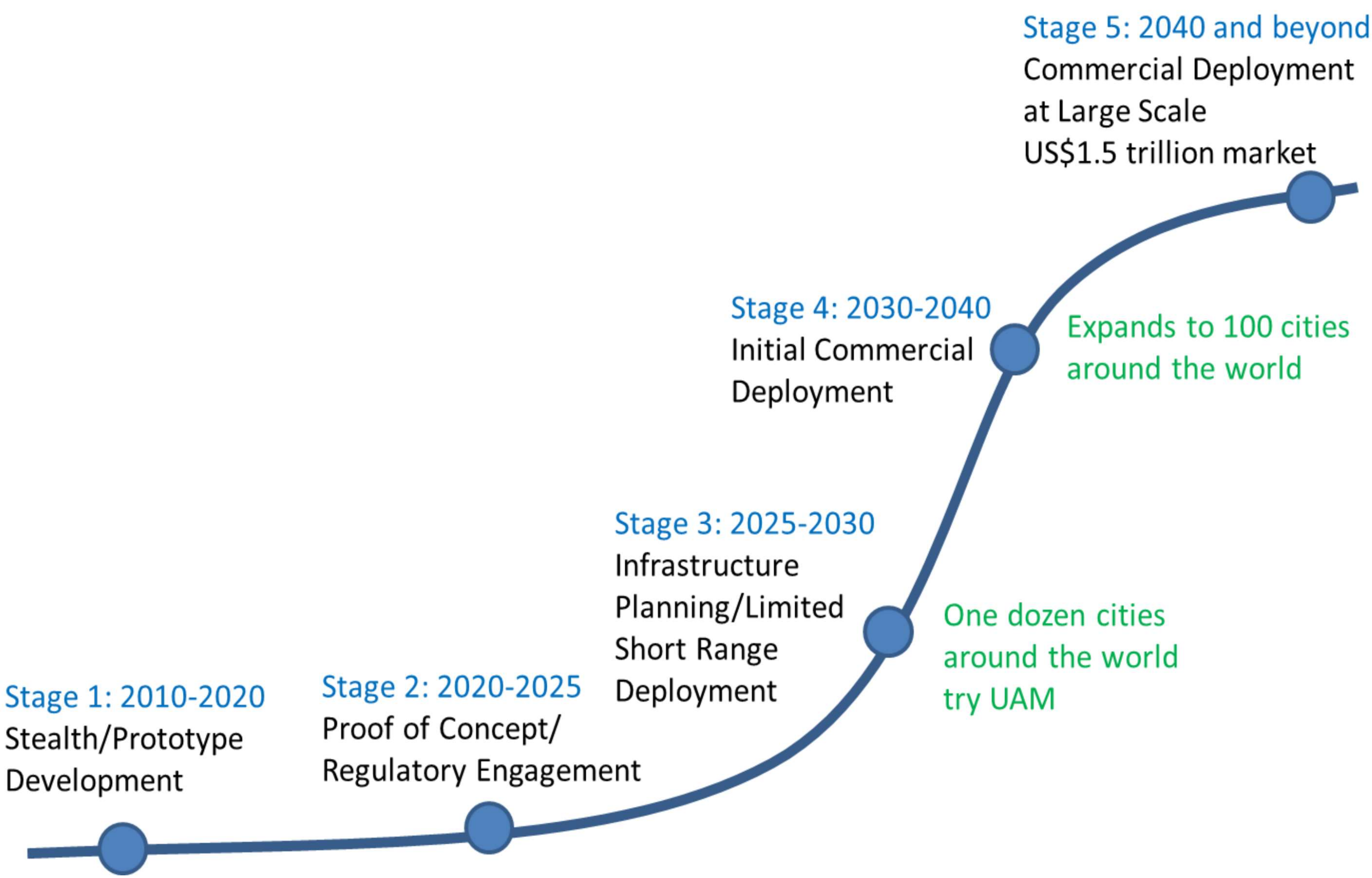
8. Certification and Vertiport Operation

by Dr. James Wang

SNUevtolclass@gmail.com

eVTOL Aircraft for UAM Adaptation Curve



Source: December 2, 2018 Morgan Stanley report
With comments by James

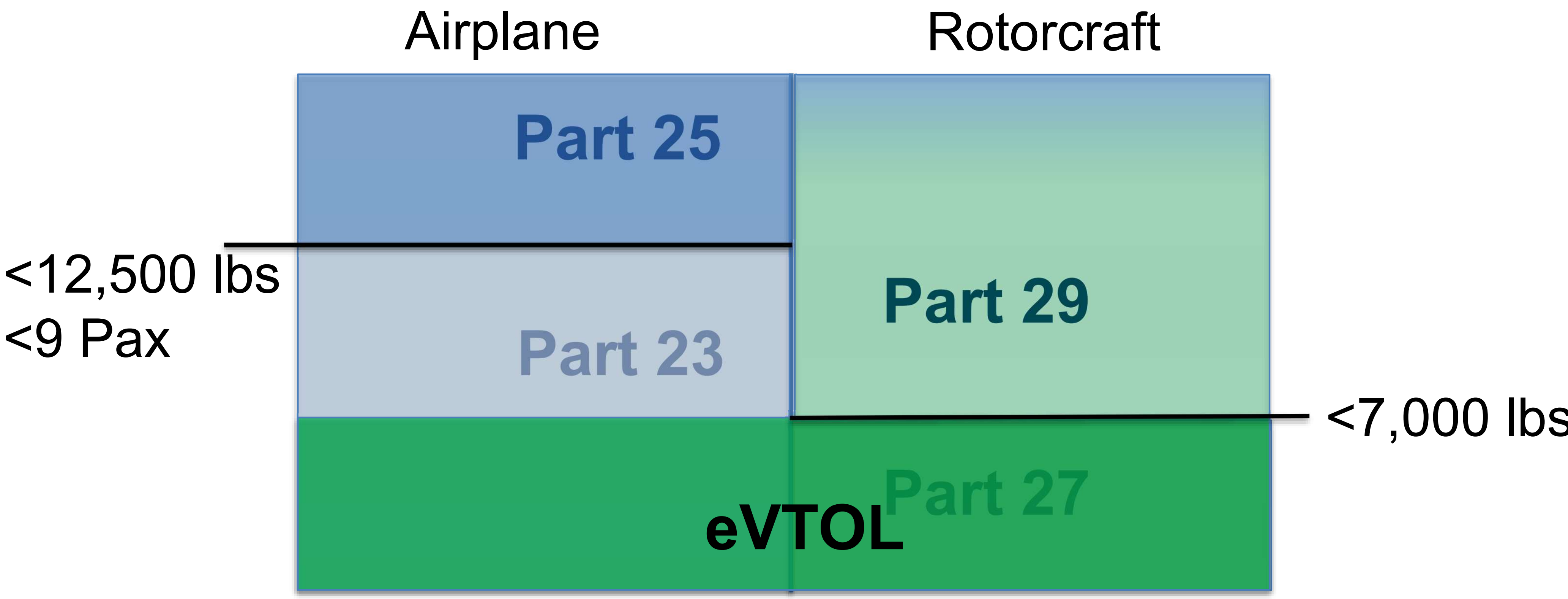
There is a Global Race for Certification

- **Aug 2017**: US’ FAA amends Title 14 CFR Part 23 Amendment 64 to accommodate UAM
- **May 2018**: UK's Civil Aviation Authority grants Bristol based Vertical Aerospace eVTOL flight test permission
- **Jan 2019**: China’s CAAC issues guidance on UAV airworthiness certification
- **Feb 2019**: EHang receives authorization from CAAC to test Ehang 184 Autonomous Aerial Vehicle
- **July 2019**: Europe's EASA publishes a “Special Condition” for eVTOL aircraft up to 3.125 tons
- **Oct 2019**: Singapore CAAS grants Volocopter flight demo in Singapore.
- **Dec 2019**: Volocopter, first to receives Design Organization Approval (DOA) from EASA
- **2021**: Jay Merkle, head of the FAA’s UAS integration office, says one may receive type certificate in 2021
- **2024**: Paris aims to beat 2024 Olympic traffic with flying taxis

FAA says

“In terms of AAM, we are viewing those aircraft as the same level of safety as any other passenger aircraft or any other manned aviation,” Merkle said. “We believe the societal expectations for these aircraft is that they will operate like any other Part 21 or 23 aircraft with Part 91 operations.”

FAA Part 23, 25 for airplane, 27, 29 for Rotorcraft



May 2020, EASA Published an 85-page Means of Compliance with the Special Condition for VTOL aircraft

The Special Condition addresses the unique characteristics of these products and prescribes airworthiness standards for the issuance of a type certificate, and changes to this type certificate, for a person-carrying VTOL aircraft in the small category, with lift/thrust units that are used to generate powered lift and control.

EASA European Union Aviation Safety Agency	Proposed Means of Compliance with the Special Condition VTOL	Doc. No: MOC SC-VTOL Issue: 1 Date: 25 May 2020

Proposed Means of Compliance with the Special Condition VTOL

Statement of Issue

EASA has received a number of requests for the type certification of vertical take-off and landing (VTOL) aircraft, which differ from conventional rotorcraft or fixed-wing aircraft. In the absence of suitable certification specifications for the type certification of this type of product, a complete set of dedicated technical specifications in the form of a Special Condition for VTOL aircraft was developed. The Special Condition addresses the unique characteristics of these products and prescribes airworthiness standards for the issuance of a type certificate, and changes to this type certificate, for a person-carrying VTOL aircraft in the small category, with lift/thrust units that are used to generate powered lift and control.

This Special Condition was subject to a public consultation process and finally issued by EASA in July 2019.

The Special Condition VTOL establishes the safety and design objectives. This approach, previously utilised for the development of CS-23 Amendment 5, is also used for VTOL designs in order not to limit technical innovation by describing prescriptive design solutions as certification standards. The Special Condition does not contain the means that are possible to demonstrate compliance with the safety and design objectives.

The Means Of Compliance (MOC) contained within this document address the applicant´s requests for clarification of EASA's interpretation of these objectives and of possibilities how to demonstrate compliance with them. Some of these MOCs contain material which should be considered to be guidance material to assist the applicant with an understanding of the objective rather than providing a definitive means of compliance.

In the preparation of these MOCs EASA has followed the same principles, and pursued the same objectives, as with the Special Condition. First, to provide sufficient flexibility to address different architectures and design concepts, although it is acknowledged that all possible cases cannot be considered in these MOCs and alternatives can be proposed by applicants to address some particular design features. In addition, the proposed MOCs should enable an equal treatment of all applicants, by establishing a level playing field and ensuring that a comparable level of safety in the compliance with the objectives of the Special Condition is achieved by all designs.

EASA is committed to continue supporting the industry in the development of safe VTOL aircraft. To this end EASA has decided to prioritise the publication of MOC with the Special Condition VTOL and to issue them in a sequential manner. This approach will allow EASA to focus its resources where the greatest safety impact will be achieved and where the need for clarity is more urgently required. It will furthermore allow the industry to gain an early insight into EASA's interpretation and expectations from the design objectives of the Special Condition which could have an important effect in the design decisions, instead of waiting until exhaustive guidance for the Special Condition is developed.

Consequently, the first issue of the MOCs mostly concerns subjects that are considered to drive basic design choices and have a higher safety impact on the overall VTOL aircraft architecture. Successive issues of this MOC document will include new MOCs as well as supplements to the existing ones.

