The University of Kansas Aerospace Engineering Flight Systems Research

Alec Bowman, Chris Hedden, Gonzalo Garcia, and Ryan Lykins
The University of Kansas

The University of Kansas (KU) is a national and international leader in research and development of radars for remote sensing and Unmanned Aerial Systems (UAS) for Earth Science missions. KU has had a long history of design, manufacturing, and flight testing UAS's dating back to 1999. As the most visible of our programs, the Meridian is also the largest UAV platform ever designed, built, and successfully flight tested autonomously by an academic institution. The Meridian is an 1,100 lb UAS designed for Polar research and has been flight tested autonomously in three continents (North America, Europe, and Antarctica). In the last few years, KU Aerospace Engineering (KUAE) has performed 75 flights and over 24 hours of autonomous line-of-sight and over-the-horizon flight test. KU has successfully flight tested different UAS platforms in one of the most hostile and remote environments known to the aviation industry (Polar Regions). KUAE's 7 autonomous fixed wing UAS range from 28 to 1,100 lbs. KUAE owns two manned experimental aircraft (Cessna C-172 and Cessna C-182) for rapid technology development. The KU Flight Systems team has three primary focuses: Avionics, guidance, navigation and control, and nonlinear dynamic analysis.

Autopilot and Avionics

The first KU Flight Systems team research area is the development of an Autonomous Flight System (AFS) and the avionics for unmanned aerial vehicles. The AFS was designed from the ground up as a highly modular and adaptive universal control system. The system's versatility allows it to be implemented on both fix and rotary wing aircrafts. The AFS busses monitor and control engine, actuators, and remote sensors. These sensors include an attitude and heading reference system, alpha/beta sensors, and control surface deflection sensors. In addition, the system incorporates redundant accelerometers, rate gyro and GPS measurements. This redundancy is handled by a Kalman filter built into the system. The filter analyzes data from all sensors and provides the controller with optimally filtered data.

The entire system is commanded by a ground station that displays and logs all sensor and trajectory data. The data can be plotted using a real time plotter that shows the ground crew performed maneuver characteristics. This data is crucial in system dynamic analysis flights. With this data, we can determine if specific aerodynamic characteristic has been adequately captured such that our dynamic analysis system identification will be optimized.

Guidance, Navigation, and Control

In addition to our highly versatile flight control system, our team has also implemented a novel guidance and control system. In this new guidance logic, instead of trying to reach a specific waypoint along a track, the system follows an imaginary target moving along a trajectory between waypoints. When this pseudo target passes within a particular threshold distance from the track end, it moves to the next segment. By following the pseudo target instead of trying to attain the trajectory itself, the overall flight path is smoothed.

The inherent nonlinearity of the aircraft together with its limited desired operation range makes the use of on-line control law computation an ideal solution. The AFS employs nonlinear model predictive control (NMPC) to perform its guidance, navigation, and control for trajectory tracking. The combination of the nonlinear UAV model, the nonlinear guidance laws in both lateral and longitudinal plans, the NMPC, and an extended Kalman filter generates on-line optimal or suboptimal control signals to keep the UAV on the trajectory. This method provides superior performance and handling characteristics.

The navigation system is directed by the ground station, but implemented on the AFS. From our ground station, waypoints can be uploaded to the aircraft in flight. These waypoints contain data ranging from position and velocity to what stability control logic should be engaged or disengaged. This versatility allows us change the entire system structure in flight. For instance, our system allows us to switch between a typical aircraft configuration to a system with redundant control surfaces and active failure detection. The ability to transition between multiple controllers in flight allows us to test new controllers while always having a proven controller as backup.

Dynamic Analysis

Due to the turbulent polar weather and the nonlinear nature of the Meridian UAS, conventional methods of parameter identification have proven to be inadequate. A model identification method called Fuzzy Logic Modeling is utilized to develop the aerodynamic models. The reduced frequency (nondimensionalized frequency) is used to represent the unsteadiness of the flow field according to Theodorsen’s theory. In roll oscillations, the unsteadiness is estimated based on the time history of the reduced frequency. Research in this area has been expanded using frequency domain analysis. CIFER (Comprehensive Identification from Frequency Responses) is being used to identify neglected cross-coupled stability and control parameters. Aerodynamic models of our other UAS’s can also be developed using this method.

Another aspect of dynamic analysis is measuring non-aerodynamic vehicle constants—specifically, moment of inertia. Traditionally, the moment of inertia is measured by decomposing the aircraft into simple shapes of known moments of inertia. These values are then added together with respect to the center of gravity of the aircraft. This method of measurement is time consuming and prone to error. Our team employs a more indirect method of measuring moment of inertia. The aircraft is first converted into a pendulum. It is swung such that it swings about an axis parallel to that of the moment of inertia axis being measured. By analyzing the period of oscillation, the moment of inertia can be determined. These swing tests produce results that are, on average, within four percent of those measured using the decomposition method. This swing method is ideal for the small unmanned aircrafts as the method is fast and accurate.

Conclusion

As described, the research and development performed by the KU flight systems team encompasses all aspects necessary to continuously perform advanced research in flight dynamics and controls. Hardware and software developed by the KU flight systems team, KU AFS, will act as the tool necessary to continue novel research in both aircraft modeling and guidance and control. With the current phase of AFS flight testing coming to a close at the end of August 2012 the KU flight systems team has begun looking into the future of possible research opportunities. Some of these research topics include split-surface control, trajectory optimization, and collision avoidance. Our experience in dynamic analysis, guidance, and control in conjunction with our versatile AFS system provide an ideal background for this future research.

