X-57 Ground Dynamics Modeling and Analysis

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Outline

- X-57 and Simulation Overview
- Simulation Development
  - Landing gear model development
  - Uncertainty analysis
- Turning Characteristics
- Piloted Handling Qualities Assessment

Image: NASA

X-57 Overview

- Distributed electric propulsion flight demonstrator [1]
- Highly modified Tecnam P2006T airframe

Mod II

Mod III

Mod IV

Image: NASA

- Simulink desktop simulation and fixed-base piloted simulation used for analysis

Landing Gear Rolling Drag Model

- 3 types of rolling drag on a landing gear wheel:
  - D_{RF}: Rolling friction due to shear traction [2]
  - $D_{RR,\,TD}$: Rolling resistance due to tire deformation (velocity-dependent) [3] [4]
  - $D_{RR,\,C}$: Rolling resistance due to ground compression (surface-dependent) [5]

- Horizontal rolling drag model:

$$D_{total} = D_{RF}(\mu) + D_{RR,\,TD}(k_{R1}, k_{R4}) + D_{RR,C}$$

  - Fit parameters to make the model match manufacturer flight test data

Rolling Drag Model Corrections

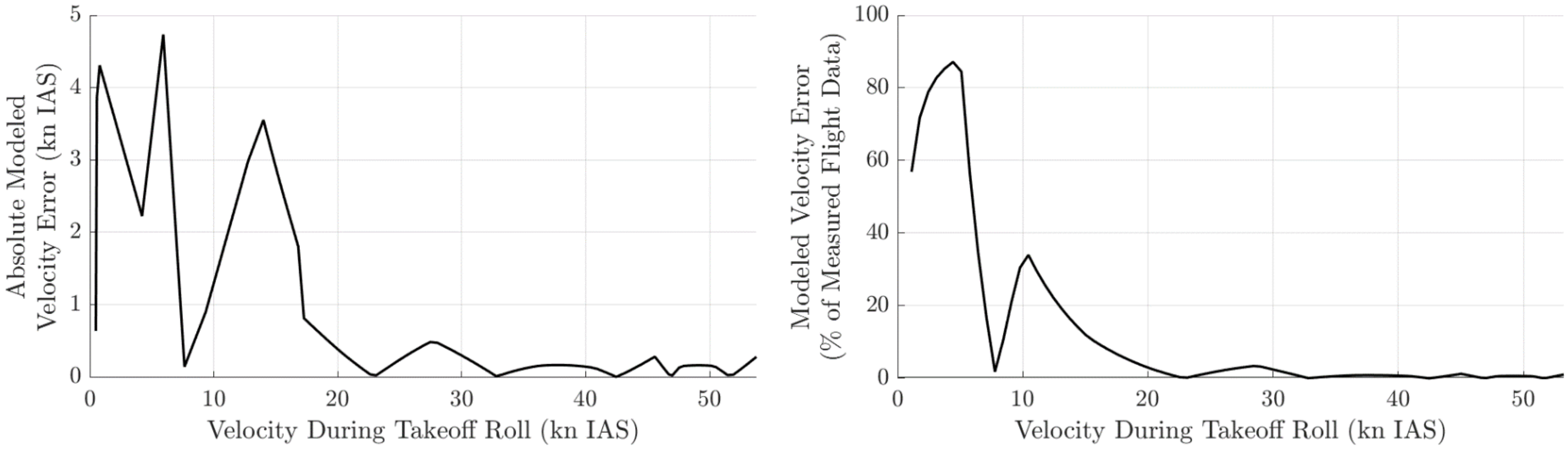
- Tecnam data: conducted on a grass field
- X-57: will operate from concrete/asphalt runways.

- Correct for surface differences:

Model resistance based on Tecnam data. → Subtract vertical compression drag forces. → Adjust rolling friction value per literature.

Rolling Drag Model Corrections

- Hooke-Jeeves gradient-free search used to estimate parameters [6]
  - Good fit above 15 kn IAS, where air data is reliable



- New model: predicted time to rotation speed for X-57 increased by over 10%

Landing Gear Model: Uncertainty Analysis

- Use test conditions' uncertainty to inform parameter uncertainty
- Use parameter uncertainty to inform kinematics uncertainty

