Urban SAFE50

Modeling, controlling, and testing safe UAS operations in low altitude settings

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Jack Casey |Devin Cody | Alyssa Deardorff | Pear Dhiantravan | Lauren Kolkman | Anthony Markowitz | Simon Martinez | Steve Schafer | Mario Sebasco

NASA MARTI

Abstract

The research and development of UAVs are quickly progressing as industries and hobbyist societies recognize their utility. NASA is focused on the technology development and safety considerations surrounding commercial use of UAV. Urban SAFE50 is focused on the necessary real-time decision algorithms and flight models prevalent in low-altitude, high-density city environments. Construction of on-board controls to respond to motor failure and wind dynamics as well as a database of computational flight models and battery discharge profiles will help policymakers to predict and regulate unmanned aircraft flight safely and effectively.

Multidisciplinary Aeronautics Research Team Initiative

MARTI is a 10-week immersive and intensive summer program that focuses on leadership, teamwork, and research in advanced technology and engineering.

Name	School	Major	Second Major
Jack Casey	University of Arizona	Aerospace Engineering	
Devin Cody	Yale University	Applied Physics	Electrical Engineering
Alyssa Deardorff	Oregon Tech	Systems Engineering and Technology Management	Renewable Energy Engineering
Pear Dhiantravan	Northwestern University	Chemical Engineering	Biology
Lauren Kolkman	Purdue University	Aeronautical and Astronautical Engineering	Applied Physics
Anthony Markowitz	Princeton	Mechanical and Aerospace Engineering	
Simon Martinez	Embry-Riddle Aeronautical University	B.S. Aerospace Engineering (Astronautics)	M.S. Aerospace Engineering (Aeronautics & Propulsion)
Steve Schafer	University of Missouri	Mechanical and Aerospace Engineering	
Mario Sebasco	University of Miami	Mechanical Engineering	

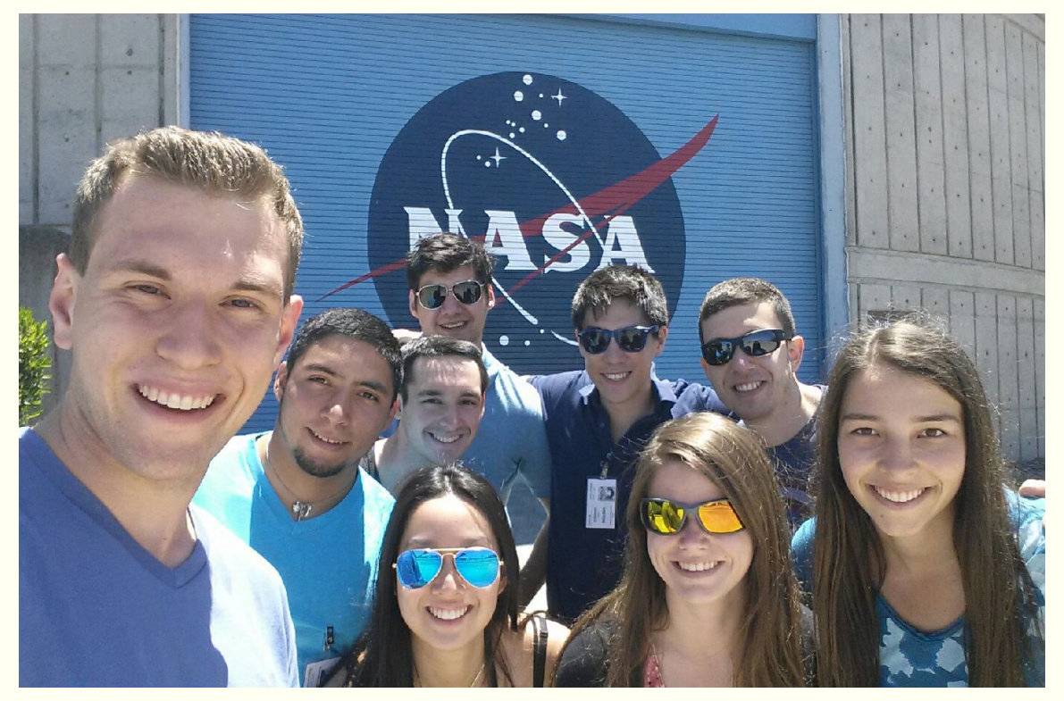

Figure 1a MARTI Summer 2015 Team

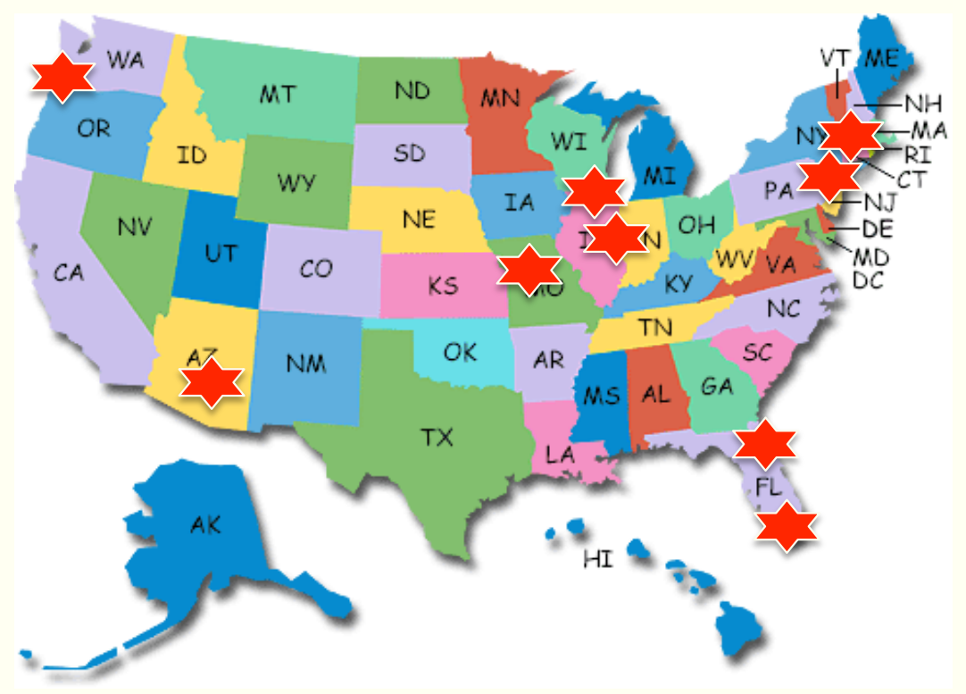

Figure 1b MARTI Universities

What is SAFE 50?

