



PAVE
PERSONAL AIR VEHICLE EXPLORATION

REVOLUTIONARY AEROSPACE SYSTEMS CONCEPTS

Personal Air Vehicles Lessons Learned

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No ITAR Restrictions - Public



What's Changed in 10 Years

Cockpit Avionics

Navigation

Communications



Garmin G300

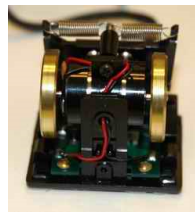


Cessna SkyCatcher

Digital Sensors and Systems

Vehicle Intelligence

Control



Prior generation mechanical gyro vs.
Current piezo crystal miniaturized gyro
(smaller, lighter, less power, reliable, cheap)

Electric Motors/Controllers

Scale-Free Power

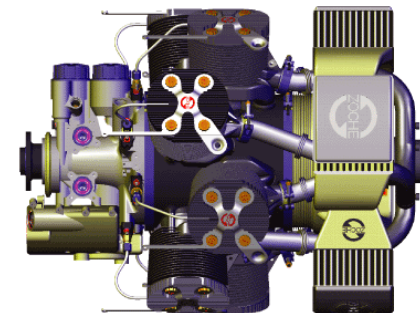
Distributed Power Solutions



Heavy Fuel Engines

Small Turbines

Lightweight IC Engines



Highly Coupled Aero-Propulsive-Control Analysis



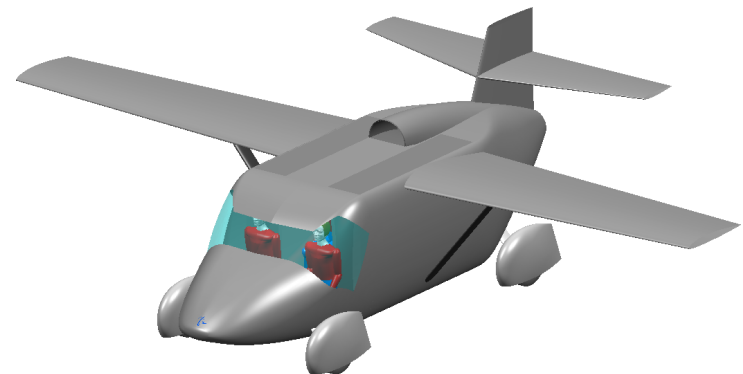
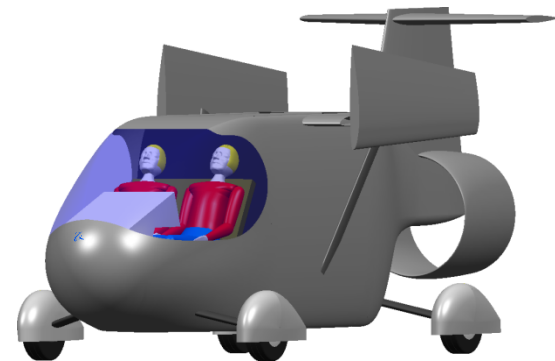
Noise Can't Be Wished Away

Dual Air-Road VTOL Concept Study, 2002

MD500 NOTAR-based Concept



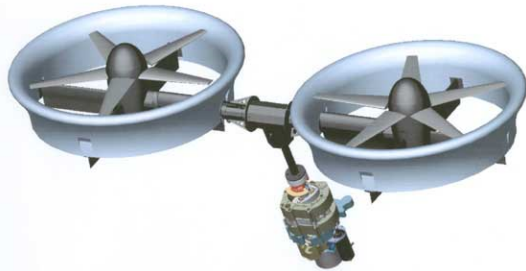
Pulsed Ejector Thrust Augmentor (PETA) Concept



Not All Ducts are Created Equal

DARPA SoloTrek VTOL Demonstrator, 2004

Disc loading $\sim 35 \text{ lb/ft}^2$
Thrust / HP $\sim 7.6 \text{ lbf/hp}$



NASA Tailfan
Low Noise
Duct, 2006



Tilt-Nacelle VTOL Concept Study, 2004

Cruise and Hover Nacelle Shape Mismatch

A photograph showing the interior of a vehicle, likely a truck or van, with two seats and a window. The seats are dark-colored with light-colored stitching. The window is on the left side of the frame, showing a view of the outside world. The interior is dimly lit, and the seats appear to be made of a durable material like vinyl or leather.

