National Aeronautics and
Space Administration

Distributed Thrust Takeoff for the NASA X-57 Mod IV Flight Demonstrator

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Takeoff Performance Requirements

- Civil airworthiness regulations for Normal Category Airplanes (14 CFR 23, CS 23) no longer reference *critical engine* in performance requirements
  - Loss of thrust from the critical engine is a key design driver for multiengine airplanes
  - Engines were traditionally required to be able to be fully isolated from other systems
  - New regulations reference *critical loss of thrust*
  - Systems may now be integrated in ways where a failure may impact thrust from multiple engines
- No public standards exist for determination of critical loss of thrust for non-traditional configurations
- Approach used to determine which failure conditions were critical for loss of thrust during takeoff for X-57 could help inform future public airworthiness standards

Meet "Maxwell"

- X-57 was a flight demonstrator concept for *Distributed Electric Propulsion (DEP) Technology*
- **Project Goals**: generate data and procedures and share these with academia, industry, standards organizations, and regulators to enable design and certification of DEP concepts
- **Project Approach**: spiral development through multiple design modifications (Mods)

Mod I: Baseline performance of gasoline-powered aircraft

Mod II: High-voltage powertrain integration, impact of electric retrofit

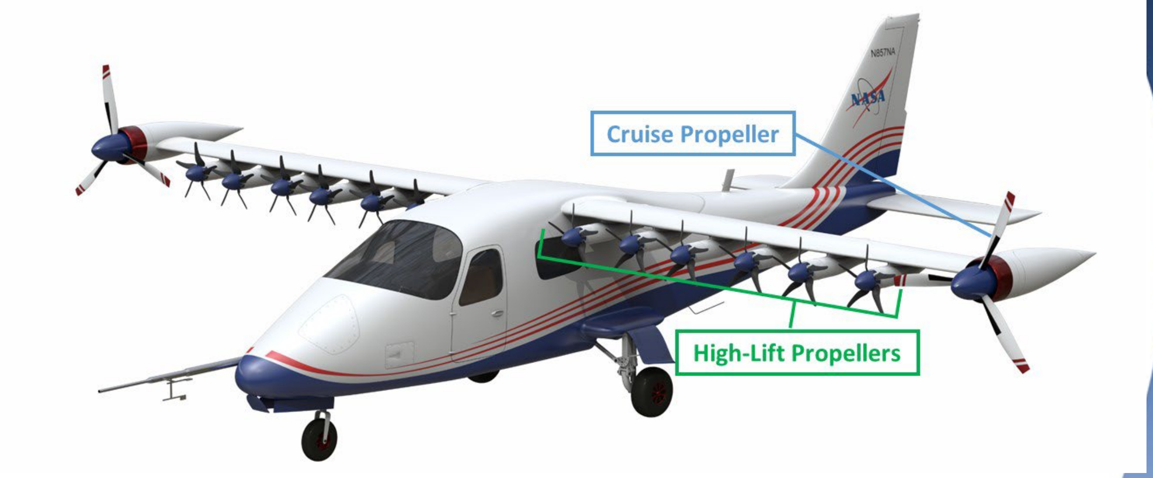
Mod IV: High-lift propeller takeoff, landing, handling qualities

What conditions impact safe takeoff operations for Mod III and Mod IV?

Mod III: Impact of cruise-sized wing, wingtip propellers

X-57 Mod IV High-Lift Propeller Systems

- X-57 Mod IV features 12 high-lift propellers (HLPs) distributed along the wing
- The HLPs are designed to augment lift at low speeds, and otherwise are turned off and passively fold against their nacelles
  - Like other high-lift devices, HLPs are an *integral part of the Mod IV low-speed aircraft configuration*
- HLPs have two control modes
  - *Airspeed* mode sets the HLP RPM based on air data and is meant primarily for landing
  - *Fixed* mode sets the HLP RPM to 4800 RPM and is meant as a contingency mode if air data is lost
    - Fixed mode also used in nominal operations: takeoff and runup

