TIME DOMAIN VALIDATION OF THE SIKORSKY GENERAL HELICOPTER (GENHEL) FLIGHT DYNAMICS SIMULATION MODEL FOR THE UH-60L WIDE CHORD BLADE MODIFICATION

by

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December 1999

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Thesis Co-Advisor: Thomas H. Lawerence

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The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

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Captain, United States Army
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December 1999

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ABSTRACT

Helicopter design at the Sikorsky Aircraft Corporation is aided by the use of the Sikorsky General Helicopter (GenHel®) Flight Dynamics Simulation Model. Specifically, GenHel output is used by both handling qualities and maneuver loads engineers as a predictive design tool. Inherent in the use of an analytical model is the requirement for validation. This report seeks to validate the GenHel® flight dynamics simulation models used in the design of the UH-60L Wide Chord Blade (WCB) modification. Initially, comparisons are made between the current analytical models and flight test data for selected trim flight conditions and dynamic maneuvers. Based on the correlation of the data, modifications are made to the analytical model where necessary. The modified analytical model will be validated through a final comparison with test flight data. The goal of this report is to validate the use of Sikorsky’s GenHel® flight simulation program as an analytic predictive tool in the design of the WCB modification and identify any areas where improvements could be applied. Validation of the WCB GenHel model serves two purposes. First it confirms the ability of GenHel to model the flight dynamic response of the UH-60L with the WCB modification. Second it confirms the predictive loads forwarded to the structural engineers during the design phase of the WCB.
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I. INTRODUCTION

Engineers at Sikorsky Aircraft use General Helicopter (GenHel®) Flight Dynamics Software as a design tool for predicting handling qualities and structural loading characteristics. Inherent in the use of an analytical model is the requirement for validation. All mathematical models are guilty until proven innocent [Ref. 1]. Sikorsky has a validated GenHel® model of the UH-60 BLACK HAWK helicopter. The model was originally developed under contract from NASA in 1980 and has been refined throughout the development cycle of the aircraft. The analytical model was recently modified to reflect the latest BLACK HAWK design evolution, the Wide Chord Blade (WCB).

Customer demands for increases to the mission gross weight and performance requirements of the UH-60 BLACK HAWK helicopter resulted in a requirement for increased rotor solidity. Sikorsky’s solution to the problem is an all-composite blade referred to as the Wide Chord Blade. The WCB is equal in length to the current UH-60 blade and maintains the same nominal non-linear twist distribution which provides an effective linearized value of -18 degrees. Improvements were attained through the incorporation of enhanced SC1095 airfoils, a 16% increase in chord length, and the addition of 20° anhedral swept tips. The 16% increase in chord length increases blade chord from 20.88 inches to 24.25 inches. The 20° anhedral swept tip is initiated at blade radius (r/R) value of 96 percent. A detailed description of the WCB is provided in Chapter II.

WCB performance characteristics used to modify the GenHel® models were determined through a combination of wind tunnel testing and theoretical analysis. Lift and drag maps for the new blades were empirically derived and dynamic stall characteristics were approximated using theory.

The new WCB GenHel® mathematical models were used to predict structural and handling qualities design parameters. The majority of the GenHel® predictive analysis was focused on quantifying the increase in performance derived from the improved
blades. Specifically, determining if the increased aerodynamic performance of the WCB would expand the aerodynamic envelope of the BLACK HAWK beyond the current structural envelope. Flight testing of the new blade’s performance on the UH-60 commenced in March of 1999.

The WCB flight test data used in this analysis was collected during 95 flight hours from 18 Mar 99 through 23 Jul 99 at Sikorsky’s West Palm Beach Flight Test Center. This report seeks to validate the predictive use of GenHel® derived design parameters through correlation with measured flight test data recorded during the UH-60L Wide Chord Blade test program and identify any areas where improvements could be applied. Validation of the WCB GenHel® models serves two purposes. First, it confirms the ability of GenHel® to model the flight dynamic response of the UH-60L with the WCB modification. Second, it confirms the predictive loads forwarded to the structural engineers during the design phase of the WCB.

The report begins with a background discussion of the WCB, an overview of GenHel®, and a description of the correlation techniques, procedures and parameters. Chapter III defines the two GenHel® models currently used at Sikorsky to model the WCB. Chapter IV contains the trim flight correlation of these two models and Chapter V contains dynamic maneuver correlations. After thorough correlation of the two current models, the models were modified in an effort to gain a better understanding of the downwash and interference effects of the new rotor system. Chapter VI first describes the modifications, and then correlates the modified model with both trim and dynamic test flight data. Finally, conclusions are drawn and recommendations for future correlation efforts are made.
II. BACKGROUND

A. DESCRIPTION OF THE WIDE CHORD BLADE MODIFICATION

The Wide Chord Blade modification was born out of a desire to meet customer demands for improved performance and increased component life in a cost-efficient manner. Figure 1 presents a schematic of the WCB. The WCB incorporates a wider chord blade, advanced airfoil, and anhedral tip. Advantages of the composite WCB include increased service life, improved damage tolerance, improved crack propagation properties, elimination of BIM requirements, reduced tip corrosion, and...
reduced production costs for material and labor [Ref. 2]. An aerodynamic comparison between the standard UH-60 rotor blade and the WCB is presented below in Table 1.

<table>
<thead>
<tr>
<th>Table 1 Aerodynamic Comparison of Rotor Blades [From Ref. 2]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Blade</strong></td>
</tr>
<tr>
<td>Chord (16% increase)</td>
</tr>
<tr>
<td>Solidity (10% increase)</td>
</tr>
<tr>
<td>Twist</td>
</tr>
</tbody>
</table>

| **Tip** | **Standard H-60 Blade** | **Wide Chord Blade** |
| Anhedral | 0° | 20° outer 4% radius |
| Sweep @ .25 chord | 20° outer 7% radius | 29.75° outer 8% radius |
| Taper | none | 1:0.6 outer 8% radius |
| Airfoil Section | SC1095 | SSC-A09 |

**B. OVERVIEW OF GENHEL®**

The GenHel® mathematical model is a total force, non-linear, large angle representation with six rigid-body degrees of freedom. The main rotor model is based on a blade element analysis which develops total rotor forces and moments from a combination of aerodynamic, mass, and inertial loads acting on the simulated blade. The model allows for rotor system modeling of rigid blades with flap, lag and rotor speed degrees of freedom. For analysis purposes, the rotor system is divided into equal annular areas. By doing so, computational effort is weighted towards areas of higher dynamic pressures and computation time is minimized. [Ref. 3]

The program is composed of modules that can be modified to create an aircraft specific model. Figure 2 illustrates the modular architecture of GenHel®.
Modular Architecture

Figure 2 Illustration of GenHel® Modular Architecture [From Ref. 4]

Modules are modified by changing their geometric, mass and aerodynamic properties to reflect those of the desired aircraft. The program is capable of modeling a vast array of helicopter dynamics and complex interactions. Downwash, sidewash and interference effects are derived at each module via theoretical and empirical methods. In addition to the downwash values calculated at each panel, fuselage downwash correction terms are added as a side force, rolling moment and pitching moment (Y, L, and M). Their values are empirically derived from BLACK HAWK and Seahawk flight test data and are applied at the center of gravity (CG) as functions of sideslip (β). The wide-ranging capabilities of GenHel® are evidenced in Figure 3.

GenHel® works by calculating and summing the forces and moments of each module at each time step and passing these values to the equations of motion module. The equations of motion module calculates accelerations by dividing the applied forces and moments by the airframe weights and inertias.
Figure 3 GenHel® Capabilities [From Ref. 4]

Accelerations are then integrated to obtain the velocities, angular rates, positions and attitudes. Earth axis reference values are obtained using Euler transformations.

Maneuvers are simulated with GenHel® in two steps. The first step is to establish trim flight conditions at the desired initial conditions. Adjustable trimmers allow the user to specify the desired method to drive the aircraft’s linear and angular accelerations to zero. Once trim flight is established, control inputs are introduced which produce the desired maneuver. Both trim and dynamic output data is recorded in the computer for follow-on analysis.

