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

\( a \)  Parabolic preflare curvature constant, rad/ft
\( a_{n_1} \)  Initial normal acceleration increment in preflare, ft/sec\(^2\)
\( b \)  Reference wing span, feet
\( \bar{c} \)  Mean aerodynamic chord, feet
\( h_0 \)  Initial center of gravity altitude, feet
\( h_1 \)  Parabolic slope intercept altitude, feet
\( h_2 \)  Inner glideslope capture height, feet
\( h_c \)  Commanded altitude, feet
\( h_{cg} \)  Height of center of gravity above runway, feet
\( h_p \)  Parabolic zero-slope altitude, feet
\( I_{xx} \)  Moment of inertia about body X-axis, slug-ft\(^2\)
\( I_{yy} \)  Moment of inertia about body Y-axis, slug-ft\(^2\)
\( I_{zz} \)  Moment of inertia about body Z-axis, slug-ft\(^2\)
\( N_z \)  Acceleration in body Z-axis, ft/sec\(^2\)
\( q_b \)  Body axis pitch rate, rad/sec
\( S \)  Reference area, feet\(^2\)
\( V_1 \)  Initial flare velocity, ft/sec
\( x_0 \)  Initial center of gravity location in runway coordinates, feet
\( x_1 \)  Parabolic slope intercept range, feet
\( x_2 \)  Inner glideslope capture range, feet
\( x_3 \)  Inner glideslope runway intercept point, feet
\( x_{ap} \)  Outer glideslope aimpoint range, feet
\( x_{cg} \)  Location of center of gravity in runway coordinates, feet
\( x_{ep} \)  X-axis location of pilot's eyepoint in aircraft coordinates, feet
\( x_p \)  Parabolic zero-slope range, feet
$y_{ep}$  Y-axis location of pilot's eyepoint in aircraft coordinates, feet
$z_{ep}$  Z-axis location of pilot's eyepoint in aircraft coordinates, feet
γ1  Outer glideslope angle, degrees
γ1  Initial preflare curvature rate, rad/sec
γ2  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
Model Description

Description of Vehicle

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
Axes, 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 showing control surface nomenclature](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:

- chord, \( \bar{c} \) = 28.24 ft
- area, \( S \) = 286.45 ft²
- span, \( b \) = 13.89 ft

Pilot eyepoint location (relative to c.g.)

- \( x_{ep} \) = 7.87 ft
- \( y_{ep} \) = -1.35 ft
- \( z_{ep} \) = -3.42 ft

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.
Inertial data

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

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></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>

Figure 3. - Landing gear geometry
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.

---

Figure 6. - Lateral stick force characteristics

Figure 7. - Lateral stick command signal versus displacement
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.

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>±2 ft/sec</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>±2 ft/sec</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>±2 ft/sec</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/hl-20/. These files are described below:

(a) README.TXT  
read for the latest information concerning the model.

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

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

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

(e) pls_aerov2.txt  
Aero tables for version 2.0 in original text table format

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

(g) getData.txt  
getData format description

(h) 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
### Glossary of Symbols and Terms

**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** = heading alignment circle
- **IN** = inches
- **LB** = pounds
- **MAX** = maximum
- **MIN** = minimum
- **NEG** = negative
- **NMI** = nautical miles
- **NOM** = nominal (usual or expected value)
- **POS** = positive
- **PSF** = pounds per square foot
- **RAD** = radians
- **RPS** = radians per second
- **TED** = trailing edge down
- **TEL** = trailing edge left
- **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*

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>ALPDEG</td>
<td>Angle of attack, deg</td>
</tr>
<tr>
<td>ALPHA</td>
<td>Angle of attack, rad</td>
</tr>
<tr>
<td>ALT</td>
<td>Altitude above runway, ft</td>
</tr>
<tr>
<td>ALTREF</td>
<td>Reference altitude on desired path, ft</td>
</tr>
<tr>
<td>ANX</td>
<td>Body frame acceleration forward, g's</td>
</tr>
<tr>
<td>ANY</td>
<td>Body frame acceleration to right, g's</td>
</tr>
<tr>
<td>ANZ</td>
<td>Body frame acceleration upward, g's (not body Z axis!)</td>
</tr>
<tr>
<td>AOMCMD</td>
<td>Commanded angle of attack, deg</td>
</tr>
<tr>
<td>AOMLD</td>
<td>Angle of attack for maximum lift/drag ratio, deg</td>
</tr>
<tr>
<td>AONOM</td>
<td>Nominal angle of attack versus Mach number, deg</td>
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<tr>
<td>AUTOBB</td>
<td>Auto speedbrake mode selected (T/F)</td>
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<tr>
<td>BEDOT</td>
<td>Estimated sideslip rate, dps (aka beta dot)</td>
</tr>
<tr>
<td>BETA</td>
<td>Sideslip angle, rad +relative wind from right</td>
</tr>
<tr>
<td>BETADEG</td>
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<tr>
<td>CDTOT</td>
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</tr>
<tr>
<td>CLTOT</td>
<td>Total lift coefficient</td>
</tr>
<tr>
<td>CLLSTOT</td>
<td>Total roll (little l) coefficient</td>
</tr>
<tr>
<td>CLNYTQT</td>
<td>Total yaw (little n) coefficient</td>
</tr>
<tr>
<td>COLMAX</td>
<td>Maximum absolute pitch stick deflection, + aft</td>
</tr>
<tr>
<td>COLUMHC</td>
<td>Column pitch command after shaping, + aft or pitch up</td>
</tr>
<tr>
<td>COORDNZ</td>
<td>Normal acceleration in coordinated turn, g's</td>
</tr>
<tr>
<td>COSALP</td>
<td>Cosine of angle of attack (alpha)</td>
</tr>
<tr>
<td>COSPHI</td>
<td>Cosine of bank angle</td>
</tr>
</tbody>
</table>

