

NASA HL-20 Lifting Body Airframe Modeled with Simulink and the Aerospace Blockset

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For most flight control designs, the airframe, or plant model, needs to be modeled, simulated, and analyzed. Ideally, this airframe would be modeled quickly, reusing blocks or model structure to reduce validation time and leave more time available for control design. This article discusses using Simulink and the Aerospace Blockset for modeling the airframe of a NASA HL-20 lifting body, which is a low-cost complement to the Space Shuttle orbiter. The Aerospace Blockset was used to rapidly assemble portions of the HL-20 airframe. The remaining portions, including the calculation of aerodynamic coefficients, were modeled with Simulink. This article examines the construction of the Simulink model of the HL-20 airframe and touches on how the aerodynamic data was used in the model.

NASA HL-20 Lifting Body

The HL-20, also known as personnel launch system (PLS), is a lifting body reentry vehicle that was designed to complement the Space Shuttle orbiter. Designed to carry up to ten people and very little cargo, the HL-20 lifting body was to be placed in orbit either launched vertically via booster rockets or transported in the payload bay of the Space Shuttle orbiter. The HL-20 lifting body was designed to deorbit using an onboard propulsion system while its reentry was to be nose-first, horizontal and unpowered.



Figure 1: Top view of the HL-20 lifting body. (NASA Langley photo)

The HL-20 lifting body was developed as a low-cost solution for getting to and from low Earth's orbit. The proposed benefits of the HL-20 were reduced operating costs due to rapid turnaround between landing and launch, improved flight safety, and ability to land conventionally on runways. Potential scenarios for the HL-20 were orbital rescue of stranded astronauts, International Space Station crew exchange if the Space Shuttle orbiter was not available, observation missions, and satellite servicing missions. Although the HL-20 is not currently an active program, the aerodynamic data from the HL-20 is being used in a current NASA project.

Modeling assumptions and limitations

There were several assumptions made when modeling the airframe. The airframe is assumed to be rigid and have constant mass, center of gravity, and inertia since the model is to represent the reentry portion of the mission. Preliminary aerodynamic data for the HL-20 lifting body was obtained from NASA TM4302. This data has additional assumptions and limitations that follow:

- HL-20 is a laterally symmetric vehicle.
- Compressibility (Mach) effects are negligible.
- Control effectiveness is assumed to vary nonlinearly with the angle of attack and linearly with the angle of deflection. Control effectiveness is not dependent on the sideslip angle.
- The nonlinear six-degrees-of-freedom (6DoF) aerodynamic model is intended for an early version of the HL-20; therefore the data is not recommended for absolute performance of HL-20.

Constructing the airframe model

The HL-20 airframe model discussed in this article, `hl20airframe.mdl`, is available for download from MATLAB Central at <http://www.mathworks.com/matlabcentral/>. An additional file containing model parameters and aerodynamic data, `init_hl20.m`, is part of the download in a zip file, `hl20.zip`. Product dependencies for this model are MATLAB, Simulink, and the Aerospace Blockset. After downloading the model, you can follow along with the article by stepping through levels of the model as you read about them. For those who are also interested in flight control systems, there is an example of an auto-land control for the HL-20 airframe in the Aerospace Blockset.

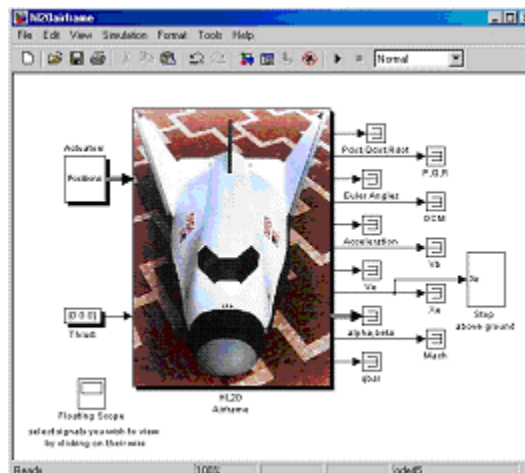


Figure 2: HL-20 airframe model.

