Aerodynamic Design of a Ducted Contra-Rotating Fan

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Photo Boris Kubrak, Ph.D., Brooklyn, NY

1. Motivation and Objectives

Current developments of eVTOL- and lightweight hybrid airplanes require new propulsion systems. Ducted contra-rotating fans are one option for compact, efficient, low noise electric driven aero engines. In this general case study, we will present the aerodynamic design of a 500N thrust system using CFturbo for the design and CFturbo SMP for 3D flow simulations. Our target is to design a ducted contra-rotating fan with more power and better efficiency at lower rotational speed than a conventional single-stage axial fan with or without stator vanes.

2. Conceptual Design

A ducted contra-rotating fan is preferred over a simple, more conventional fan because of the device's ability to recover the kinetic energy from the leading impeller by converting the relative velocity to static pressure within the trailing impeller. The innovative design of the ducted contra-rotating fan allows for an increase in aerodynamic performance at lower speeds and an overall decrease in power requirement, all at lower impeller diameters.

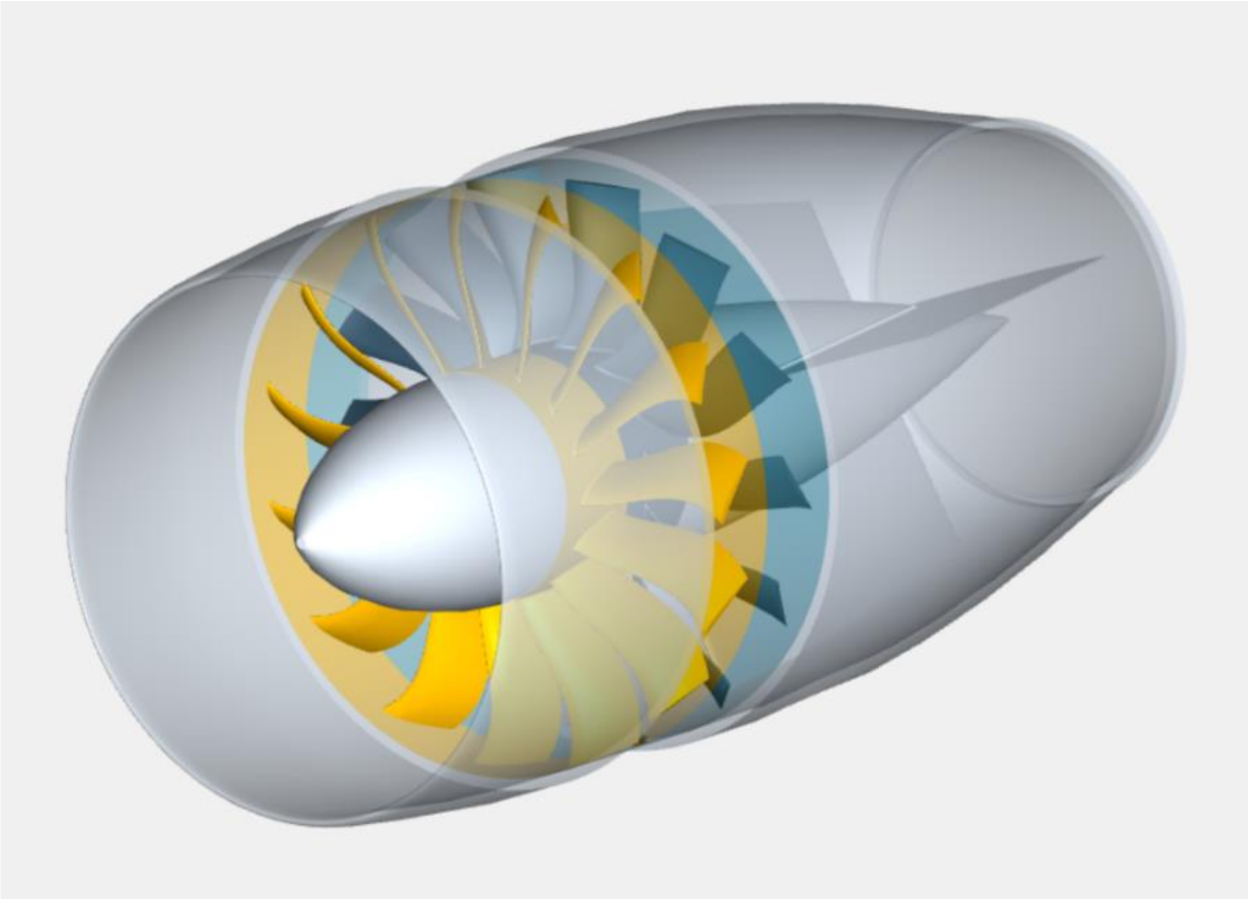
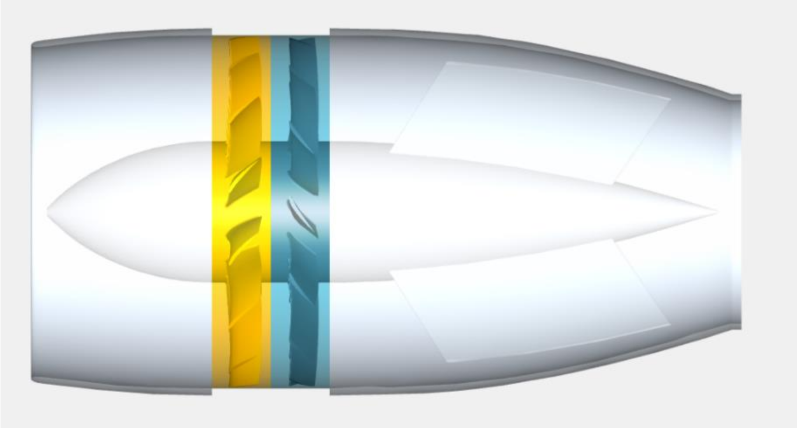


