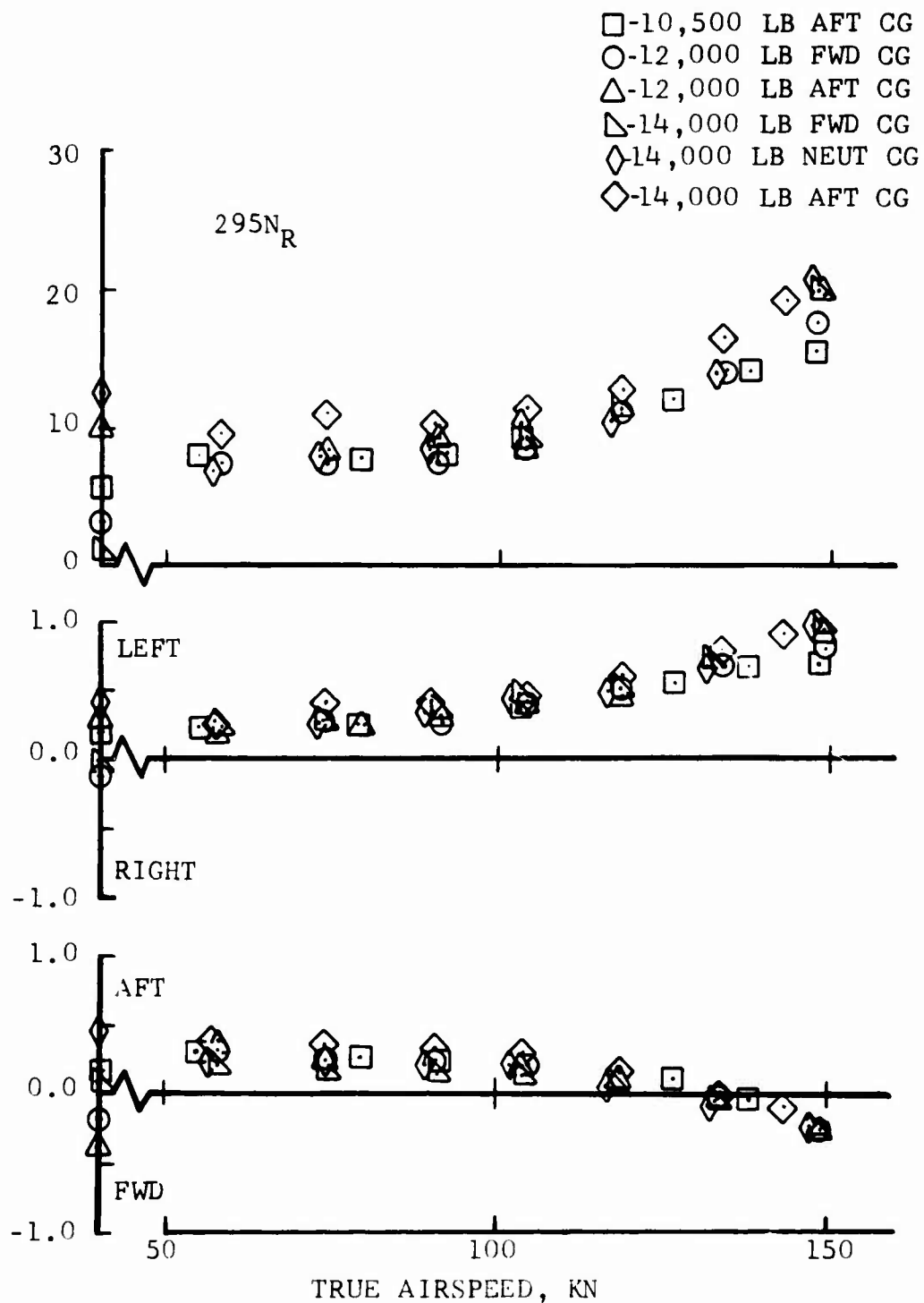


Figure 41. 1/Rev Hub Moments and Flapping Amplitudes in Level Flight, Flight Test Data.

12,000 LB AFT CG  
 14,000 LB NEUTRAL CG  
 12,000 LB FORWARD CG

OPEN SYMBOLS - ENTRY: FLAGGED - PEAK G

NOSE UP

6

4

ROTOR FLAPPING, DEG

2

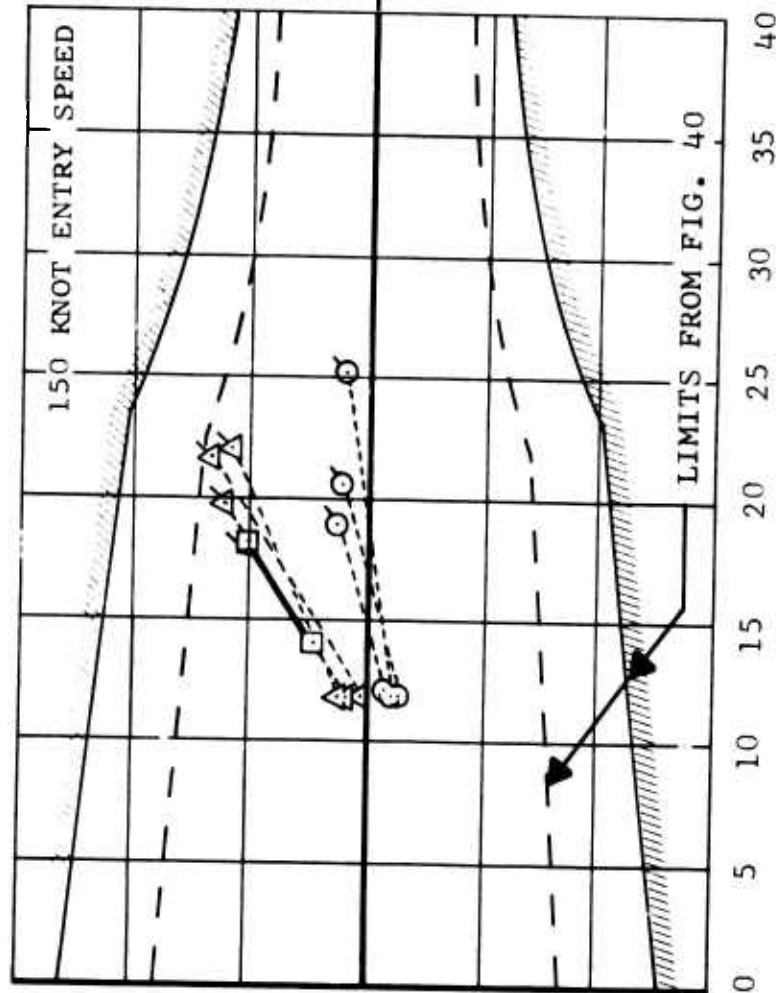
0

-2

-4

-6

NOSE DOWN



ROTOR THRUST, LB  
1000

Figure 42. Flapping as a Function of Thrust During Maneuvers, Flight Test Data.

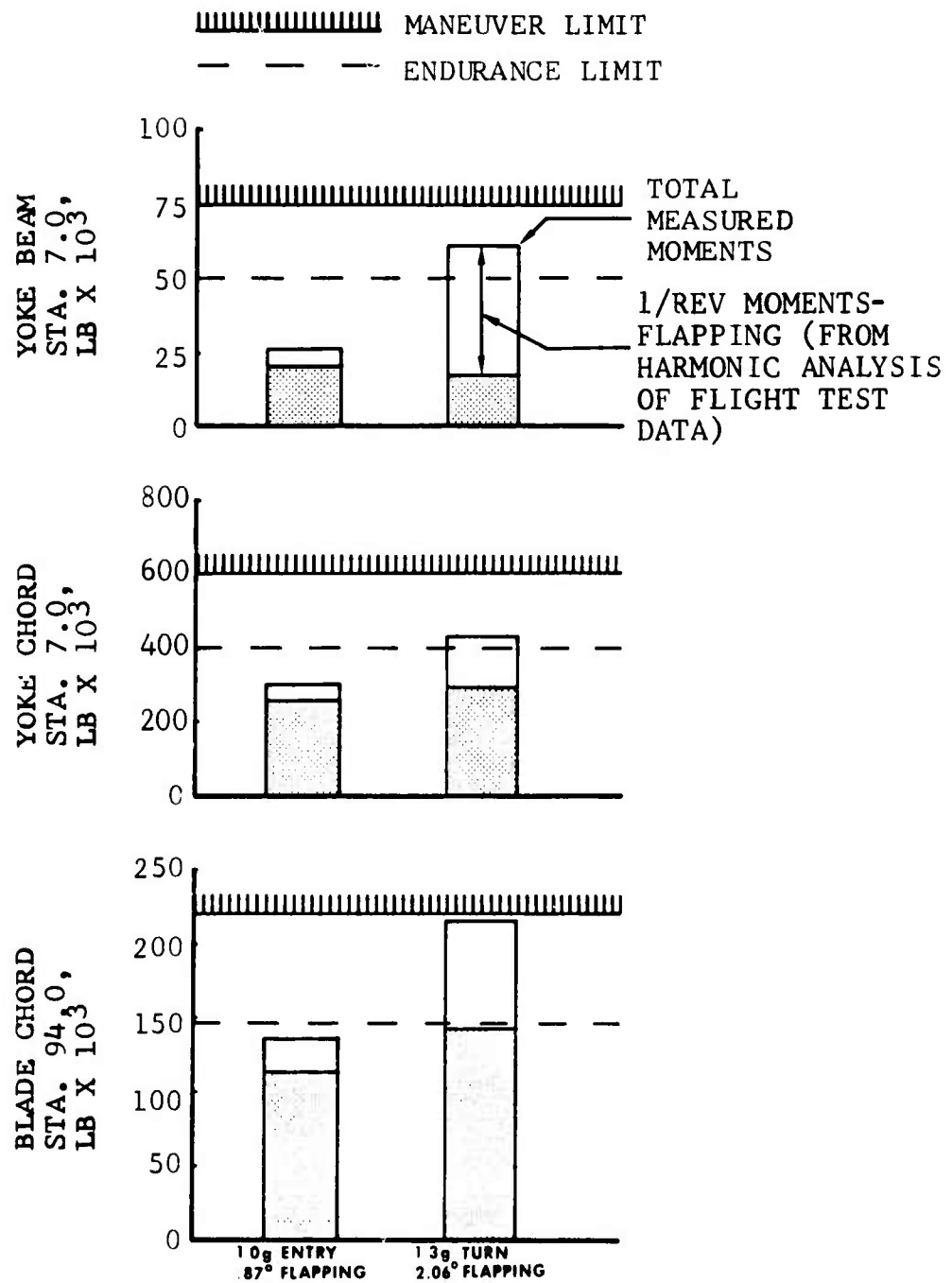


Figure 43. Flapping Contribution to Loads During a Maneuver at 14,000 Pounds GW, Flight Test Data.

the time-variant aeroelastic analysis of computer program C-81, with inputs as given in Reference 3.

### Level Flight Simulation

Blade response is a function of parameters such as the control plane angle of attack, rotor resultant force, and rotor power. If computations are to predict the rotor loads accurately, these parameters must be matched in the analysis. The performance and handling qualities sections have already shown that helicopter power, thrust, pitch attitude, and control positions have been reasonably matched by the C-81 mathematical model for three gross weight level flight conditions. For these three flight conditions, the oscillatory beam bending moments at Blade Station 7 are shown in Figure 44. At airspeeds above 60 knots, the differences between measured and computed beam bending moments are primarily due to differences between calculated flapping angles and those obtained in flight. The largest discrepancies between beam moments at speeds above 60 knots could be accounted for by only 1/2 degree of flapping. The small mismatch in flapping arises from a small deviation of the trim pitch attitude due to uncertainties in the location of the fuselage aerodynamic center. In addition, the nonlinear elevator coupling with fore and aft stick could not be matched exactly, so small variations in the elevator download occurred which contributed to the pitch attitude discrepancy.

The 12,000-pound gross weight flight was a performance flight, and the speed points were very well stabilized; selected data points were harmonically analyzed. Figure 45 presents the harmonic analysis of the beam loads. At 44.7 knots, C-81 and flight test are in reasonably good agreement. At 86.9 knots, the one-per-rev component of the computed load is larger than that in flight. At 144.8 knots, the harmonic distribution of the flight test data has shifted, whereas the C-81 distribution is proportionally the same as at lower speeds. The one-per-rev discrepancy could be explained by a flapping error of only 1/2 degree, as discussed above, or a fore-and-aft cyclic stick position error of 0.37 inch. (The mismatch between measured and computed stick position has been discussed on page 43.)

At low speeds (below 60 knots), the discrepancies between the computed and measured moments in Figure 44 are due to the modeling of the induced velocity and the modeling of the elevator stall. The computed beam bending moment for the 12,000-pound flight at low speed decreases sharply due to a change in flapping induced by the representation of

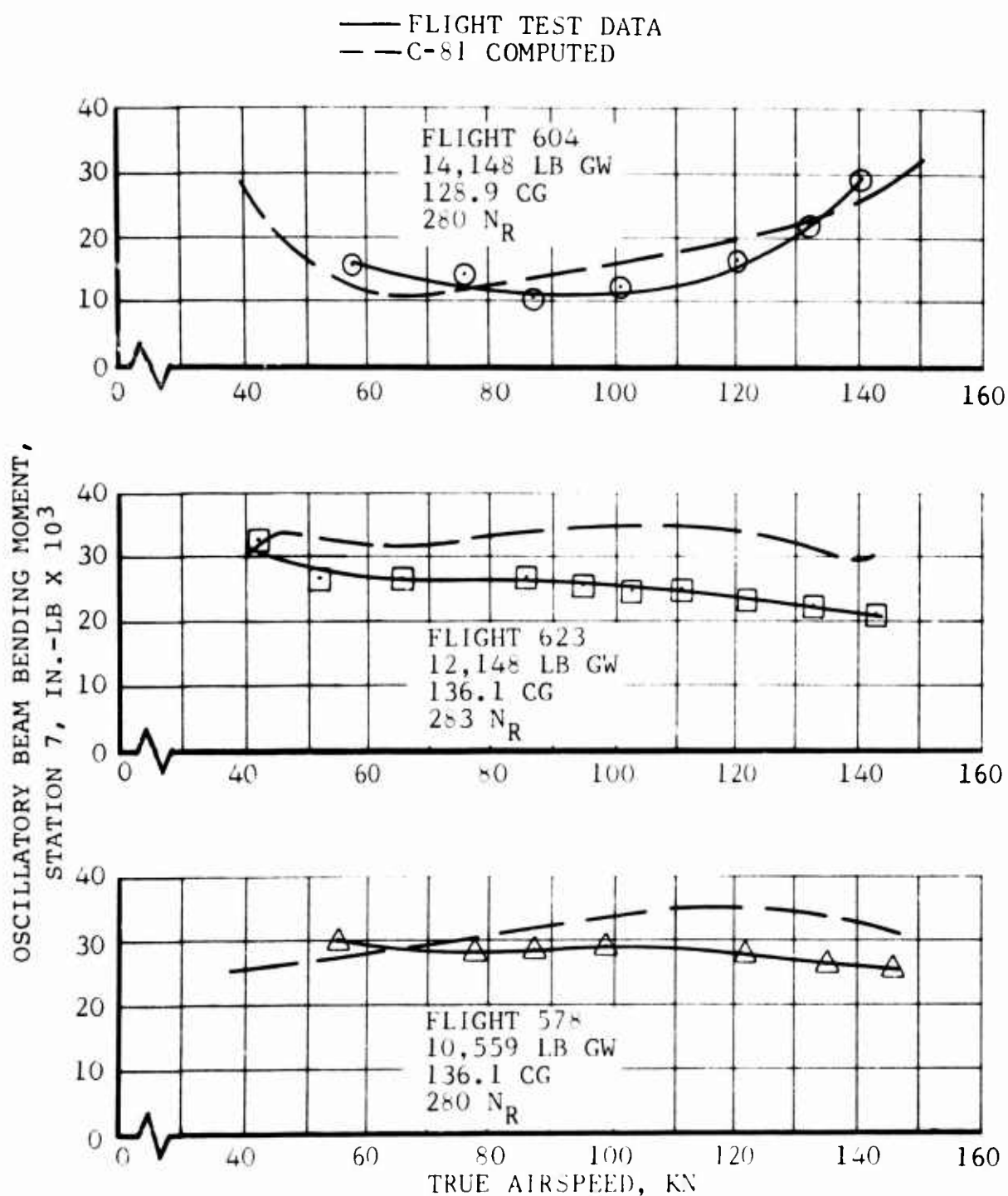


Figure 44. Measured and Computed Oscillatory Beam Bending Moment (Station 7) in Forward Flight at Three Gross Weights.

FLIGHT 623  
12,148 LB GW  
136.1 CG  
283 N<sub>R</sub>

○ FLIGHT TEST DATA  
□ C-81 COMPUTED

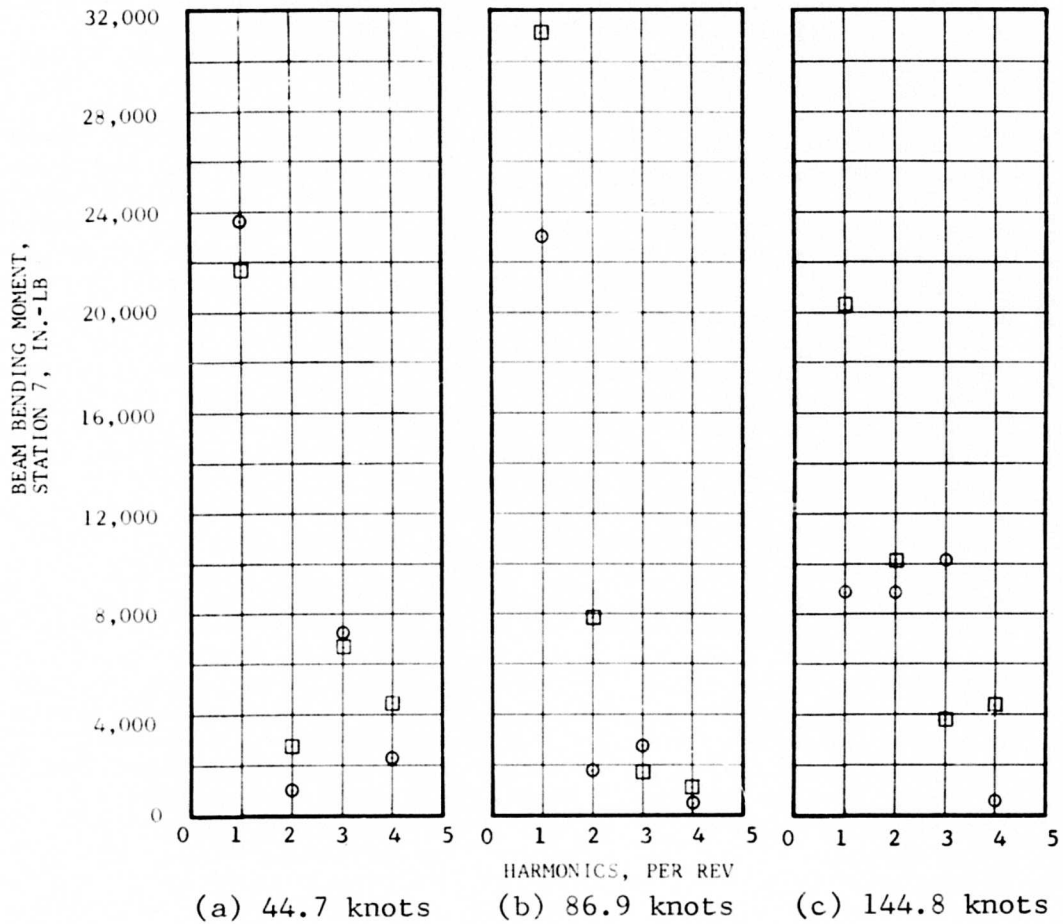


Figure 45. Measured and Computed Harmonic Analysis of Oscillatory Beam Bending Moment (Station 7) for Three Airspeeds.

elevator stall in C-81. Also, the elevator model in the program has a very sharp stall, while stall of the actual elevator is probably much less severe. An analysis of measured elevator bending moments indicates that stall occurs between 45 and 70 knots, depending upon the center of gravity and gross weight, and this is the speed range in question. The steep slope of the computed bending moment trace for the high gross weight case at 45 knots is caused by the pronounced nonlinear nature of the induced velocity model at that speed. This model, which accounts for the tip vortex and wake effects, is described in detail in Reference 9. Since the 14,000-pound gross weight flight is at neutral center of gravity (128.9), the elevator stall effects are not predominant.

A comparison of the chordwise bending moments for the three gross weights is shown in Figure 46. The measured and computed data agree quite well for the 10,500- and 12,000-pound gross weight flights. Correlation with the high gross weight case is not as good. At higher gross weights, the rotor is operating closer to stall. The differences between the measured and computed loads indicate that the airfoil model has a higher stall angle than the actual airfoil. Further support for this assumption is the fact that the helicopter operates at a lower collective pitch in C-81 than in flight. The chord moment data from the 12,000-pound flight was also harmonically analyzed and is presented in Figure 47. The overall oscillatory chordwise bending moment at Station 7 (Figure 46) shows excellent correlation between C-81 and flight test, but the harmonic contents indicate some discrepancies. The differences between the computed and measured chord loads at lower airspeeds are due to the wake and tip vortex model, as discussed in Reference 9.

The beam and chord bending moments at Blade Station 94 are given in Figure 48 for the 12,000-pound gross weight case. The correlation between computed and measured values is good, although the computed beam bending moments increase a little faster at the higher airspeed. This is due to the small flapping difference which causes the computed beam bending moment at Station 7 to be high again. The difference in the chord loads at the lower airspeeds is due to the tip vortex model (Reference 9).

Main rotor pitch link loads are shown in Figure 49. These have traditionally been difficult to predict; the C-81 results show the proper trend. The differences between the measured and calculated loads are due in part to the simplified modeling of the torsional properties of the blade and the control system. The differences are also due, in part, to the in-flight tip airfoil deformation problem (see

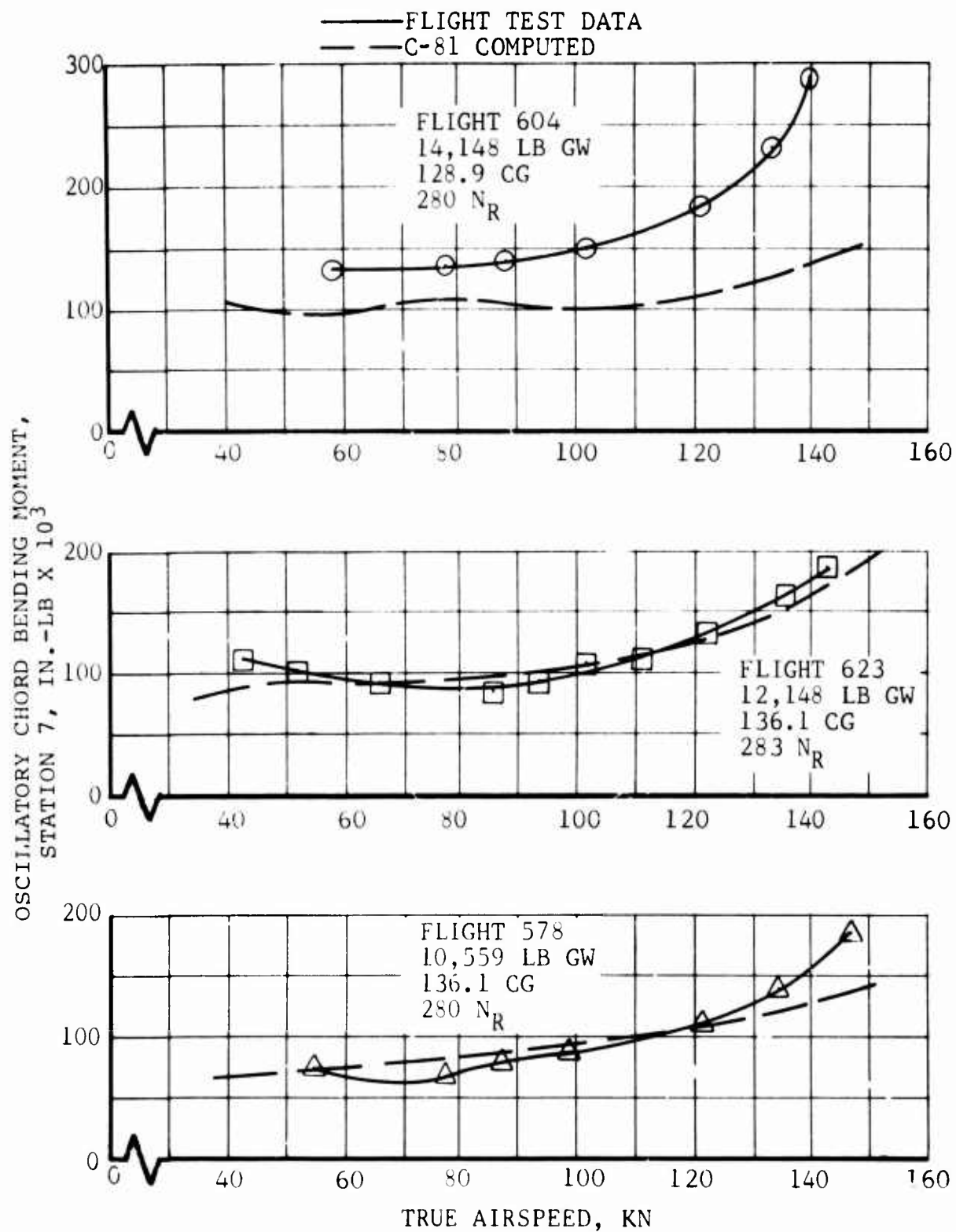


Figure 46. Measured and Computed Oscillatory Chord Bending Moment (Station 7) in Forward Flight at Three Gross Weights.

FLIGHT 623  
12,148 LB GW  
136.1 CG  
283 N<sub>R</sub>

○ FLIGHT TEST DATA  
□ C-81 COMPUTED

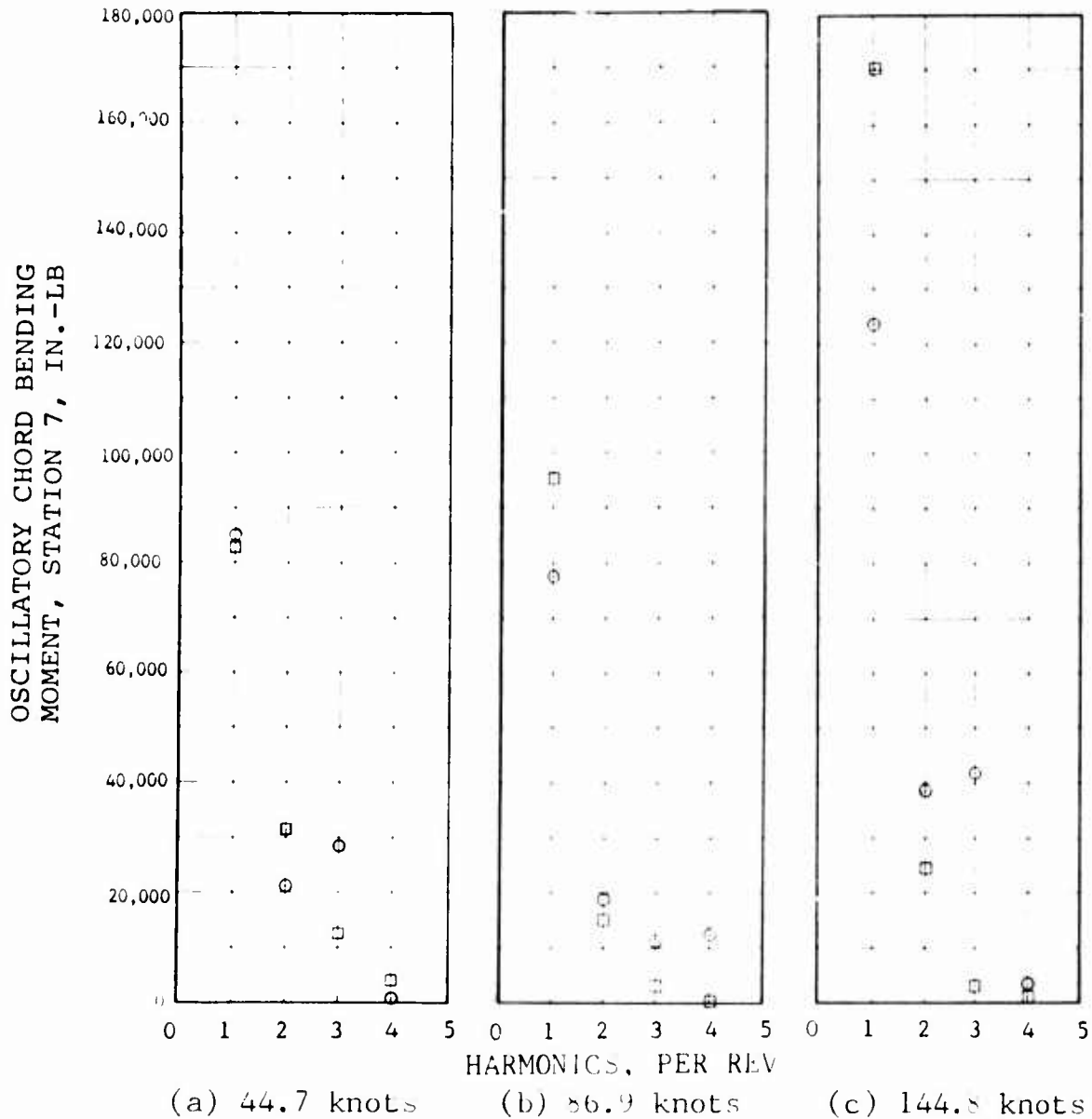
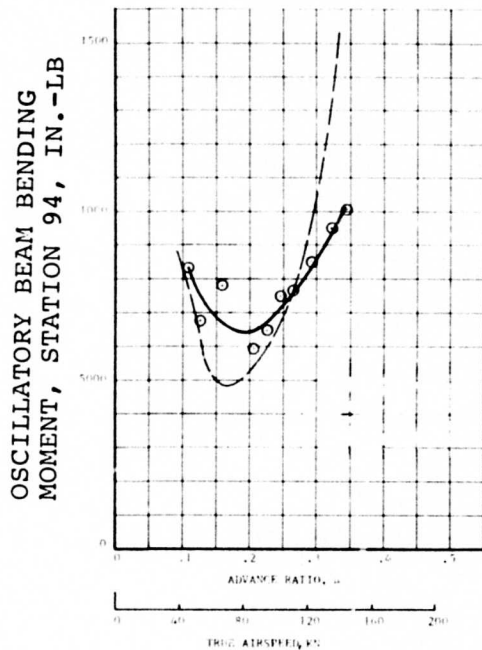


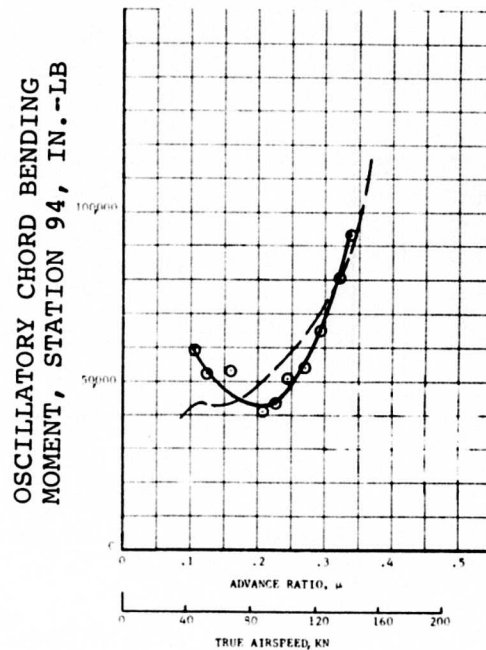
Figure 47. Measured and Computed Harmonic Analysis of Oscillatory Chord Bending Moment (Station 7) for Three Airspeeds.

FLIGHT 623  
12,143 LB GW  
136.1 CG  
283 N<sub>R</sub>

—○— FLIGHT TEST DATA  
— — C-81 COMPUTED



a) Oscillatory Beam Bending Moment



b) Oscillatory Chord Bending Moment

Figure 48. Measured and Computed Oscillatory Beam and Chord Bending Moments (Station 94) in Forward Flight.

FLIGHT 623  
 12,148 LB GW  
 136.1 CG  
 283 N<sub>R</sub>

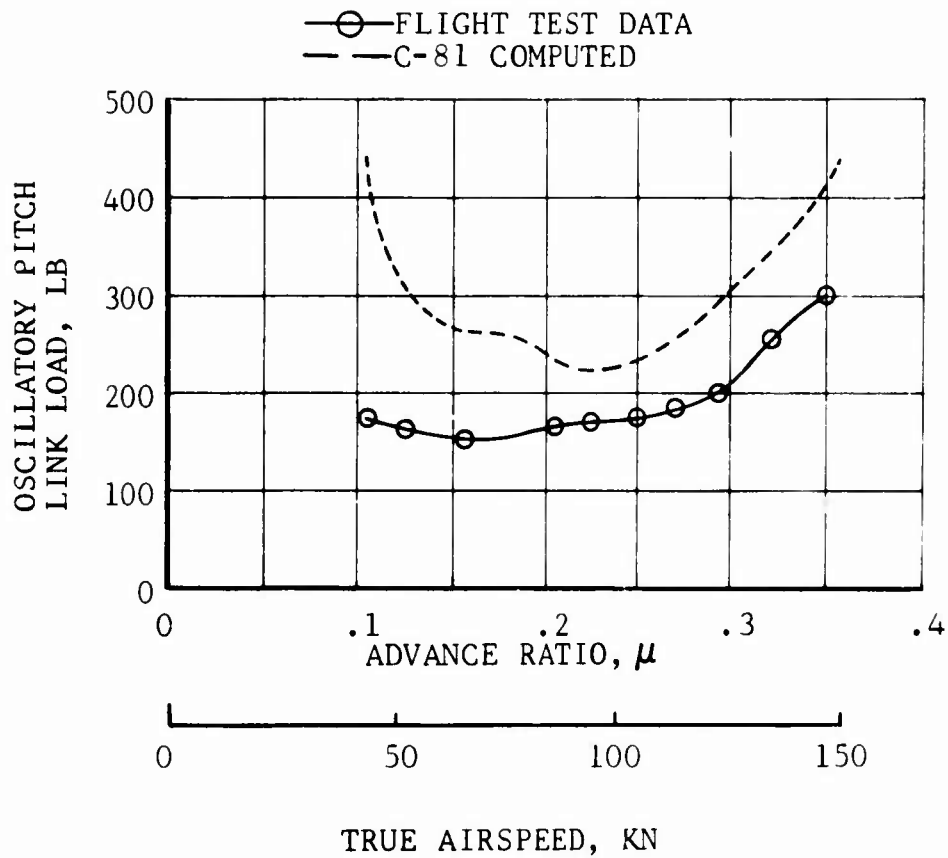


Figure 49. Measured and Computed Oscillatory Pitch Link Load in Forward Flight.

summary of technical problems) as the blade element pitching moment developed in flight would not equal the moment computed for the theoretical cross section.

### Hover

Blade loads during out-of-ground effect hover were computed in C-81 using new blade mode shapes for each rpm. The results of this analysis are given in Figures 50 through 54. The Station 7 beam bending moment correlation is excellent (Figure 50), except for the test point at 280 rpm. This point may be in error, since it does not agree with the trend established by the other three test points. The correlation of the other three points implies that the flapping has been matched almost exactly. The Station 7 chord bending moment data show the correct trend, but do not increase as fast with rpm as the measured data (Figure 51). The harmonic analysis (Figure 52) shows that much of this discrepancy is the one-per-rev load and probably indicates a slight error in the calculated first chord natural frequency. Although lower than the loads measured in flight, the bending moments computed for Station 94 (Figure 53) show the correct trend with rpm. The computed oscillatory pitch link loads (Figure 54) are somewhat low, probably because of the simplified torsional model or the uncertainties in the blade element aerodynamics due to the possible airfoil contour deformations discussed previously.

### Maneuver

Maneuvering loads were computed with C-81 using the input parameters developed during the level flight simulation. The flight path of the 1.75-G symmetric maneuver was matched (G level, pitch rate, and pitch attitude) for the four-second duration by guessing a control input, calculating the response, and modifying the control input. The calculated maneuver rotor loads are shown by dashed lines in Figures 55 and 56. Since the initial correlation of the C-81 maneuver loads with flight test was not considered satisfactory, the reasons for the discrepancies were briefly investigated.

During the level flight simulation, it was deduced that the airfoil as represented in C-81 stalled at higher angles of attack than the actual airfoil. Therefore, the input blade element aerodynamic data were altered in order to get stall effects into the simulation. The major alterations were designed to lower the lift coefficient at a given angle of attack. The lift coefficient is computed as the sum of the static lift coefficient for the angle of attack plus a  $\Delta C_L$  due to unsteady aerodynamic effects. The static

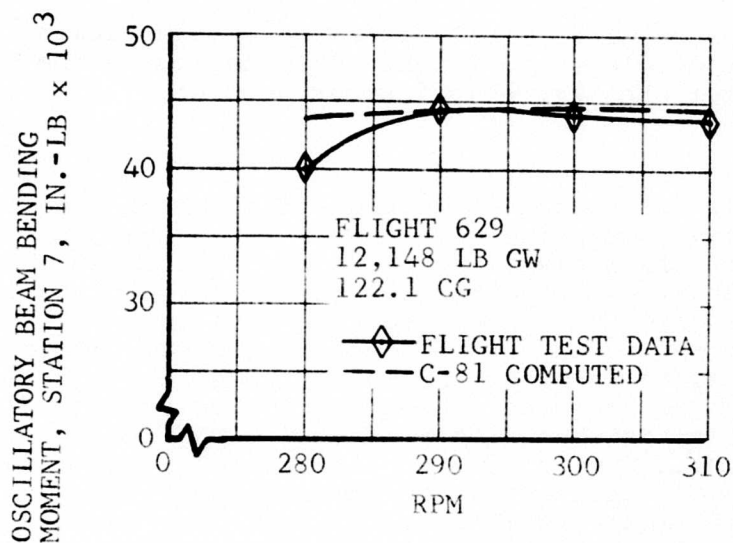


Figure 50. Measured and Computed Oscillatory Beam Bending Moment (Station 7) in Hover.

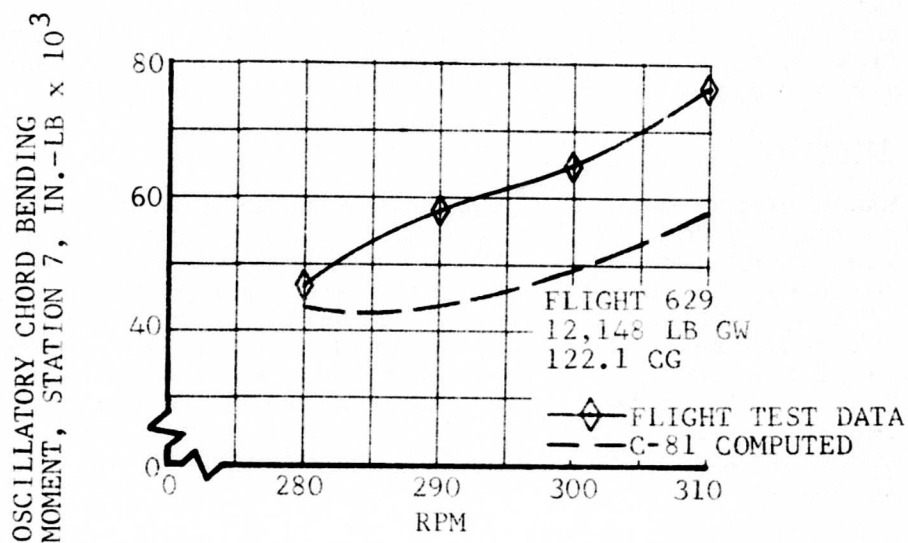
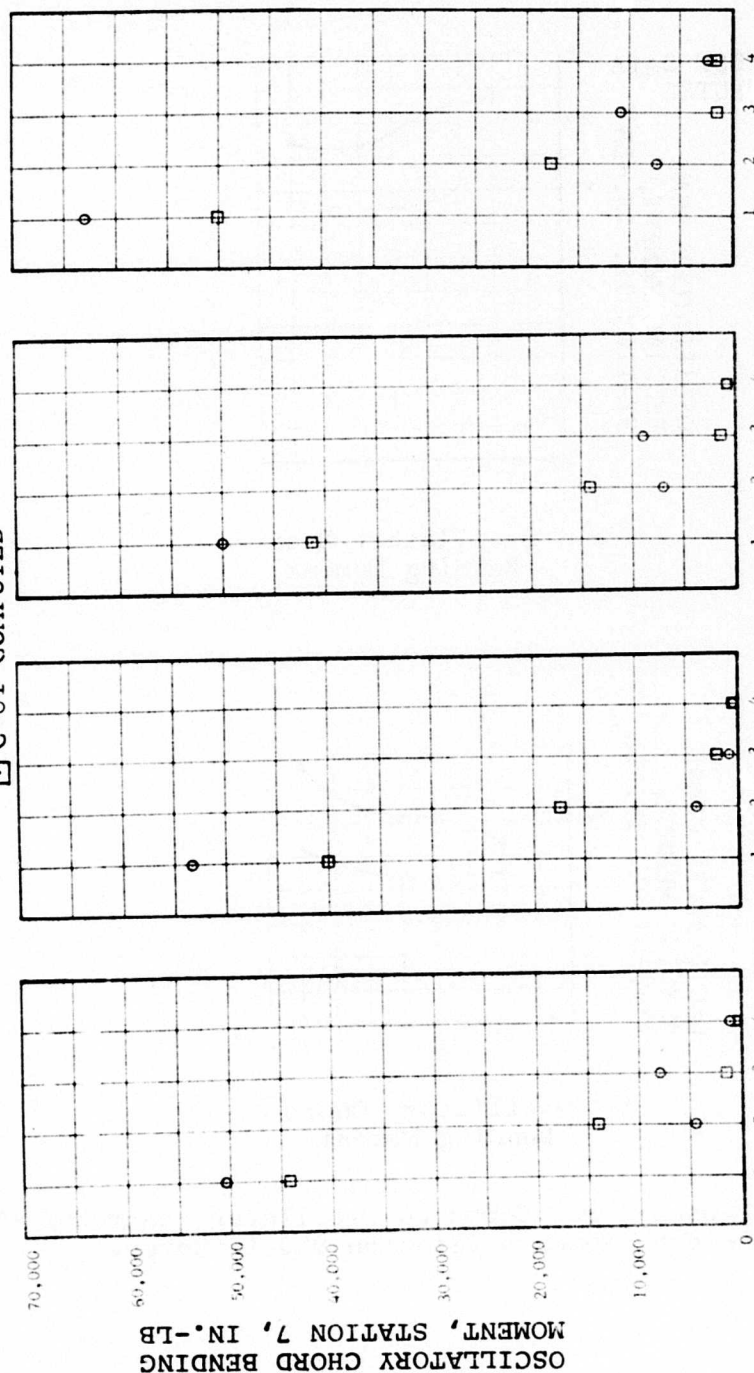


Figure 51. Measured and Computed Oscillatory Chord Bending Moment (Station 7) in Hover.

FLIGHT 629  
12,148 LB GW  
122.1 CG

○ FLIGHT TEST DATA  
□ C-81 COMPUTED

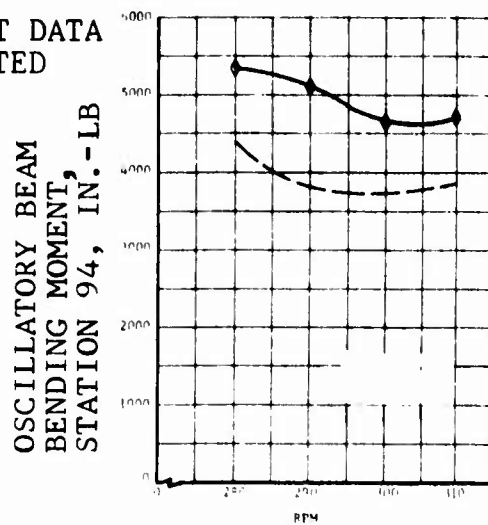


(a) 280 RPM  
(b) 290 RPM  
(c) 300 RPM  
(d) 310 RPM  
HARMONICS, PER REV  
Harmonic Analysis of Oscillatory Chord Bending Moment (Station 7) in Hover.

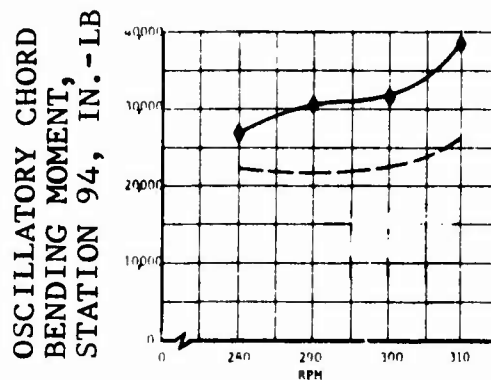
Figure 52.

FLIGHT 629  
12,148 LB GW  
122.6 CG

—◇— FLIGHT TEST DATA  
— — — C-81 COMPUTED



a) Oscillatory Beam Bending Moment



b) Oscillatory Chord Bending Moment

Figure 53. Measured and Computed Oscillatory Beam and Chord Bending Moments (Station 94) in Hover.

FLIGHT 629  
12,148 LB GW  
122.1 CG

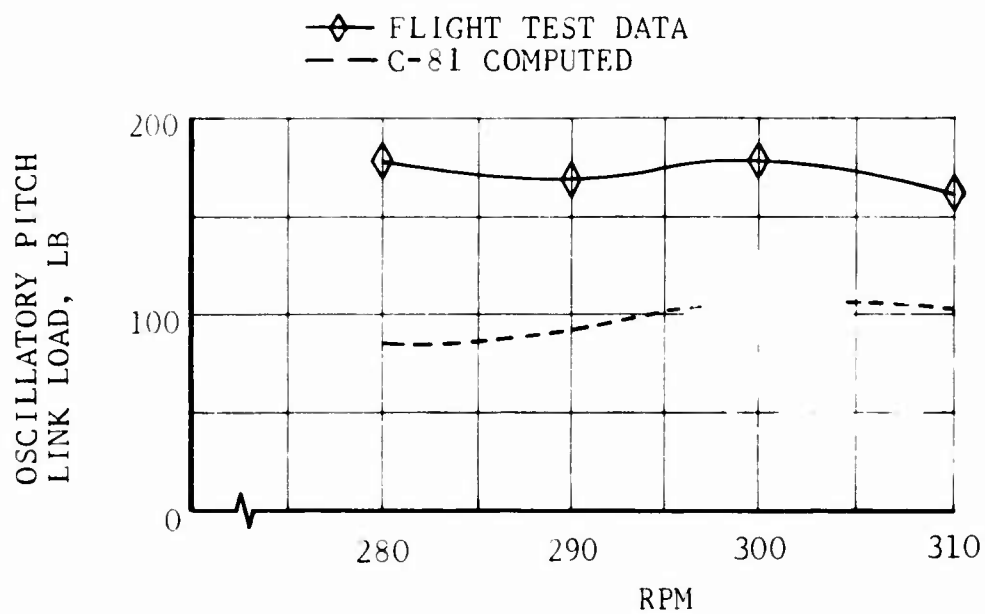


Figure 54. Measured and Computed Oscillatory Pitch Link Load in Hover.