Finally, it is recognised that the experience gained during the certification of these new products and their entry into service will allow to increase the knowledge in their certification. It is possible that a better insight into the particular characteristics of these products is gained, which might result in modifications of particular elements

PUBLIC CONSULTATION Page 1 of 85

Source: https://www.easa.europa.eu/sites/default/files/dfu/proposed_moc_sc_vtol_issue_1.pdf

EASA Says Following Replacement Words Are Used for eVTOL

“Rotorcraft” or “aeroplane” shall be replaced by “VTOL aircraft”

“Engine”, “Turbine”, “Powerplant” and “Rotor” shall be replaced by “Lift/thrust unit”

"Autorotation” shall be replaced by “Controlled Emergency Landing”

“Fuel” shall be replaced by “Energy”

“Fuel tank” shall be replaced by “Energy storage device”

Continued Flight and Safe Landing After Non-Catastrophic Failure or Failure

Examples:

- Lift/thrust unit failure
- Can not vary the rotor rpm
- Control actuator jams (blade pitch change, rotor tilt, landing gear,…)

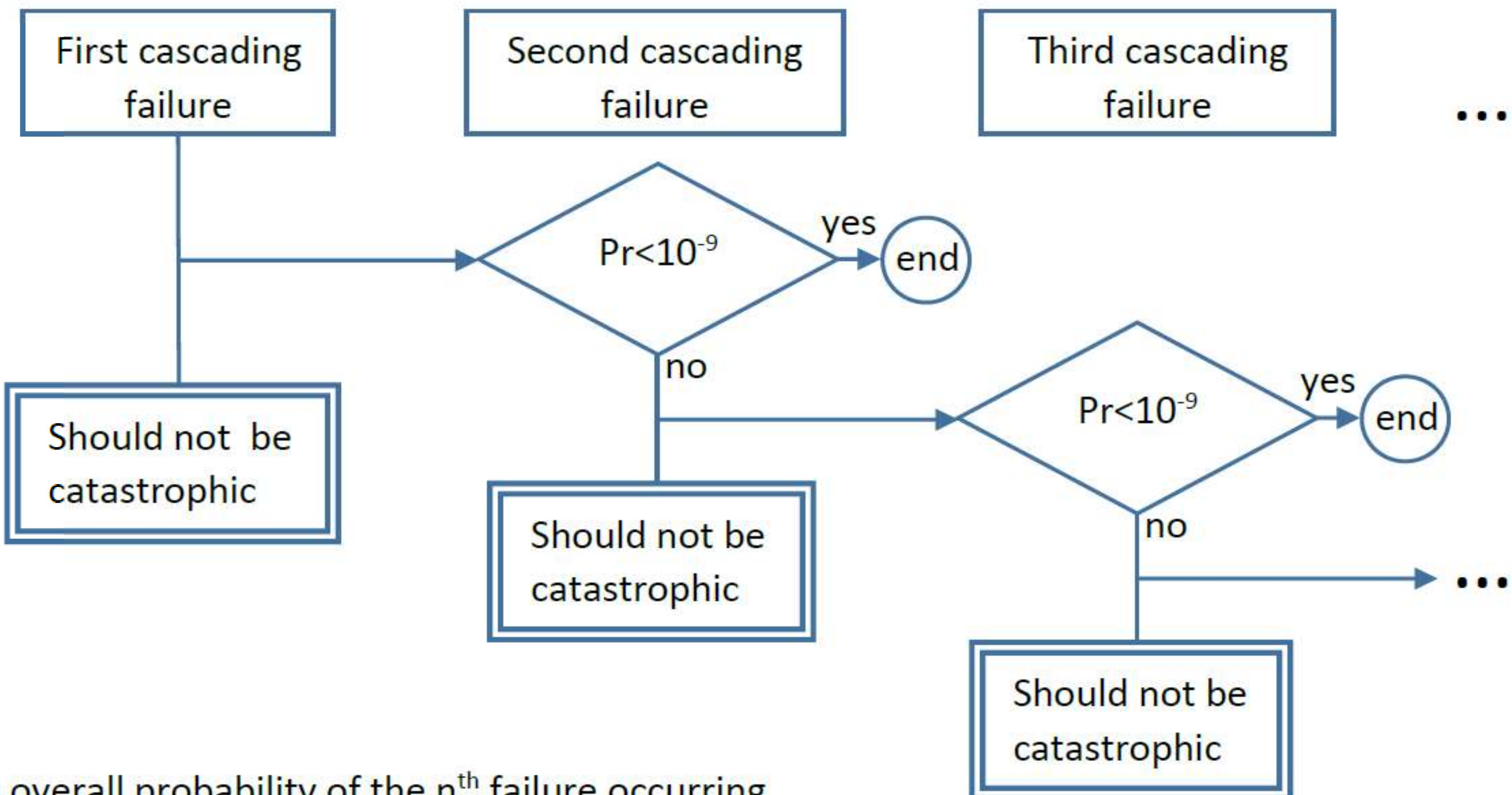
Safety Objectives

CS-23 aeroplanes	CS-27 rotorcraft	SC-VTOL
	Category A	
	Category B	
10 to 19 passengers	0 to 9 passengers	Category **Enhanced**
7 to 9 passengers		Category **Basic** - 7 to 9 passengers
2 to 6 passengers		Category **Basic** - 2 to 6 passengers
0 to 1 passenger		Category **Basic** - 0 to 1 passengers

Category A: capable of continued safe flight and landing in case of engine failure

Category B: no guaranteed capability to continue safe flight in the event of an engine failure, and unscheduled landing is assumed

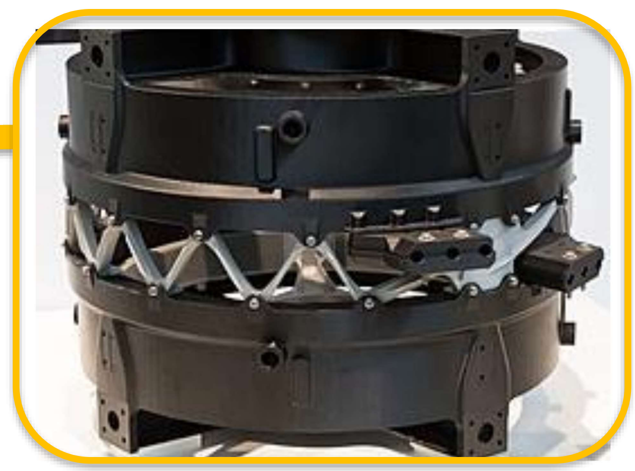
Flight Critical Items Must Have <10^{-9} per Hour probability of Failure



Pr = overall probability of the n^{th} failure occurring

How to Increase Lift/Thrust Unit Redundancy

1. **Use redundant motor/rotor**

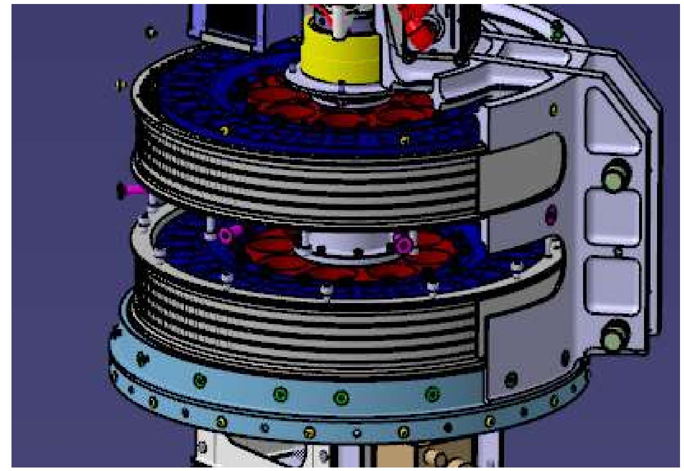


Top motor

Bottom motor

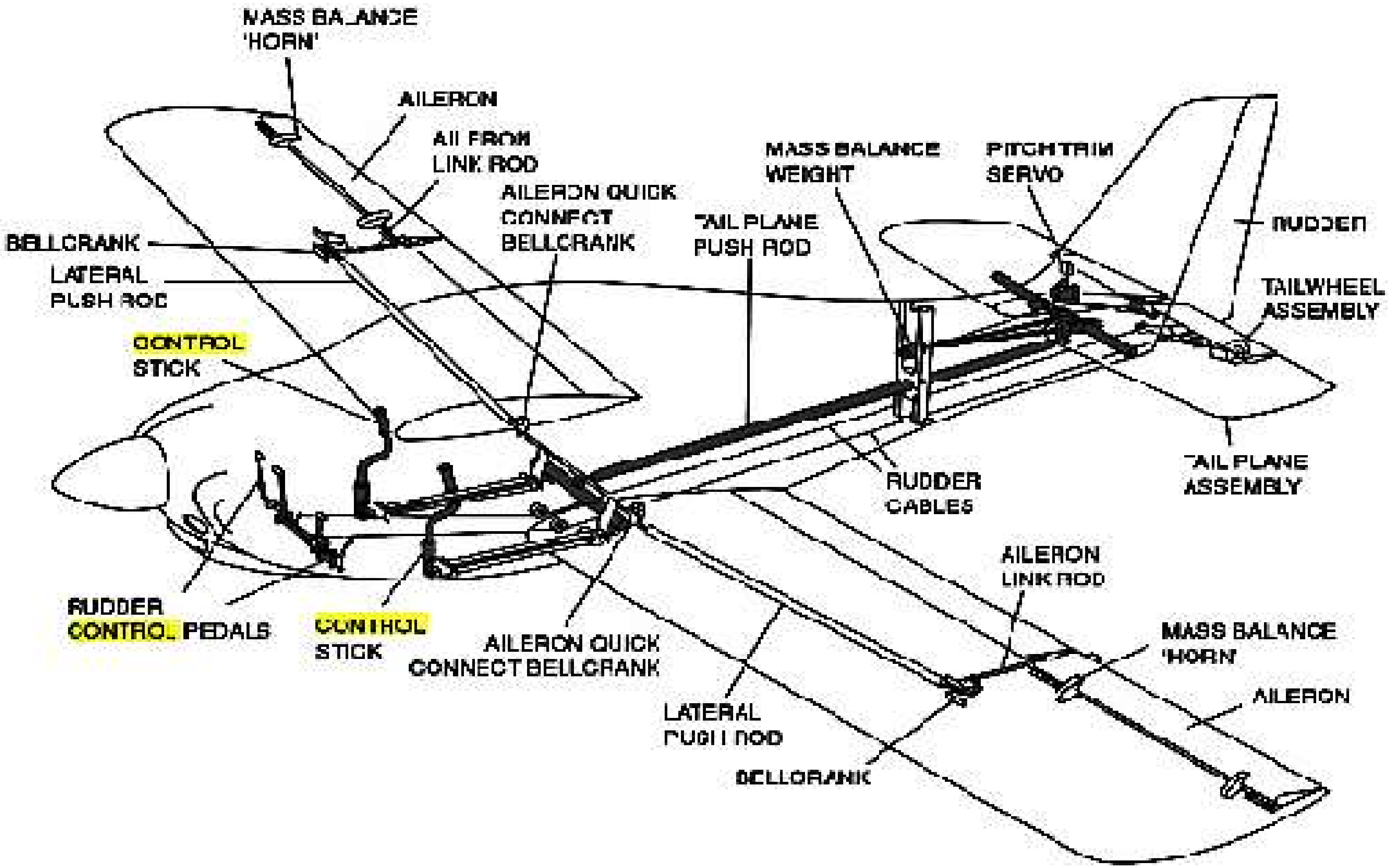
How to Increase Lift/Thrust Unit Redundancy

