AMRDL-TR-75-50

IDATION OF ROTORCRAFT FLIGHT SIMULATION PROGRAM ƆUGH CORRELATION WITH FLIGHT DATA FOR SOFT-IN-PLANE ƎELESS ROTORS

ıg Vertol Company
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EUSTIS DIRECTORATE
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Fort Eustis, Va. 23604

EUSTIS DIRECTORATE POSITION STATEMENT

This report provides an independent evaluation of the C-81 Rotorcraft Flight Simulation Computer Program as applied to hingeless rotors. However, the version of C-81 evaluated did not include the variable induced-velocity tables considered to be potentially significant for rotor loads prediction. Results of this contract are being combined with results from similar contracts and in-house efforts to identify the strong and weak areas of C-81 prediction capability and to establish a state-of-the-art position with regard to the global computer program concept for helicopter analysis. The results of this effort, while not exhaustive, are believed to be technically sound and within the originally intended scope.

Mr. G. Thomas White of the Technology Applications Division served as project engineer for this investigation.

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A study was conducted to evaluate the 300,000-byte version of the C-81 AGAJ74 helicopter simulation program's capability for prediction of performance, rotor dynamic loads, and stability for soft-in-plane hingeless rotor helicopters. Available test data were compiled for the BO-105 single-rotor helicopter to provide a basis for evaluation of computer program analytical results. Results indicated good correlation for trim and performance, and reasonable correlation for main rotor alternating flap bending moments.

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20. ABSTRACT (continued)

Poorer correlation was obtained for main rotor chord and shaft bending moments. Poor agreement was obtained for response to control inputs in hover and at 100 knots; this may have been due to selection of too large a numerical integration interval. Approximately the same damping was indicated by test and analysis for aeroelastic stability. Attempts to compare C-81 results for control power and stability derivatives with analytical results from Boeing Vertol's Y-92 computer program were not successful. Significant differences were attributed to restraint of blade flapping in C-81 during these computations.

SUMMARY

A study was conducted to evaluate the capability of the 300,000-byte version of the C-81 AGAJ74 Rotorcraft Flight Simulation Program, developed by the Bell Helicopter Company, to predict performance, dynamic loads, and stability for hingeless rotor helicopters. Available test data for the BO-105 hingeless rotor helicopter were compiled. Basic data describing rotor blade aerodynamic coefficients, fuselage aerodynamic coefficients, mass and inertia data, rotor blade modal data, geometric data, horizontal stabilizer aerodynamic data, and control system data were also compiled.

The BO-105 helicopter has a four-bladed soft-in-plane hingeless main rotor, and was initially designed for about 4400 pounds gross weight. Data were available from early flight tests conducted in West Germany in mid-1970 by Messerschmitt-Boelkow-Blohm (MBB), manufacturer of the BO-105. Data included trim versus airspeed, and main rotor blade and shaft loads in banked turns and during pullup and pushover maneuvers. A limited amount of performance data was also available. Data from more recent tests conducted at Boeing Vertol were also available for blade loads in level flight. Unpublished data were available from tests conducted by MBB to evaluate aeroelastic stability.

C-81 computer program runs were made for flight conditions corresponding to flight test conditions. Analytical results for trim versus airspeed were in good agreement with test data. C-81 main rotor flap bending moments versus blade radius were in reasonable agreement with test data for alternating, 1/rev, and 3/rev content. The analytical main rotor blade 5/rev flap bending moments versus blade radius were well below test values. This is probably due to the simplified induced velocity distribution used in the 300K version of the C-81 program. Main rotor blade alternating and 1/rev chord bending moments near the blade root were overpredicted by C-81.

Power required versus speed in level flight, maximum rate of climb, and speed for maximum rate of climb were in agreement with data reported by MBB. For banked turns, predicted main rotor blade root flap bending moments and longitudinal cyclic were in reasonable agreement with test data, while predicted main rotor shaft bending moment, root chord bending moment, and lateral cyclic were not.

The agreement between analytical and test results was poor for pullup and pushover maneuvers when the maneuver option was used in C-81. More pitch-roll coupling was indicated by

analysis results than by test data. A numerical integration interval of 30 degrees was used in these calculations. This was only about 3.1 integration intervals per period of the highest frequency blade mode and may have affected some of these results. Because of high computing costs for the maneuver cases, the integration interval could not be reduced to the recommended 10 integration intervals for the period of the highest frequency mode, i.e., the 3.87/rev main rotor blade first torsional mode.

Results for collective pitch dumps at 80, 100, and 123 knots showed good agreement for vertical accelerations and the correct trend for pitch attitude versus time.

Stability analysis results for dynamic pitch stability period and time to double amplitude were not in good agreement with test data. An attempt to compare C-81 results for stability derivatives and control power with Boeing Vertol's Y-92 trim program results was aborted due to differences in assumptions about rotor blade flapping. Programming changes to allow this comparison have been developed by Bell Helicopter Co. These changes were not received in time for incorporation in the C-81 program and rerunning the stability derivative cases.

Aeroelastic stability was evaluated by comparing decay of chord bending moments after excitation by sinusoidal cyclic control inputs. C-81 results showed about the same damping of air resonance modes as was indicated by test data.

As a result of this study, minor changes to the C-81 program are suggested to account for differences in rotor blade center of gravity and aerodynamic center along the blade radius. These affect blade torsion moment calculations.

Results indicate that C-81 is a useful tool for predicting trim and performance data for a soft-in-plane hingeless rotor helicopter. The predicted envelope of alternating flap bending loads versus radius can be roughly predicted by C-81, while the alternating chord bending moment at the root cannot.

Time to prepare input data was not excessive considering the potential capability of the C-81 program. Documentation of the C-81 program was quite good and was very helpful in accomplishing the extensive task of compilation of input data for the BO-105.

Computer running costs are considered to be excessive for the maneuver analysis.

The available test data used to evaluate C-81 were incomplete in some instances. Shaft bending moment data reported by MBB may not be the resultant shaft bending in maneuvers. A specific test program to obtain a data base for evaluation of helicopter and rotor simulation analytical programs is recommended.

Additional work should be conducted to evaluate blade load prediction capability, particularly at low airspeeds. The blade load evaluation should be done using the 600K version of the C-81 program which employs a more detailed rotor-induced velocity description.

Only a limited amount of blade and pitch link load evaluations were conducted in the time available under the present study. Further evaluation of loads by harmonic content and effects of airspeed, gross weight, and altitude should be studied.

PREFACE

This study was conducted for the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, under Contract DAAJ02-74-C-0051. Technical monitor for the Eustis Directorate was G. T. White III.

The study compared analytical results from the C-81 300K AGAJ74 helicopter simulation program with test data for a hingeless rotor helicopter. (The C-81 program was developed by Bell Helicopter Company, partially under contract to Eustis Directorate.) Analysis and test results are compared for performance, dynamic loads, and stability for the BO-105 soft-in-plane single-rotor helicopter.

F. J. Tarzanin was project manager and J. A. Staley was project engineer at Boeing Vertol Company. Mary Haley of Boeing Computer Services provided computer programming support and valuable experience from use of earlier versions of the C-81 computer program. Aerodynamic data for the BO-105 cambered airfoil blade was compiled by J. McMullen and L. Dadone of the Vertol Aerodynamics group. V. Capurso assisted in compiling fuselage and rotor blade aerodynamic data. J. Fries provided support in comparison of stability derivative data from C-81 and Boeing Vertol's Y-92 trim program. C. Chen conducted the analysis for aeroelastic stability and computed main rotor blade coupled flap-lag-torsion modes. J. Davis and I. Alansky assisted in evaluating stability and control results. Test data were provided by MBB for comparison with analytical results.

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1. INTRODUCTION

1.1 C-81 PROGRAM DEVELOPMENT AND USE

The helicopter flight simulation program referred to as C-81 was evolved over the years, since the early 1960's. The program was developed by Bell Helicopter Company. Portions of the development were funded under contract to the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory (USAAMRDL). The analytical model which evolved included:

- Six rigid-body fuselage modes
- Two rotors
- Up to six blade modes
- Up to seven blades per rotor
- Two pylon degrees of freedom per rotor
- Unsteady rotor aerodynamics
- Time-variant aeroelastic rotor analysis
- Automatic control package
- Capability for analysis of an isolated rotor (wind tunnel model)
- Aerodynamic surface and control surface, and external stores or aerodynamic brake representations
- Multiple airfoil representation along the blade span
- Induced velocity downwash distribution as a function of advance ratio, inflow ratio, blade station, and blade azimuth
- Rotor wake at each aerodynamic surface
- Alternate numerical integration methods
- Alternate trim procedures

These features are described in detail in References 1, 2, and 3 for the 1974 version (Version AGAJ74) of C-81.

The program computes aircraft trim, stability derivatives and control power, and time histories of aircraft and blade motions and loads during maneuvers. The AGAJ72 version (1972 version) of the program was used by Boeing Vertol for computation of aircraft g loading and control loads during maneuvers and for evaluation of aeroelastic stability. Boeing Vertol has also provided data for input to C-81 in proposals for new helicopters submitted to the Army in recent years.

1.2 CURRENT VERSION OF THE C-81 PROGRAM

A revised version of the program, AGAJ74, was scheduled for release in mid-1974. This program was to include capability for reading into storage five sets of rotor blade C_L, C_D, and C_M aerodynamic tables as well as a set of rotor-induced velocity distribution tables. These latter tables would be a function of (1) advance ratio, (2) inflow ratio, (3) radial station and (4) rotor harmonic; consequently, the table would be four-dimensional with a storage requirement for 16,000 constants. This version of the program would require 600,000 bytes of computer storage. This storage requirement was too large, however, for practical use on computer facilities available to Boeing Vertol. With computer facilities available in mid-1974, the 600,000-byte storage requirement would have limited computer use to weekend operation.

A smaller version of the program requiring only about 300,000 bytes of storage was also available. This version was limited to storage for two airfoil tables and used simplified equations built into the program for computing the rotor-induced

1. Davis, J. M., Bennett, R. L., Blankenship, B.L., ROTORCRAFT FLIGHT SIMULATION WITH AEROELASTIC ROTOR AND IMPROVED AERODYNAMIC REPRESENTATION, Volume I--Engineer's Manual, Bell Helicopter Company; USAAMRDL Technical Report 74-10A, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, June 1974.

2. Davis, J. M., Bennett, R. L., Blankenship, B. L., ROTORCRAFT FLIGHT SIMULATION WITH AEROELASTIC ROTOR AND IMPROVED AERODYNAMIC REPRESENTATION, Volume II-User's Manual, Bell Helicopter Company; USAAMRDL Technical Report 74-10B, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, June 1974.

3. Davis, J. M., Bennett, R. L., Blankenship, B. L., ROTORCRAFT FLIGHT SIMULATION WITH AEROELASTIC ROTOR AND IMPROVED AERODYNAMIC REPRESENTATION, Volume III--Programmer's Manual, Bell Helicopter Company; USAAMRDL Technical Report 74-10C, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, June 1974.

velocity distributions. The simplified computation of rotor-induced velocity would result in a reduced capability to compute higher harmonic blade and hub vibratory loads but was probably adequate for calculation of trim and blade loads through the third harmonic.

1.3 PLAN FOR EVALUATION OF C-81 FOR HINGELESS ROTOR AIRCRAFT

Under Contract DAAJ02-74-C-0051, Boeing Vertol would conduct a program using the 300,000-byte version of C-81 "to examine and evaluate the capability of the Rotorcraft Flight Simulation Program C-81 (AGA74 version) to predict performance, dynamic loads, and stability of hingeless rotors." This would be accomplished by comparison of selected flight test data with calculated results for the BO-105 hingeless rotor aircraft.

1.4 BO-105 DESCRIPTION

The BO-105 helicopter, shown in Figure 1, is a single-rotor 5-seat helicopter with a soft-in-plane hingeless main rotor, fiberglass main rotor blades, and two free-turbine engines. Layout studies of the helicopter were begun in 1962 by Messerschmitt-Boelkow-Blohm (MBB). A fiberglass four-bladed rotor was subsequently developed, and the first flight test of the aircraft took place in 1967.

Data recorded by MBB during 1971 flight testing of the V4 aircraft were made available to Boeing Vertol as part of a licensing agreement with Boeing Vertol for sales of the aircraft in the United States. This test aircraft had two Allison 250-C18 free-turbine engines with 270 maximum continuous horsepower each, at sea level standard. Translated MBB reports provide performance and maneuver data from these tests. Additional testing was conducted at Boeing Vertol on aircraft S50. Level flight blade load data were obtained during these tests.

1.5 TERMINOLOGY

In general, Boeing Vertol terms are used throughout this report. Corresponding terms used in C-81 documentation are as follows:

Boeing Vertol	C-81
Flap bending	Beam bending
Chord bending, lag bending	Chord bending
Longitudinal	Fore/Aft (F/A)

1.6 SIGN CONVENTIONS

The sign conventions shown in Table 1 will be useful in interpreting results presented later in this report.

TABLE 1. SIGN CONVENTIONS

Parameter	Positive Direction
Lateral cyclic	Down right
F/A cyclic	Forward
Tail-rotor collective	Nose right
Pitch attitude	Nose up
Roll attitude	Roll right
Yaw attitude	Nose right

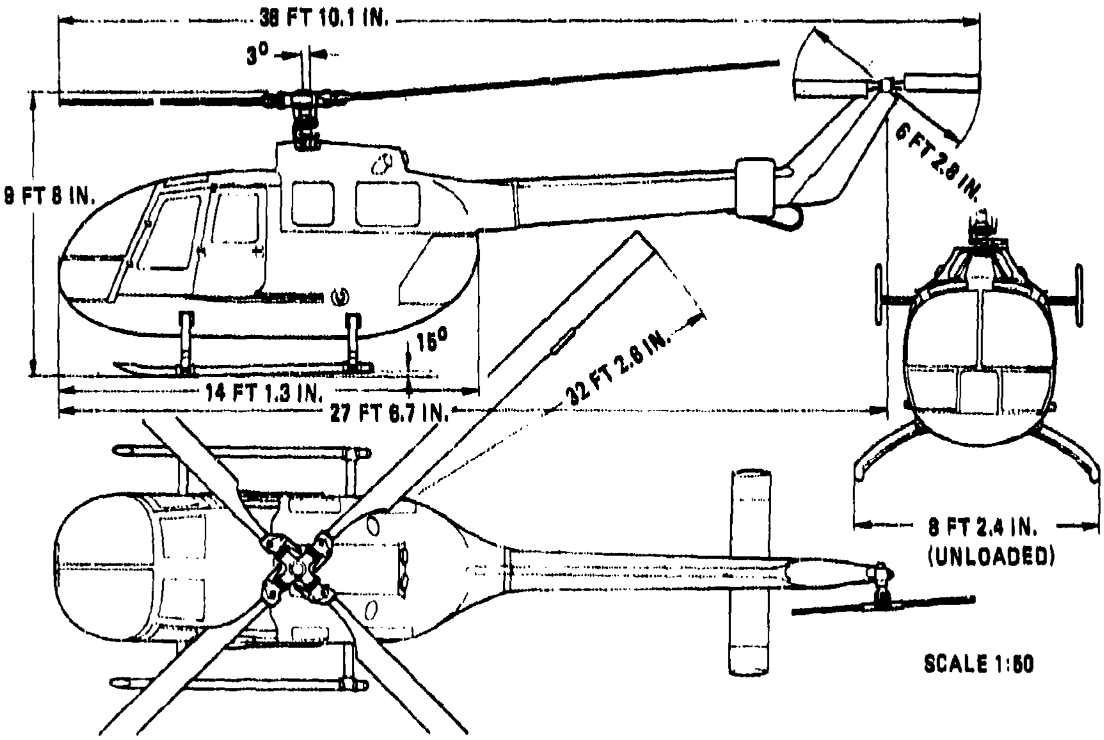

Figure 1. BO-105 Three-View Drawing.

2. PROGRAM IMPLEMENTATION AND INITIAL RUNNING EXPERIENCE

Both the 600,000- and 300,000-byte versions of the AGAJ74 C-81 program were provided to Boeing Vertol by the Army on magnetic tape. Updates to the 300,000-byte version were also provided on cards.

The 300,000-byte (300K) version was put on the Boeing Computer Services IBM 360/65 computer, and the test case provided with the computer tape was run. Discrepancies were initially found between answers provided on tape and answers for the test case obtained by Boeing. All updates were then made to the program, some minor revisions to test case input were made, and the test case was then run successfully.

In later operation of the C-81 program, the program would not trim with the soft torsion mode associated with the fiberglass cambered-airfoil main-rotor blade. This was resolved by making a minor modification in the iterative calculation of elastic effects in the subroutine which calculates compatible thrust, induced velocity distribution, and elastic deflections.

3. DATA COMPILATION

3.1 TEST DATA

Many reports containing data on BO-105 aircraft tests conducted by MBB in Germany had been provided to Boeing Vertol under licensing agreement for sale of BO-105 aircraft in the United States. Many of these reports have been translated and are maintained in files in the BO-105 project office at Boeing Vertol. The translated reports were reviewed to identify test data which could be used as a basis for evaluating C-81 for analysis of hingeless rotor aircraft performance, dynamic loads, and stability. (Typical data are given in References 4, 5, and 6.)

The form of data presented in these reports was usually smoothed data as opposed to raw data. In order to obtain some raw or unfiltered data, copies of oscillograph traces for test points for aircraft V4, Flight 372, were requested from MBB. The test conditions requested were for aircraft pullups and pushovers at 100- and 110-knot nominal airspeeds. Data requested and received included main rotor blade, rotor shaft, and pitch link loads, and aircraft control positions, attitudes, speed and altitude.

In addition to data documented in MBB reports, raw data in the form of pen recorder traces was available for air resonance tests conducted by MBB; these included rotor blade bending moment decay after excitation with sinusoidal cyclic inputs.

Finally, main rotor blade load data were also available from level flight tests on aircraft S50 conducted at Boeing Vertol in early 1974.

A set of flight test data was chosen to minimize the number of aircraft configurations to be studied while at the same time obtaining the desired variety of flight conditions and measured

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4. BO-105 FLYING QUALITIES ASSESSMENT, Report D212-10024-1, Boeing Vertol Company, Philadelphia, Pa., 1971.

5. Teleki, A., BO-105 V4 FLIGHT TESTS, 4th Section from March 24, 1970 to Sept. 18, 1970, Messerschmitt-Boelkow-Blohm GmbH Report No. D14-639, 10 Dec. 1970. (Translated by Boeing Vertol Company)

6. Teleki, A., BO-105 LOAD MEASUREMENTS OVER THE TOTAL FLIGHT ENVELOPE (FAR SECT. 27.307, 27.309, 27.321, 27.1509), Messerschmitt-Boelkow-Blohm GmbH Report No. D14-581, 5 Oct. 1970. (Translated by Boeing Vertol Company)

parameters. The selected data include level-flight aircraft trim characteristics and blade loads data for a speed range from hover to 123 knots. Data were available for banked-turn sustained-g trim points from 1.0 to 2.5 g. Maneuver data include longitudinal, lateral, and yaw control response in hover and at 100 knots, and pitch dumps at 80, 100, and 123 knots.

3.2 BASIC AIRCRAFT DATA

Basic aircraft data included weight and inertia data, fuselage aerodynamic data, and rotor blade aerodynamic and modal data. Table 2 summarizes some of these basic data. A complete listing of typical data decks is given in Appendix A. The following is a discussion of most of the C-81 input data blocks in the order that they appear in the C-81 input data deck.

Input data requirements for the AGAJ74 version of C-81 are discussed in Reference 2. The input data are divided into a logical series of data blocks; the first blocks are logic blocks.

3.2.1 Input Control Logic

The program was run with input for a full helicopter simulation. One airfoil table was read in for the main rotor except in preliminary check runs, where the C-81 internal 0012 airfoil tables were used for both main and tail rotors. Equations for a 0012 airfoil were generally used for the tail rotor. Either four or six mode shapes were read in for the main rotor (see discussion of main rotor modal data), and no mode shapes were read in for the tail rotor (rigid teetering rotor assumed). Rotor-induced velocity tables were not read in since the 300K version of C-81 was being used. The number of rotor airfoil aerodynamic subgroups was two (one each for the main and tail rotors). No pylon data or wing data were read. One set of stabilizing surface group data was used for the horizontal stabilizer. The vertical fin aerodynamic characteristics are included with the fuselage aerodynamic characteristics. No jet, stores/brake, or supplemental rotor control data were input. Maneuver data were read in for cases where maneuvers were conducted.

3.2.2 Analysis Logic

The flight condition indicator was varied depending on whether a trim for level flight, banked turns, or vertical g maneuver was being computed. The trim selector was generally used to hold yaw during trim for speeds at 60 knots or below and to hold roll for trim at speeds above 60 knots. The partial

TABLE 2. BASIC AIRCRAFT DATA

Fuselage	
Aerodynamic Center	
Station line (inches)	100.39
Butt line (inches)	0
Waterline (inches)	−1.88
Fuselage Inertia	
Rolling, I_{xx} (slug−ft^2)	1268
Pitching I_{yy} (slug−ft^2)	3479
Yawing, I_{zz} (slug−ft^2)	3203
Product, I_{xz} (slug−ft^2)	250
Main Rotor Group	
Number of blades	4
Type	Hingeless
Radius (feet)	16.11
Blade chord (inches)	10.64
Blade twist, linear (degrees)	−8.0
Normal RPM	425
Shaft tilt, forward (degrees)	3.0
Airfoil section	23012
Tail Rotor	
Number of blades	2
Radius (feet)	3.115
Blade chord (inches)	7.05
Blade twist (degrees)	0
Normal RPM	2349
Airfoil section	0012
Elevator	
Area (square feet)	8.71
Aspect ratio	8.09
Center of pressure	
Station line (inches)	277.45
Butt line (inches)	0
Waterline (inches)	25.84

derivative matrix was generally computed at every fifth iteration in the trim solution to save running time, but was computed at every iteration if convergence to a trimmed solution was difficult to achieve. Unsteady aerodynamics were not activated.

The quasi-static, time-variant trim was used for the main rotor for cases where either time history solutions or steady-state blade loads were required. This type of trim analysis computes blade elastic deflections at higher harmonics at the trim control setting based on only 1/rev blade elastic deflections (quasi-static trim). The time-variant analysis was also activated during maneuvers. Fully coupled main and tail rotor equations were used for trim throughout. Force and moment summary, partial derivative matrix, and optional trim page were printed during the trim analysis. Blade element data were also printed for trim.

3.2.3 Stability Analysis and Miscellaneous Logic

All options were off for stability derivative analysis. This produced stability derivative and control power analyses for a fully coupled main rotor, tail rotor, fuselage system.

3.2.4 Airfoil Data Tables

The BO-105 originally used a 0012 symmetrical airfoil section for the main rotor blade. The main rotor blade was later changed to a 23012 cambered airfoil section. The blade with the cambered airfoil section was on the aircraft for the BO-105 flight test data which was chosen for comparison with C-81 analytical results. Airfoil data were compiled from Reference 7 to provide lift, drag, and pitching moment coefficients for the 23012 cambered airfoil in the C-81 input format. (These tables are Boeing Vertol designation Number 666). The reference airfoil test data are for Mach numbers up to 0.85 from small negative angles of attack to angles of attack of 10 to 15 degrees. Airfoil characteristics of a V23010-1.58 airfoil (Boeing Vertol Table 294, Reference 8) were used to establish trends of data at angle of attack and Mach number conditions not covered by the Reference 7 tests. Figures 2 through 5 show plots of the resulting airfoil table data at small and large angles of attack.

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7. Dadone, L., HELICOPTER DESIGN DATCOM - VOLUME I (In preparation for U.S. Army Aviation System Command; to be released in 1976), Boeing Vertol Company, Philadelphia, Pa.

8. Dadone, L., McMullen, J., UPDATED AIRFOIL CHARACTERISTICS FOR ROTOR PERFORMANCE CALCULATIONS (1972), Report D210-10529-1, Boeing Vertol Company, Philadelphia, Pa., Vertol Division, 27 Sept. 1972.

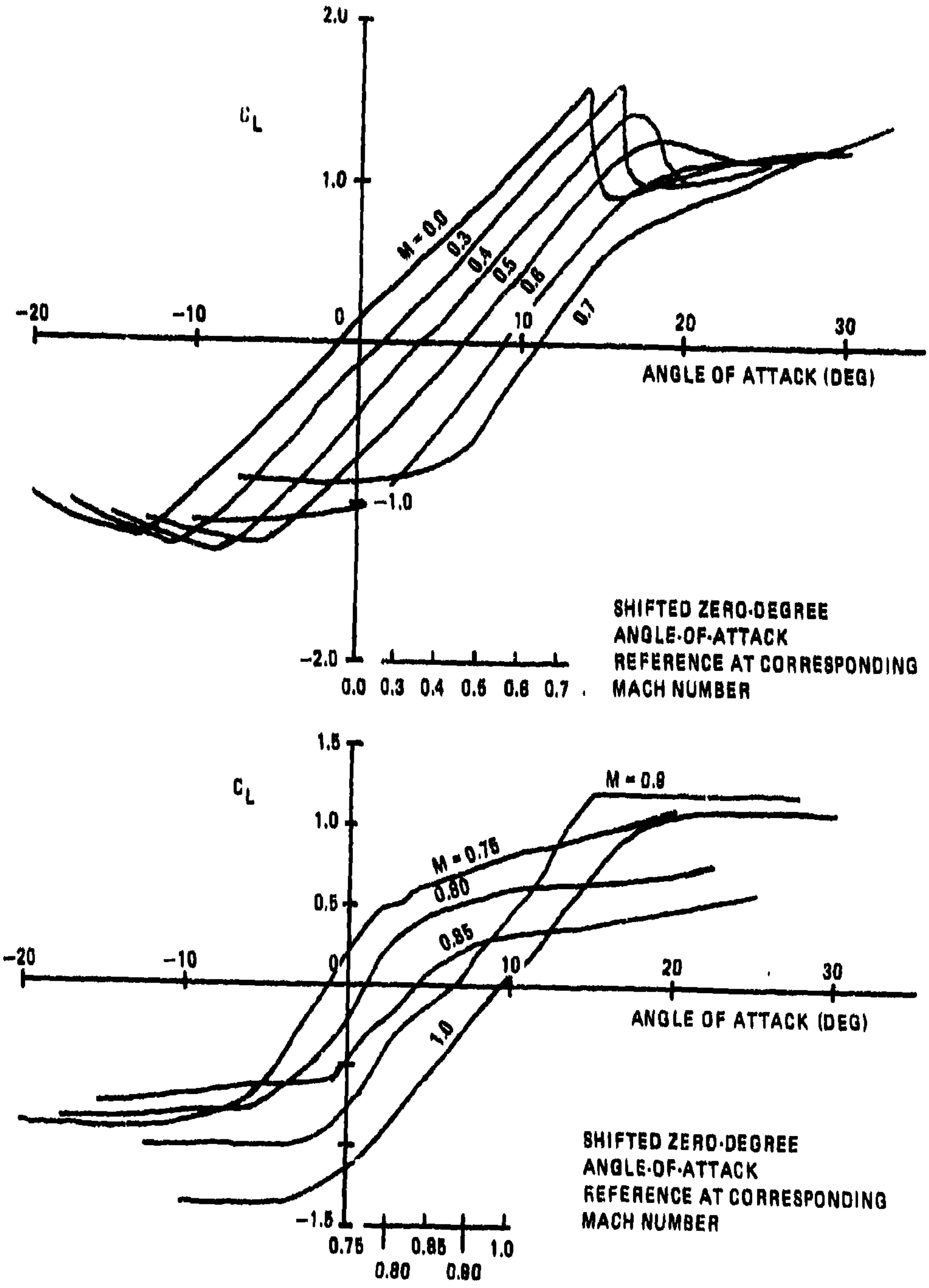


Figure 2. BO-105 Main Rotor Blade 23012 Cambered Airfoil Lift Coefficients at Small Angles of Attack

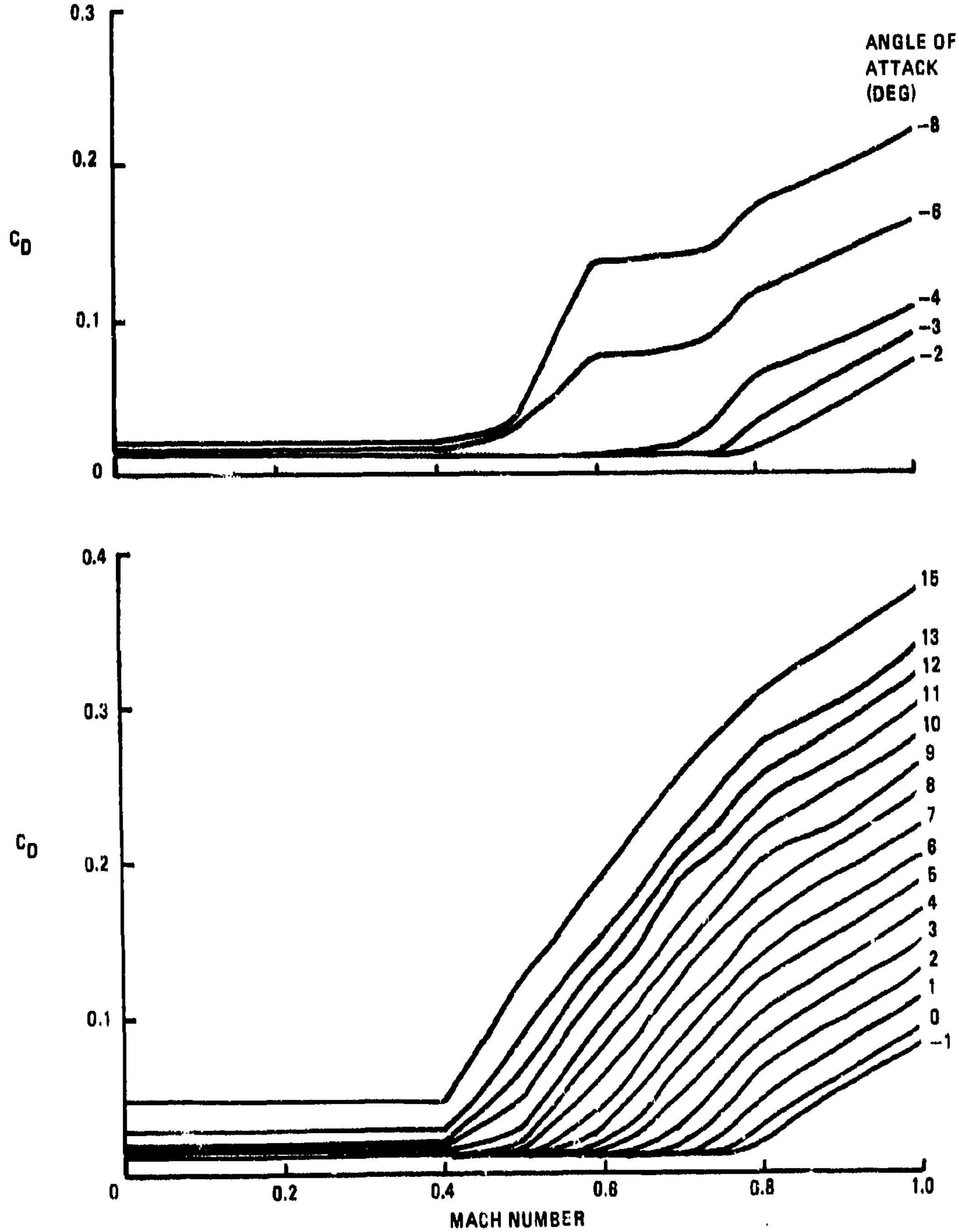


Figure 3. BO-105 Main Rotor Blade 23012 Cambered Airfoil Drag Coefficients at Small Angles of Attack.

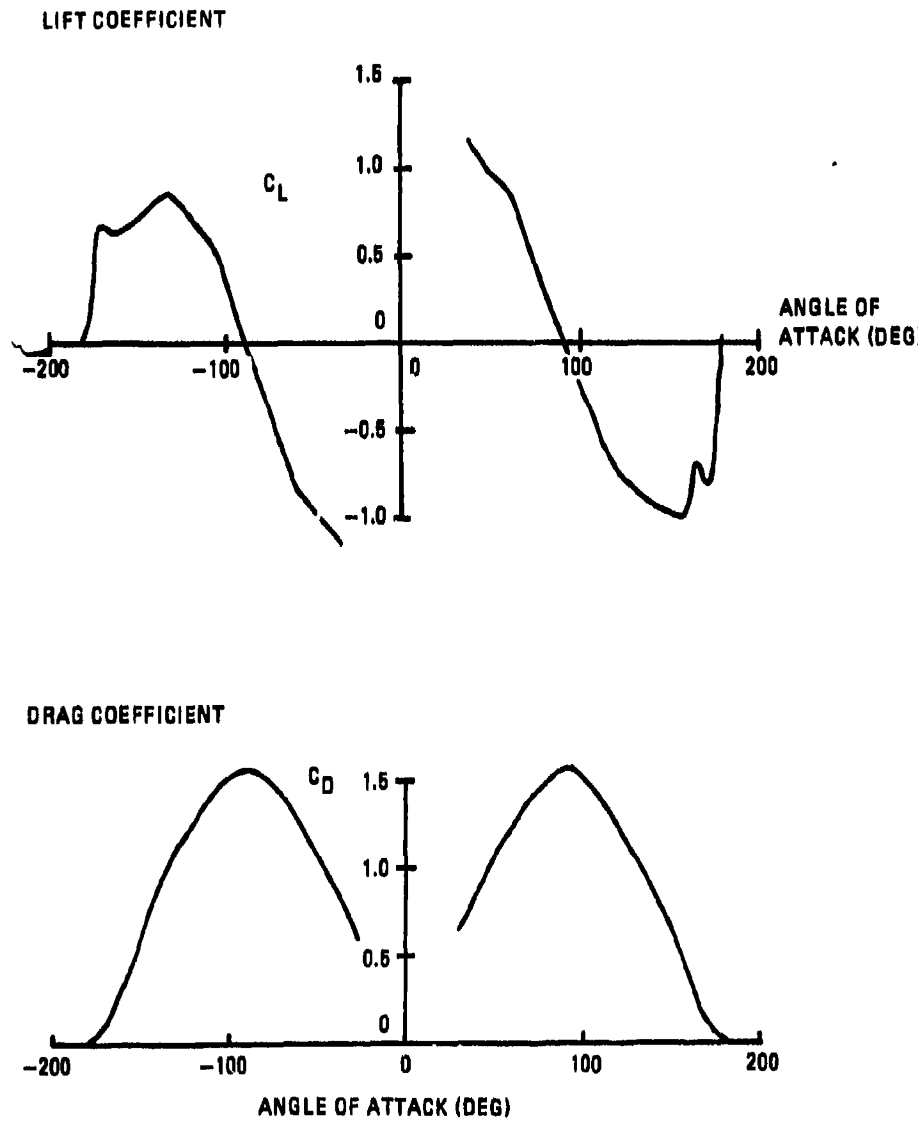
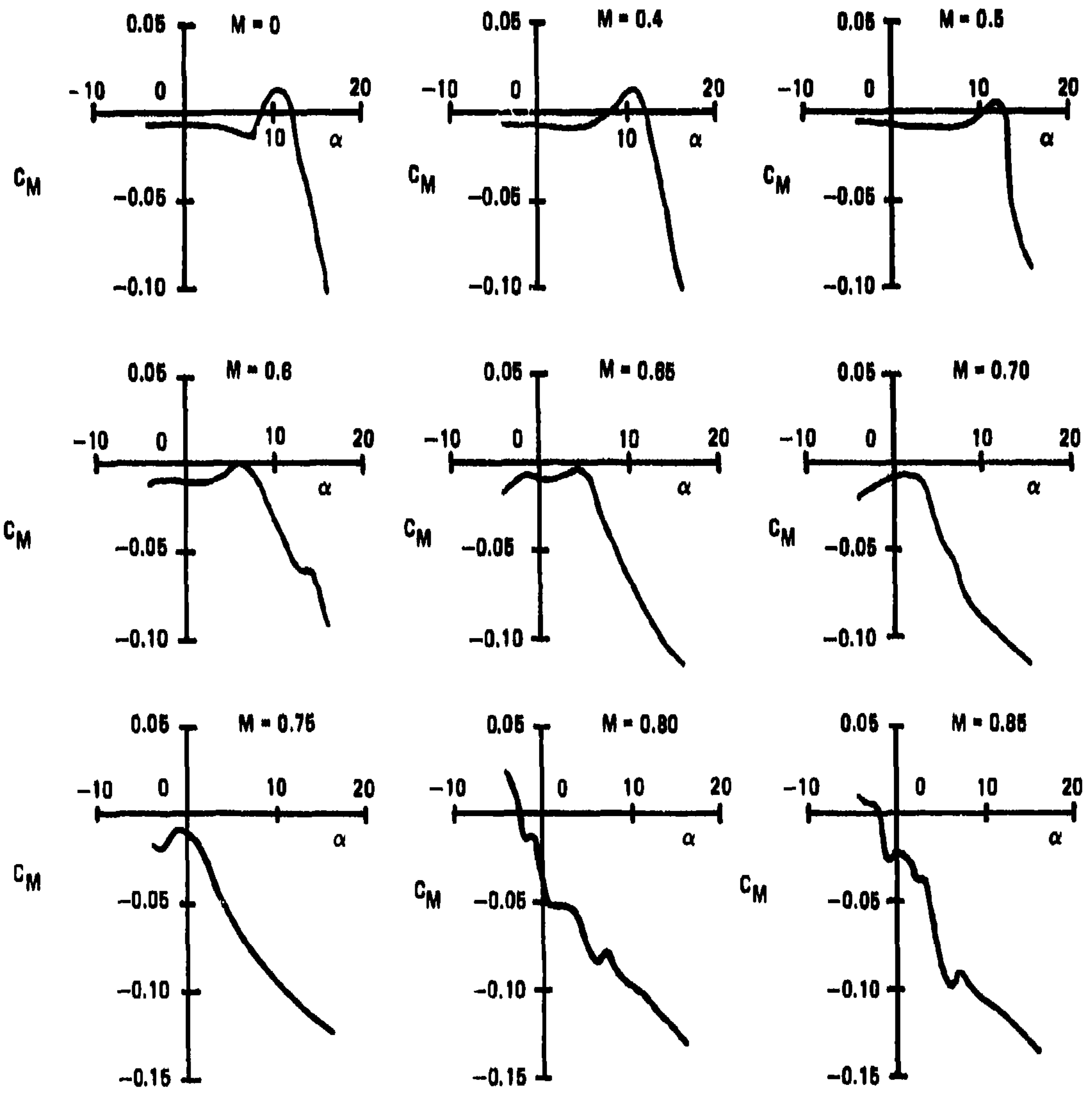


Figure 4. BO-105 Main Rotor Blade 23012 Cambered Airfoil Lift and Drag Coefficients at Large Angles of Attack.



NOTE: α = ANGLE OF ATTACK (DEG)

Figure 5. BO-105 Main Rotor Blade 23012 Cambered Airfoil Pitching Coefficients (Sheet 1 of 2).

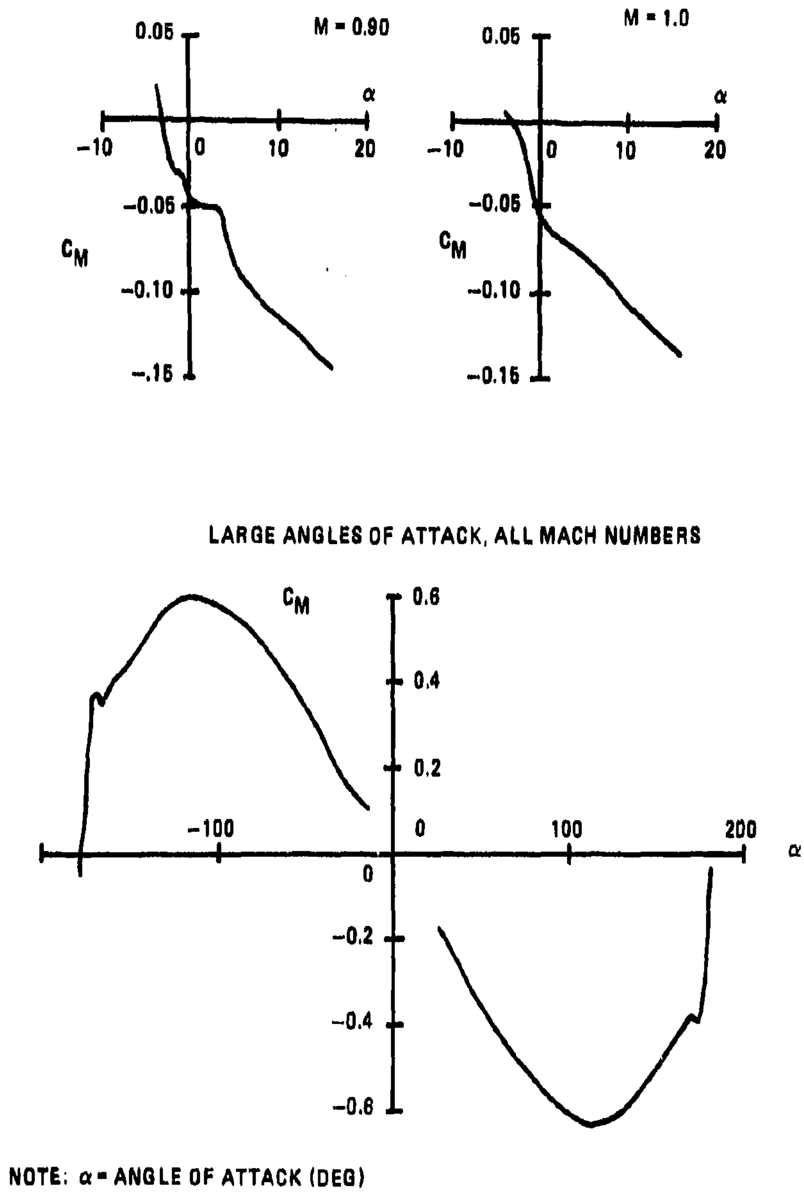


Figure 5. BO-105 Main Rotor Blade 23012 Cambered Airfoil Pitching Coefficients (Sheet 2 of 2).

3.2.5 Main Rotor Data Group

This block of data consists of main rotor blade weight and inertia distributions and modal properties. Modal data were available for the BO-105 0012 symmetrical airfoil main rotor blade when the AGAJ74 version of C-81 was first received at Boeing Vertol. Initial check runs with this version of C-81 were made with this set of modal data and with the 0012 airfoil table which is built into C-81. Modal data were then generated for the 23012 airfoil blade. Difficulty was encountered in obtaining a trimmed solution with 23012 blade modes and the 23012 aerodynamic coefficients. Consequently, many early runs were made with the combination of 23012 aerodynamic data and 0012 blade mode shapes. The 23012 blade had a softer first torsional mode and higher coupling between flap and torsion. Mass and inertia properties for the cambered airfoil blade are shown in Table 3; stiffness properties are shown in Table 4. Modal properties for the symmetrical and cambered airfoils are listed in Tables 5 and 6. The mode shapes for the cambered airfoil blade are shown in Figures 6 through 12. These coupled flap-lag-torsion mode shapes were computed using Boeing Vertol Program Y-71 (Reference 9). Blade stations are at every 5 percent blade radius starting at the blade root for C-81 input. A finer distribution of stations was used at the tip and root in the Y-71 analysis to obtain a better definition of mode shapes and natural frequencies.

3.2.6 Fuselage Group

This set of data includes aircraft weight, cg, inertia, and fuselage aerodynamics. Weight and cg data are a function of the flight test condition. Since inertia data were not available for each test condition, nominal values were taken as reported in Reference 4. The values of I_{XX}, I_{YY}, and I_{ZZ} are taken around an axis system parallel to the fuselage waterline, butt line, station axis system. The product of inertia, I_{XZ}, was not available, but was estimated to be 250 slug-ft^2.

The center of pressure ("fuselage data reference point") was taken from Reference 10, a report on BO-105 aerodynamic testing. Fuselage coordinates used in this analysis are all referenced to station zero, the most forward point on the aircraft, as shown in Figure 13. The cg reference location defining a

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9. Rinehart, S.A., COMPUTER PROGRAM Y-59 USER'S REPORT PROGRAM DOCUMENTATION FOR PREDICTING WHIRL FLUTTER, FREE VIBRATION AND FORCED RESPONSE OF A PROP-ROTOR SYSTEM, Rochester Applied Sciences Associates, Jan. 1971.

10. Davenport, E., Data Report: BVWT 039; AERODYNAMIC BO-105 TAIL ROTOR "KICK" INVESTIGATION USING THE 1/4 SCALE BO-105 STATIC MODEL, Report D212-10005-1, Boeing Vertol Company, Philadelphia, Pa., 28 Feb. 1970.

TABLE 3. MAIN ROTOR BLADE MASS DISTRIBUTION DATA(23012) INPUT FOR C-81

Blade Station Number	Weight (lb/in.)	Beamwise Inertia (in.-lb-sec^2/in.)	Chordwise Inertia (in.-lb-sec^2/in.)
1	3.3503	0.0000	0.0178
2	2.5024	0.0000	0.0480
3	0.7737	0.0000	0.0310
4	0.2921	0.0000	0.0022
5	0.2889	0.0000	0.0038
6	0.3090	0.0000	0.0050
7	0.3090	0.0000	0.0050
8	0.3090	0.0000	0.0050
9	0.3090	0.0000	0.0050
10	0.3090	0.0000	0.0050
11	0.3090	0.0000	0.0050
12	0.3090	0.0000	0.0050
13	0.3090	0.0000	0.0050
14	0.3090	0.0000	0.0050
15	0.3090	0.0000	0.0050
16	0.3090	0.0000	0.0050
17	0.3090	0.0000	0.0050
18	0.3090	0.0000	0.0050
19	0.3090	0.0000	0.0050
20	0.3084	0.0000	0.0050
Total Blade Weight = 114.36 lb	Blade Tip Weight = 0.00 LB		Flapping Inertia/Blade = 161.8 Slug-ft^2

TABLE 4. MAIN ROTOR BLADE (23012) MASS AND STIFFNESS PROPERTIES USED IN PROGRAM Y-71 TO COMPUTE MODE SHAPES AND FREQUENCIES

Y-71 STA	r (in.)	YM (in.)	M (lb-sec^2/in.)	IX, IZ (lb-in.-sec^2)	YSC (in.)	GJ (10^6 lb-in.^{2})	EI_{FLAP} (10^6 lb-in.^{2})	EI_{LAG} (10^6 lb-in.^{2})
1	193.36	0.0	0.000015	0.000097	–	–	–	–
2	190.40	−0.011	0.00385	0.024123	0.744	1.52	2.38	59.4
3	183.70	↑	0.007732	0.048439	↑	↑	↑	↑
4	174.30		↑	↑				
5	164.36							
6	154.70							
7	145.30							
8	135.36							
9	125.69							
10	116.02							
11	106.35							
12	96.69							
13	87.02							
14	77.35							
15	67.68							
16	58.01	↓	↓	↓	↓	↓	↓	↓
17	48.34	−0.011	0.007732	0.048439	0.744	1.52	2.38	59.4
18	38.67	−0.594	0.006672	0.028055	0.734	1.62	2.62	57.9
19	29.01	0.593	0.007894	0.016095	0.110	2.15	3.22	38.0
20	19.34	−0.088	0.030621	0.592690	0.460	3.21	3.66	38.1
21	9.67	−0.358	0.094402	0.344870	[illegible]	4.09	13.60	68.6
22	2.46	−0.670	0.036313	0.0	[illegible]	4.10	201.00	204.0
23	0.05	0.0	0.0	0.0	[illegible]	4.10	850.00	885.0

Note: In the Y-71 program, masses are lumped at stations; stiffness properties are between stations; moments of inertia are about the mass centers.

Legend:
- r = blade radius
- YM = mass offset from pitch axis, positive toward leading edge
- M = lumped mass
- IX, IZ = lumped pitch and lag bending inertias (assumed equal; flap inertia assumed equal to zero)
- YSC = shear center offset from pitch axis, positive toward leading edge
- GJ = torsional rigidity
- EI_{FLAP} = flap bending rigidity
- EI_{LAG} = lag bending rigidity

TABLE 5. MODE SHAPES FOR MAIN ROTOR SYMMETRIC AIRFOIL BLADE (0012)

MAIN ROTOR

	MODE SHAPE FOR MODE 1			MODE SHAPE FOR MODE 2			MODE SHAPE FOR MODE 3		
STA	OUT-OF-PLANE	INPLANE	TORSION	OUT-OF-PLANE	INPLANE	TORSION	OUT-OF-PLANE	INPLANE	TORSION
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	-0.0321	0.0	-0.0001	-0.0413
2	0.0008	-0.0001	0.0	0.0002	0.0	-0.0486	0.0	-0.0010	-0.0390
3	0.0031	-0.0002	-0.0124	0.0024	0.0003	-0.0767	-0.0002	-0.0045	-0.0299
4	0.0067	-0.0003	-0.0181	0.0079	0.0017	-0.0938	-0.0033	-0.0123	-0.0301
5	0.0109	-0.0006	-0.0058	0.0152	0.0032	-0.0800	-0.0065	-0.0245	-0.0555
6	0.0121	-0.0010	-0.0370	0.0231	0.0046	-0.1564	-0.0097	-0.0395	-0.0232
7	0.0168	-0.0016	-0.0700	0.0305	0.0063	-0.2292	-0.0130	-0.0562	0.0106
8	0.0217	-0.0023	-0.1020	0.0369	0.0075	-0.2922	-0.0161	-0.0743	0.0433
9	0.0267	-0.0030	-0.1330	0.0417	0.0083	-0.3417	-0.0191	-0.0935	0.0750
10	0.0318	-0.0039	-0.1620	0.0445	0.0087	-0.3760	-0.0219	-0.1140	0.1050
11	0.0370	-0.0048	-0.1910	0.0449	0.0086	-0.3948	-0.0246	-0.1350	0.1320
12	0.0422	-0.0057	-0.2170	0.0425	0.0079	-0.3974	-0.0272	-0.1560	0.1590
13	0.0475	-0.0068	-0.2410	0.0370	0.0067	-0.3846	-0.0297	-0.1780	0.1830
14	0.0529	-0.0078	-0.2630	0.0282	0.0048	-0.3583	-0.0322	-0.2000	0.2040
15	0.0583	-0.0088	-0.2830	0.0160	0.0024	-0.3212	-0.0346	-0.2230	0.2220
16	0.0637	-0.0098	-0.2990	0.0005	-0.0005	-0.2759	-0.0369	-0.2460	0.2370
17	0.0692	-0.0111	-0.3110	-0.0179	-0.0039	-0.2293	-0.0392	-0.2690	0.2490
18	0.0746	-0.0122	-0.3210	-0.0384	-0.0076	-0.1874	-0.0412	-0.2930	0.2570
19	0.0801	-0.0133	-0.3220	-0.0603	-0.0115	-0.1693	-0.0438	-0.3160	0.2600
20	0.0850	-0.0144	-0.3280	-0.0822	-0.0154	-0.1493	-0.0460	-0.3390	0.2640

	MODE SHAPE FOR MODE 4			MODE SHAPE FOR MODE 5			MODE SHAPE FOR MODE 6		
STA	OUT-OF-PLANE	INPLANE	TORSION	OUT-OF-PLANE	INPLANE	TORSION	OUT-OF-PLANE	INPLANE	TORSION
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	-0.0012	-0.0003	-3.2320	0.0	0.0	0.0	0.0	0.0	0.0
2	-0.0023	-0.0006	-3.6960	0.0	0.0	0.0	0.0	0.0	0.0
3	-0.0018	-0.0004	-4.2120	0.0	0.0	0.0	0.0	0.0	0.0
4	-0.0014	-0.0003	-4.8360	0.0	0.0	0.0	0.0	0.0	0.0
5	-0.0126	-0.0027	-5.6560	0.0	0.0	0.0	0.0	0.0	0.0
6	-0.0164	-0.0035	-6.7790	0.0	0.0	0.0	0.0	0.0	0.0
7	-0.0199	-0.0042	-7.8560	0.0	0.0	0.0	0.0	0.0	0.0
8	-0.0228	-0.0047	-8.9670	0.0	0.0	0.0	0.0	0.0	0.0
9	-0.0248	-0.0051	-9.9800	0.0	0.0	0.0	0.0	0.0	0.0
10	-0.0256	-0.0051	-10.9500	0.0	0.0	0.0	0.0	0.0	0.0
11	-0.0254	-0.0050	-11.8550	0.0	0.0	0.0	0.0	0.0	0.0
12	-0.0239	-0.0045	-12.6920	0.0	0.0	0.0	0.0	0.0	0.0
13	-0.0213	-0.0039	-13.4480	0.0	0.0	0.0	0.0	0.0	0.0
14	-0.0177	-0.0030	-14.1180	0.0	0.0	0.0	0.0	0.0	0.0
15	-0.0134	-0.0020	-14.6970	0.0	0.0	0.0	0.0	0.0	0.0
16	-0.0089	-0.0009	-15.1780	0.0	0.0	0.0	0.0	0.0	0.0
17	-0.0044	0.0001	-15.5570	0.0	0.0	0.0	0.0	0.0	0.0
18	-0.0005	0.0011	-15.8320	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0021	0.0020	-15.9380	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0047	0.0028	-16.0440	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 6. MODE SHAPES FOR MAIN ROTOR CAMBERED AIRFOIL BLADE (23012)

MAIN ROTOR

	MODE SHAPE FOR MODE 1			MODE SHAPE FOR MODE 2			MODE SHAPE FOR MODE 3		
STA	OUT-OF-PLANE	INPLANE	TORSION	OUT-OF-PLANE	INPLANE	TORSION	OUT-OF-PLANE	INPLANE	TORSION
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	-0.0000	0.0	0.0011	0.0	-0.0004	-0.0052	0.0000	0.0	-0.0172
2	-0.0008	0.0001	0.0086	-0.0003	-0.0032	-0.0430	0.0015	0.0004	-0.1379
3	-0.0031	0.0002	0.0097	-0.0020	-0.0101	-0.0498	0.0055	0.0015	-0.1566
4	-0.0067	0.0002	0.0304	-0.0045	-0.0213	-0.0321	0.0123	0.0032	-0.2173
5	-0.0109	0.0005	0.0390	-0.0072	-0.0352	-0.0367	0.0193	0.0050	-0.2593
6	-0.0155	0.0007	0.0819	-0.0099	-0.0507	0.0080	0.0264	0.0067	-0.3617
7	-0.0203	0.0012	0.1255	-0.0124	-0.0676	0.0527	0.0327	0.0083	-0.4531
8	-0.0252	0.0017	0.1673	-0.0147	-0.0856	0.0957	0.0379	0.0094	[illegible]
9	-0.0302	0.0023	0.2074	-0.0167	-0.1045	0.1364	0.0415	0.0102	[illegible]
10	-0.0352	0.0030	0.2458	-0.0186	-0.1241	0.1753	0.0432	0.0104	[illegible]
11	-0.0403	0.0037	0.2819	-0.0204	-0.1443	0.2114	0.0427	0.0101	-0.6463
12	-0.0454	0.0045	0.3157	-0.0221	-0.1650	0.2447	0.0397	0.0092	-0.6458
13	-0.0506	0.0053	0.3467	-0.0237	-0.1861	0.2750	0.0339	0.0076	-0.6263
14	-0.0557	0.0062	0.3747	-0.0253	-0.2075	0.3020	0.0252	0.0053	-0.5902
15	-0.0609	0.0070	0.3994	-0.0268	-0.2291	0.3255	0.0133	0.0025	-0.5421
16	-0.0661	0.0079	0.4200	-0.0282	-0.2509	0.3449	-0.0015	-0.0011	-0.4865
17	-0.0713	0.0087	0.4366	-0.0296	-0.2726	0.3604	-0.0190	-0.0051	-0.4292
18	-0.0764	0.0097	0.4492	-0.0309	-0.2948	0.3713	-0.0386	-0.0095	-0.3762
19	-0.0815	0.0107	0.4567	-0.0322	-0.3168	0.3782	-0.0596	-0.0143	-0.3489
20	-0.0860	0.0116	0.4584	-0.0330	-0.3368	0.3799	-0.0814	-0.0198	-0.3300

	MODE SHAPE FOR MODE 4			MODE SHAPE FOR MODE 5			MODE SHAPE FOR MODE 6		
STA	OUT-OF-PLANE	INPLANE	TORSION	OUT-OF-PLANE	INPLANE	TORSION	OUT-OF-PLANE	INPLANE	TORSION
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	-0.0005	0.0001	1.4703	-0.0002	0.0	0.0516	-0.0296	0.3903	56.7725
2	0.0019	0.0009	11.7436	-0.0034	-0.0001	0.4022	0.0363	0.0148	434.4312
3	0.0281	0.0059	13.0512	-0.0121	-0.0010	0.4145	0.4620	0.0962	[illegible]
4	0.0139	0.0070	14.5888	-0.0200	-0.0024	0.5151	-0.1257	0.0558	360.8695
5	0.0419	0.0161	17.3756	-0.0383	-0.0033	0.5432	0.0672	0.0957	331.7610
6	0.0556	0.0202	19.8017	-0.0477	-0.0036	0.6418	0.1758	0.0940	271.2574
7	0.0672	0.0237	22.1453	-0.0519	-0.0028	0.6721	0.2285	0.0830	208.6354
8	0.0759	0.0262	24.4017	-0.0496	-0.0009	0.6274	0.2418	0.0656	133.5989
9	0.0809	0.0277	26.5631	-0.0408	0.0019	0.5128	0.2039	0.0335	59.8699
10	0.0816	0.0279	28.6208	-0.0262	0.0054	0.3404	0.1165	-0.0050	-14.9152
11	0.0774	0.0268	30.5598	-0.0075	0.0090	0.1329	-0.0067	-0.0481	-89.0155
12	0.0684	0.0244	32.3745	0.0130	0.0122	-0.0837	-0.1430	-0.0901	-161.0875
13	0.0534	0.0207	33.8912	0.0319	0.0143	-0.2802	-0.2621	-0.1243	-229.6183
14	0.0333	0.0156	35.5569	0.0457	0.0146	-0.4286	-0.3324	-0.1482	-293.2095
15	0.0090	0.0094	36.8891	0.0507	0.0126	-0.5105	-0.3286	-0.1451	-350.4924
16	-0.0157	0.0025	38.0220	0.0495	0.0088	-5.1856	-0.2419	-0.1261	-400.0740
17	-0.0477	-0.0048	38.9348	0.0259	0.0595	-0.4626	-0.0641	-0.0902	-440.5560
18	-0.0760	-0.0122	39.6096	-0.0036	-0.0091	-0.3661	0.1110	-0.0443	-470.7192
19	-0.1317	-0.0192	40.0286	-0.0402	-0.0208	-0.2765	0.2990	0.0032	-489.3875
20	-0.0530	-0.0257	40.1306	-0.0795	-0.0314	-0.2384	-0.0915	0.0476	-494.1433

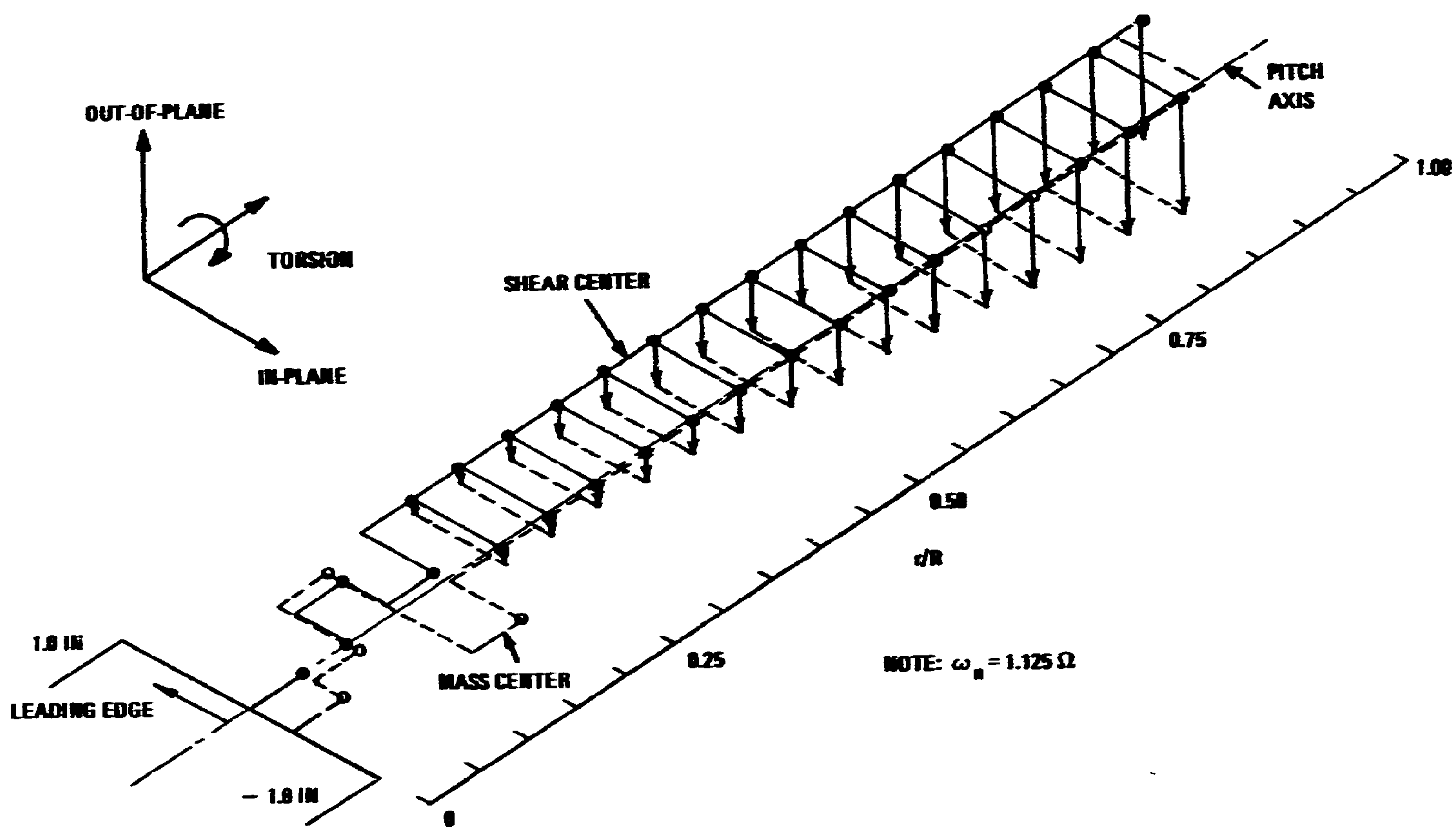

Figure 6. First Flap Mode of 23012 Cambered Airfoil Blade.

