Vertical Take-off and Landing (VTOL): Emerging and Transformational Capabilities

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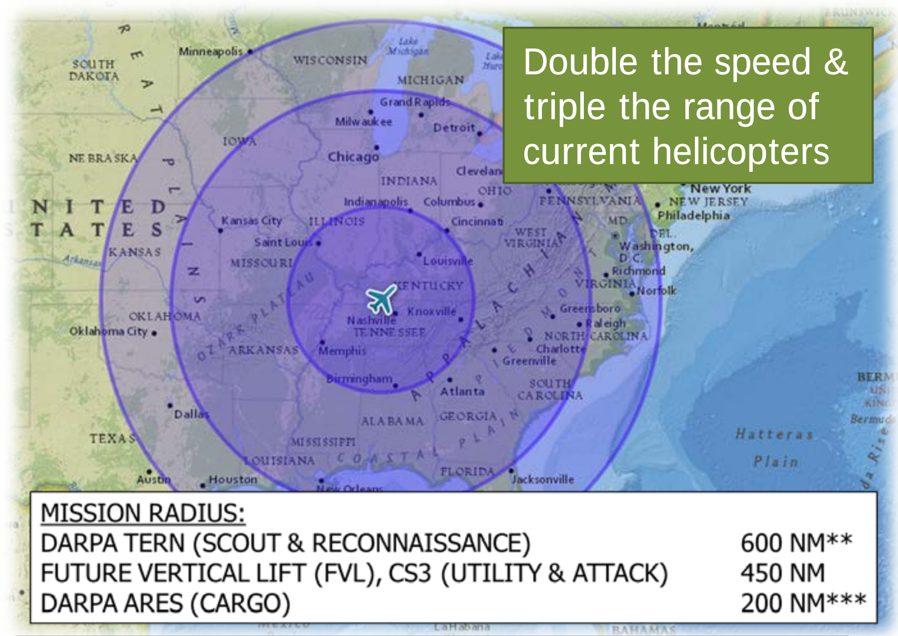
Transformation in VTOL

Civil: Revolutionary Urban Mobility

* Uber Elevate. Fast Forwarding to a Future of On-Demand Urban Air Transportation. Oct. 27 2016.

Defense: Multiplication of Tactical Reach



<u>MISSION RADIUS:</u>

DARPA TERN (SCOUT & RECONNAISSANCE)	600 NM**
FUTURE VERTICAL LIFT (FVL), CS3 (UTILITY & ATTACK)	450 NM
DARPA ARES (CARGO)	200 NM***

** TERN radius with 500 lb payload, 2 aircraft provide continuous coverage
*** ARES cargo delivery radius with a 2,000 lb payload

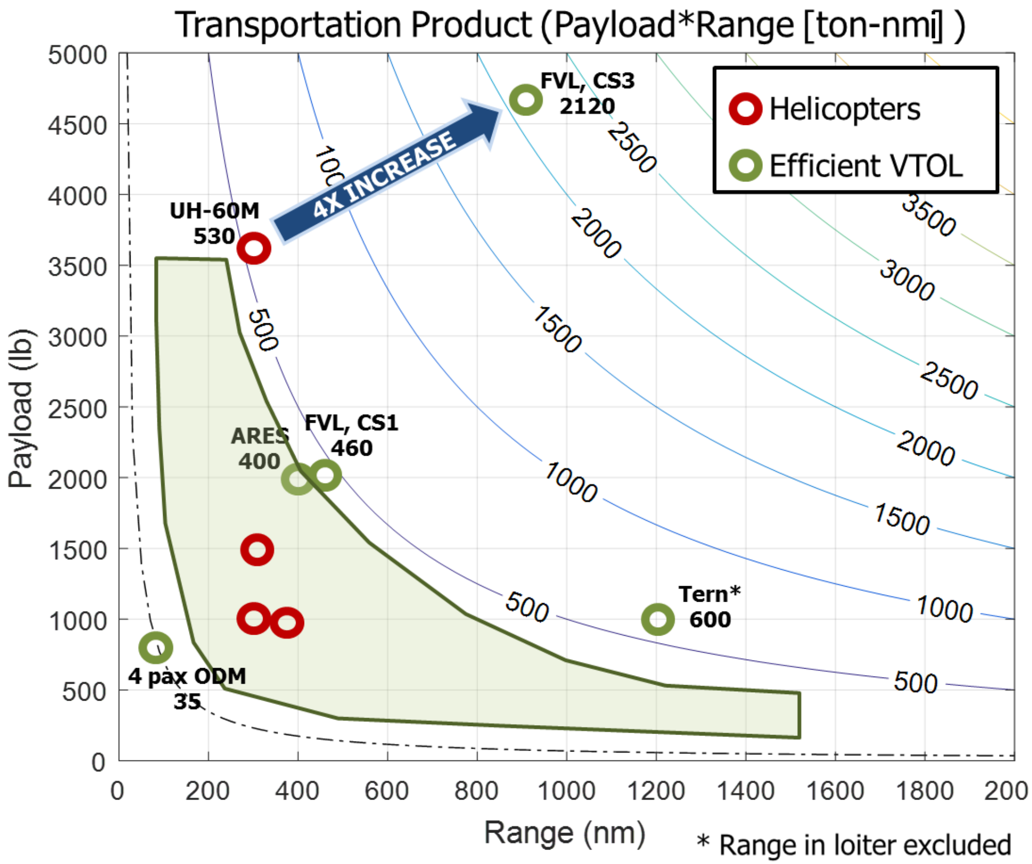
Urban
Efficiency: ¢/mile
Safety
Capacity

AIR VEHICLE
AUTONOMY

Expeditionary
Efficiency: ton-nmi/lb_{fuel}
Survivability
Capacity

Contrasting use cases drive common technologies.

Leaps in VTOL Efficiency



Efficiency enables delivery of increased payload-range with equal or reduced energy consumption.

On-demand mobility (ODM) is driving development of efficient VTOL below 40 ton-nmi.

Military is driving development of efficient VTOL above 400 ton-nmi.

Range Equations:

$$R = k\,\frac{{}^{L}/_{D}\,\eta_p \eta_t}{SFC}\,\ln\left|\frac{1}{\%W_L + \%W_{PAY}}\right|,$$

Or

$$R = k\,{}^{L}/_{D}\,\eta_p \eta_t * D_{batt} * (1 - \%W_L - \%W_{PAY})$$

Regardless of propulsion system, efficient VTOL aircraft share common terms:

$${}^{L}/_{D}\ , \eta_p, \%W_L$$

$$\%W_L = \frac{W_{OWE} + W_{reserve}}{W_{TO}}$$, includes crew

Development of mid-sized efficient VTOL aircraft could fill military and commercial needs.

But, we need:

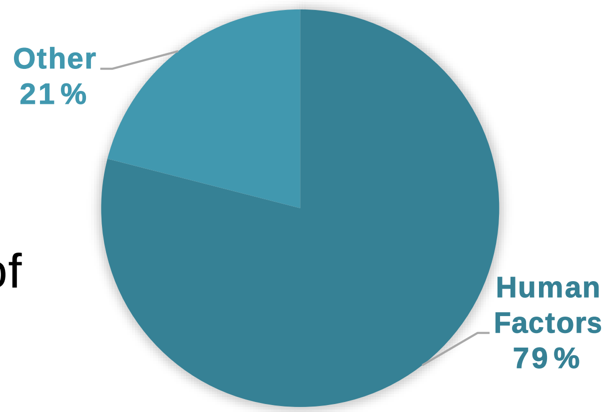
$${}^{L}/_{D}\,\eta_p \eta_t \gg \text{helicopter}$$