Figure A: CFturbo Contra-rotating Ducted Fan Design



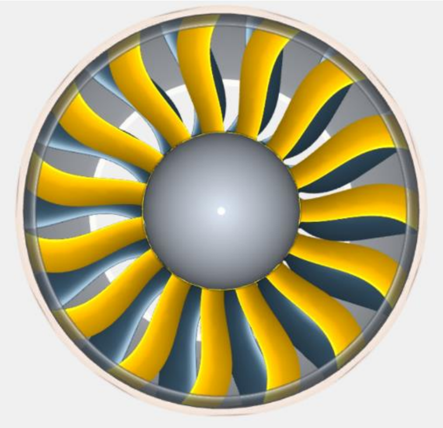
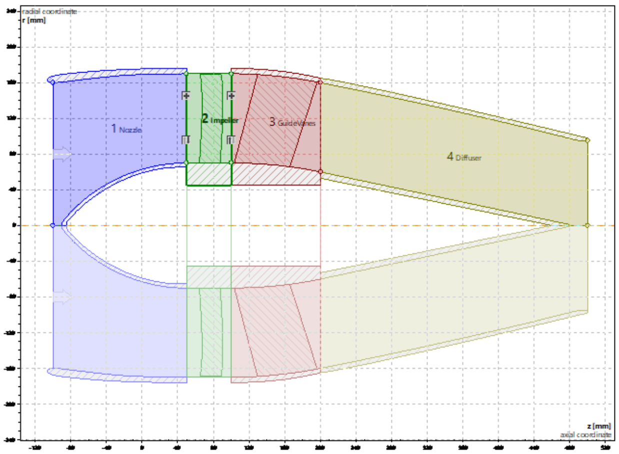


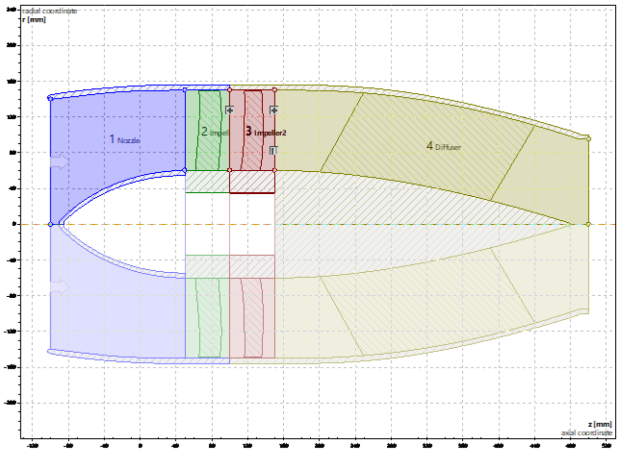
Figure B: Side View

Figure C: Front View

3. Design Parameters

	Single stage + guide vanes	Contra-rotating, two impellers
Thrust	500 N	500N
Volumetric flow rate	5 m^3/s	5 m^3/s
Nominal rot. speed	12,000 rpm	10,000 rpm
Impeller Diameter	340 mm	300 mm





4. Flow Simulation

The ducted contra-rotating fan was initially designed within CFturbo with a volumetric flow rate of 5 m^3/s, a nominal thrust of 500N, and a rotational speed of 10000 revolutions per minute, representing a specific speed of approximately 208 (EU).

