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System Identification of a Small UAS in Support of Handling Qualities Evaluations

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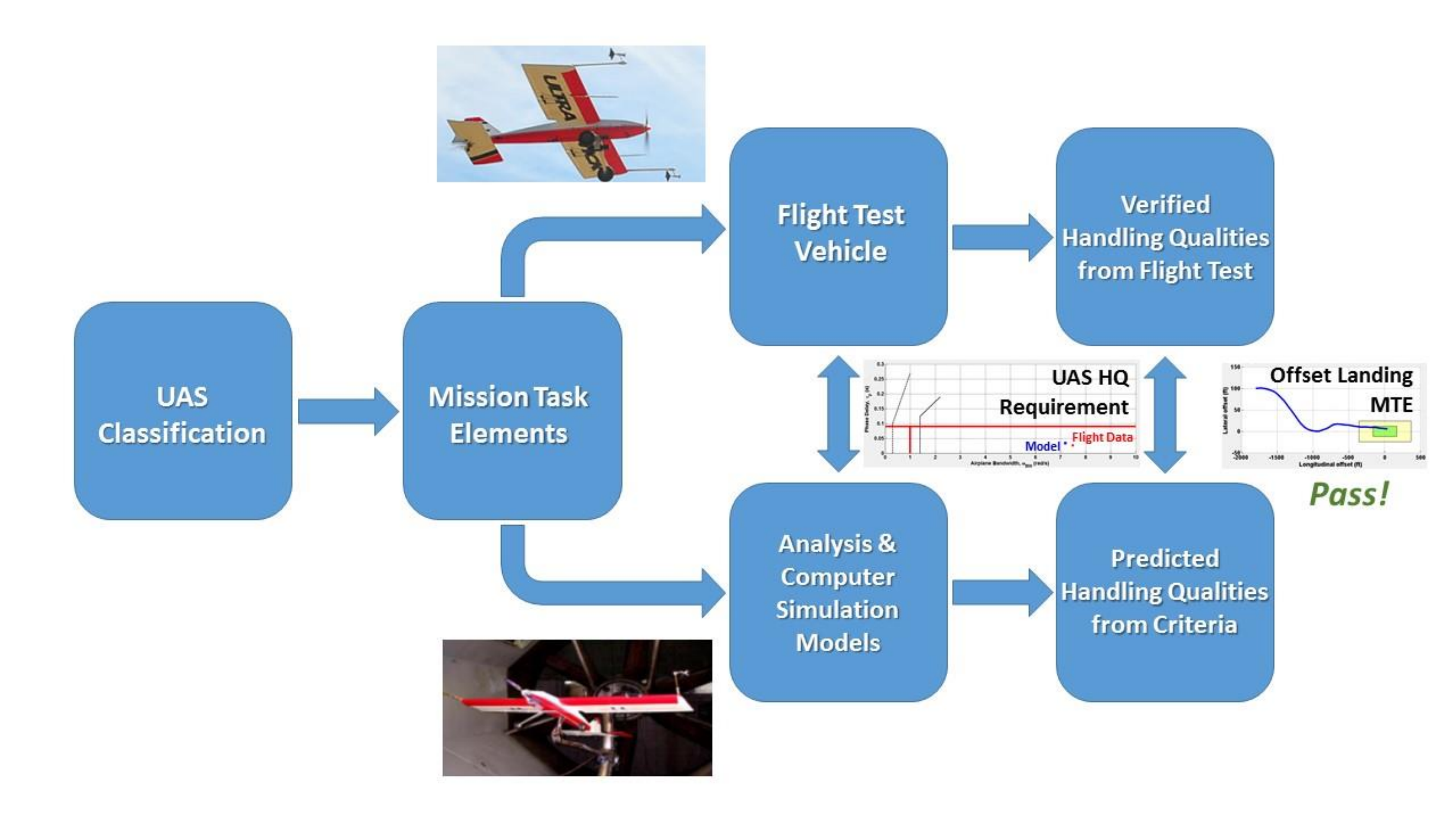
Presentation Outline