<u>S</u>afe <u>A</u>utonomous <u>F</u>light <u>E</u>nvironment within the notional last **<u>50</u>** ft of operation of 55 lb class UAS. SAFE 50 addresses an aspect of UTM technologies to enable safe scenarios.

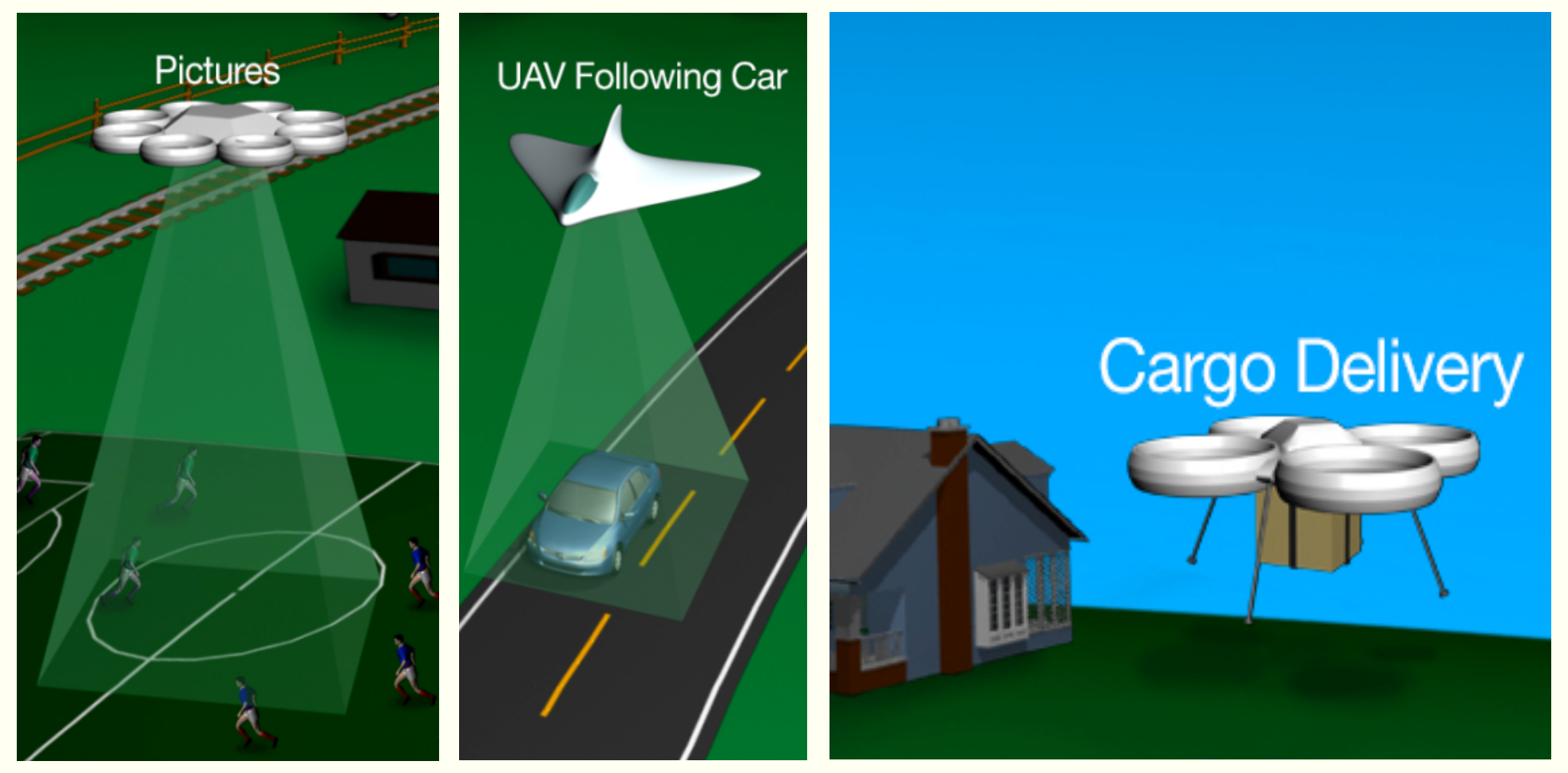

Figure 2 Possible near-ground UAS scenarios.

Computational Fluid Dynamics of Rotorcraft Vehicles

RotCFD is being utilized in order to examine rotorcraft vehicles in hover and forward flight, in and out of ground effect. This will allow for characterization of their environmental interactions, and allow for more efficient platform design.