C. CORRELATION DESCRIPTION

This section describes the aircraft configurations used, the GenHel® models used, the test flight data acquisition procedures, the parameters used, and the correlation procedure used in this report.
1. Aircraft Configurations

Limited flight test data restricted the correlation to the two aircraft configurations described in Table 2.

<table>
<thead>
<tr>
<th>Configuration One</th>
<th>Gross Weight (GW)</th>
<th>16825 pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Center of Gravity (FSCG)</td>
<td>364 inches</td>
</tr>
<tr>
<td></td>
<td>Density Altitude</td>
<td>3000 feet</td>
</tr>
<tr>
<td>Configuration Two</td>
<td>Gross Weight (GW)</td>
<td>22000 pounds</td>
</tr>
<tr>
<td></td>
<td>Center of Gravity (FSCG)</td>
<td>360 inches</td>
</tr>
<tr>
<td></td>
<td>Density Altitude</td>
<td>3000 feet</td>
</tr>
</tbody>
</table>

These two configurations are the aft center of gravity limits for the non-ESSS aircraft at their respective weights [Ref. 5]. At each flight condition, level trim, trim turns, and dynamic maneuvers are examined.

2. GenHel® Models

The three analytical models examined in this report are the Handling Qualities model (HQ model), the Maneuver Loads model (ML model) and the Modified Maneuver Loads model (Mod ML model). Chapter III describes the HQ and ML models. In Chapter IV, the HQ and ML models are correlated to trim test flight data. In Chapter V, the HQ and ML models are correlated to dynamic test flight data. After thorough correlation of the HQ and ML models, the ML model was modified in an effort to gain a better understanding of the downwash and interference effects of the new rotor system. Chapter VI first describes the modifications, and then correlates the Mod ML model with both trim and dynamic test flight data.

3. Test Flight Data Acquisition

Flight tests were conducted in UH-60L Serial Number 84-23953 with a clean aircraft. Flights 744, 747, 793, and 795 of the H-60 Growth Rotor Test Plan were used for correlation. Flights 744 and 747 were conducted at GW 16825, FSCG 364, and 3000 ft DA, and flights 793 and 795 were conducted at GW 22000, FSCG 360, 3000 ft DA. Table 3 summarizes the use of test flight data. All data was recorded as a raw data
file on the computer system in West Palm Beach. Data was manipulated for analysis using ADAPS2 computer software.

Table 3 Summary of Test Flight Data Usage

<table>
<thead>
<tr>
<th>Configuration One</th>
<th>Configuration Two</th>
</tr>
</thead>
<tbody>
<tr>
<td>GW 16825, FSCG 364, 3000 ft DA</td>
<td>GW 22000, FSCG 360, 3000 ft DA</td>
</tr>
<tr>
<td>Trim, Level</td>
<td>Flight 744</td>
</tr>
<tr>
<td></td>
<td>Runs 24-30</td>
</tr>
<tr>
<td>Trim, Fixed Coll Turn</td>
<td>Flight 747</td>
</tr>
<tr>
<td></td>
<td>Runs 33-35, 36-39</td>
</tr>
<tr>
<td>Dynamic Maneuvers</td>
<td>Flight 747</td>
</tr>
<tr>
<td></td>
<td>Runs 43, 51, 55, 58, 61, 64, 67</td>
</tr>
<tr>
<td></td>
<td>Flight 795</td>
</tr>
<tr>
<td></td>
<td>Runs 42, 48, 49, 83, 86, 89, 92</td>
</tr>
</tbody>
</table>

a. **Configuration One: GW 16825, FSCG 364, 3000 ft DA.**

Trim, level flight, test data was obtained from flight 744, run numbers 24-30. Trim, fixed collective, turning flight, test data was obtained from flight 747 run numbers 33-35 and 36-39. Dynamic maneuver test data was obtained from flight 747, runs 43, 51, 55, 58, 61, 64 and 67.

b. **GW 22000, FSCG 360, 3000 ft DA.**

Trim, level flight, test data was obtained from flight 793 run numbers 32-37. Dynamic maneuver test data was obtained from flight 795 run numbers 42, 48, 49, 83, 86, 89, and 92.

4. **Correlation Parameters**

The following parameters are correlated for trim flight: stick positions, aircraft attitudes, stabilator bending, main rotor shaft bending, and main rotor torque. For dynamic maneuvers, the correlation parameters are: stick positions, SAS output positions, aircraft attitude, aircraft rates, and aircraft accelerations. Table 4 shows all of
the correlation parameters, their units, and their corresponding GenHel® and ADAPS2 mnemonics. For consistency, all stick positions are depicted in percentage (%), all angles are in degrees (deg) and all hub moments are in foot-pound (ft-lb) and all stabilator bending moments are in inch-pounds (in-lb).

Table 4 Correlation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>GenHel Mnemonic</th>
<th>Units</th>
<th>Notes</th>
<th>ADAPS2 Mnemonic</th>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>GROSS WEIGHT</td>
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<td>lbs</td>
<td></td>
<td>W/D:1X</td>
<td>lbs</td>
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Manipulation of the data was required in two instances where GenHel® output and test flight data were not in direct correlation. The first case was the main rotor shaft bending moment and the second case was the stabilator bending moment.

a. Main Rotor Shaft Bending

In-plane main rotor shaft bending (MRSEBL1) is measured during flight test by a bending bridge on the main rotor shaft extension in the shaft axis system.
Harmonic analysis reveals the amplitude of the first harmonic bending moment (MRSEBL1:A:1U) which is used for correlation. GenHel® outputs main rotor force and moments at the center of rotation. Figure 4 illustrates the shaft axis system and the location of the hub forces and moments.

![Shaft Axis System and Hub Moment Definition](image)

Figure 4 Shaft Axis System and Hub Moment Definition

The filtered in-plane forces and moments computed by GenHel® at the center of rotation (HHBMR, JHBMR, LHBMR, MHBMR) are replaced by equivalent bending moments at the shaft extender (EMY, EMX).

\[
EMX = LHBMR - JHBMR(e) \quad \text{Eqn. (1)}
\]
\[
EMY = MHBMR + HHBMR(e) \quad \text{Eqn. (2)}
\]
\[
\text{In-Plane Bending} = (EMX^2 + EMY^2)^{1/5} \quad \text{Eqn. (3)}
\]

Equation 3 is used to determine the GenHel® in-plane bending value for correlation.
b. **Stabilator Flatwise Bending**

Similar to the main rotor shaft bending moment, the bending moment on the stabilator is not directly output by GenHel®. GenHel® calculates point loads for the left and right stabilator panels in body axis coordinates. Stabilator bending is measured during flight test with bending bridges (STBNBM1R and STBNBM1L) located 18.1 inches from the aircraft centerline on both the left and right stabilator wings (stabilator local axes). Bending up is positive.

For correlation, the point loads calculated by GenHel® are transferred to the stabilator local axis (see Figure 5) and are used to derive an equivalent bending moment at the location of the bending bridge (local axes).

![Figure 5 Local Stabilator Axis](image)

The key to deriving the bending moment on the stabilator is an accurate estimation of the spanwise pressure distribution. Accurately predicting this distribution in the turbulent airflow over the stabilator is a difficult task at best. Surprisingly, during the loads survey/envelope expansion program of the SH-60B, it was determined that a uniform distribution provides a good estimate of the spanwise lift for steady, level flight [Ref. 6]. For the purposes of this report their assumption is carried forward. Figure 6
illustrates the procedure employed in order to derive the equivalent bending moment from the GenHel® point load. The point load from GenHel® is translated to the stabilator local axis, distributed evenly across the span, and integrated to determine the shear load distribution. Integration of the shear load distribution provides the bending moment distribution. This simplified method for determining the analytical bending moment does not give due credit to the complexity of the problem, yet it will provide a consistent baseline from which to judge the models' responses.