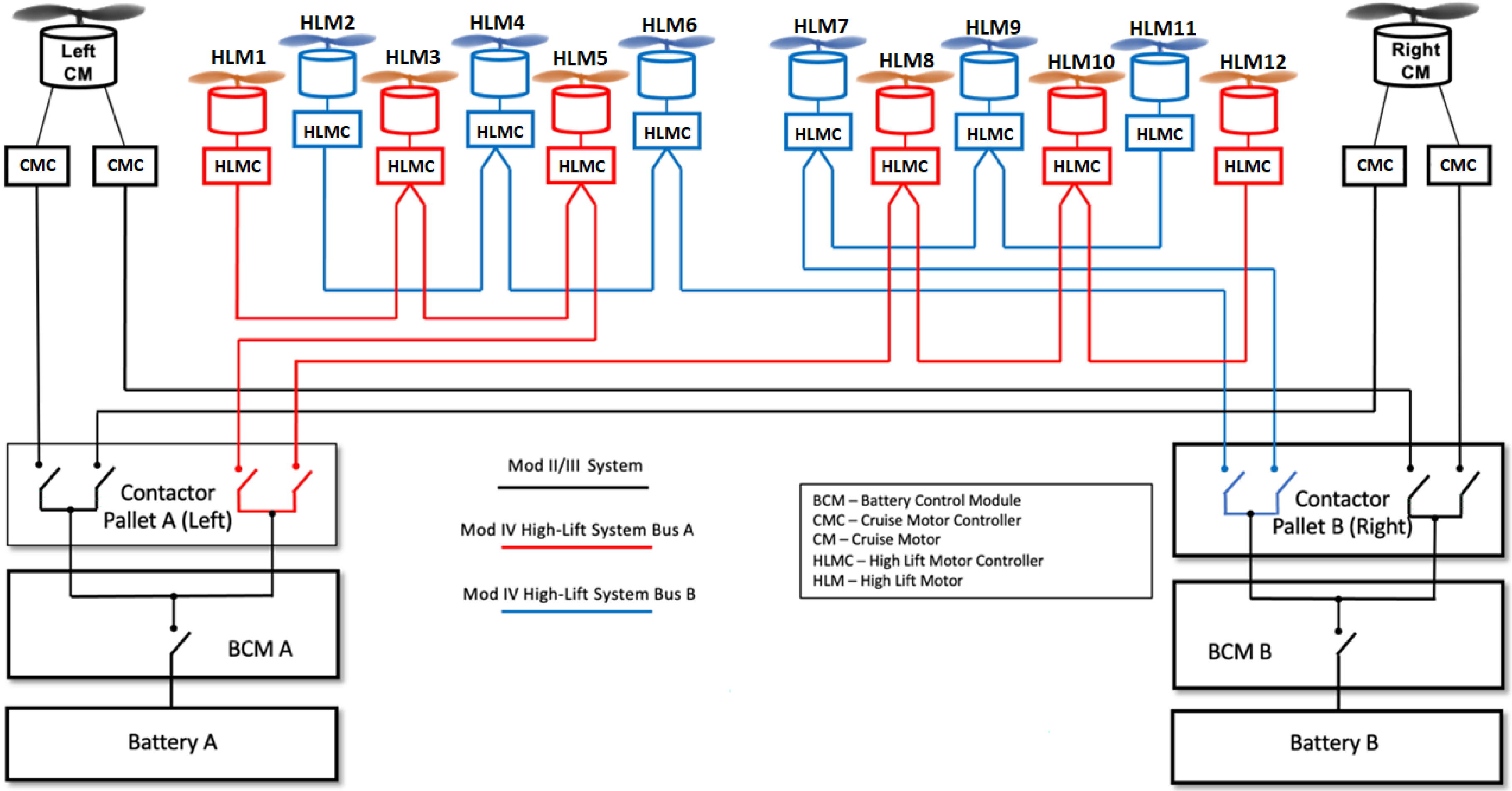


X-57 Mod IV in Low-Speed (Takeoff/Landing) Configuration

X-57 Mod IV in High-Speed (Cruise) Configuration
(Identical to X-57 Mod III)