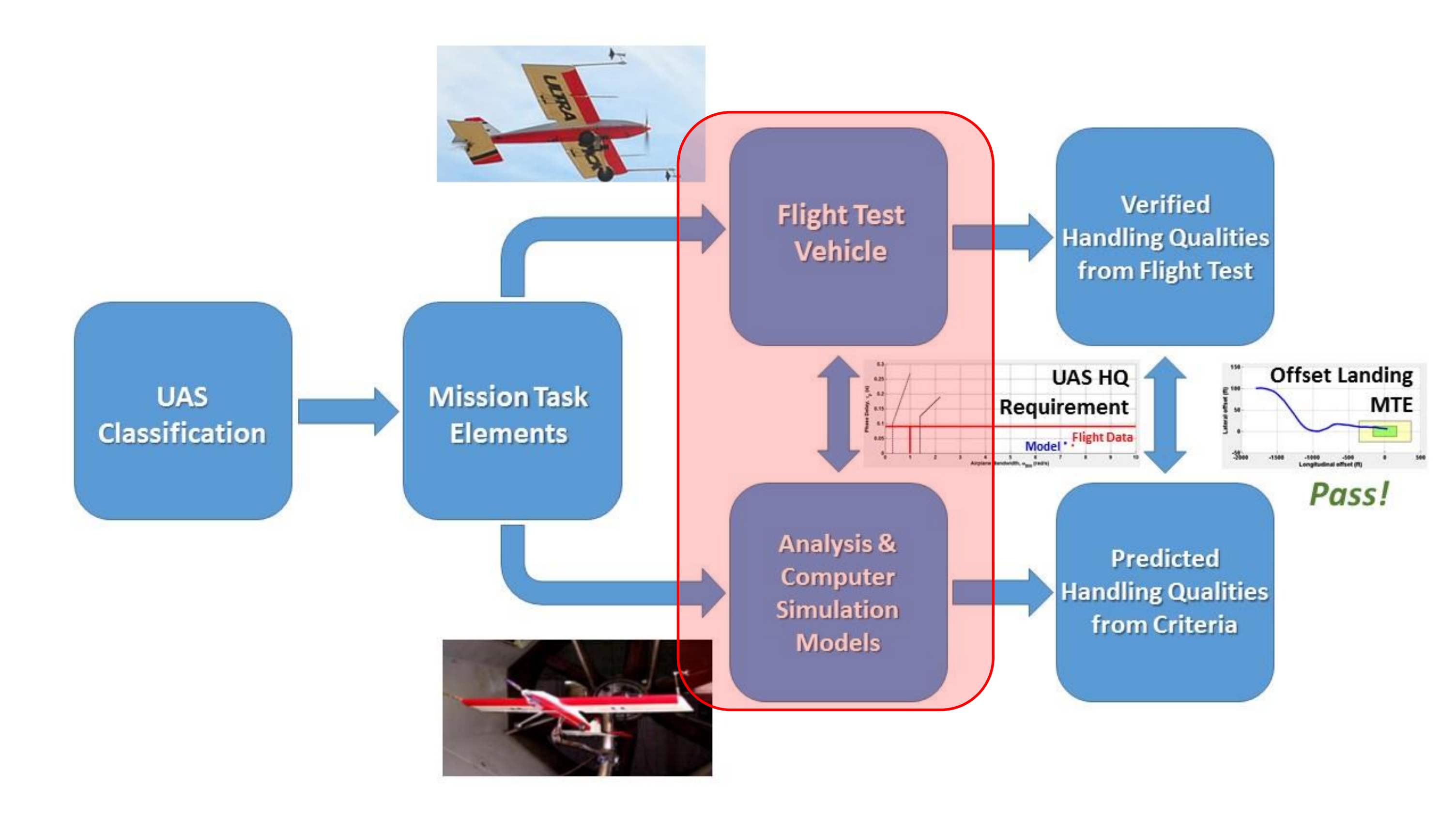
- Approach to UAS Handling Qualities
- Flight Test Campaign
  - Objective
  - Test facilities, vehicle and description
  - Excitation signals
- Model Update Process
  - Bare airframe and actuator model identification
  - Longitudinal model update
  - System identification comparison
  - Model update validation

Approach to UAS Handling Qualities

Approach to UAS Handling Qualities



Current Flight Test Activities: Fixed-Wing sUAS



Flight Test Campaign

Objectives

- The objectives for the flight test program were as follows:
  - Use several input excitation command types (frequency sweeps, multi-sines, and short duration inputs) to identify the vehicle and actuators.
    - The database will be used to determine the effectiveness of each command input, leading to recommendations that will guide future sUAS tests.
  - Generate a flight test database using a variety of flight test inputs for a fixed-wing sUAS at multiple flight conditions and aircraft configurations.
    - The database will include a nominal baseline configuration and two off-nominal configurations (e.g., a configuration with added time delay and a configuration with an unfavorable c.g. shift).
- The focus of this effort was to collect the test data, utilize the test data to update the vehicle and actuator dynamics, and compare the updated dynamics to the vehicle as identified by the other excitation inputs.

Test Facilities

- UMN UAV Lab hosted on the primary campus.
- UMore Park Test Range Airfield (Class G airspace).
- Flights coordinated with the Rosemount Research and Outreach Center Manager.
- UMN UAV lab as obtained all necessary Certificates of Authorization for legal operation of the UAS flights at the test range.

Test Platform

- UMN modified UltraStick 120
- Baseline vehicle (propulsion, batteries, receiver and servos) have been modified to include additional systems for data collection and autonomous flight modes.
- The UMN system design and added hardware allows preprogrammed excitation signals and profiles to be loaded on the vehicle for execution in flight.
- Matlab/Simulink models exist for this vehicle that include bare airframe dynamics and actuator models.

