Real-Time Simulation Model of the HL-20 Lifting Body

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Summary

This report documents the current real-time simulation model of the HL-20 lifting body vehicle, known as version 2.0, presently in use at NASA Langley Research Center. Included are data on vehicle aerodynamics, inertias, geometries, guidance and control laws, and cockpit displays and controllers. In addition, trim case and dynamic check case data are provided.

The intent of this document is to provide the reader with sufficient information to develop and validate an equivalent simulation of the HL-20 for use in real-time or analytical studies.

Introduction

A recent NASA effort to provide an alternative vehicle for manned access to space has resulted in the proposal of a new lifting body vehicle designated the HL-20. Patterned after the HL-10, this lifting-body aircraft is characterized by low aspect ratio, canted winglets, a small rudder, and both reaction and aerodynamic controls. It is intended to be launched vertically and return for a horizontal landing, and will include energy management guidance and control laws patterned after the Space Transportation System Shuttle Orbiter control laws.

A requirement for such a vehicle is the capability to perform the entire return flight, from deorbit burn through reentry to landing, automatically. This will provide increased reliability and allow for safe return of crews that are either pilotless or in which the pilot-qualified crewmembers are incapacitated.

A simulation study utilizing both the Transport Systems Research Vehicle (TSRV) and the Visual Motion Simulator (VMS) simulation cockpits at Langley Research Center (LaRC) has demonstrated the feasibility of both piloted and automatic landing methods. This report documents that simulation model in its most recent production version. This report is intended to provide other NASA Centers and other agencies with a vehicle model and checkcases to assist in building simulations of the HL-20 to be used in further development of the vehicle.
Symbols and Abbreviations

\[
\begin{align*}
\alpha & \quad \text{Parabolic preflare curvature constant, rad/ft} \\
\alpha_n & \quad \text{Initial normal acceleration increment in preflare, ft/sec}^2 \\
b & \quad \text{Reference wing span, feet} \\
c & \quad \text{Mean aerodynamic chord, feet} \\
h_0 & \quad \text{Initial center of gravity altitude, feet} \\
h_1 & \quad \text{Parabolic slope intercept altitude, feet} \\
h_2 & \quad \text{Inner glideslope capture height, feet} \\
h_c & \quad \text{Commanded altitude, feet} \\
h_{cg} & \quad \text{Height of center of gravity above runway, feet} \\
h_p & \quad \text{Parabolic zero-slope altitude, feet} \\
l_{xx} & \quad \text{Moment of inertia about body X-axis, slug-ft}^2 \\
l_{yy} & \quad \text{Moment of inertia about body Y-axis, slug-ft}^2 \\
l_{zz} & \quad \text{Moment of inertia about body Z-axis, slug-ft}^2 \\
N_z & \quad \text{Acceleration in body Z-axis, ft/sec}^2 \\
q_b & \quad \text{Body axis pitch rate, rad/sec} \\
S & \quad \text{Reference area, feet}^2 \\
V_1 & \quad \text{Initial flare velocity, ft/sec} \\
x_0 & \quad \text{Initial center of gravity location in runway coordinates, feet} \\
x_1 & \quad \text{Parabolic slope intercept range, feet} \\
x_2 & \quad \text{Inner glideslope capture range, feet} \\
x_3 & \quad \text{Inner glideslope runway intercept point, feet} \\
x_{ap} & \quad \text{Outer glideslope aimpoint range, feet} \\
x_{cg} & \quad \text{Location of center of gravity in runway coordinates, feet} \\
x_{ep} & \quad \text{X-axis location of pilot's eyepoint in aircraft coordinates, feet} \\
x_p & \quad \text{Parabolic zero-slope range, feet}
\end{align*}
\]
\( y_{ep} \)  
Y-axis location of pilot's eyepoint in aircraft coordinates, feet

\( z_{ep} \)  
Z-axis location of pilot's eyepoint in aircraft coordinates, feet

\( \gamma_1 \)  
Outer glideslope angle, degrees

\( \dot{\gamma}_1 \)  
Initial preflare curvature rate, rad/sec

\( \gamma_2 \)  
Inner glideslope angle, degrees

CGI  
Computer Generated Imagery

DEL  
Left wing flap deflection, degrees

DER  
Right wing flap deflection, degrees

DLL  
Left lower body flap deflection, degrees

DLR  
Right lower body flap deflection, degrees

DME  
Distance Measuring Equipment

DR  
Vertical tail deflection, degrees

DUL  
Left upper body flap deflection, degrees

DUR  
Right upper body flap deflection, degrees

DCPILOT  
Manual pitch control signal, units

DWPILOT  
Manual roll control signal, units

EADI  
Electronic Attitude Display Indicator

FORTRAN  
FORmula TRANslator, a computer programming language

HAC  
Heading Alignment Cylinder

HUD  
Heads-Up Display

HSI  
Horizontal Situation Indicator

NZQ  
Pitch control law using acceleration and pitch rate feedback

PLS  
Personnel Launch System

RWD  
Right wing down

SAS  
Stability Augmentation System

TACAN  
TACTical Air Navigation
The HL-20 vehicle has been designed as a component of the proposed Personnel Launch System (PLS) (see figure 1). This vehicle would be launched into orbit by a booster rocket or carried within the payload bay of the Space Transportation System (Space Shuttle) orbiter. The vehicle would then deorbit, using an on-board propulsion system, and perform a gliding reentry and horizontal unpowered landing.

The HL-20 lifting body has been designed to carry up to ten people and/or small amounts of cargo. New construction techniques will facilitate maintenance of the vehicle and permit rapid turnaround between landing and launching [1].

A lifting-body concept was chosen for the PLS role to provide sufficient cross-range capability to allow a higher number of landing opportunities, while keeping aerodynamic heating and deceleration during reentry at acceptable levels [2].

Figure 1. - HL-20 Lifting Body
Aaxes, units of measure and sign conventions

This simulation model uses conventional measurement axes and sign conventions, as defined in [3]. Units of measure are English customary, e.g. pound-foot-second, units. The diagram below (figure 2) illustrates the sign convention for the aerodynamic actuators.

![Diagram](image)

Figure 2. - Control Surface nomenclature (viewed from rear)

Atmospheric data

No atmosphere model is provided in this document; however, the Langley simulation utilized the 1962 U.S. Standard Atmosphere model for all analysis to date and for the trimmed flight condition sets and the dynamic check case data.

Model assumptions and limitations

The configuration to be studied is described as the baseline configuration in [4], with the smaller all-moving rudder.

The aerodynamic envelope will be limited to less than 105,000 feet and Mach numbers between 0 and 4.0. No reaction control system model is provided.

Assumptions include vehicle X-Z plane symmetry and rigid body dynamics. No hinge moment limits are modeled for the actuators. The actuators have yet to be specified so the actuator model included herein is provided for validation purposes only. Perfect navigation sensors are assumed.

All landings in the TSRV and VMS have been flown to a runway similar to Denver-Stapleton runway 26L, which is 10,004 by 150 ft, with at 1,000 ft approach end overrun and a 600 ft overrun on the departure end. For this study, however, the runway has been conveniently placed at sea level, so that cockpit altimeter indications are both height above ground level and height above sea level.
Aside from scaled Shuttle landing gear aerodynamic effects, no landing gear model is provided since the design of this subsystem is very preliminary. This report provides some basic landing gear geometry in case a facility desires to develop an interim gear model.

Aerodynamic model

Appendix E contains the current aerodynamic data in use at Langley Research Center for the HL-20 simulation and analytical models. This is referred to as "version 2.0" of the aerodynamics. (Version 1 was a preliminary model used for some initial control development and flying qualities studies. [5]) Version 2.0 includes data from Mach 0 to 4, angle of attack between −2 and +16 degrees (sometimes higher), and sideslip between ± 5 degrees. Actuator position limits are as follows:

± 30 degrees (rudder & wing flaps)
+ 60 degrees (lower body flaps)
− 60 degrees (upper body flaps)

The data are presented in both tabular and graphical format. The tables are usually parameters for a polynomial equation in angle of attack, based upon Mach number and deflection angle.

The aerodynamic coefficients provided in the model are measured at a moment reference center located at 54 % of body length, along the X-axis, where 0 % corresponds to the nose of the vehicle.

Refer to Appendix E for more information on the aerodynamics model.

Aircraft geometry and inertial characteristics

Reference quantities

The current HL-20 aerodynamic reference quantities are given below:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>chord</td>
<td>( c )</td>
<td>28.24 ft</td>
</tr>
<tr>
<td>area</td>
<td>( S )</td>
<td>286.45 ft²</td>
</tr>
<tr>
<td>span</td>
<td>( b )</td>
<td>13.89 ft</td>
</tr>
</tbody>
</table>

Pilot eyepoint location (relative to c.g.)

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x_{ep} )</td>
<td>7.87 ft</td>
</tr>
<tr>
<td>( y_{ep} )</td>
<td>-1.35 ft</td>
</tr>
<tr>
<td>( z_{ep} )</td>
<td>-3.42 ft</td>
</tr>
</tbody>
</table>

Landing gear geometry

A sketch of the HL-20, giving the location of the landing gear in body coordinates, is given in Figure 3. This can serve as a basis for interim site-specific landing gear models until a more formal landing gear dynamics model is developed.

- 6 -
Inertial data

Current HL-20 landing weights and inertias are listed below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>19,100 lbs</td>
</tr>
<tr>
<td>$x_{cg}$</td>
<td>55.5 %</td>
</tr>
<tr>
<td>$I_{xx}$</td>
<td>7,512 slug-ft$^2$</td>
</tr>
<tr>
<td>$I_{yy}$</td>
<td>33,594 slug-ft$^2$</td>
</tr>
<tr>
<td>$I_{zz}$</td>
<td>35,644 slug-ft$^2$</td>
</tr>
</tbody>
</table>
Pilot Interface

Pilot hand controller characteristics

The HL-20 simulation at Langley Research Center utilized a left-handed side stick with a McFadden hydraulic control loader in both the fixed-base and motion-base simulators. Rudder pedals are rarely used in the simulation, and have not been optimized; the current rudder pedal dynamic characteristics are not quantified here. The speedbrake control lever is a simple spring-loaded lever that will automatically close (retract) the speedbrake handle if released by the pilot. The speedbrake handle is located on the right side of the pilot.

Design settings for the McFadden control loader are given below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pitch</th>
<th>Roll</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakout</td>
<td>± 1 lb</td>
<td>± 1 lb</td>
</tr>
<tr>
<td>Displacement</td>
<td>18° fwd 20° aft</td>
<td>± 20°</td>
</tr>
<tr>
<td>Max Force</td>
<td>12 lb fwd 13 lb aft</td>
<td>± 6.5 lb</td>
</tr>
<tr>
<td>Velocity Limit</td>
<td>35 in/sec</td>
<td>35 in/sec</td>
</tr>
</tbody>
</table>

The length of the side stick is 7.5 inches (pivot point to top of grip).

The measured control stick characteristics are given below.
Pitch axis: Figure 4 below gives the force/displacement curve for the VMS hand controller in the pitch axis. Figure 5 gives the calibration of displacement in inches to pitch control signal DCPILOT.

By time history measurement, the pitch axis hand controller frequency and damping are 23 rad/sec and 0.85, respectively.

![Figure 4. Pitch stick force characteristics](image)

![Figure 5. Pitch stick command signal versus displacement](image)
Roll axis: Figure 6 below gives the force/displacement curve for the VMS hand controller in the roll axis. Figure 7 gives the calibration of displacement in inches to roll control signal DWPILOT.

By time history measurement, the roll axis hand controller frequency and damping are 16 rad/sec and 1.4, respectively.
Cockpit displays

*Heads Up Display.* The heads up display (HUD) symbology, depicted below in figure 8, is mixed electronically with the out-the-window visual scene and presented to the pilot in the forward field of view. This is equivalent to the projection of an actual heads-up display in the cockpit.

![Figure 8. - Heads-Up Display (HUD) schematic](image)

Key symbology includes airspeed (knots equivalent) on the left, altitude in feet on the right, a boresight symbol (+), a velocity vector symbol (−→), all shown in white, and a red (for commanded) flight director symbol (◊). When situated on final approach, a pair of white flight path reference wedges appear at -17° below the horizon. When approaching the preflare point, a pair of red preflare reference wedges move up from the bottom of the HUD. The reference wedges merge with and obscure the flight path reference wedges at the beginning of preflare. The reference wedges then trace the nominal preflare flight path angle until the inner glideslope is reached, at which point all reference markers are removed, leaving altitude, airspeed, and velocity vector for the final flare maneuver.

In addition to those symbols, a speedbrake bar is shown in the lower right hand corner of the HUD, with two triangle markers. The upper marker, colored red, shows the autospeed logic commanded speedbrake position (in percent) and the lower marker, colored white, shows the current speedbrake position command from either the autospeed logic or the manual speedbrake handle in the cockpit. The left side of the bar corresponds to retracted speedbrake, and the right side of the bar corresponds to fully extended speedbrakes.
Electronic Attitude Display. The primary heads-down display is the electronic attitude display indicator (EADI) (figure 9). This display duplicates much of the information given in the HUD, including airspeed, altitude, and pitch/roll attitude and steering information. In addition, a digital readout of angle of attack, Mach, and normal acceleration (g) is given, as well as a normal acceleration tape on the left side of the display and a sink rate tape and ground proximity warning bar on the right side of the display. Glideslope and localizer indicators are also incorporated in the EADI. A runway is depicted in perspective as well to aid in instrument approaches.

Horizontal Situation Display. A conventional horizontal situation display (HSD) is also provided in the cockpit for runway orientation and includes a winds indicator, distance to the runway (DME), and redundant glideslope and localizer information. Figure 10 depicts this display for a typical flight condition.
Figure 10. - Horizontal Situation Display (HSD) schematic
Guidance and control system

Glossary of Terms

A comprehensive list of FORTRAN variable names used in the guidance and control law listings and diagrams is given in Appendix A.

Figure 11. Approach Trajectory Schematic

Guidance laws

The VMS/PLS guidance laws provide for automatic steering and flight director commands to guide the vehicle from Mach 4 to landing. All guidance modes generate flight path angle and bank angle commands. Two guidance laws are selectable, one based on TACAN, and the other using a Heading Alignment Cylinder.

The TACAN guidance law uses relative bearing inputs to direct the vehicle to fly over the landing site, then a downwind teardrop pattern to line up with the runway on the glideslope. An angle of attack versus Mach number profile is flown until on final approach. Energy is controlled by varying the turn commands depending on altitude and DME.

A more complex Heading Alignment Cylinder (HAC) algorithm resembles the approach geometry used in the Space Shuttle. Energy is managed by comparing altitude with distance to go to touchdown, flying tangent to the HAC, around it, and then to the runway.

Final approach guidance includes a steep outer glideslope, a parabolic pullup maneuver, and a shallow inner glideslope (figure 11). Touchdown sink rate is controlled by limiting the sink rate as a function of altitude. More information about the final approach trajectory is given in Appendix B.
A set of block diagrams of the current PLS guidance and control laws are shown in Appendix B. A complete CYBER FORTRAN listing of the current VMS guidance and control laws is given in Appendix C.

Control Laws

The control laws detailed in this report include control laws for both the subsonic and supersonic flight regimes. The subsonic control laws have been optimized with pilot opinion studies and are fairly well defined. The supersonic control laws, however, are very preliminary and are provided for checkcase comparisons and initial piloted investigations.

Pitch control law. The NZQ pitch control law in the VMS/PLS simulation provides good handling qualities through the flight envelope from supersonic speeds to landing. Commands from the pilot's stick (or automatic guidance) are summed with a filtered combination of vertical acceleration, $N_z$, and pitch rate, $q_b$, to generate an elevator deflection. This provides a pitch rate response that holds $N_z$ to maintain a nearly constant flight path angle when the command is nulled. Turns are automatically coordinated, and trim is maintained via a lagged elevator position feedback. Gains vary with dynamic pressure and Mach number to provide the same response to commands throughout the flight regime.

Roll/Yaw control law. The roll/yaw channels are simple rate feedback control systems. Both roll and yaw rates are fed back into the appropriate signal for artificial stabilization, and drive aileron and rudder commands, respectively. The yaw rate feedback signal is passed through a two second washout filter to allow for steady state turns.

Speed control law. The speed control law operates on an error in equivalent airspeed. If equivalent airspeed increases or decreases from the desired outer glideslope trim value (presently 300 knots) a value proportional to the speed error is added or subtracted to the nominal (trimmed) speedbrake command. A one second lag filter is applied to the resulting command to reduce control activity to wind gusts.

Controls mixer

Incorporated in the control laws described above is mixing logic that performs several functions. The primary function of the mixer is to mix speedbrake and roll (aileron) commands into four separate body flap actuator commands.

Subsonic roll mechanization uses diagonally opposite body flaps to provide an aerodynamic rolling moment (e.g. upper left and lower right for a left roll).

Supersonic aerodynamic roll control is provided by using upper and lower body flaps to act as yaw generators (e.g. upper and lower left body flaps will cause left yaw). The resulting sideslip generates a rolling moment in the direction of the yaw, due to the dihedral effect of the lifting body shape (left roll in this case).

Speed control is achieved through simultaneous deployment of all four surfaces, with a bias between upper and lower deflections to reduce pitch coupling.
To ensure controllability, the mixer ensures that the use of body flaps for roll function has priority over speedbrake function. This is mechanized by reducing the speed brake authority by an amount equal to the absolute value of the aileron command.

Pitch control is performed by deflection of the wing flaps, with assistance for large nose up pitching moment provided by upper body flaps.

At supersonic speeds, the mixer provides artificial stabilization by feeding sideslip and sideslip rate back to the lower body flaps.

The rudder command is fed directly to the rudder actuator.

Control surface actuators

The baseline simulation of the HL-20/PLS uses the same actuator model for all seven control surfaces. The present actuator model is a first-order lag with a 20 rad/sec bandwidth (0.05 time constant) and a 20-degree-per-second rate limit.

Verification Data

Trimmed flight conditions

Appendix D lists three realistic quasi-trimmed flight conditions for validation purposes. Since the vehicle is descending at approximately constant equivalent airspeed, these conditions do not represent inertially unaccelerated flight, due to atmospheric density gradients. Instead, the vehicle experiences an almost constant deceleration. The "trimmed" flight conditions given in Appendix D are more appropriately termed "equivalent trim" points, or "constant dynamic pressure trim" points. The procedure used to generate these points was to specify angle of attack, Mach number and flight path angle, and to vary altitude and control surface positions until a normal acceleration of 1 g was achieved.

Autoland trajectory

A representative HL-20 approach trajectory, commencing at Mach 4 and 105,000 feet, was simulated using the autoland control laws and heading alignment cylinder guidance laws presented earlier in this report. Figure 12 shows the cross range, altitude, Mach number and indicated airspeed plotted against downrange distance for this simulated approach trajectory.

Since the landing gear is normally deployed at 200 feet, this trajectory is performed almost entirely gear up.
Figure 12. - Mach 4 autoland trajectory (HAC guidance)
Dynamic Check Case data

Appendix F contains time history plots that show vehicle responses to separate control input pulses in the four pilot controls (pitch stick, roll stick, rudder pedals, and speedbrake handle) in three different flight conditions (Mach 0.8, 2.0, and 4.0). These pulses, of varying duration, are input after the simulation has run for one second from the initial conditions (given in Appendix D). The magnitude and duration of the pulses are as follows:

<table>
<thead>
<tr>
<th>Control Input</th>
<th>Mag.</th>
<th>Sense</th>
<th>Duration seconds</th>
<th>Run Length seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch Stick</td>
<td>1.0</td>
<td>AFT†</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Roll Stick</td>
<td>20.0</td>
<td>RIGHT</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Yaw (Pedal)</td>
<td>0.2</td>
<td>RIGHT</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Speed brake</td>
<td>100%</td>
<td>EXTEND</td>
<td>3</td>
<td>20</td>
</tr>
</tbody>
</table>

†For the Mach 2 initial condition, the pitch stick input is forward, since the pitch control surfaces are nearly saturated in this flight condition.

For these tests, the vehicle was configured as described in this report with autospeed engaged (except for the speedbrake pulses), with the manual flight control mode (stability augmented system, or SAS) engaged and landing gear retracted.

Remarks about implementation

The HL-20/PLS simulation at NASA Langley is presently implemented on a Control Data Corporation CYBER Model 175 at a major frame size of 32 milliseconds. The model is written in FORTRAN 5.

An Evans and Sutherland CT-6 provides an out-the-window computer generated image (CGI) to three mirror-beam-splitter XKD monitors at an update rate of 50 Hz (interlaced) with a line rate of 771. These monitors provide two forward out-the-window displays and a left- or right-side out-the-window display. The forward scene is approximately 54.5° (vertical) by 40.5° (horizontal). The side is 48.5° (vertical) by 35.5° (horizontal).

A Terabit Eagle 1000 symbology generator is used to provide cockpit graphics, and its output is mixed with the forward CGI visual scene through a Terabit R-mix unit. The cockpit heads down displays are XYtron calligraphic color monitors.

The measured average visual scene latency (from a stick pulse) is 170 ± 35 ms, (including full vehicle model computational load, but not including modeled aircraft dynamics).

