Aerodynamic Modelling of a Tiltrotor during transition between Vertical Take-Off and Landing (VTOL) and aircraft mode

Anchal Goel CEng (Part time Phd Student)

Supervisors : Dr Davide Di Pasquale and Dr Mushfiqul Alam

10th June 2025

www.cranfield.ac.uk

Context

- VTOL configurations offers combined benefits of helicopter and aircraft for Military and Civil applications.
- Tiltrotor configuration includes added transition phase in addition to hover phase from helicopter mode and cruise phase from airplane mode
- Transition phase in flight operation is unpredictable and required improved understanding of aerodynamics

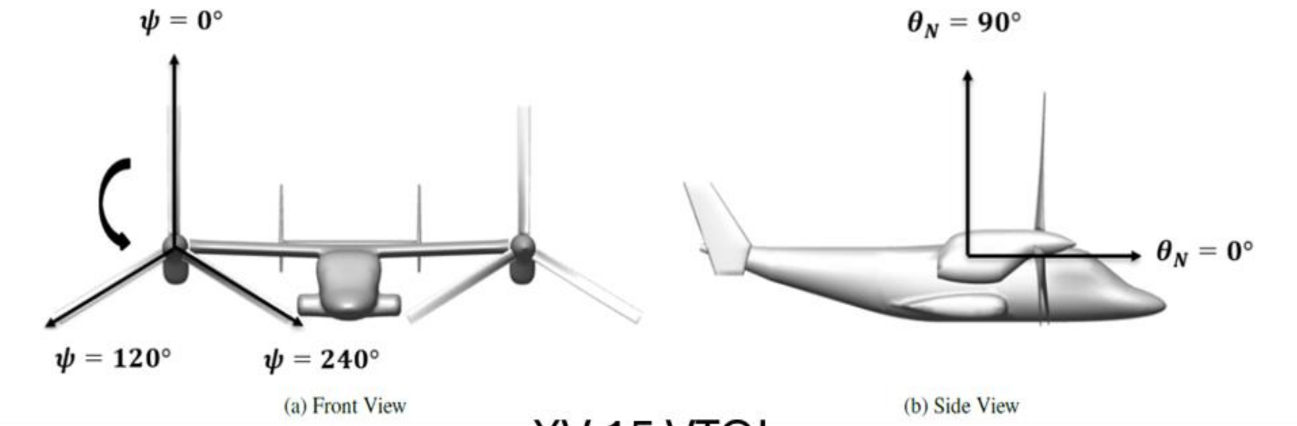
Overall Aim and Objectives

Aim

Create numerical understanding of the unpredictable aerodynamic nature for a tiltrotor aircraft during unsteady transition phase for safer and reliable flight operation

Objectives

- Use of vortex panel method via Flightstream software to create an efficient and reliable method to predict performance and aero-acoustic parameters for isolated XV-15 VTOL rotor during hover, transition and cruise phase.
- Extending the analysis to understand the interaction of rotor flow field with the rest of aircraft to predict transition protocols for flight handling qualities
- Implement the methodology to conduct a mid-fidelity analysis on a conventional VTOL configuration (6000-6500 hp) and an e-VTOL configuration.