Wingspan	1.92 m
Chord	0.43 m
Length	1.73 m
Airframe Weight	6.0 kg
Max Weight	10.0 kg
Cruise speed	23 m/s (typical)
Stall speed at Max Weight	13 m/s
Airspeed range	10-41 m/s

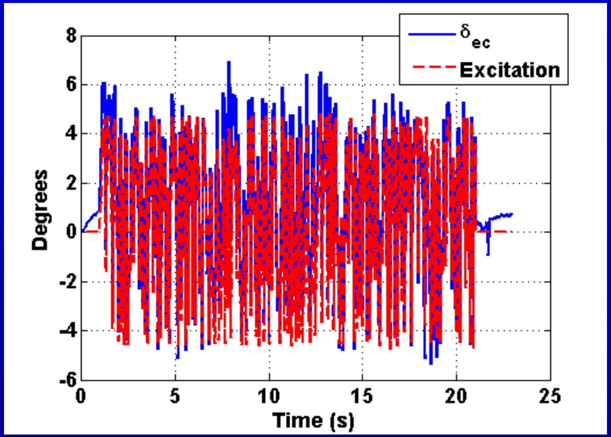
Test Description

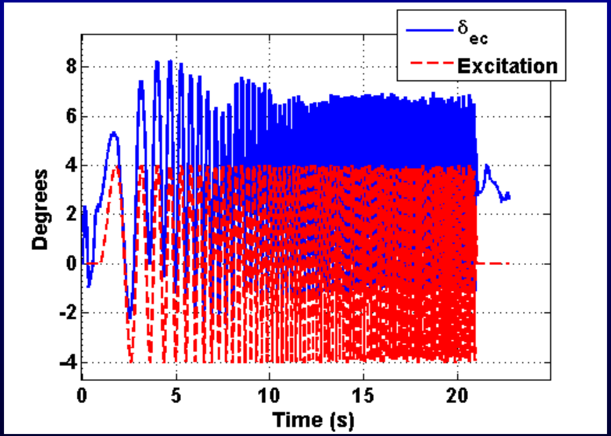
- Test data collected over multiple flights.
- Two flight conditions:
  - Approach (17 m/s with flaps extended)
  - Cruise (23 m/s)
- Three vehicle configurations:
  - Baseline
  - Off-nominal c.g.
  - Added phase delay
- Variety of automated excitation signal profiles were flown to:
  - provide system identification data for the purposes of updating the vehicle and actuator dynamics.
  - identify the vehicle from several excitation sources to understand the effectiveness of each.

Flight Test Campaign: Excitation Signals

Excitation Signals: Long Duration

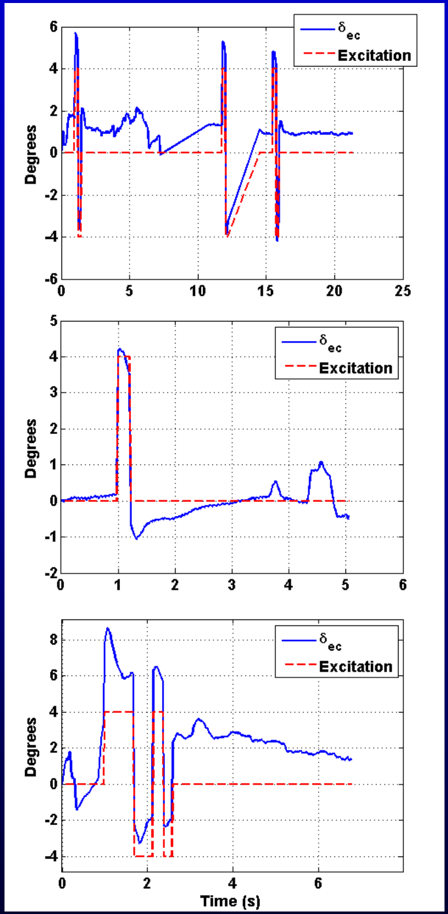
- Orthogonal multi-sine (OMS):
  - Applied to each axis independently, pitch and roll together, and all three axis in combination
  - 4 deg amplitude
  - 1-50 rad/s
  - 20 second duration
- Chirp
  - Applied to each axis independently, and pitch and roll in combination
    - Elevator increasing in frequency while aileron decreases in frequency
  - 4 deg amplitude
  - 1-50 rad/s
  - 20 second duration