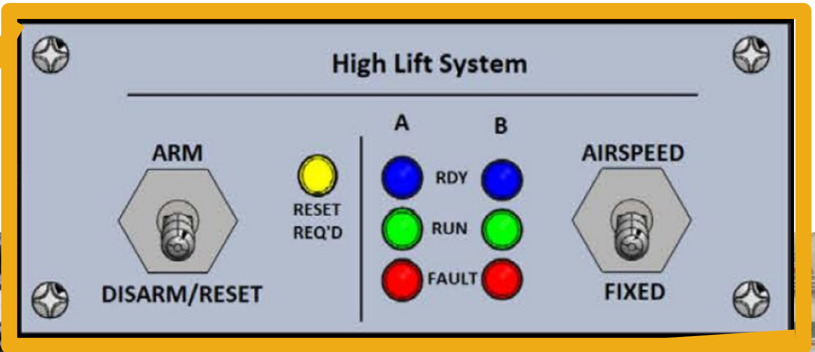
X-57 Mod IV Traction Power System

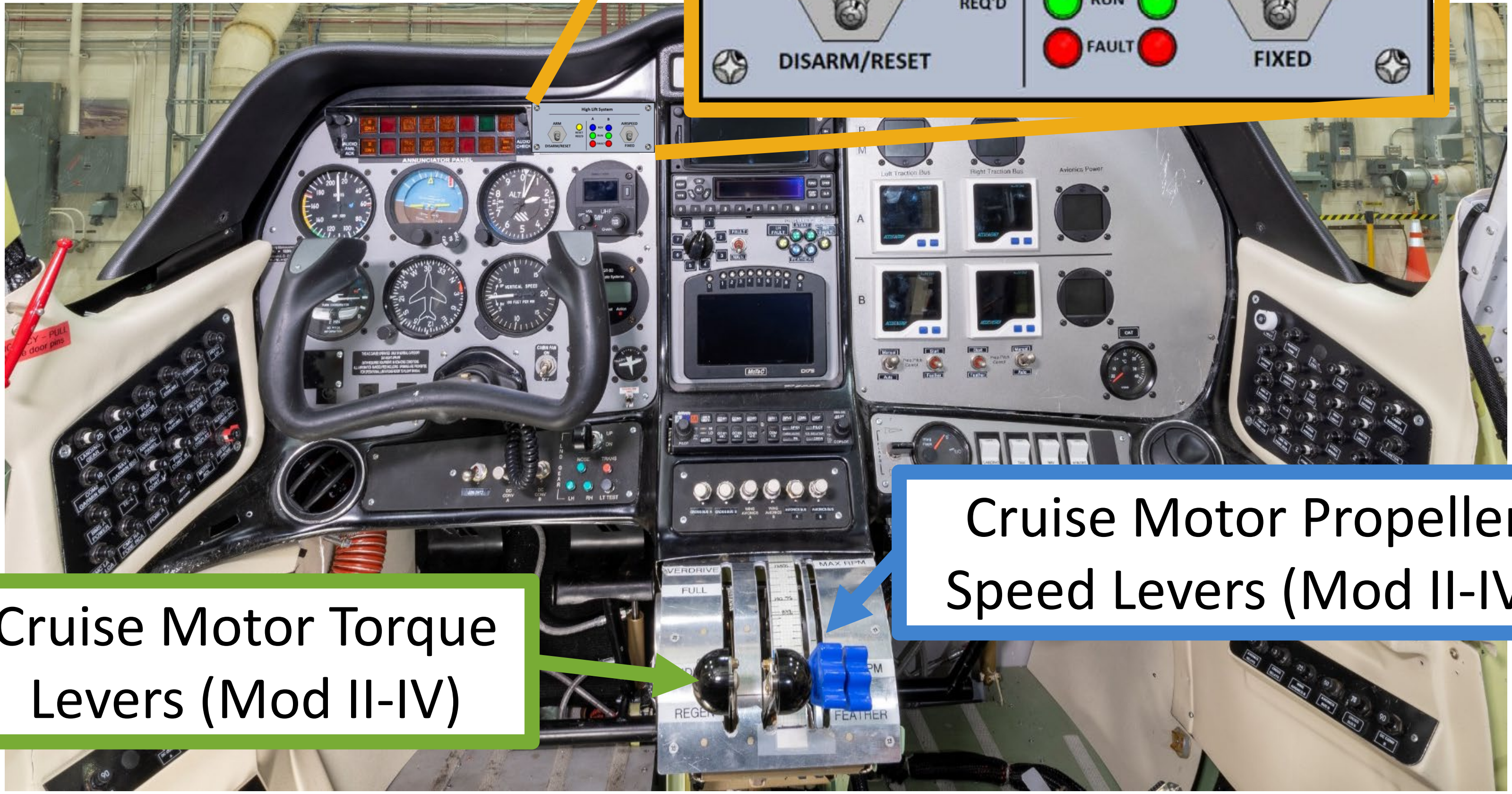
- Channelized traction power architecture allows for graceful degradation from failures
- Avionics power and data systems follow similar philosophy



