Quiet VTOL Projects

NIFS Exit Presentation

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About Me

BS Aerospace Science & Engineering

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Objectives

1. Co-Flow Duct & Experiment Design
2. OVERFLOW Co-Flow CFD Validation
3. Stacked Propellers
4. Static Test Rig

1. Co-Flow Duct & Experiment Design

Objectives

- Can we validate external CFD studies of co-flow by designing an experiment in-house?
- Do co-flow's benefits warrant further in-depth investigation?
- Design of ducting/lips and validation experiment
  - Rapid prototyping & additively manufacturing (3D-printing) ducts
  - Experimental setup of manufactured duct assembly

Preliminary Co-Flow Experiment

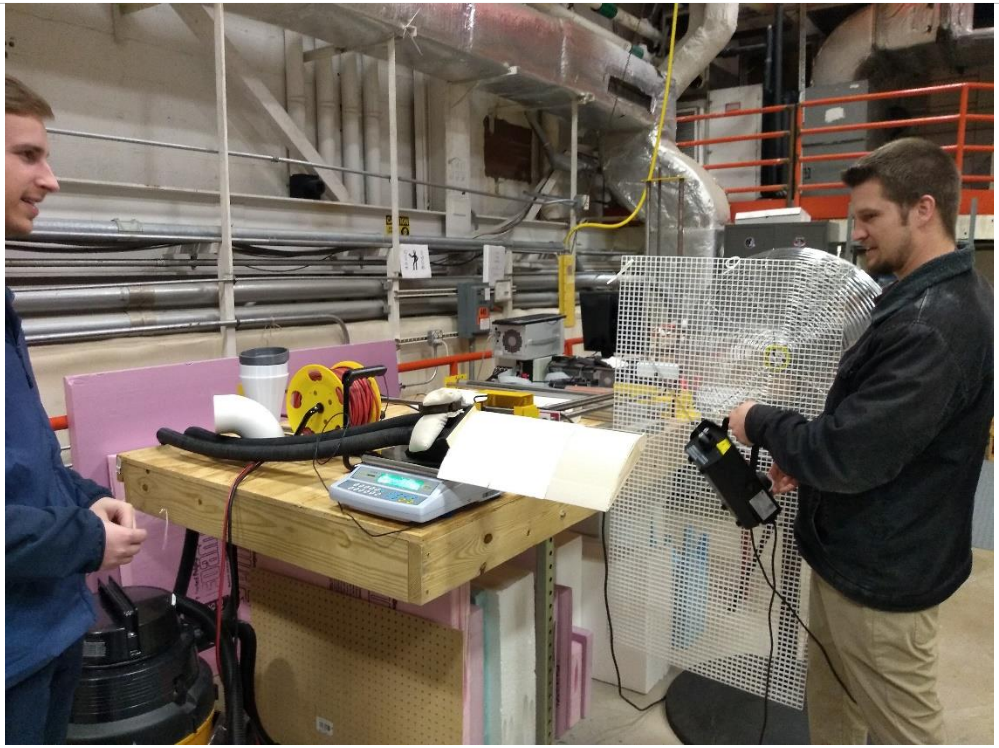
- Easily accessible; good for hands-on understanding of co-flow
- Used a co-flow hot glue wing, fan, scale, fog machine and flow straightener
  - A vacuum provides suction and injection mass flow
  - Fan provides freestream airflow
- Could an experiment as simple as this produce useful qualitative conclusions?
- Could we record any data?
- To what angles of attack does co-flow prove effective?

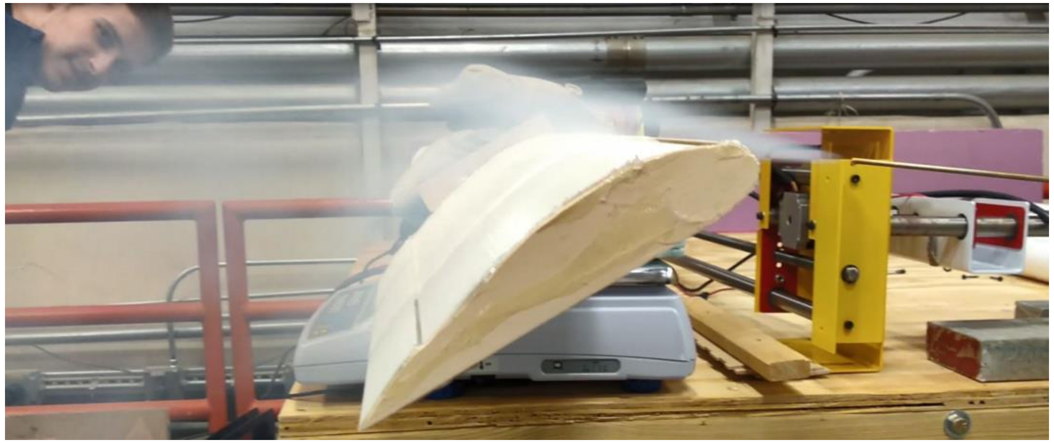
LE Injection Slot

TE Suction Slot

Preliminary Co-Flow Experiment (cont.)

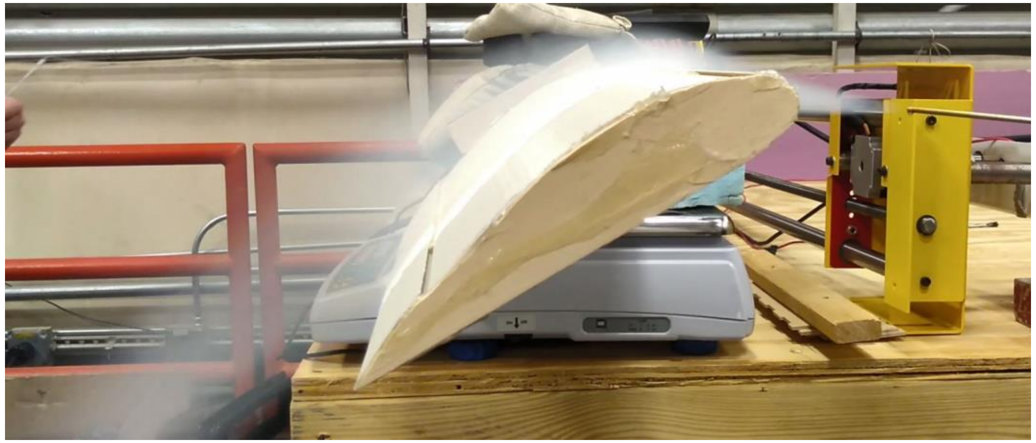
- Tested at ~35 deg. AoA
- Visual confirmation of flow attachment
- This simple experiment produced promising quantitative results
  - Produced ***~0.06lb*** of lift with co-flow off & ***~0.12lb*** with co-flow on
- Tested up to ~85 deg. AoA
  - Showed some flow attachment