The motion platform is a synergistic six degree of freedom Singer-Link motion platform with dual actuators in each leg. The measured average motion response latency (from a stick pulse to motion onset) is 82 ± 30 ms. The table below gives the design performance of the motion platform:
<table>
<thead>
<tr>
<th>Degree of Freedom</th>
<th>Position</th>
<th>Velocity</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>Forward</td>
<td>4.1 ft</td>
<td>±2 ft/sec</td>
</tr>
<tr>
<td></td>
<td>Aft</td>
<td>4.0 ft</td>
<td></td>
</tr>
<tr>
<td>Lateral</td>
<td>Left</td>
<td>4.0 ft</td>
<td>±2 ft/sec</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>4.0 ft</td>
<td></td>
</tr>
<tr>
<td>Vertical</td>
<td>Up</td>
<td>3.25 ft</td>
<td>±2 ft/sec</td>
</tr>
<tr>
<td></td>
<td>Down</td>
<td>2.50 ft</td>
<td></td>
</tr>
<tr>
<td>Yaw</td>
<td></td>
<td>±32°</td>
<td>±15°/sec</td>
</tr>
<tr>
<td>Pitch</td>
<td></td>
<td>+30°</td>
<td>±15°/sec</td>
</tr>
<tr>
<td>Roll</td>
<td></td>
<td>±22°</td>
<td>±15°/sec</td>
</tr>
</tbody>
</table>

The cockpit is a generic transport-category cockpit with two side-by-side pilot stations and an observer jump seat. The left seat includes a left hand McFadden side stick controller and was used for the majority of work in the HL-20/PLS simulation. The right seat has a conventional center stick with an F-14 stick grip, controlled by a separate McFadden hydraulic control system. Both seats have hydraulic rudder pedals that are interconnected. The left seat pilot uses a speedbrake lever on his right side; the right seat pilot uses a flap lever on his left side to control speedbrakes. The left seat pilot's speedbrake lever has a return (to retracted position) spring; the right seat pilot's flap handle does not have a return spring.

Version numbering

Each subsequent update to the HL-20 simulation model will be identified by a unique version number. This initial release outside of Langley is version 2.0.

Equations of motion

The equations used in this simulation are six-degree-of-freedom equations of motion which describe the accelerations along and about the body system of axes. The equations include provisions for the effects of a rotating round Earth (reference 1); however, for the range of airspeeds involved in this study, flat, non-rotating earth is assumed.

Landing gear model

No landing gear dynamics are provided with this model. The present landing gear design is not complete enough to use to predict any landing dynamics. It is recommended that each site modify an existing landing gear model from a similar vehicle and use that model to support landing rollouts in the interim. Landing gear geometry was given in figure 3.
Validation method.

It is recommended that the HL-20 simulation at each site be validated against data provided in this report using the following techniques:

1. **Function table data comparison.** The real-time simulation code should be used to generate plots of the stored function table values as a function of Mach, angles of attack and sideslip and control surface deflections. These plots should be compared to plots of the aerodynamic data, included in Appendix E, to ensure no errors occurred in implementation of the aerodynamic model.

2. **Equivalent Trim check cases.** The static check cases provided in Appendix D list trimmed airspeed, altitude, glide angle, vehicle attitudes and control surface deflections. The HL-20 simulation, when initialized to these values, should result in accelerations (UDOT, VDOT, WDOT, and QDOT) close to those listed in Appendix D.

3. **Dynamic check cases.** Following successful equivalent trim validation, the simulation should be tested to see if dynamic responses match the dynamic check cases included in Appendix F. These maneuvers consist of step inputs of specified amplitude and duration applied to a single pilot control, with the vehicle initially in an trimmed condition.

4. **Qualitative evaluation.** The real-time simulation of the HL-20 should be subjected to a short qualitative evaluation program by the Langley project pilot. The purpose of this evaluation would be to detect obvious modeling or implementation errors.

**Electronic distribution of portions of this model**

Portions of this model are available electronically via anonymous file transfer protocol (FTP) on the Internet, at host grissom.larc.nasa.gov, directory pub/hi-20/. These files are described below:

- **README.TXT**
  - read for the latest information concerning the model.

- **doc.wrd4.hqx**
  - Stuffed, BinHexed (for Macintosh) version of this document (in Microsoft Word 4 format)

- **plsdict.txt**
  - Symbol table dictionary (duplicated in appendix A below)

- **plsgnc.txt**
  - Guidance and control system FORTRAN model (written in CYBER FORTRAN-V)

- **pls_aerov2.txt**
  - Aero tables for version 2.0 in original text table format

- **aero_v20_pts.ftp**
  - Aero data in NASA-Ames Function Table Processor format for version 2.0

- **getdata.txt**
  - getData format description

- **ccXXXN.asc2**
  - Dynamic checkcase data in getData asc2 format, where XXX is pit, rol, yaw, spd to indicate...
control being pulsed, and \( N \) is 0, 2, or 4 to indicate subsonic, Mach 2, and Mach 4 initial conditions, respectively (total of 12 files).

(i) cctrimN.txt
Check case trim "shots" for subsonic, Mach 2 and Mach 4 initial conditions, respectively (total of 3 files)

(j) cctraj4.asc2
Autoland approach time history in getData asc2 format, commencing at Mach 4

These files will be updated as modifications are made to the HL-20 simulation at Langley. Comments may be directed to bjax@grissom.larc.nasa.gov, using conventional SMTP mail systems.

**Concluding Remarks**

This report documents the present aerodynamics, inertia, guidance laws, control laws, pilot controls and displays, and physical geometry models used at NASA Langley Research Center to study the dynamic characteristics and flying qualities of the HL-20 vehicle concept and to perform trade-off studies for candidate design changes. Included in this report are sufficient data to validate the proper implementation of these models at other simulation facilities.

Details on electronic distribution of these data, via the Internet, are included.

This report is provided to support additional explorations via simulation of the flight characteristics of the HL-20 vehicle. It is intended to be updated as additional information about the HL-20 configuration is obtained.

**References**


Appendices

A. Guidance and Control Law glossary
B. Guidance and Control Law diagrams
C. Guidance and Control Law listings
D. Trimmed Flight Condition check case data
E. Aero Data Base for HL-20 Flight Simulation Studies
F. Dynamic checks for validation purposes
Appendix A

Guidance and Control Law glossary
Appendix A: Guidance and Control Law Glossary

VMS/PLS GN&C SYMBOL DICTIONARY 920323

* NOTES

* POSITION, VELOCITY, AND ATTITUDE (EULER ANGLES) ARE BASED ON
  THE EARTH REFERENCE FRAME, ORIGIN AT THE RUNWAY THRESHOLD
  X=TRUE NORTH, Y=TRUE EAST, Z=DOWN

* THE BODY REFERENCE FRAME ORIGIN IS AT THE CENTER OF MASS,
  X-FORWARD, Y-RIGHT, Z-FLOOR OF AIRCRAFT (DOWN)

* THE RUNWAY HEADING IS TRUE NORTH, SO THE RUNWAY FRAME IS THE
  SAME AS THE EARTH REFERENCE FRAME IN THIS SIMULATION

ABBREVIATIONS

* AKA = ALSO KNOWN AS
* DEG = DEGREES
* DPS = DEGREES PER SECOND
* FPS = FEET PER SECOND
* FT = FEET
* HAC = HEAD ALIGNMENT CIRCLE
* IN = INCHES
* LB = POUNDS
* MAX = MAXIMUM
* MIN = MINIMUM
* NEG = NEGATIVE
* NOM = NOMINAL (USUAL OR EXPECTED VALUE)
* POS = POSITIVE
* PSF = POUNDS PER SQUARE FOOT
* RAD = RADIANS
* RPS = RADIANS PER SECOND
* TED = TRAILING EDGE DOWN
* TER = TRAILING EDGE RIGHT
* TEU = TRAILING EDGE UP

(T/F) MEANS THE VARIABLE IS LOGICAL (TRUE OR FALSE)
(X...Y) MEANS THE VARIABLE IS LIMITED BETWEEN X AND Y

* ALPDEG = ANGLE OF ATTACK, DEG
* ALPHA = ANGLE OF ATTACK, RAD
* ALT = ALTITUDE ABOVE RUNWAY, FT
* ALTREF = REFERENCE ALTITUDE ON DESIRED PATH, FT
* ANX = BODY FRAME ACCELERATION FORWARD, G'S
* ANY = BODY FRAME ACCELERATION TO RIGHT, G'S
* ANZ = BODY FRAME ACCELERATION UPWARD, G'S (NOT BODY Z AXIS!)
* AOACMD = COMMAND ANGLE OF ATTACK, DEG
* AOAMLD = ANGLE OF ATTACK FOR MAXIMUM LIFT/Drag RATIO, DEG
* AOANOM = NOMINAL ANGLE OF ATTACK VERSUS MACH NUMBER, DEG
* AUTOSB = AUTO SPEEDBRAKE MODE SELECTED (T/F)
* BEDOT = ESTIMATED SIDESLIP RATE, DPS (AKA BETA DOT)
* BETA = SIDESLIP ANGLE, RAD +RELATIVE WIND FROM RIGHT
* BETADEG = SIDESLIP ANGLE, DEG +RELATIVE WIND FROM RIGHT
* CDTOT = TOTAL DRAG COEFFICIENT
* CLTOT = TOTAL LIFT COEFFICIENT
* CLLITOT = TOTAL ROLL (LITTLE L) COEFFICIENT
* CLNTOT = TOTAL YAW (LITTLE N) COEFFICIENT
* CMSL = MAXIMUM ABSOLUTE PITCH STICK DEFLECTION, + AFT
* COLSHC = COLUMN PITCH COMMAND AFTER SHAPING, + AFT OR PITCH UP
* COORDNZ = NORMAL ACCELERATION IN COORDINATED TURN, G'S
* COSALP = COSINE OF ANGLE OF ATTACK (ALPHA)
* COSPHI = COSINE OF BANK ANGLE
* COSTHE  COSINE OF PITCH ANGLE
* CYTOT  TOTAL SIDE FORCE COEFFICIENT

* DAAC  AILERON COMMAND LOWER LIMIT, DEG
* DACMD  AILERON COMMAND TO CONTROL MIXER, DEG (-30...30)
* DACMDL  LIMITED AILERON MIXER COMMAND, DEG
* DACU  AILERON COMMAND UPPER LIMIT, DEG
* DADIR  AILERON RESPONSE TO WHEEL INPUT, DEG +RIGHT TEU
* DAGC  AILERON RESPONSE TO GUIDANCE COMMAND, DEG
* DAP  AILERON RESPONSE TO ROLL RATE, DEG + RIGHT TEU
* DATRIM  AILERON TRIM DEFLECTION, DEG +RIGHT TEU
* DBFMAX  MAXIMUM ABSOLUTE VALUE OF SPEEDBRAKE DEFLECTION, DEG
* DBFSBLC  LOWER BODY FLAP DUE TO SPEEDBRAKE COMMAND, DEG +TED
* DBFSBUC  UPPER BODY FLAP DUE TO SPEEDBRAKE COMMAND, DEG +TED
* DCPILLOT  PITCH STICK (COLUMN) DEFLECTION, IN +AFT (-5...9)
* DECL  ELEVATOR COMMAND LOWER LIMIT, DEG + TED
* DECMD  ELEVATOR COMMAND TO ACTUATORS, DEG + TED
* DECMDL  LIMITED ELEVATOR ACTUATOR COMMAND, DEG +TED
* DECU  ELEVATOR COMMAND UPPER LIMIT, DEG +TED
* DEEDSB  ELEVATOR COMMAND TO TRIM SPEEDBRAKE PITCH MOMENT, DEG
* DEGC  ELEVATOR RESPONSE TO GAMMA COMMAND, DEG +TED
* DEQ  ELEVATOR RESPONSE TO PITCH RATE, DEG + TED
* DETRIM  ELEVATOR TRIM ANGLE, DEG +TED
* DETRIMO  ELEVATOR TRIM ANGLE AT INITIAL CONDITION, DEG +TED
* DLE  LEFT ELEVON DEFLECTION, DEG +TED
* DLEC  LEFT ELEVON ACTUATOR COMMAND, DEG
* DLED  ELEVATOR DEFLECTION, DEG +TED
* DLEDF  FILTERED ELEVATOR DEFLECTION, DEG +TED (NOT USED)
* DLEDGP  PAST ELEVATOR DEFLECTION, DEG +TED
* DLEL  LEFT ELEVON DEFLECTION LOWER LIMIT, DEG +TED
* DLEP  LEFT ELEVON PAST DEFLECTION, DEG +TED
* DLEPP  LEFT ELEVON PAST PAST DEFLECTION, DEG +TED
* DLERU  LEFT ELEVON ACTUATOR TIME CONSTANT, SEC
* DLET  LEFT ELEVON DEFLATION UPPER LIMIT, DEG +TED
* DLEZ1  LEFT ELEVON Z TRANSFORM PAST OUTPUT COEFFICIENT
* DLEZ2  LEFT ELEVON Z TRANSFORM PRESENT INPUT COEFFICIENT
* DLEZ3  LEFT ELEVON Z TRANSFORM PAST INPUT COEFFICIENT
* DLFDA  LOWER BODY FLAP AS AILERON COMMAND, DEG +LEFT TED
* DLFDL  LOWER BODY FLAP COMMAND AS AILERON, DEG +LEFT TED
* DLFDL  LOWER BODY FLAP COMMAND LIMITED, DEG +TED
* DLFDL  LOWER BODY FLAP COMMAND AS AILERON, DEG +LEFT TED
* DLFL  LOWER BODY FLAP AS AILERON COMMAND, DEG +LEFT TED
* DLLA  LOWER BODY FLAP COMMAND LIMITED, DEG +TED
* DLLA  LOWER BODY FLAP COMMAND AS AILERON, DEG +LEFT TED
* DLLA  LOWER BODY FLAP COMMAND LIMITED, DEG +TED
* DLLC  LOWER BODY FLAP COMMAND LOWER LIMIT, DEG +TED
* DLLC  LOWER BODY FLAP COMMAND AS AILERON, DEG +TED
* DLLC  LOWER BODY FLAP COMMAND LOWER LIMIT, DEG +TED
* DLLD  LOWER BODY FLAP COMMAND LIMITED, DEG +TED
* DLLD  LOWER BODY FLAP COMMAND AS AILERON, DEG +TED
* DLLD  LOWER BODY FLAP COMMAND LIMITED, DEG +TED
* DLLD  LOWER BODY FLAP COMMAND AS AILERON, DEG +TED
* DLLD  LOWER BODY FLAP COMMAND LIMITED, DEG +TED
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* DLLD  LOWER BODY FLAP COMMAND AS AILERON, DEG +TED
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* DLLD  LOWER BODY FLAP COMMAND LIMITED, DEG +TED
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* DLLD  LOWER BODY FLAP COMMAND LIMITED, DEG +TED
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* DLLD  LOWER BODY FLAP COMMAND LIMITED, DEG +TED
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* DLLD  LOWER BODY FLAP COMMAND AS AILERON, DEG +TED
* DLLD  LOWER BODY FLAP COMMAND LIMITED, DEG +TED
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* DLLD  LOWER BODY FLAP COMMAND AS AILERON, DEG +TED
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* DLLD  LOWER BODY FLAP COMMAND AS AILERON, DEG +TED
* DLLD  LOWER BODY FLAP COMMAND LIMITED, DEG +TED
* DLLD  LOWER BODY FLAP COMMAND AS AILERON, DEG +TED
* DLLD  LOWER BODY FLAP COMMAND LIMITED, DEG +TED
* DLLD  LOWER BODY FLAP COMMAND AS AILERON, DEG +TED
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>DLRRL</td>
<td>Lower right body flap deflection rate limit, dps +TED</td>
</tr>
<tr>
<td>DLRTAU</td>
<td>Lower right body flap actuator time constant, sec</td>
</tr>
<tr>
<td>DLRTU</td>
<td>Lower right body flap deflection upper limit, deg +TED</td>
</tr>
<tr>
<td>DLRT21</td>
<td>Lower right body flap z transform past output coefficient</td>
</tr>
<tr>
<td>DLRT22</td>
<td>Lower right body flap z transform present input coefficient</td>
</tr>
<tr>
<td>DLRT23</td>
<td>Lower right body flap z transform past input coefficient</td>
</tr>
<tr>
<td>DLSB10</td>
<td>Speedbrake handle deflection (0...40)</td>
</tr>
<tr>
<td>DLSBDEG</td>
<td>Speedbrake deflection to aero, deg</td>
</tr>
<tr>
<td>DPPilot</td>
<td>Rudder pedal deflection, +right (-2.7...2.7)</td>
</tr>
<tr>
<td>DR</td>
<td>Rudder deflection, deg +tel</td>
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<tr>
<td>DRC</td>
<td>Rudder command, deg +tel</td>
</tr>
<tr>
<td>DRC1</td>
<td>Commanded rudder gain</td>
</tr>
<tr>
<td>DRC2</td>
<td>Rudder command lower limit, deg +tel</td>
</tr>
<tr>
<td>DRCMD</td>
<td>Rudder command to actuators, deg +tel</td>
</tr>
<tr>
<td>DRCMDL</td>
<td>Limited rudder command, deg +tel</td>
</tr>
<tr>
<td>DRCU</td>
<td>Rudder response to pedal deflection, deg +tel</td>
</tr>
<tr>
<td>DRD</td>
<td>Right elevon deflection, deg +tel</td>
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<tr>
<td>DREC</td>
<td>Right elevon actuator command, deg +tel</td>
</tr>
<tr>
<td>DREL</td>
<td>Right elevon deflection lower limit, deg +tel</td>
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<tr>
<td>DREP</td>
<td>Right elevon past deflection, deg +tel</td>
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<tr>
<td>DREP2</td>
<td>Right elevon past past deflection, deg +tel</td>
</tr>
<tr>
<td>DREP3</td>
<td>Right elevon past past deflection, deg +tel</td>
</tr>
<tr>
<td>DREPL</td>
<td>Right elevon deflection rate limit, dps +tel</td>
</tr>
<tr>
<td>DRETAU</td>
<td>Right elevon actuator time constant, sec</td>
</tr>
<tr>
<td>DREU</td>
<td>Right elevon deflection upper limit, deg +tel</td>
</tr>
<tr>
<td>DREZ1</td>
<td>Right elevon z transform past output coefficient</td>
</tr>
<tr>
<td>DREZ2</td>
<td>Right elevon z transform present input coefficient</td>
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<tr>
<td>DREZ3</td>
<td>Right elevon z transform past input coefficient</td>
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<tr>
<td>DRL</td>
<td>Rudder deflection lower limit, deg +tel</td>
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<td>Rudder past past deflection, deg +tel</td>
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<tr>
<td>DRRL</td>
<td>Rudder deflection rate limit, dps +tel</td>
</tr>
<tr>
<td>DRSAS</td>
<td>Rudder response to yaw damper, deg</td>
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<tr>
<td>DRTAU</td>
<td>Rudder actuator time constant, sec</td>
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<td>DRU</td>
<td>Rudder deflection upper limit, deg +tel</td>
</tr>
<tr>
<td>DRZ1</td>
<td>Rudder z transform past output coefficient</td>
</tr>
<tr>
<td>DRZ2</td>
<td>Rudder z transform present input coefficient</td>
</tr>
<tr>
<td>DRZ3</td>
<td>Rudder z transform past input coefficient</td>
</tr>
<tr>
<td>DSBAuto</td>
<td>Unfiltered speedbrake speed hold command, deg</td>
</tr>
<tr>
<td>DSBCMD</td>
<td>Speedbrake command to control mixer, deg</td>
</tr>
<tr>
<td>DSBCM1</td>
<td>Limited speedbrake mixer command, deg</td>
</tr>
<tr>
<td>DSDBDIR</td>
<td>Speedbrake response to handle deflection, deg</td>
</tr>
<tr>
<td>DSDBS</td>
<td>Speedbrake response to speed error, deg</td>
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<tr>
<td>DSDBS1</td>
<td>Filtered speedbrake response to speed error, deg</td>
</tr>
<tr>
<td>DSDBS2</td>
<td>Speedbrake shaping function gain per handle</td>
</tr>
<tr>
<td>DSBS2</td>
<td>Speedbrake shaping function gain per handle squared</td>
</tr>
<tr>
<td>DSBTR</td>
<td>Speedbrake trim deflection, deg</td>
</tr>
<tr>
<td>DTGOG</td>
<td>Total ground track distance to go to touchdown, ft</td>
</tr>
<tr>
<td>DUFD</td>
<td>Upper body flap command to assist elevators, deg +ted</td>
</tr>
<tr>
<td>DUL</td>
<td>Upper left body flap deflection, deg +tel</td>
</tr>
<tr>
<td>DULC</td>
<td>Upper left body flap command, deg +tel</td>
</tr>
<tr>
<td>DULCL</td>
<td>Upper left body flap command lower limit, deg +tel</td>
</tr>
<tr>
<td>DULCMD</td>
<td>Upper left body flap command as aileron, deg +tel</td>
</tr>
<tr>
<td>DULCM2</td>
<td>Upper left body flap limited command, deg +tel</td>
</tr>
<tr>
<td>DULCU</td>
<td>Upper left body flap command upper limit, deg +tel</td>
</tr>
<tr>
<td>DULL</td>
<td>Upper left body flap deflection lower limit, deg +tel</td>
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<tr>
<td>DULP</td>
<td>Upper left body flap past past deflection, deg +tel</td>
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<tr>
<td>DULPP</td>
<td>Upper left body flap past past deflection, deg +tel</td>
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<tr>
<td>DULRL</td>
<td>Upper left body flap deflection rate limit, dps +tel</td>
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<tr>
<td>DULTAU</td>
<td>Upper left body flap actuator time constant, sec</td>
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<td>DULU</td>
<td>Upper left body flap deflection upper limit, deg +tel</td>
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<tr>
<td>DULZ1</td>
<td>Upper left body flap z transform past output coefficient</td>
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<tr>
<td>DULZ2</td>
<td>Upper left body flap z transform present input coefficient</td>
</tr>
<tr>
<td>DULZ3</td>
<td>Upper left body flap z transform past input coefficient</td>
</tr>
<tr>
<td>DUR</td>
<td>Upper right body flap deflection, deg +tel</td>
</tr>
<tr>
<td>DURC</td>
<td>Upper right body flap command, deg +tel</td>
</tr>
</tbody>
</table>
Appendix A: Guidance and Control Law Glossary