**A-1**
* COSTHE  
  COSINE OF PITCH ANGLE
* CYTOT  
  TOTAL SIDE FORCE COEFFICIENT

* DA  
  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
* DADIR  
  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
* DCPILOT  
  PITCH STICK (COLUMN) DEFLECTION, IN +AFT (-5...9)
* DECL  
  ELEVATOR COMMAND LOWER LIMIT, DEG + TED
* DECMD  
  ELEVATOR COMMAND TO ACTUATORS, DEG + TED
* DECMDL  
  LIMIT ELEVATOR ACTUATOR COMMAND, DEG +TED
* DECU  
  ELEVATOR COMMAND UPPER LIMIT, DEG +TED
* DEDS  
  ELEVATOR COMMAND TO TRIM SPEEDBRAKE PITCH MOMENT, DEG
* DEG  
  ELEVATOR RESPONSE TO GAMMA COMMAND, 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
* DELEDC  
  ELEVATOR DEFLECTION, DEG +TED
* DELEDCF  
  FILTERED ELEVATOR DEFLECTION, DEG +TED (NOT USED)
* DELEDEGP  
  PAST ELEVATOR DEFLECTION, DEG +TED
* DLEL  
  LEFT ELEVON DEFORMATION LOWER LIMIT, DEG +TED
* DLEP  
  LEFT ELEVON PAST DEFLECTION, DEG +TED
* DLEPP  
  LEFT ELEVON PAST PAST DEFLECTION, DEG +TED
* DLER  
  LEFT ELEVON ACTUATOR TIME CONSTANT, SEC
* DLETAU  
  LEFT ELEVON ACTUATOR TIME LIMIT, DPS +TED
* DLEU  
  LEFT ELEVON DEFORMATION 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
* DLFD  
  LOWER BODY FLAP COMMAND TO ASSIST ELEVATOR, DEG +TED
* DLGCT  
  LANDING GEAR DEFLECTION, PERCENT
* DLL  
  LOWER LEFT BODY FLAP COMMAND, DEG +TED
* DLMCL  
  LOWER LEFT BODY FLAP COMMAND LOWER LIMIT, DEG +TED
* DLMCL  
  LOWER LEFT BODY FLAP COMMAND AS AILERON, DEG +TED
* DLMDL  
  LOWER LEFT BODY FLAP COMMAND LIMITED, DEG + TED
* DLLCL  
  LOWER LEFT BODY FLAP COMMAND UPPER LIMIT, DEG +TED
* DLLCU  
  LOWER LEFT BODY FLAP DEFORMATION LOWER LIMIT, DEG +TED
* DLLP  
  LOWER LEFT BODY FLAP DEFLECTION LOWER LIMIT, DEG +TED
* DLLPP  
  LOWER LEFT BODY FLAP DEFORMATION UPPER LIMIT, DEG +TED
* DLLR  
  LOWER LEFT BODY FLAP DEFORMATION RATE LIMIT, DPS +TED
* DLLTAU  
  LOWER LEFT BODY FLAP ACTUATOR TIME CONSTANT, SEC
* DLLU  
  LOWER LEFT BODY FLAP DEFLECTION UPPER LIMIT, DEG +TED
* DLL21  
  LOWER LEFT BODY FLAP Z TRANSFORM PAST OUTPUT COEFFICIENT
* DLL22  
  LOWER LEFT BODY FLAP Z TRANSFORM PRESENT INPUT COEFFICIENT
* DLL23  
  LOWER LEFT BODY FLAP Z TRANSFORM PAST INPUT COEFFICIENT
* DLR  
  LOWER RIGHT BODY FLAP DEFLECTION, DEG +TED
* DLRC  
  LOWER RIGHT BODY FLAP COMMAND, DEG +TED
* DLRTL  
  LOWER RIGHT BODY FLAP COMMAND LOWER LIMIT, DEG +TED
* DLRMDL  
  LOWER RIGHT BODY FLAP COMMAND AS AILERON, DEG +TED
* DLRCMDL  
  LOWER RIGHT BODY FLAP COMMAND LIMITED, DEG + TED
* DLRCU  
  LOWER RIGHT BODY FLAP COMMAND UPPER LIMIT, DEG +TED
* DLRNC  
  Rudder deflection to aero, DEG +TEL
* DLR  
  LOWER RIGHT BODY FLAP DEFLECTION LOWER LIMIT, DEG +TED
* DLRR  
  LOWER RIGHT BODY FLAP PAST DEFLECTION, DEG +TED
* DLLPP  
  LOWER RIGHT BODY FLAP PAST PAST DEFLECTION, DEG +TED
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<td>TOTAL GROUND TRACK DISTANCE TO GO TO TOUCHDOWN, FT</td>
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<td>UPPER LEFT BODY FLAP Z TRANSFORM PAST INPUT COEFFICIENT</td>
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<td>DUR</td>
<td>UPPER RIGHT BODY FLAP DEFLECTION, DEG +TED</td>
</tr>
<tr>
<td>DURC</td>
<td>UPPER RIGHT BODY FLAP COMMAND, DEG +TED</td>
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</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 DESTRUCTION LOWER LIMIT, DEG +TED
* DURPP  UPPER RIGHT BODY FLAP PAST DESTRUCTION, DEG +TED
* DURRL  UPPER RIGHT BODY FLAP DESTRUCTION RATE LIMIT, DPS +TED
* DURU  UPPER RIGHT BODY FLAP ACTUATOR TIME CONSTANT, SEC
* DUR21  UPPER RIGHT BODY FLAP DESTRUCTION UPPER LIMIT, DEG +TED
* DUR22  UPPER RIGHT BODY FLAP Z TRANSFORM PAST OUTPUT COEFFICIENT
* DUR23  UPPER RIGHT BODY FLAP Z TRANSFORM PRESENT INPUT COEFFICIENT
* DWPIL  ROLL STICK (WHEEL) DESTRUCTION, +RIGHT (-60...60)
* ELOC  LOCALIZER DESTRUCTION, DEG +RIGHT OF CENTERLINE (-2.5...2.5)
* FAT1  Z TRANSFORM DESTRUCTION ON PAST OUTPUT OF AUTO TRIM FILTER
* FAT2  Z TRANSFORM DESTRUCTION ON PRESENT INPUT TO AUTO TRIM FILTER
* FAT3  Z TRANSFORM DESTRUCTION ON PAST INPUT TO AUTO TRIM FILTER
* FATB  AUTO TRIM LEAD DESTRUCTION (AS+B / TS+1 FILTER)
* FATC  AUTO TRIM LAG DESTRUCTION
* FATT  AUTO TRIM TIME CONSTANT, SEC
* FATM  AUTO TRIM TIME CONSTANT FOR MANUAL MODES, SEC
* FN21  Z TRANSFORM DESTRUCTION ON PAST OUTPUT OF NZ FILTER
* FN22  Z TRANSFORM DESTRUCTION ON PRESENT INPUT TO NZ FILTER
* FN23  Z TRANSFORM DESTRUCTION ON PRESENT INPUT TO NZ FILTER
* FN2A  NZ FILTER LEAD DESTRUCTION (AS+B / TS+1 FILTER)
* FN2B  NZ FILTER LAG DESTRUCTION
* FN2T  NZ FILTER TIME CONSTANT, SEC
* FB21  Z TRANSFORM DESTRUCTION ON PAST OUTPUT OF Q-BODY FILTER
* FB22  Z TRANSFORM DESTRUCTION ON PRESENT INPUT TO Q-BODY FILTER
* FB23  Z TRANSFORM DESTRUCTION ON PAST INPUT TO Q-BODY FILTER
* FB2A  PITCH RATE (Q-BODY) FILTER LEAD DESTRUCTION (AS+B / TS+1 FILTER)
* FB2T  PITCH RATE FILTER LAG DESTRUCTION
* GMCMD  FLIGHT PATH ANGLE (GAMMA) COMMAND, DEG
* GAMCL  GAMMA COMMAND LOWER LIMIT, DEG
* GAMCML  GAMMA COMMAND UPPER LIMIT, DEG
* GAMDO  ESTIMATED FLIGHT PATH ANGLE RATE, DPS (AKA GAMMA DOT)
* GAMDOTF  GAMMA DOT FILTER OUTPUT, DPS
* GAMDOTP  PAST VALUE OF GAMMA DOT, DPS
* GAMFLL  FLIGHT PATH ANGLE FLOOR VALUE, DEG
* GAMFLLT  GAMMA FILTER OUTPUT, DEG (NOT USED)
* GAMFLR  FLIGHT PATH ANGLE DURING FLARE, DEG
* GAMMA  FLIGHT PATH ANGLE, DEG +CLIMBING
* GAMA1  OUTER GLIDE SLOPE ANGLE, DEG
* GAMA2  INNER GLIDE SLOPE ANGLE, DEG
* GMAPAD  FLIGHT PATH ANGLE (GAMMA), DEG +CLIMBING
* GAMAP  PAST VALUE OF GAMMA, DEG (NOT USED)
* GAMREF  FLIGHT PATH DESTRUCTION ON THE GLIDESLOPE, DEG
* GBFA  GAIN, LOWER BODY FLAPS AS AILERONS, DEG/DEG
* GBBB  GAIN, LOWER BODY FLAPS VERSUS BETA, DEG/DEG
* GBFB  GAIN, LOWER BODY FLAPS VERSUS BETA DOT, DEG/DPS
* GDAW1  GAIN, AILERON PER LEFT WHEEL DESTRUCTION, DEG/DEG
* GDAW2  GAIN, AILERON PER RIGHT WHEEL DESTRUCTION, DEG/DEG
* GDACC  GAIN, AILERON PER BANK ERROR, DEG/DEG
* GDAP  GAIN, HEADING PER CROSSTRAIGHT DESTRUCTION, DEG/FT
* GDAE  GAIN, AILERON PER TAU RATE, DEG/DPS
* GDAF  GAIN, BANK ANGLE PER HEADING DESTRUCTION, DEG/DEG
* GDECC  GAIN, ELEVATOR PER GAMMA DESTRUCTION, DEG/DEG
* GDECGC  GAIN, ELEVATOR PER GAMMA DOT, DEG/DPS
* GDLA  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
* GDRDA  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
* GGFFL  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
* GGUL  GAMMA COMMAND UPPER LIMIT, DEG
* GGACH  ELEVATOR GAIN AS FUNCTION OF MACH NUMBER
* GGBAR  ELEVATOR GAIN AS FUNCTION OF DYNAMIC PRESSURE
* GBGAM  GAMMA COMMAND UP LIMIT, DEG
* GQBAR  GAIN, ELEVATOR OVER DYNAMIC PRESSURE, 1/PSF
* GRND  1 = WHEELS ON THE GROUND (0 OR 1)
* GRSAS  GAIN, YAW DAMPER DEG/DPS
* GSLAP  SLAPDOWN (DEROTATION) PITCH RATE GAIN

* H  INTEGRATION TIME STEP, SEC
* HACCX  DOWNRANGE LOCATION OF HAC CENTER, FT (USUALLY NEG)
* HACCY  CROSSRANGE LOCATION OF HAC CENTER, FT
* HACDC  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
* HACMTK  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
* HPLCO  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-ADAPTER ATTACHED 3-ADAPTER 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 7-TURN TO FINAL 8-DOWNMIND 9-TACAN HOMING 5-ON HAC 6-TO HAC 7-MINIMUM ENERGY
* MGUID  GUIDANCE MODE 1-FINAL 2-TURN TO FINAL 3-DOWNMIND 4-TACAN HOMING 5-ON HAC 6-TO HAC 7-MINIMUM ENERGY
* MODE  SIMULATOR MODE 1-RESET 2-NULL 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, DEG
* PDOT  BODY ROLL ACCELERATION, RAD/SEC/SEC
* PHI  EULER ROLL ANGLE (BANK), RAD
* PHILCHO  BANK COMMAND LIMIT AT HIGH ALTITUDE, DEG
* PHILCHO  BANK COMMAND LIMIT AT LOW ALTITUDE, DEG

A-5
* 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
* PSIERR      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
* RBW21       YAW RATE WASHOUT Z TRANSFORM COEFFICIENT
* RDEG        BODY YAW RATE, DPS
* RDEGP       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
* VTOTA1I     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           DUMMY VALUE IN CLAMP LIMIT FUNCTION
* X           DISTANCE TO THRESHOLD AT INNER GLIDESLOPE INTERCEPT, FT
* XPLOCO      DISTANCE TO THRESHOLD AT PARABOLIC CURVE ZERO SLOPE, FT
* XP3INTC     DISTANCE TO THRESHOLD AT PREFLARE INTERCEPT, FT
* XTCHDN      DISTANCE FROM THRESHOLD TO TOUCHDOWN AIM POINT, FT
* XTR         DISTANCE TO THE EDGE OF THE HEADING ALIGNMENT CIRCLE, FT
Appendix A: Guidance and Control Law Glossary

* Y  SUM OF BODY FRAME FORCES TO RIGHT, LB
* Y  DUMMY VALUE IN CLAMP LIMIT FUNCTION
* Z  SUM OF BODY FRAME FORCES DOWNWARD, LB
* Z  DUMMY VALUE IN CLAMP LIMIT FUNCTION
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 \( x_{cg} > x_1 \):
  \[
  h_c = h_1 + (x_{cg} - x_1) \tan \gamma_1
  \]
  (1)

- during the parabolic flare maneuver \( x_1 > x_{cg} > x_2 \):
  \[
  h_c = h_p + a \left( x_{cg} - x_p \right)^2
  \]
  (2)

- during the final approach to touchdown \( x_{cg} \geq x_2 \):
  \[
  h_c = \max \left\{ \left( x_{cg} - x_3 \right) \tan \gamma_2, 0 \right\}
  \]
  (3)

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 path 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):

$$x_2 = \frac{h_2}{\tan \gamma_2} + x_3$$  

(4)

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):

$$\dot{\gamma}_1 = \frac{a_n}{V_1}$$  

(5)

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):

$$\frac{d\gamma}{dt} = \frac{d\gamma}{dx} \frac{dx}{dt}$$  

(6)

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

$$h = h_p + a (x - x_p)^2$$  

(7)

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

(8)

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

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

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

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

(9)

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:

$$a = \frac{\dot{\gamma}_1 \left( 1 + \tan^2 \gamma_1 \right)}{2 V_1 \cos \gamma_1}$$  

(10)
Equation (8) can be rearranged and applied at point 2 to yield an expression for the parabolic vertex downrange coordinate, $x_p$:

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

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

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

Since $h_3$ was given and $x_2$ and $x_p$ are now know, the altitude of the vertex of the parabola, $h_p$, can be determined by using equation (7) at point 2:

$$h_p = h_3 - a(x_2 - x_p)^2$$

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:

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

**Nominal trajectory parameters**

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial flare velocity</td>
<td>$V_1 = 502.3$ ft/sec</td>
</tr>
<tr>
<td>Initial normal accel. limit</td>
<td>$a_{n1} = 0.25$ g</td>
</tr>
<tr>
<td></td>
<td>$= 8.05$ ft/sec²</td>
</tr>
<tr>
<td>Initial flight path angle</td>
<td>$\gamma_1 = -17$ degrees</td>
</tr>
<tr>
<td>Final flight path angle</td>
<td>$\gamma_2 = -1$ degrees</td>
</tr>
<tr>
<td>Final flight path capture height</td>
<td>$h_2 = 75$ ft</td>
</tr>
<tr>
<td>Target touchdown point</td>
<td>$x_3 = 2200$ ft</td>
</tr>
</tbody>
</table>
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
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 (PSERR), 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 (DECM).