OFF

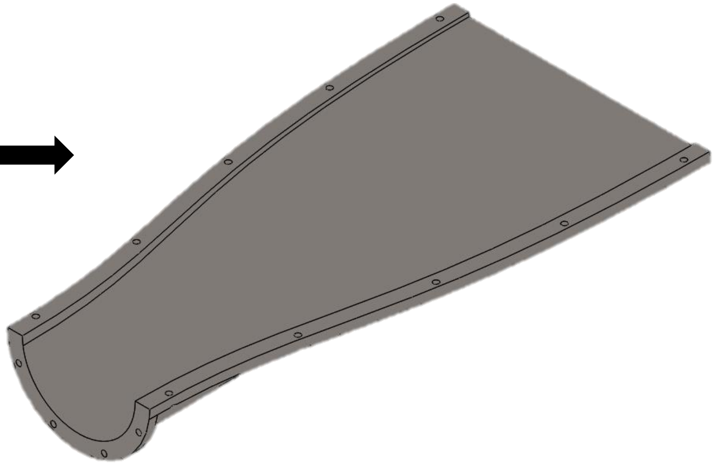
ON



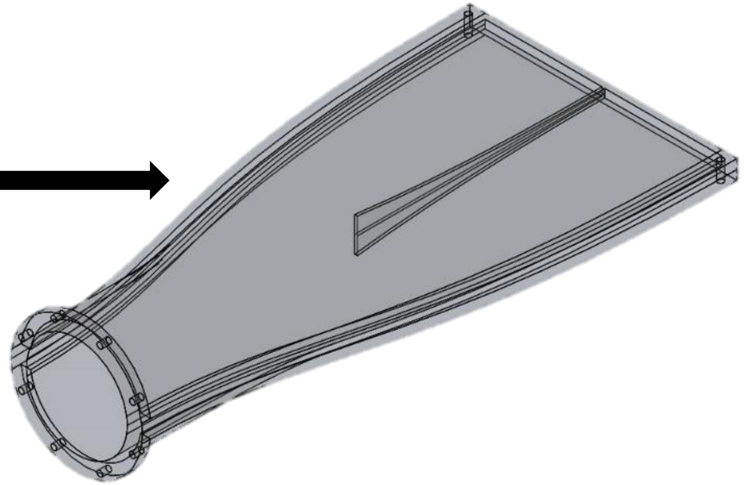
Co-Flow Duct Design – version 1

- Gechang Zha's ducts designed and used in *AIAA 2018-3062* served as the basis for redesign
  - Duct width sized down by 3x; length kept the same (v1)
  - Duct resized to 50mm EDF; halves combined to whole (v2)
- Lips printed as separate part
  - Responsible for turning flow at end of ducts
  - Geometry extracted from Gechang's duct CAD files

Ducts presented in AIAA 2018-3062



Suction duct-half – version 1



Suction duct – version 2

Co-Flow Duct Design – version 2 (cont.)

- Can this co-flow duct assembly produce the injection jet momentum coefficient required to mirror FASIP CFD simulations?
- EDF spun up to ~57,600rpm during testing (12A)
  - → $\dot{m} = 0.0143 \frac{kg}{s}$
  - → $V_j = 46.5 \frac{m}{s}$
  - → $\boldsymbol{C_\mu = 0.091}$

$$C_\mu = \frac{\dot{m} V_j}{\frac{1}{2} \rho_\infty {V_\infty}^2 S}$$

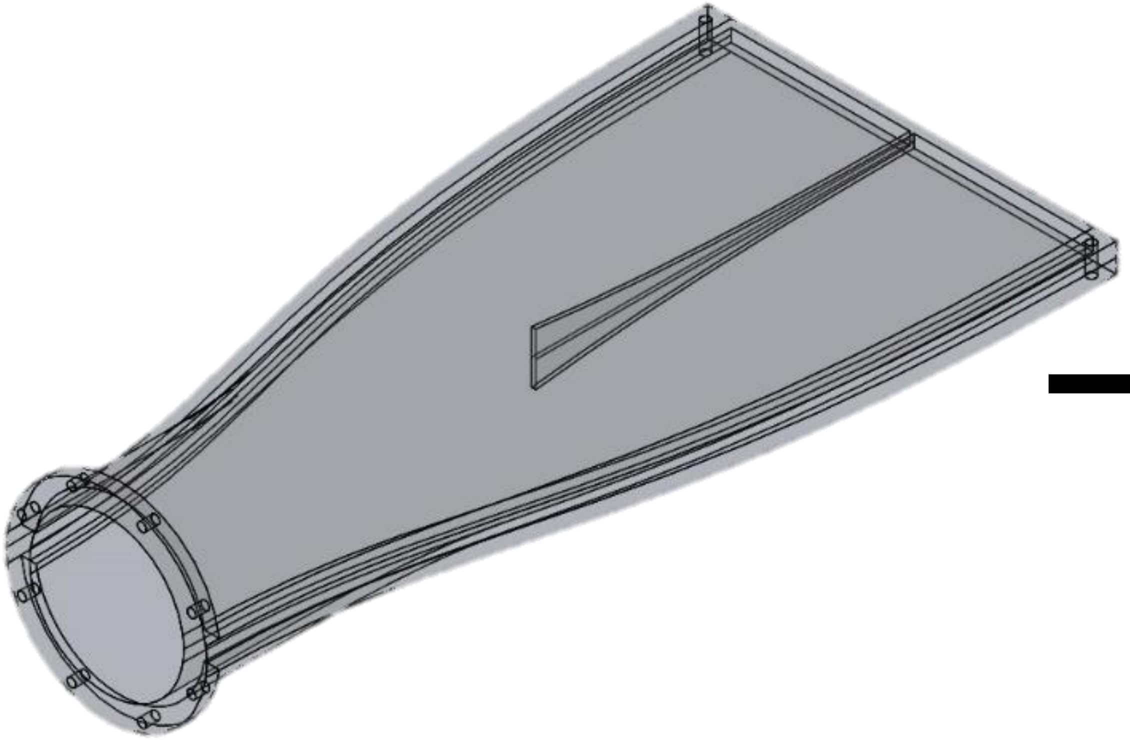
- Experimental C_μ smaller than target value
- What can be done to increase experimental C_μ?
  - Decrease slot area