* DURCL  UPPER RIGHT BODY FLAP COMMAND LOWER LIMIT, DEG +TED
* DURCMD  UPPER RIGHT BODY FLAP COMMAND AS AILERON, DEG +TED
* DURCMDL  UPPER RIGHT BODY FLAP COMMAND LIMITED, DEG +TED
* DURCU  UPPER RIGHT BODY FLAP COMMAND UPPER LIMIT, DEG +TED
* DURP  UPPER RIGHT BODY FLAP PAST DEFLECTION LOWER LIMIT, DEG +TED
* DURPP  UPPER RIGHT BODY FLAP PAST PAST DEFLECTION, DEG +TED
* DURL  UPPER RIGHT BODY FLAP DEFLECTION RATE LIMIT, DPS +TED
* DURTAU  UPPER RIGHT BODY FLAP ACTUATOR TIME CONSTANT, SEC
* DURU  UPPER RIGHT BODY FLAP DEFLECTION UPPER LIMIT, DEG +TED
* DUR21  UPPER RIGHT BODY FLAP Z TRANSFORM PAST OUTPUT COEFFICIENT
* DUR22  UPPER RIGHT BODY FLAP Z TRANSFORM PRESENT INPUT COEFFICIENT
* DUR23  UPPER RIGHT BODY FLAP Z TRANSFORM PAST PAST INPUT COEFFICIENT
* DWPILOT  ROLL STICK (WHEEL) DEFLECTION, +RIGHT (-60...60)
* ELOC  LOCALIZER ERROR, DEG +RIGHT OF CENTERLINE (-2.5...2.5)
* FAT1  Z TRANSFORM GAIN ON PAST OUTPUT OF AUTO TRIM FILTER
* FAT2  Z TRANSFORM GAIN ON PRESENT INPUT TO AUTO TRIM FILTER
* FAT3  Z TRANSFORM GAIN ON PAST INPUT TO AUTO TRIM FILTER
* FATB  AUTO TRIM LEAD GAIN (AS+T / TS+1 FILTER)
* FATT  AUTO TRIM TIME CONSTANT, SEC
* FATTA  AUTO TRIM TIME CONSTANT FOR MANUAL MODES, SEC
* FATTM  AUTO TRIM TIME CONSTANT FOR AUTO MODES, SEC
* FN21  Z TRANSFORM GAIN ON PAST OUTPUT OF NZ FILTER
* FN22  Z TRANSFORM GAIN ON PRESENT INPUT TO NZ FILTER
* FN23  Z TRANSFORM GAIN ON PAST INPUT TO NZ FILTER
* FN2A  NZ FILTER LEAD GAIN (AS+T / TS+1 FILTER)
* FN2B  NZ FILTER LAG GAIN
* FN2T  NZ FILTER TIME CONSTANT, SEC
* FQB1  Z TRANSFORM GAIN ON PAST OUTPUT OF Q-BODY FILTER
* FQB2  Z TRANSFORM GAIN ON PRESENT INPUT TO Q-BODY FILTER
* FQB3  Z TRANSFORM GAIN ON PAST INPUT TO Q-BODY FILTER
* FQBA  PITCH RATE (Q-BODY) FILTER LEAD GAIN (AS+T / TS+1 FILTER)
* FQBT  PITCH RATE FILTER LAG GAIN
* GAIN  AUTO TRIM TIME CONSTANT, SEC
* FLIGHT PATH ANGLE (GAMMA) COMMAND, DEG
* GAMCMD  GAMMA COMMAND LOWER LIMIT, DEG
* GAMCLL  GAMMA COMMAND UPPER LIMIT, DEG
* GAMCOR  FLIGHT PATH ANGLE CORRECTION, DEG
* GAMCUL  GAMMA COMMAND LIMIT, DEG
* GAMDOT  ESTIMATED FLIGHT PATH ANGLE RATE, DPS (AKA GAMMA DOT)
* GAMDOF  GAMMA DOT FILTER OUTPUT, DPS
* GAMDTP  PAST VALUE OF GAMMA DOT, DPS
* GAMFFL  FLIGHT PATH ANGLE FLOOR VALUE, DEG
* GAMFILT  GAMMA FILTER OUTPUT, DEG (NOT USED)
* GAMFLR  FLIGHT PATH ANGLE DURING FLARE, DEG
* GMAMA  FLIGHT PATH ANGLE, DEG +CLIMBING
* GMAMA1  OUTER GLIDE SLOPE ANGLE, DEG
* GMAMA2  INNER GLIDE SLOPE ANGLE, DEG
* GMAMAD  FLIGHT PATH ANGLE (GAMMA), DEG +CLIMBING
* GMAMAP  PAST VALUE OF GAMMA, DEG (NOT USED)
* GMAREF  FLIGHT PATH ANGLE ON THE GLIDESLOPE, DEG
* GBFA  GAIN, LOWER BODY FLAPS AS AILERONS, DEG/DEG
* GBFB  GAIN, LOWER BODY FLAPS VERSUS BETA, DEG/DEG
* GBFBD  GAIN, LOWER BODY FLAPS VERSUS BETA DOT, DEG/DPS
* GDAWLM  GAIN, AILERON PER LEFT WHEEL DEFLECTION, DEG/DEG
* GDAWR  GAIN, AILERON PER RIGHT WHEEL DEFLECTION, DEG/DEG
* GDAAG  GAIN, AILERON PER BANK ERROR, DEG/DEG
* GDAAP  GAIN, HEADING PER CROSSTRAIF ERROR, DEG/PT
* GDA  GAIN, AILERON PER ROLL RATE, DEG/DPS
* GDAAS  GAIN, BANK ANGLE PER HEADING ERROR, DEG/DEG
* GDECCA  GAIN, ELEVATOR PER GAMMA ERROR, DEG/DEG
* GDECCM  GAIN, ELEVATOR PER GAMMA DOT, DEG/DPS
* GDLD  GAIN, LOWER BODY FLAP AILERON 'REVERSAL' FUNCTION OF MACH
Appendix A: Guidance and Control Law Glossary

* GDQDC
  Gain, pitch rate command per column deflection, dps/in
* GRDA
  Gain, aileron to rudder crossfeed nominal, deg/deg
* GDRDAX
  Gain, aileron to rudder crossfeed, deg/deg
* GDRDP
  Gain, rudder per pedal deflection, deg/in
* GDUDA
  Gain, upper body flaps as ailerons versus mach
* GDUDE
  Gain, upper body flaps as elevators versus mach
* GGFL
  Final flare gamma, deg
* GGFLR
  Gain, floor gamma per ft, deg/ft
* GGHER
  Gain, gamma per altitude error, deg/ft
* GGLL
  Gamma command lower limit, deg
* GUL
  Gamma command upper limit, deg
* GGA
  Elevator gain as function of mach number
* GGBAR
  Elevator gain as function of dynamic pressure
* GQBAR
  Gain, elevator over dynamic pressure, 1/psf
* GRND
  1 = wheels on the ground (0 or 1)
* GRRLIM
  Gain to reduce roll rate limit at high mach
* GRSAS
  Gain, yaw damper deg/dps
* GSLAP
  Slapdown (derotation) pitch rate gain

* H
  Integration time step, sec
* HACX
  Downrange location of HAC center, ft (usually neg)
* HACCY
  Crossrange location of HAC center, ft
* HACD
  Distance to center of HAC, ft
* HACDT
  Distance to tangent point on HAC, ft
* HACDT2
  Square of HACDT
* HACGAM
  Flight path angle on HAC, deg +climbing
* HACRAD
  Heading alignment circle radius, ft
* HACXK
  Distance to edge of HAC, ft
* HDOT
  Altitude rate, fps
* HER
  Altitude error, ft, + below glideslope
* HFPCAPT
  Nominal altitude at final glideslope capture, ft
* HGS
  Altitude of the glideslope, ft
* HPLOC0
  Altitude at parabolic flare zero slope, ft
* HPSINTC
  Altitude at preflare intercept, ft
* HSTEP
  Integration time step for actuators, sec

* I
  Dummy index
* IAS
  Indicated airspeed, knots = equivalent airspeed in this simulation

* L
  Total rolling moment, ft-lb right wing down
* LFCS
  Flight control law 0-baseline 1-gamma hold 2-nz+q 3-rcah
  4-state

* M
  Total pitching moment, ft-lb nose up
* MACH
  Mach number
* MCONFIG
  Mass configuration 0-entry/landing 1-booster attached
  2-adaptor attached 3-adaptor separated
* MFCS
  Flight control mode 0-direct 1-pitch rate cmd 2-roll rate cmd
  3-pitch & roll rate cmd 4-pitch auto & roll rate
  5-pitch rate & roll auto 6-pitch & roll auto
* MGUID
  Guidance mode 1-final 2-turn to final 3-downwind
* MODE
  Simulator mode 1-reset 2-hold 3-operate
* MPAUTO
  Pitch control automatic mode

* N
  Total yawing moment, ft-lb nose right
* NZ
  Vertical body axis acceleration, g, positive up

* P
  Body roll rate, rps
* PCURVC
  Parabolic flare shaping parameter
* PDEG
  Body roll rate, dps
* PDOT
  Body roll acceleration, rad/sec/sec
* PHI
  Euler roll angle (bank), rad
* PHICLHI
  Bank command limit at high altitude, deg
* PHICLLO
  Bank command limit at low altitude, deg
Appendix A: Guidance and Control Law Glossary

* PHID  EULER ROLL ANGLE (BANK), DEG
* PHICMD  BANK ANGLE COMMAND, DEG
* PHIHAC  NOMINAL BANK ANGLE ON HAC, DEG +RIGHT WING DOWN
* PSI  EULER YAW ANGLE (HEADING), RAD
* PSICMD  HEADING COMMAND, DEG
* PSICOR  HEADING CORRECTION, DEG
* PSID  EULER YAW ANGLE (HEADING), DEG
* PSIFF  HEADING ERROR, DEG, POSITIVE FOR RIGHT TURN NEEDED
* PSIHACC  HEADING TO HAC CENTER, DEG
* PSIREF  RUNWAY HEADING, DEG
* Q  BODY PITCH RATE, RPS
* QBAR  DYNAMIC PRESSURE, PSF
* QCOORD  COORDINATED TURN BODY PITCH RATE, DPS
* QDEG  BODY PITCH RATE, DPS (AKA Q-BODY)
* QDEGF  BODY PITCH RATE FILTER OUTPUT, DPS
* QDEGP  PAST VALUE OF PITCH RATE FILTER, DPS
* QDOT  BODY PITCH ACCELERATION, RAD/SEC/SEC
* R  BODY YAW RATE, RPS
* RBWASH  YAW RATE WASHOUT FILTER, RPS
* RBW021  YAW RATE WASHOUT Z TRANSFORM COEFFICIENT
* RDEG  BODY YAW RATE, DPS
* RDEGF  PAST BODY YAW RATE, DPS
* RDOT  BODY YAW ACCELERATION, RAD/SEC/SEC
* RSQLAW  QUADRATIC STICK SHAPING RATIO 0-LINEAR 1-SQUARE
* SBAUTH  MAXIMUM ALLOWABLE SPEEDBRAKE DEFLECTION, DEG
* SINALP  SINE OF ANGLE OF ATTACK
* SINPHI  SINE OF BANK ANGLE
* SLAPRT  COMMANDED SLAPDOWN (DEROTATION) PITCH RATE, DPS
* SX  AIRCRAFT LOCATION NORTH OF RUNWAY THRESHOLD, FT
* SXDOT  AIRCRAFT NORTHWARD VELOCITY, FPS
* SY  AIRCRAFT LOCATION EAST OF RUNWAY THRESHOLD, FT
* SYDOT  AIRCRAFT EASTWARD VELOCITY, FPS
* TACBRG  BEARING TO RUNWAY THRESHOLD (OR TACAN), DEG
* TACDAZ  RELATIVE BEARING TO RUNWAY THRESHOLD (OR TACAN), DEG
* TACDME  LINE OF SIGHT RANGE TO RUNWAY THRESHOLD (OR TACAN), NMI
* TACE  AIRCRAFT LOCATION EAST OF TACAN, FT
* TACN  AIRCRAFT LOCATION NORTH OF TACAN, FT
* TANPHIL  TANGENT OF BANK ANGLE, (-1...1)
* THETA  EULER PITCH ANGLE, RAD
* THETAD  EULER PITCH ANGLE, DEG
* TRANG  TRACK ANGLE ACROSS EARTH SURFACE, DEG
* U  BODY RELATIVE VELOCITY FORWARD, FPS
* UDOT  BODY RELATIVE ACCELERATION FORWARD, FPS/SEC
* V  BODY RELATIVE VELOCITY TO RIGHT, FPS
* VDOT  BODY RELATIVE ACCELERATION TO RIGHT, FPS/SEC
* VTOTAL  BODY RELATIVE VELOCITY MAGNITUDE, FPS
* VTOTALI  EARTH REFERENCE FRAME VELOCITY MAGNITUDE, FPS
* W  BODY RELATIVE VELOCITY DOWNWARD, FPS
* WDOT  BODY RELATIVE ACCELERATION DOWNWARD, FPS
* WONG  WEIGHT ON NOSE GEAR (T/F)
* WOW  WEIGHT ON WHEELS (T/F)
* X  SUM OF BODY FRAME FORCES FORWARD, LB
* X_CAT  Dummy Value in Clamp Limit Function
* XAPCAPT  DISTANCE TO THRESHOLD AT INNER GLIDESLOPE INTERCEPT, FT
* XPLOCO  DISTANCE TO THRESHOLD AT PARABOLIC CURVE ZERO SLOPE, FT
* XPSPINTC  DISTANCE TO THRESHOLD AT PREFLARE INTERCEPT, FT
* XTPCHDN  DISTANCE FROM THRESHOLD TO TOUCHDOWN AIM POINT, FT
* XTYE  DISTANCE TO THE EDGE OF THE HEADING ALIGNMENT CIRCLE, FT
* Y  
SUM OF BODY FRAME FORCES TO RIGHT, LB
DUMMY VALUE IN CLAMP LIMIT FUNCTION

* Y

* Z  
SUM OF BODY FRAME FORCES DOWNWARD, LB
DUMMY VALUE IN CLAMP LIMIT FUNCTION

* Z
Appendix B

Guidance and Control Law diagrams
Final approach path trajectory guidance

The HL-20 autoland guidance laws use a trajectory generator that calculates desired altitude as a function of distance from the runway threshold. This same trajectory is used to provide approach path guidance for manual operation.

The approach path described by the trajectory generator consists of three sections: a steep initial approach, a parabolic flare maneuver, and a shallower final approach path leading to the touchdown point of the runway, as shown in figure B-1.

Since this trajectory is affected by changes to the vehicle configuration, such as weight and lift-to-drag ratio, it is important that the capability to modify the approach parameters at run time be provided. It is therefore suggested that the intermediate equations (given as equations (4) through (15) on the following pages) be provided in some initialization portion of the guidance software. The trajectory equations themselves (equations (1) through (3)) should be executed in the run mode portion of the software to provide continuous updates to the nominal approach path altitude.

The independent parameters which define the approach trajectory are the outer and inner glideslope angles ($\gamma_1$ and $\gamma_2$), inertial velocity at initiation of preflare ($V_1$), initial preflare normal acceleration increment, ($a_n$), altitude of inner glideslope capture, ($h_2$), and inner glideslope runway intercept point, ($x_3$).

The run-time equations are used to calculate commanded altitude ($h_c$) as a function of distance downrange from the runway threshold, $x_{cg}$, depending on where the aircraft is located in approach path, as follows:

- during the initial approach ($x_{cg} > x_1$):
  
  $$ h_c = h_1 + (x_{cg} - x_1) \tan \gamma_1 $$

- during the parabolic flare maneuver ($x_1 \geq x_{cg} > x_2$):
  
  $$ h_c = h_p + a_n (x_{cg} - x_p)^2 $$

- during the final approach to touchdown ($x_{cg} \geq x_2$):
  
  $$ h_c = \max \left\{ (x_{cg} - x_3) \tan \gamma_2, 0 \right\} $$

In order to provide this altitude guidance at run time, some intermediate calculations must be made prior to run time. These calculations relate the specified trajectory parameters ($\gamma_1$, $\gamma_2$, $V_1$, $a_n$, $h_2$, and $x_3$) to the parameters ($a$, $h_1$, $h_p$, $x_1$, $x_2$, and $x_p$) found in the real-time guidance equations (1) through (3) above. In addition, the aimpoint location $x_{ap}$ is determined.
Figure B-1. Final approach trajectory and nomenclature.
The downrange location at which the inner glideslope intercepts the parabolic preflare, \( x_2 \), is calculated from basic geometry in equation (4):

\[
x_2 = \frac{h_2}{\tan \gamma} + x_3
\]

The initial flight path angular rate can be calculated from the nominal velocity at point 1 and the desired incremental normal acceleration, as given in equation (5):

\[
\dot{\gamma}_1 = \frac{a_n}{V_1}
\]

A parabolic preflare maneuver was chosen to more closely follow a trajectory with nearly constant incremental normal acceleration. To find the proper parabola in the form of equation (2), the flight path curvature must yield the same flight path angular rate required by equation (5):

\[
\dot{\gamma} = \frac{d\gamma}{dt} = \frac{d\gamma}{dx} \frac{dx}{dt}
\]

Since, for a parabola with the vertex at \( x = x_p \) and \( h = h_p \):

\[
h = h_p + a (x - x_p)^2
\]

\[
\tan \gamma = \frac{dh}{dx} = 2a (x - x_p)
\]

\[
\gamma = \arctan [2a (x - x_p)]
\]

\[
\frac{d\gamma}{dx} = \frac{d}{dx} \{\arctan [2a(x - x_p)]\}
\]

\[
= \frac{2a}{1 + [2a(x - x_p)]^2}
\]

\[
\frac{d\gamma}{dx} = \frac{2a}{1 + \tan^2 \gamma}
\]

by substitution of equation (8).

Substituting equation (9) and the relationship

\[
\frac{dx}{dt} = V \cos \gamma
\]

into equation (6) and rearranging the result yields an expression for the parabolic curvature constant, \( a \), at point 1:

\[
a = \frac{\dot{\gamma}_1 \left( 1 + \tan^2 \gamma_1 \right)}{2 V_1 \cos \gamma_1}
\]
Equation (8) can be rearranged and applied at point 2 to yield an expression for the parabolic vertex downrange coordinate, $x_p$:

$$x_p = x_2 - \frac{\tan \gamma_2}{2a}$$

Equation (8) can then be applied to point 1 to determine the downrange location at which the preflare maneuver begins:

$$x_1 = x_p + \frac{\tan \gamma_1}{2a}$$

Since $h_2$ was given and $x_2$ and $x_p$ are now known, the altitude of the vertex of the parabola, $h_p$, can be determined by using equation (7) at point 2:

$$h_p = h_2 - a (x_2 - x_p)^2$$

In a similar fashion, the parabolic intercept altitude $h_1$ can be calculated using equation (7):

$$h_1 = h_p + a (x_1 - x_p)^2$$

Finally, the location of the aimpoint (the point at which the outer glideslope intersects the extended runway centerline) can be calculated by geometry:

$$x_{ap} = x_1 - \frac{h_1}{\tan \gamma_1}$$

**Nominal trajectory parameters**

For this study, the nominal values to be used in the trajectory profile model are as follows:

- Initial flare velocity: $V_1 = 502.3 \text{ ft/sec}$
- Initial normal accel. limit: $a_{n_1} = 0.25 \text{ g}$, $= 8.05 \text{ ft/sec}^2$
- Initial flight path angle: $\gamma_1 = -17 \text{ degrees}$
- Final flight path angle: $\gamma_2 = -1 \text{ degrees}$
- Final flight path capture height: $h_2 = 75 \text{ ft}$
- Target touchdown point: $x_3 = 2200 \text{ ft}$
Using these constants in the equations (4) through (15) yield the following parameter values:

- Final approach capture location: $x_2 = -2,096$ ft
- Initial preflare rate: $\dot{\gamma}_1 = 0.016$ rps
- Parabolic curvature constant: $a = 1.823 \times 10^{-5}$ rad/ft
- Parabolic zero-slope x location: $x_p = -1617.2$ ft
- Parabolic slope intercept range: $x_1 = -10,004$ ft
- Parabolic zero-slope h location: $h_p = 70.8$ ft
- Parabolic slope intercept alt.: $h_1 = 1,352.7$ ft
- Outer glideslope aimpoint: $x_{ap} = -5,580$ ft
Appendix B: Guidance and Control Law Diagrams

Control law diagrams (pages B-7 through B-13)

Page B-7 shows the baseline pitch guidance laws in block diagram form. Inputs to pitch guidance include altitude and flight path reference values, obtained by the equations described previously in this appendix, and shown on page B-7 as variables ALTREF and GAMREF, respectively. These inputs, along with current altitude (ALT), flight path in degrees (GAMMAD), angle of attack in degrees (ALPDEG), and Mach number (MACH), are used to provide flight path steering (GAMCMD) to both the autopilot and the flight director symbology on the head-up and head-down displays. Guidance mode selection (MGUID) is performed separately.