XV-15 VTOL

Image source :https://researchinflight.com/

Principle factors that determine the performance of V/STOL

<u>Hover</u>

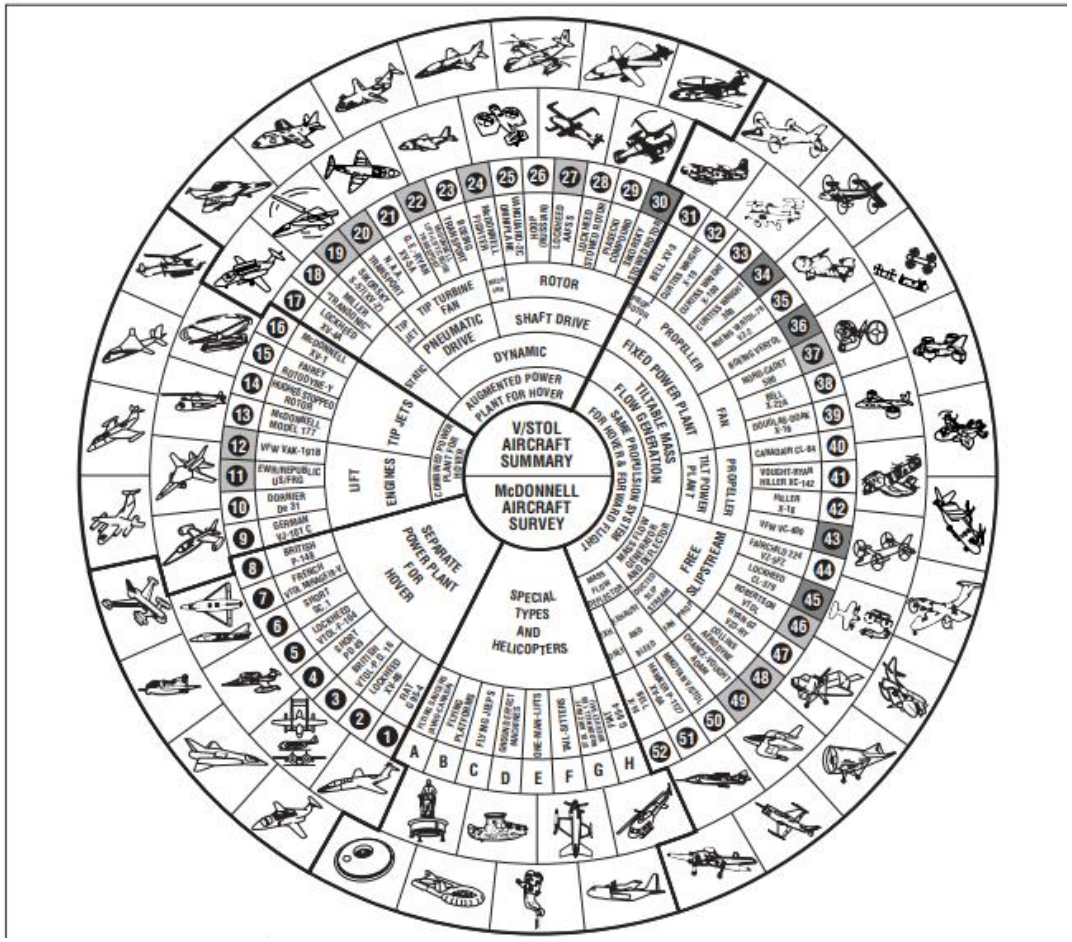
- Downward Velocity (Helicopter Vs VTOL)
- Power Required (Directly proportional to downward velocity)
- Fuel Consumption depends on power
- Downward dynamic pressure depends on slipstream disk area

<u>Cruise</u>

- Aerodynamic cleanliness to reduce the parasite power and a wing span to reduce the induced power
- VTOL power required > conventional aircraft