The typical airframe model consists of a number of components, such as:

- Equations of motion
- Environmental models
- Calculations of aerodynamic coefficients, forces, and moments

When you open the example model, hl20airframe.mdl, you will see that these components are represented as subsystems in Simulink or blocks from the Aerospace Blockset. Clicking on the HL-20 airframe subsystem in hl20airframe.mdl opens the subsystem to show the five airframe components:

- 6DoF (Euler angles)
- Environment models
- Alpha, Beta, Mach
- Aerodynamic coefficients
- Forces and moments

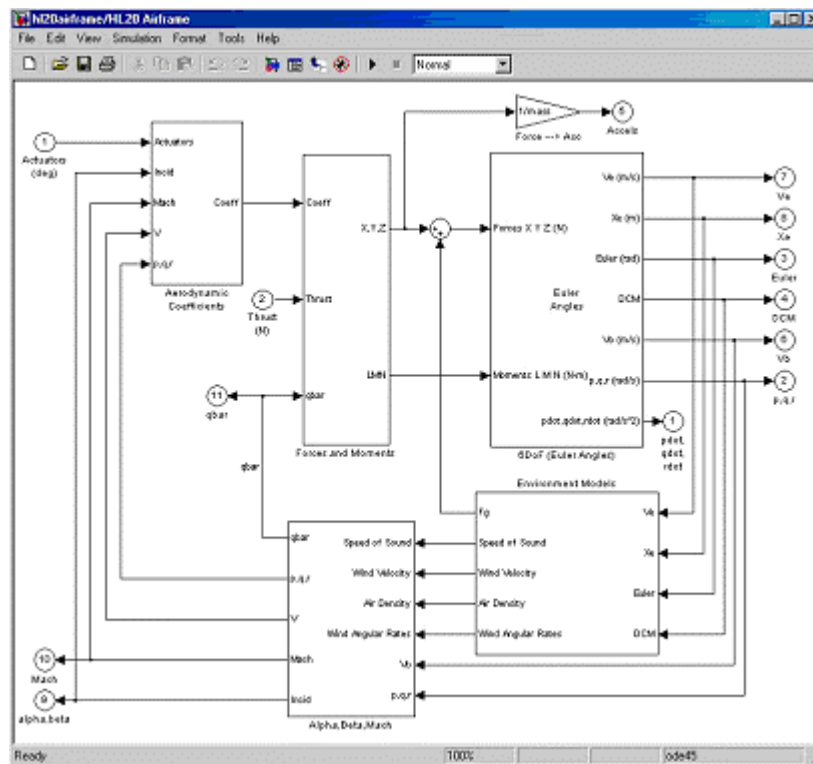


Figure 3: HL-20 airframe subsystem.

Taking a closer look at the airframe components

Examining the 6DoF (Euler angles) subsystem, you will find that it contains six-degrees-of-freedom equations of motion for the airframe. This subsystem is also one of the

equations of motion blocks from the Aerospace Blockset. In this example, the body attitude is propagated in time using an Euler angle representation. A quaternion representation is also available in the Aerospace Blockset.

Next, you can click on the subsystem Environment Models to inspect its construction. The environmental models used in the HL-20 airframe are:

- World Geodetic System of 1984 (WGS 84) for gravity
- Committee on Extension to the Standard Atmosphere (COESA) model for atmosphere
- Wind shear, Dryden turbulence, and discrete gust for wind models

Within this Environmental Models subsystem, the wind models can be found in the subsystem Wind Models. All of these standard environmental models are blocks contained in the Aerospace Blockset. These models are implementations of mathematical representations within standard references, such as U.S. Standard Atmosphere, 1976.

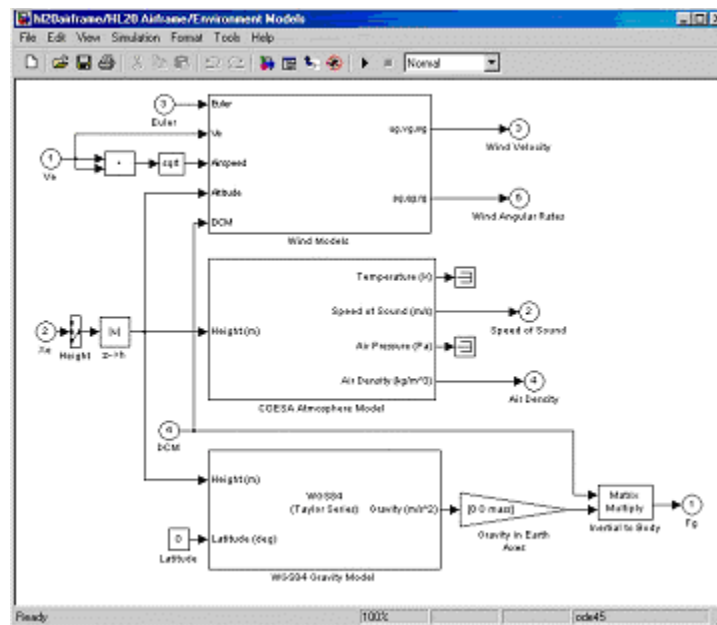


Figure 4: Environmental Models in HL-20 airframe model.