X-57 Mod IV Cockpit Propulsion Controls

High-Lift Propeller Control Panel (Mod IV)





Cruise Motor Propeller Speed Levers (Mod II-IV)

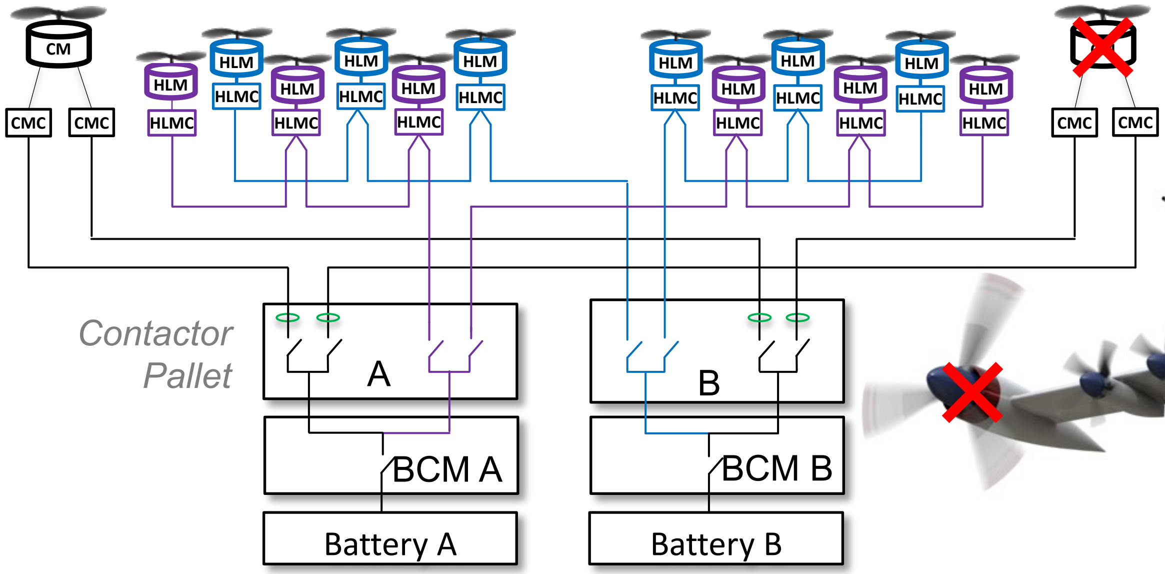
Cruise Motor Torque Levers (Mod II-IV)

Failure Scenario Development

Failure Condition	Impact	May be critical?
Cruise Propeller Control	Low for takeoff operations	No
Cruise Motor Controller	Low for takeoff operations	No
Cruise Motor	**Significant for takeoff operations**	**Yes**
High-Lift Motor	Low for takeoff operations	No
Traction Bus	**Moderate for climb but not controllability**	**Yes**
HLM Traction Contactor	**Moderate for takeoff operations**	**Yes**