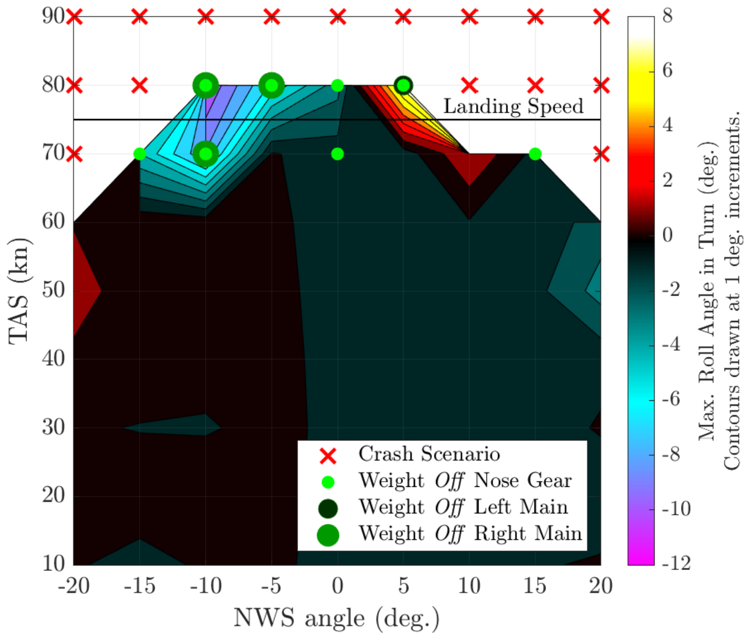
Test Condition	Estimated bounds of variable uncertainty
Mass	[-1%, 1%]
Thrust	[-1%, 1%]
C.G.	[-1%, 1%]
Compression Drag	[-100%, 100%]

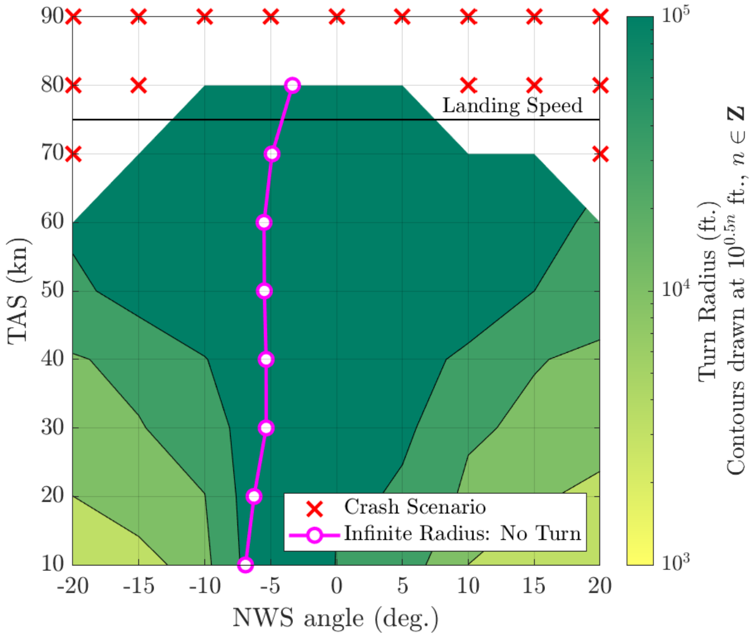
Rolling Drag Parameter	Expected bounds of parameter perturbance	Expected bounds of change in acceleration
μ	[-20.1%, 0%]	[-1.26% , +0%]
k_{R1}	[-6.7%, 0%]	[-0.946% , +0%]
k_{R4}	[-0.0133%, 57.1%]	[-0.144% , +0%]

- Uncertainty in the rolling resistance parameters, within physical reason from the Tecnam test setup, accounts for < ~1.5% uncertainty in rolling acceleration

Turning Characteristics

- Measure roll gradient and turning radius across a range of operating conditions
  - Function of speed, nosewheel steering angle, crosswind velocity, and flap deflection





Piloted Simulator Assessment

- Handling qualities assessment in the piloted simulator
- Tasks:
  - Runway Offset Capture and Hold [7]
    - Maneuverability limitations, PIO tendencies
  - Maximum Heading Capture and Stabilization [7]
    - Aircraft response to aggressiveness
  - Runway Centerline Tracking [7]
    - Closed-loop response, disturbance rejection
- Evaluation metrics:
  - Cooper-Harper rating [8]
  - Desired/adequate tracking tolerances
  - Pilot comments

Piloted simulation setup.

Piloted Simulator Assessment: Results

- Adequate tracking performance attained throughout the normal operating envelope
- PIO only observed outside normal operating envelope
- Cooper Harper rating – Level 2 handling qualities or better at:
  - ROCH: ≤ 70 kn in takeoff configuration, ≤ 60 kn in landing configuration
  - MaxHCAS: ≤ 70 kn for normal inputs, ≤ 50 kn for maximum deflection inputs
  - RCT: ≤ 70 kn in takeoff configuration, ≤ 60 kn in landing configuration
- Rolling/skidding tendencies consistent with batch simulation studies

Conclusions

- More detailed landing gear rolling drag model fit to manufacturer data
  - Only minor uncertainty in aircraft dynamics due to modeling errors

- Roll angle, turning radius, and upset tendencies assessed as function of open-loop control input across different operating conditions
  - Stable behavior in the normal operating envelope

- Piloted simulator handling qualities assessment
  - Confirmed acceptable handling qualities throughout the normal operating envelope

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References

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