A NASA Approach to Safety Considerations for Electric Propulsion Aircraft Testbeds

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NASA Aeronautics

NASA Aeronautics Vision for Aviation in the 21st Century

6 Strategic Thrusts

- Safe, Efficient Growth in Global Operations
- Innovation in Commercial Supersonic Aircraft
- Ultra-Efficient Commercial Vehicles
- Transition to Low-Carbon Propulsion
- Real-Time System-Wide Safety Assurance
- Assured Autonomy for Aviation Transformation

U.S. leadership for a new era of flight

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Strategic Thrusts 3 & 4

Hybrid Electric Propulsion Research Themes

Strategic Thrust 3: Ultra Efficient Commercial Vehicles

2015	2025	2035
Evolutionary gains for carbon neutral growth by 2020	***Revolutionary*** improvements to fleet to achieve 2005 levels	***Transformational*** capabilities for 50% reduction of 2005 Levels

Strategic Thrust 4: Transition to Low Carbon Propulsion

2015	2025	2035
Low-carbon fuels for conventional engines	Introduction of Alternative Propulsion Systems	Alternative Propulsion Systems to Aircraft of All Sizes

- **Integrated Technology Concepts (Vehicle / Synergy)**
- **Power and Propulsion Architectures**
- **HEP Components / Enablers**
- **Modeling, Simulation, and Test Capability**

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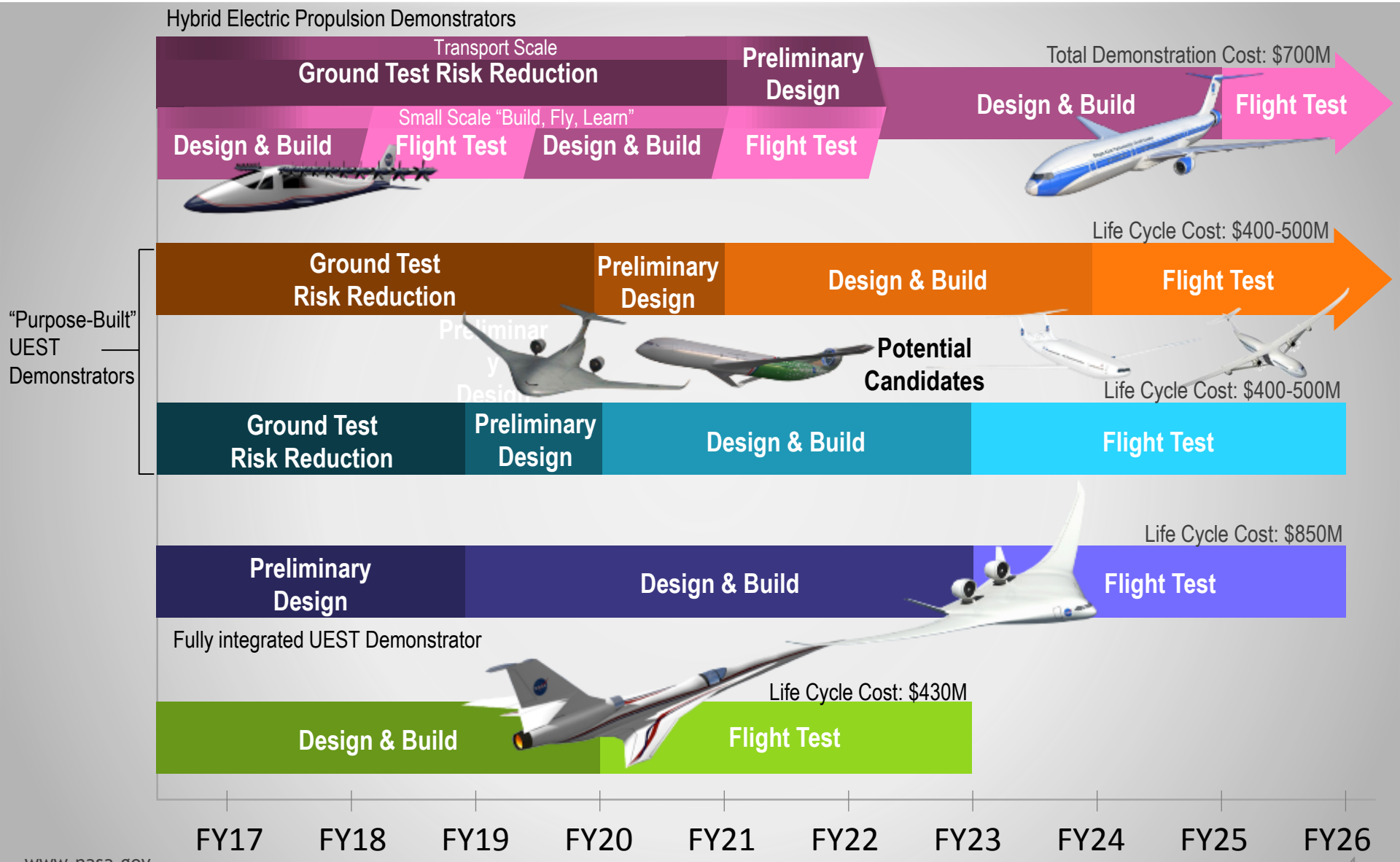
Electric & Hybrid-Electric Flight Demonstration Plan



