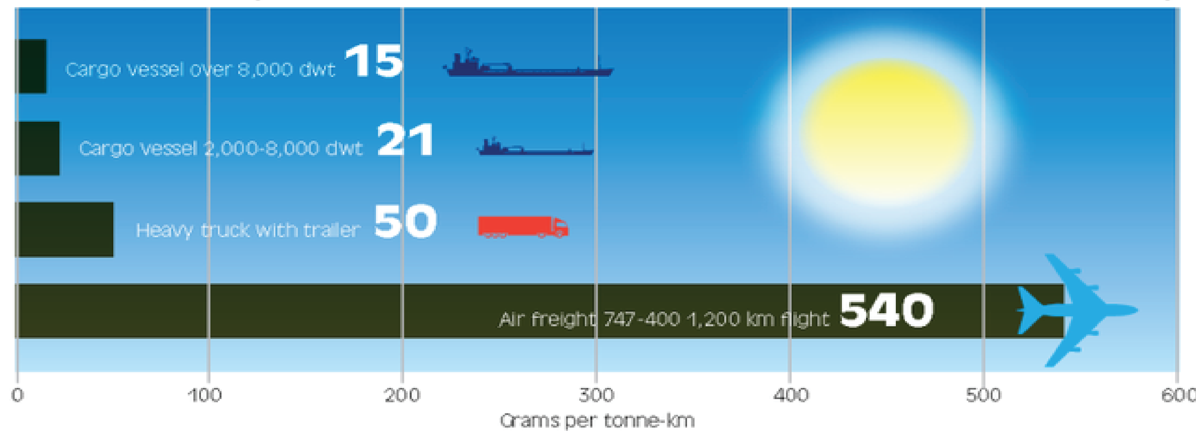
How This Changes the World

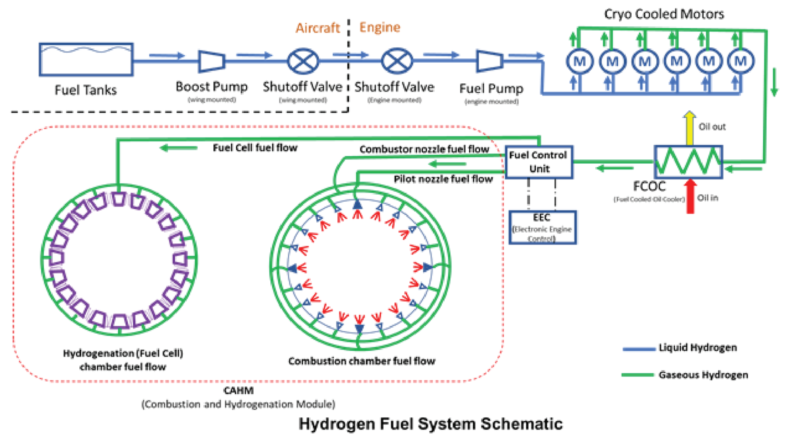
- Hydrogen fuel cells can be used for a wide range of applications such as generating power for satellites and spaceships, to powering fuel cell vehicles like automobiles, buses, or boats, and also generating primary or emergency backup power for buildings, all while being carbon free. Solid Oxide Fuel Cells hold the greatest capability due to their high electrical efficiency, high temperatures and low operating costs. This is the first carbon free propulsion system for large transport aircraft in the world!

- The system is optimized by using a combination of SOFC and hydrogen combustion for takeoff and climb with the combustion system reduced to essential pilot fuel nozzle for cruise and decent while relying on the SOFC for the majority of the power.

- Out of all the heavy modes of transport, aircraft contribute the most to CO2 emissions, as you can see below. Replacing all active 737 and A320 aircraft with our custom engine would save 51 million metric tons of CO2 per year, which is the equivalent of planting 58 million trees per year.