$$\%W_L \ < \text{helicopter}$$

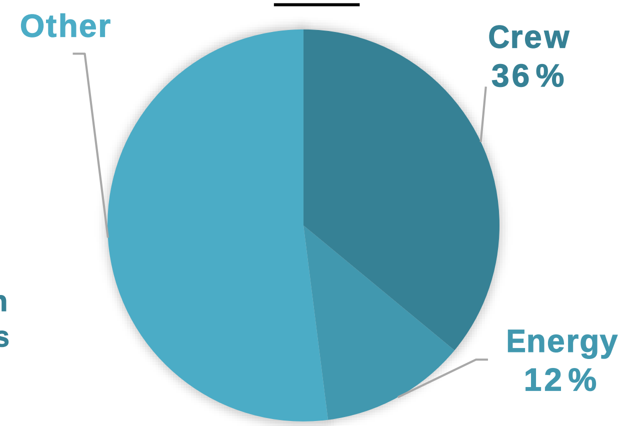
Autonomy Is a Critical Enabler for VTOL

Safety
Human factors attributed for 79% of rotorcraft fatalities[1]

Military



Civil



Costs
Direct operating costs of pilots are triple the costs for energy in ODM[2]

1. Dramatically reduce mishaps and fatalities
2. Enable routine operation in nearly all weather conditions
   Remove burden of following instrument flight rules
3. Address pilot costs, training overhead, and pilot shortages
   2 pilots ⇨ 1 pilot onboard ⇨ 0 onboard
4. Routine operation to/from small and uncontrolled areas

Airlines achieve for airport to airport ops.

Multiple programs are demonstrating significant advances

1. Couch, Mark and Lindell, Dennis. Study on Rotorcraft Survivability. Presented at the American Helicopter Society 66th Annual Forum, Phoenix, AZ, 10-13 May 2010.
2. Uber Elevate. Fast Forwarding to a Future of On-Demand Urban Air Transportation. Oct. 27 2016.

Path to Certification for Autonomous VTOL

Employ processes that achieve appropriate level of safety, and retain a means of compliance for advanced technologies:

- Planning / mapping algorithms
- High speed computing
- New sensors

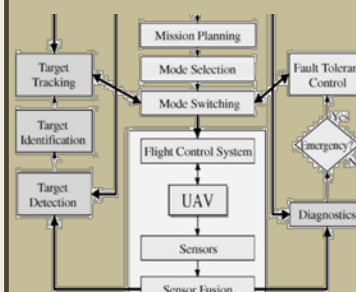
Design autonomy architectures that consider certification from concept stage:

- Hardware redundancy
- Software level of assurance
- Sensor performance (obstacle avoidance, sense and avoid, vehicle proximity, etc)
- Navigation performance
- Human machine interface

Ensure an efficient means for growth and improvement without significant re-investment.

Certification is the next major step for transition to military and civilian operations in platforms rated for human occupancy.

