



A NASA Approach to Safety Considerations for Electric Propulsion Aircraft Testbeds

NASA

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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

Strategic Thrusts 3 & 4

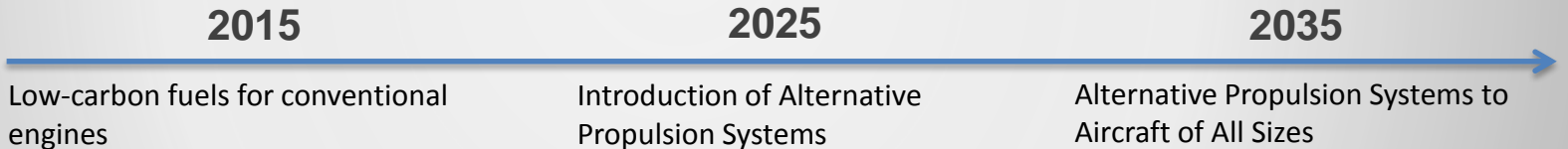
Hybrid Electric Propulsion Research Themes



Strategic Thrust 3: Ultra Efficient Commercial Vehicles



Strategic Thrust 4: Transition to Low Carbon Propulsion

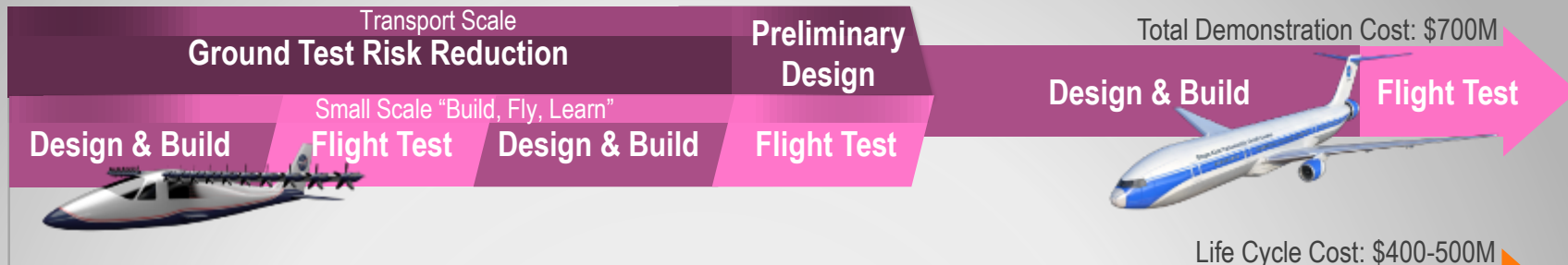


- **Integrated Technology Concepts (Vehicle / Synergy)**
- **Power and Propulsion Architectures**
- **HEP Components / Enablers**
- **Modeling, Simulation, and Test Capability**

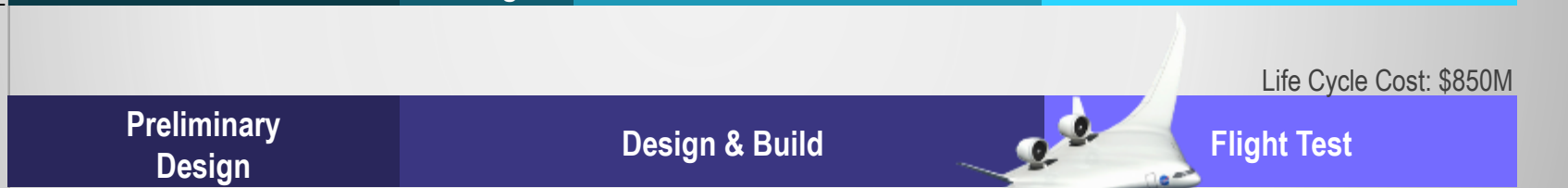
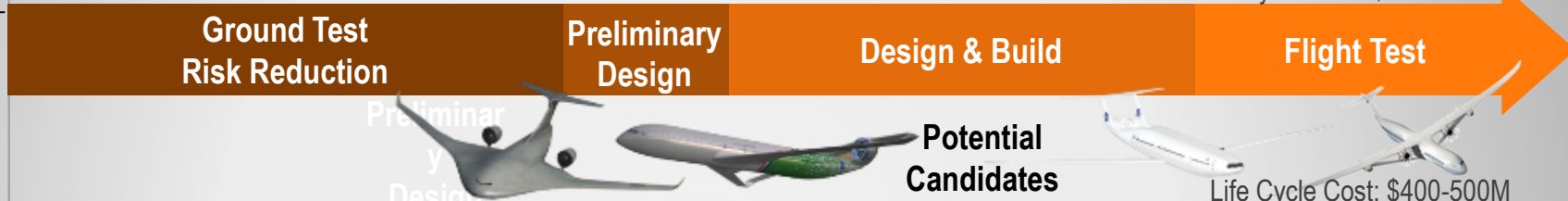
Electric & Hybrid-Electric Flight Demonstration Plan



