Hati Flight 01 Analysis

Synopsis

During Hati Flight 01, poor Euler angle tracking was discovered leading to suspension of tests and a return to landing shortly after engaging the autopilot. In autopilot mode pitch and roll stick are mapped to pitch and roll angle commands. This behavior was observed during flight as an unresponsiveness to pilot input. Post-flight, a poor Euler angle solution can be observed as a mismatch between the computed angles and the aircraft dynamics. Below is an example where the pitch angle is reported at its upper saturation limit while the aircraft is descending and the throttle command is decreasing to maintain speed.

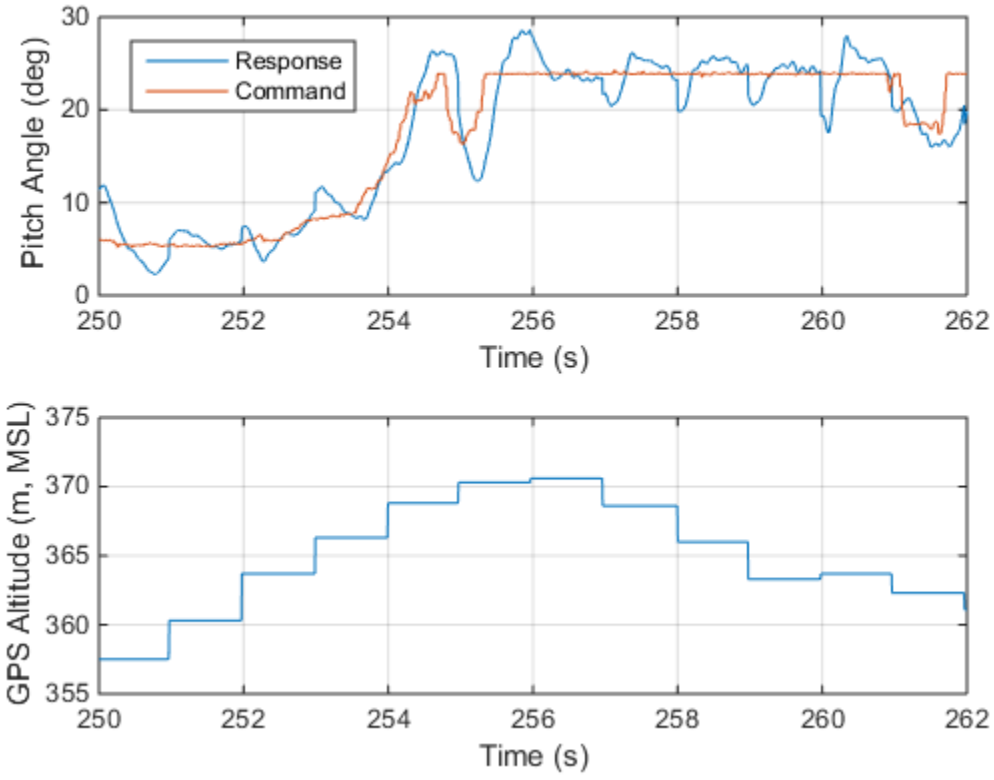


Figure 1: pitch command unresponsiveness in descent

Similarly, below is an example where the pitch angle is reported at its lower saturation limit while the aircraft does not respond.