<u>Transition (hover to cruise)</u>

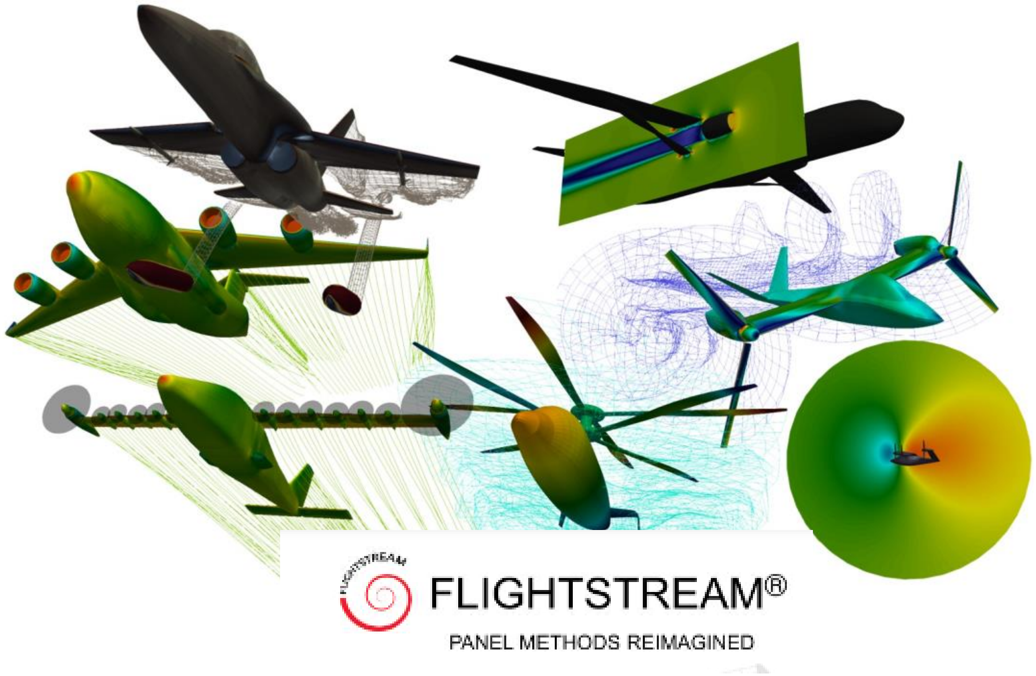
- Power requirement should not exceed power required in hovering
- Consideration : Minimum speed and STOL performance
- Power required curve in transition for low and high speed points of transition



