CFD Analysis of Distributed Propulsion Systems for Vertical Takeoff and Landing

Andrew V. Welles, Prof. Thong Dang
Department of MAE, Syracuse University
College of Engineering & Computer Science

- **Abstract**
  This computational study seeks to reverse engineer and quantify the performance of two novel distributed propulsion systems for vertical takeoff and landing (VTOL). As both of these technologies are being developed by private companies, there are no publications pertaining to either of these designs in the body of literature. These systems essentially provide powered circulation during forward flight and vertical thrust during hover, thereby delivering very high lift at low forward speeds. This analysis consists of 2D CFD calculations performed in Star-CCM+ using both RANS and URANS solvers. 2D lift coefficients in excess of 9.0 and 14.5 are reported for the CDP and ADP configurations respectively. The CDP configuration has a nearly uniform power demand across all operating flap angles with a peak power demand of approximately 16.7 kW/m² of fan flow area, which is 0.95 – 1.0 kW/m span at the simulation scale.

- **Geometric and Setup – Compound Distributed Propulsion (CDP) and Articulated Distributed Propulsion (ADP)**
  - Unstructured overset mesh regions were used to allow relative motion of the wing and flap without re-meshing for each case
  - The fan is approximated by a pressure jump interface with a target mass flow rate specified as a model parameter
  - The dP across the pressure-jump interface is adjusted until the mass flow condition is satisfied
  - ADP is identical to CDP with the stationary wing removed
  - Freestream velocity is 10 m/s

- **Reverse Engineering**
  - The Lightning Strike is being developed by Aurora Flight Sciences
  - The Lilium Jet is being developed by Lilium, a German startup
  - Photographic data from each manufacturers website and promotional literature was used to estimate the geometry of the ducts.
  - Duct design best practices and iterative simulations were used to refine the geometry for each system.

- **Design Considerations**
  - **The CDP System**
    - CDP performs well across all flap angles
    - The flow entering the fan region remains attached and relatively free of inlet distortion
  - **The ADP System**
    - ADP exhibits extremely large Cl for large flap angles
    - The flow entering the fan region beyond 40° flap angle is characterized by excessive inlet distortion which would likely degrade the fan performance severely, preventing operation in this regime

- **Next Steps**
  - Design the fan housing 3D geometry
  - Full URANS sliding mesh with fan blades
  - Develop a simplified 3D finite wing model to quantify induced drag on both CDP and ADP

- **Star-CCM+ RANS and URANS Results – CDP**
  - Wing Chord: 0.399 m (ADP slotted flap with a FWD wing section)

- **Star-CCM+ RANS and URANS Results – ADP**
  - Wing Chord: 0.163 m (Flap section from CDP, with wing removed)