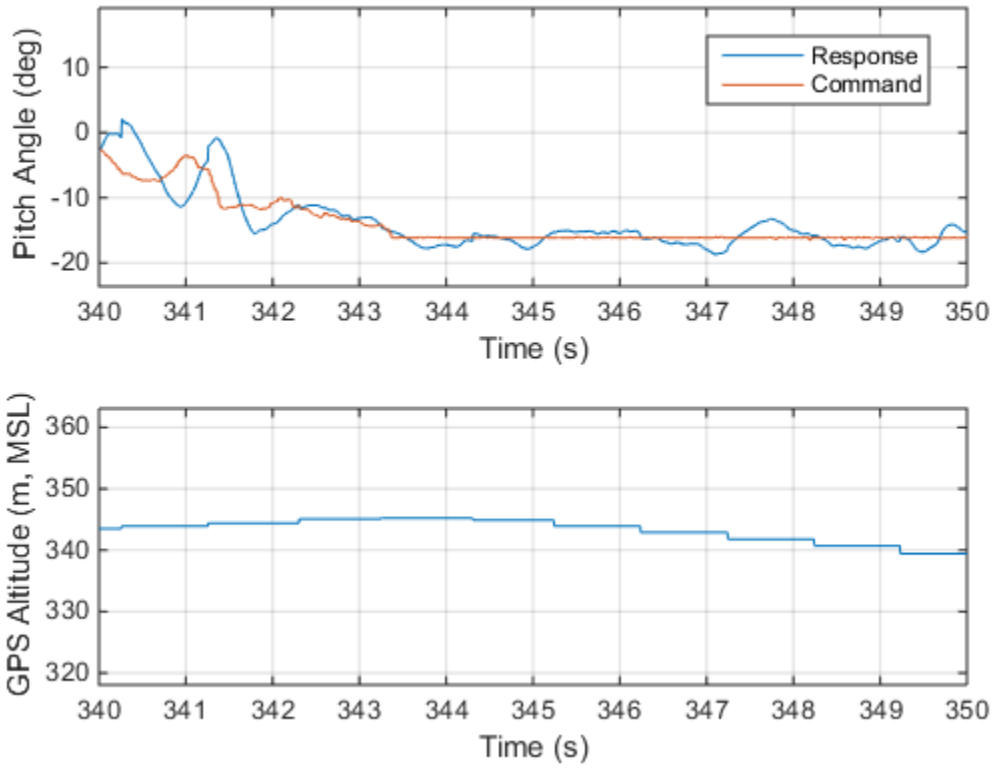
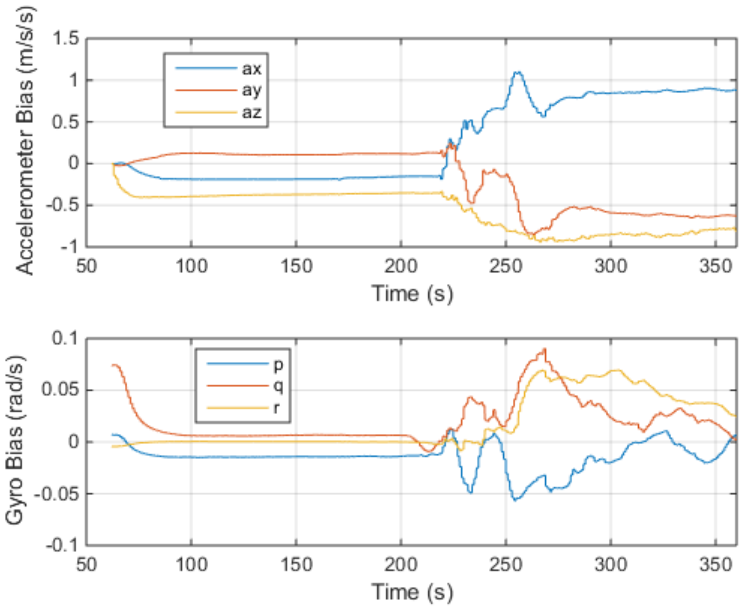