Page B-8 describes the baseline roll guidance and flight control. Using navigation information from a number of sources, a commanded heading angle is generated (PSICMD) in the guidance portion of this combined diagram. The commanded heading angle is compared to actual track angle (TKANG) to generate an error signal (PSIERR), which is then used to generate a commanded bank angle (PHICMD). The commanded bank angle is compared to actual bank angle (PHID) to generate a bank angle error signal that drives the flight director and, if autopilot is selected, the aileron command (DACMD).

Page B-9 depicts the NZQ pitch control law. The primary input is the pilot’s pitch stick position (DCPILOT). Feedback signals include pitch rate (QDEG), normal acceleration (NZ), elevator position (DLEDEG) and commanded and actual flight path angles (GAMCMD, GAMMAD). Small compensations in the pitch axis are made using bank angle (COSPHI and SINPHI), pitch angle (COSTHE) and roll rate (PDEG). Gains are scheduled using Mach number, dynamic pressure (QBAR), and total airspeed (VTOTAL). Logic selection is performed based upon weight-on-wheels (WOW), weight on nose gear (WONG) and control mode (SAS or AUTO). Output from the pitch control law is commanded elevator position (DECMD).

Page B-10 shows the yaw and speed control laws. The yaw control system adds rate damping and roll command compensation, using roll rate (RDEG) and commands aileron (DACMD) signals, to the pilot’s pedal command (DPPILOT), to generate a commanded rudder signal (DRCMD). The speed control law combines the pilot’s speedbrake command (DLSBCOM) with an optional autospeed function, using an indicated airspeed (IAS) feedback, to drive the speedbrake actuator command (DSBCMD).

Page B-11 describes the control surface mixer logic. This system drives the wing flaps directly from the commanded elevator position (DECMD) after appropriate limits are applied. The aileron command (DACMD) is combined with the speedbrake command (DSBCMD), and if necessary, the elevator command (DECMD) to drive the four body flaps, with appropriate position limiting. The rudder is driven directly from the rudder command (DRCMD) with appropriate position limiting. At supersonic Mach numbers, roll control is obtained using the lower body flaps as "ruddervators" in a reverse-aileron fashion, and yaw stability is enhanced using a sideslip rate signal (BETADOT).

Page B-12 and B-13 depict the navigation geometry to obtain and intercept the heading alignment circle (HAC), and gives the equations used to calculate the commanded heading angle to intercept the HAC.
Appendix B: Guidance and Control Law Diagrams

VMS/PLS PITCH GUIDANCE

MGUID = Guidance Mode
1 = Final
2 = Turn to Final
3 = Downwind
4 = TACAN Homing
5 = On HAC
6 = To HAC
7 = Minimum Energy

ALTREF = f(DT060)
ALT =
ALPDEG
GAMMAD
GAMREE

ALT - GGFLR = -0.02
GGFL = -0.25

To Flt Director
Appendix B: Guidance and Control Law Diagrams

VMS/PLS ROLL GUIDANCE & FLIGHT CONTROL

MGUID
1 = Final Approach
2 = Turn to Final
3 = Downwind
4 = Homing
5 = On HAC
6 = Toward HAC
7 = Minimum Energy

TACBRC to Runway Bearing to MEP

PSIREF

PSICMD
(tangent to HAC)

PSICMD
(on HAC)

HACXTK = 0.005

TKANG

PHI HAC = \frac{V_{T O T A L}^2}{G \times HACRAD}

PHICLRD = \text{(abs value limit)}

MGUID = 3, 4, 6

MGUID = 1, 2, 5, 7

PHID

PDEG

DWHEEL ± 60

DAD = 1.4

\text{GDADUL} = 1.3 \text{ MACH}

\text{i.e., limited to 40 below M1, 13.3 above M3)
**Appendix B: Guidance and Control Law Diagrams**

**VMS/PLS NZQ Pitch Control Law**

1. **DCPILOT**: 
   - 9 aft
   - 5 fwd

2. **ABS**: 
   - RsqLaw

3. **RsqLaw**: 
   - RsqLaw = 0.6

4. **1/COLMAX**: 
   - COLMAX = 9.0

5. **+ COLSHC**: 
   - COLSHC

6. **SINPHI/COSPHI**: 
   - TANPHI

7. **RDES**: 
   - QCOORD

8. **Qdeg**: 
   - \( \frac{s + 1}{5s + 1} \)

9. **NZ**: 
   - Above 2000 ft

10. **VTOT**: 
    - VTOTALI

11. **GAMCMD**: 
    - GAMMAD

12. **NZ**: 
    - \( \frac{s + 1}{3s + 1} \) GDEGC

13. **GDEGC**: 
    - GDEGC = 0.3

14. **GDEGCA**: 
    - GDEGCA = -10

15. **SAS**: 
    - WONG

16. **QBAR**: 
    - GQBAR

17. **MACH**: 
    - DETRIM

18. **DLEDEG**: 
    - \( \frac{1}{7s + 1} \) DETRIM

19. **GQBAR**: 
   - 1.79

20. **GQBAR**: 
   - Limit: 2.0 to 2.0

21. **GMACH**: 
    - GQBAR

22. **DECMD**: 
    - to Actuators
Appendix B: Guidance and Control Law Diagrams

**VMS/PLS YAW & SPEED CONTROL**

**DPPilot**: ±2.7 + left

**Rdeg**

\[ \frac{s}{2s + 1} \]

**DRDRA**

\[ GDRDA = -0.01 \]

**DRDIR**

MACH > 7.0

**DIR**

ROLL SAS or AUTO

**DRCMD**

To Actuators

**DSBCMD**

0 to 40

**DSBDF1**

\[ GDRDP = -11.1 \]

**DSBDF2**

\[ GRSAS = 40 \]

\[ DRSAS = 0.0175 \]

**DSBDIR**

**IAS**

\[ 2.0 \]

\[ 300 \] (Hard coded)

**DSBSAS**

\[ \frac{1}{s + 1} \]

MACH > 1.2 or ALT < 1200

**SBCMD**

To HUD SBACT

**DSBCMD**

To Actuators
VMS/PLS CONTROL SURFACE MIXER LOGIC

Appendix B: Guidance and Control Law Diagrams

Note: BEDOT = PDEG * SINALP
       - RDEG * COSALP
**HEADING ALIGNMENT CIRCLE**

**GEOMETRY**

Note: In VMS/PLS the runway is North, so X= North, Y= East

DTOGO is ground track range from aircraft to WP1, around the HAC to 'outer' marker, and then to WP2.

\[ ALTREF = \tan (\text{GAMREF}) \times (\text{DTOGO} - X_{AP}) \]
Appendix B: Guidance and Control Law Diagrams

**Heading to Intercept HAC**

**GIVEN** \((X_A, Y_A)\) and \((X_C, Y_C)\) and \(R\)

**FIND** \((X_I, Y_I)\)

\[ A = \Psi_i = \text{turn angle} \]

\[ X_I = X_C + R \times \cos(A + 90) = X_C - R \sin A \]

\[ Y_I = Y_C + R \times \sin(A + 90) = Y_C + R \cos A \]

\[ A = \arctan_2 \left( \frac{Y_I - Y_A}{X_I - X_A} \right) \]

\[ A = \arctan_2 \left( \frac{Y_C - Y_A + R \cos A}{X_C - X_A - R \sin A} \right) \]

\[ \Psi_C = \arctan_2 \left( \frac{Y_C - Y_A}{X_C - X_A} \right) = \text{bearing to HAC center} \]

\[ \Psi_i = \Psi_C + \sin^{-1} \left( \frac{R}{\sqrt{(X_C - X_A)^2 + (Y_C - Y_A)^2}} \right) \]

- for right turn HAC

+ for left turn HAC

limit quantity in parentheses to \(\pm 1.0\)

B-13
Appendix C

Guidance and Control Law listings
SUBROUTINE PLSGNC

* 911118 GUIDANCE NAVIGATION AND CONTROL FUNCTIONS

* LOGICAL MPAUTO

* CLAMP LIMITING FUNCTION LIMITS X BETWEEN Y AND Z
CLIMIT (X,Y,Z) = AMINI(Z,AMAXI(X,Y))

* NNNNNNNNNNNNNNN NAVIGATION FUNCTIONS NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN

* EXTERNAL INPUTS TO NAVIGATION FUNCTIONS

* ALT  ALTITUDE ABOVE GROUND, FT
* SX   DOWNRANGE DISTANCE FROM RUNWAY THRESHOLD, FT
* SY   CROSSRANGE DISTANCE FROM RUNWAY CENTERLINE, FT

* NOTE THE RUNWAY HEADING IS TRUE NORTH IN THIS SIMULATION,
  thus the runway and earth frames are the same. If
  another runway heading is used sx and sy may represent
  north and east coordinates (e.g. in tacan equations) or
  downrange and crossrange (e.g. in glideslope/localizer
  equations)

* EXTERNAL OUTPUTS OF NAVIGATION FUNCTIONS

* ELOC  LOCALIZER ERROR, DEG
* GAMREF FLIGHT PATH ANGLE ON GLIDESLOPE, DEG
* HGS   GLIDESLOPE ALTITUDE, FT
* TACBRG BEARING TO RUNWAY THRESHOLD, DEG
* TACDAZ RELATIVE BEARING TO RUNWAY THRESHOLD, DEG
* TACSNR SLANT RANGE TO RUNWAY THRESHOLD, DEG

* NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN

* GLIDESLOPE GEOMETRY DEFINITION CONSTANTS
DATA GAMMA1 , GAMMA2 , FLRVEL1 / -17.00, -1.00, 502.3 /
DATA ACCLIM1 , HPFCAPT , XTCM / 8.05, 75.0, 2200. /

* THE FOLLOWING GLIDESLOPE PARAMETERS ARE DERIVED FROM THE ABOVE CONSTANTS
DATA XAPCAPT , GAMRAT1 , PCURVC / -2097., .01603, .1824E-4 /
DATA XPLOC0 , HPLOC0 / -1618.3, 70.82 /
DATA XPSINTC , HPSINTC / -9998.6, 1351.9 /

* NOTE THE OUTER GLIDESLOPE AIMPOINT IS 5576.8 FT SOUTH OF THRESHOLD

* FLARE REFERENCE FLIGHT PATH ANGLE GAMMA
IF (ALT.LT.HPFCAPT) THEN
  GAMFLR = GAMMA2
ELSE
  IF (ALT.GT.HPLOC0) THEN
    GAMFLR = 57.2958*ATAN(-2.*PCURVC*SQR((ALT-HPLOC0)/PCURVC))
  ELSE
    GAMFLR = 0.
  ENDIF
ENDIF

*** CALCULATE GLIDE SLOPE ERROR IN DEGREES
*** GAMREF  - REFERENCE FLIGHT PATH ANGLE FOR AUTOLAND  [DEG]
*** IF (SX .LT. XPSINTC) THEN
   HGS = HPSINTC + (SX - XPSINTC) * TAN(GAMMA1)
   GAMREF = GAMMA1

C-1
ELSEIF (SX .GE. XPSINTC) .AND. (SX .LT. XAPCAPT) THEN
    HGS = HPLCO0 + PCURVC * (SX - XPLOCO)**2
    GAMREF = 57.2958 * ATAN(2.0 * PCURVC * (SX - XPLOCO))
ELSE
    HGS = AMAX1((SX - XTCHDN) * TAND(GAMMA2), 0.0)
    GAMREF = GAMMA2
ENDIF

*** CALCULATE LOCALIZER ERROR
IF (SY .NE. 0) THEN
    ELOC = SIGN(90.,SY) - 57.2958 * ATAN((10500. - SX)/SY)
ELSE
    ELOC = 90. - SIGN(90., (10500. - SX))
ENDIF

ELOC = CLIMIT(ELOC, -2.5, 2.5)

*** TACAN NAVIGATION DATA

* LOCATION NORTH AND EAST OF TACAN (ASSUMING TACAN AT ORIGIN)
  TACN = SX
  TACE = SY

* DME (SLANT RANGE TO TACAN IN NAUTICAL MILES)
  TACDME = .000165 * SQRT (TACN**2 + TACE**2 + ALT**2)

* BEARING (COMPASS DIRECTION TO TACAN FROM AIRCRAFT 0 TO 360 DEG)
  IF (TACE.EQ.0.) THEN
      TACBRG = 90. + SIGN(90., TACN)
  ELSE
      TACBRG = 180. + SIGN(90., TACE) - 57.2958 * ATAN (TACN/TACE)
  ENDIF

* RELATIVE BEARING (DIRECTION FROM AIRCRAFT NOSE TO TACAN)
  ALSO CALLED 'DELTA AZIMUTH'
  TACDAZ = TACBRG - PSID
  IF (TACDAZ.GT. 180.) TACDAZ = TACDAZ - 360.
  IF (TACDAZ.LT.-180.) TACDAZ = TACDAZ + 360.

* GGGGGGGGGGGGGGGGGG GUIDANCE FUNCTIONS GGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGG

*** PLS GUIDANCE LAWS VERSION 910905
***

* EXTERNAL INPUTS TO GUIDANCE LAWS
  ALPDEG  ANGLE OF ATTACK, DEG
  ALT     ALTITUDE ABOVE GROUND, FT
  GAMMAD  FLIGHT PATH ANGLE, DEG
  HGS     ALTITUDE OF DESIRED PATH (GLIDESLOPE), FT
  MACH    MACH NUMBER
  MODE    SIMULATION MODE 1-RESET 2-HOLD 3-OPERATE
  SX      DOWNRANGE DISTANCE FROM RUNWAY THRESHOLD, FT
  SY      CROSSRANGE DISTANCE FROM RUNWAY CENTERLINE, FT
  TACBRG  BEARING TO RUNWAY THRESHOLD, DEG
  TACDAZ  RELATIVE BEARING TO RUNWAY THRESHOLD, DEG
  TACDME  SLANT RANGE TO RUNWAY THRESHOLD, DEG
  TKANG   GROUND TRACK ANGLE, DEG
  VTOTALI MAGNITUDE OF EARTH RELATIVE VELOCITY, FPS

* EXTERNAL OUTPUTS FROM GUIDANCE LAWS
  GAMCMD FLIGHT PATH ANGLE COMMAND, DEG
**Appendix C: Guidance and Control Law Listing**

- MGUID  GUIDANCE MODE 1-FINAL 2-BASE 3-DOWNWIND 4-HOMING
- PHICMD  BANK ANGLE COMMAND, DEG

****************************************************************************** GUIDANCE MODING ******************************************************************************

- INITIALIZE MGUID WHEN IN RESET (MODE=1)
- MGUID IS GUIDANCE MODE
- 1-FINAL APPROACH & FLARE  2-TURN TO FINAL  3-DOWNWIND TEARDROP
- 4-TACAN HOMING  5-ON HAC  6-TANGENT TO HAC
- MODES CASCADE AUTOMATICALLY WHEN CONDITIONS ARE SATISFIED
- USUAL SEQUENCE IS EITHER 4,3,2,1 OR 6,5,1

* IF (MODE.EQ.1) THEN
  * MGUID = 4
  * IF (ALT.GT.5000.*TACDME .OR. MACH.LT. 1.0) MGUID = 3
  * IF (ALT.LT.32000.) MGUID = 2
  * IF (ALT.LT.12000.) MGUID = 1
- DEFaulTS TO HAC TANGENT GUIDANCE -- CHANGE TO 4 FOR TACAN HOMING
  * IF (ALT.GT.29000.) MGUID = 6

* GAMCMD = GAMMAD

ENDIF

* ALPHA SCHEDULE VS MACH MATCHES POWELL ABOVE MACH 3
* MACH  0.0  3.0  4.0 >5.0
* ALPHA  6.0  6.0  17.0  28.0
* NOTE THAT BELOW MACH 1.5 ALPHA VARIES FOR ENERGY MANAGEMENT

* IF (MACH.LE.3.0) AOANOM = 6.0
  * IF (MACH.GT.3.0) AOANOM = 11.*MACH-27.
    * IF (AOANOM.GT.28.) AOANOM = 28.

* GLIDESLOPE ALTITUDE ERROR
* NOTE HER IS POSITIVE WHEN A/C IS BELOW THE GLIDESLOPE!!!!
  * ALTREF = HGS
  * HER = ALTREF - ALT

**** MGUID = 6  HEADING ALIGNMENT CIRCLE STEERING

* DATA HACCX,HACRAD / -36300., 31000. /
* IF (MGUID.EQ.5.OR.MGUID.EQ.6) THEN

* DISTANCE TO CENTER OF HAC
  * HACCC = -HACRAD
  * HACCD = SQRT ((HACCC-SX)**2 + (HACCY-SY)**2)

* CROSSTrack DISTANCE FROM EDGE OF HAC
  * HACXTK = HACCD - HACRAD

* HEADING TO CENTER OF HAC
  * PSIHACC = 57.3*ATAN2 ( (HACCY - SY), (HACCC-SX) )
    * IF (PSIHACC.GT.360.) PSIHACC = PSIHACC - 360.
    * IF (PSIHACC.LT. 0.) PSIHACC = PSIHACC + 360.

* IF (MGUID.EQ.6) THEN
  * FLYING TO INTERCEPT HAC
    * IF (HACXTK.LT.20. .OR. ALT.LT.20000.) MGUID = 5

* DISTANCE TO HAC TANGENT
  * HACDT2 = HACCD**2 - HACRAD**2
    * IF (HACDT2.GT.0) HACDT = SQRT (HACDT2)

C-3
HEADING COMMAND
PSICMD = PSIHACC + 57.3*ASIN(HACRAD/HACDC)

DISTANCE TO GO TO RUNWAY THRESHOLD
DTOGO = HACDT + 0.01745*ABS(PSICMD)*HACRAD - HACCX

REFERENCE ALTITUDE AND ALTITUDE ERROR
ALTREF = .305 *(DTOGO - 5577.)
HER = ALTREF - ALT

ANGLE OF ATTACK COMMAND
AOACMD = AOANOM

BELLOW MACH 1.5 MODIFY ALPHA TO CORRECT ALTITUDE ERROR
IF (MACH.LT.1.5) AOACMD = CLIMIT (AOANOM+.002*HER, 4.0, 9.0)

GAMMA COMMAND FILTER TAU = 6 SEC
GAMCMD = .995*GAMCMD + .005*(GAMMA + AOACMD - ALPDEG)
ELSE

FLYING AROUND THE HAC
IF (ALT.LT.12000..OR.ALT.LT.20000..AND.ABS(SY).LT.1000.) MGUID=4

MINIMUM ENTRY POINT STEERING
* AIM TO INTERCEPT CENTERLINE 20000 FT BEFORE THRESHOLD
WHILE FLYING MAXIMUM L/D GAMMA
IF (ALT.LT.1300.*TACDME + 50.*TACDAZ) THEN
HACGAM = -12.5
PSICMD = 57.3*ATAN(SY/(SX+20000.))
ENDIF

GAMMA COMMAND FILTER TAU = 3 SEC
GAMCMD = .990*GAMCMD + .010*HACGAM
ENDIF

END OF HEADING ALIGNMENT CYLINDER GUIDANCE

**** MGUID = 4 TACAN HOMING
* FOLLOWS ALPHA VS MACH SCHEDULE UNTIL MODE 3
* MGUID = 3 DOWNWIND MODE
IF (MGUID.EQ.3) THEN
  IF (ABS(TACDAZ).GT.120. .AND. ALT.LT.3300.*TACDME) MGUID = 2
  AOACMD = 8.0
  GAMCMD = .995*GAMCMD + .005*(GAMMAD + AOACMD - ALPDEG )
  PSICMD = PSIREF + SIGN(160.,SY)
ENDIF

**** MGUID = 2 TURN TO FINAL ****

IF (MGUID.EQ.2) THEN
  IF (ABS(SY).LT.18000. .OR. ALT.LT.15000.) MGUID = 1
  AOACMD = .02
  GAMCMD = .990*GAMCMD + .010*(GAMMAD + AOACMD - ALPDEG )
  PSICOR = 57.3*ATAN(-.00005*SY)
  PSICMD = PSIREF + PSICOR
ENDIF

**** MGUID = 1 FINAL APPROACH AND FLARE
    DATA GGHER, GGFLR, GGFFL / .020 , -.020 , -0.25 /
    DATA GGLL, GGUL, AOAMLD / -22.0 , -12.0 , 12.0 /

IF (MGUID.EQ.1) THEN
  RAMP GAIN IN .002 AT 10K .020 AT 5K
  GGHER = CLIMIT (.038-.0000036*ALT, .002, .020)
  GAMCOR = GGHER * HER
  GAMCMD = CLIMIT (GAMREF + GAMCOR , GGLL, 0.0 )
  IF (ALT.GT.2000.) GAMCMD = CLIMIT (GAMCMD, GGLL, GGUL)
  IF FAR BELOW GLIDESLOPE COMMAND ALPHA = AOAMLD - ALPHA FOR MAX L/D
  IF (HER.GT.2000.) GAMCMD = GAMMAD + AOAMLD - ALPDEG

**** FINAL FLARE TO TOUCHDOWN
    GAMFL = GGFLR*ALT + GGFFL
    IF (ALT.LT.HFPCAPT .AND. GAMCMD.LT.GAMFFL) GAMCMD = GAMFFL
    IF (MPAUTO .AND. GAMCMD.LT.GAMFFL) GAMCMD = GAMFFL

    GDAP = -.00010
    IF (ALT.LT.10000.) GDAP = -.00010 * (3.0-.0002*ALT)
    PSICOR = CLIMIT (57.3*ATAN(GDAP*SY), -90., 90.)
    PSICMD = PSIREF + PSICOR
ENDIF

**** COMMAND LIMITERS ALL MODES

    DATA GAMCLL, GAMCUL, GDAPS / -22. , 0.0, 10. /
    DATA GDAPS, PHICLHI, PHICLLO / 10. , 50., 35. /

    GAMCMD = CLIMIT (GAMCMD, GAMCLL, GAMCUL )

    GAMCMD SMOOTHING (TAKE OUT BEFORE FLARE!)
    IF (ALT.GT.2000.) THEN
      IF (GAMCMD-GAMMAD .GT. 0.5) GAMCMD = GAMMAD + 0.5
      IF (GAMCMD-GAMMAD .LT.-.5) GAMCMD = GAMMAD - 0.5
    ENDIF

    IF (PSICMD.LT.0. ) PSICMD = PSICMD + 360.
    IF (PSICMD.GT.360.) PSICMD = PSICMD - 360.