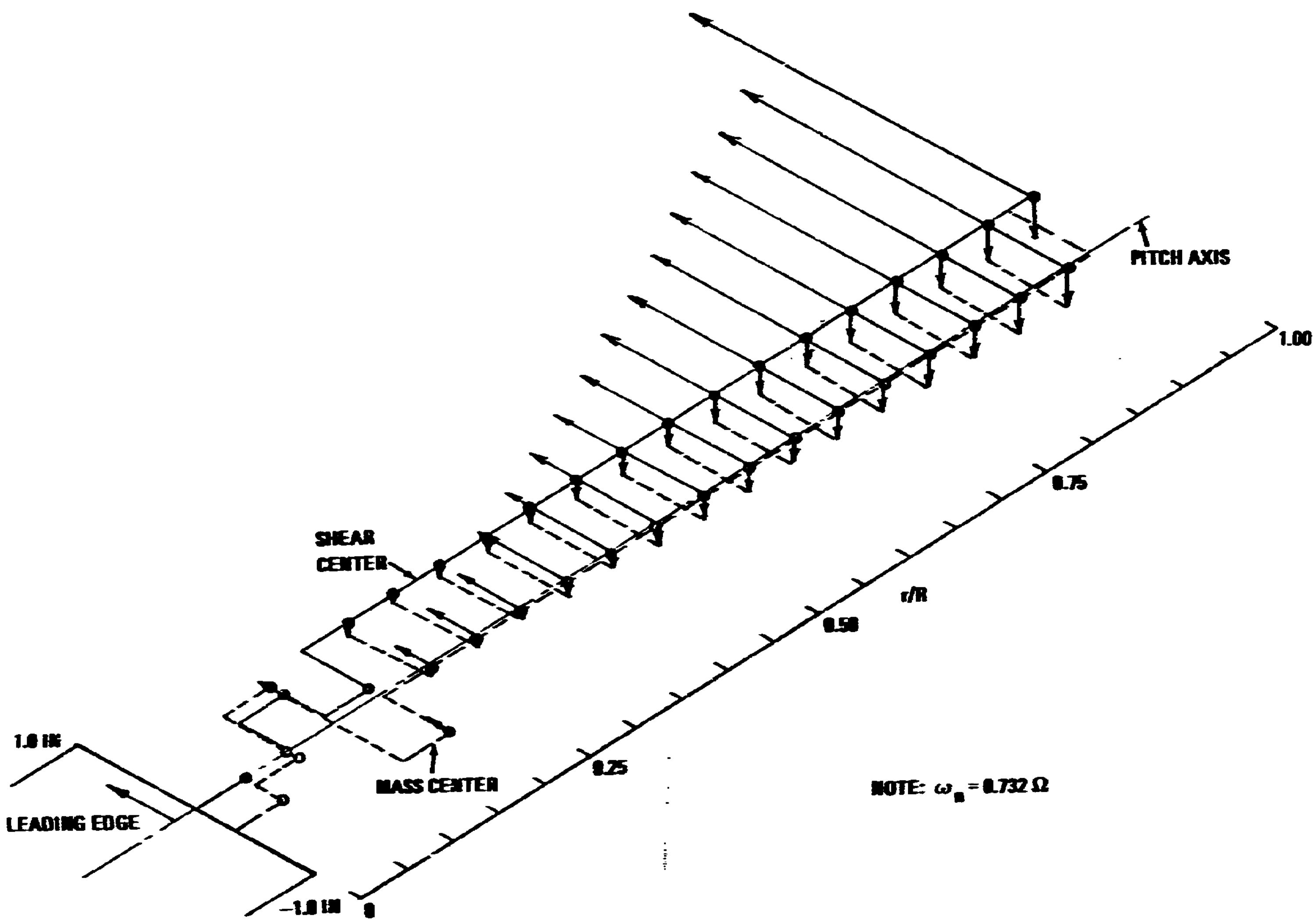

Figure 7. First Lag Mode of 23012 Cambered Airfoil Blade.

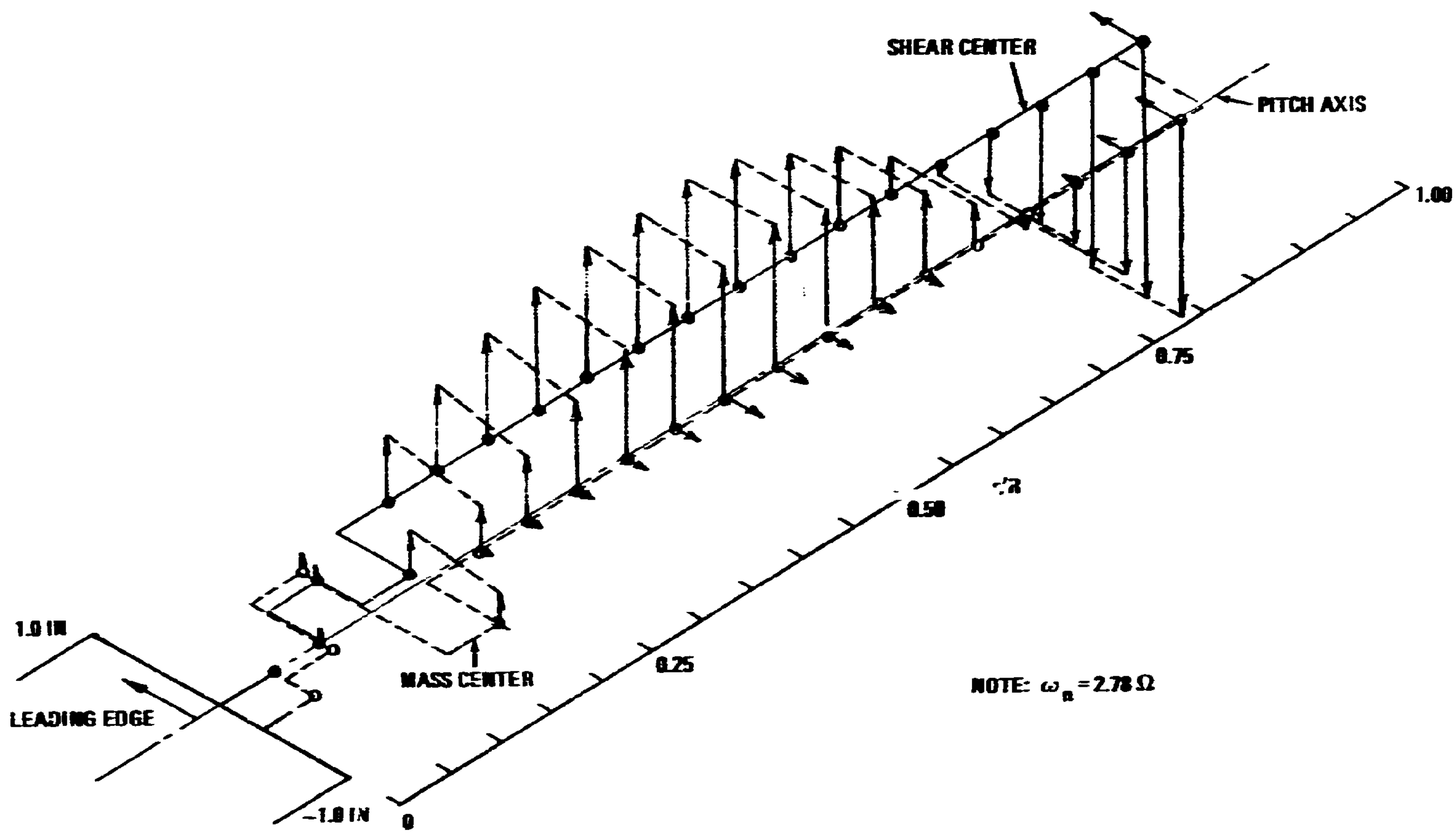

Figure 8. Second Flap Mode of 23012 Cambered Airfoil Blade.

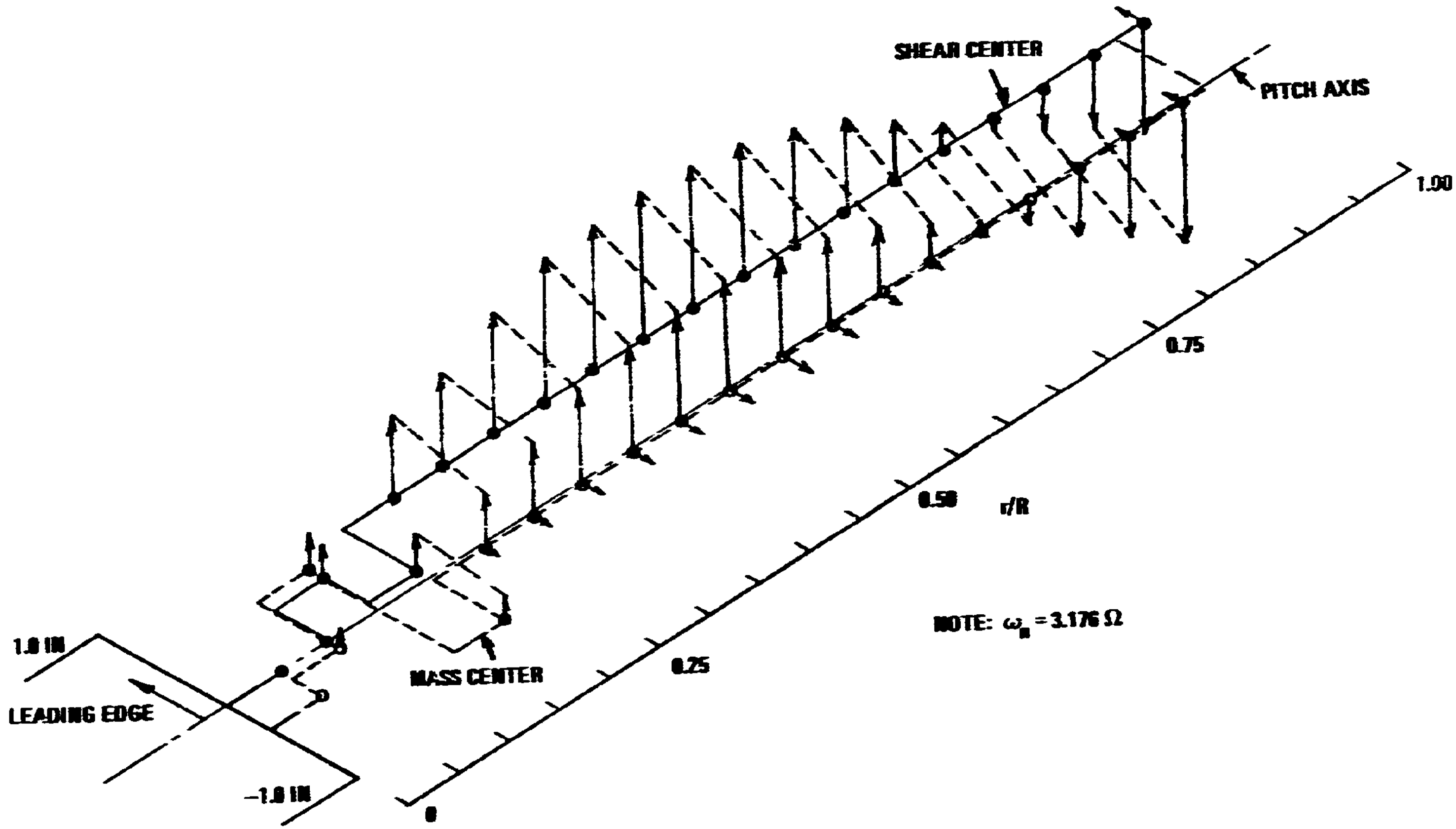

Figure 9. First Torsion Mode of 23012 Cambered Airfoil Blade.

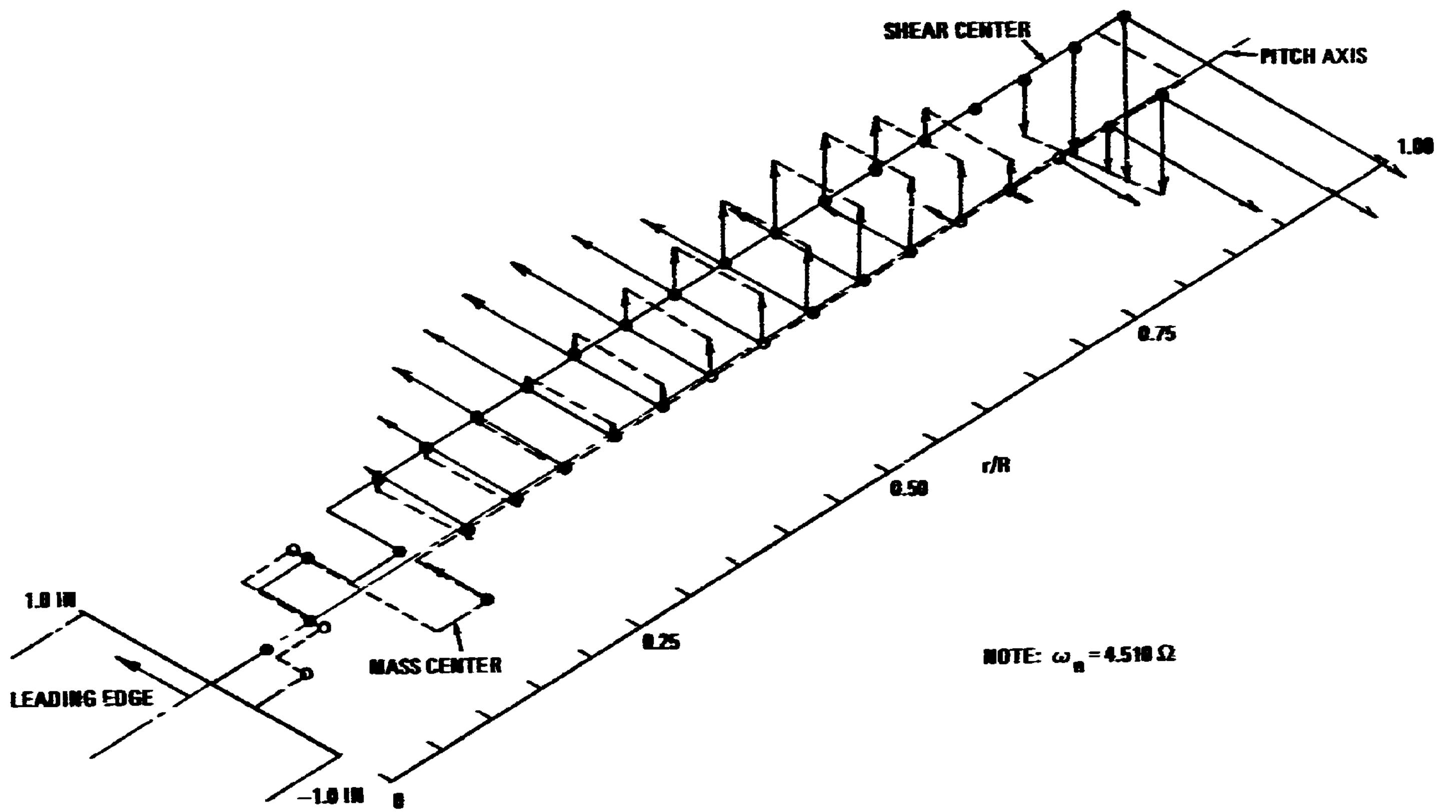

Figure 10. Second Lag Mode of 23012 Cambered Airfoil Blade.

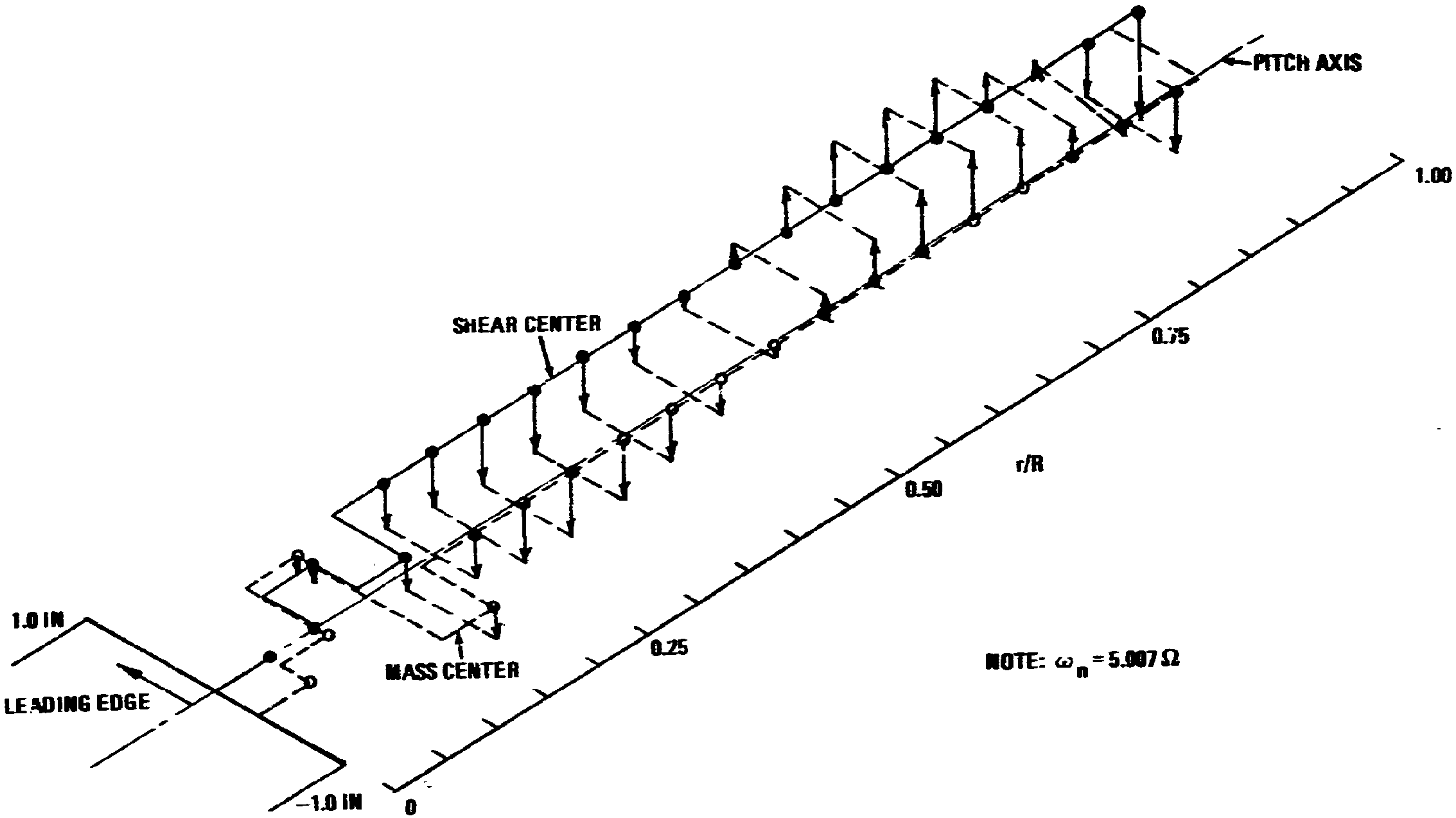

Figure 11. Third Flap Mode of 23012 Cambered Airfoil Blade.

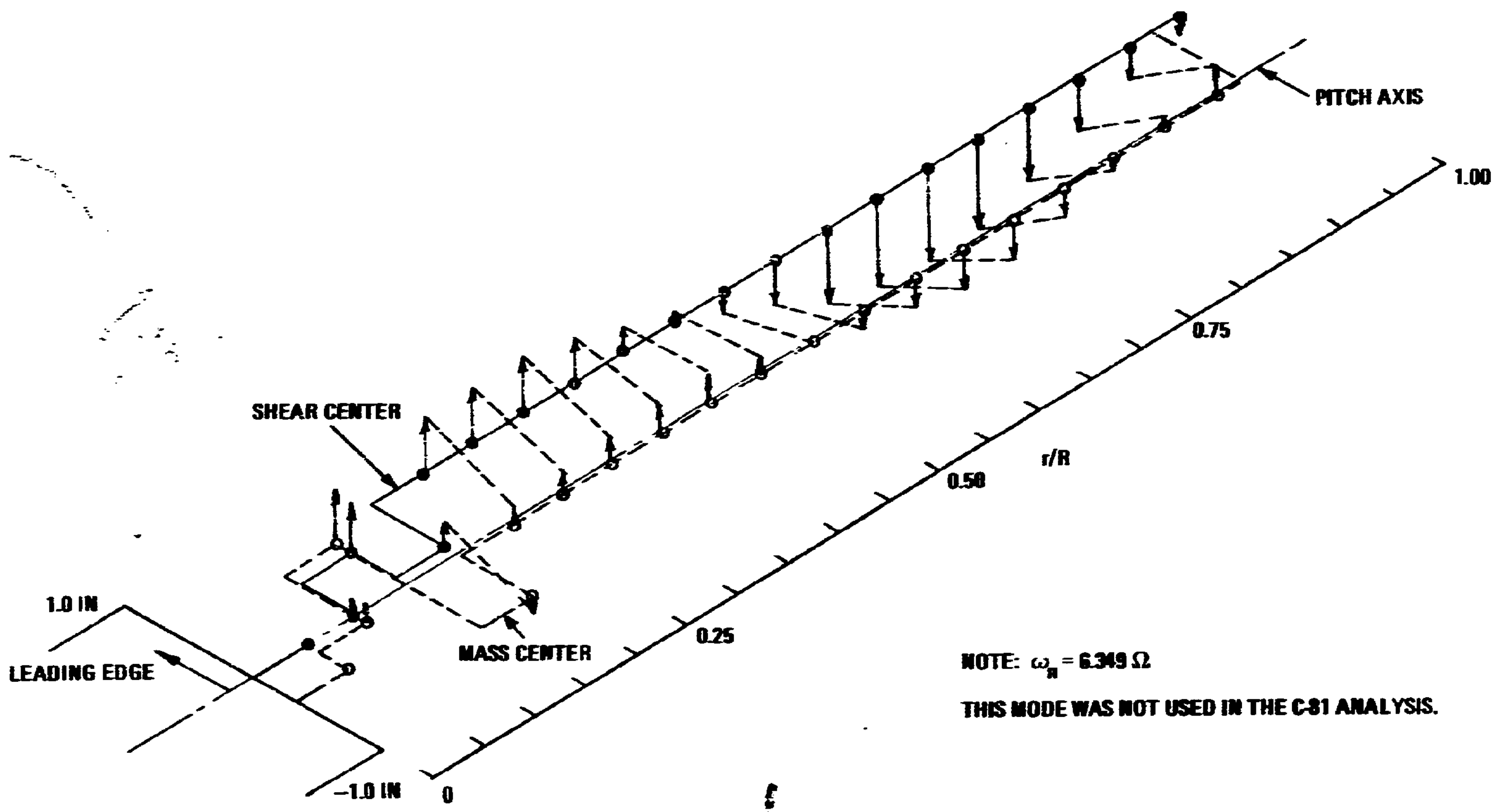

Figure 12. Second Torsion Mode of 23012 Cambered Airfoil Blade.

forward, neutral, or aft cg is the rotor reference axis (RRA). This is the station where the main and tail rotor drive shafts intersect and is at station 100.4 referenced to the nose of the aircraft.

Aerodynamic data for the fuselage were available from tests reported in Reference 10. These data were available as aerodynamic tables of force and moment coefficients for the body axis system. They were first transformed to the wind axis system, and were then processed through the Government-provided AS812A computer program which generated coefficients for equations which were curve fitted to the data as a function of yaw and pitch angles of attack. These equations are used in the AGAJ74 version of C-81; AS812A punches the equation coefficients on cards in proper format for input into C-81. The program also makes a direct comparison of the value of the aerodynamic coefficients computed by the equations versus the raw input wind tunnel test data.

Typical resulting curves of aerodynamic coefficients obtained using the curve fit equations and errors relative to the wind tunnel data are shown in Figure 14. The raw data are equal to the computed values plus the error. The coefficients are used for the low or nominal angle of attack range, which was specified to be ±15 degrees. The built-in high-angle equations were specified at angles above ±30 degrees. The two solutions are phased together when the angle of attack is at an intermediate value. Data were specified to be for forward flight conditions.

3.2.7 Rotor Aerodynamic Group

This group generally contains data for use in equations which describe airfoil aerodynamic coefficients as a function of angle of attack and Mach number. Although more detailed data are contained in aerodynamic tables, inputs for the simpler equation representation are still required since they are used if one of the unsteady aerodynamic options is activated. The initial plan was to read in a cambered airfoil table for the main rotor and use the built-in 0012 airfoil table for the tail rotor. However, as implemented at Boeing Vertol, the program would not run while simultaneously using the read-in table for the main rotor and the built-in 0012 table for the tail rotor. (The program had been run successfully using the built-in 0012 table for both the main and tail rotors, and had also been run successfully at the Eustis Directorate, reading in a table for the main rotor and using the built-in 0012 table for the tail rotor). As a solution to this problem, a read-in airfoil table was used for the main rotor while the equation approach was used for the tail rotor. Aerodynamic coefficients were computed in C-81 based on aerodynamic data

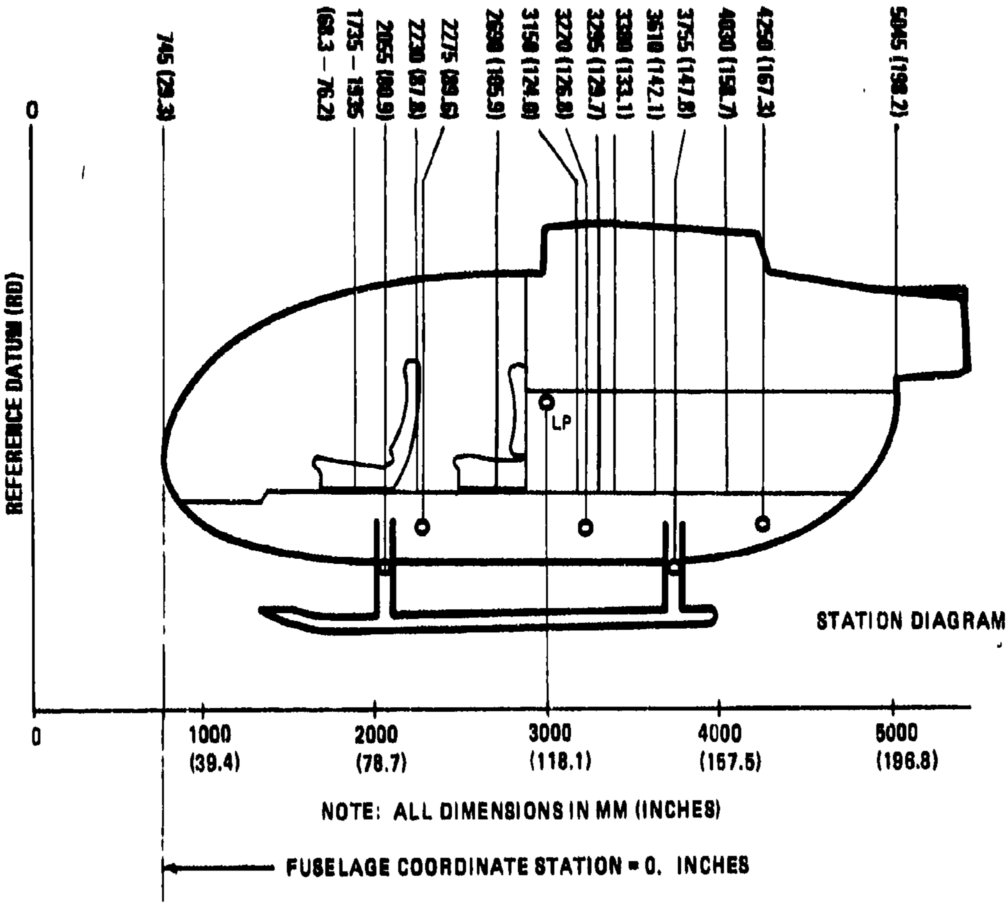

Figure 13. Fuselage Reference System.

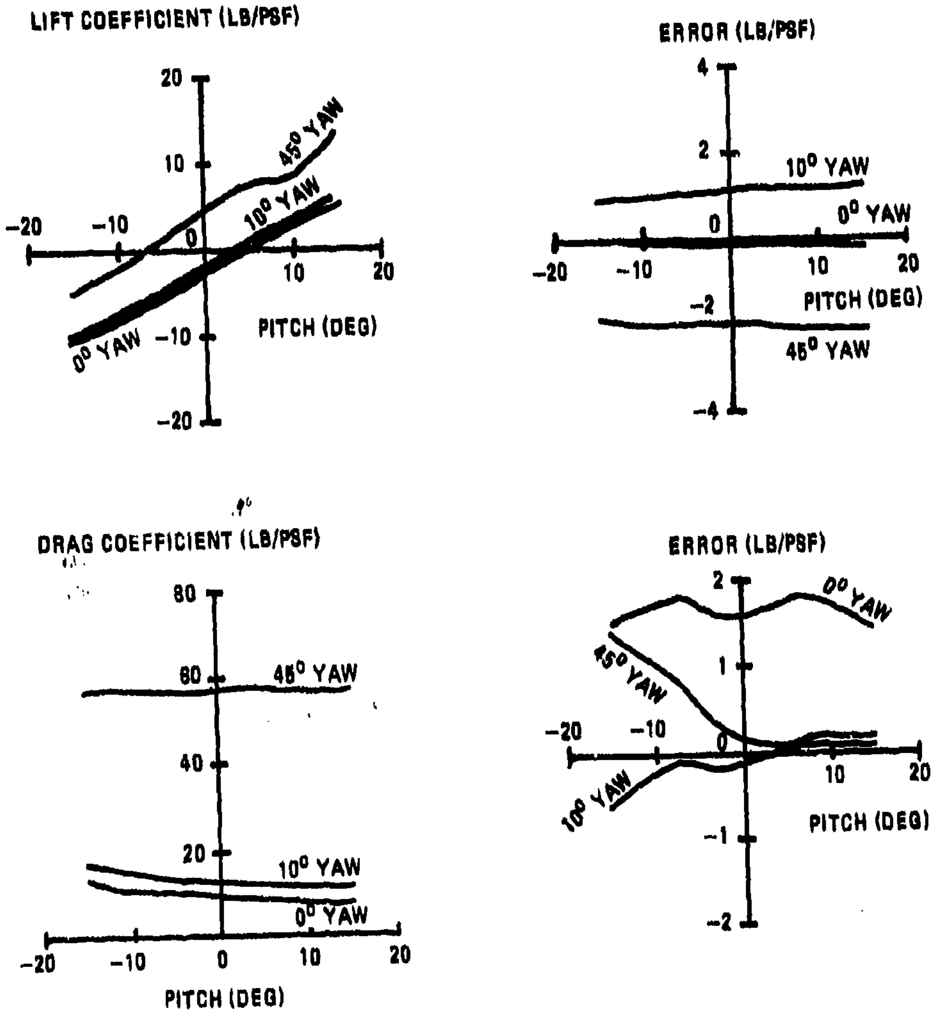

Figure 14. Fuselage Aerodynamic Coefficients for Wind Axis System (Sheet 1 of 3).

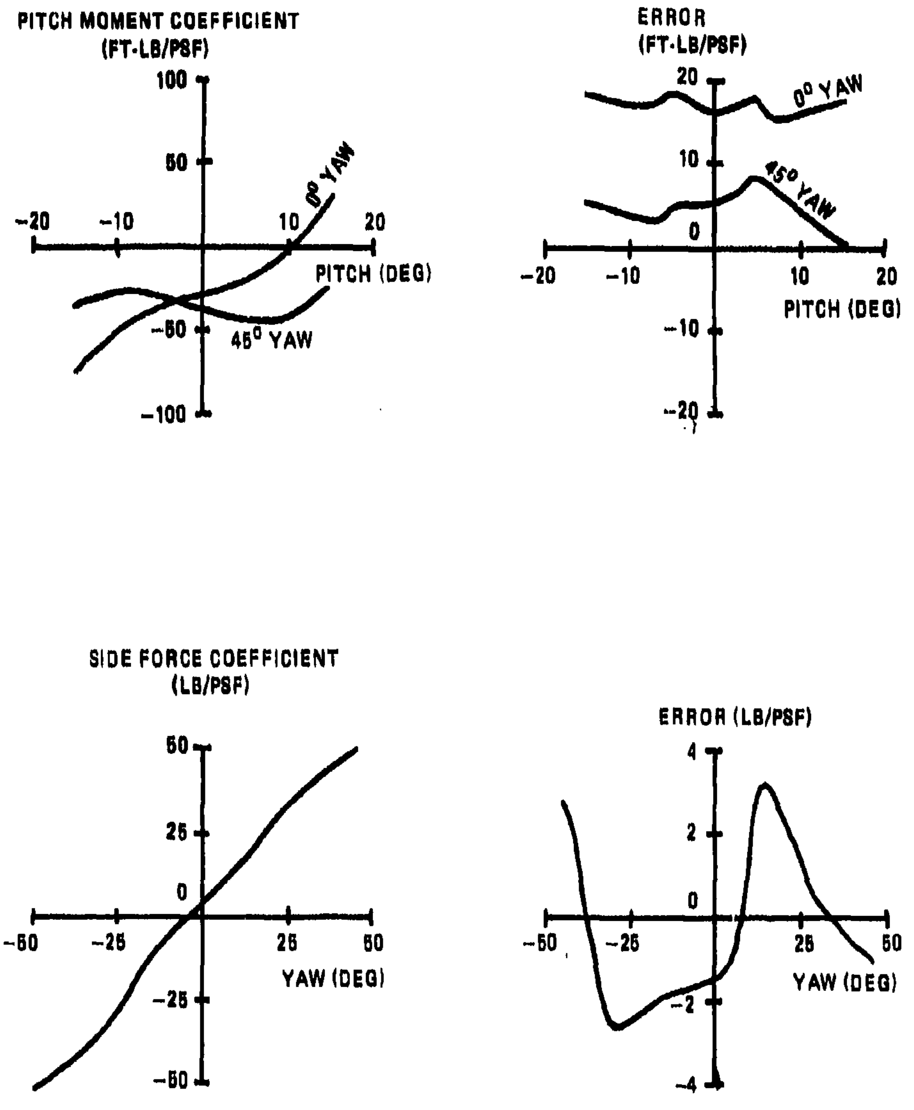

Figure 14. Fuselage Aerodynamic Coefficients for Wind Axis System (Sheet 2 of 3).

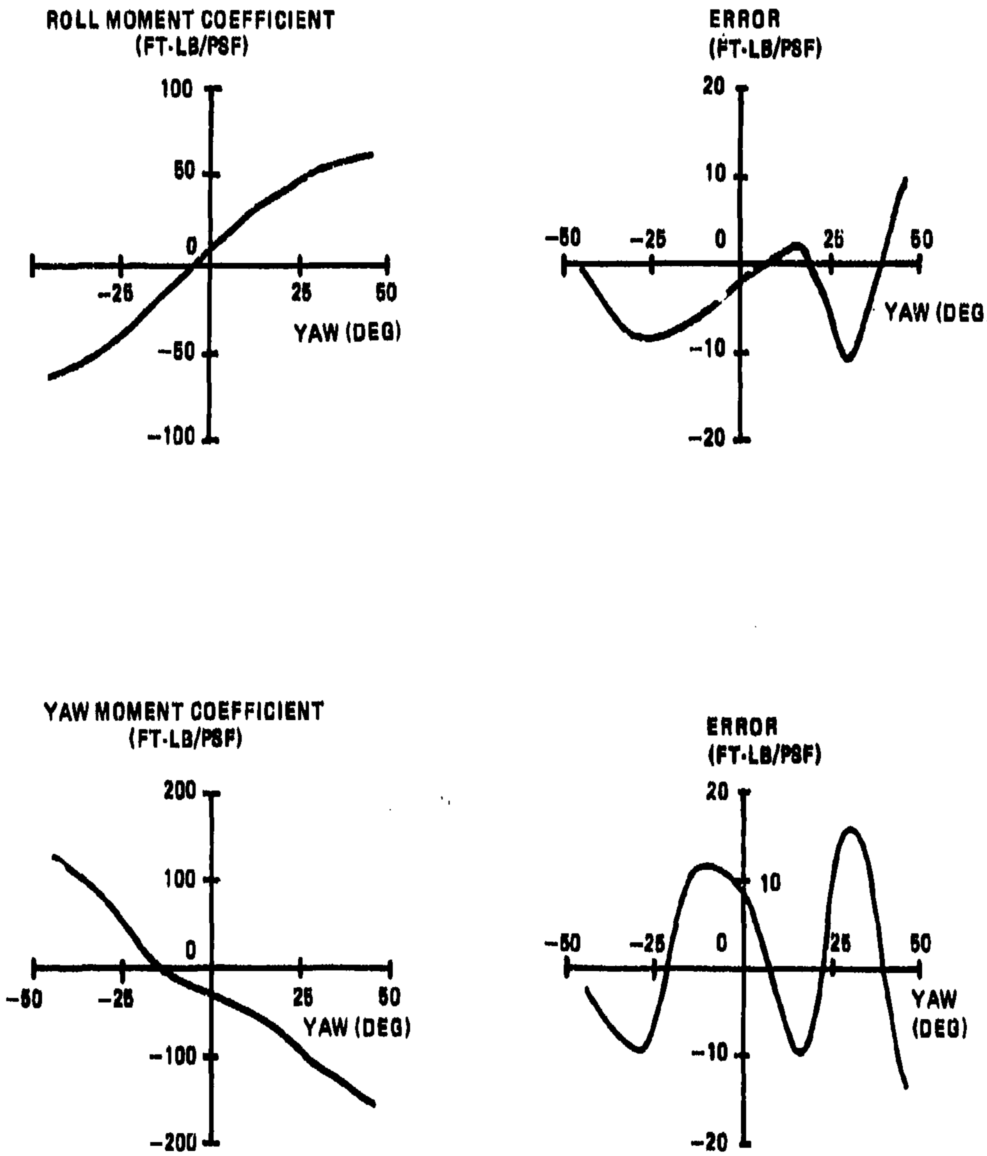

Figure 14. Fuselage Aerodynamic Coefficients for Wind Axis System (Sheet 3 of 3).

as represented by the 23012 cambered airfoil tables for the main rotor. The built-in 0012 table and definitions of coefficients given in Reference 2 were used to compute coefficients of equations for the tail rotor.

3.2.8 Main and Tail Rotor Groups

Data in these sections include geometric and other physical data and are presented in Appendix A. Blade and inertia data are indicated to be zero for the main rotor but are computed internally from the input mass distribution. The main rotor is hingeless while the tail rotor is a teetering type.

3.2.9 Stabilizer and Rotor Controls Group

Input data for the horizontal stabilizer are shown in Appendix A. Input data include location, surface area, aerodynamic data, and basic control data. The control data include ranges of stick and pedal motions in inches and degrees.

3.2.10 Iteration Logic Group

This group of inputs includes data which control step sizes and allowable errors used in the process of obtaining a trimmed solution. A trial set of values is input for trim in another input group, the Flight Constants Group. These values are for aircraft attitudes, control settings, flapping angles, and main and tail rotor thrusts. The trim procedure computes net values of the six components of forces and moments acting on the helicopter for these initial estimates of the trimmed condition. Nonzero values of forces and moments are the trim errors. Figure 15 shows a sample output for the first iteration of a trim case.

Perturbations are then made in each independent variable used in the trim analysis, and a partial derivative matrix is formed showing the sensitivity of forces and moments on the fuselage to each variable. This matrix, along with the values of errors, is used to compute the trimmed solution. The magnitudes of changes which can be made in collective, cyclic, and aircraft attitudes are limited to small values, however, since the problem is nonlinear and corrections which are too large may be computed.

Appendix A lists values input to the Iteration Logic Group which gave successful trimmed solutions for the BO-105 hingeless rotor aircraft. The starting maximum correction limit is 2.0 degrees. The minimum correction limit is 0.15 degree. The maximum value of "variable damper" in trim was set at 500 (lb or ft-lb). If aircraft moment <u>and</u> force errors are <u>above</u> this error, the maximum correction remains at the initial value of 2.0 degrees.

***** START OF ITERATION 1 *****

INDUCED VEL CHG LIMITER REACHED FOR NM1 --UNCORRECTED INDUCED VELOCITY = 13.046 UNCORRECTED CHANGE IN INDUCED VELOCITY = -3.0333

VAR(I) 39.51999 40.50000 39.10999 31.90999 1.17000 0.0 2.72000 2.43000 -1.12000 0.20000

	THRUST	H-FORCE	Y-FORCE	TORQUE	IND. V.	JET THRUST	
MAIN ROTOR	4111.	84.	-115.	2686.	15.029	RIGHT/CENTER	0.
TAIL ROTOR	-166.	2.	-1.	38.	-12.437	LEFT	0.

FORCE AND MOMENT SUMMARY

	X-FORCE	Y-FORCE	Z-FORCE	ROLL	PITCH	YAW
FUSELAGE	-107.7	70.0	23.6	60.5	-401.2	-408.0
MAIN ROTOR	171.0	-115.1	-4108.1	-520.8	-1336.6	15.8
TAIL ROTOR	-1.8	165.9	-0.7	855.1	-5.5	-3294.8
STABILIZER #1	5.6	0.0	66.3	0.0	990.0	-0.0
JETS AND GUNS	0.0	0.0	0.0	0.0	0.0	0.0
GROSS WEIGHT	-93.2	-74.0	4560.4			
M.R. TORQUE				-1127.4	-706.8	2630.4
T.R. TORQUE				0.0	-37.8	-0.6
TOTAL	-26.8	46.7	541.5	-732.6	-1497.9	-1056.6

PARTIAL DERIVATIVE MATRIX

	X-FORCE	Y-FORCE	Z-FORCE	YAW MOM	PITCH MOM	ROLL MOM	MR F/A MOM	MR LAT MOM	TR F/A MOM	TR LAT MOM
COLLECTIVE	3111.	-2999.	-63505.	35240.	-22410.	-22646.	-1006.	-14982.	0.	0.
F/A CYCLIC	347.	2623.	29836.	-3227.	2775.	4760.	-7460.	37523.	0.	0.
LAT CYCLIC	-2897.	2346.	14541.	-31395.	15470.	4993.	34408.	7294.	0.	0.
PEDAL	-638.	-5515.	11673.	108341.	6557.	-35521.	0.	0.	277.	3066.
PITCH	-3420.	-470.	-4713.	-8255.	-7209.	-9085.	-1032.	-974.	-110.	3.
YAW	-810.	2197.	12106.	-30418.	5589.	1019.	-71.	1007.	-28.	-342.
MR F/A FLAP	-720.	304.	11617.	-6929.	-6066.	-5411.	2920.	-1861.	0.	0.
MR LAT FLAP	-796.	323.	13312.	-10066.	5792.	-10619.	1662.	5809.	0.	0.
TR F/A FLAP	-799.	416.	11923.	-9560.	11217.	-5234.	0.	0.	6576.	-6487.
TR LAT FLAP	-422.	-1139.	11742.	21703.	5822.	-13057.	0.	0.	6618.	6865.
-ERROR	26.	-47.	-542.	1057.	1498.	733.	-616.	-69.	-49.	-34.

CORRECTIONS -0.0211200 -0.0163575 -0.0107477 0.0095210 0.0020626 0.0100457 -0.1351075 0.0059374 0.0003112 -0.0300300

RATIO APPLIED TO CORRECTION VECTOR IS 0.2503613 FROM COMPONENT 7

Figure 15. Sample Trim Output.

Once errors are less than 500 (lb or ft-lb), the "variable damper value" and correction limits are cut in half. Hopefully this process leads to a solution where "allowable errors" are satisfied.

This method appears to have a disadvantage in that only a single number is used. This "variable damper" number is the value of the error which controls the adjustment of the maximum trim correction; it applies to both force and moments. Two numbers should be used: one for forces and one for moments. When one number is used, moment errors will dominate the method of adjusting variables to achieve a trim. Corrections are made to improve moment errors while errors in thrust remain large.

3.2.11 Flight Constants Group

As noted earlier, this group contains data for initial guesses at the trimmed conditions for controls, aircraft attitude, and rotor thrust. These data also include forward velocity, lateral velocity, rate of climb, and altitude and atmospheric data. Engine rpm and power available are also given. A large number was used for power available to avoid an automatic cutoff of the program at a power-limited condition. Available power is indicated in the discussion of performance results. Typical data are shown in Appendix A.

3.2.12 Maneuver Input Data

Many options are available in the maneuver portion of the program. Cases actually run included response to control motions following a trimmed solution. Data for control motions are shown in the section on maneuvers, and typical data are presented in Appendix A. These are essentially tables of rates of movement of controls (collective, cyclic, and or pedal) versus time. The output of the program shows the integrated effect of these rates.

4. C-81 ANALYSIS PLAN

A list of computer cases and a computer run plan were developed based on available test data. The plan generally called for running a series of trim cases first. Where related stability analysis and control response cases were to be run, the trim followed by stability analysis option or the trim followed by maneuver option was run using tho previously run converged trim results as initial estimates for the trim condition.

Table 5, which presents data for test conditions and test/analysis comparision, lists the cases in the original computer run plan. Cases are divided into three categories: trim, maneuvers, and stability. Trim includes performance and loads as well as cases run to obtain initial conditions for maneuvers. Stability cases include cases run to evaluate aeroelastic stability. Not all cases run are listed in the computer run plan. Test cases were run initially to check out the computer program and data decks.

Additional cases that were run but not included in this original run plan include speed sweeps for control positions, aircraft attitude, and power required versus airspeed. In some instances, such as trim cases for climbs, descents, and curvilinear flight, more cases than planned were run to achieve the final trimmed condition. This was necessary since only a small variation in g level, for example, could be made until a trim at the desired g level was achieved.

"Maneuver" cases M13, M14, M15 and M16 were run as trim cases for a vertical g maneuver. This was done in an attempt to obtain an approximate simulation of the flight test conditions which include pullups at 2.0g after a high rate of descent and pushovers at 0.0g after a high rate of climb. These were run as trim cases since a satisfactory quasi-static, time-variant trim could not be obtained to provide initial conditions to enter into transient maneuvers.

TABLE 7. LIST OF C-81 COMPUTER CASES

Case ID	Condition	Acft	Flt	Test Data V (kn)	Test Data H_D (ft)	Test Data GW (lb)	Test Data CG (in)*	Test/Analysis Parameters to be Compared; Comments
I. TRIM ONLY								
T1	Level Flight	V4	174	Hover	5000	4740	97.45	Control positions, aircraft attitude, blade, shaft and pitch link loads
T2		↓	174	60	5000	4740	97.45	
T3		↓	174	100	5000	4740	97.45	
T4		↓	222	80	5500	4300	97.01	
T5		↓	222	120	5600	4300	97.01	
T6		V4	222	123	5600	4300	97.01	
T7		11498	—	90	6200	4250	95.8	
T8		V4	170	60	5000	4740	97.45	
T9		V4	170	100	5000	4740	97.45	
T10		S-58	6	60	1636	4560	96.8	
T11		S-58	6	110	1636	4560	96.8	
T12		V4	372	100	3600	4750	97.1	
T13		V4	372	110	4100	4750	97.1	
T14	Climb	V4	190	40	5000	4100	97.01	Maximum rate of climb
T15		V4	190	54	5000	4100	97.01	
T16		V4	190	80	5000	4100	97.01	
T17	Descent	V4	190	40	5000	4100	97.01	Maximum rate of descent
T18		V4	190	60	5000	4100	97.01	
T19		V4	190	80	5000	4100	97.01	
T20	Curvilinear Flight	V4	170	100	5000	4740	97.45	Control position, blade and shaft loads versus g level
T21		V4	170	100	5000	4740	97.45	
T22		V4	170	100	5000	4740	97.45	
T23		V4	170	100	5000	4740	97.45	
T24		V4	170	100	5000	4740	97.45	
T25		V4	170	100	5000	4740	97.45	
T26	Level Flight	—	—	140	5,000	4750	103.8	Flight envelope: altitude versus airspeed
T27				140	10,000	4750	103.8	
T28				150	5,000	4750	103.8	
T29				150	10,000	4750	103.8	
T30				160	5,000	4750	103.8	

*Mid-cg at sta 100.4

TABLE 7 — Continued

Case ID	Ref Case	Condition	Acft	Flt	Test Data V (kn)	H_D (ft)	GW (lb)	CG (in)*	Test/Analysis Parameters to be Compared; Comments
TRIM ONLY Continued									
T31	—	Level Flight	V4	112	55	3000	4500	97.25	Trim for air resonance
T32	—		V4	112	110	3300	4500	97.25	analysis
T33	—	Level Flight	—	—	Hover	5000	4740/4300	97.45	For stability derivative
T34	—				100	5000	4740/4300	97.45	analysis
II. MANEUVERS									
M1	T1	Pull up	V4	174	Hover	5000	4740	97.45	Control positions, attitudes,
M2	T3	Pull up		174	100	5000	4740	97.45	rates and loads
M3	T1	Push over		174	Hover	5000	4740	97.45	
M4	T3	Push over		174	100	5000	4740	97.45	
M5	T1	Lateral Right		174	Hover	5000	4740	97.45	
M6	T3	Lateral Right		174	100	5000	4740	97.45	
M7	T1	Lateral Left		174	Hover	5000	4740	97.45	
M8	T3	Lateral Left		174	100	5000	4740	97.45	
M9	T1	Tail Rotor Right		174	Hover	5000	4740	97.45	
M10	T3	Tail Rotor Right		174	100	5000	4740	97.45	
M11	T1	Tail Rotor Left		174	Hover	5000	4740	97.45	
M12	T3	Tail Rotor Left		174	100	5000	4740	97.45	
M13	T12	Pull up		372	100	3600	4750	97.10	
M14	T12	Push over		372	100	4100	4750	97.10	
M15	T13	Pull up		372	110	3600	4750	97.10	
M16	T13	Push over		372	110	4100	4750	97.10	
M17	T4	Pitch Damp		222	80	5600	4300	97.01	
M18	T5	Pitch Damp		222	100	5600	4300	97.01	
M19	T6	Pitch Damp		222	123	5600	4300	97.01	

*Mid-cg at sta 100.4

TABLE 7 – Continued

Case ID	Ref Case	Condition	Acft	Flt	Test Data V (kn)	Test Data H_D (ft)	Test Data GW (lb)	Test Data CG (in)*	Test/Analysis Parameters to be Compared; Comments
III. STABILITY									
S1	T31	Air Resonance	V4	112	55	3000	4500	97.25	Compare blade moment decay
S2	T32		V4	112	110	3300	4500	97.25	after lateral and longitudinal
S3	T31		V4	112	55	3000	4500	97.25	cyclic excitation at 2.5 Hz
S4	T32		V4	112	110	3300	4500	97.25	
S5	T2	Pitch	V4	174	60	5000	4750	97.45	Compare time to double
S6	T3	Stability	V4	174	100	5000	4750	97.45	amplitude and period versus airspeed
S7	T1	Stability	—	—	Hover	5000	4740	97.45	Compare C-81 and Boeing
S8	T33	Derivative			Hover	5000	4300	97.45	Vertol Program Y-92 stability
S9	T3				100	5000	4740	97.45	derivative
S10	T34				100	5000	4300	97.45	

*Mid-cg at sta 100.4

5. COMPARISON OF C-81 RESULTS WITH TEST DATA

This section presents a comparison of test and C-81 analysis results for trimmed flight conditions, response to control inputs, aeroelastic stability, and stability derivatives and control power.

