EVTOL PROPULSION SYSTEM SAFETY

EASA Rotorcraft & VTOL Symposium

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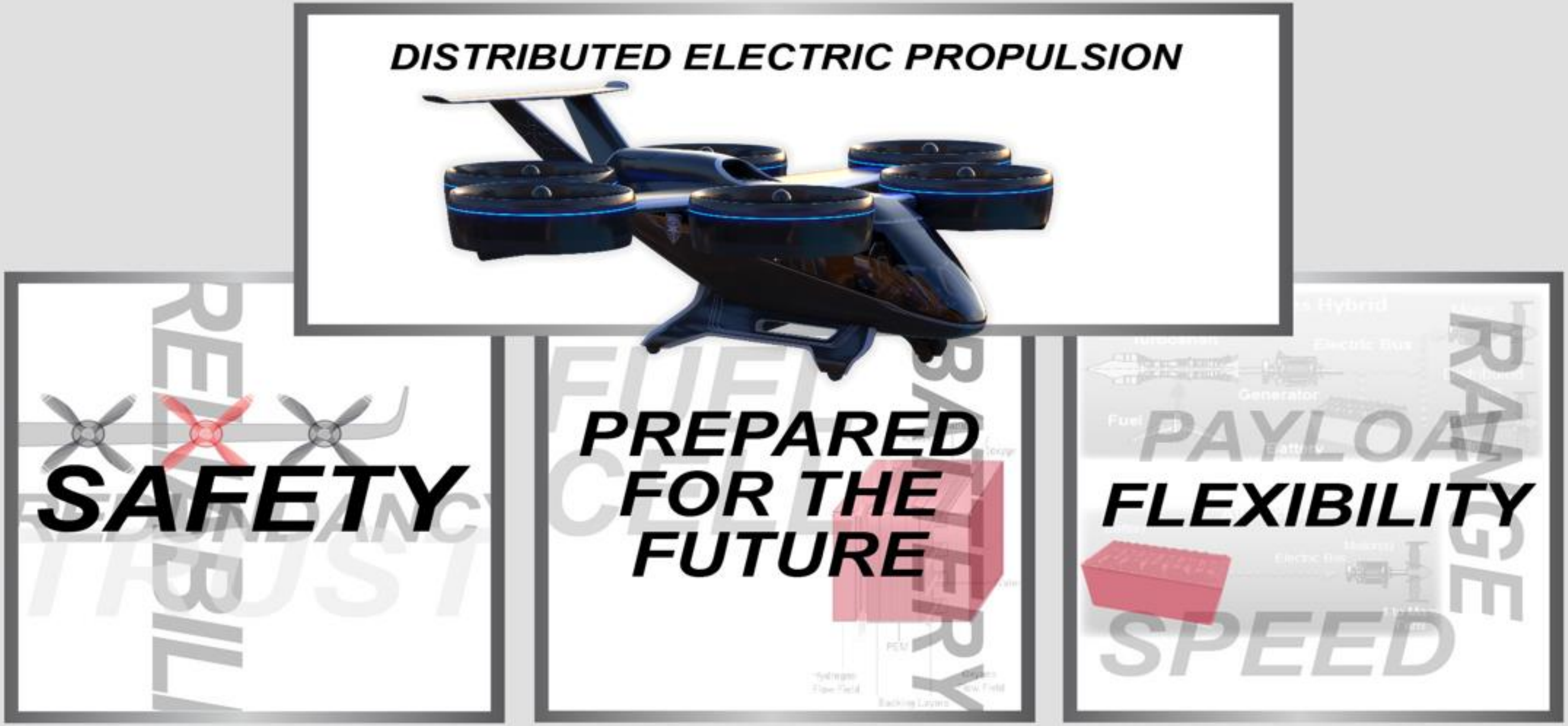

Opportunities and Challenges of Electric Propulsion

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Opportunities:

- Reduced complexity of components
- Wide number of options for system architecture and arrangement
- Elimination of (some) critical parts
- Propulsion system dissimilarity
- Integrated health monitoring
- Ease of maintenance
- Reduced pilot workload

Challenges:

- Increased system complexity
- Propulsion system closely coupled to flight controls
- Weight and cost of redundant systems and components
- Complexity of systems analysis and certification
- Heavy reliance on electronics systems and software

Trade opportunities and challenges to optimize for mission

Handling Propulsor Failure Modes

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Potential Propulsor Failure Modes:

- **Rotor Stoppage → Major Hazard if propulsion is redundant**
- **Structural Failure → Catastrophic, independent of redundancy**
  - Release of uncontained high energy debris
  - Cascading failure to other rotors
  - Imbalance & vibration
- **Loss of Rotor Speed Control → Catastrophic, independent of redundancy**
  - Severe Rotor Overspeed
  - Severe Rotor Speed Oscillation

DESIGN MUST ADDRESS ANY CATASTROPHIC FAILURE MODES
REDUNDANCY ALONE INADEQUATE → CRITICAL PARTS REQUIRED

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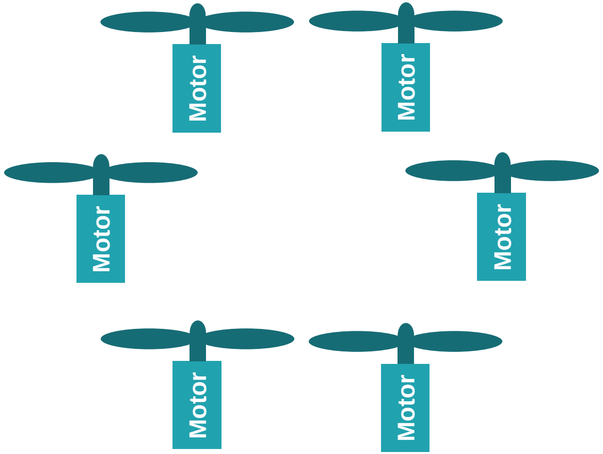
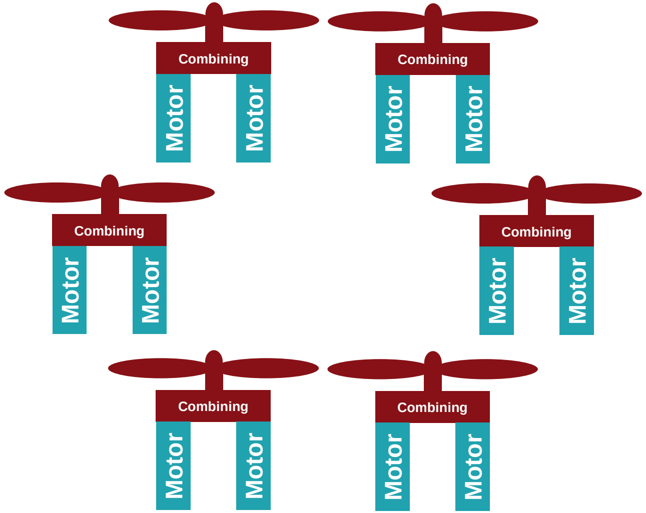
Sizing Case Study on Propulsion Architecture

Case 1:
Redundant, Non-Critical Rotors,
Single Motor per Rotor



Case 2:
Critical Rotors,
Dual-Redundant Motors per Rotor



Non-Critical Parts Critical Parts

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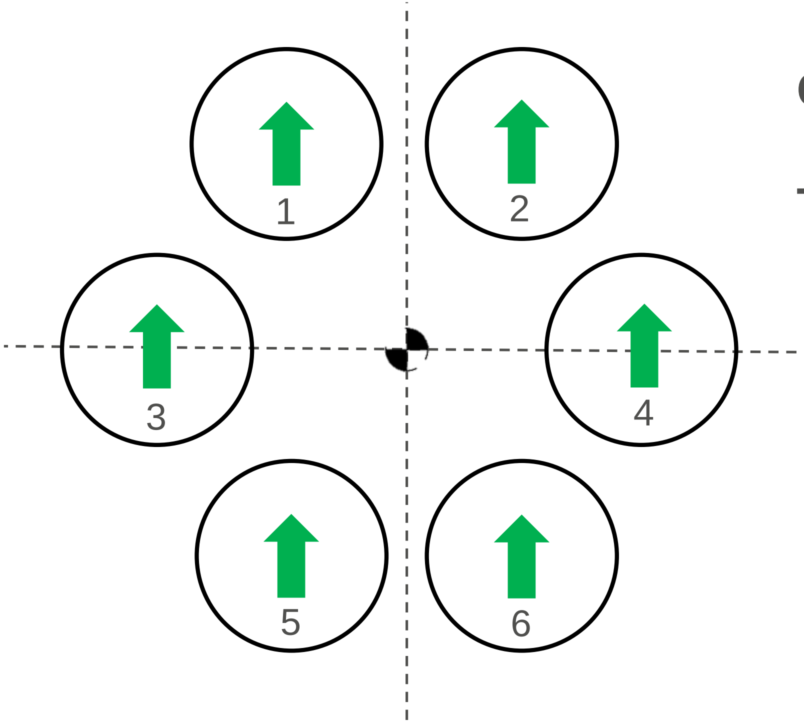
Sizing for Redundancy: Nominal Hover