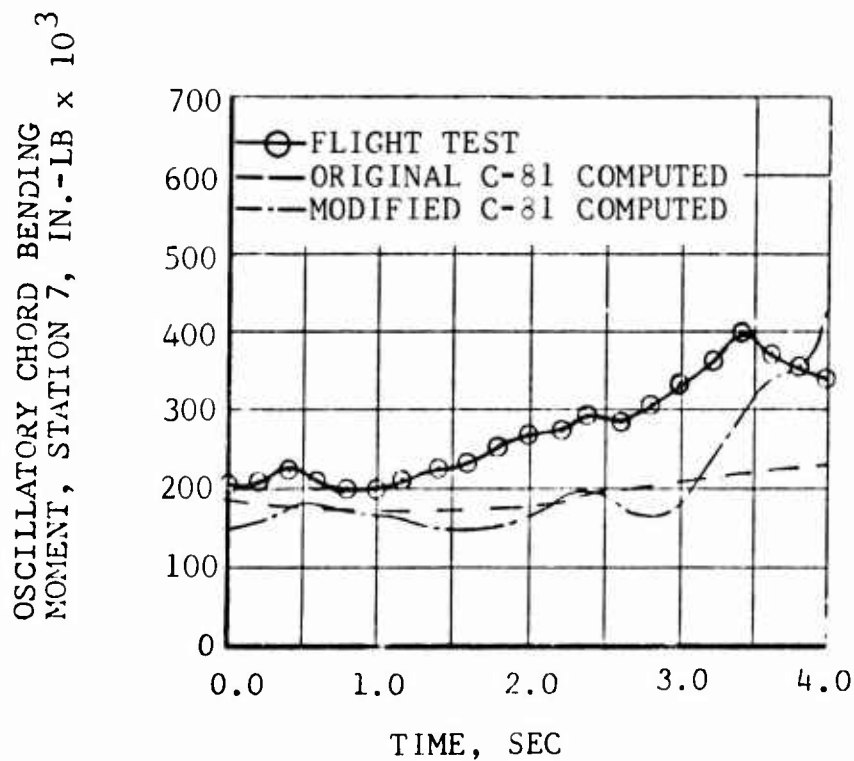
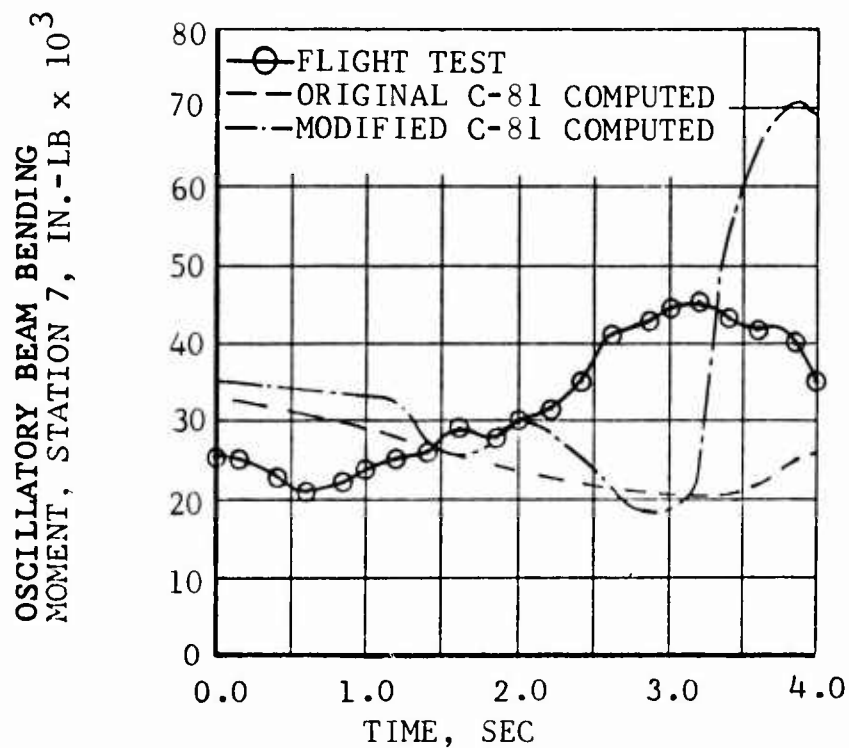
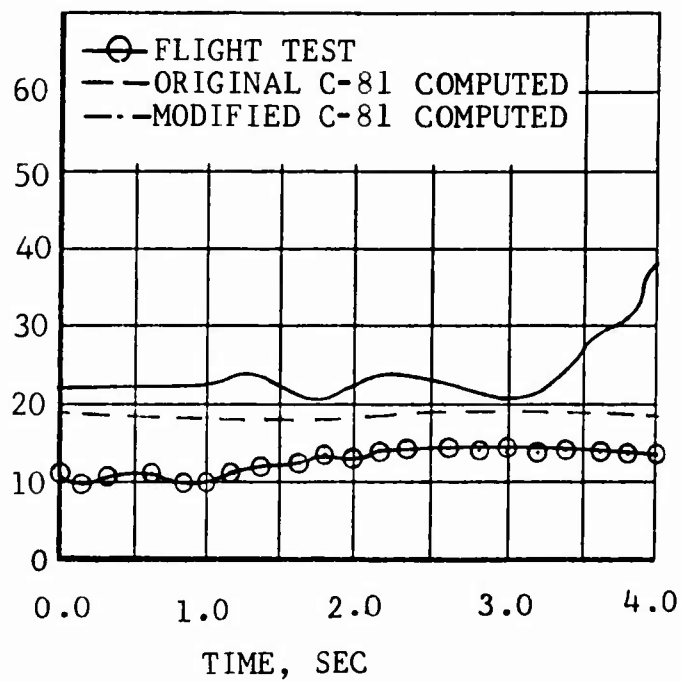


Figure 55. Time Histories of Measured and Computed Blade Loads (Station 7) for Symmetric Pullup.

OSCILLATORY BEAM BENDING MOMENT,  
STATION 94, IN.-LB  $\times 10^3$



OSCILLATORY CHORD BENDING MOMENT,  
STATION 94, IN.-LB  $\times 10^3$

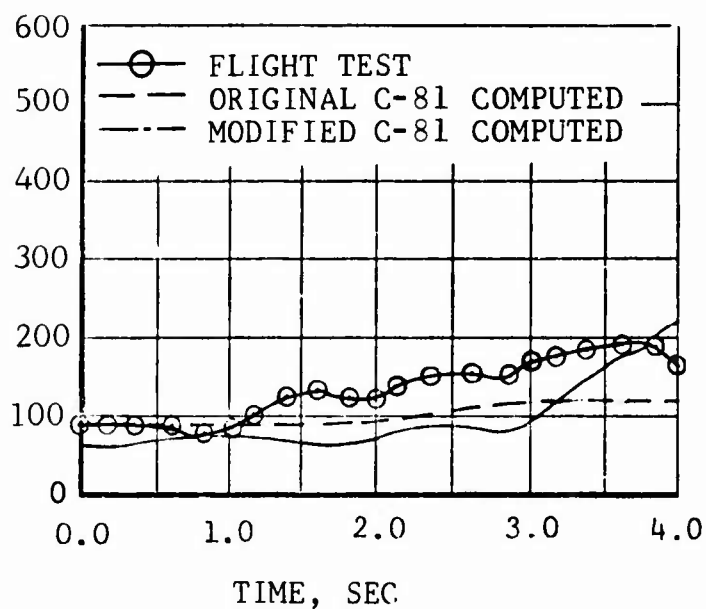


Figure 56. Time Histories of Measured and Computed Blade Loads (Station 94) for Symmetric Pullup.

$C_{L_{max}}$  was lowered, and the torsional component was removed from the blade mode shapes, as the elastic pitching velocity is the major source of the  $C_L$  terms. Higher blade element drag coefficients resulted for a given rotor thrust level because the blade elements had to operate at higher angles of attack to get the same lift coefficients and because the drag divergence Mach number was decreased. These modifications improved the correlation, as shown in Figures 55 and 56.

## LOAD LEVEL SURVEY AND FATIGUE LIFE ANALYSIS - RESULTS AND DISCUSSION

The loads that the rotor and control system encountered during flight in a utility helicopter flight spectrum were measured. Fatigue lives were then calculated from the flight measurements and frequency-of-occurrence spectrum (Table III).

### FLIGHT SPECTRUM AND FREQUENCY OF OCCURRENCE

The frequency-of-occurrence spectrum is similar to the utility helicopter spectrum of Reference 10. It differs from that spectrum in that times spent at low speeds have been reduced to allow the assignments of periods for maneuvers without affecting other areas of the spectrum.

Each condition in the flight spectrum was flown at several combinations of gross weight and cg, as shown in Table IV. The percentage of time assumed spent at each gross weight is also indicated in Table IV. (Time was not distributed on the basis of cg location.) The highest load measured at each gross weight (irrespective of cg) was used in the fatigue life analysis. Table V lists the flight conditions for each increment of the load level survey.

### CALCULATED FATIGUE LIVES OF COMPONENTS

Fatigue life calculations are based on a comparison between stresses encountered in the flight spectrum and the endurance-limit stress for the component being analyzed. Fatigue tests of Model 609 rotor blade sections established the shape of the S-N curve (stress versus cycles) and the endurance limit. Endurance limits and S-N curve shapes for other components were established from one of the following:

- Published fatigue data for the material
- Fatigue test data for a similar component
- Fatigue test data for material specimens

Calculations using data from these sources make allowances for steady stress and stress concentrations. Details of the fatigue life analysis are included in Appendix III for each component analyzed.

The calculated fatigue lives for rotor and control system components are summarized in Table VI. The most critical station for each rotor component has been analyzed. Loads from the instrumented (red) blade and hub segment in the upper half of the rotor were used in the life analysis. Loads in the lower

TABLE III. MODEL 609 SPECTRUM - FREQUENCY OF OCCURRENCE

| NO. | CONDITION            | TIME   | RPM   |
|-----|----------------------|--------|-------|
| 1   | I. GROUND CONDITIONS |        |       |
| 1   | A. NORMAL START      | 0.5000 | 295.0 |
| 2   | B. NORMAL SHUTDOWN   | 0.5000 | 295.0 |
| 3   | II. POWER-ON IGE     |        |       |
| 3   | A. HOVERING          |        |       |
| 3   | 1. STEADY            |        |       |
| 3   | (A) 280 RPM          | 3.4720 | 280.0 |
| 4   | (H) 295 RPM          | 3.4720 | 295.0 |
| 5   | 2. LEFT TURN         | 1.1110 | 285.0 |
| 6   | 3. RIGHT TURN        | 1.1110 | 285.0 |
| 7   | 4. CONTROL REVERSAL  |        |       |
| 7   | (A) LONGITUDINAL     | 0.2780 | 285.0 |
| 8   | (R) LATERAL          | 0.2780 | 285.0 |
| 9   | (C) RUDDER           | 0.2780 | 285.0 |
| 10  | B. MANEUVERS         |        |       |
| 10  | 1. SIDEWARD FLIGHT   |        |       |
| 10  | (A) TO THE RIGHT     | 0.5000 | 285.0 |
| 11  | (B) TO THE LEFT      | 0.5000 | 285.0 |
| 12  | 2. REARWARD FLIGHT   | 0.5070 | 285.0 |
| 13  | 3. NORMAL TAKE-OFF   | 0.8890 | 285.0 |
| 14  | 4. NORMAL LANDING    | 2.0830 | 285.0 |
| 15  | III. POWER-ON IGE    |        |       |
| 15  | A. LEVEL FLIGHT      |        |       |
| 15  | % VL RPM             |        |       |
| 15  | 1. 40 280            | 0.9330 | 280.0 |
| 16  | 295                  | 0.9330 | 295.0 |
| 17  | 2. 50 280            | 2.4585 | 280.0 |
| 18  | 295                  | 2.4585 | 295.0 |
| 19  | 3. 60 280            | 3.9190 | 280.0 |
| 20  | 295                  | 3.9190 | 295.0 |
| 21  | 4. 70 280            | 5.0000 | 280.0 |
| 22  | 295                  | 5.0000 | 295.0 |
| 23  | 5. 80 280            | 7.5000 | 280.0 |
| 24  | 295                  | 7.5000 | 295.0 |
| 25  | 6. 90 280            | 8.6670 | 280.0 |
| 26  | 295                  | 8.6670 | 295.0 |
| 27  | 7. 100 280           | 4.9190 | 290.0 |
| 28  | 295                  | 4.9190 | 295.0 |
| 29  | 8. VNE 280           | 1.7500 | 280.0 |
| 30  | 295                  | 1.7500 | 295.0 |
| 31  | B. MANEUVERS         |        |       |
| 31  | 1. CLIMB 0-50 KNOTS  |        |       |
| 31  | (A) M.C. POWER       | 3.0000 | 285.0 |
| 32  | (B) T.O. POWER       | 1.0000 | 285.0 |

TABLE III. Concluded

| NO.                           | CONDITION              | TIME   | RPM   |
|-------------------------------|------------------------|--------|-------|
| 33                            | 2. CYCLIC PULL-UP      |        |       |
| 33                            | (A) 50 KNOTS           | 0.1620 | 285.0 |
| 34                            | (B) 100 KNOTS          | 0.1620 | 285.0 |
| 35                            | (C) VL                 | 0.1620 | 285.0 |
| 36                            | 3. LEFT TURN           |        |       |
| 36                            | (A) 50 KNOTS           | 1.0000 | 285.0 |
| 37                            | (B) 100 KNOTS          | 1.0000 | 285.0 |
| 38                            | (C) VL                 | 0.5000 | 285.0 |
| 39                            | 4. RIGHT TURN          |        |       |
| 39                            | (A) 50 KNOTS           | 1.0000 | 285.0 |
| 40                            | (B) 100 KNOTS          | 1.0000 | 285.0 |
| 41                            | (C) VL                 | 0.5000 | 285.0 |
| 42                            | 5. CONTROL REVERSAL    |        |       |
| 42                            | (A) LONGITUDINAL       | 0.2220 | 285.0 |
| 43                            | (B) LATERAL            | 0.2220 | 285.0 |
| 44                            | (C) RUDDER             | 0.2220 | 285.0 |
| 45                            | IV. POWER TRANSITIONS  |        |       |
| 45                            | A. POWER TO AUTO       |        |       |
| 45                            | 1. 40 KNOTS            | 0.0110 | 285.0 |
| 46                            | 2. VL                  | 0.0110 | 285.0 |
| 47                            | B. AUTO TO POWER       | 0.0560 | 285.0 |
| 48                            | V. AUTOROTATION        |        |       |
| 48                            | A. STABILIZED FLIGHT   |        |       |
| 48                            | 1. 40 KNOTS            | 0.2890 | 285.0 |
| 49                            | 2. 80 KNOTS            | 0.3880 | 285.0 |
| 50                            | 3. MAX AUTO A/S        | 0.1890 | 285.0 |
| 51                            | B. TURNS. (NORMAL      |        |       |
| 51                            | AUTO A/S)              |        |       |
| 51                            | 1. TO THE LEFT         | 0.2000 | 285.0 |
| 52                            | 2. TO THE RIGHT        | 0.2000 | 285.0 |
| 53                            | C. CONTROL REVERSAL    |        |       |
| 53                            | 1. LONGITUDINAL        | 0.1000 | 285.0 |
| 54                            | 2. LATERAL             | 0.1000 | 285.0 |
| 55                            | 3. RUDDER              | 0.1000 | 285.0 |
| 56                            | D. CYCLIC PULL-UP      |        |       |
| 56                            | (NORMAL AUTO A/S)      | 0.0560 | 285.0 |
| 57                            | E. PART PWR DSNT, 80KT | 2.0830 | 285.0 |
| 58                            | F. FULL AUTO LANDING   | 0.3000 | 285.0 |
| TOTAL TIME = 100.0000 PERCENT |                        |        |       |

TABLE IV. GROSS WEIGHT AND CENTER-OF-  
GRAVITY VARIATIONS FLOWN  
FOR THE FATIGUE LIFE ANALYSIS

| Gross Weight (lb) *                                                           | C.G. Station (in.) |        |        |
|-------------------------------------------------------------------------------|--------------------|--------|--------|
|                                                                               | 10,500             | 12,000 | 14,000 |
| Forward                                                                       | -                  | 122    | 122    |
| Neutral                                                                       | -                  | -      | 129    |
| Aft                                                                           | 136                | 136    | 136    |
| Total Time Assumed at<br>Each Gross Weight                                    | 20%                | 60%    | 20%    |
| *Gross weight was maintained within $\pm 400$ lb<br>during load level survey. |                    |        |        |

**TABLE V. DESCRIPTION OF CONDITIONS FLOWN  
IN THE LOAD LEVEL SURVEY**

| No.                                                                                   | Condition              | Remarks                | TAS<br>(kn)    | Density<br>Altitude<br>(ft) |
|---------------------------------------------------------------------------------------|------------------------|------------------------|----------------|-----------------------------|
| 1, 2                                                                                  | Ground                 | Start-Stop             | -              | Ground *                    |
| 3-9                                                                                   | Hovering               | IGE                    | -              | Ground                      |
| 10-11                                                                                 | Sideward Flt           | IGE                    | 30             | Ground                      |
| 12                                                                                    | Rearward Flt           | IGE                    | 30             | Ground                      |
| 13                                                                                    | Takeoff                | Ground to OGE          | Variable       | Ground                      |
| 14                                                                                    | Landing                | OGE to Ground          | Variable       | Ground                      |
| 15,16                                                                                 | .4 $V_L$               | Level Flight           | 60             | 4,000                       |
| 17,18                                                                                 | .5                     |                        | 75             |                             |
| 19,20                                                                                 | .6                     |                        | 90             |                             |
| 21,22                                                                                 | .7                     |                        | 105            |                             |
| 23,24                                                                                 | .8                     |                        | 120            |                             |
| 25,26                                                                                 | .9                     |                        | 135            |                             |
| 27,28                                                                                 | $V_L$                  | Level Flight           | 150            |                             |
| 29,30                                                                                 | $V_{NE}$ (Dive)        | Trans. Cont.<br>Limit  | 160            | 4,000                       |
| 31                                                                                    | Climb                  | Trans. Cont.<br>Limit  | 0-60           | Ground to<br>5,000          |
| 32                                                                                    | Climb                  | Trans. T.O.<br>Limit   | 0-60           | Ground to<br>5,000          |
| 33,35                                                                                 | Cyclic<br>Pull-up      | 1.5-1.7g               | 50,100,150     | 4,000                       |
| 36,38                                                                                 | Left Turn              | 1.5-1.7g               | 50,100,150     | 4,000                       |
| 39,41                                                                                 | Right Turn             | 1.5-1.7g               | 50,100,150     | 4,000                       |
| 42,44                                                                                 | Control<br>Reversals   | Small Amp High<br>Rate | 135            | 4,000                       |
| 45,47                                                                                 | Power Transi-<br>tions | 0 to Level<br>Flt SHP  | Variable       | Ground to<br>5,000          |
| 48,58                                                                                 | Autorotation           | Level Flt SHP<br>to 0  | Variable       | Ground to<br>5,000          |
| <b>TRANSMISSION SHP LIMITS</b>                                                        |                        |                        | <b>M/R RPM</b> |                             |
|                                                                                       |                        |                        | 280            | 285                         |
|                                                                                       |                        |                        | 295            |                             |
|                                                                                       | Continuous             |                        | 1585           | 1610                        |
|                                                                                       | Takeoff                |                        | 1885           | 1620                        |
|                                                                                       |                        |                        |                | 1985                        |
| *Ground indicates flown at field elevation.<br>Density altitudes from 0 to 1000 feet. |                        |                        |                |                             |

TABLE VI. SUMMARY OF CALCULATED FATIGUE LIVES FOR  
MODEL 609 HINGELESS FLEXBEAM ROTOR SYSTEM

| Component                     | Part Number  | Life<br>Hours |
|-------------------------------|--------------|---------------|
| <u>Rotor &amp; Mast</u>       |              |               |
| Yoke, Hub                     | 609-010-102  | 811           |
| Blade Retention Fitting       | 609-010-105  | 1,593         |
| Spindle                       | 609-010-140  | 7,100         |
| Blade                         | 609-010-200  | 1,334         |
| Mast                          | 609-040-300  | Unlimited     |
| <u>Rotating Controls</u>      |              |               |
| Pitch Horn                    | 609-010-104  | Unlimited     |
| Pitch Link                    | 609 HES 45-5 | 22,485        |
| Swashplate Outer              | 609-010-401  | 11,557        |
| <u>Nonrotating Controls</u>   |              |               |
| Swashplate Inner              | 609-010-402  | Unlimited     |
| Slider Collective             | 609-010-404  | Unlimited     |
| Slider Lug Bolt               | 609-010-419  | 545           |
| Cylinder Housing (Collective) | 204-076-317  | 23,131        |
| Cylinder Housing (F/A Cyclic) | 204-076-317  | Unlimited     |
| Cylinder Housing (Lat Cyclic) | 204-076-317  | Unlimited     |

half were usually higher, but the discrepancies were not resolved, and the use of either blade was arbitrary (see the discussion in the "Technical Problem" section).

The analysis of the life of rotating control system components used measured loads from all four rotor blade pitch links. The components associated with the green blade pitch link had the shortest lives, and are therefore the only ones shown in the summary table.

The life of each of the four critical areas on the nonrotating ring of the swashplate was analyzed. Only the shortest life is shown in the summary table. The lives of all other nonrotating components analyzed are listed.

The results shown in Table VI are conservative in that the peak stresses encountered during a maneuver are assumed to exist for the duration of that maneuver. In reality, the peak stresses exist for only a portion of the time allowed for each maneuver. The effect of stresses occurring during full autorotational landings was analyzed on a cycle-count basis. The method of analysis previously outlined would be overly conservative for this maneuver, due to the small number of damage-generating cycles.

#### ANALYSIS OF RESULTS

The analyses of these components with low life estimates have been examined to determine if the analytical approach was overly conservative or if, on the other hand, the measured stresses would have been higher with only slight changes in such parameters as gross weight, center of gravity, and airspeed, resulting in an unconservative life determination.

The analysis showed that the slider lug bolt (Appendix III) has the shortest life, but it assumes that oscillatory loads in the cyclic and collective boost cylinder housings peak simultaneously to cause bending in the bolt. Direct measurement of load on this bolt is impractical, and an exact calculation of the load requires a knowledge of the relative phasing of the oscillatory load in the three boost cylinders. Examination of records from one of the conditions causing fatigue damage revealed that the loads peak simultaneously only on one out of every four load cycles. Therefore, the peak stress level used in the analysis occurs only at one per rev of the main rotor, rather than at the four per rev used in the analysis. The remaining three cycles occur at lower stress levels, and it would take a detailed analysis to determine their individual effects on fatigue lives. Thus, this preliminary analysis is conservative.

The short life shown for the main rotor yoke and blades is conservative only in that peak loads are assumed to exist for the duration of all the maneuvers except the autorotational landing.

Stress levels in the yoke (from Table XIII, Appendix III), plotted in Figure 57, illustrate that only nine conditions cause damage. Maneuvers at 14,000 pounds and  $V_L$  cause over half of the fatigue damage. The pilot limited maneuvering to 1.3G rather than the 1.7G planned, because the load meter was indicating high oscillatory loads in the rotor. In view of the damage encountered at this low load factor, it would be advisable to exclude maneuvering at 14,000 pounds and 150 knots from the flight envelope. If maneuvering speed at 14,000 pounds is reduced until maneuver loads are equal to those measured at 12,000 pounds, the calculated life of the yoke would be 2016 hours, as opposed to 811 hours, and the blade life would increase from 1334 to 3854 hours. The resulting change in the flight envelope is shown in Figure 58. Lines of constant loading (from the Rotor Loads section of this report) show the speeds at which 12,000-pound maneuver loads would be encountered at higher (and lower) gross weights.

The analysis of the rotor blade retention system includes some conservatism. Damage in this system results from starting and stopping the rotor, and the only assumption which might be questionable is the frequency of start/stop cycles. A frequency of four cycles per hour was used in the analysis. The life of the retention system would double if this number were halved, and conversely, the retention system would have to be redesigned if the frequency were greater than four starts/stops per hour. Reference 15 shows a total of 100 ground-air-ground cycles in 100 hours, but operational experience has shown that many aircraft encounter a higher frequency of occurrence. The frequency used is considered to fit the operational requirements of Army utility helicopters.

CG CODE: F-FORWARD, N-NEUTRAL, A-AFT

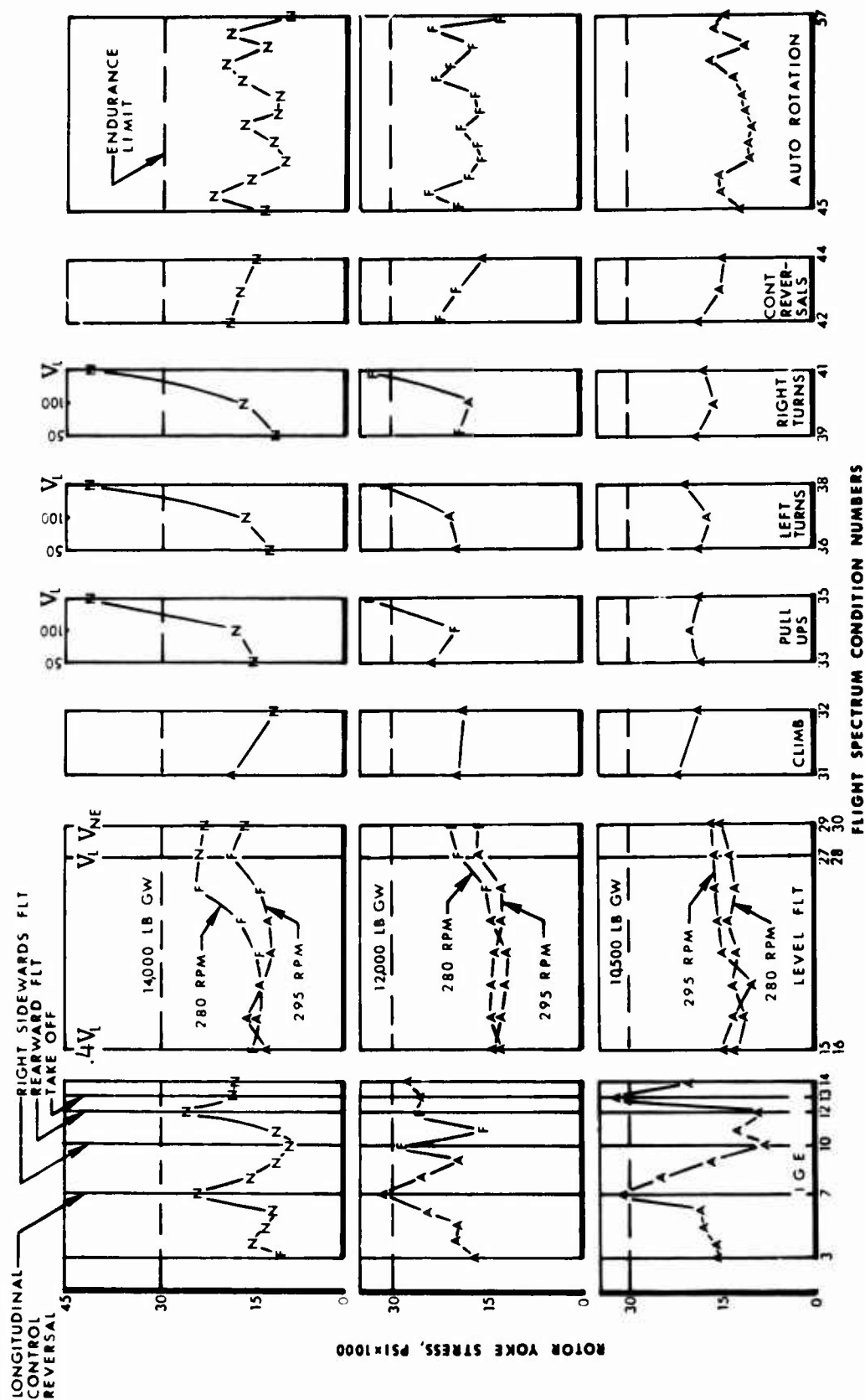


Figure 57. Main Rotor Yoke Stresses for Each Condition in the Flight Spectrum (Data From Table XIII, Appendix III).

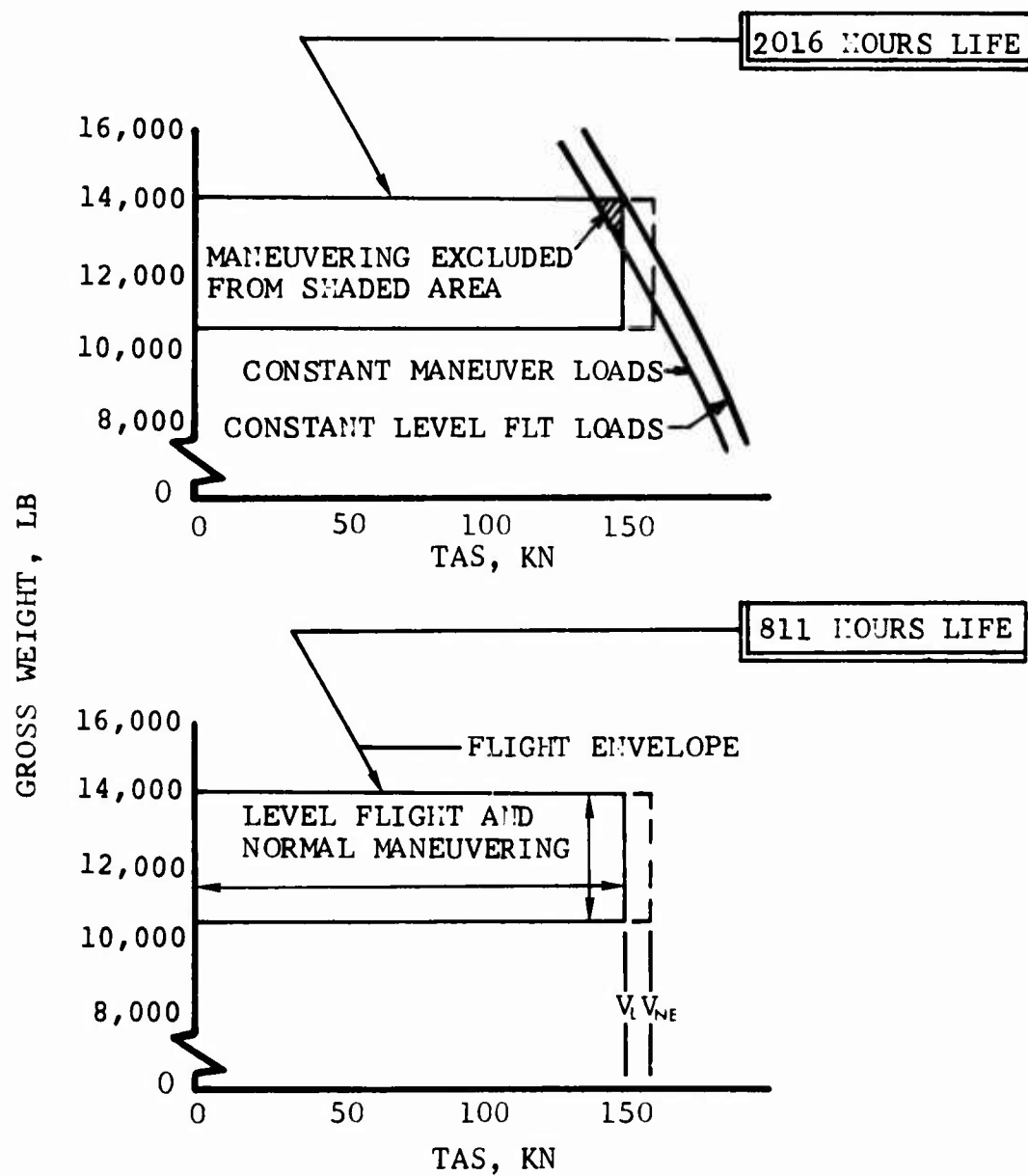


Figure 58. Effect of Maneuvering Restrictions on Rotor Yoke Fatigue Life.

## FUSELAGE VIBRATION - RESULTS AND DISCUSSION

Vibrations at the four per rev of the main rotor were the most significant vibrations in the fuselage. Because of this, analyses and investigations of vibration have been confined to four per rev.

### FLIGHT TEST RESULTS

#### Crew and Passenger Vibration Environment

Figures 59 through 61 summarize the vertical four-per-rev vibrations at the pilot's and copilot's station, and center of gravity of the test helicopter, showing the effects of changes in gross weight, center of gravity, main rotor speed, and true airspeed. (The comparison by harmonics in Figure 62 shows that four-per-rev vibration is the most significant.) These summary plots suggest the following comments:

1. Vibration decreases as center of gravity moves aft.
2. Vibration decreases slightly (Figure 61) with increasing main rotor speed.
3. Vibration is below 0.35G.

Overall, the vibration is low at four per rev, and the ride is good in the crew and passenger areas.

#### Correlation of Fuselage Vibration With Changes in Rotor Loads

Changes in fuselage vibration with airspeed and accompanying changes in rotor system loads have been plotted in Figure 63 in an attempt to establish the excitation source. The four-per-rev fuselage vibration was caused by blade four-per-rev out-of-plane (beam) loads as well as blade three-per-rev in-plane (chord) and out-of-plane loads. Rotor three-per-rev loads build with airspeed in both the beamwise and chordwise directions, and decrease with increasing rpm.

The three per rev in the rotating system is also reflected in the four-per-rev in-plane hub accelerations (fixed system). The similar increase in fuselage roll accelerations is indicated by the difference in pilot and copilot vibrations. Nose vibrations also show an rpm and speed trend.

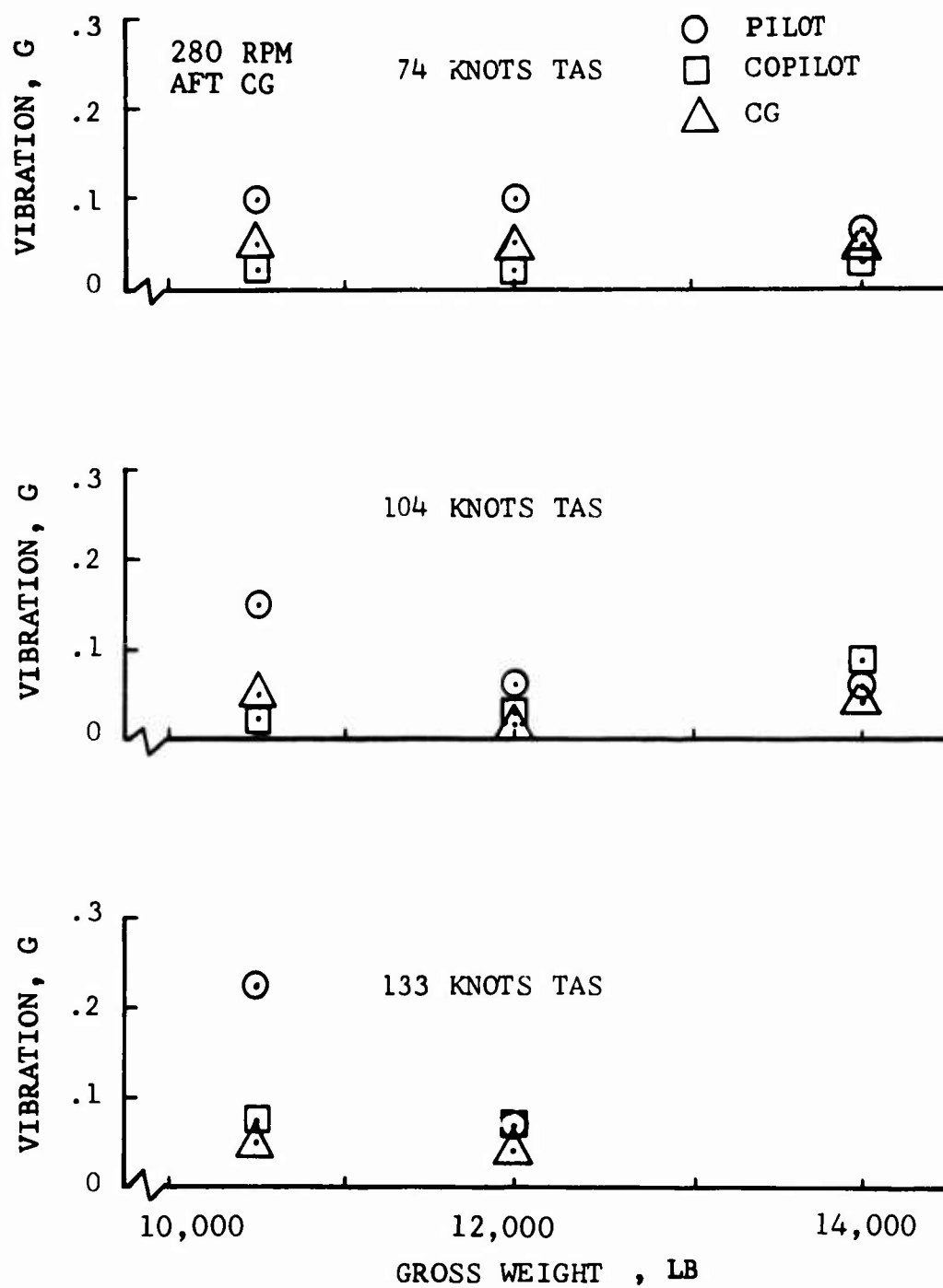


Figure 59. Summary of 4/Rev Vibration Versus Gross Weight, Flight Test Data.

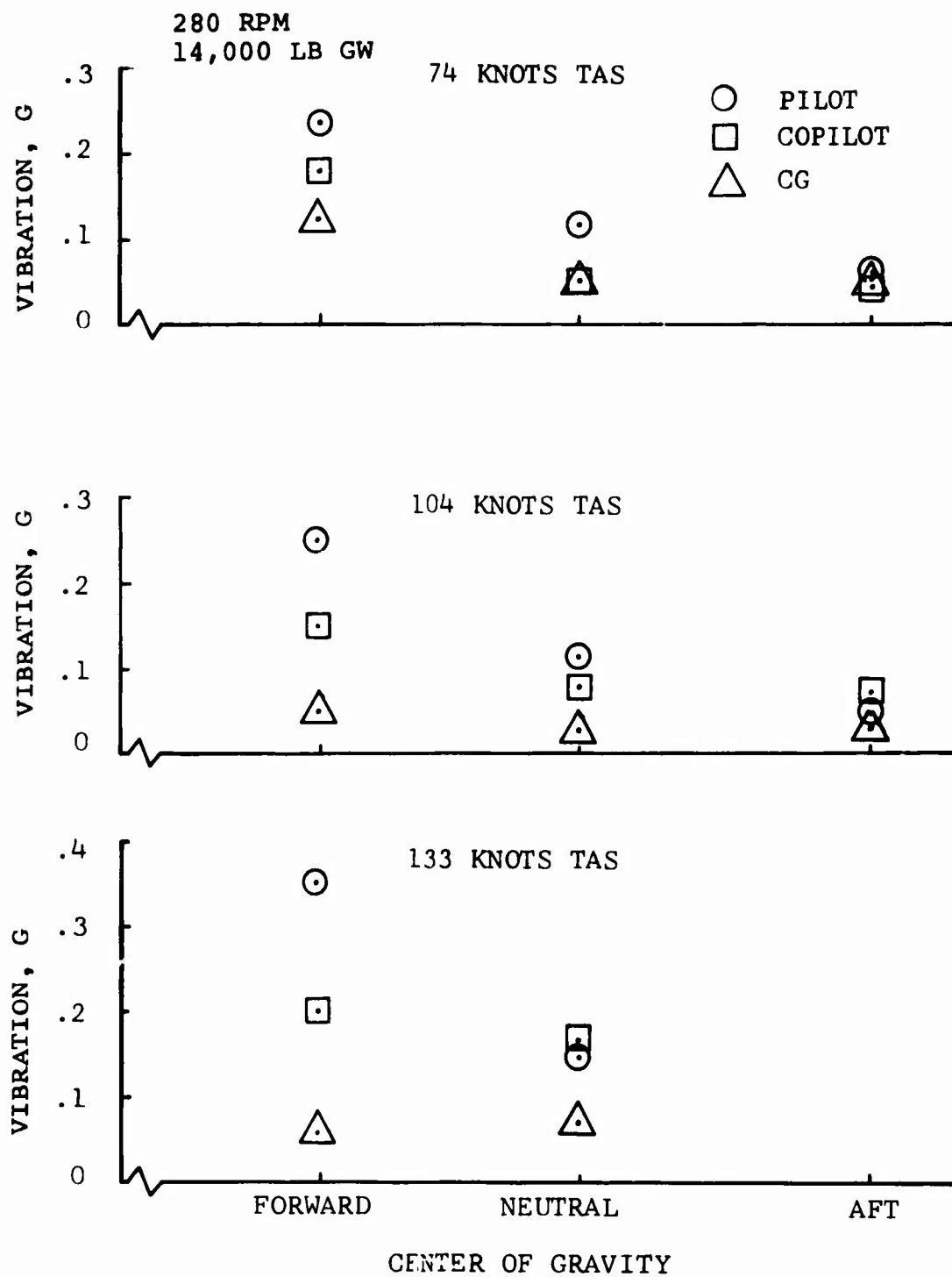


Figure 60. Summary of 4/Rev Vibration Versus Center-of-Gravity Location, Flight Test Data.

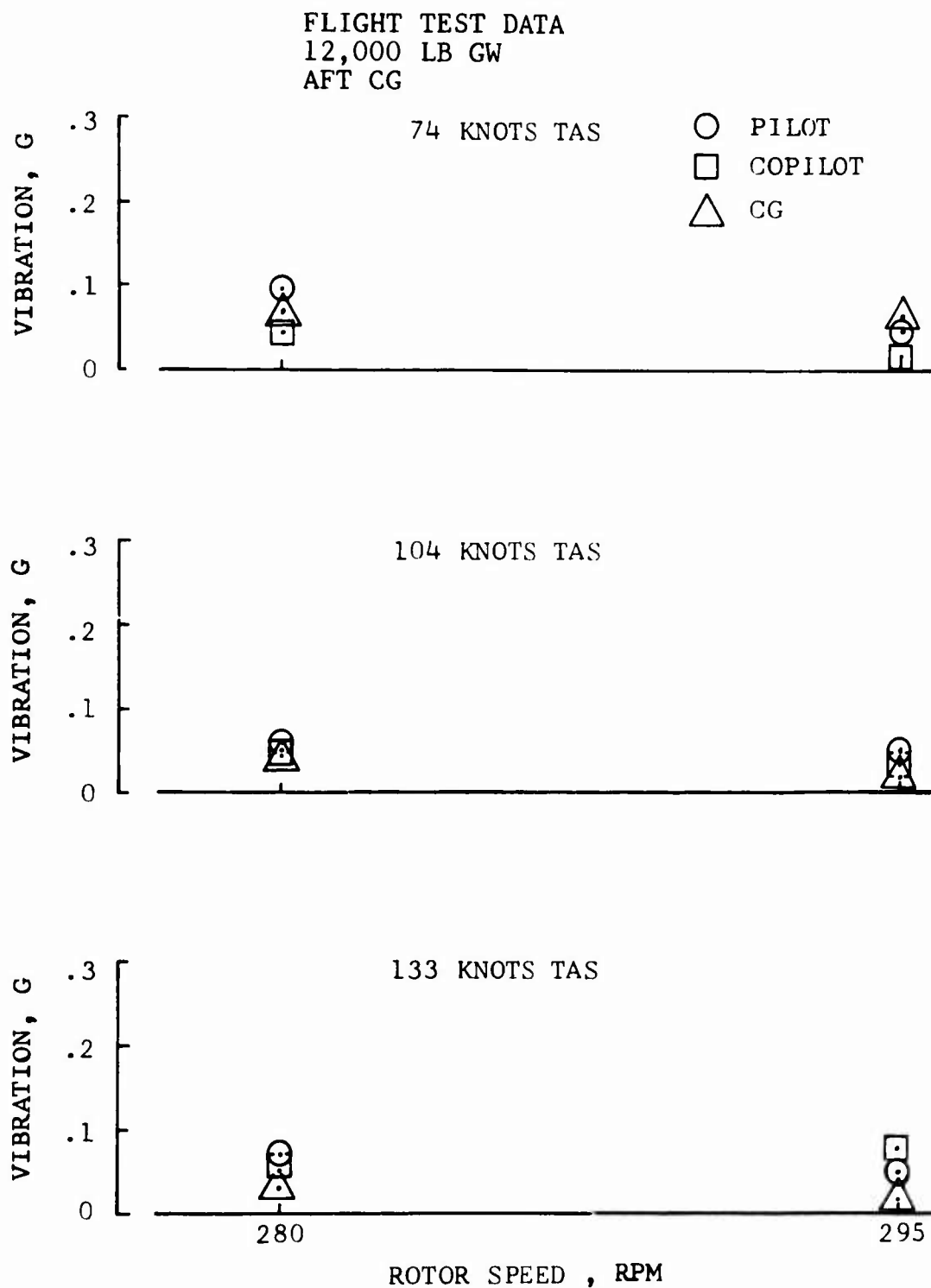


Figure 61. Summary of 4/Rev Vibration Versus Rotor Speed, Flight Test Data.

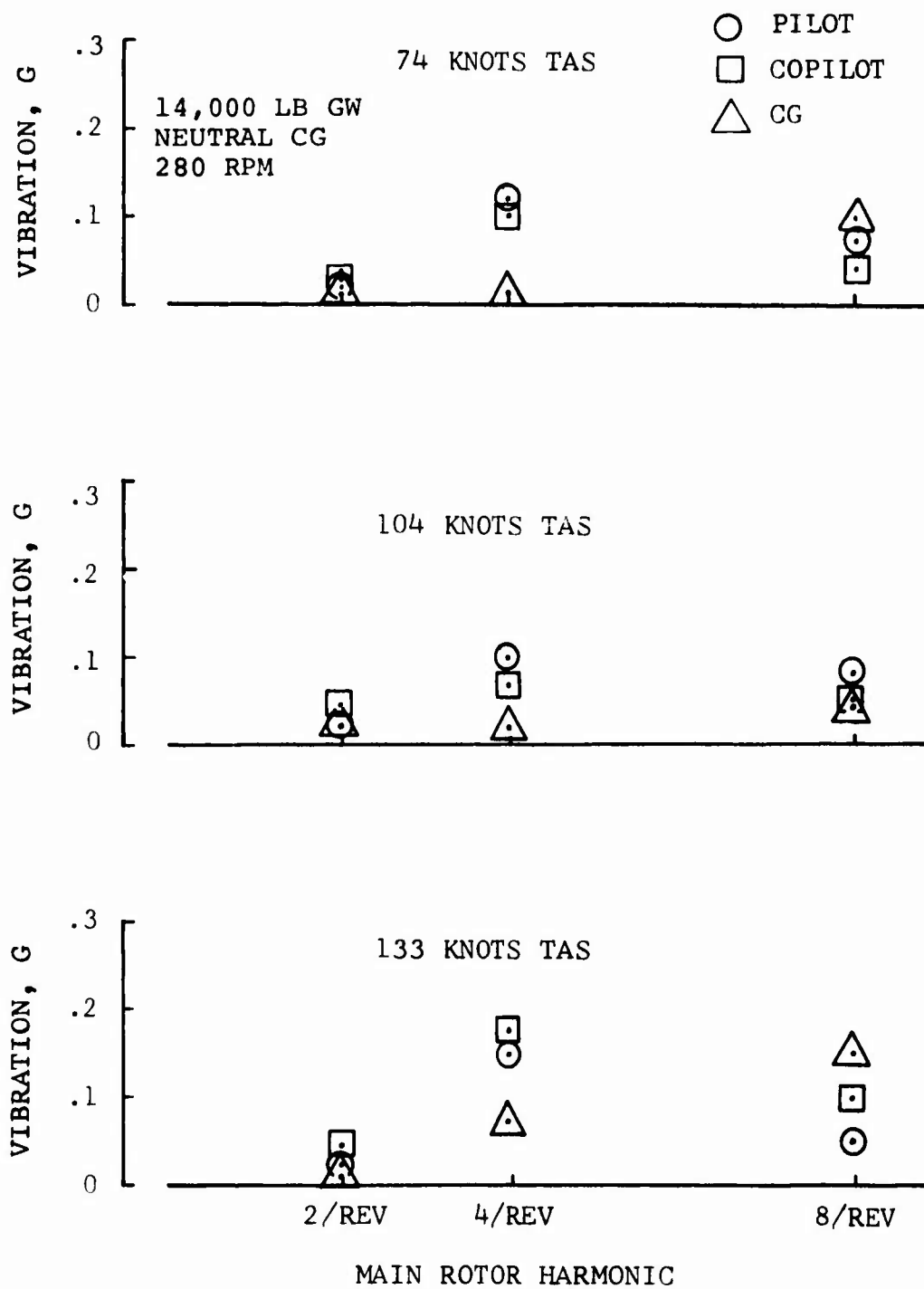


Figure 62. Summary of Vibration Versus Main Rotor Harmonic, Flight Test Data.

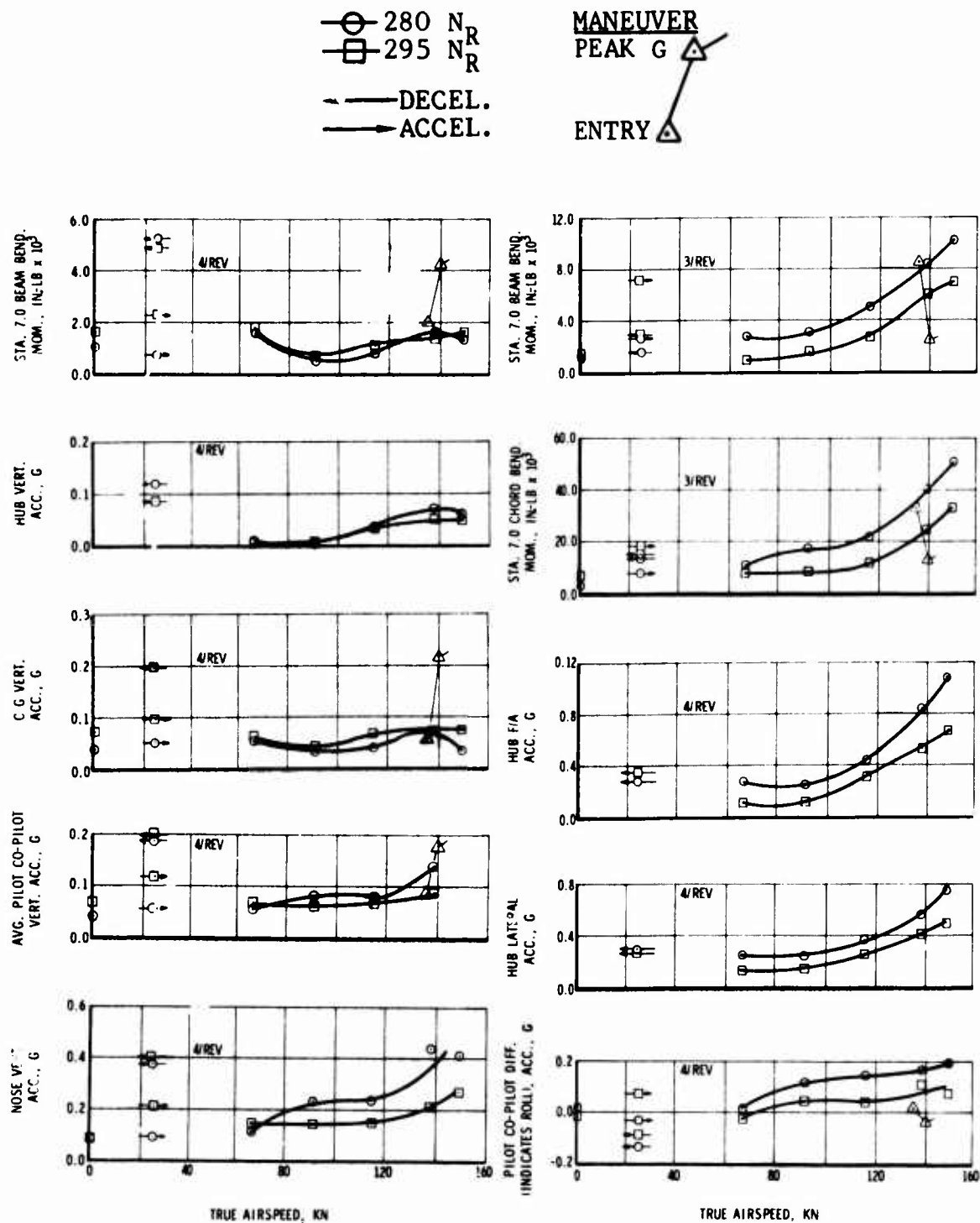


Figure 63. Correlation of 4/Rev Vibrations in the Fuselage With Rotor System Loads and Vibrations, Flight Test Data.