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 commanded 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 (DECM) after appropriate limits are applied. The aileron command (DACMD) is combined with the speedbrake command (DSBCMD), and if necessary, the elevator command (DECM) 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

GAMREF

ALT 

GGFLR

GGFL = -0.25

To FCS

To Fliit Director

B-7
Appendix B: Guidance and Control Law Diagrams

VMS/PLS Roll Guidance & Flight Control

TACBRC to Runway Bearing to MEP

PSIREF

5y → sign → 160 + +

-.00005 → atan → PSICOR + +

-.0001 → 3

atan → 1

0 → 10

PSICMD

(tangent to HAC)

PSICMD

(on HAC)

HACCTR - .005

0 + 1 → GDAPS

TKANG

PHIHAC = \frac{V_{TOTAL}^2}{G\mu HACRAD}

10

PHICLLO (abs. value limit)

MGUID = 3, 4, 6

MGUID = 1, 2, 5, 7

MGUID

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

PHID

PDEG

GDAP

-1, 4

GDADUL

.67

1

.93

1.3 MACH

(i.e. limited to 40 below M1, 13.3 above M3)

DACMD

To Actuators
Appendix B: Guidance and Control Law Diagrams

VMS/PLS NZQ PITCH CONTROL LAW

DCPILOT
9 aft
-5 fwd

ABS

RSQRAW

1 - RSQRAW

RMA

1

COLMAX

RSQRAW = 0.6

COLMAX = 9.0

= DEDIR
GQBAR

= DEQ
GQBAR

SINPHI
COSPHI
TANPHI

RDES

QDEG

QDEG = 0.5


NZ

VTOTALI

1843

VTOTALI

GAMCMD

GAMMAD

NZ

GSLAPRT

GSLAP

-4

-2.0

QBAR

GQBAR

GQBAR1 = 179

GQBAR1

GQBAR + 1

LIMIT: 2 TO 2.0

MACH

DLEDEG

1

1 - TS + 1

TS + 1

DETTRIM

T = 0.45 SAS
T = 2.0 AUTO

B-9
Appendix B: Guidance and Control Law Diagrams

VMS/PLS YAW & SPEED CONTROL

DPPilot $\pm 2.7 + \text{left}$

$\frac{s}{2s + 1}$

GRSAS $= 40$

$0.0175$

MACH $> 1.2$

ROLL SAS or AUTO

DACMD $= -0.01$

GDRDA

DRDIR

DRCMD

To Actuators

DLSBCOM $0 \rightarrow 40$

DSBSF1 $= 0$

DSBSF2 $= 0.0275$ ($0 \rightarrow 40$

DSBDIR

IAS $+ \rightarrow 2.0$

$300$ (Hard cocked)

$20$

MACH $\leq 1.2$ or ALT $\leq 1200$

$\frac{1}{s + 1}$

DSBSAS

To HUD $\rightarrow$ SBCMD

DSB CMD

To Actuators
Appendix B: Guidance and Control Law Diagrams

VMS/PLS Control - Surface Mixer Logic

Note: BEVOT = PDEG * SINALP - RDEG * COSALP
Appendix B: Guidance and Control Law Diagrams

**heading alignment circle geometry**

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

D_TOGO is groundtrack range from aircraft to WP1, around the HAC to 'outer' marker, and then to WP2.

\[ \text{ALTREF} = \tan (\text{GAMREF}) \times (\text{D_TOGO} - X_{AP}) \]
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 ±1.0
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
  LIMIT (X,Y,Z) = AMIN1(Z,AMAX1(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
* TACDME SLANT RANGE TO RUNWAY THRESHOLD, DEG
* NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
* GLIDESLOPE GEOMETRY DEFINITION CONSTANTS
  DATA GAMMA1 , GAMMA2 , FLRVEL1 / -17.00, -1.00, 502.3 /
  DATA ACCLIM1 , HFFCAPT , XTCHDN / 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.HFFCAPT) 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) * TAND(GAMMA1)
  GAMREF = GAMMA1
ELSEIF ((SX .GE. XPSINTC) .AND. (SX .LT. XAPCAPT)) THEN
    HGS = HPLOC0 + 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 = 0.002615 * 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.

*** PLS GUIDANCE LAWS
***
* 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
  5-TO HAC  6-ON HAC
* PHICMD  BANK ANGLE COMMAND, DEG

******************************************************************************
* GUIDANCE MODEING ******************************************************************************

* 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 HACX,HACRAD / -36300., 31000. /
* IF (MGUID.EQ.5.OR.MGUID.EQ.6) THEN
* DISTANCE TO CENTER OF HAC
  HACCY = -HACRAD
  HACDC = SQRT ((HACX-SX)**2 + (HACCY-SY)**2)
* CROSSTrack DISTANCE FROM EDGE OF HAC
  HACXTK = HACDC - HACRAD
* HEADING TO CENTER OF HAC
  PSIHACC = 57.3*ATAN2 ((HACCY - SY),(HACX - 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 = HACDC**2 - HACRAD**2
  IF (HACDT2.GT.0) HACDT = SQRT (HACDT2)

C-3
HEADING COMMAND

\[ PSICMD = PSIHACC + 57.3 \times \text{ASIN} \left( \frac{HACRAD}{HACDC} \right) \]

DISTANCE TO GO TO RUNWAY THRESHOLD

\[ DTOGO = HACDT + 0.01745 \times \text{ABS} \left( PSICMD \right) \times HACRAD - HACX \]

REFERENCE ALTITUDE AND ALTITUDE ERROR

\[ ALTREF = 0.305 \times (DTOGO - 5577.) \]
\[ HER = ALTREF - ALT \]

ANGLE OF ATTACK COMMAND

\[ AOACMD = AOANOM \]

BELOW MACH 1.5 MODIFY ALPHA TO CORRECT ALTITUDE ERROR

\[ \text{IF} \ (\text{MACH} < 1.5) \ \text{AOACMD} = \text{CLIMIT} \ (\text{AOANOM} + 0.002 \times \text{HER}, 4.0, 9.0) \]

GAMMA COMMAND FILTER \[ \tau = 6 \text{ SEC} \]

\[ \text{GAMCMD} = 0.995 \times \text{GAMCMD} + 0.005 \times (\text{GAMMAD} + \text{AOACMD} - \text{ALPDEG}) \]

FLYING AROUND THE HAC

\[ \text{IF} (\text{ALT} < 1.2000 \text{ OR. ALT. } < 20000 \text{ AND. ABS} (\text{SY}) < 1.000.) \ \text{MGUID} = 1 \]

NOMINAL BANK ANGLE AND HEADING COMMAND ON HAC

\[ \text{PHIHAC} = 57.3 \times \text{ATAN} \left( \frac{\text{VTOTALI}^2}{32.2 \times HACRAD} \right) \]
\[ PSICMD = \text{PSIHACC} + 90. - 0.003 \times HACXTK - \text{PHIHAC}/\text{GDAPS} \]

\[ PSICMD = \text{SIGN} (\text{PSICMD}, -\text{SY}) \]

\[ \text{IF} (\text{PSICMD} > 180.) \ \text{PSICMD} = 360. \]
\[ \text{IF} (\text{PSICMD} < -180.) \ \text{PSICMD} = \text{PSICMD} + 360. \]

DISTANCE TO GO AROUND HAC TO RUNWAY THRESHOLD

\[ DTOGO = 0.01745 \times \text{ABS} \left( PSICMD \right) \times HACRAD - HACX \]

REFERENCE ALTITUDE AND ALTITUDE ERROR

\[ ALTREF = 0.305 \times (DTOGO - 5577.) \]
\[ HER = ALTREF - ALT \]

GAMMA COMMAND ON HAC

\[ \text{HACGAM} = \text{CLIMIT} (-17. + 0.002 \times \text{HER}, -25., -14.) \]

MINIMUM ENTRY POINT STEERING

AIM TO INTERCEPT CENTERLINE 20000 FT BEFORE THRESHOLD

WHILE FLYING MAXIMUM L/D GAMMA

\[ \text{IF} (\text{ALT} < 1.300 \times \text{TACDME} + 50. \times \text{TACDAZ}) \ \text{THEN} \]
\[ \text{HACGAM} = -12.5 \]
\[ \text{PSICMD} = 57.3 \times \text{ATAN} (\text{SY}/(\text{SX} + 20000.).) \]
\[ \text{ENDIF} \]

GAMMA COMMAND FILTER \[ \tau = 3 \text{ SEC} \]

\[ \text{GAMCMD} = 0.990 \times \text{GAMCMD} + 0.010 \times \text{HACGAM} \]
\[ \text{ENDIF} \]

END OF HEADING ALIGNMENT CYLINDER GUIDANCE

ENDIF

**** MGUID = 4 TACAN HOMING

FOLLOWS ALPHA VS MACH SCHEDULE UNTIL MODE 3

\[ \text{IF} (\text{MGUID.EQ.4}) \ \text{THEN} \]
\[ \text{IF} (\text{TACDME.LT.15.0 \ OR. MACH.LT. 1.0}) \ \text{MGUID} = 3 \]
\[ \text{GAMCMD} = 0.997 \times \text{GAMCMD} + 0.003 \times (\text{GAMMAD} + \text{AOACMD} - \text{ALPDEG}) \]
\[ \text{PSICMD} = \text{TACBRG} \]
\[ \text{ENDIF} \]

**** MGUID = 3 DOWNWIND MODE

C-4
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 = .020
  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, .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 )
  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
  GAMFFL = GGFLR*ALT + GGFFL
  IF (ALT.LT.HFPCAPT .AND. GAMCMD.LT.GAMFFL) GAMCMD = GAMFFL
  IF (MPAUTO .AND. GAMCMD.LT.GAMFFL) GAMCMD = GAMFFL