    PSIERR = PSICMD - TKANG
    IF (PSIERR.GT. 180.) PSIERR = PSIERR - 360.
    IF (PSIERR.LT.-180.) PSIERR = PSIERR + 360.

    PHIHAC = 57.3*ATAN(VTOTALI**2 / (32.2*HACRAD) )
    PHICLLO = CLIMIT(PHIHAC+10., -PHICLHI, PHICLHI)

    PHICMD = CLIMIT(GDAPS * PSIERR,-PHICLHI, PHICLHI)
Appendix C: Guidance and Control Law Listing

IF (MGUID.LE.2) PHICMD = CLIMIT (GDAPS * PSIERR,-PHICLLO,PHICLLO)
IF (MGUID.EQ.5) PHICMD = CLIMIT (GDAPS * PSIERR,-PHICLLO,PHICLLO)

PLS FLIGHT CONTROL LAWS NZQ ALGORITHM

EXTERNAL INPUTS TO FLIGHT CONTROL LAWS

AUTOSB AUTO SPEEDBRAKE MODE (T/F)
COSPHI COSINE OF ROLL ANGLE
COSTHE COSINE OF PITCH ANGLE
GAMCMD FLIGHT PATH ANGLE COMMAND, DEG
GAMMAD FLIGHT PATH ANGLE, DEG
DCPILOT COLUMN (STICK) DEFLECTION, IN +AFT
DLEDEG ELEVATOR ANGLE FEEDBACK, DEG
DLSBCOM SPEEDBRAKE HANDLE DEGLECTION, DEG
DPPILLOT RUDDER PEDAL DEFLECTION, IN +LEFT
DPWILLOT WHEEL (STICK) DEFLECTION, DEG +RIGHT
GRND 1 = WHEELS ON GROUND
IAS INDICATED AIRSPEED (ACTUALLY EQUIVALENT AIRSPEED)
MACH MACH NUMBER
MFCS FLIGHT CONTROL MODE 0-DIRECT 1-PITCH RATE 2-ROLL RATE
3-RATE CMD 4-PITCH AUTO 5-ROLL AUTO 6-AUTOLAND
NZ BODY AXIS VERTICAL ACCELERATION, G'S
PDEG BODY ROLL RATE, DPS
PHID ROLL ANGLE COMMAND, DEG
PHID ROLL ANGLE, DEG
QBAR DYNAMIC PRESSURE, PSF
QDEG BODY PITCH RATE, DPS
RDEG BODY YAW RATE, DPS
SINPHI SINE OF ROLL
THETAD PITCH ANGLE, DEG
VTOTALI MAGNITUDE OF EARTH RELATIVE VELOCITY, FPS
WONG WEIGHT ON NOSE GEAR (T/F)

EXTERNAL OUTPUTS FROM FLIGHT CONTROL LAWS

DACMD AILERON COMMAND, DEG +TO ROLL RIGHT
DECMMD ELEVATOR COMMAND, DEG +TRAILING EDGE DOWN
DRCMD RUDDER COMMAND, DEG +TRAILING EDGE LEFT
DSBCMD SPEEDBRAKE COMMAND, DEG

Z-TRANSFORM FORMULA USED IN 1ST ORDER FILTERS

INITIALIZE OUT AND INPAST IN RESET DT = INTEGRATION TIME STEP

Z = (A+B)/(C+S+1) -> K = Z1 = EXP(-DT/C) Z3 = K*A*C Z2 = B*(1-K)+K*A/C

OUT = Z1*OUT + Z2*IN + Z3*INPAST 'PAST VALUE OF OUT IMPLIED

INPAST = IN

MFCS: 1-PITCH RATE CMD 2-ROLL RATE CMD 3-PITCH AND ROLL RATE CMD
4-PITCH AUTO ROLL RATE 5-ROLL AUTO PITCH RATE 6-AUTOLAND

INITIAL VALUES
DATA DBSAS,DESB / 20.0, 0.0 /
DATA H,DATRIM / 0.03, 0.0 /

100 MFAUTO = MFCS.EQ.4 .OR. MFCS.EQ.6

************* PITCH CONTROL *************
ELEVATOR TRIM AT RESET
   IF (MODE.EQ.1) DETRIM = DETRIM0

FILTERS
   AS + B / TS + 1

FILTER VALUES FOR NZ, QBODY, AND AUTOTRIM
   DATA FNZA,FNZB,FNZT / 0.10, 1.00, 0.30 /
   DATA FQB1,FQB2,FQB3 / 1.00, 1.00, 0.50 /
   DATA FATA,FATB,FATT,FATM,FATTA / 0., 1.0, 0.45, 2.00 /

CHANGE TRIM TAU IN AUTOLAND
   FATT = FATM
   IF (MPAUTO) FATT = FATTA

INITIAL VALUES FOR FILTERS IN RESET (MODE=1)
   IF (MODE.EQ.1) THEN
      QDEGF = QDEG
      QDEGP = QDEG
      GAMDOTF = 0.
      GAMDOTP = 0.0
      DLEDEGF = DLEDEG
      DLEDEGP = DLEDEG
      GAMFILT = GAMMA
      DSBP = DLSBDEG
   ENDIF

Z-TRANSFORM COEFFICIENTS FOR FILTERS
   IF (FNZT.EQ.0) THEN
      FNZ1 = 0.0
      FNZ2 = FNZB
      FNZ3 = 0.0
   ELSE
      FNZ1 = EXP (-0.03/FNZT)
      FNZ3 = -FNZA*FNZ1/FNZT
      FNZ2 = FNZB*(1.0-FNZ1) - FNZ3
   ENDIF

   IF (FQBT.EQ.0) THEN
      FQB1 = 0.0
      FQB2 = FQBB
      FQB3 = 0.0
   ELSE
      FQB1 = EXP (-0.03/FQBT)
      FQB3 = -FQBA*FQB1/FQBT
      FQB2 = FQBB*(1.0-FQB1) - FQB3
   ENDIF

   IF (FATT.EQ.0) THEN
      FAT1 = 0.0
      FAT2 = FATB
      FAT3 = 0.0
   ELSE
      FAT1 = EXP (-0.03/FATT)
      FAT3 = -FATA*FAT1/FATT
      FAT2 = FATB*(1.0-FAT1) - FAT3
   ENDIF

***********************************************************************
<table>
<thead>
<tr>
<th>OPERATE LOOP</th>
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</thead>
<tbody>
<tr>
<td>DEQ = DEGC = 0.</td>
</tr>
<tr>
<td>QUADRATIC STICK SHAPING 0=LINEAR 1 = SQUARE LAW</td>
</tr>
<tr>
<td>DATA RSQLAW, COLMAX / 0.6, 7.5</td>
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</tbody>
</table>

C-7
COLSHC = (1.0-RSQLAW)*DCPILOT + RSQLAW*DCPILOT*ABS(DCPILOT)/COLMAX

NZQ CONTROL LAW

QBAR AND MACH GAIN COMPENSATION

DATA GQBAR1 / 179. /
GQBAR = CLIMIT (GQBAR1/(QBAR+.1),0.2,2.0)
GMACH = CLIMIT (5.0*MACH-4.0,1.0,6.0)
GQBAR = GQBAR * GMACH

PITCH RATE COMMAND, FEEDBACK & FILTER

DATA GDQDC, GDEGCM, GDEGCA / 5.0, -3.0, -10.0 /
TANPHIL = CLIMIT ( SINPHI/COSPHI, -1.0, 1.0 )
QCOORD = QDEG - RDEG * TANPHIL
QDEGF = FQBI*QDEGF + FQB2*QCOORD + FQB3*QDEGP
QDEGP = QCOORD
DEQ = GQBAR * (QDEGF - GDQDC*COLSHC)

NZ FEEDBACK USED TO ESTIMATE GAMMA DOT

COORDNZ = CLIMIT (COSTHE/COSPHI, 0.90, 1.41 )
GAMDOT = 1843. * (NZ-COORDNZ) / VTOTALI
IF (.NOT.MPAUTO) THEN
GAMDOTF - FNZ1*GAMDOTF + FNZ2*GAMDOT + FNZ3*GAMDOTP
GAMDOTP = GAMDOT
DEGC = -GDEGCM * GQBAR * GAMDOTF
ENDIF

PITCH AUTOLAND

DATA GSLAP, SLAPRT / -2.0, -4.0 /
IF (MPAUTO) THEN
DEGC = GDEGCA*GQBAR*(GAMCMD-GAMMAD- 922. *(NZ-1.)/VTOTALI)
IF (GRND.EQ.1.) DEGC = GSLAP*GQBAR*(SLAPRT-QDEG)
IF (GRND.EQ.1. .AND. THETAD.LT.5.) DEGC = 0.
ENDIF

AUTO TRIM -- LAGGED ELEVATOR FEEDBACK

TRIMS ONLY IN OPERATE AND OFF THE GROUND

IF (MODE.EQ.3 .AND. GRND.EQ.0) THEN
DETTRIM = FAT1*DETTRIM + FAT2*DLEDEG + FAT3*DLEDEGP
DLEDEGP = DLEDEG
ENDIF

TOTAL ELEVATOR COMMAND

DECMD = DEQ + DEGC + DETTRIM

*************** ROLL CONTROL ***********************

DATA GDAP, GDAGC / -1.4, 1.4 /
DATA GDADWL, GDADWR / 0.67, 0.67 /

200 DADIR = DAP = DAGC = 0.

DIRECT AILERON COMMAND

STICK LEFT -60.0 DEG --> -30.0 DEG LEFT AILERON COMMAND
STICK RIGHT +60.0 DEG --> +30.0 DEG RIGHT AILERON COMMAND

 IF (DWPILOT.LT.0.0) DADIR = GDADWL * DWPILOT
 IF (DWPILOT.GE.0.0) DADIR = GDADWR * DWPILOT

REDUCE MAX RATE COMMAND AT SUPersonic SPEED
GRLIM = CLIMIT (1.33-.33*MACH,0.33,1.00)
DADIR = GRLIM*DADIR

C-8
ROLL RATE DAMPING
   IF (MFC.GE.2) DAP = GDAP * PDEG

AUTO GUIDANCE COMMAND
   IF (MFC.GE.5) DAGC = CLIMIT (GDAGC * (PHICMD-PHID), -15.0, 15.0)

   DACMD = DADIR + DAP + DAGC
   DACMD = CLIMIT (DACMD, -30., 30.)

********************** YAW CONTROL ****************************

   DATA GDRDP, GDRDA, GRSAS / -11.1, -0.01, 40. /
   DATA RBWASH, RDEGP, RBWOZI / 0., 0., 0.98511 /

   NOTE RUDDER AND PEDAL ARE POSITIVE FOR TRAILING EDGE LEFT

   DRDIR = DRSAS = 0.
               DIRECT RUDDER COMMAND
   PEDAL LEFT +2.70 DEG --> +30 DEG LEFT RUDDER
   PEDAL RIGHT -2.70 DEG --> -30 DEG RIGHT RUDDER
               YAW RATE WASHOUT TAU = 2.0 SEC
   RBWASH = RBWOZI * (RBWASH + RDEG - RDEGP)
   RDEGP = RDEG

   DISCONNECT AILERON TO RUDDER INTERCONNECT BELOW MACH 1
   GDRDAX = 0.
   IF (MACH.GT.0.9) GDRDAX = GDRDA
   IF (MFC.GE.2) DRSAS = GDRDAX * DACMD + GRSAS * RBWASH * .01745
               YAW COMMAND
   DRCMD = DRDIR + DRSAS

******************* SPEED CONTROL ****************************

   IF (MODE.EQ.1) DSBSAS = DSBTRIM
               HANDLE FULL AFT 40 DEG --> 60 DEG SPEEDBRAKE
               QUADRATIC SPEEDBRAKE FUNCTION
   DATA DSBSF1, DSBSF2 / 0.0, .0375 /
   LINEAR DSBSF1 = 1.5 DSBSF2 = 0
   DSBDIR = DSBSF1 * DLSCOM + DSBSF2 * DLSCOM**2
               FILTERED AUTO SPEEDBRAKE
   DESIGNED TO HOLD 300 KIAS
   IF (.NOT.WONG.AND. (MFC.GE.4 .OR. MFC.GE.6 .OR. AUTOSB)) THEN
   DSBDIR = 0.
   DSBAUTO = CLIMIT (20.0 + 2.0*(IAS-300.), 0., 60.0)
   IF (ALT.LT.1200. .OR. MACH.GT.1.2) DSBAUTO = 0.
   DSBSAS = .9704 * DSBSAS + .0296 * DSBAUTO
   ELSE
   DSBSAS = 0.
   ENDIF
   DSBCMD = DSBDIR + DSBSAS

END
SUBROUTINE PLSURF

***

PLS AERO CONTROL SURFACE ACTUATOR MODEL

***

EXTERNAL INPUTS TO ACTUATOR MODEL

* BETADEG * SIDESLIP ANGLE, DEG + RELATIVE WIND FROM RIGHT
* COSALP * COSINE OF ANGLE OF ATTACK
* DACMD *AILERON COMMAND, DEG + TO ROLL RIGHT
* DECMD ELEVATOR COMMAND, DEG + TRAILING EDGE DOWN
* DRCDMD RUDDER COMMAND, DEG + TRAILING EDGE LEFT
* DSCMD SPEEDBRAKE COMMAND, DEG
* MACH * MACH NUMBER
* PDEG BODY ROLL RATE, DPS
* RDEG BODY YAW RATE, DPS
* SINALP SINE OF ANGLE OF ATTACK
* WONG WEIGHT ON NOSE GEAR (T/F)

NOTE--PARAMETERS MARKED WITH * ARE IN THIS SUBROUTINE
FOR CALCULATION OF THE BODY FLAP 'REVERSE AILERON' FUNCTION,
WHICH MIGHT NORMALLY BE CALCULATED ELSEWHERE

EXTERNAL OUTPUTS FROM ACTUATOR MODEL

* DLE LEFT ELEVON DEFLECTION, + TRAILING EDGE DOWN
* DLL LOWER LEFT BODY FLAP DEFLECTION, + TRAILING EDGE DOWN
* DLR LOWER RIGHT BODY FLAP DEFLECTION, + TRAILING EDGE DOWN
* DR RUDDER DEFLECTION, + TRAILING EDGE LEFT
* DRE RIGHT ELEVON DEFLECTION, + TRAILING EDGE DOWN
* DUL UPPER LEFT BODY FLAP DEFLECTION, - TRAILING EDGE UP
* DUR UPPER RIGHT BODY FLAP DEFLECTION, - TRAILING EDGE UP

THE FOLLOWING PREFIXES ARE USED:

***

***

THE FOLLOWING SUFFIXES ARE USED:

***

THE FOLLOWING SUFFIXES ARE USED:

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Appendix C: Guidance and Control Law Listing

*** -U  UPPER LIMIT
*** -Z  Z-TRANSFORM COEFFICIENT 

******************************************************************************
* CLAMP LIMITING FUNCTION LIMITS X BETWEEN Y AND Z 
CLIMIT (X,Y,Z) = AMIN1(Z,AMAX1(X,Y))
******************************************************************************

*************************** EI_VON COI_NDS **********************************

LIMITED ELEVATOR COMMAND

DECMDL = CLIMIT (DECMD, DECL, DECU)

COMMANDED ELEVONS

DLEC = DECM DL
DREC = DECM DL

************************** RUDDER COMMAND ************************************

LIMITED RUDDER COMMAND

DRCMDL = CLIMIT (DRCMD, DRCL, DRCU)

COMMANDED RUDDER

NOTE DRCG1 ALLOWS QUICK SCALING CHANGE
DRC = DRCMDL * DRCG1

AILERON COMMAND

LIMITED AILERON COMMAND

DACMDL = CLIMIT (DACMD, DACL, DACU)

SPEEDBRAKE COMMAND

C-11
LIMITED SPEED BRAKE COMMAND

SBAUTH = DBFMAX - ABS(DACMDL)
DSBCMDL = CLIMIT(DSBCMD, 0.001, SBAUTH)

******************** BODY FLAP COMMAND MIXER ********************

* BODY FLAPS AS SPEEDBRAKES
* SHAPED TO MINIMIZE SUBSONIC PITCHING MOMENT

DBFSBLC = DSBCMDL
DBFSBUC = 0.333 * DBFSBLC
IF (DBFSBLC .GT. 15.) DBFSBUC = 10. - DBFSBLC
IF (WONG) DBFSBUC = - DBFSBLC

BREAK AILERON COMMAND INTO BODY FLAP COMMANDS

* BODY FLAPS FUNCTION AS CONVENTIONAL AILERONS BELOW MACH 1.2
* IF (MACH .LT. 1.2) THEN
  DULCMD = DACMDL
  DLLCMD = DACMDL
  DURCMD = -DACMDL
  DLRCMD = -DACMDL
* ELSE
  'REVERSE AILERON' LOWER BODY FLAP CONTROL METHOD AT MACH > 1.2
  DATA GBFA, GBFB, GBFBD / 2.0, 10.0, 20.0 /
  UPPER BODY FLAP GAIN SCHEDULE VS MACH 1 AT M1 4 AT MACH > 4
  GDUDA = CLIMIT (MACH, 1.0, 4.0)
* LOWER BODY FLAP GAIN SCHEDULE VS MACH 'REVERSE AILERON'
* LOWER BODY FLAPS FUNCTION AS YAW MOMENT GENERATORS IN THIS MODE
  -1 AT M2, 0 AT M1.5, 1 AT M1
  GDLDA = CLIMIT (3. - 2.*MACH, -1., 1.)
* ESTIMATED BETA DOT
  BEDOT = PDEG*SINALP - RDEG*COSALP
* LOWER BODY FLAP AS AILERON DEFLECTION COMMAND
  DLFDA = GBFA*GDLDA*DACMD - GBFB*BEADEG - GBFBD*BEDOT
  DLLCMD = DLFDA
  DLRCMD = -DLFDA
  DULCMD = GDUDA*DACMDL
  DURCMD = -GDUDA*DACMDL
* ENDIF

* BODY FLAP AS AILERON COMMAND LIMITS
* DULCMDL = CLIMIT(DULCMD, DULCL, DULCU)
  DLLCMDL = CLIMIT(DLLCMD, DLLCL, DLLCU)
  DURCMDL = CLIMIT(DURCMD, DURCL, DURCU)
  DLRCMDL = CLIMIT(DLRCMD, DLRCCL, DLRCU)

* BODY FLAP TO ASSIST ELEVATORS
* GAIN SCHEDULE 1 AT MACH 1 4 ABOVE MACH 1.5
  GDUDE = CLIMIT (6.*MACH-5., 1., 4.)
Appendix C: Guidance and Control Law Listing

* DUFDE = 0.
   IF (DLEC.LT.-15.) DUFDE = GDUDE*(DLEC + 15.)
*
* DLFDE = 0.
   IF (DLEC.GT.15.) DLFDE = DLEC - 15.
*** TOTAL BODY FLAP COMMANDS
**
DULC = DULCMDL + DBFSBUC + DUFDE
DURC = DURCMDL + DBFSBUC + DUFDE
DLLC = DLLCMDL + DBFSBLC + DLFDE
DLRC = DLRCMDL + DBFSBLC + DLFDE

***********************************************************************
* FIRST ORDER RATE AND POSITION LIMITED ACTUATOR MODEL
* ***********************************************************************
* Z-TRANSFORM FORMULA USED IN 1ST ORDER FILTERS
* INITIALIZE OUT AND INPAST IN RESET DT = INTEGRATION TIME STEP
* (AS+B)/(CS+I) = K=1=EXP(-DT/C) Z3=-K*A/* Z2=B*(1-K)+K*A/C
* OUT = Z1*OUT + Z2*IN + Z3*INPAST 'PAST VALUE OF OUT IMPLIED
* INPAST = IN
*
*** WHILE IN RESET (MODE = 1) INITIALIZE Z-TRANSFORM COEFFICIENTS
*** FOR ACTUATOR TRANSFER FUNCTIONS
* IF (MODE.EQ.1) THEN
**
HSTEP = H * 0.5
**
*** LEFT ELEVON Z-TRANSFORM COEFFICIENTS
**
DLEZ1 = EXP(-1.0 * HSTEP / DLETAU)
DLEZ2 = 0.0
DLEZ3 = 1.0 - DLEZ1 - DLEZ2
***
*** RIGHT ELEVON Z-TRANSFORM COEFFICIENTS
**
DREZ1 = EXP(-1.0 * HSTEP / DRETAU)
DREZ2 = 0.0
DREZ3 = 1.0 - DREZ1 - DREZ2
***
*** UPPER LEFT BODY FLAP Z-TRANSFORM COEFFICIENTS
**
DULZ1 = EXP(-1.0 * HSTEP / DULTAU)
DULZ2 = 0.0
DULZ3 = 1.0 - DULZ1 - DULZ2
***
*** UPPER RIGHT BODY FLAP Z-TRANSFORM COEFFICIENTS
**
DURZ1 = EXP(-1.0 * HSTEP / DURTAU)
DURZ2 = 0.0
DURZ3 = 1.0 - DURZ1 - DURZ2
***
*** LOWER LEFT BODY FLAP Z-TRANSFORM COEFFICIENTS
**
DLLZ1 = EXP(-1.0 * HSTEP / DLLTAU)
DLLZ2 = 0.0
DLLZ3 = 1.0 - DLLZ1 - DLLZ2
***
*** LOWER RIGHT BODY FLAP Z-TRANSFORM COEFFICIENTS
**
Appendix C: Guidance and Control Law Listing

\[
\begin{align*}
\text{DLRZ1} &= \exp(-1.0 \times \text{HSTEP} / \text{DLRTAU}) \\
\text{DLRZ2} &= 0.0 \\
\text{DLRZ3} &= 1.0 - \text{DLRZ1} - \text{DLRZ2} \\
\text{DRZ1} &= \exp(-1.0 \times \text{HSTEP} / \text{DRTAU}) \\
\text{DRZ2} &= 0.0 \\
\text{DRZ3} &= 1.0 - \text{DRZ1} - \text{DRZ2}
\end{align*}
\]
**