2. Stack multiple motors on one rotor shaft

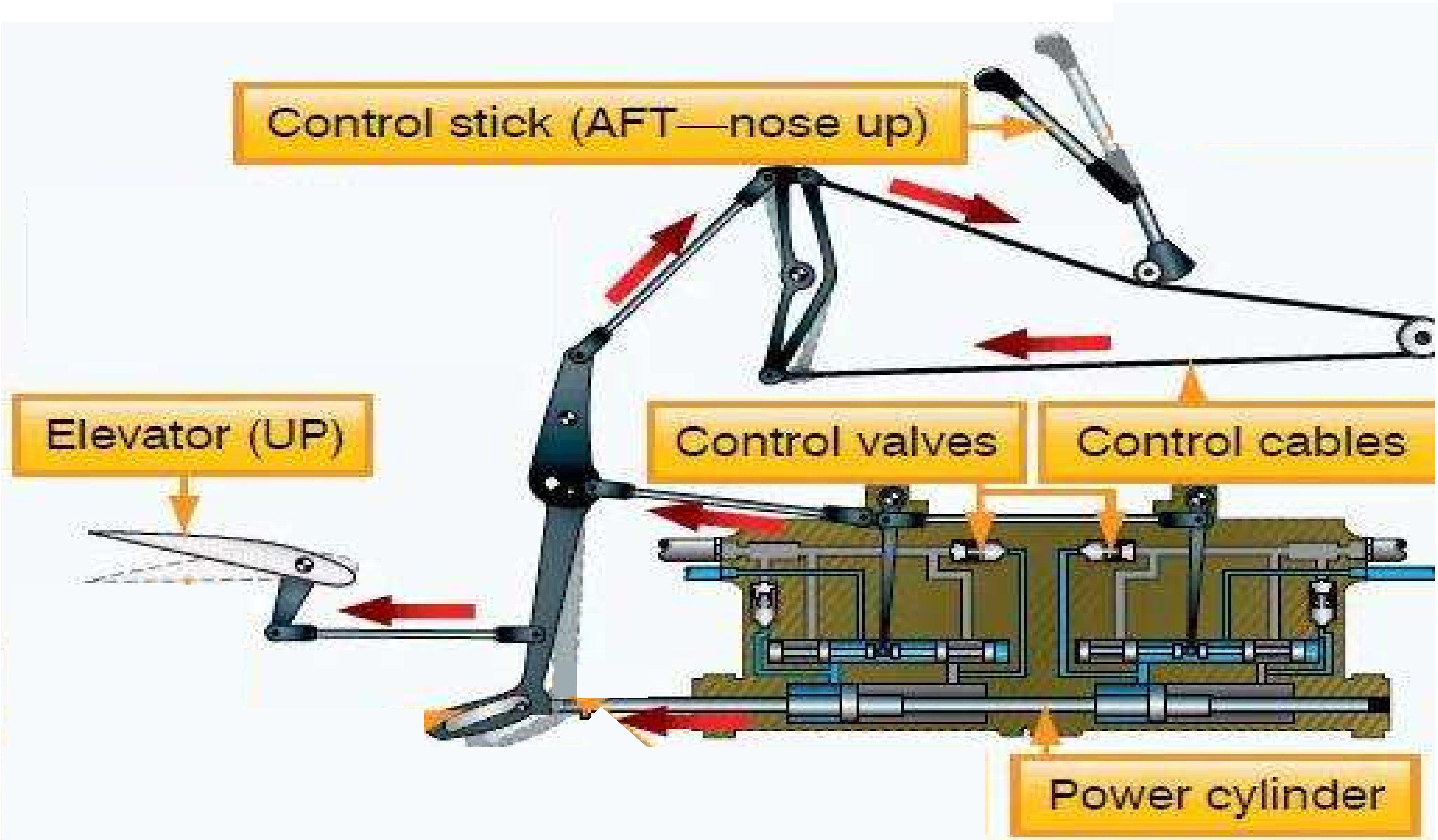


3. Multiple windings inside each motor

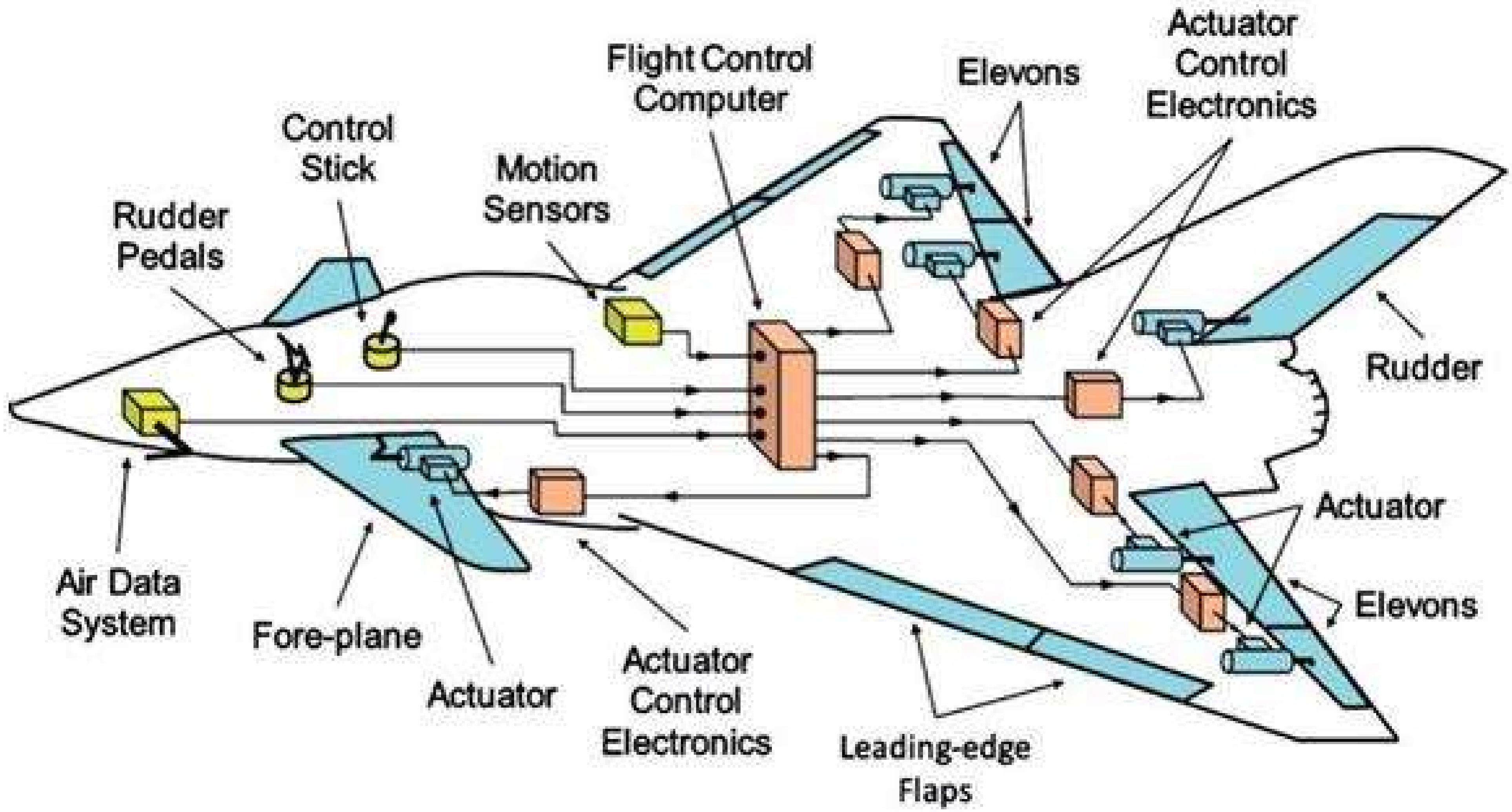
Classical Mechanical Flight Control



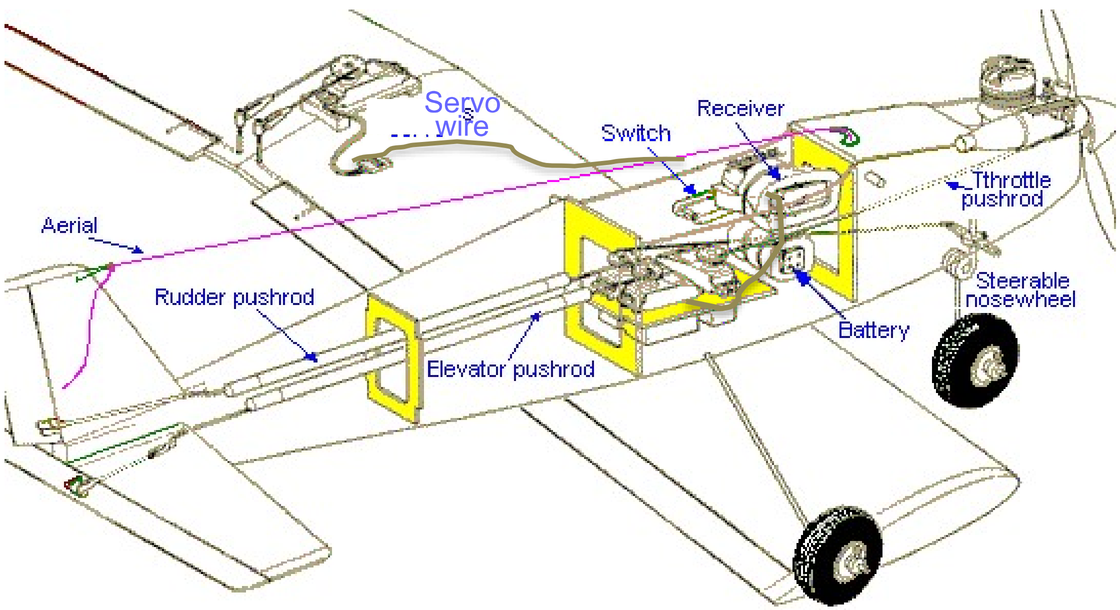
Mechanical Flight Control with Hydraulics