C.G. Centered, Static Hover, System Nominal

$$T_1 = T_2 = T_3 = T_4 = T_5 = T_6 = T_n$$

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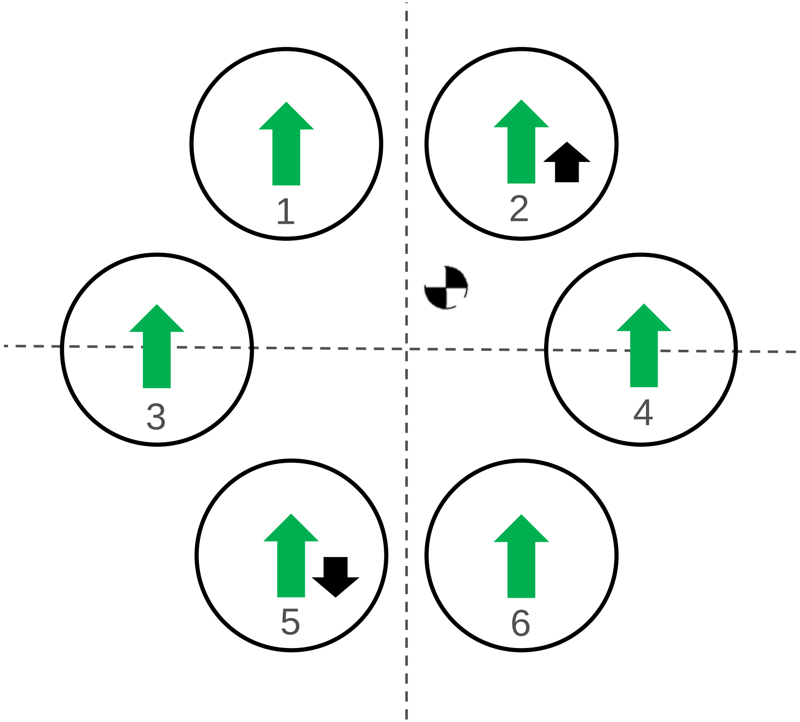
Nominal Hover, Offset C.G.



C.G. Offset, Systems Nominal

T_n (Nominal Thrust, $6T_n$=Gross Weight

Assume 20% Thrust margin for C.G.

$T_2 = 1.2\ T_n$

$T_1 = T_3 = T_4 = T_6 = T_n$

$T_5 = .8\ T_n$

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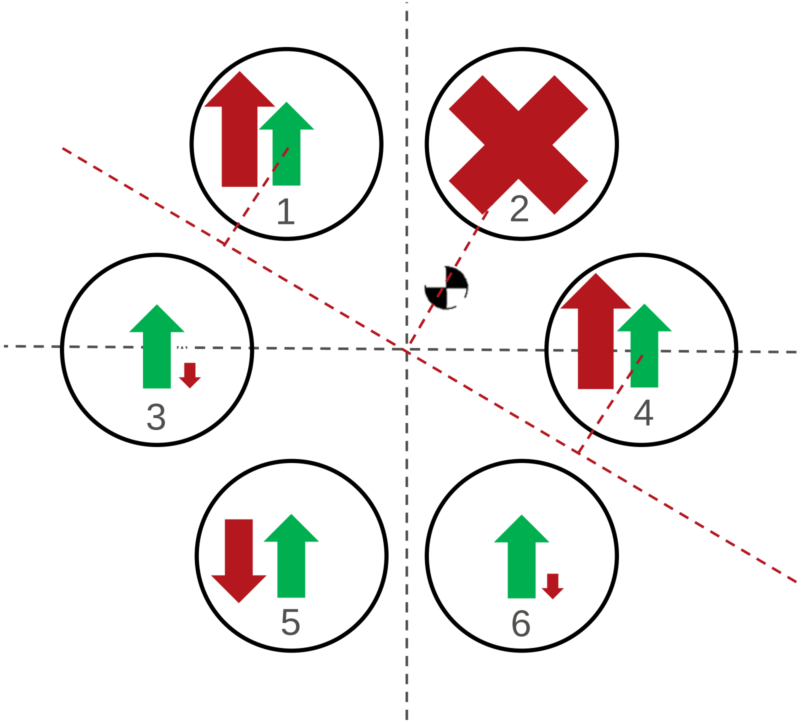

C.G. Offset, Rotor 2 Failure

$T_2 = T_5 = 0$
$T_1 = T_4 = 1.7\ T_n$
$T_3 = T_6 = 1.3\ T_n$

$P_i \approx T_i^{1.5}$

$P_1 = P_4 = 2.2\ P_n$

FAILURE OF SINGLE (HEX) ROTOR REQUIRES 2.2X HOVER POWER RATING!