Co-flow duct assembly – version 2; resized to 50mm EDF

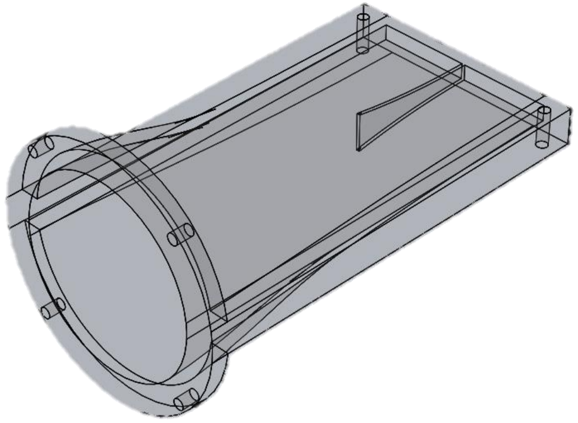

Version 2 test setup

Co-Flow Duct Design – version 3

- Latest version of ducts are scaled down to investigate the lower limit of wing chord length for co-flow powered by the 50mm fan
  - Duct length reduced by more than 2x
- Version 3 could not be tested due to COVID-19



Suction duct – version 2



Suction duct – version 3

Next Steps

- In progress
  - Research whether off-the-shelf fans could be used or if we should borrow compressors from Gechang Zha
  - Record flow parameters produced by fan/compressor in version 3 duct assembly
  - Continue planning the manufacture of the wing OML, internal mounting assembly, and experiment
- Planned for future
  - Possibly conduct duct aerodynamic design to optimize area distribution of ducts
  - Conduct tests measuring the lift and flow deflection of the co-flow wing

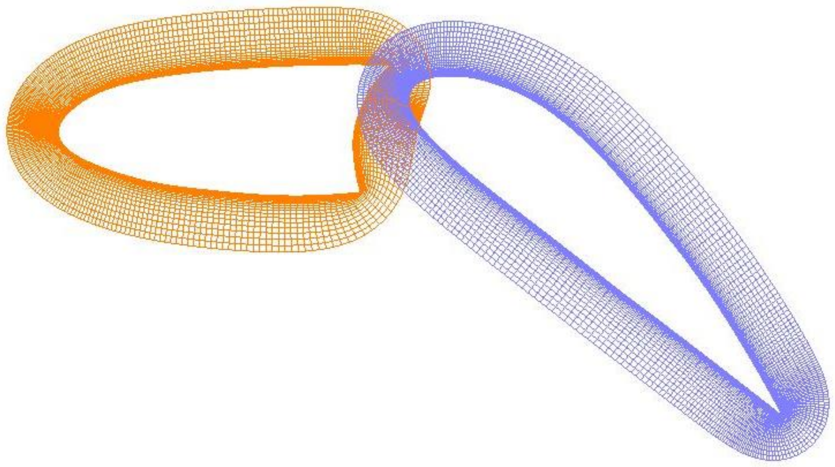
2. OVERFLOW Co-Flow Validation

CFD Validation Case - Objectives

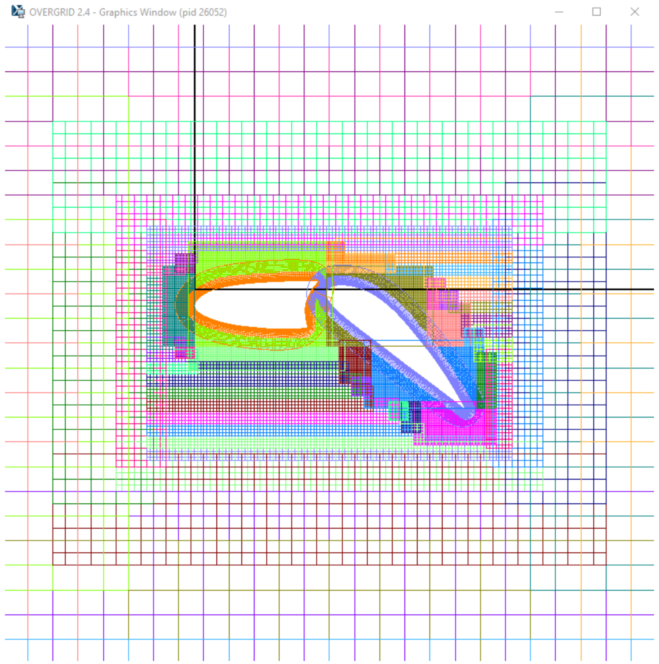
- Validate Gechang Zha's FASIP CFD simulation of a co-flow wing
- Can we produce a configuration that replicates case D245 in OVERFLOW?
- Are the results from an OVERFLOW simulation of D245 similar to results produced by FASIP CFD?
- Produce multi-element airfoil configuration for initial familiarization with OVERFLOW

Initial OVERFLOW Familiarization Configuration

- Developed airfoil geometry representing multi-element wing
  - Good introduction to multi-element gridding techniques in Chimera Grid Tools (CGT)
  - Near-body grids for boundary layer effects
  - Off-body grids communicate with near-body grids to ensure flow information moves correctly between the two grid systems