Figure 2: pitch command unresponsiveness in level-flight

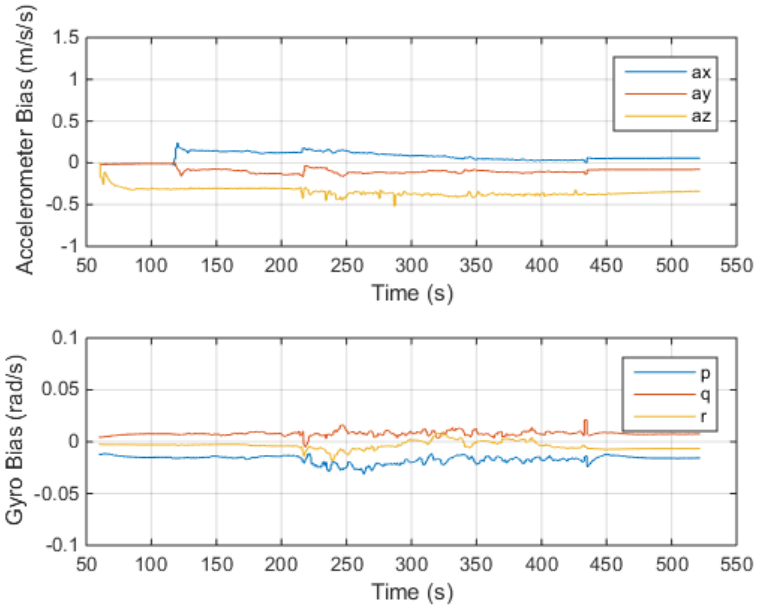
A side-effect of the poor Euler angle solution were a few Pilot Induced Oscillations (PIO), which likely occurred as a result of the mismatch between the faulty aircraft Euler angle and the observed aircraft attitude from the ground.

Causality

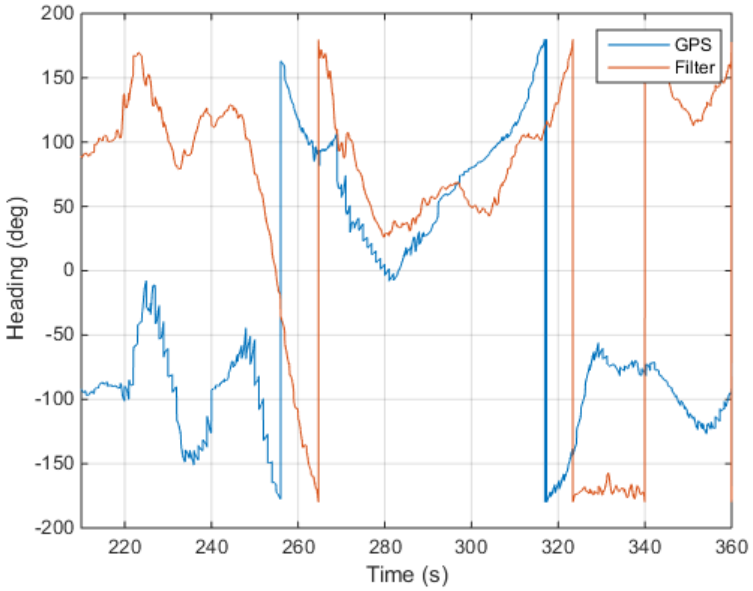
The 15 state EKF filter computes and records accelerometer and gyro biases. Initially, these biases converge, but immediately following the aircraft release at about 220 seconds, these biases diverge.



For comparison, Skoll flight 12 biases are below with the y-axis scaling applied.