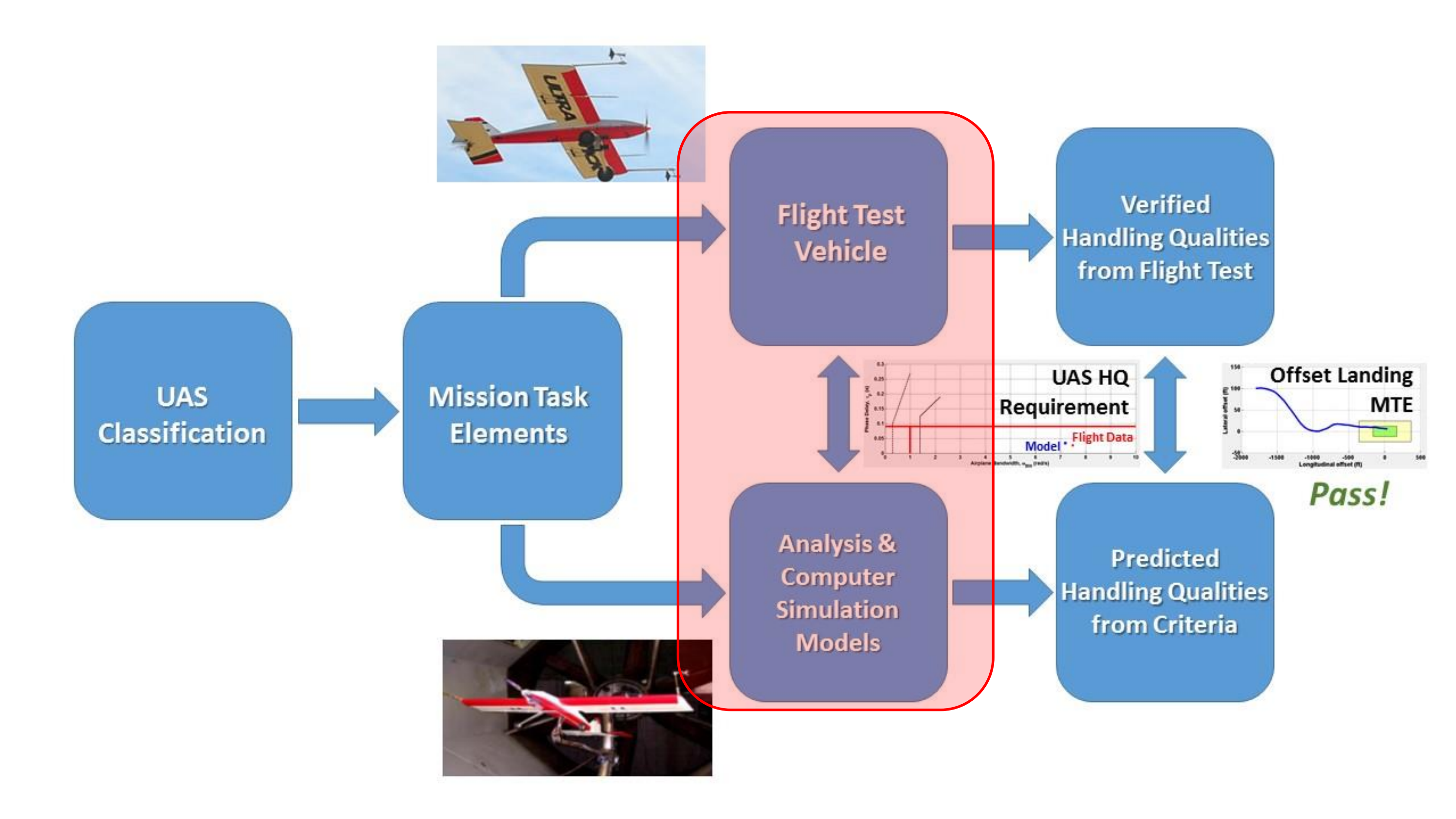
Excitation Signals: Short Duration

- Doublet
  - Applied to each axis independently
  - 4 deg amplitude
  - Pulse width varies based upon axis of interest
    - Width defined by 0.7/(2* target frequency), with the target frequency specified in Hz
    - Pitch target frequency was the short period mode, estimated at 1.51Hz
    - Aileron and rudder target frequency was based on Dutch roll frequency, estimated at 0.65Hz
- Pulse
  - Same profile, parameters and configuration as the doublet
- 3-2-1-1
  - Applied to each axis independently
  - 4 deg amplitude
  - A series of 3 pulses, in widths of 3 seconds, 2 seconds and 1 second
  - Each pulse reverses direction