![Diagram of Bending Moment Distribution](image)

Figure 6 Stabilator Loads Estimation

5. **Correlation Procedure**

   a. **Trim Runs**

   Trim test flight run data was obtained from the Test Flight Center using a data tabulation program in ADAPS2. GenHel® data was obtained for correlation from trim print-outs commanded after the model was established in the desired trim conditions (level flight or collective fixed turn). For level flight, GenHel® was trimmed using pitch
attitude to trim longitudinal acceleration, roll attitude to trim lateral acceleration (>60 knots), collective to trim vertical acceleration, and cyclic and pedals to trim the angular accelerations. Runs were conducted from 40-150 knots in 10 knot increments, 155 knots, and 160 knots. For the collective fixed turns, the yaw rate required to match the flight test angle of bank was determined by Equation 4. Velocity and rate of descent were commanded to match flight test. Runs were conducted in left and right 30°, 45°, and 60° roll angles.

\[ \psi = \frac{g \tan(\phi)}{V} \]  \hspace{1cm} \text{Eqn. (4)}

The test and analytical data was then transferred to a spreadsheet for further manipulation and graphing. Appendix A contains sample GenHel® command files used to establish trim conditions in the models. Appendix B contains the processed trim flight data for these flights.

b. Dynamic Runs

Dynamic test flight run data was obtained from the Test Flight Center in raw form via the CTDIF function in ADAPS2. All dynamic test flight data was acquired at \( V_h \). For correlation of dynamic maneuvers, the GenHel® model was first established in trim, level flight at the conditions defined in the run log. The maneuver was then commanded in the model by the actual test flight stick inputs using Input B. Inputs were not commanded for the off-axis cyclic input. For example, to simulate a longitudinal stick pulse, the lateral cyclic was held constant at trim value, while the test pilot's inputs were commanded in the model for the longitudinal cyclic, collective, and pedal deflections. This precluded the introduction of any off-axis bias due to modeling inaccuracies of the pitch-to-roll or roll-to-pitch coupling. Input A was used concurrently to remove any trim bias which may have existed from trim flight stick positions. The GenHel® output data was then saved in SAVRUN format for further manipulation and graphing in MATLAB®. Appendix A contains sample GenHel® command files used to run dynamic maneuvers.
III. GENHEL® UH-60L WIDE CHORD BLADE MODEL DESCRIPTIONS

A. HANDLING QUALITIES MODEL

The WCB Handling Qualities (HQ) Model was developed by modifying the standard UH-60L model to reflect the geometric, inertial, and aerodynamic properties of the WCB. The baseline HQ model used in this report has the filename “UH60LWCB”. In order to ensure accurate correlation, the model was further modified to reflect the current main and tail rotor rigging of the test aircraft (84-23953). Table 5 presents the main and tail rotor rigging values used in this report. The primary change from the

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Tail Rotor Engineering Rig Check – Aircraft 84-23953
Date: 3/9/99
Blade: Blue
Engineer: Anne West

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baseline HQ model was the inclusion of 3° of tail rotor bias present on the test aircraft. Appendix A contains sample GenHel® command files used to modify and establish trim conditions with the HQ Model.

B. MANEUVER LOADS MODEL

The HQ model described above is primarily used as a handling qualities tool. The WCB Maneuver Loads (ML) model was created from the HQ model in order to make GenHel® output compatible with software used for structural analysis. To use GenHel® as a tool for predictive analysis of aircraft structural loads, several modifications to the HQ model are required.

Figure 7 Sikorsky H-60 NASTRAN® Model

The first modification involves the downwash correction terms used in the HQ model. The downwash correction terms derived from BLACK HAWK and Seahawk flight test data (described in Chapter II) were added to the HQ model at the CG. Their
presence at the CG results in an imbalance of forces if applied directly as boundary conditions for NASTRAN® analysis. To remedy this problem, the downwash correction forces and moments (Y, L, and M) are instead added at the fuselage waterline and buttline in the ML model.

Also added to the fuselage waterline and buttline in the ML model are changes in forces in moments (Z,Y,L, and N). These changes account for the differences which exist between unpowered wind tunnel tests (where fuselage aerodynamic data is derived) and powered flight. The changes are based on S-92 powered wind tunnel tests.

Changes were also made to the stabilator and tail rotor modules. The stabilator modules in the HQ model have equal main rotor downwash values on the left and right stabilator panels. In reality, the right stabilator panel would see larger downwash magnitudes than the left panel. The ML model was modified to reflect a more accurate picture of the downwash seen by the stabilator by changing the main rotor interference maps to reflect a greater downwash distribution on the right side of the stabilator. Additionally, tail rotor flapping moments derived from test data are applied at the tail rotor center of rotation and included in the total tail rotor bending moment.

The ML model used in this report has the filename “H60WCBML”. Rigging and mass data were confirmed prior to correlation. Appendix A contains sample GenHel® command files used to run dynamic maneuvers with the ML model.
IV. HQ AND ML MODELS TRIM FLIGHT CORRELATION

A. DISCUSSION

1. Level Flight (Figures 8-17)

For both configurations, all stick positions trend well with no deviations greater than 14%. Longitudinal cyclic is consistently 2% aft of test data and lateral cyclic is consistently 6-7% right of test data. Collective correlates well from 40-100 knots then under predicts (max -14%) from 100-160 knots. Pedal position correlates well from 40-100 knots then diverges to a maximum of 8-9% right of test. The collective and pedal divergence is linked to an under estimation of torque in the same speed regime. Less torque requires less collective which requires less left pedal.

Pitch attitude trends very well and is consistently 2 degrees lower than test data. The yaw and roll attitude are difficult to correlate because of the transition of the trim variables. At airspeeds greater than 120 knots, yaw is within 1 degree of test data. Stabilator bending is under predicted by both models on the right panel and is under predicted by the ML model on the left panel. The HQ model correlates very well with the left panel bending moment.

Main rotor shaft bending is more accurately predicted by the HQ model. In both configurations, and for both models, the 40-60 knot range is modeled poorly.

2. Turns (Figures 18-22)

Longitudinal cyclic correlates very well in both left and right turns. Both models under predict the amount of left cyclic required to hold left turns and both models over predict the amount of right cyclic to hold right turns. For the pedals, likewise, both models under predict the left pedal required in a left turn and over predict the amount of right pedal to hold a right turn.

Pitch attitude is slightly under predicted in turns as was the case in level flight.
Stabilator bending trends well, however the values are suspect due to our assumption of uniform lift distribution's requirement for level flight. The HQ model correlates well with main rotor shaft bending. The ML model trends well but under predicts bending in both left and right turns.
B. CORRELATION PLOTS

1. Level Flight Trim Plots GW 16825 lb, FSCG 364, 3000 ft DA

Figure 8 Trim LF Cyclic Comparison 16825 lb, FSCG 364 in, 3000 ft DA
Figure 9 Trim LF Collective and Pedal Comparison 16825 lb, FSCG 364 in, 3000 ft DA
Figure 10 Trim LF Attitude Comparison 16825 lb, FSCG 364 in, 3000 ft DA
Figure 11 Trim LF Stabilator Bending Comparison 16825 lb, FSCG 364 in, 3000 ft DA
Figure 12 Trim LF MR Shaft Moment Comparison 16825 lb, FSCG 364 in, 3000 ft DA
2. Level Flight Trim Data 22000 lb, FSCG 360, 3000 ft DA

Figure 13 Trim LF Cyclic Comparison 22000 lb, FSCG 360 in, 3000 ft DA
Figure 14 Trim LF Collective and Pedal Comparison 22000 lb, FSCG 360 in, 3000 ft DA
Figure 15 Trim LF Attitude Comparison 22000 lb, FSCG 360 in, 3000 ft DA
Figure 16 Trim LF Stabilator Bending Comparison 22000 lb, FSCG 360 in, 3000 ft DA
Figure 17  Trim LF MR Shaft Moment Comparison 22000 lb, FSCG 360 in, 3000 ft DA
3. Turning Flight Trim Plots 16825 lb, FSCG 364, 3000 ft DA

Figure 18 Trim Turn Cyclic Comparison 16825 lb, FSCG 364 in, 3000 ft DA
Figure 19  Trim Turn Collective and Pedal Comparison 16825 lb, FSCG 364 in, 3000 ft DA
Figure 20  Trim Turn Pitch Attitude Comparison 16825 lb, FSCG 364 in, 3000 ft DA
Figure 21 Trim Turn Stabilator Bending Comparison 16825 lb, FSCG 364 in, 3000 ft DA
Figure 22 Trim Turn MR Shaft Moment Comparison 16825 lb, FSCG 364 in, 3000 ft DA
V. HQ AND ML DYNAMIC MANEUVER CORRELATION

A. DISCUSSION

The time domain analysis of the HQ and ML models yielded very good results. Longitudinal and lateral step and pulse inputs were evaluated for both configurations. Both models had excellent correlation of the on-axis response to pulse inputs.