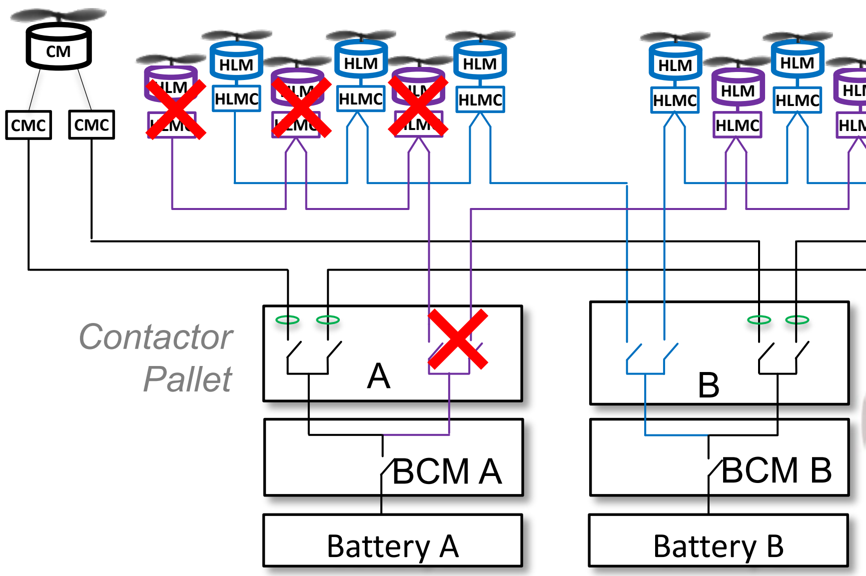
Team identifies failure scenarios that can lead to loss of thrust → Test pilots evaluate failures using X-57 fixed-base simulator → Test pilots flag failures that have clear impact on controllability and performance

Cruise Motor Failure



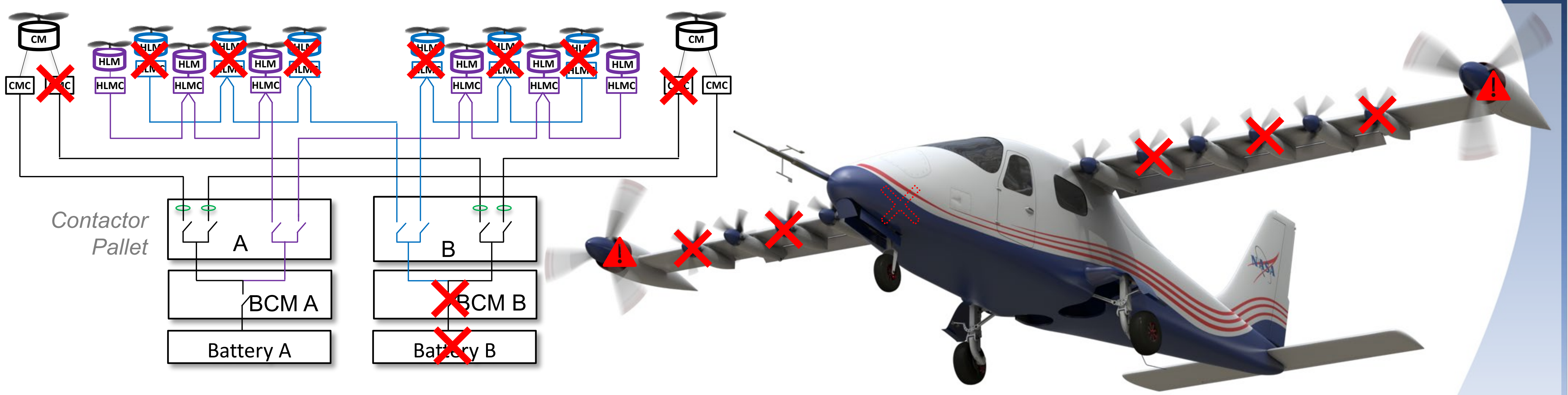
- Complete loss of thrust from a cruise motor (CM)
- High thrust asymmetry due to large moment arm, particularly at high thrust settings (takeoff → low speed, high power setting) results in large yaw moment