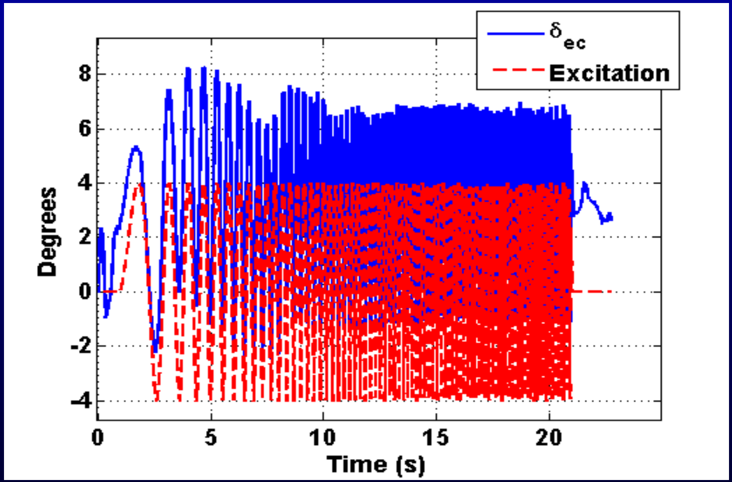
Model Update

Current Flight Test Activities: Fixed-Wing sUAS



Considered Data

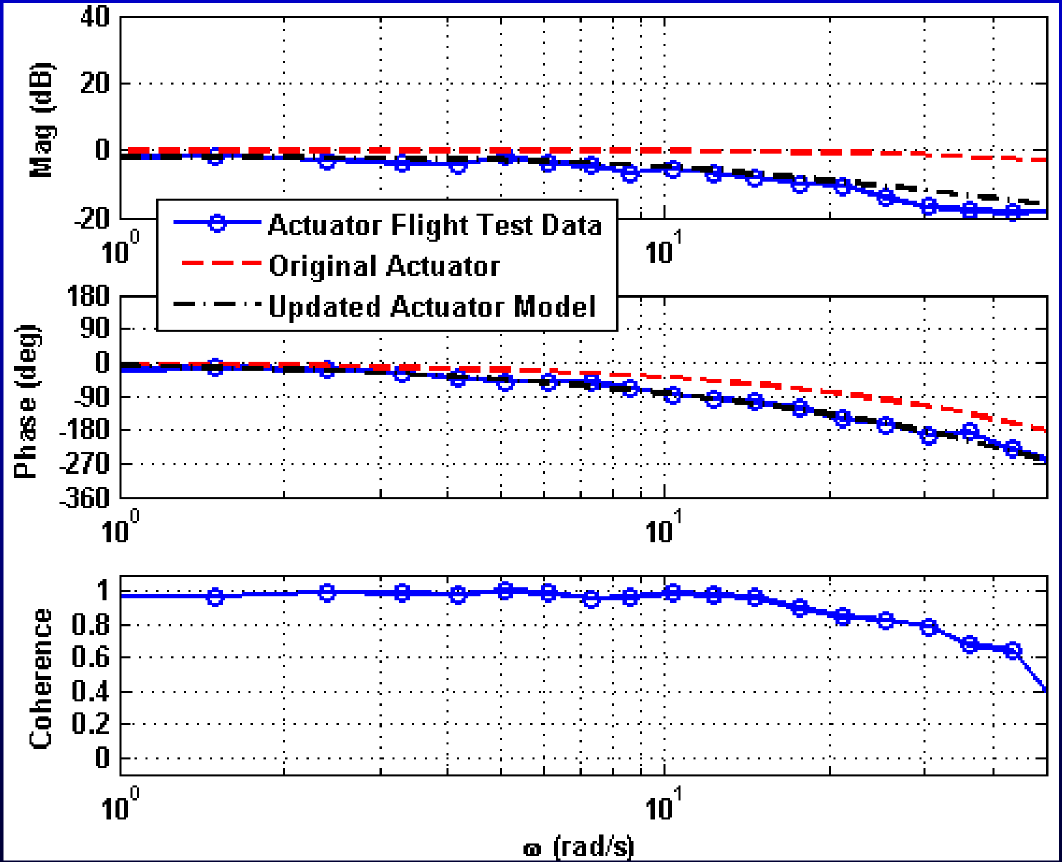
- Cruise condition in the baseline configuration.
- Single axis frequency sweep data.
  - 4 deg amplitude
  - 1-50 rad/s
  - 20 second duration



Actuator Update Process

- Collect flight test data.
- Compute the frequency response of the actuator input/output to identify the "flight" actuator model.
- Compare the "flight" actuator model with the frequency response of the as modeled actuator, a 1st order transfer function with added delay.
- Match the magnitude response by modifying the inverse time constant of the actuator model and gain as appropriate.
- Match the phase response by adding delay in the form of e^{-st} where *t* is the added delay.
- With the phase response matched, the "flight" model and the updated actuator model were compared once again to ensure a desired fit was found.