In both configurations, both models under predicted the attitude response to forward and right step inputs and over predicted the attitude response to left lateral steps. The attitude responses in question may have been skewed by the authors lack of experience in controlling the off-axis response. This is evidenced by the nearly flawless results obtained during the relatively quick pulse inputs compared to the less remarkable results obtained during the slower developing step inputs. More careful management of the off-axis controls is required for step input analysis.
B. CORRELATION PLOTS

1. Dynamic Correlation Plots, 16825 lb, FSCG 364, 3000 ft DA

   a. *Forward Longitudinal Step Flight 953-747 Run 043*

![Figure 23 Flight 953-747 Run 043 Stick Positions 16825, FSCG 364, 3000 ft DA]

![Figure 24 Flight 953-747 Run 043 SAS Positions 16825, FSCG 364, 3000 ft DA]
Figure 25 Flight 953-747 Run 043 On-Axis Response 16825, FSCG 364, 3000 ft DA

Figure 26 Flight 953-747 Run 043 Off-Axis Response 16825, FSCG 364, 3000 ft DA
b. Left Lateral Step, Flight 953-747 Run 051

Figure 27 Flight 953-747 Run 051 Stick Positions 16825, FSCG 364, 3000 ft DA

Figure 28 Flight 953-747 Run 051 SAS Positions 16825, FSCG 364, 3000 ft DA
Figure 29  Flight 953-747 Run 051 On-Axis Response 16825, FSCG 364, 3000 ft DA

Figure 30  Flight 953-747 Run 051 Off-Axis Response 16825, FSCG 364, 3000 ft DA
c. **Right Lateral Step, Flight 953-747 Run 055**

![Stick Positions Graph]

Figure 31 Flight 953-747 Run 055 Stick Positions 16825, FSCG 364, 3000 ft DA

![SAS Output Graph 1]

![SAS Output Graph 2]

Figure 32 Flight 953-747 Run 055 SAS Positions 16825, FSCG 364, 3000 ft DA
Figure 33  Flight 953-747 Run 055 On-Axis Response 16825, FSCG 364, 3000 ft DA

Figure 34  Flight 953-747 Run 055 Off Axis Response 16825, FSCG 364, 3000 ft DA
Forward Longitudinal Pulse, Flight 953-747 Run 058

Figure 35 Flight 953-747 Run 058 Stick Positions 16825, FSCG 364, 3000 ft DA

Figure 36 Flight 953-747 Run 058 SAS Positions 16825, FSCG 364, 3000 ft DA
Figure 37 Flight 953-747 Run 058 On-Axis Response 16825, FSCG 364, 3000 ft DA

Figure 38 Flight 953-747 Run 058 Off-Axis Response 16825, FSCG 364, 3000 ft DA
e. Aft Longitudinal Pulse, Flight 953-747 Run 061

Figure 39 Flight 953-747 Run 061 Stick Positions 16825, FSCG 364, 3000 ft DA

Figure 40 Flight 953-747 Run 061 SAS Positions 16825, FSCG 364, 3000 ft DA
Figure 41  Flight 953-747 Run 061 On-Axis Response 16825, FSCG 364, 3000 ft DA

Figure 42  Flight 953-747 Run 061 Off-Axis Response 16825, FSCG 364, 3000 ft DA
f. Left Lateral Pulse, Flight 953-747 Run 064

Figure 43 Flight 953-747 Run 064 Stick Positions 16825, FSCG 364, 3000 ft DA

Figure 44 Flight 953-747 Run 064 SAS Positions 16825, FSCG 364, 3000 ft DA
Figure 45 Flight 953-747 Run 064 On-Axis Response 16825, FSCG 364, 3000 ft DA

Figure 46 Flight 953-747 Run 064 Off-Axis Response 16825, FSCG 364, 3000 ft DA
g. Right Lateral Pulse, Flight 953-747 Run 067

![Stick Positions](image)

Figure 47 Flight 953-747 Run 067 Stick Positions 16825, FSCG 364, 3000 ft DA

![SAS Output](image)

Figure 48 Flight 953-747 Run 067 SAS Positions 16825, FSCG 364, 3000 ft DA
Figure 49 Flight 953-747 Run 067 On-Axis Response 16825, FSCG 364, 3000 ft DA

Figure 50 Flight 953-747 Run 067 Off-Axis Response 16825, FSCG 364, 3000 ft DA
2. Dynamic Correlation Plots 22000 lb, FSCG 360, 3000 ft DA

a. *Aft Longitudinal Step, Flight 953-795 Run 042*

![Figure 51 Flight 953-795 Run 042 Stick Positions 22000, FSCG 360, 3000 ft DA](image1)

![Figure 52 Flight 953-795 Run 042 SAS Positions 22000, FSCG 360, 3000 ft DA](image2)

52
Figure 53 Flight 953-795 Run 042 On-Axis Response 22000, FSCG 360, 3000 ft DA

Figure 54 Flight 953-795 Run 042 Off-Axis Response 22000, FSCG 360, 3000 ft DA
b. **Left Lateral Step, Flight 953-795 Run 048**

Figure 55 Flight 953-795 Run 048 Stick Positions 22000, FSCG 360, 3000 ft DA

Figure 56 Flight 953-795 Run 048 SAS Positions 22000, FSCG 360, 3000 ft DA
Figure 57 Flight 953-795 Run 048 On-Axis Response 22000, FSCG 360, 3000 ft DA

Figure 58 Flight 953-795 Run 048 Off-Axis Response 22000, FSCG 360, 3000 ft DA
c. Right Lateral Step, Flight 953-795 Run 049

Figure 59 Flight 953-795 Run 049 Stick Positions 22000, FSCG 360, 3000 ft DA

Figure 60 Flight 953-795 Run 049 SAS Positions 22000, FSCG 360, 3000 ft DA
Figure 61  Flight 953-795 Run 049 On-Axis Response 22000, FSCG 360, 3000 ft DA

Figure 62  Flight 953-795 Run 049 Off-Axis Response 22000, FSCG 360, 3000 ft DA
d. Forward Longitudinal Pulse, Flight 953-795 Run 083

Figure 63 Flight 953-795 Run 083 Stick Positions 22000, FSCG 360, 3000 ft DA

Figure 64 Flight 953-795 Run 083 SAS Positions 22000, FSCG 360, 3000 ft DA
Figure 65 Flight 953-795 Run 083 On-Axis Response 22000, FSCG 360, 3000 ft DA

Figure 66 Flight 953-795 Run 083 Off-Axis Response 22000, FSCG 360, 3000 ft DA
e. *Aft Longitudinal Pulse, Flight 953-795 Run 086*

![Stick Positions](image)

**Figure 67** Flight 953-795 Run 086 Stick Positions 22000, FSCG 360, 3000 ft DA

![SAS Output Positions](image)

**Figure 68** Flight 953-795 Run 086 SAS Positions 22000, FSCG 360, 3000 ft DA
Figure 69  Flight 953-795 Run 086 On-Axis Response 22000, FSCG 360, 3000 ft DA