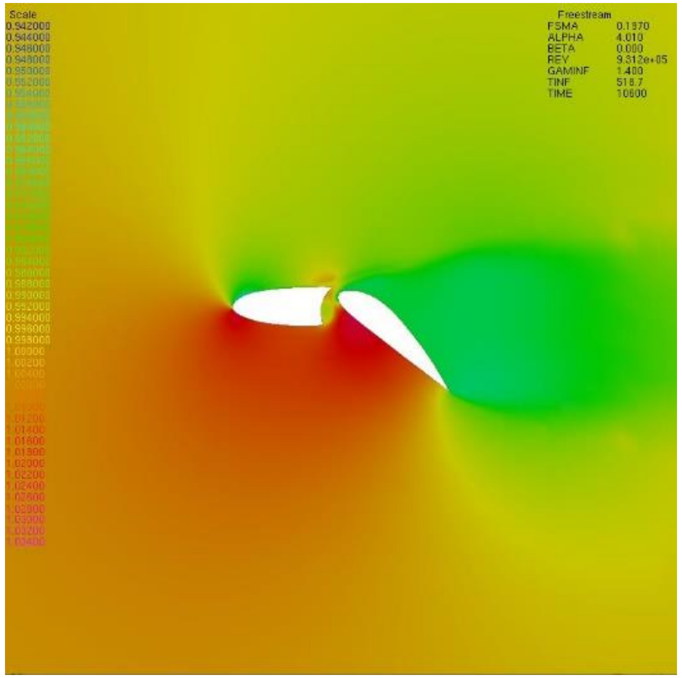
Airfoil geometry and near-body grids



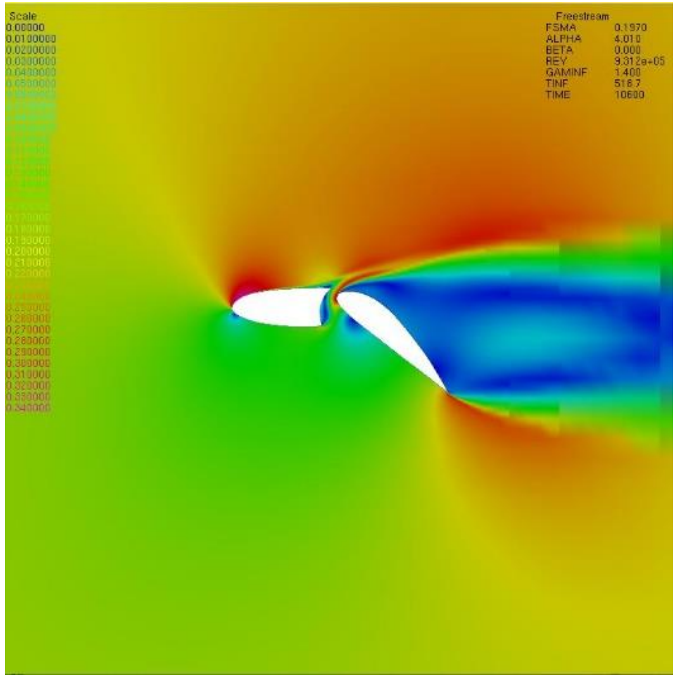
Off-body grids

Multi-Element Airfoil OVERFLOW Results

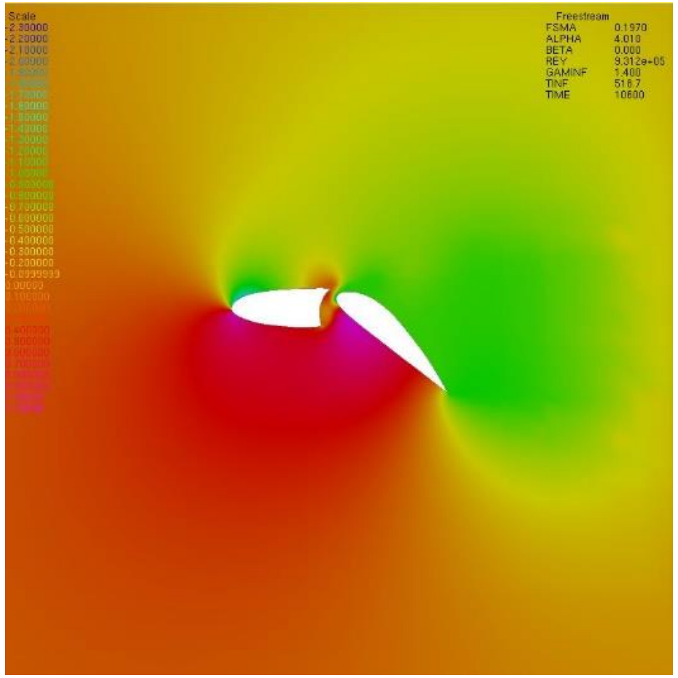
- 35-degree flap deflection
- Clear flow separation in Mach number contour plot



