Building Space Concordia's First Rocket Engine Turbopump in AxSTREAM

Summary

Client: Space Concordia Rocketry Division

Need: Design and manufacture a complete turbopump assembly as a university final year capstone project within the 8-month term deadline. With this deadline, detailed and long design runs were not possible. Instead, the teams needed to use 1D-2D methods to quickly generate a reliable design.

Solution: AxSTREAM was used to design the inducer and main impeller geometries of the liquid oxygen and JET-A fuel pumps as well as the supersonic impulse gas turbine. AxSTREAM RotorDynamics was used to determine critical speeds, produce Campbell diagrams, determine critical unbalances, and find the forced response of the single turbopump shaft. AxSTREAM's AxMAP feature allowed off-design performance to be modeled as well as cold flow performance estimates for the pumps and the turbine.

Product Requirements:

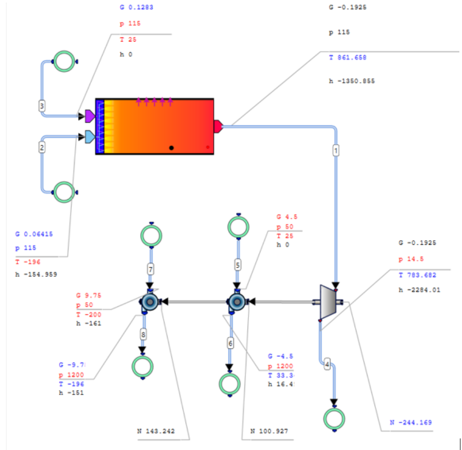
A 1-hour operational design life for all components, which must be compact enough to fit inside Space Concordia's Rocket (6" maximum diameter). Must be able to provide greater than 80 bars of pressure rise for the pumps flowing 15kg/s of propellant while also being able to operate without significant performance losses due to cavitation. The turbine must be a single stage to avoid part complexity and provide the 250+ horsepower needed to power both propellant pumps.

Results:

The turbopump was successfully designed and manufactured and is now undergoing full system integration and component testing.

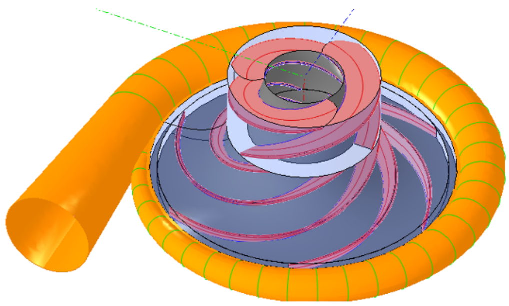
Rocket Engine Cycle Modeling

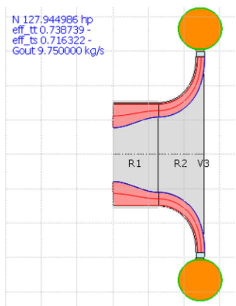
During the initial turbopump design phase, AxSTREAM System Simulation was utilized to model various rocket engine and turbopump cycles. This software enabled the team to conduct parametric cycle studies to determine overall system performance, mass flow requirements, temperatures, and estimate efficiencies. The data generated from AxSTREAM System Simulation was then used to create preliminary designs in AxSTREAM



Pump Design

AxSTREAM's flow path modules were used to design the integrated inducer-impeller for both the liquid fuel and liquid oxygen pumps. This integrated design reduced part count while also localizing any cavitation to the inducer. The software was employed to generate the initial preliminary design and facilitate fine-tuning of the geometries using the blade profiler. Once the final design was reached, AxSTREAM's map tool was used to determine off-design performance and cold flow test performance (with water).

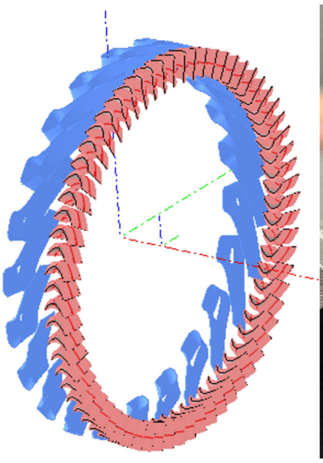


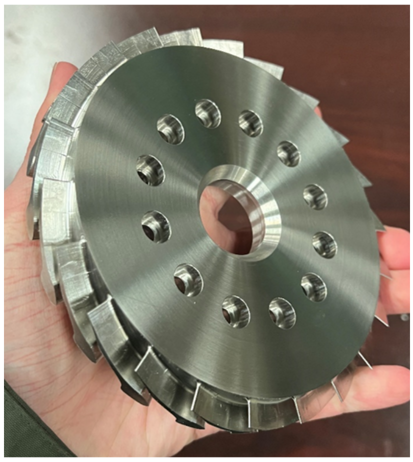


Turbine and Stator Design

The AxSTREAM platform was also used to create a preliminary design of the turbine, featuring a single-stage full-admission supersonic milled nozzle. This was achieved by inputting the turbine's boundary conditions in terms of power delivery, RPM, and mass flow rate. As the turbine was manufactured using DMLS 3D metal printing, the turbine blade design had to be manually adjusted to accommodate additive manufacturing constraints. This adjustment was easily accomplished using AxSTREAM's blade profiler, where changes in blade shape provided immediate performance feedback through the 1D-2D streamline analysis tool.

Cold gas testing performance was also calculated using AxSTREAM by changing the working fluid to nitrogen gas. Pushing the capabilities of the AxSTREAM platform further, AxMAP computed a performance map of the turbine with respect to different RPMs, mass flow rates, and pressure ratios.





Rotordynamics

AxSTREAM RotorDynamics was used to conduct a comprehensive vibration analysis of the system, determining the minimum requirements for shaft design. It performed axial and lateral calculations crucial for assessing the mechanical design's viability and safety. Using 1D/2D methods, AxSTREAM RotorDynamics rapidly analyzed varying shaft dimensions, materials, and loading conditions. It generated Campbell Diagrams and computed the forced/harmonic response of the system under various unbalance excitations and unsteady forces. Critical whirling values determined blade-casing clearances for the turbopump. Additionally, AxSTREAM Bearing facilitated the creation of customized bearings for damped/finite stiffness bearing calculations, seamlessly integrating them into the rotor dynamics simulation.