General steps of Vortex Panel Method

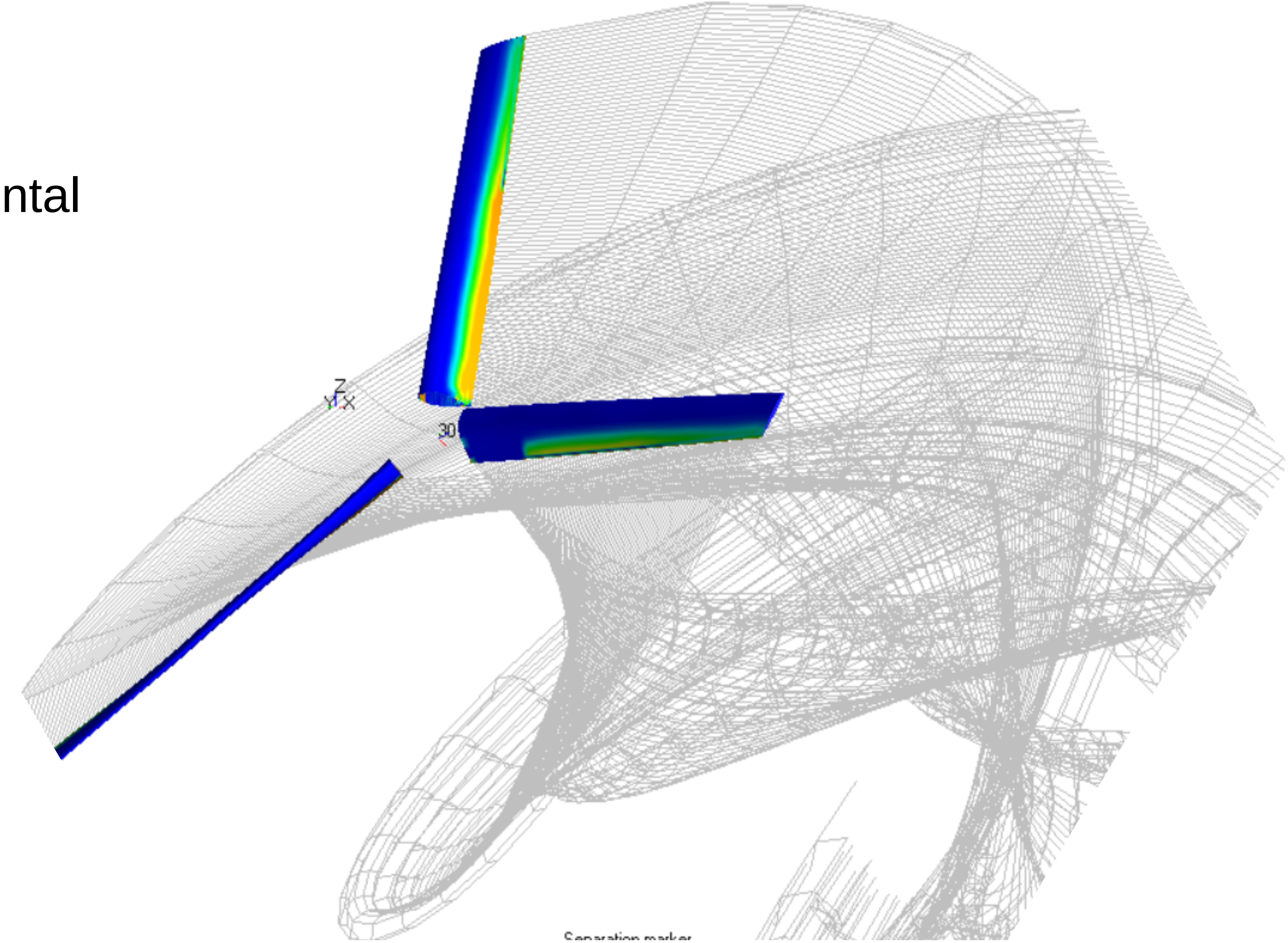
1. Discretisation
2. Singularity Distributions
3. Influence Coefficients
4. Boundary conditions
5. Solving the system
6. Flow Field Calculation
7. Forces and Moments Calculation