Hybrid Electric Propulsion Demonstrators



"Purpose-Built" UEST Demonstrators

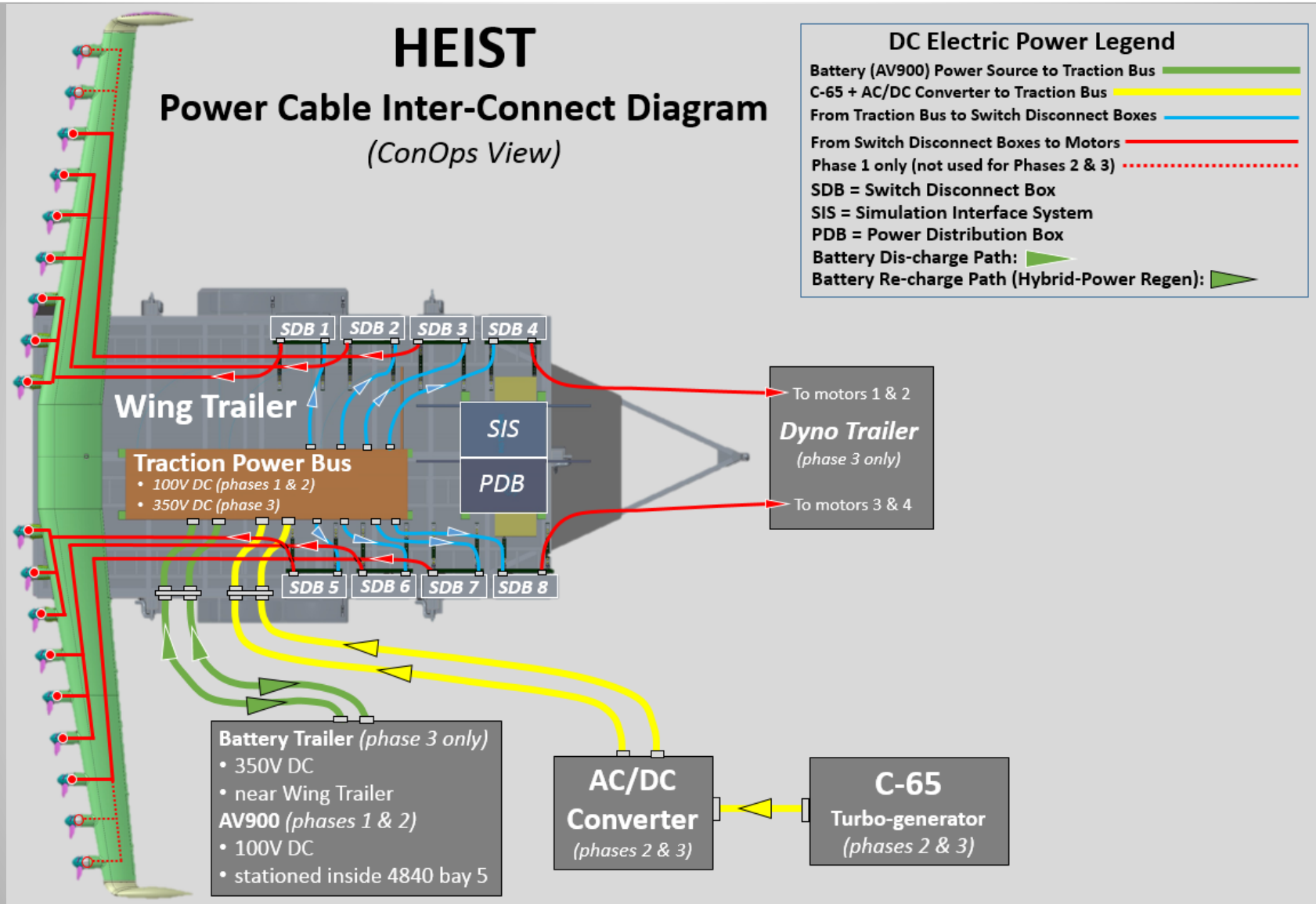


Fully integrated UEST Demonstrator

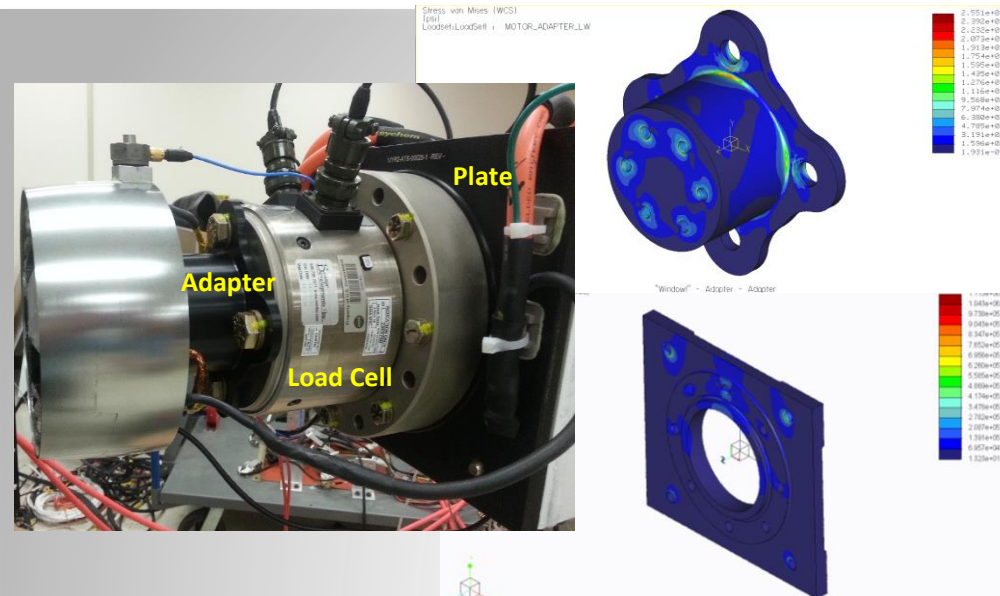


FY17 FY18 FY19 FY20 FY21 FY22 FY23 FY24 FY25 FY26

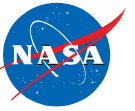
Hybrid-Electric Integrated Systems Testbed (HEIST)



Airvolt – Fully Instrumented, Single-Propulsor Test Stand



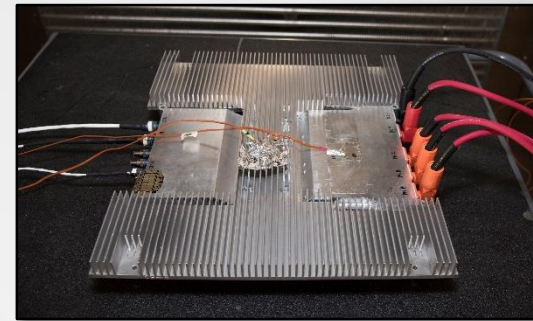
X-57 Maxwell (SCEPTOR)