Fly-By-Wire Flight Control



Hobby RC Airplane and Quadcopters are FBW

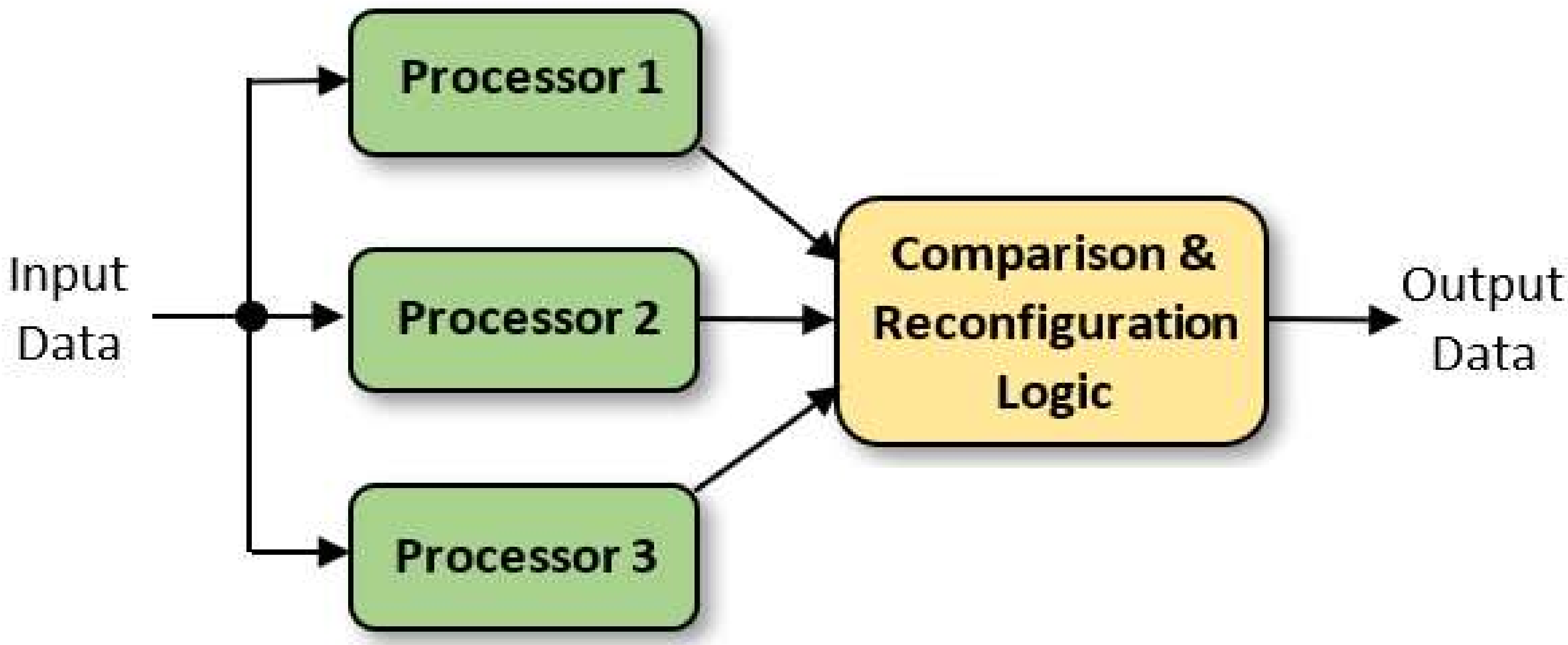


eVTOL Almost Have to be Fly-by-Wire

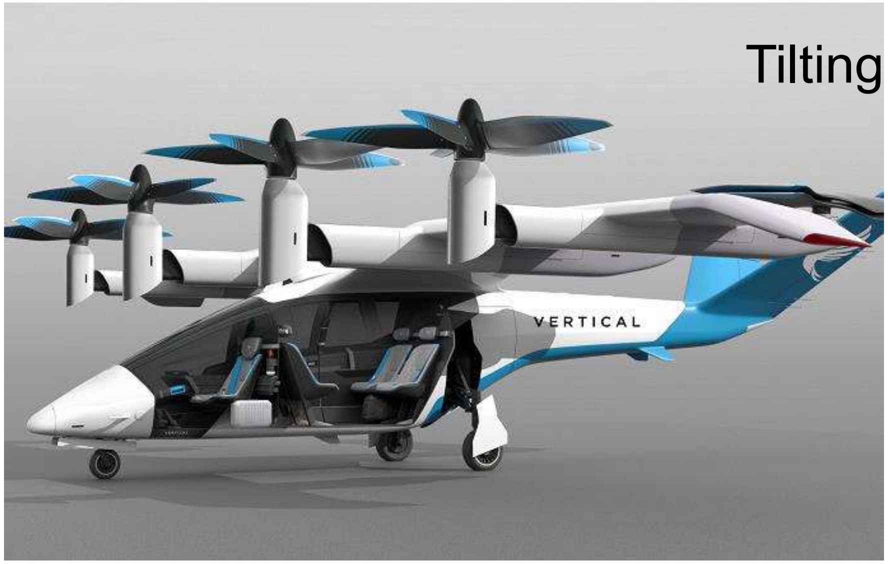
City Airbus

Vahana

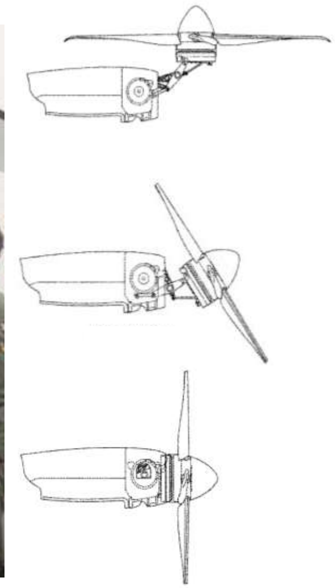
Use Triple and Quad Redundancy for FBW



Many eVTOLs Will Have Tilting Rotors or Wings



Tilting rotors



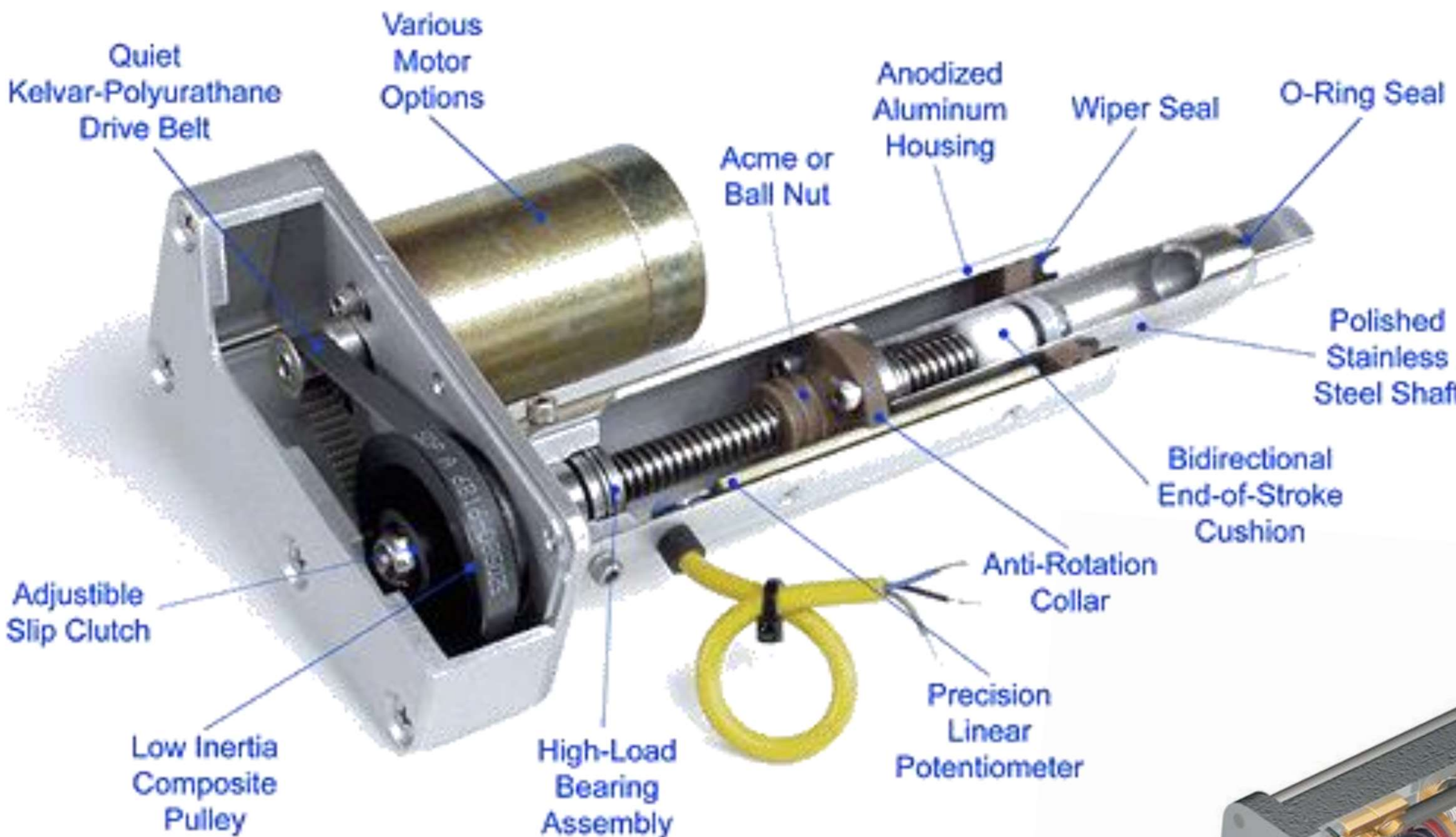
Tilting wing

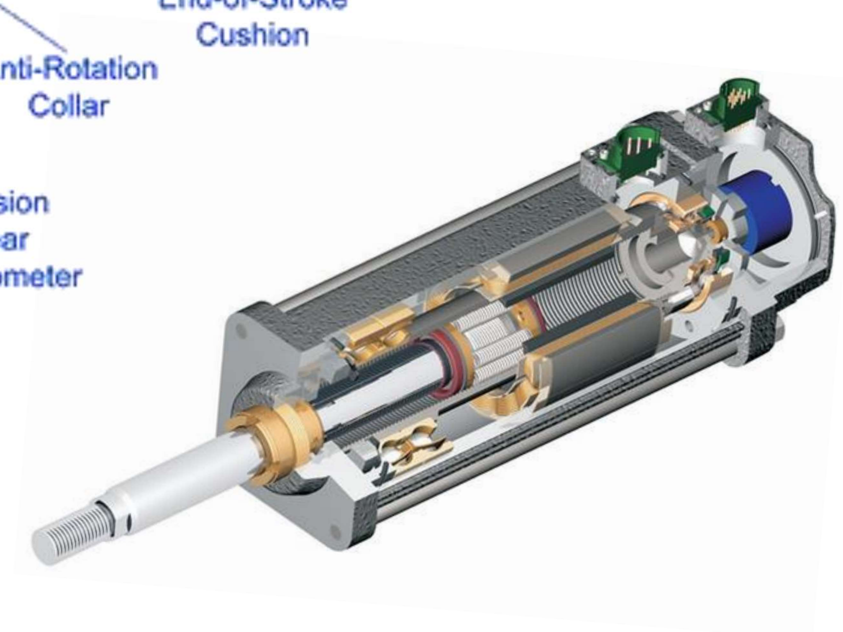
Only Two Civil Fly-by-Wire Rotorcraft Exist, Neither Received Certification Yet