5.1 TRIMMED FLIGHT CONDITIONS

5.1.1 Level Flight

5.1.1.1 Trim Versus Airspeed--Figure 16 shows test and analysis results for main rotor lateral and longitudinal cyclic and collective, tail rotor collective, and aircraft pitch attitude versus airspeed. Results are shown for speeds from hover to 120 knots. The main rotor was represented by the first four modes of the 23012 cambered airfoil blade. Test results are from Reference 4. Main rotor control settings calculated by C-81 are in good agreement with test results. Greater disagreement is seen between test and analysis data for pitch attitude and tail rotor collective setting. The simplified representation of the tail rotor using a rigid blade and aerodynamic equations instead of more detailed 0012 airfoil tables probably accounts for the difference in tail rotor collective setting. Cyclic values are swashplate angles; main rotor collective is shown at .7R (root collective minus 5.6 degree twist).

5.1.1.2 Level Flight Blade Loads--Level flight main rotor blade loads data were available from flight tests conducted at Boeing Vertol on aircraft S50. Data for Flight 6 were harmonically analyzed for flap bending gages located at 10, 14, 34, 50, 67, and 88 percent radius and one chord bending gage located at 50 percent radius. Speeds of 61 and 118 knots were selected for simulation with C-81.

Figure 17 shows a comparison of alternating flap bending moment versus blade radius at 61 and 118 knots. Test and analysis results are generally in agreement in trend versus radius, but C-81 results are higher than indicated by test near the root.

Figures 18 and 19 show a comparison of C-81 and test waveforms (moment versus blade azimuth position). These waveforms were reconstituted from the first eight harmonics of C-81 analysis and test results. Zero azimuth corresponds to a blade in the aft position. C-81 results indicate significant 2/rev flap bending moments at 10 percent blade radius not indicated by test data; the C-81 result is higher than the test data. At 50 percent blade radius, waveforms are in reasonable agreement; the predominant moment is at 1/rev.

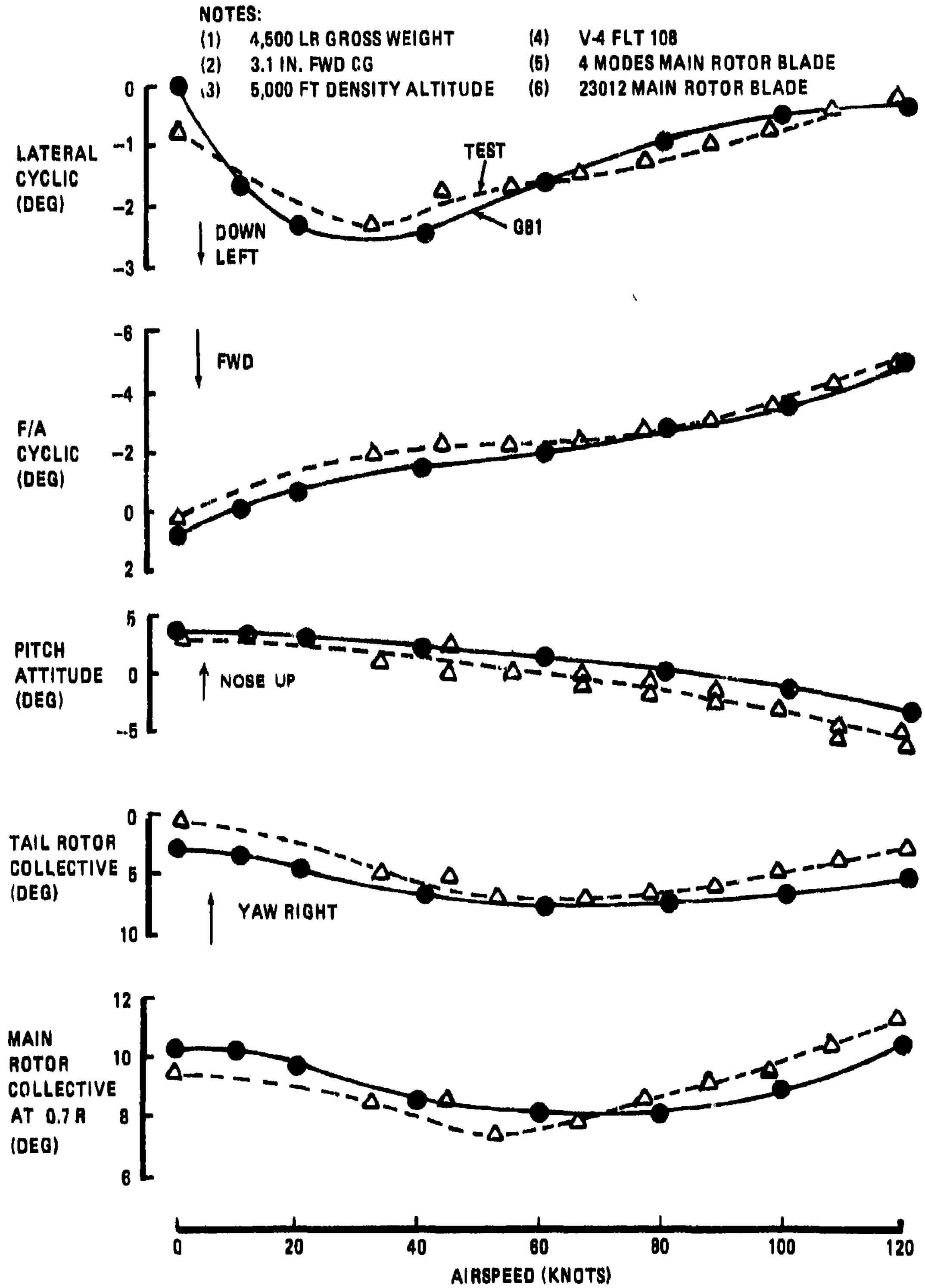

Figure 16. Trim vs Airspeed.

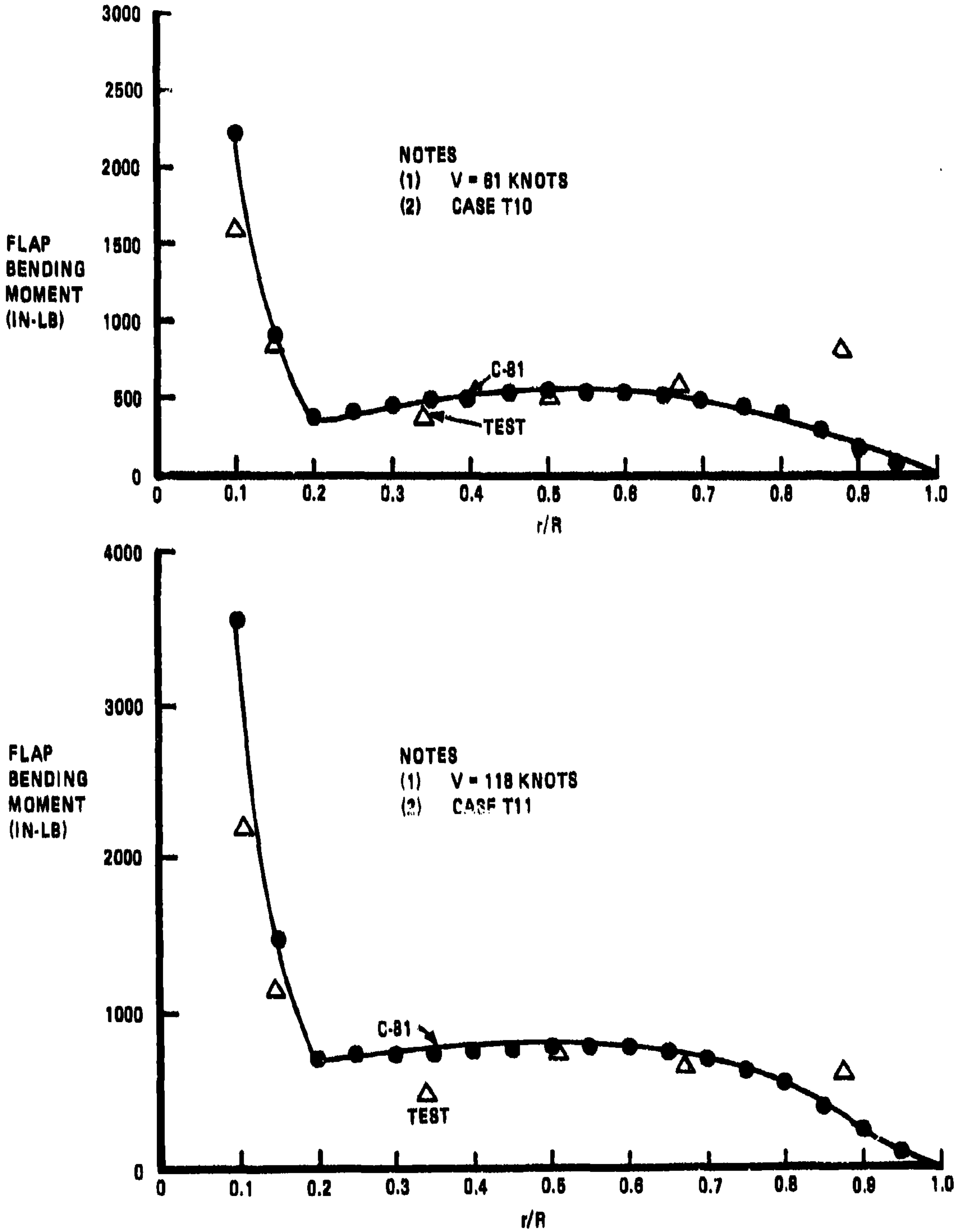

Figure 17. Alternating Flap Bending Moment vs Blade Radius at 61 and 118 Knots.

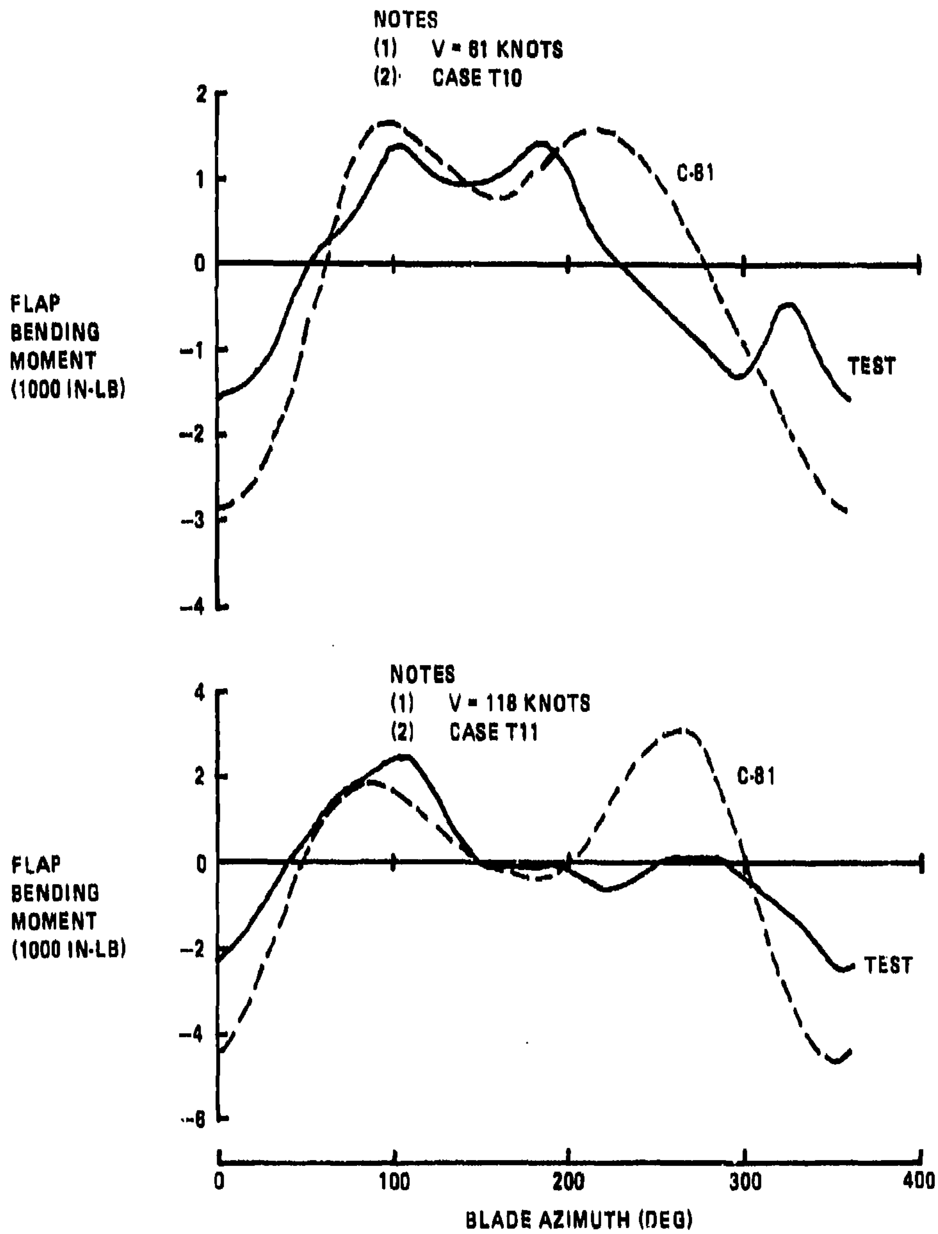

Figure 18. Flap Bending Moment at 10 Percent Blade Radius vs Blade Azimuth Position at 61 and 118 Knots.

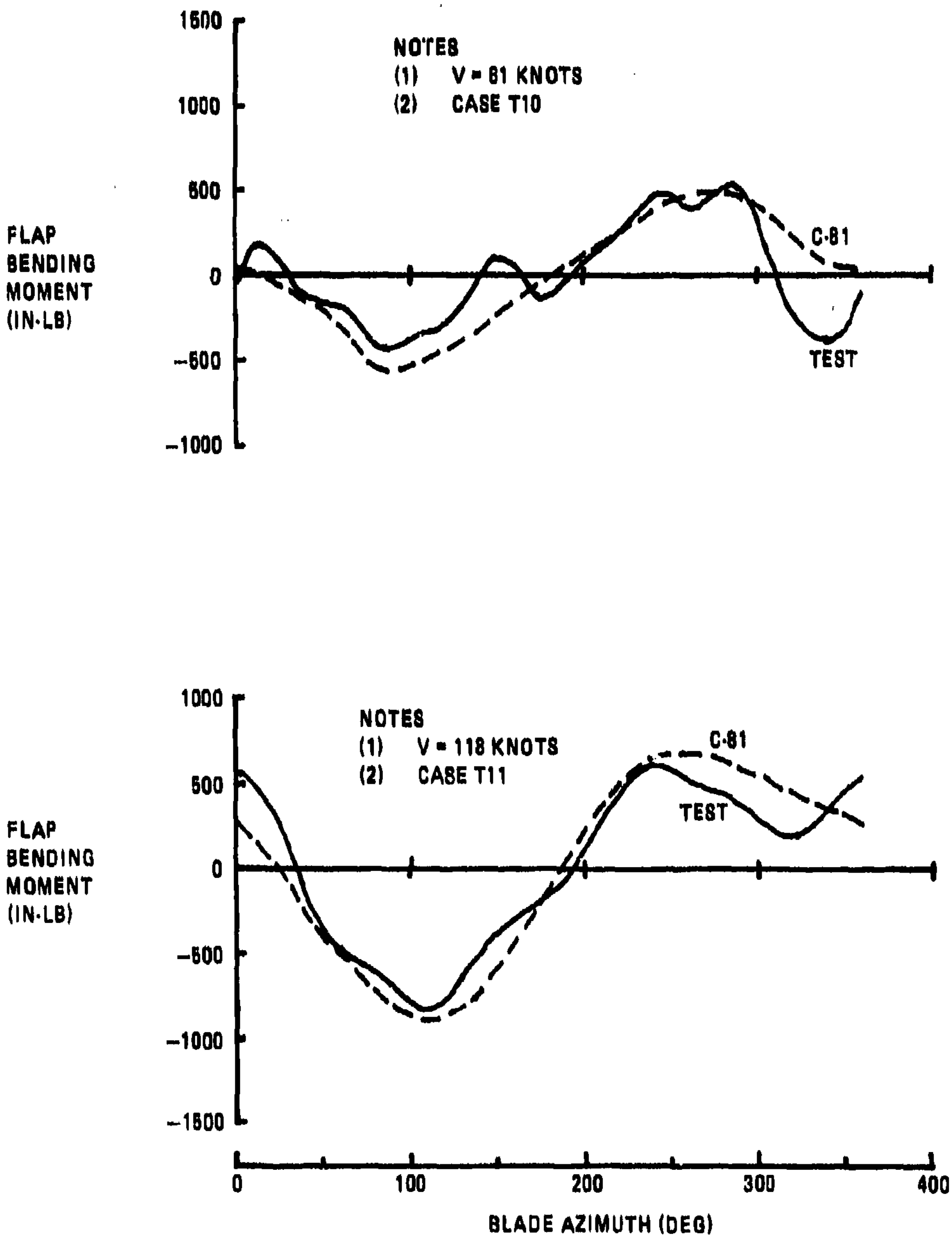

Figure 19. Flap Bending Moment at 50 Percent Blade Radius vs Blade Azimuth Position at 61 and 118 Knots.

Figure 20 shows 1/rev and 2/rev flap bending moments versus blade radius at 61 knots. One/rev moments are in reasonable agreement, while C-81 predicted 2/rev moments are high compared to test data. Figure 21 shows corresponding data at 118 knots. One/rev moments are in reasonable agreement, 2/rev results are in better agreement, but C-81 results are higher than test results at the root.

Figure 22 shows a comparison of test and analysis results for third harmonic flap bending moments versus blade radius at 61 and 118 knots. Moments are in reasonable agreement near the root but are not in good agreement along the outboard half of the blade. This is probably due to the simplified downwash representation in C-81.

Figure 23 shows a comparison of fifth harmonic flap bending moment data at 61 and 118 knots. The C-81 prediction is well below the test data. This is again probably due to the simplified downwash representation used in the 300K version of C-81.

Figure 24 shows C-81 alternating chord bending moment data versus radius at 61 and 118 knots. One test data point is also shown near 10 percent blade radius. The C-81 test results appear to be much higher than test data. Similar results are indicated by the 1/rev chord bending moment results in Figure 25.

Figure 26 shows a comparison of test and analysis alternating pitch link loads vs airspeed. Pitch link loads show a large overprediction at low speed (3 to 1) and large underpredictions at high speed (1 to 2). In addition, the predicted waveform is predominately 3/rev, while the test data is almost totally 1/rev. It is clear that the predicted control system loads could not be used for design. The C-81 analysis was run with unsteady aerodynamic options off.

The version of C-81 used in this study has the following limitations which may affect loads predictions: 1) 20 blade mass stations are used at fixed increments of five percent blade radius; for good loads predictions, a finer breakdown of stations is generally required near the blade root and near the blade tip; 2) the program had a limitation on number of blade modes of six blade modes per rotor blade; for higher harmonic blade loads predictions, more than three flap bending modes are required in addition to the blade lower torsion and lag bending modes; capability to use five blade flap bending, two blade torsion, and two lag bending modes should be provided for a four-bladed rotor; more modes may be required for rotors with a higher number of blades; 3) the program does not account for shear center and mass center variation with radius in computing torsional moments along the blade; this may affect pitch link load computation; 4) the torsional moment summation along the blade radius is affected by the rotor blade center of gravity/aerodynamic center relationship; rotor blade aerodynamic coefficient tables used in C-81 and other rotor analysis programs are usually established by tests which assume that the aerodynamic center is at the quarter chord; in C-81, the aerodynamic force and pitching moment are computed at the mass center using aerodynamic lift and moment coefficients defined at the quarter chord; no information is input into C-81 defining the chordwise location of the mass center so that the aerodynamic pitching moment coefficient could be computed about the mass center; predictions of trim, stability, and loads are expected to be very sensitive to differences in aerodynamic center and mass center of the order of 1 percent of the blade chord; this may not be a significant problem for the C-81 analysis of the BO-105 23012 cambered-airfoil blade since the blade center of mass is only about 0.1 percent (0.011 inches) aft of the quarter chord (i.e., outboard of the blade cutout); and 5) the simplified downwash representation used in the 300,000-byte version of C-81 is not adequate for computing vibratory loads above the third harmonic; use of the simplified representation of the downwash may be the explanation for poorer agreement of test and analysis vibratory moment results in the outboard portion of the blade.

5.1.1.3 Power Required--Results obtained from C-81 for power required versus airspeed are shown in Figure 27. The condition is for a gross weight of 4409 pounds with a mid cg at sea level standard. Test data were not readily available for comparison with C-81 results. Power required data were reported in Reference 11 for this condition and are shown for comparison. C-81 generally predicts the same power required as the data in Reference 11 in hover, at transition and at high speed, but C-81 results are lower than those given in Reference 11 at speeds between hover and transition and between transition and high speed. The lower C-81 results may be due to options which were not activated such as radial flow, unsteady aerodynamics, etc.

5.1.2 Banked Turns

Figure 28 shows a comparison of analysis and test results for main rotor cyclic control settings, main rotor root bending moments, and resultant shaft bending moments. Test data are from References 5 and 6 for 1.45 to 2.1g banked turns. Analysis results are from cases T20 to T25 for 1.4 to 1.8g banked

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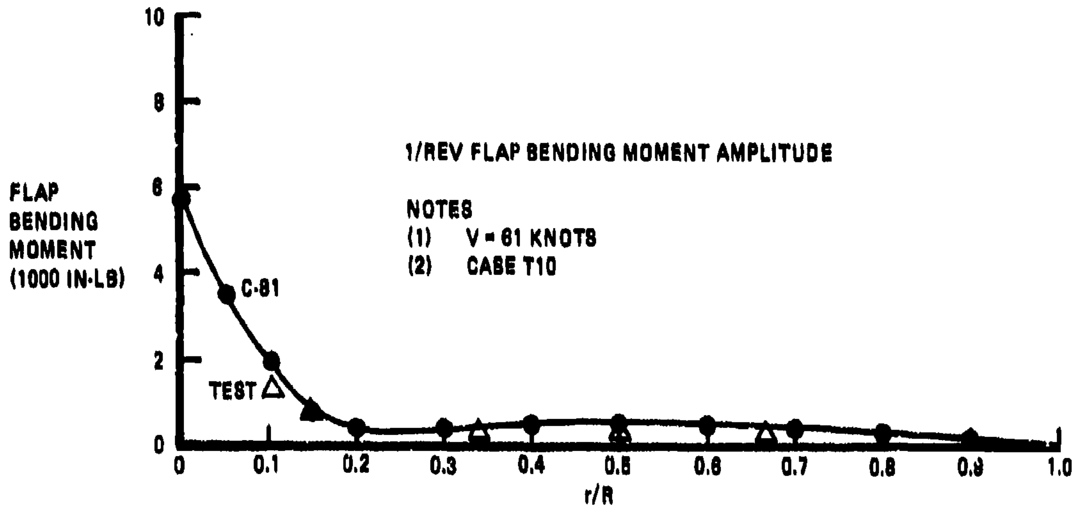
11. Weiland, E. F., DEVELOPMENT AND TEST OF THE BO-105 RIGID ROTOR HELICOPTER, Paper No. 200 presented at 24th Annual National Forum Proceedings, Washington, D.C., May 1968.



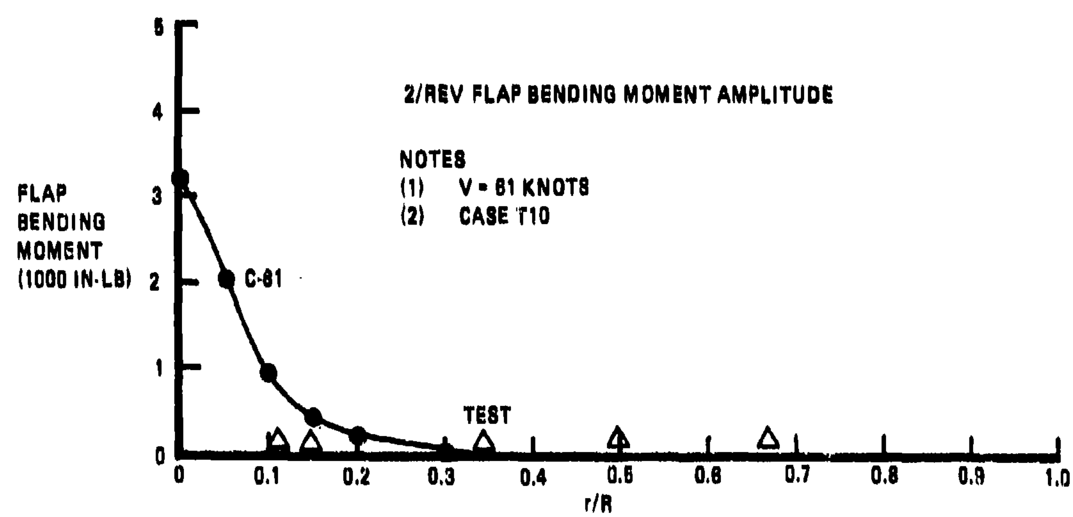


Figure 20. 1/Rev and 2/Rev Flap Bending Moment Amplitudes vs Radius at 61 Knots.

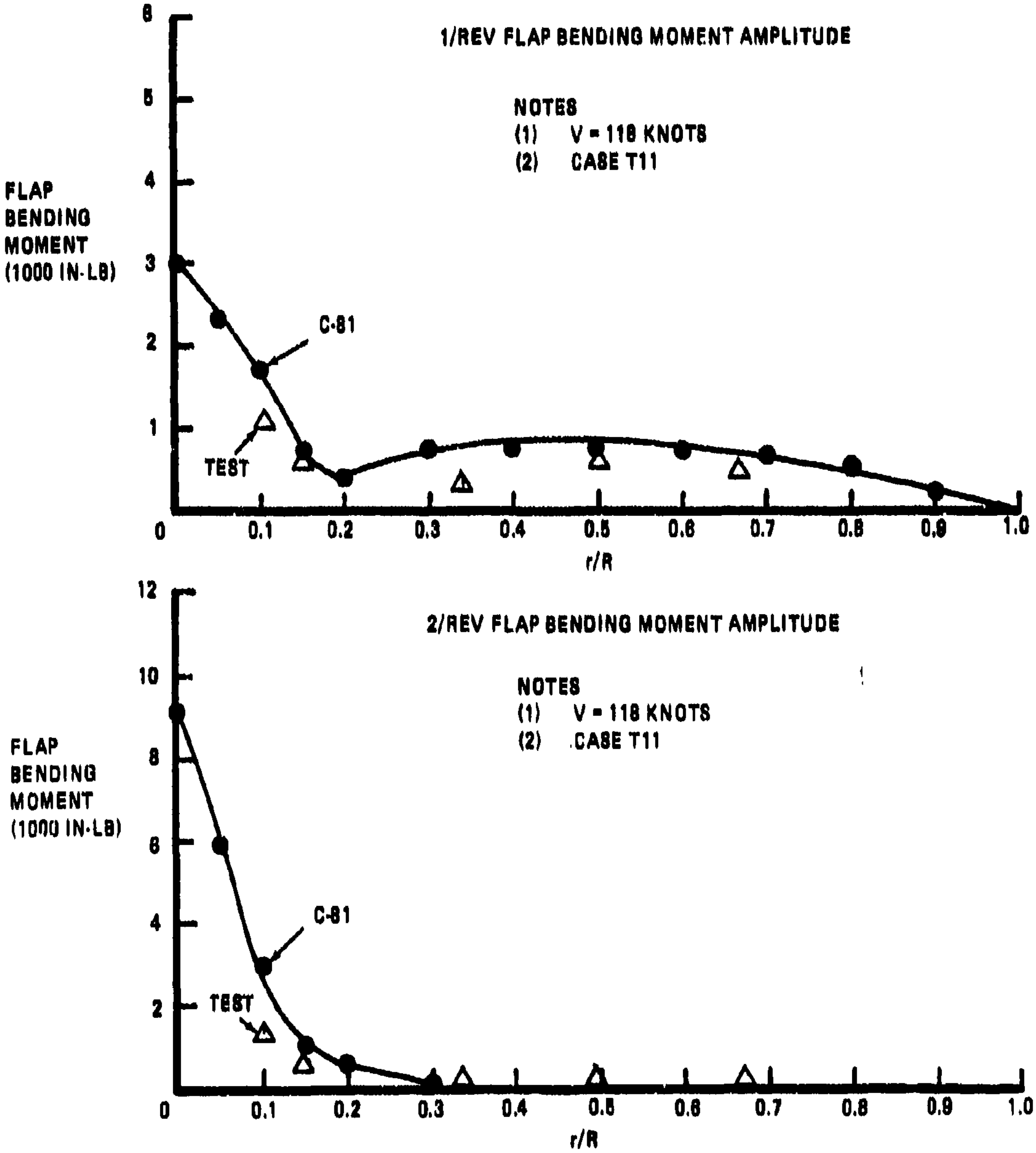


Figure 21. 1/Rev and 2/Rev Flap Bending Moment Amplitudes vs Blade Radius at 118 Knots.

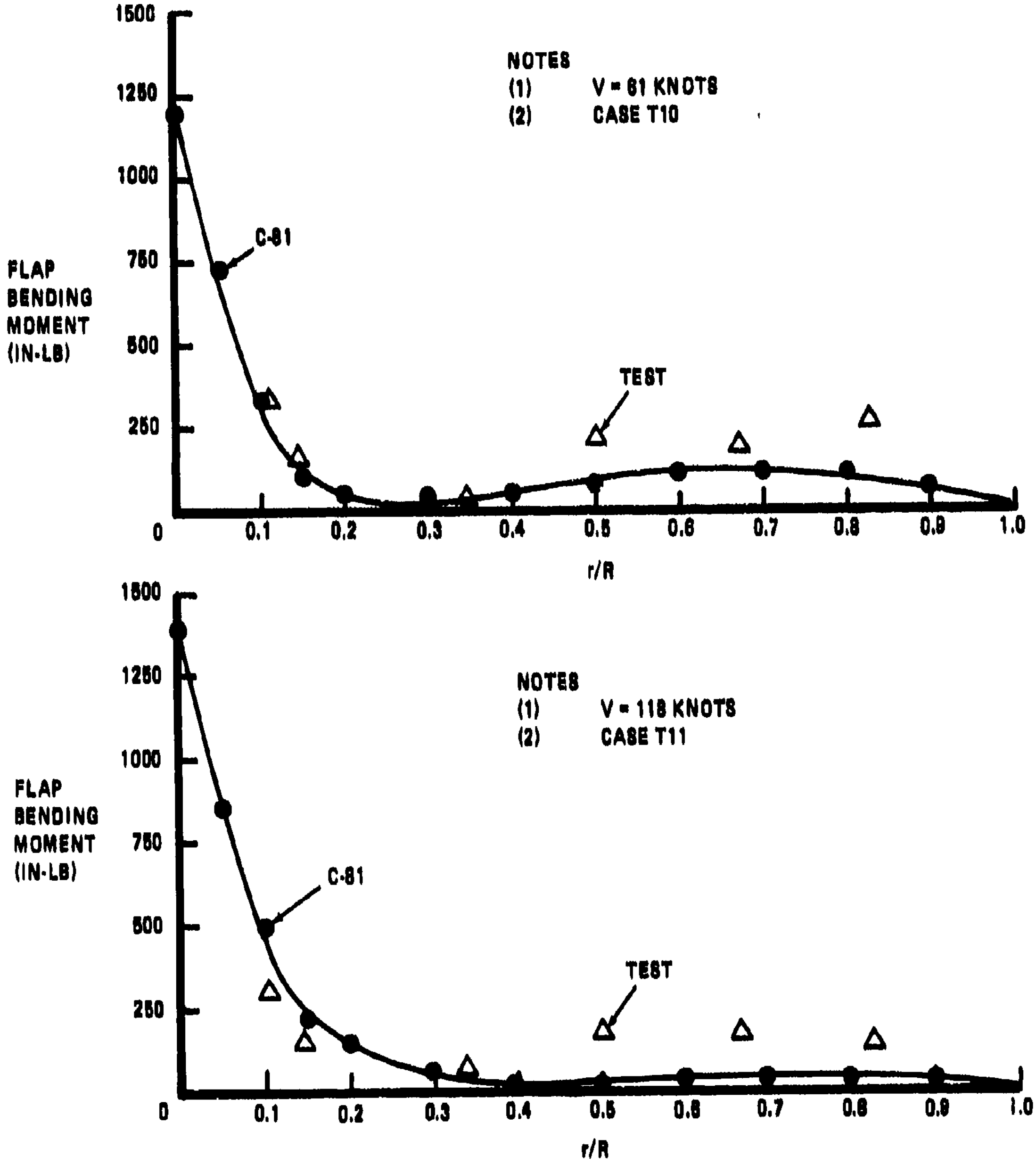


Figure 22. Third Harmonic Flap Bending Moment Amplitude vs Radius at 61 and 118 Knots.

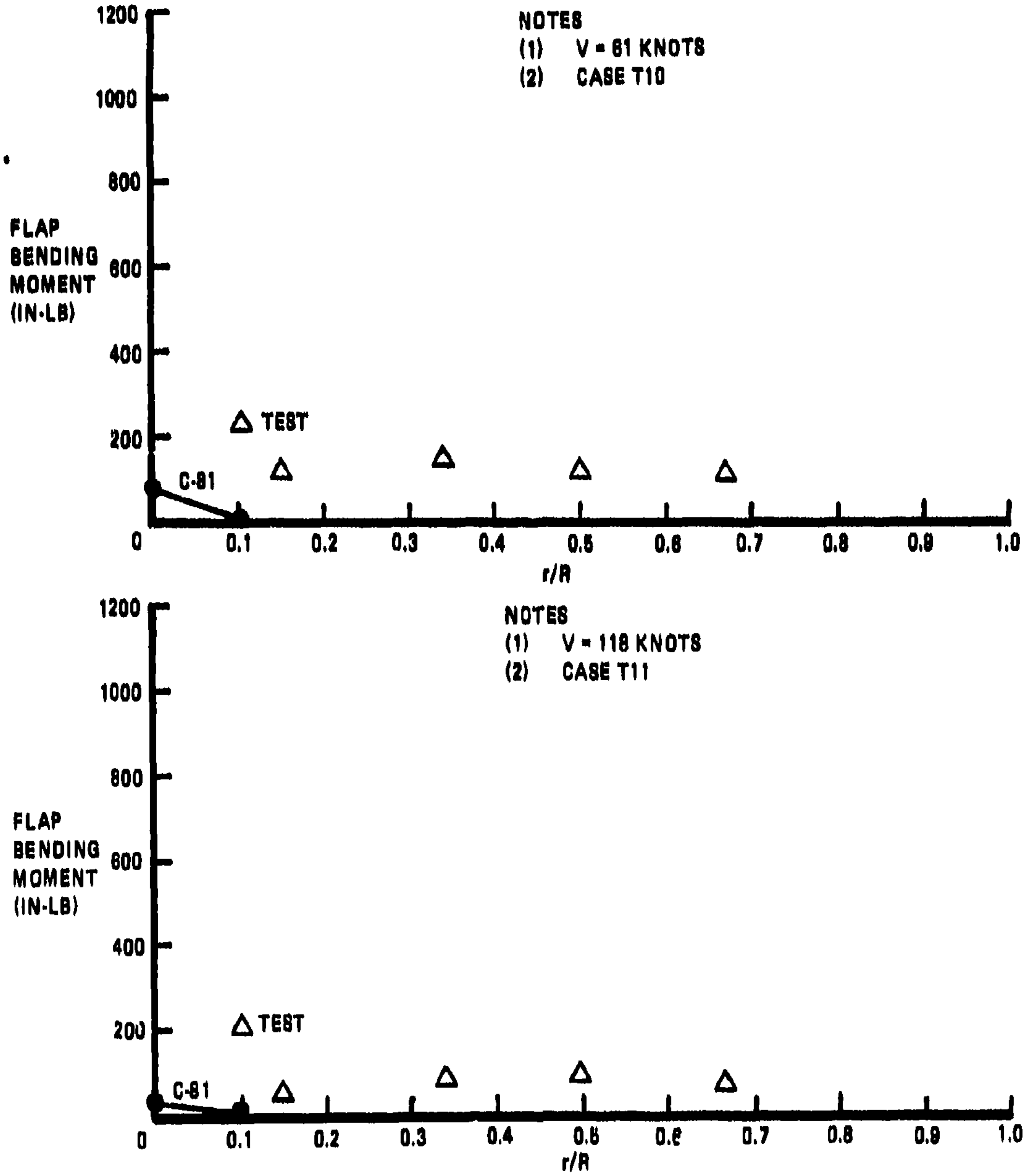


Figure 23. Fifth Harmonic Flap Bending Moment Amplitude vs Radius at 61 and 118 Knots.

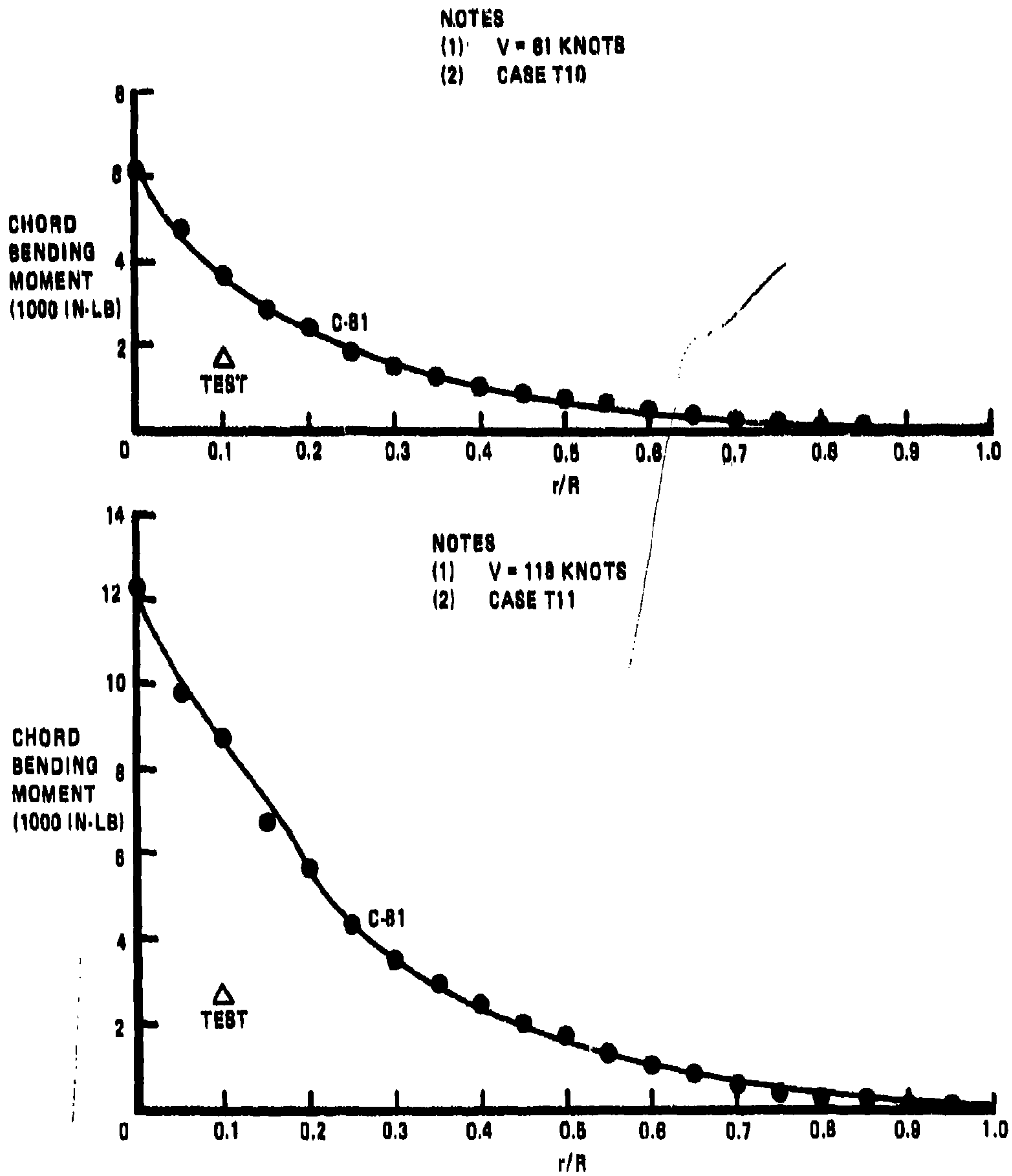


Figure 24. Alternating Chord Bending Moment vs Blade Radius at 61 and 118 Knots.

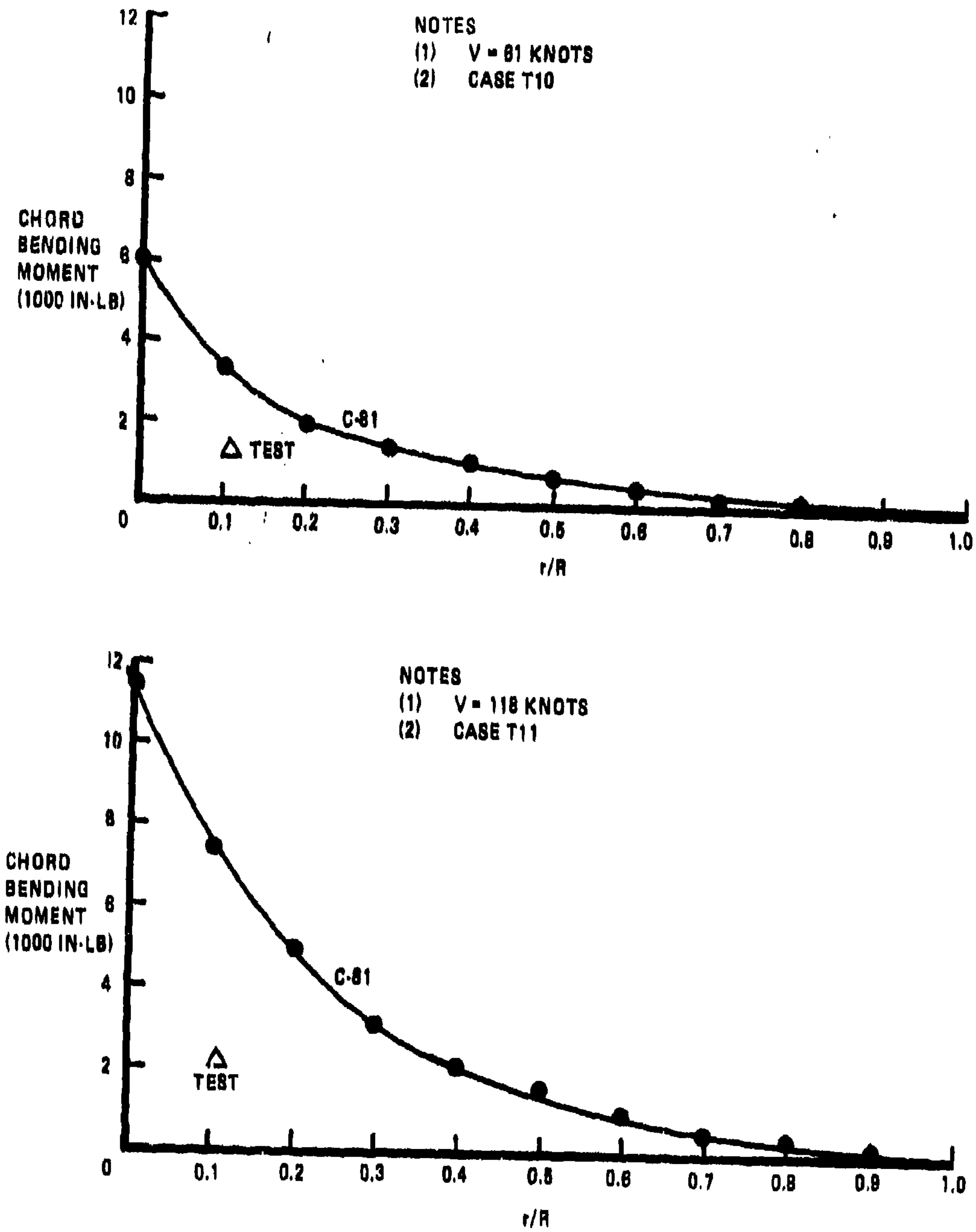


Figure 25. 1/Rev Chord Bending Moment Amplitude vs Radius at 61 and 118 Knots.

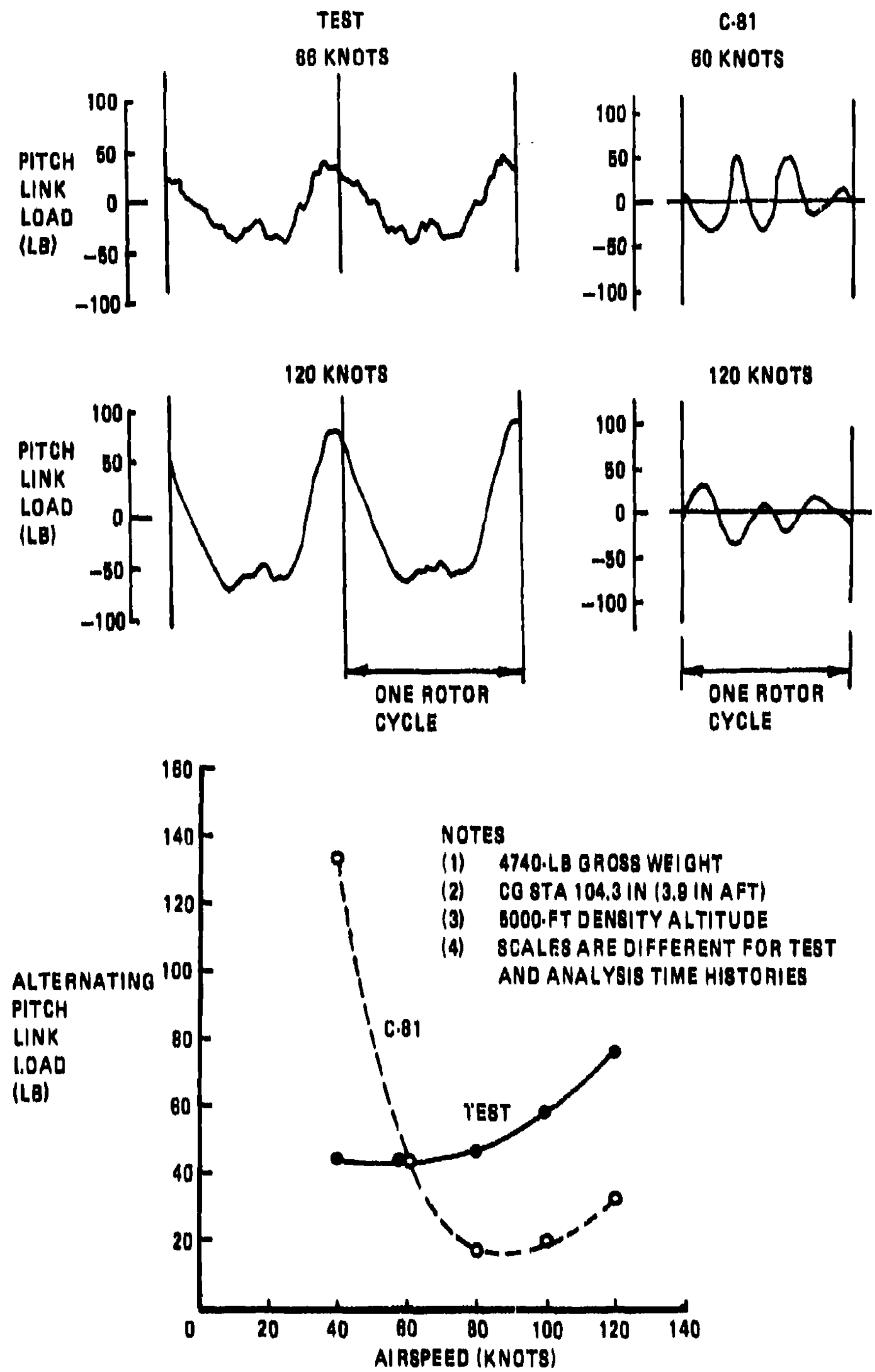


Figure 26. Alternating Pitch Link Load vs Airspeed.

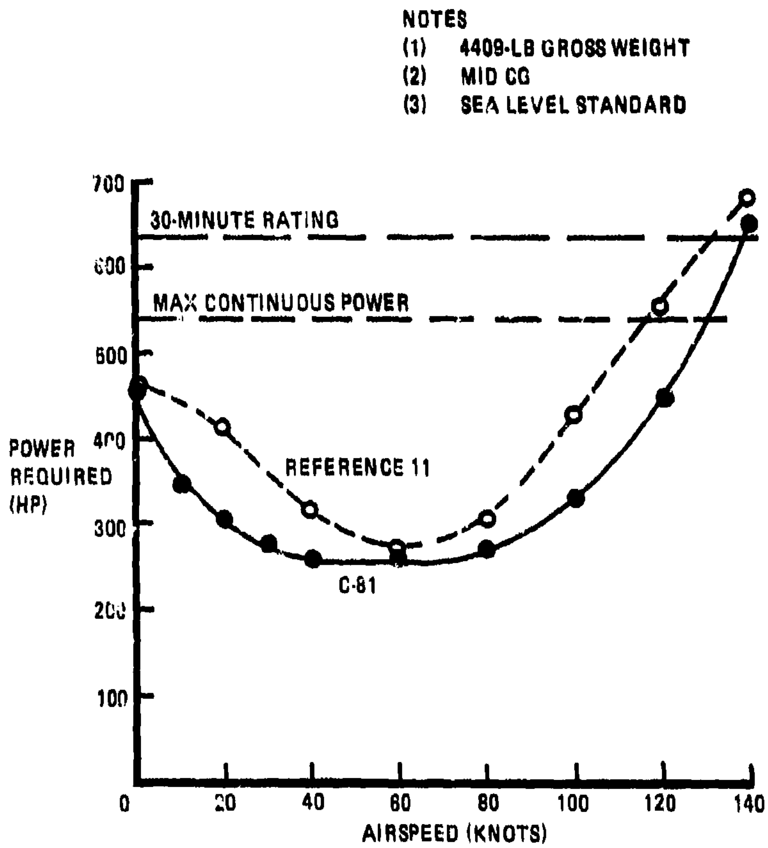


Figure 27. Power Required vs Airspeed at Sea Level Standard.

turns. C-81 banked turn cases were run using the multiple case option for trim. With this option, several cases for trim can be run in a single computer run. One or more of the flight constants can be changed for each successive case, and the trim results for the previous case can be used as the guess for the new trimmed condition. Banked turn cases were run at 1.1, 1.2, 1.3, 1.4, 1.5, 1.6 and 1.8g in this manner. An attempt to trim at 1.9g was not successful. Apparently the increment in g level from 1.8 to 1.9g was too large. The computer time required to run the cases for 1.1 to 1.8g and the attempt at 1.9g was approximately 20 cpu minutes on an IBM 370-158 computer. Because of cost of computer time, additional runs at banked turn g levels above 1.8g could not be made.

Test and analysis results are in good agreement for longitudinal cyclic control. Analysis results are not in good agreement with test data for lateral cyclic. Test and analysis results are in good agreement for alternating flap bending moment at 10 percent blade radius. The predicted chord bending moment at 15 percent blade radius is much higher than the test moment at 14 percent blade radius. Analysis results for shaft bending moments are lower than indicated by test results. The analysis shaft bending moment result was computed from the harmonic content of the blade root flap bending moment in the C-81 trim output. The test result may include a portion of moment due to in-plane hub loads. Reference 6 does not discuss the test instrumentation.

5.1.3 Climbs and Descents

Figure 29 shows power required computed using C-81 at 40, 54, and 60 knots versus rate of climb and rate of descent. The horsepower available from the two Allison C-18 engines for this flight condition is assumed to be 90 percent of continuous rated power or 405 hp. Figure 29 indicates that minimum power required is at 54 knots, which agrees with test results of Reference 12. C-81 results in Figure 30 indicate a maximum rate of climb of 900 fpm. The test results reported in Reference 12 indicate considerable scatter in test data with a maximum rate of climb at 54 knots of from 700 to 925 fpm.

5.1.4 Flight Envelope

The upper portion of Figure 31 shows C-81 results for power required near maximum speed as a function of density altitude. Analysis points were run at 140, 150, and 160 knots at 5000,

12. Dasko, D., BO-105 V4/S4 PERFORMANCE FLIGHTS, Messerschmitt-Boelkow-Blohm GmbH Report D122-13/70, 1970. (Translated by Boeing Vertol Company)

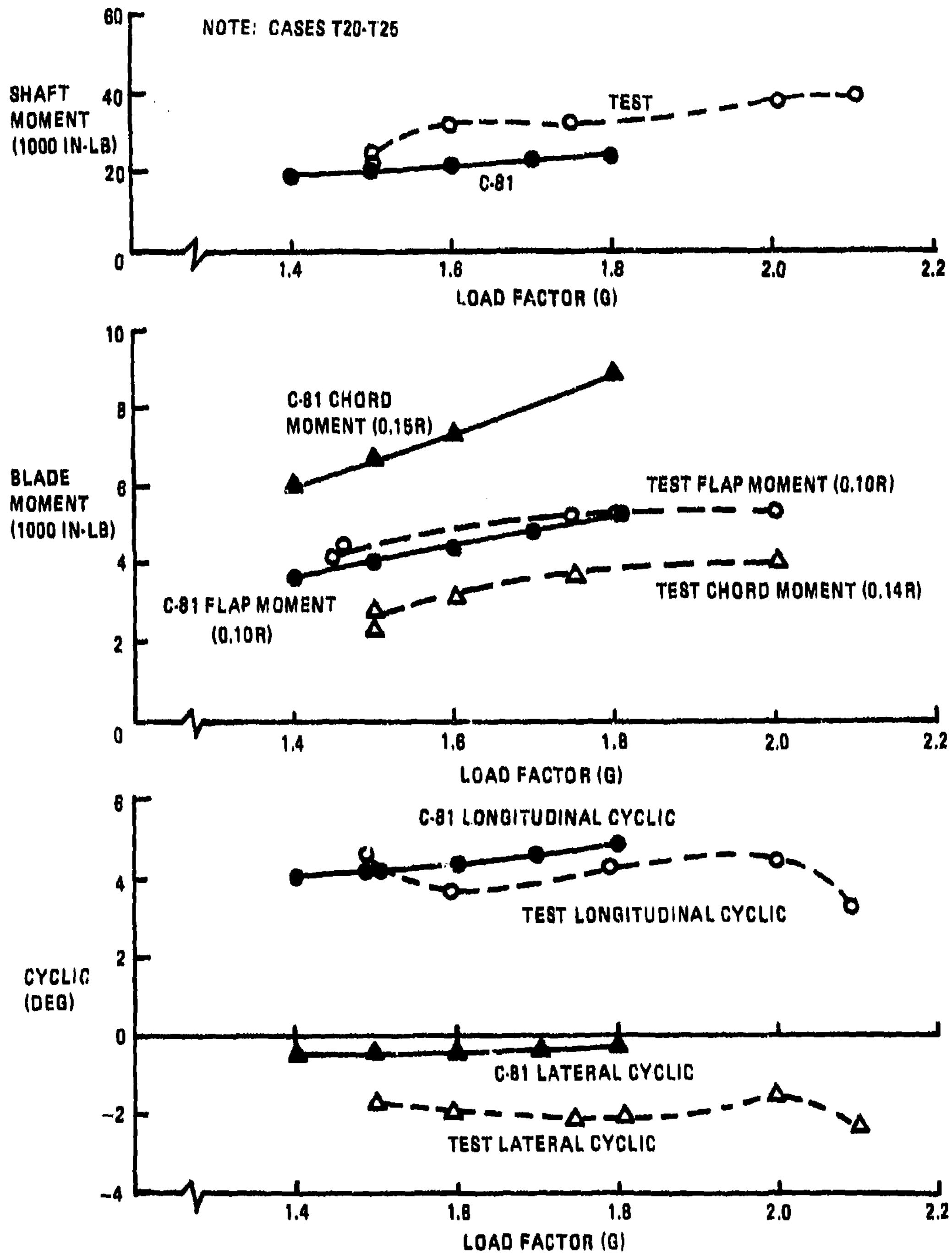


Figure 28. Main Rotor Shaft Moment, Blade Moment, and Cyclic vs Banked Turn Load Factor.