Actuator Update Results



Original

$$\frac{\delta_e}{\delta_{ec}} = \frac{50.27}{s + 50.27} e^{-0.05s}$$

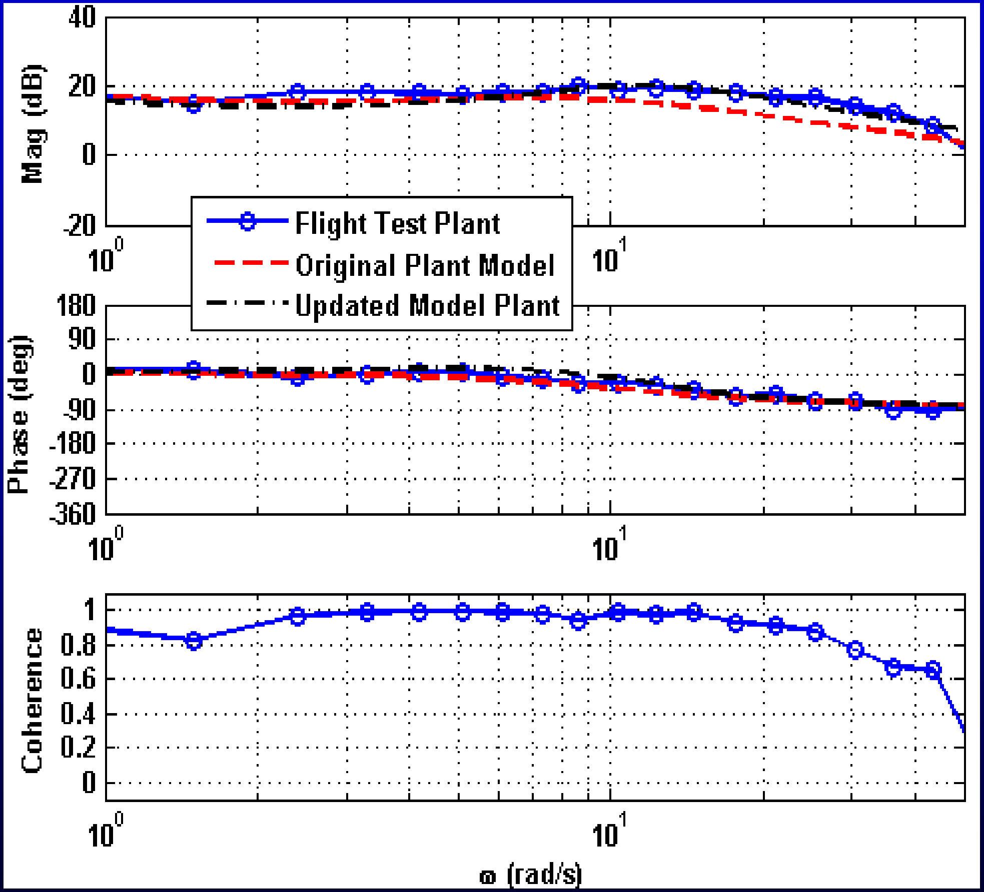
New

$$\frac{\delta_e}{\delta_{ec}} = \frac{8}{s + 10} e^{-0.065s}$$

Bare Airframe Update Process

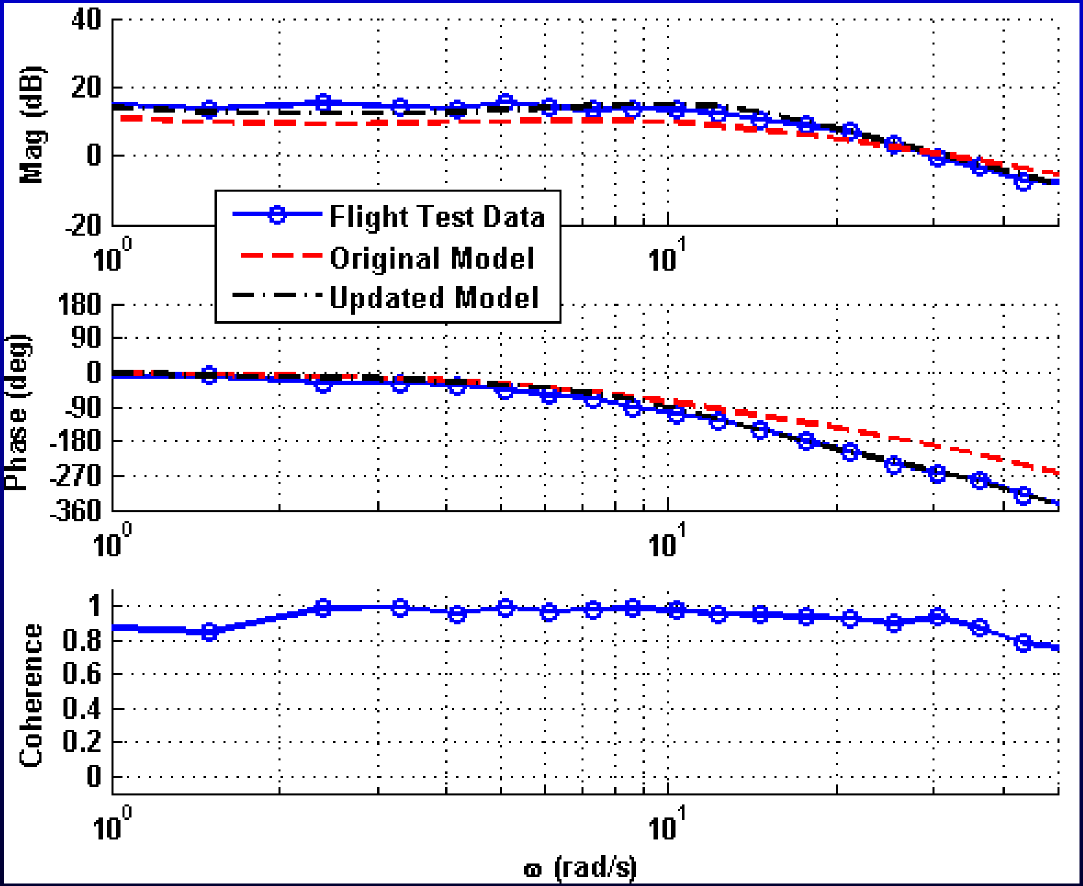
- Collect the flight test data.
- Compute the frequency response of the measured elevator actuator position and measured pitch rate to identify the “flight” longitudinal model.
- Compare the “flight” longitudinal model with the as modeled vehicle dynamics.
- Identify any model discrepancies relative to the flight test data and adjust the modal parameters to achieve an improved match to the flight test data.
  - Phugoid and short period modes were considered for adjustment.
  - The necessary adjustments were limited to the short period mode only.
  - Changes to the gain were made as required to match the magnitude.
- With both the magnitude and phase responses matched, the “flight” model and the updated vehicle dynamics model were compared once again to ensure a desired fit was found.