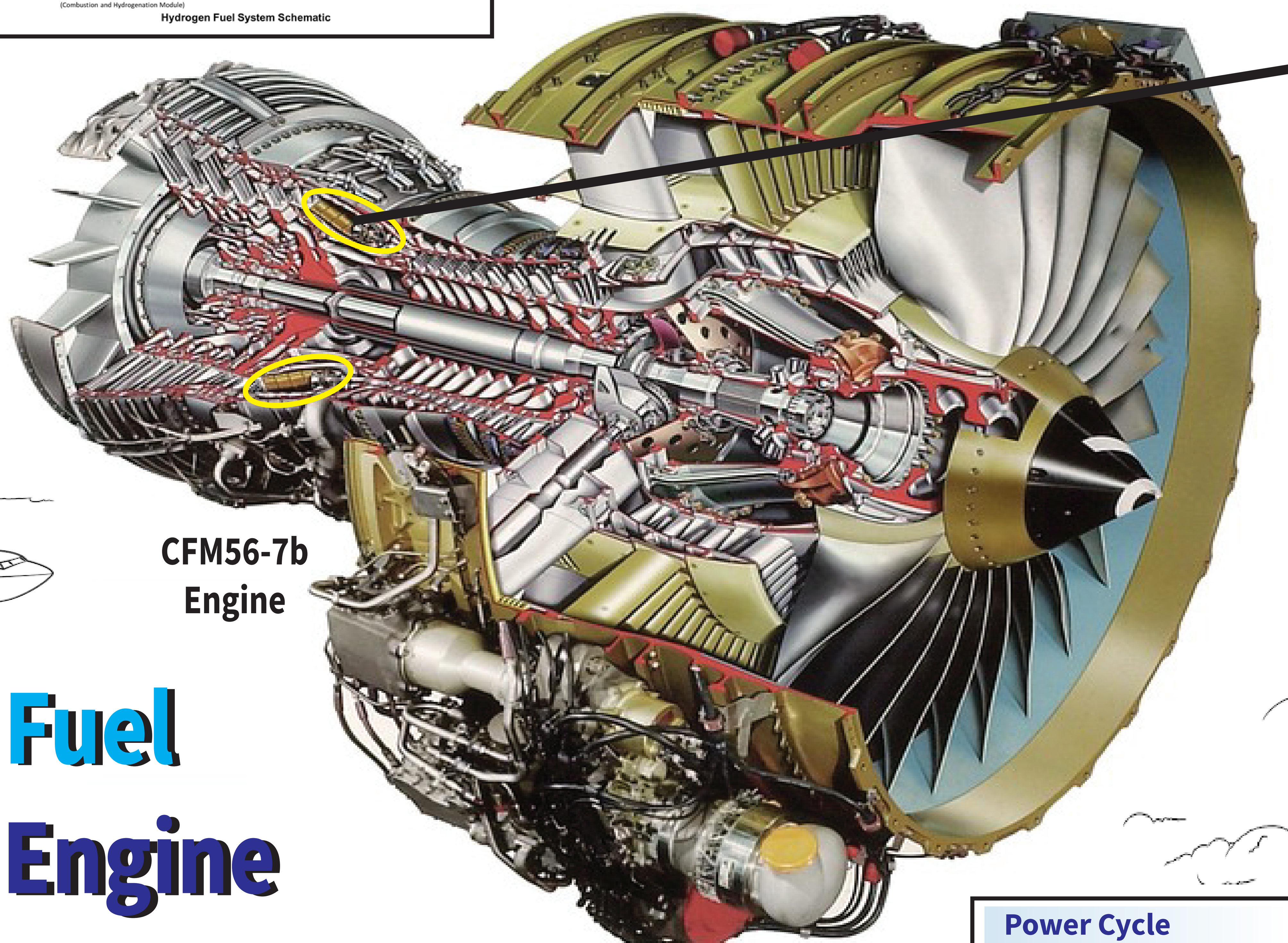


- The power unit produces 6.33 MW of electric power that runs through cryogenically cooled electric motors. The remaining waste thermal power is captured by the low pressure turbine and transferred to the low pressure shaft. You can see our Hydrogen Fuel System to the right.