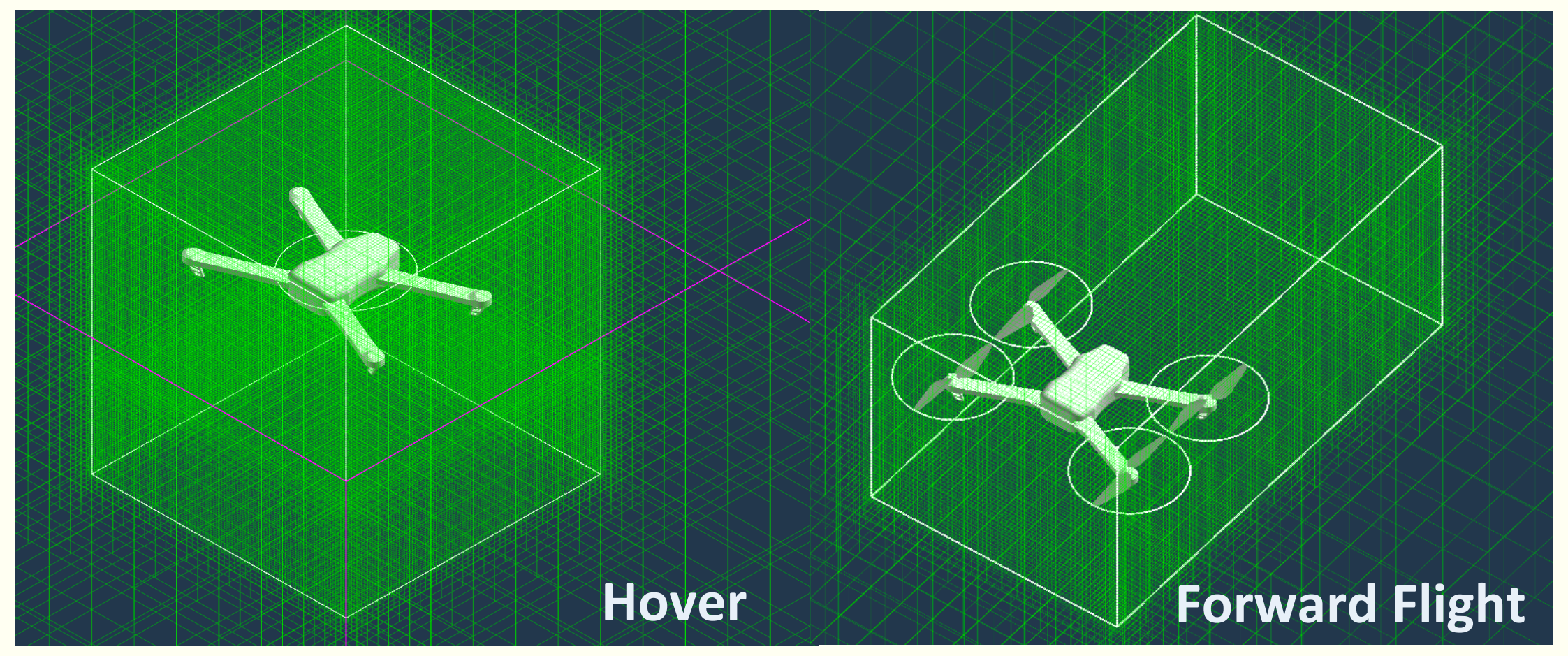

Figure 3 Initial grid setup for hover and forward flight. Depicted in each is the local refinement, which helps ensure a robust, accurate solution.

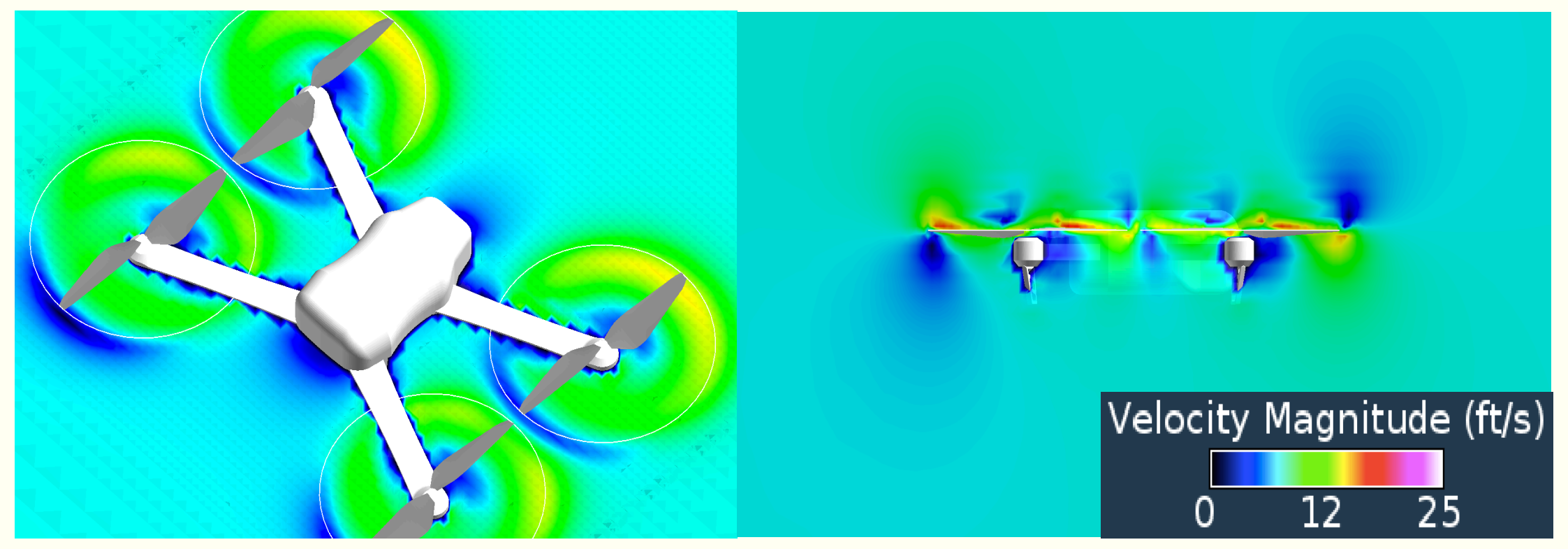

Figure 4 Initial velocity profiles of IRIS+ hovering in low speed wind (5 mph).