The cg and average of pilot- and copilot-seat vibrations do not show strong rpm and airspeed trends. Vibrations at these stations seem to follow more closely the beamwise four per rev in the rotor, which is transmitted vertically into the fuselage. Thus, superposition of responses to vertical and horizontal excitations is indicated. However, the vertical (beamwise) four per rev is clearly the dominant excitation in the high-speed maneuver.

Vibrations occurring during transitional flight are also presented in Figure 63. The accelerations and decelerations are shown separately with the decelerations having the higher four-per-rev vibrations. The predominant exciting force, as can be seen from Figure 63, is the rotor four-per-rev beamwise load.

#### COMPUTED HUB MOTIONS

The C-81 flight simulation analysis couples the elastic response of the rotor with the fuselage. The analytical model of the fuselage has three degrees of freedom: pylon roll, pitch of the pylon about its focal point, and vertical rigid body fuselage motions. It generates hub vibrations during the rotor loads computations. Computed fixed-system hub vibrations are compared in Figure 64 with vibrations measured during the pylon evaluation flights. (Hub vibrations were not recorded on subsequent flights.) Since the analytical model has only three degrees of freedom, perfect correlation cannot be expected. The comparison is encouraging, nevertheless, suggesting that the program's aeroelastic treatment of the rotor may be adequate for predicting four-per-rev vibrations when more definitive fuselage modeling is included in the analysis.

#### NASTRAN ANALYSIS AND MODEL CORRELATION

Fuselage vibration was evaluated analytically with the structural dynamics computer program NASTRAN, which is defined in Reference 11. NASTRAN uses a matrix technique to solve the differential equations of a finite element structural model.

A ground vibration test defined the lower-frequency fuselage modes and the four-per-rev fuselage response. It excited the fuselage in three directions with the helicopter in a basic fuselage configuration weighing 11,594 pounds and a dummy hub weighing 1,900 pounds. The excitation directions were vertical, lateral, and fore and aft. The primary fuselage frequencies determined during the test are listed in Table VII.

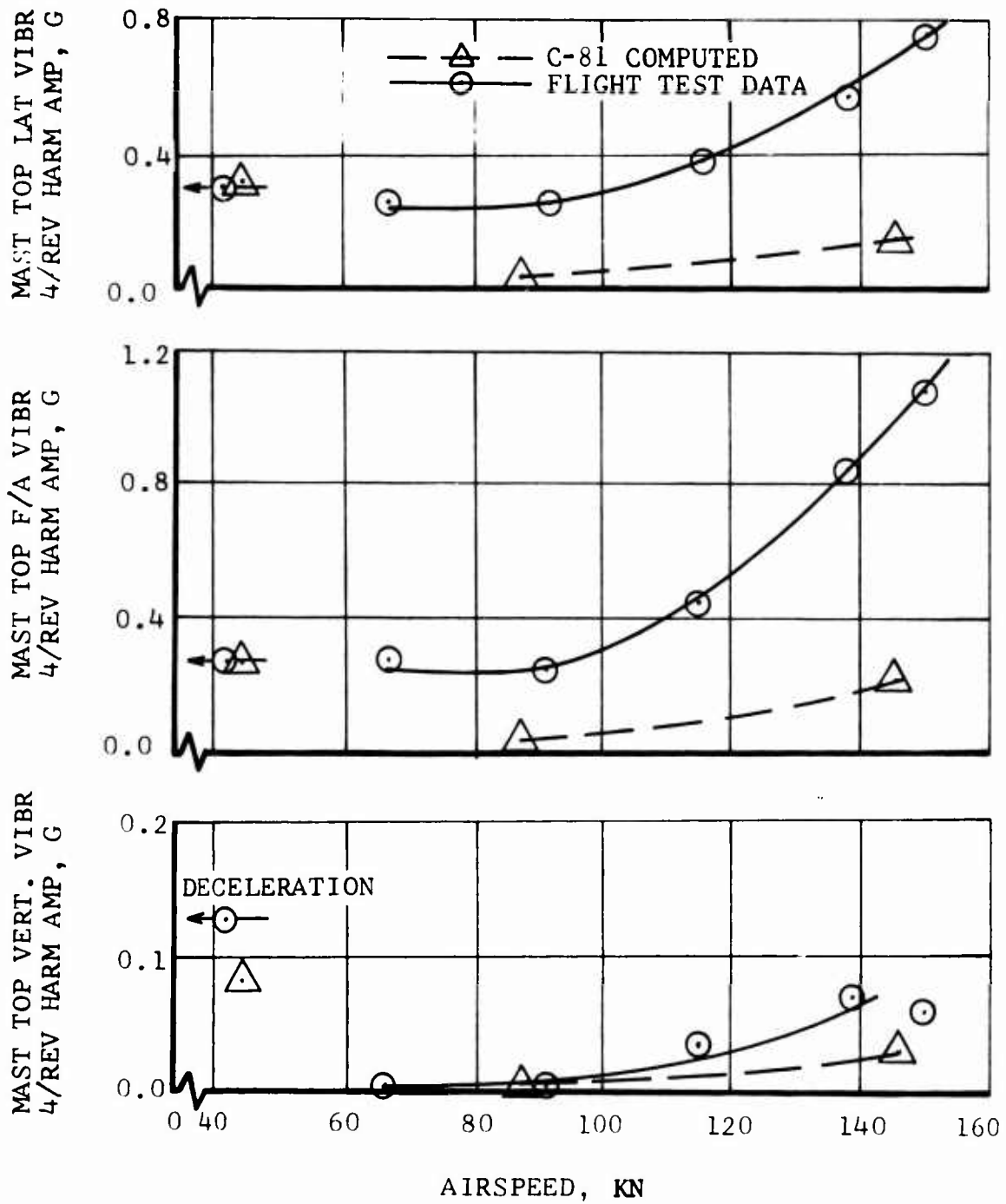


Figure 64. Comparison of Computed and Measured Hub Vibrations, 12,000 Pounds GW, Neutral CG.

| TABLE VII. SHAKE TEST CORRELATION |                  |         |
|-----------------------------------|------------------|---------|
|                                   | FREQUENCIES (Hz) |         |
|                                   | Vibration Test   | NASTRAN |
| 1st Fuselage Lateral              | 6.1 - 6.3        | 6.9     |
| 1st Fuselage Vertical             | 7.5 - 8.2        | 7.8     |
| 2nd Fuselage Lateral              | 11.3 - 11.8      | 11.2    |
| 2nd Fuselage Vertical             | 13.1 - 14.1      | 13.9    |

The structural model of the test helicopter was established by determining the approximate inertia of the fuselage in segments along the elastic axis of the fuselage and modeling it on NASTRAN as lumped masses connected with structural elements (Figure 65). The NASTRAN model was tuned by forcing it at the same points that the test vehicle was forced during the ground vibration test and adjusting the location of the lumped masses and stiffness of the model to correlate its response with the measured fuselage mode shapes and frequencies. The results, as seen in Figure 66, show good correlation with the lower fuselage modes.

#### NASTRAN MODE SHAPE SIMULATION

The NASTRAN structural model was used to analyze the fuselage dynamics. The effective mass of the main rotor was calculated and placed at the main rotor hub of the NASTRAN model. This model was then excited with four-per-rev vertical forces, fore-and-aft forces, and moments at the hub. The excitations were varied to force the model to respond as close as possible to the same four-per-rev mode seen in flight. The results are shown in Figure 67 for 12,000 pounds gross weight and forward, neutral, and aft cg locations. The flight test results are not faired since accelerometer data were not available at the elevator (station 400). The exciting forces used to produce the computed mode shapes are indicated in the figure.

The results of the analysis do not correlate very well with flight test results, possibly for the following reasons:

1. Modeling of the pylon did not include friction damping.
2. The engine mode was not included.

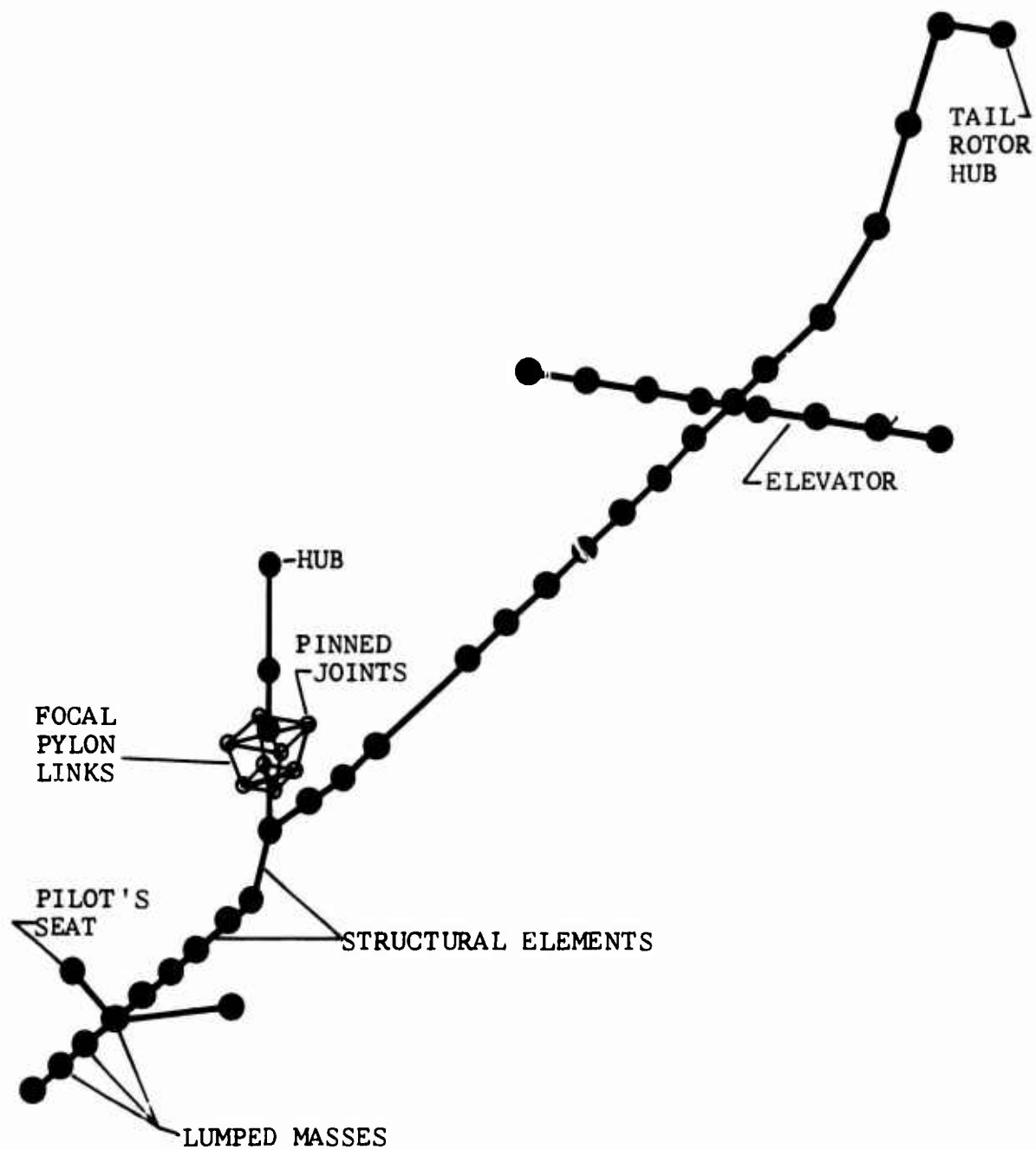


Figure 65. NASTRAN Finite Element Model.

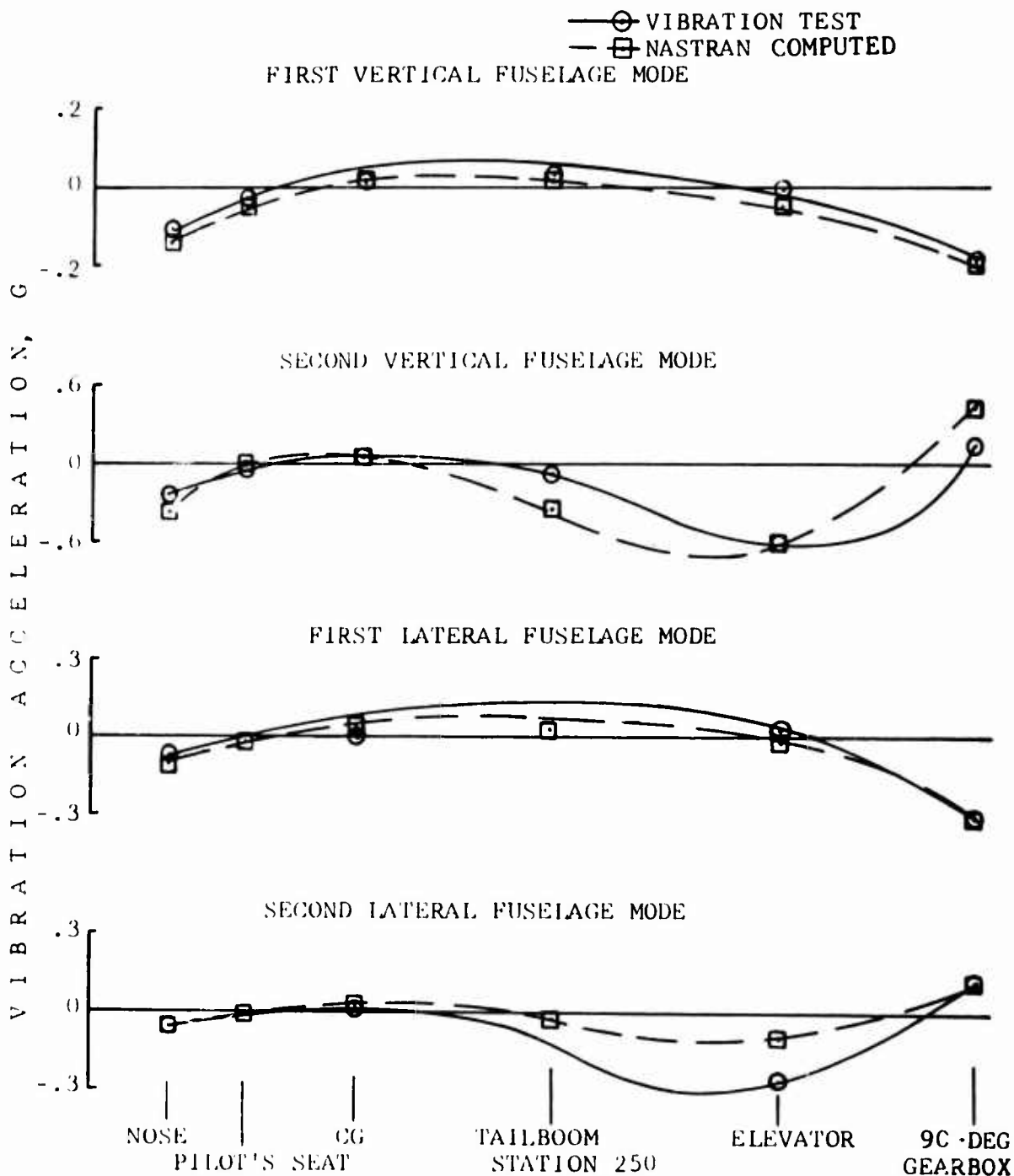


Figure 66. NASTRAN and Vibration Test Mode Shape Correlation.

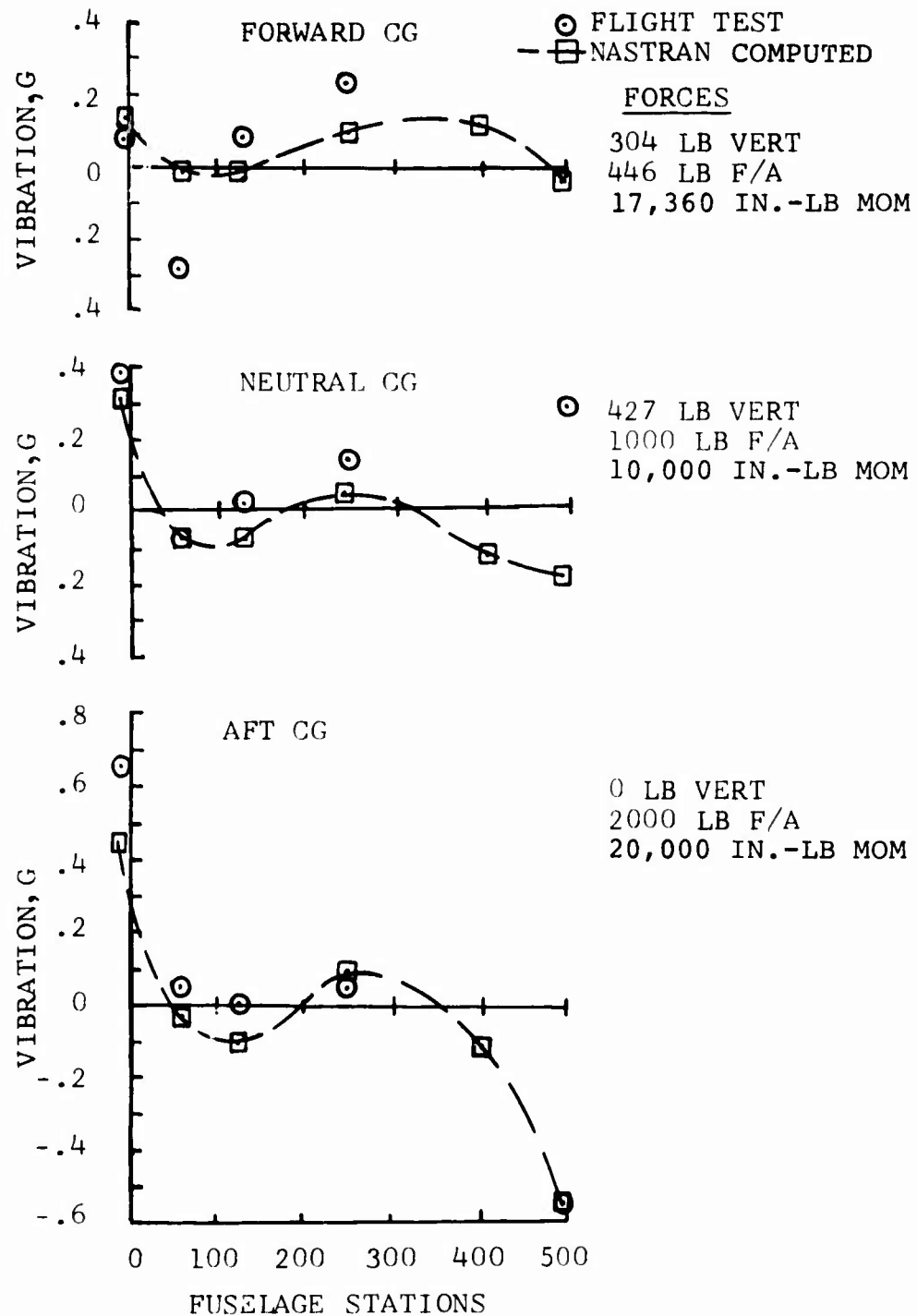


Figure 67. NASTRAN 4/Rev Mode Shape Correlation With Flight Test Data.

3. Second-order aerodynamic excitation was neglected.

Had the helicopter been shake tested in more than one cg ballast configuration, the need for considering some of the above would probably have been recognized.

#### FOCUSED PYLON EVALUATION

The focused pylon in the test helicopter consisted of four links attaching the transmission to the fuselage and four pylon springs restraining pylon motion and providing a means for tuning the pylon-fuselage dynamic system to isolate rotor hub shears and moments (see schematic, page 4). The four links vary the focal point through changes in the attachments on the fuselage deck (Figure 85, Appendix I). Elastomeric springs on each side of the transmission restrain it laterally. Similar springs (not visible in the figure) restrain it fore and aft through the torque restraint system in front of the pylon.

#### Analysis

The analysis used in predicting the optimum combination of focal point and spring rate is described in Reference 12. It is based on having two rigid bodies connected through a hinge with a torsional spring restraint about the hinge, as seen in Figure 68. The rotor is treated as a lumped mass. Pylon damping and aerodynamic effects are neglected.

The analysis calculated the loci of minimum fuselage responses to four-per-rev excitations as functions of focal point and torsional spring rate (Figure 69). With this established, the four-per-rev mode shapes of the pylon were calculated for the combinations of focal point and spring rate that were selected for evaluation in flight test. The results will be shown in a later section.

#### Flight Tests

The eight pylon configurations listed in Table VIII were evaluated in flight. The configurations included three focal points and various pylon-spring combinations at these focal points. The pylon configurations were evaluated at two rotor speeds (280 rpm and 295 rpm) and several flight conditions: hover, acceleration, deceleration, climb, left turn, right turn, and level flight from 60 to 130 knots.

The pylon configurations were evaluated against four criteria: pitch response of the fuselage, roll response of the fuselage, vertical response of the pilots' seats, and helicopter handling characteristics. The results

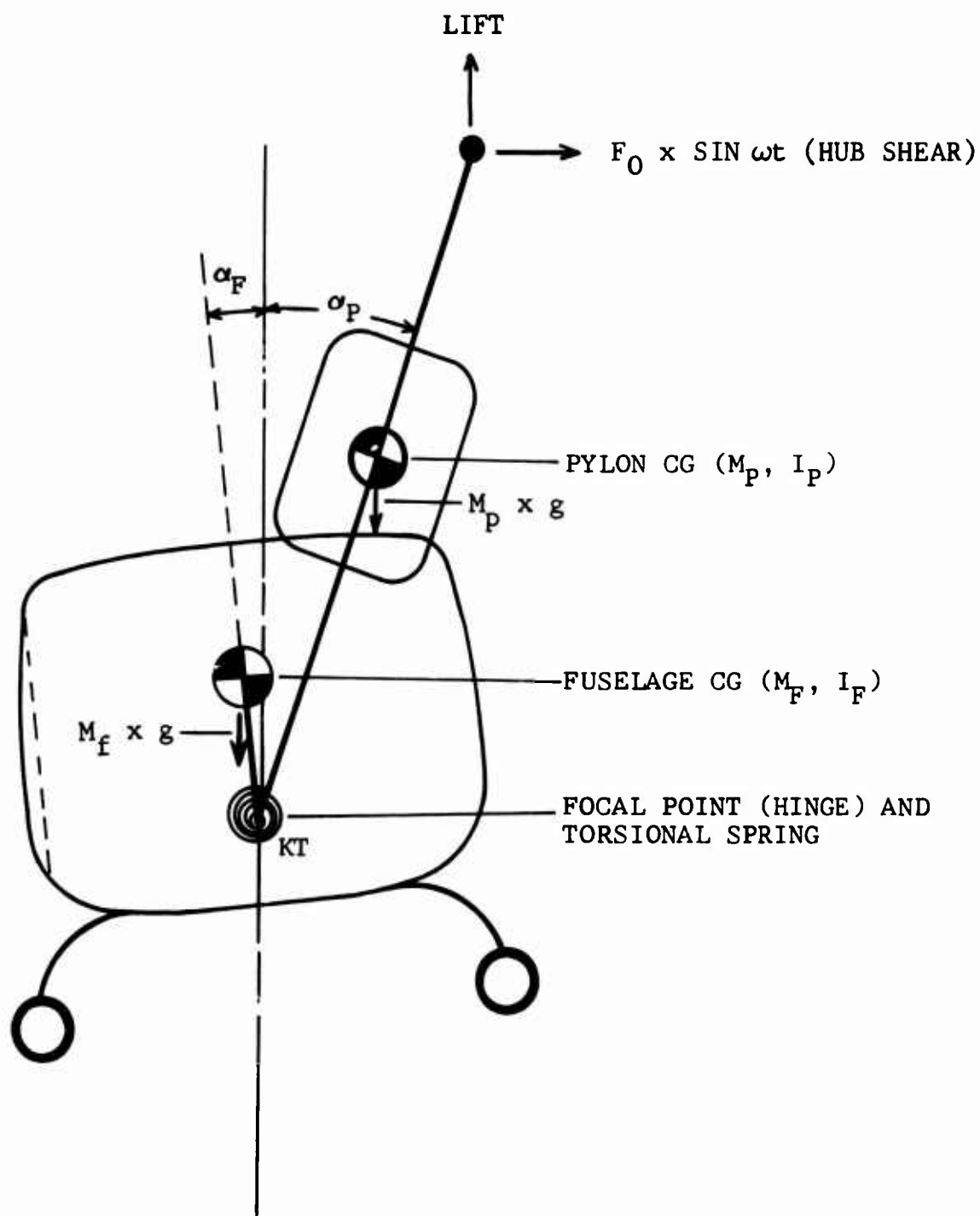


Figure 68. Rigid Body Analysis Model.

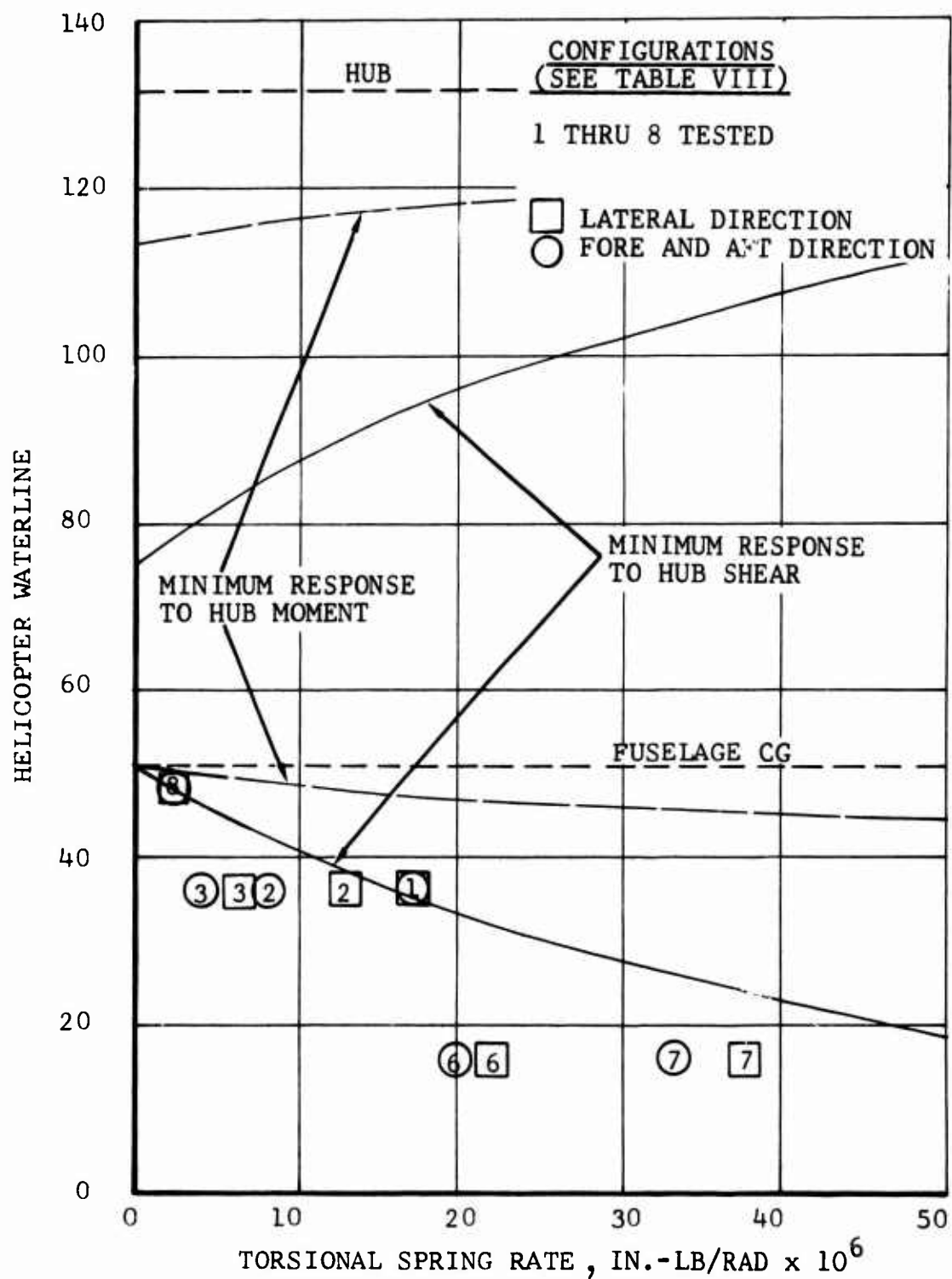


Figure 69. Test Configurations Compared to Theoretical 4/Rev Minimum Fuselage Response Locus.

| TABLE VIII. FLIGHT TEST PYLON CONFIGURATIONS    |                          |                       |                                                            |                                                                                 |
|-------------------------------------------------|--------------------------|-----------------------|------------------------------------------------------------|---------------------------------------------------------------------------------|
| Configuration                                   | Focal Point<br>Waterline | Direction             | Total Elastomer<br>Mount Linear<br>Spring Rate<br>(lb/in.) | Equivalent Pylon<br>Torsional<br>Spring Rate<br>(in.-lb/rad x 10 <sup>6</sup> ) |
| 1                                               | 36<br>36                 | Fore & Aft<br>Lateral | 20000<br>20000                                             | 17.4<br>17.46                                                                   |
| 2                                               | 36<br>36                 | Fore & Aft<br>Lateral | 9000<br>15000                                              | 7.83<br>13.08                                                                   |
| 3                                               | 36<br>36                 | Fore & Aft<br>Lateral | 4500<br>7500                                               | 3.92<br>6.54                                                                    |
| 4                                               | 36<br>36                 | Fore & Aft<br>Lateral | Rigid<br>20000                                             | -<br>17.46                                                                      |
| 5                                               | 36<br>36                 | Fore & Aft<br>Lateral | Rigid<br>Rigid                                             | -<br>-                                                                          |
| 6                                               | 16<br>16                 | Fore & Aft<br>Lateral | 9000<br>9000                                               | 19.92<br>22.15                                                                  |
| 7                                               | 16<br>16                 | Fore & Aft<br>Lateral | 15000<br>15000                                             | 33.2<br>37.5                                                                    |
| *8                                              | 48<br>48                 | Fore & Aft<br>Lateral | 20000<br>20000                                             | 7.19<br>6.19                                                                    |
| *Handling characteristic unacceptable to pilot. |                          |                       |                                                            |                                                                                 |

are presented below for 280 main rotor rpm and 120 knots indicated airspeed. As a result of this evaluation, all subsequent contracted flight-test tasks were conducted with the focal point at WL 36, with two linear mounts of 10,000 pounds per inch each in the fore-and-aft direction, and with two linear mounts of 4,500 pounds per inch each in the lateral direction.

#### Fuselage Pitch Response

The four-per-rev mode shapes measured for the pylon configurations evaluated are shown in Figures 70 and 71 together with the NASTRAN computed rigid body mode shapes. The flight-test mode shapes represent the fore-and-aft responses of three accelerometers focused on the transmission and two accelerometers on the fuselage. The computed mode shapes were determined by applying a hub shear large enough to force the top of the mast of the rigid body model to respond at the same amplitude as the flight test hub responds in flight.

The measured mode shapes show very little fuselage pitching for any of the configurations tested. The effectiveness of the pylon system in isolating fore-and-aft four-per-rev hub motions was not related to the stiffness of the pylon mount or the location of the focal point.

The measured data also show that the angular motion between the pylon and fuselage is not about the intended focal point. Relatively low values of hub shears in the analytical model reproduced the measured hub accelerations. The magnitude of the fore-and-aft rotor forces was probably not large enough to cause the pylon to overcome the friction in the focus link bearings and the torque restraint tube bearings. Mast bending or mast bearing deflections and structural deflections of the transmission supports were apparently sufficient to isolate the relatively low four-per-rev rotor forces acting on the mast.

The system used in these tests would probably have functioned in the fore-and-aft direction if the rotor exciting forces and motions had been larger. A one-G acceleration of the hub at four per rev, which was typical, corresponds to displacements of less than  $\pm 0.030$  inch; see Figure 72. A system with bearings and joints is hardly appropriate for such small motions but did function satisfactorily in the lateral direction, which had less friction.

#### Fuselage Roll Response

The focused pylon had a significant effect on fuselage four-per-rev response in the lateral direction, as seen in

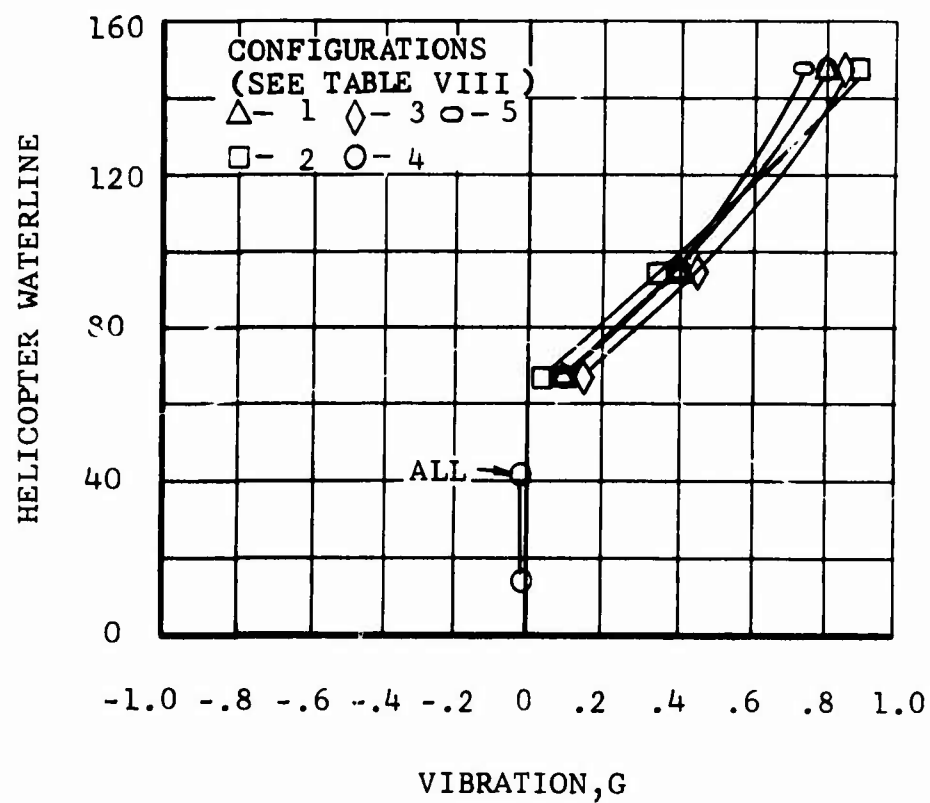


Figure 70. Pylon Fore and Aft 4/Rev Mode Shapes, Focused at WL 36, Flight Test Data.

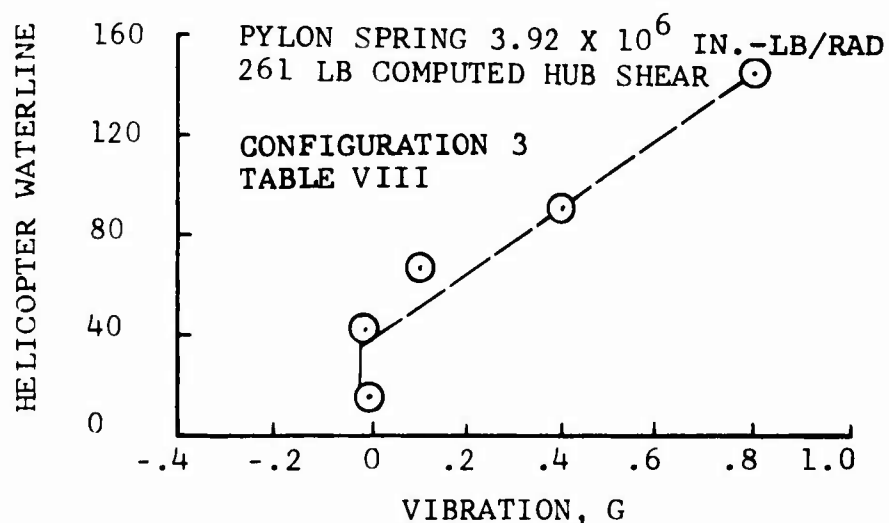
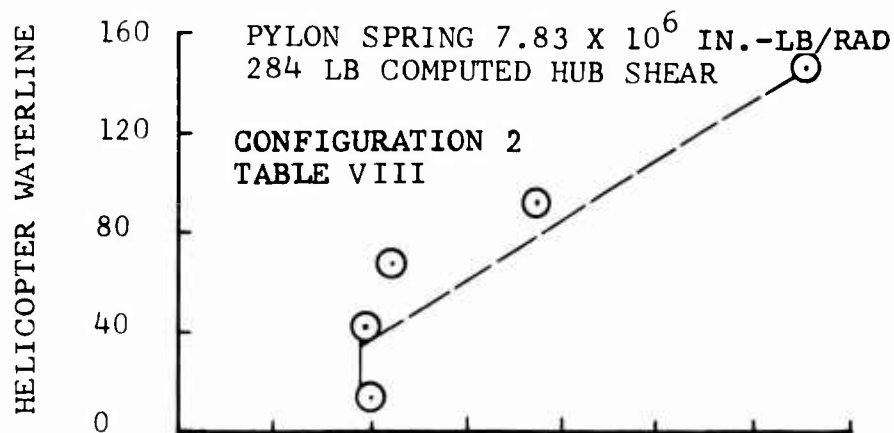
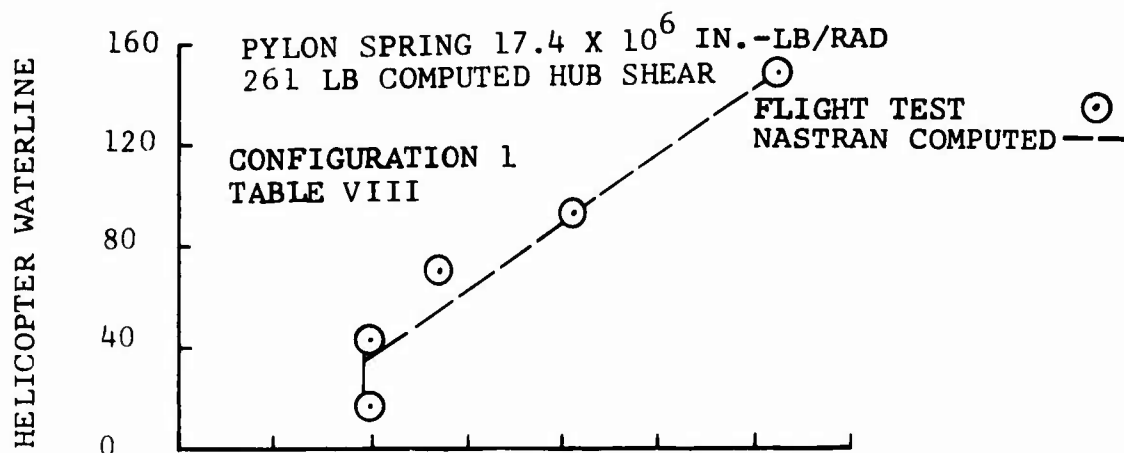
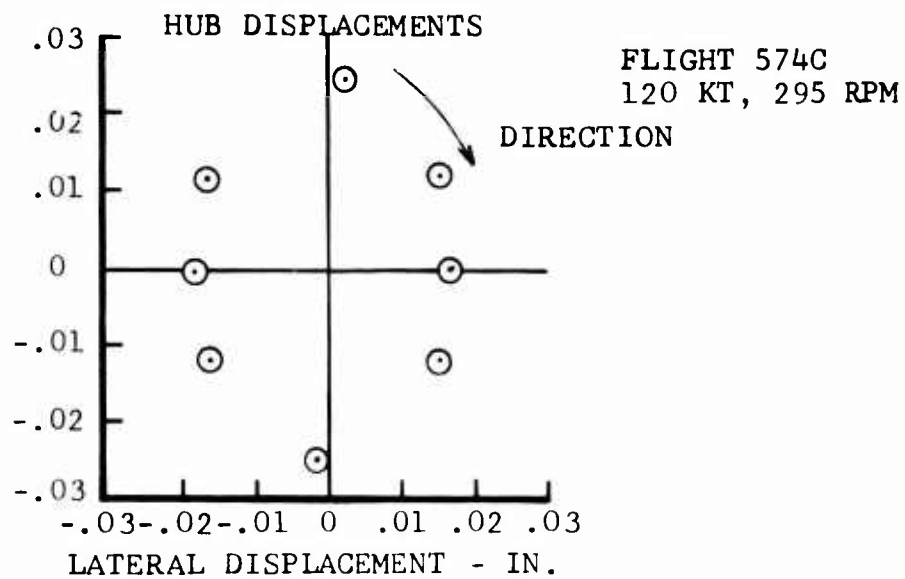


Figure 71. Computed and Measured Pylon Fore and Aft 4/Rev Mode Shapes, Focused at WL 36.

FORE AND AFT DISPLACEMENT, IN.



FORE AND AFT VIBRATION, G

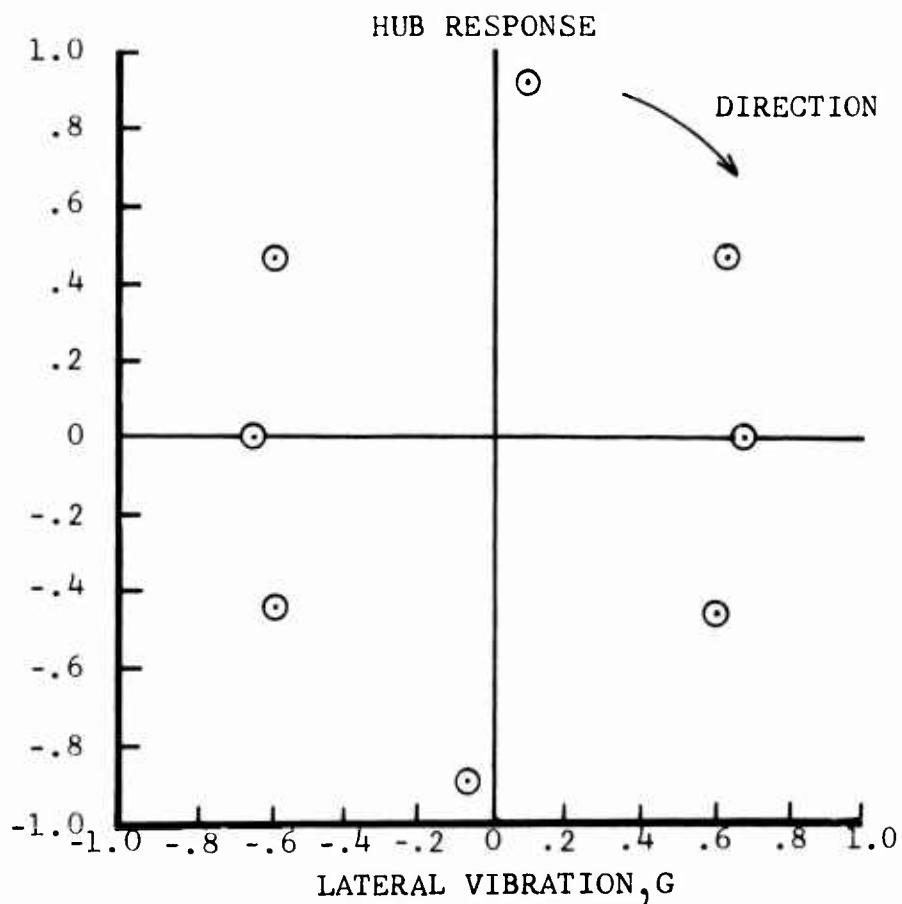


Figure 72. Typical 4/Rev Hub Vibration Displacement and Response in the Fixed System, Flight Test Data.

the lateral pylon mode shapes of Figures 73 and 74. Also presented in these figures are the computed rigid body mode shapes for the same configurations. The NASTRAN computed mode shapes were forced in the same manner as the fore-and-aft mode shapes. Like the fore-and-aft modes, the lateral modes involve some mast bending, but pylon motions in the lateral direction are essentially about the focus point. Changes in spring stiffness altered the fuselage response. As seen in Figure 74, the best roll isolation is achieved with a pylon spring rate range from 6 million to 13 million inch-pounds per radian. The analysis (Figure 69) predicted that optimum isolation for shear would be obtained with a spring rate of 15 million inch-pounds per radian with the focus at WL 36.

#### Vertical Response of Pilots' Seats

The vertical response of the pilots' seats was evaluated for each of the pylon configurations. These responses are summarized in Figure 75 as functions of the lateral pylon spring, since it appeared to have the greatest effect. As the figure shows, the softer the pylon spring, the lower the vertical response of the pilot's seat; the stiffer the pylon spring, the lower the response of the copilot's seat. The lowest average vertical response of the two seats falls in the center range of pylon springs evaluated with the pylon focused at WL 36. The best compromise between the vertical responses of the two seats occurs at a lateral pylon spring rate between 7 and 14 million inch-pounds per radian.

#### Helicopter Handling Characteristics

The helicopter handling characteristics were evaluated by considering the pilot's reaction to the various pylon configurations. The pilot noticed significant differences in the response of the helicopter to control inputs for the various pylon configurations, and was more sensitive to fore-and-aft changes in the pylon configuration than to lateral changes. The stiffest fore-and-aft pylon spring gave the best handling characteristics; the pylon configuration focused at WL 48 gave the worst handling characteristics because it felt too soft and was, therefore, considered to be unacceptable by the pilot.

#### Final Pylon Configuration

The final fore-and-aft pylon configuration was based primarily on handling characteristics. It had the stiffest pylon springs (17.4 million inch-pounds per radian) and was focused at WL 36.

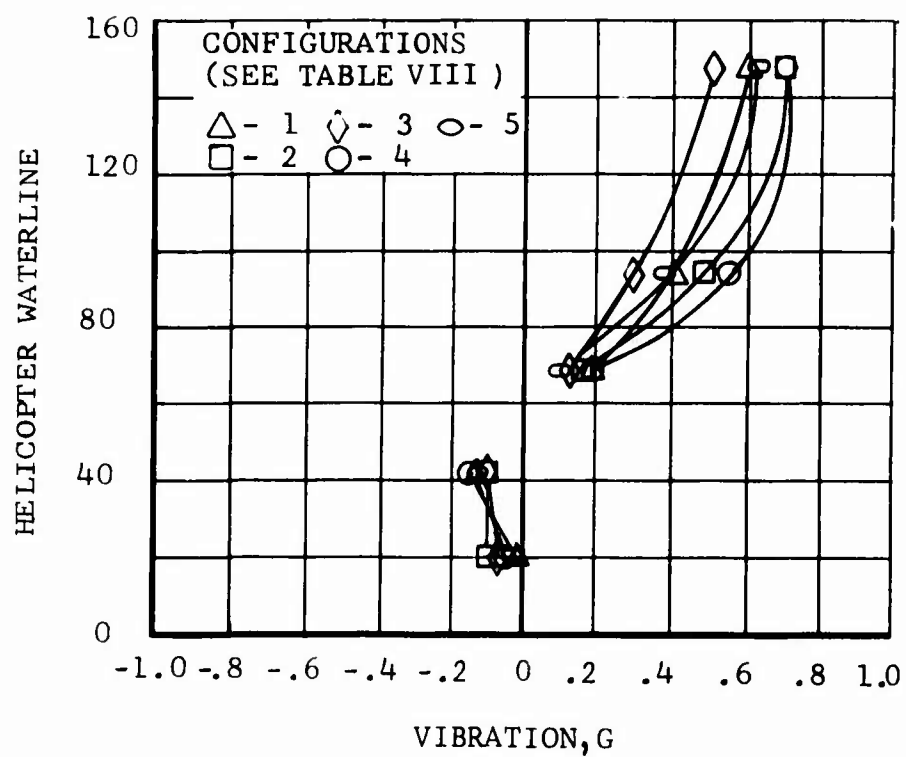


Figure 73. Pylon Lateral 4/Rev Mode Shapes, Focused at WL 36, Flight Test Data.