FlightStream is a modernized panel-method based aerodynamic solver. The original inviscid theory is enhanced with several novel features to provide a more realistic and comprehensive aerodynamic analysis tool compared to legacy panel codes



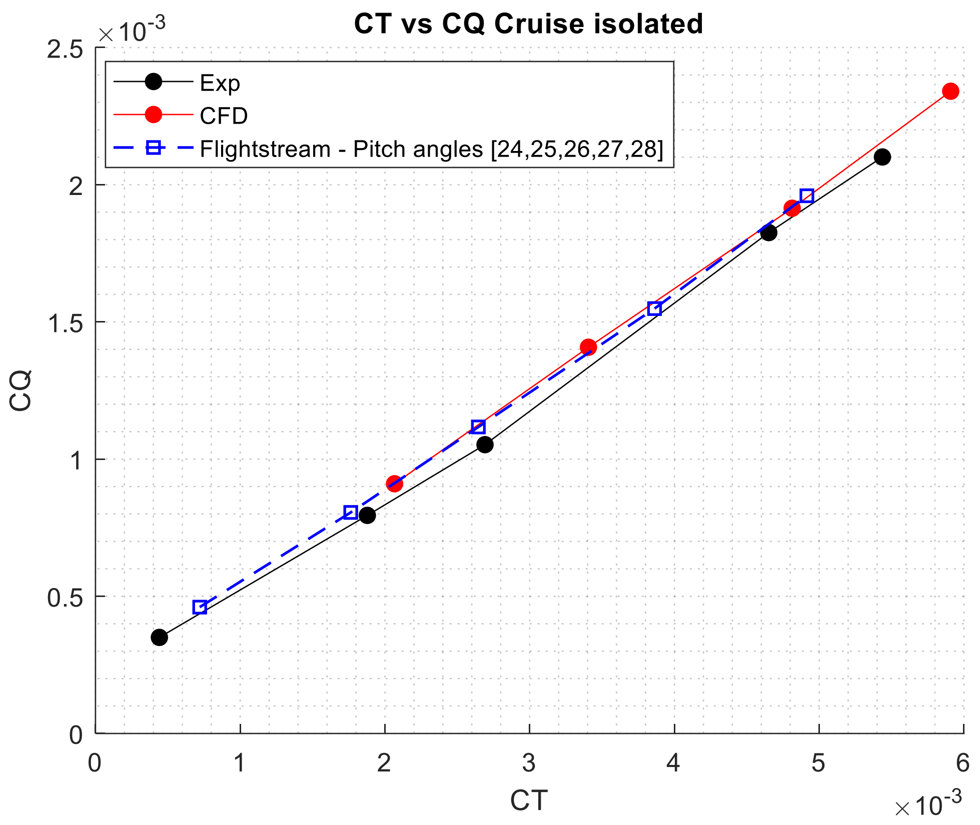
Flightstream Results

- Cruise (vs CFD and Experimental)
- Hover (vs CFD, DUST and Experimental
- Transition at 30 (vs Experimental)
- Transition at 60 (vs Experimental)



Results for Isolated XV-15 Rotor – Cruise

Parameters	Cruise
Pitch Angles	24,25,26,27,28
RPM	460.2
Tip speed	183.77 m/s
V(KTAS)	120 knots
V(m/s)	61.73 m/s
Resultant Velocity	195.1
Density	1.153
Assumed altitude	609 m
Temperature	284.35 K
Speed of sound	338 m/s
Pressure	94188 Pa



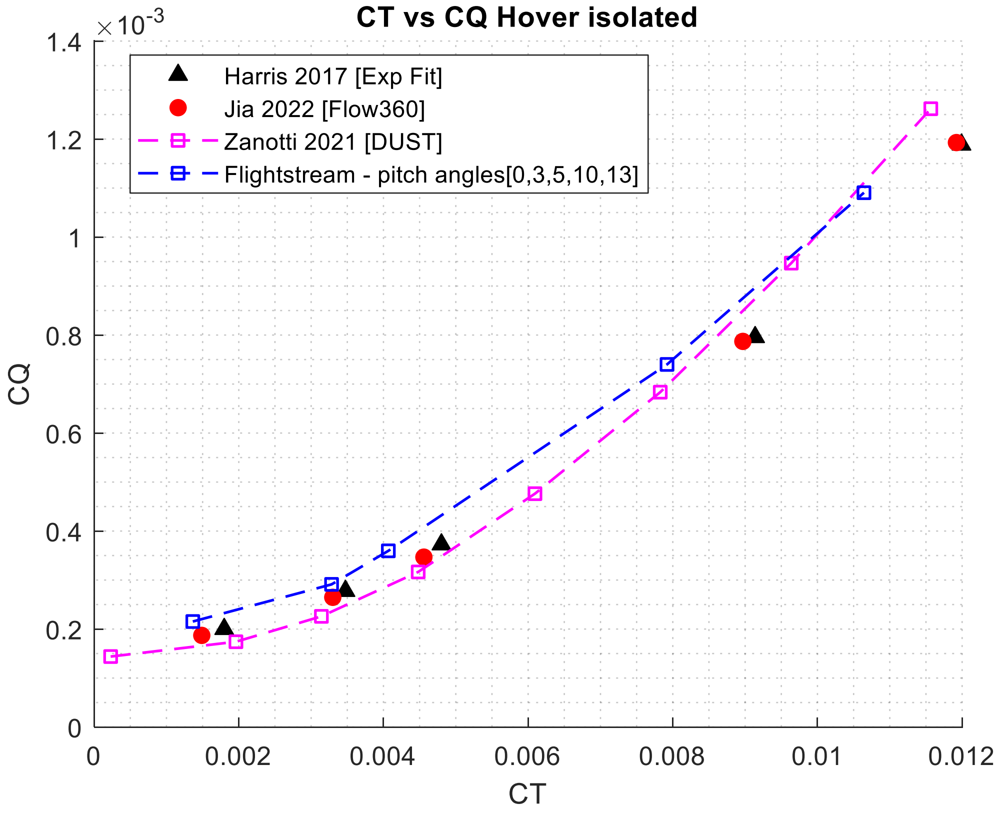
[1] Anon, "Advancement of Proprotor Technology Task 2 - Wind-Tunnel Test Results," Nasa Cr 114363, 1971

[2] Jia, F., Moore, J., and Wang, Q., "Assessment of Detached Eddy Simulation and Sliding Mesh

[3] Interface in predicting Tiltrotor Performance in Helicopter and Airplane Modes," AIAA AVIATION 2021 FORUM, American Institute of Aeronautics and Astronautics, AIAA 2021-2601.