Bare Airframe Update Results



	ω_{sp}	ζ_{sp}	Gain
Original	9.48 (rad/s)	0.753	-
New	12.5 (rad/s)	0.5	1.5

Combined Bare Airframe + Actuator

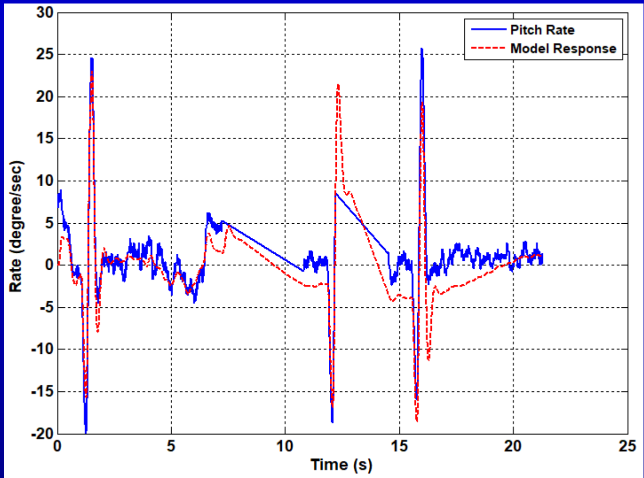


Model Update Validation

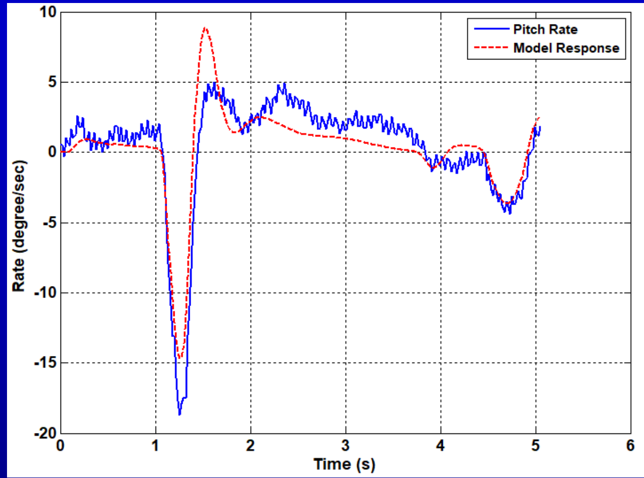
Model Validation Updates

- To validate the updated model, simulated time history responses of the model were compared against flight test responses generated from short duration inputs for the same test condition.
- These short duration inputs were the same doublets, pulses, and 3-2-1-1s described above.
- The actual flight test inputs were used to generate the model responses, so a true one-to-one comparison could be performed.
- Two sets of data dropouts from ~7-11 seconds and ~12-15 seconds region affected the later portion of the doublet maneuver.
  - Even in the presence of these dropouts, the model response for the doublet excitation exhibited a close match to the excitation flight data.
  - The pulse and 3-2-1-1 excitation response demonstrated a good model fit as well; however there is a modest amount of amplitude mismatch.
  - This mismatch, which occurs for the lower frequency inputs, is likely due to system nonlinearities, such as actuator free play.
- On the whole, these responses validate the model updates made above and the process used to generate the model revisions.