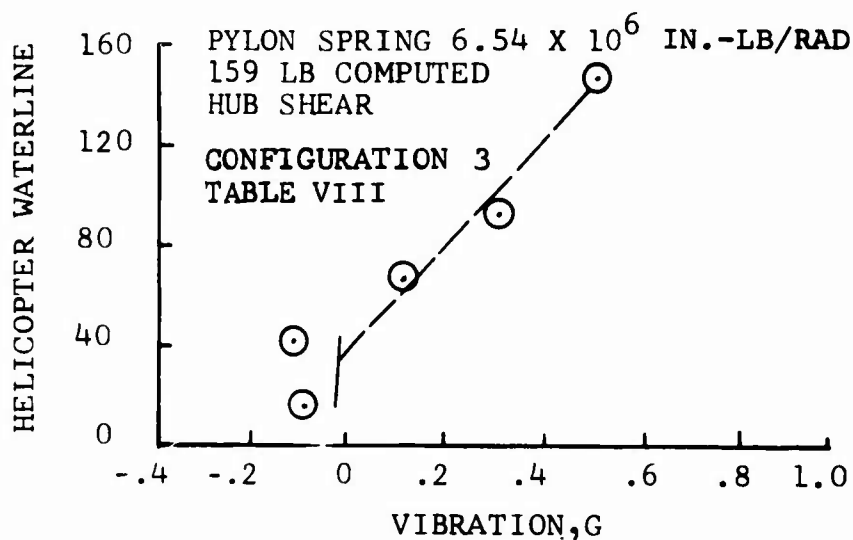
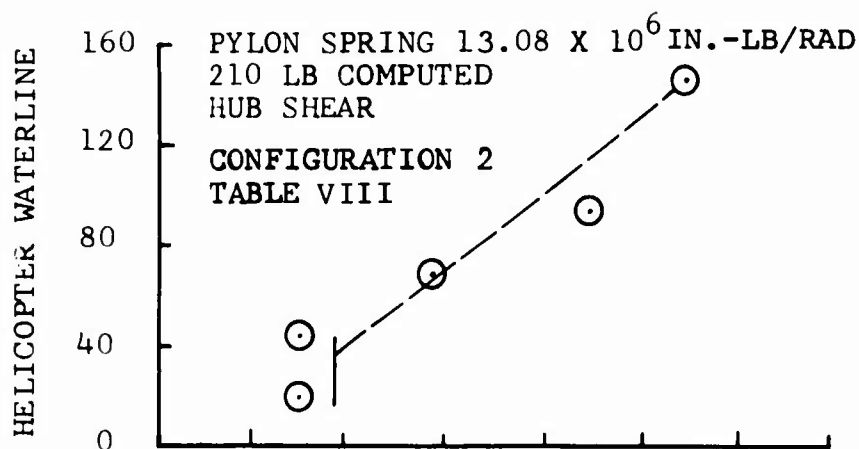
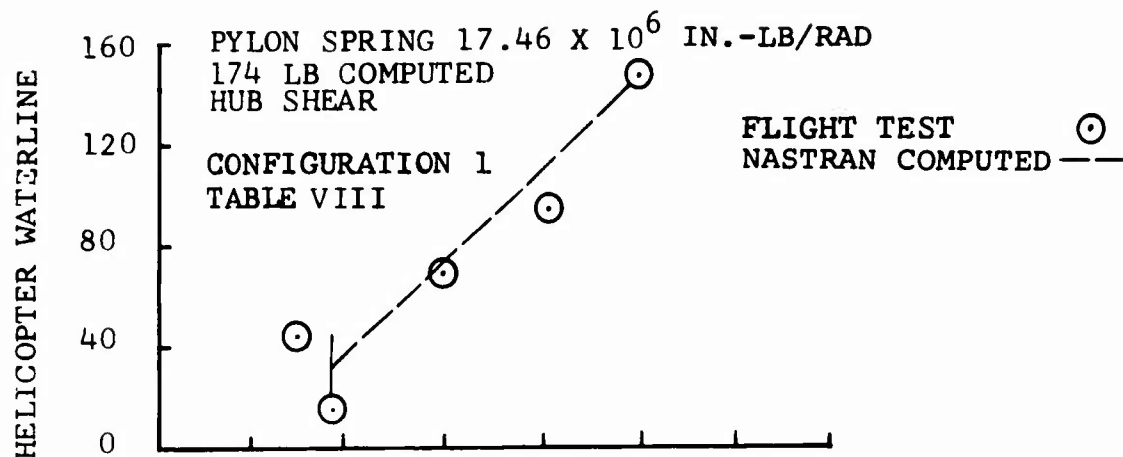


Figure 74. Computed and Measured Lateral 4/Rev Mode Shapes, Focused at WL 36.

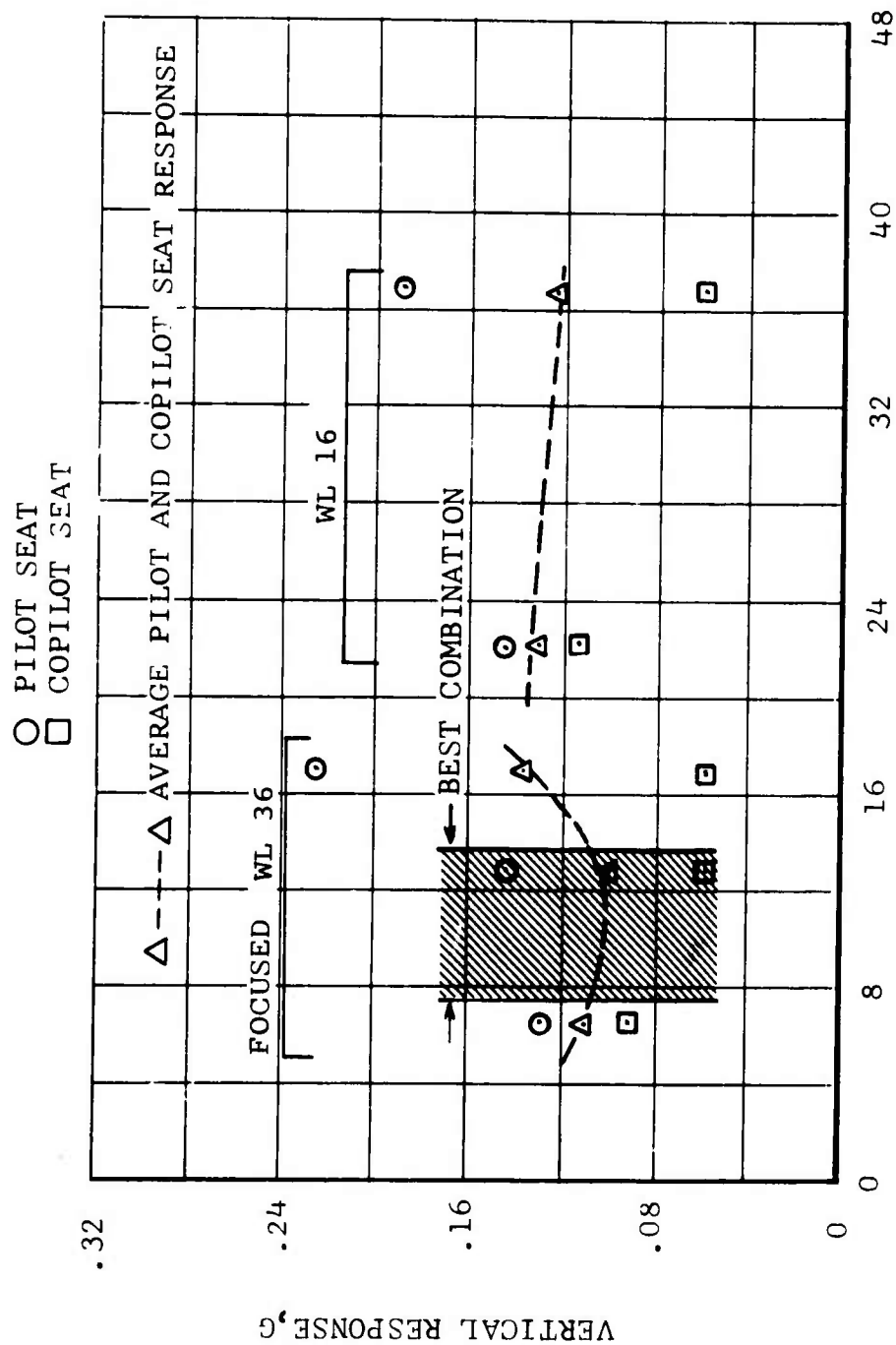


Figure 75. Effect of Pylon Focal Point Location and Spring Rate on Pilot and Copilot Seat Vertical Response at 120 Knots Airspeed, Flight Test Data.

The focused pylon was very effective for isolating lateral (roll) vibration. Therefore, the final lateral pylon configuration was based on all the criteria mentioned. The best tradeoff between the configurations was 7.85 million inch-pounds per radian of spring rate at WL 36.

## SUMMARY OF TECHNICAL PROBLEM AREAS

Technical problems encountered during a research task can be of major benefit by identifying risk areas in future programs and/or by indicating the need for additional work. This section discusses difficulties encountered with the Model 609 rotor which are not explained in other sections of the report. Other technical problems encountered during the evaluation, but not rotor-related, are reported in the Flight Test Data Report, Reference 13. Table IX (page 128) contains a brief summary of problems with causes or reasons indicated, if known, and possible solutions offered whenever available.

### MAIN ROTOR CLAMP SET

As mentioned in the section entitled Pilot Observations, one-per-rev vibrations sometimes occurred due to shifting of the rotor hub to mast clamp set, necessitating a retorquing. The clamp set replaced (in 1971) an automatic blade-folding device which had a similar but more pronounced problem. The one-per-rev vibrations occurred more frequently on the high-gross-weight and maneuver flights.

Figure 81 (Appendix I) shows the clamp set with its separate yokes and cone sets. The shifting of the rotor clamp set resulted from the many faying surfaces preventing a firm clamp-up and the differential bending or torsion in the separate yokes causing "unseating" or a slight loosening of the system. One way to avoid the problem would be to bolt the yokes together and use one set of splines to drive both pairs of blades. Then differential torsion between the rotor pairs would not transmit back through the clamp set.

### LOAD DIFFERENCES BETWEEN UPPER AND LOWER BLADE PAIRS

The load level survey showed differences between the upper and the lower rotor blades. These differences became greater in maneuvers, with the lower blades having 15 percent higher loads than the upper blades. Faulty instrumentation was ruled out as the reason for the differences after a check of the calibrations showed the gages to be functioning properly.

There are two possible explanations for the observed differences in upper and lower rotor loads. One is that the vortex field from the upper rotor caused the higher blade loads in the lower rotor, and further studies using techniques such as schlieren flow visualization with models could check this hypothesis. The other is that air pressure caused the hollow blade (Figure 82, Appendix I) to change contour in flight. (See blade deformation discussion, below.)

## POPPING OUT OF TRACK

Popping out of track of one or more blades was first encountered during the IR&D flights in 1971. It occurs at high advancing-tip Mach numbers. In 1971, there was a "deep" encounter producing one-per-rev vibrations of 1G amplitude at the pilot's station. During the 1972 flights, the onset of this phenomenon was mapped, as shown in Figure 76 and found to occur at an advancing-tip Mach number of .89. The pilots perceive the onset as increase in one-per-rev cabin vibrations to the  $\pm 0.1$  to  $\pm 0.25G$  level. They also see changes in track with the help of an in-flight strobe tracker. Usually, one blade changes its track relative to the other three. Occasionally, changes in track are random, with the relative position of more than one blade changing.

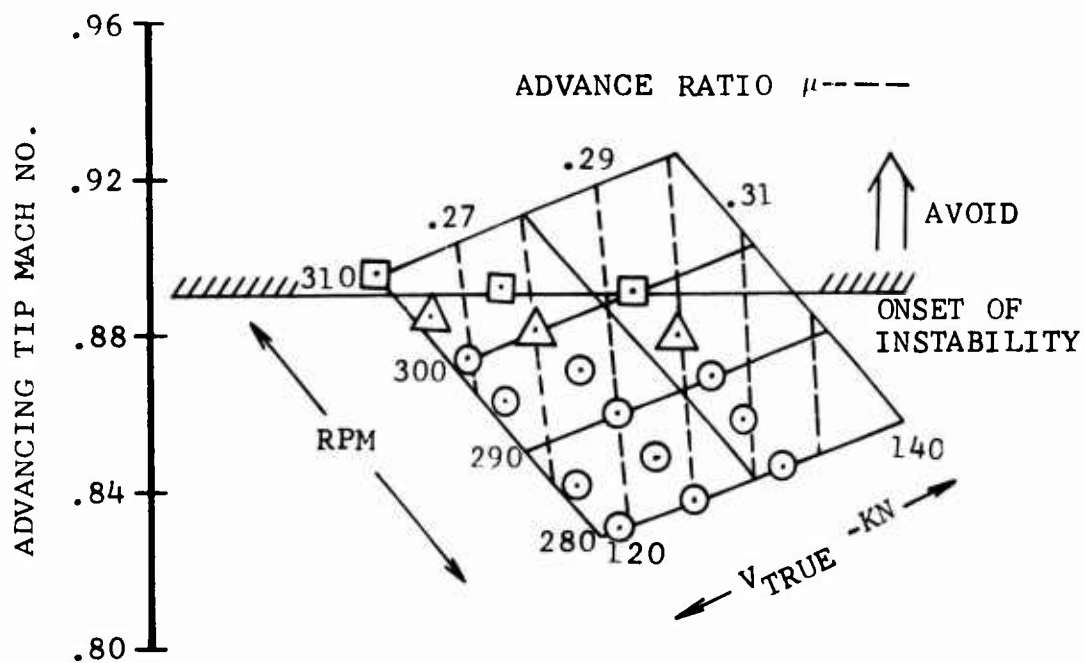
The primary cause of the out-of-track condition has been identified to be Mach number effects, rather than rpm, airspeed, or dynamic pressure. Higher dynamic pressures at the advancing tip were reached on warmer days (higher speed of sound), without any problem, than during the high Mach number flights on colder days. Furthermore, the observed out-of-track boundary shows that the problem is not a direct function of either rpm or airspeed.

The calculated angle-of-attack distribution of the rotor is shown in Figure 77 for the advancing blade at the onset of the out-of-track condition. The drag divergence Mach number is an indicator of the adverse aerodynamic effects associated with high Mach numbers, Reference 14. Figure 78 presents the areas of the rotor disc operating above the blade drag-divergence Mach number as a function of advancing-tip Mach number. The blade angle-of-attack calculations, along with the blade airfoil data, were used in determining these boundaries. The tips of the rotor blades are operating above drag divergence, when the Mach number of the advancing tip is 0.86 or higher.

Figure 79 presents measured blade torsional moments and pilot's seat vertical accelerations. There are large moment excursions on the advancing side of the rotor disc, with noticeable one-per-rev vibration levels. The moments are not the same for each blade; hence, blade dissimilarities coupled with large aerodynamic forces cause the out-of-track condition.

Following the flights in which the onset of the out of track was mapped (Figure 76), the rotor blades were modified to increase torsional stability. The tuning weights at the tips of the blades were replaced with heavier, reshaped weights which moved the cg of the blades forward. The rotor was then flown to an advancing tip Mach number of 0.94 before a change in track was observed. Since air turbulence can cause momentary changes in Mach number and angle of attack, a lower Mach number (0.92) was used as a safe limit. The out-of-track condition could be

- ◻ — OBJECTIONABLE 1/REV
- △ — NOTICEABLE 1/REV
- — LIGHT OR NO 1/REV



FLIGHT 579

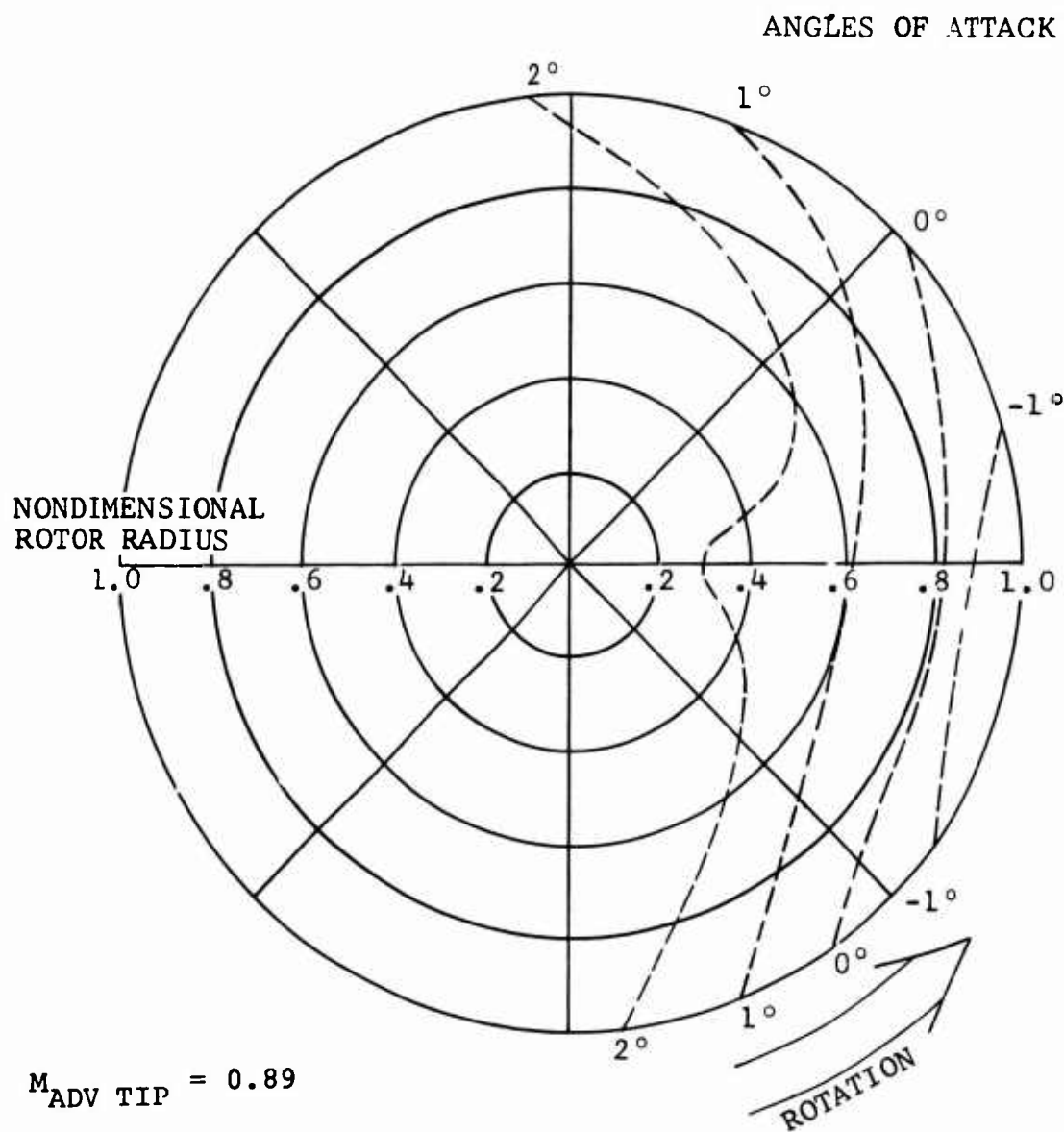
HIGH TIP MACH NO. INVESTIGATION

Figure 76. "Popping-Out-Of-Track" Boundary, Flight Test Data.

609 ROTOR  
F-35 COMPUTED DATA



WIND



132 KTAS

Figure 77. Lines of Constant Angle of Attack.

609 ROTOR  
F-35 COMPUTED DATA

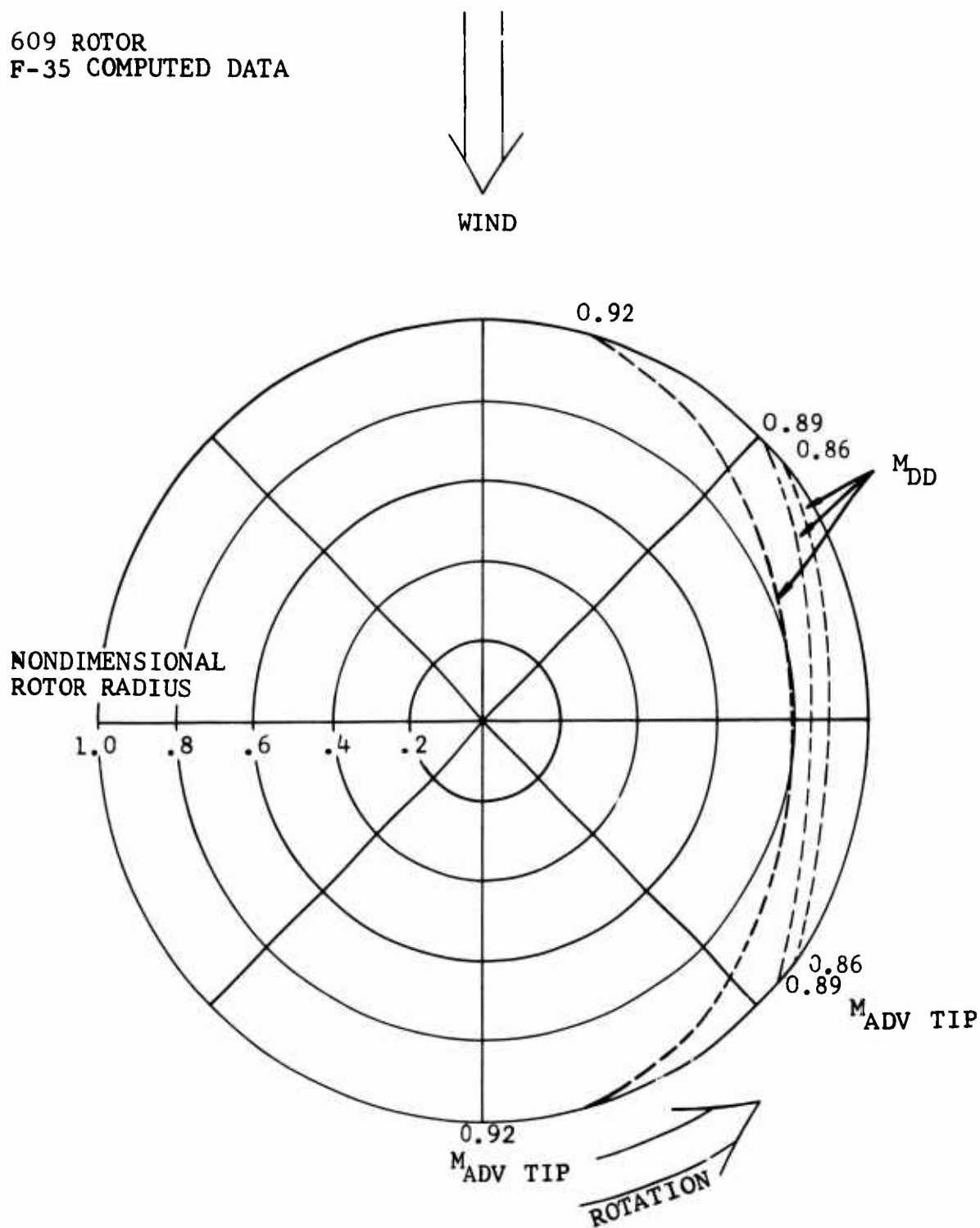
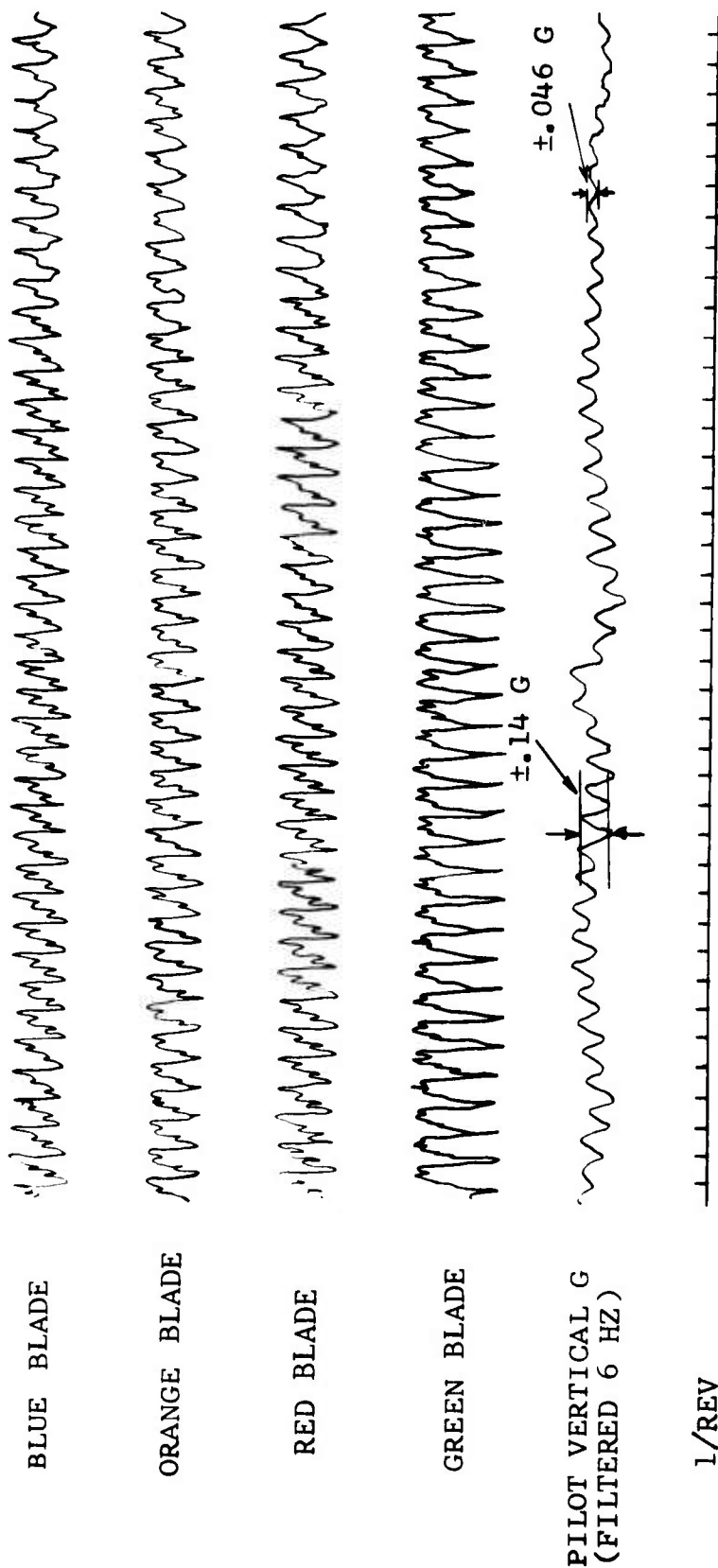


Figure 78. Mach Drag Divergence for Various  $M_{Adv Tip}$ .

# BLADE TORSION GAGES STATION 243



$M_{ADV. TIP} = .87$   
RPM = 289

$M_{ADV. TIP} = .89$   
RPM = 300

DECREASING RPM

HIGH TIP MACH NO. INVESTIGATION  
FLIGHT TEST (FLIGHT 579A)  
GROSS WEIGHT 10,500 LB  
CTR. 609

Figure 79. Measured Blade Torsional Moments and Pilot Vertical Acceleration.

alleviated further, and higher advancing tip Mach numbers could be obtained if the torsional stability of the blades were increased and if the tip airfoils were changed to airfoils with better high-Mach-number characteristics.

#### PERMANENT DEFORMATIONS IN BLADE CONTOURS

Following the contractor evaluation flights and during the Government evaluation tests, the contour at the outboard end of one blade deformed in flight and caused extremely high one-per-rev vibrations. After the helicopter had landed, permanent creases in the upper and lower surfaces of the blade were visible.

An internal examination of the blade revealed that vent holes at the tip had become clogged. The skin panels (Figure 82, Appendix I) were bulged out, and the inner skins had buckled. A stiffening structure between the skin panels in the outboard three feet of the blade had detached from the lower skin panel. The internal pressure at the tip of a blade with plugged vents was calculated to be as much as five psi above ambient. Spread over the outboard two feet of blade, this pressure produces approximately 2500 pounds force, spreading the skins apart. This is apparently what bulged the contour. A positive venting system or nonhollow blade construction would eliminate the problem. The remaining blades were inspected internally with a borescope, and two blades were found to have unbonded stiffening structure.

Either the bulged blade or one of the blades with the unbonded stiffening structure was flown during the contracted tests. These discrepancies could also account for the observed differences, discussed above, between the loads in the upper and lower rotor and for the sensitivity of this rotor to the popped-out-of-track condition.

#### BLADE TRACKING

The elimination of one-per-rev vertical vibrations from a multi-bladed rotor can be a time-consuming process of making trial and error adjustments to pitch links or blade tabs to equalize all blades aerodynamically throughout the helicopter's velocity envelope. During the Model 609 test program, a Strobex Tracker was used for this process. Reflective coded targets were placed on each blade tip and observed visually when "stopped" by the powerful light that was synchronized with the rotor speed. This relatively small and easily portable unit allows tracking in forward flight as well as on the ground, and works well even in bright sunlight.

During the test program, the behavior of each rotor blade was monitored visually throughout the rpm and speed range. There were significant differences between blades because of small

differences in twist or contour causing blade "crossovers" in certain speed regimes. The visual track mapping technique was used to make up the best combinations (pairings) of individual blades with no time lost to random experimentation.

The 3-inch vertical separation of upper and lower rotors made tracking a little more difficult than it would have been with all four blades in one plane, but 2-per-rev fuselage vibrations were a good indication of mismatches between upper and lower blade sets.

| TABLE IX. SUMMARY OF TECHNICAL PROBLEMS ENCOUNTERED DURING THE 609 FLEXBEAM ROTOR PROGRAM |                                                                                                                                         |                                                                                                            |             |
|-------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|-------------|
| Problem                                                                                   | Cause/Reason                                                                                                                            | Comment/Solution/<br>Suggestion                                                                            | See<br>Page |
| Calculated hovering performance compares poorly to measurements.                          | (a) Performance<br><br>Unequal thrusts of the two blade pairs were not modeled, and use of blade element momentum theory is optimistic. | Use free wake analysis for hover calculation and investigate blade pair separation effects on performance. | 16          |
|                                                                                           | (b) Handling Qualities                                                                                                                  |                                                                                                            |             |
| High gust sensitivity.                                                                    | Inherent in rigid type rotors. Sensitivity increases with hub restraint.                                                                | SCAS was effective in reducing gust response.                                                              | 10, 21      |
| High control sensitivity at high speeds.                                                  | Same as above.                                                                                                                          | Force feel system adequately managed the control sensitivity.                                              | 9, 43       |
| Blade angles did not correspond to stick inputs for steps or pulses.                      | Elasticity in control system and pylon coupling.                                                                                        | Measured blade angles at the rotor were used for analysis and correlation when exactness was needed.       | -           |

| TABLE IX. Continued                                                                                       |                                                                                                                                                     |                                                                                                                                                                                                                    |
|-----------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Problem                                                                                                   | Cause/Reason                                                                                                                                        | Comment/Solution/<br>Suggestion                                                                                                                                                                                    |
| Permanent blade deformations occurred.                                                                    | (c) Blade and Rotor<br><br>Blade vent holes became clogged, and internal pressure loads adding to normal forces and moments caused the deformation. | Positive venting system or nonhollow blade construction.                                                                                                                                                           |
| Blades would "pop" out-of-track at high forward speeds, causing large 1/rev vibrations in the helicopter. | High tip Mach numbers coupled with blade dissimilarities, torsional flexibility, and contour flexibility.                                           | Increase blade torsional stability, solid core instead of shell blade construction for contour stability, and use airfoils at the blade tip that have good moment characteristics at high Mach numbers.            |
| Maneuvers limited by 1/rev beam and chord loads in yoke and 1/rev chord loads in the blade.               | High amplification of 1/rev aerodynamic chord loads combined with flapping and Coriolis moments.                                                    | Use some type of elevator system feedback during maneuvers to reduce rotor flapping and accompanying Coriolis moments. Conceptual changes in the rotor design are required to reduce the high 1/rev amplification. |

126

10, 121

64

TABLE IX. Continued

| Problem                                                                                                                                                     | Cause/Reason                                                                                                                                                                   | Comment/Solution/<br>Suggestion                                                                                                                                           | See<br>Page |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| (c) Blade and Rotor - Continued                                                                                                                             |                                                                                                                                                                                |                                                                                                                                                                           |             |
| High yoke stresses in autorotation landings.                                                                                                                | High flapping after initial ground contact.                                                                                                                                    | After tail skid contact it is normal to use both cyclic and collective to cushion main gear contact, but the pilot has no indication of when he is using too much cyclic. | 92          |
| 1/rev vibrations would occur in the ship during high gross weight and/or maneuver flights.                                                                  | Slight "unseating" of the main rotor retention system.                                                                                                                         | Bolt the yokes together and use one set of splines to drive both pairs of blades.                                                                                         | 11, 120     |
| Load differences between the instrumented blades. The lower rotor (orange blade) loads were up to 15 percent higher than the upper rotor (red blade) loads. | Vortex field from the upper rotor causes the higher loads in the lower rotor or airfoil contour changed in flight and differing aerodynamic forces caused the different loads. | Investigate blade separation effects. Schlieren flow visualization could be used on models.                                                                               | 120         |
| Initial difficulty in blade tracking.                                                                                                                       | Used "flag," difficult to determine from ground runs whether to adjust blade tab or pitch.                                                                                     | Strobe tracker allowed in-flight observations and thereby allowed relatively quick tracking of all four blades.                                                           | 126         |

TABLE IX. Continued

| Problem                                                                   | Cause/Reason                                                                                                           | Comment/Solution/<br>Suggestion                                                                                                                                                                                                      | See<br>Page |
|---------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
|                                                                           | (d) Fuselage Vibration                                                                                                 |                                                                                                                                                                                                                                      |             |
| Increased 4/rev vibration in maneuvers.                                   | Increased out-of-plane blade response in third symmetric beam mode.                                                    | Some increase in vibrations with load factor is desirable. Relocation of the third symmetric beam mode might be effective in reducing vibration. However, the increased 4/rev appears to be due to increased aerodynamic excitation. | 100, 101    |
| Increased 4/rev vibration in transition.                                  | Increased out-of-plane rotor response at 4/rev and some increased coupled in-plane and out-of-plane response at 3/rev. | Vortex interference is probable cause. More investigation is recommended in this area.                                                                                                                                               | 100, 101    |
| Insensitivity to pylon spring rate changes in the fore and aft direction. | Friction in the focus links and pylon torque restraint system prevented the small pylon deflections required at 4/rev. | The use of elastic elements in lieu of bearings would avoid this and the next problem.                                                                                                                                               | 111         |

| TABLE IX. Concluded                                                                                                            |                                                                                                                                                                                                                           |                                                                                                                                                                          |             |
|--------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| Problem                                                                                                                        | Cause/Reason                                                                                                                                                                                                              | Comment/Solution/<br>Suggestion                                                                                                                                          | See<br>Page |
| (d) Fuselage Vibration - Concluded                                                                                             |                                                                                                                                                                                                                           |                                                                                                                                                                          |             |
| Increase in 4/rev vibration in all flight regimes midway through the test program.                                             | Bearing became unstaked in the left front pylon focus link.                                                                                                                                                               | Fuselage vibrations were lower after the link was replaced. Since angular pylon deflections are so small, any looseness in joints significantly alters dynamic response. | 11          |
| Initial fuselage mode shape analyses were inconsistent. Reduced data showed unexplained phase shifts among the accelerometers. | Accelerometer data were recorded on different channels on the magnetic tape system. Different type analog filters were used to reduce the data on the different channels which introduced the phase shifts into the data. | The same filters were used to reduce the accelerometer data when used for mode shape analysis.                                                                           | -           |

## CONCLUSIONS

The conclusions in this section are in the order in which the topics were first discussed. Conclusions are separated into those pertaining to computer correlation and those resulting from flight test.

### PERFORMANCE

#### C-81 Computer Correlation

- The computed forward flight performance is very sensitive to changes in the blade drag data. After drag input values were adjusted, the performance of the test aircraft correlated well with that predicted by means of computer program C-81.
- Predicted hover performance of the test aircraft correlated poorly with measured data.

### HANDLING QUALITIES

#### Flight Test

- The helicopter was statically and dynamically stable in all flight conditions, with the overall handling qualities good to excellent.
- High control sensitivity at high speeds was managed adequately with the aid of a force feel system.
- The pilots commented on high gust sensitivity but the use of SCAS alleviated the problem.

#### C-81 Computer Correlation

- Correlation between measured handling qualities and those predicted by computer program C-81 was good.

### FUSELAGE VIBRATIONS

#### Flight Test

- Vibrations were primarily four-per-rev and generally of a low enough amplitude to give the pilot and copilot a comfortable ride.

### NASTRAN Computer Correlation

- The focused pylon generally behaved as predicted in the lateral direction. Friction in the system prevented the pylon from making the small deflections it should have made at four-per-rev in the fore-and-aft direction.
- Correlation between measured fuselage vibrations and those resulting from NASTRAN calculations was poor.

### ROTOR LOADS IN LEVEL FLIGHT AND MANEUVERS

#### Flight Test

- Maneuvering above 1.3 G's at high gross weight (14,000 pounds) and high speed (150 knots) was precluded by loads in the yoke and the inboard section of the blade.
- High loads in maneuvers were caused by the high amplification of chordwise one-per-rev aerodynamic forces and by Coriolis moments resulting from flapping and coning.
- At high advancing blade tip Mach numbers, the blade track changed suddenly; this was caused by blade contour flexibility, torsional flexibility, and blade dissimilarities.
- The rotor was stable in all test conditions.
- Level flight blade and yoke loads were within endurance limits. There were no resonant conditions in the blades within the operating envelope.

### C-81 Computer Correlation

- Forward flight chord moment correlation is good above  $\mu = .15$ . Beam moment correlation is good outboard of the flexure. Beam moment correlation in the flexure is poor. Errors in the computations that cause slight differences in flapping (e.g., different trim attitudes) also cause poor beam moment correlation. Additionally, more accurate modeling of the flexure would improve the correlation.
- Prediction of loads in hover is poor.
- The correlation of loads during the maneuver is fair, but further work is needed in this area.

## FATIGUE LIFE ANALYSIS

### Flight Test

- The rotor system meets the fatigue life requirements of the utility helicopter flight spectrum (defined in Table III) with the following exceptions:
  1. Flight procedures must be developed for avoiding high rotor yoke stresses during autorotation landings.
  2. The high-speed, high-gross-weight maneuvers must be deleted from the flight envelope.
- With the above qualifications, the rotor system would have over 2000 hours fatigue life.

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## APPENDIX I TEST VEHICLE AND ROTOR

### MAIN ROTOR SYSTEM

The Model 609 is a hingeless flexbeam rotor. Its inboard area is shown in Figure 80. The hub has two titanium flexbeam yokes individually mounted to the mast. (Mounting details are shown in Figure 81.) The steel spindles are mounted in needle bearings for feathering freedom. Wire straps carry the centrifugal load.

The blades are of panel construction, with 301 1/2-hard stainless steel skins (Figure 82). They have inboard doublers for stiffness and strength, and are retained in the grips by two bolts (per blade) arranged in the chordwise direction.

For purposes of simplified mathematical modeling, the 609 flexbeam rotor can be represented as a flapwise articulated rotor with rigid blades. The equivalent hinge offset of such an articulated rotor produces a hub moment per degree flapping equal to the moment produced by the flexbeam rotor. Define flapping in the hingeless rotor as the angle between a line from the centerline of the hub to 75 percent radius and a perpendicular to the mast. Then, the equivalent flapping hinge offset (for the articulated rotor) is located at 5 percent radius. The hub moment is approximately 1920 foot-pounds/degree per blade. For control power calculations, the mast and pylon have to be accounted for separately.

The dimensions of the main rotor, tail rotor, and aircraft are listed in Table X. The dimensions, travels, and riggings of the control system are given in Table XI and Figure 83.

### ENGINE AND TRANSMISSION

A Lycoming T55-L-7B or -7C turboshaft engine, with a normal rated power of 2400 shp, drives the main and tail rotors. The engine is fuel-flow limited to 2250 shp.

The transmission is a development model, designated Model 583. It is rated at 1680 hp at 6300 input shaft rpm for continuous operation, and 2000 hp at the same input rpm for five minutes. Table XII gives the speeds of its shafts.

### FOCUSED PYLON

An overall view of the rotor and pylon system is shown in Figure 84. The pylon is supported by four links that can be focused at various mast stations and restrained by spring and lever arrangements. The torsional and longitudinal restraints are two forward-facing links which are attached to fulcrums. The fulcrums are connected by a torque tube for the torsional restraint and connect to springs for the longitudinal restraint. Lateral pylon motion is restrained by two lateral links connected to springs. Figure 85 shows a closeup of the pylon and lateral restraint link (also see schematic, page 4).

### FLIGHT CONTROL SYSTEMS

The main rotor is controlled by collective and cyclic pitch controls with the travel ranges as given in Table XI. The control sticks and pedals are arranged as in a UH-1 helicopter. The elevator settings can be changed  $\pm 2.0^\circ$  about the initial trim position by an electric actuator. A meter displays the trim position to the pilot. The SCAS and force feel system are described in the next sections.

### STABILITY AND CONTROL AUGMENTATION SYSTEM (SCAS)

A three-axis SCAS allows the response, sensitivity, and damping to be tailored for the desired handling qualities, as well as decreasing the influence of external disturbances and cross-coupling between axes. SCAS authority is limited to  $\pm 7.5$  percent of longitudinal,  $\pm 7.5$  percent of lateral, and  $\pm 10$  percent of directional control. In the event of an electrical or hydraulic failure, or when the system is turned off, the actuators slowly center and lock.

### FORCE-FEEL SYSTEM

The electric-hydraulic cyclic force feel system generates artificial stick feel and trims the stick. It commands lateral stick force gradient as a function of airspeed, and longitudinal stick force gradient as a function of airspeed and pitch rate. Different force gradients can be selected for the lateral and longitudinal axes. These are shown in Figure 86.

Figure 87 shows the pitch rate portion of the longitudinal stick force generated when the pitch rate gain is adjusted to maximum and the airspeed gradient is set to the minimum position. The total longitudinal stick force is a combination of the gradient produced by the pitch rate input and the gradient produced by airspeed.

Also controlled by airspeed are the stick trim rates, as shown in Figure 88. The variation of gradient and trim rate with airspeed allows the helicopter to have a light gradient and fast trim rate at hover and low speed, and a firm, positive maneuvering gradient and slower trim rate at higher speeds.

TABLE X. DIMENSIONAL DATA

Aircraft Weight

|                      |           |
|----------------------|-----------|
| Maximum Gross Weight | 14,170 lb |
| Minimum Gross Weight | 10,500 lb |

Aircraft Inertias

Nominal Gross Weight of 12,000 lb

|                         |                             |
|-------------------------|-----------------------------|
| I <sub>YY</sub> (Pitch) | 18,500 slug-ft <sup>2</sup> |
| I <sub>XX</sub> (Roll)  | 4,500 slug-ft <sup>2</sup>  |
| I <sub>ZZ</sub> (Yaw)   | 12,500 slug-ft <sup>2</sup> |
| I <sub>XZ</sub>         | 1,050 slug-ft <sup>2</sup>  |

Engine

|                    |             |
|--------------------|-------------|
| Mfg. Number        | T55-L7B/-7C |
| Normal Rated Power | 2250 HP     |

Main Rotor System

|                                              |                         |
|----------------------------------------------|-------------------------|
| Type                                         | Flexbeam Hingeless      |
| Number of Blades                             | 4                       |
| Rotor Diameter                               | 48.3 ft                 |
| Rotor Disc Area                              | 1833 ft <sup>2</sup>    |
| Disc Loading at Minimum Weight               | 5.73 lb/ft <sup>2</sup> |
| Disc Loading at Maximum Weight               | 7.73 lb/ft <sup>2</sup> |
| Rotor Solidity                               | 0.092                   |
| Airfoil Section                              |                         |
| Inboard                                      | NACA 64 x 18 Mod        |
| Tip                                          | NACA 0008 Drooped Mod   |
| Blade Chord                                  | 21.0 IN.                |
| Blade Twist                                  | -8.97 deg               |
| Blade Area (one Blade)                       | 42.27 ft <sup>2</sup>   |
| Minus Hub                                    | 36.32 ft <sup>2</sup>   |
| Location of Center of Hub                    |                         |
|                                              | FS 130.78               |
|                                              | WL 130.82               |
|                                              | BL -3.31                |
| Mast Tilt with Respect to Fuselage Waterline |                         |
|                                              | F/A 3 deg fwd           |
|                                              | Lat 2 deg left          |

TABLE X. - Concluded

Tail Rotor System

|                                                                                                         |                                 |
|---------------------------------------------------------------------------------------------------------|---------------------------------|
| Number of Blades                                                                                        | 2                               |
| Rotor Diameter                                                                                          | 9.66 ft                         |
| Rotor Disc Area                                                                                         | 73.3 ft <sup>2</sup>            |
| Rotor Solidity                                                                                          | .132                            |
| Airfoil Section                                                                                         | 10.5% Symmetrical               |
| Blade Chord                                                                                             | 12.0 in.                        |
| Gearing Ratio to Main Rotor                                                                             | 5.19                            |
| Location of Center of Hub                                                                               | FS 501.3<br>WL 126.5<br>BL -12. |
| Pitch-Flap Coupling - $\delta_3$<br>(Flap axis offset 30 deg to<br>avoid feathering due to<br>flapping) | 30 deg                          |
| Maximum Flapping Freedom                                                                                | 9.5 deg about<br>flapping axis  |

Horizontal Stabilizer

|                            |                      |
|----------------------------|----------------------|
| Area (Total)               | 38.3 ft <sup>2</sup> |
| Span (Total)               | 11.5 ft <sup>2</sup> |
| Chord                      | 40.0 in.             |
| Airfoil Section            | NACA 0012            |
| Aspect Ratio               | 3.45                 |
| Location of 25% Chord Line | FS 380.0<br>WL 58.0  |

Vertical Stabilizer

|                                                       |                      |
|-------------------------------------------------------|----------------------|
| Area (Total)                                          | 26.3 ft <sup>2</sup> |
| Aspect Ratio                                          | 1.96                 |
| Incidence of Zero Lift Line to<br>Aircraft Centerline | 7.0 deg right        |
| Location of Center of Pressure                        | FS 465.0<br>WL 88.0  |

TABLE XI. FLIGHT CONTROL SYSTEMS

CYCLIC CONTROLSLongitudinal Cyclic

|                                                                     |                                          |
|---------------------------------------------------------------------|------------------------------------------|
| Stick Travel                                                        | 12.50 in.                                |
| F/A Swashplate Incidence Angle<br>with Respect to Mast              |                                          |
| - Stick Full Forward                                                | 6.8 deg down fwd                         |
| - Stick Full Aft                                                    | 4.8 deg down aft                         |
| Ratio of Blade Feathering Angle<br>to Swashplate Angle              | 17/11                                    |
| Elevator Incidence at Mid Stick<br>Travel with Respect to Waterline | -3.4 DEG                                 |
| Elevator Gearing (See Figure 83)                                    |                                          |
| Pylon Motion Coupling Ratio                                         |                                          |
| Blade Angle/Fwd Pylon Tilt                                          | 1.02 $\frac{\text{deg}}{\text{deg}}$ aft |
| Blade Angle/Left Pylon Tilt                                         | 0.85 $\frac{\text{deg}}{\text{deg}}$ aft |

Lateral Cyclic

|                                                            |                                            |
|------------------------------------------------------------|--------------------------------------------|
| Stick Travel                                               | 12.50 in.                                  |
| Lateral Swashplate Incidence<br>Angle with Respect to Mast |                                            |
| - Stick Full Left                                          | 4.9 deg left                               |
| - Stick Full Right                                         | 3.1 deg right                              |
| Ratio of Blade Feathering Angle<br>to Swashplate Angle     | 17/11                                      |
| Pylon Motion Coupling Ratio                                |                                            |
| Blade Angle/Fwd Pylon Tilt                                 | 1.02 $\frac{\text{deg}}{\text{deg}}$ left  |
| Blade Angle/Left Pylon Tilt                                | 0.85 $\frac{\text{deg}}{\text{deg}}$ right |

COLLECTIVE CONTROLS

|                                |                                         |
|--------------------------------|-----------------------------------------|
| Stick Travel                   | 10.45 in.                               |
| Collective Blade Angle at Grip |                                         |
| - Stick Full Down              | 7.0 deg                                 |
| - Stick Full Up                | 25.0 deg                                |
| Pylon Motion Coupling Ratio    |                                         |
| Blade Angle/Fwd Pylon Tilt     | 1.13 $\frac{\text{deg}}{\text{deg}}$ Up |
| Blade Angle/Left Pylon Tilt    | 0 Collective                            |

TABLE XI.- Concluded

DIRECTIONAL CONTROLS

|                              |          |
|------------------------------|----------|
| Pedal Travel                 | 6.50 in. |
| Blade Pitch Angle with Pedal |          |
| - Full Left                  | 17.4 deg |
| - Full Right                 | -3.7 deg |

TABLE XII. COMPONENT SPEED RATIOS

| Component              | rpm  |      |      |      |
|------------------------|------|------|------|------|
| Input Shaft            | 5500 | 6000 | 6300 | 7000 |
| M/R Mast ( $N_R$ )     | 259  | 283  | 297  | 330  |
| T/R Driveshaft         | 4318 | 4711 | 4946 | 5496 |
| T/R Mast ( $N_{T/R}$ ) | 1345 | 1467 | 1541 | 1712 |

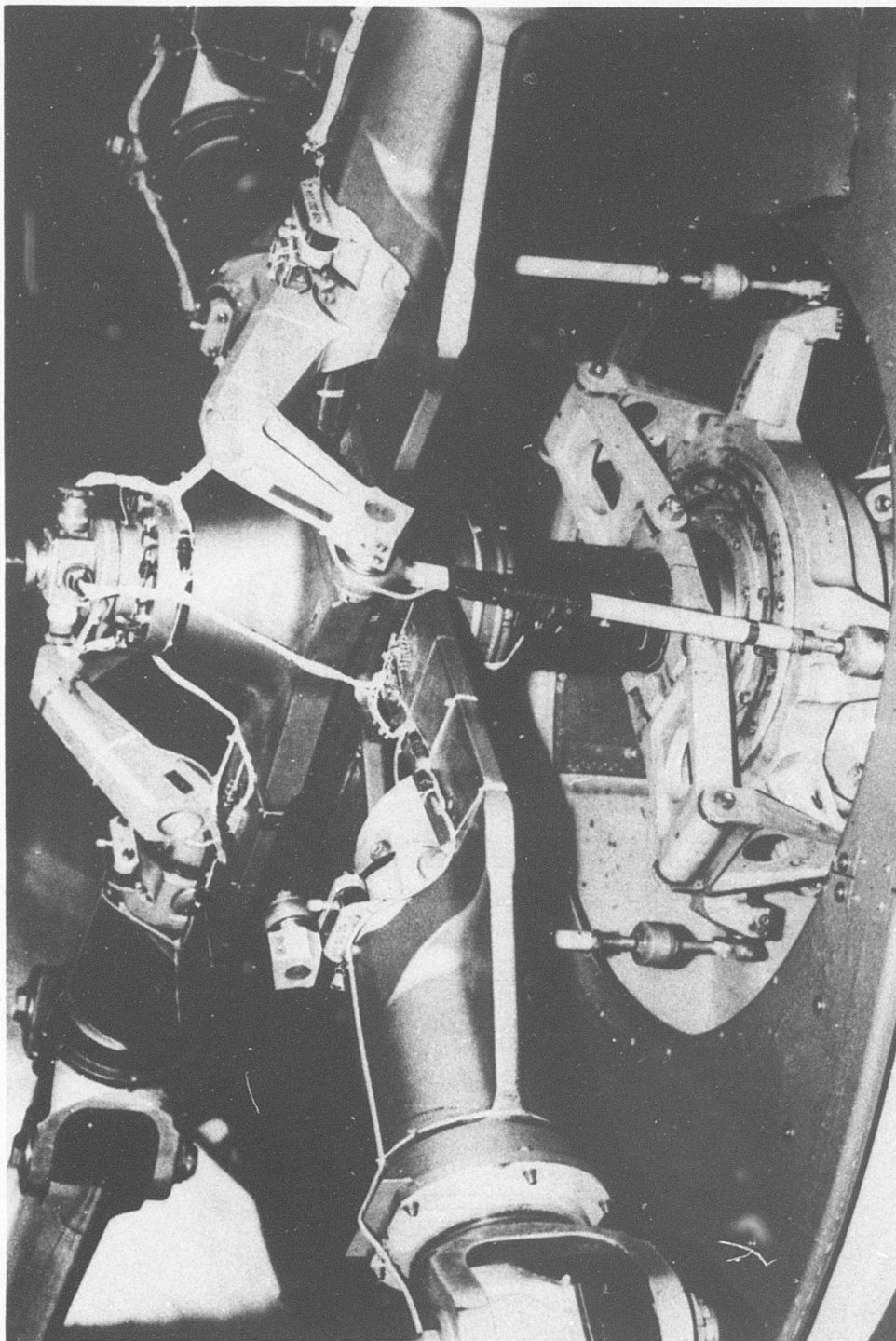


Figure 80. 609 Main Rotor System.