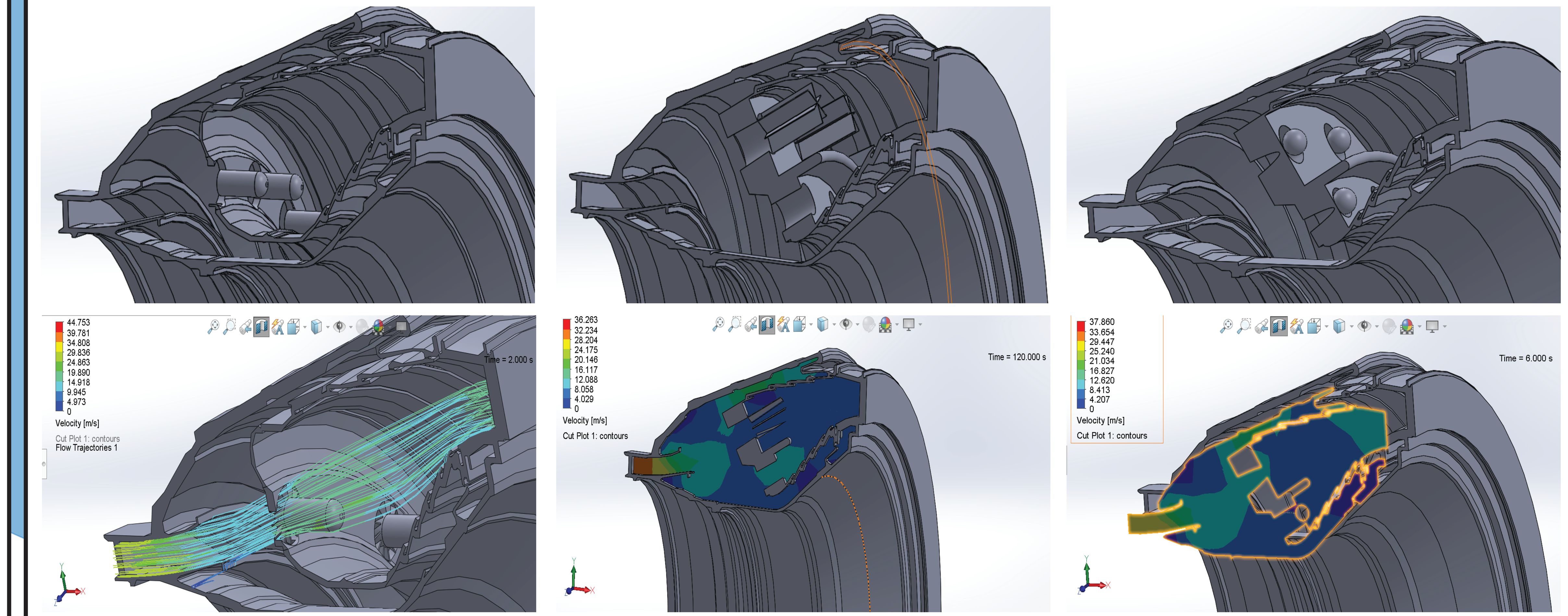
References

- https://www.business-wire.com/news/home/20150223005522/en/F-CO-Power-Develops-Next-Generation-Solid-Oxide-Fuel
- https://www.bloomenergy.com/blog/every-thing-you-need-know-about-solid-oxide-fuel-cells
- https://www.thermofisher.com/blog/materials/analyz-ing-the-com-position-of-a-solid-oxide-fuel-cell-during-thermal-cycling/
- http://www.supercoloring.com/coloring-pages/boeing-737
- https://petrolog.typepad.com/climate_change/2009/09/car-bon-emissions-from-aircraft-and-ships.html



CFM56-7b Engine

Solid Oxide Fuel Cell Turbofan Engine



Testing

After building an annular combustion chamber (seen above), we performed many computational fluid dynamics runs in order to validate the CFD model. In an attempt to accurately model the mixing within the combustion chamber, swirlers were added to the metering panel in the forward part of the combustion chamber. To get better heat transfer, we turned to using simple heating fins. All the faces were defined to give out a set amount of power and placed just in front of the inlets. To see if the heating element was ruining the flow, we used a sphere for the heating element as it would disturb the flow the least. This did dramatically decrease the surface area interacting with the flow, but we were hoping the lack of interference with the flow would allow at least a portion of the coreflow to heat up to the right temperature. This was all done in an attempt to model the heat transfer associated with combustion because SolidWorks could not model combustion.

Project Goal

To determine if large commercial aircraft can be powered by non-carbon emitting engines while still attaining similar range and payload properties of existing commercial aircraft (targeted to 737 and A320 sized aircraft).

Why?