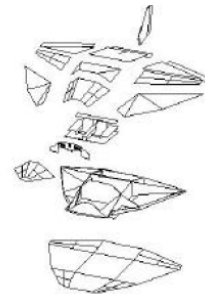
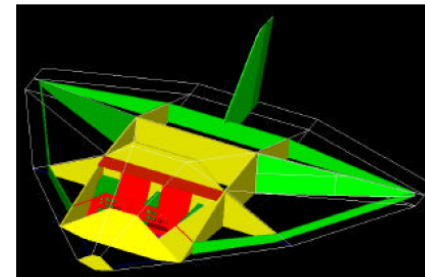
-
- L.E. Blowing
- T.E. Exhaust Blowing
- Intake
- Gas Generators
- Tip-Driven Fan
- blade Exit Mach Number
- Rotor/Stator Spacing
- Fan Tip S
- Cruise CC blowing inward
- Hover CC blowing outward
- Virtual diffuser area



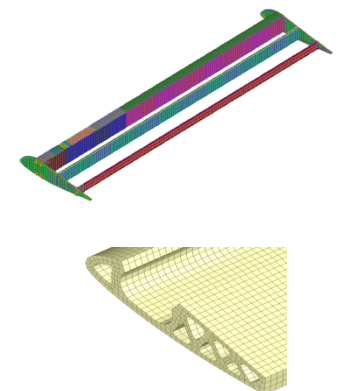
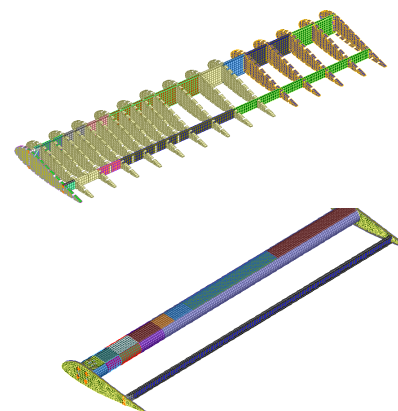
Quantity Has a Quality of It's Own

Design for Affordability, Tailfan Study, 2005

- Lean design to reduce touch labor
- Designed for automated manufacturing (higher production volumes than typical aircraft production)
- Use of COTS products
- Extensive use of symmetry for reduced parts count
- Simplified concepts for minimum gage structures
 - Foam core composite
 - Honeycomb composite
 - Spanwise and chordwise beading to achieve skin-stiffened structures