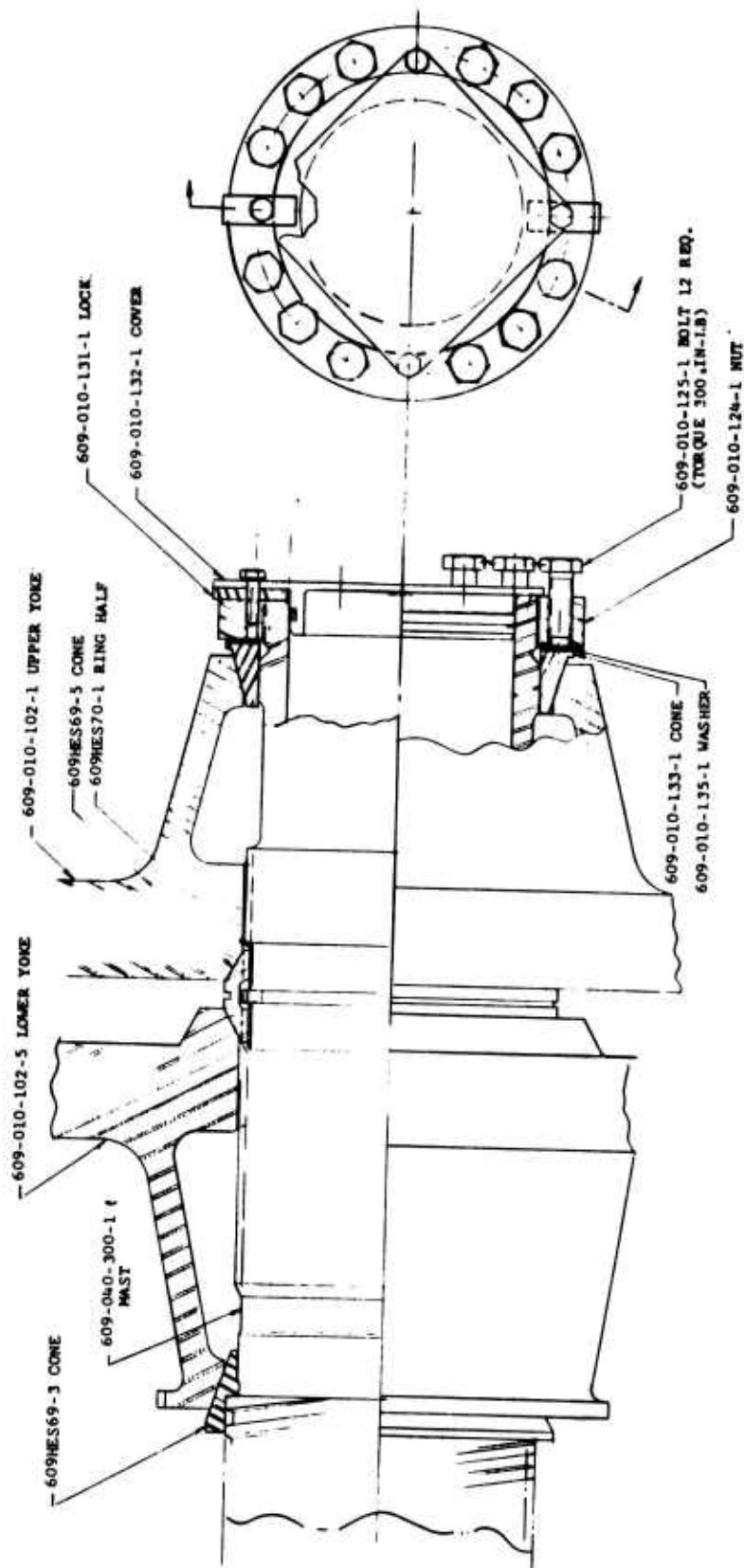


Figure 81. 609 Yoke and Mast Mounting Details.

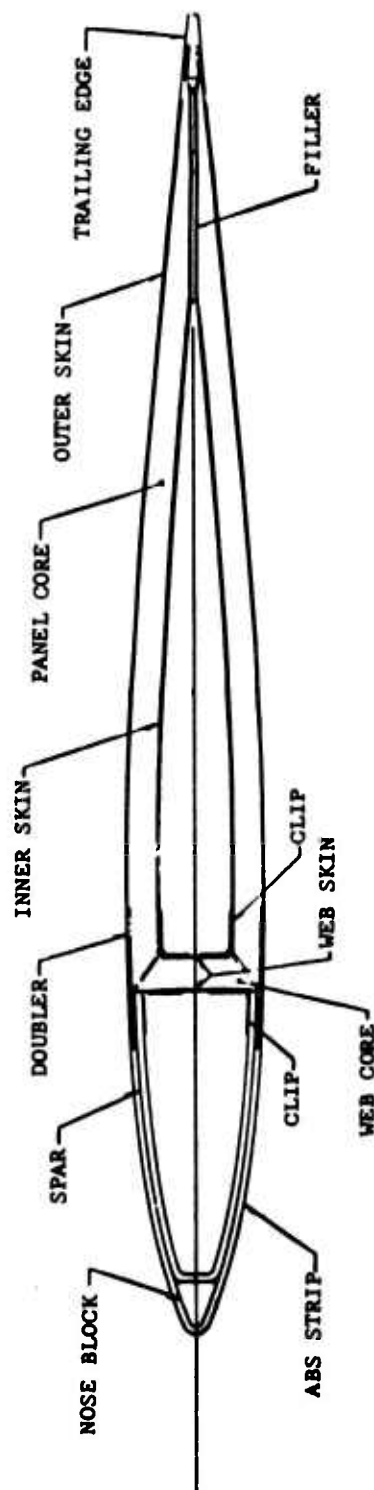
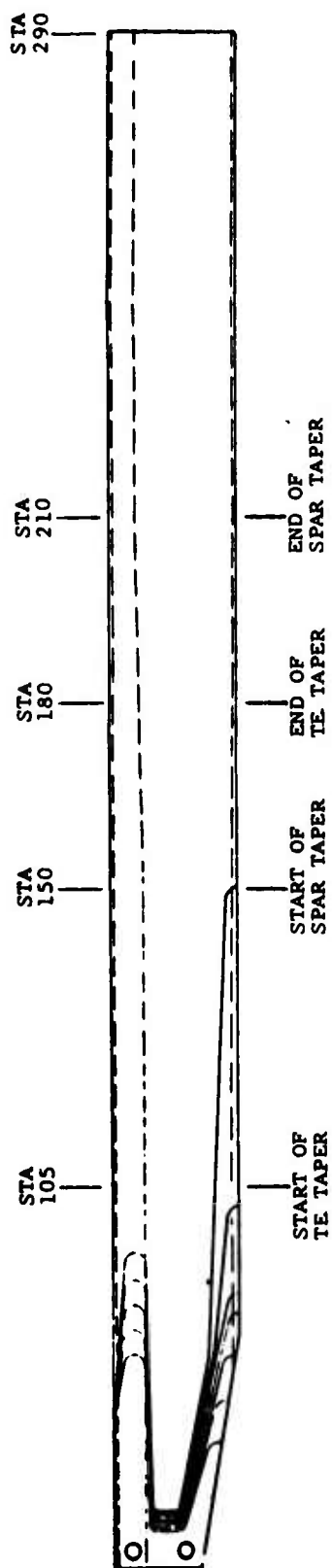
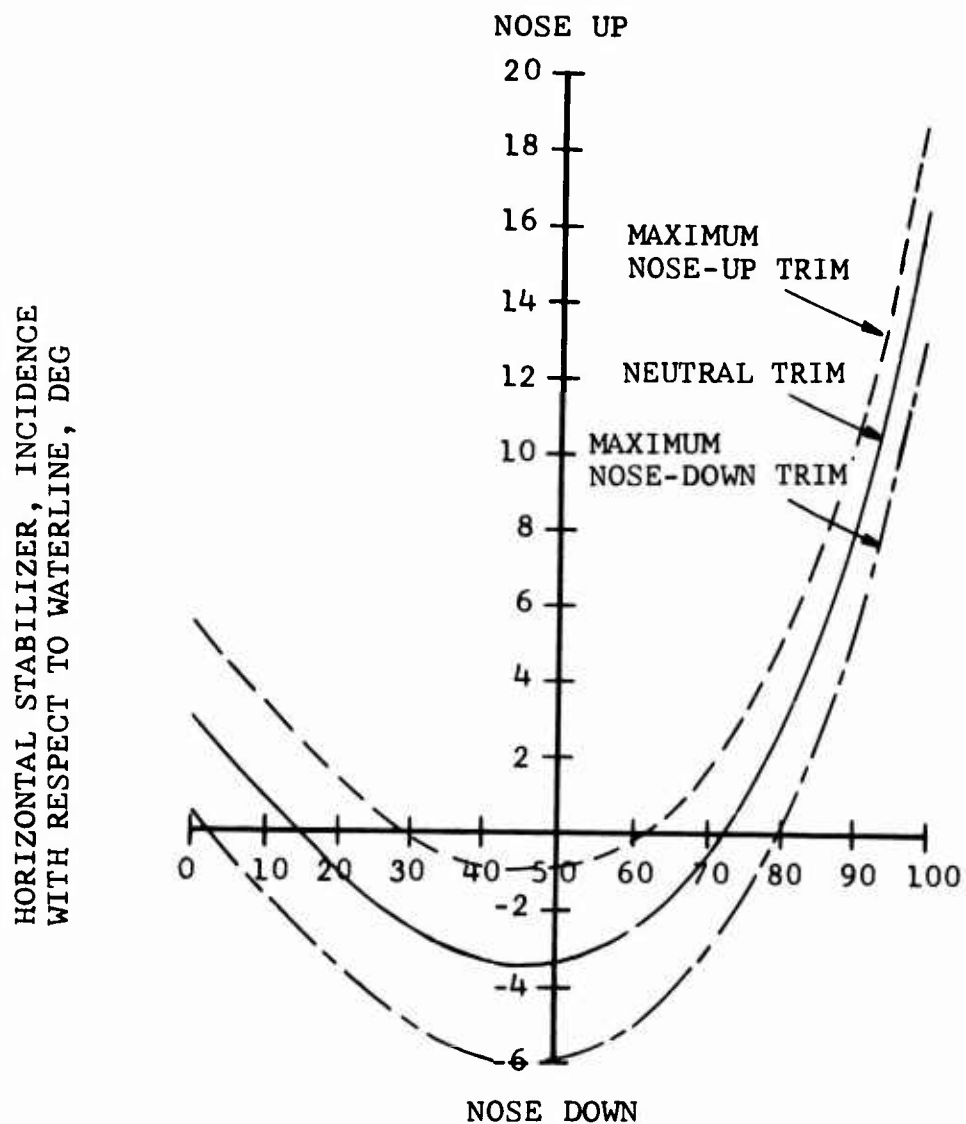


Figure 82. 609 Blade Assembly.



F/A CYCLIC STICK POSITION, 100% FULL FORWARD

Figure 83. Stabilizer and Trim Angle Versus Longitudinal Stick Position.

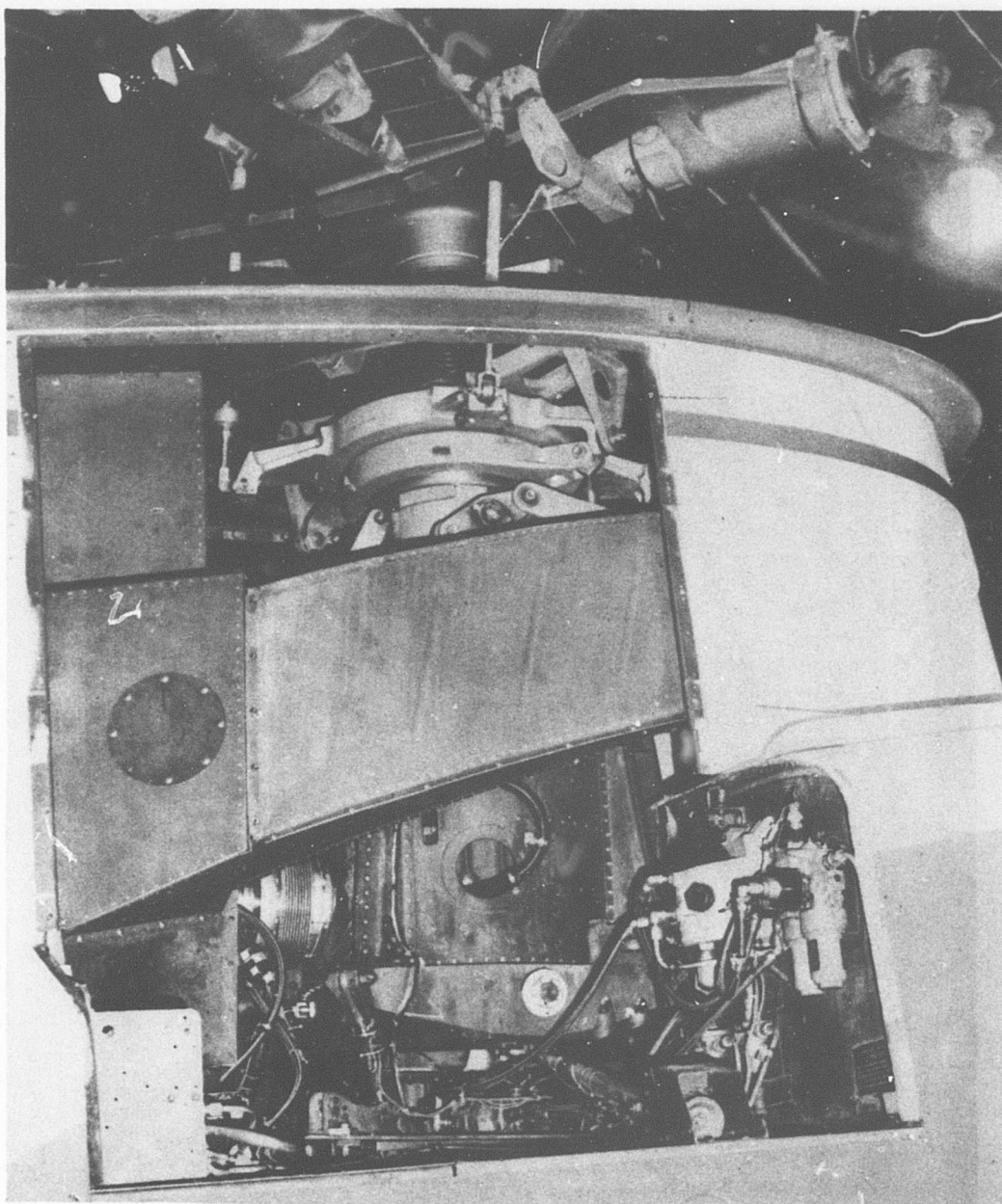


Figure 84. Pylon and 609 Main Rotor Assembly.

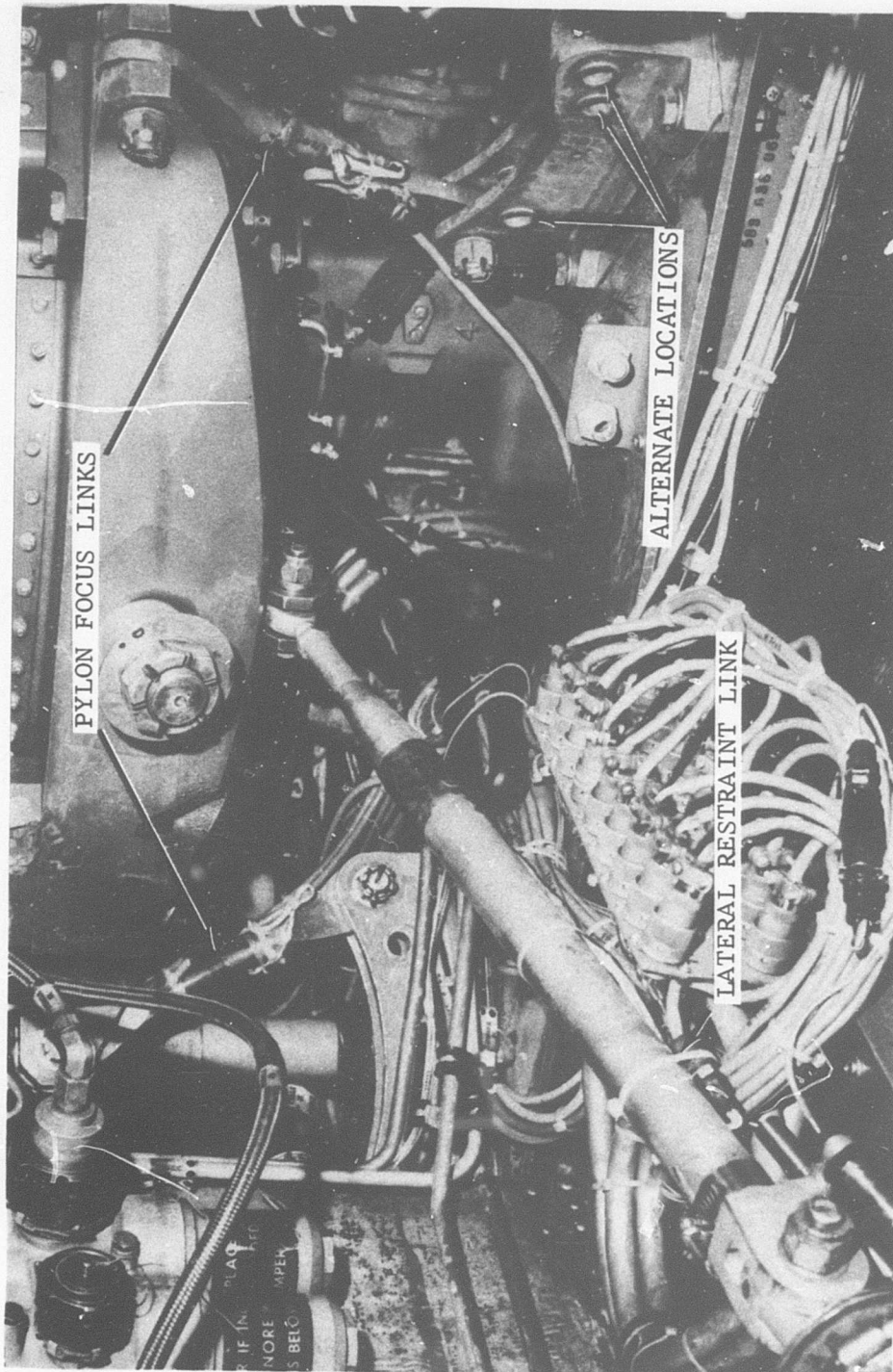


Figure 85. Pylon Base and Lateral Restraint Link.

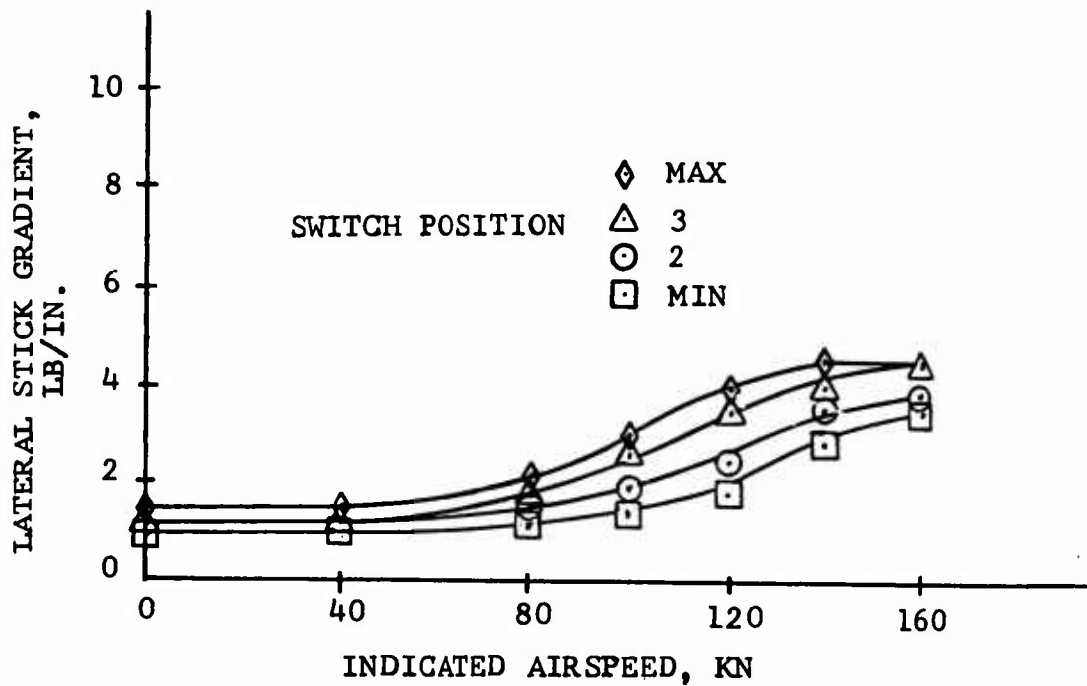
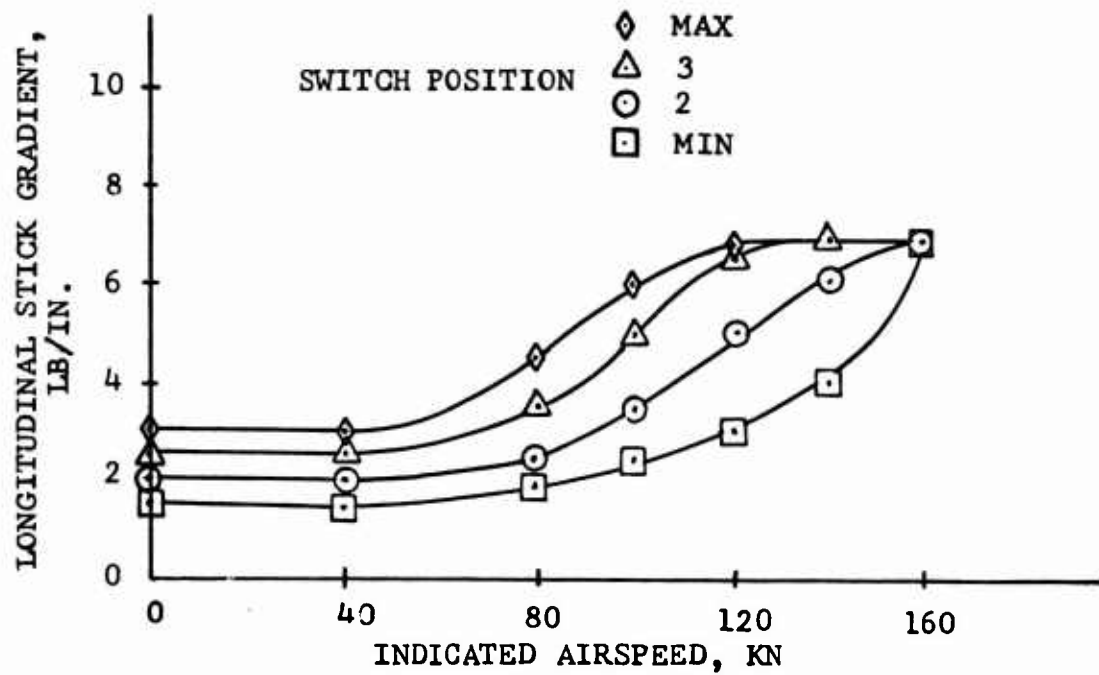


Figure 86. Measured Stick Gradients as a Function of Airspeed and Switch Position.

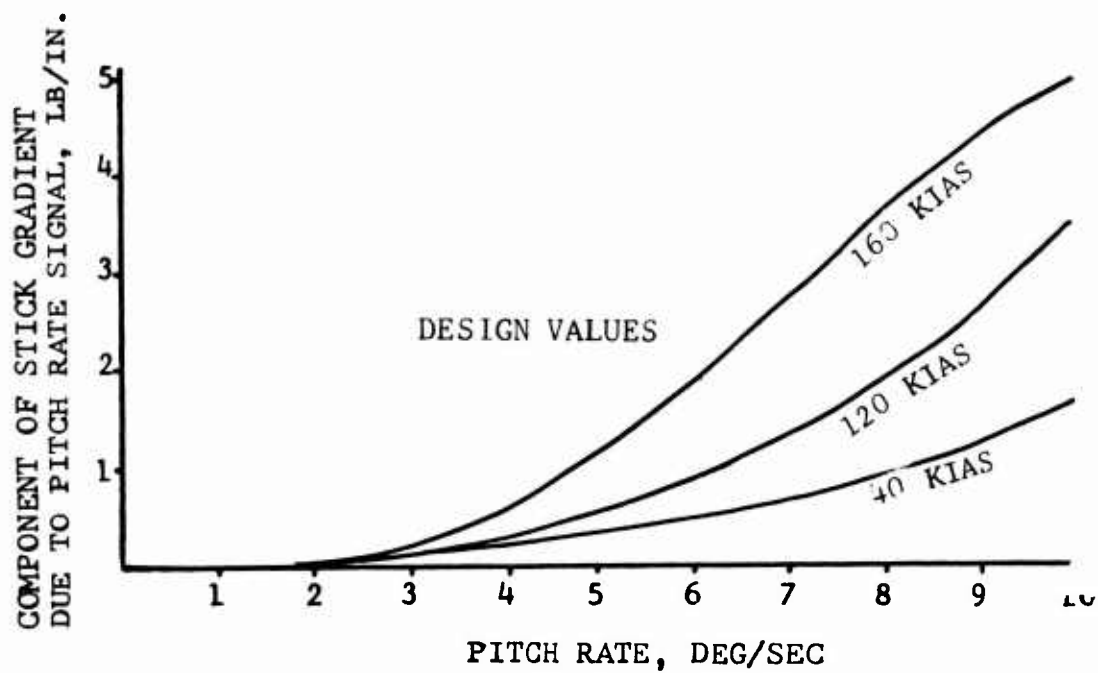


Figure 87. Stick Gradients due to Pitch Rate.

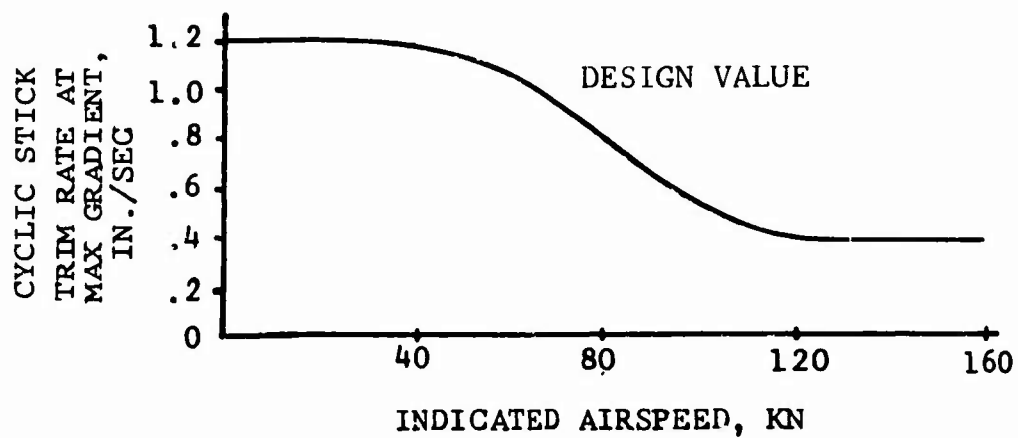


Figure 88. Cyclic Stick Trim Rates Versus Airspeed.

## APPENDIX II

### WIND-TUNNEL DATA

Full-scale wind-tunnel data from Reference 15 and previously unpublished rotor loads data from the same test are shown in Figures 89, 90, and 91 for different advance ratios. This was a two-bladed semirigid rotor with a diameter of 44 feet and a 21-inch chord. The plots show a very orderly mapping of oscillatory blade chord loads, power coefficients, and collective control positions versus lift and drag coefficients. Intercepts of constant collective and constant moment ( $\pm 28,000$ ) loci have been cross-plotted and were shown earlier in Figure 37 of the main body of the report.

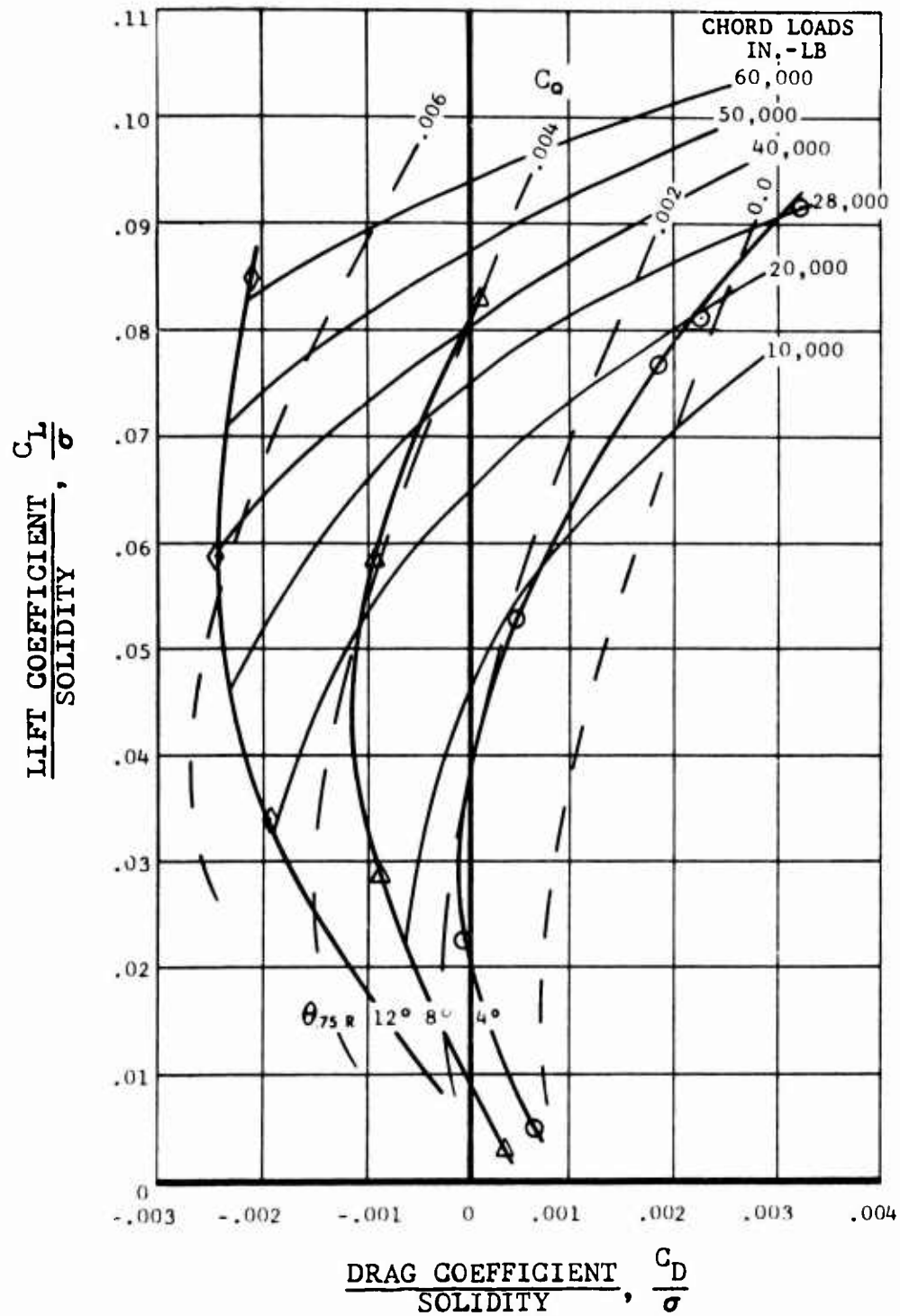


Figure 89. Lift Versus Drag Coefficients for Advance Ratio of .36.

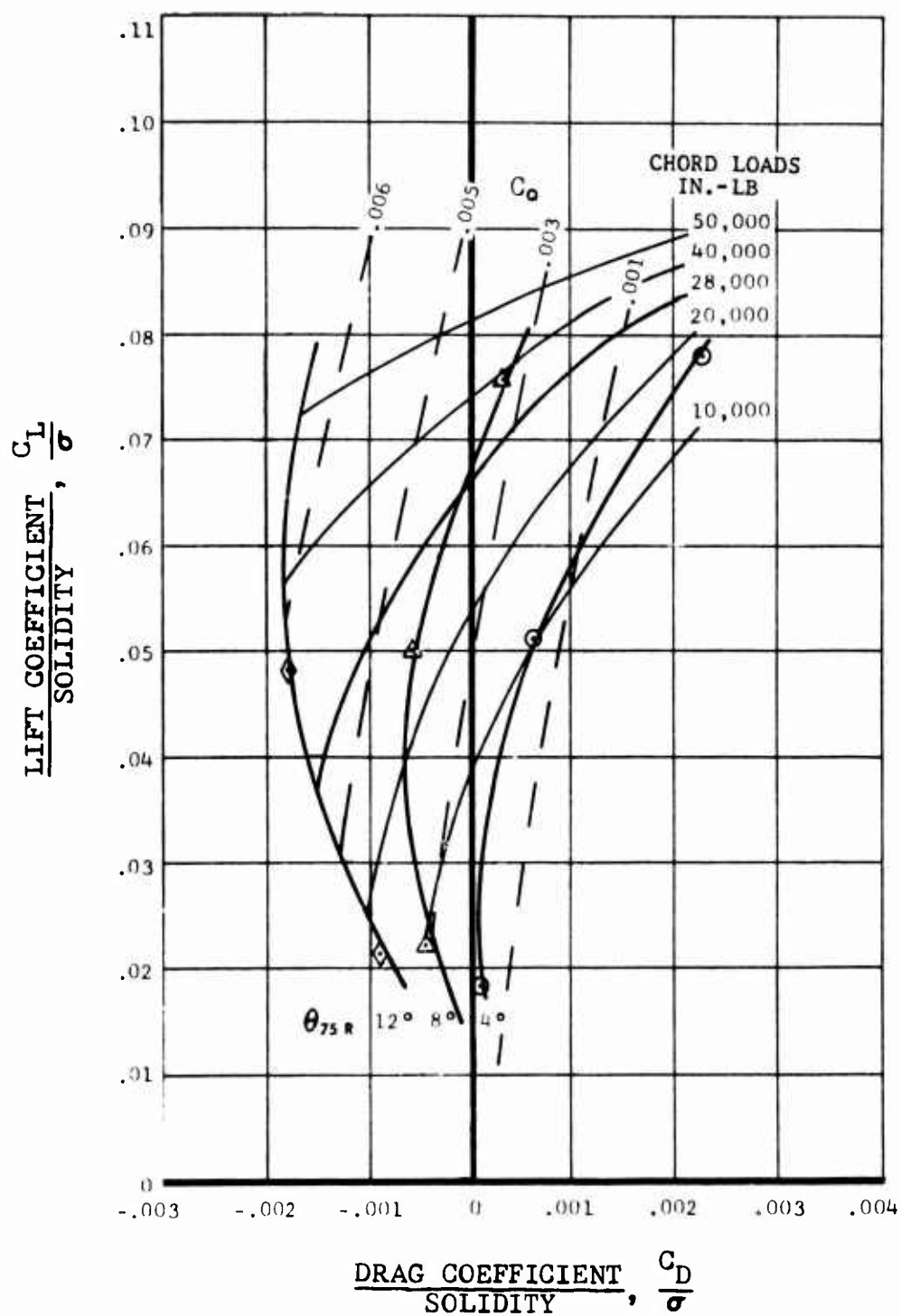


Figure 90. Lift Versus Drag Coefficients for Advance Ratio of .40.

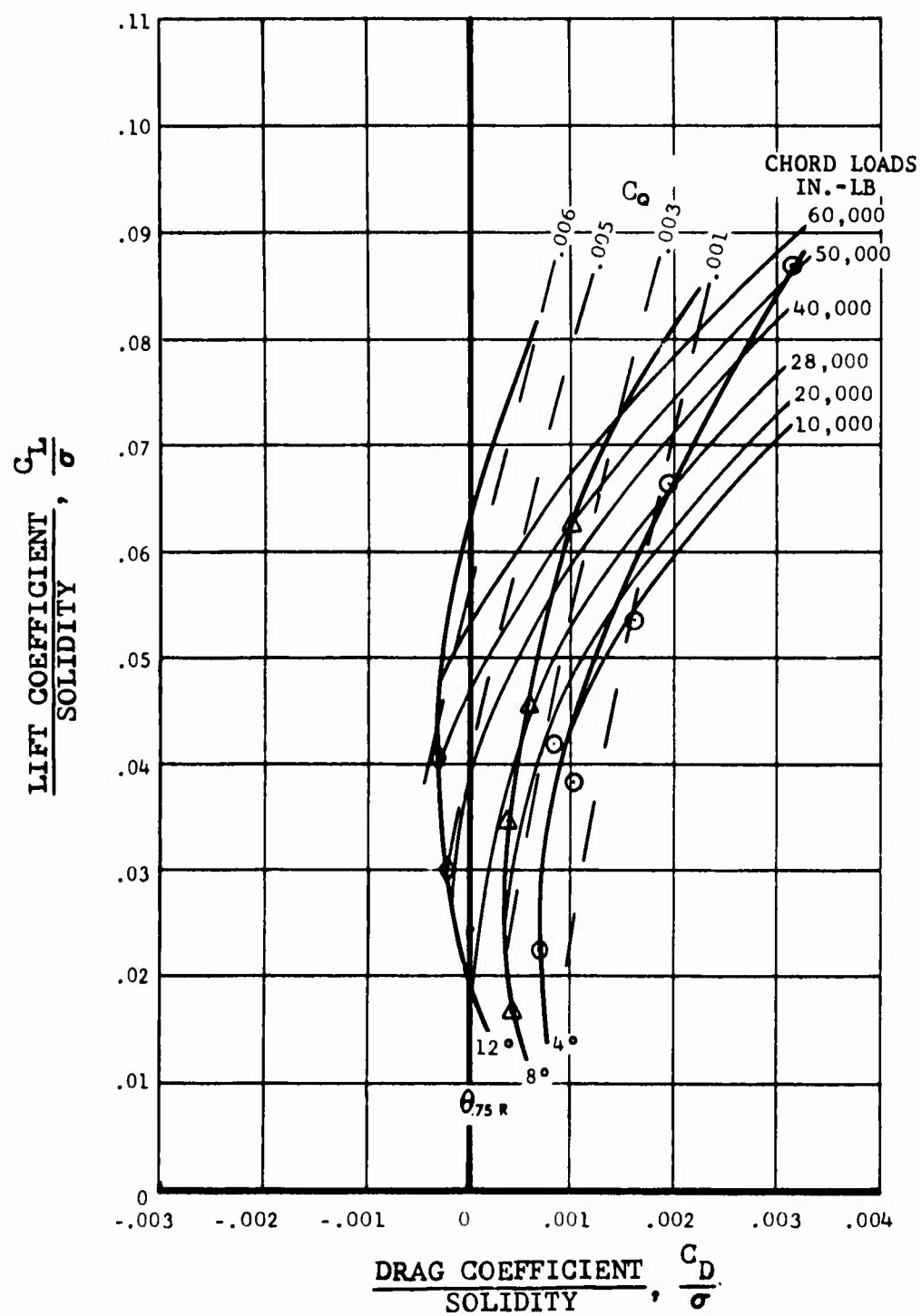


Figure 91. Lift Versus Drag Coefficients  
for Advance Ratio of .51.

### APPENDIX III FATIGUE LIFE ANALYSIS

The fatigue lives of the Model 609 main rotor and controls are based on loads measured during the flight loads survey. These were used in conjunction with a frequency-of-occurrence spectrum in order to determine the fatigue lives of the various dynamic components. The frequency-of-occurrence spectrum was established as representative of actual helicopter operations in the utility role.

#### FREQUENCY OF OCCURRENCE

The frequency-of-occurrence spectrum developed for this analysis (shown in Table III) was based on the utility helicopter spectrum presented in Reference 10. The spectrum of Reference 10 was modified to allow for those flight conditions which are allotted a number of occurrences per hundred hours. The occurrences per 100 flight hours were converted to percentage of flight time, and this percentage of time was subtracted from the appropriate flight conditions in order to keep the total flight time at 100 percent.

The load level survey documented the magnitudes and frequencies per revolution of loads, and these loads were then used to calculate fatigue lives of all dynamic components in the rotor system. In order to establish a representative loads spectrum, six gross weight/center-of-gravity configurations were used. These are shown in Table IV. The maximum loads were generated during high-speed maneuvers at the heavy gross weights.

#### LIFE CALCULATIONS

Fatigue life calculations were based on a comparison between flight stresses and the endurance limit of the component being analyzed. In most cases, only nominal stresses were evaluated. Stress concentration factors were incorporated into the analysis as reductions in the endurance limit. Endurance limits were established by the following methods:

1. Fatigue tests of the specific component.
2. Fatigue tests of a similar component.
3. Published data on material allowables.

Endurance limits were usually obtained for one value of mean stress. The effect of different mean stresses was then evaluated by use of a Goodman diagram similar to that of Figure 92.

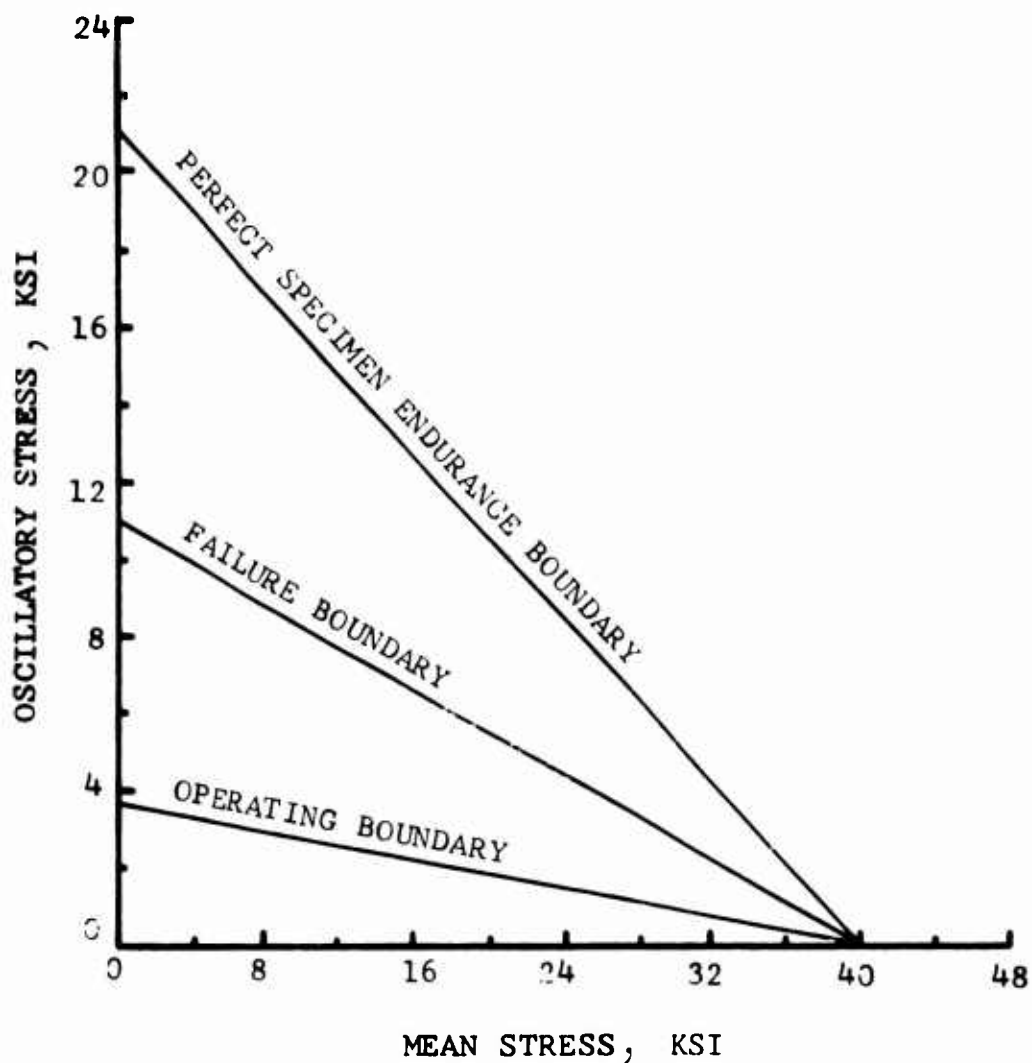


Figure 92. Modified Goodman Diagram for 2024-T4 and/or 2024-T42 Aluminum Alloy.

Once the ratio of operating stress to endurance limit (S/E) was established, those conditions which generate fatigue damage (S/E>1) were evaluated quantitatively by means of the theory of linear cumulative damage as expressed by Miner's Rule:

$$\sum_{i=1}^k n_i/N_i = 1 \quad \text{failure}$$

where  $n_i$  = number of cycles at a given ( $i^{\text{th}}$ ) load level

$N_i$  = number of cycles to failure at a given ( $i^{\text{th}}$ ) load level

$k$  = number of conditions

The theory and its application are discussed in detail in Reference 16.