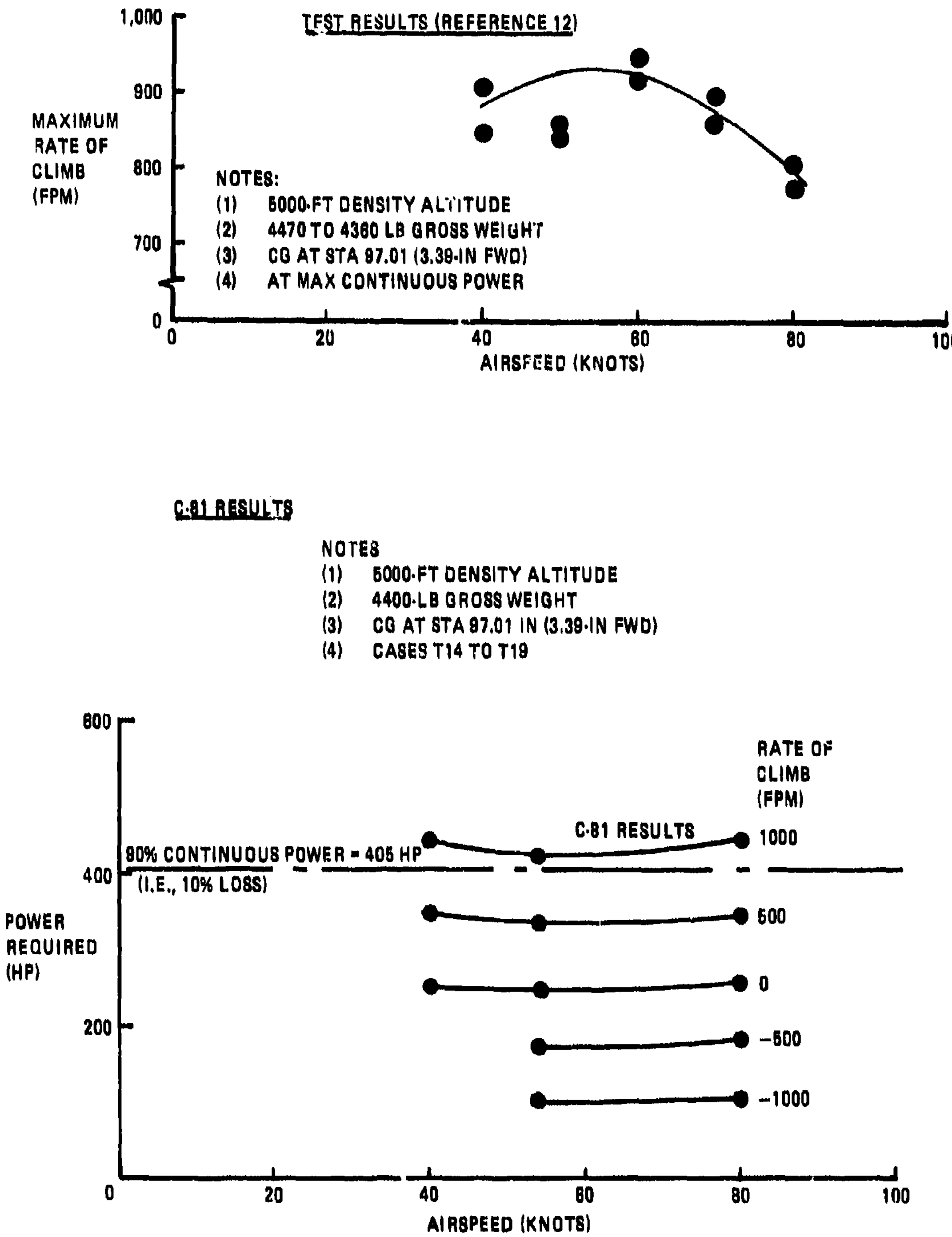


Figure 29. Speed for Maximum Rate of Climb.

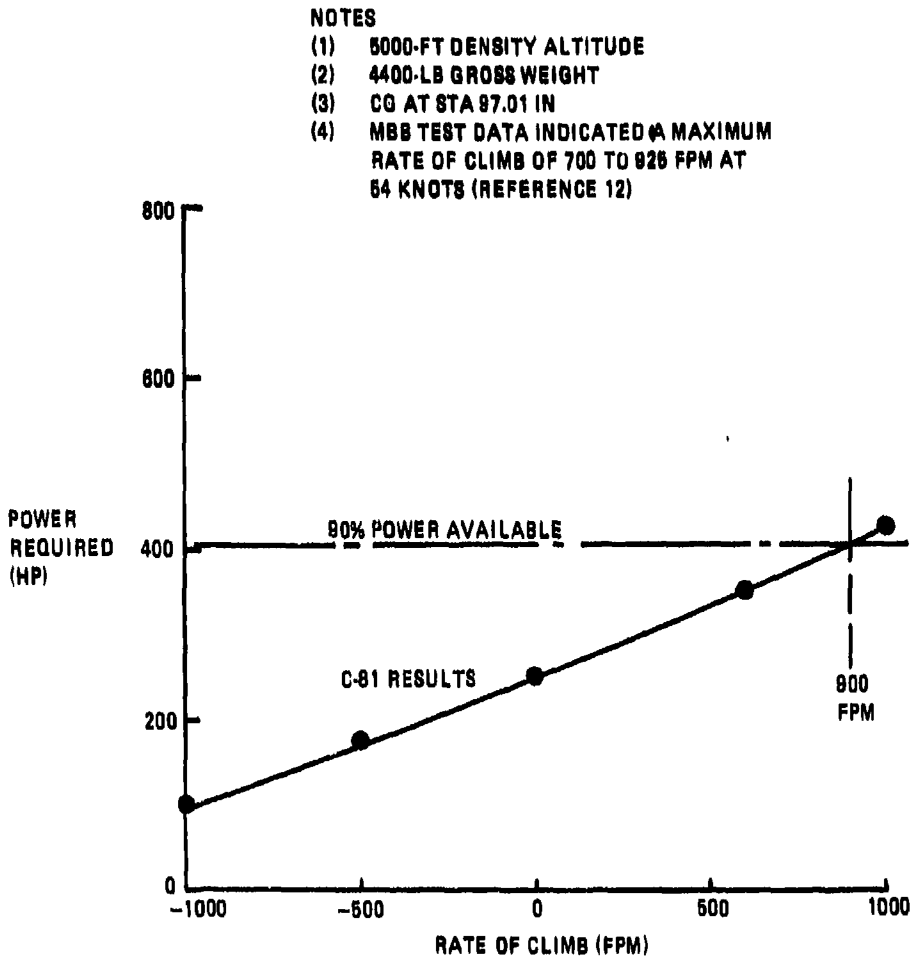


Figure 30. Maximum Rate of Climb at 54 Knots.

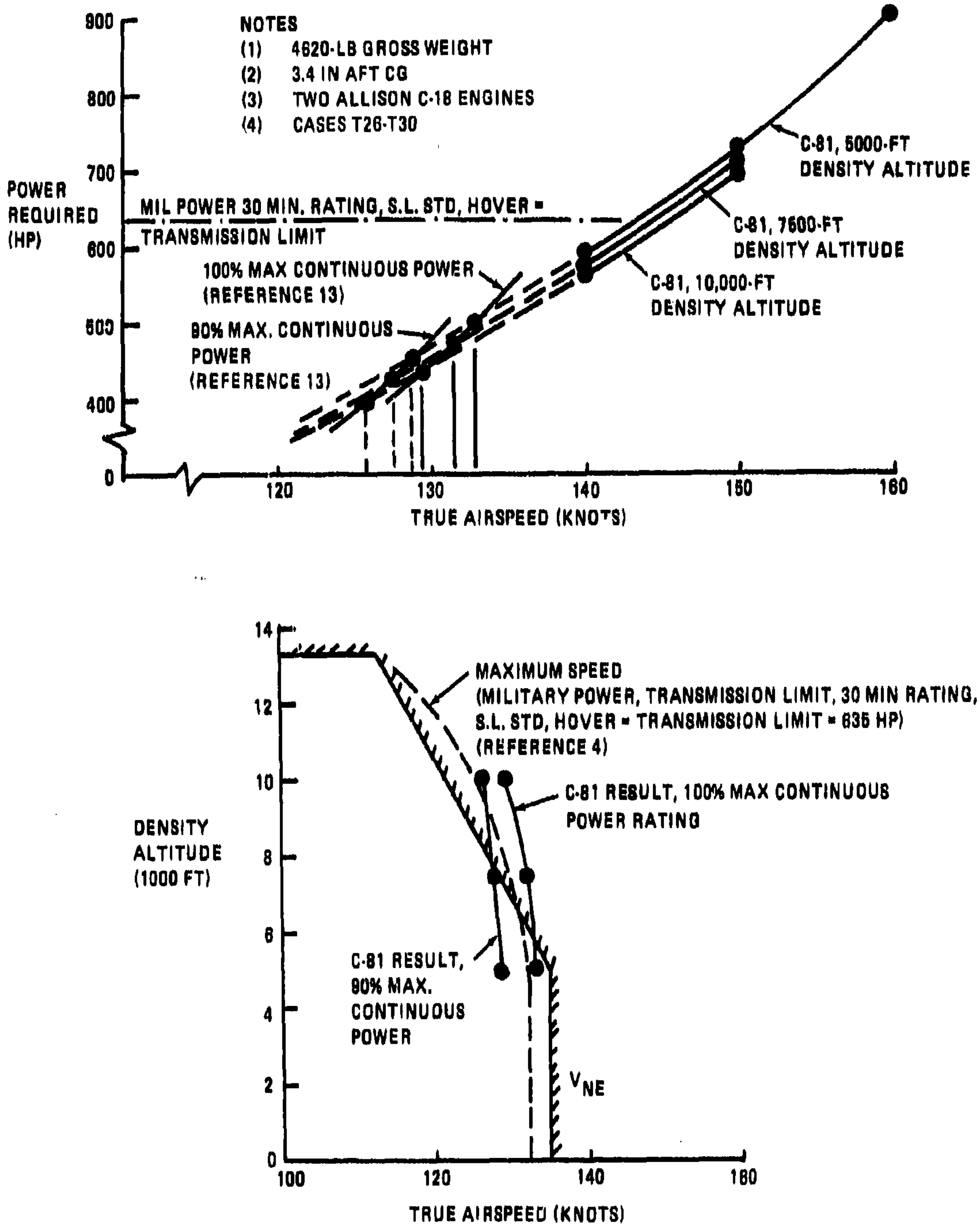


Figure 31. Flight Envelope Near Maximum Speed.

7500, and 10,000 feet density altitude. These results were extrapolated to speeds near 130 knots. Curves for 90 and 100 percent power available at these flight conditions (from data in Reference 13) were cross-plotted against these curves. This cross-plot yielded a curve for maximum airspeed versus density altitude. These results are plotted in the lower portion of Figure 31 against curves for V_{NE} and maximum speed (based on military power and transmission limits) taken from Reference 4. C-81 results indicate less power required than results previously published for the BO-105 aircraft: Reference 4 indicates a speed limit of about 132 knots at 634 horsepower while C-81 results indicate that this speed can be achieved with about 470 horsepower. These results are consistent with the low prediction by C-81 for power required at 120 to 140 knots indicated in Figure 27.

5.2 CONTROL RESPONSE

Data were reported in Reference 5 for response to longitudinal, lateral, and tail-rotor control inputs in hover and at 100 knots. Test results were also reported for pitch dumps near 100 knots. These results included aircraft attitudes and rates, main rotor shaft bending moment, and vertical acceleration versus time.

The C-81 simulation for these cases was made by first running a quasi-static, time-variant trim followed by a time-variant maneuver. The integration interval was $\Delta\psi = 30$ degrees, and maneuvers were generally run for about 2.0 seconds real time. Main rotor blades were represented by four "0012 blade modes" (first and second flap, first lag, and first torsion modes) with the highest natural frequency at 3.87/rev for the torsion mode. This gave only 3.1 integration intervals per period for the 3.87/rev mode, which is less than the 10 integration intervals per shortest mode period recommended for numerical integration. However, computer run time and corresponding computer cost were overriding considerations, and the integration interval could not practically be reduced.

Cost for a 2-second maneuver was running near $200 per case for a $\Delta\psi$ of 30 degrees at 425 rpm. For 10 integration intervals per highest frequency mode period, the cost of one computer run would have increased to about $650. Results obtained with this integration interval (30 degrees) were generally not satisfactory. However, one case was repeated with a 15-degree integration interval (6.1 integration intervals per highest mode period) without any significant effect on analytical results.

13. MODEL SPECIFICATION No. C731-E, COMMERCIAL TURBO SHAFT ENGINE MODEL 250-C18, Detroit Diesel Allison Division of General Motors Corporation, Sept. 1970.

Thus, any disagreements between test and analysis results cannot be entirely attributed to the large integration interval.

In one series of cases (2.0g pullups and 0.0g pushovers after high rates of climb and high rates of descent), a satisfactory quasi-static, time-varient trim could not be achieved for defining initial conditions for the maneuver. These were then run as trimmed cases, since the 2.0 or 0.0g conditions were held for about 2.0 seconds.

The trim could not be defined at the beginning of the maneuver since test data were not recorded for the start of the maneuver. The time histories for the test data which were available generally included significant rates of change of airspeed, high rates of climb or descent, and high pitch rates. These conditions prevented running quasi-static, time-variant trims followed by the pullup or pushover maneuvers with C-81. Cases were run as quasi-static, time-varient trim cases near 2.0 or 0.0g vertical acceleration conditions; results are compared to test data in general for the maneuvers in Figures 37, 38 and 39 and in detail at times where the aircraft was at a steady g condition with a nearly zero rate of climb in Figures 41, 42, and 43.

5.2.1 Pullups and Pushovers

Figures 32 through 35 show analysis and test results for pullups and pushovers in hover and at 100 knots. Main rotor and tail rotor collectives were held constant during these maneuvers. Control variation was input as a table of rate of change of control versus time. The primary input was longitudinal cyclic with a slight variation in lateral cyclic input in most cases. The C-81 steady values for control (values at time equal to zero for the maneuver) are whatever resulted from the C-81 trim solution.

Figure 32 shows the resulting longitudinal and lateral cyclic output from C-81 for a pullup in hover. The variations with time agree with the test data for longitudinal and lateral cyclic, indicating that the rate of change of control position versus time was input correctly into C-81. A steady error of about one degree in lateral cyclic is indicated, but this is a discrepancy for control position in trim and should not affect the maneuver solution.

Resulting pitch attitude, roll attitude, pitch rate, roll rate, and yaw rate as computed by C-81 are compared with test results reported in Reference 5. Pitch attitude computed by C-81 has the correct trend, but the computed magnitude is higher than that indicated by test data. The test data indicates no roll, while the analysis results indicate significant roll motion. Calculated values of pitch rate are in reasonable agreement

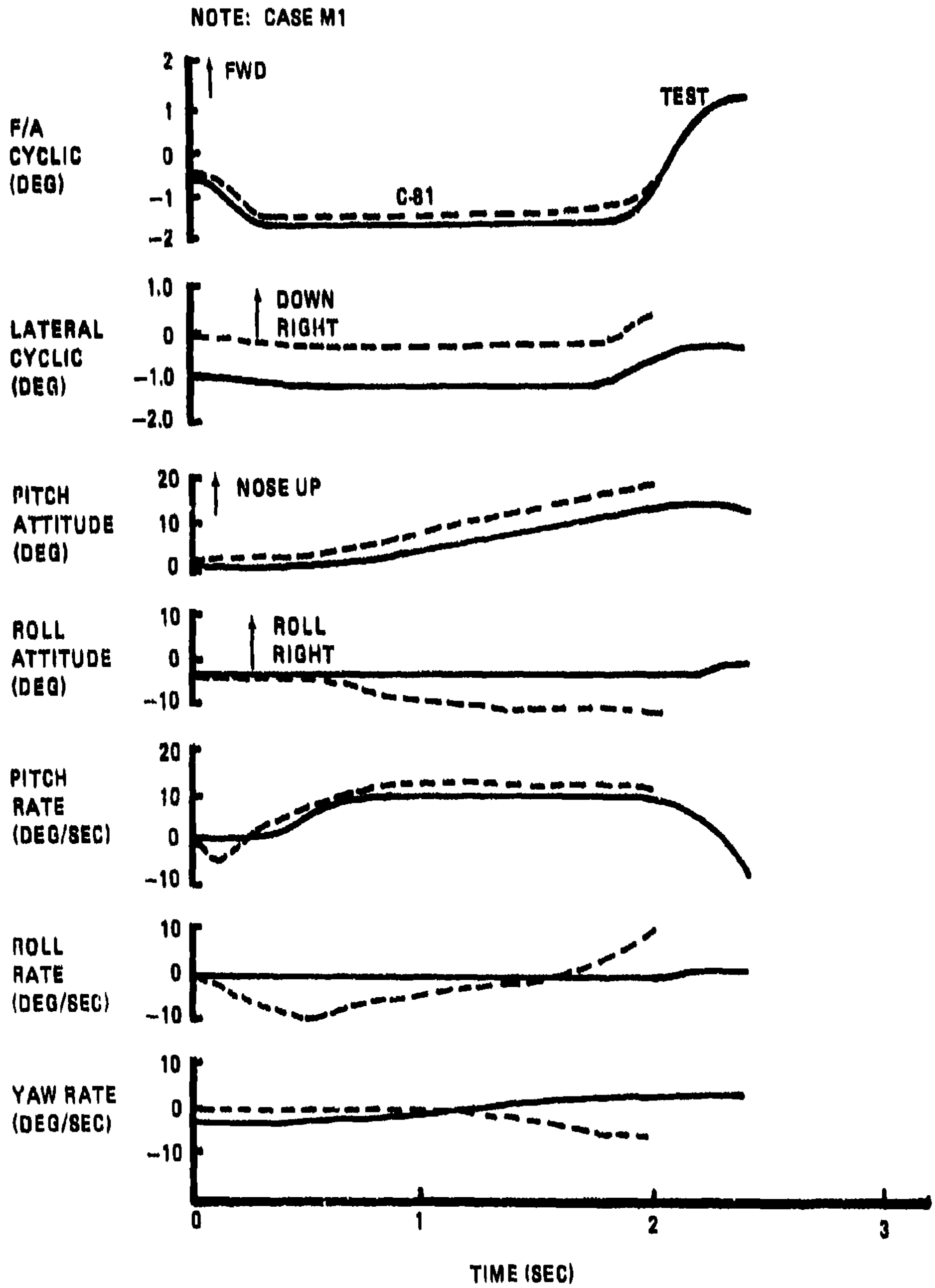


Figure 32. Pullup in Hover.

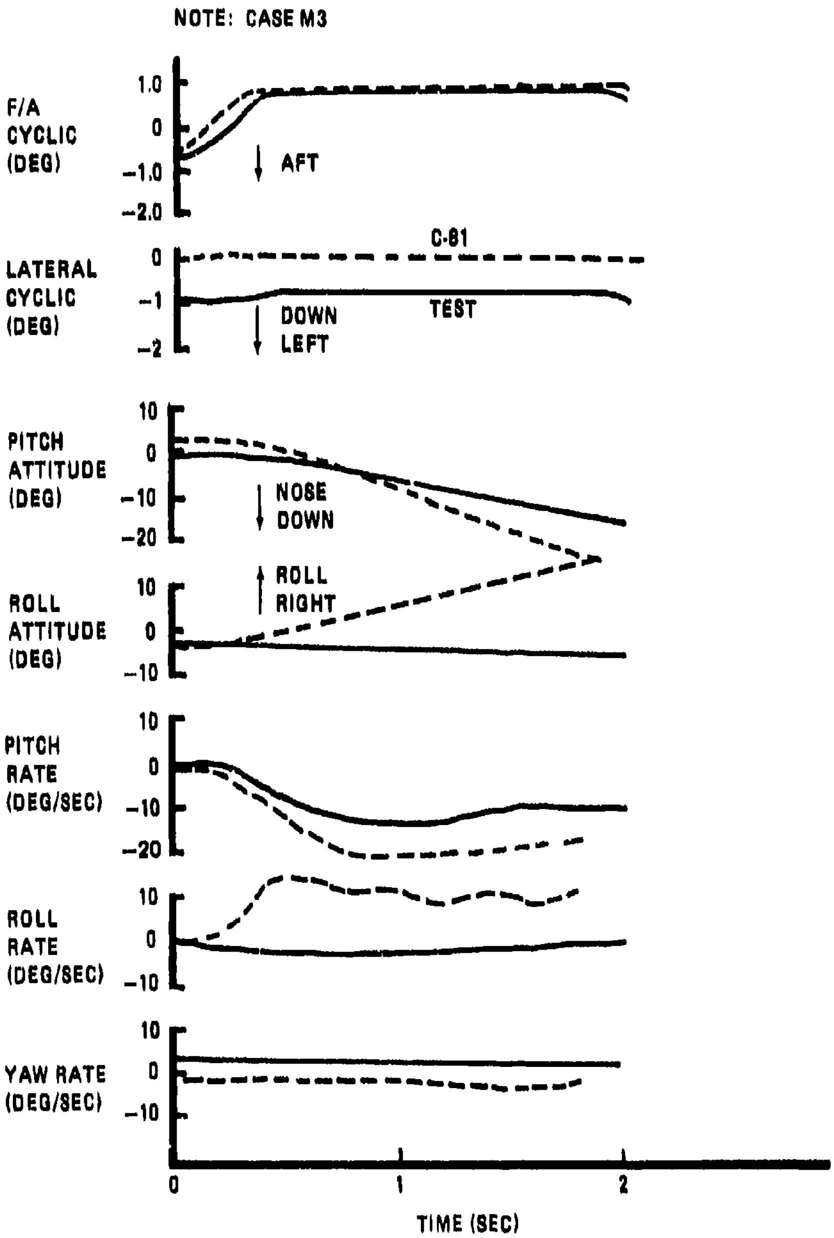


Figure [illegible]. Pushover in Hover.

with test results except for an initial discrepancy after the control motion began. Roll rate shows significant values while test data indicate no roll rate. A change of yaw rate is indicated by the analysis results in a direction opposite to that reported for test results.

It should be noted that test results shown are assumed to be "smoothed" data, as opposed to raw data. The raw data for test control motions may contain higher frequency components not shown in the smoothed data. A comparison of smoothed and raw data for control motion is presented in a later section of this report.

Figure 33 shows similar results for a pushover in hover. Rate of change of control inputs for the analysis match test data reasonably well. Pitch attitude and pitch rate analytical results follow trends of test results, but are not in good agreement with test data. Test data show very little change of pitch attitude or pitch rate, while analysis results show a rapid buildup of roll rate which results in a significant roll displacement. Very little response in yaw was indicated by test and analysis results.

Results in Figures 32 and 33 are for an integration interval corresponding to an azimuth increment of $\Delta\psi = 30$ degrees. This integration interval is only 3.1 intervals per period of the highest frequency blade mode used in the analysis. The recommended integration interval corresponds to 10 intervals per highest blade mode period. This would be an increment of about 10 degrees of blade azimuth. Case M3 for the pushover in hover was repeated with an azimuth increment of 15 degrees for the first second of the maneuver. Results are essentially the same as obtained with the 30-degree azimuth increment, as can be seen by comparing Figures 33 and 34. Consequently, the 30-degree azimuth increment was used for all remaining maneuver cases.

Figures 35 and 36 show test and analysis results for a pullup and a pushover at 100 knots. The longitudinal cyclic initial condition offset is the result of a trim position iterated to by C-81 which is slightly different from flight test. Analysis results in Figure 35 for a pullup at 100 knots indicate a possible instability in the numerical integration scheme with large pitch, yaw, and roll rates occurring. It should be noted that C-81 results were printed at only every 0.059 second. Analytical results for pitch attitude and roll attitude are not in good agreement with test data.

Figure 36 shows analysis and test results for a pushover at 100 knots. The trend of analysis results for pitch attitude and rate are in the correct directions compared to test data. Significant roll coupling is indicated by analysis results but not by test data. Very little yaw response is indicated by both test and analysis results.

Figures 37 through 43 show analysis and test results for additional pullup and pushover maneuvers at speeds near 100 knots. Data for these tests was reported in Reference 14. Data for mast moment, pitch attitude, engine speed, vertical acceleration, control inputs, etc., were "smoothed" data, however. Copies of oscillograph traces of raw data were requested and received from MBB for direct comparison with C-81 output. Test data indicated high rates of climbs, descents and pitch rates which did not permit achieving satisfactory initial conditions for running a C-81 maneuver analysis to simulate these tests.

An attempt was made to use the trim analysis to simulate the steady g conditions achieved in the pullups and pushovers since these g levels were held for about 2.0 seconds. This approach was successful for cases M13, M15, and M16 for a pullup at 100 knots and a pullup and pushover at 110 knots, respectively, as indicated in Figures 37, 38, and 39. Results were not satisfactory for the 0.0g pushover at 100 knots. For case M14, at .15g vertical acceleration, the quasi-static, time-variant trim gave a 1/rev shaft bending moment of 32,500 in-lb (based on root flap bending moments on two opposite blades). This is much higher than the results indicated by test data in Figure 38. Relatively large root flap bending moments were indicated at all harmonics, e.g., 16,000 in-lb at 3/rev. The quasi-static trim results for pitch rate and fore/aft cyclic were reasonably good as shown in Figure 38. Figures 37, 38, and 39 show data from Reference 14 for a pullup and pushover at 100 knots and a pullup at 110 knots. Figure 40 shows raw data from oscillograph traces for the 2.0g pullup at 110 knots. These data should be compared with data in Figure 39. The longitudinal cyclic, in particular, has higher frequency content not seen in the "smoothed" data.

The trim analysis was used to simulate the maximum or minimum g condition achieved in the maneuver. The trim solution was assumed to simulate a time where zero rate of climb was achieved.

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14. Glockl, TERRAIN FOLLOWING MANEUVERS, Messerschmitt-Boelkow-Blohm GmbH Report D14-765, Aug. 1971. (Translated by Boeing Vertol Company)

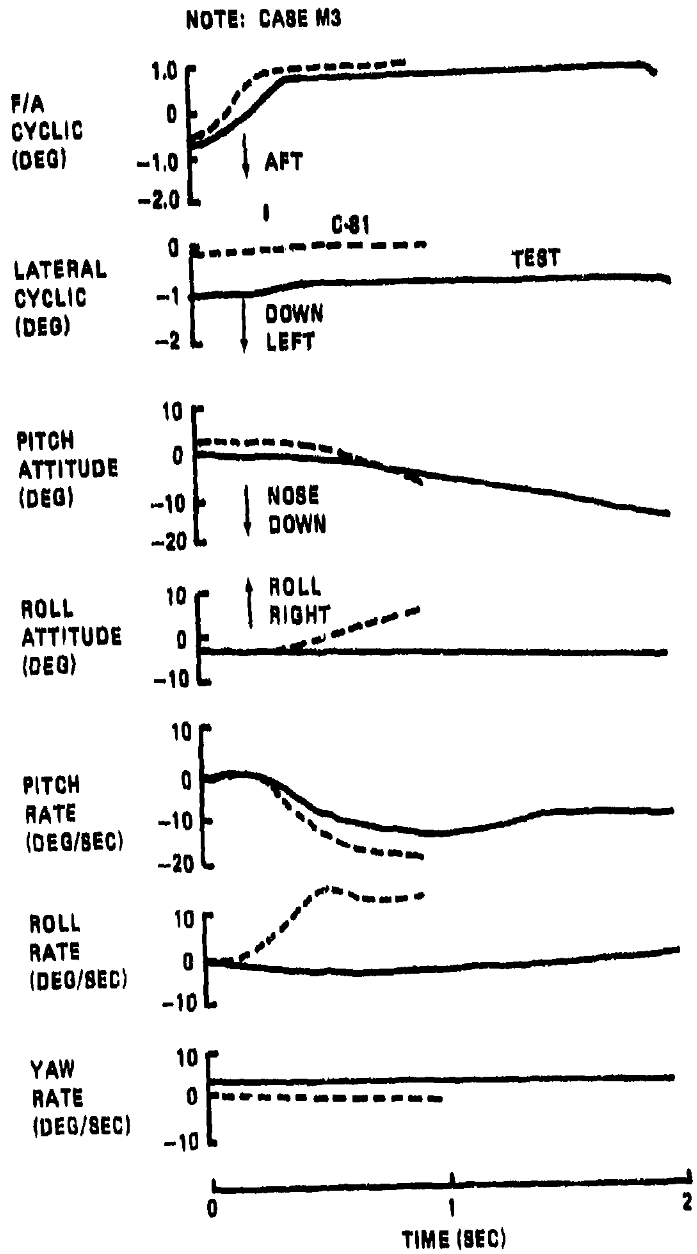

Figure 34. Pushover in Hover, 15-Degree Integration Interval.

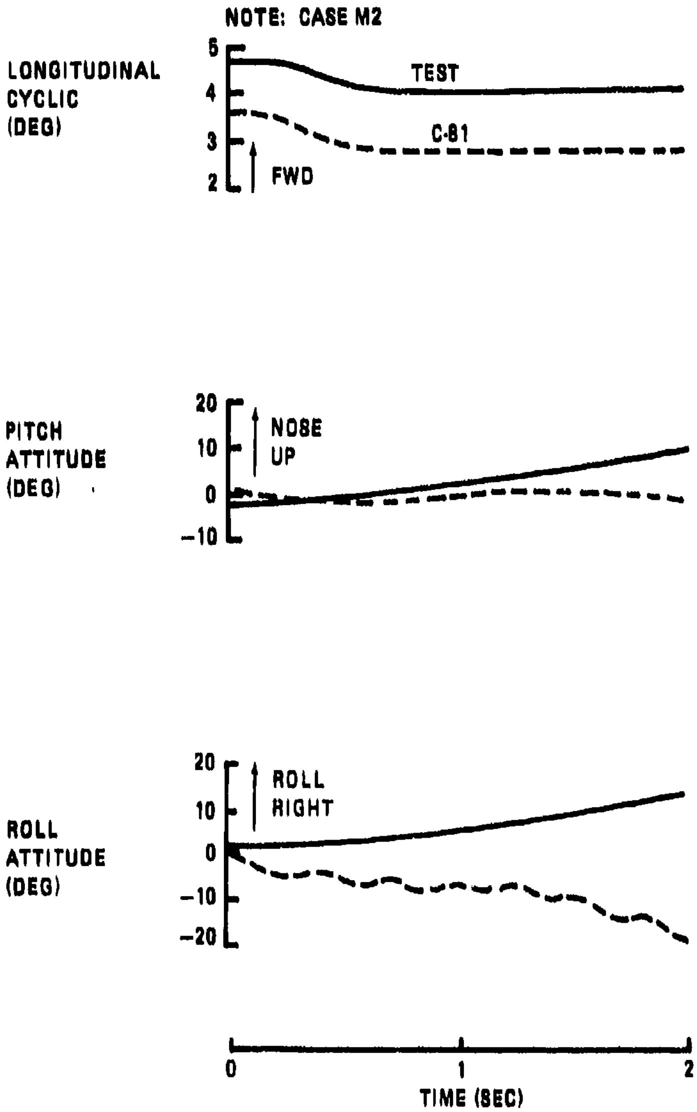

Figure 35. Pullup at 100 Knots (Sheet 1 of 2).

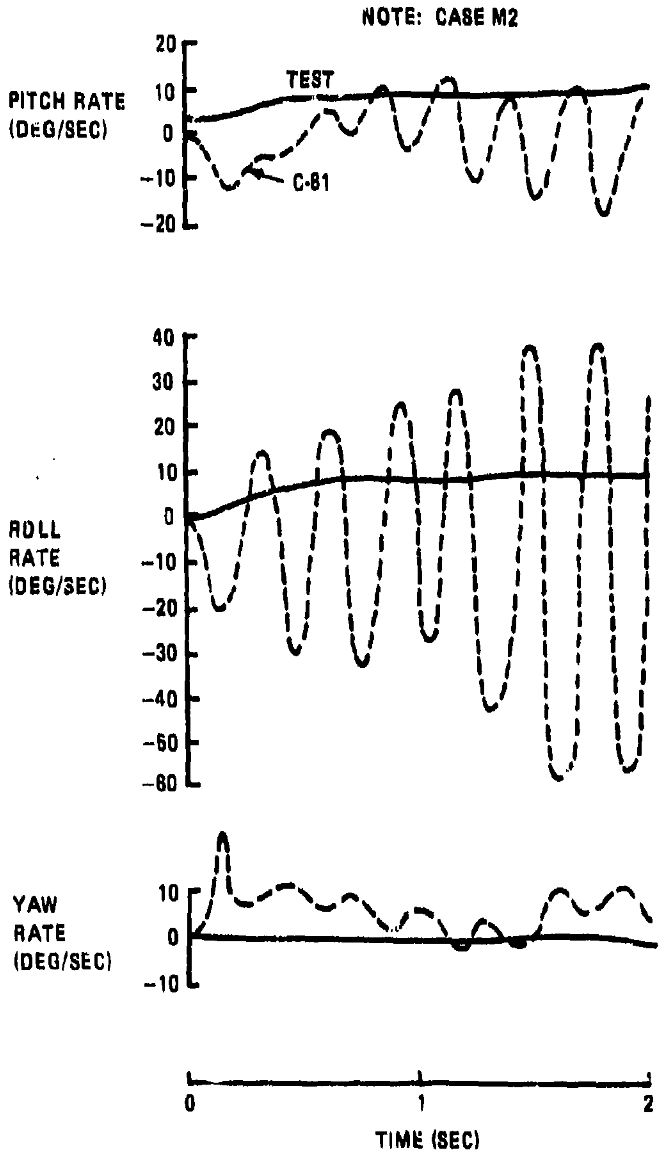

Figure 35. Pullup at 100 Knots (Sheet 2 of 2).

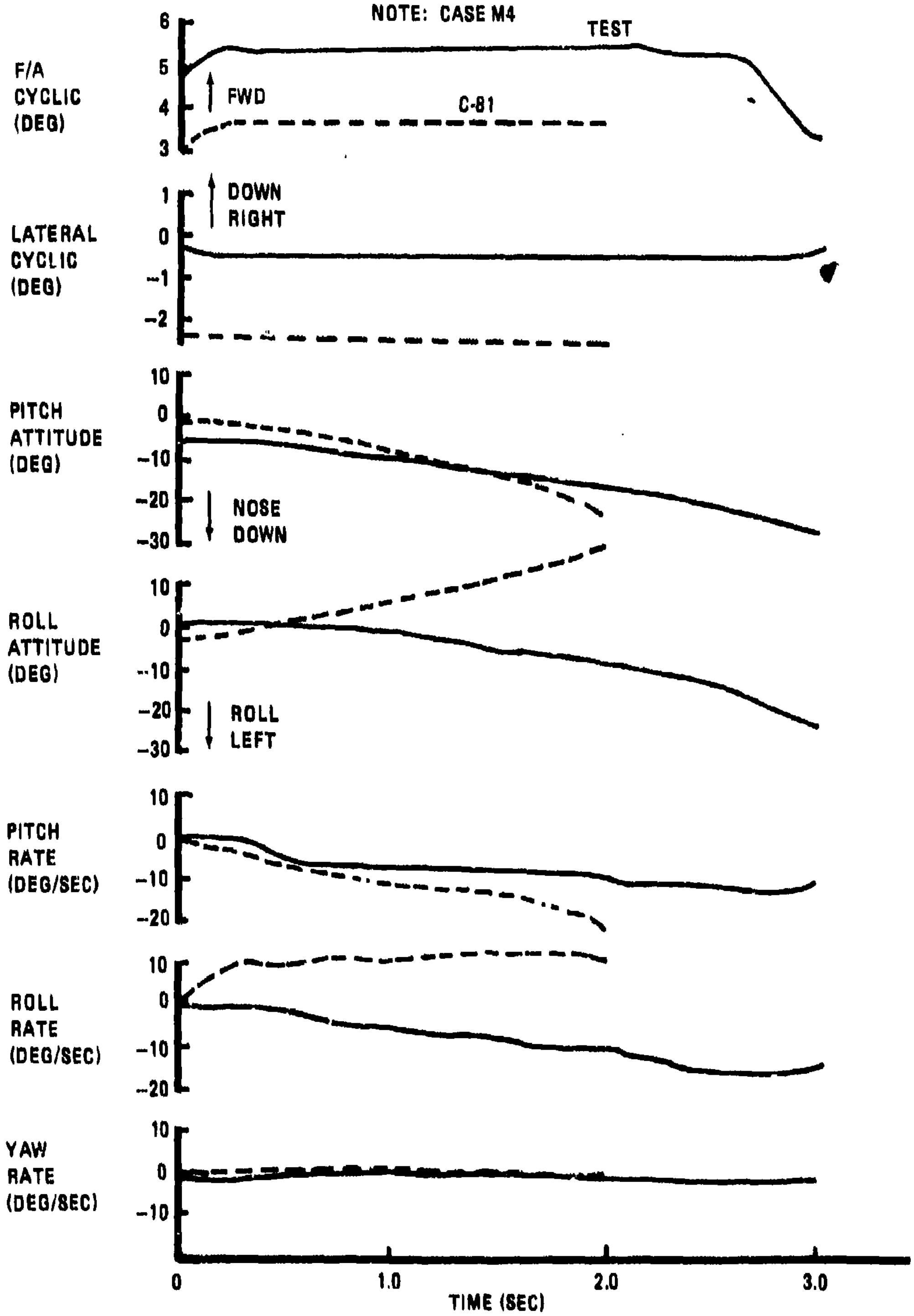

Figure 36. Pushover at 100 Knots.

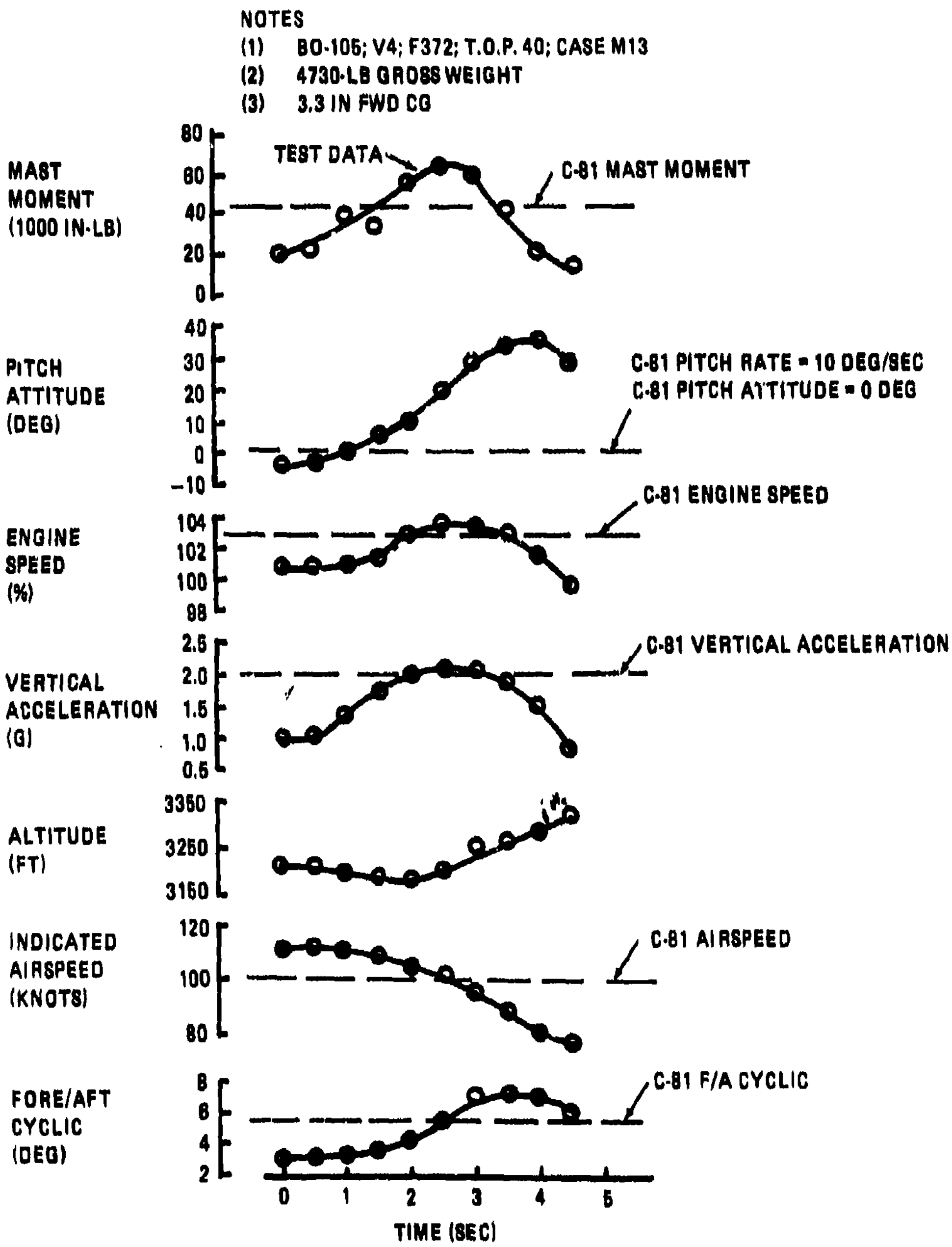

Figure 37. C-81 Results and Test Data for 2.0-G Pullup at 100 Knots.

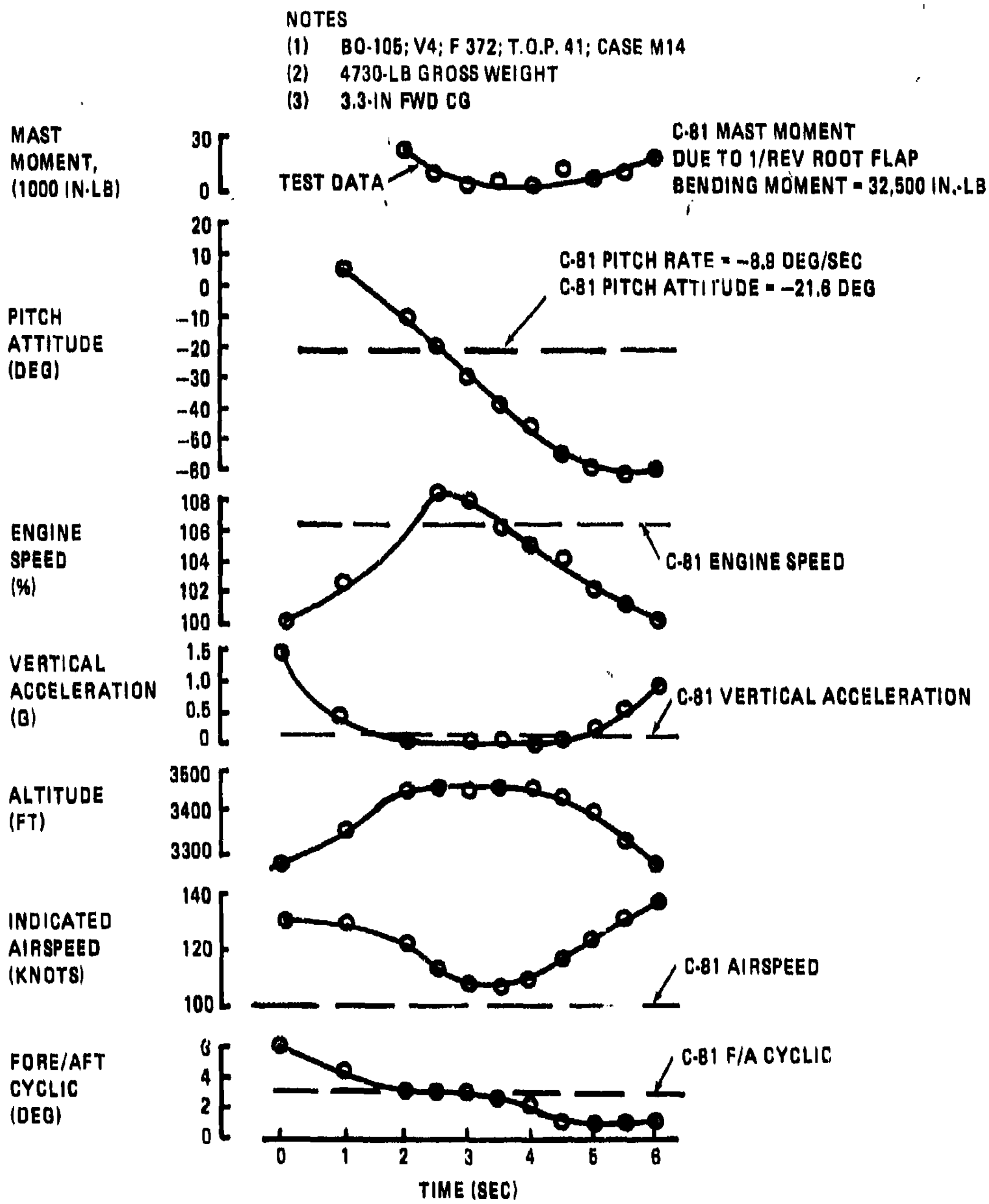

Figure 38. C-81 Results and Test Data for 0.0-G Pushover at 100 Knots.

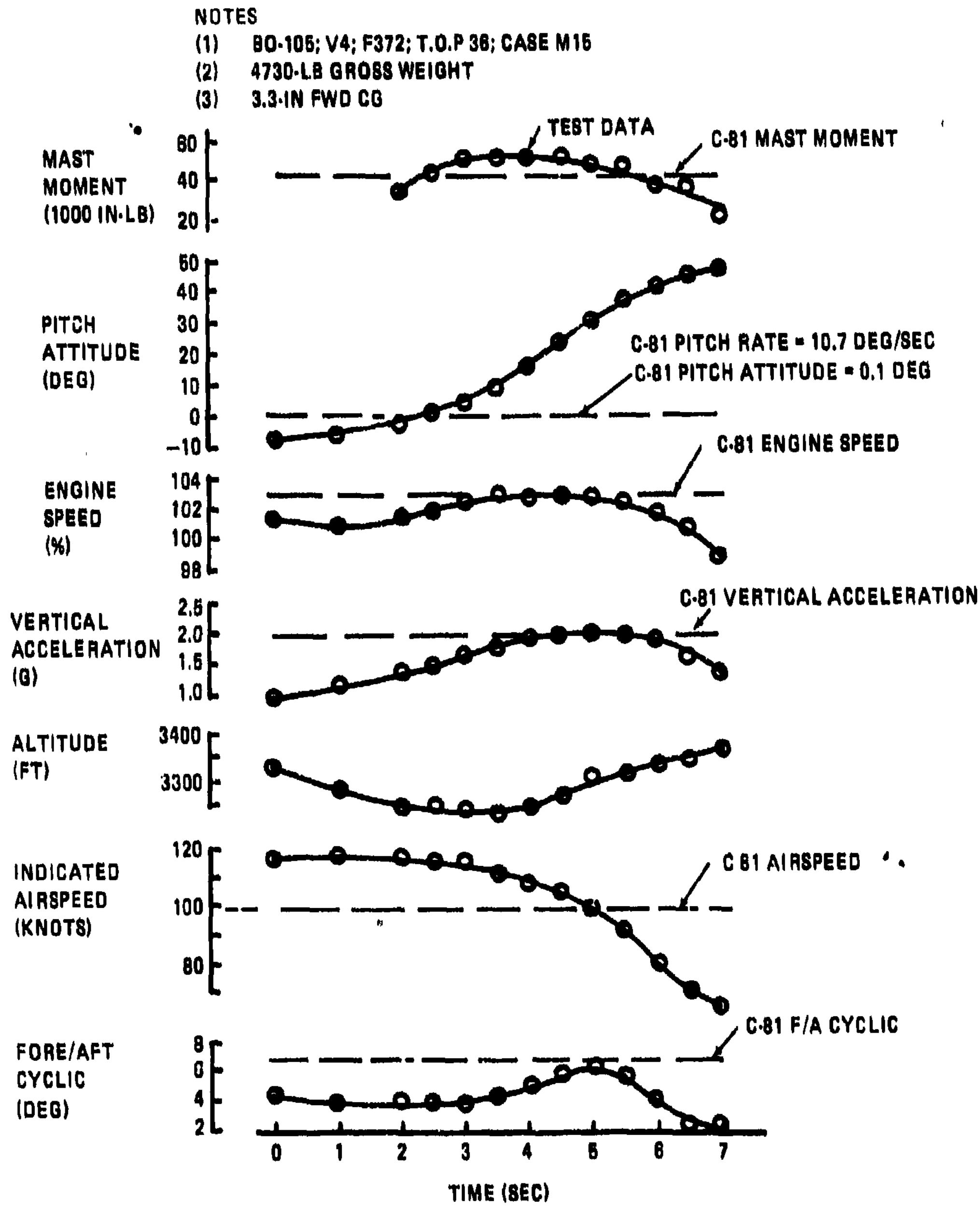

Figure 39. C-81 Results and Test Data for 2.0-G Pullup at 110 Knots.

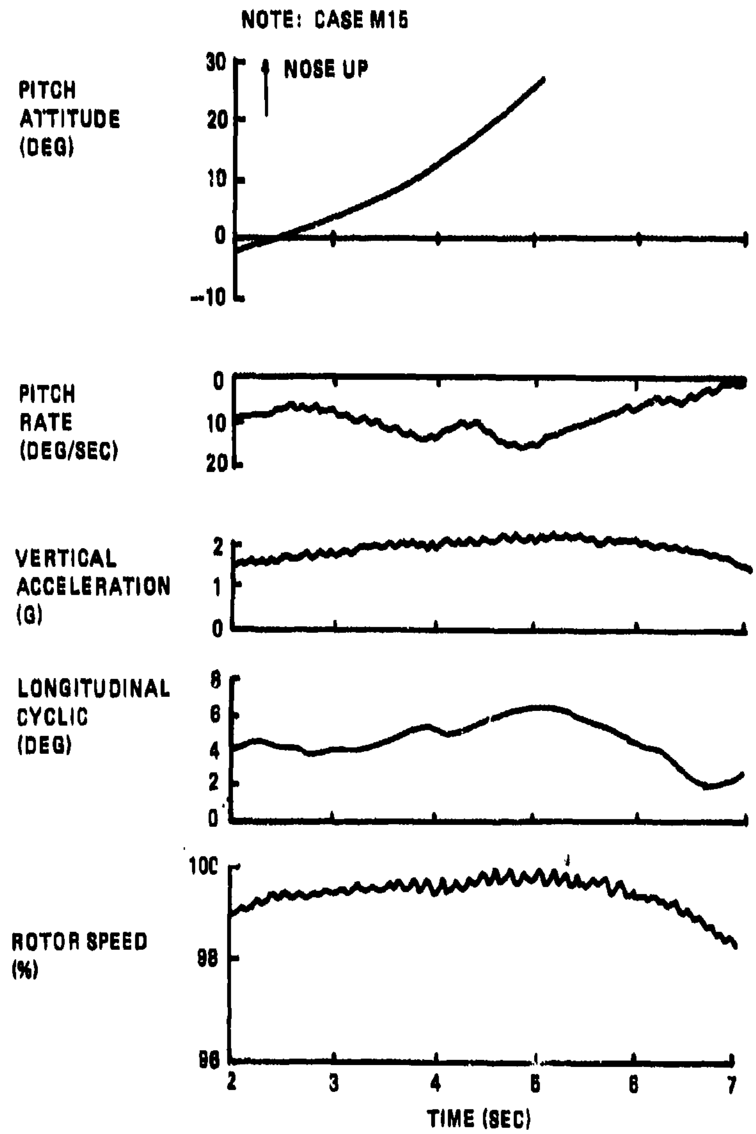

Figure 40. Raw Test Data for 2.0-G Pullup at 110 Knots.

General trim results for C-81 for cases M13, M15, and M16 are compared with test data in Figures 37, 38, and 39. Engine speed, vertical acceleration, rate of climb, and airspeed were input values, while mast moment, pitch rate, and fore and aft cyclic were computed by C-81.

More detailed time history data for loads are shown in Figures 41, 42, and 43 for shaft bending moment, blade bending moment, and vibratory pitch link loads. The test shaft bending moment data are from a 0-180 degree shaft bending gage. The C-81 shaft bending moment result would be valid for a bending gage located at any azimuth on the shaft (and rotating with the shaft) except for a shift in phase, since the C-81 result is for a trimmed condition. The test shaft bending moment would also be valid for a gage located at any shaft azimuth if the trimmed assumption is valid, i.e., if transients have decayed, and the maneuver is stabilized at a steady g pullup or pushover condition.

Figure 41 shows data for a 2.0g pullup at 100 knots. C-81 and test flap bending moments are in reasonable agreement. Predicted chord bending moment and pitch link load are high compared to test. Predicted shaft bending moment is low compared to test, although the test shaft bending moment does not appear to have achieved a steady-state value.

Figure 42 shows test and analysis results for a 2.0g pullup at 110 knots. Root flap bending moments are in reasonable agreement and root chord moment is slightly lower for analysis than for test. Pitch link load is higher for analysis than for test. Test shaft bending moment is higher than analysis, which is surprising since the flap bending moments for test and analysis were in reasonable agreement.

Figure 43 shows test and analysis results for a 0.0g pushover at 110 knots. Flap bending moment amplitudes are in rough agreement; analysis chord bending moment and pitch link loads are lower than test. Shaft bending moment is in rough agreement with test.

5.2.2 Lateral Control, Left and Right

Figures 44 through 47 show analytical and test results for response to lateral cyclic control inputs in hover and at 100 knots. Figure 44 shows results for a right lateral ramp input in hover. Trends for analysis results for roll rate and roll attitude are in reasonable agreement with test data, but predicted roll rate and roll attitude magnitudes are higher than indicated by test. Analysis results for pitch rate and pitch displacement are slightly higher than indicated by test. The analytical value for yaw rate is higher than shown by test.

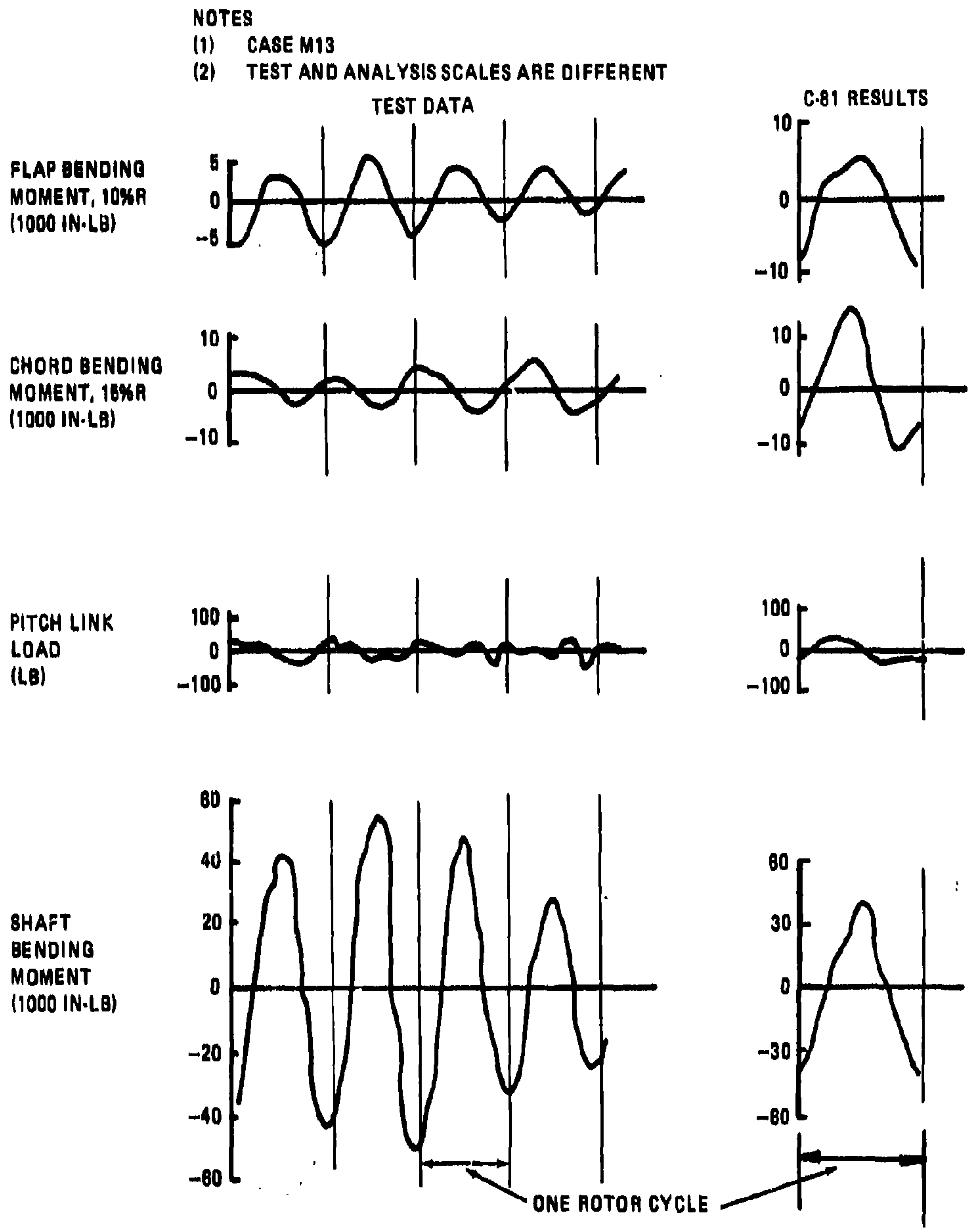

Figure 41. Main Rotor Loads for 2.0-G Pullup, 100 Knots.

