# Final Quadsim Project

## 525.661 Unmanned Aerial Vehicles Systems and Control

**You will hand in a document answering the following questions with analysis and figures. Each question can be answered with no more than a paragraph of analysis. If figures are expected, it will be specified in the question. Please provide your code in an appendix (mapChannelsToMotors.m, quadsim_forces_moments.m, quadsim_sensors.m, quadsim_estimates.m, quadsim_control.m, and trajectory control if done outside of quadsim_control.m).**

1) **Describe the similarities and differences between the forces & moments on a fixed wing and multi-rotor UAV.** Discuss the differences in how the vehicles create control forces and moments. Discuss the differences in how aerodynamic forces act on the vehicle (think lift and drag). (2 points)

2) **Provide the derivation for the trim throttle condition.** Plug in numbers into the derived equation to show the quadsim trim throttle condition. (2 points)

3) **Provide the derivation of the autopilot design model transfer functions (Throttle to altitude, Elevator to pitch, aileron to roll, rudder to yaw).** Plug in numbers into the derived transfer functions to show the analytical TFs for the quadsim model. (2 points)

4) **Describe the similarities and differences between the fixed-wing and quadcopter autopilot control structures.** (e.g. both have autopilot algorithms that allow the vehicles to climb to an altitude and fly to a waypoint, but the autopilots achieve those desired conditions in different ways with different loop closures.) Discuss both the inner and outer loops. (2 points)

5) **Describe the similarities [redacted] the two types** [redacted] practical to implement a Pitot sensor on a multi-rotor. (2 points)

*(Read and think about Problem 9 while working problems 6-8.)*

6) **Using the transfer functions, compare the analytical open loop linear models (from problem 3) with the numerically derived open loop linear models (via A and B matrices).** If any are different, comment on how that difference affects the modeled behavior. Show the resulting transfer functions & provide plots comparing the analytical and numerical open loop step responses for each of your models. Please plot the analytical and numerical model responses on the same figure, with one figure for each model (dt2alt, de2theta, da2phi, dr2yaw). (Winds and loop biases in the P structure must be zeroed for linearizing.) (2 points)

7) **Now compare the open-loop linear step responses (from problem 6) with open-loop step responses using quadsim.** Provide plots showing the quadsim response to small deviations from trim elevator, aileron, rudder, and throttle. You should provide one plot for each control surface deviation, with an appropriately scaled linear step response overlaid. *Discuss how the quadsim responses compare to your linear model responses.* (2 points)

8) **Problems 1-7 were all open loop modeling to understand the plant. Now, develop the closed-loop controllers necessary for quadsim.** Describe the controller design process you used and list the gains you chose for each controller. Provide plots of the linear step responses overlaid on example small 6DOF step responses (altitude, pitch, roll, yaw, x horz velocity, y horz velocity). (It is helpful to delay the 6DOF step until after the altitude integrator is settled.) (4 points)

9) **Describe the purpose and benefits of using linearized models in tuning and verifying a controller.** For both uavsim and quadsim, we used both analytically derived models and numerically derived models. Why did we bother? What was the benefit? How did we verify the models were representative, and why is it important to verify they are representative? Consider both open-loop (Probs. 6-7) and closed-loop (Prob. 8) assessments. (2 points)

10) **Provide figures showing the Test Trajectory results with 140 seconds worth of flight.** Please see get_quadsim_trajectory_commands.m & make_quadsim_plots. As per the provided [redacted] are enabled for these final plots. If your quad isn't well controlled or the [redacted] too noisy, re-tune! (4 points)
[redacted]

See hints and tips on following page…

**Further hints/tips for quadsim project:**

- The “Quadsim Design Project Steps” slide provided checks for your resulting transfer functions. If you don’t match those, you did something wrong or are interpreting the results incorrectly.
    - For example, if your numerical dt2alt response isn’t approximately -1*H(kpd,kdt)=47.9/s/(s-a), with an unstable pole, then check your code.

- When providing linear step responses, specify an end-time for the step() command, e.g. [y,t]=step(…,5), etc. When comparing linear step responses with 6DOF, you may need to scale or shift the linear responses to appropriately overlay them on the 6DOF output. (If scaling, please state your scaling factor, or show the plotting commands.)

- When providing the requested plots, please make sure to understand the difference between “open-loop step responses” of the uncontrolled plant (Problems 6 & 7) and “closed-loop step responses” of the various tuned control systems (Problem 8).

- We use the linearized models to help us design reasonable controllers. But sometimes when we test those controllers in a full 6DOF (or a flight test) we might find that they don’t perform as well as expected. There is a lot of flexibility in tuning the controllers for this project. If you find that the 6DOF doesn’t perform as well as it should (e.g. underdamped oscillations or a lot of motor signal fluctuation), it is your responsibility to adjust your tuning and re-test in the 6DOF.
    - For example, if your resulting altitude and/or yaw steps in the “make_quadsim_plots.m” figures are too underdamped/oscillatory, re-tune!
    - If your throttle is riding at the 90% limit during most a large climb, you should consider reducing the gains!

- Verify that your GPS Smoother is working! Estimated east/north/alt positions, alt rate, speed and course should all “curve” smoothly between 1Hz updates. (zoom to verify)

- One of the “make_quadsim_plots.m” figures has a zoom in of the motor signals. We use this to assess whether there is “too much” motor signal fluctuation (in a flying quad it is very audible when there is too much motor signal fluctuation). Some examples of good and bad quadsim outputs, given winds and biases, are shown below: