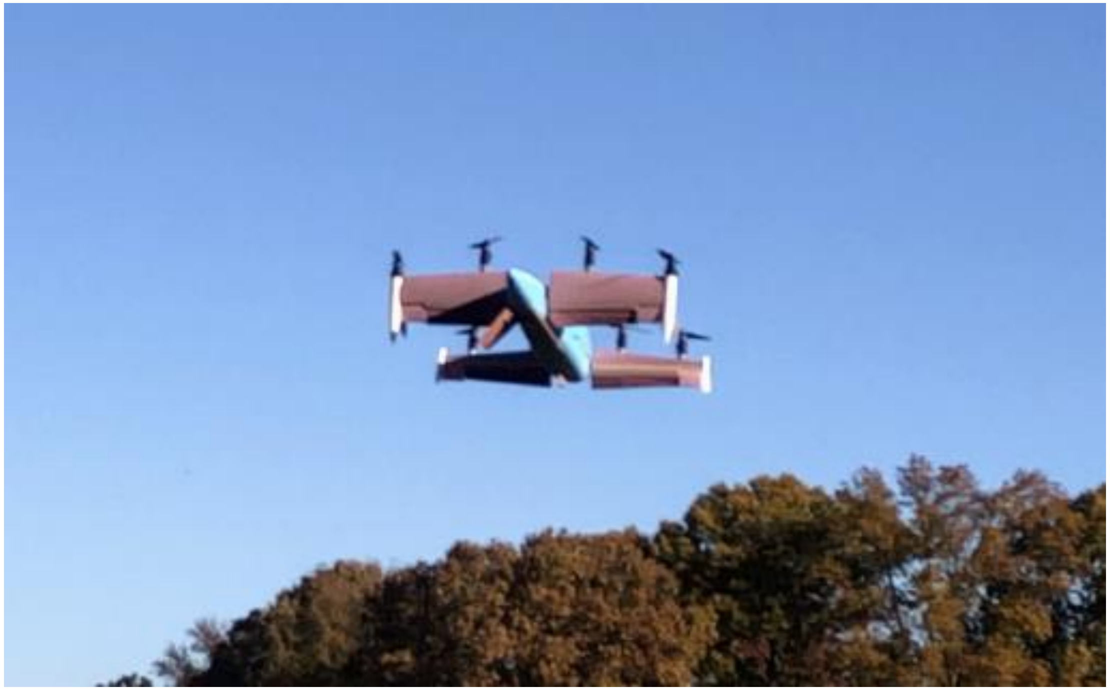
Flight Testing of a Scale Urban Air Mobility Technology Testbed



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AIAA SciTech Forum
January 2021
Control ID 3452348

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Motivation for LA-7 VTOL

- **A 50% scale (4 foot span) version of LA-8 was built and taken through flight testing to :**
  - Verify and build confidence in the tandem tilt wing configuration and 3-board flight control scheme
  - Train pilots and crew. Provide a similar experience to LA-8 but at a lower investment level
  - Provide insight into trim and damping values for the LA-8