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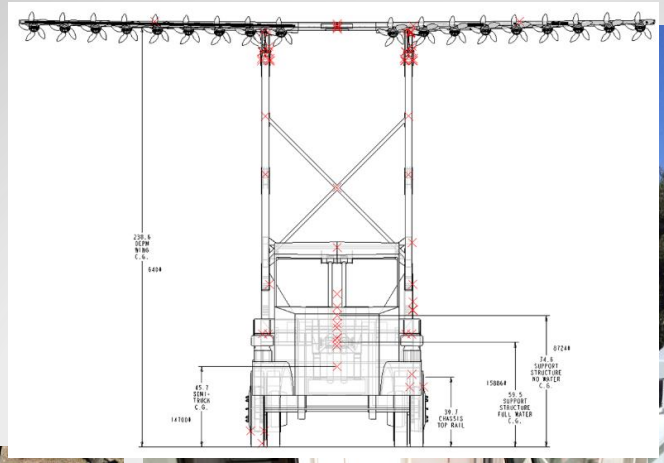
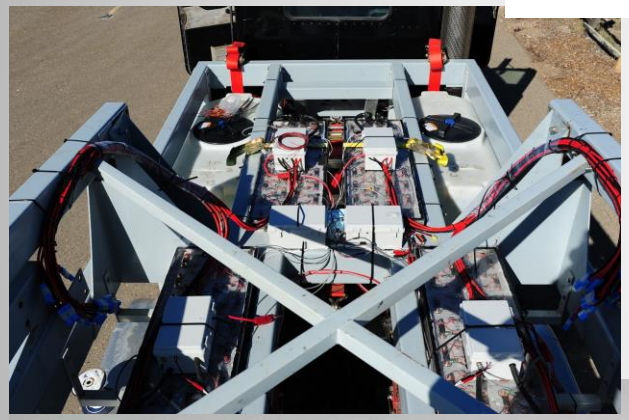
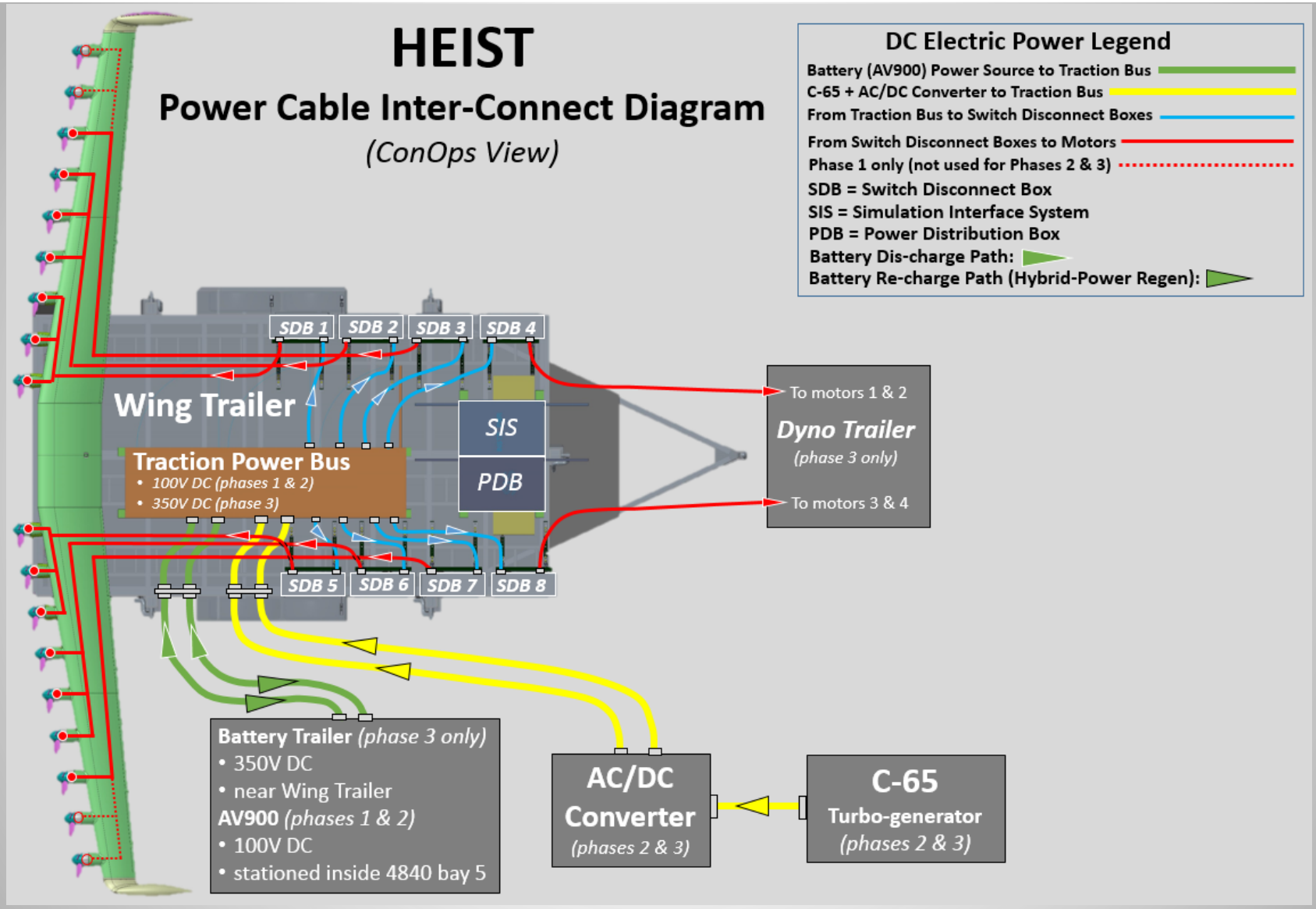
The LEAPTech Truck Experiment