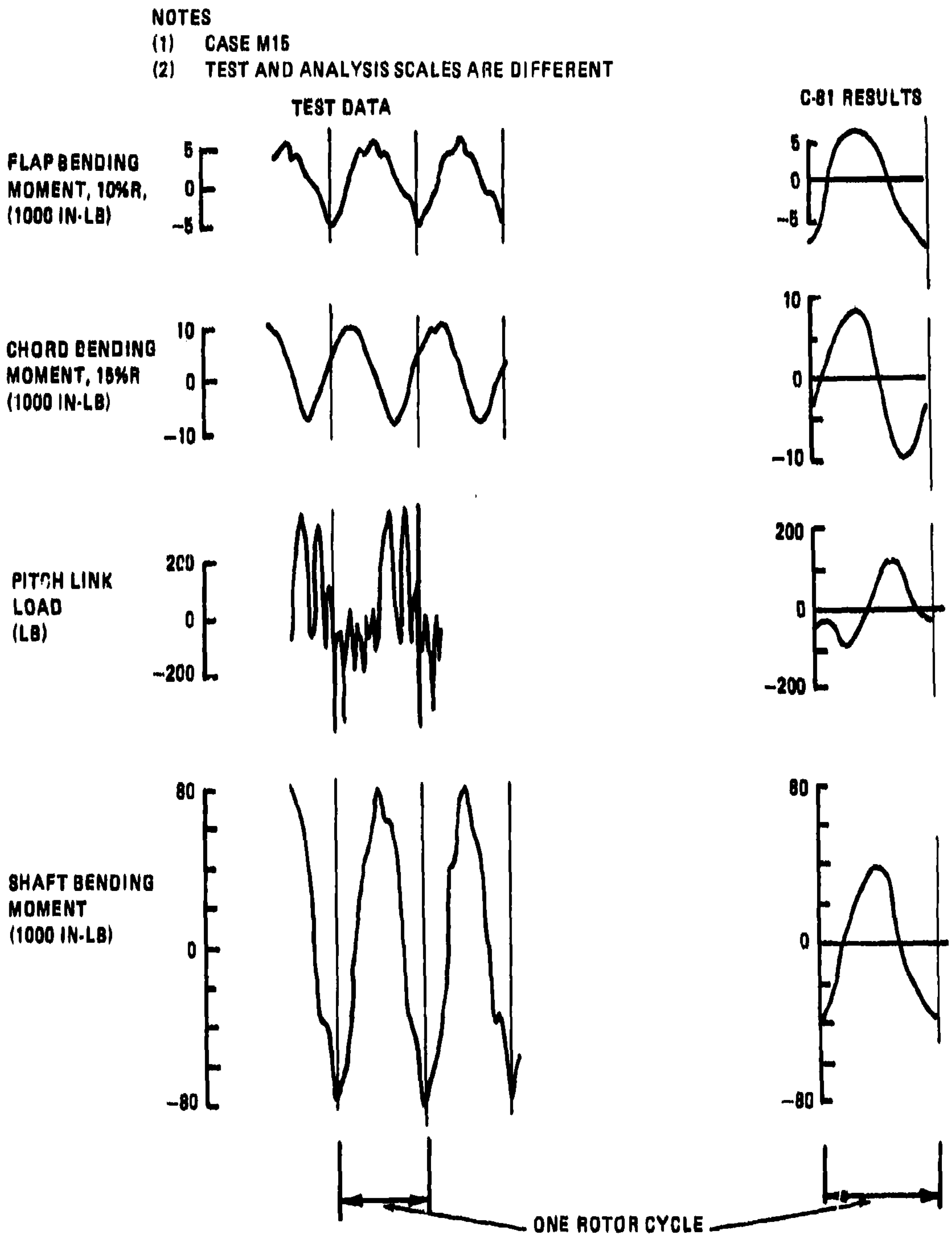

Figure 42. Main Rotor Loads for 2.0-G Pullup, 110 Knots.

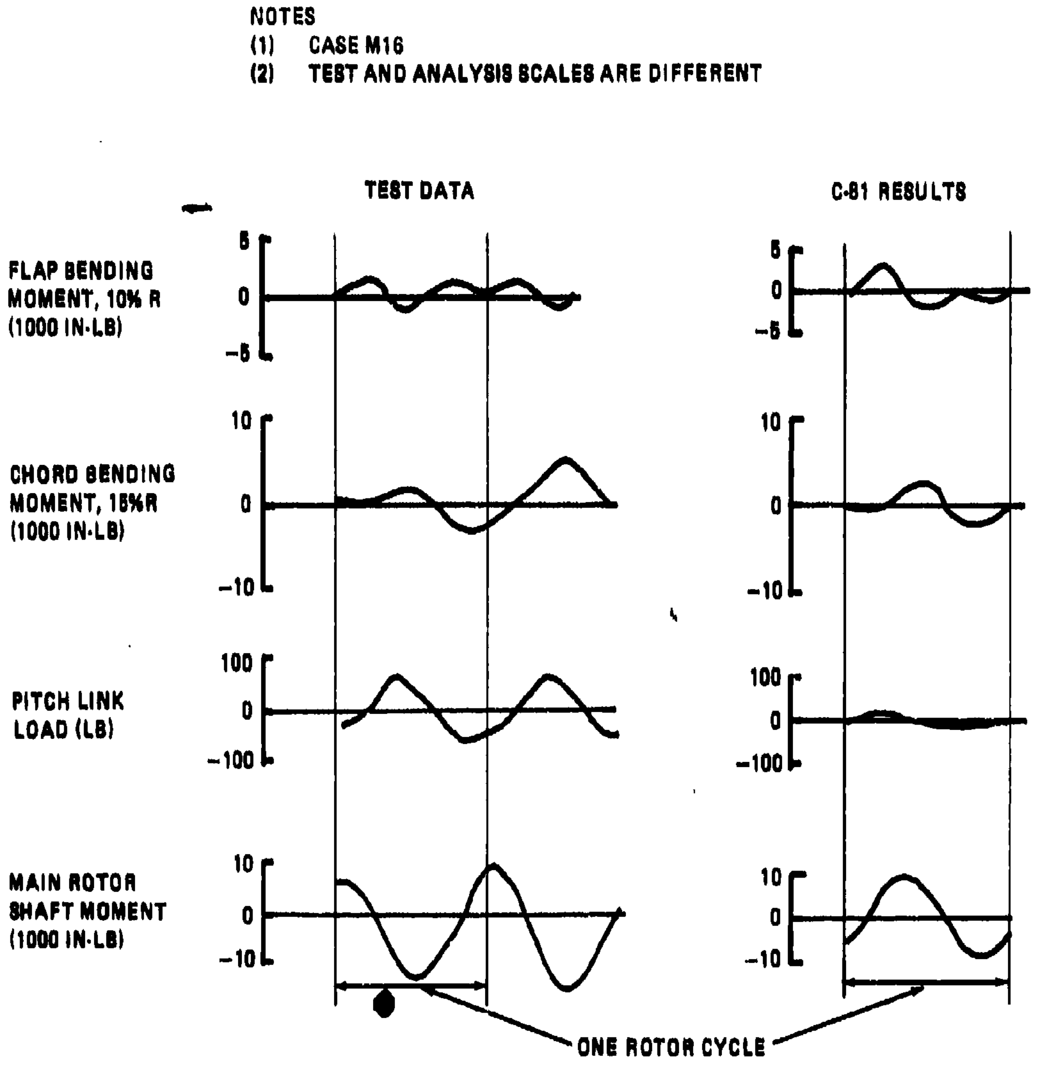

Figure 43. Main Rotor Loads for 0.0-G Pushover, 110 Knots.

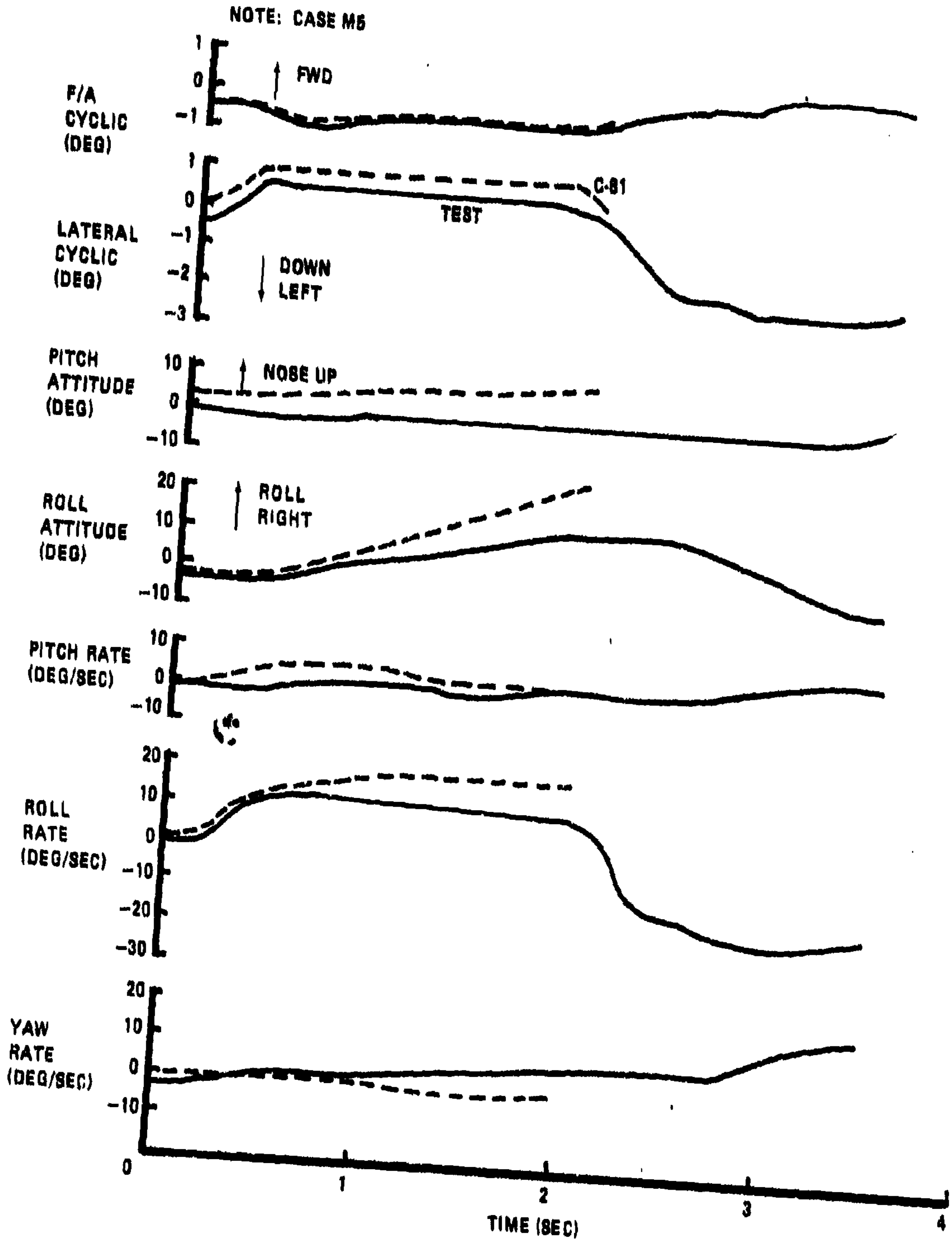

Figure 44. Right Lateral Cyclic Ramp Input in Hover.

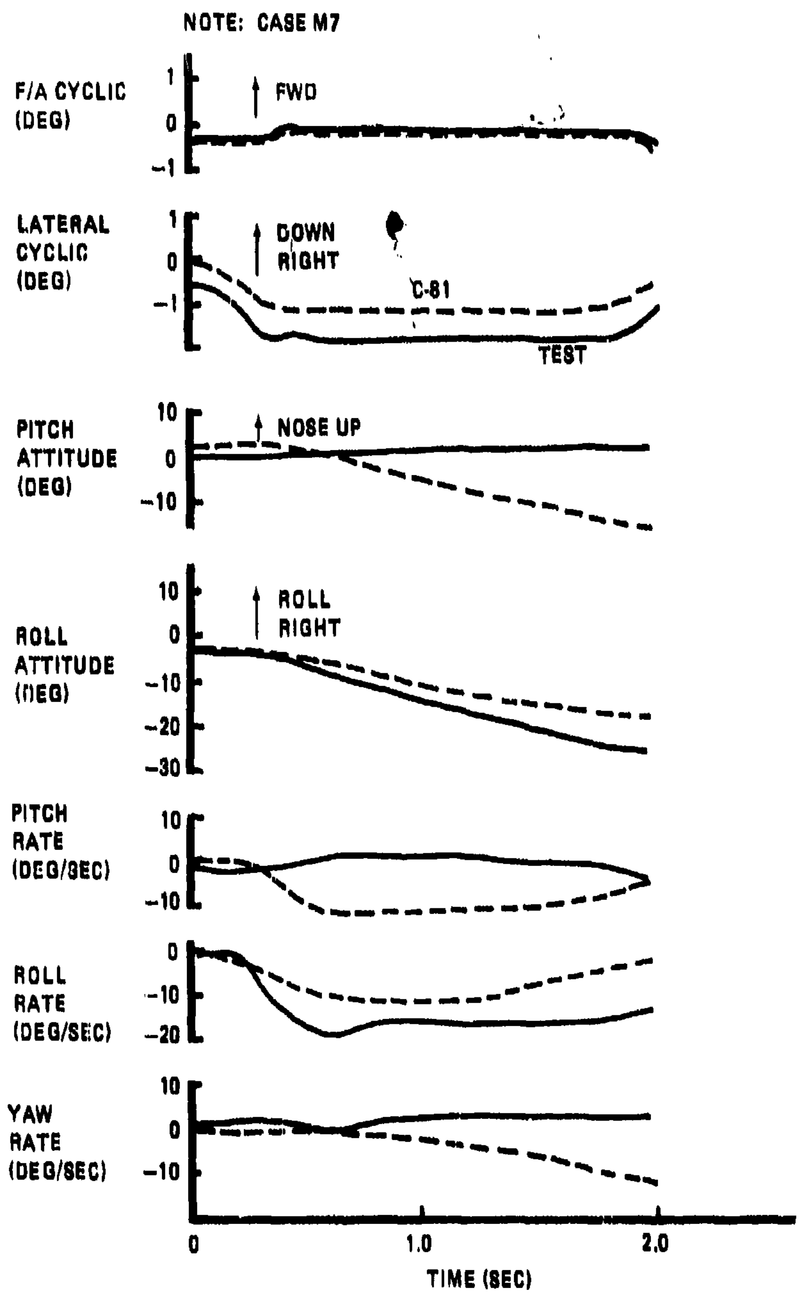

Figure 45. Left Lateral Cyclic Ramp Input in Hover.

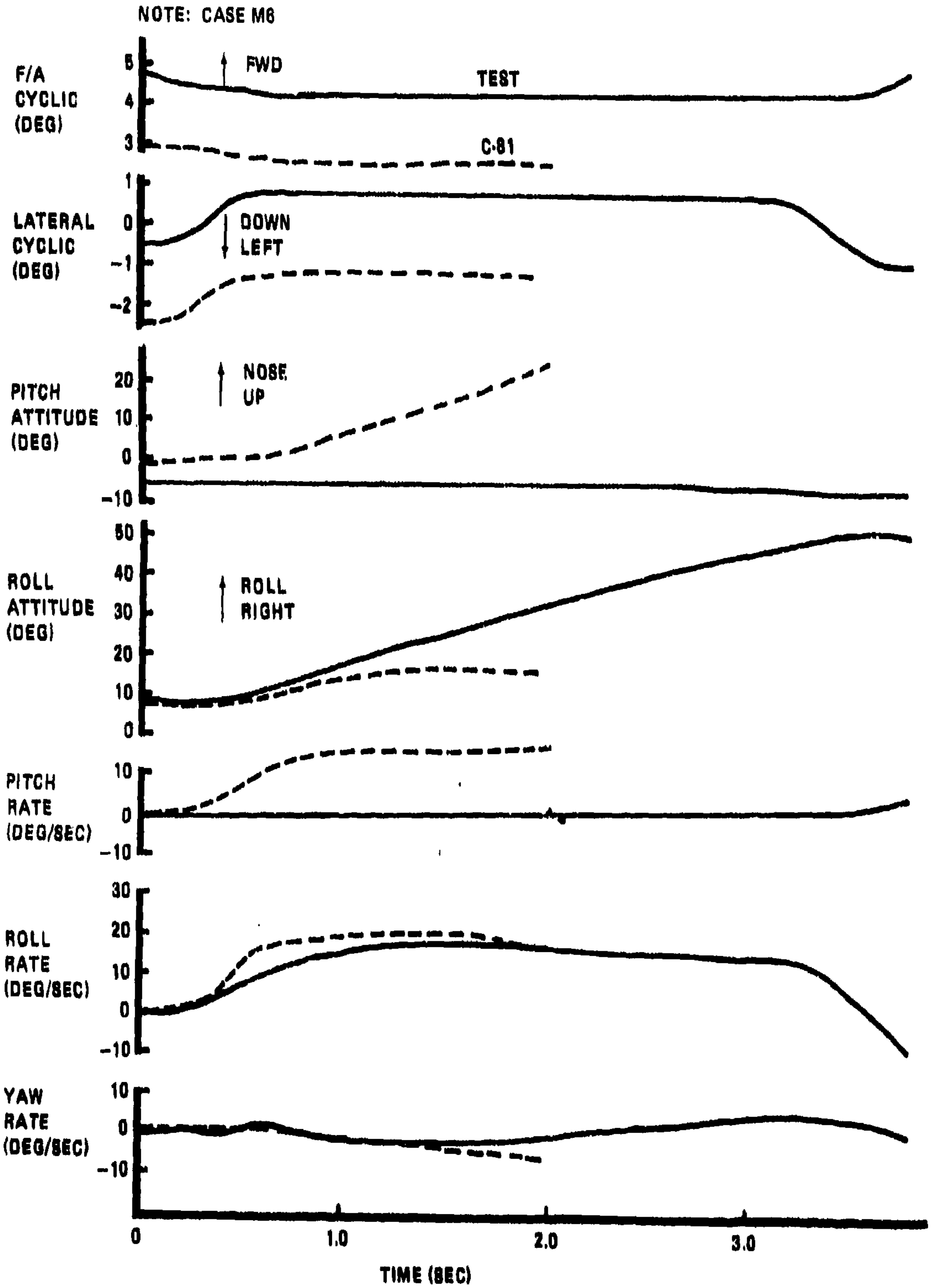

Figure 46. Right Lateral Cyclic Ramp Input at 100 Knots.

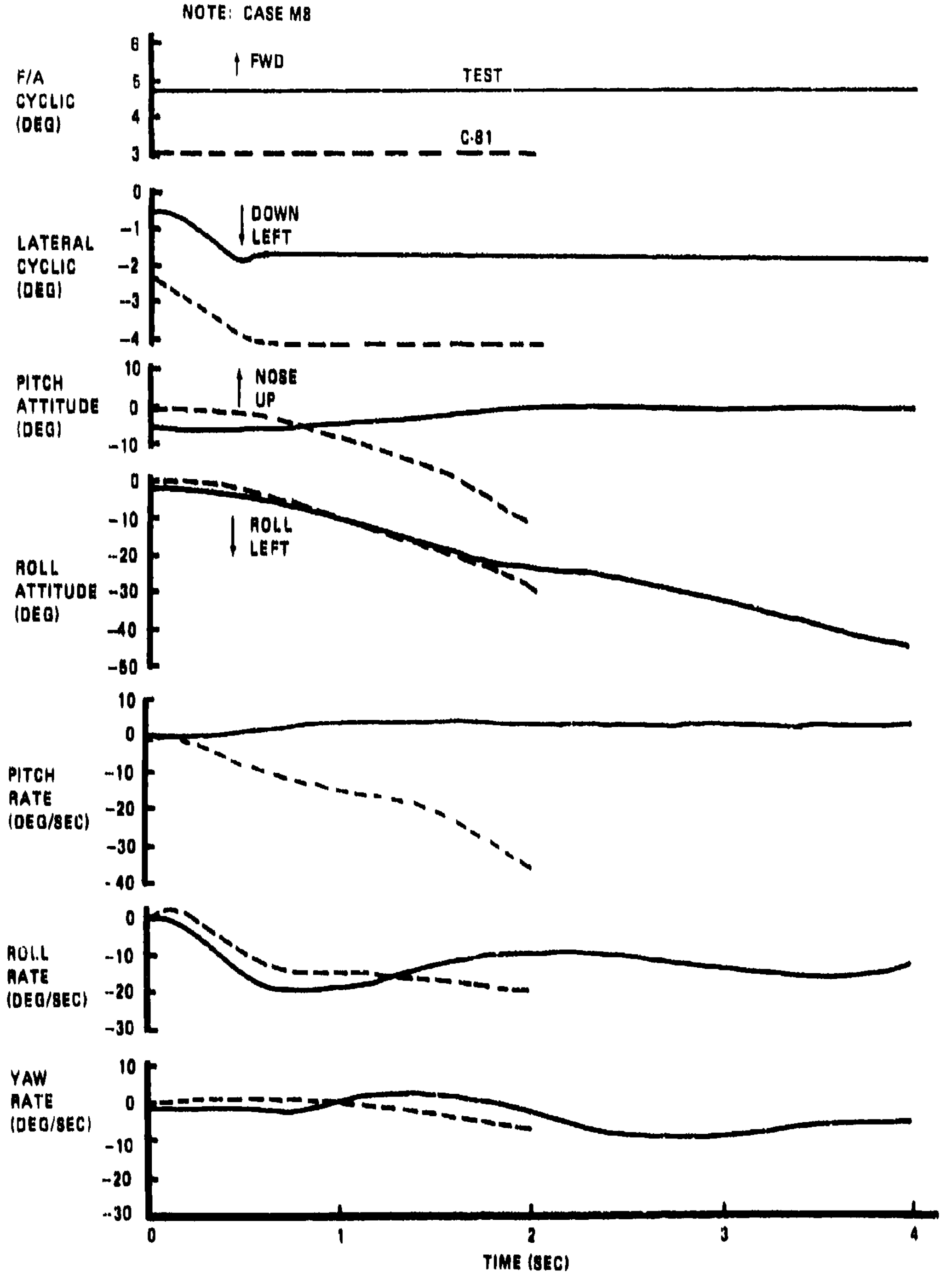

Figure 47. Left Lateral Cyclic Ramp Input at 100 Knots.

Figure 45 indicates test and analysis responses for a left lateral ramp input in hover. Analysis results for roll rate and roll attitude are lower than indicated by test. Significant pitch rate and attitude are indicated by analysis but not by test. Analysis results also show a buildup in yaw rate not shown by test data.

Figure 46 shows results for a right lateral ramp input at 100 knots. The analytical results show a roll rate which does not achieve and maintain the final rate indicated by test data. This results in a lower roll attitude indicated by analysis than indicated by test. Test pitch rate is essentially zero, while the analysis results show a significant buildup in pitch rate and a resulting significant pitch attitude not indicated by test data. Test and analysis yaw rates were small and in reasonable agreement.

Figure 47 shows response to a left lateral control input at 100 knots. Analysis and test values for roll rate are in reasonable agreement up to about 1.25 seconds; resulting analytical roll attitude is in reasonable agreement with test data. Significant pitch rate and a resulting buildup of pitch attitude are indicated by the analysis, while test results indicate very little change of pitch rate or pitch attitude. Yaw rates are in rough agreement.

The analytical results for response to lateral inputs shown in this section and for response to longitudinal control inputs shown in Section 5.2.1 generally show significant pitch-roll coupling not indicated in the test data. This result may be related to the fact that the hingeless rotor first flap natural frequency is near 1.13/rev.

5.2.3 Directional Control, Left and Right

Figures 48 through 51 show responses to tail rotor inputs in hover and at 100 knots. Figure 48 shows response to a right pedal input in hover. Results show a discrepancy between test and analysis yaw rates. The test yaw rate shows no response for about 0.5 second and is obviously not in trim. The analysis shows an immediate buildup of yaw rate which continues at about the same yaw acceleration. Once the test yaw rate does start to build up, it increases for about 0.5 second at about the same rate as the analytical yaw rate. The test yaw rate then begins to show a lower yaw acceleration than analysis results.

Analytical low-frequency values of pitch and roll rates are in reasonable agreement with test data. The analytical roll rate shows an oscillation with about a 0.3-second period. Analysis and test pitch attitudes are in reasonable agreement, but the roll attitude builds up to a slight positive value not indicated

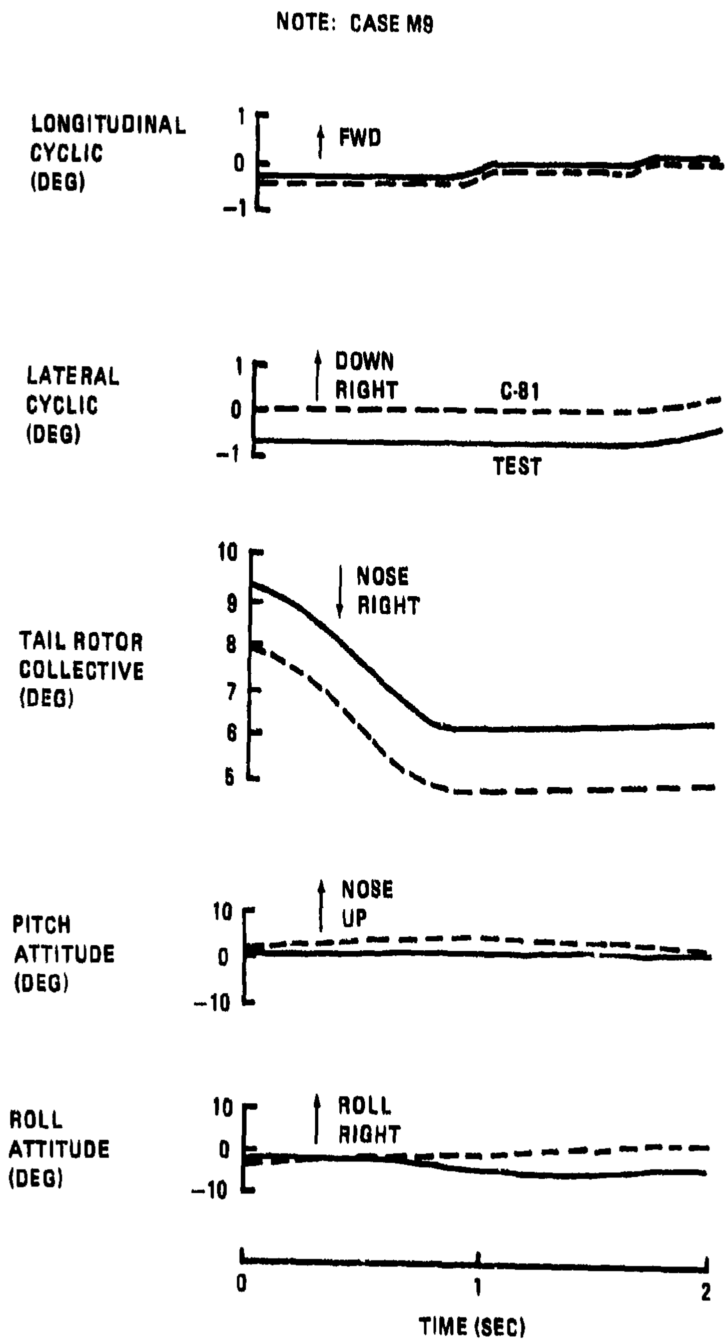

Figure 48. Right Pedal Ramp Input in Hover (Sheet 1 of 2).

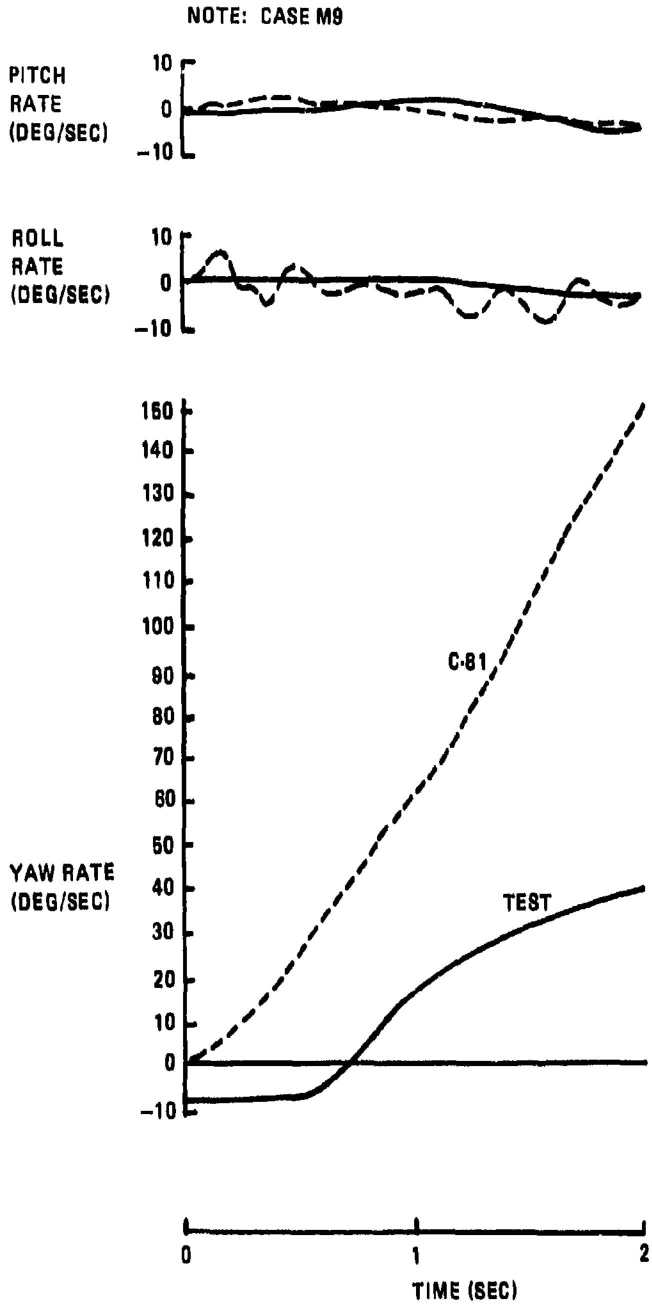

Figure 48. Right Pedal Ramp Input in Hover (Sheet 2 of 2).

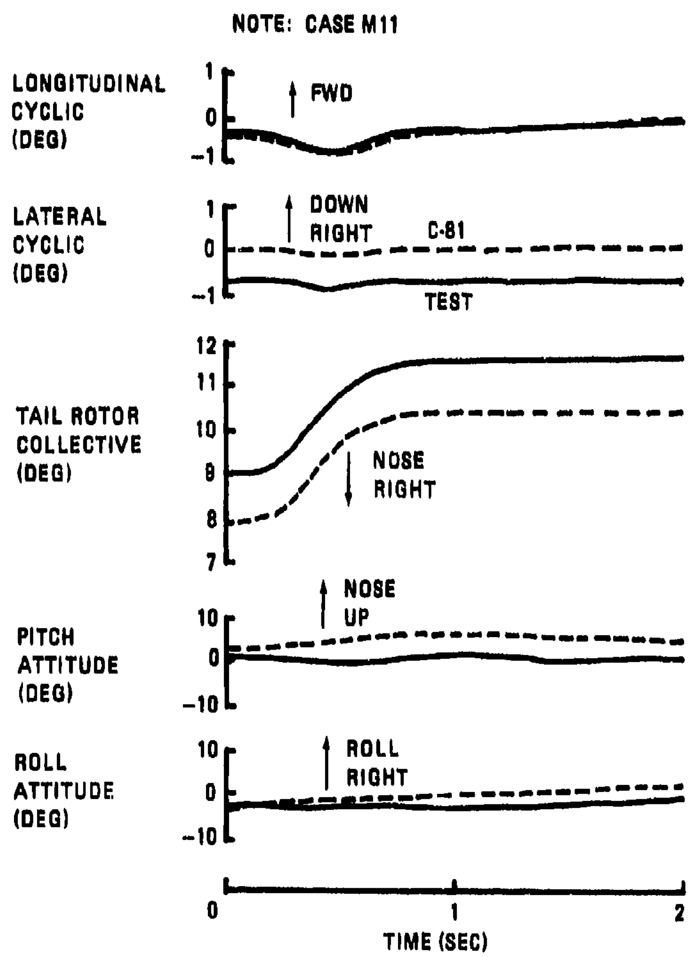

Figure 49. Left Pedal Ramp Input in Hover (Sheet 1 of 3).

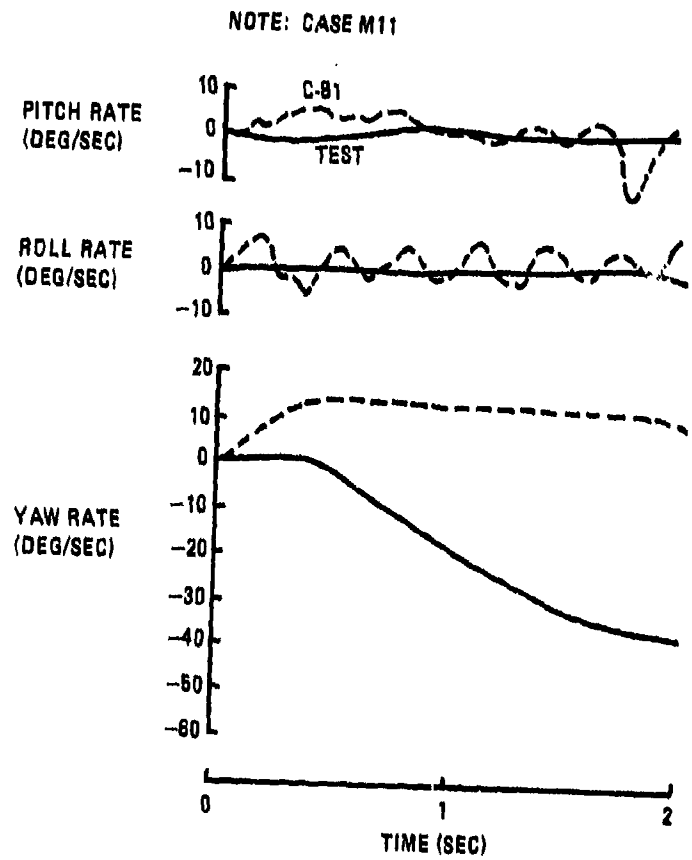

Figure 49. Left Pedal Ramp Input in Hover (Sheet 2 of 3).

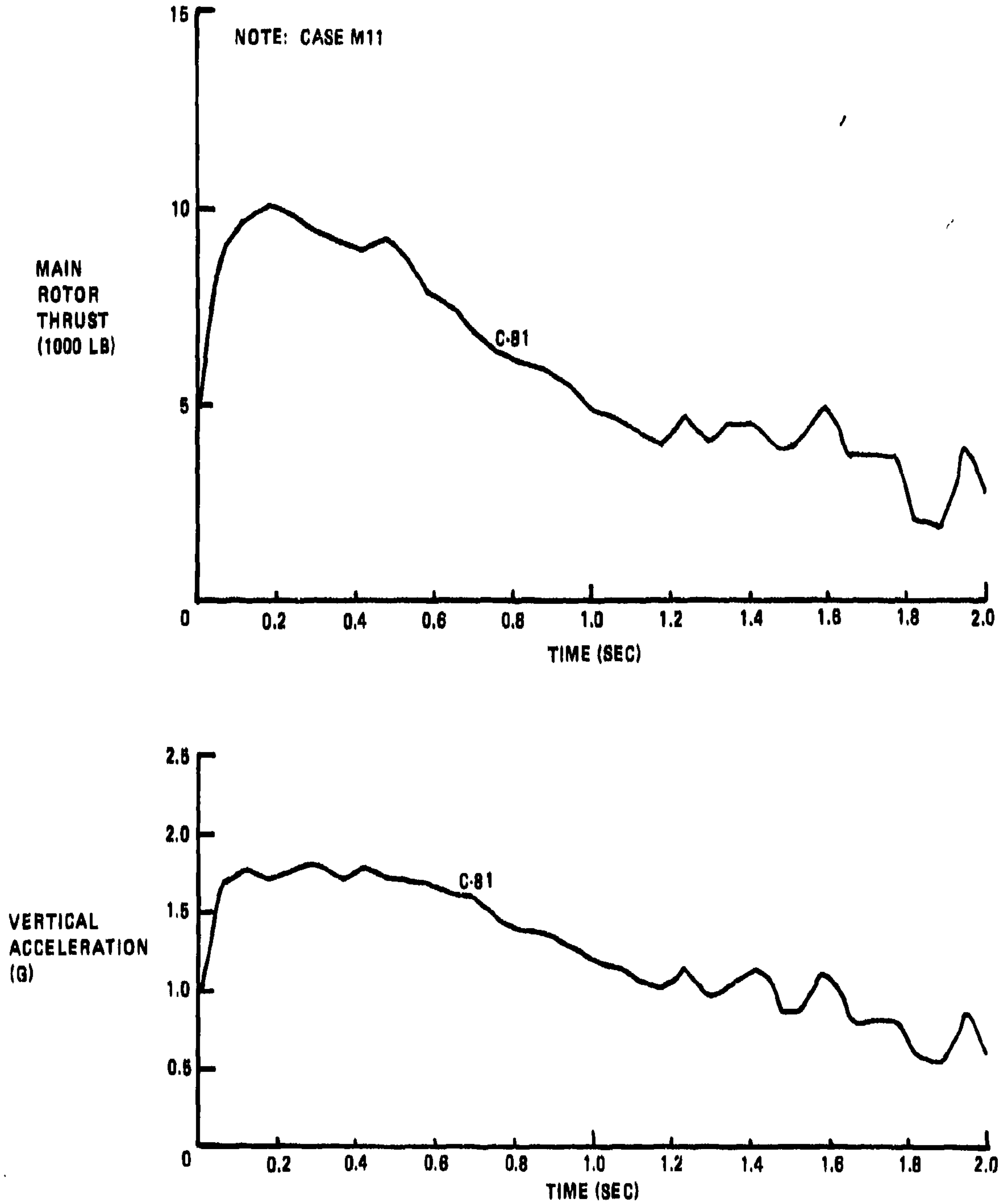

Figure 49. Left Pedal Ramp Input in Hover (Sheet 3 of 3).

by the analysis. Figure 49 shows response to a left pedal input in hover. The analysis yaw rate does not follow the expected yaw rate indicated by test. The computer run results were examined, and it was determined that just after the maneuver started, there was an immediate buildup in main rotor thrust without any buildup in main rotor collective (main rotor collective was held constant). This resulted in a corresponding buildup in main rotor torque which caused the resulting error in yaw rate. The cause of this buildup in main rotor thrust is not understood, but might be associated with a numerical integration instability. Remaining analysis results in Figure 49 are questionable due to this error in thrust.

Figure 50 shows response to a right pedal input at 100 knots. The analysis values for yaw rate generally follow the test values, but a higher frequency oscillation in the analysis values for yaw rate is indicated. Analysis values for roll and pitch rates show significantly higher frequency oscillations. Analysis values for roll attitude are not in good agreement with test results.

Figure 51 shows response to a left pedal control input at 100 knots. The trend for yaw rate analysis results is similar to test results for the low-frequency content, but the analysis amplitude is lower; a high-frequency component is indicated in the test result. The analysis results for pitch and roll rates show large components of high-frequency oscillations. Variation of roll attitude with time is in rough agreement for analysis and test results, while variation in pitch attitude is not in good agreement.

5.2.4 Pitch Dumps

Figures 52 through 54 show test and analysis results for main rotor collective pitch dumps at 80, 100, and 123 knots. Inputs for main rotor collective and longitudinal cyclic are shown.

Figure 52 shows inputs and results for a pitch dump at 80 knots. A greater change in pitch attitude is indicated by analysis than by test. Test and analysis results for vertical acceleration are in reasonable agreement.

Figure 53 shows inputs and response for a pitch dump at 100 knots. Again, the pitch attitude change predicted by the analysis is greater than indicated by test, although the trend is in agreement. Vertical acceleration results are in reasonable agreement.

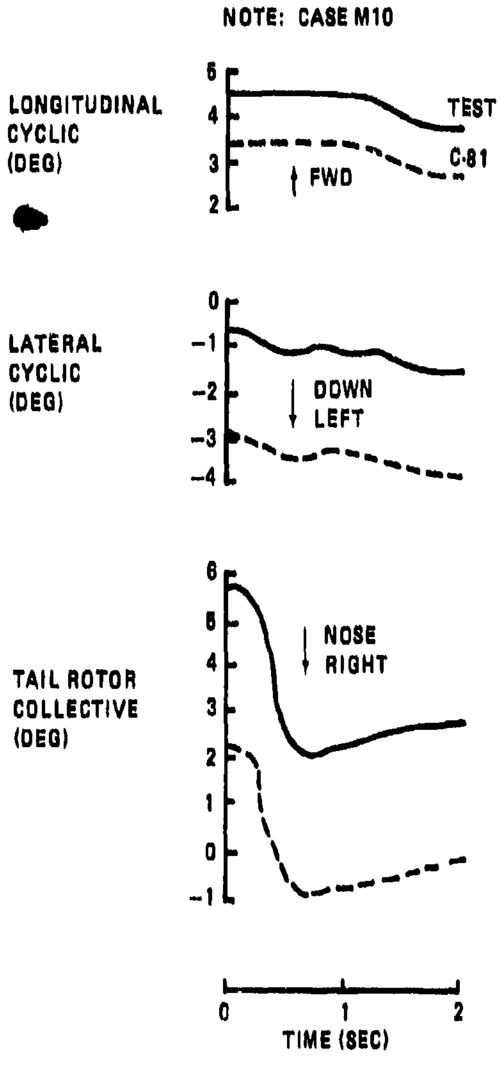

Figure 50. Right Pedal Ramp Input at 100 Knots (Sheet 1 of 2).

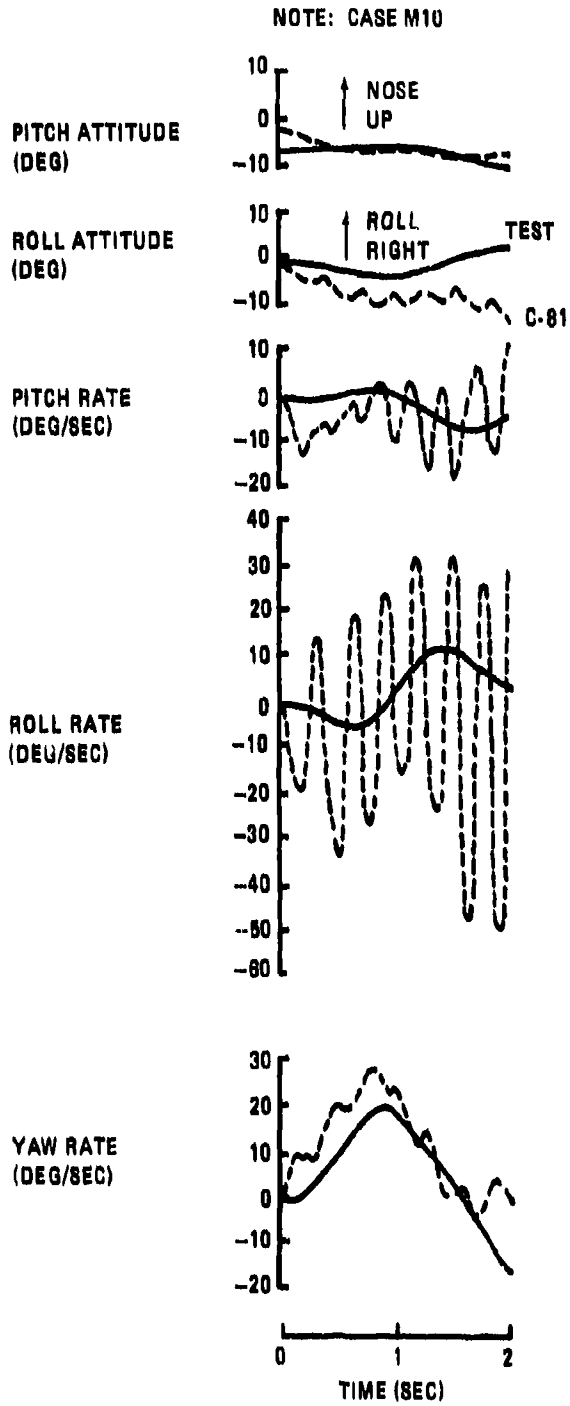

Figure 50. Right Pedal Ramp Input at 100 Knots (Sheet 2 of 2).

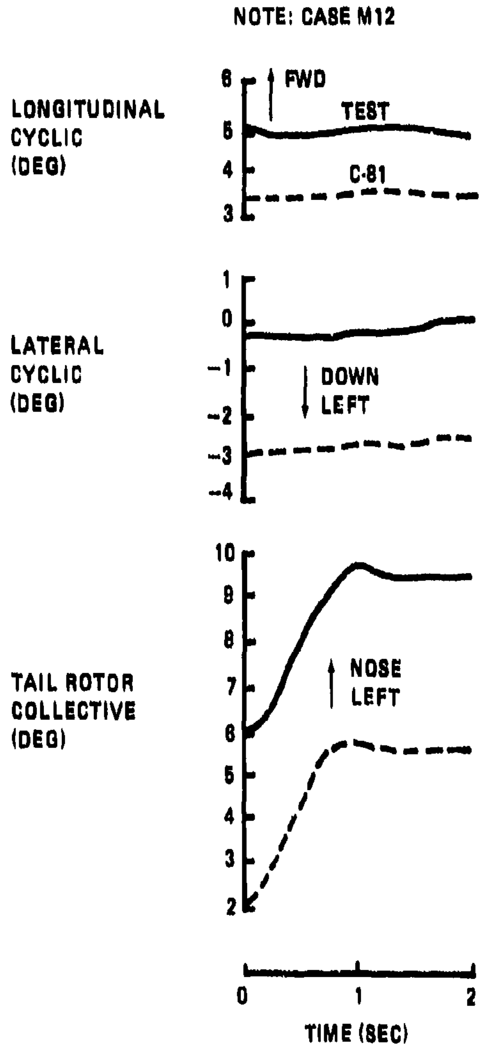

Figure 51. Left Pedal Ramp Input at 100 Knots (Sheet 1 of 2).

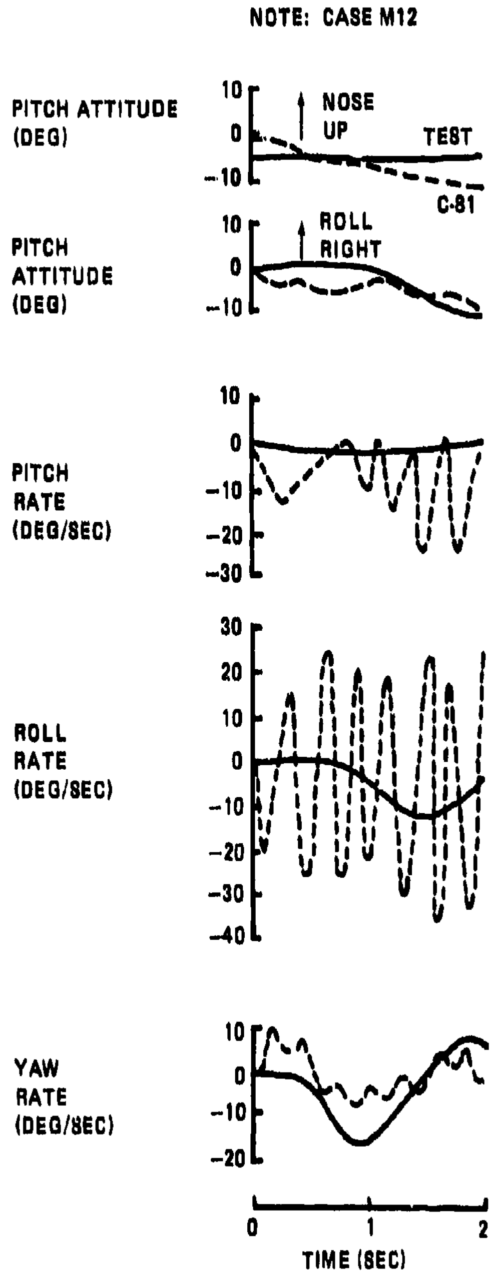

Figure 51. Left Pedal Ramp Input at 100 Knots (Sheet 2 of 2).

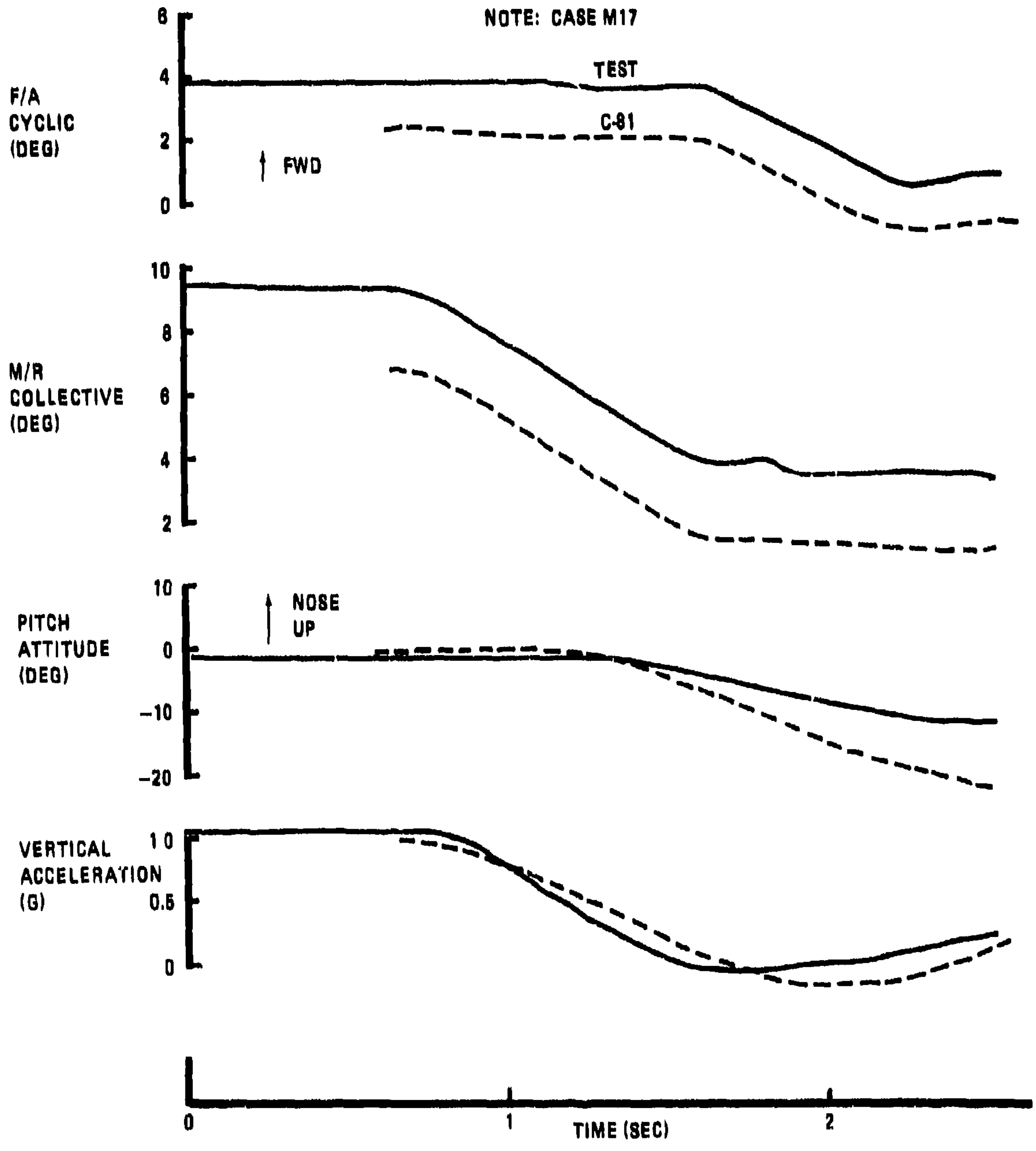

Figure 52. Collective Pitch Dump at 80 Knots.

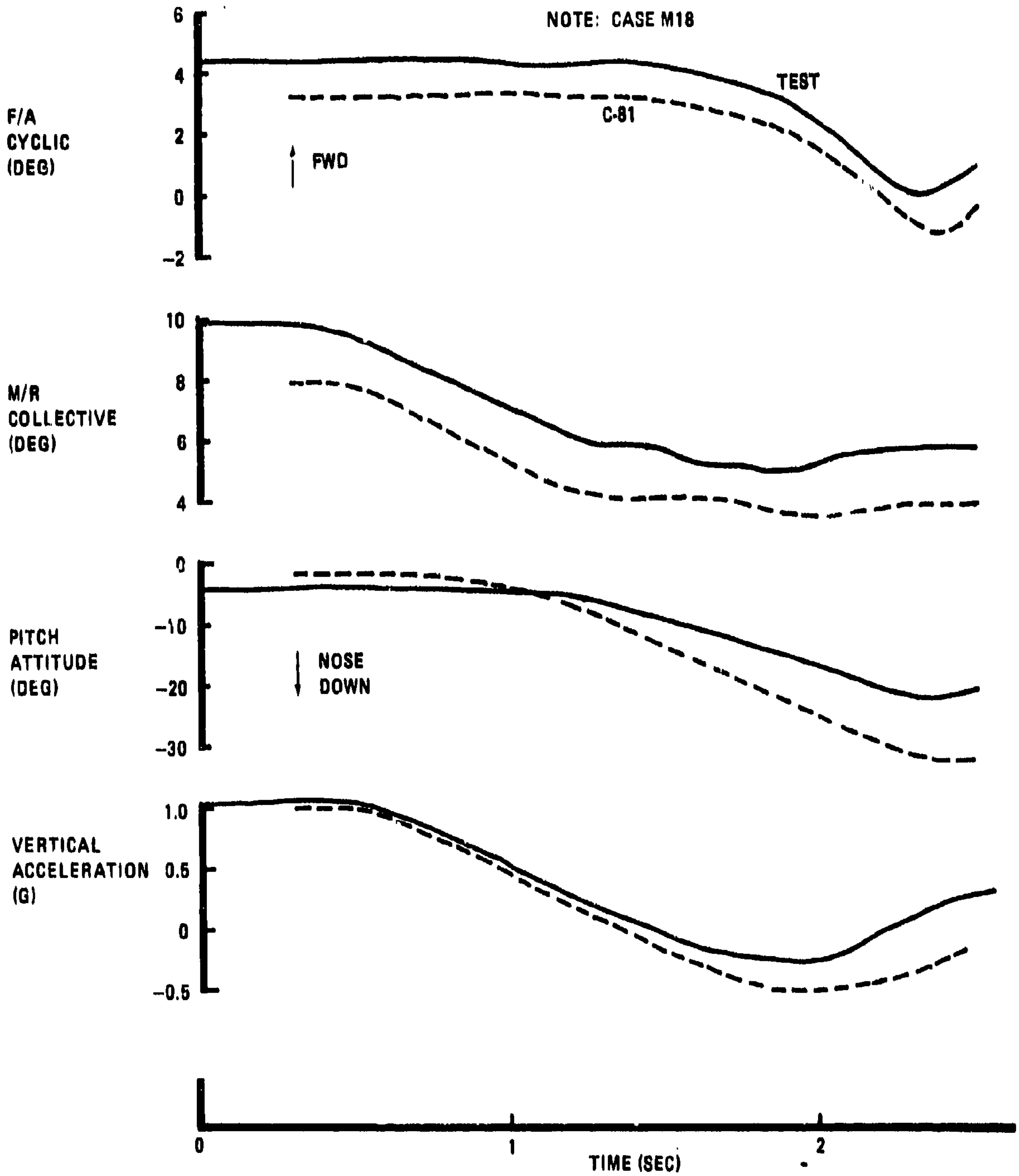

Figure 53. Collective Pitch Dump at 100 Knots.

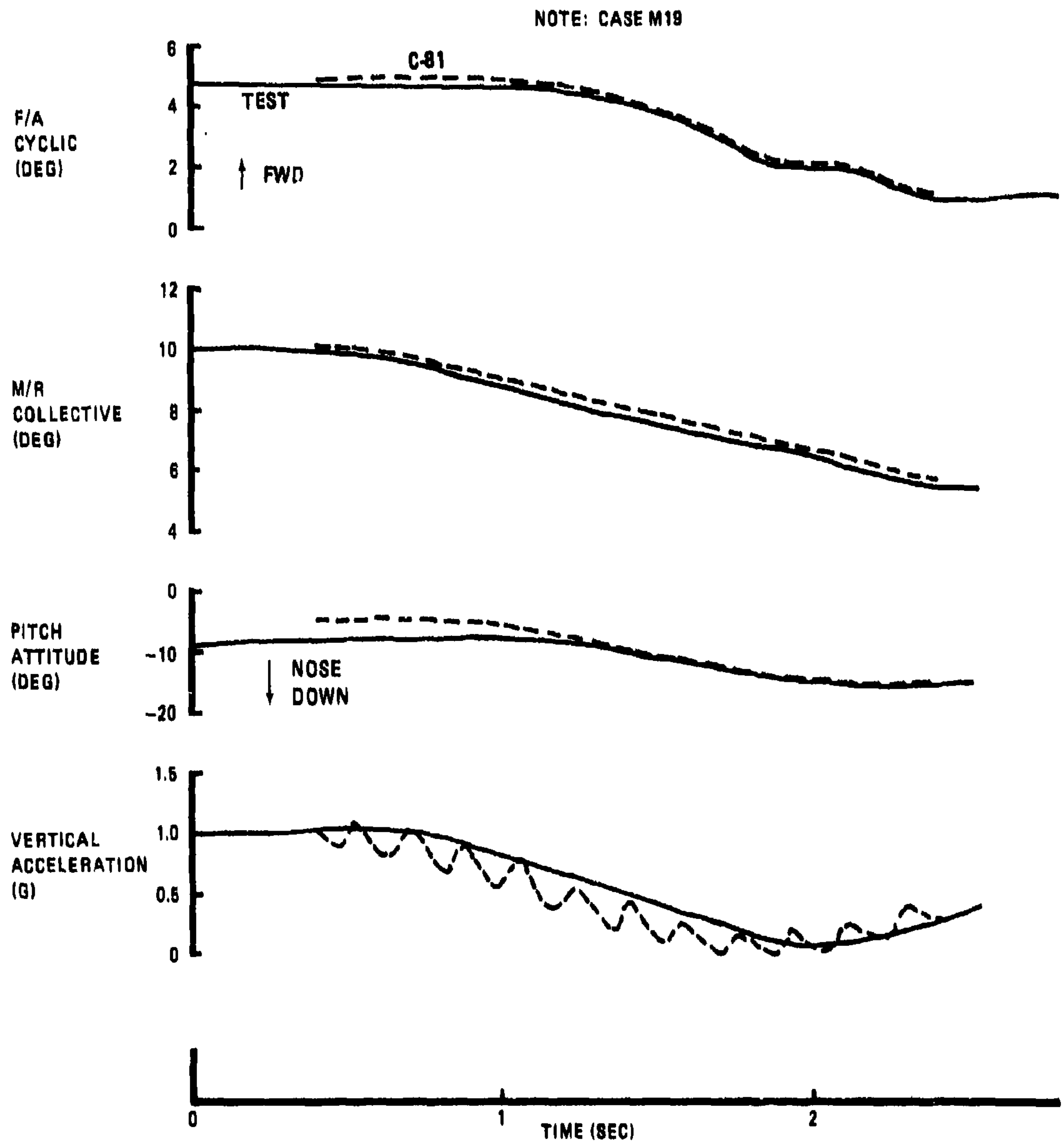

Figure 54. Collective Pitch Dump at 123 Knots.