High-Lift Traction Contactor Failure



- Total loss of thrust from three high-lift propellers (HLPs)
- Moderate thrust asymmetry (yaw moment) from loss of HLP thrust
- Moderate lift asymmetry (roll moment) from loss of HLP-induced lift
- Possible pro-spin situation
- More potential impact on landing rather than takeoff performance

Traction Bus Failure



- Total loss of thrust from six high-lift propellers, half thrust for both CMs
  - Half of the total thrust of the pre-failure configuration
- Symmetric failure – little impact on handling characteristics
  - Could result in induced stall, but takeoff (and approach) speeds selected to provide margin
- Large impact on rate of climb
  - Can reconfigure by moving to overdrive position of torque lever for increased CM thrust

Takeoff Techniques

- Mod III takeoff
  - Full torque to each CM: 255 Nm
  - Maximum rotational speed for each cruise propeller: 2700 RPM
  - HLPs not present or inactive
  - Prior work (Wallace et al. 2024) indicated very poor handling qualities and performance in presence of failures
- Mod IV Distributed Thrust Takeoff (DiTTo)
  - Full torque to each CM: 255 Nm
  - Lower rotational speed for each cruise propeller: 1800 RPM
  - HLPs in "fixed" mode – 4800 RPM
    - This ensured HLPs did not have a failure mode associated with air data issues
  - Analysis indicated far less thrust asymmetry in this configuration, additional controllability due to influence of HLPs
  - HLPs more effective at lower takeoff speeds

Simulator Experiments

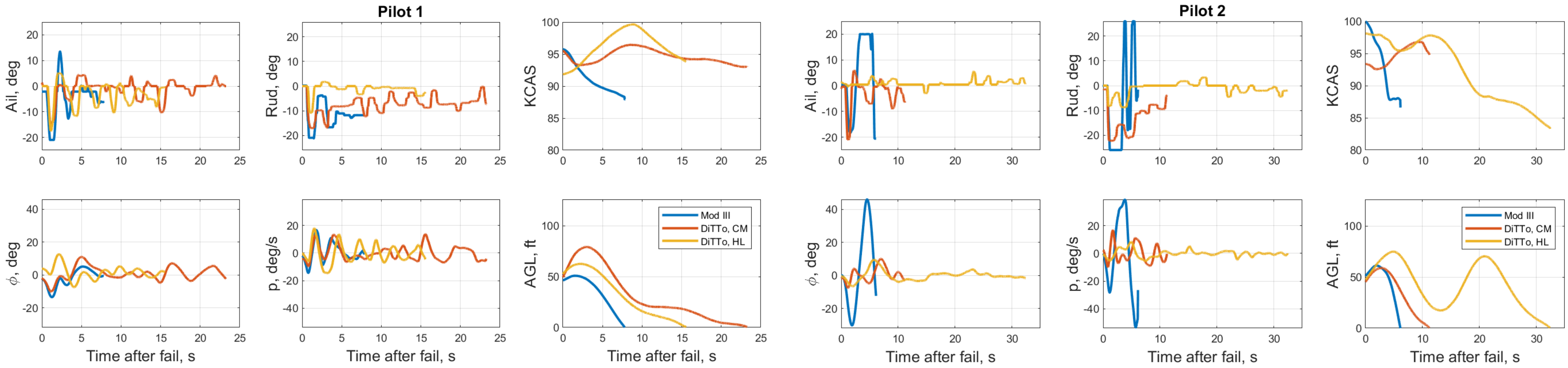
- Conducted detailed simulator experiments with both project test pilots
- Scrutinized performance and pilot notes for handline qualities evaluation
- Failure height of 50 ft above ground level – **critical for evaluation of recovery**
- Evaluated DiTTo at Mod III and Mod IV speeds

Speed	Mod III Speeds	Mod IV Speeds
Rotation	88 KIAS	77 KIAS
Initial Climb	97 KIAS	84 KIAS