Q1 contours



Mach number contours



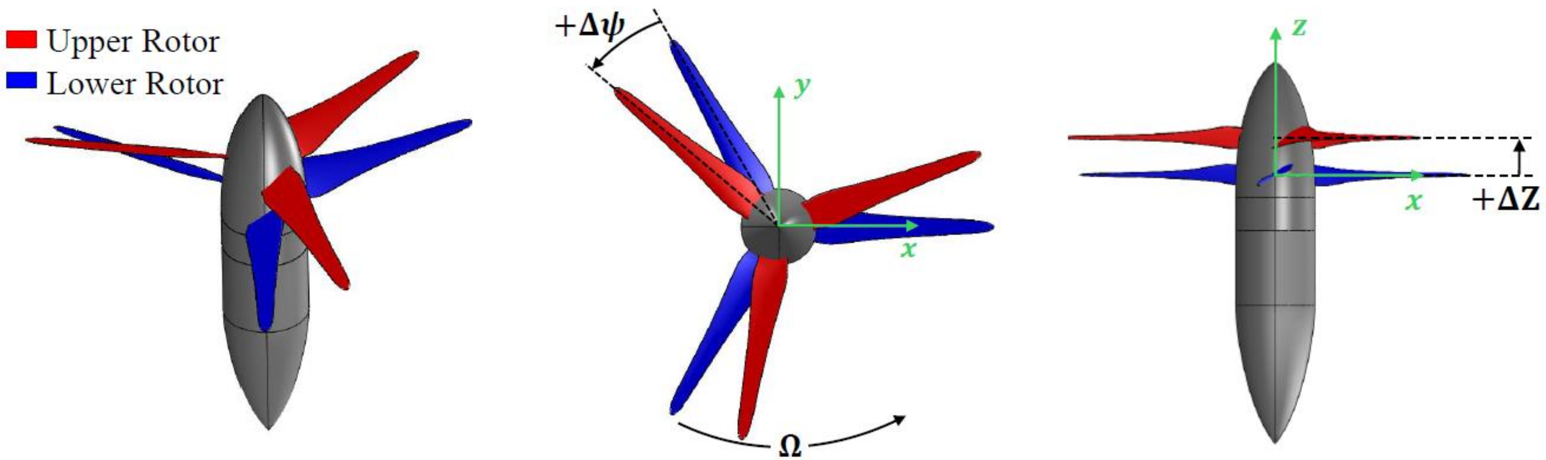
Pressure coefficient contours

OVERFLOW Co-Flow Validation Case

- Gechang's D245 case geometry imported into CGT and a configuration was developed (Joe Derlaga and Shali Subramanian)
- Latest developments:
  - Study of co-flow jet boundary conditions
  - Co-flow jet grid systems cleaned up
- D245 geometry successfully manipulated
  - These new drawings can be imported into CGT, grids developed and OVERFLOW simulations run for this sweep of geometries
- Future studies: Compare OVERFLOW predictions with FASIP CFD predictions

3. Stacked Propellers

Stacked Propellers

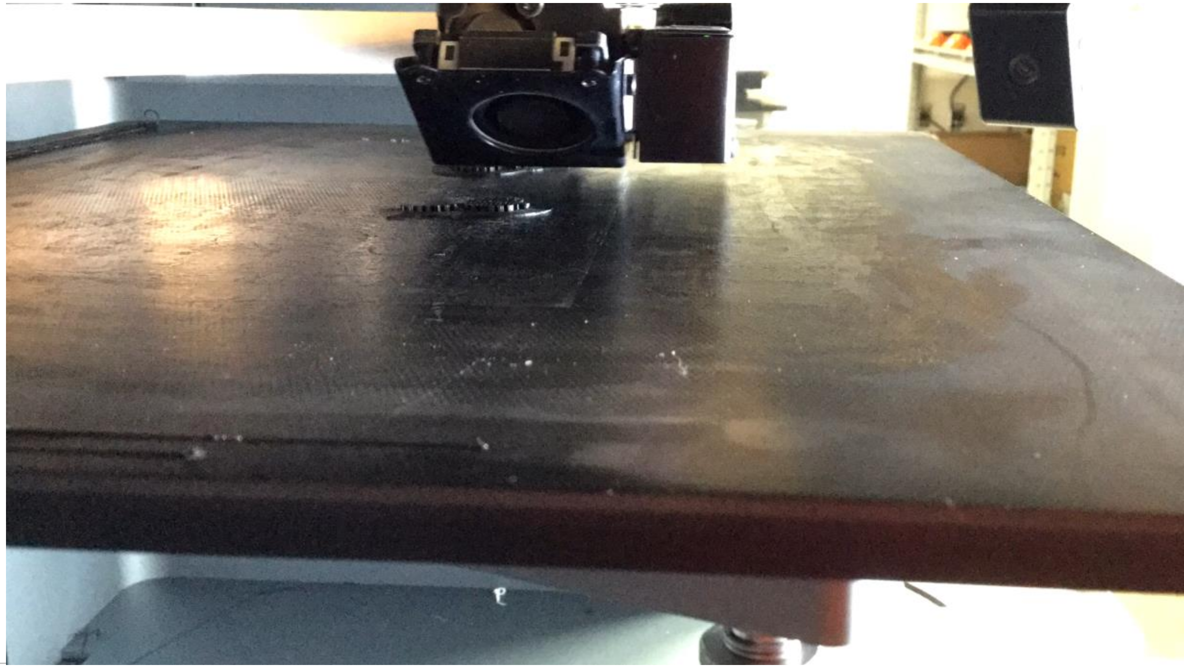


(a) Isometric view (b) Top view (c) Side view

- Co-rotating blades on same shaft with axial offset
- Investigating 3D-printed blades to use for performance & acoustic tests
  - Printing inconsistencies were experienced during Fall 2019
- How can the blades be printed more reliably?