To investigate the fan's performance curves, both steady-state and transient computational fluid dynamic simulations were performed using CFturbo SMP (Simerics MP) while varying volumetric flow rates and rotational speeds. For numerical reasons, an inflow area (1 x D) and an outflow area (3 x D) were added to the flow domain.

The steady-state simulations utilized a total of 500 iterations and a first-order upwind scheme for both the velocity and pressure calculations. The transient simulations utilized a total of 360 timesteps, a second-order upwind scheme for the velocity calculation, and a first-order upwind scheme for the pressure calculation. The mesh contained approximately 4.7 million cells.

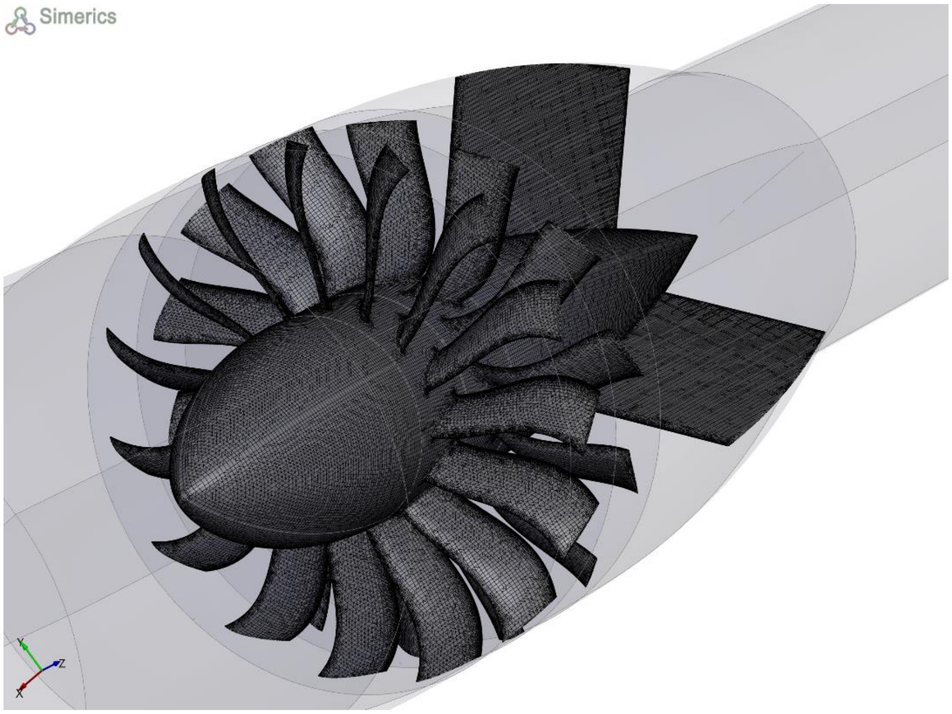


Figure D: Surface Mesh in SimericsMP

5. Key Results

Data regarding the aerodynamic performance of the fan was extracted from CFturbo SMP (SimericsMP) and plotted below.

The base design for the ducted contra-rotating fan comfortably meets the initial design point, allowing for a total pressure difference of approximately 12000 Pascals between the stage—defined as the inlet of the leading impeller and the outlet of the trailing impeller. Figure G shows that the steady-state simulation results coincide with the transient simulation results, with some discrepancies at lower volumetric flow rates. The results for the total pressure difference within the stage exhibit the classic performance shape for axial devices.

The results for the stage efficiencies are displayed in Figure H. Overall, the impellers within the contra-rotating ducted fans were highly efficient, with peak aerodynamic efficiencies of 90% for every rotational speed within the operating range. The no-swirl outflow is a key characteristic of contra-rotating Turbomachinery, a suitable choice for propulsion. The power requirement results for the ducted contra-rotating fan are displayed in Figure I.

The power requirement increases with increasing rotational speed. With approximately equal efficiencies and an overall overperformance in total pressure difference across the stage, the designer can confidently adjudicate for a ducted contra-rotating fan with impellers rotating at lower speeds to decrease power requirements while meeting the design point.