Figure 70  Flight 953-795 Run 086 Off-Axis Response 22000, FSCG 360, 3000 ft DA
f. Left Lateral Pulse, Flight 953-795 Run 089

Figure 71 Flight 953-795 Run 089 Stick Positions 22000, FSCG 360, 3000 ft DA

Figure 72 Flight 953-795 Run 089 SAS Positions 22000, FSCG 360, 3000 ft DA
Figure 73  Flight 953-795 Run 089 On-Axis Response 22000, FSCG 360, 3000 ft DA

Figure 74  Flight 953-795 Run 089 Off-Axis Response 22000, FSCG 360, 3000 ft DA
g. Right Lateral Pulse, Flight 953-795 Run 092

Figure 75 Flight 953-795 Run 092 Stick Positions 22000, FSCG 360, 3000 ft DA

Figure 76 Flight 953-795 Run 092 SAS Positions 22000, FSCG 360, 3000 ft DA
Figure 77  Flight 953-795 Run 092 On-Axis Response 22000, FSCG 360, 3000 ft DA

Figure 78  Flight 953-795 Run 092 Off-Axis Response 22000, FSCG 360, 3000 ft DA
VI. MODIFIED ML MODEL CORRELATION

A. EXPLANATION OF THE MODIFICATIONS

This chapter catalogs the modifications which were made to the ML model in an effort to document the effects on stabilator and main rotor shaft bending moments due to:

1. Downwash correction terms.
2. Forces and moments added as a result of powered wind tunnel tests.
3. Interference on the horizontal tail.

This effort was precipitated by the apparent under prediction of the stabilator bending values by both the HQ and the ML models in trim flight. This entire analysis is hostage to our assumption of uniform lift distribution on the stabilator. Table 6 depicts the terms in question and their GenHel® variable names. All plots examined in this section include the baseline HQ and ML models for reference and comparison.

Table 6 Modification Parameters

<table>
<thead>
<tr>
<th>Term</th>
<th>Source</th>
<th>Action</th>
<th>GenHel® Variable Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downwash Correction Terms on Fuselage</td>
<td>UH-60 / SH-60 Test Data</td>
<td>Side Force</td>
<td>Lodata\YDWCMP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rolling Moment</td>
<td>Lodata\LDWCMP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pitching Moment</td>
<td>Lodata\MDWCMP</td>
</tr>
<tr>
<td>Δ Forces on Fuselage</td>
<td>S-92 Powered Wind Tunnel Tests</td>
<td>Lift Force</td>
<td>Lodata\FL1MAP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Side Force</td>
<td>Lodata\FY1MAP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rolling Moment</td>
<td>Lodata\FR1MAP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yawing Moment</td>
<td>Lodata\MRDNQFMP</td>
</tr>
<tr>
<td>Horizontal Tail Interference</td>
<td>Test And Theory</td>
<td>Right Panel Velocity</td>
<td>Lodata\DAEPP1MP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left Panel Velocity</td>
<td>Lodata\DAEPP2MP</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lodata\DBEPP1MP</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lodata\DBEPP2MP</td>
</tr>
</tbody>
</table>
The effects of the forces added from S-92 powered wind tunnel test were negligible and thus attention was focused on the downwash correction terms and the horizontal tail interference. Figure 79 depicts the effects of separately removing the downwash correction terms and the stabilator interference terms on the main rotor shaft.
bending and the stabilator bending to establish a baseline for further analysis.

Figure 79 shows that the baseline ML model (with downwash correction terms) has the same stabilator bending values as the ML model with the downwash correction terms removed. There is, however, a difference in the main rotor shaft bending. The impact of the downwash correction terms is witnessed at the main rotor shaft, where the bending values for the model without the downwash correction terms are higher than that of the baseline ML model at high speed. The downwash correction terms essentially lower main rotor shaft bending values without effecting stabilator bending.

The left panel stabilator values correlate well with the stabilator interference velocities removed. If our assumption of uniform lift distribution was correct, then GenHel® still under-predicts the download seen on the right panel.

The second round of investigations involved removing the stabilator interference velocities from the left panel and observing increasing values of right panel stabilator interference. Figure 80 shows the results of this analysis. As expected, as the interference velocities are increased over the right panel, the stabilator bending values increase, inducing an increase in the main rotor shaft bending moment. Increasing the stabilator interference velocity by a factor of two brought the right stabilator panel bending moment to a close correlation with the test data. In doing so, however, the main rotor shaft bending values increased beyond an acceptable limit.

The next investigation examines the effects of changing the magnitudes of the downwash correction terms on the main rotor shaft bending moment. Figure 81 depicts the results. Increasing the pitching moment downwash term (MDWCMP) decreases the bending at the main rotor shaft without changing the loads seen by the stabilator. However, no physics-based justification for this change can be provided. For the purposes of this report, the values depicted graphically as 1.5 x MDWCMP (~75 ft$^3$ from baseline) are used for MDWCMP in order to achieve a better correlation.

The last modification was an increase in 2 square feet of fuselage drag to account for test equipment external to the aircraft. In summary, the final Modified ML Model used no left stabilator interference, twice the baseline value of right stabilator...
interference, -75 ft$^3$ MDWCMP, and increased the fuselage flat plate area by 2 square feet. The GenHel® command file used to trim the Mod ML model is located in Appendix A.

Figure 80 Increasing Right Panel Interference, Left Panel Interference Removed
Figure 81 Modified Down Wash Correction Terms

The following sections correlate the Mod ML model in a manner similar to the HQ and ML models.
B. TRIM CORRELATION

In all areas but main rotor shaft bending and stabilator bending the Mod ML model values closely mirror those of the HQ and ML models. As described in the previous section, the modifications created the desired increase in the stabilator bending moment. The resultant increase in main rotor shaft bending was partially offset by the modification to the pitching moment portion of the downwash correction. Clearly a better picture of the flow over the stabilator and in the rotor wake is required to justify these changes.
1. Modified Level Flight Trim Plots GW 16825 lb, FSCG 364, 3000 ft DA

Figure 82 Modified Trim LF Cyclic Comparison 16825 lb, FSCG 364 in, 3000 ft DA
Figure 83  Modified Trim LF Collective and Pedal Comparison 16825 lb, FSCG 364 in, 3000 ft DA

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Figure 84  Modified Trim LF Attitude Comparison 16825 lb, FSCG 364 in, 3000 ft DA
Figure 85 Modified Trim LF Stabilator Bending Comparison 16825 lb, FSCG 364 in, 3000 ft DA
MR Shaft Extender Bending Moment Comparison
LF,16825,FSCG 364,3000ft DA

MR Shaft Torque Comparison
LF,16825,FSCG 364,3000ft DA

Figure 86 Modified Trim LF MR Shaft Moment Comparison 16825 lb, FSCG 364 in, 3000 ft DA

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2. Modified Level Flight Trim Plots GW 22000 lb, FSCG 360, 3000 ft DA

Figure 87 Modified Trim LF Cyclic Comparison 22000 lb, FSCG 360 in, 3000 ft DA
Figure 88 Modified Trim LF Collective and Pedal Comparison 22000 lb, FSCG 360 in, 3000 ft DA
Figure 89 Modified Trim LF Attitude Comparison 22000 lb, FSCG 360 in, 3000 ft DA
Figure 90 Modified Trim LF Stabilator Bending Comparison 22000 lb, FSCG 360 in, 3000 ft DA
Figure 91 Modified Trim LF MR Shaft Moment Comparison 22000 lb, FSCG 360 in, 3000 ft DA
3. Modified Turning Flight Trim Plots 16825 lb, FSCG 364, 3000 ft DA

Figure 92 Modified Trim Turn Cyclic Comparison 16825 lb, FSCG 364 in, 3000 ft DA
Figure 93 Modified Trim Turn Collective and Pedal Comparison 16825 lb, FSCG 364 in, 3000 ft DA
Figure 94 Modified Trim Turn Pitch Attitude Comparison 16825 lb, FSCG 364 in, 3000 ft DA
Figure 95 Modified Trim Turn Stabilator Bending Comparison 16825 lb, FSCG 364 in, 3000 ft DA
Figure 96 Modified Trim Turn MR Shaft Moment Comparison 16825 lb, FSCG 364 in, 3000 ft DA
C. DYNAMIC CORRELATION