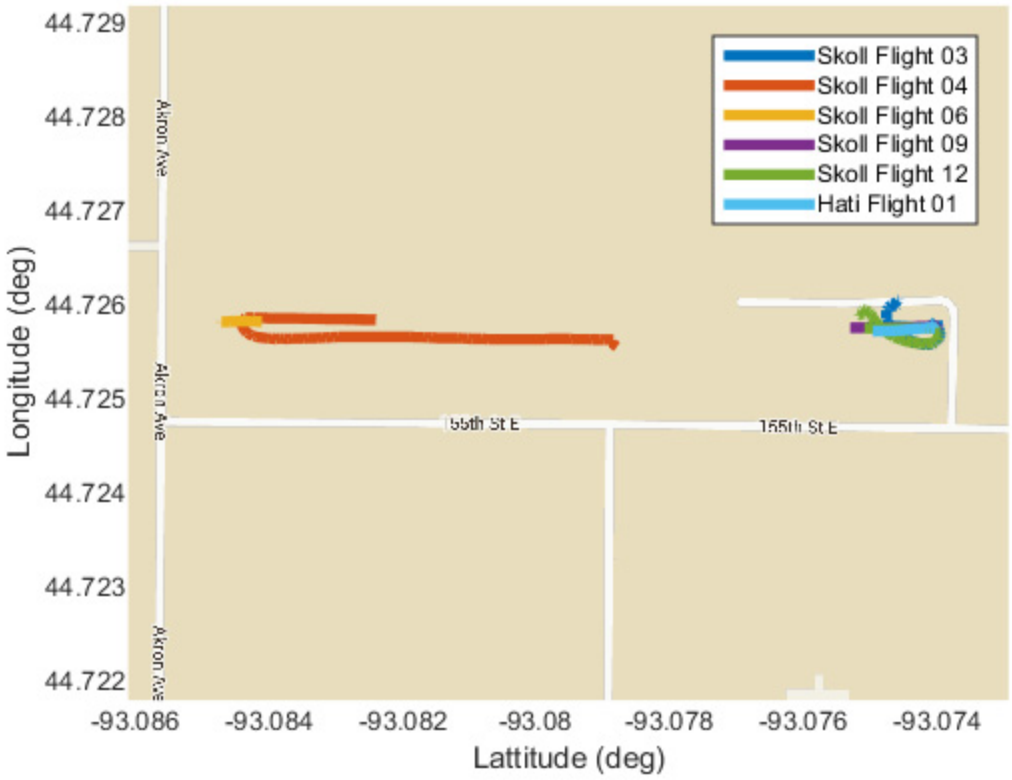
The 15 state EKF was initialized with hard coded values of +8 degrees pitch angle, 0 degrees roll angle, and +90 degrees heading. These values were used because this is how the filter was flown in the past with multiple hundred flights over several years without noticeable problems. Following initialization, these should converge to the true values. During this flight, heading angle did not converge prior to flight.



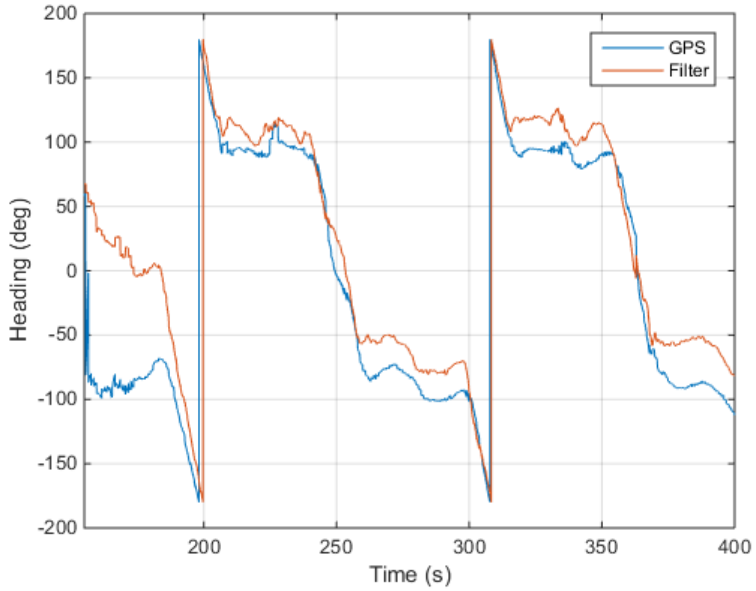
During most flights, the aircraft software is loaded and initialized. Following initialization and some quick checks, the aircraft is moved or taxied to the runway prior to launch. During mAEWing1 testing, occasionally, the software has been reset on the launch truck just prior to launch due to either, a) observing a GPS fault or lock loss or b) needing to move the aircraft a long distance to align with favorable wind conditions. The typical operating direction for mAEWing1 is a launch on a West heading, but operations have occasionally been conducted launching on a East heading, which due to the long distance to setup, has necessitated a software reset on the truck.