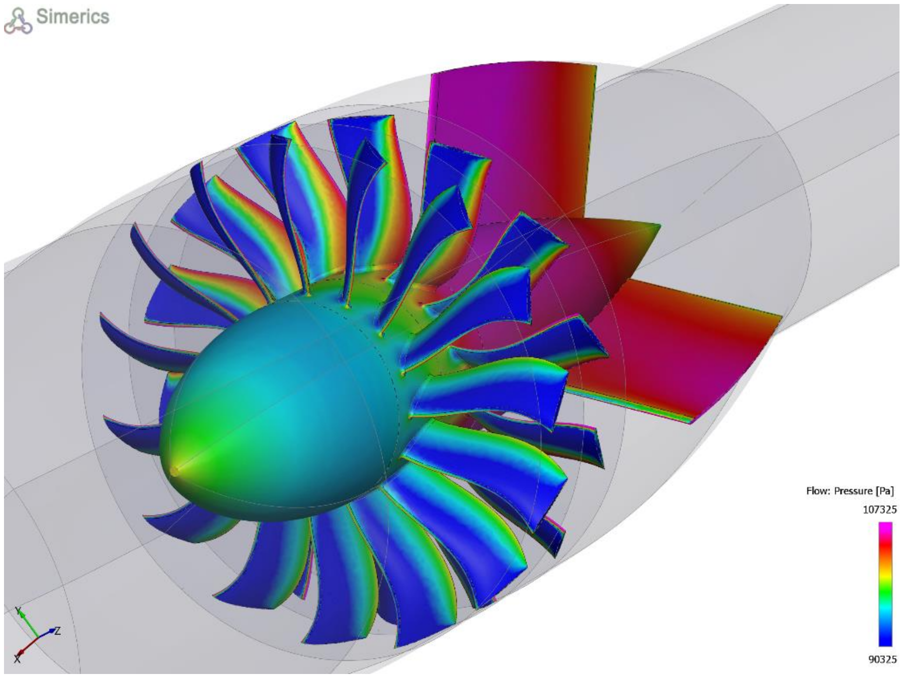


Figure E: Pressure Distribution, CFturbo SMP (steady state, 5 m^3/s, 10000rpm)

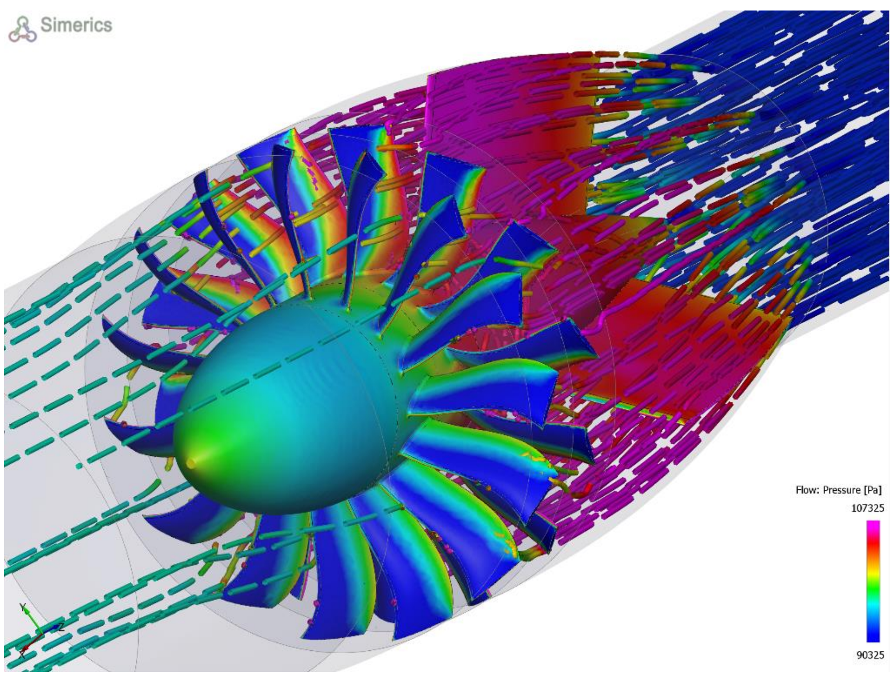


Figure F: Pressure with Streamlines CFturbo SMP (transient, 5 m^3/s, 10000rpm)

No swirl downstream of the 2^{nd} fan stage!