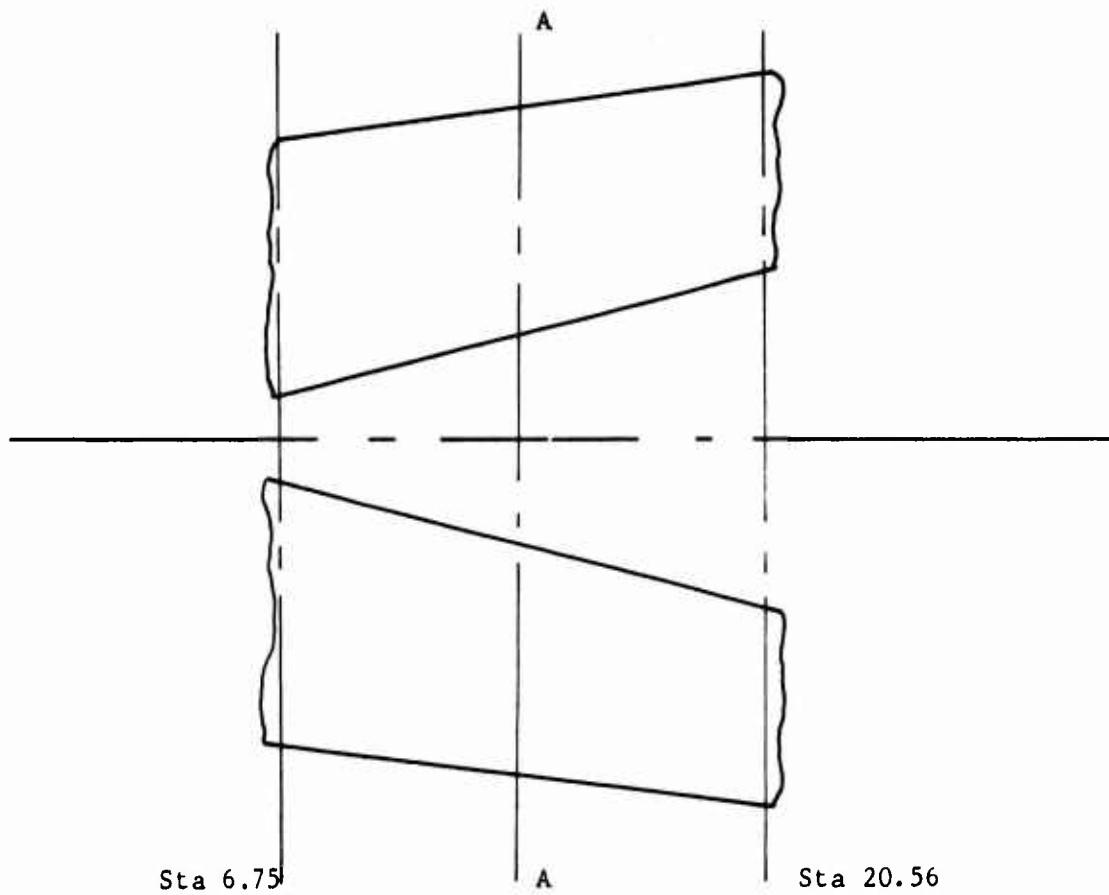
The calculation of S/E ratio was based on the maximum oscillatory load or stress measured during a maneuver, which was assumed to occur during the entire maneuver. This procedure was followed for all conditions except the full autorotation landing. The damage fraction for this condition was calculated on a cycle-by-cycle basis. (This method of fatigue life calculation was used only when the first method had been shown to be overly conservative.) Data for a full autorotation landing are available only for the emergency landing on May 23, 1973, and are not considered representative of loads generated during normal autorotation landings; for this reason, this maneuver is cycle-counted.

#### MAIN ROTOR HUB AND BLADE

##### Main Rotor Yoke Part No. 609-010-102-1

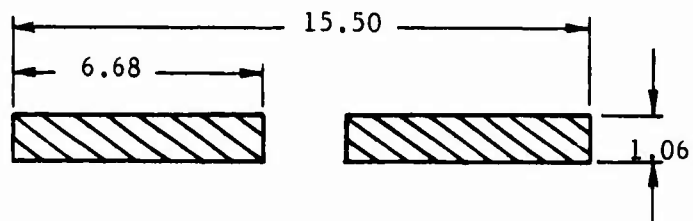
The main rotor yoke is a 6Al-4V titanium flexure subjected to beam and chord bending as well as to centrifugal loading in the axial direction. The two cross-sections at which the yoke was analyzed are shown in Figure 93. Analysis showed the yoke to be critical in fatigue at station 6.75. The flexure was analyzed as a slotted beam by the methods set forth on page 161 of Reference 17. The stress equation used for station 6.75 was:

$$\sigma_b = 0.707(C.F.) + 0.402(M_{B7.0}) + 0.024(M_{C13.65}) + 0.004(M_{C0.0})$$



All Dimensions in Inches

Sta 6.75



Sta 20.56

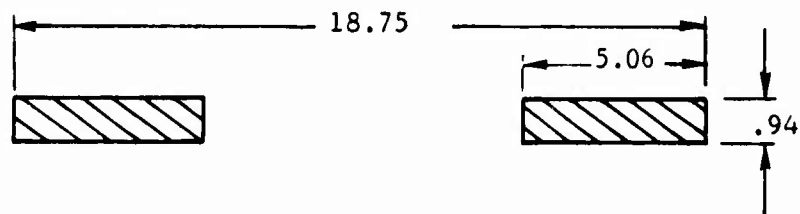


Figure 93. Main Rotor Yoke, Part No. 609-010-102-1.

where C.F. = centrifugal force at station 6.75

$M_{B7.0}$  = beam bending at station 7.0

$M_{C13.65}$  = chord bending at station 13.65

$M_{C0.0}$  = chord bending at station 0.0

An endurance limit of 30,000 psi at zero steady was used as the endurance limit for the yoke, which experiences a loading frequency of one cycle per revolution. On this basis, a fatigue life of 811 hours was substantiated for the Model 609 yoke, and Table XIII shows the calculations.

#### Main Rotor Spindle Part No. 609-010-140-1

The 609 main rotor spindle is made from 4340 steel, heat treated to an ultimate tensile strength of 180-200 ksi. The spindle acts as a grip for the main rotor blade and is attached to the yoke by means of the retention system (strap, fitting, and retention bolts). The spindle is subjected to beam and chord bending and an axial stress due to the centrifugal force. The loading frequency of the spindle is one cycle per revolution of the main rotor.

The spindle was evaluated at two locations, the main rotor blade attachment tangs at station 41.0 and a cross-section taken at station 34.75 (Section A-A in Figure 94). Section A-A was found to be more critical in fatigue, and therefore life calculations were based on stress at this section.

The cross-section of the spindle at station 34.75 is similar to the 204-011-102-17 yoke at its critical section (station 6.3). Both components are of 4340 steel, heat treated to the same tensile range (see Reference 18 for a comparison). Therefore the endurance limit established for the 204-011-102-17 yoke was used for the 609 spindle. (The S-N curve for the 204 yoke is shown in Figure 95.) An additional Goodman reduction for mean stress was used to obtain the value of 27,500 psi used as the endurance limit for the 609 spindle. Table XIV shows a summary of the fatigue life calculations, which substantiated a fatigue life of 7100 hours for the 609-010-140-1 spindle.

#### Main Rotor Blade Retention System

The oscillatory loading on the components of the blade retention system differs from that on other components of the main rotor system in that the major oscillatory stress on the retention system arises from start and stop of the main rotor (i.e., the application and removal of centrifugal force). In the

TABLE XIII. FATIGUE LIFE DETERMINATION OF 609  
M/R YOKE, PART NO. 609-010-102-1

| FLIGHT CONDITION            | FREQUENCY OF<br>OCCURRENCE<br>PCT. CYCLES IN<br>TIME 100 HRS. | OSCILLATORY<br>BENDING STR.<br>IN M/R YOKE<br>@ STA. 7.0 | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION |
|-----------------------------|---------------------------------------------------------------|----------------------------------------------------------|-------------------------------------|--------------------|
| <b>I. GROUND CONDITIONS</b> |                                                               |                                                          |                                     |                    |
| A. NORMAL START             | 0.1000                                                        | 1770                                                     | 0 AA                                | 0.0                |
|                             | 0.3000                                                        | 5310                                                     | 14496 CA                            | 0.0                |
|                             | 0.1000                                                        | 1770                                                     | 0 FA                                | 0.0                |
| B. NORMAL SHUTDOWN          | 0.1000                                                        | 1770                                                     | 9219 AA                             | 0.0                |
|                             | 0.3000                                                        | 5310                                                     | 8321 BA                             | 0.0                |
|                             | 0.1000                                                        | 1770                                                     | 0 FA                                | 0.0                |
| <b>II. POWER-ON ICE</b>     |                                                               |                                                          |                                     |                    |
| A. HOVERING                 |                                                               |                                                          |                                     |                    |
| 1. STEADY                   |                                                               |                                                          |                                     |                    |
| (A) 280 RPM                 | 0.6944                                                        | 11666                                                    | 16385 AA                            | 0.0                |
|                             | 2.0832                                                        | 34998                                                    | 16867 CA                            | 0.0                |
|                             | 0.6944                                                        | 11666                                                    | 11327 DA                            | 0.0                |
| (B) 295 RPM                 | 0.6944                                                        | 12291                                                    | 16251 AA                            | 0.0                |
|                             | 2.0832                                                        | 36873                                                    | 20166 CA                            | 0.0                |
|                             | 0.6944                                                        | 12291                                                    | 15518 EA                            | 0.0                |
| 2. LEFT TURN                | 0.2222                                                        | 3800                                                     | 18631 AA                            | 0.0                |
|                             | 0.6666                                                        | 11399                                                    | 19693 CA                            | 0.0                |
|                             | 0.2222                                                        | 3800                                                     | 13259 EA                            | 0.0                |
| 3. RIGHT TURN               | 0.2222                                                        | 3800                                                     | 19019 AA                            | 0.0                |
|                             | 0.6666                                                        | 11399                                                    | 24578 CA                            | 0.0                |
|                             | 0.2222                                                        | 3800                                                     | 11552 EA                            | 0.0                |
| 4. CONTROL REVERSAL         |                                                               |                                                          |                                     |                    |
| (A) LONGITUDINAL            | 0.0556                                                        | 951                                                      | 31091 AA                            | 2.022 0.000470     |
|                             | 0.1668                                                        | 2852                                                     | 31928 CA                            | 1.022 0.002792     |
|                             | 0.0556                                                        | 951                                                      | 24868 EA                            | 0.0                |
| (B) LATERAL                 | 0.0556                                                        | 951                                                      | 25151 AA                            | 0.0                |
|                             | 0.1668                                                        | 2852                                                     | 25038 CA                            | 0.0                |
|                             | 0.0556                                                        | 951                                                      | 15973 EA                            | 0.0                |
| (C) RUDDER                  | 0.0556                                                        | 951                                                      | 17903 AA                            | 0.0                |
|                             | 0.1668                                                        | 2852                                                     | 19249 CA                            | 0.0                |
|                             | 0.0556                                                        | 951                                                      | 11842 EA                            | 0.0                |
| B. MANEUVERS                |                                                               |                                                          |                                     |                    |
| 1. SIDEWARD FLIGHT          |                                                               |                                                          |                                     |                    |
| (A) TO THE RIGHT            | 0.1000                                                        | 1710                                                     | 8064 AA                             | 0.0                |
|                             | 0.3000                                                        | 5130                                                     | 29308 BA                            | 0.0                |
|                             | 0.1000                                                        | 1710                                                     | 10111 FA                            | 0.0                |
| (B) TO THE LEFT             | 0.1000                                                        | 1710                                                     | 13170 AA                            | 0.0                |
|                             | 0.3000                                                        | 5130                                                     | 16098 BA                            | 0.0                |
|                             | 0.1000                                                        | 1710                                                     | 11598 EA                            | 0.0                |
| 2. REARWARD FLIGHT          | 0.1000                                                        | 1710                                                     | 9099 AA                             | 0.0                |
|                             | 0.3000                                                        | 5130                                                     | 26426 BA                            | 0.0                |
|                             | 0.1000                                                        | 1710                                                     | 26205 EA                            | 0.0                |
| 3. NORMAL TAKE-OFF          | 0.1778                                                        | 3040                                                     | 32581 AA                            | 0.682 0.004460     |
|                             | 0.5334                                                        | 9121                                                     | 26354 CA                            | 0.0                |

TABLE XIII - Continued

| FLIGHT CONDITION  | FREQUENCY OF<br>OCCURRENCE<br>PCT. CYCLES IN<br>TIME 100 HRS. |        | OSCILLATORY<br>BENDING STR.<br>IN M/R YOKE<br>@ STA. 7.0 | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION |
|-------------------|---------------------------------------------------------------|--------|----------------------------------------------------------|-------------------------------------|--------------------|
| 4. NORMAL LANDING | 0.1778                                                        | 3040   | 19034 EA                                                 |                                     | 0.0                |
|                   | 0.4166                                                        | 7124   | 20855 AA                                                 |                                     | 0.0                |
|                   | 1.2498                                                        | 21372  | 27453 CA                                                 |                                     | 0.0                |
|                   | 0.4166                                                        | 7124   | 18452 EA                                                 |                                     | 0.0                |
| III. POWER-ON IGF |                                                               |        |                                                          |                                     |                    |
| A. LEVEL FLIGHT   |                                                               |        |                                                          |                                     |                    |
| % VL              | RPM                                                           |        |                                                          |                                     |                    |
| 1. 40             | 280                                                           | 0.1866 | 3135                                                     | 13671 AA                            | 0.0                |
|                   |                                                               | 0.5598 | 9405                                                     | 14088 CA                            | 0.0                |
|                   |                                                               | 0.1866 | 3135                                                     | 15536 FA                            | 0.0                |
|                   |                                                               | 0.1866 | 3303                                                     | 13859 AA                            | 0.0                |
|                   | 295                                                           | 0.5598 | 9908                                                     | 13555 CA                            | 0.0                |
|                   |                                                               | 0.1866 | 3303                                                     | 13610 FA                            | 0.0                |
|                   |                                                               | 0.4917 | 8261                                                     | 12568 AA                            | 0.0                |
|                   |                                                               | 1.4751 | 24782                                                    | 13296 CA                            | 0.0                |
| 2. 50             | 280                                                           | 0.4917 | 8261                                                     | 14502 FA                            | 0.0                |
|                   |                                                               | 0.4917 | 8703                                                     | 12964 AA                            | 0.0                |
|                   |                                                               | 1.4751 | 26109                                                    | 13632 CA                            | 0.0                |
|                   |                                                               | 0.4917 | 8703                                                     | 16049 FA                            | 0.0                |
| 3. 60             | 280                                                           | 0.7838 | 13168                                                    | 13020 AA                            | 0.0                |
|                   |                                                               | 2.3514 | 39503                                                    | 12471 CA                            | 0.0                |
|                   |                                                               | 0.7838 | 13168                                                    | 13765 DA                            | 0.0                |
|                   |                                                               | 0.7838 | 13873                                                    | 13870 AA                            | 0.0                |
|                   | 295                                                           | 2.3514 | 41620                                                    | 13327 CA                            | 0.0                |
|                   |                                                               | 0.7838 | 13873                                                    | 14467 FA                            | 0.0                |
|                   |                                                               | 1.0000 | 16800                                                    | 13406 AA                            | 0.0                |
|                   |                                                               | 3.0000 | 50400                                                    | 12799 CA                            | 0.0                |
| 4. 70             | 280                                                           | 1.0000 | 16800                                                    | 14229 DA                            | 0.0                |
|                   |                                                               | 1.0000 | 17700                                                    | 14754 AA                            | 0.0                |
|                   |                                                               | 3.0000 | 53100                                                    | 13411 CA                            | 0.0                |
|                   |                                                               | 1.0000 | 17700                                                    | 13522 FA                            | 0.0                |
| 5. 80             | 280                                                           | 1.5000 | 25200                                                    | 14173 AA                            | 0.0                |
|                   |                                                               | 4.5000 | 75600                                                    | 13849 CA                            | 0.0                |
|                   |                                                               | 1.5000 | 25200                                                    | 17517 DA                            | 0.0                |
|                   |                                                               | 1.5000 | 26550                                                    | 15461 AA                            | 0.0                |
|                   | 295                                                           | 4.5000 | 79650                                                    | 13118 CA                            | 0.0                |
|                   |                                                               | 1.5000 | 26550                                                    | 13650 FA                            | 0.0                |
|                   |                                                               | 1.7334 | 29121                                                    | 13664 AA                            | 0.0                |
|                   |                                                               | 5.2002 | 87363                                                    | 15339 BA                            | 0.0                |
| 6. 90             | 280                                                           | 1.7334 | 29121                                                    | 24648 DA                            | 0.0                |
|                   |                                                               | 1.7334 | 30681                                                    | 16343 AA                            | 0.0                |
|                   |                                                               | 5.2002 | 92044                                                    | 13391 CA                            | 0.0                |
|                   |                                                               | 1.7334 | 30681                                                    | 13793 DA                            | 0.0                |
| 7. 100            | 280                                                           | 0.9838 | 16528                                                    | 13706 AA                            | 0.0                |
|                   |                                                               | 2.9514 | 49583                                                    | 19618 BA                            | 0.0                |

TABLE XIII - Continued

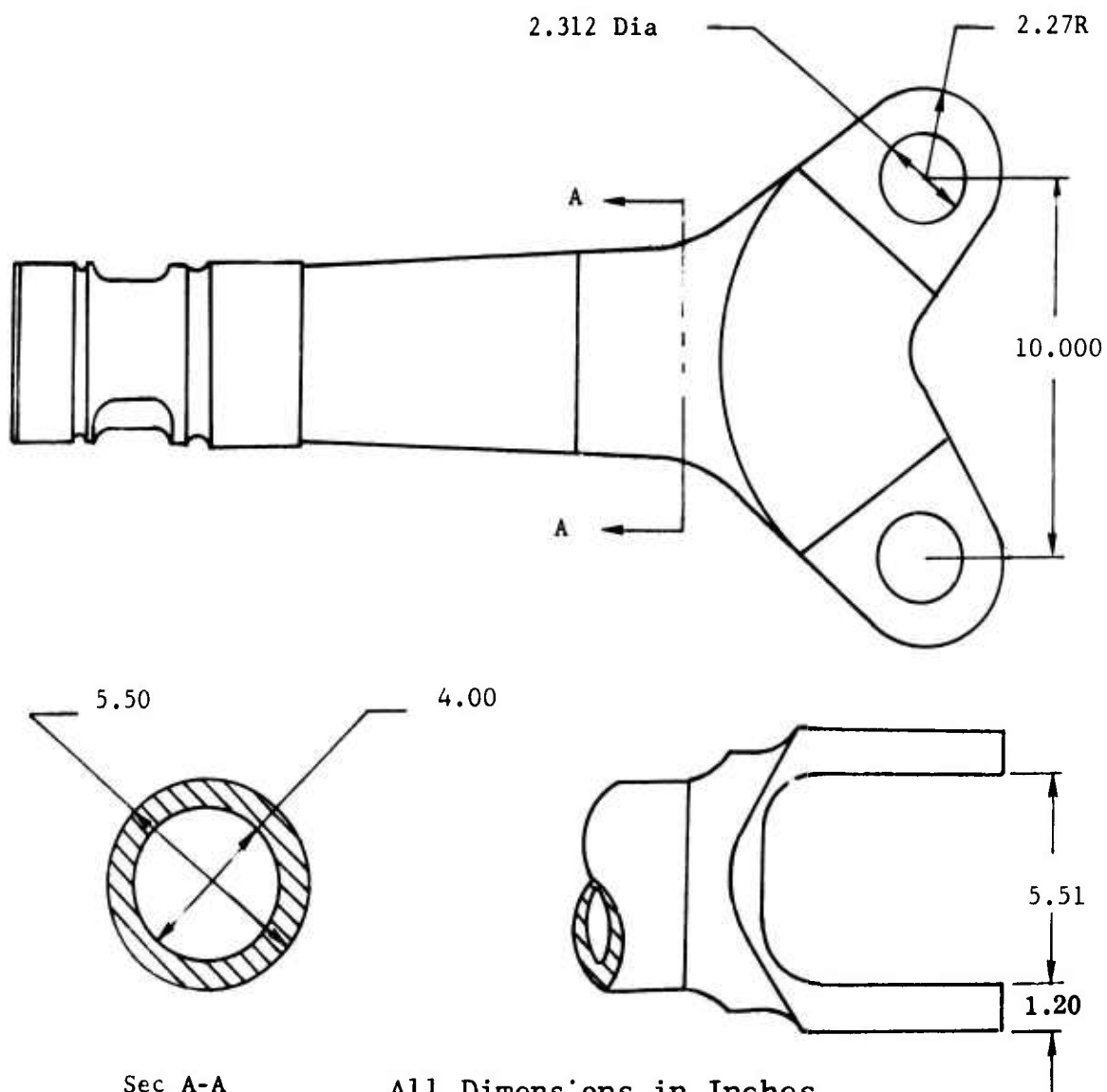
| FLIGHT CONDITION    |        | FREQUENCY OF OCCURRENCE<br>PCT. CYCLES IN<br>TIME LOC HRS. |          | OSCILLATORY<br>BENDING STR.<br>IN M/R YOKE<br>D STA. 7.0 | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION |
|---------------------|--------|------------------------------------------------------------|----------|----------------------------------------------------------|-------------------------------------|--------------------|
| 9. VNE              | 295    | 0.9838                                                     | 16528    | 23252 FA                                                 |                                     | 0.0                |
|                     |        | 0.9838                                                     | 17413    | 15972 AA                                                 |                                     | 0.0                |
|                     |        | 2.9514                                                     | 52240    | 16374 CA                                                 |                                     | 0.0                |
|                     | 280    | 0.9838                                                     | 17413    | 18467 DA                                                 |                                     | 0.0                |
|                     |        | 0.3500                                                     | 5880     | 14945 AA                                                 |                                     | 0.0                |
|                     |        | 1.0500                                                     | 17640    | 20805 BA                                                 |                                     | 0.0                |
|                     | 295    | 0.3500                                                     | 5880     | 23787 FA                                                 |                                     | 0.0                |
|                     |        | 0.3500                                                     | 6195     | 15357 AA                                                 |                                     | 0.0                |
|                     |        | 1.0500                                                     | 19585    | 15925 BA                                                 |                                     | 0.0                |
|                     | 0.3500 | 6195                                                       | 16419 EA |                                                          | 0.0                                 |                    |
| B. MANEUVERS        |        |                                                            |          |                                                          |                                     |                    |
| 1. CLIMB 0-60 KNOTS |        |                                                            |          |                                                          |                                     |                    |
| (A) M.C. POWER      |        | 0.6000                                                     | 10260    | 22135 AA                                                 |                                     | 0.0                |
|                     |        | 1.8000                                                     | 30780    | 19338 CA                                                 |                                     | 0.0                |
|                     |        | 0.6000                                                     | 10260    | 18962 FA                                                 |                                     | 0.0                |
| (B) T.O. POWER      |        | 0.2000                                                     | 3420     | 19263 AA                                                 |                                     | 0.0                |
|                     |        | 0.6000                                                     | 10260    | 18872 CA                                                 |                                     | 0.0                |
|                     |        | 0.2000                                                     | 3420     | 12103 EA                                                 |                                     | 0.0                |
| 2. CYCLIC PULL-UP   |        |                                                            |          |                                                          |                                     |                    |
| (A) 50 KNOTS        |        | 0.0324                                                     | 554      | 18446 AA                                                 |                                     | 0.0                |
|                     |        | 0.0972                                                     | 1662     | 23003 CA                                                 |                                     | 0.0                |
|                     |        | 0.0324                                                     | 554      | 15332 EA                                                 |                                     | 0.0                |
| (B) 100 KNOTS       |        | 0.0324                                                     | 554      | 19897 AA                                                 |                                     | 0.0                |
|                     |        | 0.0972                                                     | 1662     | 19565 CA                                                 |                                     | 0.0                |
|                     |        | 0.0324                                                     | 554      | 18346 EA                                                 |                                     | 0.0                |
| (C) VL              |        | 0.0324                                                     | 554      | 19203 AA                                                 |                                     | 0.0                |
|                     |        | 0.0972                                                     | 1662     | 34697 BA                                                 | 0.269                               | 0.006183           |
|                     |        | 0.0324                                                     | 554      | 42521 EA                                                 | 0.049                               | 0.011401           |
| 3. LEFT TURN        |        |                                                            |          |                                                          |                                     |                    |
| (A) 50 KNOTS        |        | 0.2000                                                     | 3420     | 18975 AA                                                 |                                     | 0.0                |
|                     |        | 0.6000                                                     | 10260    | 19390 CA                                                 |                                     | 0.0                |
|                     |        | 0.2000                                                     | 3420     | 13370 EA                                                 |                                     | 0.0                |
| (B) 100 KNOTS       |        | 0.2000                                                     | 3420     | 17765 AA                                                 |                                     | 0.0                |
|                     |        | 0.6000                                                     | 10260    | 20322 CA                                                 |                                     | 0.0                |
|                     |        | 0.2000                                                     | 3420     | 16609 EA                                                 |                                     | 0.0                |
| (C) VL              |        | 0.1000                                                     | 1710     | 20536 AA                                                 |                                     | 0.0                |
|                     |        | 0.3000                                                     | 5130     | 31613 BA                                                 | 1.151                               | 0.004457           |
|                     |        | 0.1000                                                     | 1710     | 42621 EA                                                 | 0.049                               | 0.035189           |
| 4. RIGHT TURN       |        |                                                            |          |                                                          |                                     |                    |
| (A) 50 KNOTS        |        | 0.2000                                                     | 3420     | 19447 AA                                                 |                                     | 0.0                |
|                     |        | 0.6000                                                     | 10260    | 19541 BA                                                 |                                     | 0.0                |
|                     |        | 0.2000                                                     | 3420     | 11885 EA                                                 |                                     | 0.0                |
| (B) 100 KNOTS       |        | 0.2000                                                     | 3420     | 16685 AA                                                 |                                     | 0.0                |
|                     |        | 0.6000                                                     | 10260    | 16384 CA                                                 |                                     | 0.0                |
|                     |        | 0.2000                                                     | 3420     | 17198 FA                                                 |                                     | 0.0                |
| (C) VL              |        | 0.1000                                                     | 1710     | 17998 AA                                                 |                                     | 0.0                |

TABLE XIII - Continued

| FLIGHT CONDITION            | FREQUENCY OF OCCURRENCE<br>PCT. CYCLES IN<br>TIME 100 HRS. |      | OSCILLATORY BENDING STR. IN M/R YOKE @ STA. 7.0 | CYC. TO FAILURE X 10**(-6) | DAMAGE FRACTION |
|-----------------------------|------------------------------------------------------------|------|-------------------------------------------------|----------------------------|-----------------|
|                             | 0.3000                                                     | 5130 | 33732 BA                                        | 0.382                      | 0.013413        |
|                             | 0.1000                                                     | 1710 | 42621 EA                                        | 0.049                      | 0.035189        |
| 5. CONTROL REVERSAL         |                                                            |      |                                                 |                            |                 |
| (A) LONGITUDINAL            | 0.0444                                                     | 759  | 17863 AA                                        |                            | 0.0             |
|                             | 0.1332                                                     | 2278 | 22122 BA                                        |                            | 0.0             |
|                             | 0.0444                                                     | 759  | 18937 EA                                        |                            | 0.0             |
| (B) LATERAL                 | 0.0444                                                     | 759  | 14689 AA                                        |                            | 0.0             |
|                             | 0.1332                                                     | 2278 | 19919 CA                                        |                            | 0.0             |
|                             | 0.0444                                                     | 759  | 17922 EA                                        |                            | 0.0             |
| (C) RUDDER                  | 0.0444                                                     | 759  | 14301 AA                                        |                            | 0.0             |
|                             | 0.1332                                                     | 2278 | 14247 CA                                        |                            | 0.0             |
|                             | 0.0444                                                     | 759  | 14975 EA                                        |                            | 0.0             |
| IV. POWER TRANSITIONS       |                                                            |      |                                                 |                            |                 |
| A. POWER TO AUTO            |                                                            |      |                                                 |                            |                 |
| 1. 40 KNOTS                 | 0.0022                                                     | 38   | 11512 AA                                        |                            | 0.0             |
|                             | 0.0066                                                     | 113  | 19744 BA                                        |                            | 0.0             |
|                             | 0.0022                                                     | 38   | 13760 EA                                        |                            | 0.0             |
| 2. VL                       | 0.0022                                                     | 38   | 14369 AA                                        |                            | 0.0             |
|                             | 0.0066                                                     | 113  | 24505 BA                                        |                            | 0.0             |
|                             | 0.0022                                                     | 38   | 21735 EA                                        |                            | 0.0             |
| B. AUTO TO POWER            | 0.0112                                                     | 192  | 14766 AA                                        |                            | 0.0             |
|                             | 0.0336                                                     | 575  | 16800 BA                                        |                            | 0.0             |
|                             | 0.0112                                                     | 192  | 15890 EA                                        |                            | 0.0             |
| V. AUTOROTATION             |                                                            |      |                                                 |                            |                 |
| A. STABILIZED FLIGHT        |                                                            |      |                                                 |                            |                 |
| 1. 40 KNOTS                 | 0.0578                                                     | 988  | 9750 AA                                         |                            | 0.0             |
|                             | 0.1734                                                     | 2965 | 16655 BA                                        |                            | 0.0             |
|                             | 0.0578                                                     | 988  | 10686 EA                                        |                            | 0.0             |
| 2. 80 KNOTS                 | 0.0776                                                     | 1327 | 10132 AA                                        |                            | 0.0             |
|                             | 0.2328                                                     | 3981 | 16978 BA                                        |                            | 0.0             |
|                             | 0.0776                                                     | 1327 | 11999 EA                                        |                            | 0.0             |
| 3. MAX AUTO A/S             | 0.0378                                                     | 646  | 9499 AA                                         |                            | 0.0             |
|                             | 0.1134                                                     | 1939 | 19408 BA                                        |                            | 0.0             |
|                             | 0.0378                                                     | 646  | 16320 EA                                        |                            | 0.0             |
| B. TURNS. (NORMAL AUTO A/S) |                                                            |      |                                                 |                            |                 |
| 1. TO THE LEFT              | 0.0400                                                     | 684  | 10925 AA                                        |                            | 0.0             |
|                             | 0.1200                                                     | 2052 | 16879 BA                                        |                            | 0.0             |
|                             | 0.0400                                                     | 684  | 11902 EA                                        |                            | 0.0             |
| 2. TO THE RIGHT             | 0.0400                                                     | 684  | 10859 AA                                        |                            | 0.0             |
|                             | 0.1200                                                     | 2052 | 17423 BA                                        |                            | 0.0             |
|                             | 0.0400                                                     | 684  | 11650 EA                                        |                            | 0.0             |
| C. CONTROL REVERSAL         |                                                            |      |                                                 |                            |                 |
| 1. LONGITUDINAL             | 0.0200                                                     | 342  | 12655 AA                                        |                            | 0.0             |

TABLE XIII - Concluded

| FLIGHT CONDITION                                    | FREQUENCY OF<br>OCCURRENCE<br>PCT. CYCLES IN<br>TIME 100 HRS. | OSCILLATORY<br>BENDING STR.<br>IN M/R YOKE<br># STA. 7.0 | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION               |
|-----------------------------------------------------|---------------------------------------------------------------|----------------------------------------------------------|-------------------------------------|----------------------------------|
|                                                     | 0.0600                                                        | 1026                                                     | 23606 BA                            | 0.0                              |
|                                                     | 0.0200                                                        | 342                                                      | 17775 EA                            | 0.0                              |
| 2. LATERAL                                          | 0.0200                                                        | 342                                                      | 16372 AA                            | 0.0                              |
|                                                     | 0.0600                                                        | 1026                                                     | 21151 BA                            | 0.0                              |
|                                                     | 0.0200                                                        | 342                                                      | 19619 EA                            | 0.0                              |
| 3. RUDDER                                           | 0.0200                                                        | 342                                                      | 10731 AA                            | 0.0                              |
|                                                     | 0.0600                                                        | 1026                                                     | 17239 BA                            | 0.0                              |
|                                                     | 0.0200                                                        | 342                                                      | 13859 EA                            | 0.0                              |
| D. CYCLIC PULL-UP<br>(NORMAL AUTO A/S)              | 0.0112                                                        | 192                                                      | 15668 AA                            | 0.0                              |
|                                                     | 0.0336                                                        | 575                                                      | 24080 BA                            | 0.0                              |
|                                                     | 0.0112                                                        | 192                                                      | 19326 EA                            | 0.0                              |
| E. PART PWR DSAT, 80KT                              | 0.4166                                                        | 7124                                                     | 13598 AA                            | 0.0                              |
|                                                     | 1.2498                                                        | 21372                                                    | 13189 BA                            | 0.0                              |
|                                                     | 0.4166                                                        | 7124                                                     | 9988 EA                             | 0.0                              |
| F. FULL AUTO LANDING                                | 0.0600                                                        | 1026                                                     | 0 AA                                | 0.0                              |
|                                                     | 0.1800                                                        | 3078                                                     | 72276 BA                            | * 0.009818                       |
|                                                     | 0.0600                                                        | 1026                                                     | 0 FA                                | 0.0                              |
| ZER. STEADY END. LIMIT = 30000.0                    |                                                               |                                                          |                                     | TOTAL DAMAGE (D) = 0.123372      |
| MATERIAL = TIT                                      |                                                               |                                                          |                                     |                                  |
| FREQUENCY = 1 / REV OF M/R                          |                                                               |                                                          |                                     | FATIGUE LIFE = 100/D = 811 HOURS |
| * DAMAGE CALCULATED FROM MEASURED LOAD FREQUENCIES. |                                                               |                                                          |                                     |                                  |



$$I = 32.35 \text{ in.}^4$$

$$A = 11.19 \text{ in.}^2$$

$$C = 2.75 \text{ in.}$$

$$\sigma_b = (M_c^2 + M_b^2)^{1/2} (0.085 \text{ in.}^{-3})$$

$$\sigma_{cf} = P/(11.19 \text{ in.}^2)$$

Figure 94. Main Rotor Spindle, Part No. 609-010-140-1.

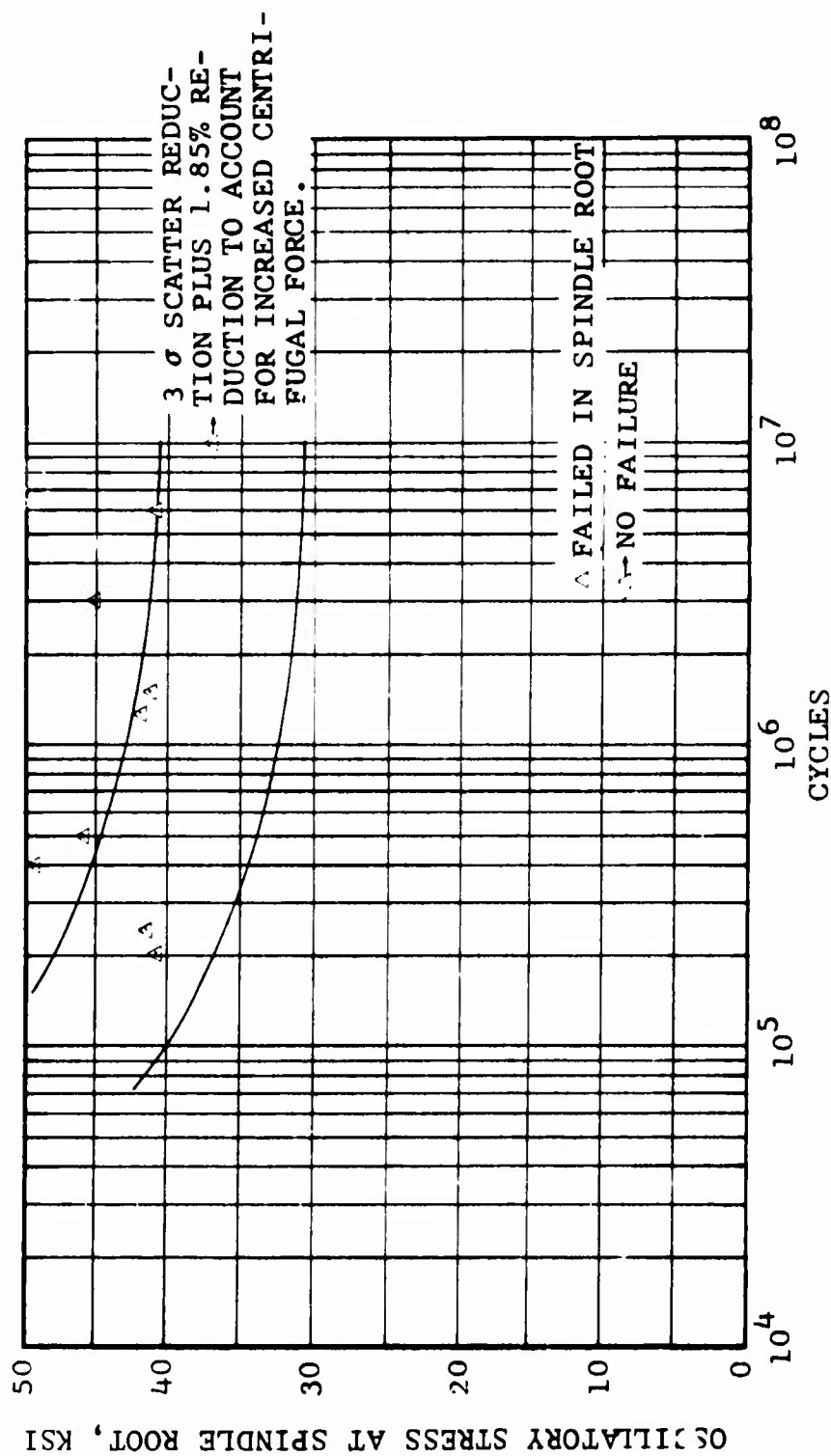


Figure 95. Oscillatory Stress Versus Cycles for the 204-011-102-17 Main Rotor Yoke Used To Substantiate the 609-010-140-1 Spindle.

TABLE XIV. FATIGUE LIFE DETERMINATION OF 609 M/R  
SPINDLE, PART NO. 609-010-140-1

| FLIGHT CONDITION     | FREQUENCY OF OCCURRENCE<br>PCT. CYCLES IN<br>TIME 100 HRS. |       | Oscillatory bend-<br>ing stress @ STA. 34.75 | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION |
|----------------------|------------------------------------------------------------|-------|----------------------------------------------|-------------------------------------|--------------------|
| I. GROUND CONDITIONS |                                                            |       |                                              |                                     |                    |
| A. NORMAL START      | 0.1000                                                     | 1770  | 0 AA                                         |                                     | 0.0                |
|                      | 0.3000                                                     | 5310  | 2911 CA                                      |                                     | 0.0                |
|                      | 0.1000                                                     | 1770  | 0 FA                                         |                                     | 0.0                |
| B. NORMAL SHUT-DOWN  | 0.1000                                                     | 1770  | 2462 AA                                      |                                     | 0.0                |
|                      | 0.3000                                                     | 5310  | 1217 CA                                      |                                     | 0.0                |
|                      | 0.1000                                                     | 1770  | 0 FA                                         |                                     | 0.0                |
| II. POWER-ON IGE     |                                                            |       |                                              |                                     |                    |
| A. HOVERING          |                                                            |       |                                              |                                     |                    |
| 1. STEADY            |                                                            |       |                                              |                                     |                    |
| (A) 280 RPM          | 0.6944                                                     | 11666 | 3707 AA                                      |                                     | 0.0                |
|                      | 2.0832                                                     | 34998 | 5145 CA                                      |                                     | 0.0                |
|                      | 0.6944                                                     | 11666 | 5906 FA                                      |                                     | 0.0                |
| (B) 295 RPM          | 0.6944                                                     | 12291 | 3248 AA                                      |                                     | 0.0                |
|                      | 2.0832                                                     | 36873 | 8057 CA                                      |                                     | 0.0                |
|                      | 0.6944                                                     | 12291 | 12041 EA                                     |                                     | 0.0                |
| 2. LEFT TURN         | 0.2222                                                     | 3800  | 5146 AA                                      |                                     | 0.0                |
|                      | 0.6666                                                     | 11399 | 6110 CA                                      |                                     | 0.0                |
|                      | 0.2222                                                     | 3800  | 5267 EA                                      |                                     | 0.0                |
| 3. RIGHT TURN        | 0.2222                                                     | 3800  | 6024 AA                                      |                                     | 0.0                |
|                      | 0.6666                                                     | 11399 | 6701 CA                                      |                                     | 0.0                |
|                      | 0.2222                                                     | 3800  | 5237 EA                                      |                                     | 0.0                |
| 4. CONTROL REVERSAL  |                                                            |       |                                              |                                     |                    |
| (A) LONGITUDINAL     | 0.0556                                                     | 951   | 8650 AA                                      |                                     | 0.0                |
|                      | 0.1668                                                     | 2852  | 11239 CA                                     |                                     | 0.0                |
|                      | 0.0556                                                     | 951   | 15027 EA                                     |                                     | 0.0                |
| (B) LATERAL          | 0.0556                                                     | 951   | 9531 AA                                      |                                     | 0.0                |
|                      | 0.1668                                                     | 2852  | 11688 BA                                     |                                     | 0.0                |
|                      | 0.0556                                                     | 951   | 11047 EA                                     |                                     | 0.0                |
| (C) RUDDER           | 0.0556                                                     | 951   | 5547 AA                                      |                                     | 0.0                |
|                      | 0.1668                                                     | 2852  | 5793 CA                                      |                                     | 0.0                |
|                      | 0.0556                                                     | 951   | 5762 EA                                      |                                     | 0.0                |
| B. MANEUVERS         |                                                            |       |                                              |                                     |                    |
| 1. SIDEWARD FLIGHT   |                                                            |       |                                              |                                     |                    |
| (A) TO THE RIGHT     | 0.1000                                                     | 1710  | 6883 AA                                      |                                     | 0.0                |
|                      | 0.3000                                                     | 5130  | 12480 BA                                     |                                     | 0.0                |
|                      | 0.1000                                                     | 1710  | 4064 EA                                      |                                     | 0.0                |
| (B) TO THE LEFT      | 0.1000                                                     | 1710  | 6771 AA                                      |                                     | 0.0                |
|                      | 0.3000                                                     | 5130  | 7846 CA                                      |                                     | 0.0                |
|                      | 0.1000                                                     | 1710  | 7535 EA                                      |                                     | 0.0                |
| 2. REARWARD FLIGHT   | 0.1000                                                     | 1710  | 5525 AA                                      |                                     | 0.0                |
|                      | 0.3000                                                     | 5130  | 10309 BA                                     |                                     | 0.0                |
|                      | 0.1000                                                     | 1710  | 13343 EA                                     |                                     | 0.0                |
| 3. NORMAL TAKE-OFF   | 0.1778                                                     | 3040  | 12112 AA                                     |                                     | 0.0                |
|                      | 0.5334                                                     | 9121  | 10674 CA                                     |                                     | 0.0                |

TABLE XIV- Continued

| FLIGHT CONDITION  | FREQUENCY OF OCCURRENCE |                    | Oscillatory bend- ing stress @ 34.75 | CYC. TO FAILURE X 10**(-6) | DAMAGE FRACTION |
|-------------------|-------------------------|--------------------|--------------------------------------|----------------------------|-----------------|
|                   | PCT. TIME               | CYCLES IN 100 HRS. |                                      |                            |                 |
| 4. NORMAL LANDING |                         | 0.1778             | 3040                                 | 13256 EA                   | 0.0             |
|                   |                         | 0.4166             | 7124                                 | 9395 AA                    | 0.0             |
|                   |                         | 1.2498             | 21372                                | 13611 CA                   | 0.0             |
|                   |                         | 0.4166             | 7124                                 | 15473 EA                   | 0.0             |
| IX. POWER-ON IGF  |                         |                    |                                      |                            |                 |
| A. LEVEL FLIGHT   |                         |                    |                                      |                            |                 |
| % VL              | RPM                     |                    |                                      |                            |                 |
| 1. 40             | 230                     | 0.1866             | 3135                                 | 6007 AA                    | 0.0             |
|                   |                         | 0.5598             | 9405                                 | 8118 CA                    | 0.0             |
|                   |                         | 0.1866             | 3135                                 | 10954 FA                   | 0.0             |
|                   |                         | 295                | 0.1866                               | 3303                       | 5666 AA         |
|                   |                         | 0.5598             | 9908                                 | 7619 CA                    | 0.0             |
|                   |                         | 0.1866             | 3303                                 | 9562 DA                    | 0.0             |
| 2. 50             | 230                     | 0.4917             | 8261                                 | 5347 AA                    | 0.0             |
|                   |                         | 1.4751             | 24782                                | 7621 CA                    | 0.0             |
|                   |                         | 0.4917             | 8261                                 | 10465 FA                   | 0.0             |
|                   |                         | 295                | 0.4917                               | 8703                       | 5036 AA         |
|                   |                         | 1.4751             | 26109                                | 7893 CA                    | 0.0             |
|                   |                         | 0.4917             | 8703                                 | 10120 FA                   | 0.0             |
| 3. 60             | 280                     | 0.7838             | 13168                                | 6030 AA                    | 0.0             |
|                   |                         | 2.3514             | 39503                                | 7970 CA                    | 0.0             |
|                   |                         | 0.7838             | 13168                                | 10643 DA                   | 0.0             |
|                   |                         | 295                | 0.7838                               | 13873                      | 5463 AA         |
|                   |                         | 2.3514             | 41620                                | 7828 CA                    | 0.0             |
|                   |                         | 0.7838             | 13873                                | 10711 EA                   | 0.0             |
| 4. 70             | 280                     | 1.0000             | 16800                                | 6662 AA                    | 0.0             |
|                   |                         | 3.0000             | 50400                                | 8699 BA                    | 0.0             |
|                   |                         | 1.0000             | 16800                                | 11641 DA                   | 0.0             |
|                   |                         | 295                | 1.0000                               | 17700                      | 6494 AA         |
|                   |                         | 3.0000             | 53100                                | 8271 CA                    | 0.0             |
|                   |                         | 1.0000             | 17700                                | 11616 EA                   | 0.0             |
| 5. 80             | 280                     | 1.5000             | 25200                                | 8908 AA                    | 0.0             |
|                   |                         | 4.5000             | 75600                                | 10920 BA                   | 0.0             |
|                   |                         | 1.5000             | 25200                                | 14522 DA                   | 0.0             |
|                   |                         | 295                | 1.5000                               | 26550                      | 7834 AA         |
|                   |                         | 4.5000             | 79650                                | 9242 CA                    | 0.0             |
|                   |                         | 1.5000             | 26550                                | 11847 EA                   | 0.0             |
| 6. 90             | 280                     | 1.7334             | 29121                                | 11298 AA                   | 0.0             |
|                   |                         | 5.2002             | 87363                                | 13677 BA                   | 0.0             |
|                   |                         | 1.7334             | 29121                                | 21258 DA                   | 0.0             |
|                   |                         | 295                | 1.7334                               | 30681                      | 9786 AA         |
|                   |                         | 5.2002             | 92044                                | 11286 BA                   | 0.0             |
|                   |                         | 1.7334             | 30681                                | 14324 DA                   | 0.0             |
| 7. 100            | 280                     | 0.9838             | 16528                                | 13874 AA                   | 0.0             |
|                   |                         | 2.9514             | 49583                                | 17010 BA                   | 0.0             |

TABLE XIV- Continued

| FLIGHT CONDITION    | FREQUENCY OF OCCURRENCE |                    | Oscillatory bending stress @ STA. FAILURE |                            | DAMAGE FRACTION |
|---------------------|-------------------------|--------------------|-------------------------------------------|----------------------------|-----------------|
|                     | PCT. TIME               | CYCLES IN 100 HRS. | 34.75                                     | CYC. TO FAILURE X 10**(-6) |                 |
| 8. VNF 280          |                         | 0.9838             | 16528                                     | 20587 EA                   | 0.0             |
|                     |                         | 0.9838             | 17413                                     | 11944 AA                   | 0.0             |
|                     |                         | 2.9514             | 52240                                     | 15724 CA                   | 0.0             |
|                     |                         | 0.9838             | 17413                                     | 17466 DA                   | 0.0             |
|                     |                         | 0.3500             | 5880                                      | 15333 AA                   | 0.0             |
|                     |                         | 1.0500             | 17640                                     | 16440 CA                   | 0.0             |
|                     |                         | 0.3500             | 5880                                      | 17922 EA                   | 0.0             |
|                     | 295                     | 0.3500             | 6195                                      | 12098 AA                   | 0.0             |
|                     |                         | 1.0500             | 18585                                     | 14557 CA                   | 0.0             |
|                     |                         | 0.3500             | 6195                                      | 14461 EA                   | 0.0             |
| H. MANEUVERS        |                         |                    |                                           |                            |                 |
| 1. CLIMB 3-60 KNOTS |                         |                    |                                           |                            |                 |
| (A) M.C. POWER      |                         | 0.6000             | 10260                                     | 9219 AA                    | 0.0             |
|                     |                         | 1.8000             | 30780                                     | 9309 CA                    | 0.0             |
|                     |                         | 0.6000             | 10260                                     | 11490 EA                   | 0.0             |
| (B) T.O. POWER      |                         | 0.2000             | 3420                                      | 7911 AA                    | 0.0             |
|                     |                         | 0.6000             | 10260                                     | 9342 CA                    | 0.0             |
|                     |                         | 0.2000             | 3420                                      | 10760 EA                   | 0.0             |
| 2. CYCLIC PULL-UP   |                         |                    |                                           |                            |                 |
| (A) 50 KNOTS        |                         | 0.0324             | 554                                       | 7412 AA                    | 0.0             |
|                     |                         | 0.0972             | 1662                                      | 12516 CA                   | 0.0             |
|                     |                         | 0.0324             | 554                                       | 10306 EA                   | 0.0             |
| (B) 100 KNOTS       |                         | 0.0324             | 554                                       | 10346 AA                   | 0.0             |
|                     |                         | 0.0972             | 1662                                      | 13951 CA                   | 0.0             |
|                     |                         | 0.0324             | 554                                       | 14767 EA                   | 0.0             |
| (C) VL              |                         | 0.0324             | 554                                       | 16282 AA                   | 0.0             |
|                     |                         | 0.0972             | 1662                                      | 26517 CA                   | 0.0             |
|                     |                         | 0.0324             | 554                                       | 32106 EA                   | 0.282           |
| 3. LEFT TURN        |                         |                    |                                           |                            |                 |
| (A) 50 KNOTS        |                         | 0.2000             | 3420                                      | 7834 AA                    | 0.0             |
|                     |                         | 0.6000             | 10260                                     | 10012 CA                   | 0.0             |
|                     |                         | 0.2000             | 3420                                      | 12316 EA                   | 0.0             |
| (B) 100 KNOTS       |                         | 0.2000             | 3420                                      | 9880 AA                    | 0.0             |
|                     |                         | 0.6000             | 10260                                     | 12059 CA                   | 0.0             |
|                     |                         | 0.2000             | 3420                                      | 16959 EA                   | 0.0             |
| (C) VL              |                         | 0.1000             | 1710                                      | 16212 AA                   | 0.0             |
|                     |                         | 0.3000             | 5130                                      | 22266 BA                   | 0.0             |
|                     |                         | 0.1000             | 1710                                      | 32106 EA                   | 0.282           |
| 4. RIGHT TURN       |                         |                    |                                           |                            |                 |
| (A) 50 KNOTS        |                         | 0.2000             | 3420                                      | 8660 AA                    | 0.0             |
|                     |                         | 0.6000             | 10260                                     | 11452 CA                   | 0.0             |
|                     |                         | 0.2000             | 3420                                      | 10750 EA                   | 0.0             |
| (B) 100 KNOTS       |                         | 0.2000             | 3420                                      | 9840 AA                    | 0.0             |
|                     |                         | 0.6000             | 10260                                     | 13244 CA                   | 0.0             |
|                     |                         | 0.2000             | 3420                                      | 14999 EA                   | 0.0             |
| (C) VL              |                         | 0.1000             | 1710                                      | 18444 AA                   | 0.0             |