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



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

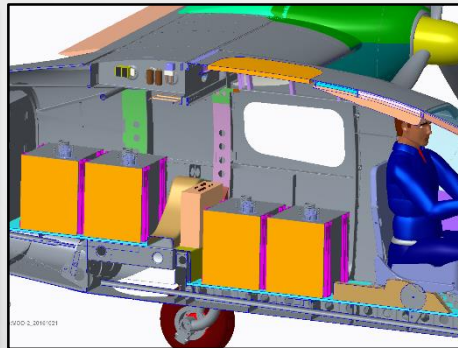


Cruise Motor Inverter Environmental Testing at NASA

Prototype Cruise Motor



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



One Battery Pack (4 Module, ½ Ship Set)



NASA Armstrong Hazard Assessment Matrices



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

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

	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.

Example of a Distributed Electric Propulsion Hazard



X-57 Maxwell HR-3 traction bus failure																																																																																		
Causes	Effects																																																																																	
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	* 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)																																																																																	
AFRC hazard action matrices																																																																																		
<table border="1"> <thead> <tr> <th colspan="2"></th> <th colspan="5">Probability</th> <th colspan="5"></th> </tr> <tr> <th colspan="2"></th> <th>A</th><th>B</th><th>C</th><th>D</th><th>E</th> <th>A</th><th>B</th><th>C</th><th>D</th><th>E</th> </tr> </thead> <tbody> <tr> <td rowspan="4" style="vertical-align: middle;">Severity</td> <td>Cat I</td> <td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td> <td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td> </tr> <tr> <td>Cat II</td> <td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td> <td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td> </tr> <tr> <td>Cat III</td> <td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td> <td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td> </tr> <tr> <td>Cat IV</td> <td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td> <td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td><td style="background-color: red;"></td> </tr> <tr> <td colspan="2"></td> <td colspan="5" style="text-align: center;">Human</td> <td colspan="5" style="text-align: center;">Asset / Mission</td> </tr> </tbody> </table>			Probability												A	B	C	D	E	A	B	C	D	E	Severity	Cat I											Cat II											Cat III											Cat IV													Human					Asset / Mission					
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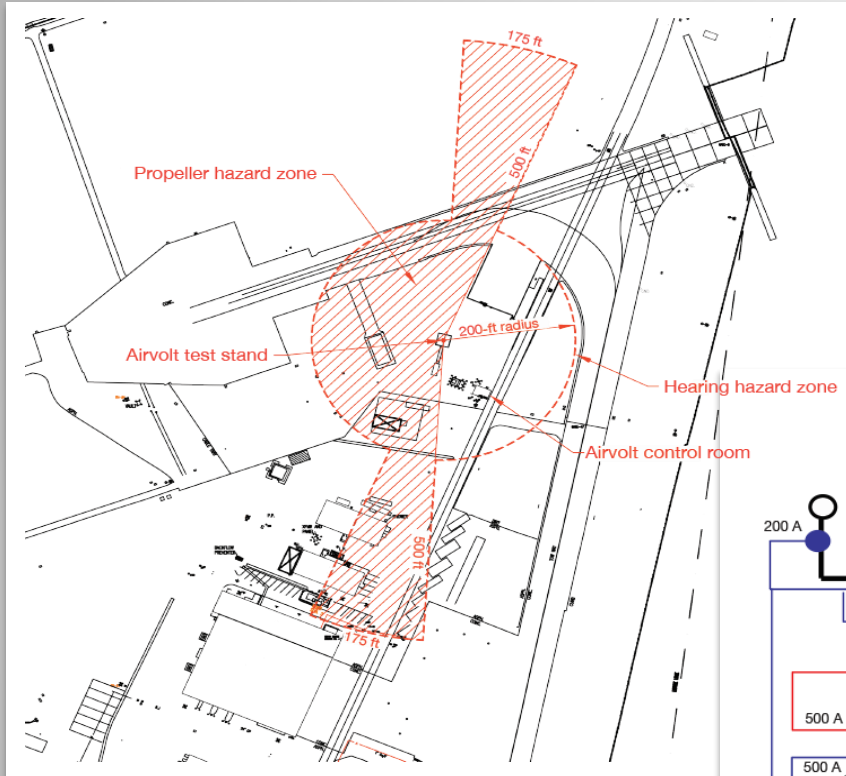
Electric & Hybrid-Electric Testbed-Specific Hazards