University of Kansas Aerospace Engineering Flight Systems Research

Alec Bowman, Chris Hedden, Gonzalo Garcia, and Ryan Lykins

Aircraft Modeling and Control

Moment of Inertia

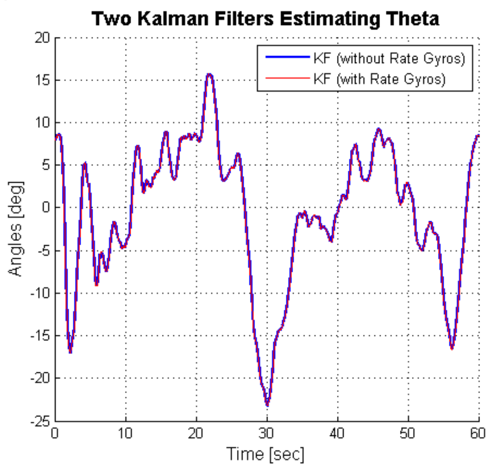
Pendulum Fixture to Measure Moment of Inertia about the X Axis (Left) and Z Axis (Right)

- Theoretical approach to measuring moment of inertia is time consuming and prone to error due to measuring the size, weight, and location of each component of the aircraft.
- Experimental approach is more accurate. By measuring the response of the aircraft set up as a pendulum with an arbitrary, impulse the moments of inertia can be calculated.

	Decomposition Method	Pendulum Method	Difference
Ixx (slug ft²)	1.089	1.099	0.92%
Iyy (slug ft²)	2.107	2.280	8.2%
Izz (slug ft²)	3.038	3.090	1.7%

Utilizing Flight Measurements

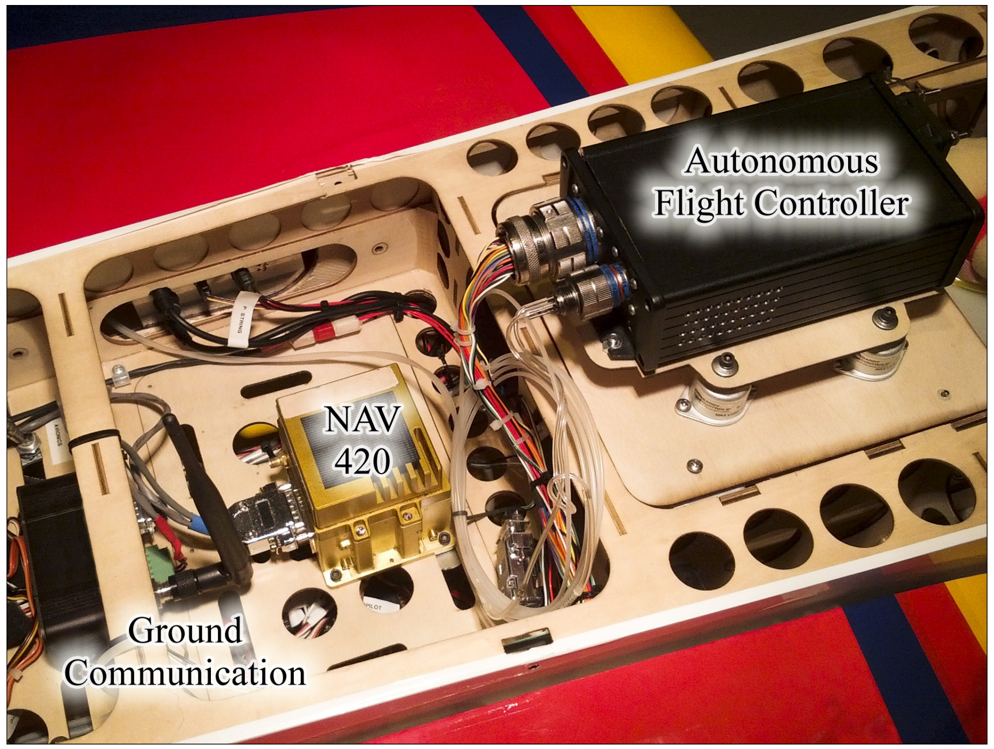
To counteract the inherent noise and to estimate unmeasured states in the system, two generations of Kalman Filters have been implemented to provide our system with the best possible information.



The KU Autonomous Flight System

The KU Autonomous Flight System was designed from the ground up as a highly modular and adaptable universal control system to be used on different classes of fixed– and rotary-wing UAS.

- The main vehicle busses monitor and control the engine, actuators, and remote sensors
- Sensors include attitude and heading reference system, alpha/beta sensors, control surface deflection sensors, and NAV 420 data, which provides redundant accelerometer, gyroscopic, and GPS measurements.
- The ground communication system transmitted all data to the ground station where data is displayed and recorded and can be analysis for real time trajectory optimization and system/parameter identification.



Novel Guidance and Control

- The inherent nonlinearity of the aircraft together with its limited desired operation range makes the use of on-line control law computation an ideal solution.
- A NMPC is designed to perform guidance, navigation, and control of a fixed-wing UAV in a waypoint trajectory tracking.
- The combination of the nonlinear UAV model, the nonlinear guidance laws in both lateral and longitudinal plans, the NMPC, and an extended Kalman filter generates on-line optimal or suboptimal control signals to keep the UAV on the trajectory.
- The NMPC produces superior performance and handling characteristics over other controllers