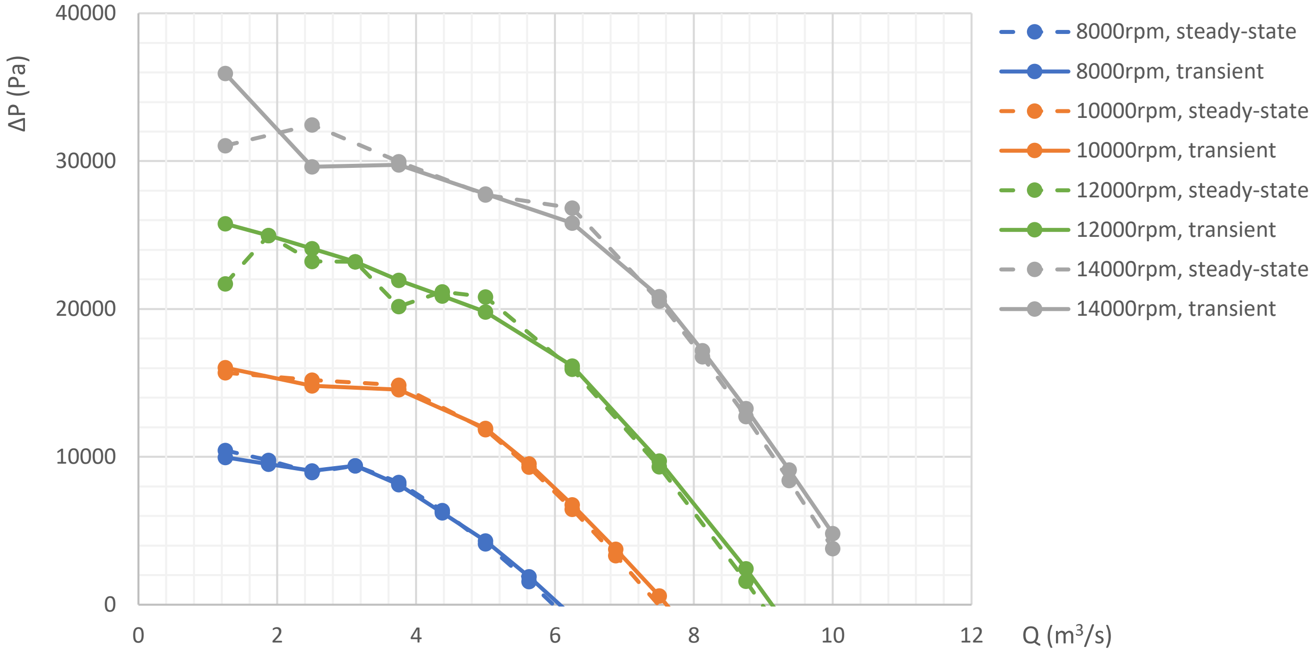


Figure G: Total Pressure Differences, Stage

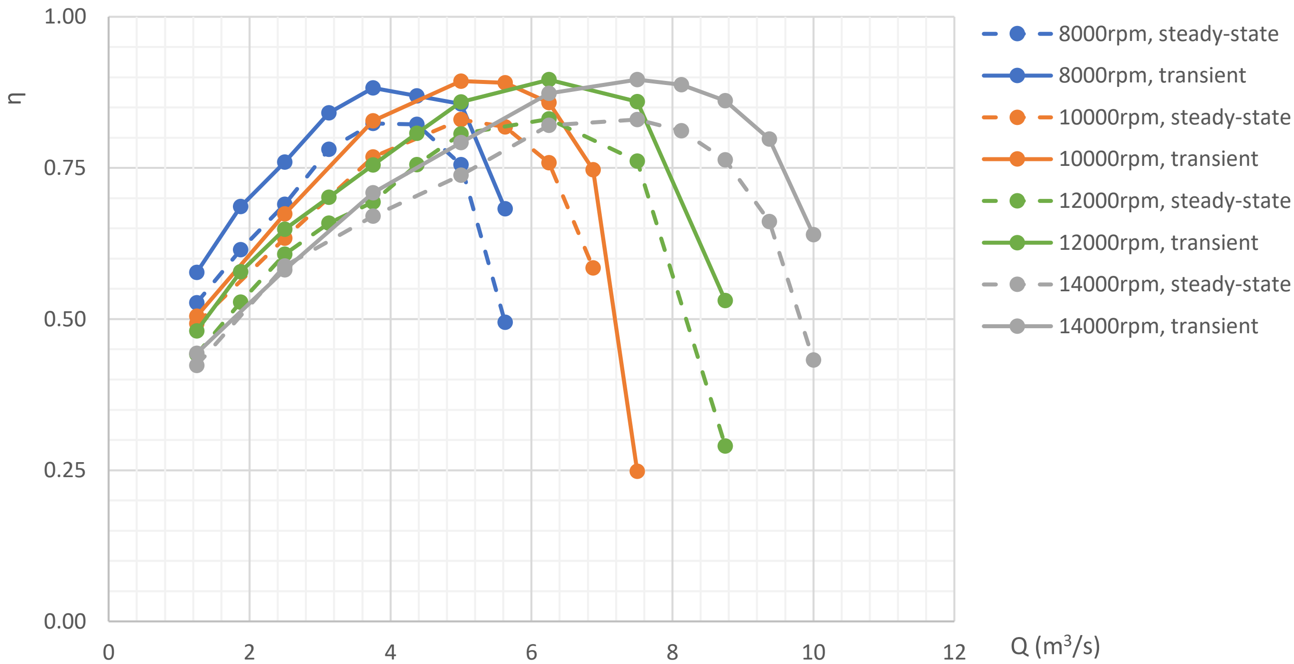


Figure H: Aerodynamic Efficiency, Stage

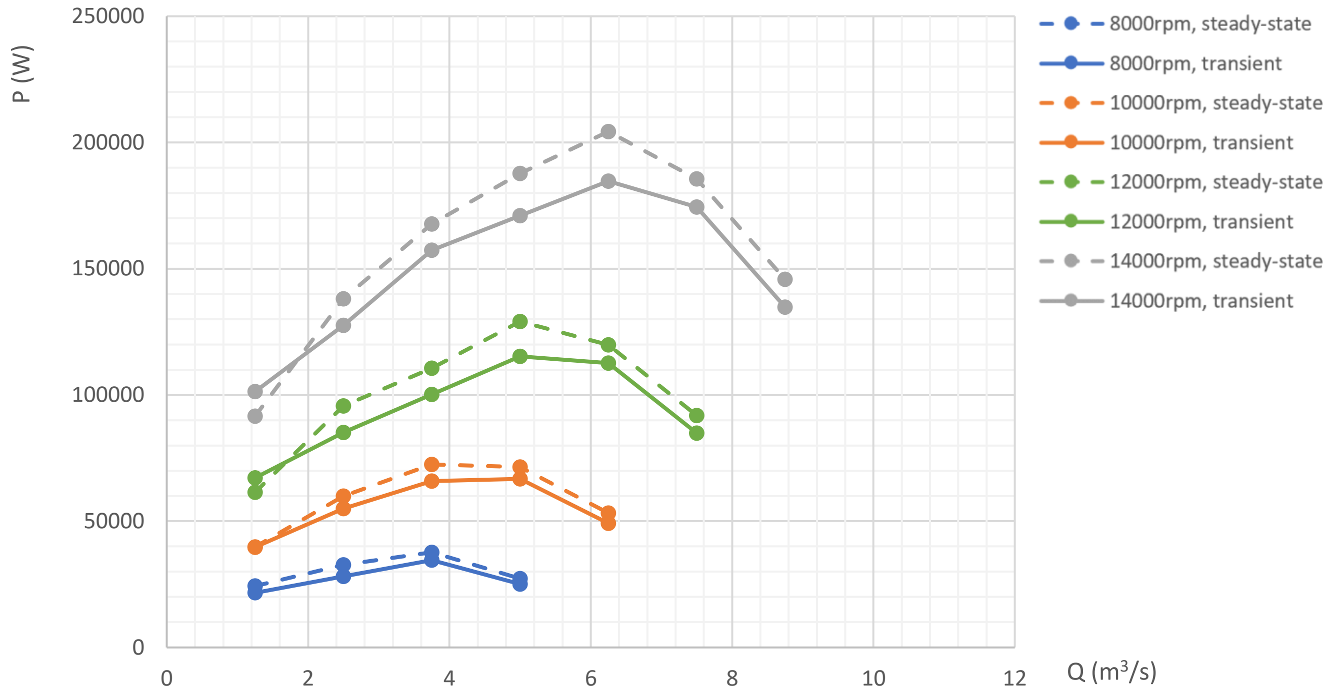


Figure I: Shaft Power

The total pressure difference and efficiency results for each impeller are displayed in Figures J, K, L, and M.

We see the typical offset between steady-state and transient results over the whole operating range when calculating power and efficiency.

The leading impeller performs slightly better than the trailing impeller for every rotational speed within the operating range. However, the aerodynamic efficiency of about 90% is very remarkable because this design was an initial conceptual design without any optimization.