Computational Fluid Dynamics of Rotorcraft Environments

In order to better design not only the UAS, but the safety aspects around their operations, a complete understanding of the environments in which they operate is necessary.

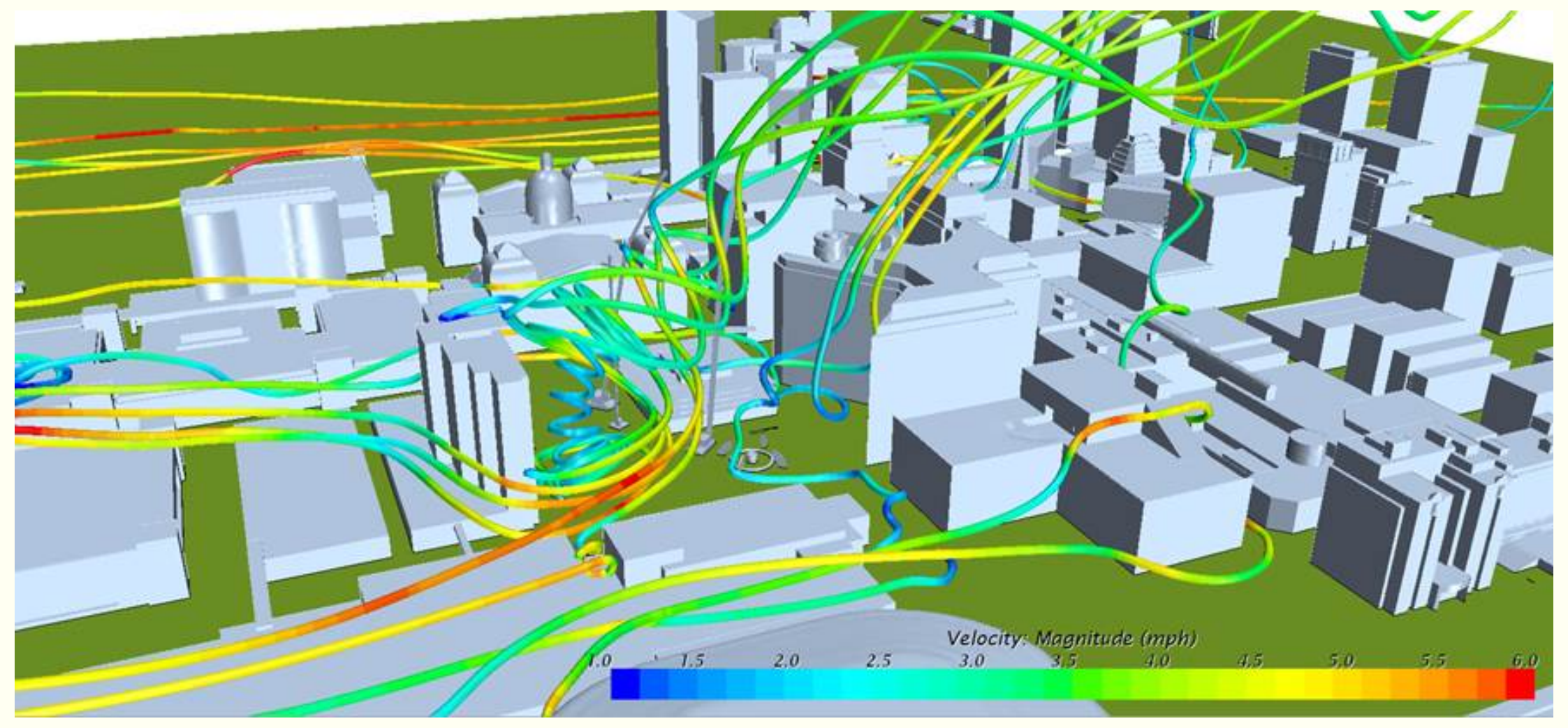

Figure 5 An example of wind profiles through CFD analysis.