Performance at Touchdown	Desired	Adequate
Bank Angle	7.0 deg	9.0 deg
Distance from Runway Centerline	75 ft	150 ft
Sink Rate	Undefined	7.0 ft/s

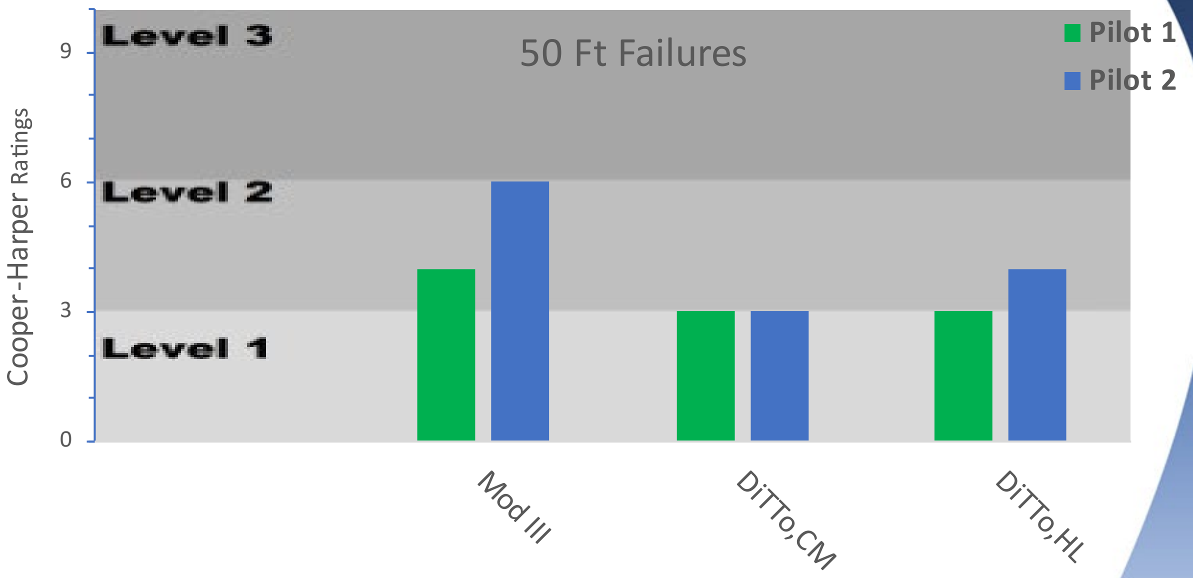
Time History: Mod III Speeds

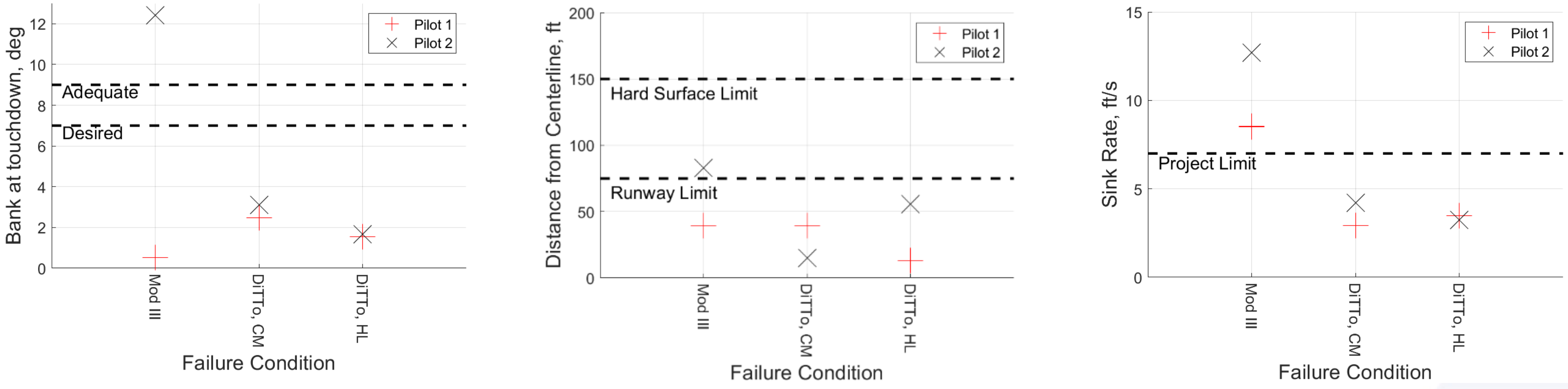
- Mod III CM failures highly dynamic and difficult to control; required immediate response
  - Pilot 1 had more practice with this configuration; may have been able to “train out” of it
- Mod IV DiTTo failures less dynamic, gave more control and more time
- Mod IV high-lift contactor failures not much of an issue for takeoff