AW609

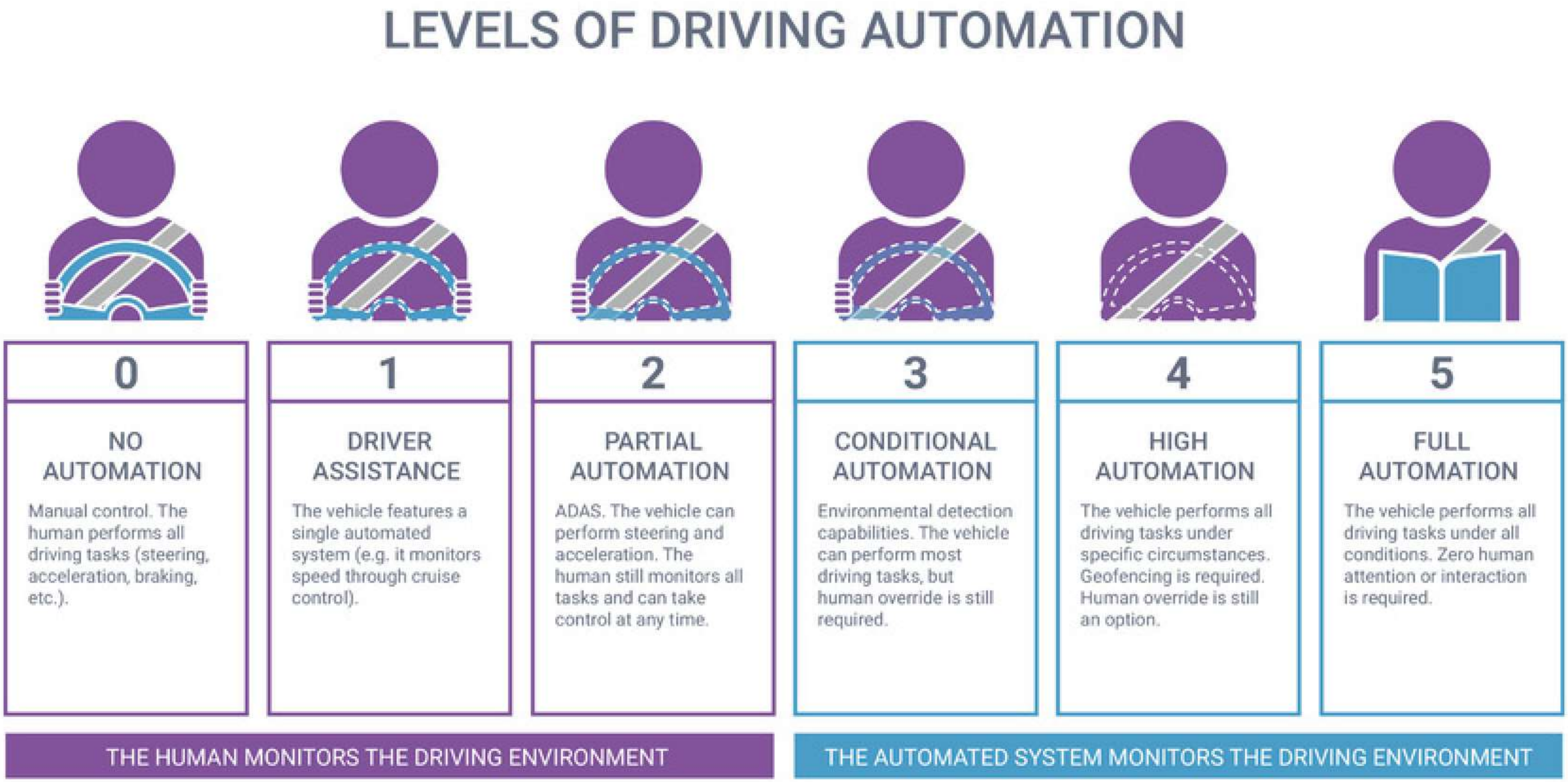
Bell525

Electro Mechanical Actuators (EMA) are New

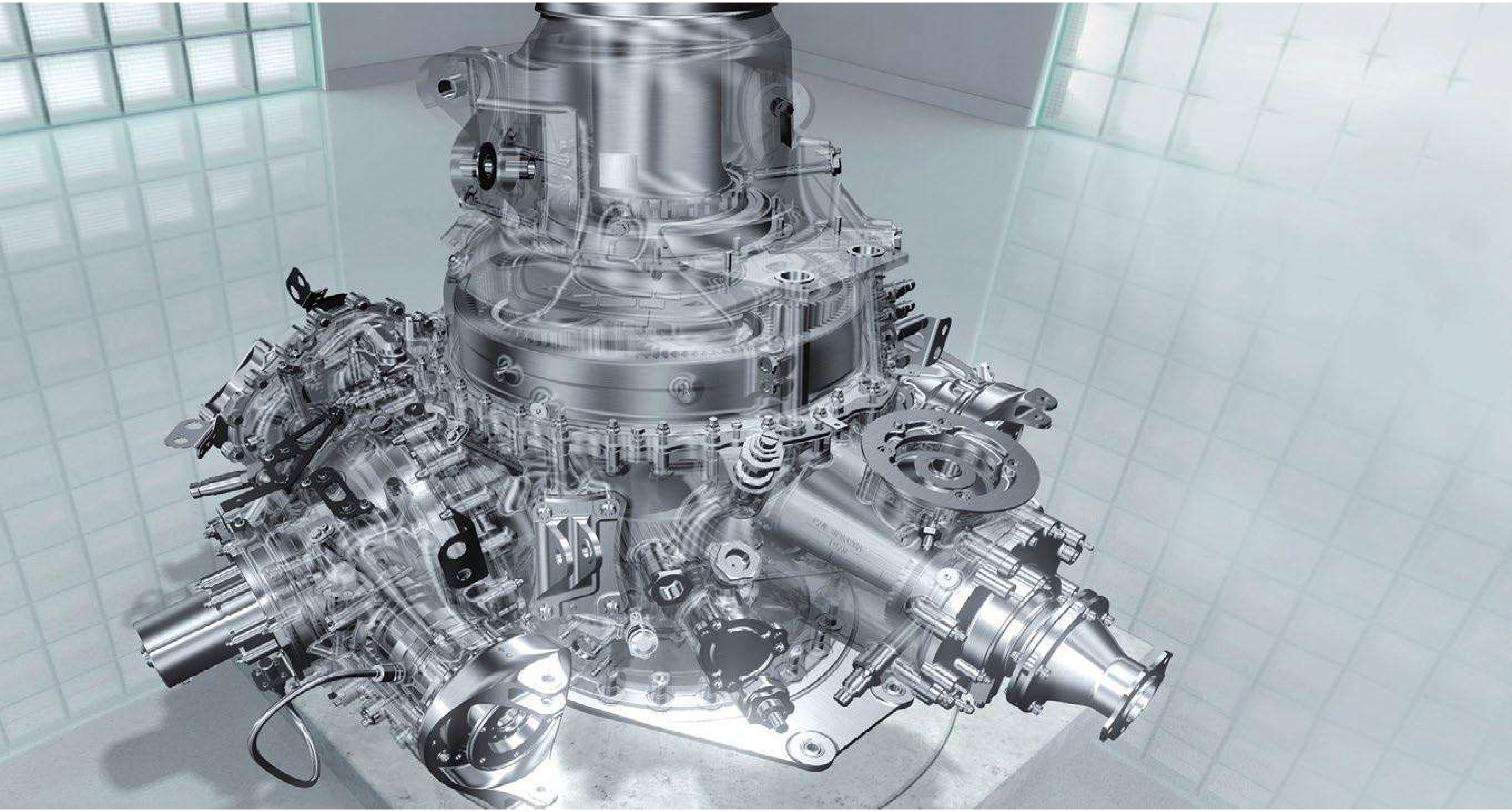




Most eVTOLs Aim to Achieve Level 5



Helicopter type gearbox is complex. It is required to run dry for 30 minutes

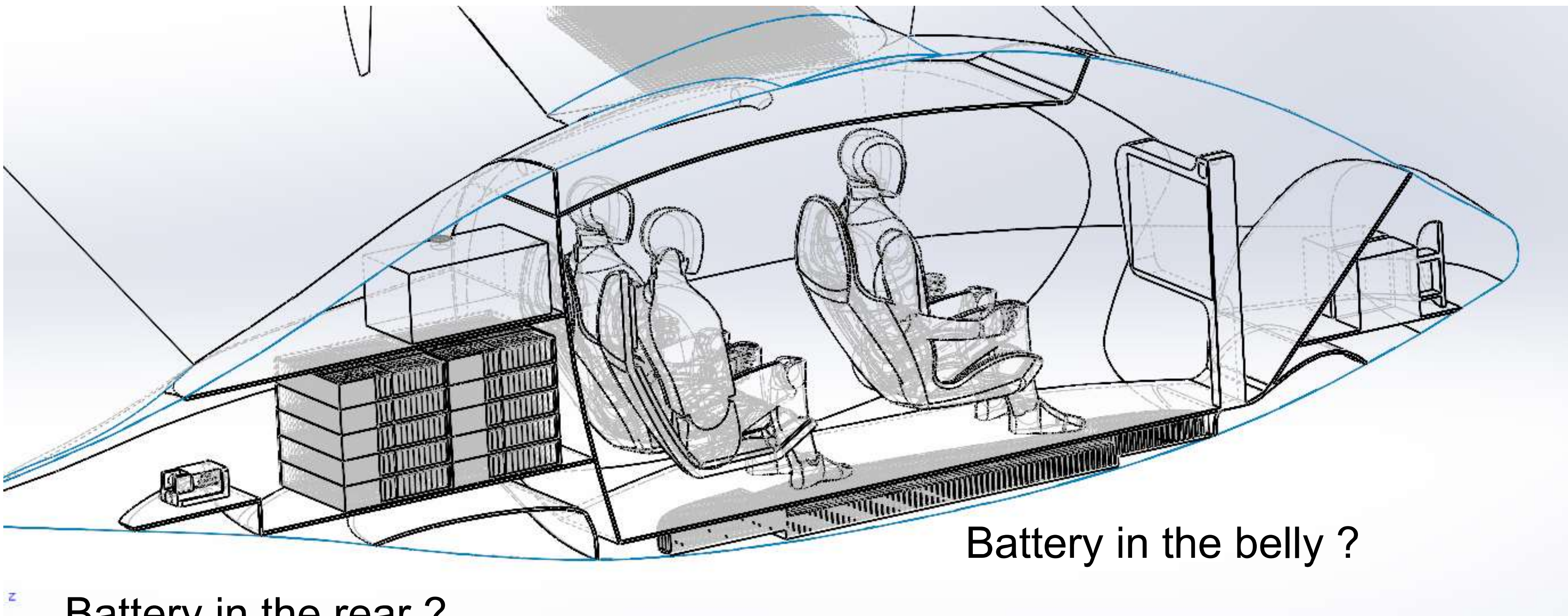


Direct Electric Drive Has Many Advantages

Crashworthiness

Battery fire is a concern. EASA says, must minimize the hazard to occupants caused by energy storage systems following an otherwise survivable impact (crash landing)

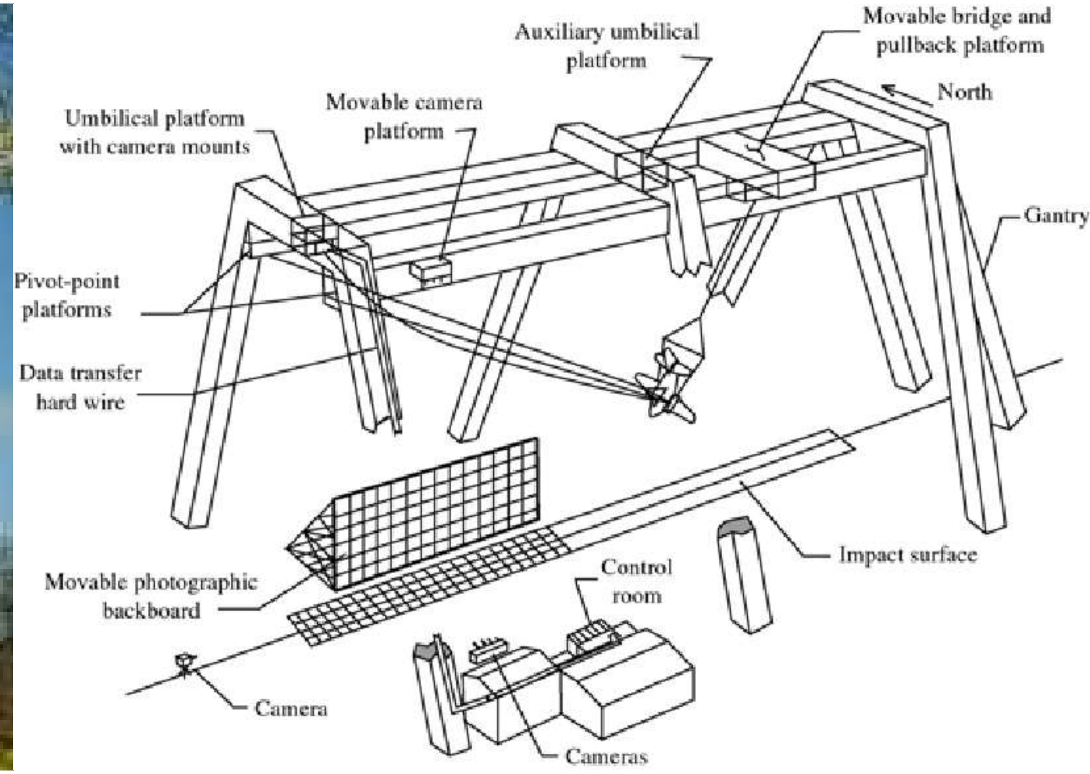
Battery in the wing ?

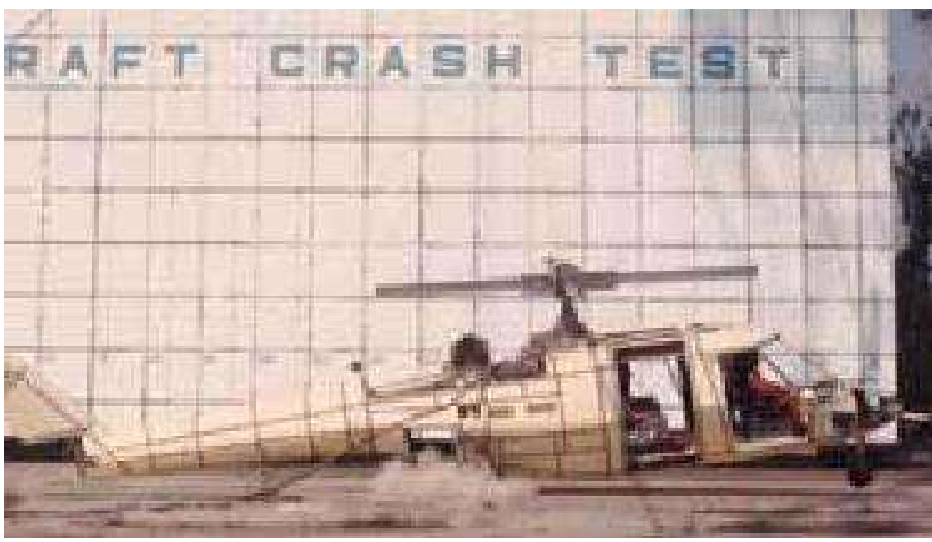


Battery in the belly ?

Battery in the rear ?

Fuselage Drop Test and Crash Test





Drop Test of Energy Storage System

- Drop height should be at least 15.2 m (50 ft).
- Should not lead to a fire, leakage of harmful fluids, fumes or gases.
- Any fire or leakage should be contained for at least 15 minutes in non-occupied areas and outside the evacuation path.

- For energy storage in the cabin:

  Upward – 4 g
  Forward – 16 g (18 g for CTOL)
  Sideward – 8 g
  Downward – 20 g
  Rearward – 1.5 g

For adjacent to cabin:

Upward – 1.5 g.
Forward – 12 g.
Sideward – 6 g.
Downward – 12 g.
Rearward – 1.5 g.

Electromagnetic Interference (EMI)

- EMI can cause interference with flight instrument and communication equipment
- Pay attention to putting wires in close proximity
- More attention required if going above 800 volts

Heat Buildup

- Electric motors and inverters can get very hot, 80 to 100 degree C
- A 3000 kg eVTOL can consume 1 to 2 MW of power in hover
- At 800 volts that is over 1000 amps of current
- Power wires can get hot if too small
- Cooling for motors, inverters and batteries? (liquid cool or air cool)

Emergencies

- Designer must decide automatic thermal shut down of inverter and motor at what temperature and current?
- Need fast acting fuses
- Consider separating the battery into different modules to drive different motors
- Can the aircraft glide? (having a wing becomes advantageous)
- Many eVTOL aircraft use lift/thrust rotor/motor for flight control, if motor stops means no direct controls (like multicopters)

- What happen if motors stop in hover? Ballistic parachute?
- Lithium battery fire suppression