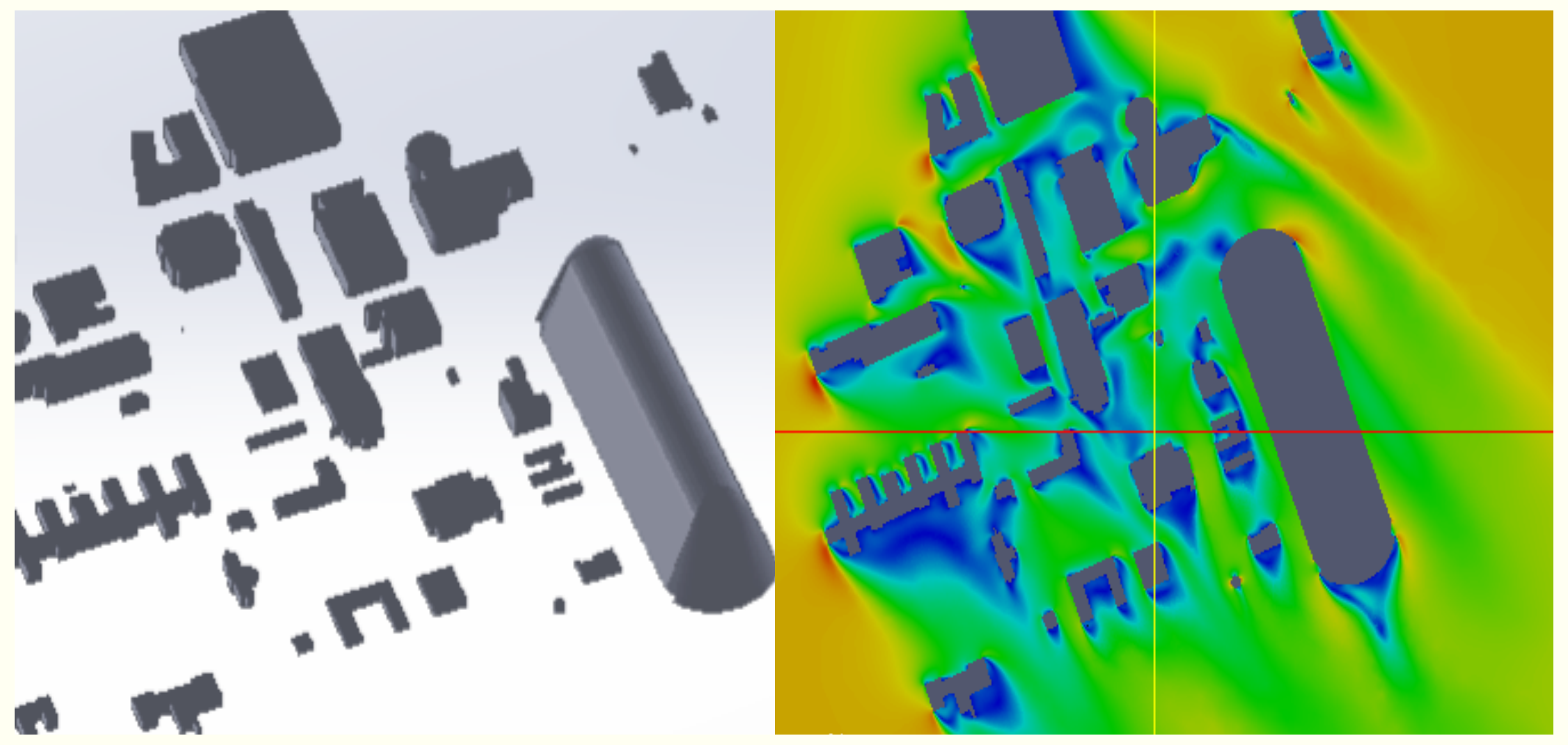

Figure 6 A 3D model of NASA Ames, which is being used for initial wind profile estimate through CFD analysis.

Controls for Motor Failure

When a Motor is lost, the multi rotor system will quickly lose control and spiral out of the sky unless the failure is discovered quickly and appropriate action is taken.

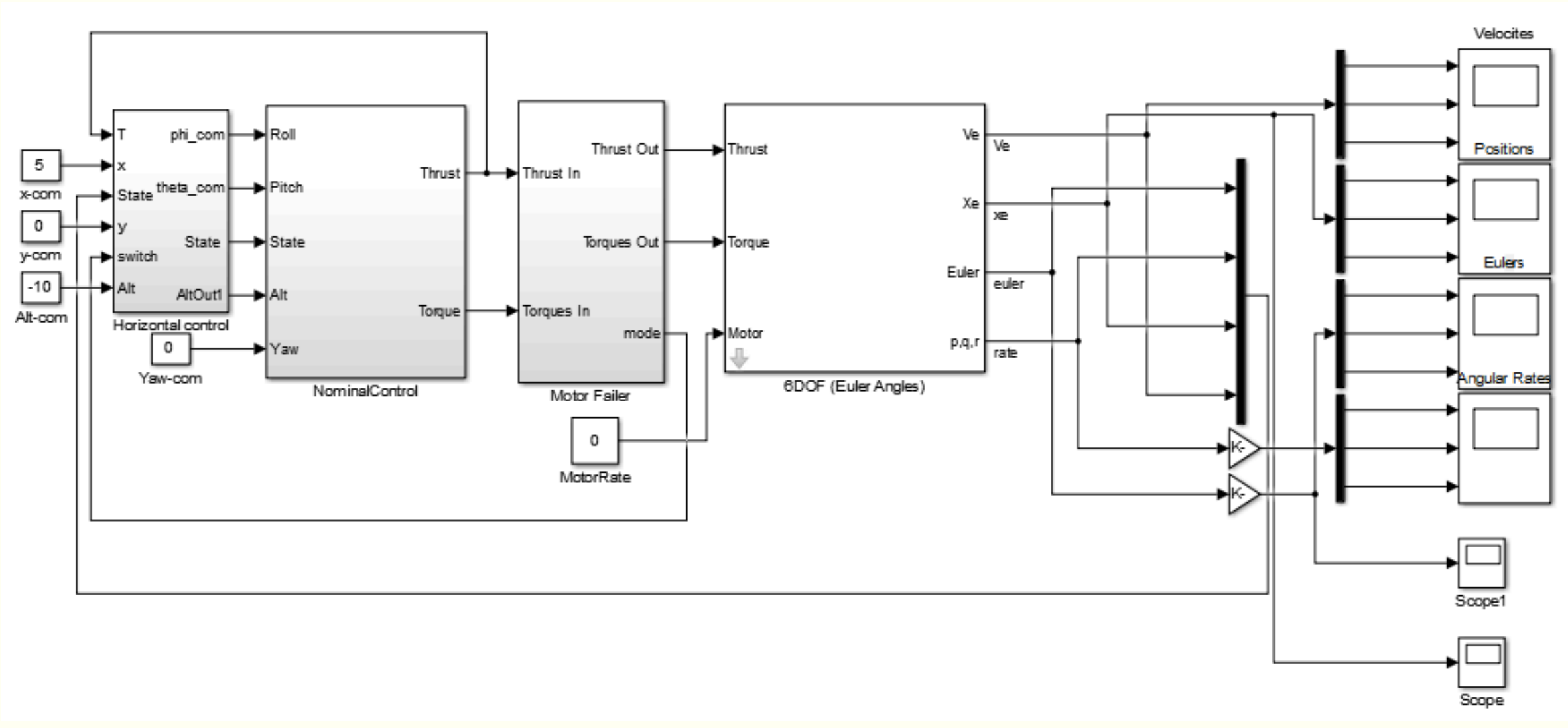

Figure 7 Simulink Model: simulates multicopter dynamics and lends intuition for understanding the interaction between control theory and actuality.