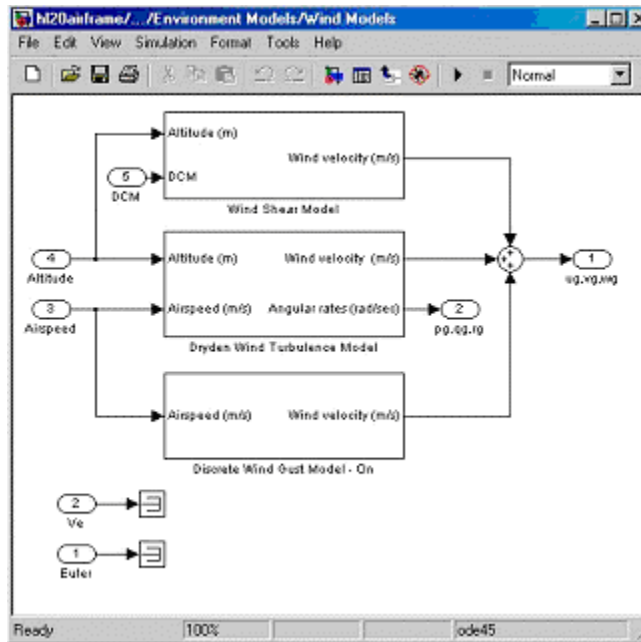


Figure 5: Wind Models in HL-20 airframe model.

Opening the Alpha, Beta, Mach subsystem, you will find additional calculated parameters that are needed for the aerodynamic coefficient computation and lookup. In addition to calculating Mach number and incidence angles, total velocity and dynamic pressure are computed. Also, wind velocity and wind angular acceleration are added to the body velocity and body rates, respectively.

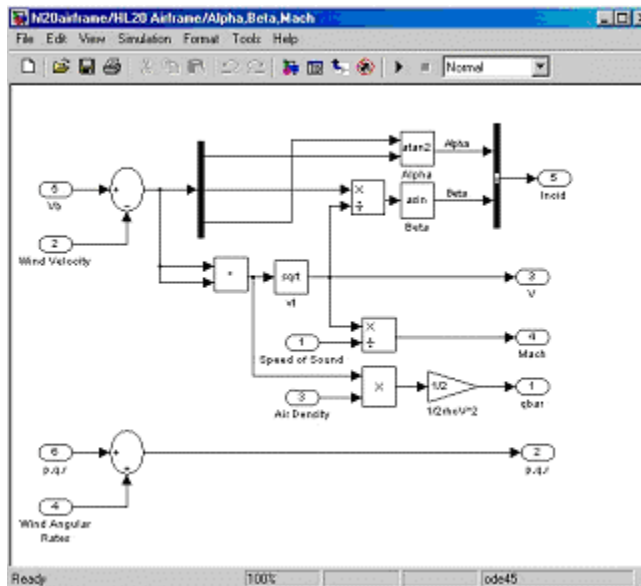


Figure 6: Additional calculated parameters for HL-20 airframe model (Alpha, Beta, Mach Subsystem).

Following the majority of the calculated parameters' signal flow brings you to the Aerodynamic Coefficients subsystem. Within this subsystem, aerodynamic data and equations for calculating the six aerodynamic coefficients are implemented as in NASA TM4302, however the ground effects and the landing gear effects are not used in this aerodynamic model.

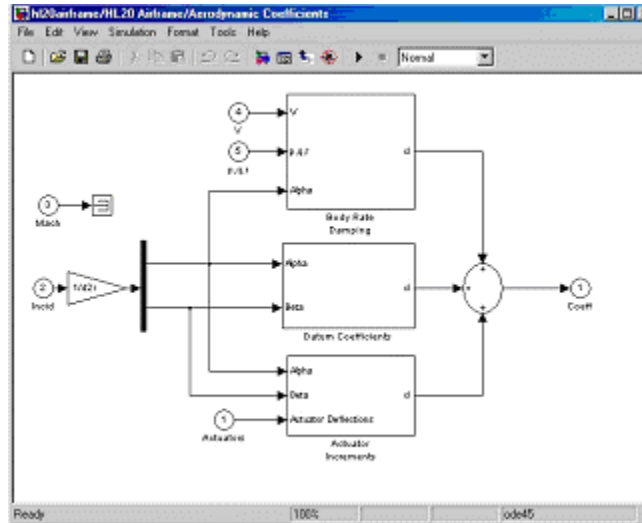


Figure 7: Aerodynamic Coefficients in HL-20 airframe model.