1st Experiment of HEIST





Hybrid-Electric Integrated Systems Testbed (HEIST)



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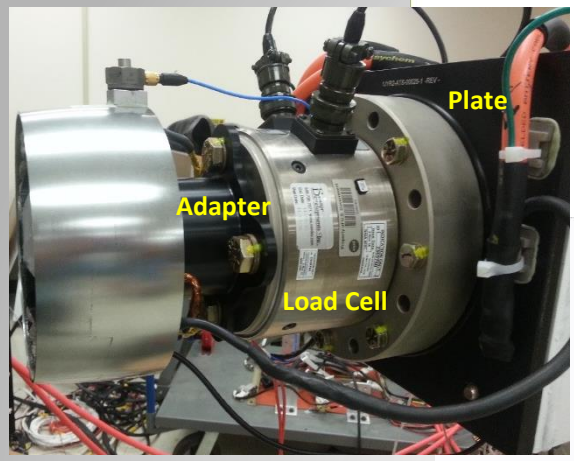
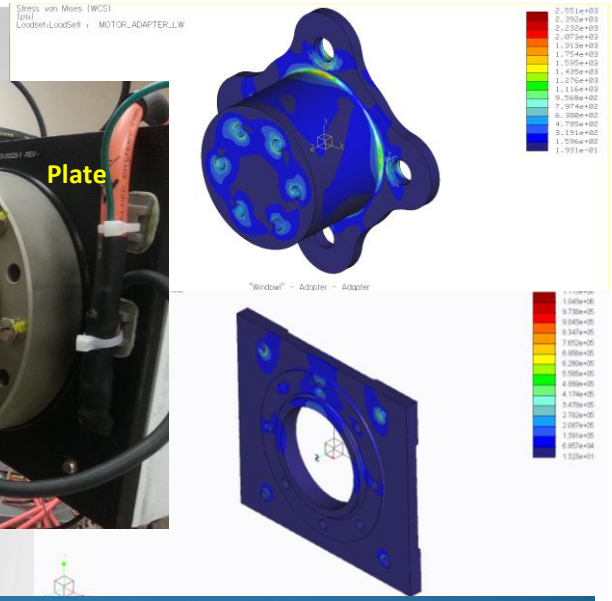
Airvolt – Fully Instrumented, Single-Propulsor Test Stand

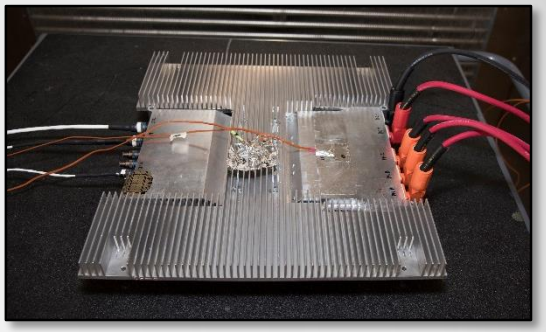




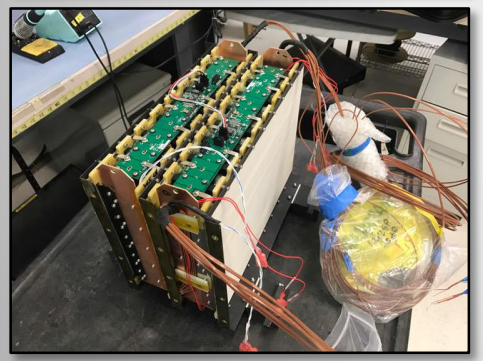
X-57 Maxwell (SCEPTOR)

JSC Test Unit With Interstitial Barrier and Heat Spreader (Design Template)

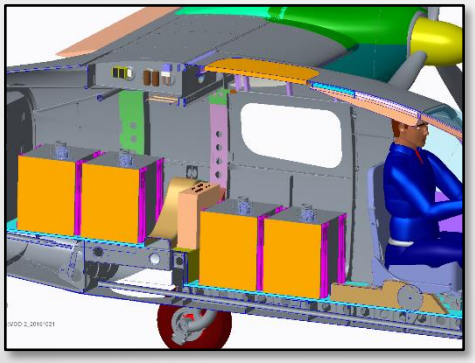
X-57 Battery Module (¼ Pack) before Short Circuit Test