$$\begin{bmatrix} Thrust \\ \tau_{roll} \\ \tau_{pitch} \\ \tau_{yaw} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & \cancel{1} & 1 & 1 \\ R_{21} & R_{22} & R_{23} & R_{24} & R_{25} & \cancel{R_{26}} & R_{27} & R_{28} \\ R_{31} & R_{32} & R_{33} & R_{34} & R_{35} & \cancel{R_{36}} & R_{37} & R_{38} \\ a & -a & a & -a & a & \cancel{-a} & a & -a \end{bmatrix} \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \\ f_7 \\ f_8 \end{bmatrix}$$

Figure 8 Control Matrix: By inverting the control matrix in the middle, we can solve for the individual motor forces (far right vector). When a motor failure is detected, we alter the control matrix before inverting. Before the device lifts off, a control matrix for every contingency is calculated.

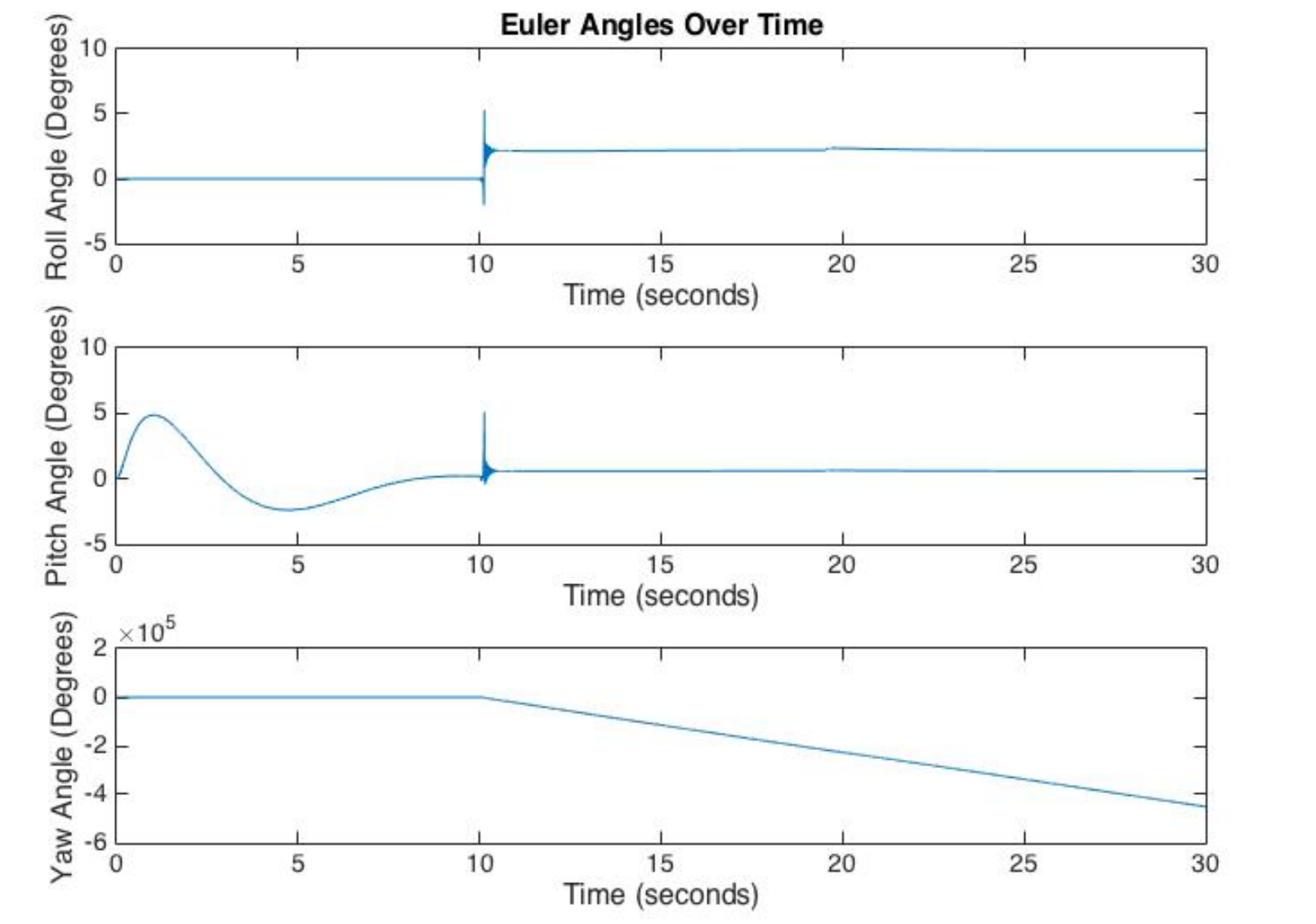

Figure 9 Simulation Results: This figure shows the Euler angles of the quadcopter over time. At 10 seconds, a motor fails and the control system is modified to control the quadcopter by sacrificing yaw. As expected, the roll and pitch angles settle while the yaw goes off to infinity.