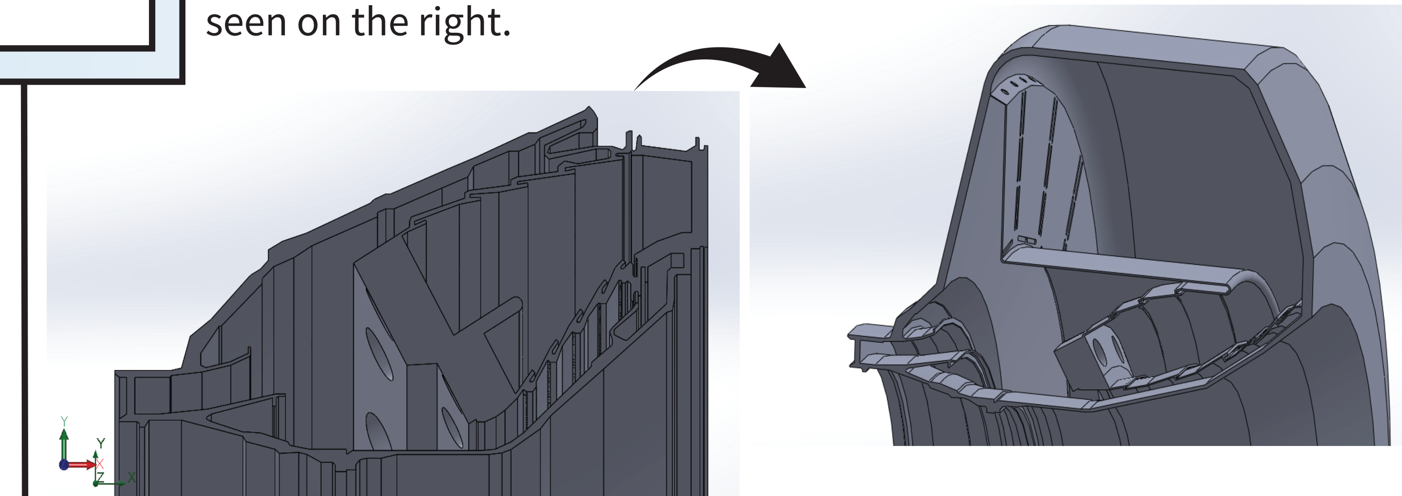
Aircraft account for 12 percent of all U.S. transportation and greenhouse emissions and 3 percent of total U.S. GHG emissions. Given the increased public awareness of the aviation sector's current impact on global greenhouse emissions, there is growing pressure to limit aviation generated greenhouse emissions.

What We Did!

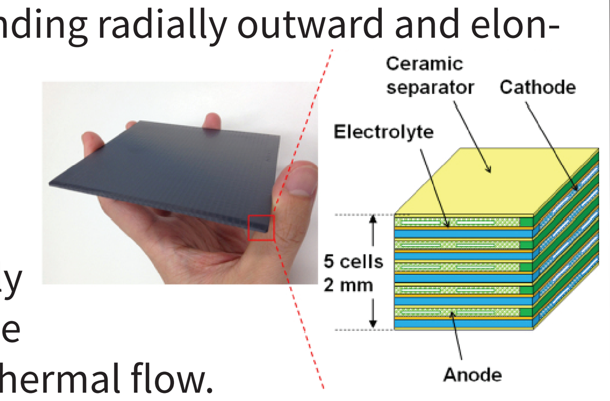
Our group looked at the high electric and thermal output of solid oxide fuel cells (SOFC) and found that, with some adjustments to existing turbo fan engines, a hybrid engine could be created that uses both combustion and solid oxide fuel cells to provide carbon free propulsion for large transport aircraft.

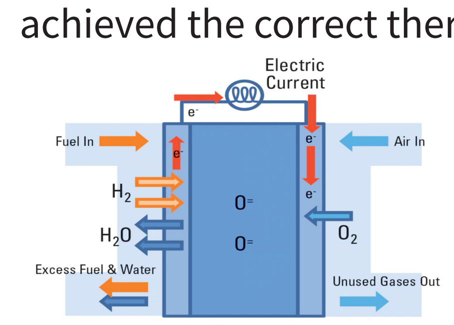
What We Made

- The base Dual Annular Combustion Chamber (DAC on the left) had to be customized to fit our Fuel Cell Stacks. The finished product can be seen on the right.