Cruise Motor Inverter Environmental Testing at NASA

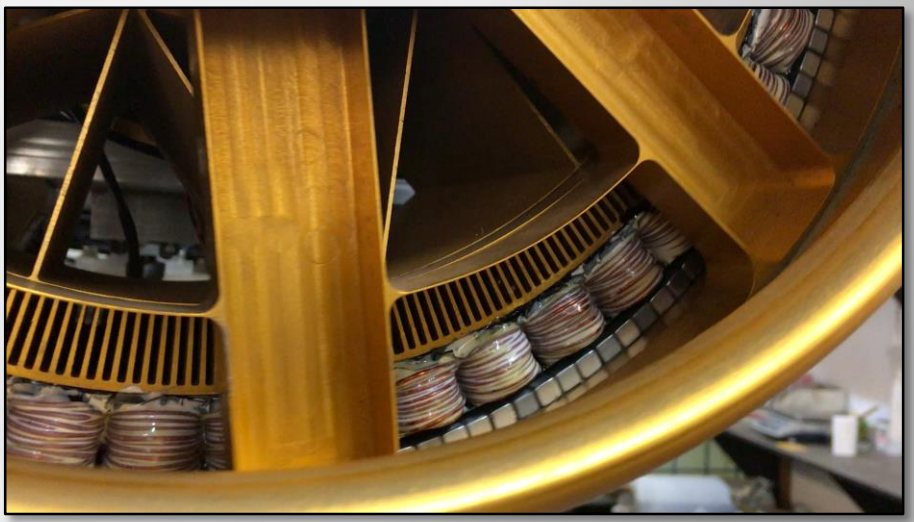


X-57 Thermal Runaway Unit (2 Trays; ½ Module)



One Battery Pack (4 Module, ½ Ship Set)

Prototype Cruise Motor



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NASA Armstrong Hazard Assessment Matrices

	Injury severity classifications				
	A: Frequent	B: Probable	C: Occasional	D: Remote	E: Improbable
I: Catastrophic					
II: Critical					
III: Moderate					
IV: Negligible					

	Asset/mission severity classifications				
	A: Frequent	B: Probable	C: Occasional	D: Remote	E: Improbable
I: Catastrophic					
II: Critical					
III: Moderate					
IV: Negligible					

	Requires Center Director approval and may require approval by a higher authority. These hazards are defined as "Accepted Risks."
	Risk acceptance requires Center Director approval. These hazards are defined as "Accepted Risks."
	Risk acceptance requires Project Manager approval.

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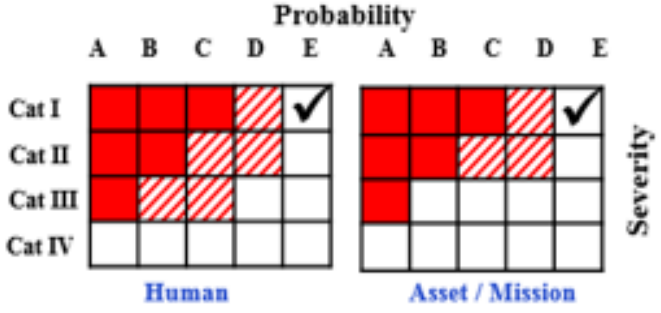
Example of a Distributed Electric Propulsion Hazard

X-57 Maxwell HR-3 traction bus failure

Causes

A. Electrical short
B. Wiring defect
C. Design error
D. Circuit protection component failure
E. Installation error
F. External/environmental abuse (thermal/mechanical)
G. Grounding isolation fault
H. Inadequate grounding
I. Operational / procedural error
J. Lightning strike

AFRC hazard action matrices



Effects

* Loss of essential avionics power
* Total loss of aircraft power
* Motor failure
* Propeller governor failure
* Fire
* Damage or loss of aircraft
* Damage to ground assets
* Injury or death to personnel

Mitigations

1 Design avionics bus for single fault tolerance (A,B,C,D,E)
2 Ground test (CST) (A,B,C,D,E,F,G,I)
3 Grounding checks (G,H)
4 Design with margin (de-rate power system) (C,D,F)
5 Quality control process (B,E,I)
6 Peer review of design (C)
7 VFR operations only (J)
8 Perform visual inspection of system components (A,B,D,E,F)
9 Adhere to X-57 operational placards and procedures (E,F,H,I,J)

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Electric & Hybrid-Electric Testbed-Specific Hazards