Aerodynamic data was gathered from wind tunnel tests. Wind tunnel data was mainly collected on scaled models of preliminary subsonic aerodynamic model of the HL-20. This data was curve fitted and most of the aerodynamic coefficients are described by polynomial functions of angle of attack and sideslip angle. In-depth details about the aerodynamic data and the data reduction can be found in NASA TM4302. The polynomial functions that are contained in the M-file, `init_hl20.m`, are used to calculate lookup tables used in the model by the model's preload function. In this model, lookup tables are used instead of polynomial functions. Depending on the order and implementation of the function, using lookup tables can be more efficient than recalculating values at each time step with functions. To further help model efficiency, most tables are implemented as PreLook-up Index Search and Interpolation (n-D) using PreLook-up blocks. These blocks improve efficiency most when there are a number of tables with identical breakpoints. These blocks reduce the number of times searching for a breakpoint is done in a time step. Once the tables are populated by the preload function, the aerodynamic coefficient can be computed. The equations for calculating the six aerodynamic coefficients are divided among three subsystems: Datum Coefficients, Body Rate Damping, and Actuator Increments.

The Datum Coefficients subsystem calculates coefficients for the basic configuration without control surface deflection. These datum coefficients are only dependent on the incidence angles of the body.

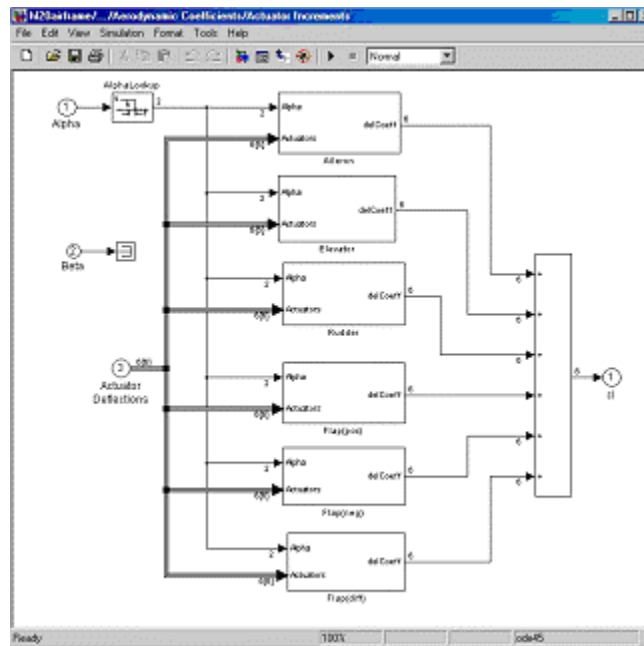


Figure 10: Actuator Increments subsystem.

Summing the Datum Coefficients, Body Rate Damping, and Actuator Increments subsystem outputs generates the six aerodynamic coefficients used to calculate the airframe forces and moments.

The last subsystem in the HL-20 airframe model is Forces and Moments. Examining the Forces and Moments subsystem, you will find the calculation of body forces and body moments about the center of gravity acting on the airframe. These forces and moments are dependent on the aerodynamic coefficients, thrust, dynamic pressure, and reference airframe parameters. The equations defining the body forces and body moments are found in NASA TM4302.

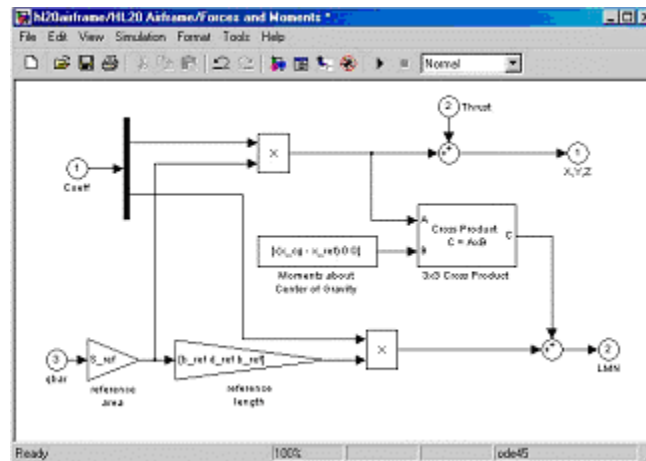


Figure 11: Forces and Moments subsystem.

The Simulink and the Aerospace Blockset subsystems that you have examined complete the HL-20 airframe. The next step in the flight control design process is to analyze, trim, and linearize the HL-20 airframe so that a flight control system can be designed for it. An example of an auto-land flight control for the HL-20 airframe, aeroblk_HL20_main.m, is included in the Aerospace Blockset.

References

¹Jackson E. B., Cruz C. L., "Preliminary Subsonic Aerodynamic Model for Simulation Studies of the HL-20 Lifting Body," *NASA TM4302* (August 1992) (Included in the zip file available from MATLAB Central)

²Morring, F. Jr., "ISS Lifeboat Study Includes ELVs," *Aviation Week & Space Technology* (May 20, 2002)
<http://www.aviationnow.com/content/publication/awst/20020520/aw46.htm>

Additional information about the HL-20 lifting body can be found at
<http://www.astronautix.com/craft/hl20.htm>. 