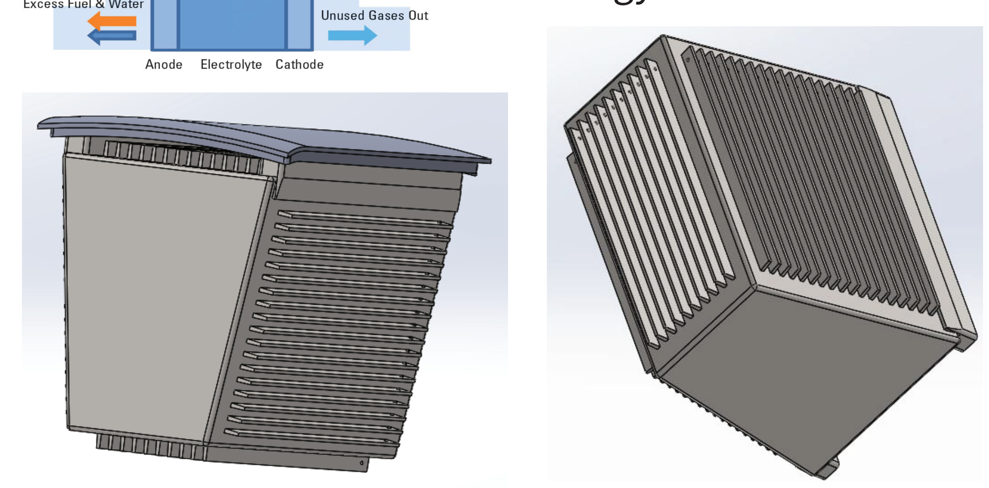


- We took the total volume and target power needed and compared those with the power output of the 3D printed cells we are using. Then found the correct volume needed to use the original fuel injector spaces for 20 fuel cell stacks. We optimized the dimensions of the stacks while expanding radially outward and elongating the DAC. With the help of heat fins and strategic hole patterns on the metering panel directly forward of the cells, we achieved the correct thermal flow.