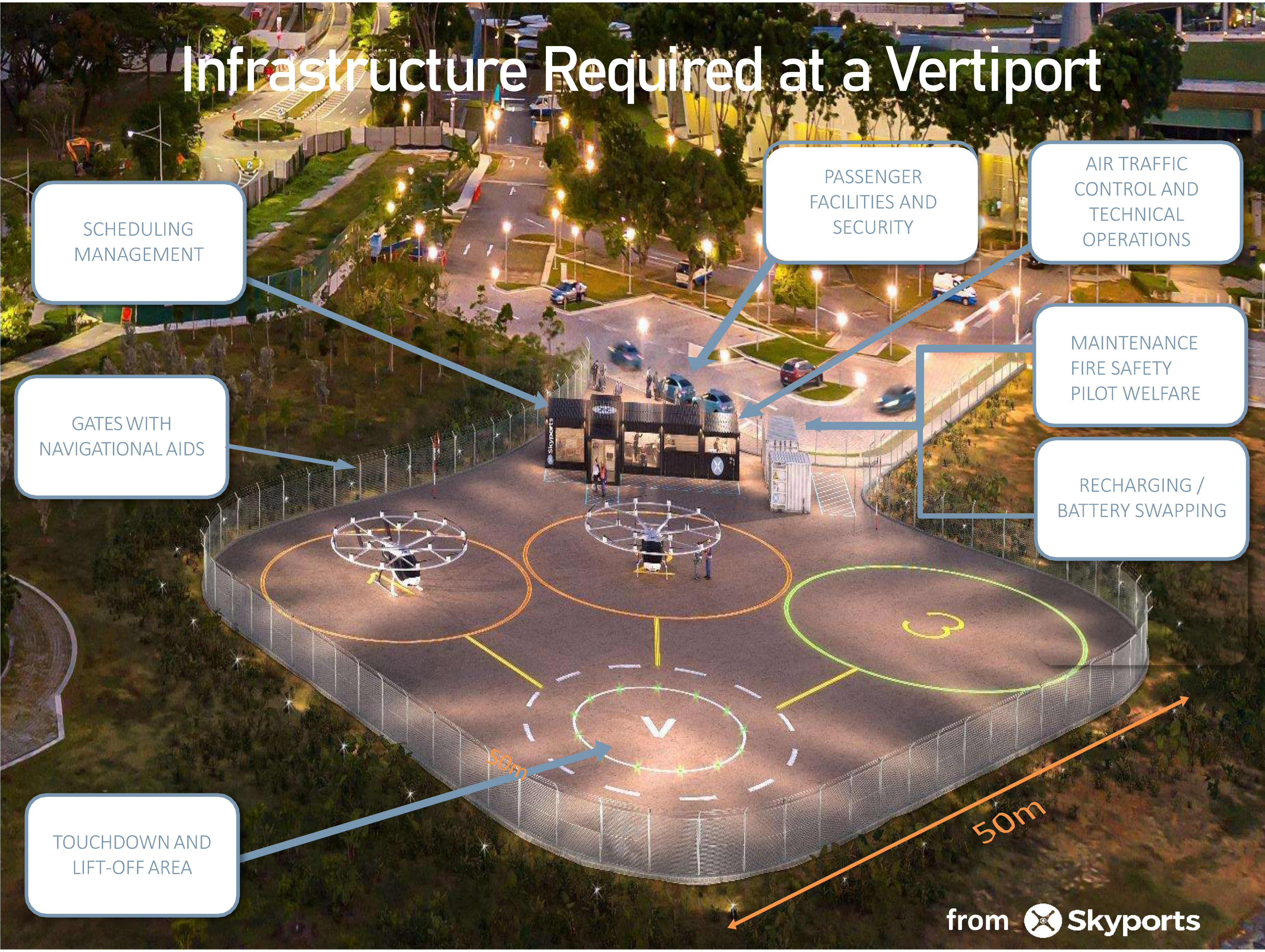
Other Considerations

- Acoustic noise
- Public acceptance
- Cyber security/hijacking
- Recycling of lithium batteries
- Integrating with other manned aviation and unmanned aircraft
- Private ownership

Vertiport Operation

Considerations for Designing a Vertiport

- Fit in the neighborhood/public acceptance
- Safe to fly in/out
- Compatibility with diverse eVTOL aircraft
- Adequate electric power supply
- Throughput per hour
- Connection to ground transports
- Passenger experience


Infrastructure Required at a Vertiport
SCHEDULING MANAGEMENT
PASSENGER FACILITIES AND SECURITY
AIR TRAFFIC CONTROL AND TECHNICAL OPERATIONS
MAINTENANCE
FIRE SAFETY
PILOT WELFARE
GATES WITH NAVIGATIONAL AIDS
RECHARGING / BATTERY SWAPPING
TOUCHDOWN AND LIFT-OFF AREA
50m
50m
from Skyports

Vertiport Requirements

There are several location and site considerations in the development of a vertiport. Skyports undertake extensive site analysis and work with the landlord to assess each site for suitability

BUILDING & ENVIRONMENT

- Available footprint
- Loading capacity
- Approach and departure paths
- Multi-modal connectivity
- Weather conditions

SERVICES

- Power grid access and capacity
- Passenger access

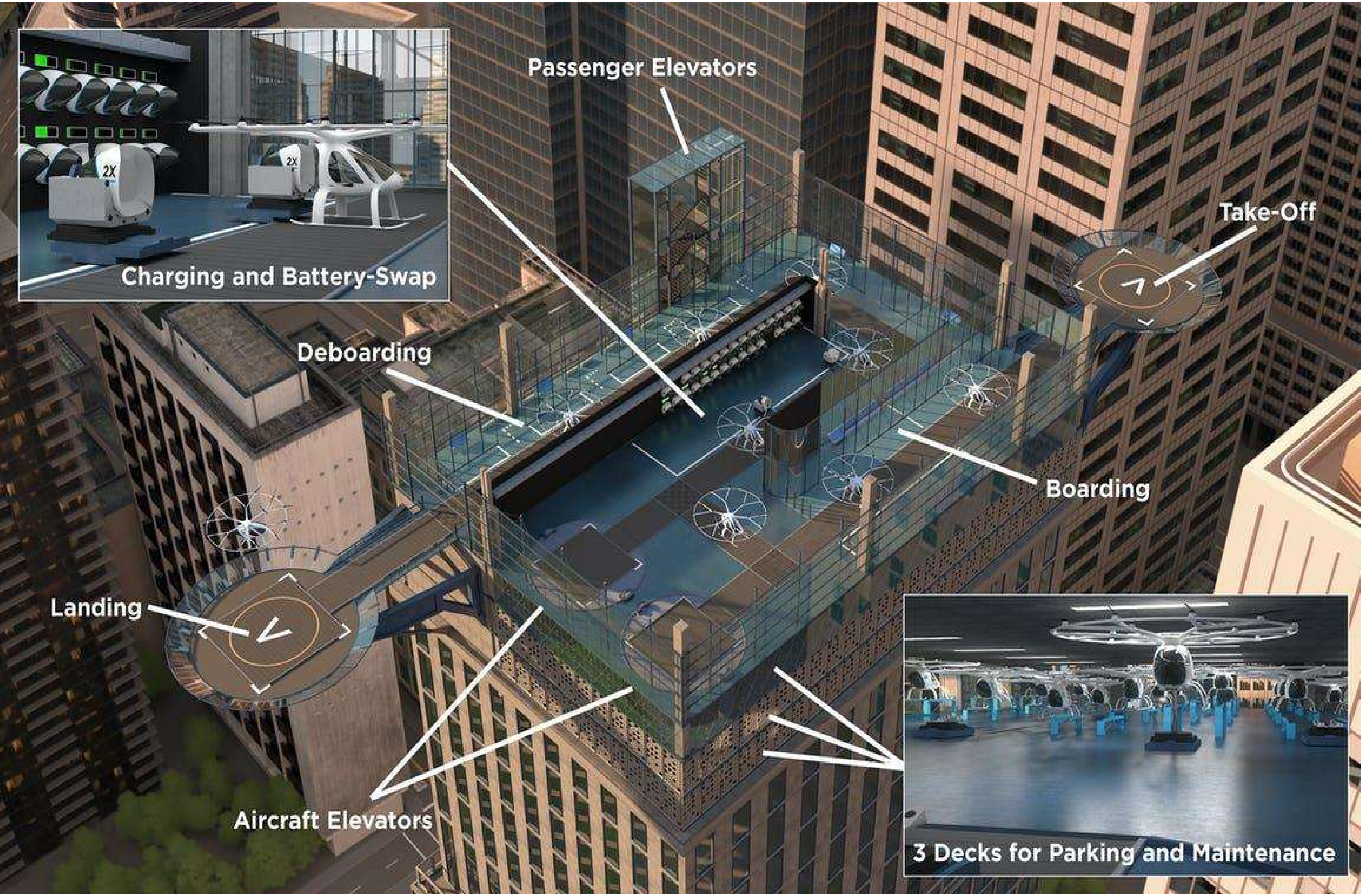
PLANNING & REGULATION

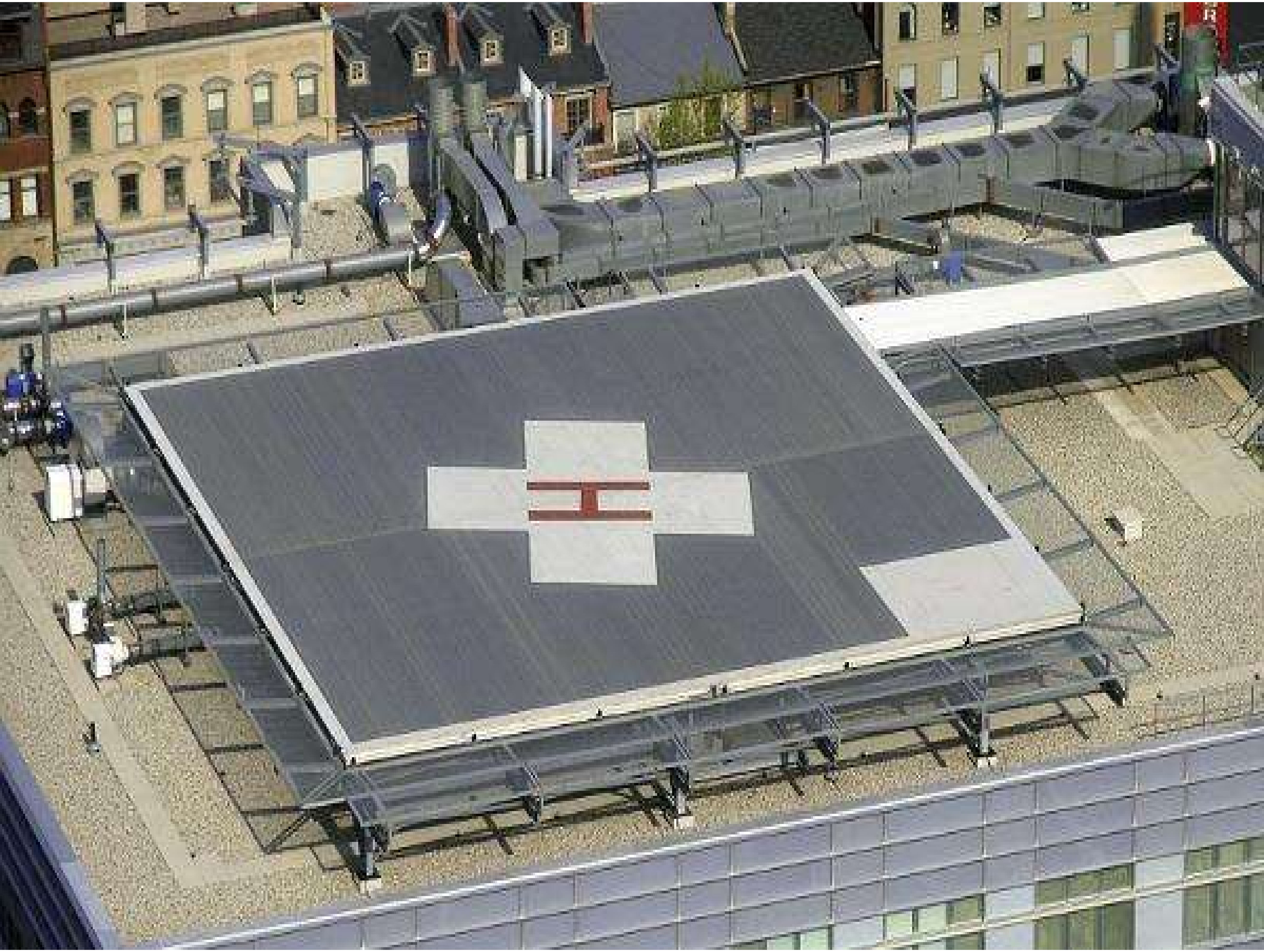
- Planning permission
- Aviation regulation approval
- Emergency services approval