Similar to the HQ and ML time domain response, the Mod ML model correlated well with test data in response to pulse inputs. Step response likewise exhibited similar characteristics to that of the HQ and ML models. The model under predicted the attitude response to the forward and right step and over predicted the roll attitude response to the left lateral step function.
Dynamic Correlation, 16825, FSCG 364, 3000 ft DA

a. Forward Longitudinal Step, Modified 953-747 Run 043

Figure 97 Modified 953-747 Run 043 Stick Positions 16825, FSCG 364, 3000 ft DA

Figure 98 Modified 953-747 Run 043 SAS Positions 16825, FSCG 364, 3000 ft DA
Figure 99 Modified 953-747 Run 043 On-Axis Response 16825, FSCG 364, 3000 ft DA

Figure 100 Modified 953-747 Run 043 Off-Axis Response 16825, FSCG 364, 3000 ft DA
b. Left Lateral Step, Modified 953-747 Run 051

Figure 101 Modified 953-747 Run 051 Stick Positions 16825, FSCG 364, 3000 ft DA

Figure 102 Modified 953-747 Run 051 SAS Positions 16825, FSCG 364, 3000 ft DA
Figure 103 Modified 953-747 Run 051 On-Axis Response 16825, FSCG 364, 3000 ft DA

Figure 104 Modified 953-747 Run 051 Off-Axis Response 16825, FSCG 364, 3000 ft DA
c. Right Lateral Step, Modified 953-747 Run 055

Figure 105 Modified 953-747 Run 055 Stick Positions 16825,FSCG 364, 3000 ft DA

Figure 106 Modified 953-747 Run 055 SAS Positions 16825,FSCG 364, 3000 ft DA

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Figure 107 Modified 953-747 Run 055 On-Axis Response 16825,FSCG 364, 3000 ft DA

Figure 108 Modified 953-747 Run 055 Off-Axis Response 16825,FSCG 364, 3000 ft DA
d. **Forward Longitudinal Pulse, Modified 953-747 Run 058**

![Stick Positions diagram](image)

Figure 109 Modified 953-747 Run 058 Stick Positions 16825,FSCG 364, 3000 ft DA

![SAS Output Positions diagram](image)

Figure 110 Modified 953-747 Run 058 SAS Positions 16825,FSCG 364, 3000 ft DA
Figure 111 Modified 953-747 Run 058 On-Axis Response 16825,FSCG 364, 3000 ft DA

Figure 112 Modified 953-747 Run 058 Off-Axis Response 16825,FSCG 364, 3000 ft DA
e. *Aft Longitudinal Pulse, Modified 953-747 Run 061*

![Stick Positions](image)

Figure 113 Modified 953-747 Run 061 Stick Positions 16825, FSCG 364, 3000 ft DA

![SAS Output](image)

Figure 114 Modified 953-747 Run 061 SAS Positions 16825, FSCG 364, 3000 ft DA

98
Figure 115 Modified 953-747 Run 061 On-Axis Response 16825, FSCG 364, 3000 ft DA

Figure 116 Modified 953-747 Run 061 Off-Axis Response 16825, FSCG 364, 3000 ft DA
f. Left Lateral Pulse, Modified 953-747 Run 064

Figure 117 Modified 953-747 Run 064 Stick Positions 16825,FSCG 364, 3000 ft DA

Figure 118 Modified 953-747 Run 064 SAS Positions 16825,FSCG 364, 3000 ft DA
Figure 119 Modified 953-747 Run 064 On-Axis Response 16825,FSCG 364, 3000 ft DA

Figure 120 Modified 953-747 Run 064 Off-Axis Response 16825,FSCG 364, 3000 ft DA
g. **Right Lateral Pulse, Modified 953-747 Run 067**

Figure 121 Modified 953-747 Run 067 Stick Positions 16825,FSCG 364, 3000 ft DA

Figure 122 Modified 953-747 Run 067 SAS Positions 16825,FSCG 364, 3000 ft DA
Figure 123  Modified 953-747 Run 067 On-Axis Response 16825,FSCG 364, 3000 ft DA

Figure 124  Modified 953-747 Run 067 Off-Axis Response 16825,FSCG 364, 3000 ft DA
2. Dynamic Correlation, 22000, FSCG 360, 3000 ft DA

a. Aft Longitudinal Step, Modified 953-795 Run 042

![Stick Positions](image1)

![SAS Output Plots](image2)

Figure 125 Modified 953-795 Run 042 Stick Positions 22000, FSCG 360, 3000ft DA

Figure 126 Modified 953-795 Run 042 SAS Positions 22000, FSCG 360, 3000ft DA
Figure 127 Modified 953-795 Run 042 On-Axis Response 22000,FSCG 360, 3000ft DA

Figure 128 Modified 953-795 Run 042 Off-Axis Response 22000,FSCG 360, 3000ft DA
b. Left Lateral Cyclic, Modified 953-795 Run 048

![Graph of stick positions](image)

Figure 129 Modified 953-795 Run 048 Stick Positions 22000,FSCG 360, 3000ft DA

![Graph of SAS output positions](image)

Figure 130 Modified 953-795 Run 048 SAS Positions 22000,FSCG 360, 3000ft DA
Figure 131 Modified 953-795 Run 048 On-Axis Response 22000,FSCG 360, 3000ft DA

Figure 132 Modified 953-795 Run 048 Off-Axis Response 22000,FSCG 360, 3000ft DA
c. **Right Lateral Step, Modified 953-795 Run 049**

![Stick Positions](image)

**Figure 133** Modified 953-795 Run 049 Stick Positions 22000,FSCG 360, 3000ft DA

![SAS Output Positions](image)

**Figure 134** Modified 953-795 Run 049 SAS Positions 22000,FSCG 360, 3000ft DA
Figure 135 Modified 953-795 Run 049 On-Axis Response 22000,FSCG 360, 3000ft DA

Figure 136 Modified 953-795 Run 049 Off-Axis Response 22000,FSCG 360, 3000ft DA
d. Forward Longitudinal Pulse, Modified 953-795 Run 083

Figure 137 Modified 953-795 Run 083 Stick Positions 22000,FSCG 360, 3000ft DA

Figure 138 Modified 953-795 Run 083 SAS Positions 22000,FSCG 360, 3000ft DA
Figure 139 Modified 953-795 Run 083 On-Axis Response. 22000, FSCG 360, 3000ft DA

Figure 140 Modified 953-795 Run 083 Off-Axis Response 22000, FSCG 360, 3000ft DA
e. **Aft Longitudinal Pulse, Modified 953-795 Run 086**

![Figure 141 Modified 953-795 Run 086 Stick Positions 22000,FSCG 360, 3000ft DA](image)

![Figure 142 Modified 953-795 Run 086 SAS Positions 22000,FSCG 360, 3000ft DA](image)
Figure 143 Modified 953-795 Run 086 On-Axis Response 22000, FSCG 360, 3000ft DA

Figure 144 Modified 953-795 Run 086 Off-Axis Response 22000, FSCG 360, 3000ft DA
f. Left Lateral Pulse, Modified 953-795 Run 089

Figure 145 Modified 953-795 Run 089 Stick Positions 22000,FSCG 360, 3000ft DA

Figure 146 Modified 953-795 Run 089 SAS Positions 22000,FSCG 360, 3000ft DA
Figure 147 Modified 953-795 Run 089 On-Axis Response 22000,FSCG 360, 3000ft DA

Figure 148 Modified 953-795 Run 089 Off-Axis Response 22000,FSCG 360, 3000ft DA
g. Right Lateral Pulse, Modified 953-795 Run 092

Figure 149 Modified 953-795 Run 092 Stick Positions 22000,FSCG 360, 3000ft DA

Figure 150 Modified 953-795 Run 092 SAS Positions 22000,FSCG 360, 3000ft DA
Figure 151  Modified 953-795 Run 092 On-Axis Response 22000,FSCG 360, 3000ft DA

Figure 152  Modified 953-795 Run 092 Off-Axis Response 22000,FSCG 360, 3000ft DA
VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This report examined two aircraft configurations in trim and dynamic flight maneuvers with three mathematical models. Several conclusions can be drawn from the results.