Support Structure Development

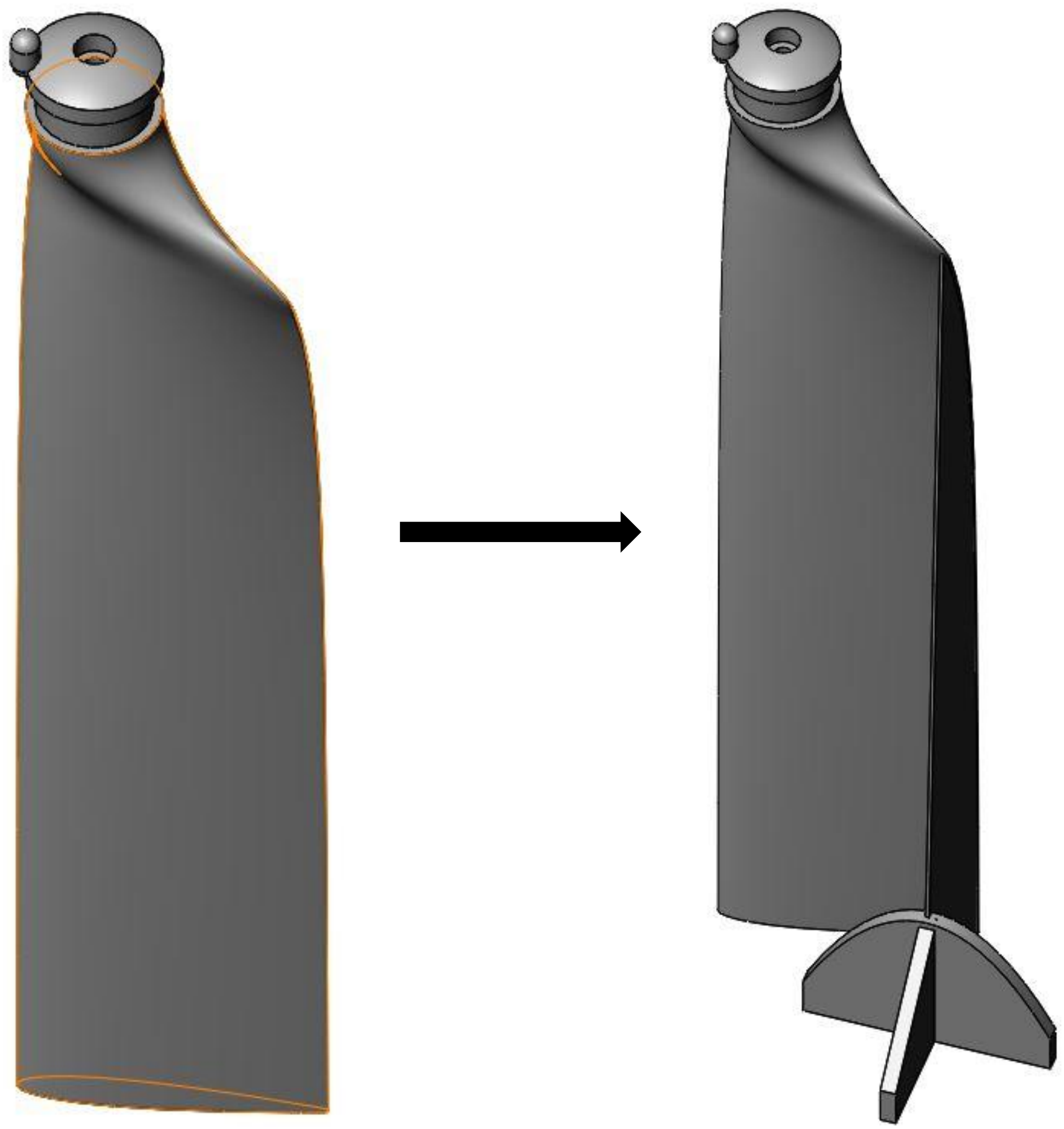
- With blade root at printbed, print area was very small
- MarkForged[3] supports (accordion structure) are unreliable for tall, thin structures such as a propeller blade
  - Caused failures when print approached blade tip
- Can a support structure be designed that would allow for repeatable and reliable prints?
- Can prints with support structure achieve accurate dimensions, adequate surface finish and consistent weight?