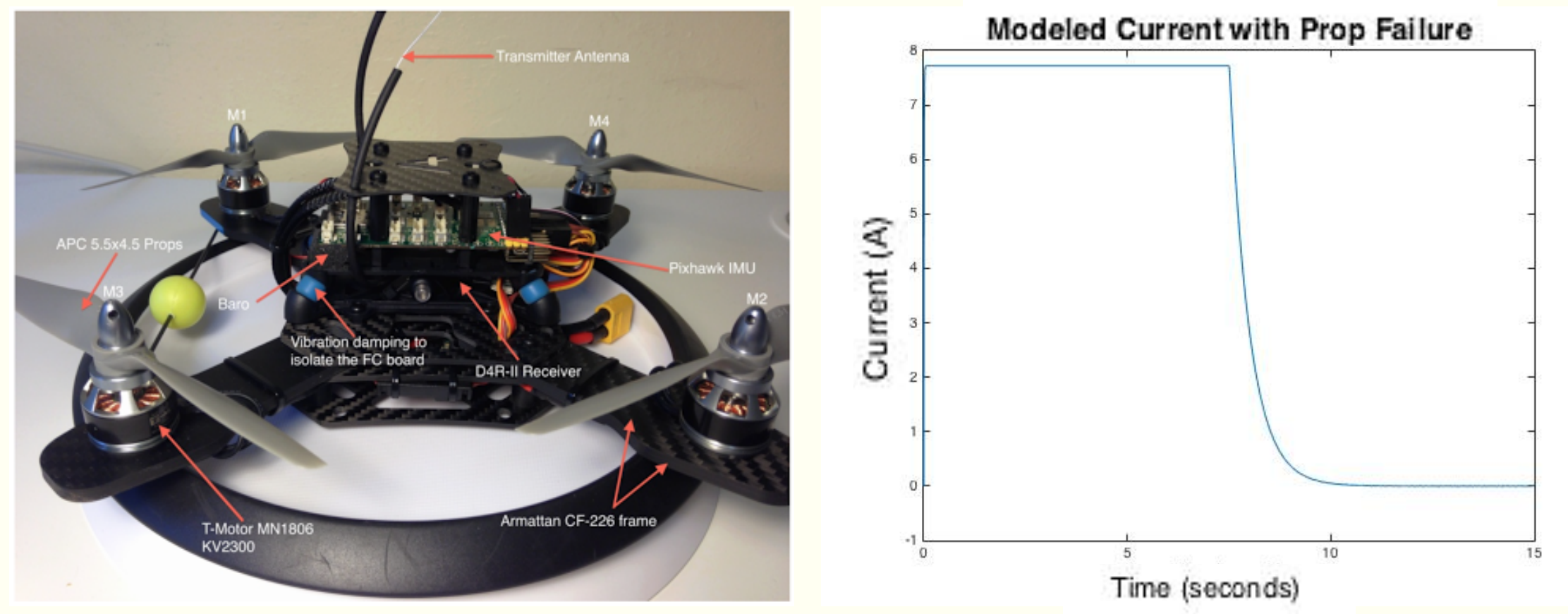

Figure 10 Hardware:

(a) This quadrotor was built by our mentors to test their motor failure protocol. We will be integrating our work into its flight controller to test our motor failure work.

(b) This figure shows how the current model changes when a propeller flies off of its motor. At 10 seconds, the current drops rapidly because there is no aerodynamic drag on the motor anymore.

Battery Prognostics

Electric UAVs need to have reliable energy systems in order to ensure the best opportunity for safe flight. Assessing battery conditions throughout flight simulations and modeling an energy storage fault tree analysis may help determine UAV protocol during failure events.

Iris+ Lithium Polymer Battery Prognostics

- Code TI Systems health, analytics, resilience, and physics modeling (SHARP) laboratory