  GDAKP = -.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.-0.5) 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)
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 DELECTION, DEG
DPPILLOT RUDDER PEDAL DEACEMENT, IN LEFT
DPWPILOT WHEEL (STICK) DEFLECTION, DEG RIGHT
GRND I 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
PHICMD 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 ANGLE
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
DECMC 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
(A+B)/(C+S+1) K=Z1=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

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 DBBSAS, DEDSB / 20.0, 0.0 /
DATA RA, DATRIM / 0.03, 0.0 /

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

******************************************************************************** PITCH CONTROL ********************************************************************************
ELEVATOR TRIM AT RESET
If (MODE.EQ.1) DETRIM = DETRIMO

FILTERS
\[ AS + B \over TS + 1 \]

FILTER VALUES FOR NZ, QBODY, AND AUTOTRIM
DATA FNZA,FNZB,FNZT / 0.10, 1.00, 0.30 /
DATA FQBA,FQBB,FQBT / 1.00, 1.00, 0.50 /
DATA FATB,FATB,FATTM,FATTA / 0., 1.0, 0.45, 2.00 /

CHANGE TRIM Tau IN AUTOLAND
FATT = FATTM
If (MPAUTO) FATT = FATTA

INITIAL VALUES FOR FILTERS IN RESET (MODE=1)
If (MODE.EQ.1) THEN
\begin{align*}
QDEGF &= QDEG \\
QDEGP &= QDEG \\
GAMDOTF &= 0. \\
GAMDOTP &= 0.0 \\
DLEDEGF &= DLEDEG \\
DLEDEGP &= DLEDEG \\
GAMFILT &= GAMMAD \\
DSBP &= DLSBDEG \\
\end{align*}
ENDIF

Z-TRANSFORM COEFFICIENTS FOR FILTERS
If (FNZT.EQ.0) THEN
\begin{align*}
FNZ1 &= 0.0 \\
FNZ2 &= FNZB \\
FNZ3 &= 0.0 \\
\end{align*}
ELSE
\begin{align*}
FNZ1 &= \exp (-.03/FNZT) \\
FNZ3 &= -FNZA*FNZ1/FNZT \\
FNZ2 &= FNZB*(1.0-FNZ1) - FNZ3 \\
\end{align*}
ENDIF

If (FQBT.EQ.0) THEN
\begin{align*}
FQB1 &= 0.0 \\
FQB2 &= FQBB \\
FQB3 &= 0.0 \\
\end{align*}
ELSE
\begin{align*}
FQB1 &= \exp (-.03/FQBT) \\
FQB3 &= -FQBA*FQB1/FQBT \\
FQB2 &= FQBB*(1.0-FQB1) - FQB3 \\
\end{align*}
ENDIF

If (FATT.EQ.0) THEN
\begin{align*}
FAT1 &= 0.0 \\
FAT2 &= FATB \\
FAT3 &= 0.0 \\
\end{align*}
ELSE
\begin{align*}
FAT1 &= \exp (-.03/FATT) \\
FAT3 &= -FATA*FAT1/FATT \\
FAT2 &= FATB*(1.0-FAT1) - FAT3 \\
\end{align*}
ENDIF

*************** OPERATE LOOP ***************

DEQ = DEGC = 0.

QUADRATIC STICK SHAPING
0 = LINEAR 1 = SQUARE LAW
DATA RSQ LAW, COLMAX / 0.6, 7.5 /
**Appendix C: Guidance and Control Law Listing**

\[
\text{COLSHC} = (1.0-\text{RSQ LAW}) \cdot \text{DCPILOT} + \text{RSQ LAW} \cdot \text{DCPILOT} \cdot \text{ABS(\text{DCPILOT})} / \text{COLMAX}
\]

**NZQ Control Law**

**Qbar and Mach Gain Compensation**

\[
\text{QBAR} = \text{CLIMIT} \left( \frac{\text{QBAR}_1 / \text{QBAR} + 1}{0.2, 2.0} \right)
\]

\[
\text{GMACH} = \text{CLIMIT} \left( 5.0 \cdot \text{MACH} - 4.0, 1.0, 6.0 \right)
\]

**Pitch Rate Command, Feedback & Filter**

\[
\text{TANPHIL} = \text{CLIMIT} \left( \frac{\text{SINPHI} / \text{COSPHI}, -1.0, 1.0}{} \right)
\]

\[
\text{QCOORD} = \text{QDEG} - \text{RDEG} \cdot \text{TANPHIL}
\]

\[
\text{QDEGF} = \text{QFB1} \cdot \text{QDEGF} + \text{QFB2} \cdot \text{QCOORD} + \text{QFB3} \cdot \text{QDEGP}
\]

\[
\text{QDEGP} = \text{QCOORD}
\]

\[
\text{DEQ} = \text{QBAR} \cdot ( \text{QDEGF} - \text{GDQDC} \cdot \text{COLSHC})
\]

**NZ Feedback Used to Estimate \( \Gamma \) Dot**

\[
\text{COORDNZ} = \text{CLIMIT} \left( \frac{\text{COSTHE} / \text{COSPHI}, 0.90, 1.41}{} \right)
\]

\[
\text{GAMDOT} = 1843. \cdot (\text{NZ} - \text{COORDNZ}) / \text{VTOTALI}
\]

**Pitch Autoland**

\[
\text{DEGC} = \text{GDEGCA} \cdot \text{GQBAR} \cdot \left( \text{GAMCMD} - \text{GAMMAD} - \frac{922. \cdot (\text{NZ} - 1)}{\text{VTOTALI}} \right)
\]

**Auto Trim -- Lagged Elevator Feedback**

**Trim Only in Operate and Off the Ground**

\[
\text{DETTRIM} = \text{FAT1} \cdot \text{DETTRIM} + \text{FAT2} \cdot \text{DLEDEG} + \text{FAT3} \cdot \text{DLEDEGP}
\]

**Total Elevator Command**

\[
\text{DECMD} = \text{DEQ} + \text{DEGC} + \text{DETTRIM}
\]

****** Roll Control ***********

\[
\text{DATA GDAP, GDAGC} / -1.4, 1.4 /
\]

\[
\text{DATA GDADWL, GDADWR} / 0.67, 0.67 /
\]

\[
200 \text{ DADIR} = \text{DAP} = \text{DAGC} = 0.
\]

**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

\[
\text{IF (DWPILOT.LT.0.)} \quad \text{DADIR} = \text{GDADWL} \cdot \text{DWPILOT}
\]

\[
\text{IF (DWPILOT.GE.0.)} \quad \text{DADIR} = \text{GDADWR} \cdot \text{DWPILOT}
\]

**Reduce Max Rate Command at Supersonic Speed**

\[
\text{GRRLIM} = \text{CLIMIT} \left( 1.33 \cdot 0.33 \cdot \text{MACH}, 0.33, 1.00 \right)
\]

\[
\text{DADIR} = \text{GRRLIM} \cdot \text{DADIR}
\]
ROLL RATE DAMPING
   IF (MFC$ \geq 2) DAP = GDAP * PDEG

AUTO GUIDANCE COMMAND
   IF (MFC$ \geq 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, RBWOZ1 / 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
   DRDIR = GDRDP * DPPIL0T

YAW RATE WASHOUT TAU = 2.0 SEC
   RBWASH = RBWOZ1 * (RBWASH + RDEG - RDEGP)
   RDEGP = RDEG

DISCONNECT AILERON TO RUDDER INTERCONNECT BELOW MACH 1
   GDRDAX = 0.
   IF (MACH > 0.9) GDRDAX = GDRDA
   IF (MFC$ \geq 2) DRSAS = GDRDAX * DACMD + GRSAS * RBWASH * 0.01745

DRCMD = DRDIR + DRSAS

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

   IF (MODE.EQ.1) DSBSAS = DSBTRIM
   DIRECT SPEEDBRAKE COMMAND
   HANDLE FULL AFT 40 DEG --> 60 DEG SPEEDBRAKE
   QUADRATIC SPEEDBRAKE FUNCTION
   DATA DSBFS1, DSBFS2 / 0.0, 0.0375 /
   LINEAR DSBFS1=1.5 DSBFS2=0
   DSBDIR = DSBFS1 * DLSBCOM + DSBFS2 * DLSBCOM**2

   FILTERED AUTO SPEEDBRAKE COMMAND TAU = 1 SEC
   DESIGNED TO HOLD 300 KEAS
   IF (.NOT.WONG.AND.(MFC$ \geq 4 .OR. MFC$ \geq 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
- **DRCMD** * RUDDER COMMAND, DEG + TRAILING EDGE LEFT
- **DSBCMD** * SPEED BRAKE 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:*

- **DA-** AILERON DEFLECTION
- **DE-** ELEVATOR DEFLECTION
- **DLE-** LEFT ELEVON DEFLECTION
- **DLL-** LOWER LEFT BODY FLAP DEFLECTION
- **DLR-** LOWER RIGHT BODY FLAP DEFLECTION
- **DRE-** RIGHT ELEVON DEFLECTION
- **DR-** RUDDER DEFLECTION
- **DSB-** SPEED BRAKE DEFLECTION
- **DUL-** UPPER LEFT BODY FLAP DEFLECTION
- **DUR-** UPPER RIGHT BODY FLAP DEFLECTION

*THE FOLLOWING SUFFIXES ARE USED:*

- **-C** COMMANDED DEFLECTIONS
- **-CMD** COMMAND DEFLECTIONS FROM FLIGHT CONTROL SYSTEM
- **-CMDL** LIMITED COMMAND DEFLECTION
- **-L** LOWER LIMIT
- **-P** PAST VALUE
- **-PP** PAST-PAST VALUE
- **-RL** RATE LIMIT
- **-TAU** TIME CONSTANT

**C-10**
Appendix C: Guidance and Control Law Listing

DATA

DLEU, DLEL, DLERL / 30., -30., 200. /
DREU, DREL, DRERL / 30., -30., 200. /
DULU, DULL, DULRL / 0., -60., 200. /
DURU, DURL, DURRL / 0., -60., 200. /
DLLU, DLLL, DLLRL / 60., 0., 200. /
DLRU, DLRl, DLRRL / 60., 0., 200. /
DRLU, DRL, DRLRL / 30., -30., 200. /

DATA DECL, DECU / -30.0, 30.0 /
DATA DACL, DACU / 0.0, 30.0 /
DATA DRCL, DRCU / -30.0, 30.0 /

DATA DULC, DULCU, DULCL / 0., 0., -100.0 /
DATA DURC, DURCU, DURCL / 0., 0., -100.0 /
DATA DLLC, DLLCU, DLLCL / 0., 100.0, 0. /
DATA DLRC, DLRCU, DLRLC / 0., 100.0, 0. /

DATA DLEP, DLEPP, DREP, DREP / 0.0, 0.0, 0.0, 0.0 /
DATA DULP, DULPP, DURP, DURPP / 0.0, 0.0, 0.0, 0.0 /
DATA DLLP, DLLPP, DLRP, DLRPP / 0.0, 0.0, 0.0, 0.0 /
DATA DRP, DRPP / 0.0, 0.0 /

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

******************************* ELEVON COMMANDS *******************************

***** LIMITED ELEVATOR COMMAND *****
DECMDL = CLIMIT (DECMD, DECL, DECU)

***** COMMANDED ELEVONS *****
DLEC = DECMDL
DREC = DECMDL

******************************* 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 *******************************
** 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 AILERSONS 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 DEFLCTION COMMAND  
DLFDA = GBFA*GDLDA*DACMD - GBFB*BETADEG - 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.)