Trim analysis revealed very good correlation of the models in all regions with some degradation in the high-speed regimes. Unfortunately, this area ($V_h$) was where all of the available test flight data for analysis of handling qualities performance was recorded. Considering that all dynamic maneuvers covered in this report were conducted at $V_h$ and at the aircraft's aft center of gravity limits, the on-axis response correlated very well. The lack of correlation in the off-axis response is more attributable to the author's lack of modeling experience than to a problem with the models.

The fact that the handling qualities model most accurately modeled the main rotor shaft bending while having the least accurate prediction of stabilator bending casts doubt on the assumption of uniform lift distribution across the stabilator. In other words, the point loads generated by GenHel$^\circledR$ on the stabilator most likely generate a larger bending moment than was assumed in this report.

B. RECOMMENDATIONS

Recommendations for future correlation work include:

1. During time-domain analysis, attempt to more closely monitor the off-axis response.
2. Request handling quality test runs at lower airspeeds.
3. Further study is required regarding the relationship between the shaft bending values and the stabilator bending. Clearly a more accurate picture of the flow across the stabilator would allow for more accurate modeling. Another option is to increase the number of bending bridges on the stabilator so as to remove the requirement for a distribution assumption.
Sample Command File for HQ Model Trim Run

S
HTRIM=3000
OAT=48.32
WEIGHT=16825
FSCG=364
TRMPRT=1
MXTHR(1)=24.9
ENGIN=.F
&RETURN &
ED
MS
S
A
V
40
60
80
100
120
140
150
155
160
&RETURN &
E
E

Sample Command File for HQ Model Dynamic Run (Lateral Input)

ED
ML
I
INPUTB
16
&RETURN &
E
C
I
1
ST
XA(2)
N
-4.46447
&RETURN &
I
2
ST
XC(2)
N
-7.67920
&RETURN &
I
3
ST
XP(2)
N
-3.76958
&RETURN &
E
E
S
WEIGHT=22000
FSCG=360
HTRIM=3000
V=40
OAT=48.32
TIMLIM=10
DSASSW=.T.
ASASSW=.T.
MXTHR(1)=24.9
ENGIN=.F.
TRMPRT=.F.
TFILMR=0.29
TFILTM=0.0
VARPB(1)=A'XA(3)
VARPB(2)=A'XC(3)
VARPB(3)=A'XP(3)
FILENMPB='795_048.CTDIF
SLOADPB=.T.
RMBIASPB=.T.
ADAPS=.T.
VNAMEWPB(1)=LATSTKI
VNAMEWPB(2)=COLLSTKI
VNAMEWPB(3)=PEDI
TMVRSR(1)=A'WEIGHT
TMVRSR(2)=A'FSCG
TMVRSR(3)=AHTRIM
TMVRSR(4)=AV
TMVRSR(5)=AOAT
TMVRSR(6)=ATIMLIM
VARSR(1)=A'XAPC
VARSR(2)=A'XBPC
VARSR(3)=A'XCPC
VARSR(4)=A'XPPC
VARSR(5)=A'XAILS
VARSR(6)=A'XBILS
VARSR(7)=A'PHIB

122
Sample Command File for HQ Model Dynamic Run (Longitudinal Input)

ED
ML
I
INPU
16
&RETURN &
EC
I
1
ST
XB(2)
N
3.11422
&RETURN &
I
2
ST
XC(2)
N
-7.80865
&RETURN &
I
3
ST
XP(2)
N
-3.67734
&RETURN &
EE
S
WEIGHT=22000
FSCG=360
HTRIM=3000
V=40
OAT=48.32
TIMLIM=10
DSASSW=.T.
ASASSW=.T.
MXTHR(1)=24.9
ENGIN=.F.
TRMPRT=.F.
TFILMR=0.29
TFILTM=0.0
VARPB(1)=A'XB(3)
VARPB(2)=A'XC(3)
VARPB(3)=A'XP(3)
FILENMPB='795_041.CTDIF
SLOADPB=.T.
RMBIASPB=.T.
ADAPS=.T.
VNAMEWPB(1)='LGSTKI
VNAMEWPB(2)='COLLSTKI
VNAMEWPB(3)='PEDI
TMVRSR(1)=A'WEIGHT
TMVRSR(2)=A'FSCG
TMVRSR(3)=A'HTRIM
TMVRSR(4)=A'V
TMVRSR(5)=A'OAT
TMVRSR(6)=ATIMLIM
VARSR(1)=A'XAPC
VARSR(2)=A'XBPC
VARSR(3)=A'XCPC
VARSR(4)=A'XPPC
VARSR(5)=A'XAILS
VARSR(6)=A'XBILS
VARSR(7)=A'PHIB
VARSR(8)=ATHETAB
VARSR(9)=A'BETFRE
VARSR(10)=A'PDEG
VARSR(11)=A'QDEG
VARSR(12)=A'RDEG
VARSR(13)=A'PDOT
VARSR(14)=A'QDOT
VARSR(15)=A'RDOT
VARSR(16)=A'QHBMAR
VARSR(17)=A'LHBMAR
VARSR(18)=A'MHBMAR
VARSR(19)=A'ZP1
VARSR(20)=A'ZP2
&RETURN &
Sample Command File for ML Model Trim Run

ED
ML
6
D
6
D
6
D
6
D
6
E
MS
S
A
V
40
60
80
100
120
140
150
155
160
&RETURN &
E
E
S
HTRIM=3000
OAT=48.32
WEIGHT=16825
FSCG=364
TRMPRT=1
MXTHR(1)=24.9
ENGIN=.F
&RETURN &

Sample Command File for ML Model Dynamic Run (Lateral input)

ED
ML
6
D
6
D
6
D
6
D
6

125
D
15
I
INPUTB
15
&RETURN &
I
INPUTA
16
&RETURN &
E
C
I
1
ST
XA(2)
N
-4.46447
&RETURN &
I
2
ST
XC(2)
N
-7.87920
&RETURN &
I
3
ST
XP(2)
N
-3.76958
&RETURN &
E
E
S
WEIGHT=22000
FSCG=360
HTRIM=3000
V=40
OAT=48.32
TIMLIM=10
DSASSW=.T.
ASASSW=.T.
MXTHR(1)=24.9
ENGIN=.F.
TRMPRT=.F.
TFILMR=0.29
TFILTM=0.0
VARPB(1)=A'XA(3)
VARPB(2)=A'XC(3)
VARPB(3)=A'XP(3)
FILENMPB='795_048.CTDIF
SLOADPB=.T.
RMBIASPB=.T.
ADAPS=.T.
VNAMEWPB(1)=‘LATSTKI
VNAMEWPB(2)=‘COLLSTKI
VNAMEWPB(3)=‘PEDI
TMVRSR(1)=‘AWEIGHT
TMVRSR(2)=‘AFSCG
TMVRSR(3)=‘AHTRIM
TMVRSR(4)=‘AV
TMVRSR(5)=‘AOAT
TMVRSR(6)=‘ATIMLIM
VARSR(1)=‘AXAPC
VARSR(2)=‘AXBPC
VARSR(3)=‘AXCPC
VARSR(4)=‘AXPPC
VARSR(5)=‘AXAILS
VARSR(6)=‘AXBILS
VARSR(7)=‘APHIB
VARSR(8)=‘ATHETAB
VARSR(9)=‘ABETFRE
VARSR(10)=‘APDEG
VARSR(11)=‘AQDEG
VARSR(12)=‘ARDEG
VARSR(13)=‘APDOT
VARSR(14)=‘AQDOT
VARSR(15)=‘ARDOT
VARSR(16)=‘AQBHMR
VARSR(17)=‘AQLHMR
VARSR(18)=‘AMHBMR
VARSR(19)=‘AZP1
VARSR(20)=‘AZP2
&RETURN &