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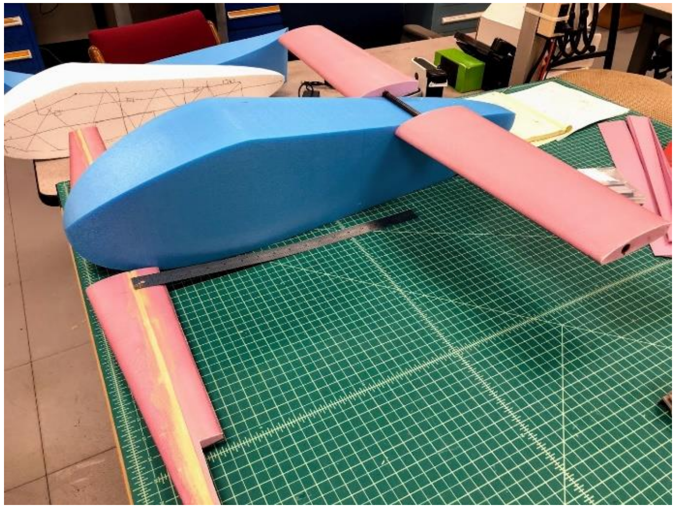
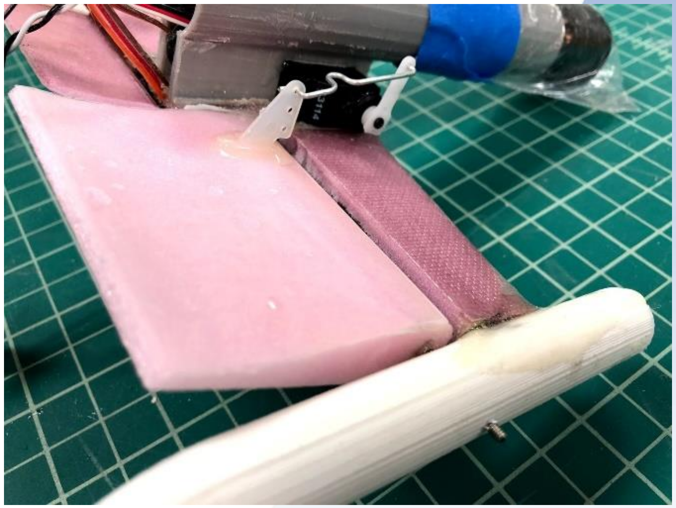
LA-7 Fabrication

- Hotwired foam fuselage with plywood and 3-D printed internal chassis
- Hotwired foam wings with fiberglass overlay and carbon fiber spar
- 3-D printed motor mounts, wing tilt mechanisms, flap hinges, winglets
- Same flight control boards and control outputs (20) as LA-8 (KK2.1.5 + OpenAeroVTOL)
- Standard RC transmitter and receiver
- No data acquisition system





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Progression of LA-7 Flight Testing

1. Single motor thrust stand testing
2. Full model 8-motor static thrust testing
3. Pitch axis tuning stand
4. Indoor tethered hover testing
5. Indoor free flight hover testing
6. Outdoor free flight hover testing
7. Outdoor free flight transition testing

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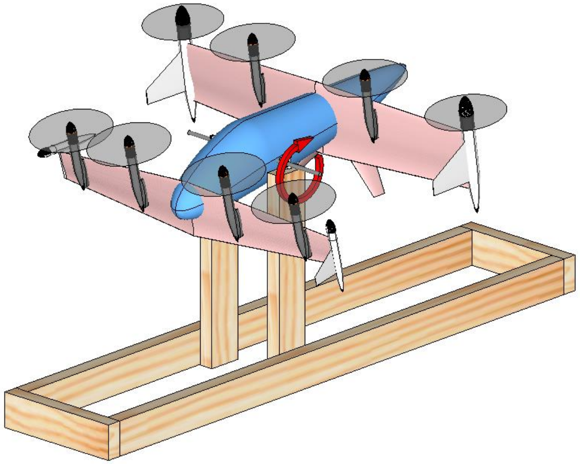
LA-7-2 Pitch Axis Tuning Stand

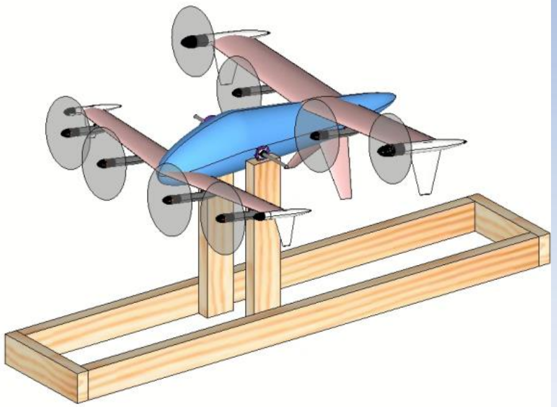
- Prior to indoor tethered hovering, a stand with a rotation axle along the pitch axis located at the aircraft C.G. was built to tune auto-leveling and pitch rate gain in hover and forward flight wing configurations

- Tuning of pitch auto-level and pitch rotation rate damping coefficients to achieve well-damped pitch behavior was performed by perturbation in the pitch axis with a stick.

- Although “wind-on” forward flight conditions are not achieved with this rig, it provided a best guess at a starting point for gain settings. It was assumed that passive aero damping in pitch should add to propulsion system active damping.