Handling Qualities: Mod III Takeoff Speeds

- Cooper-Harper evaluation favored DiTTo
- Project pilots able to complete tasks in "desired" performance range for DiTTo, could not for Mod III takeoff





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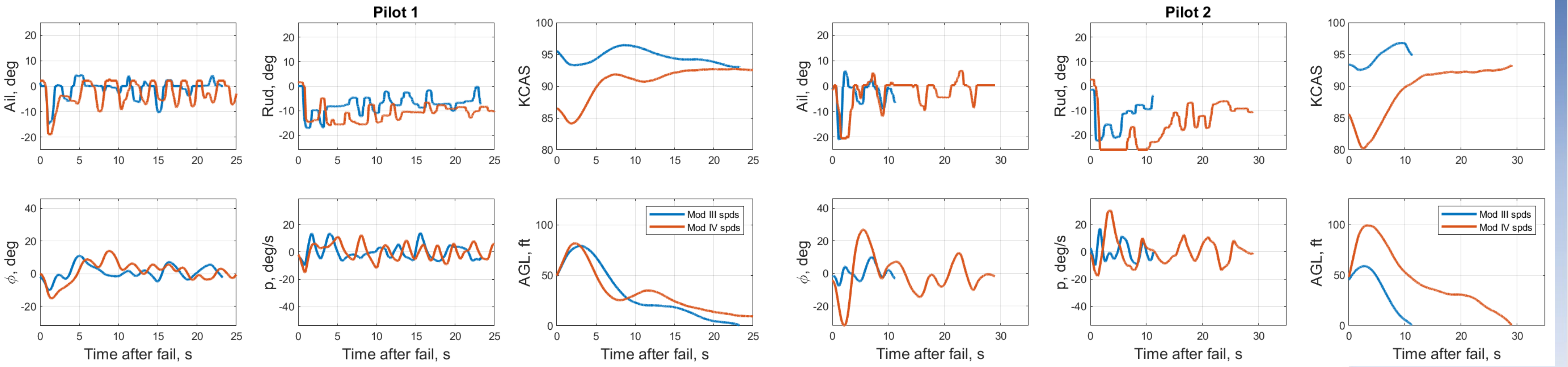
Time History: Mod IV Speeds

- Mod IV CM failures at Mod IV takeoff speeds enabled higher excess thrust after failure
- Impact of CM failure at Mod IV speeds using DiTTO slightly more difficult to recognize for pilot 2, resulted in loss of speed and some controllability issues
  - Consider procedures/training or improved annunciation to better inform pilot of failure



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Summary

- Distributed electric propulsion enables new opportunities for aircraft, but challenges remain with understanding failure scenarios associated with critical loss of thrust
- Identified several scenarios to consider for DEP aircraft like X-57
- Generally, most adverse condition was loss of a single wingtip cruise motor
- Distributed Thrust Takeoff approach developed to leverage the thrust and lift of the HLP system, and operate the cruise motors at lower power settings for takeoff
- DiTTo resulted in better post-failure performance and handling qualities in X-57 piloted simulator experiments
- Plan to use this information to help develop airworthiness standards associated with critical loss of thrust

Higher, Ever Higher

"What has hitherto done, however, has by no means exhausted the field of electrical research. It has rather opened up that field, by pointing out subjects of enquiry, and furnishing us with means of investigation."

James Clerk Maxwell (1873)