C-12
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
* (AS+B)/(CS+I) => K=Z1=EXP(-DT/C)  Z3=-K*A/ Z2=-(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

\[ DLRZ1 = \exp(-1.0 \times HSTEP / DLRTAU) \]
\[ DLRZ2 = 0.0 \]
\[ DLRZ3 = 1.0 - DLRZ1 - DLRZ2 \]

** RUDDER z-TRANSFORM COEFFICIENTS **
\[ DRZ1 = \exp(-1.0 \times HSTEP / DRTAU) \]
\[ DRZ2 = 0.0 \]
\[ DRZ3 = 1.0 - DRZ1 - DRZ2 \]

ENDIF

**

** RUN ACTUATOR LOGIC AT 60 Hz (MAIN SIM RUNS AT 30 Hz) **

DO 10 I=1,2

** ELEVON DEFLECTIONS **
\[ DLE = DLEZ1 \times DLEP + DLEZ2 \times DLEPP + DLEZ3 \times DLEC \]
\[ DRE = DREZ1 \times DREP + DREZ2 \times DREP + DREZ3 \times DREC \]

** RATE LIMITS - ELEVONS **
IF ((DLE - DLEP) .GT. (HSTEP * DLERL)) THEN
\[ DLE = DLEP + HSTEP \times DLERL \]
ELSEIF ((DLEP - DLE) .GT. (HSTEP * DLERL)) THEN
\[ DLE = DLEP - HSTEP \times DLERL \]
ENDIF

IF ((DRE - DREP) .GT. (HSTEP * DRERL)) THEN
\[ DRE = DREP + HSTEP \times DRERL \]
ELSEIF ((DREP - DRE) .GT. (HSTEP * DRERL)) THEN
\[ DRE = DREP - HSTEP \times DRERL \]
ENDIF

** POSITION LIMITS - ELEVONS **
\[ DLE = CLIMIT(DLE, DLEL, DLEU) \]
\[ DRE = CLIMIT(DRE, DREL, DREU) \]

** PAST VALUES FOR ELEVON DEFLECTIONS **
\[ DLEPP = DLEP \]
\[ DLEP = DLE \]
\[ DREP = DRE \]

** BODY FLAP DEFLECTIONS **
\[ DUL = DULZ1 \times DULP + DULZ2 \times DULPP + DULZ3 \times DULC \]
\[ DUR = DURZ1 \times DURP + DURZ2 \times DURPP + DURZ3 \times DURC \]
\[ DLL = DLLZ1 \times DLLP + DLLZ2 \times DLLPP + DLLZ3 \times DLLC \]
\[ DLR = DLRZ1 \times DLRP + DLRZ2 \times DLRPP + DLRZ3 \times DLRC \]

** RATE LIMITS - BODY FLAPS **
IF ((DUL - DULP) .GT. (HSTEP * DULRL)) THEN
\[ DUL = DULP + HSTEP \times DULRL \]
ELSEIF ((DULP - DUL) .GT. (HSTEP * DULRL)) THEN
\[ DUL = DULP - HSTEP \times DULRL \]
ENDIF

IF ((DUR - DURP) .GT. (HSTEP * DURRL)) THEN
\[ DUR = DURP + HSTEP \times DURRL \]
ELSEIF ((DURP - DUR) .GT. (HSTEP * DURRL)) THEN
\[ DUR = DURP - HSTEP \times DURRL \]
ENDIF
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
DULP = DUL
DURPP = DURP
DURP = DUR
DLLPP = DLLP
DLLP = DLL
DLRPP = DLRP
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
DRP = DR

CONTINUE
END
Appendix D

Trimmed Flight Condition check case data
Appendix D: Trimmed Flight Condition Check Case Data Sets

"cctrim0.txt" - Subsonic trim shot

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<th>10K, Y1, 10H, 10L, HK, 2D, 4D, 4B, 4S, P1, P2, P3, P4, M? 10K</th>
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Aerodynamic coefficient buildups

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### Appendix D: Trimmed Flight Condition Check Case Data Sets

"cctrim2.txt" - Mach 2 trim shot

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**TEST DESCRIPTION** | MACH 2 TRIM

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<th>THETA</th>
<th>ALT</th>
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<th>DSB</th>
<th>HER</th>
<th>XRWY</th>
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| DME, BRG, XT, AC, GC, PSC, PHC= | 16.5 | 95.0 | 58894.0 | 6.0 | -14.0 | 147.1 | 1.2 |

**WEIGHT, AREA, CBAR, SPAN, QBAR, MACH**

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<th>ZB</th>
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<th>MB</th>
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<td>0.0</td>
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<table>
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<th>FPS^2 OR RPS^2</th>
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<tr>
<td>-1.2664D+02</td>
<td>0.4223D+16</td>
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| NBP (1-12) | 8 | 2 | 1 | 1 | 1 | 1 | 1 |

| WN (1-12) | 4.45740151235E-18 | -1.868.993867273 | 0.0 | 2941.167058824 |

| ALPHA | 6.002195965025 |
| BETA  | 4.007150396168E-20 |

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<th>P, Q, R</th>
<th>RPS = 3.189616514552E-17</th>
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| DUL | -37.9910951146 |
| DUR | -37.9910951146 |
| DLE | -24.497713267525 |
| DRE | -24.497713267525 |
| DR  | -6.68205228152E-17 |
| XCG  | -0.4236 |
| H/B  | 4224.984668183 |

GEAR = 0.0
### Aerodynamic Coefficient Buildups

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<th>Value 3</th>
<th>Value 4</th>
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<td>-.8236D-02</td>
<td>.5932D-06</td>
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<td>CMBAS, CMULBF, CMURBF, CMLLB, CMLRF, CMDR</td>
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<td>.3706D-02</td>
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"cctrim4.txt" - Mach 4 trim shot

IC CASE 10K,Y1,10L,HK,2D,4D,4B,4S,P1,P2,P3,P4,M? 4D
TEST DESCRIPTION 7 MACH 4 TRIM
NZQ SAS MODE

<table>
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<tr>
<th>T</th>
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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

| BODY AXIS F&M | XB, YB, ZB, LB, MB, NB |
| BODY AXIS F&M | XS, YS, ZS, LS, MS, NS |

ACCEL UDOT, VDOT, WDOT, QDOT, RDOT FPS**2 OR RPS**2

| STAB AXIS F&M |
| STAB AXIS F&M |

WEIGHT, AREA, CBAR, SPAN, QBAR, MACH

| NBP(I-12) |
| WN(1-12) |

ALPHA= 17.00190937982 BETA= 3.296392158263E-18

DUL= -.0002404135789491 DUR= -.0002404135789491

DLL= .0007219626995468 DLR= .0007219626995468

DLE= 4.133305502178 DRE= 4.133305502178

D-5
### Aerodynamic Coefficient Buildups

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<th>Aerodynamic Coefficient Buildups</th>
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</tr>
</tbody>
</table>
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:

\[
\text{COEFF} = ((A3*\text{ALPHA}) + A2) * \text{ALPHA} + A1 ) * \text{ALPHA} + A0
\]

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 [ \( f(\text{Mach}) \) ].

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). [ \( f(\text{deflection, Mach}) \) ]

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 (\( C_{nr} \))
- \( a_0, a_1, a_2, a_3 \) for coeff. of roll damping due to roll rate (\( C_{rp} \))
- \( a_0, a_1, a_2, a_3 \) for coeff. of roll damping due to yaw rate (\( C_{nr} \))
- \( a_0, a_1, a_2, a_3 \) for coeff. of yaw damping due to yaw rate (\( C_{ir} \))

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):

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

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

\begin{align*}
\text{Span:} & \quad 13.89 \text{ ft} \\
\text{Area:} & \quad 286.45 \text{ ft}^2 \\
\text{Chord:} & \quad 28.24 \text{ ft}
\end{align*}

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 DATABASE

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

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

\[ C_m = C_{m,BASIC} + \Delta C_{m,BF} + \Delta C_{m,E} + \Delta C_{m,R} + \Delta C_{m,GE} + \Delta C_{m,LG} \]

\[ C_Y = \begin{pmatrix} \frac{g_e}{2V} \\ \frac{|\Delta C_{Y,R}|}{2V} + \frac{|\Delta C_{Y,E}|}{2V} + \frac{|\Delta C_{Y,BF}|}{2V} + \frac{|\Delta C_{Y,GE}|}{2V} + \frac{|\Delta C_{Y,LG}|}{2V} \end{pmatrix} \]

\[ C_n = \begin{pmatrix} \frac{|\Delta C_{n,BF}|}{2V} + \frac{|\Delta C_{n,E}|}{2V} + \frac{|\Delta C_{n,R}|}{2V} + \frac{|\Delta C_{n,GE}|}{2V} + \frac{|\Delta C_{n,LG}|}{2V} \end{pmatrix} \]

\[ C_I = \begin{pmatrix} \frac{|\Delta C_{I,BF}|}{2V} + \frac{|\Delta C_{I,E}|}{2V} + \frac{|\Delta C_{I,R}|}{2V} + \frac{|\Delta C_{I,GE}|}{2V} + \frac{|\Delta C_{I,LG}|}{2V} \end{pmatrix} \]

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

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

($a_0$, $a_1$, $a_2$, $a_3$ 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