COMMERCIAL VIABILITY

- Route & network analysis
- Passenger throughput & cash flow analysis

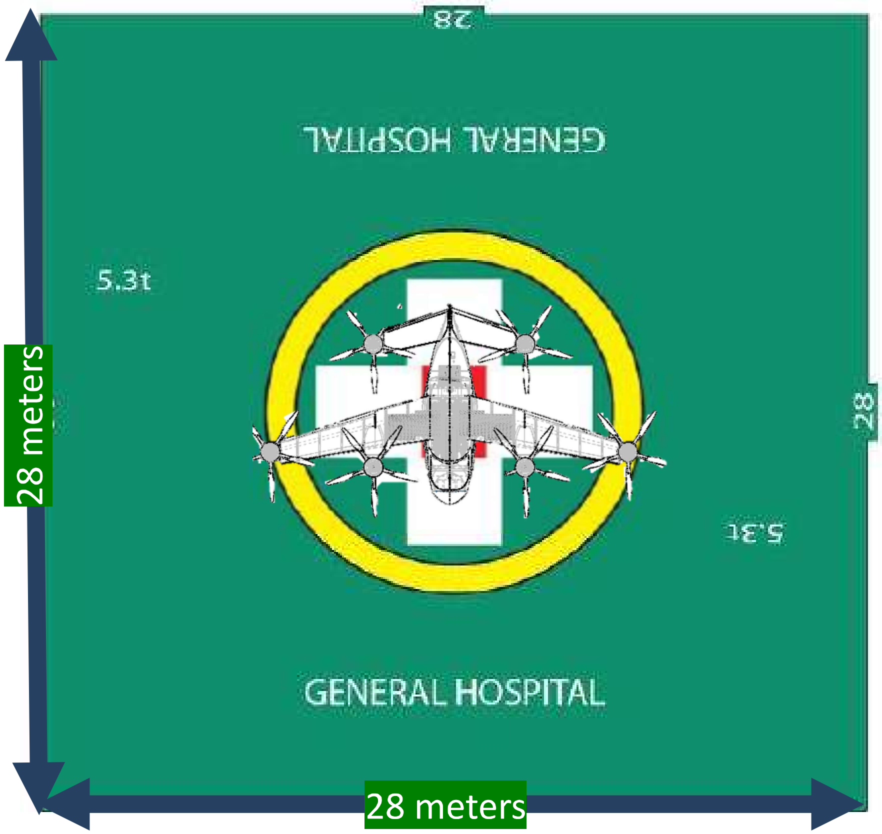
Roof Top Operation





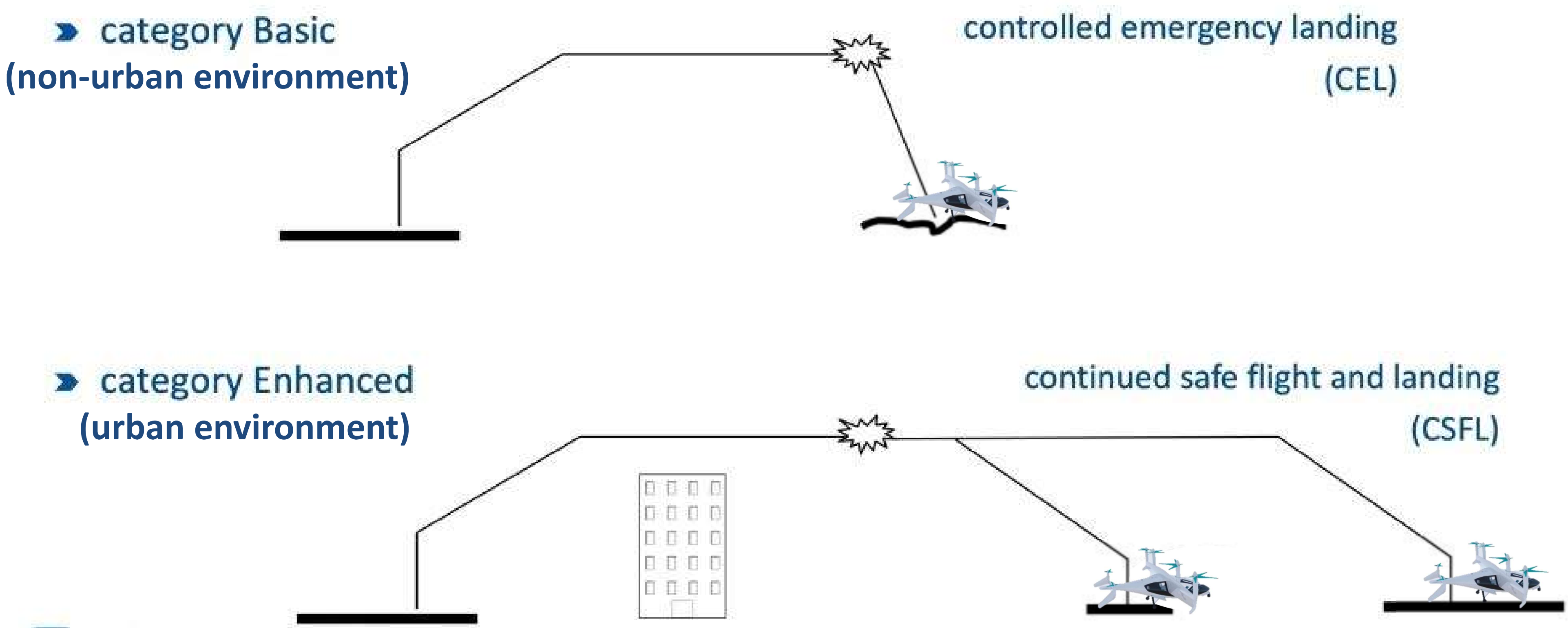
D-Value

Design to Fit Heliports and Vertiports



Type	D-value (m)	Rotor diameter (m)	Max weight (kg)	't' value
Bolkow Bo 105D	12.00	9.90	2400	2.4t
EC 135 T2+	12.20	10.20	2910	2.9t
H135 (EC 135 T3)	12.20	10.20	2980	3.0t
MD902	12.37	10.34	3250	3.3t
Eurocopter AS355	12.94	10.69	2600	2.6t
Bell 427	13.00	11.28	2971	3.0t
Agusta A119	13.02	10.83	2720	2.7t
H145	13.03	11.00	3585	3.6t
Agusta A109	13.05	11.00	2600	2.6t
Bell 429	13.11	10.98	3175	3.2t
BK117D2/EC145T2/H145	13.63	11.00	3650	3.7t
Dauphin AS365 N2	13.68	11.93	4250	4.3t
eVTOL	**13.0 m**		**3175**	**3.2t**

Category Basic vs Enhanced



Source: https://rotorcraftvtolsymposium2021.eu/

Catastrophic Definitions

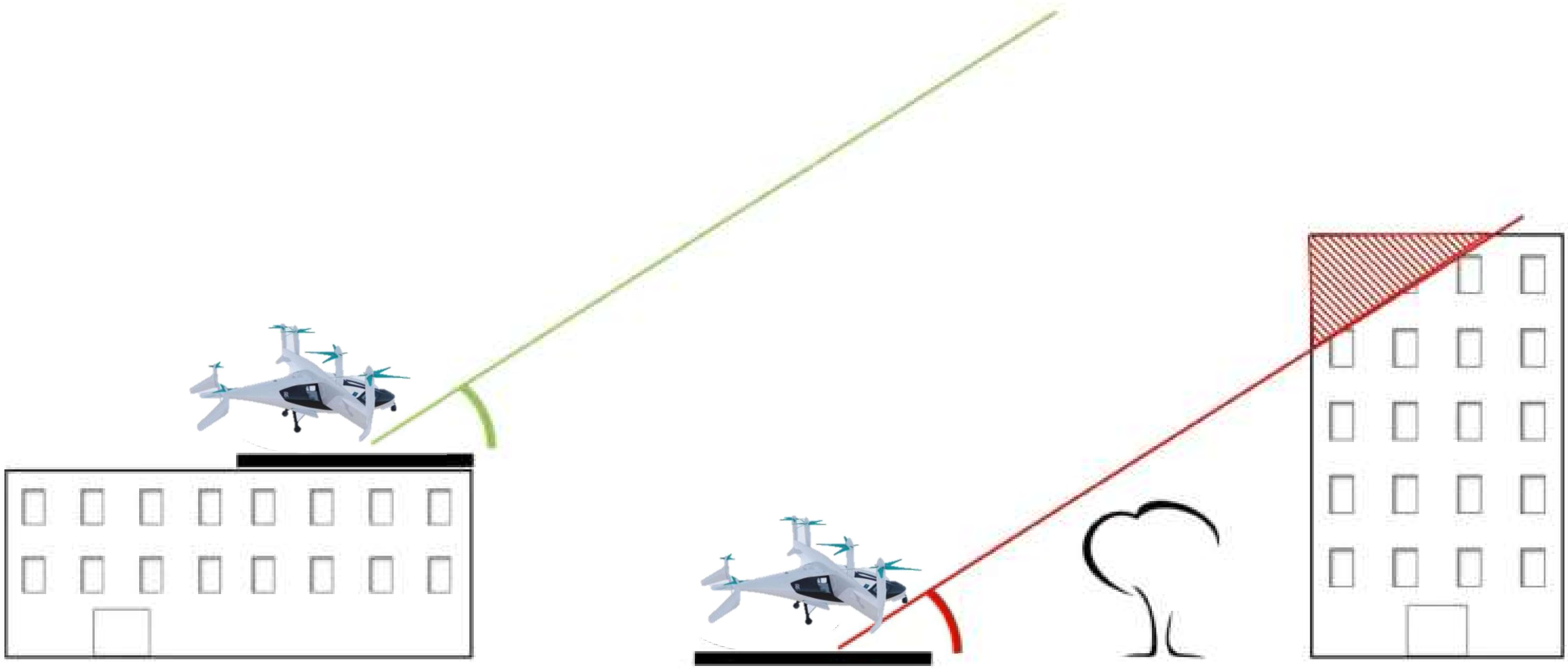
- current definitions for Catastrophic (AC27-1B):
  - "an event that could prevent **Continued Safe Flight and Landing"**
  - "means the **inability to conduct an autorotation** to a safe landing"
  - "any structural failure, which results in **death, severe injury**, or loss of the aircraft"
  - "Hazardous: Adverse effects on occupants, including serious or potentially **fatal injuries, to a small number** of those occupants."

- VTOL definitions for Catastrophic

category	failure causing	failure preventing
Basic	multiple fatalities	controlled emergency landing
Enhanced	one or more fatalities	continued safe flight and landing

