Aerodynamic Testing, Analysis, & Modeling of Powered-Lift

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From VTOL to eVTOL Workshop
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Outline

- Powered-lift for VTOL flight (Non-Rotary Wing)
- Some of the past projects, programs, and facilities at Ames that we have used in VTOL / STOL research. Some of the multi-disciplinary research
  - Aircraft Flight Testing - The X-14A, the Augmentor Wing Jet STOL Research Aircraft (AWJSRA), Quiet Short - Haul Research Aircraft (QSRA), and V/STOL Systems Research Aircraft (VSRA)
  - Wind Tunnels Tests at The National Full-Scale Aerodynamics Complex (NFAC) including the 40 X 80 Foot Wind Tunnel, 80 X 120 Foot Wind Tunnel and Outdoor Aerodynamic Research Facility
  - CFD - The “From Computation to Flight” the Computational Approach to Aeronautics Research
  - Vehicle / Airspace / Environment Integration
- Summary, future work, and take away points
Powered-Lift for VTOL Flight

• Flight regime of “powered-lift” for VTOL applications.
  – Size and velocity of the flow field
    • ‘High’ disc loading. Low mass flow with high kinetic energy
  – Vehicles with propulsion systems comprising of direct jets, ducted fans, or augmented jets
  – In-ground-effect and out-of-ground effect show distinct and different flow field characteristics
  – A flow field whose “average” dynamic pressure (q) may not be relevant
  – Mission profile: Hover, transition, cruise, transition, and back to hover

• It is understood that using electric power changes many of the issues, especially hot gas ingestion, but most aerodynamic characteristics remain relevant

• “Are you sure you need to hover during take-off and landing?”
  – Please consider “Short” Take-Off and Landing (STOL)
VTOL ‘Wheel’

- A wheel of (mis)fortune
  - Technically, vehicles were flown successfully
  - ‘Misfortune’ is due to program issues and failure to identify real requirements
    - Almost always found a 5,000 foot runway somewhere to fly in and out was cheaper than hovering
  - The technology is worthy of revisiting due to:
    - Electric Propulsion
    - Control Systems including Autonomy
    - Advances in CFD, flow modeling, vehicle structural design process
    - Missions have ‘true’ need to hover
VTOL Flow Field – Effects
The Ames VTOL / STOL Projects of the Past

• Some of them even before my time
A History of Ames in VTOL

- The X-14A
  - Flew from 1958 until 1981
  - Helped to provide understanding of jet-borne hover, including the Apollo lunar lander
The Augmentor Wing and Quiet Short Haul Research Aircraft
A History of Ames in VTOL

• The Augmentor Wing STOL Research Aircraft

Note the use of the choke flap to facilitate high frequency lift and roll response. It could create drag too, and made a lot of noise (a whistle)!
A History of Ames in VTOL

• The Augmentor Wing STOL Research Aircraft

The Curved-Decelerating Descending Approach
A History of Ames in VTOL

• The Quiet Short-Haul Research Aircraft

Figure 1. Quiet Short Haul Research Aircraft.
QRSA FLIGHT DEMONSTRATION
(GROSS WEIGHT = 46,000 lb, NO WIND)

NOISE ABATEMENT DEPARTURE

2-SEGMENT LANDING APPROACH

STEEP CLIMB

MANEUVERABILITY

CLOSE-IN LANDING APPROACH
A History of Ames in VTOL

• The V/STOL Systems Research Aircraft
  – Significant contributions to the JSF (F-35B) program in the area of integrated flight / propulsion controls
  – Ability to test other V/STOL flight control configurations
The 40 X 80 Foot Wind Tunnel

• Early Powered, Powered-Lift Models

Swept Augmentor Wing

Externally Blown Flap
Avrocar
The 40 X 80 Foot Wind Tunnel

• Early Powered Models

Swept Augmentor Wing Acoustic Suppression Model
The 40 X 80 Foot Wind Tunnel

• Full-Scale Powered Models
  – Airspeeds ranging from about 30 knots to almost 300 knots
    – Almost hover conditions, low-speed transition and then high-speed transition through cruise

The E-7 Ejector Concept in the Tunnel

The E-7 Ejector Concept Under Construction
STOL Acoustic Testing in the 40 X 80

• Aerodynamics / Propulsion / Acoustics Integration Tests
• Lockheed Martin SACD was powered by Williams turbofans
• Cal Poly hybrid wing/powered-lift model was powered by TPS (high pressure air)
Small-Scale Testing in the Full-Scale Facility

• Consider small-scale testing in the NFAC if you need large spaces to get unimpeded flow and reduce wall-effects on flow field
• You will want a ground plane, the tunnel’s boundary layer is too big
Small-Scale Testing in the Full-Scale Facility

Transition from/to hover flight in off nominal flow fields and orientations
The Outdoor Aerodynamic Research Facility (OARF)

- Model Check-Out and Thrust Calibrations
The Outdoor Aerodynamic Research Facility (OARF)

- Hover Testing In- and Out-of-Ground-Effect

Smoke demonstrates just how large the hover flow field can be.
The Outdoor Aerodynamic Research Facility (OARF)

- Jet Decay Rake Measuring Pressure Distribution of the Lift Fan Jet Exhaust
Airspace / Vehicle Integrated Operations

• The aircraft, its trajectory, airspace, and environment all work together
  • The powered-lift aircraft has the ability to fly off-normal landing approaches. Can we optimize that?
NM-STAT Noise Mitigation Smart Terminal Area Trajectory (Worst Acronym Ever!)

The C-17 Noise Measurement Team

September 2005 – A demonstration of low cost testing techniques to measure the noise footprint of STOL approaches in the vicinity of an airport
NM-STAT Noise Mitigation Smart Terminal Area Trajectory

- The Lakebed Acoustic Array Set Up and Three Types of Landing Approaches
NM-STAT Noise Mitigation Smart Terminal Area Trajectory

Typical Microphone / Computer Station with Cal Poly Student Operator

Acoustic Footprint over adjacent areas
Summary

- Ames has unique capabilities built on its long history and expertise in VTOL / STOL powered-lift
  - A History of Flying Unique VTOL and STOL Aircraft
  - Large-Scale Tests at the NFAC and OARF
  - Small-Scale Testing
  - CFD for complex VTOL flow fields
  - Acoustics of powered / augmented lift
  - Flight control systems research
  - Development of new displays and procedures to aid the pilot during unique take-off, transitions, and landing
  - Integration of aircraft and trajectory with the airspace and environment in the take-off and landing area
Contributions to VTOL Powered-Lift State of the Art

• Scale Effects
  – Analyzed how small-scale testing can be used as a cost-effective data source as long as a limited amount of full-scale testing supplements the database
    – One needs to match the jet decay characteristics for the scaling to be valid

• Effect of Jet Decay
  • The jet structure effects the entrainment, mixing properties of the secondary flow
  • Significant impact to the jet-noise
  • Swirl introduced into the jet can bias the flow field

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Future Work That Will Be Needed for UAM

• Flow Field
  – Minimize negative flow effects, entrainment, re-circulation
  – Jet-induced moment predictions are poor
  – Understanding jet decay of lighter disc load fans
  – The optimization of electrical systems to facilitate VTOL aerodynamics
  – Understanding internal flows better
    • Auxiliary systems, especially cooling!
  – Measuring flow field in the presence of other structures
  – Foreign Object Damage (FOD)

• Noise!
Take-Away Points

• Ames has unique capabilities built on its long history and expertise in VTOL / STOL powered-lift

• VTOL / STOL powered-lift flight is not trivial, and you’ll be amazed how uncooperative the flow field will be