2005



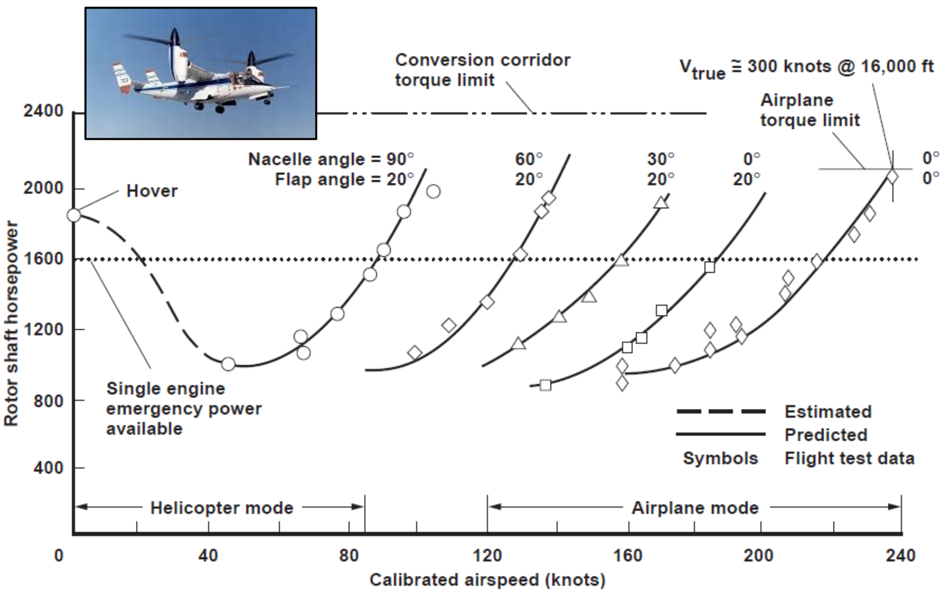
DARPA Software Enabled Control

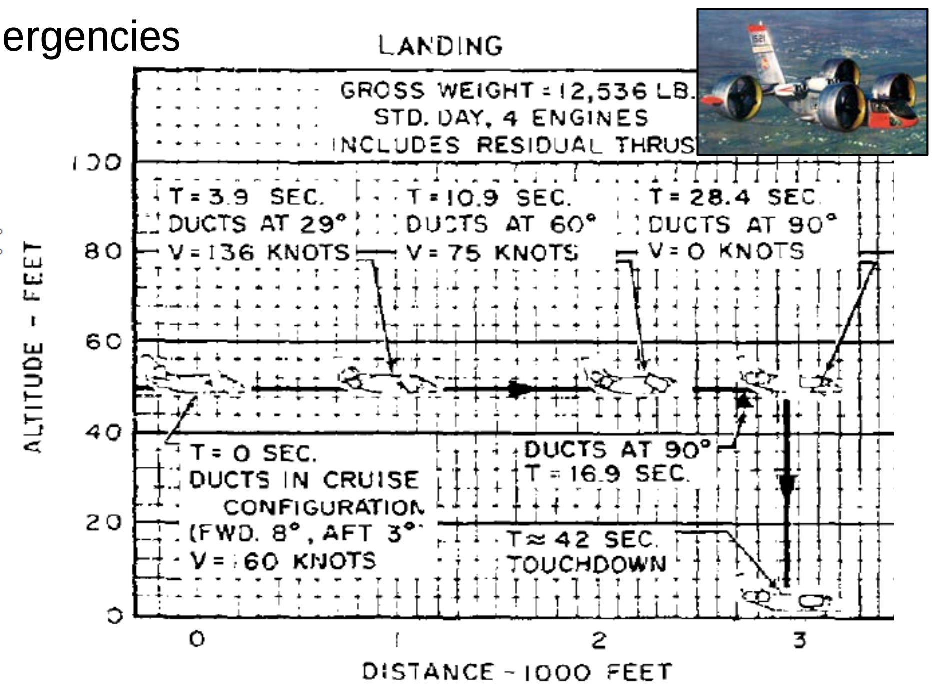
2017

DARPA ALIAS, ONR AACUS

Design for Conversion

- Efficient VTOL aircraft must convert from hovering flight (T=W+margin) to cruise flight where P<< W*V/4.
- Low-speed maneuvers include approaches, go-arounds, aborted take-offs, and descents as well as failures (engine, motor, power bus, tilt actuator, etc)
- Wheeled landing gear bypasses conversion
  - Rolling take-offs and landings may be very short, and consume less energy
  - Rolling landings provide options in emergencies





Modelling of the aircraft dynamics, trim, and loads through the conversion corridor is essential early in the design process.

Summary

- Military and commercial VTOL industries are developing and flying demonstrators at an incredible pace.
- Autonomy is central to both use cases.
- Certification of more autonomous, new air vehicles is the next step for both use cases.
- **The momentum and common interest provides an incredible opportunity for advancement.**

A few civil VTOL demonstrators:





Military VTOL demonstrators with recent or imminent first flights:





www.darpa.mil