Results for Isolated XV-15 Rotor – Hover

Parameters	Hover
Pitch Angles	0,3,5,10,13
RPM	589
Tip speed	235 m/s
V(KTAS)	0 knots
V(m/s)	0 m/s
Resultant Velocity	235 m/s
Density	1.225 kg/m3
Assumed altitude	0 m
Temperature	288.17 K
Speed of sound	340.29m/s
Pressure	101324 Pa



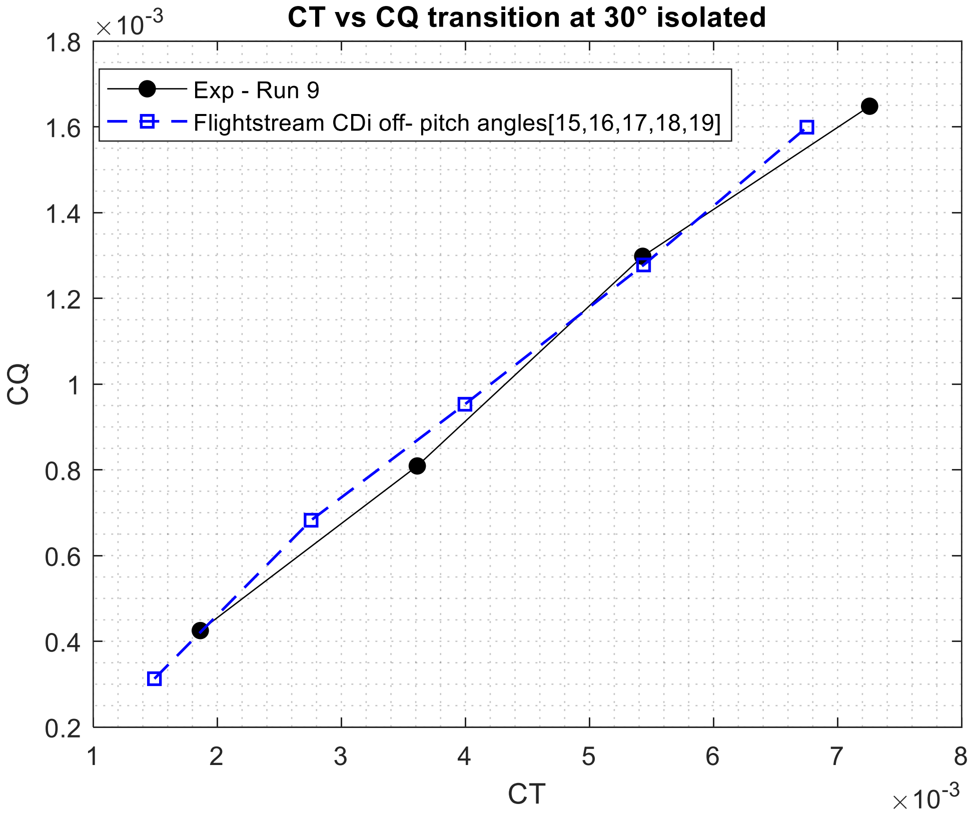
[1] Anon, "Advancement of Proprotor Technology Task 2 - Wind-Tunnel Test Results," Nasa Cr 114363, 1971.

[2] Harris, F., "Robust prediction of high lift using surface vorticity," Hover Performance of Isolated Proprotors and Propellers-Experimental Data; Technical Report CR—2017–219486, 2017.