Figure 54 shows inputs and responses for a pitch dump at 123 knots. Results for pitch attitude and vertical acceleration are in reasonable agreement.

5.3 STABILITY AND CONTROL POWER

Two types of stability analyses were performed. The first stability analyses were performed following a trimmed flight condition to obtain results for stability derivatives and control power. These C-81 results were compared with results obtained from Boeing Vertol's Y-92 single-rotor helicopter trim program (Reference 15). Pitch stability was also evaluated by comparing C-81 stability analysis results with test data for period and time to double amplitude. The second analysis included an aeroelastic stability investigation during transient or maneuver flight. In the maneuver, a full cycle of sinusoidal longitudinal and lateral cyclic excitation was separately introduced to excite the first chord mode of the main rotor. Decay of blade chord bending moments was then evaluated to determine the degree of stability of coupled rotor-airframe modes (aeroelastic stability).

5.3.1 Dynamic Pitch Stability

Figure 55 shows a comparison of test and analysis results for dynamic pitch stability. Test data are from Reference 5 for speeds from about 65 to 110 knots. Two C-81 stability analyses were run at 60 and 100 knots. The results show time to double amplitude and period for pitching motion. The C-81 result for period of pitching motion is in reasonable agreement with test data of 60 knots but is more than twice the test value at 100 knots. The C-81 result for time to double amplitude is low by a factor of more than two at 60 knots and appears to be too high at 100 knots. Apparently, the total rotor/fuselage aerodynamics are not indicating the same pitch damping and pitch stiffness for test and analysis results.

5.3.2 Stability Derivatives and Control Power

Stability derivatives and control power were computed using C-81 for hover and 100 knots. Stability derivatives are the changes in aircraft forces and moments per unit change in aircraft translational velocities and aircraft rotational rates. Control power is the change in aircraft forces and moments per unit change in control position.

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15. Memorandum 8-7433-1-234, SINGLE ROTOR TRIM AND STABILITY ANALYSIS, IBM Program Y-92, Boeing Vertol Company, Philadelphia, Pa., Sept. 1973.

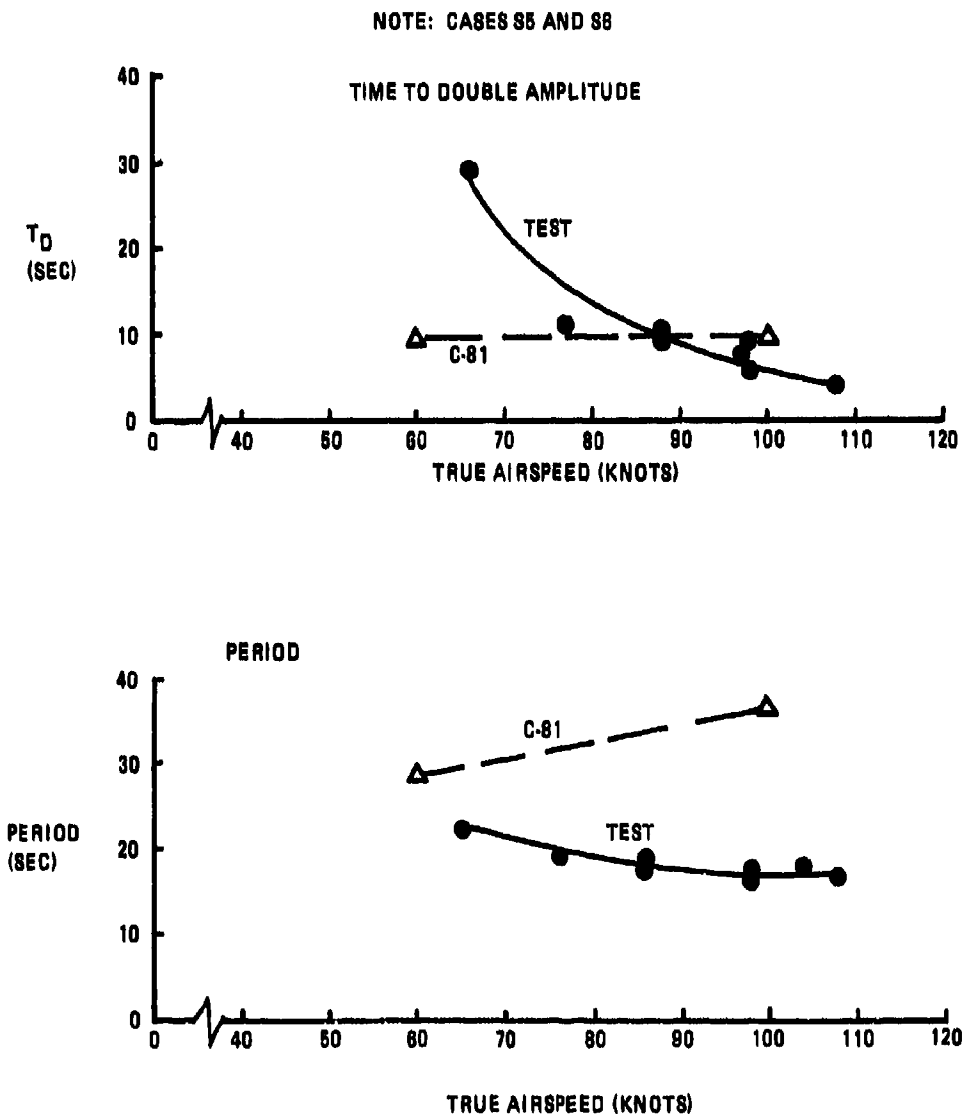

Figure 55. Dynamic Pitch Stability.

Stability derivatives were also computed using Boeing Vertol's Y-92 single hingeless rotor helicopter trim program, which uses a rigid blade equivalent hinge offset method to represent the hingeless rotor. The same fuselage aerodynamic data tables used to derive C-81 fuselage aerodynamic equation coefficients were used in Y-92 for the fuselage aerodynamics. However, after stability derivatives and control power results were obtained from the two programs, significant differences were noted when comparing results. The differences were found to be due to a difference in the definitions and assumptions made in the two programs.

In C-81, the stability derivatives and control power are computed based on the assumption that rotor flapping does not change; i.e., rotor flapping components are independent degrees of freedom. In Vertol's Y-92 program, the assumption is made that the main rotor is free to flap in response to changes in aircraft velocities, rates, and control positions. This yields fundamental differences, particularly in the stability derivatives and control power for pitch and roll moments.

A change in the C-81 program was provided which would make C-81 give results with blades free to flap. However, this change could not be incorporated into C-81 at Boeing Vertol in time to provide results for an appropriate comparison with Y-92 results under this study. Results which were obtained from C-81 with blade flapping restrained and from Y-92 are documented in Tables 8 through 13 for use in any further study which might be made of this problem. The large differences in pitch moment due to longitudinal (F/A) cyclic and roll moment due to lateral cyclic should be noted.

5.3.3 Aeroelastic Stability

Aeroelastic stability (sometimes called air resonance due to its counterpart, ground resonance) refers to the stability of modes where blade lead-lag motion is coupled with fuselage motion, particularly aircraft roll. Unpublished test data was available for the BO-105 to evaluate aeroelastic stability; these tests were discussed in Reference 16.

In recent years, a considerable effort has been devoted to the study of aeroelastic stability of hingeless rotor helicopters. C-81 has been used by Boeing Vertol in the study of this problem. In the BO-105 aeroelastic stability tests, about 10 cycles of sinusoidal lateral and longitudinal cyclic excitation were separately introduced at a frequency which would excite the main rotor first chord mode. The excitation would

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16. Lytwyn, R. T., Miao, W., Woitsch, W., AIRBORNE AND GROUND RESONANCE OF HINGELESS ROTORS, Presented at the 26th Annual National Forum, American Helicopter Society, Washington, D.C., June 1970.

TABLE 8. STABILITY DERIVATIVES IN HOVER (4740 POUNDS GROSS WEIGHT; CASE S7)

Force or Moment	Computer Program No.	Aircraft Velocities and Rates					
		U	W	Q	V	P	R
$\frac{x}{m}$	C-81	−0.0554	0.0403	0.245	−0.0302	−2.05	−0.0871
	Y-92	−0.0206	0.0113	1.67	0.0009	−0.63	−0.074
$\frac{z}{m}$	C-81	0.0843	−0.234	0.774	0.0366	0.983	3.59
	Y-92	0.00841	−0.296	−0.84	−0.0070	−0.071	2.35
$\frac{M}{I_{YY}}$	C-81	0.0142	−0.0157	−0.104	0.0070	0.065	0.025
	Y-92	0.025	−0.0047	−3.86	−0.0062	−0.038	−0.036
$\frac{y}{m}$	C-81	0.0138	−0.0060	0.0873	−0.0684	−0.684	1.37
	Y-92	−0.0045	−0.0033	−0.65	−0.028	−2.05	0.17
$\frac{L}{I_{XX}}$	C-81	0.0092	−0.0041	0.053	−0.031	−0.37	0.81
	Y-92	−0.020	−0.0017	0.13	−0.074	−10.9	−0.25
$\frac{N}{I_{ZZ}}$	C-81	−0.0175	0.0052	−0.082	0.046	0.26	−1.38
	Y-92	0.0017	0.0038	0.23	0.0084	0.14	−0.36

U	=	longitudinal velocity, fps	P	=	roll rate, rad/sec	m	=	aircraft mass, slug
V	=	lateral velocity, fps	Q	=	pitch rate, rad/sec			
W	=	vertical velocity, fps	R	=	yaw rate, rad/sec	I_{YY}	=	aircraft pitch inertia, slug−ft^2
x	=	longitudinal force, lb	L	=	roll moment, ft lb	I_{XX}	=	aircraft roll inertia, slug−ft^2
y	=	lateral force, lb	M	=	pitch moment, ft lb			
z	=	vertical force, lb	N	=	yaw moment, ft lb	I_{ZZ}	=	aircraft yaw inertia, slug−ft^2

TABLE 9. STABILITY DERIVATIVES AT 100 KNOTS (4740 POUNDS GROSS WEIGHT; CASE S9)

Force or Moment	Computer Program No.	Aircraft Velocities and Rates					
		U	W	Q	V	P	R
$\frac{x}{m}$	C-81	−0.0335	−0.043	0.32	0.0063	0.198	−0.173
	Y-92	−0.0478	0.010	2.18	0.0020	−0.41	−0.067
$\frac{z}{m}$	C-81	0.053	−1.037	0.909	−0.0029	−0.798	3.85
	Y-92	−0.013	−0.791	0.26	0.0098	−2.36	1.82
$\frac{M}{I_{YY}}$	C-81	−0.0009	−0.0378	−0.554	−0.0015	−0.0536	0.0060
	Y-92	0.023	0.0189	4.20	−0.0012	0.86	0.044
$\frac{y}{m}$	C-81	0.0077	−0.0425	2.59	−0.147	−0.698	1.498
	Y-92	0.0172	−0.0022	0.37	−0.024	−0.784	0.778
$\frac{L}{I_{XX}}$	C-81	−0.0005	−0.023	0.077	−0.052	−0.480	0.856
	Y-92	0.0016	−0.020	0.090	−0.082	−6.21	0.301
$\frac{N}{I_{ZZ}}$	C-81	−0.005	−0.0060	0.0494	0.0711	0.382	−1.415
	Y-92	−0.013	−0.0137	−0.197	0.0216	−0.556	−0.857

TABLE 10. CONTROL POWER IN HOVER
(4740 POUNDS GROSS WEIGHT; CASE 87)

Force or Moment	Computer Program No.	Main Rotor Collective	Longitudinal Cyclic	Lateral Cyclic	Pedal
X Force	C-81	0.628	0.464	−0.277	0.0344
	Y-92	0.263	0.788	−0.0203	−0.1272
Y Force	C-81	−0.0953	0.273	0.474	3.77
	Y-92	−0.0514	0.019	0.785	−1.73
Z Force	C-81	−13.66	0.172	0.119	−0.725
	Y-92	−8.60	0.00173	0.004	−0.012
Yaw Moment	C-81	0.705	−0.0211	−0.0290	−3.40
	Y-92	0.660	−0.00909	0.0355	1.60
Pitch Moment	C-81	−0.187	−0.0877	0.0542	−0.0996
	Y-92	−0.182	−0.989	0.2080	0.0750
Roll Moment	C-81	−0.143	0.147	0.2529	2.25
	Y-92	−0.156	0.573	2.711	−1.15

NOTE: Values are divided by appropriate mass or inertia values and are in units of ft/sec^2 or rad/sec^2 per inch of control motion.

TABLE 11. CONTROL POWER IN HOVER
(4300 POUNDS GROSS WEIGHT; CASE 88)

Force or Moment	Computer Program No.	Main Rotor Collective	Longitudinal Cyclic	Lateral Cyclic	Pedal
X Force	C-81	0.712	0.493	−0.284	−0.0017
	Y-92	0.312	0.799	−0.024	−0.137
Y Force	C-81	−0.0935	0.286	0.496	4.16
	Y-92	−0.0405	0.028	0.782	−1.88
Z Force	C-81	−15.25	0.046	−0.00338	−0.0034
	Y-92	−9.32	0.0999	−0.00984	−0.0191
Yaw Moment	C-81	0.680	−0.0124	−0.0198	−3.45
	Y-92	0.584	0.0082	0.0377	1.57
Pitch Moment	C-81	−0.171	−0.0847	0.502	−0.084
	Y-92	−0.182	−0.974	0.208	0.088
Roll Moment	C-81	−0.133	0.139	0.240	2.28
	Y-92	−0.131	0.580	2.668	−1.13

NOTE: Values are divided by appropriate aircraft mass or inertia values and are in units of ft/sec^2 or rad/sec^2 per inch of control motion.

TABLE 12. CONTROL POWER AT 100 KNOTS
(4740 POUNDS GROSS WEIGHT; CASE S9)

Force or Moment	Computer Program No.	Main Rotor Collective	Longitudinal Cyclic	Lateral Cyclic	Pedal
X Force	C-81	0.512	0.133	−0.323	−0.117
	Y-92	−0.346	0.777	−0.0807	−0.023
Y Force	C-81	−0.665	0.378	0.343	4.41
	Y-92	−0.244	0.130	0.809	−2.29
Z Force	C-81	−15.4	4.01	0.902	−1.21
	Y-92	−0.117	2.82	0.604	0.021
Yaw Moment	C-81	0.462	−0.0792	−0.144	−4.02
	Y-92	0.376	0.0313	−0.0144	2.1
Pitch Moment	C-81	−0.166	−0.0136	0.0630	−0.0448
	Y-92	0.882	−1.081	0.2026	0.0355
Roll Moment	C-81	−0.420	0.203	0.194	2.68
	Y-92	−0.724	0.626	2.73	−1.53

NOTE: Values are divided by appropriate aircraft mass or inertia values and are in units of ft/sec^2 or rad/sec^2 per inch of control motion.

TABLE 13. CONTROL POWER AT 100 KNOTS
(4300 POUNDS GROSS WEIGHT; CASE S10)

Force or Moment	Computer Program No.	Main Rotor Collective	Longitudinal Cyclic	Lateral Cyclic	Pedal
X Force	C-81	0.597	0.134	−0.350	−0.119
	Y-92	−0.279	0.765	−0.0712	−0.043
Y Force	C-81	−0.687	0.393	0.361	4.87
	Y-92	−0.228	0.129	0.824	−2.52
Z Force	C-81	−16.94	4.42	0.985	−1.35
	Y-92	−12.96	3.12	0.536	0.016
Yaw Moment	C-81	0.436	−0.074	−0.129	−4.02
	Y-92	0.35	0.021	−0.014	2.09
Pitch Moment	C-81	−0.160	−0.0104	0.0627	−0.044
	Y-92	0.854	−1.081	0.195	0.033
Roll Moment	C-81	−0.395	0.191	0.183	2.88
	Y-92	−0.683	0.613	2.70	−1.52

NOTE: Values are divided by appropriate aircraft mass or inertia values and are in units of ft/sec^2 or rad/sec^2 per inch of control motion.

be terminated and the rate of decay of blade flap and lag bending moments and aircraft pitch and roll motion would be observed.

Figure 56 shows C-81 results for the time histories of flap bending moment, chord bending moment, aircraft pitch, and aircraft roll after a full cycle of ± 1 degree of lateral cyclic at a frequency of 2.0 Hz. The cycle of lateral cyclic is introduced just after the maneuver computation in C-81 is started. This sinusoidal cyclic is superimposed on the trim value of lateral cyclic. Of the four parameters monitored, chord bending moment decay after the full cycle of lateral cyclic is the best indicator of the degree of stability.

Before the lateral cyclic was introduced, there was a background level of 1/rev chord bending moment. The transient response at the chord mode frequency of about 0.7/rev is superimposed on this 1/rev oscillation, and the signal which results has a beat at the difference frequency. The envelope of these superimposed 0.7 and 1.0/rev oscillations will decay at the rate of decay of the 0.7/rev oscillation. Thus the decay of the envelope determines the degree of stability of the air resonance mode.

The decay of the C-81 chord bending moment indicates 2.26 percent critical damping at 55 knots. Corresponding test results are shown in Figure 57, where lateral cyclic input and flap and chord bending moments are shown. Chord bending moment decay curves indicate a critical damping ratio of 3.37 percent. Figures 58 through 63 show similar results for decay after longitudinal cyclic excitation at 55 knots and for lateral and longitudinal cyclic excitation at 110 knots. Test data were averaged for damping on two opposite blades.

Figure 64 summarizes C-81 and test results for air resonance mode damping values based on decay of chord bending moments. Possible reasons for the differences between test and analysis results for aeroelastic stability include: 1) a different test value of inherent blade modal damping than the 1.0% assumed in input data for the C-81 analysis, 2) effects of airframe flexibility not included in the C-81 analysis, 3) a manual analysis of test and C-81 data was conducted to obtain damping results; analysis of the decaying waveforms should be automated to obtain accurate results, and 4) incorrect representation of the blade flap/pitch coupling in the data input to C-81 for the main rotor blade.

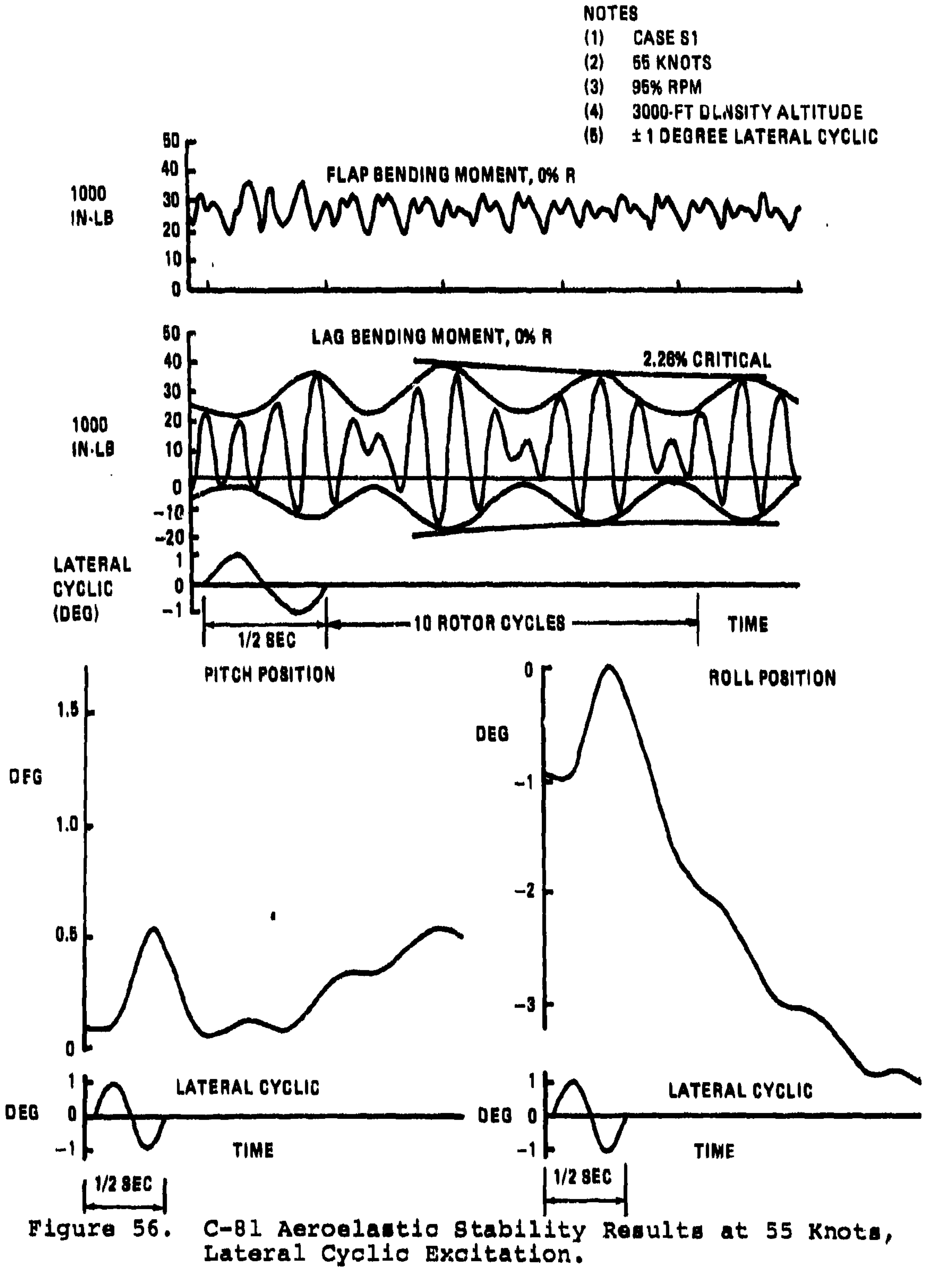

Figure 56. C-81 Aeroelastic Stability Results at 55 Knots, Lateral Cyclic Excitation.

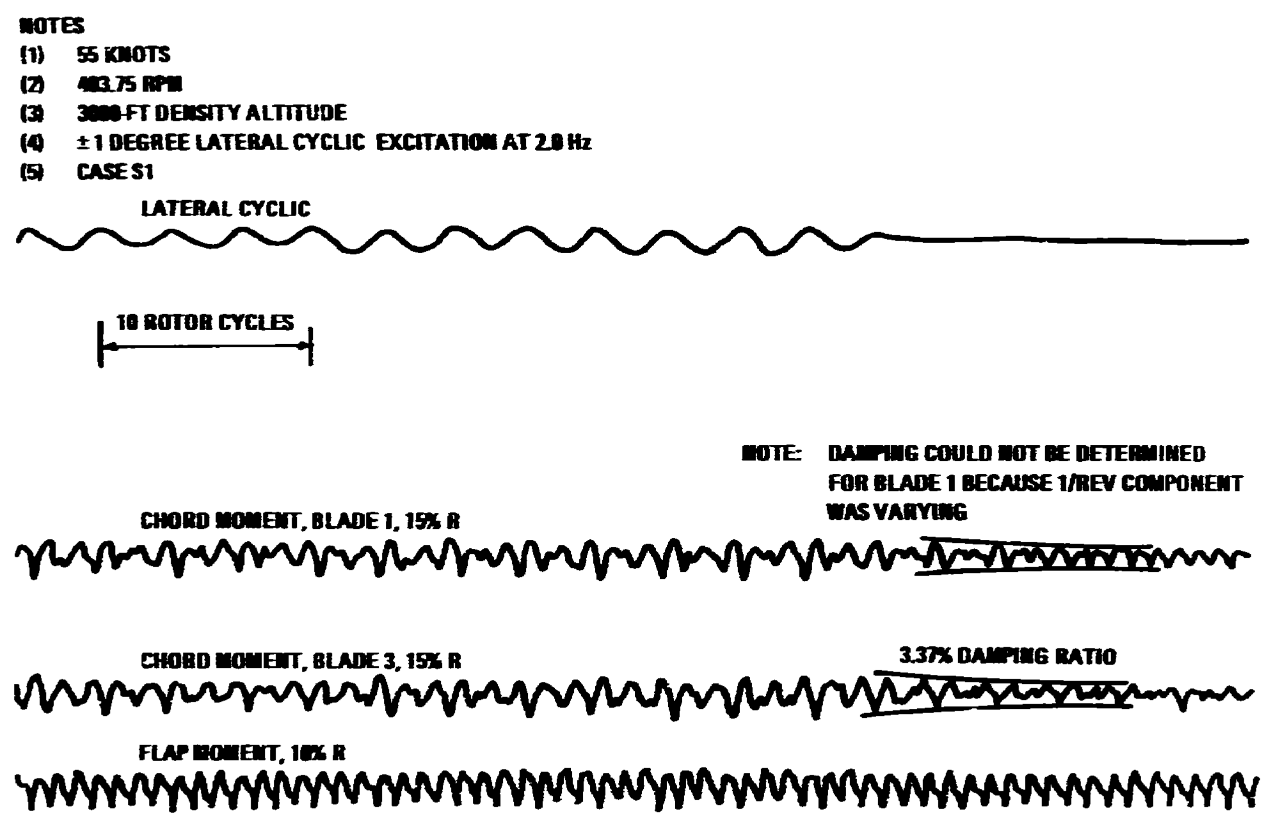

Figure 57. Test Aeroelastic Stability Results at 55 Knots, Lateral Cyclic Excitation.

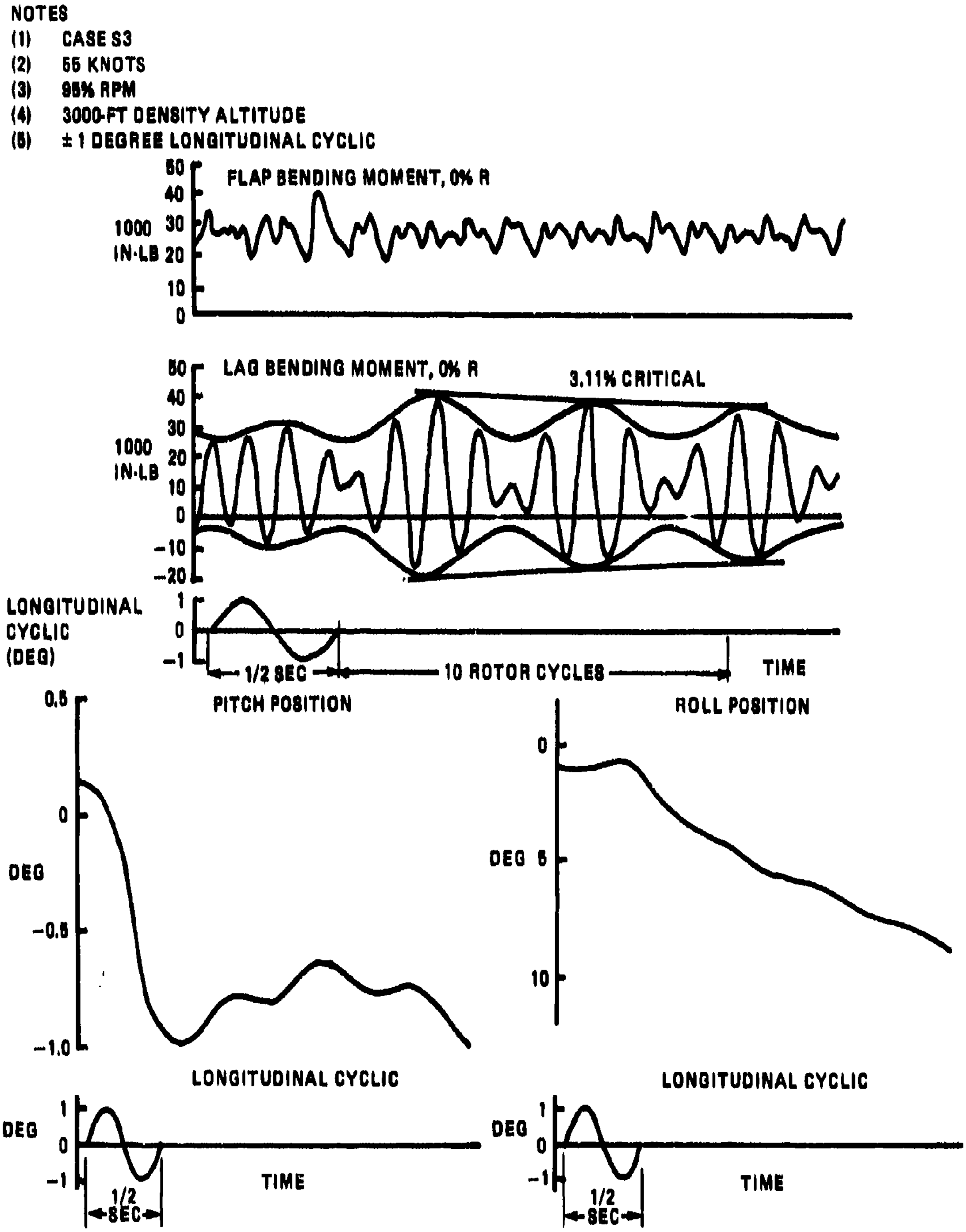

Figure 58. C-81 Aeroelastic Stability Results at 55 Knots, Longitudinal Cyclic Excitation.

NOTES

(1) 55 KNOTS
(2) 403.75 RPM
(3) 3000-FT DENSITY ALTITUDE
(4) ±1 DEGREE LONGITUDINAL CYCLIC EXCITATION AT 2.8 Hz
(5) CASE S3

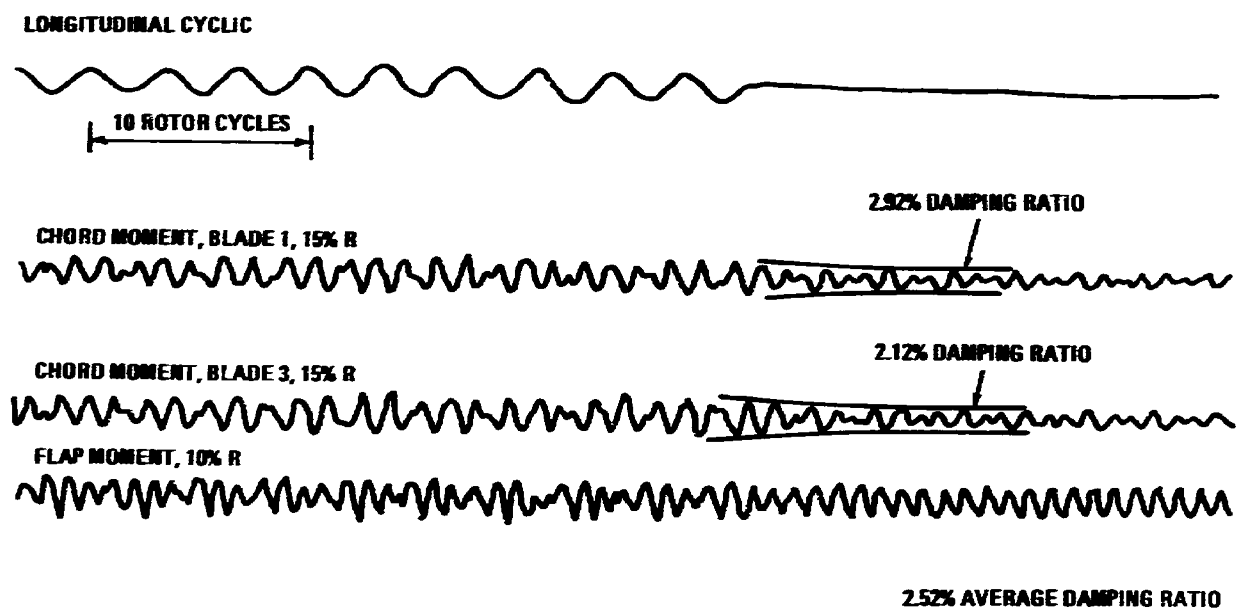

Figure 59. Test Aeroelastic Stability Results at 55 Knots, Longitudinal Cyclic Excitation.

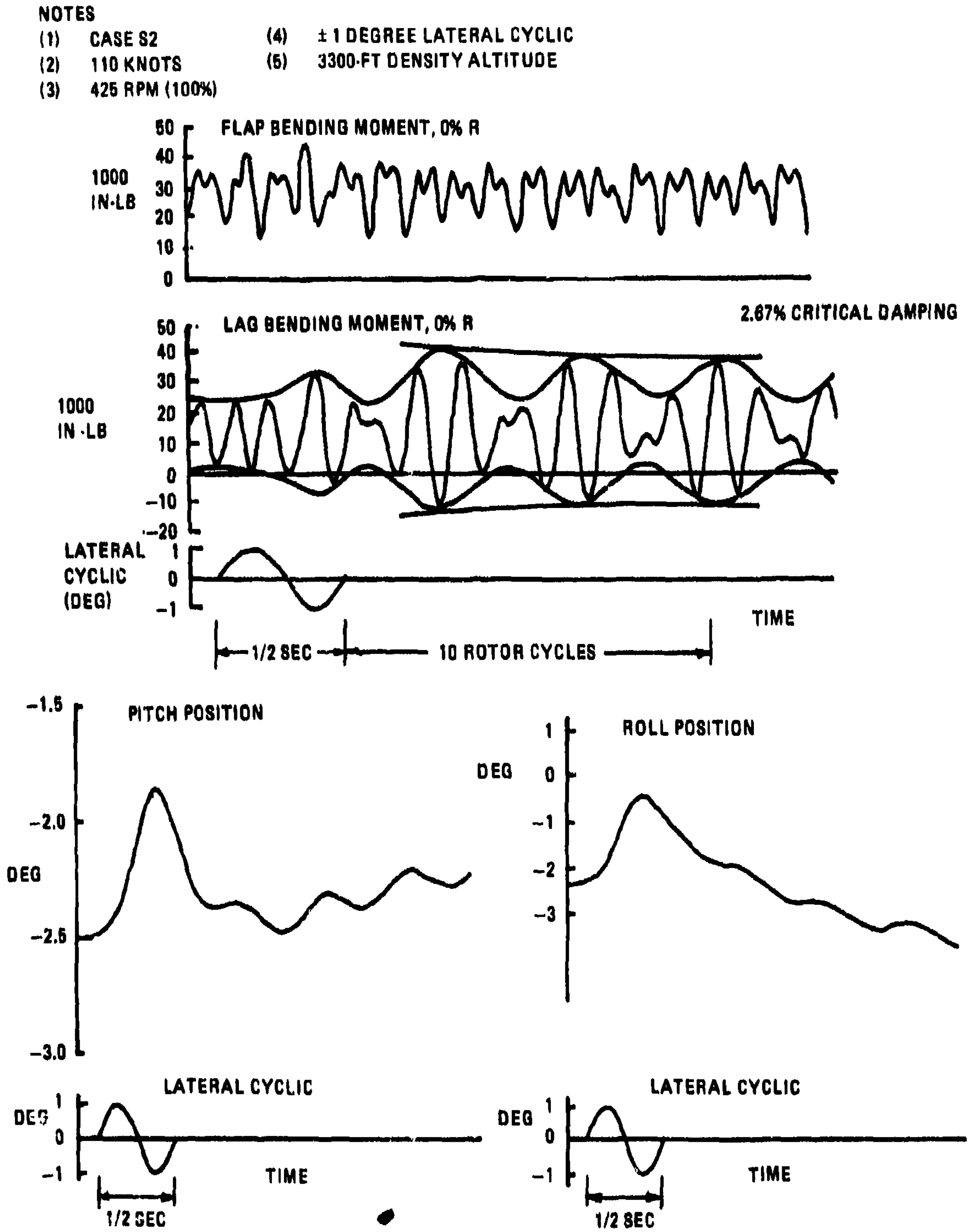

Figure 60. C-81 Aeroelastic Stability Results at 110 Knots, Lateral Cyclic Excitation.

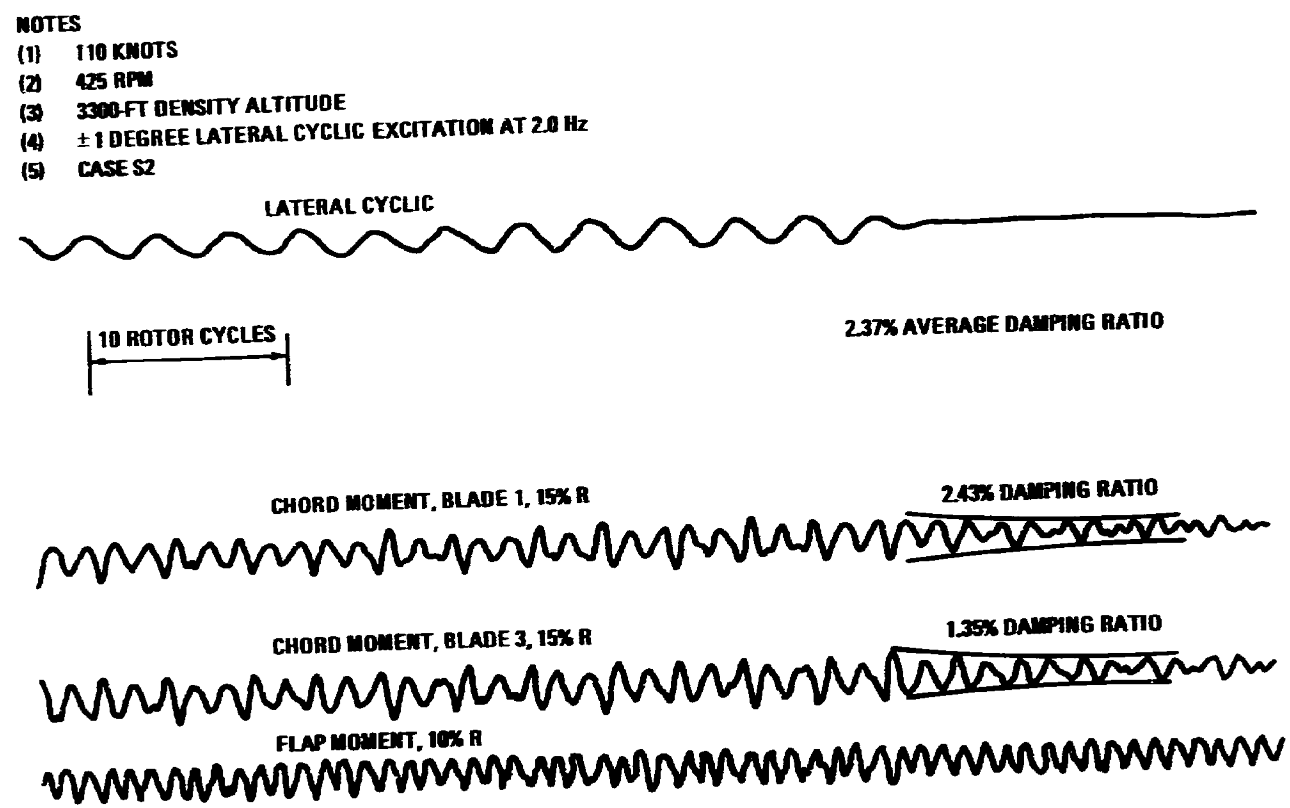

Figure 61. Test Aeroelastic Stability Results at 110 Knots, Longitudinal Cyclic Excitation.

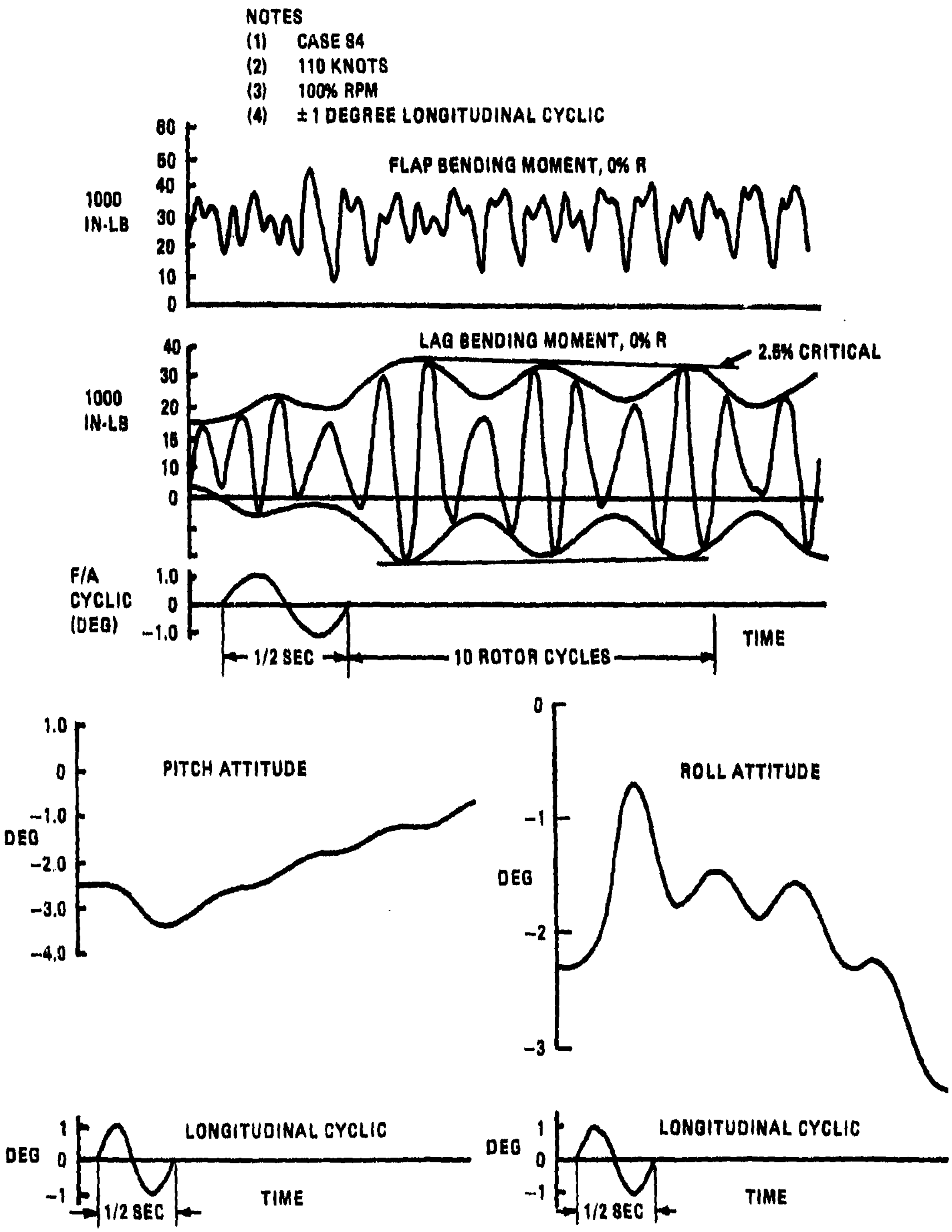

Figure 62. C-81 Aeroelastic Stability Results at 110 Knots, Longitudinal Cyclic Excitation.

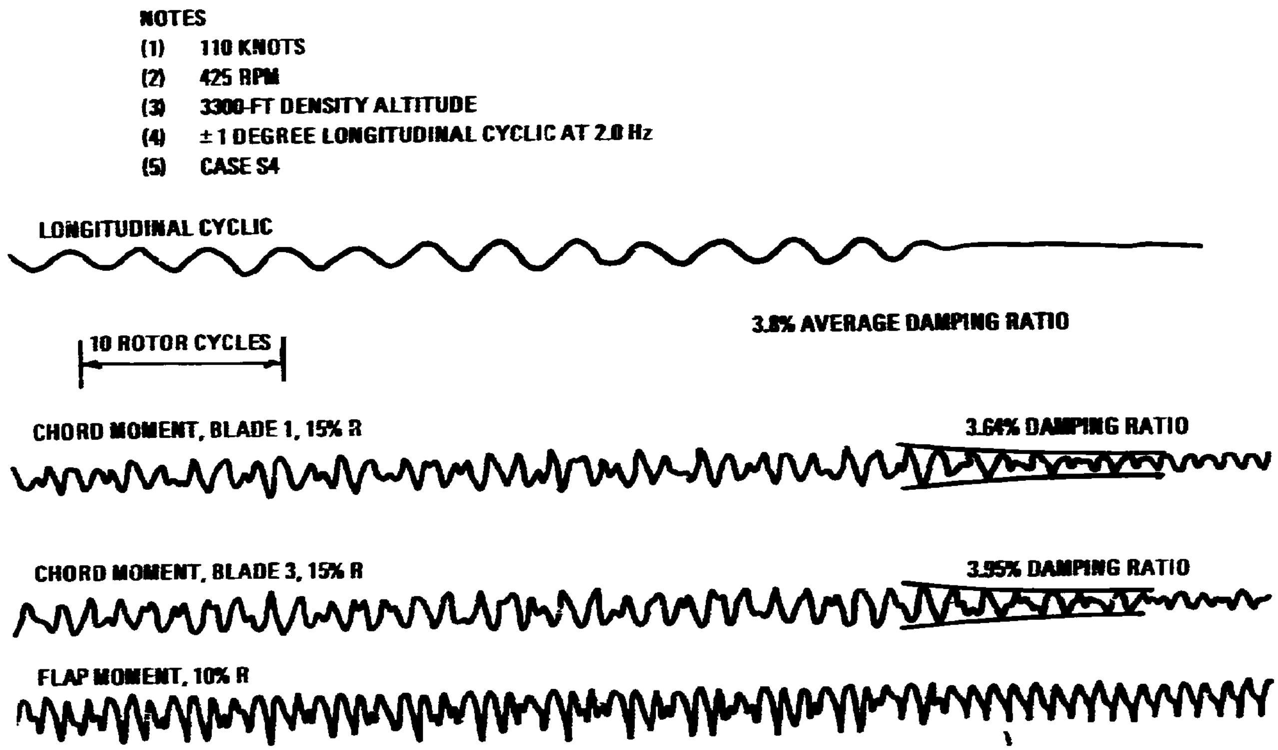

Figure 63. Test Aeroelastic Stability Results at 110 Knots, Longitudinal Cyclic Excitation.

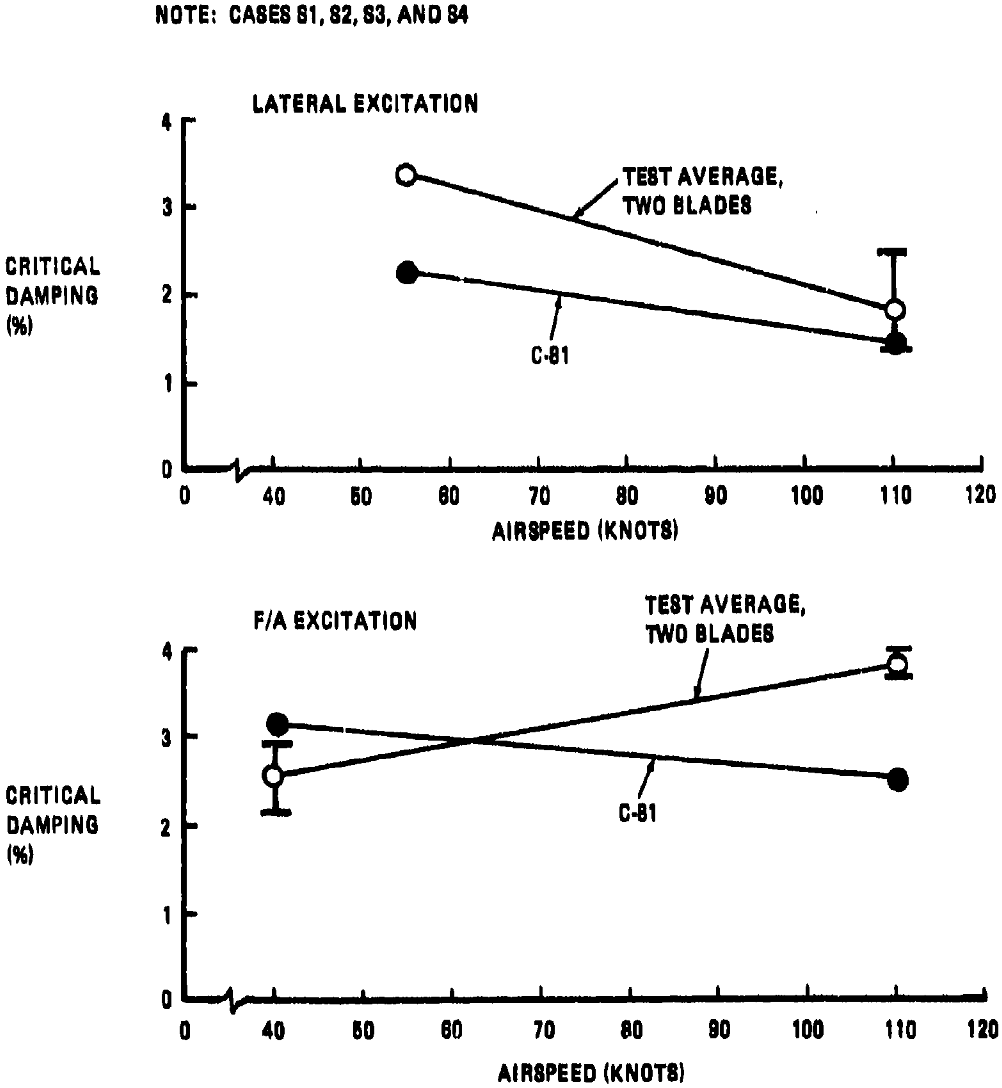

Figure 64. Summary of Test and C-81 Air Resonance Mode Damping Results.

6. CONCLUSIONS AND RECOMMENDATIONS

The 300K version of C-81 was used to study loads, performance, and stability of the BO-105 hingeless single-rotor helicopter. Analytical results were compared with available flight test data, and where no flight test data were available, with results from Boeing Vertol analytical programs. Conclusions and recommendations are as follows.

6.1 AIRCRAFT TRIM

Aircraft trim for level flight was predicted reasonably accurately by C-81. Test and analysis results for main rotor lateral and longitudinal cyclic, main and tail rotor collective, and aircraft pitch attitude were good for speeds from hover to 120 knots.

6.2 MAIN ROTOR BLADE LOADS, LEVEL FLIGHT

For a hingeless rotor, this program generally provides fair flap bending moment predictions, although chord bending moment and control load predictions are poor.

The flap bending moment predictions are good for 1/rev and generally poor for 2/rev and larger. For hingeless rotors, the 1/rev component of flap bending moment is by far the largest. Therefore, the flap bending moment amplitude is dominated by the good 1/rev predictions, resulting in good correlation of calculated flap bending moment amplitudes with test results. However, due to the poor higher harmonic bending moment predictions, care should be exercised when using this program for hingeless rotor blade design. This is especially critical when the blade design has a flap natural frequency near an integer multiple of the rotor speed, and the possibility of large higher harmonic loads is of concern. This higher harmonic deficiency may be due to the simplified rotor downwash representation used in this version of C-81.

Alternating and 1/rev chord bending moments were significantly overpredicted, and could not be used for hingeless rotor blade design.

Pitch link loads showed a large overprediction at low speed (3 to 1) and large underpredictions at high speed (1 to 2). In addition, the predicted waveform is predominantly 3/rev while the test data are almost totally 1/rev. It is clear that the predicted control system loads could not be used for design.

6.3 POWER REQUIRED IN LEVEL FLIGHT

C-81 computations for power required in level flight are in agreement with results reported in Reference 11 at hover, 60 knots, and 140 knots, but C-81 results are lower than reported in Reference 11 at 30 and 90 knots.

6.4 BANKED TURNS

For banked turns at 1.4 to 1.8g's, C-81 predicted main rotor shaft moments are generally lower than indicated by test data by about 30 percent. Predicted main rotor blade flap moment at 10 percent radius and longitudinal cyclic are in reasonable agreement with test data. The predicted chord bending moment at 15 percent radius is about 2 to 3 times higher than test data. Lateral cyclic predicted by C-81 is different from test data by about 1.0 to 2.0 degrees. This may be due to the low torsional stiffness of the BO-105 main rotor blade and the blade chordwise cg/aerodynamic center differences not accounted for in the C-81 program.

6.5 RATE OF CLIMB AND FLIGHT ENVELOPE

C-81 results indicated a maximum rate of climb of about the same value and at the same speed indicated by test data. For the BO-105, C-81 indicated about the same flight envelope near maximum speed as that reported in Reference 4.

6.6 CONTROL RESPONSE

C-81 analyses for response to longitudinal, lateral, and tail rotor inputs in hover and at 100 knots indicated:

1. Significant pitch/roll coupling not reported in test data. This may be due to blade chordwise cg/aerodynamic center differences not represented in C-81.

2. Apparent numerical integration instability when using an integration interval of $\Delta\psi = 30$ degrees with the highest frequency main rotor mode at 3.87/rev.

Results for pitch dump cases at 80, 100, and 123 knots showed reasonable agreement for vertical acceleration, and generally larger changes in pitch attitude than indicated by test. This again may be due to blade cg/aerodynamic center differences not represented in C-81.

6.7 DYNAMIC PITCH STABILITY

Results from the C-81 stability analysis for dynamic pitch stability at 60 and 100 knots indicated:

1. A predicted pitching frequency of more than twice the test value at 100 knots; better agreement at 60 knots.

2. A predicted time to double amplitude of about half the test value at 60 knots; better agreement at 100 knots.

The above differences may also be due to blade chordwise cg/aerodynamic center differences not accounted for by C-81.

6.8 STABILITY DERIVATIVES AND CONTROL POWER

Comparison of values from C-81 for stability derivatives and control power with results from Boeing Vertol's Y-92 trim program showed significant differences. These differences are attributed to the fact that blades are not allowed to flap during these calculations in C-81 (i.e., the values of blade flapping are held at the trimmed condition), while blades are allowed to flap during these calculations in Y-92. Programming changes were provided for the C-81 program to allow blade flapping response to control inputs and aircraft motions in stability derivative and control power calculations, but they were received too late to make program changes at Boeing Vertol and to rerun stability derivative cases.

6.9 AEROELASTIC STABILITY

Damping of air resonance modes was evaluated by introducing sinusoidal cyclic excitation at a frequency near the main rotor blade first chord mode natural frequency. Damping was determined from the rate of blade chord bending moment decay after the excitation was terminated. At 55 and 110 knots, damping indicated by C-81 results was approximately the same as indicated by test data.

6.10 GENERAL COMMENTS

1. C-81 appears to give good results for trim and performance.

2. Blade load calculations at frequencies of 4/rev and higher might improve with a better induced-velocity representation (which could be obtained using the 600K version of C-81).

3. Time history (maneuver) cases were expensive to run, and results probably would have been improved with reduced integration interval (long running time).

4. The C-81 input section termed Iteration Logic Group, which sets the computer program trim solution convergence parameters, should be discussed in more detail in the C-81 user's manual. Separate inputs for force and moment should be specified for the variable damper in the Iteration Logic Group. This term defines the maximum error allowed in force or moment balance about the fuselage cg before the trim correction limit is halved. Since the moment error is likely to be numerically larger than the force error, the moment error will dominate in this test to determine when the maximum allowed correction for collective, cyclic, etc., is halved in the trim analysis.

5. The program does not appear to have the capability to account for a chordwise variation in elastic axis, cg, and aerodynamic center with blade radius. These variations affect calculation of blade torsional moments, torsional deflections, trim, pitch link loads, and aerodynamic moment about the mass center. If the mass and aerodynamic centers are not coincident, a transfer of aerodynamic coefficients should be made to compute the aerodynamic pitching moment about the mass center. The cg/aerodynamic center differences may affect maneuver and trim calculations.

6. Manuals provided with the C-81 program were generally well written. A fairly good understanding of the program and its use results after reading the program manuals and initial use of the program. More detailed flow diagrams should be provided along with equations and derivations for each subroutine.