TABLE XIV- Continued

| FLIGHT CONDITION            | FREQUENCY OF<br>OCCURRENCE<br>PCT. TIME | CYCLES IN<br>100 HRS. | Oscillatory bending stress @ STA. 34.75 | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION |
|-----------------------------|-----------------------------------------|-----------------------|-----------------------------------------|-------------------------------------|--------------------|
|                             | 0.3000                                  | 5130                  | 23274 CA                                |                                     | 0.0                |
|                             | 0.1000                                  | 1710                  | 32106 EA                                | 0.282                               | 0.006057           |
| 5. CONTROL REVERSAL         |                                         |                       |                                         |                                     |                    |
| (A) LONGITUDINAL            | 0.0444                                  | 759                   | 10608 AA                                |                                     | 0.0                |
|                             | 0.1332                                  | 2278                  | 17203 BA                                |                                     | 0.0                |
|                             | 0.0444                                  | 759                   | 16692 EA                                |                                     | 0.0                |
| (B) LATERAL                 | 0.0444                                  | 759                   | 11381 AA                                |                                     | 0.0                |
|                             | 0.1332                                  | 2278                  | 20014 CA                                |                                     | 0.0                |
|                             | 0.0444                                  | 759                   | 17842 EA                                |                                     | 0.0                |
| (C) RUDDER                  | 0.0444                                  | 759                   | 9982 AA                                 |                                     | 0.0                |
|                             | 0.1332                                  | 2278                  | 13364 CA                                |                                     | 0.0                |
|                             | 0.0444                                  | 759                   | 15804 EA                                |                                     | 0.0                |
| IV. POWER TRANSITIONS       |                                         |                       |                                         |                                     |                    |
| A. POWER TO AUTO            |                                         |                       |                                         |                                     |                    |
| 1. 40 KNOTS                 | 0.0022                                  | 38                    | 5412 AA                                 |                                     | 0.0                |
|                             | 0.0066                                  | 113                   | 9002 CA                                 |                                     | 0.0                |
|                             | 0.0022                                  | 38                    | 11419 FA                                |                                     | 0.0                |
| 2. VL                       | 0.0022                                  | 38                    | 12710 AA                                |                                     | 0.0                |
|                             | 0.0066                                  | 113                   | 14895 BA                                |                                     | 0.0                |
|                             | 0.0022                                  | 38                    | 16172 FA                                |                                     | 0.0                |
| B. AUTO TO POWER            | 0.0112                                  | 192                   | 7664 AA                                 |                                     | 0.0                |
|                             | 0.0336                                  | 575                   | 7121 CA                                 |                                     | 0.0                |
|                             | 0.0112                                  | 192                   | 12963 EA                                |                                     | 0.0                |
| V. AUTOROTATION             |                                         |                       |                                         |                                     |                    |
| A. STABILIZED FLIGHT        |                                         |                       |                                         |                                     |                    |
| 1. 40 KNOTS                 | 0.0578                                  | 988                   | 3354 AA                                 |                                     | 0.0                |
|                             | 0.1734                                  | 2965                  | 4983 CA                                 |                                     | 0.0                |
|                             | 0.0578                                  | 988                   | 4474 EA                                 |                                     | 0.0                |
| 2. 80 KNOTS                 | 0.0776                                  | 1327                  | 4103 AA                                 |                                     | 0.0                |
|                             | 0.2328                                  | 3981                  | 5800 CA                                 |                                     | 0.0                |
|                             | 0.0776                                  | 1327                  | 5193 EA                                 |                                     | 0.0                |
| 3. MAX AUTO A/S             | 0.0378                                  | 646                   | 4763 AA                                 |                                     | 0.0                |
|                             | 0.1134                                  | 1939                  | 7743 CA                                 |                                     | 0.0                |
|                             | 0.0378                                  | 646                   | 7242 FA                                 |                                     | 0.0                |
| B. TURNS. (NORMAL AUTO A/S) |                                         |                       |                                         |                                     |                    |
| 1. TO THE LEFT              | 0.0400                                  | 684                   | 4250 AA                                 |                                     | 0.0                |
|                             | 0.1200                                  | 2052                  | 5213 CA                                 |                                     | 0.0                |
|                             | 0.0400                                  | 684                   | 4882 EA                                 |                                     | 0.0                |
| 2. TO THE RIGHT             | 0.0400                                  | 684                   | 4541 AA                                 |                                     | 0.0                |
|                             | 0.1200                                  | 2052                  | 4547 CA                                 |                                     | 0.0                |
|                             | 0.0400                                  | 684                   | 4481 FA                                 |                                     | 0.0                |
| C. CONTROL REVERSAL         |                                         |                       |                                         |                                     |                    |
| 1. LONGITUDINAL             | 0.0200                                  | 342                   | 4902 AA                                 |                                     | 0.0                |

TABLE XIV- Concluded

| TABLE XIV- Concluded                                |                                         |                       |                                                 |                                     |                    |
|-----------------------------------------------------|-----------------------------------------|-----------------------|-------------------------------------------------|-------------------------------------|--------------------|
| FLIGHT CONDITION                                    | FREQUENCY OF<br>OCCURRENCE<br>PCT. TIME | CYCLES IN<br>100 HRS. | Oscillatory bend-<br>ing stress @ STA.<br>34.75 | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION |
| 2. LATERAL                                          | 0.0600                                  | 1026                  | 6445 BA                                         |                                     | 0.0                |
|                                                     | 0.0200                                  | 342                   | 7081 FA                                         |                                     | 0.0                |
|                                                     | 0.0200                                  | 342                   | 7088 AA                                         |                                     | 0.0                |
|                                                     | 0.0600                                  | 1026                  | 11361 CA                                        |                                     | 0.0                |
|                                                     | 0.0200                                  | 342                   | 8979 EA                                         |                                     | 0.0                |
| 3. RUDDER                                           | 0.0200                                  | 342                   | 3864 AA                                         |                                     | 0.0                |
|                                                     | 0.0600                                  | 1026                  | 4974 CA                                         |                                     | 0.0                |
|                                                     | 0.0200                                  | 342                   | 6195 EA                                         |                                     | 0.0                |
| D. CYCLIC PULL-UP<br>(NORMAL AUTO A/S)              | 0.0112                                  | 192                   | 6278 AA                                         |                                     | 0.0                |
|                                                     | 0.0336                                  | 575                   | 6506 CA                                         |                                     | 0.0                |
|                                                     | 0.0112                                  | 192                   | 7219 EA                                         |                                     | 0.0                |
| E. PART PWR DSNT. 80KT                              | 0.4166                                  | 7124                  | 5464 AA                                         |                                     | 0.0                |
|                                                     | 1.2498                                  | 21372                 | 5630 CA                                         |                                     | 0.0                |
|                                                     | 0.4166                                  | 7124                  | 5917 EA                                         |                                     | 0.0                |
| F. FULL AUTO LANDING                                | 0.0600                                  | 1026                  | 0 AA                                            |                                     | 0.0                |
|                                                     | 0.1800                                  | 3078                  | 28373 BA                                        | *                                   | 0.000007           |
|                                                     | 0.0600                                  | 1026                  | 0 FA                                            |                                     | 0.0                |
| ENDURANCE LIMIT = 27500.0                           |                                         |                       | TOTAL DAMAGE (D) = 0.014084                     |                                     |                    |
| MATERIAL = STL2                                     |                                         |                       | FATIGUE LIFE = 100/D = 7100 HOURS               |                                     |                    |
| FREQUENCY = 1 / REV OF M/R                          |                                         |                       |                                                 |                                     |                    |
| * DAMAGE CALCULATED FROM MEASURED LOAD FREQUENCIES. |                                         |                       |                                                 |                                     |                    |

retention system, the most critical component in fatigue is the 609-010-105-3 fitting, Figure 96, which is machined from 2024 aluminum alloy in the T-42 condition. It was analyzed for axial stress at the juncture of barrel and flange. The oscillatory stress calculated for a load of 96,000 pounds applied at the inboard fitting was  $\sigma = 16,095$  psi. The number of cycles to failure was calculated to be 6373. This calculation used the Weibull Equation of Reference 16:

$$N = \frac{K}{\left( \frac{S - E^{\infty}}{\bar{E}} \right)^m}$$

where

$N$  = number of cycles to failure at a given oscillatory stress level,  $S$

$\bar{E} = 3600$  psi, component endurance limit

Material Constants

$$E^{\infty} = 2881$$

$$K = 4.76845 \times 10^5$$

$$m = 3.3184$$

The frequency of occurrence of load cycles on the main rotor retention system was based on four rotor starts and stops per flight hour. Using this spectrum, a life of 1593 hours was substantiated for the main rotor retention system. Calculations for the -105-3 fitting are shown below.

Material: Aluminum

$$A = 5.96 \text{ in.}^2$$

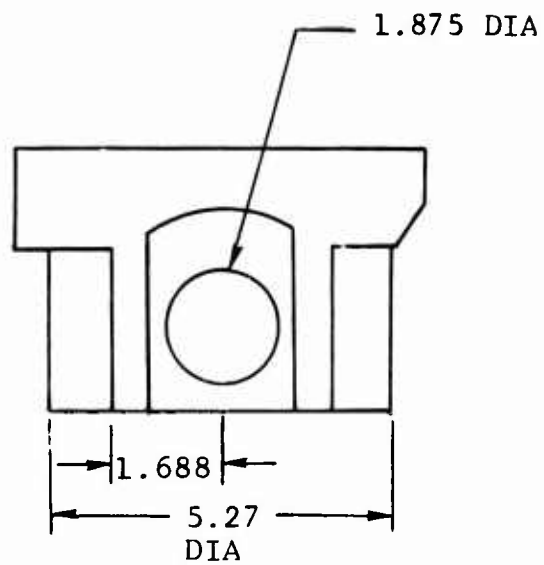
$$\text{C.F.} = 96,000 \text{ lb}$$

$$\sigma = (\text{C.F.})/A = 16,095 \text{ psi}$$

$$N = 6373 \text{ cycles}$$

$$\text{Fatigue life} = N/4 \text{ cycles/hour}$$

$$\text{Fatigue life} = 1593 \text{ hours}$$



All Dimensions in Inches

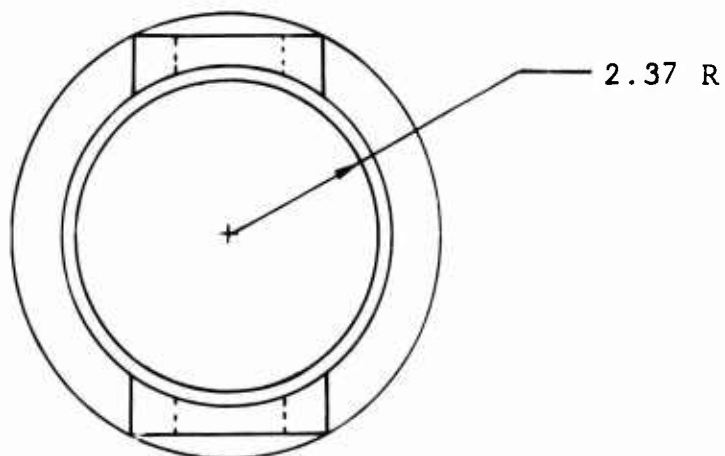


Figure 96. Main Rotor Blade Retention Fitting, Part No. 609-010-105-3.

## Main Rotor Blade Part No. 609-010-200-1

Several sections of the blade were analyzed to determine the most critical combination of mean and oscillatory stress. An examination of the loading during various flight conditions showed the blade to be critical in fatigue at station 94.0. The major component of oscillatory stress is due to the chordwise bending moment; the steady stress in the blade is due to the centrifugal loading in addition to chordwise bending. The maximum stress at station 94.0 occurred at the trailing edge for which the stress is given by

$$\begin{aligned}\sigma_{\text{mean}} &= (0.16) (M_{\text{C}94.0}) + 38422.0 \\ \sigma_{\text{osc}} &= (0.16) (M_{\text{C}94.0})\end{aligned}$$

where

$M_{\text{C}94.0}$  is the chord moment at station 94.0, mean and oscillatory respectively.

For an endurance limit of 22,500 psi, the fatigue life calculated for the main rotor blade was 1334 hours. The fatigue life calculations for this component are shown in Table XV.

## ROTATING CONTROLS

The rotating control system of the Model 609 main rotor includes the pitch horns and the outer ring of the swashplate, and all dynamic components in between. Analysis of these components showed the outer ring of the swashplate to be the most critical in fatigue.

The 609-010-401-3 outer ring, of 2014 aluminum alloy, is loaded by the four main rotor pitch links and by the main rotor drive links. Analysis showed the outer ring to be critical in bending at the arm-to-ring juncture (Section A-A of Figure 97). The stress equation for this location is:

$$\sigma_{\text{B}} = 6.86 (\text{pitch link load})$$

In the absence of fatigue test results, an endurance limit of 3600 psi was used for the swashplate outer ring, a value obtained from material allowables given in Reference 16. With these figures, a fatigue life of 11,557 hours was calculated for the 609-010-401-3 swashplate outer ring. All other components in the 609 main rotor rotating control system are at least as good as the swashplate outer ring in fatigue. Table XVI shows the fatigue life calculations for the swashplate outer ring; fatigue lives calculated for other major components of the rotating control system are shown in Table VI.

TABLE XV. FATIGUE LIFE DETERMINATION OF 609 M/R  
BLADE, PART NO. 609-010-200-1

| FLIGHT CONDITION     | FREQUENCY OF OCCURRENCE<br>PCT. CYCLES IN<br>TIME 100 HRS. |       | OSCILLATORY BENDING STR. IN M/R BLADE @ STA. 94.0 | CYC. TO FAILURE X 10**(-6) | DAMAGE FRACTION |
|----------------------|------------------------------------------------------------|-------|---------------------------------------------------|----------------------------|-----------------|
| I. GROUND CONDITIONS |                                                            |       |                                                   |                            |                 |
| A. NORMAL START      | 0.1000                                                     | 1770  | 0 AA                                              |                            | 0.0             |
|                      | 0.3000                                                     | 5310  | 3265 CA                                           |                            | 0.0             |
|                      | 0.1000                                                     | 1770  | 0 FA                                              |                            | 0.0             |
| B. NORMAL SHUTDOWN   | 0.1000                                                     | 1770  | 2766 AA                                           |                            | 0.0             |
|                      | 0.3000                                                     | 5310  | 1367 CA                                           |                            | 0.0             |
|                      | 0.1000                                                     | 1770  | 0 FA                                              |                            | 0.0             |
| II. POWER-ON IGF     |                                                            |       |                                                   |                            |                 |
| A. HOVERING          |                                                            |       |                                                   |                            |                 |
| 1. STEADY            |                                                            |       |                                                   |                            |                 |
| (A) 280 RPM          | 0.6944                                                     | 11666 | 3437 AA                                           |                            | 0.0             |
|                      | 2.0832                                                     | 34998 | 5406 CA                                           |                            | 0.0             |
|                      | 0.6944                                                     | 11666 | 6772 EA                                           |                            | 0.0             |
| (B) 295 RPM          | 0.6944                                                     | 12291 | 3097 AA                                           |                            | 0.0             |
|                      | 2.0832                                                     | 36873 | 8274 CA                                           |                            | 0.0             |
|                      | 0.6944                                                     | 12291 | 13330 EA                                          |                            | 0.0             |
| 2. LEFT TURN         | 0.2222                                                     | 3800  | 4830 AA                                           |                            | 0.0             |
|                      | 0.6666                                                     | 11399 | 6202 CA                                           |                            | 0.0             |
|                      | 0.2222                                                     | 3800  | 5607 EA                                           |                            | 0.0             |
| 3. RIGHT TURN        | 0.2222                                                     | 3800  | 5807 AA                                           |                            | 0.0             |
|                      | 0.6666                                                     | 11399 | 6545 CA                                           |                            | 0.0             |
|                      | 0.2222                                                     | 3800  | 5873 EA                                           |                            | 0.0             |
| 4. CONTROL REVERSAL  |                                                            |       |                                                   |                            |                 |
| (A) LONGITUDINAL     | 0.0556                                                     | 951   | 9728 AA                                           |                            | 0.0             |
|                      | 0.1668                                                     | 2852  | 11231 CA                                          |                            | 0.0             |
|                      | 0.0556                                                     | 951   | 16253 EA                                          |                            | 0.0             |
| (B) LATERAL          | 0.0556                                                     | 951   | 10281 AA                                          |                            | 0.0             |
|                      | 0.1668                                                     | 2852  | 12718 BA                                          |                            | 0.0             |
|                      | 0.0556                                                     | 951   | 11015 EA                                          |                            | 0.0             |
| (C) RUDDER           | 0.0556                                                     | 951   | 5443 AA                                           |                            | 0.0             |
|                      | 0.1668                                                     | 2852  | 6157 CA                                           |                            | 0.0             |
|                      | 0.0556                                                     | 951   | 6004 EA                                           |                            | 0.0             |
| B. MANEUVERS         |                                                            |       |                                                   |                            |                 |
| 1. SIDEWARD FLIGHT   |                                                            |       |                                                   |                            |                 |
| (A) TO THE RIGHT     | 0.1000                                                     | 1710  | 7267 AA                                           |                            | 0.0             |
|                      | 0.3000                                                     | 5130  | 13317 BA                                          |                            | 0.0             |
|                      | 0.1000                                                     | 1710  | 4570 EA                                           |                            | 0.0             |
| (B) TO THE LEFT      | 0.1000                                                     | 1710  | 7398 AA                                           |                            | 0.0             |
|                      | 0.3000                                                     | 5130  | 8050 CA                                           |                            | 0.0             |
|                      | 0.1000                                                     | 1710  | 8228 EA                                           |                            | 0.0             |
| 2. REARWARD FLIGHT   | 0.1000                                                     | 1710  | 6210 AA                                           |                            | 0.0             |
|                      | 0.3000                                                     | 5130  | 10579 BA                                          |                            | 0.0             |
|                      | 0.1000                                                     | 1710  | 14947 EA                                          |                            | 0.0             |
| 3. NORMAL TAKE-OFF   | 0.1778                                                     | 3040  | 12347 AA                                          |                            | 0.0             |
|                      | 0.5334                                                     | 9121  | 11188 CA                                          |                            | 0.0             |

TABLE XV - Continued

| FLIGHT CONDITION  |     | FREQUENCY OF<br>OCCURRENCE<br>PCT. CYCLES IN<br>TIME 100 HRS. |       | OSCILLATORY<br>BENDING STR.<br>IN M/R BLADE<br>@ STA. 94.0 | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION |
|-------------------|-----|---------------------------------------------------------------|-------|------------------------------------------------------------|-------------------------------------|--------------------|
| 4. NORMAL LANDING |     | 0.1778                                                        | 3040  | 14501 EA                                                   |                                     | 0.0                |
|                   |     | 0.4166                                                        | 7124  | 14140 AA                                                   |                                     | 0.0                |
|                   |     | 1.2498                                                        | 21372 | 14744 CA                                                   |                                     | 0.0                |
|                   |     | 0.4166                                                        | 7124  | 17618 EA                                                   |                                     | 0.0                |
| III. POWER-ON IGE |     |                                                               |       |                                                            |                                     |                    |
| 4. LEVEL FLIGHT   |     |                                                               |       |                                                            |                                     |                    |
| X VL RPM          |     |                                                               |       |                                                            |                                     |                    |
| 1. 40             | 280 | 0.1866                                                        | 3135  | 6271 AA                                                    |                                     | 0.0                |
|                   |     | 0.5598                                                        | 9405  | 8691 CA                                                    |                                     | 0.0                |
|                   |     | 0.1866                                                        | 3135  | 12345 FA                                                   |                                     | 0.0                |
|                   |     | 0.1866                                                        | 3303  | 5683 AA                                                    |                                     | 0.0                |
|                   | 295 | 0.5598                                                        | 9908  | 8622 CA                                                    |                                     | 0.0                |
|                   |     | 0.1866                                                        | 3303  | 10627 DA                                                   |                                     | 0.0                |
|                   |     | 0.4917                                                        | 8261  | 5387 AA                                                    |                                     | 0.0                |
|                   |     | 1.4751                                                        | 24782 | 8153 CA                                                    |                                     | 0.0                |
| 2. 50             | 280 | 0.4917                                                        | 8261  | 11639 EA                                                   |                                     | 0.0                |
|                   |     | 0.4917                                                        | 8703  | 5346 AA                                                    |                                     | 0.0                |
|                   |     | 1.4751                                                        | 26109 | 8537 CA                                                    |                                     | 0.0                |
|                   |     | 0.4917                                                        | 8703  | 10774 FA                                                   |                                     | 0.0                |
|                   | 295 | 0.7838                                                        | 13168 | 5560 AA                                                    |                                     | 0.0                |
|                   |     | 2.3514                                                        | 39503 | 7938 BA                                                    |                                     | 0.0                |
|                   |     | 0.7838                                                        | 13168 | 10946 DA                                                   |                                     | 0.0                |
|                   |     | 0.7838                                                        | 13873 | 5325 AA                                                    |                                     | 0.0                |
| 3. 60             | 280 | 2.3514                                                        | 41620 | 7738 CA                                                    |                                     | 0.0                |
|                   |     | 0.7838                                                        | 13873 | 10975 EA                                                   |                                     | 0.0                |
|                   |     | 1.0000                                                        | 16800 | 6364 AA                                                    |                                     | 0.0                |
|                   |     | 3.0000                                                        | 50400 | 9293 BA                                                    |                                     | 0.0                |
|                   | 295 | 1.0000                                                        | 16800 | 12375 DA                                                   |                                     | 0.0                |
|                   |     | 1.0000                                                        | 17700 | 6106 AA                                                    |                                     | 0.0                |
|                   |     | 3.0000                                                        | 53100 | 8337 CA                                                    |                                     | 0.0                |
|                   |     | 1.0000                                                        | 17700 | 12146 EA                                                   |                                     | 0.0                |
| 5. 80             | 280 | 1.5000                                                        | 25200 | 8812 AA                                                    |                                     | 0.0                |
|                   |     | 4.5000                                                        | 75600 | 11641 BA                                                   |                                     | 0.0                |
|                   |     | 1.5000                                                        | 25200 | 15048 DA                                                   |                                     | 0.0                |
|                   |     | 1.5000                                                        | 26550 | 8035 AA                                                    |                                     | 0.0                |
|                   | 295 | 4.5000                                                        | 79650 | 9642 CA                                                    |                                     | 0.0                |
|                   |     | 1.5000                                                        | 26550 | 12907 EA                                                   |                                     | 0.0                |
|                   |     | 1.7334                                                        | 29121 | 11446 AA                                                   |                                     | 0.0                |
|                   |     | 5.2002                                                        | 87363 | 14434 BA                                                   |                                     | 0.0                |
| 6. 90             | 280 | 1.7334                                                        | 29121 | 20974 DA                                                   |                                     | 0.0                |
|                   |     | 1.7334                                                        | 30681 | 9906 AA                                                    |                                     | 0.0                |
|                   |     | 5.2002                                                        | 92044 | 12541 BA                                                   |                                     | 0.0                |
|                   |     | 1.7334                                                        | 30681 | 15020 DA                                                   |                                     | 0.0                |
|                   | 295 | 0.9838                                                        | 16528 | 14380 AA                                                   |                                     | 0.0                |
|                   |     | 2.9514                                                        | 49583 | 18250 CA                                                   |                                     | 0.0                |
| 7. 100            | 280 |                                                               |       |                                                            |                                     |                    |
|                   |     |                                                               |       |                                                            |                                     |                    |

TABLE XV - Continued

| FLIGHT CONDITION    |     | FREQUENCY OF<br>OCCURRENCE<br>PCT. CYCLES IN<br>TIME 100 HRS. |        | OSCILLATORY<br>BENDING STR.<br>IN M/R BLADE<br>@ STA. 94.0 | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION |     |
|---------------------|-----|---------------------------------------------------------------|--------|------------------------------------------------------------|-------------------------------------|--------------------|-----|
| R. VNE              | 295 | 0.9838                                                        | 16528  | 21894 EA                                                   |                                     | 0.0                |     |
|                     |     | 0.9838                                                        | 17413  | 12725 AA                                                   |                                     | 0.0                |     |
|                     |     | 2.9514                                                        | 52240  | 17257 CA                                                   |                                     | 0.0                |     |
|                     | 280 | 0.9838                                                        | 17413  | 19431 DA                                                   |                                     | 0.0                |     |
|                     |     | 0.3500                                                        | 5880   | 16051 AA                                                   |                                     | 0.0                |     |
|                     |     | 1.0500                                                        | 17640  | 17648 CA                                                   |                                     | 0.0                |     |
|                     |     | 0.3500                                                        | 5880   | 18682 EA                                                   |                                     | 0.0                |     |
|                     |     | 295                                                           | 0.3500 | 6195                                                       | 13093 AA                            |                    | 0.0 |
|                     |     | 1.0500                                                        | 18585  | 15778 CA                                                   |                                     | 0.0                |     |
|                     |     | 0.3500                                                        | 6195   | 15682 EA                                                   |                                     | 0.0                |     |
| R. MANEUVERS        |     |                                                               |        |                                                            |                                     |                    |     |
| 1. CLIMB 3-60 KNOTS |     |                                                               |        |                                                            |                                     |                    |     |
| (A) M.C. POWER      |     | 0.6000                                                        | 10260  | 9218 AA                                                    |                                     | 0.0                |     |
|                     |     | 1.8000                                                        | 30780  | 9175 CA                                                    |                                     | 0.0                |     |
|                     |     | 0.6000                                                        | 10260  | 12648 EA                                                   |                                     | 0.0                |     |
| (B) T.O. POWER      |     | 0.2000                                                        | 3420   | 7505 AA                                                    |                                     | 0.0                |     |
|                     |     | 0.6000                                                        | 10260  | 8786 CA                                                    |                                     | 0.0                |     |
|                     |     | 0.2000                                                        | 3420   | 12151 EA                                                   |                                     | 0.0                |     |
| 2. CYCLIC PULL-UP   |     |                                                               |        |                                                            |                                     |                    |     |
| (A) 50 KNOTS        |     | 0.0324                                                        | 554    | 7418 AA                                                    |                                     | 0.0                |     |
|                     |     | 0.0972                                                        | 1662   | 13298 CA                                                   |                                     | 0.0                |     |
|                     |     | 0.0324                                                        | 554    | 11474 EA                                                   |                                     | 0.0                |     |
| (B) 100 KNOTS       |     | 0.0324                                                        | 554    | 10236 AA                                                   |                                     | 0.0                |     |
|                     |     | 0.0972                                                        | 1662   | 14503 CA                                                   |                                     | 0.0                |     |
|                     |     | 0.0324                                                        | 554    | 16216 EA                                                   |                                     | 0.0                |     |
| (C) VL              |     | 0.0324                                                        | 554    | 17520 AA                                                   |                                     | 0.0                |     |
|                     |     | 0.0972                                                        | 1662   | 27849 CA                                                   | 0.187                               | 0.008903           |     |
|                     |     | 0.0324                                                        | 554    | 34315 EA                                                   | 0.072                               | 0.007712           |     |
| 3. LEFT TURN        |     |                                                               |        |                                                            |                                     |                    |     |
| (A) 50 KNOTS        |     | 0.2000                                                        | 3420   | 7704 AA                                                    |                                     | 0.0                |     |
|                     |     | 0.6000                                                        | 10260  | 10401 CA                                                   |                                     | 0.0                |     |
|                     |     | 0.2000                                                        | 3420   | 14001 EA                                                   |                                     | 0.0                |     |
| (B) 100 KNOTS       |     | 0.2000                                                        | 3420   | 9702 AA                                                    |                                     | 0.0                |     |
|                     |     | 0.6000                                                        | 10260  | 12522 CA                                                   |                                     | 0.0                |     |
|                     |     | 0.2000                                                        | 3420   | 18868 EA                                                   |                                     | 0.0                |     |
| (C) VL              |     | 0.1000                                                        | 1710   | 17112 AA                                                   |                                     | 0.0                |     |
|                     |     | 0.3000                                                        | 5130   | 22363 BA                                                   |                                     | 0.0                |     |
|                     |     | 0.1000                                                        | 1710   | 34315 EA                                                   | 0.072                               | 0.003803           |     |
| 4. RIGHT TURN       |     |                                                               |        |                                                            |                                     |                    |     |
| (A) 50 KNOTS        |     | 0.2000                                                        | 3420   | 8390 AA                                                    |                                     | 0.0                |     |
|                     |     | 0.6000                                                        | 10260  | 12206 CA                                                   |                                     | 0.0                |     |
|                     |     | 0.2000                                                        | 3420   | 11765 EA                                                   |                                     | 0.0                |     |
| (B) 100 KNOTS       |     | 0.2000                                                        | 3420   | 9645 AA                                                    |                                     | 0.0                |     |
|                     |     | 0.6000                                                        | 10260  | 13660 CA                                                   |                                     | 0.0                |     |
|                     |     | 0.2000                                                        | 3420   | 15963 EA                                                   |                                     | 0.0                |     |
| (C) VL              |     | 0.1000                                                        | 1710   | 19688 AA                                                   |                                     | 0.0                |     |

TABLE XV - Continued

| FLIGHT CONDITION               | FREQUENCY OF<br>OCCURRENCE<br>PCT. CYCLES IN<br>TIME 100 HRS. | OSCILLATORY<br>BENDING STR.<br>IN M/R BLADE<br>@ STA. 94.0 | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION |          |
|--------------------------------|---------------------------------------------------------------|------------------------------------------------------------|-------------------------------------|--------------------|----------|
|                                | 0.3000                                                        | 5130                                                       | 24807 BA                            | 0.497              | 0.010327 |
|                                | 0.1000                                                        | 1710                                                       | 34315 EA                            | 0.072              | 0.023803 |
| 5. CONTROL REVERSAL            |                                                               |                                                            |                                     |                    |          |
| (A) LONGITUDINAL               | 0.0444                                                        | 759                                                        | 10939 AA                            |                    | 0.0      |
|                                | 0.1332                                                        | 2278                                                       | 18316 BA                            |                    | 0.0      |
|                                | 0.0444                                                        | 759                                                        | 18299 EA                            |                    | 0.0      |
| (B) LATERAL                    | 0.0444                                                        | 759                                                        | 11054 AA                            |                    | 0.0      |
|                                | 0.1332                                                        | 2278                                                       | 20769 CA                            |                    | 0.0      |
|                                | 0.0444                                                        | 759                                                        | 19033 EA                            |                    | 0.0      |
| (C) RUDDER                     | 0.0444                                                        | 759                                                        | 9766 AA                             |                    | 0.0      |
|                                | 0.1332                                                        | 2278                                                       | 14543 BA                            |                    | 0.0      |
|                                | 0.0444                                                        | 759                                                        | 17044 EA                            |                    | 0.0      |
| IV. POWER TRANSITIONS          |                                                               |                                                            |                                     |                    |          |
| A. POWER TO AUTO               |                                                               |                                                            |                                     |                    |          |
| 1. 40 KNOTS                    | 0.0022                                                        | 38                                                         | 5369 AA                             |                    | 0.0      |
|                                | 0.0066                                                        | 113                                                        | 9824 CA                             |                    | 0.0      |
|                                | 0.0022                                                        | 38                                                         | 12560 EA                            |                    | 0.0      |
| 2. VL                          | 0.0022                                                        | 38                                                         | 13660 AA                            |                    | 0.0      |
|                                | 0.0066                                                        | 113                                                        | 16671 BA                            |                    | 0.0      |
|                                | 0.0022                                                        | 38                                                         | 17396 EA                            |                    | 0.0      |
| B. AUTO TO POWER               | 0.0112                                                        | 192                                                        | 8301 AA                             |                    | 0.0      |
|                                | 0.0336                                                        | 575                                                        | 7367 CA                             |                    | 0.0      |
|                                | 0.0112                                                        | 192                                                        | 14680 EA                            |                    | 0.0      |
| V. AUTOROTATION                |                                                               |                                                            |                                     |                    |          |
| A. STABILIZED FLIGHT           |                                                               |                                                            |                                     |                    |          |
| 1. 40 KNOTS                    | 0.0578                                                        | 988                                                        | 3323 AA                             |                    | 0.0      |
|                                | 0.1734                                                        | 2965                                                       | 5091 CA                             |                    | 0.0      |
|                                | 0.0578                                                        | 988                                                        | 5265 EA                             |                    | 0.0      |
| 2. 80 KNOTS                    | 0.0776                                                        | 1327                                                       | 3846 AA                             |                    | 0.0      |
|                                | 0.2328                                                        | 3981                                                       | 5061 CA                             |                    | 0.0      |
|                                | 0.0776                                                        | 1327                                                       | 5912 EA                             |                    | 0.0      |
| 3. MAX AUTO A/S                | 0.0378                                                        | 646                                                        | 5314 AA                             |                    | 0.0      |
|                                | 0.1134                                                        | 1939                                                       | 8391 CA                             |                    | 0.0      |
|                                | 0.0378                                                        | 646                                                        | 23072 EA                            | 2.085              | 0.000310 |
| B. TURNS. (NORMAL<br>AUTO A/S) |                                                               |                                                            |                                     |                    |          |
| 1. TO THE LEFT                 | 0.0400                                                        | 684                                                        | 3964 AA                             |                    | 0.0      |
|                                | 0.1200                                                        | 2052                                                       | 4626 CA                             |                    | 0.0      |
|                                | 0.0400                                                        | 684                                                        | 5782 EA                             |                    | 0.0      |
| 2. TO THE RIGHT                | 0.0400                                                        | 684                                                        | 4430 AA                             |                    | 0.0      |
|                                | 0.1200                                                        | 2052                                                       | 4452 CA                             |                    | 0.0      |
|                                | 0.0400                                                        | 684                                                        | 5569 EA                             |                    | 0.0      |
| C. CONTROL REVERSAL            |                                                               |                                                            |                                     |                    |          |
| 1. LONGITUDINAL                | 0.0200                                                        | 342                                                        | 5274 AA                             |                    | 0.0      |

TABLE XV - Concluded

| FLIGHT CONDITION                                    | FREQUENCY OF<br>OCCURRENCE<br>PCT. CYCLES IN<br>TIME 100 HRS. | OSCILLATORY<br>BENDING STR.<br>IN M/R BLADE<br>@ STA. 94.0 | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION                |
|-----------------------------------------------------|---------------------------------------------------------------|------------------------------------------------------------|-------------------------------------|-----------------------------------|
|                                                     | 0.0600                                                        | 1026                                                       | 6834 CA                             | 0.0                               |
|                                                     | 0.0200                                                        | 342                                                        | 7284 EA                             | 0.0                               |
| 2. LATERAL                                          | 0.0200                                                        | 342                                                        | 6817 AA                             | 0.0                               |
|                                                     | 0.0600                                                        | 1026                                                       | 10836 CA                            | 0.0                               |
|                                                     | 0.0200                                                        | 342                                                        | 10647 EA                            | 0.0                               |
| 3. RUDDER                                           | 0.0200                                                        | 342                                                        | 3736 AA                             | 0.0                               |
|                                                     | 0.0600                                                        | 1026                                                       | 5356 CA                             | 0.0                               |
|                                                     | 0.0200                                                        | 342                                                        | 6462 EA                             | 0.0                               |
| D. CYCLIC PULL-UP<br>(NORMAL AUTO 4/S)              | 0.0112                                                        | 192                                                        | 6181 AA                             | 0.0                               |
|                                                     | 0.0336                                                        | 575                                                        | 5970 CA                             | 0.0                               |
|                                                     | 0.0112                                                        | 192                                                        | 7842 EA                             | 0.0                               |
| E. PART PWR DSNT. 80KT                              | 0.4166                                                        | 7124                                                       | 5223 AA                             | 0.0                               |
|                                                     | 1.2498                                                        | 21372                                                      | 5995 CA                             | 0.0                               |
|                                                     | 0.4166                                                        | 7124                                                       | 6792 EA                             | 0.0                               |
| F. FULL AUTO LANDING                                | 0.0600                                                        | 1026                                                       | 0 AA                                | 0.0                               |
|                                                     | 0.1800                                                        | 3078                                                       | 26395 BA                            | *                                 |
|                                                     | 0.0600                                                        | 1026                                                       | 0 FA                                | 0.0                               |
| ENDURANCE LIMIT = 22500.0                           |                                                               |                                                            |                                     | TOTAL DAMAGE (D) = 0.074948       |
| MATERIAL = ST12                                     |                                                               |                                                            |                                     |                                   |
| FREQUENCY = 1 / REV OF M/R                          |                                                               |                                                            |                                     | FATIGUE LIFE = 100/D = 1334 HOURS |
| * DAMAGE CALCULATED FROM MEASURED LOAD FREQUENCIES. |                                                               |                                                            |                                     |                                   |

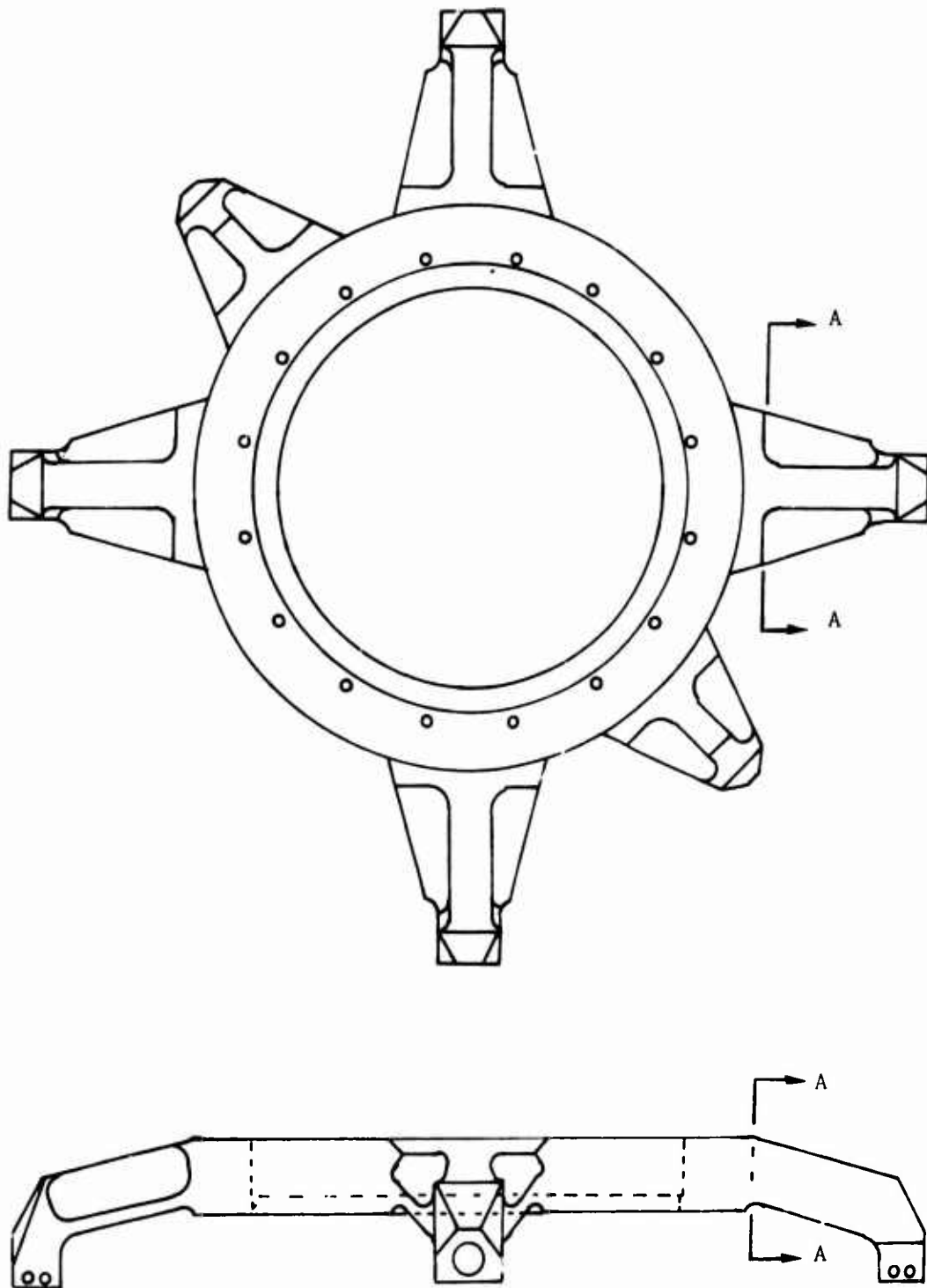
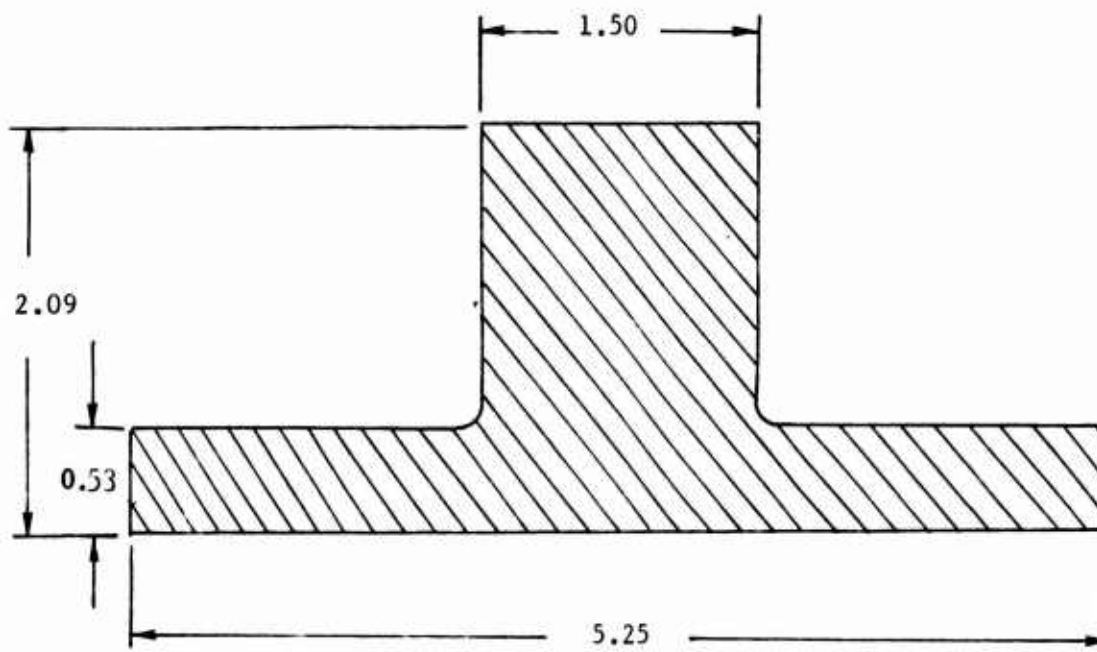


Figure 97. Swashplate Outer Ring, Part No. 609-010-401-3.



All Dimensions in Inches

Sec A-A

$$A = 5.12 \text{ in.}^2$$

$$I_y = 1.81 \text{ in.}^4$$

$$C = 1.30 \text{ in.}$$

$$M = (9.56 \text{ in.})(\text{Pitch Link Load})$$

$$\sigma_b = (6.86/\text{in.}^2)(\text{Pitch Link Load})$$

Figure 97. Concluded.