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

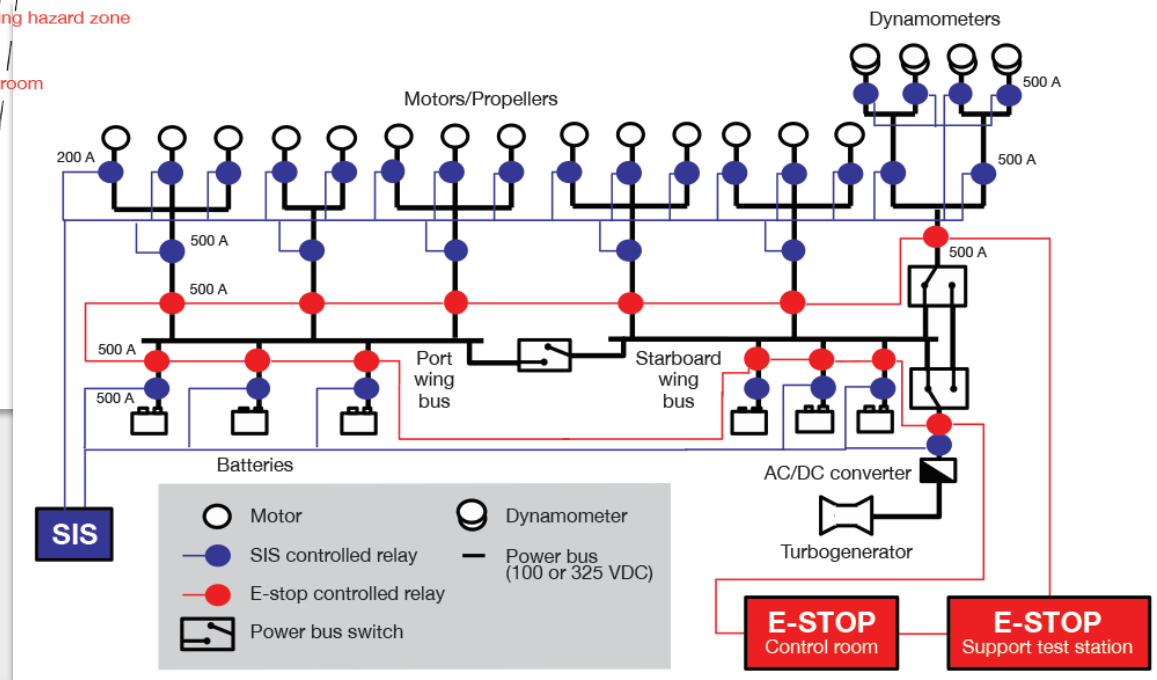
Project hazard summary	Severity/probability Classification	
	Human	Asset
HEIST		
HR-1 Propeller failure	I E	III C
HR-2 Traction battery fire	II E	III D
HR-3 Inadvertent system activation	I E	III E
HR-4 Electrical discharge / shock / arc flash	I E	III E
HR-5 HEIST ground asset collision	I E	II E
HR-6 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