Source: https://rotorcraftvtolsymposium2021.eu/

VTOL Trajectories and Vertiports

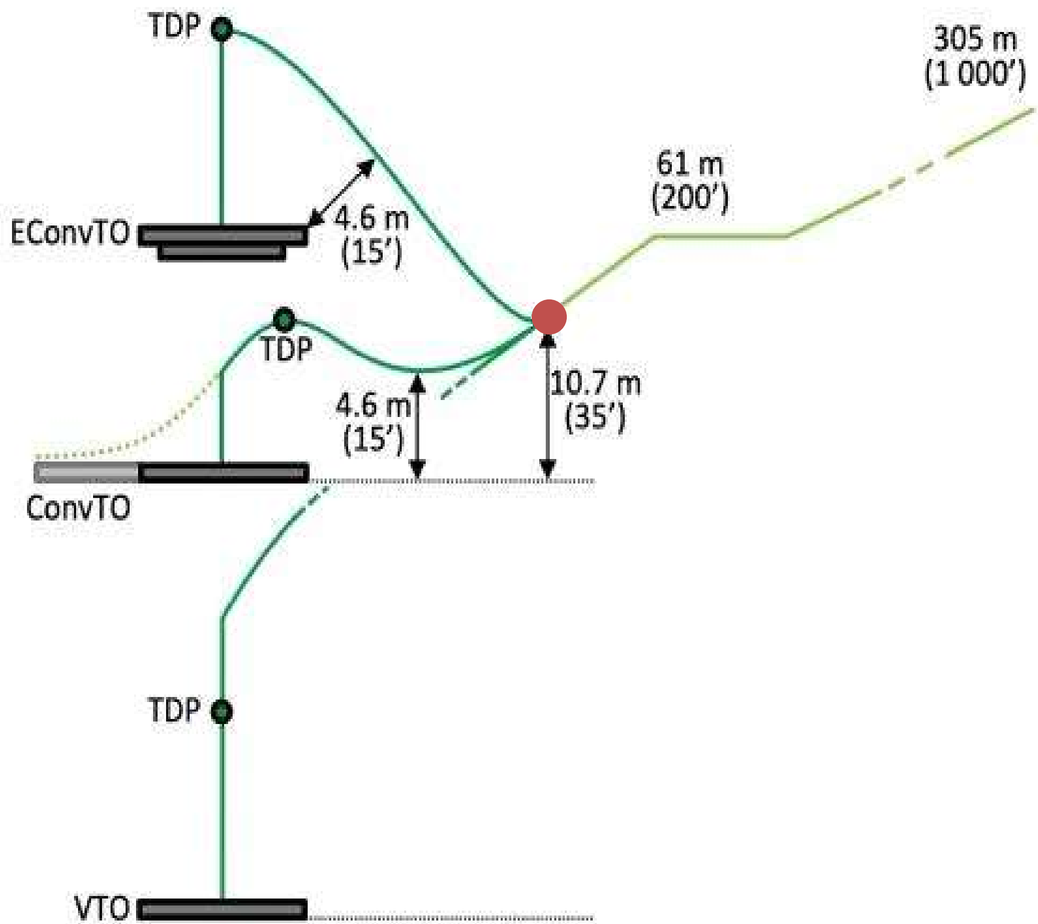


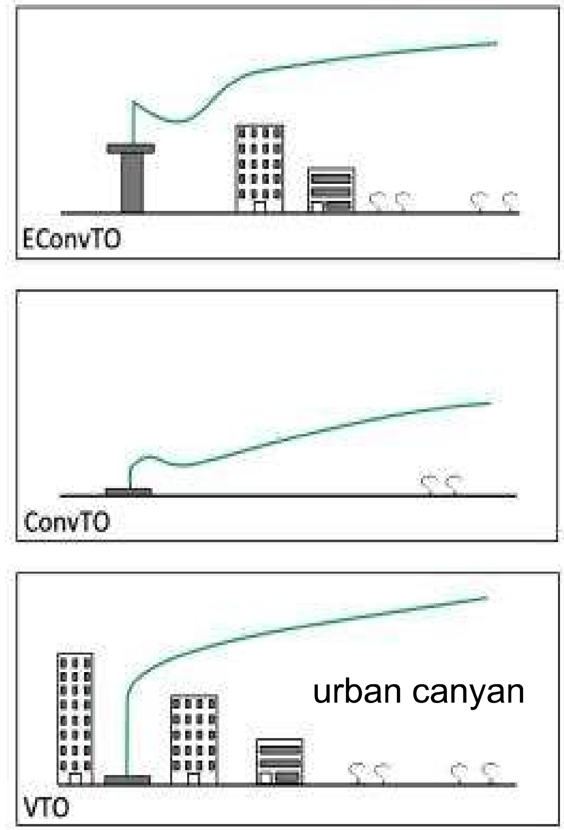
Taking off from rooftop

Taking off from ground

Source: https://rotorcraftvtolsymposium2021.eu/

Three Take-off Profiles





EConvTO = Elevated conventional takeoff

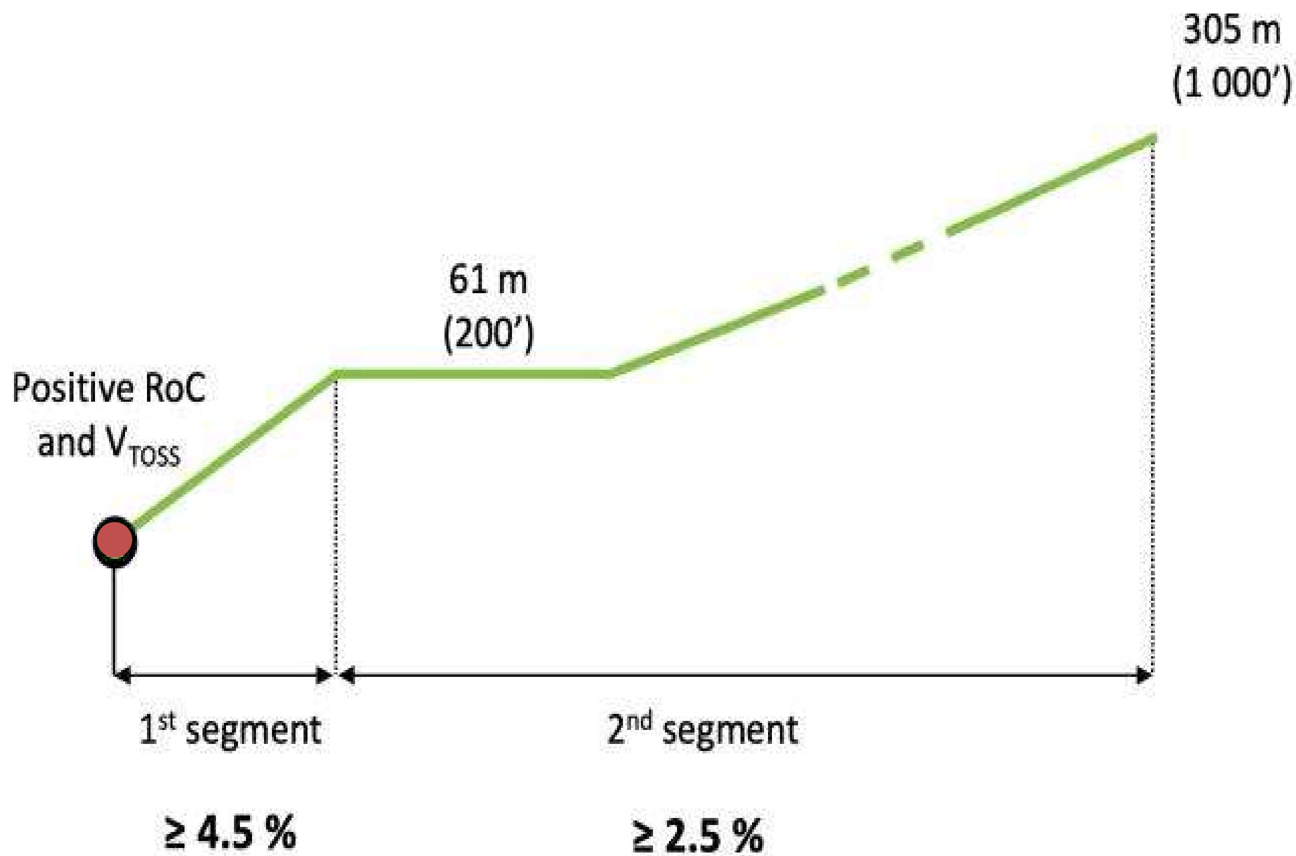
ConvTO = conventional takeoff

VTO = vertical takeoff

TDP = takeoff decision point

Source: https://rotorcraftvtolsymposium2021.eu/

Takeoff Profile



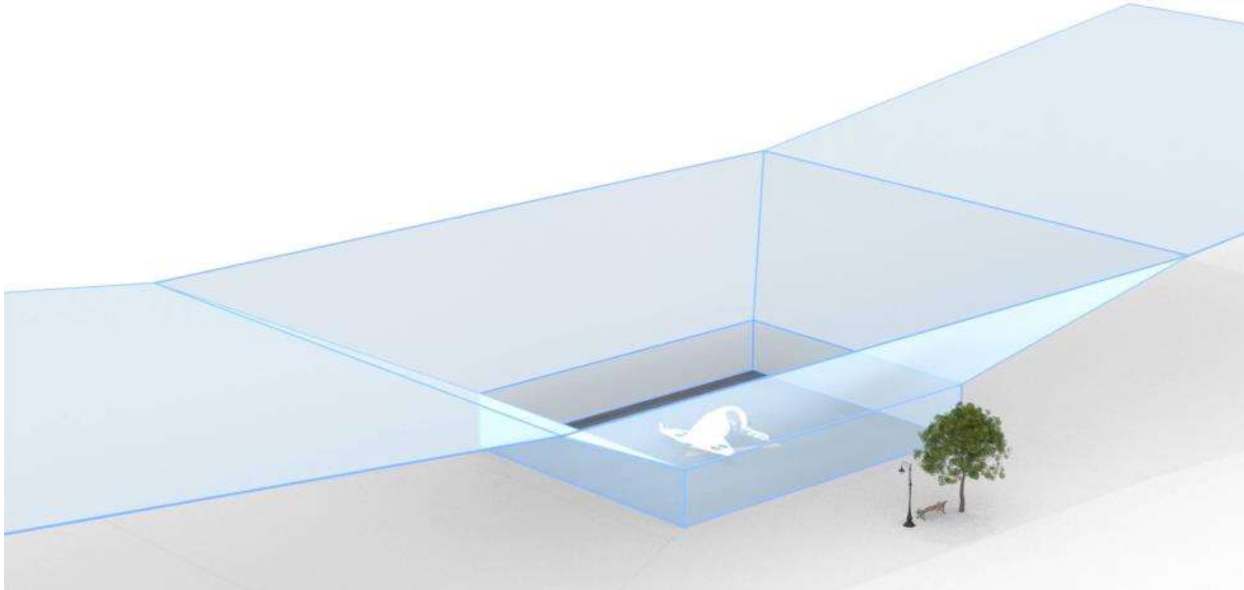
V_{TOSS} = vertical takeoff safety speed

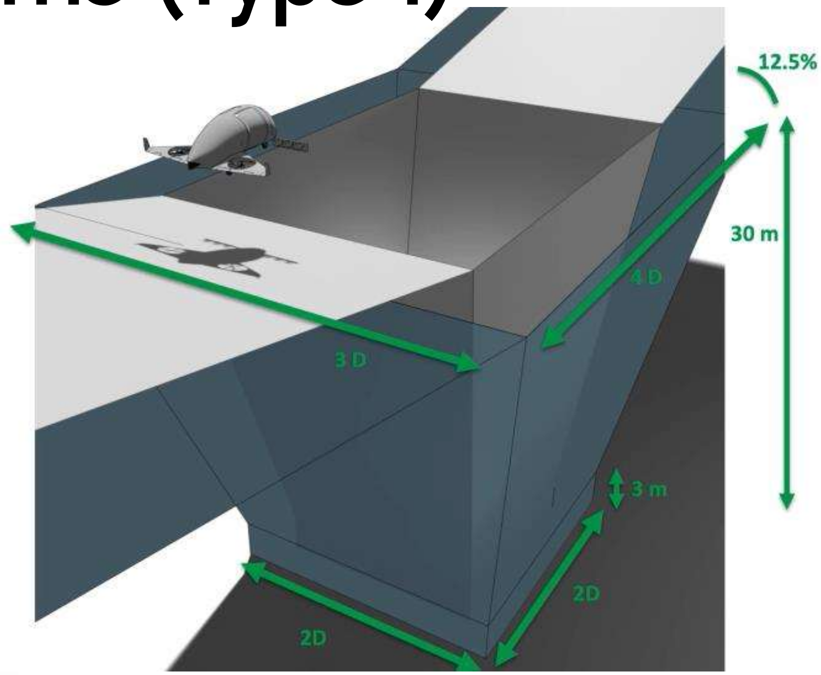
RoC = rate of climb

4.5% and 2.5% = climb gradient

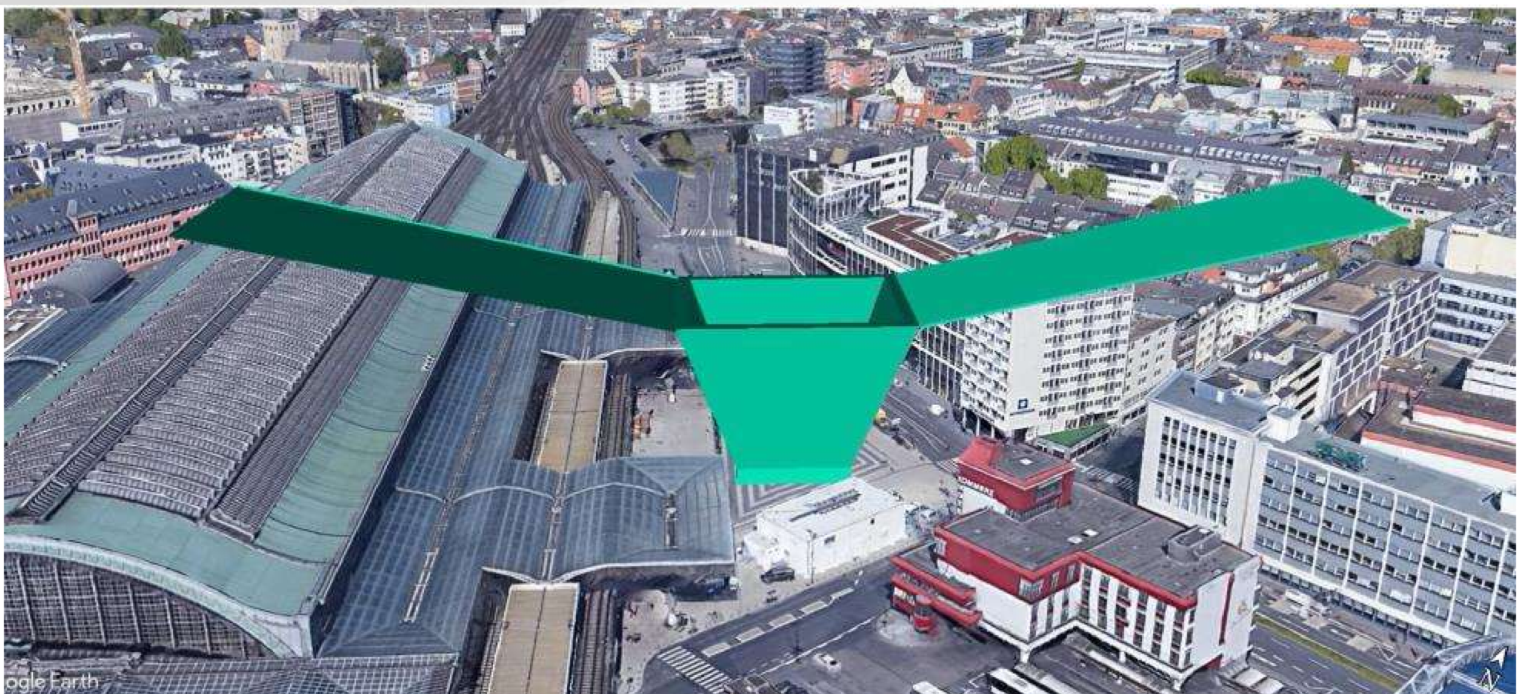
Source: https://rotorcraftvtolsymposium2021.eu/

Recommended Takeoff Volume (Type 1)





D = D-value



Source: https://rotorcraftvtolsymposium2021.eu/

8. Certification and Vertiport Operation

by Dr. James Wang

SNUevtolclass@gmail.com