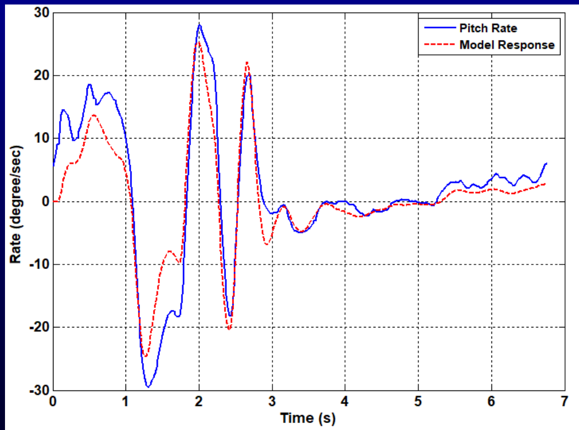
Example SysID Results



Doublet



Pulse

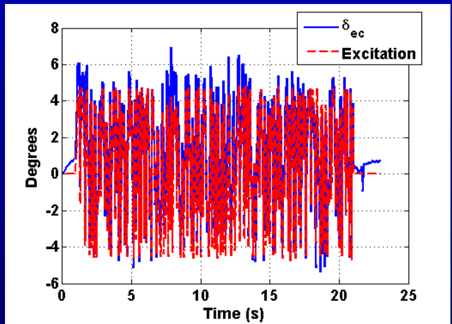


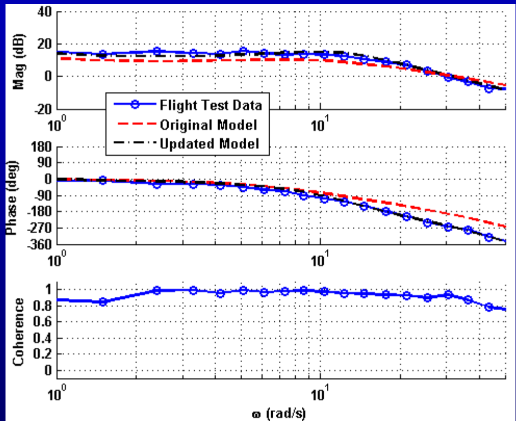
3-2-1-1

System Identification Signal Comparison

Considered Data

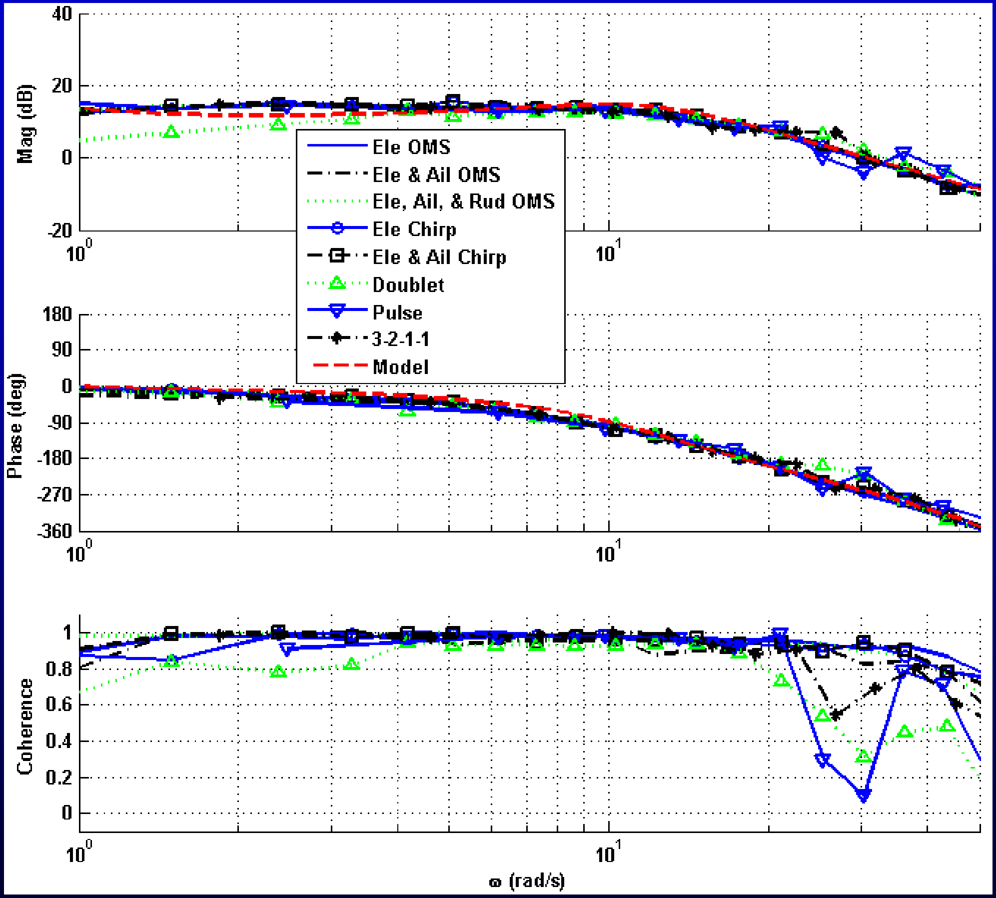
- Cruise condition in the baseline configuration.
- All combinations of each input:
  - Orthogonal multi-sine
  - Chirp
  - Doublet
  - Pulse
  - 3-2-1-1
- Pitch axis only.





Actuator	Bare-Airframe
$\frac{\delta_e}{\delta_{ec}} = \frac{8}{s+10} e^{-0.065s}$	$\frac{q}{\delta_e} = \frac{75.03(0)(0.3977)(5.966)}{[0.3078, 0.5362][0.50, 12.5]}$

Excitation Signal Comparison



System Identification Results

- An encouraging result from this evaluation is the relative uniformity of the identified systems, even in the presence of excitations of the other control surfaces.
- This result suggests that the OMS input excitation can be performed in multiple axes without interfering with or contaminating the results of the others, as has been exemplified by Morelli* and others.
  - This characteristic means that fewer numbers of flights are required to perform the identification of the vehicle, saving time and cost during the test campaign.
- As for the OMS identification, the chirp exhibits the ability to have multi-axis input excitations not adversely affect the system identification.
- The short duration inputs also provided relatively close matches of the modeled system to the rest of the identifications.
  - As expected, the coherence for these identifications was lower at the high frequencies and did have some variance in the lower frequencies from the OMS and chirp input signals.
  - The doublet had the greatest mismatch of the magnitude at the lower frequencies; and the pulse and doublet had some trouble matching the magnitude and phase at the highest frequencies.

* Morelli, E.A., "Multiple Input Design for Real-Time Parameter Estimation in the Frequency Domain," Paper REG-360, *13th IFAC Symposium on System Identification*, Rotterdam, The Netherlands, August 2003.

Concluding Remarks

Summary

- The Flight Test Vehicle block of the proposed UAS handling qualities process was executed on an exemplar fixed-wing sUAS.
- The system identification and model update process component were successfully demonstrated on the UltraStick120, providing an initial validation of the system identification and model update component of the proposed UAS handling qualities process.
- Multiple excitation input profiles were considered including chirps, multi-sine and short duration inputs.
- The chirp inputs were demonstrated as an effective identification method suitable for application to identifying and updating the vehicle dynamics models.

Observations

- The orthogonal multi-sines and chirp inputs provided consistent system identification results.
- The orthogonal multi-axis inputs provided an effective excitation means across the axes reviewed with no undesirable artifacts.
- The short duration inputs provided close matches with the OMS and chirp input profiles in a limited frequency range around the dominant mode for a given axis (e.g., the short period), but as expected, input power degraded at the higher and lower ends of the frequency region of interest.
- The short duration inputs (doublet, pulse, 3-2-1-1) generated using the updated model, applying the test inputs from flight, closely matched the vehicle response from flight test.
- The techniques described here have long been used to identify the characteristics of manned aircraft for handling qualities assessments. The results shown here establish the ease of using these methods to properly characterize sUAS as part of a process that will ultimately reveal the suitability of the handling qualities of a selected vehicle for a given mission.

Discussion/Questions

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