Distributed Electric Propulsion Hazard Mitigation Examples



Propeller and audio decibel-level threshold keep out zone

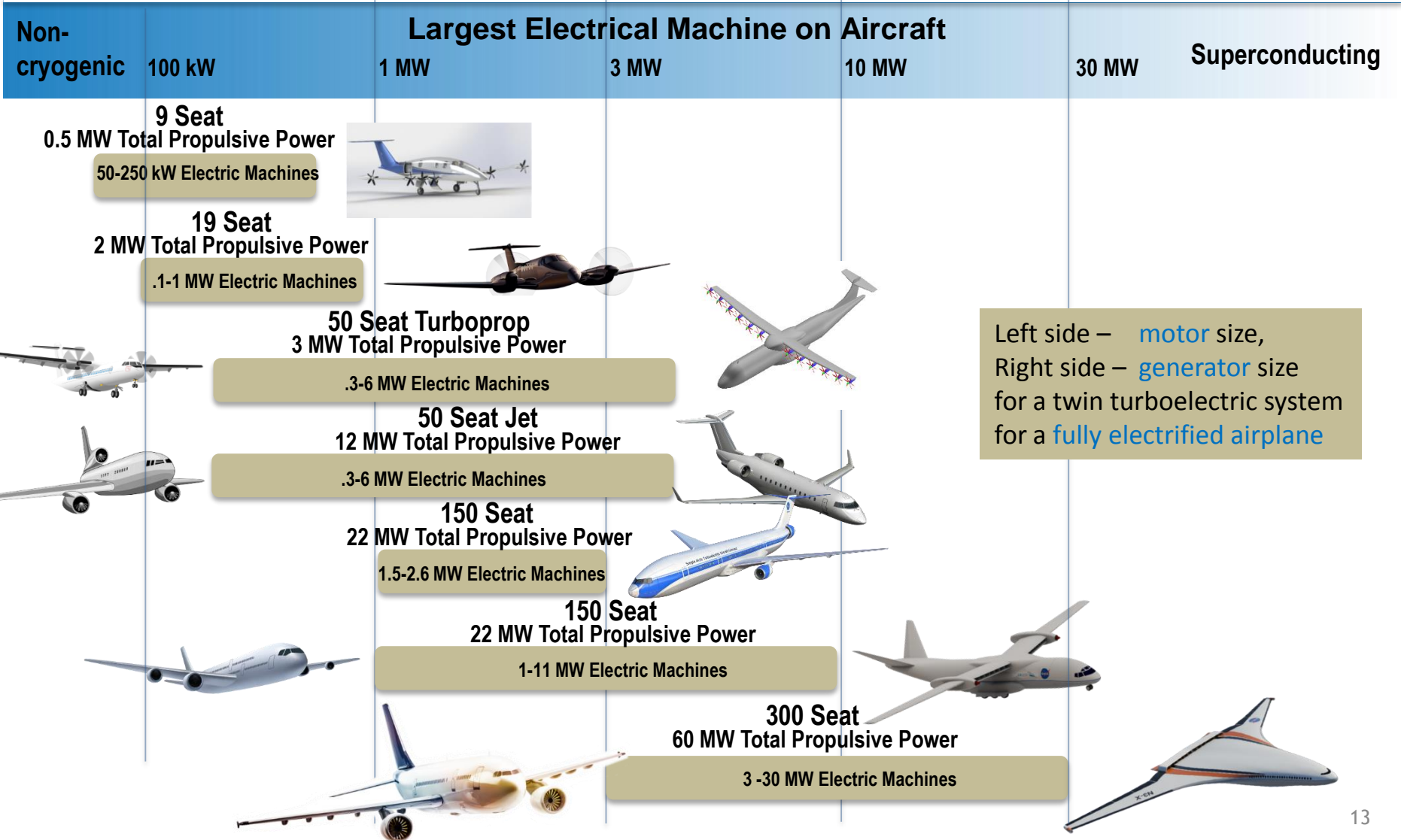
Manual hardware-only Emergency-Stop (E-Stop) relay network



Where do we go from here?



2015 → 2035



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

Backup Slides