- After tuning at multiple transition levels, the model was able to go through a full transition from hover to forward flight at 50% throttle with the fuselage remaining very level and well damped.





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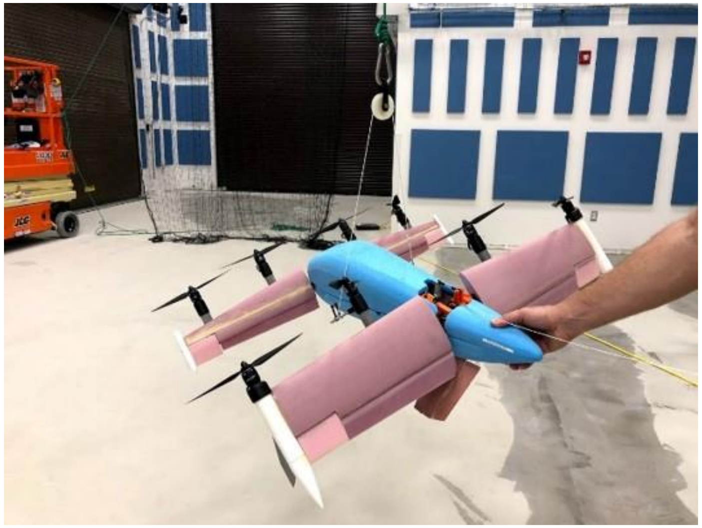
Indoor Hover Flight Testing

1. Tethered testing with model suspended and slightly below hover thrust using a bridle that allowed yaw axis rotation only (pitch and roll constrained)
2. Tethered testing with model suspended and slightly below hover thrust using a bridle that allowed pitch, roll and yaw axis rotation
3. Tethered testing at hover thrust
4. Free flight hover testing
5. Battery characterization resulted in hover flight time of approx. 5 min. with 20% energy reserve.
6. IR camera was used to measure motor housing temperatures



Tethered model with pitch, roll, yaw bridle

Indoor free flight hovering

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Outdoor Hover Testing

- Short hover flights to verify indoor tuning and trimming
- A series of small stick perturbations increasing to half-doublets was used to assess and tune auto-leveling and rotation rate damping in the pitch and roll axes
- Climbing and descending behavior and damping was assessed
- Maximum forward speed in hover (0% transition) is approximately 10 knots with pitch stick at maximum

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Outdoor Transition Testing

- An incremental approach of proceeding through transition at 5% steps was used
- Straight and level flight at each transition percentage point was established and then trim and damping was assessed and tuned
- Initial set of propellers had too low of a pitch and top speed was only slightly above stall. A second set of higher pitch propellers resulted in a substantially higher top speed
- A persistent pitch oscillation on low power inbound transitions was observed but solved with proper pitch rate gain setting on motors.

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Conclusions / Lessons Learned

- Using three (3) KK2.1.5 flight control boards simultaneously works
- A combination of differential motor RPM, blown elevons, and tilted wingtip rotors was needed to achieve effective yaw control
- Select propellers that are suitable for both hover and forward flight
- Hovering in winds above 5 knots is difficult due to large wing area normal to wind
- Tethered hover testing and pitch rigs (1 degree of freedom) can speed tuning while limiting risk to the vehicle
- Transition testing should proceed in small increments with trimming and PID tuning that allows “hands-off” straight and level flight at each transition point.
- Propulsion forces (vs. forces from control surfaces) are dominant. Solving control and damping issues should start with the motors / propellers.

Thanks

Questions ?

Design, Testing, and Modeling for the LA-8 Tilt-Wing VTOL Aircraft I & II References

1. North, D. D., Howland, G., and Busan, R. C., "Design and Fabrication of the LA-8 Distributed Electric Propulsion VTOL Testbed"
2. Busan, R. C., Murphy, P. C., Hatke, D. B., and Simmons, B. M., "Wind Tunnel Testing Techniques for a Tandem Tilt-Wing, Distributed Electric Propulsion VTOL Aircraft"
3. Simmons, B. M., "System Identification for Propellers at High Incidence Angles"
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5. Simmons, B. M., and Murphy, P. C., "Wind Tunnel-Based Aerodynamic Model Identification for a Tilt-Wing, Distributed Electric Propulsion Aircraft"