*** RUDDER Z-TRANSFORM COEFFICIENTS ***
**

\[
\begin{align*}
\text{ELEMON DEFLCCTIONS} \\
\text{DLE} &= \text{DLEZ1} \times \text{DLEP} + \text{DLEZ2} \times \text{DLEPP} + \text{DLEZ3} \times \text{DLEC} \\
\text{DRE} &= \text{DREZ1} \times \text{DREP} + \text{DREZ2} \times \text{DREP} + \text{DREZ3} \times \text{DREC}
\end{align*}
\]
**

*** RATE LIMITS - ELEVONS ***
**

\[
\begin{align*}
\text{IF } ((\text{DLE} - \text{DLEP}) \gt (\text{HSTEP} \times \text{DLERL})) \text{ THEN} &
\text{DLE} = \text{DLEP} + \text{HSTEP} \times \text{DLERL} \\
\text{ELSEIF } ((\text{DLEP} - \text{DLE}) \gt (\text{HSTEP} \times \text{DLERL})) \text{ THEN} &
\text{DLE} = \text{DLEP} - \text{HSTEP} \times \text{DLERL} \\
\text{ENDIF} \\
\text{IF } ((\text{DRE} - \text{DREP}) \gt (\text{HSTEP} \times \text{DRERL})) \text{ THEN} &
\text{DRE} = \text{DREP} + \text{HSTEP} \times \text{DRERL} \\
\text{ELSEIF } ((\text{DREP} - \text{DRE}) \gt (\text{HSTEP} \times \text{DRERL})) \text{ THEN} &
\text{DRE} = \text{DREP} - \text{HSTEP} \times \text{DRERL} \\
\text{ENDIF}
\end{align*}
\]
**

*** POSITION LIMITS - ELEVONS ***
**

\[
\begin{align*}
\text{DLE} &= \text{CLIMIT(DLE, DLEL, DLEU)} \\
\text{DRE} &= \text{CLIMIT(DRE, DREL, DREU)}
\end{align*}
\]
**

*** PAST VALUES FOR ELEVON DEFLCCTIONS ***
**

\[
\begin{align*}
\text{DLEPP} &= \text{DLE} \\
\text{DREP} &= \text{DLE} \\
\text{DREPP} &= \text{DREP} \\
\text{DREP} &= \text{DRE}
\end{align*}
\]
**

*** BODY FLAP DEFLCCTIONS ***
**

\[
\begin{align*}
\text{DUL} &= \text{DULZ1} \times \text{DULP} + \text{DULZ2} \times \text{DULPP} + \text{DULZ3} \times \text{DULC} \\
\text{DUR} &= \text{DURZ1} \times \text{DURP} + \text{DURZ2} \times \text{DURPP} + \text{DURZ3} \times \text{DURC} \\
\text{DLL} &= \text{DLLZ1} \times \text{DLLP} + \text{DLLZ2} \times \text{DLLPP} + \text{DLLZ3} \times \text{DLLC} \\
\text{DLR} &= \text{DLRZ1} \times \text{DLRP} + \text{DLRZ2} \times \text{DLRPP} + \text{DLRZ3} \times \text{DLRC}
\end{align*}
\]
**

*** RATE LIMITS - BODY FLAPS ***
**

\[
\begin{align*}
\text{IF } ((\text{DUL} - \text{DULP}) \gt (\text{HSTEP} \times \text{DULRL})) \text{ THEN} &
\text{DUL} = \text{DULP} + \text{HSTEP} \times \text{DULRL} \\
\text{ELSEIF } ((\text{DULP} - \text{DUL}) \gt (\text{HSTEP} \times \text{DULRL})) \text{ THEN} &
\text{DUL} = \text{DULP} - \text{HSTEP} \times \text{DULRL} \\
\text{ENDIF} \\
\text{IF } ((\text{DUR} - \text{DURP}) \gt (\text{HSTEP} \times \text{DURRL})) \text{ THEN} &
\text{DUR} = \text{DURP} + \text{HSTEP} \times \text{DURRL} \\
\text{ELSEIF } ((\text{DURP} - \text{DUR}) \gt (\text{HSTEP} \times \text{DURRL})) \text{ THEN} &
\text{DUR} = \text{DURP} - \text{HSTEP} \times \text{DURRL} \\
\text{ENDIF}
\end{align*}
\]

C-14
IF ((DLL - DLLP) .GT. (HSTEP * DLLRL)) THEN
  DLL = DLLP + HSTEP * DLLRL
ELSEIF ((DLLP - DLL) .GT. (HSTEP * DLLRL)) THEN
  DLL = DLLP - HSTEP * DLLRL
ENDIF

IF ((DLR - DLRP) .GT. (HSTEP * DLRRL)) THEN
  DLR = DLRP + HSTEP * DLRRL
ELSEIF ((DLRP - DLR) .GT. (HSTEP * DLRRL)) THEN
  DLR = DLRP - HSTEP * DLRRL
ENDIF

** POSITION LIMITS - BODY FLAPS
**
DUL = CLIMIT(DUL, DULL, DULU)
DUR = CLIMIT(DUR, DURL, DURU)
DLL = CLIMIT(DLL, DLLL, DLLU)
DLR = CLIMIT(DLR, DLRL, DLRU)

** PAST VALUES FOR BODY FLAP DEFLECTIONS
**

(DULPP, DULP, DUL)
(DURPP, DURP, DUR)
(DLLPP, DLLP, DLL)
(DLRPP, DLRP, DLR)

** RUDDER DEFLECTION
**
DR = DRZ1 * DRP + DRZ2 * DRPP + DRZ3 * DRC

** RATE LIMITS - RUDDER
**
IF ((DR - DRP) .GT. (HSTEP * DRRL)) THEN
  DR = DRP + HSTEP * DRRL
ELSEIF ((DRP - DR) .GT. (HSTEP * DRRL)) THEN
  DR = DRP - HSTEP * DRRL
ENDIF

** POSITION LIMITS - RUDDER
**
DR = CLIMIT(DR, DRL, DRU)
DLRDEG = DR

** PAST VALUES FOR RUDDER DEFLECTION
**

(DRPP, DRP, DR)

CONTINUE

END
Appendix D

Trimmed Flight Condition check case data
IC CASE 10K, Y1, 10H, 10L, HK, 2D, 4D, 4B, 4S, P1, P2, P3, P4, W? 10K

TEST DESCRIPTION 10K TRIM
NZQ SAS MODE

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<th>ALT</th>
<th>ALPHA</th>
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.544 330.0 0.0 -171.2 .99 0.0 -17.0 0.0 132

03/30/92, 09.26.22. PLT=BATMAN LFT=T FCSILM=23 WND= 0.0. TRB= 0.0.

DE, BRG, XT, AC, GC, PSC, PHC= 6.5 330.0 0.4. 4.5 -18.2 330.0 0.0

WEIGHT, AREA, CBAR, SPAN, QBAR, MACH

.1910D+05 .2865D+03 .2824D+02 .1389D+02 .3010D+03 .5435D+00

BODY AXIS F&M XB, YB, LB, NC, MB, NB

-.4689D+04 -.2359D-13 -.1894D+05 -.6667D-10 -.1481D+03 .5903D-13

STAB AXIS F&M XS, ZS, LS, MS, NS

-.6540D+04 -.2359D-13 -.1838D+05 -.6633D-10 -.1481D+03 .6656D-11

ACCEL UDOT, VDOT, WDOT, PDOT, QDOT, DROT, RFS**2 OR RPS**2

-.1583D+01 .7143D-14 -.3529D+00 .0000D+00 -.4049D-02 .0000D+00

NBP (1-12) = 1 4 2 4 2 3 3 1 8 1 1 1

WN (1-12) = .8116733002521 .5720564112974 .09461025536921

.5720564112974 .09461025536921 .3637276570303 .3637276570303

.0. -286.8191850114 0. -2941.167058824 .00032

ALPHA = 5.679390868367 BETA = 2.236532855333E-17

DUL = -6.419153830538 DUR = -6.419153830538

DLL = 16.41915383054 DLR = 16.41915383054

DLE = 5.455914855455 DRE = 5.455914855455

DR = 0. DXCG = -.4236

H/B = 719.5479625286 GEAR = 0.
### Aerodynamic coefficient buildups

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"cctrim2.txt" - Mach 2 trim shot

IC CASE 10K,Y1,10H,10L,HK,2D,4D,4B,4S,P1,P2,P3,P4,M? 2D
TEST DESCRIPTION ? MACH 2 TRIM
NZQ SAS MODE
MACH IAS THETA ALT ALPHA DE DSB HER XRWY ICMD
.00 364.0 -8.0 58700. 6.0 -24.5 .0 5628. 46430. 0
1.997 147.0 .0 -467.7 1.00 .0 .0 -14.0 -66309. 632
DME, BRG, XT, AC, GC, PSC, PHC= 16.5 95.0 58894. 6.0 -14.0 147.1 1.2
WEIGHT, AREA, CBAR, SPAN, QBAR, MACH .1910D+05 .2865D+03 .2824D+02
BODY AXIS F&M XB, YB, ZB, LB, MB, NB
-.1848D+05 -.4005D-14 -.1920D+05 .9899D-11 -.1959D+03 .4695D-11
STAB AXIS F&M XS, YS, ZS, LS, MS, NS
-.2039D+05 -.4005D-14 -.1716D+05 .1034D-10 -.1959D+03 .3634D-11
ACCEL UDOT, VDOT, WDOT, PDOT, QDOT, RDOT FPS**2 OR RPS**2
-.2664D+02 .4223D-16 -.4731D+00 .9968D-15 -.7551D-02 -.1324D-15
NBP (1-12) = 8 2 1 2 1 1 1 1 1 1 1
WN (1-12) = .989927582443 .4672603256935 .0004813084663607
.4672603256935 .0004813084663607 .3668190883164 .3668190883164
4.457401521235E-18 -1688.993867273 0. -2941.167058824
.000032
ALPHA= 6.002195965025 BETA= 4.007150396168E-20
P, Q, R RPS=3.189616514552E-17 -.0002416216751572 -4.237438306065E-18
DUL= -.37.9910951146 DUR= -.37.9910951146
DIL= -.000721962699541 DLR= -.0007219626995526
DLE= -.24.49771367525 DRE= -.24.49771367525
DR= -.6.682052281852E-17 DXCG= -.4236
H/B = 4224.984668183 GEAR = 0.
## Appendix D: Trimmed Flight Condition Check Case Data Sets

**Aerodynamic coefficient buildups**

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"cttrim4.txt" - Mach 4 trim shot

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<td>4D</td>
<td>4B</td>
<td>4S</td>
<td>P1</td>
<td>P2</td>
<td>P3</td>
<td>P4</td>
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**Test Description:** MACH 4 TRIM

| NZQ SAS MODE | T | IAS | THETA | ALT | ALPHA | DE | DSB | HER | XRWY | ICMD | MACH | HDG | PHI | HDOT | NZ | DAC | DR | GAMMA | YRWY | MODE |
| 3.999 | 154.0 | .0 | -208.0 | 1.00 | .0 | .0 | -3.0 | -72000. | 632 |

**DME, BRG, XT, AC, GC, FSC, PHC:** 62.9 138.7 367290. 17.0 -3.0 148.6 -50.0

**Weight, Area, CBAR, Span, QBAR, MACH:**

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<th>CBAR</th>
<th>SPAN</th>
<th>QBAR</th>
<th>MACH</th>
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**Body Axis F&M:**

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<th>LB</th>
<th>MB</th>
<th>NB</th>
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**Stab Axis F&M:**

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<th>YS</th>
<th>ZS</th>
<th>LS</th>
<th>MS</th>
<th>NS</th>
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**ACCEL:**

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<th>WDOT</th>
<th>QDOT</th>
<th>RDOT</th>
<th>FPS**2</th>
<th>OR</th>
<th>RPS**2</th>
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**NBP(1-12):** 12 4 1 4 1 3 1 8 1 1 1

| WN(1-12): | .9979 17169 8185 | .9998 39724 281 | .0000 48130 8466 3645 |
|---|---|---|
| .9998 39724 281 | .0000 48130 8466 3645 | .2755 5370 0145 2 |
| 0 | -.2993 76871 2475 | 0 | -.2941 16705 8824 | .00032 |

**ALPHA:** 17.0 019077982 | **BETA:** 3.296392158263E-18

**P, Q, R:**

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**DXCG:** -.4236 | **H/B:** 7486.92178 1187 | **GEAR:** 0.0.
### Appendix D: Trimmed Flight Condition Check Case Data Sets

#### Aerodynamic coefficient buildups

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<th>Value 2</th>
<th>Value 3</th>
<th>Value 4</th>
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Appendix E

Aero Data Base for HL-20 Flight Simulation Studies
Aerodynamic Tables

All aerodynamic functions are encoded as third-order polynomials in angle of attack (alpha):

$$C_i = a_0 + a_1 \alpha + a_2 \alpha^2 + a_3 \alpha^3$$

A good FORTRAN implementation might be:

$$\text{COEFF} = (((A3*\alpha) + A2) * \alpha + A1) * \alpha + A0$$

The polynomial coefficients $a_0, a_1, a_2,$ and $a_3$ are given in the enclosed tables.

For a given Mach number (and deflection, for control 'delta' tables), the rows of the tables are as follows:

- $a_0, a_1, a_2, a_3$ for coeff. of lift ($C_L$)
- $a_0, a_1, a_2, a_3$ for coeff. of drag ($C_D$)
- $a_0, a_1, a_2, a_3$ for coeff. of pitching moment ($C_m$)
- $a_0, a_1, a_2, a_3$ for coeff. of sideforce ($C_y$)
- $a_0, a_1, a_2, a_3$ for coeff. of yawing moment ($C_n$)
- $a_0, a_1, a_2, a_3$ for coeff. of rolling moment ($C_I$)

Thus, for a given Mach number (and deflection) there are $6 \times 4 = 24$ entries.

Table 1 is for basic (no controls deflected) aerodynamics [ f(Mach) ].

Tables 2 through 5 given coefficient increments for deflections of the upper left body flap, lower left body flap, left wing flap (elevon), and all-moveable fin (rudder). [ f(deflection, Mach) ]

Table 6 is slightly unusual: it gives coefficients for damping derivatives in the following order:

- $a_0, a_1, a_2, a_3$ for coeff. of pitch damping ($C_{mq}$)
- $a_0, a_1, a_2, a_3$ for coeff. of yaw damping due to roll rate ($C_{np}$)
- $a_0, a_1, a_2, a_3$ for coeff. of roll damping due to roll rate ($C_{ip}$)
- $a_0, a_1, a_2, a_3$ for coeff. of roll damping due to yaw rate ($C_{ir}$)
- $a_0, a_1, a_2, a_3$ for coeff. of yaw damping due to yaw rate ($C_{tr}$)

These are functions of alpha only! (constant with Mach)

Table 7 gives ground effect deltas, as a function of normalized height above ground (altitude above runway/wing span, or h/b). We are using height of the c.g. as the altitude to be normalized.

Table 8 gives landing gear effect deltas, as a function of gear angle (0-90°) where 90° is fully extended.

Deflection angles are in degrees; negative indicates trailing edge up (flaps and elevons) or trailing edge left (rudder).
Control deltas are assumed symmetrical, so the effects for right body flaps and elevons are duplicates of the left surfaces longitudinally and negated for the lateral/directional data. Rudder data is for trailing edge left, and needs to be mirrored for right deflections (long = same, lat/dir = -same).

Database Limits

Angle of attack limits (degrees):

\[0 \leq \text{Mach} < 1.1 : -2 < \alpha \leq 26\]
\[1.1 \leq \text{Mach} < 1.6 : -2 < \alpha \leq 15\]
\[1.6 \leq \text{Mach} < 3.0 : -2 < \alpha \leq 15 @ \text{M}=1.6, \text{ramps to 30} @ \text{M}=3\]
\[3.0 \leq \text{Mach} < 4.0 : -2 < \alpha \leq 30\]

Surface limits (degrees):

\[-60 \leq \text{upper body flaps} \leq 0\]
\[0 \leq \text{lower body flaps} \leq +60\]
\[-30 \leq \text{wing flaps} \leq +30\]
\[-30 \leq \text{all-moveable fin} \leq +30\]

Reference Quantities

Span: 13.89 ft
Area: 286.45 ft²
Chord: 28.24 ft

Center of Gravity - Moment transfer

The aero data presented here was measured at a moment reference center at 54 % of body length, along the Z-axis. For center of gravity locations other than 54 %, the moment coefficients will have to be adjusted to account for the shift in location, using conventional moment reference center transfer relationships. [The current center of gravity being tested in the simulator at Langley is 55.5 %.]
AERO COEFFICIENT DEFINITIONS USED FOR HL-20 DATA BASE

\[ C_L = C_{L,BASIC} + \Delta C_{L,BF} + \Delta C_{L,E} + \Delta C_{L,R} + \Delta C_{L,GE} + \Delta C_{L,FG} \]

\[ C_D = C_{D,BASIC} + \Delta C_{D,BF} + \Delta C_{D,E} + \Delta C_{D,R} + \Delta C_{D,GE} + \Delta C_{D,FG} \]

\[ C_m = C_{m,BASIC} + \Delta C_{m,BF} + \Delta C_{m,E} + \Delta C_{m,R} + \Delta C_{m,GE} + \Delta C_{m,FG} + \left( C_{m,q} \right) \left( \frac{q}{2V} \right) \]

\[ C_Y = \left( C_{Y_{\beta},BASIC} \right) (\beta) + \Delta C_{Y,BF} + \Delta C_{Y,E} + \Delta C_{Y,R} + \left( \Delta C_{Y_{\beta},GE} \right) (\beta) + \left( \Delta C_{Y_{\beta},FG} \right) (\beta) \]

\[ C_n = \left( C_{n_{\beta},BASIC} \right) (\beta) + \Delta C_{n,BF} + \Delta C_{n,E} + \Delta C_{n,R} + \left( \Delta C_{n_{\beta},GE} \right) (\beta) + \left( \Delta C_{n_{\beta},FG} \right) (\beta) + \left( \Delta C_{n_{p}} \right) \left( \frac{p}{2V} \right) + \left( \Delta C_{n_{r}} \right) \left( \frac{r}{2V} \right) \]

\[ C_L = \left( C_{L_{\beta},BASIC} \right) (\beta) + \Delta C_{L,BF} + \Delta C_{L,E} + \Delta C_{L,R} + \left( \Delta C_{L_{\beta},GE} \right) (\beta) + \left( \Delta C_{L_{\beta},FG} \right) (\beta) + \left( \Delta C_{L_{p}} \right) \left( \frac{p}{2V} \right) + \left( \Delta C_{L_{r}} \right) \left( \frac{r}{2V} \right) \]

- "BF" denotes contributions from 4 separate flaps
- "E" denotes contributions from 2 separate flaps
- \( S_{\text{ref}} = 286.45 \text{ ft}^2 \)
- \( c_{\text{ref}} = 28.24 \text{ ft} \)
- \( b_{\text{ref}} = 13.89 \text{ ft} \)
- \( x_{\text{cg,ref}} = 0.54 \ c_{\text{ref}} \)
- \( z_{\text{cg,ref}} = 0 \) (nose)
# AERO DATA BASE FORMAT

Example: \( C_{L, \text{BASIC}} = a_0 + a_1 \alpha + a_2 \alpha^2 + a_3 \alpha^3 \)

\( (a_0, a_1, a_2, a_3 \text{ tabulated in data base}) \)

Mach numbers: 0.3, 0.6, 0.9, 0.95, 1.1, 1.2, 1.6, 2.0, 2.5, 3.0, 3.5, 4.0

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<th>( C_D )</th>
<th>( C_m )</th>
<th>( C_{Y_\beta} )</th>
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<th>( C_{l_\beta} )</th>
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<tbody>
<tr>
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<td>( \Delta C_D )</td>
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<td></td>
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<td>( \Delta C_n )</td>
<td>( \Delta C_l )</td>
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<td>Left elevon</td>
<td>( \Delta C_L )</td>
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<tr>
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<td>( C_{l_p} )</td>
<td>( C_{n_r} )</td>
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<td>( \Delta C_D )</td>
<td>( \Delta C_m )</td>
<td>( h/b = 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, 2.5 )</td>
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E-30
### HL-20 Aerodynamics Tables (version 2.0)

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**E-37**
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E-38
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AERO DATABASE FOR HL-20 FLIGHT SIMULATION STUDIES

BASIC AERODYNAMIC COEFFICIENTS

LaRC/SSD
JAN. 1991

MACH

- 0.30
- 0.60
- 0.80
- 0.90
- 0.95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