<table>
<thead>
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<th>Basic coefficients</th>
<th>$C_L \quad C_D \quad C_m \quad C_Y \beta \quad C_n \beta \quad C_I \beta$</th>
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<tbody>
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<td>$\Delta C_L \quad \Delta C_D \quad \Delta C_m$</td>
</tr>
<tr>
<td>Lower left body flap</td>
<td>$\Delta C_Y \quad \Delta C_n \quad \Delta C_I$</td>
</tr>
<tr>
<td>Left elevon</td>
<td>13 Mach nos., $\delta = -60^\circ, -45^\circ, -30^\circ, -15^\circ, 0^\circ$</td>
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**TABLE 1 - AERO FOR BASIC CONFIGURATION**

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- Coefficients are given in engineering notation.
- Each row represents a different configuration with corresponding coefficients.
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| -0.16738E-01 | -0.78862E-03 | 0.72262E-04 |
| 0.73066E-01 | 0.14925E-02 | -0.22878E-04 |
| -0.71297E-01 | -0.95228E-03 | 0.19516E-03 |
| 0.48236E-01 | 0.21738E-02 | -0.48468E-04 |

| 0.14262E-01 | -0.57430E-03 | 0.44260E-04 |
| 0.10596E-01 | 0.14942E-02 | -0.12110E-03 |
| -0.54949E-02 | 0.32500E-03 | -0.27705E-04 |
| 0.23109E-01 | 0.31743E-03 | -0.82055E-04 |
| -0.28765E-01 | -0.11153E-02 | 0.15674E-03 |
| 0.15828E-01 | 0.23082E-02 | -0.22024E-06 |

| 0.18469E-01 | 0.14000E-03 | 0.39088E-04 |
| 0.28981E-02 | 0.10573E-02 | -0.69909E-04 |
| -0.45391E-02 | 0.36181E-03 | -0.11608E-04 |
| 0.14597E-01 | 0.15263E-03 | -0.78121E-04 |
| -0.20079E-01 | -0.76259E-03 | 0.13224E-01 |
| 0.10014E-01 | 0.11346E-03 | -0.53997E-05 |

| 0.11304E-01 | -0.10759E-02 | 0.14995E-03 |
| 0.78121E-02 | 0.53750E-03 | -0.11104E-04 |
| -0.34254E-02 | 0.36181E-03 | -0.11608E-04 |
| 0.13224E-01 | 0.11346E-03 | -0.82055E-04 |
| -0.15551E-01 | -0.49143E-03 | 0.70042E-05 |
| 0.83182E-02 | 0.22455E-04 | -0.22024E-06 |

| 0.53634E-02 | -0.30421E-03 | 0.24265E-04 |
| 0.32057E-02 | 0.30236E-03 | -0.41340E-05 |
| -0.19808E-02 | 0.72374E-04 | -0.33542E-05 |
| 0.80792E-02 | 0.33934E-04 | 0.76059E-05 |
| -0.11175E-01 | -0.21721E-03 | 0.84232E-06 |
| 0.54989E-02 | -0.15398E-04 | 0.60903E-05 |

| 0.51469E-02 | -0.11230E-03 | 0.66521E-05 |
| 0.24146E-02 | 0.23487E-03 | 0.42076E-05 |
| -0.16211E-02 | 0.60726E-04 | -0.42994E-05 |
| 0.74572E-02 | 0.69281E-04 | 0.69953E-05 |
| -0.95470E-02 | -0.16391E-03 | -0.72604E-05 |
| 0.48707E-02 | -0.18696E-04 | 0.76938E-05 |

| 0.48448E-02 | 0.21213E-03 | -0.29325E-04 |
| 0.21824E-02 | 0.30604E-03 | -0.11453E-04 |
| -0.16041E-02 | 0.56623E-04 | -0.29449E-05 |
| 0.68196E-02 | 0.49787E-05 | 0.12879E-04 |
| -0.87831E-02 | -0.66390E-04 | -0.17779E-04 |
| 0.45740E-02 | -0.51972E-04 | 0.11292E-04 |
### HL-20 Aerodynamics Tables (version 2.0)

**TABLE 5 - AERO INCREMENTS DUE TO RUDDER DEFLECTION**

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DUE TO RUDDER DEFLECTION
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| 2.50  | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| 3.00  | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| 3.50  | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| 4.00  | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| 15.0  | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| 0.30  | -0.13646E-01 | 0.81105E-02 | -0.70197E-03 | 0.15341E-04 | 0.15341E-04 |
| 0.60  | 0.26486E-01 | 0.56887E-02 | -0.10650E-02 | 0.32543E-04 | 0.32543E-04 |
| 0.80  | 0.16977E-01 | -0.29680E-02 | -0.40849E-04 | 0.54696E-05 | 0.54696E-05 |
| 0.90  | -0.22058E-02 | 0.39553E-04 | -0.99083E-06 | 0.00000E+00 | 0.00000E+00 |

HL-20 Aerodynamics Tables (version 2.0)
### HL-20 Aerodynamics Tables (version 2.0)

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| 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |

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| 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |

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| 0.90       | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
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| 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |

| 0.95       | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
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| 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |

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| 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |

| 1.20       | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
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## HL-20 Aerodynamics Tables (version 2.0)

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Additional coefficients for angles 2.50, 3.00, 3.50, and 4.00 are listed above.
### TABLE 6 - DYNAMIC DAMPING COEFFICIENTS

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### TABLE 7 - AERO INCREMENTS DUE TO GROUND EFFECTS

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E-38
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<th>Angle (deg)</th>
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**Table 8 - AERODYNAMIC INCREMENTS DUE TO LANDING GEAR**
**SYMBOLS**

- $h$: height from ground to wing root leading edge
- $\Delta$: aero coefficient increment

**SUBSCRIPTS**

- GE: ground effect
- LLBF: lower left body flap
- LE: left elevator
- LG: landing gear
- R: rudder
- ULBF: upper left body flap
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_l

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

BASIC AERODYNAMIC COEFFICIENTS

MACH

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

\( C_d \) vs. \( \alpha \), degs

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

BASIC AERODYNAMIC COEFFICIENTS

MACH

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

\[ C_m \sim \alpha, \text{ degs} \]
BASIC AERODYNAMIC COEFFICIENTS

\[ C_{\alpha} \]

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

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

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

LaRC/SSD
JAN. 1991

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

MACH

$0.30 \ 0.80 \ 0.95 \ 1.10 \ 1.20 \ 1.60 \ 2.00 \ 2.50 \ 3.00 \ 3.50 \ 4.00$

$\alpha, \text{ degs}$

$C_D$

E-47
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

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LaRC/SSD
JAN. 1991

$\Delta C_D$

\[ \text{MACH} \]
- $\circ$  .30
- $\square$  .60
- $\diamond$  .80
- $\triangle$  .90
- $\diamondsuit$  .95
- $\blacklozenge$  1.10
- $\blacktriangle$  1.20
- $\blacklozenge$  1.60
- $\blacklozenge$  2.00
- $\lozenge$  2.50
- $\lozenge$  3.00
- $\lozenge$  3.50
- $\lozenge$  4.00

$\alpha$, degs
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

\[ \Delta C_m \]

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

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

NASA
LaRC/SSD
JAN. 1991

![Graph showing increments due to $\delta_{ULBF} = -60^\circ$]
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

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JAN. 1991

MACH

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

MACH

0.3 0.6 0.9 0.95 1.1 1.2 1.6 2.0 2.5 3.0 3.5 4.0

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

$\alpha$, degs

$C^1$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

LaRC/SSD
JAN. 1991

$\Delta C_L$

$\alpha$, degs

MACH

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

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

LaRC/SSD
JAN. 1991

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AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

LaRC/SSD
JAN. 1991

MACH

\[ \delta_{ulbf} = -45^\circ \]

INCREMENTs DUE TO \( \delta_{ulbf} = -45^\circ \)
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

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 $\delta_{\text{ULBF}} = -45^\circ$

MACH

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

$\alpha$, degs
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

$\Delta C_m$ 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 $\delta_{ULBF} = -30^\circ$

LaRC/SSD
JAN. 1991

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AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

LaRC/SSD
JAN. 1991

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

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- 0.95
- 1.10
- 1.20
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- 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

\[ \Delta C_D \]

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

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 $\delta_{ULBF} = -15^\circ$

LaRC/SSD
JAN. 1991

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AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

LaRC/SSD
JAN. 1991

MACH
- $\Phi$ .30
- $\Box$ .60
- $\Diamond$ .80
- $\Delta$ .90
- $\bigcirc$ .95
- $+$ 1.10
- $\triangle$ 1.20
- $\times$ 1.60
- $\blacklozenge$ 2.00
- $\lozenge$ 2.50
- $\blacksquare$ 3.00
- $\blacktriangle$ 3.50
- $\blacklozenge$ 4.00
INCREMENTS DUE TO $\delta_{ULBF} = -15^\circ$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

NASA
LaRC/SSD
JAN. 1991

$\Delta C_1$ vs $\alpha$, degs

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AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

LaRC/SSD
JAN. 1991

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

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

E-72
INCENDENTS DUE TO $\delta_{\text{LLBF}} = +15^\circ$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

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
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

NASA

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JAN. 1991

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

$V_C$

$0.016 \quad 0.014 \quad 0.012 \quad 0.010 \quad 0.008 \quad 0.006 \quad 0.004 \quad 0.002 \quad 0.000$

$-0.5 \quad 0 \quad 5 \quad 10 \quad 15 \quad 20 \quad 25 \quad 30 \quad 35$

$\alpha$, degs

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

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

LaRC/SSD
JAN. 1991

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</table>

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

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 $\delta_{LLBF} = +30^\circ$

$\alpha$, degs

$\Delta C_{D}$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

LaRC/SSD
JAN. 1991

MACH

- $\square$ .30
- $\square$ .60
- $\square$ .80
- $\square$ .90
- $\square$ .95
- $\square$ 1.10
- $\square$ 1.20
- $\square$ 1.60
- $\square$ 2.00
- $\square$ 2.50
- $\square$ 3.00
- $\square$ 3.50
- $\square$ 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

- • .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 \( \delta_{\text{LEF}} = +30^\circ \)

\[ AC1 \]

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

\[ MACH \]

\[ \cdot 30 \quad \cdot 60 \quad \cdot 80 \quad \cdot 90 \quad \cdot 95 \quad \cdot 1.10 \quad \cdot 1.20 \quad \cdot 1.60 \quad \cdot 2.00 \quad \cdot 2.50 \quad \cdot 3.00 \quad \cdot 3.50 \quad \cdot 4.00 \]