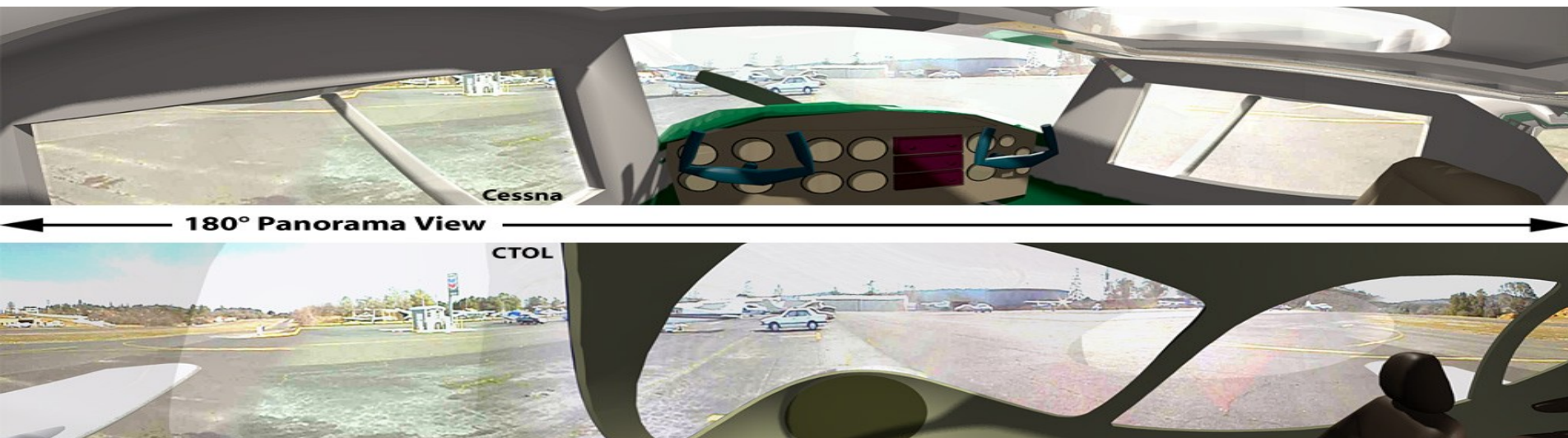
NASA STTR Facetmobile Conceptual Study

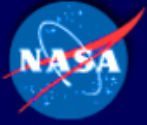


Don't Forget the Ilities

Many other factors

- Visibility critical for safe VTOL operations
- TO/Landing footprint
- Ground personnel safety
- Cabin environment NVH
- CG variability
- Mission flexibility
- Vehicle robustness and damage tolerance
- Altitude, temperature sensitivities





Electric Propulsion is a VTOL Enabler

- *Problem:* Small VTOL aircraft platforms are plagued with mechanical powertrain problems due to small turbine and reciprocating engines integration issues; resulting in complex, inefficient, noisy, and poor performance vehicles which are not capable of satisfying the current and future mission needs.
 - ◆ Poor efficiency and reliability of small engines, must be designed to accommodate engine-out through cross-shafting to multiple propulsors, highly sensitive to altitude and temperature, power only available at a single rpm, ...
 - ◆ High VTOL power requirement is for less than 2 minute duration, with throttle down to 20-30% power for endurance missions.
 - ◆ High / Hot capability degrades air breathing engines by up to 30%
 - ◆ VTOL missions are typically in close proximity to people, so noise is a key concern.
- *Solution:* Electric propulsion offers a scale-free technology integration path, with new degrees of aircraft integration freedom.
 - ◆ Scale-Free: Electric motors have the same efficiencies (>90%) and power to weight (2 hp/lbm) across large changes in size (from 1 hp to 300 hp).
 - ◆ New Integration DOF: Able to design highly redundant propulsion systems that eliminate need to cross-shaft, able to design entire system for low noise.

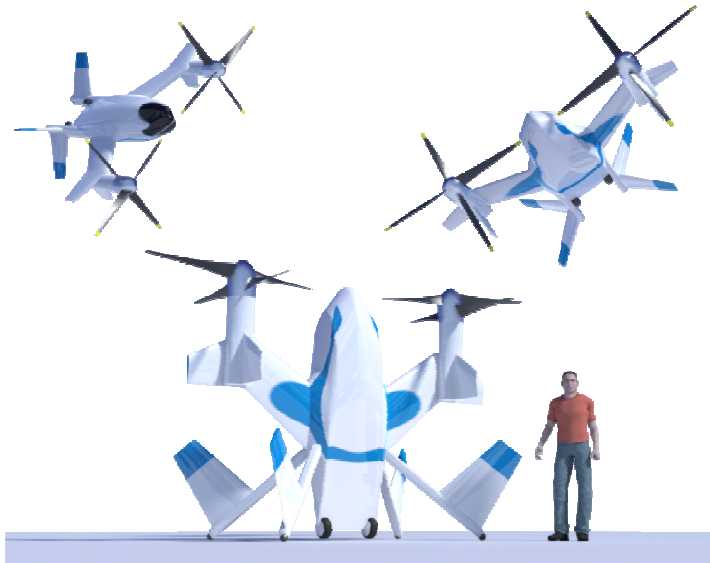
Electric Propulsion is a VTOL Enabler

Puffin VTOL Tailsitter Study, 2009

- Gross weight ~600 lb
- Useful load of 280 lb
- Hover power 60 hp
- Control power margin up to 120 hp (2 min)
- Cruise power 20 hp
- Cruise speed 150 mph
- Cruise L/D 14.5
- Cruise Range 50 nm with SOA batteries
- High altitude dash of 300 mph @ 30k ft

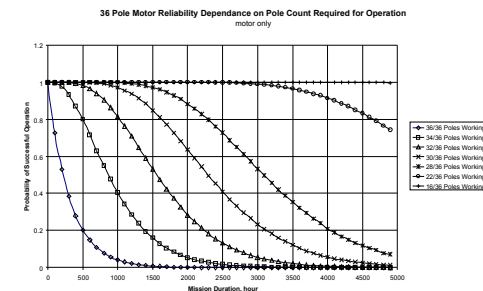
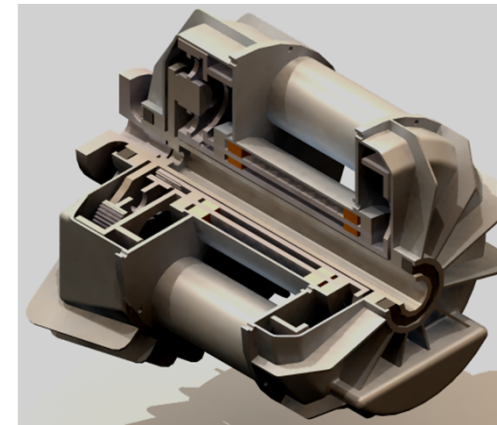
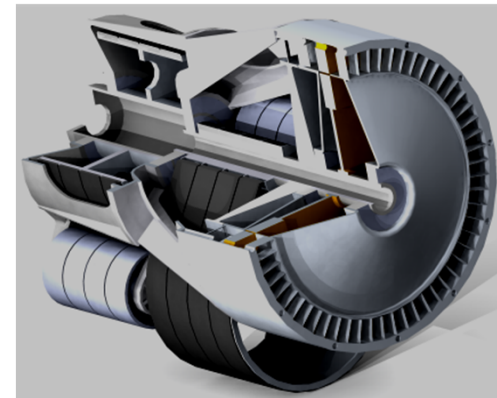
Electric Propulsion Attributes

Extremely Quiet
Scale-free Integration
Safety through Redundancy
Low Cooling Drag
High Reliability
No thrust lapse with altitude
No warm up ground idle delay
Variable RPM Capability
Permits Low Tip-Speed Cruise



Electric Propulsion is a VTOL Enabler

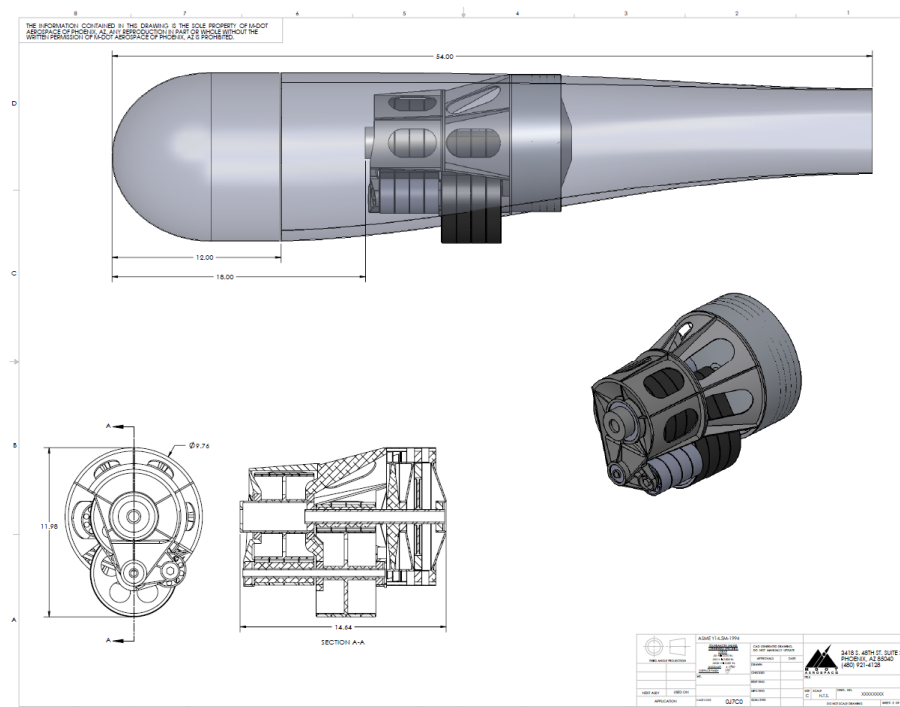
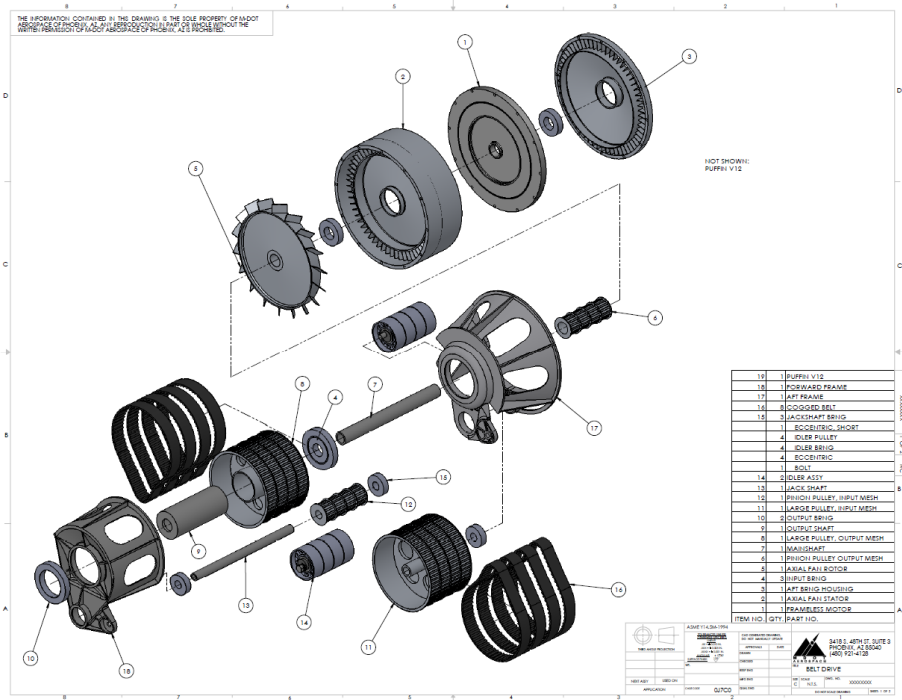
- Designed 5 Redundant Electric Motor Systems
 - Integral motor and gearbox to achieve 30 hp at 500 rpm
 - Ring motors without gear reduction were shown to be infeasible at this power level (too heavy/power, too large of diameter for the required rpm).
 - 36 Pole Motor with Belt Drive weighs 28.6 lbs, 92% efficiency, can fail up to 4 poles and/or half of belts and still produce full power. Failure of 5th pole permits rated power for 2 minutes prior to thermal runaway.
 - Quad Motor with Planetary weighs 58.0 lbs, 92% efficiency, can fail 1 motor and/or a single gear planet and still produce full power. Failure of another motor permits rated power for 2 minutes prior to thermal runaway.
- Analysis to Satisfy FAA Multi-Engine Reliability
 - Fault tree analysis utilizing Navy reliability tool set, including individual component by component build-up to capture parts count, complexity, and failure rates of specific components.
 - Reliability during 1st 500 hour period of 99.8% (with no inspections or replacement during that period), with probability of success (no subsequent critical failure during 2 minute period emergency period) of 99.99997.





Electric Propulsion is a VTOL Enabler

36 Pole Motor with 8 Belt Reduction Redundant System



All VTOLs Can Fly, But Can They Transition

Dos Samara VTOL UAV Concept Study, 2009

Proof of a VTOL is successful transition through a robust corridor; sub-scale demonstrations can be very useful to validate the many transition control assumptions required during conceptual design.



All VTOLs Can Fly, But Can They Transition

Samarai Roadable VTOL Concept Study, 2010

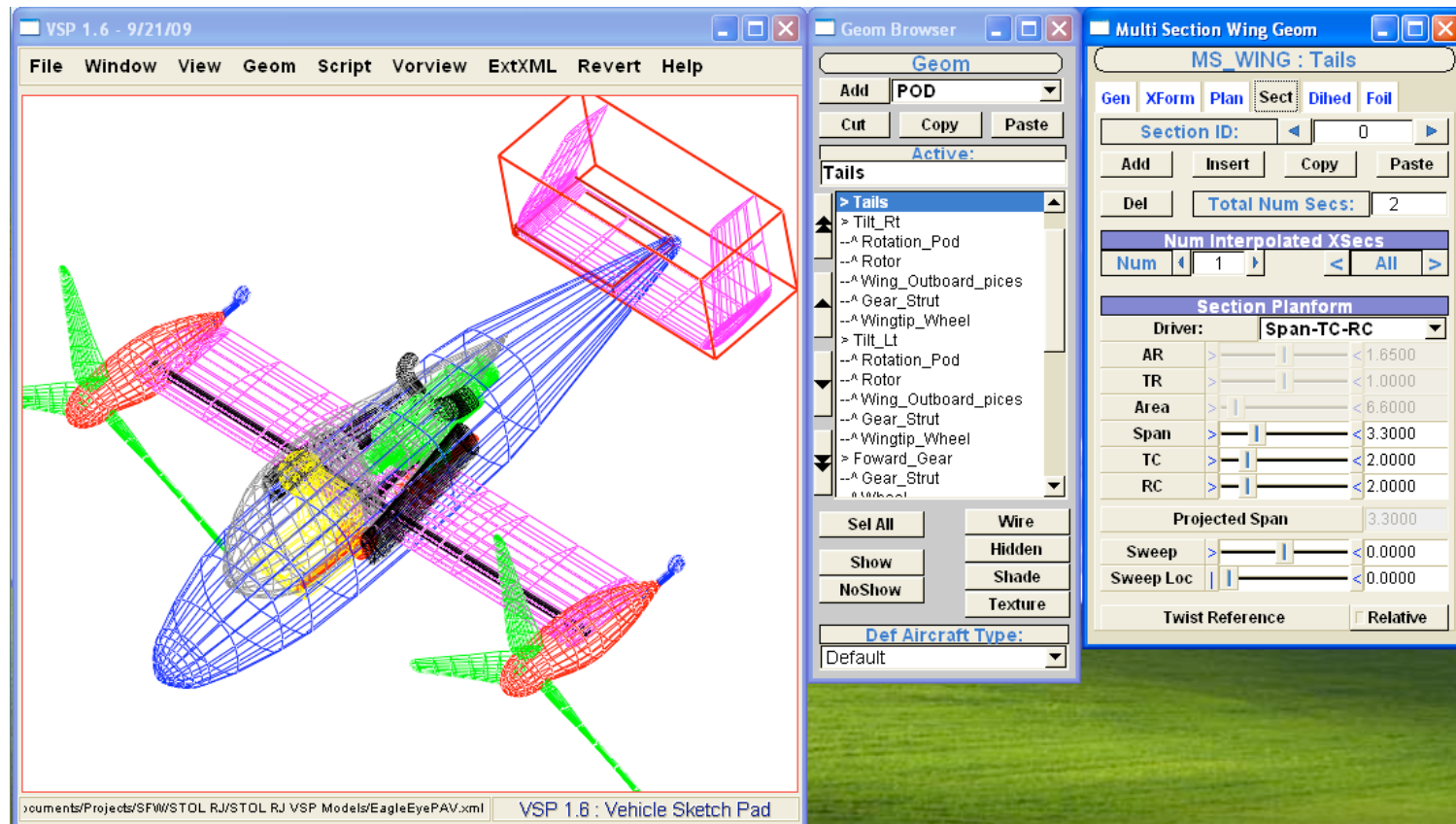
Attempts to achieve redundancy through the entire propulsion system (even blade failure), while maintaining lower disc loading without the need for cyclic (and maybe even collective) rotor control.