[3] Zanotti, A., Savino, A., Palazzi, M., Tugnoli, M., and Vincenzo Muscarell, "Assessment of a Mid-Fidelity Numerical Approach for the Investigation of Tiltrotor Aerodynamics," Applied Sciences, 2011

Results for Isolated XV-15 Rotor – Transition at 30

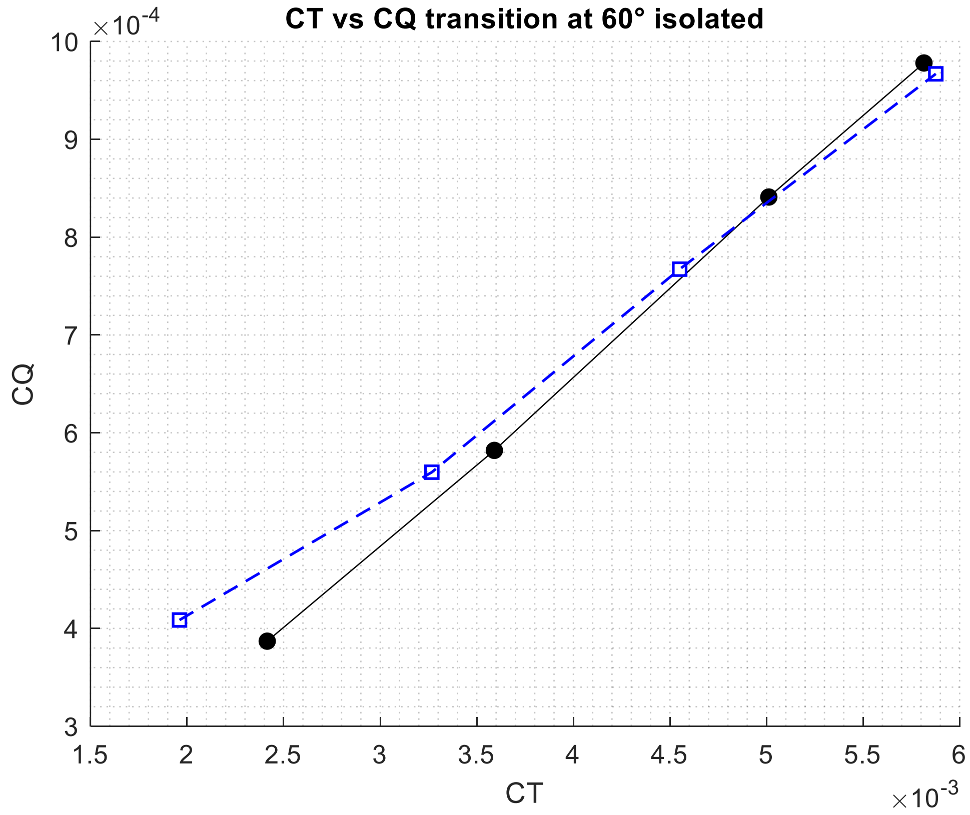
Parameters	Transition at 30
Pitch Angles	15,16,17,18,19
RPM	535.2
Tip speed	213.42 m/s
V(KTAS)	100 knots
V(m/s)	51.4 m/s
Resultant Velocity	219.52 m/s
Density	1.1826 kg/m3
Assumed altitude	365.8 m
Temperature	285.77 K
Speed of sound	338.19 m/s
Pressure	97008 Pa



[1] Anon, "Advancement of Proprotor Technology Task 2 - Wind-Tunnel Test Results," Nasa Cr 114363, 1971.

Results for Isolated XV-15 Rotor – Transition at 60

Parameters	Transition at 60
Pitch Angles	10,11,12,13
RPM	565.2
Tip speed	225.5 m/s
V(KTAS)	140 knots
V(m/s)	72.022 m/s
Resultant Velocity	236.72 m/s
Density	1.1549 kg/m3
Assumed altitude	609.6 m
Temperature	284.19 K
Speed of sound	337.9 m/s
Pressure	94213 Pa



[1] Anon, "Advancement of Proprotor Technology Task 2 - Wind-Tunnel Test Results," Nasa Cr 114363, 1971.

Ongoing Work

- Ongoing - Matlab code using blade element theory to predict cruise and hover isolated propeller cases.
- Full aircraft simulation on flightstream – currently working on XV15 full aircraft mesh.
- Calculate uncertainty error bars from experimental results.