TABLE XVI. FATIGUE LIFE DETERMINATION OF 609 SWASHPLATE  
OUTER RING, PART NO. 609-010-401-3

| FLIGHT CONDITION     | FREQUENCY OF OCCURRENCE |                    | OSCILLATORY BENDING STR. IN S/P ARM OUTER RING | CYC. TO FAILURE X 10**(-6) | DAMAGE FRACTION |
|----------------------|-------------------------|--------------------|------------------------------------------------|----------------------------|-----------------|
|                      | PCT. TIME               | CYCLES IN 100 HRS. |                                                |                            |                 |
| I. GROUND CONDITIONS |                         |                    |                                                |                            |                 |
| A. NORMAL START      | 0.1000                  | 1770               | 0 AA                                           |                            | 0.0             |
|                      | 0.3000                  | 5310               | 782 CA                                         |                            | 0.0             |
|                      | 0.1000                  | 1770               | 0 FA                                           |                            | 0.0             |
| B. NORMAL SHUTDOWN   | 0.1000                  | 1770               | 700 AA                                         |                            | 0.0             |
|                      | 0.3000                  | 5310               | 453 CA                                         |                            | 0.0             |
|                      | 0.1000                  | 1770               | 0 FA                                           |                            | 0.0             |
| II. POWER-ON ICE     |                         |                    |                                                |                            |                 |
| A. HOVERING          |                         |                    |                                                |                            |                 |
| 1. STEADY            |                         |                    |                                                |                            |                 |
| (A) 280 RPM          | 0.6944                  | 11666              | 761 AA                                         |                            | 0.0             |
|                      | 2.0832                  | 34998              | 1104 CA                                        |                            | 0.0             |
|                      | 0.6944                  | 11666              | 1564 EA                                        |                            | 0.0             |
| (B) 295 RPM          | 0.6944                  | 12291              | 782 AA                                         |                            | 0.0             |
|                      | 2.0832                  | 36873              | 1276 CA                                        |                            | 0.0             |
|                      | 0.6944                  | 12291              | 1948 EA                                        |                            | 0.0             |
| 2. LEFT TURN         | 0.2222                  | 3800               | 885 AA                                         |                            | 0.0             |
|                      | 0.6666                  | 11399              | 885 CA                                         |                            | 0.0             |
|                      | 0.2222                  | 3800               | 1166 EA                                        |                            | 0.0             |
| 3. RIGHT TURN        | 0.2222                  | 3800               | 954 AA                                         |                            | 0.0             |
|                      | 0.6666                  | 11399              | 1111 CA                                        |                            | 0.0             |
|                      | 0.2222                  | 3800               | 1015 EA                                        |                            | 0.0             |
| 4. CONTROL REVERSAL  |                         |                    |                                                |                            |                 |
| (A) LONGITUDINAL     | 0.0556                  | 951                | 1255 AA                                        |                            | 0.0             |
|                      | 0.1668                  | 2852               | 1468 CA                                        |                            | 0.0             |
|                      | 0.0556                  | 951                | 1269 EA                                        |                            | 0.0             |
| (B) LATERAL          | 0.0556                  | 951                | 1221 AA                                        |                            | 0.0             |
|                      | 0.1668                  | 2852               | 1269 CA                                        |                            | 0.0             |
|                      | 0.0556                  | 951                | 1194 EA                                        |                            | 0.0             |
| (C) RUDDER           | 0.0556                  | 951                | 816 AA                                         |                            | 0.0             |
|                      | 0.1668                  | 2852               | 857 CA                                         |                            | 0.0             |
|                      | 0.0556                  | 951                | 947 EA                                         |                            | 0.0             |
| B. MANEUVERS         |                         |                    |                                                |                            |                 |
| 1. SIDEWARD FLIGHT   |                         |                    |                                                |                            |                 |
| (A) TO THE RIGHT     | 0.1000                  | 1710               | 1091 AA                                        |                            | 0.0             |
|                      | 0.3000                  | 5130               | 1667 BA                                        |                            | 0.0             |
|                      | 0.1000                  | 1710               | 748 EA                                         |                            | 0.0             |
| (B) TO THE LEFT      | 0.1000                  | 1710               | 906 AA                                         |                            | 0.0             |
|                      | 0.3000                  | 5130               | 1091 CA                                        |                            | 0.0             |
|                      | 0.1000                  | 1710               | 1255 EA                                        |                            | 0.0             |
| 2. REARWARD FLIGHT   | 0.1000                  | 1710               | 1235 AA                                        |                            | 0.0             |
|                      | 0.3000                  | 5130               | 1626 BA                                        |                            | 0.0             |
|                      | 0.1000                  | 1710               | 2092 EA                                        |                            | 0.0             |
| 3. NORMAL TAKE-OFF   | 0.1778                  | 3040               | 2003 AA                                        |                            | 0.0             |
|                      | 0.5334                  | 9121               | 1811 BA                                        |                            | 0.0             |

TABLE XVI- Continued

| FLIGHT CONDITION  | FREQUENCY OF OCCURRENCE |                    | OSCILLATORY BENDING STR. IN S/P ARM OUTER RING | CYC. TO FAILURE X 10**(-6) | DAMAGE FRACTION |     |
|-------------------|-------------------------|--------------------|------------------------------------------------|----------------------------|-----------------|-----|
|                   | PCT. TIME               | CYCLES IN 100 HRS. |                                                |                            |                 |     |
| 4. NORMAL LANDING |                         | 0.1778             | 3040                                           | 1900 EA                    | 0.0             |     |
|                   |                         | 0.4166             | 7124                                           | 1832 AA                    | 0.0             |     |
|                   |                         | 1.2498             | 21372                                          | 2367 CA                    | 0.0             |     |
|                   |                         | 0.4166             | 7124                                           | 2627 EA                    | 0.0             |     |
| III. POWER-ON IGF |                         |                    |                                                |                            |                 |     |
| A. LEVEL FLIGHT   |                         |                    |                                                |                            |                 |     |
| % VL              | RPM                     |                    |                                                |                            |                 |     |
| 1. 40             | 280                     | 0.1866             | 3135                                           | 1098 AA                    | 0.0             |     |
|                   |                         | 0.5598             | 9405                                           | 1098 CA                    | 0.0             |     |
|                   |                         | 0.1866             | 3135                                           | 1585 FA                    | 0.0             |     |
|                   |                         | 295                | 0.1866                                         | 3303                       | 1125 AA         | 0.0 |
|                   |                         | 0.5598             | 9908                                           | 1077 CA                    | 0.0             |     |
|                   |                         | 0.1866             | 3303                                           | 1461 FA                    | 0.0             |     |
|                   |                         | 280                | 0.4917                                         | 8261                       | 1056 AA         | 0.0 |
|                   |                         |                    | 1.4751                                         | 24782                      | 1132 CA         | 0.0 |
|                   |                         | 0.4917             | 8261                                           | 1605 FA                    | 0.0             |     |
|                   |                         | 295                | 0.4917                                         | 8703                       | 1050 AA         | 0.0 |
|                   |                         |                    | 1.4751                                         | 26109                      | 1098 CA         | 0.0 |
|                   |                         |                    | 0.4917                                         | 8703                       | 1598 FA         | 0.0 |
| 3. 60             | 280                     | 0.7838             | 13168                                          | 1180 AA                    | 0.0             |     |
|                   |                         | 2.3514             | 39503                                          | 1303 CA                    | 0.0             |     |
|                   |                         | 0.7838             | 13168                                          | 1784 FA                    | 0.0             |     |
|                   |                         | 295                | 0.7838                                         | 13873                      | 1228 AA         | 0.0 |
|                   |                         | 2.3514             | 41620                                          | 1200 CA                    | 0.0             |     |
|                   |                         | 0.7838             | 13873                                          | 1749 FA                    | 0.0             |     |
|                   |                         | 280                | 1.0000                                         | 16800                      | 1249 AA         | 0.0 |
|                   |                         |                    | 3.0000                                         | 50400                      | 1303 CA         | 0.0 |
|                   |                         | 1.0000             | 16800                                          | 2223 FA                    | 0.0             |     |
|                   |                         | 295                | 1.0000                                         | 17700                      | 1406 AA         | 0.0 |
|                   |                         |                    | 3.0000                                         | 53100                      | 1290 CA         | 0.0 |
|                   |                         |                    | 1.0000                                         | 17700                      | 1907 FA         | 0.0 |
| 5. 80             | 280                     | 1.5000             | 25200                                          | 1489 AA                    | 0.0             |     |
|                   |                         | 4.5000             | 75600                                          | 1509 BA                    | 0.0             |     |
|                   |                         | 1.5000             | 25200                                          | 2291 DA                    | 0.0             |     |
|                   |                         | 295                | 1.5000                                         | 26550                      | 1646 AA         | 0.0 |
|                   |                         | 4.5000             | 79650                                          | 1358 BA                    | 0.0             |     |
|                   |                         | 1.5000             | 26550                                          | 2017 FA                    | 0.0             |     |
|                   |                         | 280                | 1.7334                                         | 29121                      | 1859 AA         | 0.0 |
|                   |                         |                    | 5.2002                                         | 87463                      | 1976 BA         | 0.0 |
|                   |                         | 1.7334             | 29121                                          | 3307 DA                    | 0.0             |     |
|                   |                         | 295                | 1.7334                                         | 30681                      | 2188 AA         | 0.0 |
|                   |                         |                    | 5.2002                                         | 92044                      | 1996 CA         | 0.0 |
|                   |                         |                    | 1.7334                                         | 30681                      | 2579 FA         | 0.0 |
| 7. 100            | 280                     | 0.9838             | 16528                                          | 2326 AA                    | 0.0             |     |
|                   |                         | 2.9514             | 49583                                          | 2614 CA                    | 0.0             |     |

TABLE XVI- Continued

| FLIGHT CONDITION    |                | FREQUENCY OF OCCURRENCE<br>PCT. CYCLES IN<br>TIME 100 HRS. |         | OSCILLATORY<br>BENDING STR.<br>IN S/P ARM<br>OUTER RING | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION |     |
|---------------------|----------------|------------------------------------------------------------|---------|---------------------------------------------------------|-------------------------------------|--------------------|-----|
| R. VNE              | 295            | 0.9838                                                     | 16528   | 3114 EA                                                 |                                     | 0.0                |     |
|                     |                | 0.9838                                                     | 17413   | 2559 AA                                                 |                                     | 0.0                |     |
|                     |                | 2.9514                                                     | 52240   | 3293 CA                                                 |                                     | 0.0                |     |
|                     | 280            | 0.9838                                                     | 17413   | 3361 EA                                                 |                                     | 0.0                |     |
|                     |                | 0.3500                                                     | 5880    | 2346 AA                                                 |                                     | 0.0                |     |
|                     |                | 1.0500                                                     | 17640   | 2792 CA                                                 |                                     | 0.0                |     |
|                     |                | 0.3500                                                     | 5880    | 2785 EA                                                 |                                     | 0.0                |     |
|                     |                | 295                                                        | 0.3500  | 6195                                                    | 3190 AA                             |                    | 0.0 |
|                     |                | 1.0500                                                     | 18585   | 3533 CA                                                 |                                     | 0.0                |     |
|                     |                | 0.3500                                                     | 6195    | 3499 EA                                                 |                                     | 0.0                |     |
| R. MANEUVERS        |                |                                                            |         |                                                         |                                     |                    |     |
| 1. CLIMB 0-60 KNOTS |                |                                                            |         |                                                         |                                     |                    |     |
| (A) M.C. POWER      | 0.6000         | 10260                                                      | 1417 AA |                                                         | 0.0                                 |                    |     |
|                     | 1.8000         | 30780                                                      | 1276 CA |                                                         | 0.0                                 |                    |     |
|                     | 0.6000         | 10260                                                      | 1886 EA |                                                         | 0.0                                 |                    |     |
|                     | (B) T.O. POWER | 0.2000                                                     | 3420    | 1626 AA                                                 |                                     | 0.0                |     |
|                     |                | 0.6000                                                     | 10260   | 1447 CA                                                 |                                     | 0.0                |     |
|                     |                | 0.2000                                                     | 3420    | 1886 EA                                                 |                                     | 0.0                |     |
| 2. CYCLIC PULL-UP   |                |                                                            |         |                                                         |                                     |                    |     |
| (A) 50 KNOTS        | 0.0324         | 554                                                        | 1441 AA |                                                         | 0.0                                 |                    |     |
|                     | 0.0972         | 1662                                                       | 1681 CA |                                                         | 0.0                                 |                    |     |
|                     | 0.0324         | 554                                                        | 1585 EA |                                                         | 0.0                                 |                    |     |
|                     | (B) 100 KNOTS  | 0.0324                                                     | 554     | 1777 AA                                                 |                                     | 0.0                |     |
|                     |                | 0.0972                                                     | 1662    | 1976 CA                                                 |                                     | 0.0                |     |
|                     |                | 0.0324                                                     | 554     | 2291 EA                                                 |                                     | 0.0                |     |
| (C) VL              | 0.0324         | 554                                                        | 2374 AA |                                                         | 0.0                                 |                    |     |
|                     | 0.0972         | 1662                                                       | 5083 CA | 2.436                                                   | 0.000682                            |                    |     |
|                     | 0.0324         | 554                                                        | 6270 EA | 0.583                                                   | 0.000951                            |                    |     |
| 3. LEFT TURN        |                |                                                            |         |                                                         |                                     |                    |     |
| (A) 50 KNOTS        | 0.2000         | 3420                                                       | 1249 AA |                                                         | 0.0                                 |                    |     |
|                     | 0.6000         | 10260                                                      | 1331 CA |                                                         | 0.0                                 |                    |     |
|                     | 0.2000         | 3420                                                       | 1777 EA |                                                         | 0.0                                 |                    |     |
|                     | (B) 100 KNOTS  | 0.2000                                                     | 3420    | 1454 AA                                                 |                                     | 0.0                |     |
|                     |                | 0.6000                                                     | 10260   | 1866 BA                                                 |                                     | 0.0                |     |
|                     |                | 0.2000                                                     | 3420    | 2380 EA                                                 |                                     | 0.0                |     |
| (C) VL              | 0.1000         | 1710                                                       | 2675 AA |                                                         | 0.0                                 |                    |     |
|                     | 0.3000         | 5130                                                       | 3821 BA | 41.084                                                  | 0.000125                            |                    |     |
|                     | 0.1000         | 1710                                                       | 6270 EA | 0.583                                                   | 0.002935                            |                    |     |
| 4. RIGHT TURN       |                |                                                            |         |                                                         |                                     |                    |     |
| (A) 50 KNOTS        | 0.2000         | 3420                                                       | 1310 AA |                                                         | 0.0                                 |                    |     |
|                     | 0.6000         | 10260                                                      | 1550 CA |                                                         | 0.0                                 |                    |     |
|                     | 0.2000         | 3420                                                       | 1482 EA |                                                         | 0.0                                 |                    |     |
|                     | (B) 100 KNOTS  | 0.2000                                                     | 3420    | 1571 AA                                                 |                                     | 0.0                |     |
|                     |                | 0.6000                                                     | 10260   | 1688 CA                                                 |                                     | 0.0                |     |
|                     |                | 0.2000                                                     | 3420    | 2051 EA                                                 |                                     | 0.0                |     |
| (C) VL              | 0.1000         | 1710                                                       | 2895 AA |                                                         | 0.0                                 |                    |     |

TABLE XVI- Continued

| FLIGHT CONDITION            | FREQUENCY OF OCCURRENCE |                    | OSCILLATORY BENDING STR. IN S/P ARM OUTER RING | CYC. TO FAILURE X 10**(-6) | DAMAGE FRACTION |
|-----------------------------|-------------------------|--------------------|------------------------------------------------|----------------------------|-----------------|
|                             | PCT. TIME               | CYCLES IN 100 HRS. |                                                |                            |                 |
|                             | 0.3000                  | 5130               | 4637 CA                                        | 5.161                      | 0.000994        |
|                             | 0.1000                  | 1710               | 6270 EA                                        | 0.583                      | 0.002935        |
| 5. CONTROL REVERSAL         |                         |                    |                                                |                            |                 |
| (A) LONGITUDINAL            | 0.0444                  | 759                | 2175 AA                                        |                            | 0.0             |
|                             | 0.1332                  | 2278               | 2223 BA                                        |                            | 0.0             |
|                             | 0.0444                  | 759                | 2655 EA                                        |                            | 0.0             |
| (B) LATERAL                 | 0.0444                  | 759                | 1996 AA                                        |                            | 0.0             |
|                             | 0.1332                  | 2278               | 2531 CA                                        |                            | 0.0             |
|                             | 0.0444                  | 759                | 2867 EA                                        |                            | 0.0             |
| (C) RUDDER                  | 0.0444                  | 759                | 1886 AA                                        |                            | 0.0             |
|                             | 0.1332                  | 2278               | 1996 BA                                        |                            | 0.0             |
|                             | 0.0444                  | 759                | 2497 EA                                        |                            | 0.0             |
| IV. POWER TRANSITIONS       |                         |                    |                                                |                            |                 |
| A. POWER TO AUTO            |                         |                    |                                                |                            |                 |
| 1. 40 KNOTS                 | 0.0022                  | 38                 | 1022 AA                                        |                            | 0.0             |
|                             | 0.0066                  | 113                | 1159 CA                                        |                            | 0.0             |
|                             | 0.0022                  | 38                 | 1578 EA                                        |                            | 0.0             |
| 2. VL                       | 0.0022                  | 38                 | 1893 AA                                        |                            | 0.0             |
|                             | 0.0066                  | 113                | 2326 BA                                        |                            | 0.0             |
|                             | 0.0022                  | 38                 | 2689 EA                                        |                            | 0.0             |
| B. AUTO TO POWER            | 0.0112                  | 192                | 1228 AA                                        |                            | 0.0             |
|                             | 0.0336                  | 575                | 1056 CA                                        |                            | 0.0             |
|                             | 0.0112                  | 192                | 1605 EA                                        |                            | 0.0             |
| V. AUTOROTATION             |                         |                    |                                                |                            |                 |
| A. STABILIZED FLIGHT        |                         |                    |                                                |                            |                 |
| 1. 40 KNOTS                 | 0.0578                  | 988                | 837 AA                                         |                            | 0.0             |
|                             | 0.1734                  | 2965               | 637 CA                                         |                            | 0.0             |
|                             | 0.0578                  | 988                | 857 EA                                         |                            | 0.0             |
| 2. 80 KNOTS                 | 0.0776                  | 1327               | 960 AA                                         |                            | 0.0             |
|                             | 0.2328                  | 3981               | 1043 CA                                        |                            | 0.0             |
|                             | 0.0776                  | 1327               | 919 EA                                         |                            | 0.0             |
| 3. MAX AUTO A/S             | 0.0378                  | 646                | 1043 AA                                        |                            | 0.0             |
|                             | 0.1134                  | 1939               | 1255 CA                                        |                            | 0.0             |
|                             | 0.0378                  | 646                | 1166 EA                                        |                            | 0.0             |
| B. TURNS. (NORMAL AUTO A/S) |                         |                    |                                                |                            |                 |
| 1. TO THE LEFT              | 0.0400                  | 684                | 974 AA                                         |                            | 0.0             |
|                             | 0.1200                  | 2052               | 1111 CA                                        |                            | 0.0             |
|                             | 0.0400                  | 684                | 988 EA                                         |                            | 0.0             |
| 2. TO THE RIGHT             | 0.0400                  | 684                | 809 AA                                         |                            | 0.0             |
|                             | 0.1200                  | 2052               | 809 CA                                         |                            | 0.0             |
|                             | 0.0400                  | 684                | 851 EA                                         |                            | 0.0             |
| C. CONTROL REVERSAL         |                         |                    |                                                |                            |                 |
| 1. LONGITUDINAL             | 0.0200                  | 342                | 1132 AA                                        |                            | 0.0             |

TABLE XVI- Concluded

| FLIGHT CONDITION                                    | FREQUENCY OF<br>OCCURRENCE<br>PCT. CYCLES IN<br>TIME 100 HRS. | OSCILLATORY<br>BENDING STR.<br>IN S/P ARM<br>OUTER RING | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION |
|-----------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------|-------------------------------------|--------------------|
| 2. LATERAL                                          | 0.0600                                                        | 1026                                                    | 1125 CA                             | 0.0                |
|                                                     | 0.0200                                                        | 342                                                     | 1043 EA                             | 0.0                |
|                                                     | 0.0200                                                        | 342                                                     | 1036 AA                             | 0.0                |
|                                                     | 0.0600                                                        | 1026                                                    | 1063 CA                             | 0.0                |
| 3. RUDDER                                           | 0.0200                                                        | 342                                                     | 1029 EA                             | 0.0                |
|                                                     | 0.0200                                                        | 342                                                     | 906 AA                              | 0.0                |
|                                                     | 0.0600                                                        | 1026                                                    | 933 CA                              | 0.0                |
|                                                     | 0.0200                                                        | 342                                                     | 974 EA                              | 0.0                |
| D. CYCLIC PULL-UP<br>(NORMAL AUTO A/S)              | 0.0112                                                        | 192                                                     | 1084 AA                             | 0.0                |
|                                                     | 0.0336                                                        | 575                                                     | 1022 CA                             | 0.0                |
|                                                     | 0.0112                                                        | 192                                                     | 1104 EA                             | 0.0                |
|                                                     | F. PART PWR DSNT. ROKT                                        | 0.4166                                                  | 7124                                | 1050 AA            |
| 1.2498                                              |                                                               | 21372                                                   | 1022 CA                             | 0.0                |
| 0.4166                                              |                                                               | 7124                                                    | 974 EA                              | 0.0                |
| F. FULL AUTO LANDING                                |                                                               | 0.0600                                                  | 1026                                | 0 AA               |
|                                                     | 0.1800                                                        | 3078                                                    | 5941 BA                             | *                  |
|                                                     | 0.0600                                                        | 1026                                                    | 0 FA                                | 0.000031           |
|                                                     |                                                               |                                                         |                                     | 0.0                |
| ENDURANCE LIMIT = 3600.0                            |                                                               | TOTAL DAMAGE (D) = 0.008652                             |                                     |                    |
| MATERIAL = ALUM                                     |                                                               |                                                         |                                     |                    |
| FREQUENCY = 1 / REV OF M/R                          |                                                               | FATIGUE LIFE = 100/D = 11557 HOURS                      |                                     |                    |
| * DAMAGE CALCULATED FROM MEASURED LOAD FREQUENCIES. |                                                               |                                                         |                                     |                    |

## NONROTATING CONTROLS

The nonrotating control system of the Model 609 main rotor includes all dynamic components below the outer ring of the swashplate, to and including the three boost cylinder housings. Analysis of these components showed the 609-010-419-5 slider lug attachment bolt to be the most critical in fatigue.

This bolt, of H-11 steel heat treated to an ultimate tensile strength of 256-284 ksi, is critical in bending. The bending stress equation at the point of maximum stress is:

$$\sigma_B = 16.2 \text{ (collective boost tube load)} \\ +44.4 \text{ (cyclic boost tube load)}$$

An endurance limit of 38,079 psi in bending was established for the 540-011-478-1 and -416-1 pins during tests of the 540-011-404-1 and -5 swashplate outer rings. These pins, of the same material as the -419-5 bolt and loaded in the same manner, have the S-N curve shown in Figure 98. Their characteristics were used to calculate a fatigue life of 545 hours for the -419-5 bolt. Table XVII shows the fatigue life calculations. They were based on a loading frequency of four cycles per main rotor revolution, which is a conservative estimate. Analysis of the flight test data showed that the phasing relationship between the collective and cyclic boost tubes is such that the stress calculated by the above equation occurs only once every rotor revolution. It is because the other three cycles are at a lower stress level that the above analysis is conservative. A detailed analysis of the loading on this component would result in a higher life estimate. A summary of fatigue lives calculated for some of the major components of the nonrotating control system is included in Table VI.

## CONCLUSIONS

Fatigue lives have been calculated for the dynamic components of the Model 609 main rotor system, and are summarized in Table VI. They establish as the minimum fatigue life of the entire system the 545 hours of helicopter operation which is the fatigue life of the 609-010-419-5 slider lug attachment bolt.

These lives were based on the frequency-of-occurrence spectrum shown in Table III and should not be considered applicable in cases where the spectrum of operation differs radically from it. Spectrums consisting mainly of operations at high gross weights and aft cg locations cause substantial reductions in fatigue life, whereas low gross weights and forward or neutral

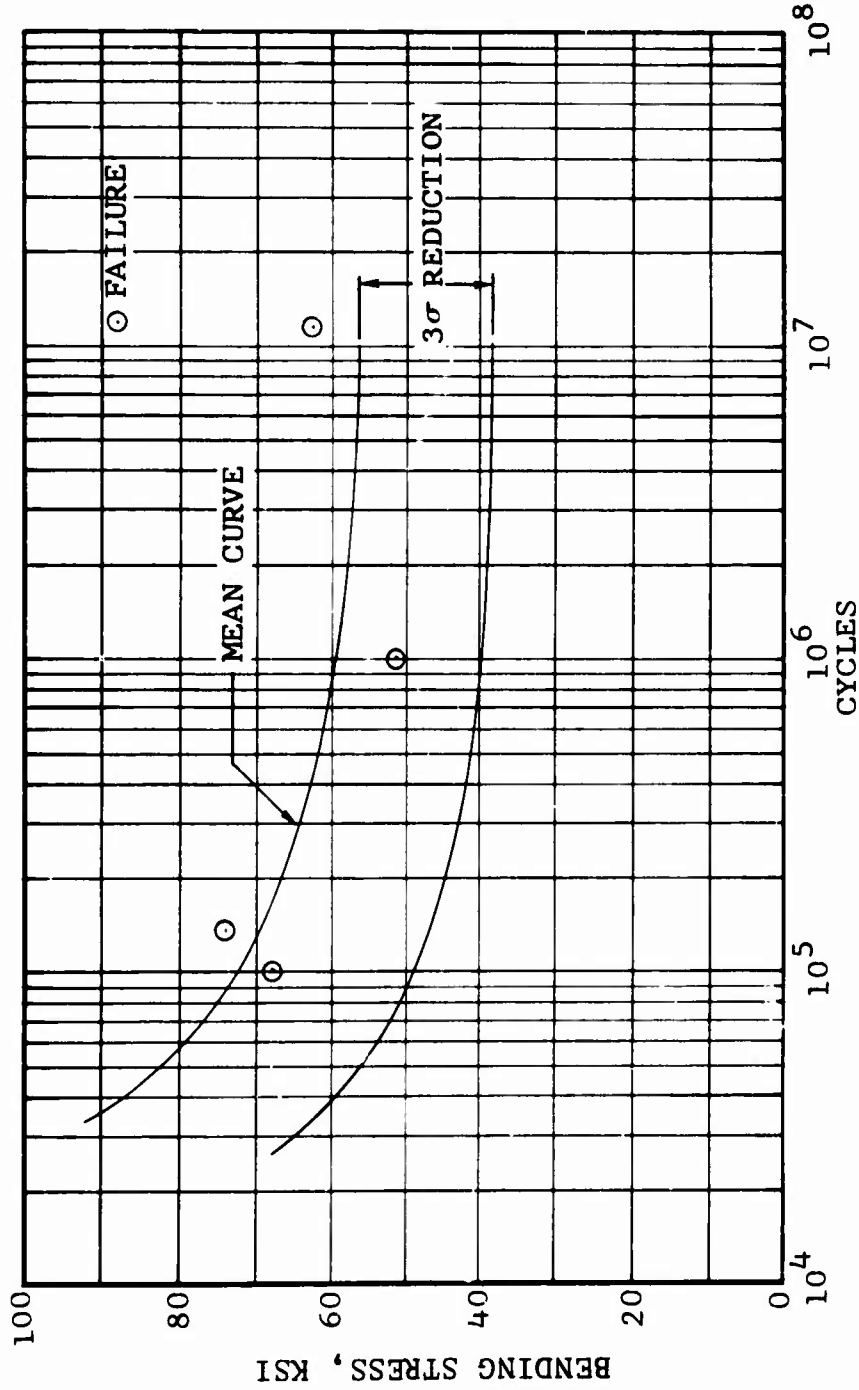


Figure 98. Oscillatory Stress Versus Cycles for the 540-011-478-1 Swashplate Outer Ring Pin Used To Substantiate the 609-010-419-5 Slider Lug Bolt.

TABLE XVII. FATIGUE LIFE DETERMINATION OF 609 SLIDER  
LUG BOLT, PART NO. 609-010-419-5

| FLIGHT CONDITION     | FREQUENCY OF OCCURRENCE<br>PCT. CYCLES IN TIME 100 HRS. |        | OSCILLATORY BENDING STR. IN SLIDER LUG BOLT | CYC. TO FAILURE X 10**(-6) | DAMAGE FRACTION |
|----------------------|---------------------------------------------------------|--------|---------------------------------------------|----------------------------|-----------------|
| I. GROUND CONDITIONS |                                                         |        |                                             |                            |                 |
| A. NORMAL START      | 0.1000                                                  | 7080   | 0 AA                                        |                            | 0.0             |
|                      | 0.3000                                                  | 21240  | 5391 CA                                     |                            | 0.0             |
|                      | 0.1000                                                  | 7080   | 0 FA                                        |                            | 0.0             |
| B. NORMAL SHUTDOWN   | 0.1000                                                  | 7080   | 6493 AA                                     |                            | 0.0             |
|                      | 0.3000                                                  | 21240  | 5788 CA                                     |                            | 0.0             |
|                      | 0.1000                                                  | 7080   | 0 FA                                        |                            | 0.0             |
| II. POWER-ON IGF     |                                                         |        |                                             |                            |                 |
| A. HOVERING          |                                                         |        |                                             |                            |                 |
| 1. STEADY            |                                                         |        |                                             |                            |                 |
| (A) 280 RPM          | 0.6944                                                  | 46664  | 4877 AA                                     |                            | 0.0             |
|                      | 2.0832                                                  | 139991 | 7588 CA                                     |                            | 0.0             |
|                      | 0.6944                                                  | 46664  | 15892 EA                                    |                            | 0.0             |
| (B) 255 RPM          | 0.6944                                                  | 49164  | 5196 AA                                     |                            | 0.0             |
|                      | 2.0832                                                  | 147490 | 7706 CA                                     |                            | 0.0             |
|                      | 0.6944                                                  | 49164  | 10168 EA                                    |                            | 0.0             |
| 2. LEFT TURN         | 0.2222                                                  | 15198  | 7330 AA                                     |                            | 0.0             |
|                      | 0.6666                                                  | 45595  | 7429 CA                                     |                            | 0.0             |
|                      | 0.2222                                                  | 15198  | 10460 EA                                    |                            | 0.0             |
| 3. RIGHT TURN        | 0.2222                                                  | 15198  | 7647 AA                                     |                            | 0.0             |
|                      | 0.6666                                                  | 45595  | 9832 BA                                     |                            | 0.0             |
|                      | 0.2222                                                  | 15198  | 8558 EA                                     |                            | 0.0             |
| 4. CONTROL REVERSAL  |                                                         |        |                                             |                            |                 |
| (A) LONGITUDINAL     | 0.0556                                                  | 3803   | 12436 AA                                    |                            | 0.0             |
|                      | 0.1668                                                  | 11409  | 12107 CA                                    |                            | 0.0             |
|                      | 0.0556                                                  | 3803   | 14705 EA                                    |                            | 0.0             |
| (B) LATERAL          | 0.0556                                                  | 3803   | 11308 AA                                    |                            | 0.0             |
|                      | 0.1668                                                  | 11409  | 6782 BA                                     |                            | 0.0             |
|                      | 0.0556                                                  | 3803   | 9648 EA                                     |                            | 0.0             |
| (C) RUDDER           | 0.0556                                                  | 3803   | 6141 AA                                     |                            | 0.0             |
|                      | 0.1668                                                  | 11409  | 6495 CA                                     |                            | 0.0             |
|                      | 0.0556                                                  | 3803   | 7816 EA                                     |                            | 0.0             |
| B. MANEUVERS         |                                                         |        |                                             |                            |                 |
| 1. SIDEWARD FLIGHT   |                                                         |        |                                             |                            |                 |
| (A) TO THE RIGHT     | 0.1000                                                  | 6840   | 6797 AA                                     |                            | 0.0             |
|                      | 0.3000                                                  | 20520  | 10310 BA                                    |                            | 0.0             |
|                      | 0.1000                                                  | 6840   | 6081 EA                                     |                            | 0.0             |
| (B) TO THE LEFT      | 0.1000                                                  | 6840   | 5376 AA                                     |                            | 0.0             |
|                      | 0.3000                                                  | 20520  | 5281 CA                                     |                            | 0.0             |
|                      | 0.1000                                                  | 6840   | 7683 EA                                     |                            | 0.0             |
| 2. REARWARD FLIGHT   | 0.1000                                                  | 6840   | 5363 AA                                     |                            | 0.0             |
|                      | 0.3000                                                  | 20520  | 10276 CA                                    |                            | 0.0             |
|                      | 0.1000                                                  | 6840   | 13159 EA                                    |                            | 0.0             |
| 3. NORMAL TAKE-OFF   | 0.1778                                                  | 12162  | 10255 AA                                    |                            | 0.0             |
|                      | 0.5334                                                  | 36485  | 13343 BA                                    |                            | 0.0             |

TABLE XVII - Continued

| FLIGHT CONDITION  |     | FREQUENCY OF OCCURRENCE<br>PCT. CYCLES IN<br>TIME 100 HRS. |        | OSCILLATORY<br>BENDING STR.<br>IN SLIDER<br>LUG BOLT | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION |
|-------------------|-----|------------------------------------------------------------|--------|------------------------------------------------------|-------------------------------------|--------------------|
| 4. NORMAL LANDING |     | 0.1778                                                     | 12162  | 10955 EA                                             |                                     | 0.0                |
|                   |     | 0.4166                                                     | 28495  | 13016 AA                                             |                                     | 0.0                |
|                   |     | 1.2498                                                     | 85486  | 15809 CA                                             |                                     | 0.0                |
|                   |     | 0.4166                                                     | 28495  | 23929 EA                                             |                                     | 0.0                |
| III. POWER-ON IGF |     |                                                            |        |                                                      |                                     |                    |
| A. LEVEL FLIGHT   |     |                                                            |        |                                                      |                                     |                    |
| % VL              | RPM |                                                            |        |                                                      |                                     |                    |
| 1. 40             | 230 | 0.1866                                                     | 12540  | 6071 AA                                              |                                     | 0.0                |
|                   |     | 0.5598                                                     | 37619  | 6892 BA                                              |                                     | 0.0                |
|                   | 295 | 0.1866                                                     | 12540  | 9182 DA                                              |                                     | 0.0                |
|                   |     | 0.1866                                                     | 13211  | 5472 AA                                              |                                     | 0.0                |
|                   |     | 0.5598                                                     | 39634  | 7300 CA                                              |                                     | 0.0                |
|                   |     | 0.1866                                                     | 13211  | 8363 FA                                              |                                     | 0.0                |
| 2. 50             | 230 | 0.4917                                                     | 33042  | 6226 AA                                              |                                     | 0.0                |
|                   |     | 1.4751                                                     | 99127  | 6688 CA                                              |                                     | 0.0                |
|                   |     | 0.4917                                                     | 33042  | 8498 DA                                              |                                     | 0.0                |
|                   |     | 0.4917                                                     | 34812  | 6517 AA                                              |                                     | 0.0                |
|                   | 295 | 1.4751                                                     | 104437 | 7446 CA                                              |                                     | 0.0                |
|                   |     | 0.4917                                                     | 34812  | 7854 DA                                              |                                     | 0.0                |
| 3. 60             | 230 | 0.7838                                                     | 52671  | 7567 AA                                              |                                     | 0.0                |
|                   |     | 2.3514                                                     | 158014 | 7216 BA                                              |                                     | 0.0                |
|                   |     | 0.7838                                                     | 52671  | 10114 DA                                             |                                     | 0.0                |
|                   |     | 0.7838                                                     | 55493  | 8468 AA                                              |                                     | 0.0                |
|                   | 295 | 2.3514                                                     | 166479 | 7766 BA                                              |                                     | 0.0                |
|                   |     | 0.7838                                                     | 55493  | 9777 DA                                              |                                     | 0.0                |
| 4. 70             | 230 | 1.0000                                                     | 67200  | 8181 AA                                              |                                     | 0.0                |
|                   |     | 3.0000                                                     | 201600 | 7924 BA                                              |                                     | 0.0                |
|                   |     | 1.0000                                                     | 67200  | 11584 FA                                             |                                     | 0.0                |
|                   |     | 1.0000                                                     | 70800  | 8766 AA                                              |                                     | 0.0                |
|                   | 295 | 3.0000                                                     | 212400 | 9025 CA                                              |                                     | 0.0                |
|                   |     | 1.0000                                                     | 70800  | 10847 DA                                             |                                     | 0.0                |
| 5. 80             | 230 | 1.5000                                                     | 100800 | 8459 AA                                              |                                     | 0.0                |
|                   |     | 4.5000                                                     | 302400 | 8320 BA                                              |                                     | 0.0                |
|                   |     | 1.5000                                                     | 100800 | 11392 CA                                             |                                     | 0.0                |
|                   |     | 1.5000                                                     | 105200 | 4923 AA                                              |                                     | 0.0                |
|                   | 295 | 4.5000                                                     | 318600 | 9098 BA                                              |                                     | 0.0                |
|                   |     | 1.5000                                                     | 106200 | 10770 DA                                             |                                     | 0.0                |
| 6. 90             | 230 | 1.7334                                                     | 116484 | 9589 AA                                              |                                     | 0.0                |
|                   |     | 5.2002                                                     | 349453 | 9039 CA                                              |                                     | 0.0                |
|                   |     | 1.7334                                                     | 116484 | 14037 DA                                             |                                     | 0.0                |
|                   |     | 1.7334                                                     | 122725 | 12605 AA                                             |                                     | 0.0                |
|                   | 295 | 5.2002                                                     | 368174 | 12181 CA                                             |                                     | 0.0                |
|                   |     | 1.7334                                                     | 122725 | 12749 FA                                             |                                     | 0.0                |
| 7. 100            | 230 | 0.9833                                                     | 66111  | 11261 AA                                             |                                     | 0.0                |
|                   |     | 2.9514                                                     | 198334 | 13035 CA                                             |                                     | 0.0                |

TABLE XVII - Continued

| FLIGHT CONDITION    | FREQUENCY OF<br>OCCURRENCE<br>PCT. CYCLES IN<br>TIME 100 HRS. | OSCILLATORY<br>BENDING STR. FAILURE<br>IN SLIDER<br>LUG BOLT | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION |
|---------------------|---------------------------------------------------------------|--------------------------------------------------------------|-------------------------------------|--------------------|
|                     | 0.9838                                                        | 66111                                                        | 12994 EA                            | 0.0                |
| 295                 | 0.9838                                                        | 69653                                                        | 13941 AA                            | 0.0                |
|                     | 2.9514                                                        | 208959                                                       | 19603 CA                            | 0.0                |
|                     | 0.9838                                                        | 69653                                                        | 16702 EA                            | 0.0                |
| 8. VNE 280          | 0.3500                                                        | 23520                                                        | 11670 AA                            | 0.0                |
|                     | 1.0500                                                        | 70560                                                        | 15839 CA                            | 0.0                |
|                     | 0.3500                                                        | 23520                                                        | 14948 EA                            | 0.0                |
| 295                 | 0.3500                                                        | 24780                                                        | 17750 AA                            | 0.0                |
|                     | 1.3500                                                        | 74340                                                        | 21910 CA                            | 0.0                |
|                     | 0.3500                                                        | 24780                                                        | 18915 EA                            | 0.0                |
| H. MANEUVERS        |                                                               |                                                              |                                     |                    |
| 1. CLIMB 0-60 KNOTS |                                                               |                                                              |                                     |                    |
| (A) M.C. POWER      | 0.6000                                                        | 41040                                                        | 7966 AA                             | 0.0                |
|                     | 1.8000                                                        | 123120                                                       | 6857 CA                             | 0.0                |
|                     | 0.6000                                                        | 41040                                                        | 8221 DA                             | 0.0                |
| (B) T.O. POWER      | 0.2000                                                        | 13680                                                        | 6221 AA                             | 0.0                |
|                     | 0.6000                                                        | 41040                                                        | 6872 BA                             | 0.0                |
|                     | 0.2000                                                        | 13680                                                        | 7898 EA                             | 0.0                |
| 2. CYCLIC PULL-UP   |                                                               |                                                              |                                     |                    |
| (A) 50 KNOTS        | 0.0324                                                        | 2216                                                         | 9115 AA                             | 0.0                |
|                     | 0.0972                                                        | 6648                                                         | 10586 CA                            | 0.0                |
|                     | 0.0324                                                        | 2216                                                         | 11717 EA                            | 0.0                |
| (B) 100 KNOTS       | 0.0324                                                        | 2216                                                         | 10793 AA                            | 0.0                |
|                     | 0.0972                                                        | 6648                                                         | 12582 CA                            | 0.0                |
|                     | 0.0324                                                        | 2216                                                         | 13116 EA                            | 0.0                |
| (C) VL              | 0.0324                                                        | 2216                                                         | 11579 AA                            | 0.0                |
|                     | 0.0972                                                        | 6648                                                         | 30856 CA                            | 0.0                |
|                     | 0.0324                                                        | 2216                                                         | 49872 EA                            | 0.087 0.025533     |
| 3. LEFT TURN        |                                                               |                                                              |                                     |                    |
| (A) 50 KNOTS        | 0.2000                                                        | 13680                                                        | 8710 AA                             | 0.0                |
|                     | 0.6000                                                        | 41040                                                        | 9839 BA                             | 0.0                |
|                     | 0.2000                                                        | 13680                                                        | 11773 EA                            | 0.0                |
| (B) 100 KNOTS       | 0.2000                                                        | 13680                                                        | 10181 AA                            | 0.0                |
|                     | 0.6000                                                        | 41040                                                        | 10860 BA                            | 0.0                |
|                     | 0.2000                                                        | 13680                                                        | 14716 EA                            | 0.0                |
| (C) VL              | 0.1000                                                        | 6840                                                         | 17888 AA                            | 0.0                |
|                     | 0.3000                                                        | 20520                                                        | 21047 BA                            | 0.0                |
|                     | 0.1000                                                        | 6840                                                         | 49872 EA                            | 0.087 0.078804     |
| 4. RIGHT TURN       |                                                               |                                                              |                                     |                    |
| (A) 50 KNOTS        | 0.2000                                                        | 13680                                                        | 7408 AA                             | 0.0                |
|                     | 0.6000                                                        | 41040                                                        | 9038 BA                             | 0.0                |
|                     | 0.2000                                                        | 13680                                                        | 8920 EA                             | 0.0                |
| (B) 100 KNOTS       | 0.2000                                                        | 13680                                                        | 9845 AA                             | 0.0                |
|                     | 0.6000                                                        | 41040                                                        | 10555 CA                            | 0.0                |
|                     | 0.2000                                                        | 13680                                                        | 12365 EA                            | 0.0                |
| (C) VL              | 0.1000                                                        | 6840                                                         | 10497 AA                            | 0.0                |

TABLE XVII - Continued

| FLIGHT CONDITION               | FREQUENCY OF<br>PCT. OCCURRENCE<br>TIME | CYCLES IN<br>100 HRS. | OSCILLATORY<br>BENDING STR. FAILURE<br>IN SLIDER<br>LUG BOLT | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION |
|--------------------------------|-----------------------------------------|-----------------------|--------------------------------------------------------------|-------------------------------------|--------------------|
|                                | 0.3000                                  | 20520                 | 22489 CA                                                     |                                     | 0.0                |
|                                | 0.1000                                  | 6840                  | 49872 EA                                                     | 0.087                               | 0.078804           |
| 5. CONTROL REVERSAL            |                                         |                       |                                                              |                                     |                    |
| (A) LONGITUDINAL               | 0.0444                                  | 3037                  | 12676 AA                                                     |                                     | 0.0                |
|                                | 0.1332                                  | 9111                  | 14950 CA                                                     |                                     | 0.0                |
|                                | 0.0444                                  | 3037                  | 12639 EA                                                     |                                     | 0.0                |
| (B) LATERAL                    | 0.0444                                  | 3037                  | 10284 AA                                                     |                                     | 0.0                |
|                                | 0.1332                                  | 9111                  | 11827 CA                                                     |                                     | 0.0                |
|                                | 0.0444                                  | 3037                  | 11789 EA                                                     |                                     | 0.0                |
| (C) RUDDER                     | 0.0444                                  | 3037                  | 9258 AA                                                      |                                     | 0.0                |
|                                | 0.1332                                  | 9111                  | 10040 BA                                                     |                                     | 0.0                |
|                                | 0.0444                                  | 3037                  | 10372 EA                                                     |                                     | 0.0                |
| IV. POWER TRANSITIONS          |                                         |                       |                                                              |                                     |                    |
| A. POWER TO AUTO               |                                         |                       |                                                              |                                     |                    |
| 1. 40 KNOTS                    | 0.0022                                  | 150                   | 7655 AA                                                      |                                     | 0.0                |
|                                | 0.0066                                  | 451                   | 8826 CA                                                      |                                     | 0.0                |
|                                | 0.0022                                  | 150                   | 9286 EA                                                      |                                     | 0.0                |
| 2. VL                          | 0.0022                                  | 150                   | 12692 AA                                                     |                                     | 0.0                |
|                                | 0.0066                                  | 451                   | 16835 CA                                                     |                                     | 0.0                |
|                                | 0.0022                                  | 150                   | 16482 EA                                                     |                                     | 0.0                |
| B. AUTO TO POWER               | 0.0112                                  | 766                   | 10081 AA                                                     |                                     | 0.0                |
|                                | 0.0336                                  | 2298                  | 10030 CA                                                     |                                     | 0.0                |
|                                | 0.0112                                  | 766                   | 10980 EA                                                     |                                     | 0.0                |
| V. AUTOROTATION                |                                         |                       |                                                              |                                     |                    |
| A. STABILIZED FLIGHT           |                                         |                       |                                                              |                                     |                    |
| 1. 40 KNOTS                    | 0.0578                                  | 3954                  | 5504 AA                                                      |                                     | 0.0                |
|                                | 0.1734                                  | 11861                 | 5428 BA                                                      |                                     | 0.0                |
|                                | 0.0578                                  | 3954                  | 5672 EA                                                      |                                     | 0.0                |
| 2. 30 KNOTS                    | 0.0776                                  | 5308                  | 6658 AA                                                      |                                     | 0.0                |
|                                | 0.2328                                  | 15924                 | 7214 BA                                                      |                                     | 0.0                |
|                                | 0.0776                                  | 5308                  | 5924 EA                                                      |                                     | 0.0                |
| 3. MAX AUTO A/S                | 0.0378                                  | 2586                  | 10912 AA                                                     |                                     | 0.0                |
|                                | 0.1134                                  | 7757                  | 10171 BA                                                     |                                     | 0.0                |
|                                | 0.0378                                  | 2586                  | 9860 EA                                                      |                                     | 0.0                |
| B. TURNS. (NORMAL<br>AUTO A/S) |                                         |                       |                                                              |                                     |                    |
| 1. TO THE LEFT                 | 0.0400                                  | 2736                  | 7538 AA                                                      |                                     | 0.0                |
|                                | 0.1200                                  | 8208                  | 8933 BA                                                      |                                     | 0.0                |
|                                | 0.0400                                  | 2736                  | 5983 EA                                                      |                                     | 0.0                |
| 2. TO THE RIGHT                | 0.0400                                  | 2736                  | 6919 AA                                                      |                                     | 0.0                |
|                                | 0.1200                                  | 8208                  | 6922 CA                                                      |                                     | 0.0                |
|                                | 0.0400                                  | 2736                  | 6736 EA                                                      |                                     | 0.0                |
| C. CONTROL REVERSAL            |                                         |                       |                                                              |                                     |                    |
| 1. LONGITUDINAL                | 0.0200                                  | 1368                  | 13736 AA                                                     |                                     | 0.0                |

TABLE XVII - Concluded

| FLIGHT CONDITION                                    | FREQUENCY OF<br>OCCURRENCE<br>PCT. TIME | CYCLES IN<br>100 HRS. | OSCILLATORY<br>BENDING STR.<br>IN SLIDER<br>LUG BOLT | CYC. TO<br>FAILURE<br>X<br>10**(-6) | DAMAGE<br>FRACTION |
|-----------------------------------------------------|-----------------------------------------|-----------------------|------------------------------------------------------|-------------------------------------|--------------------|
| 2. LATERAL                                          | 0.0600                                  | 4104                  | 13190 BA                                             |                                     | 0.0                |
|                                                     | 0.0200                                  | 1368                  | 10942 FA                                             |                                     | 0.0                |
|                                                     | 0.0200                                  | 1368                  | 9679 AA                                              |                                     | 0.0                |
|                                                     | 0.0600                                  | 4104                  | 11093 CA                                             |                                     | 0.0                |
| 3. RUDDER                                           | 0.0200                                  | 1368                  | 6668 EA                                              |                                     | 0.0                |
|                                                     | 0.0200                                  | 1368                  | 7019 AA                                              |                                     | 0.0                |
|                                                     | 0.0600                                  | 4104                  | 6191 BA                                              |                                     | 0.0                |
|                                                     | 0.0200                                  | 1368                  | 6203 EA                                              |                                     | 0.0                |
| D. CYCLIC PULL-UP<br>(NORMAL AUTO A/S)              | 0.0112                                  | 766                   | 9983 AA                                              |                                     | 0.0                |
|                                                     | 0.0336                                  | 2298                  | 7635 BA                                              |                                     | 0.0                |
|                                                     | 0.0112                                  | 766                   | 7517 EA                                              |                                     | 0.0                |
| E. PART PWR DSNT. HOKT                              | 0.416                                   | 28495                 | 7409 AA                                              |                                     | 0.0                |
|                                                     | 1.2498                                  | 85486                 | 5960 BA                                              |                                     | 0.0                |
|                                                     | 0.4166                                  | 28495                 | 6545 EA                                              |                                     | 0.0                |
| F. FULL AUTO LANDING                                | 0.0600                                  | 4104                  | 0 AA                                                 |                                     | 0.0                |
|                                                     | 0.1800                                  | 12312                 | 42635 BA                                             | *                                   | 0.000147           |
|                                                     | 0.0600                                  | 4104                  | 0 FA                                                 |                                     | 0.0                |
| ENDURANCE LIMIT = 38079.0                           |                                         |                       | TOTAL DAMAGE (D) = 0.183288                          |                                     |                    |
| MATERIAL = STL1                                     |                                         |                       |                                                      |                                     |                    |
| FREQUENCY = 4 / REV OF M/R                          |                                         |                       | FATIGUE LIFE = 100/D = 545 HOURS                     |                                     |                    |
| * DAMAGE CALCULATED FROM MEASURED LOAD FREQUENCIES. |                                         |                       |                                                      |                                     |                    |

cg locations increase it. The fatigue analysis also shows that the weight could be reduced significantly if the various components were redesigned. Furthermore, more extensive fatigue testing would allow the use of analytical methods which are less conservative than those used for this analysis.

## LIST OF SYMBOLS

|          |                                                                                                         |
|----------|---------------------------------------------------------------------------------------------------------|
| a        | speed of sound, fps                                                                                     |
| b        | number of blades                                                                                        |
| c        | blade chord, ft                                                                                         |
| $C_D$    | rotor drag coefficient<br>$C_D = \frac{D}{\rho \pi R^2 (\Omega R)^2}$                                   |
| $C_{do}$ | average minimum blade section profile drag coefficient                                                  |
| $C_L$    | rotor lift coefficient<br>$C_L = \frac{L}{\rho \pi R^2 (\Omega R)^2}$                                   |
| $C_P$    | rotor-shaft power coefficient<br>$C_P = \frac{\text{horsepower} \times 550}{\rho \pi R^2 (\Omega R)^3}$ |
| $C_Q$    | rotor torque coefficient<br>$C_Q = \frac{Q}{\rho \pi R^2 (\Omega R)^2 R}$                               |
| $C_T$    | rotor thrust coefficient<br>$C_T = \frac{T}{\rho \pi R^2 (\Omega R)^2}$                                 |
| cg       | center of gravity                                                                                       |
| D        | drag, lb                                                                                                |
| f        | equivalent drag area, ft <sup>2</sup>                                                                   |
| $F_O$    | hub shear force, lb                                                                                     |
| g        | acceleration of gravity, in./sec <sup>2</sup>                                                           |
| G        | acceleration divided by acceleration of gravity, nondimensional                                         |

# LIST OF SYMBOLS (Continued)

|                |                                                                                                                                        |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------|
| $I_F$          | inertia of the fuselage about the fuselage cg,<br>in.-lb-sec <sup>2</sup>                                                              |
| $I_P$          | inertia of the pylon about the pylon cg,<br>in.-lb-sec <sup>2</sup>                                                                    |
| KT             | effective torsional spring rate about hinge,<br>in.-lb/rad                                                                             |
| L              | lift, lb                                                                                                                               |
| $M_{DD}$       | drag divergence Mach number (Mach number at which<br>slope of curve of drag coefficient versus Mach<br>number attains a value of 0.10) |
| $M_{Adv\ Tip}$ | advancing blade tip Mach number<br>$M_{Adv\ Tip} = \frac{1.688V + \Omega R}{a}$                                                        |
| $M_F$          | mass of the fuselage, lb-sec <sup>2</sup> /in.                                                                                         |
| $M_P$          | mass of the pylon, lb-sec <sup>2</sup> /in.                                                                                            |
| $N_R$          | main rotor speed, rpm                                                                                                                  |
| Q              | rotor shaft torque, ft-lb                                                                                                              |
| R              | rotor radius, ft                                                                                                                       |
| T              | rotor thrust, lb                                                                                                                       |
| t              | time, sec                                                                                                                              |
| V              | velocity, kn                                                                                                                           |
| $\alpha_F$     | angular motion of the fuselage, rad                                                                                                    |
| $\alpha_P$     | angular motion of the pylon, rad                                                                                                       |
| $\beta$        | 1/rev rotor flapping                                                                                                                   |
| $\theta_{.75}$ | blade collective pitch angle at the 75% radial<br>blade station, deg                                                                   |

LIST OF SYMBOLS (Concluded)

|           |                                                                                                     |
|-----------|-----------------------------------------------------------------------------------------------------|
| $\theta'$ | ratio of temperature to sea level standard temperature in deg Kelvin                                |
| $\mu$     | advance ratio, $\mu = V/(\Omega R)$                                                                 |
| $\rho$    | density of air, lb-sec <sup>2</sup> /ft <sup>4</sup>                                                |
| $\rho_0$  | density of air at sea level standard day<br>$\rho_0 = .002377$ lb-sec <sup>2</sup> /ft <sup>4</sup> |
| $\sigma$  | rotor solidity, $\sigma = bc/\pi R$                                                                 |
| $\sigma'$ | air density ratio, $\sigma' = \rho/\rho_0$                                                          |
| $\psi$    | rotor azimuth angle, zero when the red blade is over the tailboom, deg                              |
| $\Omega$  | rotor shaft angular velocity, rad/sec                                                               |
| $\omega$  | excitation frequency, rad/sec                                                                       |