Project hazard summary	Severity/probability classification	
	Human	Asset
X-57 Maxwell		
HR-1 Aircraft traction battery fire	I D	I D
HR-2 Structural failure of wing	I D	I D
HR-3 Traction bus failure	I E	I E
HR-5 Aircraft damage due to exposure to excessive environmental conditions during ground operations	N/A	III D
HR-7 Wing control surface system failure	I D	I D
HR-9 Inadequate stability control	I D	I D
HR-11 Failure of motor mounts	I E	I E
HR-12 Whirl flutter	I D	I D
HR-13 Symmetric loss of cruise propeller thrust (partial/total)	II E	II E
HR-14 Avionics bus failure	III E	II E
HR-15 Cruise propeller performance degradation and/or separation	I E	I E
HR-17 Battery modules separate from attach points	I E	I E
HR-18 Abrupt asymmetric thrust	I D	I D
HR-19 Electromagnetic interference in flight	N/A	IV D
HR-20 Landing gear structural failure	II D	I D
HR-21 Failure of propulsor system	I E	I E
HR-22 Restricted and/or obstructed crew egress	I E	N/A
HR-23 Cockpit air contamination	I E	I E
HR-24 Inadvertent cruise motor propeller rotation	I E	III E
HR-25 Equipment pallet separates from attach points	I E	III E
HR-26 Personnel exposed to high voltage/current	I E	N/A
HR-27 High lift propeller damage and/or separation	Analysis in work	
HR-28 Classic flutter	I E	N/A

Project hazard summary	Severity/probability Classification	
	Human	Asset
HEIST		
HR-1 Propeller failure	I E	III C
HR-2 Traction battery fire	II E	III D
HR-3 Inadvertent system activation	I E	III E
HR-4 Electrical discharge / shock / arc flash	I E	III E
HR-5 HEIST ground asset collision	I E	II E
HR-6 JM-1 motor failure	I E	IV B
HR-7 Electrical fire	II E	III D
HR-8 Damage to HEIST assets due to environmental factors	N/A	III E
HR-9 Test article support structure failure	I E	III E
HR-10 Excessive noise exposure	II E	N/A
HR-12 Dynamometer system failure	I E	III C
HR-15 Software operation outside of intended parameters	N/A	III C
HR-16 Electromagnetic interference	N/A	IV D
HR-17 Loss of hardware communication link	N/A	IV D
Airvolt		
HR-1: Lithium polymer battery fire	II E	IV E
HR-2: Airvolt test stand structural failure	I E	III E
HR-3: Electrical fire	III D	II E
HR-4: Electrical discharge/shock	I E	III E
HR-5: Propeller / motor failure	I E	IV E
HR-6: Test personnel exposed to excessive noise during system operation	II E	N/A