Tight Packaging Requires Creativity

Vehicle Sketch Pad (VSP) Facilitates Rapid, Creative Design

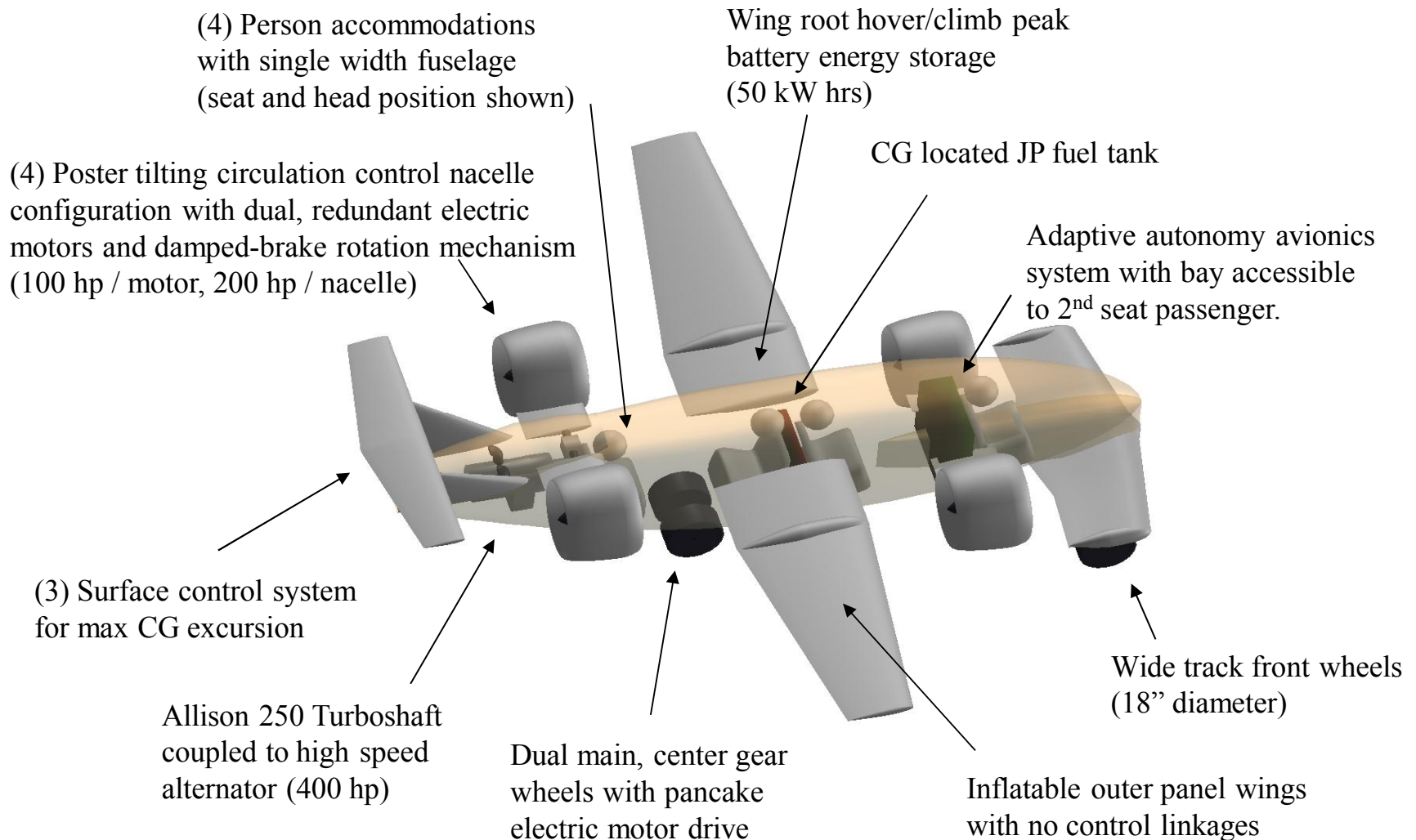
Rapid and intuitive conceptual geometry front-end to design that using parametric input (Aspect Ratio, Sweep, Twist, etc— not like CAD). Available from NASA to U.S. citizens, including source, models, manuals, etc at no cost through a Software Users Agreement.





Tight Packaging Requires Creativity

VSP Example





Tight Packaging Requires Creativity

VSP Example