BASIC AERODYNAMIC COEFFICIENTS

\[ C_d \] vs. \[ \alpha, \text{degs} \]

MACH

\[ .30 \]
\[ .60 \]
\[ .80 \]
\[ .90 \]
\[ .95 \]
\[ 1.10 \]
\[ 1.20 \]
\[ 1.60 \]
\[ 2.00 \]
\[ 2.50 \]
\[ 3.00 \]
\[ 3.50 \]
\[ 4.00 \]
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

BASIC AERODYNAMIC COEFFICIENTS

NASA

LaRC/SSD
JAN. 1991

MACH

.30
.60
.80
.90
.95
1.10
1.20
1.60
2.00
2.50
3.00
3.50
4.00

C_m

-0.10
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08
0.10

α, degs

-5 0 5 10 15 20 25 30 35
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

BASIC AERODYNAMIC COEFFICIENTS

LaRC/SSD
JAN. 1991

MACH

- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00

\[ C_{n_p} \] vs. \( \alpha \), degs

\[ E-45 \]
BASIC AERODYNAMIC COEFFICIENTS

MACH

0.30
0.60
0.90
0.95
1.10
1.20
1.60
2.00
2.50
3.00
3.30
4.00

\( C_g \)

\( \alpha, \text{ degs} \)
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{ULBF} = -60^\circ$

LaRC/SSD
JAN. 1991

\[ \Delta C_L \]

MACH

- \( \circ \) .30
- \( \square \) .60
- \( \diamond \) .80
- \( \triangle \) .90
- \( \triangledown \) .95
- \( \blacktriangle \) 1.10
- \( \blacktriangledown \) 1.20
- \( \blacktriangleleft \) 1.60
- \( \blacktriangleright \) 2.00
- \( \blacklozenge \) 2.50
- \( \blacklozenge \) 3.00
- \( \blacklozenge \) 3.50
- \( \blacklozenge \) 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{ULBF} = -60^\circ$

LaRC/SSD
JAN. 1991

$\Delta C_D$ vs $\alpha$, degs

MACH
- ○ 0.30
- □ 0.60
- △ 0.80
- ◇ 0.90
- ▽ 0.95
- ▼ 1.10
- ▲ 1.20
- △ 1.60
- ▼ 2.00
- ▲ 2.50
- △ 3.00
- ▽ 3.50
- ○ 4.00
INCREMENTS DUE TO $\delta_{ULBF} = -60^\circ$

AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

NASA
LaRC/SSD
JAN. 1991

$\Delta C_m$

$\alpha$, degs

MACH
- 0.30
- 0.60
- 0.80
- 0.90
- 0.95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{ULBF} = -60^\circ$

MACH

- 0.30
- 0.60
- 0.80
- 0.90
- 0.95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{ULBF} = -60^\circ$

MaCH
- 0.30
- 0.60
- 0.80
- 0.90
- 0.95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00

LaRC/SSD
JAN. 1991
INCREMENTS DUE TO $\delta_{ULBF} = -60^\circ$

$MACH$

- $0.30$
- $0.60$
- $0.80$
- $0.90$
- $0.95$
- $1.10$
- $1.20$
- $1.60$
- $2.00$
- $2.50$
- $3.00$
- $3.50$
- $4.00$
INCREMENTS DUE TO $\delta_{ULBR} = -45^\circ$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{ULBF} = -45^\circ$

MACH

.30
.60
.80
.90
.95
1.10
1.20
1.60
2.00
2.50
3.00
3.50
4.00

$\alpha$, degs
AERODYNAMIC DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{ULBF} = -45^\circ$

NASA
LaRC/SSD
JAN. 1991

MACH

- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00

$\Delta C_m$ vs $\alpha$, degs
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{ULBF} = -45^\circ$

LaRC/SSD
JAN. 1991

MACH

- $0.30$
- $0.60$
- $0.80$
- $0.90$
- $0.95$
- $1.10$
- $1.20$
- $1.60$
- $2.00$
- $2.50$
- $3.00$
- $3.50$
- $4.00$

$\Delta C_Y$ vs $\alpha$, degs
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{ULBF} = -45^\circ$

NASA
LaRC/SSD
JAN. 1991

MACH
- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00

$\Delta C_n$ vs $\alpha$, degs
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{ULBF} = -45^\circ$

LaRC/SSD
JAN. 1991

MACH

- $\bigcirc$ 0.30
- $\bigcirc$ 0.60
- $\bigcirc$ 0.80
- $\bigcirc$ 0.90
- $\bigcirc$ 0.95
- $\bigcirc$ 1.10
- $\bigcirc$ 1.20
- $\bigcirc$ 1.60
- $\bigcirc$ 2.00
- $\bigcirc$ 2.50
- $\bigcirc$ 3.00
- $\bigcirc$ 3.50
- $\bigcirc$ 4.00
INCREMENTS DUE TO $\delta_{ULBF} = -30^\circ$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{ULBF} = -30^\circ$

NASA
LaRC/SSD
JAN. 1991

\[ \Delta C_D \]

\[ \alpha, \text{ degs} \]

MACH

\[ .30 \]
\[ .60 \]
\[ .80 \]
\[ .90 \]
\[ .95 \]
\[ 1.10 \]
\[ 1.20 \]
\[ 1.60 \]
\[ 2.00 \]
\[ 2.50 \]
\[ 3.00 \]
\[ 3.50 \]
\[ 4.00 \]
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{ULBF} = -30^\circ$

NASA
LaRC/SSD
JAN. 1991

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$\Delta C_m$ vs $\alpha$, degs
INCREMENTS DUE TO $\delta_{ULBF} = -30^\circ$
INCREMENTS DUE TO $\delta_{ULBF} = -30^\circ$

$\Delta C_n$

$\alpha$, degs

MACH
- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{ULBF} = -15^\circ$

LaRC/SSD
JAN. 1991

MACH

- 0.30
- 0.60
- 0.80
- 0.90
- 0.95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00
INCREMENTS DUE TO $\delta_{ULBF} = -15^\circ$

-$\Delta C_D$ vs $\alpha$, degress

MACH
- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00

NASA
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JAN. 1991
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

E-67
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{ULBF} = -15^\circ$

LaRC/SSD
JAN. 1991

MACH

- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{ULBF} = -15^\circ$

$\alpha$, degs

$\chi$

0.022 0.018 0.014 0.010 0.006 0.002 0.000 0.002 0.006 0.010

0 5 10 15 20 25 30 35
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{ULBP} = -15^\circ$

MACH

0.30
0.60
0.90
0.95
1.10
1.20
1.60
2.00
2.50
3.00
3.50
4.00

LaRC/SSD
JAN. 1991
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

N.A.S.A.

LaRC/SSD

JAN. 1991

MACH

.30  .60  .90  .95  1.10  1.20  1.60  2.00  2.50  3.00  3.50  4.00

INCREMENTS DUE TO $\delta_{\text{LLBF}} = +15^\circ$

$C_T$

$\alpha$, degs
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{\text{LBF}} = +15^\circ$

LaRC/SSD
JAN. 1991

MACH

- $\circ \quad .30$
- $\vartriangle \quad .60$
- $\vartriangleleft \quad .80$
- $\vartriangleleft \quad .90$
- $\vartriangleleft \quad .95$
- $\vartriangleleft \quad 1.10$
- $\vartriangleleft \quad 1.20$
- $\vartriangleleft \quad 1.60$
- $\vartriangleleft \quad 2.00$
- $\vartriangleleft \quad 2.50$
- $\vartriangleleft \quad 3.00$
- $\vartriangleleft \quad 3.50$
- $\vartriangleleft \quad 4.00$

$\Delta C_D$

$\alpha$, degs
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{\text{LLBF}} = +15^\circ$

LaRC/SSD
JAN. 1991

$\Delta C_m$ vs $\alpha$, degs

MACH

- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{\text{LLBF}} = +15^\circ$

NASA
LaRC/SSD
JAN. 1991

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$\Delta C_Y$ vs $\alpha$, degs
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{\text{ILBF}} = +15^\circ$

E-75
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

LaRC/SSD
JAN. 1991

MACH

.30
.60
.90
.95
1.10
1.20
1.60
2.00
2.50
3.00
3.50
4.00

INCREMENTS DUE TO \( \delta_{11BF} = +15^\circ \)

\( C_1 \)

\( C_2 \)

\( C_3 \)

\( C_4 \)

\( C_5 \)

\( \alpha \), degs

E-76
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LLBF} = +30^\circ$

LaRC/SSD
JAN. 1991

MACH

- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00

$\Delta C_L$ vs $\alpha$, degs
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LLBF} = +30^\circ$

NASA
LaRC/SSD
JAN. 1991

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INCREMENTS DUE TO $\delta_{LLBF} = +30^\circ$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LLBF} = +30^\circ$

LaRC/SSD
JAN. 1991

$\Delta C_y$

$\alpha$ , degs

MACH
- $\bigcirc$ .30
- $\square$ .60
- $\diamond$ .80
- $\triangle$ .90
- $\downarrow$ .95
- $\bigtriangledown$ 1.10
- $\blacktriangle$ 1.20
- $\blacktriangledown$ 1.60
- $\blacklozenge$ 2.00
- $\blacklozenge$ 2.50
- $\blacklozenge$ 3.00
- $\blacklozenge$ 3.50
- $\blacklozenge$ 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LLBF} = +30^\circ$

LaRC/SSD
JAN. 1991

$\Delta C_n$ vs $\alpha$, degs

MACH

- $0.30$
- $0.60$
- $0.80$
- $0.90$
- $0.95$
- $1.10$
- $1.20$
- $1.60$
- $2.00$
- $2.50$
- $3.00$
- $3.50$
- $4.00$
INCREMENTS DUE TO $\delta_{\text{LEF}} = +30^\circ$
AERIAL DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{\text{LBF}} = +45^\circ$

NASA
LaRC/SSD
JAN. 1991

\begin{align*}
\Delta C_L & \quad \text{vs. } \alpha, \text{ degs} \\
MACH & \quad .30 \quad .60 \quad .80 \quad .90 \quad .95 \\
& \quad 1.10 \quad 1.20 \quad 1.60 \quad 2.00 \quad 2.50 \quad 3.00 \quad 3.50 \quad 4.00
\end{align*}
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LLBF} = +45^\circ$

NASA
LaRC/SSD
JAN. 1991

$\Delta C_D$

$\alpha$, degs

MACH

- $\bullet$ .30
- $\square$ .60
- $\triangle$ .80
- $\diamond$ .90
- $\bigtriangleup$ .95
- $\bigtriangledown$ 1.10
- $\bigcirc$ 1.20
- $\bigotimes$ 1.60
- $\bigodot$ 2.00
- $\bigcirc$ 2.50
- $\bigcirc$ 3.00
- $\bigcirc$ 3.50
- $\bigcirc$ 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{\text{LLBF}} = +45^\circ$

LaRC/SSD
JAN. 1991

MA CH
- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

LaRC/SSD
JAN. 1991

MACH

.30 .60 .80 .90 1.10 1.20 1.60 2.00 2.50 3.00 3.50 4.00

INCREMENTS DUE TO \( \delta_{LBF} = +45^\circ \)

\( \alpha \), degs

\( \alpha \)

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AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LLBF} = +45^\circ$

NASA
LaRC/SSD
JAN. 1991

$\Delta C_1$

-5 0 5 10 15 20 25 30 35

$\alpha$, degs
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LLBF} = +60^\circ$

LaRC/SSD
JAN. 1991

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AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LLBF} = +60^\circ$

LaRC/SSD
JAN. 1991

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AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

MACH

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0.40
0.50
0.60
0.70
0.80
0.90
0.95
1.00
1.10
1.20
1.30
1.40
1.50
2.00
2.50
3.00
3.50
4.00

INCREMENTS DUE TO $\delta_{\text{LBF}} = +60^\circ$

$\alpha$, degs
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{\text{LLBF}} = +60^\circ$

NASA
LaRC/SSD
JAN. 1991

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$\Delta C_Y$ vs $\alpha$, degs
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{\text{LLBF}} = +60^\circ$

LaRC/SSD
JAN. 1991

$\Delta C_n$

MACH

- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00

$\alpha, \text{degs}$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{\text{LLBF}} = +60^\circ$

MACH

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$\Delta C_1$ vs $\alpha$, degs
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LE} = -30^\circ$

LaRC/SSD
JAN. 1991

$\Delta C_D$

$\alpha$, degs

MACH
- $0.30$
- $0.60$
- $0.80$
- $0.90$
- $0.95$
- $1.10$
- $1.20$
- $1.60$
- $2.00$
- $2.50$
- $3.00$
- $3.50$
- $4.00$

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AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LE} = -30^\circ$

NASA
LaRC/SSD
JAN. 1991

MACH

- $0.30$
- $0.60$
- $0.80$
- $0.90$
- $0.95$
- $1.10$
- $1.20$
- $1.60$
- $2.00$
- $2.50$
- $3.00$
- $3.50$
- $4.00$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LE} = -30^\circ$

LaRC/SSD
JAN. 1991

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INCREMENTS DUE TO $\delta_{LE} = -30^\circ$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LE} = -15^\circ$

NASA
LaRC/SSD
JAN. 1991

$\Delta C_L$ vs $\alpha, \text{degs}$

MACH
- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LE} = -15^\circ$

LaRC/SSD
JAN. 1991

MACH

- 0.30
- 0.40
- 0.80
- 0.90
- 0.95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00

$\Delta C_D$ vs $\alpha$, degress
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LE} = -15^\circ$

LaRC/SSD
JAN. 1991

MACH

- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00
INCREMENTS DUE TO $\delta_{LE} = -15^\circ$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LE} = -15^\circ$

NASA
LaRC/SSD
JAN. 1991

\begin{align*}
\Delta C_n & \text{ vs } \alpha, \text{ degress} \\
\text{MACH} & \\
\circ & .30 \\
\square & .60 \\
\triangle & .80 \\
\diamond & .90 \\
\star & .95 \\
\triangleleft & 1.10 \\
\triangleright & 1.20 \\
\triangledown & 1.60 \\
\trianglelefteq & 2.00 \\
\trianglerighteq & 2.50 \\
\triangledowneq & 3.00 \\
\starleft & 3.50 \\
\starright & 4.00
\end{align*}
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LE} = -15^\circ$

LaRC/SSD
JAN. 1991

MACH

- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00

$\Delta C_1$ vs $\alpha$, degs
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LE} = +15^\circ$

MACH

0.30
0.50
0.50
0.90
1.10
1.20
1.40
1.60
2.00
2.50
3.00
3.50
4.00

E-107
INCREMENTS DUE TO $\delta_{LE} = +15^\circ$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LE} = +15^\circ$

LaRC/SSD
JAN. 1991

MACH

- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LE} = +15^\circ$

LaRC/SSD
JAN. 1991

$\Delta C_n$ vs $\alpha$, degs

MACH

0.30
0.60
0.80
0.90
0.95
1.10
1.20
1.60
2.00
2.50
3.00
3.50
4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO \( \delta_{LE} = +15^\circ \)

\[
\begin{align*}
\Delta C_1 & \approx 0.08 \\
& \approx 0.07 \\
& \approx 0.06 \\
& \approx 0.05 \\
& \approx 0.04 \\
& \approx 0.03 \\
& \approx 0.02 \\
& \approx 0.01 \\
& \approx 0.00 \\
\end{align*}
\]

\( \alpha, \text{ degs} \)

MACH
- \( \circ \) 0.30
- \( \square \) 0.60
- \( \triangle \) 0.80
- \( \diamond \) 0.90
- \( \downarrow \) 0.95
- \( \uparrow \) 1.10
- \( \downarrow \) 1.20
- \( \triangle \) 1.60
- \( \diamond \) 2.00
- \( \downarrow \) 2.50
- \( \uparrow \) 3.00
- \( \square \) 3.50
- \( \circ \) 4.00

LaRC/SSD
JAN. 1991
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LE} = +30^\circ$

LaRC/SSD
JAN. 1991

E-113

$\Delta C_L$

$\alpha$, degs
INCREMENTS DUE TO $\delta_{LE} = +30^\circ$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTs DUE TO $\delta_{LE} = +30^\circ$

MACH

- $0.30$
- $0.60$
- $0.80$
- $0.90$
- $0.95$
- $1.10$
- $1.20$
- $1.60$
- $2.00$
- $2.50$
- $3.00$
- $3.50$
- $4.00$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LE} = +30^\circ$

\[ \Delta C_y \]

\[ \alpha, \text{ degs} \]

MACH
- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00

LaRC/SSD
JAN. 1991
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LE} = +30^\circ$

LaRC/SSD
JAN. 1991

MACH

-  .30
-  .60
-  .80
-  .90
-  .95
-  1.10
-  1.20
-  1.60
-  2.00
-  2.50
-  3.00
-  3.50
-  4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_{LE} = +30^\circ$

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure.png}
\end{figure}

MACH
- 0.30
- 0.60
- 0.80
- 0.90
- 0.95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00

LaRC/SSD
JAN. 1991
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO \( \delta_R = +15^\circ \)

LaRC/SSD
JAN. 1991

\( \Delta C_L \) vs. \( \alpha \), degs

MACH

\[ \begin{array}{c}
.30 \\
.60 \\
.80 \\
.90 \\
.95 \\
1.10 \\
1.20 \\
1.60 \\
2.00 \\
2.50 \\
3.00 \\
3.50 \\
4.00
\end{array} \]
INCREMENTS DUE TO $\delta_r = +15^\circ$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_R = +15^\circ$

NASA
LaRC/SSD
JAN. 1991

MACH

- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_r = +15^\circ$

MACH
- $0.30$
- $0.60$
- $0.80$
- $0.90$
- $0.95$
- $1.10$
- $1.20$
- $1.60$
- $2.00$
- $2.50$
- $3.00$
- $3.50$
- $4.00$

LaRC/SSD
JAN. 1991
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_R = +15^\circ$

NASA

LaRC/SSD
JAN. 1991

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AEREO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

LaRC/SSD
JAN, 1991

MACH

0.30
0.60
0.80
0.95
1.10
1.20
1.60
2.00
2.50
3.00
3.50
4.00

INCREMENTS DUE TO \( \delta_R = +15^\circ \)

\( C_A \), degs

\( -0.4 \)
(0.0)
(0.2)
(0.3)
(0.4)

\( -0.1 \)
(0.0)
(0.1)
(0.2)
(0.3)
(0.4)

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AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_R = +30^\circ$

LaRC/SSD
JAN. 1991

MACH

- .30
- .60
- .80
- .90
- .95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO \( \delta_R = +30^\circ \)

\( \Delta C_D \) vs. \( \alpha, \) degs

MACH

- 0.30
- 0.60
- 0.80
- 0.90
- 0.95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00

NASA
LaRC/SSD
JAN. 1991
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_R = +30^\circ$

LaRC/SSD
JAN. 1991

MACH

- 0.30
- 0.60
- 0.80
- 0.90
- 0.95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO $\delta_R = +30^\circ$

NASA
LaRC/SSD
JAN. 1991

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INCREMENTS DUE TO $\delta_R = +30^\circ$

\[ \Delta C_1 \]

\[ \alpha, \text{ degs} \]

MACH
- 0.30
- 0.60
- 0.80
- 0.90
- 0.95
- 1.10
- 1.20
- 1.60
- 2.00
- 2.50
- 3.00
- 3.50
- 4.00

E-130
DYNAMIC DAMPING COEFFICIENTS

\( \frac{d}{du} \alpha, \text{degs} \)

\( \alpha \)

\( \frac{d}{du} \)

\( \Omega \)
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

DYNAMIC DAMPING COEFFICIENTS

\( C_{\text{Lr}} \)

\( \alpha, \text{degs} \)

1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
-5
0
5
10
15
20
25
30
35

LaRC/SSD
JAN. 1991

NASA
INCREMENTS DUE TO GROUND EFFECTS

E-137
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO GROUND EFFECTS

LaRC/SSD
JAN. 1991

\[ \Delta C_m \]

\[ \alpha, \text{ degs} \]

\begin{tabular}{c|c}
\hline
h/b & \\
\hline
.2 & \\
.4 & \\
.6 & \\
.8 & \\
1.0 & \\
1.5 & \\
2.0 & \\
2.5 & \\
\hline
\end{tabular}
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO GROUND EFFECTS

LaRC/SSD
JAN. 1991

<table>
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<td>2.5</td>
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Graph showing the relationship between $\Delta C_{n_{\beta}}$ and $\alpha$ (degrees) for different values of $h/b$. The graph includes data points for $h/b$ values ranging from .2 to 2.5.
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO GROUND EFFECTS

NASA
LaRC/SSD
JAN. 1991

\[ \Delta C_{1\beta} \]

\[ \alpha, \text{ degs} \]

\[ h/b \]

- 0.2
- 0.4
- 0.6
- 0.8
- 1.0
- 1.5
- 2.0
- 2.5
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO LANDING GEAR

\[ \Delta C_l \]

\[ \alpha, \text{ degs} \]

\( \text{ANGLE} \)

- 0.0
- 15.0
- 30.0
- 60.0
- 90.0

LaRC/SSD
JAN. 1991
INCREMENTS DUE TO LANDING GEAR

ANGULAR DUE TO LANDING GEAR

LaRC/SSD
JAN. 1991

E-143
Appendix F

Dynamic checks for validation purposes
Dynamic check case plots

This appendix contains time history plots of the response of the Langley HL-20 real-time simulation to pulse inputs in each pilot control, conducted in three different flight regimes. They are intended as a "graduation exercise"; that is, an end-to-end comparison between the Langley simulation implementation and HL-20 simulations implemented at other facilities.