7. Computer run time was typically as follows (IBM 370-158 computer):

Computation	Computer CPU Time (Seconds)
• Quasi-static, time-variant trim	208
• Quasi-static trim followed by a stability analysis	176
• Quasi-static, time-variant trim followed by a 2.0-second maneuver, 30-degree integration interval at 425 rpm	776

8. A limited amount of data was available for evaluating the sensitivity of analytical results to helicopter input data. Cases run to obtain results for comparison with test data were generally run to match specific flight test conditions rather than to study effects of variations in helicopter parameters. C-81 cases which were run included variations in gross weight and cg. Figure 65 shows effects of gross weight variations from 4300 to 4750 lb on trim. Figure 66 shows effects of a cg variation of from 2.95 inches forward to 3.9 inches aft. These sensitivities may be used to assess the effects of any assumed errors in reported test values for gross weight and cg location on test versus analysis trim comparisons.

9. The engineering time required to prepare the BO-105 basic input data deck for C-81 is summarized below. Times are based on receiving new documentation for a new version of the program, generating new blade modal data, and converting existing fuselage wind tunnel data to C-81 input data. Since more than one person worked on preparing input data, some duplication of time was required for studying program documentation. Five engineers were involved in preparing various portions of detailed input to the C-81 program for the BO-105 analysis.

	TASK	MAN-HOURS
a.	Read documentation to understand program methods being used and detailed input data requirements.	80
b.	Prepare airfoil tables from test data.	80
c.	Process wind tunnel fuselage data and convert to C-81 input format.	80
d.	Define fuselage weight and inertia data.	20
e.	Define main rotor blade modal data.	40
f.	Prepare rotor airfoil aerodynamic subgroups (this set of input appears to be almost entirely redundant if airfoil tables are used, and it is suggested the program compute these constants, if they are required, from airfoil tables).	40

TASK	MAN-HOURS
g. Prepare data for main rotor group, tail rotor group, stabilizing surface, control linkage, iteration logic, and flight constants.	60
Total	400

The time required to prepare data would be considerably less after familiarity with documentation and experience in running C-81 had been gained. Each data item listed above might require more or less time depending on the availability and status of data required. For example, if airfoil tables existed in punched card form in the detail required for input to C-81 but not in the correct format, a small computer program could be written to convert these data to C-81 input data on punched cards. In such a case, less engineering time would be required to prepare airfoil tables than indicated above.

6.11 RECOMMENDATIONS

The following recommendations are made for further validation of the C-81 program for hingeless rotor helicopters in areas where differences between test and analysis results occurred during this study:

1. The 600K version of C-81 with input induced-velocity tables should be used to compute higher harmonics of blade flapping moments; these are important for computing vibratory hub loads on hingeless rotors with four or more blades.

2. The changes to C-81 which will allow computation of stability derivatives and control power should be implemented (they are available), and results with these changes should be compared with other available results.

3. The program should read in data for rotor blade chordwise mass cg and aerodynamic center offsets, and should make use of these in blade load and maneuver calculations.

4. Additional testing of a hingeless rotor helicopter should be considered to obtain a specific data base for evaluation of helicopter simulation programs. This test program should include a comprehensive set of data for performance, rotor system loads, and stability.

5. The causes of discrepancies between test and analysis for maneuvers should be more thoroughly evaluated. The time history (maneuver) portion should be made more efficient (lower run time) so that its use could become more practical.

6. Additional work should be conducted in the area of level-flight blade load analysis and correlation with test data; additional test data are available for the BO-105 from tests conducted at Boeing Vertol. Analysis should cover the entire BO-105 speed range, particularly low speed, where loads tend to be high. Only a brief evaluation of the capability of C-81 to predict blade and pitch link load data was possible under the current study. A more detailed study should be conducted of the harmonic content of loads, and variation of loads with airspeed and cg position, gross weight, and altitude (C_T/σ).

NOTES:
(1) 100-KNOTS AIRSPEED
(2) 5,000-FT DENSITY ALTITUDE
(3) 2.95-IN. FWD CG

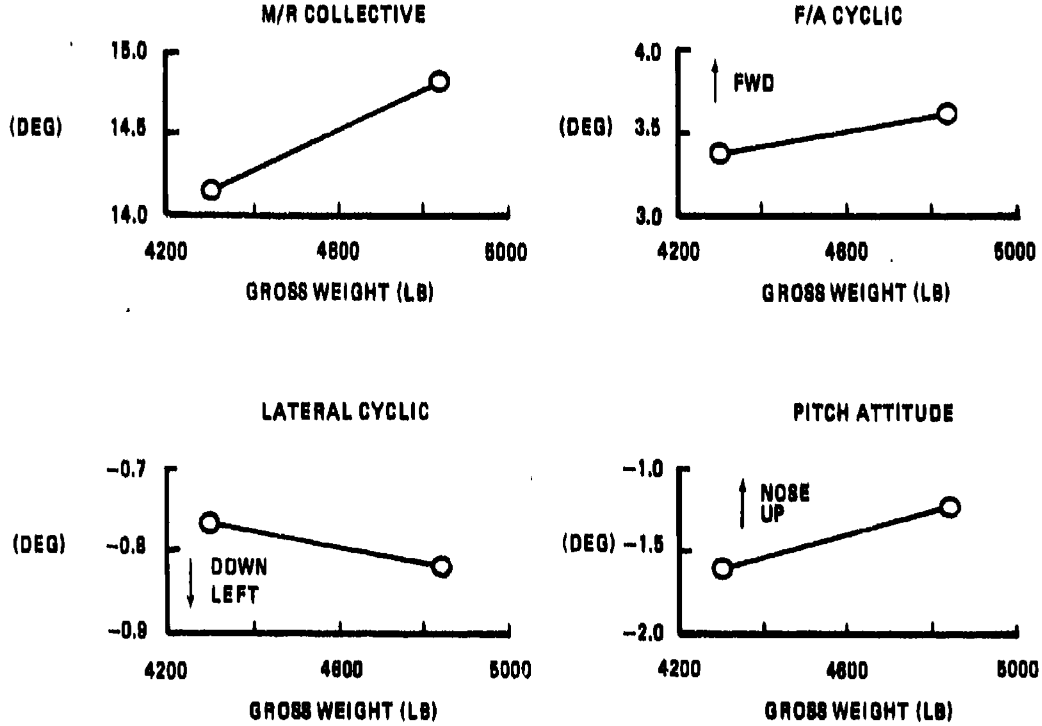

Figure 65. Effect of Gross Weight on C-81 Trim Results at 100 Knots.

NOTES:
(1) 100-KNOTS AIRSPEED
(2) 5,000-FT DENSITY ALTITUDE
(3) 4,740-LB GROSS WEIGHT

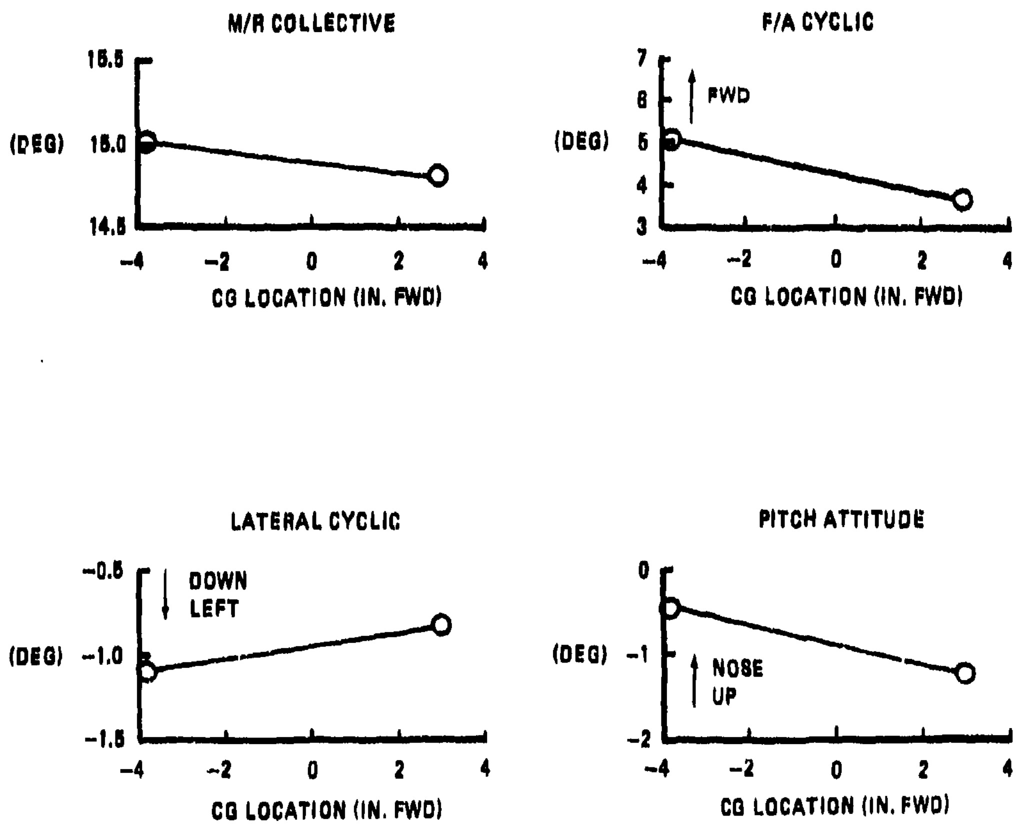

Figure 66. Effect of CG Location on C-81 Trim Results at 100 Knots.

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APPENDIX A

INPUT DATA AND LISTING OF INPUT DATA DECKS FOR SAMPLE CASES

A portion of the definitions and corresponding input data used for the BO-105 C-81 analysis is presented in this Appendix. The definitions of input data are reproduced from the C-81 user;s manual, Reference 2 of this report. Tables A-1, A-2, and A-3 list C-81 input data decks for typical trim, maneuver, and stability runs; cases T10, M3, and S8, respectively.

CARD 06 Input Group Control Logic (14I5 format)

IPL	(1)	Switch for reading reduced data deck (0 = off)	0
	(2)	Number of airfoil data tables (= 0, 1, 2, 3, 4, or 5)	1
	(3)	Number of M/R mode shape inputs (0 = none)	6
	(4)	Number of T/R mode shape inputs (0 = none)	0
	(5)	Switch for reading rotor-induced velocity distribution table (0 = off)	0
	(6)	Number of Rotor Airfoil Aerodynamic Subgroups (= 1, 2, 3, 4, or 5)	2
	(7)	Switch for deleting rotor groups (0 = off)	0
	(8)	Switch for reading rotor pylon cards (0 = off)	0
	(9)	Switch for reading wing inputs (0 = off)	0
	(10)	Switch for reading Stabilizing Surface inputs (0 = off)	-1
	(11)	Switch for reading Jet Group (0 = off)	0
	(12)	Number of Store/Brake subgroups (= 0, 1, 2, 3, or 4)	0
	(13)	Switch for reading Supplemental Rotor Controls subgroup (0 = off)	0
	(14)	Switch for reading maneuver input groups (0 = off)	0

CARD 07 Analysis Logic (14I5 format)

IPL	(15)	Flight condition indicator (0 = turn or unaccelerated flight)	0
	(16)	Euler angle iteration selector for TRIM (0 = holds yaw angle constant)	1
	(17)	Switch for computing partial derivative matrix (0 = every fifth iteration)	3
	(18)	Control variable for main rotor steady-state aerodynamics	1
	(19)	Control variable for tail rotor steady-state aerodynamics	2
	(20)	Switch for activating unsteady rotor aerodynamic options (0 = off)	0
	(21)	Switch for specifying which rotor can use the time-variant (TV) analysis (0 = none; both rotors use quasi-static (QS) analysis)	1
	(22)	Switch for activating TV analysis in TRIM and MANU when IPL(21) $\neq$ 0 (0 = QS trim followed by TV trim and maneuver)	0
	(23)	Control variable for rebalancing main rotor in TRIM (0 = off)	0
	(24)	Control variable for rebalancing tail rotor in TRIM (0 = off)	0
	(25)	Print control for trim iteration data (0 = minimum output)	1
	(26)	Print control for optional trim page (0 = page omitted)	3
	(27)	Print control for blade element aerodynamic data (0 = none)	3
	(28)	Switch for locking fuselage degrees of freedom in maneuver (0 = unlocked)	0

CARD 08 Stability Analysis and Miscellaneous Logic (14I5 format)

IPL	(29)	Switch for fuselage coupling in STAB (0 = uncoupled)	1
	(30)	Switch for pylon degrees of freedom in STAB (0 = off)	0
	(31)	Switch for rotor degrees of freedom in STAB (0 = off)	3
	(32)	Switch for rebalancing rotors in STAB when IPL(31) = 0 (0 = rebalance)	0
	(33)	Output control for STAB matrices (0 = print only)	0
	(34)	Output selector for STAB diagnostics (0 = off)	0
	(35)		
	(36)	Print control for input data (0 = print all input data)	0
	(37)	Switch for reading Rotor Wake at Surfaces (RWAS) tables (0 = off)	0
	(38)		
	(39)		
	(40)		
	(41)	Rotor fold indicator (0 = unfolded)	0
	(42)	Switch for shifting cg with rotor folding (0 = no shift)	0

2.4 FUSELAGE GROUP (include only if IPL(1) = 0)

CARD 20 Fuselage Group Identification Card

2.4.1 Basic Inputs

CARD 21

XFS	(1)	Gross weight		(lb)	4562.
	(2)	Stationline	Location of fuselage data reference point	(in.)	100.39
	(3)	Buttline		(in.)	0.
	(4)	Waterline		(in.)	-1.86
	(5)	Stationline	Location of center of gravity	(in.)	96.80
	(6)	Buttline		(in.)	0.
	(7)	Waterline		(in.)	6.9

CARD 22

XFS	(8)	Aircraft rolling inertia, I_{xx}	(slug-ft^2)	1268.
	(9)	Aircraft pitching inertia, I_{yy}	(slug-ft^2)	3479.
	(10)	Aircraft yawing inertia, I_{zz}	(slug-ft^2)	3203.
	(11)	Aircraft product of inertia, I_{xz}	(slug-ft^2)	250.
	(12)	Force and moment equation use indicator, LGF		0.
	(13)	Phasing Angle (Nominal/Phasing)	(deg)	15.
	(14)	Phasing Angle (High/Phasing)	(deg)	30.

2.4.2 Aerodynamic Inputs (Wind Axis)

Cards 23 through 2E contain the coefficients for the High Angle and Nominal Angle Equations. The asterisk (*) indicates the input is considered a necessary one; see Section 3.4.

2.4.2.1 Coefficients for Lift Equations

CARD 23

XFS	*(15)	L/q at $\psi_w = \theta_w = 0°$ (Fwd. Flt.)	(ft^2)	-2.8103
	(16)	L/q at $\psi_w = 180°$, $\theta_w = 0°$ (Rwd. Flt.)	(ft^2)	
	(17)	Approx. peak L/q for $0° \leq \theta_w \leq 90°$, $\psi_w = 0°$	(ft^2)	
	(18)	Value of θ_w for XFS(17)	(deg)	
	(19)	L/q at $\psi_w = 0°$, $\theta_w = 90°$ (Vert. Flt.)	(ft^2)	
	(20)	L/q at $\psi_w = 90°$, $\theta_w = 0°$ (Sideward Flt.)	(ft^2)	
	(21)	$\partial(L/q)/\partial\psi_w$	(ft^2/deg)	0.026886

NOTE: **Values not shown are left blank on input data cards; asterisk items are considered necessary according to Reference 2.**

CARD 24

XFS	(22)	$\partial(L/q)/\partial(\psi_w{}^2)$	(ft^2/deg^2)	0.003745
	*(23)	$\partial(L/q)/\partial\theta_w$; lift curve slope at $\psi_w = 0^\circ$	(ft^2/deg)	0.569222
	(24)	$\partial(\partial(L/q)/\partial\psi_w)\partial\theta_w$	(ft^2/deg^2)	0.00013
	(25)	$\partial(\partial(L/q)/\partial(\psi_w{}^2))/\partial\theta_w)$	(ft^2/deg^3)	0.000052
	(26)	$\partial(L/q)/\partial(\theta_w{}^2)$	(ft^2/deg^2)	-0.000192
	(27)	$\partial(\partial(L/q)/\partial\psi_w)/\partial(\theta_w{}^2)$	(ft^2/deg^3)	-0.000003
	(28)	$\partial(L/q)/\partial(\theta^3{}_w)$	(ft^2/deg^3)	-0.000166

2.4.2.2 Coefficients for Drag Equations

CARD 25

XFS	*(29)	D/q at $\psi_w = \theta_w = 0^\circ$ (Fwd. Flt)	(ft^2)	9.1025
	(30)	D/q at $\psi_w = 180^\circ$, $\theta_w = 0^\circ$ (Rwd. Flt)	(ft^2)	
	(31)	D/q at $\psi_w = 90^\circ$, $\theta_w = 0^\circ$ (Sideward Flt)	(ft^2)	
	(32)	D/q at $\theta_w = -90^\circ$ (Ascending Vertical Flt)	(ft^2)	
	(33)	D/q at $\theta_w = +90^\circ$ (Descending Vertical Flt)	(ft^2)	0.017826
	(34)			
	(35)	$\partial(D/q)/\partial\psi_w$	(ft^2/deg)	0.028820

CARD 26

XFS	*(36)	$\partial(D/q)/\partial(\psi_w{}^2)$; variation of drag with $\psi_w{}^2$ at $\theta_w = 0^\circ$	(ft^2/deg^2)	
	*(37)	$\partial(D/q)/\partial\theta_w$; variation of drag with θ_w at $\psi_w = 0^\circ$	(ft^2/deg)	-0.158123
	(38)	$\partial(\partial(D/q)/\partial\psi_w)/\partial\theta_w$	(ft^2/deg^2)	0.000702
	(39)	$\partial(\partial(D/q)/\partial(\psi_w{}^2))/\partial\theta_w$	(ft^2/deg^3)	0.000085
	*(40)	$\partial(D/q)/\partial(\theta_w{}^2)$; variation of drag with $\theta_w{}^2$ at $\psi_w = 0^\circ$	(ft^2/deg^2)	0.006891
	(41)	$\partial(\partial(D/q)/\partial\psi_w)/\partial(\theta^2{}_w)$	(ft^2/deg^3)	0.000023
	(42)	$\partial(D/q)/\partial(\theta_w{}^3)$	(ft^2/deg^3)	-0.000177

2.4.2.3 Coefficients for Pitching Moment Equations

CARD 27

XFS	*(43)	M/q at $\psi_w = \theta_w = 0^\circ$ (Fwd Flt)	(ft^3)	-29.3444
	(44)	M/q at $\psi_w = 180^\circ$, $\theta_w = 0^\circ$ (Rwd. Flt)	(ft^3)	
	(45)	Approx. peak M/q for $0^\circ \leq \theta_w \leq 90^\circ$, $\psi_w = 0^\circ$	(ft^3)	
	(46)	Value of θ_w for XFS(45)	(deg)	
	(47)	M/q at $\psi_w = 0^\circ$, $\theta_w = 90^\circ$ (Vertical Flt)	(ft^3)	
	(48)	M/q at $\psi_w = 90^\circ$, $\theta_w = 0^\circ$ (Sideward Flt)	(ft^3)	
	(49)	$\partial(M/q)/\partial\psi_w$	(ft^3/deg)	0.056265

CARD 28

XFS	(50)	$\partial(M/q)/\partial(\psi_w^2)$	(ft^3/deg^2)	-0.006806
	*(51)	$\partial(M/q)/\partial\theta_w$; static longitudinal stability	(ft^3/deg)	1.575644
	(52)	$\partial(\partial(M/q)/\partial\psi_w)\partial\theta_w$	(ft^3/deg^2)	-0.011048
	(53)	$\partial(\partial(M/q)/\partial(\psi_w^2))/\partial\theta_w$	(ft^3/deg^3)	-0.001690
	(54)	$\partial(M/q)/\partial(\theta_w^2)$	(ft^3/deg^2)	0.031490
	(55)	$\partial(\partial(M/q)/\partial\psi_w)/\partial(\theta_w^2)$	(ft^3/deg^3)	0.000402
	(56)	$\partial(M/q)/\partial(\theta_w^3)$	(ft^3/deg^3)	0.010432

2.4.2.4 Coefficients for Side Force Equations

CARD 29

XFS	(57)	Y/q at $\psi_w = 90^\circ$, $\theta_w = 0^\circ$ (Sideward Flt)	(ft^2)	
	(58)	Approx. peak Y/q for $0 \leq \psi_w \leq 90^\circ$, $\theta_w = 0^\circ$	(ft^2)	
	(59)	Value of ψ_w for XFS(58)	(deg)	
	(60)	Y/q at $\psi_w = \theta_w = 0^\circ$ (Fwd Flt)	(ft^2)	5.849701
	(61)	$\partial(Y/q)/\partial\theta_w$	(ft^2/deg)	-0.032884
	(62)	$\partial(Y/q)/\partial(\theta_w^2)$	(ft^2/deg^2)	-0.003029
	(63)	$\partial(Y/q)/\partial(\theta_w^3)$	(ft^2/deg^3)	0.000373

CARD 2A

XFS *(64) $\partial(Y/q)/\partial\psi_w$; slope of Y vs. ψ_w at $\theta_w = 0^\circ$ (ft^2/deg) 0.823888

(65) $\partial(\partial(Y/q)/\partial\theta_w)/\partial\psi_w$ (ft^2/deg^2) 0.003138

(66) $\partial(\partial(Y/q)/\partial(\theta_w{}^2))/\partial\psi_w$ (ft^2/deg^3) 0.000116

(67) $\partial(Y/q)/\partial(\psi_w{}^2)$ (ft^2/deg^2) -0.007640

(68) $\partial(\partial(Y/q)/\partial\theta_w)/\partial(\psi_w{}^2)$ (ft^2/deg^3) -0.000038

(69) $\partial(Y/q)/\partial(\psi_w^3)$ (ft^2/deg^3) 0.001128

(70) $\partial(\partial(Y/q)/\partial\theta_w)/\partial(\psi_w{}^3)$ (ft^2/deg^4) -0.000001

2.4.2.5 Coefficients for Rolling Moment Equations

CARD 2B

XFS (71) $1/q$ at $\psi_w = 90^\circ$, $\theta_w = 0^\circ$ (Sideward Flt) (ft^3)

(72) Approx. peak $1/q$ for $0 \leq \psi_w \leq 90^\circ$, $\theta_w = 0^\circ$ (ft^3)

(73) Value of ψ_w for XFS(72) (deg)

(74) $1/q$ at $\psi_w = \theta_w = 0^\circ$ (Fwd Flt) (ft^3) 9.732055

(75) $\partial(1/q)/\partial\theta_w$ (ft^3/deg) -0.986104

(76) $\partial(1/q)/\partial(\theta_w{}^2)$ (ft^3/deg^2) 0.019363

(77) $\partial(1/q)/\partial(\theta_w{}^3)$ (ft^3/deg^3) 0.000492

CARD 2C

XFS *(78) $\partial(1/q)/\partial\psi_w$; slope of RM curve for ψ_w at $\theta_w = 0^\circ$ (ft^3/deg) 1.695225

(79) $\partial(\partial(1/q)/\partial\theta_w)/\partial\psi_w$ (ft^3/deg^2) -0.074555

(80) $\partial(\partial(1/q)/\partial(\theta_w{}^2)/\partial\psi_w$ (ft^3/deg^3) -0.000724

(81) $\partial(1/q)/\partial(\psi_w{}^2)$ (ft^3/deg^2) -0.012898

(82) $\partial(\partial(1/q)/\partial\theta_w)/\partial(\psi_w{}^2)$ (ft^3/deg^3) 0.000703

(83) $\partial(1/q)/\partial(\psi_w{}^3)$ (ft^3/deg^3) 0.000603

(84) $\partial(\partial(1/q)/\partial\theta_w)/\partial(\psi_w{}^3)$ (ft^3/deg^4) -0.000075

2.4.2.6 Coefficients for Yawing Moment Equations

CARD 2D

XFS	(85)	N/q at $\psi_w = 90^\circ$, $\theta_w = 0^\circ$ (Sideward Flt.)	(ft^3)	
	(86)	Approx. peak N/q for $0 \leq \psi_w \leq 90^\circ$, $\theta_w = 0^\circ$	(ft^3)	
	(87)	Value of ψ_w for XFS(86)	(deg)	
	(88)	N/q at $\psi_w = \theta_w = 0^\circ$ (Fwd Flt)	(ft^3)	-34.23
	(89)	$\partial(N/q)/\partial\theta_w$	(ft^3/deg)	1.564
	(90)	$\partial(N/q)/\partial(\theta_w^{\ 2})$	(ft^3/deg^2)	0.0146
	(91)	$\partial(N/q)/\partial(\theta_w^{\ 3})$	(ft^3/deg^3)	-0.00321

CARD 2E

XFS	*(92)	$\partial(N/q)/\partial\psi_w$; Slope of YM curve for ψ_w at $\theta_w = 0^\circ$	(ft^3/deg)	-0.9909
	(93)	$\partial(\partial(N/q)/\partial\theta_w)/\partial\psi_w$	(ft^3/deg^2)	-0.021176
	(94)	$\partial(\partial(N/q)/\partial(\theta_w^{\ 2}))/\partial\psi_w$	(ft^3/deg^3)	0.000109
	(95)	$\partial(N/q)/\partial(\psi_w^{\ 2})$	(ft^3/deg^2)	0.029939
	(96)	$\partial(\partial(N/q)/\partial\theta_w)/\partial(\psi_w^{\ 2})$	(ft^3/deg^3)	0.00023
	(97)	$\partial(N/q)/\partial(\psi_w^{\ 3})$	(ft^3/deg^3)	-0.004625
	(98)	$\partial(\partial(N/q)/\partial\theta_w)/\partial(\psi_w^{\ 3})$	(ft^3/deg^4)	0.000009

2.5.1 Rotor Airfoil Aerodynamic (RAA) Subgroup No. 1

CARD 31A

YRR	(1,1)	Drag divergence Mach number for $\alpha = 0$		0.84
	(2,1)	Mach number for lower boundary of supersonic region		1.27
	(3,1)	Maximum C_L, normal flow, $M = 0$		1.3
	(4,1)	Coefficients of Mach number in maximum C_L equation, normal flow		-0.7
	(5,1)			0.
	(6,1)			0.
	(7,1)	Maximum C_L, reversed flow, $M = 0$		0.7

CARD 31B

YRR	(8,1)	Slope of lift curve for $M = 0$	(/deg)	0.095
	(9,1)	Coefficients of M for lift curve slope in subsonic region	(/deg)	0.
	(10,1)		(/deg)	0.0475
	(11,1)		(/deg)	0.
	(12,1)	C_D for $\alpha = 0$, $M = 0$		0.01
	(13,1)	Coefficients of α in nondivergent drag equation	(/deg)	0.
	(14,1)		(/deg^2)	0.00004

CARD 31C

YRR	(15,1)	Coefficient in supersonic drag equation		0.04
	(16,1)	Maximum nondivergent C_D		0.34
	(17,1)	Thickness/chord ratio		0.098
	(18,1)	Control variable for using data table		1.
	(19,1)	Drag rise coefficient	(/deg)	0.
	(20,1)	Coefficient of yaw angle in Mach number equation		0.2
	(21,1)	Exponent in Mach number equation for yawed flow		1.

CARD 31D

YRR	(22,1)	Coefficients of α for Mach Critical in steady C_M equation	(/deg^2)	0.
	(23,1)		(/deg)	0.
	(24,1)			0.
	(25,1)	C_M for $\alpha = 0$, $M = 0$		0.
	(26,1)			0.
	(27,1)			0.
	(28,1)	Maximum value of yawed flow angle	(deg)	0.

CARD 31E

YRR	(29,1)	Zero lift line orientation at $M = 0$,	(deg)	0.
		normal flow		0.
	(30,1)	Coefficients for zero lift line orientation as a function of Mach number	(deg)	0.
	(31,1)		(deg)	0.
	(32,1)		(deg)	0.
	(33,1)	Switch for UNSAN yawed flow effects (0 = off)		0.
	(34,1)			0.
	(35,1)			

2.5.1 Rotor Airfoil Aerodynamic (RAA) Subgroup No. 1 (Tail Rotor)

CARD 32A

YRR	(1,1)	Drag divergence Mach number for $\alpha = 0$		0.79
	(2,1)	Mach number for lower boundary of supersonic region		1.06
	(3,1)	Maximum C_L, normal flow, M = 0		1.334
	(4,1)	Coefficients of Mach number in		0.8334
	(5,1)	maximum C_L equation, normal		-4.924
	(6,1)	flow		3.853
	(7,1)	Maximum C_L, reversed flow, M = 0		0.78

CARD 32B

YRR	(8,1)	Slope of lift curve for M = 0	(/deg)	0.11
	(9,1)	Coefficients of M for	(/deg)	0.02468
	(10,1)	lift curve slope in sub-	(/deg)	-0.1956
	(11,1)	sonic region	(/deg)	0.3779
	(12,1)	C_D for $\alpha = 0$, M = 0		0.008
	(13,1)	Coefficients of α in non-	(/deg)	-0.00099
	(14,1)	divergent drag equation	(/deg^2)	0.00278

CARD 32C

YRR	(15,1)	Coefficient in supersonic drag equation		0.04
	(16,1)	Maximum nondivergent C_D		0.4
	(17,1)	Thickness/chord ratio		0.12
	(18,1)	Control variable for using data table		0.
	(19,1)	Drag rise coefficient	(/deg)	0.028
	(20,1)	Coefficient of yaw angle in Mach number equation		1.
	(21,1)	Exponent in Mach number equation for yawed flow		1.

CARD 32D

YRR	(22,1)	Coefficients of α for Mach	(/deg^2)	-0.002488
	(23,1)	Critical in steady C_M	(/deg)	-0.009456
	(24,1)	equation		0.82
	(25,1)	C_M for $\alpha = 0$, M = 0		
	(26,1)			
	(27,1)			
	(28,1)	Maximum value of yawed flow angle	(/deg)	0.

CARD 32E

YRR	(29,1)	Zero lift line orientation at M = 0, normal flow	(deg)	0.
	(30,1)	Coefficients for zero lift line	(deg)	0.
	(31,1)	orientation as a function of Mach number	(deg)	0.
	(32,1)		(deg)	0.
	(33,1)	Switch for UNSAN yawed flow effects (0 = off)		0.
	(34,1)			0.
	(35,1)			0.

2.6 MAIN ROTOR GROUP (omit if IPL(7) = 1 or 3)

CARD 40 Main Rotor Group Identification Card

CARD 41

XMR	(1)	Number of blades		4.
	(2)	Undersling	(in.)	0.
	(3)			
	(4)	Radius	(ft)	16.11
	(5)	Chord (ONLY if constant)	(in.)	10.64
	(6)	Total twist (ONLY if linear)	(deg)	-8.
	(7)	Flapping stop location	(deg)	90.

CARD 42

XMR	(8)	Stationline } Location of mast pivot	(in.)	98.444
	(9)	Buttline } point for mast tilt and	(in.)	0.
	(10)	Waterline } conversion maneuvers	(in.)	61.20
	(11)	Blade weight (ignored if IPL(3) ≠ 0)	(lb)	0.
	(12)	Blade inertia (ignored if IPL(3) ≠ 0)	($slug\text{-}ft^2$)	0.
	(13)	Rotor to engine gear ratio	(Rotor RPM/Engine RPM)	1.
	(14)			

CARD 43

XMR	(15)	Station number for blade moments (0.0 = hub)		0.
	(16)	Hub-type indicator (0.0 = gimbaled)		1.
	(17)	Flapping stop spring rate	(ft-lb/deg)	0.
	(18)	Flapping spring rate	(ft-lb/deg)	0.
	(19)	Reduced rotor frequency for UNSAN option	(/rev)	1.
	(20)	Lead-lag damper	(lb-sec/ft)	0.
	(21)	Hub extent	(ft)	3.22

CARD 44

XMR	(22)	Precone	(deg)	2.5
	(23)	Pitch change axis location (0.0 = 25% chord)	(chords)	0.
	(24)	Pitch-flap coupling angle, δ_3	(deg)	0.
	(25)	Drag coefficient for hub		0.015
	(26)			
	(27)	Coefficient for tip-vortex effect (0.0 = off)		10.
	(28)			

CARD 45

XMR	(29)	Tip sweep angle (+ aft)	(deg)	0.
	(30)	Shift in ac at tip (+ aft)	(in.)	0.
	(31)	Moment arm of pitch-link attach point (+ fwd)	(in.)	-6.48
	(32)	Distance from hub to pitch-horn attach point	(in.)	6.66
	(33)			
	(34)			
	(35)			

CARD 46

XMR	(36)	Rotor nacelle weight	(lb)	0.
	(37)	Stationline } Location of rotor nacelle	(in.)	0.
	(38)	Buttline } center of gravity	(in.)	0.
	(39)	Waterline }	(in.)	0.
	(40)	Rotor nacelle differential flat plate drag area	(ft^2)	0.
	(41)	Distance from mast pivot point to rotor nacelle aerodynamic center	(ft)	0.
	(42)			

CARD 47

XMR	(43)	Control phasing	(deg)	-10.
	(44)	F/A mast tilt (+ fwd)	(deg)	3.
	(45)	Lateral mast tilt (+ right)	(deg)	0.
	(46)	Mast length (+ up)	(ft)	0.
	(47)	Incremental torsional inertia of mast	(slug-ft^2)	0.
	(48)	Torsional spring constant of mast	(ft-lb/deg)	0.
	(49)	Torsional damping ratio for mast		0.

2.7 TAIL ROTOR GROUP (omit if IPL(1) ≠ 0 or if IPL(7) = 2 or 3)

CARD 50 Tail Rotor Group Identification Card

CARD 51

XTR	(1)	Number of blades		2.
	(2)	Undersling	(in.)	0.
	(3)			
	(4)	Radius	(ft)	3.115
	(5)	Chord (ONLY if constant)	(in.)	7.05
	(6)	Total twist (ONLY if linear)	(deg)	0.0001
	(7)	Flapping stop location	(deg)	90.

CARD 52

XTR	(8)	Stationline } Location of mast pivot	(in.)	335.
	(9)	Buttline } point for mast tilt and	(in.)	-12.5
	(10)	Waterline } conversion maneuvers	(in.)	68.7
	(11)	Blade weight (ignored if IPL(4) ≠ 0)	(lb)	4.851
	(12)	Blade inertia (ignored if IPL(4) ≠ 0)	(slug-ft^2)	0.487
	(13)	Rotor to engine gear ratio	(Rotor RPM/Engine RPM)	5.527
	(14)			

CARD 53

XTR	(15)	Station Number for blade moments (0.0 = hub)		0.
	(16)	Hub-type indicator (0.0 = gimbaled)		1.
	(17)	Flapping stop spring rate	(ft-lb/deg)	0.
	(18)	Flapping spring rate	(ft-lb/deg)	0.
	(19)	Reduced rotor frequency for UNSAN option	(/rev)	1.
	(20)	Lead-lag damper	(lb-sec/ft)	0.
	(21)	Hub extent	(ft)	0.

CARD 54

XTR	(22)	Precone	(deg)	0.
	(23)	Pitch change axis location (0.0 = 25% chord)	(chords)	0.
	(24)	Pitch-flap coupling angle, δ_3	(deg)	45.
	(25)	Drag coefficient for hub		0.
	(26)			
	(27)	Coefficient for tip vortex effect (0.0 = off)		0.
	(28)	Sidewash coefficient	(deg/deg)	0.

CARD 55

XTR	(29)	Tip sweep angle (+ aft)	(deg)	0.
	(30)	Shift in aerodynamic center at tip (+ aft)	(in.)	0.
	(31)	Moment arm of pitch-link attach point (+ fwd)	(in.)	0.
	(32)	Distance from hub to pitch-horn attach point	(in.)	0.
	(33)			
	(34)			
	(35)			

CARD 56

XTR	(36)	Rotor nacelle weight	(lb)	0.
	(37)	Stationline } Location of rotor nacelle	(in.)	0.
	(38)	Buttline } center of gravity	(in.)	0.
	(39)	Waterline }		0.
	(40)	Rotor nacelle differential flat plate drag area	(ft^2)	0.
	(41)	Distance from mast pivot point to rotor nacelle	(ft)	0.
	(42)			

CARD 57

XTR	(43)	Control phasing	(deg)	0.
	(44)	F/A mast tilt (+ fwd)	(deg)	-4.
	(45)	Lateral mast tilt (= ±90 for tail rotor)	(deg)	-90.
	(46)	Mast length	(ft)	0.
	(47)	Incremental torsional inertia of mast	(slug-ft^2)	0.
	(48)	Torsional spring rate of mast	(ft-lb/deg)	0.
	(49)	Torsional damping ratio of mast		

2.9.1 Stabilizing Surface Group No. 1 (include only if $|IPL(10)| \geq 1$)

CARD 70 Stabilizing Surface Group No. 1 Identification Card

2.9.1.1 Basic Inputs

CARD 71

XSTB1	(1)	Stabilizing Surface Area	(ft^2)	8.71
	(2)	Stationline } Location of center	(in.)	277.45
	(3)	Buttline } of pressure for the	(in.)	0.
	(4)	Waterline } stabilizing surface	(in.)	25.84
	(5)	Incidence angle	(deg)	0.
	(6)	Effective dihedral angle (+ up)	(deg)	0.
	(7)	Sweep angle of quarter chord line (+ aft)	(deg)	0.

CARD 72

XSTB1	(8)	Geometric aspect ratio of surface		8.09
	(9)	Spanwise efficiency factor		1.
	(10)	Taper ratio		1.
	(11)	Tail-boom bending coefficient	(rad/lb)	0.
	(12)	Dynamic pressure reduction at surface due to fuselage		0.
	(13)	Downwash at surface due to wing	(deg)	0.
	(14)	Control surface deflection	(deg)	0.

CARD 73

XSTB1	(15)	Coefficients for a change in lift	(/deg)	0.
	(16)	coefficient as a function of control surface deflection	($/deg^2$)	0.
	(17)	Coefficients for change in maximum	(/deg)	0.
	(18)	lift coefficient as a function of control surface deflection	($/deg^2$)	0.
	(19)	Coefficients for change in profile	(/deg)	0.
	(20)	drag as a function of control surface deflection	($/deg^2$)	0.
	(21)			

CARD 74

XSTB1	(22)	Coefficients for change in surface pitching moment coefficient as a function of control surface deflection	(/deg)	0.
	(23)		($/deg^2$)	0.
	(24)	Coefficients for downwash at surface due to the fuselage	(deg)	0.
	(25)		(deg/deg)	0.
	(26)		(deg/deg^2)	0.
	(27)	Coefficients for sidewash at the surface due to the fuselage	(deg/deg)	0.
	(28)		(deg/deg^3)	0.

CARD 75

XSTB1	(29)	Effect of Rotor 1 wake on the surface		1.
	(30)	Velocity at which surface starts to enter Rotor 1 wake	(KTAS)	-5.
	(31)	Velocity at which surface is completely in the Rotor 1 wake	(KTAS)	0.
	(32)	Effect of Rotor 2 wake on the surface		0.
	(33)	Velocity at which surface starts to enter Rotor 2 wake	(KTAS)	1.
	(34)	Velocity at which surface is completely in the Rotor 2 wake	(KTAS)	2.
	(35)			

CARD 130 Controls Group Identification Card

2.12.1 Basic Controls Subgroup

CARD 131

XCON	(1)	Range of collective stick	(in.)	9.
	(2)	Collective pitch for Rotor 1 with stick full down ($\beta_M = 0$)	(deg)	6.
	(3)	Range of collective pitch for Rotor 1 ($\beta_M = 0$)	(deg)	16.
	(4)	Rotor 1 collective pitch lock indicator (≠ 0 for locked)		0.
	(5)	Rotor 1 root collective pitch if XCON(4) ≠ 0	(deg)	0.
	(6)	Change in Jet Thrust with collective stick position	(lb/in.)	0.
	(7)			

CARD 132

XCON	(8)	Range of F/A cyclic stick	(in.)	12.12
	(9)	Rotor 1 F/A cyclic pitch with stick full aft	(deg)	-4.7
	(10)	Range of F/A cyclic pitch for Rotor 1	(deg)	14.
	(11)	Rotor 1 F/A cyclic pitch lock indicator (≠ 0 for locked)		0.
	(12)	Rotor 1 F/A cyclic pitch if XCON(11) ≠ 0	(deg)	0.
	(13)	Change in Jet Thrust with F/A cyclic stick position	(lb/in.)	0.
	(14)			

CARD 133

XCON	(15)	Range of lateral cyclic stick	(in.)	8.65
	(16)	Rotor 1 lateral cyclic pitch with stick full left	(deg)	-5
	(17)	Range of lateral cyclic pitch for Rotor 1	(deg)	10.
	(18)	Rotor 1 lateral cyclic pitch lock indicator (≠ 0 for locked)		0.
	(19)	Rotor 1 lateral cyclic pitch if XCON(18) ≠ 0	(deg)	0.
	(20)	Change in Jet Thrust with lateral cyclic stick position	(lb/in.)	0.
	(21)			

CARD 134

XCON	(22)	Range of pedals	(in.)	4.34
	(23)	Rotor 2 collective pitch with pedals full right	(deg)	6.00
	(24)	Range of collective pitch for Rotor 2	(deg)	-40.
	(25)	Rotor 2 collective pitch lock indicator (≠ 0 for locked)		0.
	(26)	Rotor 2 collective pitch if XCON(25) ≠ 0	(deg)	0.
	(27)	Change in Jet Thrust with pedal position	(lb/in.)	0.
	(28)			

2.13 ITERATION LOGIC GROUP

CARD 140 Iteration Logic Group Identification Card

CARD 141

XIT	(1)	Iteration limit for TRIM		20.
	(2)	ΔΨ of rotor(s) for time-variant trim	(deg)	0.
	(3)	Limiter for change in average rotor-induced velocity	(ft/sec)	0.
	(4)	Partial derivative increment for STAB		0.5
	(5)			
	(6)			
	(7)			

CARD 142

XIT	(8)	Minimum value for main rotor flapping angle correction limit	(deg)	0.2
	(9)	Minimum value for tail rotor flapping angle correction limit	(deg)	0.2
	(10)	Maximum value for use of variable damper for main rotor	(ft-lb)	15000.
	(11)	Maximum value for use of variable damper for tail rotor	(ft-lb)	15000.
	(12)	Starting value for TRIM correction limit	(deg)	2.
	(13)	Minimum value for TRIM correction limit	(deg)	0.15
	(14)	Maximum value for use of variable damper in TRIM	(lb or ft-lb)	500.

CARD 143

XIT	(15)	Allowable error in F/A force balance	(lb)	12.5
	(16)	Allowable error in lateral force balance	(lb)	50.
	(17)	Allowable error in vertical force balance	(lb)	50.
	(18)	Allowable error in pitching and yawing moment balance	(ft-lb)	100.
	(19)	Allowable error in rolling moment balance	(ft-lb)	100.
	(20)	Allowable error in main rotor flapping moment balance	(ft-lb)	500.
	(21)	Allowable error in tail rotor flapping moment balance	(ft-lb)	500.

2.14 FLIGHT CONSTANTS GROUP

NOTE: There is no CARD 150 because there is no Group Identification Card for Flight Constants Group.

CARD 151

XFC	(1)	Forward velocity (ground reference)	(kt)	61.
	(2)	Lateral velocity (ground reference)	(kt)	0.
	(3)	Rate of climb (ground reference)	(ft/sec)	0.
	(4)	Altitude (geometric)	(ft)	1636.
	(5)	Euler angle yaw (heading angle)	(deg)	0.
	(6)	Euler angle pitch	(deg)	1.17
	(7)	Euler angle roll	(deg)	-0.93

CARD 152

XFC	(8)	Collective stick position	(%)	39.
	(9)	F/A cyclic stick position	(%)	50.
	(10)	Lateral cyclic stick position	(%)	39.
	(11)	Pedal position	(%)	32.
	(12)	g level		0.
	(13)			
	(14)			

CARD 153

XFC	(15)	Main rotor F/A flapping angle	(deg)	2.7
	(16)	Main rotor lateral flapping angle	(deg)	2.4
	(17)	Tail rotor F/A flapping angle	(deg)	-1.1
	(18)	Tail rotor lateral flapping angle	(deg)	0.2
	(19)	Main rotor thrust	(lb)	4602.
	(20)	Tail rotor thrust	(lb)	-139.
	(21)			

CARD 154

XFC	(22)			
	(23)			
	(24)	Maximum engine horsepower available	(hp)	10000.
	(25)	Engine RPM	(rpm)	425.
	(26)	Atmospheric logic switch (0.0 = Std. Day)		0.
	(27)	Pressure altitude	(ft)	1636.
	(28)	Ambient temperature	(°C or °F)	0.

NOTE: END OF TRIM OR TRIM-STAB DECK.

TABLE A-1. C-81 INPUT DATA DECK FOR CASE T10

```
 1                                                                                          01
          1 BO-105 C-81 CONTRACT CASE8 T10                                                  02
          1 BO-105 C-81 CONTRACT DECK D2-1                                                  03
          1 EQ FOR TR 23012 FOR MR                                                          04
            BO-105 LOGIC GROUP                                                              05
    0    1    6    0    0    2    0    0    0   -1    0    0    0    0                      06
    0    1    5    1    2    0    1    0    0    0    1    3    3    0                      07
    1    0    3    0    0    0         0    0                   0    0                      08
            BO-105 AERO TABLES                                                 11
 666 NACA 23012 LD/JMM 8/74   113911451144
        0.      0.3     0.4     0.5     0.6     0.7     0.75    0.8     0.85
        0.9     1.
-180.   .04     .04     .04     .04     .04     .04     .04     .04     .04
        .04     .04
-174.   .65     .65     .65     .65     .65     .65     .65     .65     .65
        .65     .65
-170.   .65     .65     .65     .65     .65     .65     .65     .65     .65
        .65     .65
-166.   .62     .62     .62     .62     .62     .62     .62     .62     .62
        .62     .62
-133.   .865    .865    .865    .865    .865    .865    .865    .865    .865
        .865    .865
-113.   .635    .635    .635    .635    .635    .635    .635    .635    .635
        .635    .635
-58.    -.89    -.89    -.89    -.89    -.89    -.89    -.89    -.89    -.89
        -.89    -.89
-38.    -1.14   -1.14   -1.14   -1.14   -1.14   -1.14   -1.14   -1.14   -1.14
        -1.14   -1.14
-20.    -.98    -1.03   -1.07   -1.13   -1.14   -.868   -.86    -.845   -.74
        -1.01   -1.34
-15.    -1.165  -1.225  -1.285  -1.23   -1.13   -.88    -.892   -.827   -.685
        -1.01   -1.34
-13.5   -1.22   -1.28   -1.33   -1.26   -1.12   -.88    -.885   -.814   -.677
        -1.01   -1.34
-12.    -1.095  -1.15   -1.2    -1.14   -1.092  -.86    -.877   -.791   -.655
        -1.01   -1.25
-9.5    -.89    -.93    -.97    -.93    -1.05   -.83    -.85    -.77    -.62
        -.947   -1.1
-5.5    -.47    -.493   -.51    -.55    -.585   -.64    -.688   -.65    -.58
        -.41    -.61
-4.     -.312   -.33    -.335   -.36    -.39    -.41    -.5     -.475   -.28
        -.22    -.43
-2.     -.1     -.107   -.105   -.115   -.12    -.12    -.127   -.16    -.165
        -.085   -.185
-1.     0.0     0.0     0.0     0.0     .01     .025    .015    .05     -.005
        -.015   -.06
0.0     .11     .11     .12     .13     .14     .17     .19     .24     .06
        .11     .06
2.      .32     .332    .35     .375    .41     .475    .485    .37     .208
        .39     .3
3.      .425    .443    .467    .5      .547    .62     .5      .415    .26
        .52     .426
4.      .53     .55     .58     .62     .68     .675    .57     .475    .28
        .63     .545
6.      .742    .772    .815    .868    .91     .767    .67     .51     .32
        .92     .787
8.      .95     .995    1.035   1.115   .995    .856    .732    .545    .395
        1.19    1.03
10.     1.165   1.22    1.26    1.27    1.075   .942    .791    .58     .393
```

TABLE A-1 – Continued

11.	1.19 1.268	1.095 1.328	1.38	1.278	1.092	.985	.825	.6	.413
12.	1.19 1.375	1.095 1.44	1.42	1.25	1.113	1.028	.852	.615	.432
13.	1.19 1.48	1.095 1.55	1.395	1.225	1.13	1.069	.885	.633	.45
13.5	1.19 1.53	1.095 1.6	1.27	1.207	1.141	1.09	.9	.641	.461
14.	1.19 1.505	1.095 1.095	1.14	1.19	1.15	1.112	.913	.65	.47
15.	1.19 .915	1.095 .962	1.	1.192	1.17	1.155	.946	.668	.49
20.	1.19 1.	1.095 1.05	1.09	1.2	1.26	1.367	1.1	.76	.59
30.	1.19 1.135	1.095 1.135	1.135	1.135	1.135	1.135	1.135	1.135	1.135
50.	1.135 .89	1.135 .89	.89	.89	.89	.89	.89	.89	.89
113.	.89 -.635	.89 -.635	-.635	-.635	-.635	-.635	-.635	-.635	-.635
133.	-.635 -.865	-.635 -.865	-.865	-.865	-.865	-.865	-.865	-.865	-.865
150.	-.865 -1.	-.865 -1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.
166.	-1. -.72	-1. -.72	-.72	-.72	-.72	-.72	-.72	-.72	-.72
170.	-.72 -.82	-.72 -.82	-.82	-.82	-.82	-.82	-.82	-.82	-.82
180.	-.82 .04	-.82 .04	.04	.04	.04	.04	.04	.04	.04
	.04 0.0	.04 0.4	0.5	0.6	0.65	0.7	0.75	0.8	0.85
-180.	0.9 .015	1.0 .015	.015	.015	.015	.015	.015	.015	.015
-175.	.015 .04	.015 .04	.04	.04	.04	.04	.04	.04	.04
-170.	.04 .11	.04 .11	.11	.11	.11	.11	.11	.11	.11
-164.	.11 .22	.11 .22	.22	.22	.22	.22	.22	.22	.22
-155.	.22 .51	.22 .51	.51	.51	.51	.51	.51	.51	.51
-130.	.51 1.08	.51 1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
-100.	1.08 1.51	1.08 1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51
-90.	1.51 1.56	1.51 1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56
-80.	1.56 1.51	1.56 1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51
-60.	1.51 1.24	1.51 1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
-40.	1.24 .9	1.24 .9	.9	.9	.9	.9	.9	.9	.9
-25.	.9 .51	.9 .51	.51	.51	.51	.51	.51	.51	.51
-8.	.51 .0205	.51 .0205	.067	.136	.1375	.1405	.144	.17	.1818
-6.	.193 .0154	.2175 .0154	.03	.075	.0765	.079	.087	.115	.127

TABLE A–1 – Continued

-4.	.138 .0112	.1615 .0112	.0115	.0141	.0163	.0182	.0287	.06	.0715
-3.	.083 .0107	.1062 .0107	.01095	.0123	.01335	.01445	.0117	.0322	.0448
-2.	.0625 .0104	.089 .0104	.0104	.0105	.0104	.0107	.011	.0137	.0284
-1.	.0425 .0105	.0715 .0105	.0103	.01035	.01035	.0105	.0104	.0177	.0373
0.	.0512 .0106	.0612 .0106	.0102	.0102	.0103	.0103	.0131	.0287	.0445
1.	.06 .0105	.091 .0105	.0103	.01035	.01075	.0119	.0217	.0474	.0631
2.	.079 .0104	.1105 .0104	.0104	.0105	.0112	.0186	.0384	.0659	.082
3.	.0975 .0106	.1293 .0106	.0107	.0118	.015	.0298	.0569	.0848	.101
4.	.1165 .0108	.1485 .0108	.011	.0131	.0236	.0484	.0755	.1035	.1195
5.	.135 .0114	.167 .0114	.01175	.0191	.0345	.067	.0944	.122	.1383
6.	.153 .012	.186 .012	.0125	.0293	.053	.086	.113	.141	.157
7.	.172 .01265	.205 .01265	.0133	.0426	.072	.1047	.1319	.16	.176
8.	.1915 .0133	.223 .0133	.0153	.061	.0905	.1235	.1508	.1788	.195
9.	.21 .0137	.2425 .0137	.0212	.0798	.1092	.1422	.1693	.198	.2135
10.	.229 .0153	.261 .0153	.03	.0983	.1275	.1607	.188	.217	.232
11.	.248 .0175	.28 .0175	.0483	.118	.1465	.179	.207	.236	.2505
12.	.266 .0205	.299 .0205	.067	.1357	.165	.1985	.225	.256	.27
13.	.285 .0282	.318 .0282	.0858	.1545	.1835	.217	.244	.275	.289
15.	.304 .0465	.3365 .0465	.1233	.192	.221	.254	.281	.3135	.3265
30.	.34 .66	.374 .66	.66	.66	.66	.66	.66	.66	.66
50.	.66 1.07	.66 1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
80.	1.07 1.5	1.07 1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
90.	1.5 1.56	1.5 1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56
100.	1.56 1.51	1.56 1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51
120.	1.51 1.23	1.51 1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23
140.	1.23 .89	1.23 .89	.89	.89	.89	.89	.89	.89	.89
155.	.89 .5	.89 .5	.5	.5	.5	.5	.5	.5	.5
164.	.5 .22	.5 .22	.22	.22	.22	.22	.22	.22	.22
170.	.22 .11	.22 .11	.11	.11	.11	.11	.11	.11	.11
175.	.11 .04	.11 .04	.04	.04	.04	.04	.04	.04	.04