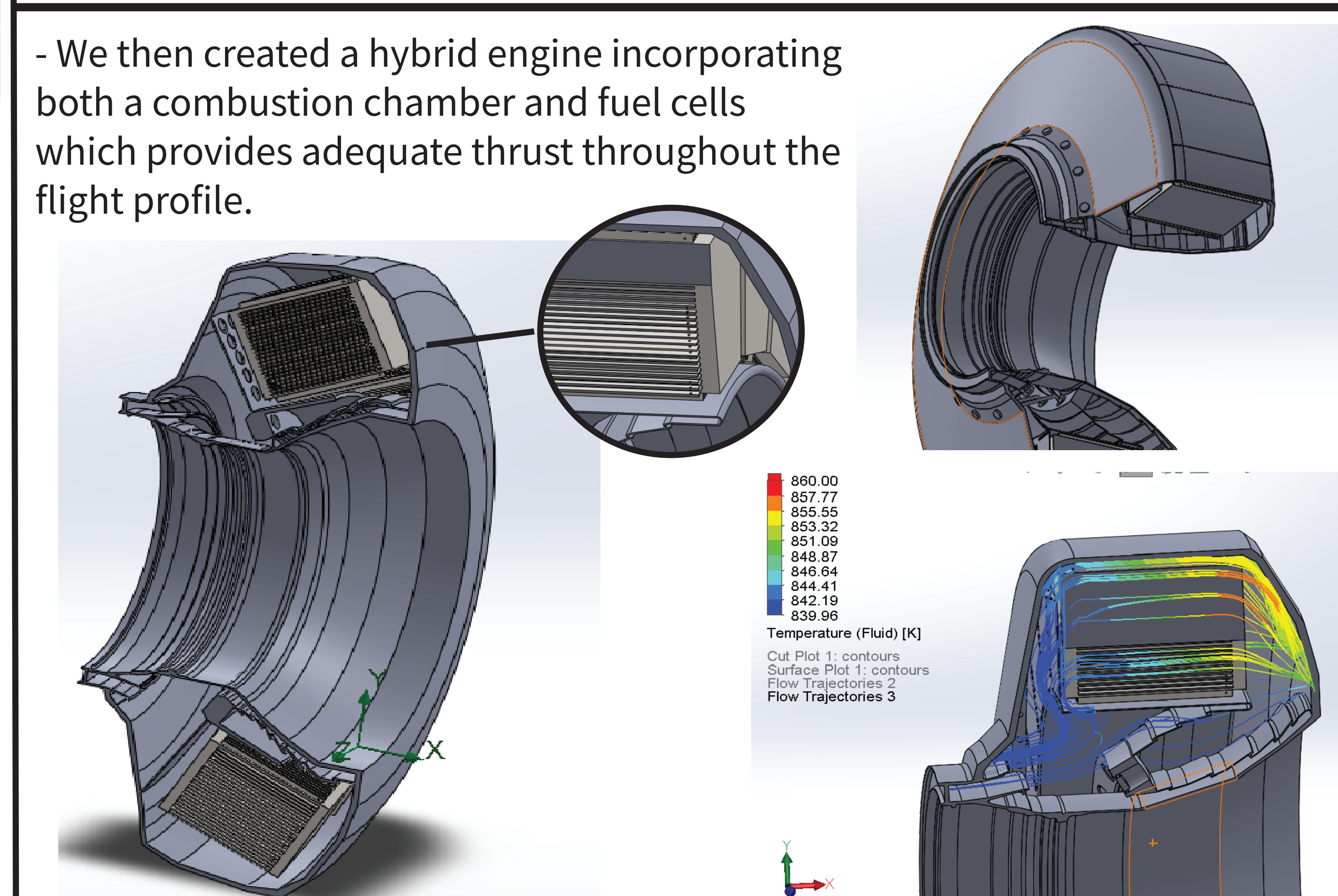




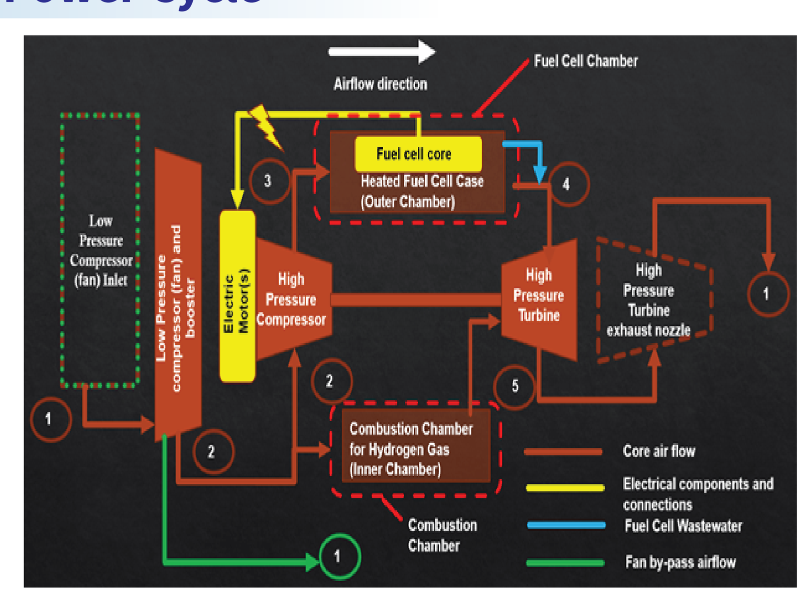
-The 3D printed cell stack our design is based off of has 1/10 the thickness of conventional technology!



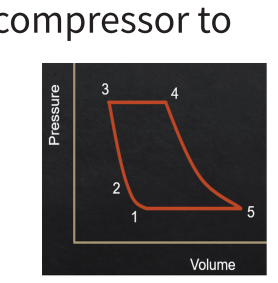
- We then created a hybrid engine incorporating both a combustion chamber and fuel cells which provides adequate thrust throughout the flight profile.



Power Cycle



Our solid oxide fuel cell design will provide high energy output in the form of both electrical and thermal energy. These cells are expected to reach around 1100 degrees celsius, where this thermal energy will be used to help maintain core flow. The electrical energy from the cells will run to the high pressure compressor to also help maintain core flow. This electric energy will run to six 1.1 MW electric motors that will run the compressor. Each number corresponds to a location on the Brayton Cycle diagram.



Human Constraints

- Limited access to the fuel cell assembly for maintenance.
- Working with hydrogen/fuel cells requires special training and safety procedures.
- Building and reading a system to monitor every step and aspect of the hydrogen fuel/fuel cell. These systems will be complex and require special training to monitor.

Technical Constraints

- Hydrogen fuel is lighter than regular JET-A fuel but has a larger volume and thus requires more storage. High density solutions such as Cryogenic storage work well but is very expensive.
- The fabrication of a 3D printed SOFC is still being explored in the advancement of fuel cell production. Having to use a traditional SOFC could result in not enough power (Thermal and Electric) and adding too much weight.
- The infrastructure for production of Liquid Hydrogen needs to be developed to support aviation usage.

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