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

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

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 $\delta_{LLBF} = +45^\circ$

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
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

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

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

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

NASA
LaRC/SSD
JAN. 1991

$\Delta C_Y$

MACH
- $\bigcirc$ .30
- $\square$ .60
- $\bigtriangleup$ .80
- $\bigtriangledown$ .90
- $\blacktriangle$ .95
- $\blacktriangledown$ 1.10
- $\blacklozenge$ 1.20
- $\blacklozenge$ 1.60
- $\blackdiamondsuit$ 2.00
- $\blacklozenge$ 2.50
- $\blacklozenge$ 3.00
- $\blacklozenge$ 3.50
- $\bigstar$ 4.00

$\alpha$, degs

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

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

LaRC/SSD
JAN. 1991

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

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

$C_D$

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

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

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

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

LaRC/SSD
JAN. 1991

MACH

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

$C_d$

$\alpha$, deg$

E-90
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

$\text{MACH}$

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$\alpha$, degs

$\text{E-91}$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

LaRC/SSD
JAN. 1991

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

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

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

NASA
LaRC/SSD
JAN. 1991

$\Delta C_1$

$a$, 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

LaRC/SSD
JAN. 1991

MACH

[Graph showing data points and MACH values]

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

$\alpha$, degs

E-95
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

NASA
LaRC/SSD
JAN. 1991

MACH

- \( \circ \) .30
- \( \triangle \) .60
- \( \triangledown \) .80
- \( \triangleright \) .90
- \( \triangleright \) .95
- \( \bowtie \) 1.10
- \( \bowtie \) 1.20
- \( \bowtie \) 1.60
- \( \bowtie \) 2.00
- \( \bowtie \) 2.50
- \( \bowtie \) 3.00
- \( \bowtie \) 3.50
- \( \bowtie \) 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

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

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

\[ \Delta C_y \]
\[ \alpha, \text{ degs} \]
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 $\delta_{\text{LE}} = -30^\circ$

LaRC/SSD
JAN. 1991

MACH
- $\circ$ .30
- $\square$ .60
- $\diamond$ .80
- $\triangle$ .90
- $\triangledown$ .95
- $\downarrow$ 1.10
- $\uparrow$ 1.20
- $\triangleleft$ 1.60
- $\triangleright$ 2.00
- $\leftarrow$ 2.50
- $\rightarrow$ 3.00
- $\Leftarrow$ 3.50
- $\Rightarrow$ 4.00
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

LaRC/SSD
JAN. 1991

$\Delta C_L$

$\alpha$, 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 $\delta_{LE} = -15^\circ$

NASA
LaRC/SSD
JAN. 1991

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

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

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

LaRC/SSD
JAN. 1991

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<td>$\blacktriangle$</td>
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<td>$\triangleleft$</td>
</tr>
<tr>
<td>$\blacktriangleleft$</td>
</tr>
<tr>
<td>$\blacklozenge$</td>
</tr>
<tr>
<td>$\lozenge$</td>
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</tbody>
</table>
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

MACH

\(\delta_{LE} = -15^\circ\)

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

\(u, v\)
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

$$\Delta C_L$$

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 $\delta_{LE} = +15^\circ$
AERODYNAMIC DATABASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

MACH

$\phi$ $\phi$ $\phi$ $\phi$ $\phi$ $\phi$ $\phi$ $\phi$ $\phi$ $\phi$

$\alpha$, degs
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
-1.20
-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 $\delta_{LE} = +15^\circ$

LaRC/SSD
JAN. 1991

\begin{align*}
\Delta C_n &\quad \alpha, \text{ degrs} \\
\hline
\text{MACH} &\quad 0.30 \quad 0.60 \quad 0.80 \quad 0.90 \quad 0.95 \\
\quad &\quad 1.10 \quad 1.20 \quad 1.60 \quad 2.00 \quad 2.50 \\
\quad &\quad 3.00 \quad 3.50 \quad 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

- 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
AERDATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

$CL$ vs $\alpha$, degs

MACH

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 $\delta_{LE} = +30^\circ$

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
AER Data Base for HL-20 Flight Simulation Studies

Increments Due to $\delta_{LE} = +30^\circ$

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\[
\Delta C_m = f(\alpha, \text{MACH})
\]

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

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

MACH

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

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

$\alpha, \text{ degs}$

$Y_C$

$X_C$

E-116
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

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 $\delta_{LE} = +30^\circ$

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 $\delta_r = +15^\circ$
INCREMENTS DUE TO $\delta_R = +15^\circ$
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

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 $\delta_R = +15^\circ$

NASA
LaRC/SSD
JAN. 1991

$\Delta C_y$

MACH

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

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

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

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

$\Delta C_1$

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

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

E-125
INCREMENTS DUE TO $\delta_R = +30^\circ$
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 $\delta_R = +30^\circ$

**NASA**

LaRC/SSD
JAN. 1991

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AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

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

LaRC/SSD
JAN. 1991

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$\Delta C_n = \frac{0.06}{\alpha, \text{degs}}$
INCREMENTS DUE TO $\delta_R = +30^\circ$
DYNAMIC DAMPING COEFFICIENTS

\[ \alpha, \text{ degs} \]
DYNAMIC DAMPING COEFFICIENTS

\[ C_{np} \text{ vs } \alpha, \text{ degs} \]
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

DYNAMIC DAMPING COEFFICIENTS

\[ C_{\mu} \]

\[ -5 \quad 0 \quad 5 \quad 10 \quad 15 \quad 20 \quad 25 \quad 30 \quad 35 \]

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

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NASA
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

DYNAMIC DAMPING COEFFICIENTS

\[ C_{nr} \] vs \[ \alpha, \text{ degs} \]

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

DYNAMIC DAMPING COEFFICIENTS

\[ C_{\alpha} \]

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

LaRC/SSD
JAN. 1991
INCREMENTS DUE TO GROUND EFFECTS

\[ \Delta C_l \]

\[ h/b \]

$\phi$ $\phi$ $\phi$ $\phi$ $\phi$ $\phi$

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

INCREMENTS DUE TO GROUND EFFECTS

LaRC/SSD
JAN. 1991

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

-5 0 5 10 15 20 25 30 35

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 GROUND EFFECTS

LaRC/SSD
JAN. 1991

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

\( \alpha \), 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 GROUND EFFECTS

LaRC/SSD
JAN. 1991

\[
\Delta C_{n_p} = f(\alpha, h/b)
\]

- \(h/b = 0.2\)
- \(h/b = 0.4\)
- \(h/b = 0.6\)
- \(h/b = 0.8\)
- \(h/b = 1.0\)
- \(h/b = 1.5\)
- \(h/b = 2.0\)
- \(h/b = 2.5\)
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO GROUND EFFECTS

LaRC/SSD
JAN. 1991

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

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

INCREMENTS DUE TO LANDING GEAR

NASA
LaRC/SSD
JAN. 1991

\[ \Delta C_L \]

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

<table>
<thead>
<tr>
<th>ANGLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
</tr>
<tr>
<td>15.0</td>
</tr>
<tr>
<td>30.0</td>
</tr>
<tr>
<td>60.0</td>
</tr>
<tr>
<td>90.0</td>
</tr>
</tbody>
</table>
INCREMENTS DUE TO LANDING GEAR

\[ \Delta C_D \]

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

\[ \begin{align*}
0.0 \\
15.0 \\
30.0 \\
60.0 \\
90.0
\end{align*} \]
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO LANDING GEAR

LaRC/SSD
JAN. 1991

\[ \Delta C_m \text{ vs } \alpha, \text{ degs} \]

- \( \bigcirc \) 0.0
- \( \square \) 15.0
- \( \diamond \) 30.0
- \( \triangle \) 60.0
- \( \downarrow \) 90.0

ANGLE
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO LANDING GEAR

 NASA
LaRC/SSD
JAN. 1991

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

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

ANGLE

- 0.0
- 15.0
- 30.0
- 60.0
- 90.0
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO LANDING GEAR

LaRC/SSD
JAN. 1991

\[ \Delta C_{nq} \]

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

ANGLE
-  0.0
-  15.0
-  30.0
-  60.0
-  90.0
AERO DATA BASE FOR HL-20 FLIGHT SIMULATION STUDIES

INCREMENTS DUE TO LANDING GEAR

NASA
LaRC/SSD
JAN. 1991

\[ \Delta C_{1p} \]

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

-5 0 5 10 15 20 25 30 35

ANGLE
- 0.0
- 15.0
- 30.0
- 60.0
- 90.0

E-147
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>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pilot inputs</td>
<td>DCPilot, DwPilot, DpPilot, DlsBCom (units)</td>
</tr>
<tr>
<td>2</td>
<td>Velocities</td>
<td>IAS (knots), QBAR (psf), VTotal (fps), MACH</td>
</tr>
<tr>
<td>3</td>
<td>Flow &amp; flight path angles</td>
<td>AlpDeg, BetaDeg, GammaDeg, 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>
</tr>
<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

The plots therefore comprise $20 \frac{\text{pages}}{\text{maneuver}} \times 4 \frac{\text{maneuvers}}{\text{trim case}} \times 3 \text{ trim cases} = 240 \text{ pages}$ 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

Flow & flight path angles
Page 3 of 20
Aft Pitch Stick Pulse at 300 KEAS, 10,000 ft

Euler angles (degrees)

Page 5 of 20

F-7
Aft Pitch Stick Pulse at 300 KEAS, 10,000 ft

---

Body axis angular rates

Page 7 of 20
Aft Pitch Stick Pulse at 300 KEAS, 10,000 ft

Body axis linear accelerations

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

Aero coefficients - moments
Page 11 of 20
Aft Pitch Stick Pulse at 300 KEAS, 10,000 ft

Aerodynamic moments
Page 13 of 20
Aft Pitch Stick Pulse at 300 KEAS, 10,000 ft

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

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

Guidance errors
Page 17 of 20
HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at 300 KEAS, 10,000 ft

- DECMD
- DACMD
- DRCMD
- DSBCMD

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

DUL

DUR

DLL

DLR

Surface positions - body flaps
Page 20 of 20
Flow & flight path angles
Page 3 of 20

F-25
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

- ALT

- SX

- SY

C.G. position states
Right Roll Stick Pulse at 300 KEAS, 10,000 ft
Body axis velocities
Page 6 of 20
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