TABLE A-1 – Continued

	.04	.04							
180.	.015	.015	.015	.015	.015	.015	.015	.015	.015
	.015	.015							
	0.	0.4	0.5	0.6	0.65	0.7	0.75	0.8	0.85
	0.9	1.0							
-180.	-.04	-.04	-.04	-.04	-.04	-.04	-.04	-.04	-.04
	-.04	-.04							
-172.	.37	.37	.37	.37	.37	.37	.37	.37	.37
	.37	.37							
-168.	.35	.35	.35	.35	.35	.35	.35	.35	.35
	.35	.35							
-164.	.39	.39	.39	.39	.39	.39	.39	.39	.39
	.39	.39							
-156.	.42	.42	.42	.42	.42	.42	.42	.42	.42
	.42	.42							
-150.	.445	.445	.445	.445	.445	.445	.445	.445	.445
	.445	.445							
-130.	.575	.575	.575	.575	.575	.575	.575	.575	.575
	.575	.575							
-115.	.6	.6	.6	.6	.6	.6	.6	.6	.6
	.6	.6							
-90.	.55	.55	.55	.55	.55	.55	.55	.55	.55
	.55	.55							
-60.	.4	.4	.4	.4	.4	.4	.4	.4	.4
	.4	.4							
-40.	.26	.26	.26	.26	.26	.26	.26	.26	.26
	.26	.26							
-30.	.18	.18	.18	.18	.18	.18	.18	.18	.18
	.18	.18							
-16.	.105	.105	.105	.105	.105	.105	.105	.105	.105
	.105	.105							
-4.	-.0075	-.0075	-.0065	-.0105	-.015	-.018	-.0175	.0238	.009
	.02	.005							
-3.	-.007	-.007	-.0067	-.0091	-.0112	-.015	-.0189	.009	.0055
	-.006	-.002							
-2.	-.007	-.0065	-.007	-.0075	-.0075	-.012	-.01	-.013	.004
	-.031	-.0095							
-1.	-.0075	-.0075	-.0075	-.0084	-.0084	-.0105	-.009	-.012	-.0275
	-.03	-.035							
0.0	-.008	-.008	-.008	-.009	-.009	-.009	-.008	-.033	-.0215
	-.0435	-.057							
1.	-.0085	-.0085	-.0083	-.009	-.0088	-.0075	-.0125	-.0505	-.0235
	-.05	-.0615							
2.	-.009	-.009	-.0087	-.009	-.0085	-.007	-.025	-.0515	-.037
	-.0505	-.068							
3.	-.0093	-.0093	-.009	-.0076	-.006	-.011	-.0415	-.0525	-.0375
	-.051	-.072							
4.	-.01	-.0095	-.0095	-.006	-.0035	-.0225	-.0525	-.057	-.06
	-.0655	-.0745							
5.	-.01	-.009	-.009	-.0024	-.005	-.04	-.0405	-.076	-.084
	-.0825	-.0805							
6.	-.0115	-.0075	-.0085	0.	-.015	-.0505	-.067	-.083	-.0975
	-.0935	-.085							
7.	-.013	-.0045	-.0078	.0005	-.031	-.058	-.0755	-.0785	-.09
	-.099	-.091							
8.	-.015	-.0005	-.007	-.011	-.0425	-.077	-.082	-.089	-.097
	-.104	-.096							
9.	.006	.006	-.006	-.0223	-.0525	-.082	-.089	-.094	-.102
	-.1088	-.1009							
10.	.0125	.0125	-.003	-.0315	-.0624	-.0869	-.096	-.0989	-.1068

```
         -.1137 -.1058
11.      .0135  .0135  .001    -.0415 -.0723 -.0918 -.101   -.1028 -.1118
         -.1186 -.1106
12.      .0035  .0035  .0035   -.0514 -.0822 -.0966 -.1058 -.1087 -.1167
         -.1235 -.1155
13.      -.0185 -.0185 -.005   -.0613 -.0922 -.1017 -.1107 -.1137 -.1215
         -.1285 -.1205
14.      -.0435 -.0435 -.0565  -.0612 -.1023 -.1065 -.1157 -.1186 -.1266
         -.1335 -.1255
16.      -.102  -.102  -.0885  -.0912 -.1122 -.1165 -.1252 -.1285 -.1365
         -.143  -.1354
20.      -.175  -.175  -.175   -.175  -.175  -.175  -.175  -.175  -.175
         -.175  -.175
40.      -.29   -.29   -.29    -.29   -.29   -.29   -.29   -.29   -.29
         -.29   -.29
60.      -.43   -.43   -.43    -.43   -.43   -.43   -.43   -.43   -.43
         -.43   -.43
90.      -.58   -.58   -.58    -.58   -.58   -.58   -.58   -.58   -.58
         -.58   -.58
115.     -.63   -.63   -.63    -.63   -.63   -.63   -.63   -.63   -.63
         -.63   -.63
140.     -.555  -.555  -.555   -.555  -.555  -.555  -.555  -.555  -.555
         -.555  -.555
160.     -.43   -.43   -.43    -.43   -.43   -.43   -.43   -.43   -.43
         -.43   -.43
168.     -.38   -.38   -.38    -.38   -.38   -.38   -.38   -.38   -.38
         -.38   -.38
172.     -.39   -.39   -.39    -.39   -.39   -.39   -.39   -.39   -.39
         -.39   -.39
176.     -.28   -.28   -.28    -.28   -.28   -.28   -.28   -.28   -.28
         -.28   -.28
180.     -.04   -.04   -.04    -.04   -.04   -.04   -.04   -.04   -.04
         -.04   -.04
            BO-105 MAIN ROTOR DATA BLOCK                                 16
 3.35027  2.50239   .77366   .29209   .28886   .30902   .30902          16A1
 .30902   .30902    .30902   .30902   .30902   .30902   .30902          16A2
 .30902   .30902    .30902   .30902   .30902   .3084    .0000154        16A3
 0.       0.        0.       0.       0.       0.       0.              16B1
 0.       0.        0.       0.       0.       0.       0.              16B2
 0.       0.        0.       0.       0.       0.       0.              16B3
 .01784   .04797    .03097   .00210   .00385   .00501   .00501          16C1
 .00501   .00501    .00501   .00501   .00501   .00501   .00501          16C2
 .00501   .00501    .00501   .00501   .00501   .005                     16C3
   0.00000  -0.00000   0.00000  -0.00005  -0.00000   0.00115
  -0.00079   0.00008   0.00859  -0.00306   0.00017   0.00974
  -0.00670   0.00025   0.03037  -0.01092   0.00050   0.03896
  -0.01553   0.00075   0.08194  -0.02031   0.00117   0.12549
  -0.02521   0.00175   0.16738  -0.03018   0.00233   0.20743
  -0.03520   0.00300   0.24582  -0.04028   0.00375   0.28192
  -0.04541   0.00450   0.31578  -0.05056   0.00533   0.34667
  -0.05573   0.00617   0.37474  -0.06092   0.00700   0.39938
  -0.06610   0.00792   0.42001  -0.07127   0.00875   0.43663
  -0.07640   0.00967   0.44923  -0.08149   0.01067   0.45668
  -0.08603   0.01158   0.45840 1.125     0.         .01
                                                                       16D121
   0.00000  -0.00000   0.00000   0.00000  -0.00042  -0.00516
  -0.00030  -0.00317  -0.04297  -0.00205  -0.01013  -0.04985
  -0.00453  -0.02127  -0.03209  -0.00725  -0.03516  -0.03667
  -0.00993  -0.05073   0.00802  -0.01240  -0.06762   0.05272
  -0.01466  -0.08561   0.09569  -0.01672  -0.10448   0.13637
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TABLE A-1 – Continued

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-0.01864  -0.12409   0.17534  -0.02044  -0.14428   0.21144
-0.02214  -0.16499   0.24467  -0.02375  -0.18608   0.27504
-0.02530  -0.20750   0.30197  -0.02679  -0.22914   0.32546
-0.02823  -0.25095   0.34495  -0.02961  -0.27284   0.36042
-0.03094  -0.29482   0.37130  -0.03222  -0.31683   0.37818
-0.03303  -0.33882   0.37990 .7232      0.         .01
                                                                    16D122
 0.00000  -0.00000   0.00000   0.00003  -0.00000  -0.01719
 0.00146   0.00038  -0.13786   0.00552   0.00148  -0.15465
 0.01230   0.00320  -0.21734   0.01929   0.00498  -0.25934
 0.02639   0.00674  -0.36191   0.03273   0.00826  -0.45313
 0.03787   0.00943  -0.52922   0.04147   0.01017  -0.58790
 0.04317   0.01043  -0.62686   0.04268   0.01011  -0.64634
 0.03967   0.00918  -0.64577   0.03390   0.00761  -0.62629
 0.02516   0.00533  -0.59019   0.01335   0.00247  -0.54206
-0.00147  -0.00106  -0.48648  -0.01898  -0.00511  -0.42918
-0.03865  -0.00957  -0.37818  -0.05963  -0.01427  -0.34093
-0.08140  -0.01905  -0.33005 2.784      0.         .01
                                                                    16D123
 0.00000  -0.00000   0.00000  -0.00051   0.00006   1.47032
 0.00193   0.00091  11.74363   0.024090  0.00583  13.05122
 0.01386   0.00700  14.88883   0.04190   0.01608  17.37564
 0.05564   0.02025  19.80173   0.06722   0.02367  22.14529
 0.07592   0.02617  24.40176   0.08094   0.02767  26.56313
 0.08162   0.02792  28.62077   0.07744   0.02683  30.55980
 0.06845   0.02442  32.37450   0.05342   0.02067  33.89122
 0.03334   0.01558  35.55693   0.00896   0.00942  36.88916
-0.01868   0.00250  38.02199  -0.04772  -0.00483  38.93477
-0.07605  -0.01217  39.60863  -0.10174  -0.01917  40.02461
-0.08304  -0.02575  40.13062 3.176      0.         .01
                                                                    16D124
 0.00000  -0.00000   0.00000  -0.00023  -0.00000   0.05157
-0.00338  -0.00009   0.40225  -0.01214  -0.00098   0.41428
-0.02598  -0.00241   0.51513  -0.03827  -0.00334   0.54320
-0.04775  -0.00360   0.64176  -0.05186  -0.00280   0.67213
-0.04962  -0.00091   0.62743  -0.04084   0.00192   0.51283
-0.02623   0.00540   0.34036  -0.00746   0.00903   0.13294
 0.01305   0.01224  -0.08366   0.03193   0.01434  -0.28020
 0.04566   0.01465  -0.42860   0.05070   0.01261  -0.51054
 0.04954   0.00079  -5.18565   0.02587   0.00051  -0.46241
-0.00357  -0.00906  -0.36615  -0.04017  -0.01998  -0.27046
-0.07954  -0.03137  -0.238375.007       0.         .01
                                                                    16D125
 0.00000  -0.00000   0.00000  -0.02956   0.39031  56.77284
 0.03628   0.01484 434.43130   0.46204   0.09617 414.37060
-0.12575   0.05578 380.81000   0.08718   0.09567 331.76120
 0.17579   0.09396 271.25800   0.22850   0.08302 204.63540
 0.24178   0.06343 133.59490   0.20393   0.03357  59.64987
 0.11648  -0.00497 -14.91519  -0.00668  -0.04807 -89.01556
-0.14304  -0.09014-161.08750  -0.26212  -0.12433-229.61830
-0.33237  -0.14417-293.20970  -0.32885  -0.14513-350.49260
-0.24194  -0.12607-400.07420  -0.08409  -0.09017-440.55660
 0.11101  -0.04432-470.71940   0.29898   0.00323-489.38760
-0.09149   0.04764-494.14350 6.349     0.         .01
                                                                    16D126
            BO-105 FUSELAGE GROUP                                   20
4562.       100.39     0.         -1.86      96.80      0.        6.9       21
1268.       3479.      3203.      -290.      0.         15.       30.       22
   -2.8103                                                      0.0268F6AGAJ73  23
 0.003745   0.569222   0.000130   0..00052  -0.000192  -0.000003  -0.000166AGAJ73  24
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      9.1025                                                                0.017826AGAJ73   25
    0.028820 -0.158123  0.000702  0.000085  0.006891 -0.000023 -0.000177AGAJ73   26
    -29.3444                                                                0.056265AGAJ73   27
   -0.006806  1.575644 -0.011048 -0.001690  0.031490  0.000402  0.010432AGAJ73   28
                                  5.449701 -0.032884 -0.003029  0.000373AGAJ73   29
    0.823688  0.003138  0.000116 -0.007640 -0.000038  0.001128 -0.000001AGAJ73   2A
                                  9.732055 -0.986104  0.019363  0.000492AGAJ73   2B
    1.695225 -0.074555 -0.000724 -0.012898  0.000703  0.000603 -0.000075AGAJ73   2C
                                -34.232162  1.564419  0.014620 -0.003211AGAJ73   2D
   -0.990902 -0.021176  0.000109  0.029939  0.000230 -0.004625  0.000009AGAJ73   2E
              BO-105 ROTOR AERO GROUP                                     30
 .84          1.27        1.3         -.7         0.          0.          .7          31A
 .095         0.          .0475       0.          .01         0.          .00004      31B
 .04          .34         .098        1.          0.          .2          1.          31C
                                                                                      31D
                                                                                      31E
 .79          1.06        1.334       .8334       -4.924      3.853       .78         32A
 .11          .02446      -.1956      .3779       .008        -.00099     .00278      32B
 .04          .4          .12         0.          .028        1.          1.          32C
 -.002488     -.009456    .82         0.                                  0.          32D
                                                                                      32E
              BO-105 MAIN ROTOR GROUP                                                 40
   4.         0.                      16.11       10.64       -8.         90.         41
  98.444      0.          61.70       0.          0.          1.                      42
   0.         1.          0.          0.          1.          0.          3.22        43
   2.5        0.          0.          .015                    10.                     44
   0.         0.          -6.48       6.66                                            45
   0.         0.          0.          0.          0.          0.                      46
  -10.        3.          0.          0.          0.          0.          0.          47
              BO-105 TAIL ROTOR GROUP                                                  50
   2.         0.                      3.115       7.05        .0001       90.         51
  335.        -12.5       68.70       4.451       .487        5.527                   52
   0.         1.          0.          0.          1.          0.          0.          53
   0.         0.          45.         0.                      0.          0.          54
   0.         0.          0.          0.                                              55
   0.         0.          0.          0.          0.          0.                      56
   0.         -4.         -90.        0.          0.          0.                      57
              BO-105 STAB SURF  ELEVATOR                                              70
  8.71        277.45      0.          25.84       0.          0.          0.          71
  8.09        1.          1.          0.          0.          0.          0.          72
  0.          0.          0.          0.          0.          0.          0.          73
  0.          0.          0.          0.          0.          0.          0.          74
  1.          -5.         0.          0.          1.          2.                      75
  .989        1.0099      1.          0.          0.          0.          1.          76
  .103        0.          0.          0.          .0089       -.00015     .00017      77
  0.          .2          .12         0.          .011                                78
  -.00248     -.009456    .82         0.                                              79
              BO-105 MAIN ROTOR CONTROLS GROUP                                        130
  9.          6.          16.         0.          0.          0.                      131
  12.12       -4.7        14.         0.          0.          0.                      132
  8.65        -5.7        10.         0.          0.          0.                      133
  4.34        6.00        -28.        0.          0.          0.                      134
              BO-105 ITERATION LOGIC GROUP                                            140
 20.          0.          0.          .5                                              141
 .2           .2          15000.      15000.      2.          .15         500.0       142
 12.5         50.         50.         100.        100.        500.        500.        143
 61.          0.          0.          1636.       0.          1.17        -.93        151
 39.52        49.6        39.11       31.99       0.0                                 152
 2.72         2.43        -1.12       .20         4602.       -139.                   153
                          10000.      425.                    1636.                   154
```

TABLE A–2. C-81 INPUT DATA DECK FOR CASE M3

```
  2    5                                0                                   0                          01
              1 BO-105 C-81 CONTRACT CASE M3                                                              02
              1 BO-105 C-81 CONTRACT DECK D1                                                              03
              1 EQ FOR TR 23012 FOR MR                                                                    04
                BO-105 LOGIC GROUP                                                                        05
     0      1      4      0      0      2      0      0      0     -1      0      0      0      1          06
     0      0      1      1      2  .   0      1      0      0      0      1      3      3      0          07
     1      0      3      0      0      0             0      0                          0      0          08
                BO-105 AERO TABLES                                                         11
   666 NACA 230 2 LD/JMM 8/74   113911451144
            0.        0.3       0.4       0.5       0.6       0.7       0.75      0.8       0.85
            0.9       1.
 -180.      .04       .04       .04       .04       .04       .04       .04       .04       .04
            .04       .04
 -174.      .65       .65       .65       .65       .65       .65       .65       .65       .65
            .65       .65
 -170.      .65       .65       .65       .65       .65       .65       .65       .65       .65
            .65       .65
 -166.      .62       .62       .62       .62       .62       .62       .62       .62       .62
            .62       .62
 -133.      .865      .865      .865      .865      .865      .865      .865      .865      .865
            .865      .865
 -113.      .635      .635      .635      .635      .635      .635      .635      .635      .635
            .635      .635
 -58.       -.89      -.89      -.89      -.89      -.89      -.89      -.89      -.89      -.89
            -.89      -.89
 -38.       -1.14     -1.14     -1.14     -1.14     -1.14     -1.14     -1.14     -1.14     -1.14
            -1.14     -1.14
 -20.       -.98      -1.03     -1.07     -1.13     -1.14     -.868     -.86      -.845     -.74
            -1.01     -1.34
 -15.       -1.165    -1.225    -1.285    -1.23     -1.13     -.88      -.892     -.827     -.685
            -1.01     -1.34
 -13.5      -1.22     -1.28     -1.33     -1.26     -1.12     -.88      -.885     -.814     -.677
            -1.01     -1.34
 -12.       -1.095    -1.15     -1.2      -1.14     -1.092    -.86      -.877     -.791     -.655
            -1.01     -1.25
 -9.5       -.89      -.93      -.97      -.93      -1.05     -.83      -.85      -.77      -.62
            -.947     -1.1
 -5.5       -.47      -.493     -.51      -.55      -.585     -.64      -.688     -.65      -.58
            -.41      -.61
 -4.        -.312     -.33      -.335     -.36      -.39      -.41      -.5       -.475     -.28
            -.22      -.43
 -2.        -.1       -.107     -.105     -.115     -.12      -.12      -.127     -.16      -.165
            -.085     -.185
 -1.        0.0       0.0       0.0       0.0       .01       .025      .015      .05       -.005
            -.015     -.06
 0.0        .11       .11       .12       .13       .14       .17       .19       .24       .06
            .11       .06
 2.         .32       .332      .35       .375      .41       .475      .485      .37       .208
            .39       .3
 3.         .425      .443      .467      .5        .547      .62       .5        .415      .26
            .52       .426
 4.         .53       .55       .58       .62       .68       .675      .57       .475      .28
            .63       .545
 6.         .742      .772      .815      .868      .91       .767      .67       .51       .32
            .92       .787
 8.         .95       .995      1.035     1.115     .995      .856      .732      .545      .355
            1.19      1.03
 10.        1.165     1.22      1.26      1.27      1.075     .942      .791      .58       .393
```

TABLE A–2 – Continued

	1.19	1.095							
11.	1.268	1.328	1.38	1.278	1.092	.985	.825	.6	.413
	1.19	1.095							
12.	1.375	1.44	1.42	1.25	1.113	1.028	.852	.615	.432
	1.19	1.095							
13.	1.48	1.55	1.395	1.225	1.13	1.069	.885	.633	.45
	1.19	1.095							
13.5	1.53	1.6	1.27	1.207	1.141	1.09	.9	.641	.461
	1.19	1.095							
14.	1.585	1.095	1.14	1.19	1.15	1.112	.913	.65	.47
	1.19	1.095							
15.	.915	.962	1.	1.192	1.17	1.155	.946	.668	.49
	1.19	1.095							
20.	1.	1.05	1.09	1.2	1.26	1.367	1.1	.76	.59
	1.19	1.095							
38.	1.135	1.135	1.135	1.135	1.135	1.135	1.135	1.135	1.135
	1.135	1.135							
58.	.89	.89	.89	.89	.89	.89	.89	.89	.89
	.89	.89							
113.	-.635	-.635	-.635	-.635	-.635	-.635	-.635	-.635	-.635
	-.635	-.635							
133.	-.865	-.865	-.865	-.865	-.865	-.865	-.865	-.865	-.865
	-.865	-.865							
158.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.
	-1.	-1.							
166.	-.72	-.72	-.72	-.72	-.72	-.72	-.72	-.72	-.72
	-.72	-.72							
170.	-.82	-.82	-.82	-.82	-.82	-.82	-.82	-.82	-.82
	-.82	-.82							
180.	.04	.04	.04	.04	.04	.04	.04	.04	.04
	.04	.04							
	0.0	0.4	0.5	0.6	0.65	0.7	0.75	0.8	0.85
	0.9	1.0							
-180.	.015	.015	.015	.015	.015	.015	.015	.015	.015
	.015	.015							
-175.	.04	.04	.04	.04	.04	.04	.04	.04	.04
	.04	.04							
-170.	.11	.11	.11	.11	.11	.11	.11	.11	.11
	.11	.11							
-164.	.22	.22	.22	.22	.22	.22	.22	.22	.22
	.22	.22							
-155.	.51	.51	.51	.51	.51	.51	.51	.51	.51
	.51	.51							
-130.	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
	1.08	1.08							
-100.	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51
	1.51	1.51							
-90.	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56
	1.56	1.56							
-80.	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51
	1.51	1.51							
-60.	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
	1.24	1.24							
-40.	.9	9	.9	.9	.9	.9	.9	.9	.9
	.9								
-25.	.51	.51	.51	.51	.51	.51	.51	.51	.51
	.51	.51							
-8.	.0205	.0205	.067	.136	.1375	.1405	.144	.17	.1818
	.193	.2175							
-6.	.0154	.0154	.03	.075	.0765	.079	.087	.115	.127

TABLE A-2 – Continued

-4.	.138 .0112 .083	.1615 .0112 .1062	.0115	.0141	.0163	.0182	.0287	.06	.0715
-3.	.0107 .0625	.0107 .089	.01095	.0123	.01335	.01445	.0117	.0322	.0448
-2.	.0104 .0425	.0104 .0715	.0104	.0105	.0104	.0107	.011	.0137	.0284
-1.	.0105 .0512	.0105 .0812	.0103	.01035	.01035	.0105	.0104	.0177	.0373
0.	.0106 .06	.0106 .091	.0102	.0102	.0103	.0103	.0131	.0287	.0445
1.	.0105 .079	.0105 .1105	.0103	.01035	.01075	.0119	.0217	.0474	.0631
2.	.0104 .0975	.0104 .1293	.0104	.0105	.0112	.0186	.0384	.0659	.082
3.	.0106 .1165	.0106 .1485	.0107	.0118	.015	.0298	.0569	.0848	.101
4.	.0108 .135	.0108 .167	.011	.0131	.0236	.0484	.0755	.1035	.1195
5.	.0114 .153	.0114 .186	.01175	.0191	.0345	.067	.0944	.127	.1383
6.	.012 .172	.012 .205	.0125	.0293	.053	.086	.113	.141	.157
7.	.01265 .1915	.01265 .223	.0133	.0426	.072	.1047	.1319	.16	.176
8.	.0133 .21	.0133 .2425	.0153	.061	.0905	.1235	.1505	.1788	.195
9.	.0137 .229	.0137 .261	.0212	.0798	.1092	.1422	.1693	.198	.2135
10.	.0153 .248	.0153 .28	.03	.0983	.1275	.1607	.188	.217	.232
11.	.0175 .266	.0175 .299	.0483	.118	.1465	.179	.207	.236	.2505
12.	.0205 .285	.0205 .318	.067	.1357	.165	.1985	.225	.256	.27
13.	.0282 .304	.0282 .3365	.0858	.1545	.1835	.217	.244	.275	.289
15.	.0465 .34	.0465 .374	.1233	.192	.221	.254	.281	.3135	.3265
30.	.66 .66	.66 .66	.66	.66	.66	.66	.66	.66	.66
50.	1.07 1.07	1.07 1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
80.	1.5 1.5	1.5 1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
90.	1.56 1.56	1.56 1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56
100.	1.51 1.51	1.51 1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51
120.	1.23 1.23	1.23 1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23
140.	.89 .89	.89 .89	.89	.89	.89	.89	.89	.89	.89
155.	.5 .5	.5 .5	.5	.5	.5	.5	.5	.5	.5
164.	.22 .22	.22 .22	.22	.22	.22	.22	.22	.22	.22
170.	.11 .11	.11 .11	.11	.11	.11	.11	.11	.11	.11
175.	.04	.04	.04	.04	.04	.04	.04	.04	.04

TABLE A-2 – Continued

	.04	.04							
180.	.015	.015	.015	.015	.015	.015	.015	.015	.015
	.015	.015							
	0.	0.4	0.5	0.6	0.65	0.7	0.75	0.8	0.85
	0.9	1.0							
-180.	-.04	-.04	-.04	-.04	-.04	-.04	-.04	-.04	-.04
	-.04	-.04							
-172.	.37	.37	.37	.37	.37	.37	.37	.37	.37
	.37	.37							
-168.	.35	.35	.35	.35	.35	.35	.35	.35	.35
	.35	.35							
-164.	.39	.39	.39	.39	.39	.39	.39	.39	.39
	.39	.39							
-156.	.42	.42	.42	.42	.42	.42	.42	.42	.42
	.42	.42							
-150.	.445	.445	.445	.445	.445	.445	.445	.445	.445
	.445	.445							
-130.	.575	.575	.575	.575	.575	.575	.575	.575	.575
	.575	.575							
-115.	.6	.6	.6	.6	.6	.6	.6	.6	.6
	.6	.6							
-90.	.55	.55	.55	.55	.55	.55	.55	.55	.55
	.55	.55							
-60.	.4	.4	.4	.4	.4	.4	.4	.4	.4
	.4	.4							
-40.	.26	.26	.26	.26	.26	.26	.26	.26	.26
	.26	.26							
-30.	.18	.18	.18	.18	.18	.18	.18	.18	.18
	.18	.18							
-16.	.105	.105	.105	.105	.105	.105	.105	.105	.105
	.105	.105							
-4.	-.0075	-.0075	-.0065	-.0105	-.015	-.018	-.0175	.0238	.009
	.02	.005							
-3.	-.007	-.007	-.0067	-.0091	-.0112	-.015	-.0189	.009	.0055
	-.006	-.002							
-2.	-.007	-.0065	-.007	-.0075	-.0075	-.012	-.01	-.013	.004
	-.031	-.0095							
-1.	-.0075	-.0075	-.0075	-.0084	-.0084	-.0105	-.009	-.012	-.0275
	-.03	-.035							
0.0	-.008	-.008	-.008	-.009	-.009	-.009	-.008	-.033	-.0215
	-.0435	-.057							
1.	-.0085	-.0085	-.0083	-.009	-.0088	-.0075	-.0125	-.0505	-.0235
	-.05	-.0615							
2.	-.009	-.009	-.0087	-.009	-.0085	-.007	-.025	-.0515	-.037
	-.0505	-.068							
3.	-.0093	-.0093	-.009	-.0076	-.006	-.011	-.0415	-.0525	-.0375
	-.051	-.072							
4.	-.01	-.0095	-.0095	-.006	-.0035	-.0225	-.0525	-.057	-.06
	-.0655	-.0745							
5.	-.01	-.009	-.009	-.0024	-.005	-.04	-.0605	-.076	-.084
	-.0825	-.0805							
6.	-.0115	-.0075	-.0085	0.	-.015	-.0505	-.067	-.083	-.0975
	-.0935	-.085							
7.	-.013	-.0045	-.0078	.0005	-.031	-.058	-.0755	-.0785	-.09
	-.099	-.091							
8.	-.015	-.0005	-.007	-.011	-.0425	-.077	-.082	-.089	-.097
	-.104	-.096							
9.	.006	.006	-.006	-.0223	-.0525	-.082	-.089	-.094	-.102
	-.1088	-.1009							
10.	.0125	.0125	-.003	-.0315	-.0624	-.0869	-.096	-.0989	-.1048

TABLE A-2 – Continued

	-.1137	-.1058							
11.	.0135	.0135	.001	-.0415	-.0723	-.0918	-.101	-.1028	-.1118
	-.1186	-.1106							
12.	.0035	.0035	.0035	-.0514	-.0822	-.0966	-.1058	-.1087	-.1167
	-.1235	-.1155							
13.	-.0185	-.0185	-.005	-.0613	-.0922	-.1017	-.1107	-.1137	-.1215
	-.1285	-.1205							
14.	-.0435	-.0435	-.0565	-.0612	-.1023	-.1065	-.1157	-.1186	-.1266
	-.1335	-.1255							
16.	-.102	-.102	-.0885	-.0912	-.1122	-.1165	-.1252	-.1285	-.1365
	-.143	-.1354							
25.	-.175	-.175	-.175	-.175	-.175	-.175	-.175	-.175	-.175
	-.175	-.175							
40.	-.29	-.29	-.29	-.29	-.29	-.29	-.29	-.29	-.29
	-.29	-.29							
60.	-.43	-.43	-.43	-.43	-.43	-.43	-.43	-.43	-.43
	-.43	-.43							
90.	-.58	-.58	-.58	-.58	-.58	-.58	-.58	-.58	-.58
	-.58	-.58							
115.	-.63	-.63	-.63	-.63	-.63	-.63	-.63	-.63	-.63
	-.63	-.63							
140.	-.555	-.555	-.555	-.555	-.555	-.555	-.555	-.555	-.555
	-.555	-.555							
160.	-.43	-.43	-.43	-.43	-.43	-.43	-.43	-.43	-.43
	-.43	-.43							
168.	-.38	-.38	-.38	-.38	-.38	-.38	-.38	-.38	-.38
	-.38	-.38							
172.	-.39	-.39	-.39	-.39	-.39	-.39	-.39	-.39	-.39
	-.39	-.39							
176.	-.28	-.28	-.28	-.28	-.28	-.28	-.28	-.28	-.28
	-.28	-.28							
180.	-.04	-.04	-.04	-.04	-.04	-.04	-.04	-.04	-.04
	-.04	-.04							

BO-105 MAIN ROTOR DATA BLOCK 16

3.35027	2.50239	.77366	.29209	.28886	.30902	.30902	16A1
.30902	.30902	.30902	.30902	.30902	.30902	.30902	16A2
.30902	.30902	.30902	.30902	.30902	.3084	.0000154	16A3
0.	0.	0.	0.	0.	0.	0.	16B1
0.	0.	0.	0.	0.	0.	0.	16B2
0.	0.	0.	0.	0.	0.	0.	16B3
.01784	.04797	.03097	.00218	.00385	.00501	.00501	16C1
.00501	.00501	.00501	.00501	.00501	.00501	.00501	16C2
.00501	.00501	.00501	.00501	.00501	.005		16C3
0.	0.	0.	0.	0.	0.		16D11
.0001	-.0001	0.	.0119	-.0002	-.0124		16D21
.0389	-.0003	-.0167	.0077	-.0006	-.0058		16D31
.0121	-.001	-.037	.0168	-.0016	-.07		16D41
.0217	-.0023	-.102	.0267	-.003	-.133		16D51
.0318	-.0039	-.162	.037	-.0048	-.191		16D61
.0422	-.0057	-.217	.0475	-.0068	-.241		16D71
.0529	-.0078	-.263	.0583	-.0088	-.283		16D81
.0637	-.0098	-.299	.0692	-.01111	-.311		16D91
.0746	-.0122	-.321	.0801	-.0133	-.322		16D101
.085	-.0144	-.328	1.15	0.	.01		16D111
							16D121
0.	0.	0.	0.	0.	-.0321		16D12
.0002	0.	-.0486	.0024	.0003	-.0767		16D22
.0079	.0017	-.0738	.0152	.0032	-.08		16D32
.0231	.0048	-.1564	.0305	.0063	-.2292		16D42
.0369	.0075	-.2922	.0417	.0083	-.3417		16D52

.0445	.0087	-.3760	.0449	.0086	-.3948		16062	
.0425	.0079	-.3974	.037	.0067	-.3846		16072	
.0282	.0048	-.3583	.016	.0024	-.3212		16082	
.0005	-.0005	-.2759	-.0179	-.0039	-.2293		16092	
-.0384	-.0076	-.1874	-.0603	-.0115	-.1693		160102	
-.0822	-.0154	-.1493	2.83	0.	.01		160112	
							160122	
0.	0.	0.	0.	-.0001	-.0413		16013	
0.	-.001	-.039	-.0008	-.0045	-.0299		16023	
-.0033	-.0123	-.0301	-.0065	-.0245	-.0555		16033	
-.0097	-.0395	-.0232	-.013	-.0562	.0106		16043	
-.0161	-.0743	.0433	-.0191	-.0935	.075		16053	
-.0219	-.114	.105	-.0246	-.135	.132		16063	
-.0272	-.156	.159	-.0297	-.178	.183		16073	
-.0322	-.2	.204	-.0346	-.223	.222		16083	
-.0369	-.246	.237	-.0392	-.269	.249	16093		
-.0412	-.293	.257	-.0438	-.316	.26		160103	
-.046	-.339	.264	.696	0.	.01		160113	
							160123	
0.	0.	0.	-.0012	-.0003	-3.232		16014	
-.0023	-.0006	-3.696	-.0018	-.0004	-4.212		16024	
-.0014	-.0003	-4.836	-.0126	-.0027	-5.696		16034	
-.0164	-.0035	-6.779	-.0199	-.0042	-7.896		16044	
-.0228	-.0047	-8.967	-.0248	-.0051	-9.98		16054	
-.0256	-.0051	-10.95	-.0254	-.005	-11.855		16064	
-.0239	-.0045	-12.692	-.0213	-.0039	-13.448		16074	
-.0177	-.003	-14.118	-.0134	-.002	-14.697		16084	
-.0089	-.0009	-15.178	-.0044	.0001	-15.5570		16094	
-.0005	.0011	-15.832	.0021	.002	-15.938		160104	
.0047	.0028	-16.044	3.87	0.	.01		160114	
							160124	
	BO-105 FUSELAGE GROUP						20	
4140.	100.39	0.	-1.86	97.45	0.	6.9	21	
1268.	3479.	3203.	0.	0.	15.	30.	22	
-2.8103						0.026886AGAJ73		23
0.003745	0.569222	0.000130	0.000052	-0.000192	-0.000003	-0.000166AGAJ73		24
9.1025						0.017826AGAJ73		25
0.028820	-0.158123	0.000702	0.000085	0.006891	-0.000023	-0.000177AGAJ73		26
-29.3444						0.056265AGAJ73		27
-0.006806	1.575644	-0.011048	-0.001690	0.031490	0.000402	0.010432AGAJ73		28
			5.849701	-0.032884	-0.003029	0.000373AGAJ73		29
0.823888	0.003138	0.000116	-0.007640	-0.000038	0.001128	-0.000[illegible]01AGAJ73		2A
			9.732055	-0.986104	0.019363	0.000492AGAJ73		2B
1.695225	-0.074555	-0.000724	-0.012898	0.000703	0.000603	-0.000075AGAJ73		2C
			-34.232162	1.564419	0.014620	-0.003211AGAJ73		2D
-0.990902	-0.021176	0.000109	0.029939	0.000230	-0.004625	0.000009AGAJ73		2E
	BO-105 ROTOR AERO GROUP						30	
.84	1.27	1.3	-.7	0.	0.	.7	31A	
.095	0.	.0475	0.	.01	0.	.00004	31B	
.04	.34	.098	1.	0.	.2	1.	31C	
							31D	
							31E	
.79	1.06	1.334	.8334	-4.924	3.853	.78	32A	
.11	.02468	-.1956	.3779	.008	-.00099	.00278	32B	
.04	.4	.12	0.	.028	1.	1.	32C	
-.002488	-.009456	.82	0.			0.	32D	
							32E	
	BO-105 MAIN ROTOR GROUP						40	
4.	0.		16.11	10.64	-8.	90.	41	
98.444	0.	61.20	0.	0.	1.		42	

TABLE A-2 – Continued

0.	1.	0.	0.	1.	0.	1.37		43
2.5	0.	0.	.015		10.			44
0.	0.	-6.48	6.66					45
0.	0.	0.	0.	0.	0.			46
-10.	3.	0.	0.	0.	0.	0.		47
	BO-105 TAIL ROTOR GROUP							50
2.	0.		3.115	7.05	.0001	90.		51
335.	-12.5	68.70	4.851	.487	5.527			52
0.	1.	0.	0.	1.	0.	0.		53
0.	0.	45.	0.		0.	0.		54
0.	0.	0.	0.					55
0.	0.	0.	0.	0.	0.			56
0.	-4.	-90.	0.	0.	0.			57
	BO-105 STAB SURF ELEVATOR							70
8.71	277.45	0.	25.84	0.	0.	0.		71
8.09	1.	1.	0.	0.	0.	0.		72
0.	0.	0.	0.	0.	0.	0.		73
0.	0.	0.	0.	0.	0.	0.		74
1.	-5.	0.	0.	1.	2.			75
.989	1.0099	1.	0.	0.	0.	1.		76
.103	0.	0.	0.	.0089	-.00015	.00017		77
0.	.2	.12	0.	.011				78
-.00248	-.009456	.82	0.					79
	BO-105 MAIN ROTOR CONTROLS GROUP							130
9.	6.	16.	0.	0.	0.			131
12.12	-4.7	14.	0.	0.	0.			132
8.65	-5.7	10.	0.	0.	0.			133
4.34	6.00	-28.	0.	0.	0.			134
	BO-105 ITERATION LOGIC GROUP							140
20.	0.	0.	.5					141
.2	.2	15000.	15000.	5.	.05	10000.		142
50.	50.	50.	100.	100.	500.	500.		143
.001	0.	0.	5000.	0.	2.792	-3.101		151
52.92	30.80	55.72	50.26	0.				152
2.486	-3.254	0.	0.	4477.	-266.			153
		10000.	425.	0.	5000.	0.		154
	NO BOBWEIGHT GROUP							
								201
	NO WEAPONS GROUP							210
								211
	NO SCAS GROUP							220
								221
								222
								223
								224
	NO STAB TIMES							230
9								231
								232
	NO BLADE EL DATA TIMES							240
9								241
								242
0.	30.	1.9	30.					301
1 1	99.							311
1 2	0.	0.	.1	.1	6.28	.3		312
1 2	.3	0.	2.					313
1 3	0.	0.	.2	.2	.865	.4		314
1 3	.4	-.058	2.					315
0 4	0.	.047	1.	1.	0.	2.		316
3								401
230 231 232 1 1								402A

TABLE A–2 – Continued

223	224	225	1	1	402B
250	259	268	1	1	402C
241			1	0	402D

TABLE A–3. C-81 INPUT DATA DECK FOR CASE 88

```
9                                                                                  01
            1 BO-105 C-81 CONTRACT CASE S8                                         02
            1 BO-105 C-81 CONTRACT DECK C                                          03
            1 EQ FOR TR 23012 FCR MR                                               04
              BO-105 LOGIC GROUP                                                   05
     0     1     4     0     0     2     0     0     0    -1     0     0     0     0      06
     0     0     5     1     2     0     0     0     0     0     1     3     3     0      07
     1     0     3     1     0     0           0     0                       0     0      08
              BO-105 AERO TABLES                                          11
  660 NACA 23012 LD/JMM 8/74   113911451144
        0.      0.3     0.4     0.5     0.6     0.7     0.75    0.8     0.85
        0.9     1.
-180.   .04     .04     .04     .04     .04     .04     .04     .04     .04
        .04     .04
-174.   .65     .65     .65     .65     .65     .65     .65     .65     .65
        .65     .65
-170.   .65     .65     .65     .65     .65     .65     .65     .65     .65
        .65     .65
-166.   .62     .62     .62     .62     .62     .62     .62     .62     .62
        .62     .62
-133.   .865    .865    .865    .865    .865    .865    .865    .865    .865
        .865    .865
-113.   .635    .635    .635    .635    .635    .635    .635    .635    .635
        .635    .635
-98.    -.89    -.89    -.89    -.89    -.89    -.89    -.89    -.89    -.89
        -.89    -.89
-30.    -1.14   -1.14   -1.14   -1.14   -1.14   -1.14   -1.14   -1.14   -1.14
        -1.14   -1.14
-20.    -.98    -1.03   -1.07   -1.13   -1.14   -.868   -.86    -.845   -.74
        -1.01   -1.34
-15.    -1.165  -1.225  -1.285  -1.23   -1.13   -.88    -.892   -.827   -.685
        -1.01   -1.34
-13.5   -1.22   -1.28   -1.33   -1.26   -1.12   -.88    -.885   -.814   -.677
        -1.01   -1.34
-12.    -1.095  -1.15   -1.2    -1.14   -1.092  -.86    -.877   -.741   -.655
        -1.01   -1.25
-9.5    -.89    -.93    -.97    -.93    -1.05   -.83    -.85    -.77    -.62
        -.947   -1.1
-5.5    -.47    -.493   -.51    -.55    -.585   -.64    -.688   -.65    -.58
        -.41    -.61
-4.     -.312   -.33    -.335   -.36    -.39    -.41    -.5     -.475   -.28
        -.22    -.43
-2.     -.1     -.107   -.105   -.115   -.12    -.12    -.127   -.16    -.165
        -.085   -.185
-1.     0.0     0.0     0.0     0.0     .01     .025    .015    .05     -.005
        -.015   -.06
0.0     .11     .11     .12     .13     .14     .17     .19     .24     .06
        .11     .06
2.      .32     .332    .35     .375    .41     .475    .485    .37     .208
        .39     .3
3.      .425    .443    .467    .5      .547    .62     .5      .415    .26
        .52     .426
4.      .53     .55     .58     .62     .68     .675    .57     .475    .28
        .63     .545
6.      .742    .772    .815    .868    .91     .767    .67     .51     .32
        .92     .787
8.      .95     .995    1.035   1.115   .995    .856    .732    .545    .355
        1.19    1.03
10.     1.165   1.22    1.26    1.27    1.075   .942    .791    .58     .393
```

TABLE A–3 – Continued

	1.19	1.095							
11.	1.268	1.328	1.38	1.278	1.092	.985	.825	.6	.413
	1.19	1.095							
12.	1.375	1.44	1.42	1.25	1.113	1.028	.852	.615	.432
	1.19	1.095							
13.	1.48	1.55	1.395	1.225	1.13	1.069	.885	.633	.45
	1.19	1.095							
13.5	1.53	1.6	1.27	1.207	1.141	1.09	.9	.641	.461
	1.19	1.075							
14.	1.585	1.095	1.14	1.19	1.15	1.112	.913	.65	.47
	1.19	1.095							
18.	.915	.962	1.	1.192	1.17	1.155	.946	.668	.49
	1.19	1.095							
20.	1.	1.05	1.09	1.2	1.26	1.367	1.1	.76	.59
	1.19	1.095							
30.	1.135	1.135	1.135	1.135	1.135	1.135	1.135	1.135	1.135
	1.135	1.135							
58.	.89	.89	.89	.89	.89	.89	.89	.89	.89
	.89	.89							
113.	-.635	-.635	-.635	-.635	-.635	-.635	-.635	-.635	-.635
	-.635	-.635							
133.	-.865	-.865	-.865	-.865	-.865	-.865	-.865	-.865	-.865
	-.865	-.865							
158.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.
	-1.	-1.							
166.	-.72	-.72	-.72	-.72	-.72	-.72	-.72	-.72	-.72
	-.72	-.72							
170.	-.82	-.82	-.82	-.82	-.82	-.82	-.82	-.82	-.82
	-.82	-.82							
180.	.04	.04	.04	.04	.04	.04	.04	.04	.04
	.04	.04							
	0.0	0.4	0.5	0.6	0.65	0.7	0.75	0.8	0.85
	0.9	1.0							
-180.	.015	.015	.015	.015	.015	.015	.015	.015	.015
	.015	.015							
-175.	.04	.04	.04	.04	.04	.04	.04	.04	.04
	.04	.04							
-170.	.11	.11	.11	.11	.11	.11	.11	.11	.11
	.11	.11							
-166.	.22	.22	.22	.22	.22	.22	.22	.22	.22
	.22	.22							
-155.	.51	.51	.51	.51	.51	.51	.51	.51	.51
	.51	.51							
-130.	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
	1.08	1.08							
-100.	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51
	1.51	1.51							
-90.	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56
	1.56	1.56							
-80.	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51
	1.51	1.51							
-60.	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
	1.24	1.24							
-40.	.9	.9	.9	.9	.9	.9	.9	.9	.9
	.9	.9							
-25.	.51	.51	.51	.51	.51	.51	.51	.51	.51
	.51	.51							
-8.	.0205	.0205	.067	.136	.1375	.1405	.144	.17	.1818
	.193	.2175							
-6.	.0154	.0154	.03	.075	.0765	.079	.087	.115	.127

TABLE A-3 – Continued

	.138	.1615							
-4.	.0112	.0112	.0115	.0141	.0163	.0182	.0287	.06	.0715
	.083	.1062							
-3.	.0107	.0107	.01095	.0123	.01335	.01445	.0117	.0222	.0448
	.0625	.089							
-2.	.0104	.0104	.0104	.0105	.0104	.0107	.011	.0137	.0284
	.0425	.0715							
-1.	.0105	.0105	.0103	.01035	.01035	.0105	.0104	.0177	.0373
	.0512	.0812							
0.	.0106	.0106	.0102	.0102	.0103	.0103	.0141	.0287	.0445
	.06	.091							
1.	.0105	.0105	.0103	.01035	.01075	.0119	.0217	.0474	.0631
	.079	.1105							
2.	.0104	.0104	.0104	.0105	.0112	.0186	.0384	.0659	.082
	.0975	.1293							
3.	.0106	.0106	.0107	.0118	.015	.0298	.0569	.0848	.101
	.1165	.1485							
4.	.0108	.0108	.011	.0131	.0236	.0484	.0755	.1035	.1195
	.135	.167							
5.	.0114	.0114	.01175	.0191	.0345	.067	.0944	.122	.1383
	.153	.186							
6.	.012	.012	.0125	.0293	.053	.086	.113	.141	.157
	.172	.205							
7.	.01265	.01265	.0133	.0426	.072	.1047	.1319	.16	.176
	.1915	.223							
8.	.0133	.0133	.0153	.061	.0905	.1235	.1505	.1780	.195
	.21	.2425							
9.	.0137	.0137	.0212	.0798	.1092	.1422	.1693	.198	.2135
	.229	.261							
10.	.0153	.0153	.03	.0983	.1275	.1607	.188	.217	.232
	.248	.28							
11.	.0175	.0175	.0483	.118	.1465	.179	.207	.236	.2505
	.266	.297							
12.	.0205	.0205	.067	.1357	.165	.1985	.225	.256	.27
	.285	.318							
13.	.0282	.0282	.0858	.1545	.1835	.217	.244	.275	.289
	.304	.3365							
15.	.0465	.0465	.1233	.192	.221	.254	.281	.3135	.3265
	.34	.374							
30.	.66	.66	.66	.66	.66	.66	.66	.66	.66
	.66	.66							
50.	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
	1.07	1.07							
80.	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	1.5	1.5							
90.	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56
	1.56	1.56							
100.	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51
	1.51	1.51							
120.	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23
	1.23	1.23							
140.	.89	.89	.89	.89	.89	.89	.89	.89	.89
	.89	.89							
155.	.5	.5	.5	.5	.5	.5	.5	.5	.5
	.5	.5							
164.	.22	.22	.22	.22	.22	.22	.22	.22	.22
	.22	.22							
170.	.11	.11	.11	.11	.11	.11	.11	.11	.11
	.11	.11							
175.	.04	.04	.04	.04	.04	.04	.04	.04	.04

TABLE A-3 – Continued

	.04	.04							
180.	.015	.015	.015	.015	.015	.015	.015	.015	.015
	.015	.015							
	0.	0.4	0.5	0.6	0.65	0.7	0.75	0.8	0.85
	0.9	1.0							
-180.	-.04	-.04	-.04	-.04	-.04	-.04	-.04	-.04	-.04
	-.04	-.04							
-172.	.37	.37	.37	.37	.37	.37	.37	.37	.37
	.37	.37							
-168.	.35	.35	.35	.35	.35	.35	.35	.35	.35
	.35	.35							
-164.	.39	.39	.39	.39	.39	.39	.39	.39	.39
	.39	.39							
-156.	.42	.42	.42	.42	.42	.42	.42	.42	.42
	.42	.42							
-150.	.445	.445	.445	.445	.445	.445	.445	.445	.445
	.445	.445							
-130.	.575	.575	.575	.575	.575	.575	.575	.575	.575
	.575	.575							
-115.	.6	.6	.6	.6	.6	.6	.6	.6	.6
	.6	.6							
-90.	.55	.55	.55	.55	.55	.55	.55	.55	.55
	.55	.55							
-60.	.4	.4	.4	.4	.4	.4	.4	.4	.4
	.4	.4							
-40.	.26	.26	.26	.26	.26	.26	.26	.26	.26
	.26	.26							
-30.	.18	.18	.18	.18	.18	.18	.18	.18	.18
	.18	.18							
-16.	.105	.105	.105	.105	.105	.105	.105	.105	.105
	.105	.105							
-4.	-.0075	-.0075	-.0065	-.0105	-.015	-.018	-.0175	.0238	.009
	.02	.005							
-3.	-.007	-.007	-.0067	-.0091	-.0112	-.015	-.0189	.009	.0055
	-.006	-.002							
-2.	-.007	-.0065	-.007	-.0075	-.0075	-.012	-.01	-.013	.004
	-.031	-.0295							
-1.	-.0075	-.0075	-.0075	-.0084	-.0084	-.0105	-.009	-.012	-.0275
	-.03	-.035							
0.0	-.008	-.008	-.008	-.009	-.009	-.009	-.008	-.033	-.0215
	-.0435	-.057							
1.	-.0085	-.0085	-.0083	-.009	-.0088	-.0075	-.0125	-.0505	-.0235
	-.05	-.0615							
2.	-.009	-.009	-.0087	-.009	-.0085	-.007	-.025	-.0515	-.037
	-.0505	-.068							
3.	-.0093	-.0093	-.009	-.0076	-.006	-.011	-.0415	-.0525	-.0375
	-.051	-.072							
4.	-.01	-.0095	-.0095	-.006	-.0035	-.0225	-.0525	-.057	-.06
	-.0655	-.0745							
5.	-.01	-.009	-.009	-.0024	-.005	-.04	-.0605	-.076	-.084
	-.0825	-.0805							
6.	-.0115	-.0075	-.0085	0.	-.015	-.0505	-.067	-.083	-.0975
	-.0935	-.085							
7.	-.013	-.0045	-.0078	.0005	-.031	-.058	-.0755	-.0785	-.09
	-.099	-.091							
8.	-.015	-.0005	-.007	-.011	-.0425	-.077	-.082	-.089	-.097
	-.104	-.096							
9.	.006	.006	-.006	-.0223	-.0525	-.082	-.089	-.094	-.102
	-.1088	-.1009							
10.	.0125	.0125	-.003	-.0315	-.0624	-.0869	-.096	-.0989	-.1068

```
        -.1137 -.1050
11.     .0135  .0135  .001   -.0415 -.0723 -.0918 -.101  -.1028 -.1118
        -.1186 -.1106
12.     .0035  .0045  .0035  -.0514 -.0822 -.0966 -.1058 -.1047 -.1167
        -.1235 -.1155
13.     -.0185 -.0185 -.005  -.0613 -.0922 -.1017 -.1107 -.1137 -.1215
        -.1285 -.1205
14.     -.0435 -.0435 -.0565 -.0612 -.1023 -.1065 -.1157 -.1166 -.1266
        -.1335 -.1255
16.     -.102  -.102  -.0085 -.0912 -.1122 -.1165 -.1252 -.1445 -.1365
        -.143  -.1354
25.     -.175  -.175  -.175  -.175  -.175  -.175  -.175  -.175  -.175
        -.175  -.175
40.     -.29   -.29   -.29   -.29   -.29   -.29   -.29   -.29   -.29
        -.29   -.29
60.     -.43   -.43   -.43   -.43   -.43   -.43   -.43   -.43   -.43
        -.43   -.43
90.     -.58   -.58   -.58   -.58   -.58   -.58   -.58   -.58   -.58
        -.58   -.58
115.    -.63   -.63   -.63   -.63   -.63   -.63   -.63   -.63   -.63
        -.63   -.63
140.    -.555  -.555  -.555  -.555  -.555  -.555  -.555  -.555  -.555
        -.555  -.555
160.    -.43   -.43   -.43   -.43   -.43   -.43   -.43   -.43   -.43
        -.43   -.43
168.    -.38   -.30   -.38   -.38   -.38   -.38   -.38   -.38   -.38
        -.38   -.38
172.    -.39   -.39   -.39   -.39   -.39   -.39   -.39   -.39   -.39
        -.39   -.39
176.    -.28   -.20   -.28   -.28   -.28   -.28   -.28   -.28   -.28
        -.28   -.28
180.    -.04   -.04   -.04   -.04   -.04   -.04   -.04   -.04   -.04
        -.04   -.04
             BO-105 MAIN ROTOR DATA BLOCK                                 16
3.35027  2.50234  .77365   .29209   .28886   .30902   .30902     16A1
.30902   .30902   .30902   .30902   .30902   .30902   .30902     16A2
.30902   .30902   .30702   .30902   .30902   .3084    .0000154   16A3
0.       0.       0.       0.       0.       0.       0.         16B1
0.       0.       0.       0.       0.       0.       0.         16B2
0.       0.       0.       0.       0.       0.       0.         16B3
.01784   .04797   .03097   .00218   .00385   .00501   .00501     16C1
.00501   .00501   .00501   .00501   .00501   .00501   .00501     16C2
.00501   .00501   .00501   .00501   .00501   .005               16C3
  0.00000  -0.00000   0.00000  -0.00005  -0.00000   0.00115
 -0.00079   0.00008   0.00859  -0.00306   0.00017   0.00974
 -0.00670   0.00025   0.03037  -0.01092   0.00050   0.03896
 -0.01553   0.00075   0.08194  -0.02031   0.00117   0.12549
 -0.02921   0.00175   0.16732  -0.03018   0.00233   0.20743
 -0.03920   0.00300   0.24582  -0.04028   0.00375   0.28192
 -0.04541   0.00450   0.31572  -0.05056   0.00533   0.34667
 -0.05573   0.00617   0.37474  -0.06092   0.00700   0.39938
 -0.06610   0.00792   0.42001  -0.07127   0.00875   0.43663
 -0.07640   0.00967   0.44923  -0.08149   0.01067   0.45668
 -0.08603   0.01158   0.45840 1.125     0.          .01
                                                                 16D121
  0.00000  -0.00000   0.00000   0.00000  -0.00042  -0.00516
 -0.00030  -0.00317  -0.04297  -0.00205  -0.01013  -0.04985
 -0.00453  -0.02127  -0.03209  -0.00725  -0.03516  -0.03667
 -0.00993  -0.05073   0.00802  -0.01240  -0.06762   0.05272
 -0.01466  -0.08561   0.09569  -0.01672  -0.10448   0.13637
```

TABLE A-3 – Continued

-0.01864	-0.12409	0.17534	-0.02044	-0.14420	0.21144		
-0.02214	-0.16499	0.24467	-0.02375	-0.18608	0.27504		
-0.02530	-0.20750	0.30197	-0.02679	-0.22914	0.32546		
-0.02823	-0.25095	0.34495	-0.02961	-0.27284	0.36042		
-0.03094	-0.29482	0.37130	-0.03222	-0.31683	0.37818		
-0.03303	-0.33882	0.37990	.7232	0.	.01		
							160122
0.00000	-0.00000	0.00000	0.00003	-0.00000	-0.01719		
0.00146	0.00038	-0.13786	0.00552	0.00148	-0.15465		
0.01230	0.00320	-0.21734	0.01929	0.00498	-0.25934		
0.02639	0.00674	-0.36191	0.03273	0.00826	-0.45313		
0.03787	0.00943	-0.52922	0.04147	0.01017	-0.58790		
0.04317	0.01043	-0.62686	0.04268	0.01011	-0.64634		
0.03967	0.00918	-0.64577	0.03390	0.00761	-0.62629		
0.02516	0.00533	-0.59019	0.01335	0.00247	-0.54206		
-0.00167	-0.00106	-0.48648	-0.01898	-0.00511	-0.42918		
-0.03865	-0.00957	-0.37818	-0.05963	-0.01427	-0.34093		
-0.08140	-0.01905	-0.33005	2.784	0.	.01		
							160123
0.00000	-0.00000	0.00000	-0.00051	0.00006	1.47032		
0.00193	0.00091	11.74363	0.024090	0.00583	13.05122		
0.01386	0.00700	14.38883	0.04190	0.01608	17.37564		
0.05564	0.02025	19.80173	0.06722	0.02367	22.14529		
0.07592	0.02617	24.40176	0.08094	0.02767	26.56313		
0.08162	0.02792	28.62077	0.07746	0.02683	30.55980		
0.06845	0.02442	32.37450	0.05342	0.02067	33.89122		
0.03334	0.01558	35.55693	0.00896	0.00942	36.88916		
-0.01868	0.00250	38.02199	-0.04772	-0.00483	38.93477		
-0.07605	-0.01217	39.60863	-0.10174	-0.01917	40.02461		
-0.08304	-0.02575	40.13062	3.176	0.	.01		
							160124
	BO-105 FUSELAGE GROUP						20
4400.	100.39	0.	-1.86	97.45	0.	6.9	21
1268.	3479.	3203.	-250.	0.	15.	30.	22
-2.8103						0.026886AGAJ73	23
0.003745	0.569222	0.000130	0.000052	-0.000192	-0.000003	-0.000166AGAJ73	24
9.1025						0.017826AGAJ73	25
0.028820	-0.158123	0.000702	0.000085	0.006891	-0.000023	-0.000177AGAJ73	26
-29.3444						0.056265AGAJ73	27
-0.006806	1.575666	-0.011048	-0.001690	0.031490	0.000402	0.010432AGAJ73	28
			5.849701	-0.032804	-0.003029	0.000373AGAJ73	29
0.823888	0.003138	0.000116	-0.007640	-0.000038	0.001128	-0.000001AGAJ73	2A
			9.732055	-0.986104	0.019363	0.000472AGAJ73	2B
1.695225	-0.074555	-0.000724	-0.012898	0.000703	0.000603	-0.000075AGAJ73	2C
			-34.232162	1.564419	0.014620	-0.003211AGAJ73	2D
-0.990902	-0.021176	0.000109	0.029939	0.000230	-0.004625	0.000009AGAJ73	2E
	BO-105 ROTOR AERO GROUP						30
.84	1.27	1.3	-.7	0.	0.	.7	31A
.095	0.	.0475	0.	.01	0.	.00004	31B
.04	.34	.098	1.	0.	.2	1.	31C
							31D
							31E
.79	1.06	1.334	.8334	-4.924	3.053	.78	32A
.11	.02468	-.1956	.3779	.008	-.00099	.00278	32B
.06	.4	.12	0.	.028	1.	1.	32C
-.002488	-.009456	.82	0.			0.	32D
							32E
	BO-105 MAIN ROTOR GROUP						40
4.	0.		16.11	10.64	-8.	90.	41
98.444	0.	61.20	0.	0.	1.		42

TABLE [illegible]-3 – Continued

0.	1.	0.	0.	1.	0.	1.37	43
2.5	0.	0.	.015		10.		44
0.	0.	-6.48	6.66				45
0.	0.	0.	0.	0.	0.		46
-10.	3.	0.	0.	0.	0.	0.	47
	BO-105 TAIL ROTOR GROUP						50
2.	0.		3.115	7.05	.0001	90.	51
335.	-12.5	68.70	4.851	.487	5.527		52
0.	1.	0.	0.	1.	0.	0.	53
0.	0.	45.	0.		0.	0.	54
0.	0.	0.	0.				55
0.	0.	0.	0.	0.	0.		56
0.	-4.	-90.	0.	0.	0.		57
	BO-105 STAB SURF ELEVATOR						70
8.71	277.45	0.	25.84	0.	0.	0.	71
8.09	1.	1.	0.	0.	0.	0.	72
0.	0.	0.	0.	0.	0.	0.	73
0.	0.	0.	0.	0.	0.	0.	74
1.	-5.	0.	0.	1.	2.		75
.989	1.0099	1.	0.	0.	0.	1.	76
.103	0.	0.	0.	.0089	-.00015	.00017	77
0.	.2	.12	0.	.011			78
-.00248	-.009456	.82	0.				79
	BO-105 MAIN ROTOR CONTROLS GROUP						130
9.	6.	16.	0.	0.	0.		131
12.12	-4.7	14.	0.	0.	0.		132
8.65	-5.7	10.	0.	0.	0.		133
4.34	6.00	-28.	0.	0.	0.		134
	BO-105 ITERATION LOGIC GROUP						140
20.	0.	-.5	.1				141
.2	.2	15000.	15000.	.8	.10	500.00	142
12.5	50.	50.	100.	100.	500.	500.	143
.001	0.	0.	5000.	0.	2.792	-3.101	151
5[illegible].92	30.80	55.75	50.26	0.			152
2.486	-3.25	0.	0.	4477.	-266.		153
		10000.	423.	0.	5000.	0.	154