[3]https://markforged.com/

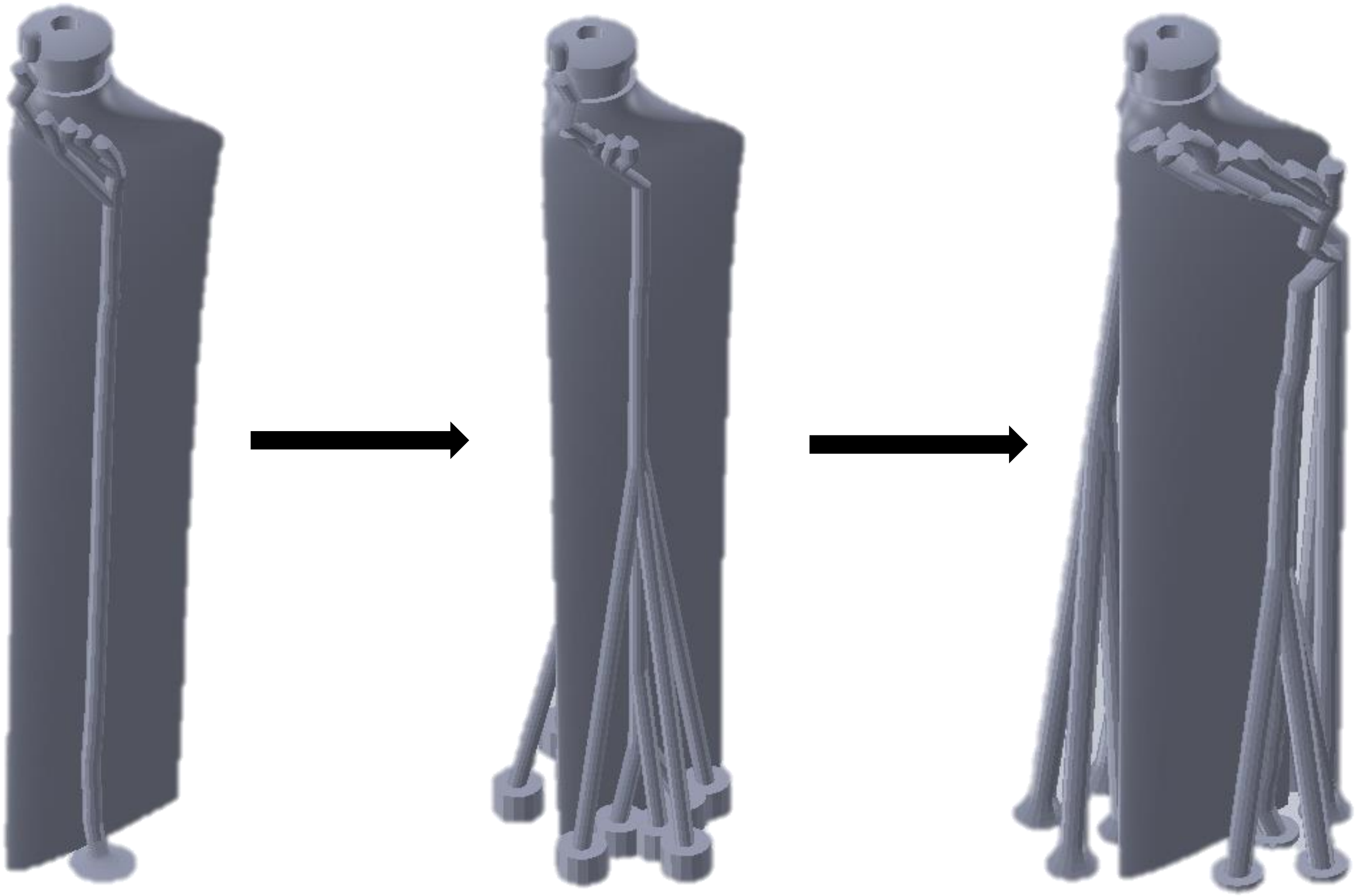
Support Structure Development

- Flipped blade upside down; printed with blade tip on printbed
  - Increased printbed area by significant amount which increases stability
- No supports are generated because there are no overhanging features
  - Print became unstable at very top
- Designed support structure emanating from blade trailing edge to a base on printbed
  - Designed in CAD; very stable
  - Structure is too difficult to remove from part; results in undesirable TE roughness



Support Structure Development

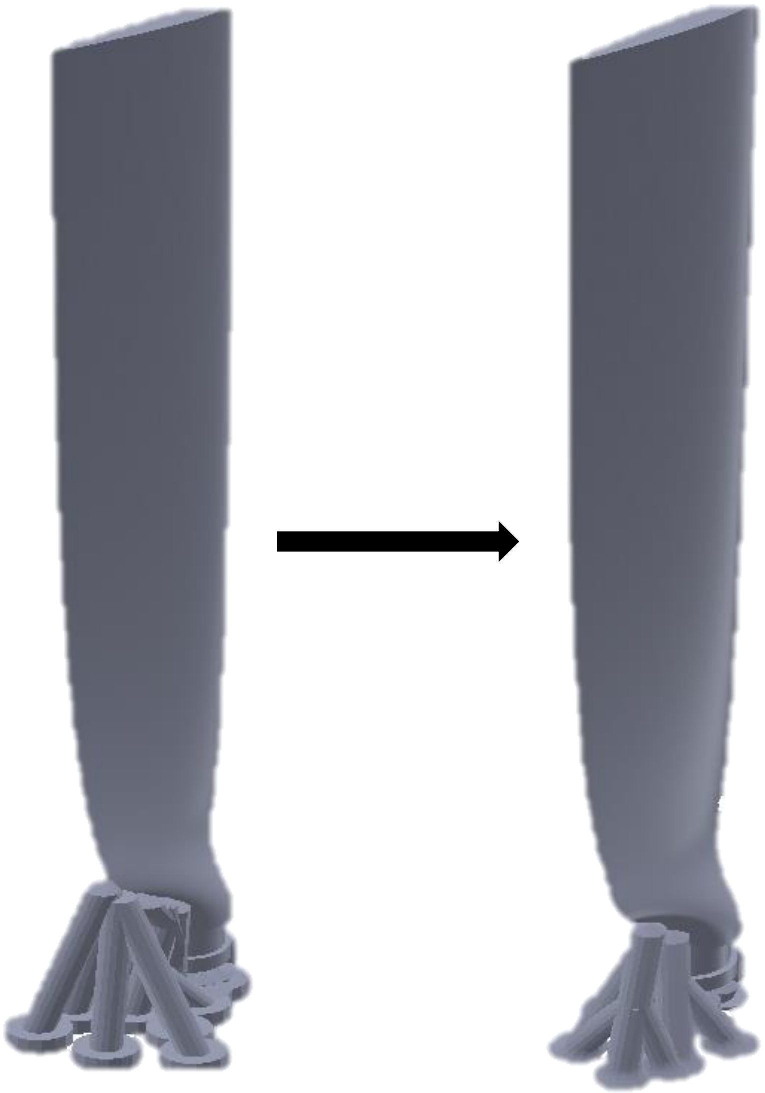
- New supports were generated in Meshmixer[4] STL-editor software
- These configurations resulted in successful prints
- Support removal produced undesirable defects on lifting surface of blade and weight inconsistency



[4]http://www.meshmixer.com/

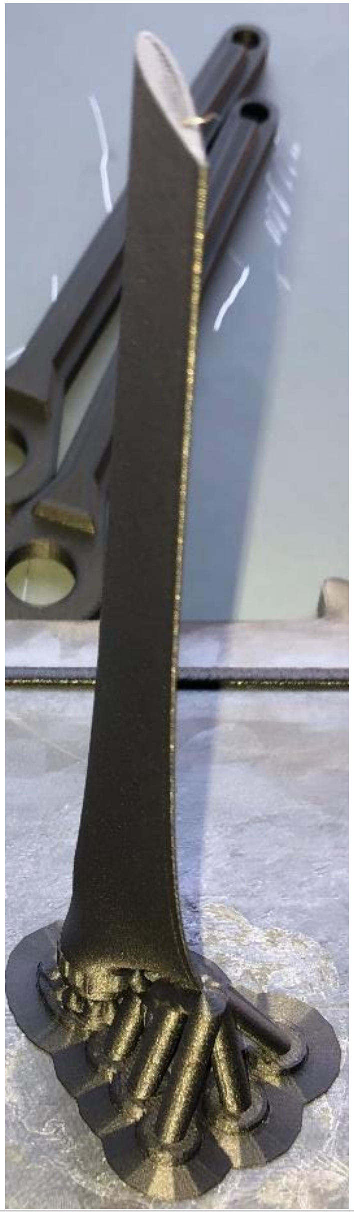
Support Structure Development

- Reoriented blade with root at printbed so Meshmixer-defined supports contacted blade at a non-lifting surface
- Successful prints resulted
  - Minimal defects; occurred on a non-lifting surface
  - Defects would not affect performance or acoustic testing in a significant way
- Resulting surface irregularities may cause inconsistencies in weight