Body axis angular rates

F-29
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

**PDOT**

**QDOT**

**RDOT**

Body axis angular accelerations

F-31
HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

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

Aero forces
Page 12 of 20

F-34
HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at 300 KEAS, 10,000 ft

Aerodynamic moments
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F-35
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

Surface positions - elevons, rudder & gear
Page 19 of 20
HL-20 Dynamic Check Case Data Plots 911206
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

DCPILOT

DWPILOT

DPPILOT

DLSBCOM

F-43
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

- IAS
- QBAR
- VTOTAL
- MACH

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

C.G. position states
Page 4 of 20
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

- ALT

- PHID

- THETAD

- PSID

Euler angles (degrees)
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

Body axis velocities

Page 6 of 20
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

Body axis angular rates

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

Body axis linear accelerations

F-50
Body axis angular accelerations

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

Aerodynamic moments

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F-55
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

- **HER**
  - Scale: $10^0$
  - Range: 0.00 - 40.00

- **PSIERR**
  - Scale: $10^0$
  - Range: 0.00 - 15.00

- **XTK**
  - Scale: $10^0$
  - Range: 0.00 - 0.0100

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

DECMD

DACMD

DRCMD

DSBCMD

FCS Surface commands

F-60
HL-20 Dynamic Check Case Data Plots 911206
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

Surface positions - elevons, rudder & gear
Page 19 of 20
Right Rudder Pedal Pulse at 300 KEAS, 10,000 ft

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

- DCPILOT

- DWPILOT

- DPPILOT

- DLSBCOM
HL-20 Dynamic Check Case Data Plots 911206

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

**ALPDEG**

- Time: 0.00 to 20.00 x 10^0
- Values: 5.500 to 7.500

**BETADEG**

- Time: 0.00 to 20.00 x 10^0
- Values: -60.00 to 20.00

**GAMMAD**

- Time: 0.00 to 20.00 x 10^0
- Values: -18.00 to -17.00

**TKANG**

- Time: 0.00 to 20.00 x 10^0
- Values: 40.00 to 30.00

Flow & flight path angles

Page 3 of 20
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

ALT

SX

SY

C.G. position states
Page 4 of 20
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

Euler angles (degrees)

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

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

Body axis angular accelerations

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F-71
HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

Aero coefficients - force
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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
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Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

C.G. accelerations (G)

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

- DECMD

- DACMD

- DRCMD

- DSBCMD

FCS Surface commands
Surface positions - elevons, rudder & gear
Page 19 of 20
Speed Brake Handle Pulse at 300 KEAS, 10,000 ft

Surface positions - body flaps

F-82
HL-20 Dynamic Check Case Data Plots 911206
Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

Pilot Inputs
Page 1 of 20  F-83
Velocities
Page 2 of 20

F-84
HL-20 Dynamic Check Case Data Plots 911206
Fwd Pitch 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
Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

C.G. position states
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HL-20 Dynamic Check Case Data Plots 911206
Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

Euler angles (degrees)
Page 5 of 20
Body axis velocities
Page 6 of 20
HL-20 Dynamic Check Case Data Plots 911206
Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

Body axis linear accelerations
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Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

Body axis angular accelerations
HL-20 Dynamic Check Case Data Plots 911206
Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

Aero coefficients - moments
Fwd Pitch Stick Pulse at Mach 2 and 58,700 ft

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

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

AOACMD

GAMCMD

PHICMD

PSICMD

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

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

DCPILOT

DWPILLOT

DPPILOT

DLSBCOM

Pilot Inputs
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HL-20 Dynamic Check Case Data Plots 911206
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

C.G. position states
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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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Right Roll Stick Pulse at Mach 2 and 58,700 ft

Body axis velocities
Body axis linear accelerations
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HL-20 Dynamic Check Case Data Plots 911206
Right Roll Stick Pulse at Mach 2 and 58,700 ft

Body axis angular accelerations
Page 9 of 20
Right Roll Stick Pulse at Mach 2 and 58,700 ft

CLTOT

CDTOT

CYTOT

Aero coefficients - force
Page 10 of 20
Right Roll Stick Pulse at Mach 2 and 58,700 ft

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

Aerodynamic moments
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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

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

AOACMD

GAMCMD

PHICMD

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

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

FCS Surface commands
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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
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

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

C.G. position states
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F-126
HL-20 Dynamic Check Case Data Plots 911206
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

Euler angles (degrees)
F-127
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

Body axis velocities
Body axis angular rates

TIME (x10

PDEG

QDEG

RDEG

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

Body axis linear accelerations

F-130
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

Body axis angular accelerations

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

Aero coefficients - force

F-132
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft
HL-20 Dynamic Check Case Data Plots 911206
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

Time plots for X, Y, and Z axes showing the response of the rudder pedal pulse at Mach 2 and 58,700 ft. The graphs display the forces acting on the aircraft over time.
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

Aerodynamic moments
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

C.G. accelerations (G)

Page 14 of 20
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

FCS mode flags
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

AOACMD

GAMCMD

PHICMD

PSICMD

Guidance commands
Right Rudder Pedal Pulse at Mach 2 and 58,700 ft

- HER
- PSIERR
- XTK

Guidance errors
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Right Rudder Pedal Pulse at Mach 2 and 59,700 ft

Surface positions - elevons, rudder & gear
HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at Mach 2 and 58,700 ft

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

Velocities
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Flow & flight path angles
Page 3 of 20
HL-20 Dynamic Check Case Data Plots 911206
Speed Brake Handle Pulse at Mach 2 and 58,700 ft

ALT

TIME

SX

TIME

SY

TIME
Speed Brake Handle Pulse at Mach 2 and 58,700 ft

Euler angles (degrees)

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

Body axis velocities

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Body axis angular accelerations
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Speed Brake Handle Pulse at Mach 2 and 58,700 ft

Aero coefficients - force

CLTOT

CDTOT

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

Aero coefficients - moments
Page 11 of 20

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

**ANX**

-0.800
-1.000
-1.200
-1.400

TIME

0.00 5.00 10.00 15.00 20.00

**ANY**

0.00
-20.00
-40.00
-60.00

TIME

0.00 5.00 10.00 15.00 20.00

**ANZ**

1.000
0.500
0.000

TIME

0.00 5.00 10.00 15.00 20.00

C.G. accelerations (G)

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Tue Dec 10 14:59:42 1991
TUE DEC 10 14:59:52 1991

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

**FCS mode flags**
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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

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

FCS Surface commands
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F-160
Surface positions - elevons, rudder & gear
Surface positions - body flaps
HL-20 Dynamic Check Case Data Plots 911206
Att Pitch Stick Pulse at Mach 4 and 104,000 ft

Wed Dec 11 05:05:07 1991

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

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

Flow & flight path angles
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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)
HL-20 Dynamic Check Case Data Plots 911206
Aft Pitch Stick Pulse at Mach 4 and 104,000 ft

Body axis velocities
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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
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F-170
Body axis angular accelerations
HL-20 Dynamic Check Case Data Plots 911206
Alt Pitch Stick Pulse at Mach 4 and 104,000 ft

- CLTOT

- CDTOT

- CYTOT

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

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

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

C.G. accelerations (G)
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Aft Pitch Stick Pulse at Mach 4 and 104,000 ft

FCS mode flags
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Aft Pitch Stick Pulse at Mach 4 and 104,000 ft

AOACMD

GAMCMD

PHICMD

PSICMD

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

Pilot Inputs
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Right Roll Stick Pulse at Mach 4 and 104,000 ft

- IAS
- QBAR
- VTOTAL
- MACH
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Right Roll Stick Pulse at Mach 4 and 104,000 ft

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

C.G. position states

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

Euler angles (degrees)
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Right Roll Stick Pulse at Mach 4 and 104,000 ft

Body axis velocities
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Right Roll Stick Pulse at Mach 4 and 104,000 ft

Body axis angular rates
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Right Roll Stick Pulse at Mach 4 and 104,000 ft

Body axis linear accelerations

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

Body axis angular accelerations
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Right Roll Stick Pulse at Mach 4 and 104,000 ft

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

Aero coefficients - moments
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Right Roll Stick Pulse at Mach 4 and 104,000 ft

Aero forces
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Right Roll Stick Pulse at Mach 4 and 104,000 ft

Aerodynamic moments
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Right Roll Stick Pulse at Mach 4 and 104,000 ft

C.G. accelerations (G)

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

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

**Graphs:**
- **IAS**
- **QBAR**
- **VTOTALI**
- **MACH**

**Legend:**
- IAS
- QBAR
- VTOTALI
- MACH

**Axes:**
- Y-axis: velocities (x10^0)
- X-axis: time

**Data Points:**
- IAS: 255.5, 255.0, 254.5, 254.0, 253.5
- QBAR: 221.0, 220.0, 219.0, 218.0, 217.0
- VTOTALI: 3950, 3900, 3850, 3800
- MACH: 4.00, 3.95, 3.90, 3.85

**Date:** Tue Dec 10 15:29:43 1991
Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

ALPDEG

BETADEG

GAMMAD

TKANG

Flow & flight path angles

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

C.G. position states
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Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

Euler angles (degrees)
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Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

Body axis velocities

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

Body axis angular rates

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

Body axis linear accelerations

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Body axis angular accelerations

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Aero coefficients - force
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Aero coefficients - moments
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Guidance commands
Right Rudder Pedal Pulse at Mach 4 and 104,000 ft

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

Surface positions - elevons, rudder & gear

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

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

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**DCPILOT**

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**DWPilot**

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**DPPILOT**

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**DLSBCOM**

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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

Graphs showing:
- IAS (Inertial Airspeed) vs. Time
- QBAR (Static Pressure) vs. Time
- VTotal (Total Velocity) vs. Time
- Mach Number vs. Time

Velocities
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Speed Brake Handle Pulse at Mach 4 and 104,000 ft

Flow & flight path angles
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Speed Brake Handle Pulse at Mach 4 and 104,000 ft

C.G. position states

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

Euler angles (degrees)

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Body axis linear accelerations
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Body axis angular accelerations
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Speed Brake Handle Pulse at Mach 4 and 104,000 ft

Aero coefficients - force
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Speed Brake Handle Pulse at Mach 4 and 104,000 ft

Aero coefficients - moments

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

Aero forces
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Speed Brake Handle Pulse at Mach 4 and 104,000 ft

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

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Surface positions - body flaps
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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.