For Hati Flight 01, a West launch heading was used, but the software was reset on the truck because of the new higher sampling rate. This flight was the first using a 150 Hz sampling rate, which limits the flight data recording time to just over 8 minutes. With flight times of about 6 minutes, the decision was made to reset software on the truck just prior to launch. The hypothesis is that without significant heading motion or time prior to launch, and the initialization of a value 180 degrees from the true value, the EKF did not converge prior to launch.

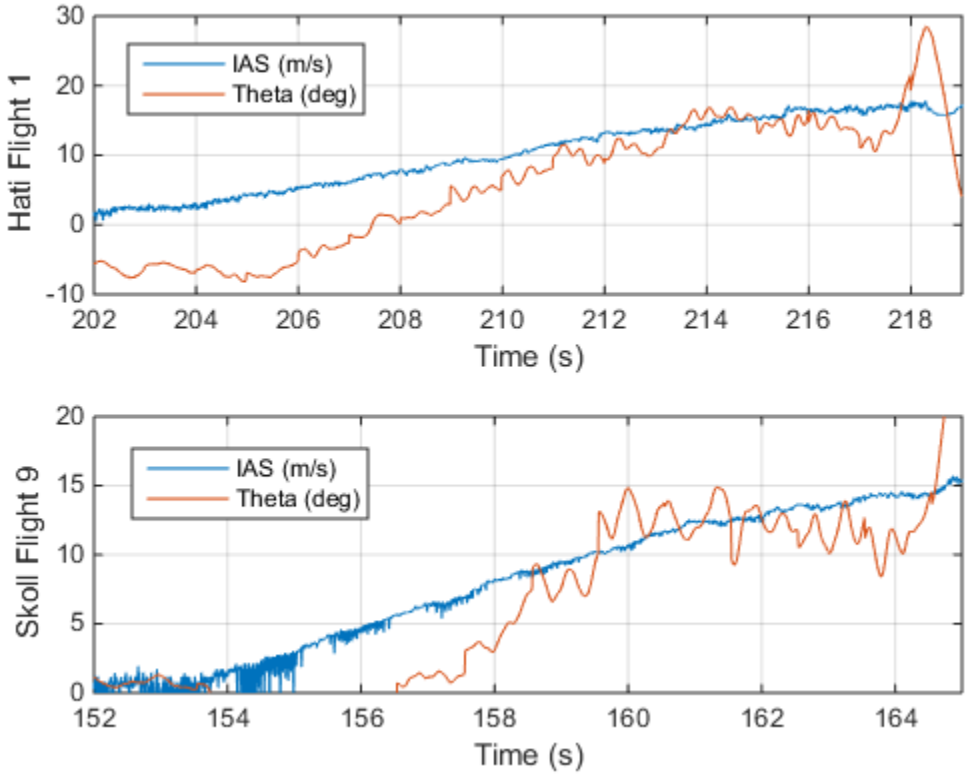
Examining other mAEWing1 flights, all of the previous flights, except one, were either initialized and then driven to the launch location with the software running or, when a software reset was performed on the truck, the launch direction happened to be East.



The one other flight where a West launch direction was used immediately following a software reset occurred on Skoll Flight 09. It is interesting to note the similarities between Skoll Flight 09 and Hati Flight 01. First, the heading angle was not correct until the first turn to the East to set up for the initial test point.



Second, on both flights, the pitch angle increases during the truck acceleration up to launch speed. This behavior was not observed on any other Skoll flights and is known to be inaccurate based on launch videos.



Other Faults

It was also discovered that the GPS data (position, altitude, speed, and course) may have been truncated. This likely did not cause the filter divergence, but it appears to be leading to less smooth navigation filter estimates for position and speed and should be rectified.

Corrections

The GPS data truncation will be corrected. Additionally, accelerometer data will be used to compute pitch and roll attitude angle to initialize the navigation filter. Either magnetometer or GPS course data will be used to initialize the navigation filter heading. If we use GPS course data, the aircraft will need to be in motion during heading initialization. As a short term solution, the initial heading could be set based on the launch direction. An additional correction would be the addition of a trigger to begin data recording to allow for a longer timer after navigation filter initialization before the beginning of flight.