Future Studies

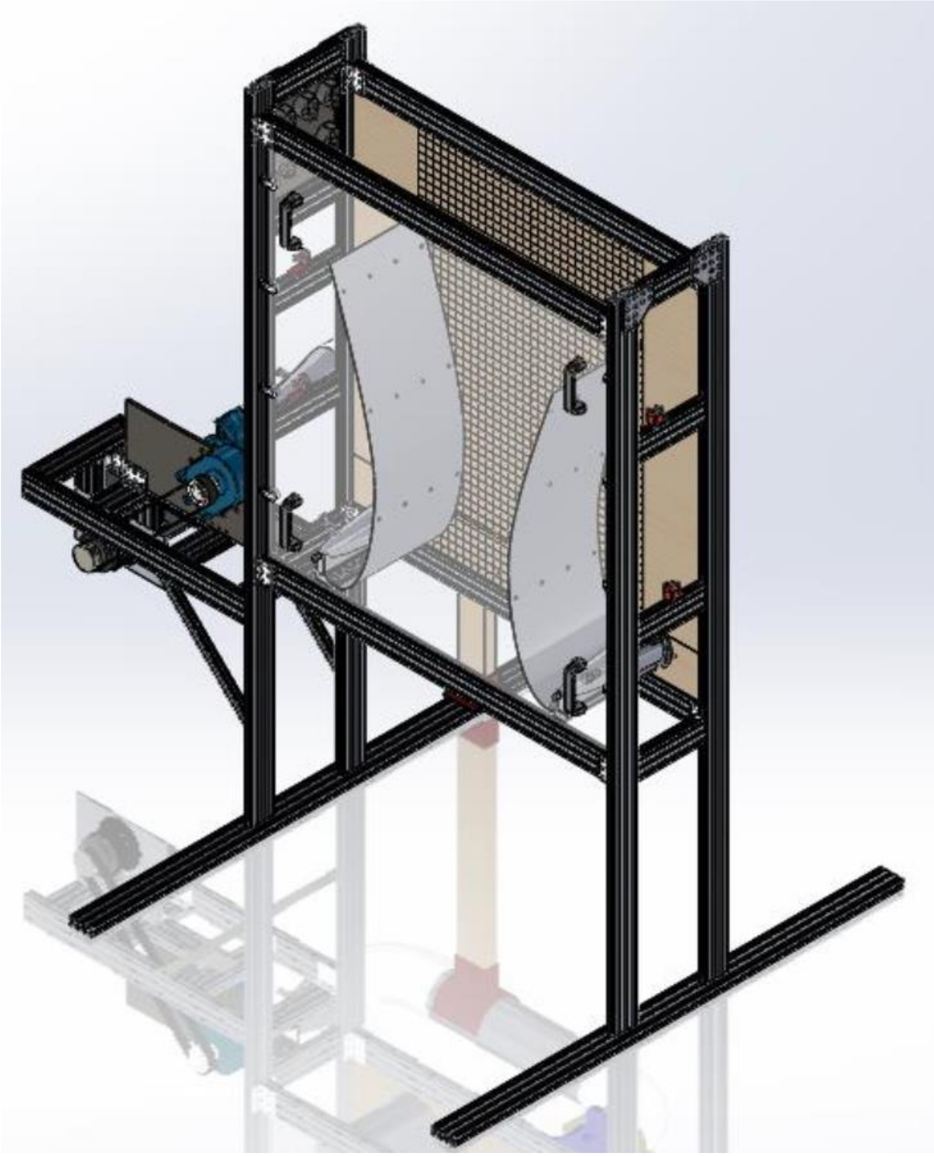
- Produced 5 blades that will be available for performance/acoustic testing
- Print on X7 to study if blade quality is enhanced by smaller layer height
- Blades to be sent to Aeroacoustics Branch for further performance and acoustic testing
- Study different roof, floor, and wall layers; infill patterns
- Study support structure that does not produce inconsistencies in weight



4. Thrust Augmentor Static Test Rig

Static Test Rig

- Static test rig designed by Paul Rothhaar and Bill Fredericks (Advanced Aircraft Company)
- Procurement of parts and initial setup by Beau Pollard, Shali Subramanian and Paul Rothhaar
- Manufacture and build nearly completed: piping assembly only part incomplete



Static Test Rig - Progress

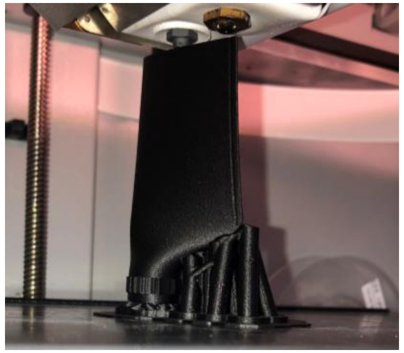
- Couldn't locate correctly-sized pipes in B1232
- Used existing 90-degree elbows, designed adapters in CAD and 3D-printed them in Makerspace (B1238)
- Two adapters:
  - One connected to custom T-pipe and the other connecting to supercharger
  - Printed with high extrusion ratio to ensure no air leakage
- Bought 4" pipe to finish piping assembly
- Finished assembly of pipes
- Ran supercharger to see if mass flow seemed reasonable

Future Studies

- Finish assembly by installing sheet metal
- Run tests on the test rig to study lift generation

Summary

- Co-Flow Experiment and Duct Design
  - Duct assembly at good stage to begin testing inside a wing assembly
  - Wing manufacture and experiment in planning stages
- Co-Flow OVERFLOW CFD Validation
  - Co-flow OVERFLOW comparison case setup complete
  - Sweep of geometries created for future OVERFLOW investigations



- Stacked Propellers Support Structure
  - Support structure produces stable prints, good surface finish and accurate dimensions
  - Ready for future prints and performance/acoustic testing
- Thrust Augmentor Static Test Rig
  - Assembly nearly complete (sheet metal remaining)
  - Ready for testing

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QUESTIONS?