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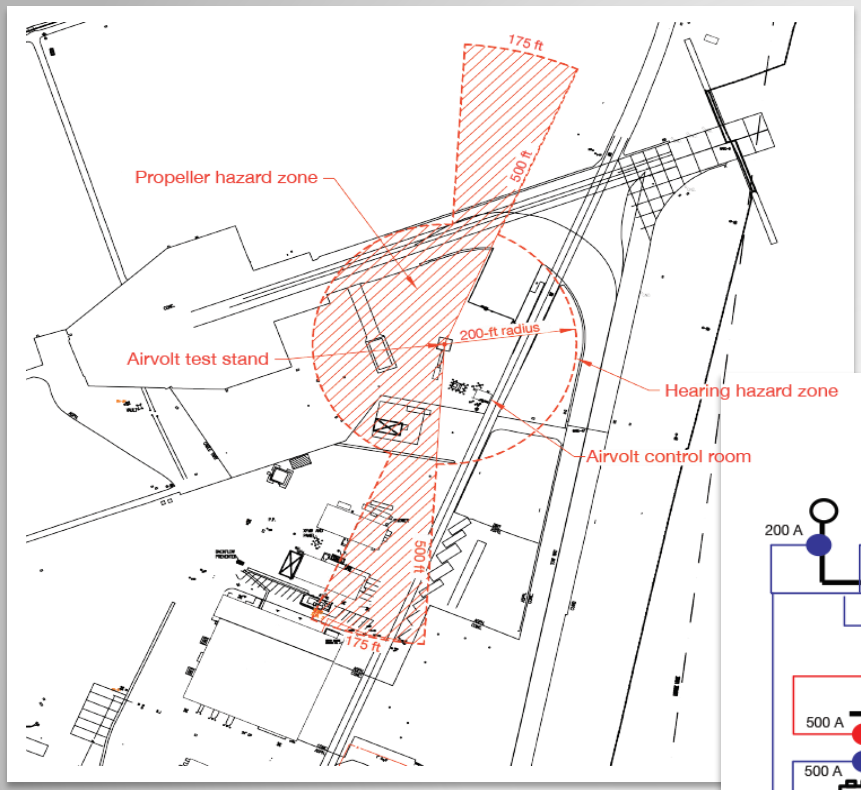
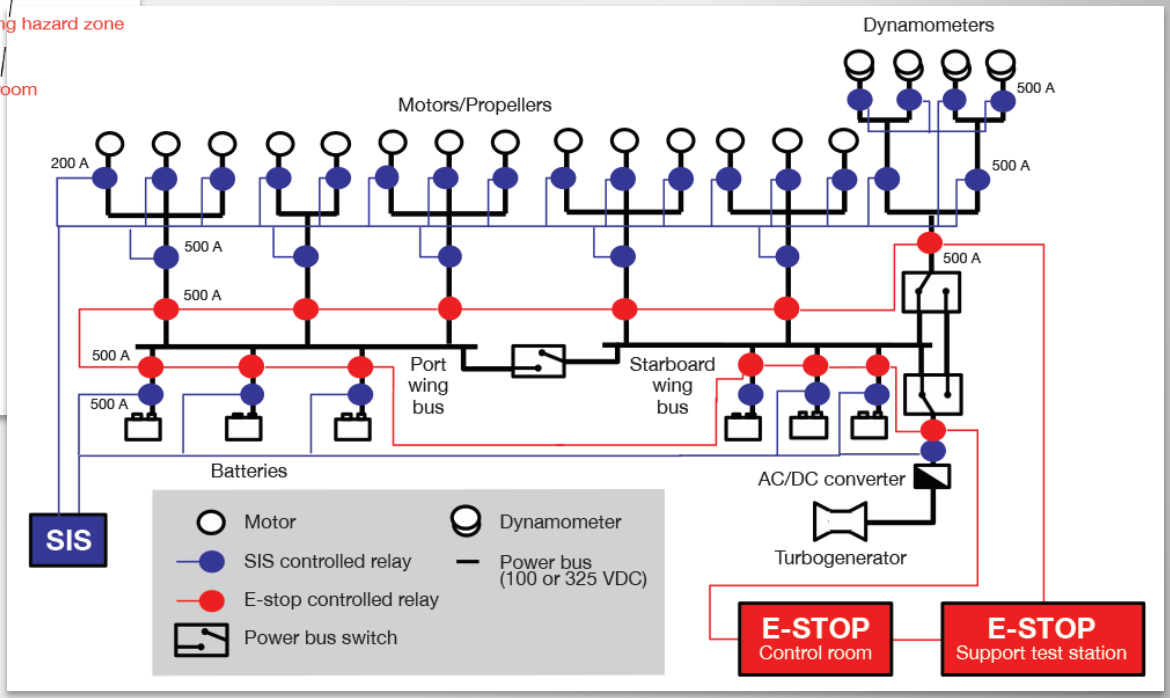
Distributed Electric Propulsion Hazard Mitigation Examples



Propeller and audio decibel-level threshold keep out zone

Manual hardware-only Emergency-Stop (E-Stop) relay network



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Where do we go from here?

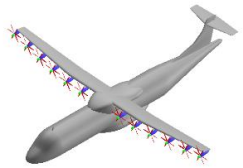
2015 → 2035

Largest Electrical Machine on Aircraft

Non-cryogenic | 100 kW | 1 MW | 3 MW | 10 MW | 30 MW | Superconducting

9 Seat
0.5 MW Total Propulsive Power
50-250 kW Electric Machines

19 Seat
2 MW Total Propulsive Power
.1-1 MW Electric Machines



50 Seat Turboprop
3 MW Total Propulsive Power
.3-6 MW Electric Machines

50 Seat Jet
12 MW Total Propulsive Power
.3-6 MW Electric Machines

150 Seat
22 MW Total Propulsive Power
1.5-2.6 MW Electric Machines

150 Seat
22 MW Total Propulsive Power
1-11 MW Electric Machines

300 Seat
60 MW Total Propulsive Power
3 -30 MW Electric Machines

Left side – motor size,
Right side – generator size
for a twin turboelectric system
for a fully electrified airplane

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