Characterize failure modes and fault tree analysis

Battery certification protocol

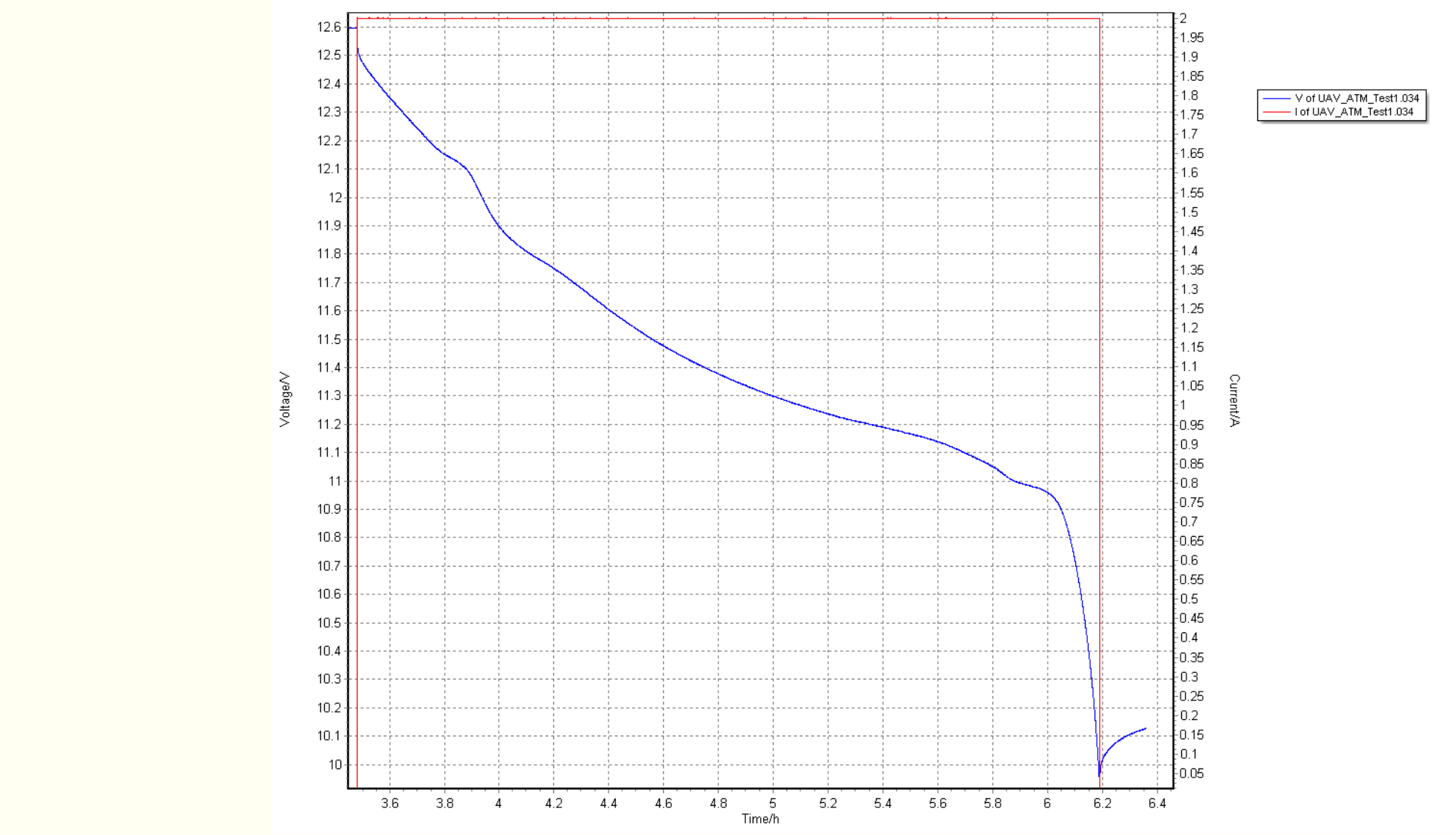

Figure 11 Iris+ batter and 2A Discharge Profile on MACCOR.

Integration Environment: Reflection

NASA Reflection simulation software will be utilized to as the validation environment along with hardware testing with the Iris+ in order to integrate CFD modeling, intelligent controls, and battery prognostics.

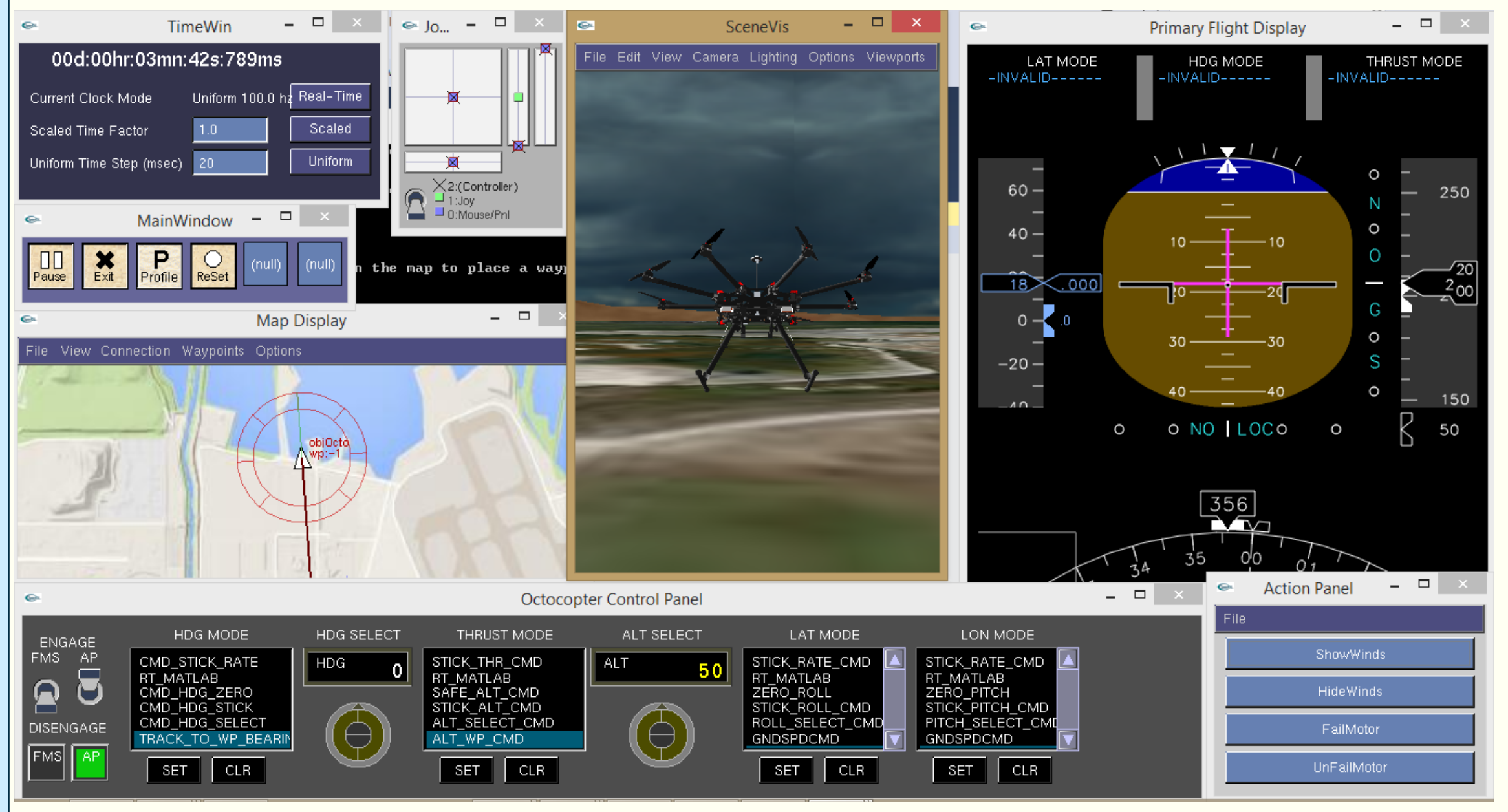

Figure 12 NASA developed software program, Reflection running a flight simulation.

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