As described in the text of the report, these check cases were run with the same aerodynamics, inertias, and control laws described elsewhere in this report. The control laws were configured for manual operation. The center of gravity was 55.5%, the landing gear was not extended. Note that the autoland system is not engaged, therefore, the guidance errors (plot page 17) are non-zero.

There are three different flight conditions represented, which correspond to the three trim conditions given in the previous appendix (Appendix E):

- **Trim case '0':** 300 KEAS at 10,000 feet altitude
- **Trim case '2':** Mach 2 at 58,700 feet altitude
- **Trim case '4':** Mach 4 at 105,000 feet altitude

For each check case, there are four separate maneuvers plotted, corresponding to four different control inputs. For each case, the control inputs occur in the same order:

- Aft pitch stick pulse of one second duration, commencing at \( t = 1 \) second
- Right roll stick pulse of one second duration, commencing at \( t = 1 \) second
- Right rudder pedal pulse of one second duration, starting at \( t = 1 \) second
- Speedbrake handle pulse of three seconds duration, starting at \( t = 1 \) second

Each set of time history is 10 seconds long (20 seconds for the speedbrake cases). Each set of 69 parameter time histories is given, on 20 different pages, in the following order (see the glossary, appendix A, for a definition of the signal names):

<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
<th>Parameters</th>
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<tr>
<td>1</td>
<td>Pilot inputs</td>
<td>DCPilot, DWpilot, DPpilot, DLSbcom (units)</td>
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<td>2</td>
<td>Velocities</td>
<td>IAS (knots), Qbar (psf), VTotal1 (fps), Mach</td>
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<tr>
<td>3</td>
<td>Flow &amp; flight path angles</td>
<td>ALPDEG, BETADEG, GAMMAD, TKANG (degrees)</td>
</tr>
<tr>
<td>4</td>
<td>C. G. position states</td>
<td>ALT, SX, SY (feet)</td>
</tr>
<tr>
<td>5</td>
<td>Euler angles</td>
<td>ALT (feet), PHID, THETAD, PSID (degrees)</td>
</tr>
<tr>
<td>6</td>
<td>Body axis velocities</td>
<td>U, B, W, HDot (ft/sec)</td>
</tr>
<tr>
<td>7</td>
<td>Body axis angular rates</td>
<td>PDEG, QDEG, RDEG (degrees/second)</td>
</tr>
<tr>
<td>8</td>
<td>Body axis lin. accels</td>
<td>Udot, Vdot, Wdot (ft/sec²)</td>
</tr>
<tr>
<td>9</td>
<td>Body axis ang. accels</td>
<td>PDot, Qdot, RDot (rad/sec²)</td>
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<tr>
<td>10</td>
<td>Aero coefficients - force</td>
<td>CLTot, CDTot, CYTot</td>
</tr>
</tbody>
</table>
11 Aero coeffs. - moments
12 Aero forces
13 Aero moments
14 C.G. accelerations
15 FCS mode flags
16 Guidance commands
17 Guidance errors
18 FCS surface commands
19 Surf. positions #1
20 Surf. positions #2

CLTOT, CMTOT, CLNTOT (measured at mom. ref.)
X, Y, Z (lbs)
L, M, N (ft-lbs)
ANX, ANY, ANZ ("g" units)
LFCS, MFCS, MGUID, MCONFIG (integers)
AOACMD, GAMCMD, PHICMD, PSICMD (degrees)
HER, PSIERR, XTK (various units)
DECMD, DACMD, DRCMD, DSBCMD (degrees)
DLE, DRE, DLRDEG, DLGPCT (degrees)
DUL, DUR, DLL, DLR (degrees)

The plots therefore comprise $20 \frac{\text{pages}}{\text{maneuver}} \times 4 \frac{\text{maneuvers}}{\text{trim case}} \times 3$ trim cases = 240 pages of
time history plots, arranged as follows:

Trim case 0 (subsonic):

Pitch pulse .......................................................... F-3
Lateral pulse ......................................................... F-23
Directional pulse .................................................. F-43
Speed brake pulse ............................................... F-63

Trim case 2 (Mach 2):

Pitch pulse .......................................................... F-83
Lateral pulse ......................................................... F-103
Directional pulse .................................................. F-123
Speed brake pulse ............................................... F-143

Trim case 4 (Mach 4):

Pitch pulse .......................................................... F-163
Lateral pulse ......................................................... F-183
Directional pulse .................................................. F-203
Speed brake pulse ............................................... F-223
Aft Pitch Stick Pulse at 300 KEAS, 10,000 ft

DCPILOT

DWPILOT

DPPILOT

DLSBCOM
HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at 300 KEAS, 10,000 ft

---

**Velocity Plots**

**V_{TOTAL}**

- Units: knots
- Range: 585.0 to 0.0
- Scale: 10 x 10^0
- Time: 0.00 to 10.00

**MACH**

- Range: 0.545 to 0.525
- Scale: 10 x 10^0
- Time: 0.00 to 10.00

---

**Pressure Plots**

**P_{BAR}**

- Range: 301.0 to 300.0
- Scale: 10 x 10^0
- Time: 0.00 to 10.00

---

**IAS**

- Range: 298.2 to 297.7
- Scale: 10 x 10^0
- Time: 0.00 to 10.00

---

**Velocities**

Page 2 of 20

F-4
Flow & flight path angles
HL-20 Dynamic Check Case Data Plots 911206
Alt Pitch Stick Pulse at 300 KEAS, 10,000 ft

- ALT

- SX

- SY

C.G. position states
Page 4 of 20
Aft Pitch Stick Pulse at 300 KEAS, 10,000 ft

**Graphs:**
- **ALT**
- **PHID**
- **THETAD**
- **PSID**

**Euler angles (degrees)**

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Alt Pitch Stick Pulse at 300 KEAS, 10,000 ft

Body axis angular rates
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Aft pitch stick pulse at 300 KEAS, 10,000 ft

Body axis linear accelerations
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Aft Pitch Stick Pulse at 300 KEAS, 10,000 ft

Body axis angular accelerations
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Aero coefficients - force
Page 10 of 20
HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at 300 KEAS, 10,000 ft

Aero coefficients - moments
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HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at 300 KEAS, 10,000 ft

Aero forces
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HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at 300 KEAS, 10,000 ft

Aerodynamic moments
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HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at 300 KEAS, 10,000 ft

Guidance errors
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Surface positions - elevons, rudder & gear
Right Roll Stick Pulse at 300 KEAS, 10,000 ft
HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

1. IAS
   - x10^0
   - Time (0.00 to 10.00 x10^0)
   - Values: 298.2, 298.0, 297.8

2. QBAR
   - x10^0
   - Time (0.00 to 10.00 x10^0)
   - Values: 301.0, 300.5, 300.0

3. VTOTAL
   - x10^0
   - Time (0.00 to 10.00 x10^0)
   - Values: 585.0, 580.0, 575.0, 570.0

4. MACH
   - x10^0
   - Time (0.00 to 10.00 x10^0)
   - Values: 0.545, 0.540, 0.535, 0.530
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

ALPDEG

BETADEG

GAMMAD

TKANG

Flow & flight path angles
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

C.G. position states
HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

Euler angles (degrees)
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F-27
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

Body axis angular rates
Body axis linear accelerations
Page 8 of 20
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

Body axis angular accelerations

F-31
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

Aero coefficients - moments
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Right Roll Stick Pulse at 300 KEAS, 10,000 ft

Aero Forces
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

C.G. accelerations (G)

F-36
HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

FCS mode flags
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Right Roll Stick Pulse at 300 KEAS, 10,000 ft

AOACMD

GAMCMD

PHICMD

PSICMD

Guidance commands
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HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

Graph 1: HER

Graph 2: PSIERR

Graph 3: XTK

Guidance errors
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HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

Surface positions - elevons, rudder & gear

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Right Roll Stick Pulse at 300 KEAS, 10,000 ft

Surface positions - body flaps

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Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft
Flow & flight path angles
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F-45
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

Body axis velocities
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HL-20 Dynamic Check Case Data Plots 911206
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

Body axis angular rates
Page 7 of 20
HL-20 Dynamic Check Case Data Plots 911206
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

Body axis linear accelerations

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Body axis angular accelerations

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Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

HL-20 Dynamic Check Case Data Plots 911206

Aero coefficients - force

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HL-20 Dynamic Check Case Data Plots 911206
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

Aero coefficients - moments
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Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft
HL-20 Dynamic Check Case Data Plots 911206
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

FCS mode flags
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Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

AOACMD

GAMCMD

PHICMD

PSICMD

Guidance commands
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Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

DECMD

DACMD

DRCMD

DSBCMD
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

Surface positions - elevons, rudder & gear
HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

Pilot Inputs
Page 1 of 20
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

Velocities
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

ALT

SX

SY
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

Euler angles (degrees)
Body axis velocities
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Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

Body axis angular rates

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HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

Body axis angular accelerations
HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

Aero coefficients - moments
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HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

Aero forces
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HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

Aerodynamic moments
Page 13 of 20
C.G. accelerations (G)
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

FCS mode flags

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HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

AOACMD

GAMCMD

PHICMD

PSICMD

Guidance commands
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HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

Guidance errors
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F-79
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft
HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

Surface positions - elevons, rudder & gear
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F-81
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

Surface positions - body flaps
HL-20 Dynamic Check Case Data Plots 911206
Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

Pilot Inputs
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HL-20 Dynamic Check Case Data Plots 911206
Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

Velocities
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Flow & flight path angles
Page 3 of 20
Body axis velocities
Page 6 of 20

F-88
HL-20 Dynamic Check Case Data Plots 911206
Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

Body axis linear accelerations
Page 8 of 20

F-90
HL-20 Dynamic Check Case Data Plots 911206
Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

Aero coefficients - force
Page 10 of 20
Fwd Pitch Stick Pulse at Mach 2 and 56,700 ft

Aero coefficients - moments

Page 11 of 20
Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

- X

- Y

- Z

Aero forces
Page 12 of 20
HL-20 Dynamic Check Case Data Plots 911206
Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

C.G. accelerations (G)
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Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

FCS mode flags
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Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

Guidance errors
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HL-20 Dynamic Check Case Data Plots 911206
Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

- DLE
- DRE
- DLRDEG
- DLGPCT

Surface positions - elevons, rudder & gear
Page 19 of 20
Surface positions - body flaps
Right Roll Stick Pulse at Mach 2 and 58,700 ft
Right Roll Stick Pulse at Mach 2 and 58,700 ft

Graphs showing:
- IAS
- QBAR
- VTOTALI
- MACH

Velocities
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F-104
Right Roll Stick Pulse at Mach 2 and 58,700 ft

Flow & flight path angles
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HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at Mach 2 and 58,700 ft

Euler angles (degrees)
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F-107
Right Roll Stick Pulse at Mach 2 and 58,700 ft

Body axis velocities

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Right Roll Stick Pulse at Mach 2 and 58,700 ft
Right Roll Stick Pulse at Mach 2 and 58,700 ft

Aero coefficients - force
Right Roll Stick Pulse at Mach 2 and 58,700 ft

Aero coefficients - moments
Page 11 of 20
HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at Mach 2 and 58,700 ft

Aero forces
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HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at Mach 2 and 58,700 ft

Aerodynamic moments
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HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at Mach 2 and 58,700 ft

C.G. accelerations (G)

F-116
Right Roll Stick Pulse at Mach 2 and 58,700 ft
Right Roll Stick Pulse at Mach 2 and 58,700 ft

AOACMD

GAMCMD

PHICMD

PSICMD

Guidance commands
Right Roll Stick Pulse at Mach 2 and 58,700 ft

HER

PSIERR

XTK

Guidance errors
Page 17 of 20
Right Roll Stick Pulse at Mach 2 and 58,700 ft
HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at Mach 2 and 58,700 ft

Surface positions - elevons, rudder & gear
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Surface positions - body flaps
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Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

- DCPILOT
- DWPILOT
- DPPILLOT
- DLSBCOM

Pilot Inputs
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft
Flow & flight path angles
Page 3 of 20
HL-20 Dynamic Check Case Data Plots 911206
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

Euler angles (degrees)

F-127

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Body axis velocities
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Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

Body axis angular rates

F-129
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

Body axis linear accelerations

F-130
HL-20 Dynamic Check Case Data Plots 911206
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

Aero coefficients - force
Page 10 of 20
HL-20 Dynamic Check Case Data Plots 911206
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

Aero coefficients - moments
Page 11 of 20
HL-20 Dynamic Check Case Data Plots 911206
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

0.00 2.00 4.00 6.00 8.00 10.00
0.00 2.00 4.00 6.00 8.00 10.00
0.00 2.00 4.00 6.00 8.00 10.00

x10^3

x10^0

x10^3

Aero forces
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F-134
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

Aerodynamic moments
Page 13 of 20
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

- HER
- PSIERR
- XTK

Guidance errors

Page 17 of 20
HL-20 Dynamic Check Case Data Plots 911206
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

DECMD

DACMD

DRCMD

DSB_CMD

FCS Surface commands
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F-140
Speed Brake Handle Pulse at Mach 2 and 58,700 ft

Pilot Inputs
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F-143
HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at Mach 2 and 58,700 ft

Velocities
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F-144
HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at Mach 2 and 58,700 ft

C.G. position states
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F-146
HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at Mach 2 and 58,700 ft

Euler angles (degrees)
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F-147
Body axis velocities
Speed Brake Handle Pulse at Mach 2 and 58,700 ft

Body axis angular rates

Page 7 of 20
Body axis linear accelerations

F-150
Speed Brake Handle Pulse at Mach 2 and 58,700 ft

Aero coefficients - force
Page 10 of 20

F-152
Aero coefficients - moments
Page 11 of 20
Speed Brake Handle Pulse at Mach 2 and 58,700 ft

THE X-AXIS

-25.00

-20.00

-10.00

-0.00

10.00

20.00

TIME

10^3

THE Y-AXIS

-10.00

-5.00

0.00

5.00

10.00

15.00

20.00

TIME

10^-11

THE Z-AXIS

-20.00

-15.00

-10.00

-5.00

0.00

10.00

15.00

20.00

TIME

10^3
Speed Brake Handle Pulse at Mach 2 and 58,700 ft.

C.G. accelerations (G)

F-156
Speed Brake Handle Pulse at Mach 2 and 58,700 ft

FCS mode flags
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F-157
Speed Brake Handle Pulse at Mach 2 and 58,700 ft

AOACMD

GAMCMD

PHICMD

PSICMD
HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at Mach 2 and 58,700 ft

Guidance errors
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F-159
Speed Brake Handle Pulse at Mach 2 and 58,700 ft
HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at Mach 2 and 58,700 ft

Surface positions - elevons, rudder & gear
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F-161
Surface positions - body flaps

F-162
HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at Mach 4 and 104,000 ft

Wed Dec 11 06:05:07 1991

DCPILOT

DWPILOT

DPILOT

DLSBCOM

Pilot Inputs
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F-163
HL-20 Dynamic Check Case Data Plots 911206
Alt Pitch Stick Pulse at Mach 4 and 104,000 ft

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Alt Pitch Stick Pulse at Mach 4 and 104,000 ft

C.G. position states
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HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at Mach 4 and 104,000 ft

Euler angles (degrees)
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HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at Mach 4 and 104,000 ft

Body axis velocities
Page 6 of 20

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HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at Mach 4 and 104,000 ft

Body axis angular rates
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HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at Mach 4 and 104,000 ft

Body axis linear accelerations
Page 8 of 20
Body axis angular accelerations

F-171
HL-20 Dynamic Check Case Data Plots 911206
Alt Pitch Stick Pulse at Mach 4 and 104,000 ft

Aero coefficients - force
Page 10 of 20
Aft Pitch Stick Pulse at Mach 4 and 104,000 ft

Aero coefficients - moments
Page 11 of 20
HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at Mach 4 and 104,000 ft

\[ x_{10^0} \]

\[ x_{10^{-13}} \]

\[ x_{10^3} \]
Aerodynamic moments
Page 13 of 20
HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at Mach 4 and 104,000 ft

C.G. accelerations (G)
Page 14 of 20
Aft Pitch Stick Pulse at Mach 4 and 104,000 ft
HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at Mach 4 and 104,000 ft

AOACMD

GAMCMD

PHICMD

PSICMD

Guidance commands
Page 16 of 20
Aft Pitch Stick Pulse at Mach 4 and 104,000 ft

- HER
- PSIERR
- XTK

Guidance errors
Page 17 of 20
HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at Mach 4 and 104,000 ft

---

FCS Surface commands
Page 18 of 20

---
Surface positions - elevons, rudder & gear
Right Roll Stick Pulse at Mach 4 and 104,000 ft

1. **IAS**
   - Time (x10^0): 0.00, 2.00, 4.00, 6.00, 8.00, 10.00
   - Velocities: 253.5, 254.0, 254.5, 255.0, 255.5

2. **QBAR**
   - Time (x10^0): 0.00, 2.00, 4.00, 6.00, 8.00, 10.00
   - Velocities: 216.0, 217.0, 218.0, 219.0, 220.0

3. **VTOTALI**
   - Time (x10^0): 0.00, 2.00, 4.00, 6.00, 8.00, 10.00
   - Velocities: 3950, 3900, 3850, 3800

4. **MACH**
   - Time (x10^0): 0.00, 2.00, 4.00, 6.00, 8.00, 10.00
   - Velocities: 4.000, 3.950, 3.900, 3.850
Right Roll Stick Pulse at Mach 4 and 104,000 ft

- ALPDEG
- BETADEG
- GAMMAD
- TKANG

Flow & flight path angles
Page 3 of 20
Right Roll Stick Pulse at Mach 4 and 104,000 ft

- ALT

- SX

- SY

C.G. position states
Page 4 of 20

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HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at Mach 4 and 104,000 ft

Euler angles (degrees)
Page 5 of 20  F-187
Right Roll Stick Pulse at Mach 4 and 104,000 ft
Body axis linear accelerations
Right Roll Stick Pulse at Mach 4 and 104,000 ft

Body axis angular accelerations

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F-191
HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at Mach 4 and 104,000 ft

Aero coefficients - force
Page 10 of 20
Right Roll Stick Pulse at Mach 4 and 104,000 ft

Aero coefficients - moments
HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at Mach 4 and 104,000 ft

TIME

X

Y

Z

F-194
Right Roll Stick Pulse at Mach 4 and 104,000 ft

L: Aerodynamic moment

M: Aerodynamic moment

N: Aerodynamic moment

Aerodynamic moments
Page 13 of 20
HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at Mach 4 and 104,000 ft

C.G. accelerations (G)
Page 14 of 20
HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at Mach 4 and 104,000 ft

FCS mode flags
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Right Roll Stick Pulse at Mach 4 and 104,000 ft

AOACMD

GAMCMD

PHICMD

PSICMD

Guidance commands
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HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at Mach 4 and 104,000 ft

Guidance errors
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F-199
Right Roll Stick Pulse at Mach 4 and 104,000 ft

FCS Surface commands
Page 18 of 20
Surface positions - body flaps

F-202
Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

DCPILOT

DWPILOT

DPPilot

DLSBCOM

Pilot Inputs
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F-203
Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

1. IAS

2. QBAR

3. VTOTALI

4. MACH

Velocities
Page 2 of 20
Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

Flow & flight path angles
Page 3 of 20
Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

Body axis velocities

F-208
Left Rudder Pedal Pulse at Mach 4 and 104,000 ft

Body axis angular rates
Page 7 of 20
Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

Body axis angular accelerations

F-211
Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

Aero coefficients - moments

F-213
HL-20 Dynamic Check Case Data Plots 911206
Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

Aero forces
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Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

C.G. accelerations (G)

F-216
Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

FCS mode flags
Page 15 of 20
HL-20 Dynamic Check Case Data Plots 911206
Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

AOACMD

GAMCMD

PHICMD

PSICMD

Guidance commands
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Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

Guidance errors
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Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

FCS Surface commands
Page 18 of 20

F-220
Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

Surface positions - elevons, rudder & gear
Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

Surface positions - body flaps

F-222
Speed Brake Handle Pulse at Mach 4 and 104,000 ft

Pilot Inputs
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HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at Mach 4 and 104,000 ft

Velocities
Page 2 of 20
Speed Brake Handle Pulse at Mach 4 and 104,000 ft

C.G. position states
Page 4 of 20
Body axis velocities
Page 6 of 20
F-228

HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at Mach 4 and 104,000 ft

---

U

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V

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W

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HDOT
Body axis angular rates

F-229
Speed Brake Handle Pulse at Mach 4 and 104,000 ft

Body axis linear accelerations

Page 8 of 20
Body axis angular accelerations

PAGE 9 OF 20
HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at Mach 4 and 104,000 ft

Aero forces
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HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at Mach 4 and 104,000 ft

Aerodynamic moments
Page 13 of 20
F-235
HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at Mach 4 and 104,000 ft

- ANX

- ANY

- ANZ

C.G. accelerations (G)
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**Title and Subtitle**

Real-Time Simulation Model of the HL-20 Lifting Body

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**Abstract**

A proposed manned spacecraft design, designated the HL-20, has been under investigation at Langley Research Center. Included in that investigation are flight control design and flying qualities studies utilizing a man-in-the-loop real-time simulator. This report documents the current real-time simulation model of the HL-20 lifting body vehicle, known as version 2.0, presently in use at NASA Langley Research Center. Included are data on vehicle aerodynamics, inertias, geometries, guidance and control laws, and cockpit displays and controllers. In addition, trim case and dynamic check case data is provided. The intent of this document is to provide the reader with sufficient information to develop and validate an equivalent simulation of the HL-20 for use in real-time or analytical studies.

**Subject Terms**

LIFTING BODY
HL-20 SIMULATOR
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AERODYNAMICS
CONTROL LAWS

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Unclassified

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