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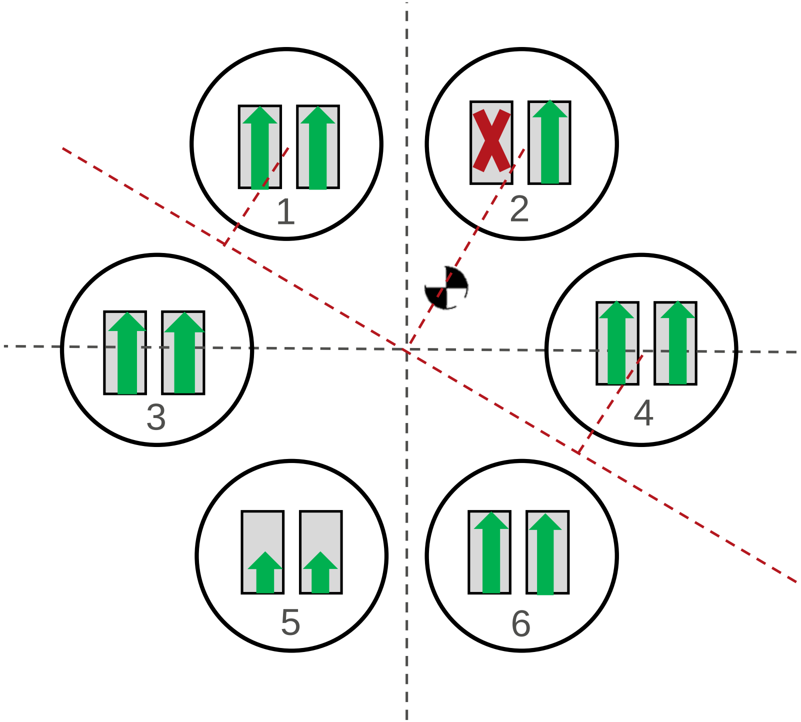

C.G. Offset, Single Motor Failure

$T_2 = .7\ T_n$
$T_1 = T_4 = 1.2\ T_n$
$T_3 = T_6 = 1.2\ T_n$
$T_5 = .5\ T_n$

$P_1 = P_4 = 1.3\ P_n$

HEX ROTOR, DUAL MOTOR, SINGLE FAILURE: 1.3X HOVER POWER RATING

Critical vs Non-Critical Rotors

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Issues Addressed by Design	Case 1: Redundant Non-Critical Rotors, Single Motor per Rotor	Case 2: Critical Rotors, Dual-Redundant Motors per Rotor
Rotor Stoppage	✓ Redundancy	✓ Critical Rotor
Rotor Structural Failure	✗	✓ Critical Rotor
Loss of Speed Control	✗	✓ Critical Rotor
Power Rating	2.2x Hover	1.3x Hover

Critical Rotor Design is Lighter and Addresses Safety Requirements

VTOL Aircraft With Critical Rotors & Redundant Propulsion

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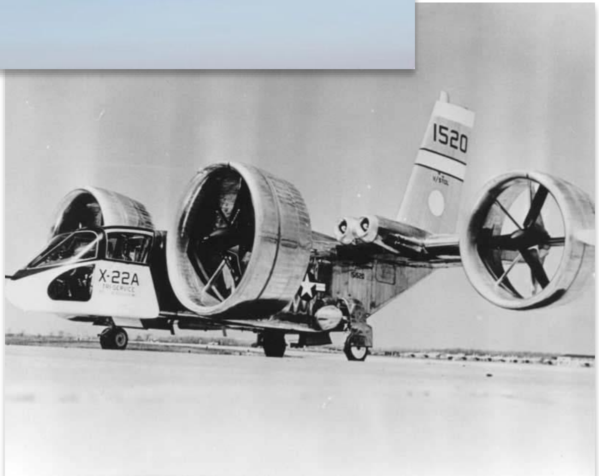

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THANK YOU