Sample Command File for ML Model Dynamic Run (Longitudinal Input)

ED
ML
D
6
D
6
D
6
D
6
D
6
D
15
I
INPUTB
15
&RETURN &
I
INPUTA
16
&RETURN &
E
C
I
1
ST
XB(2)
N
3.11422
&RETURN &
I
2
ST
XC(2)
N
-7.80865
&RETURN &
I
3
ST
XP(2)
N
-3.67734
&RETURN &
E
E
S
WEIGHT=22000
FSCG=360
HTRIM=3000
V=40
OAT=48.32
TIMLIM=10
DSASSW=.T.
ASASSW=.T.
MXTHR(1)=24.9
ENGIN=.F.
TRMPRT=.F.
TFILMR=0.29
TFILTM=0.0
VARPB(1)=A'XB(3)
VARPB(2)=A'XC(3)
VARPB(3)=A'XP(3)
FILENMPB='795_041.CTDIF
SLOADPB=.T.
RMBIASPB=.T.
ADAPS=.T.
VNAMEWPB(1)=LGSTKI
VNAMEWPB(2)=COLLSTKI
VNAMEWPB(3)=PEDI
Sample Command File for Mod ML Model Dynamic Run (Lateral input)

For brevity, only one Mod ML model command file is provided.

ED
ML
D
6
D
6
D
6
D
6
D
15
| INPUTB
15
&RETURN &
| INPUTA
16
&RETURN &
E
C
1
ST
XA(2)
N
-4.46447
&RETURN &
1
2
ST
XC(2)
N
-7.87920
&RETURN &
1
3
ST
XP(2)
N
-3.76958
&RETURN &
E
E
E
S
WEIGHT=22000
FSCG=360
HTRIM=3000
V=40
OAT=48.32
TIMLIM=10
DSASSW=.T.
ASASSW=.T.
MXTHR(1)=24.9
ENGIN=.F.
TRMPRT=.F.
TFILMR=0.29
TFILTM=0.0
VARPB(1)=A'XA(3)
VARPB(2)=A'XC(3)
VARPB(3)=A'XP(3)
FILENMPB='795_048.CTDIF
SLOADPB=.T.
RMBIASPB=.T.
ADAPS=.T.
VNAMEWPB(1)='LATSTKI
VNAMEWPB(2)='COLLSTKI
VNAMEWPB(3)='PEDI
TMVRSR(1)=A'WEIGHT
TMVRSR(2)=A'FSCG
TMVRSR(3)=A'HTRIM
TMVRSR(4)=A'V
TMVRSR(5)=A'OAT
TMVRSR(6)=ATIMLIM
VARSR(1)=A'XAPC
VARSR(2)=A'XBPC
VARSR(3)=A'XCPC
VARSR(4)=A'XPPC
VARSR(5)=A'XAILS
VARSR(6)=A'XBILS
VARSR(7)=A'PHIB
VARSR(8)=ATHETAB
VARSR(9)=A'BETFRE
VARSR(10)=A'PDEG
VARSR(11)=A'QDEG
VARSR(12)=A'RDEG
VARSR(13)=A'PDOT
VARSR(14)=A'QDOT
VARSR(15)=A'RDOT
VARSR(16)=A'QHIBMR
VARSR(17)=A'LBIBMR
VARSR(18)=A'MHIBMR
VARSR(19)=A'ZP1
VARSR(20)=A'ZP2
LODATA(1)DAEPP1MP=0
LODATA(2)DAEPP1MP=575.54
LODATA(3)DAEPP1MP=989.22
LODATA(4)DAEPP1MP=1169.08
LODATA(5)DAEPP1MP=1043.18
LODATA(6)DAEPP1MP=521.58
LODATA(7)DAEPP1MP=0
LODATA(8)DAEPP1MP=-521.58
LODATA(9)DAEPP1MP=-1043.18
LODATA(10)DAEPP1MP=-1169.08
LODATA(11)DAEPP1MP=-989.22
LODATA(12)DAEPP1MP=-575.54
LODATA(13)DAEPP1MP=0
LODATA(14)DAEPP1MP=0
LODATA(15)DAEPP1MP=449.64
LODATA(16)DAEPP1MP=755.54
LODATA(17)DAEPP1MP=899.22
LODATA(18)DAEPP1MP=771.38
LODATA(19)DAEPP1MP=395.68
LODATA(20)DAEPP1MP=0
LODATA(21)DAEPP1MP=-395.68
LODATA(22)DAEPP1MP=-771.38
LODATA(23)DAEPP1MP=-899.22
LODATA(24)DAEPP1MP=-755.54
LODATA(25)DAEPP1MP=449.64
LODATA(26)DAEPP1MP=0
LODATA(27)DAEPP1MP=0
LODATA(28)DAEPP1MP=287.78
LODATA(29)DAEPP1MP=503.6
LODATA(30) DAEPP1MP=575.54
LODATA(31) DAEPP1MP=503.6
LODATA(32) DAEPP1MP=251.8
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LODATA(35) DAEPP1MP=-503.6
LODATA(36) DAEPP1MP=-575.54
LODATA(37) DAEPP1MP=-503.6
LODATA(38) DAEPP1MP=-287.6
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LODATA(40) DAEPP1MP=0
LODATA(41) DAEPP1MP=125.9
LODATA(42) DAEPP1MP=251.8
LODATA(43) DAEPP1MP=305.76
LODATA(44) DAEPP1MP=251.8
LODATA(45) DAEPP1MP=125.9
LODATA(46) DAEPP1MP=0
LODATA(47) DAEPP1MP=-125.9
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LODATA(62) DAEPP1MP=0
LODATA(63) DAEPP1MP=0
LODATA(64) DAEPP1MP=0
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LODATA(2) DBEPP1MP=417.98
LODATA(3) DBEPP1MP=247.68
LODATA(4) DBEPP1MP=0
LODATA(5) DBEPP1MP=743.04
LODATA(6) DBEPP1MP=619.2
LODATA(7) DBEPP1MP=247.68
LODATA(8) DBEPP1MP=0
LODATA(9) DBEPP1MP=1099.08
LODATA(10) DBEPP1MP=464.4
LODATA(11) DBEPP1MP=61.92
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LODATA(2) DAEPP2MP=0
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LODATA(4) DAEPP2MP=0
LODATA(5) DAEPP2MP=0

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LODATA(59)\DAEPP2MP=0
LODATA(60)\DAEPP2MP=0
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LODATA(9)\DBEPP2MP=0
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LODATA(11)\DBEPP2MP=0
LODATA(12)\DBEPP2MP=0
LODATA(9)\MDWCOMP=-232
LODATA(10)\MDWCOMP=-75
DQF0=2
&RETURN &
APPENDIX B. PROCESSED TRIM DATA

Stick Position and Attitude Data for Configuration 1: GW 16825, FSCG 364, 3000 ft DA

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135
### MR and Stab Bending Data for Configuration 1: GW 16825, FSCG 364, 3000 ft DA

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### Stab Bending Data

| Resultant L          | 12252.09 |
| Resultant M          | 10764.37  |
| Resultant H          | 5708.09   |

### MR and Stab Bending Data for Configuration 2: GW 16825, FSCG 364, 3000 ft DA

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### Stab Bending Data

| Resultant L          | 12252.09 |
| Resultant M          | 10764.37  |
| Resultant H          | 5708.09   |

### MR and Stab Bending Data for Configuration 3: GW 16825, FSCG 364, 3000 ft DA

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### Stab Bending Data

| Resultant L          | 12252.09 |
| Resultant M          | 10764.37  |
| Resultant H          | 5708.09   |
Stick Position and Attitude Data for Configuration 2: GW 22000, FSCG 360, 3000 ft DA

**TEST FLIGHT DATA**

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