Modeling and Control of Flight Dynamics

A control system requires the following parts/models:

The Plant

The plant model relates the system inputs to the system outputs. It's basically how the rocket responds to the forces acting on it. For the full system, the plant outputs (the plant state) are:

- 3-D Acceleration
- 3-D Velocity
- 3-D Position
- Roll, Pitch, and Yaw angular acceleration
- Roll, Pitch, and Yaw angular velocity (rotation rate)
- Roll, Pitch, and Yaw angular position (orientation)

The inputs are

- The forces acting through the center of mass
- The torques acting about the center of mass

The sources/causes of these forces and torques are

- The 3-D thrust
- The 3-D drag cause by body, nose cone, and fins

The transfer functions come from Newton's Second Law and have as parameters

- The mass and location of the center of mass.
- The moments of inertia about the Roll, Pitch, and Yaw axes.

Sections 3 & 4 of the Open Rocket Technical Manual contain a great deal of information about modeling the plant. Pay special attention to the damping. You will ultimately need the full 3-D model to properly control the rocket flight, but for the purposes of this project, you need to at least develop a 2-D model (horizontal and vertical position, velocity, and acceleration, and pitch angle, angular velocity, and angular acceleration). Consider the full 3-D model to be a stretch goal after you get the 2-D model working.

The Sensors

The sensors are what you use to measure properties that can be turned into the plant state. Assume that the sensors are:

- 3 axes of accelerometers sampled at up to 1000 SPS with the noise and accuracy characteristics of the ICM-20948.
- 3 axes of rate gyros sampled at up to 1000 SPS with the noise and accuracy characteristics of the ICM-20948.
- A 3-axis magnetometer sampled at up to 100 SPS with the noise and accuracy characteristics of the ICM-20948.
- A pressure sensor sampled at up to 50 Hz with the noise and accuracy characteristics of the MS5611-01BA03

- A GPS sampled at up to 10 Hz with the specs of the Ublox SAM-M8Q.

You may add if you desire

- A Pitot-static tube with 16 bits of pressure resolution.
- A video camera or diode array
- Other physically realistic sensors.

The Controller

The controller takes in the outputs from the sensors, calculates the assumed state vector of the plant, and uses the difference between the assumed and desired state vectors for the plant to generate control signals that are sent to the actuators.

The Actuators

The actuators (such as servos, valves, electric motors, etc. connected to the thrust vector gimbal, the controllable fins, gas jet thrusters, and/or gyro wheel RCS components) receive the control signals from the controller and generate the control inputs to the plant (the intentionally generated forces and torques). These all have dynamic components because they cannot act instantaneously. If the time constants of the actuators are at least 10 times smaller than the time constants of the plant, they can usually be ignored.

The Disturbances

The disturbances are random or systematic inputs to the plant that cause it to respond in undesired ways. Example of disturbances are the wind, wind gusts, off-axis motors, irregularities in the motor thrust both in magnitude and direction, misaligned fins, or other such things. These must be modeled and included in the system model to see how it responds.

Deliverables

The deliverables are divided into three categories: expected for the project, stretch goals, and even stretchier goals.

Expected Deliverables:

- A 2-D plus roll angle dynamic model for the plant with realistic values for the mass, moment of inertia, drag, and aerodynamic damping. The model should map how the inputs to the system map to the outputs.
- Dynamic models for the sensors including accuracy, resolution, response time, and sampling rate. The models should map how the plant model outputs map to the sensor outputs.
- A dynamic controller model that maps the sensor outputs to the calculated/assumed plant state vector, and then maps the difference between the calculated plant state vector and the desired plant state vector to the controller outputs. It can be as simple as proportional control.
- Dynamic actuator models that map the controller outputs to the actuator outputs/plant control inputs.

- A disturbance model with a minimum of a wind model with a DC component of 7 mph and a sinusoidally varying component of ±0.7 mph and a frequency of 1 hz.
- Plots and evaluations of how well the control system works for at least three different motors.

Stretch Goals:
- Add a full 3-D model to the expected deliverables.
- Add a more sophisticated controller model.
- Add more realistic disturbances.

Even Stretchier Goals:
- Complete hardware plans for the rocket, sensors, controller, and actuators.
- Code to implement the controller on the chosen hardware.
- A full state estimation model for the controller (such as a Kalman filter) with a sophisticated control algorithm.
- Build, fly, and test the rocket and control system.