Further design exploration could be done manually in an iterative process or using mathematical algorithms combining CFturbo with third-party optimization software. CFturbo integrates well with optiSLang (Ansys), HEEDS (SIEMENS), DAKOTA (open source), and others.

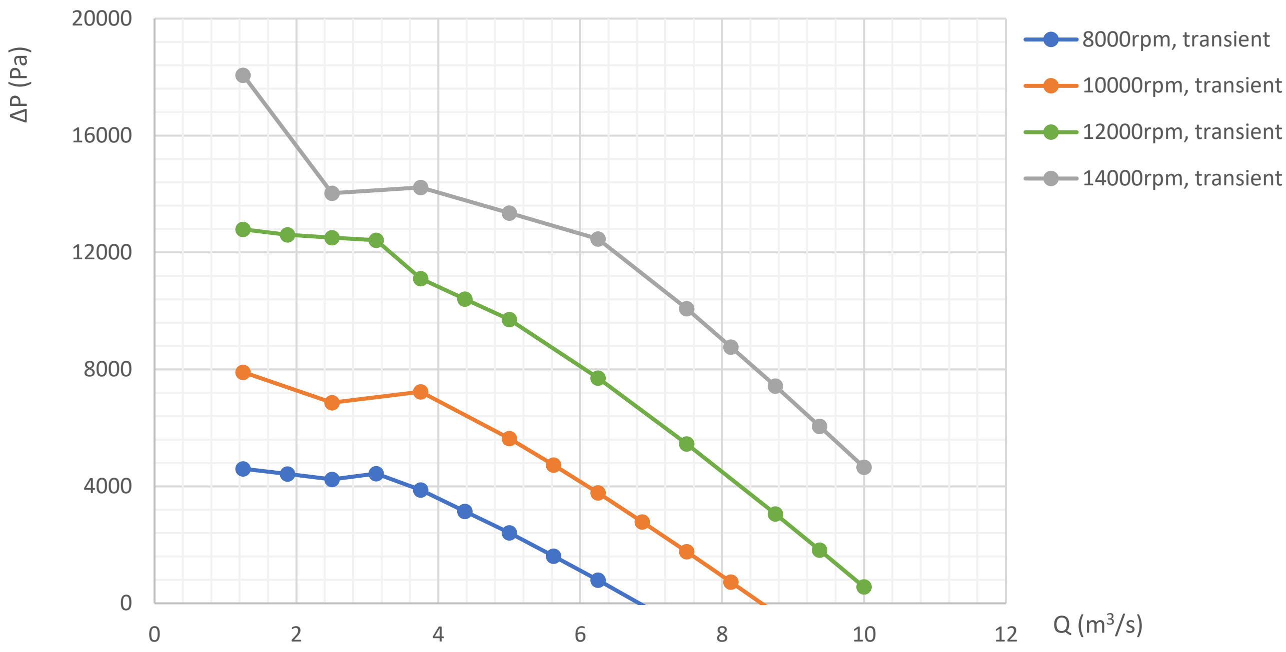


Figure J: Total Pressure Difference, Impeller 1

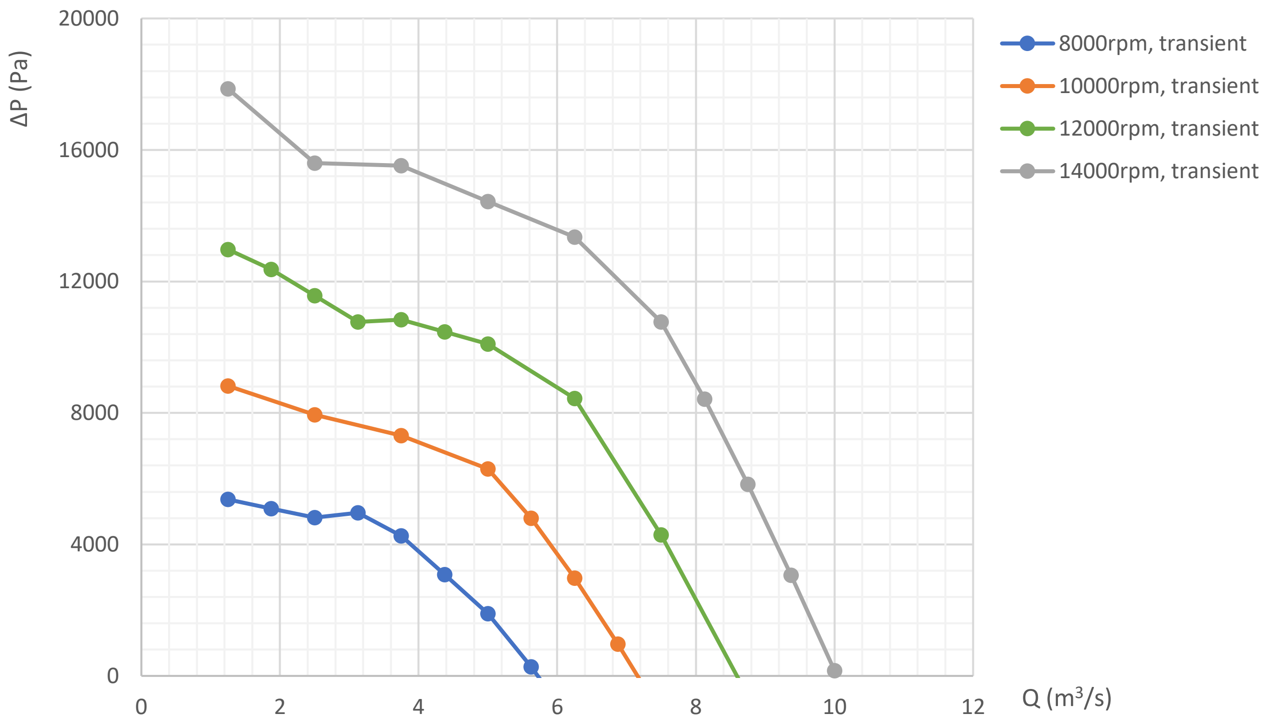


Figure K: Total Pressure Difference, Impeller 2

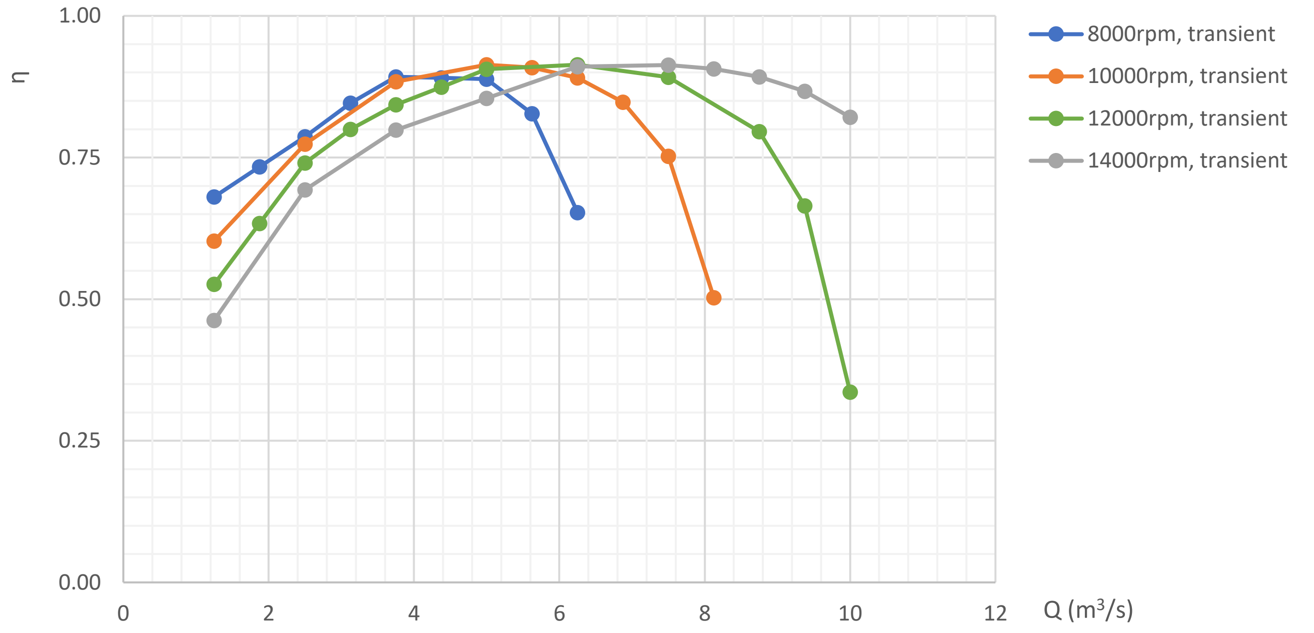


Figure L: Aerodynamic Efficiency, Impeller 1

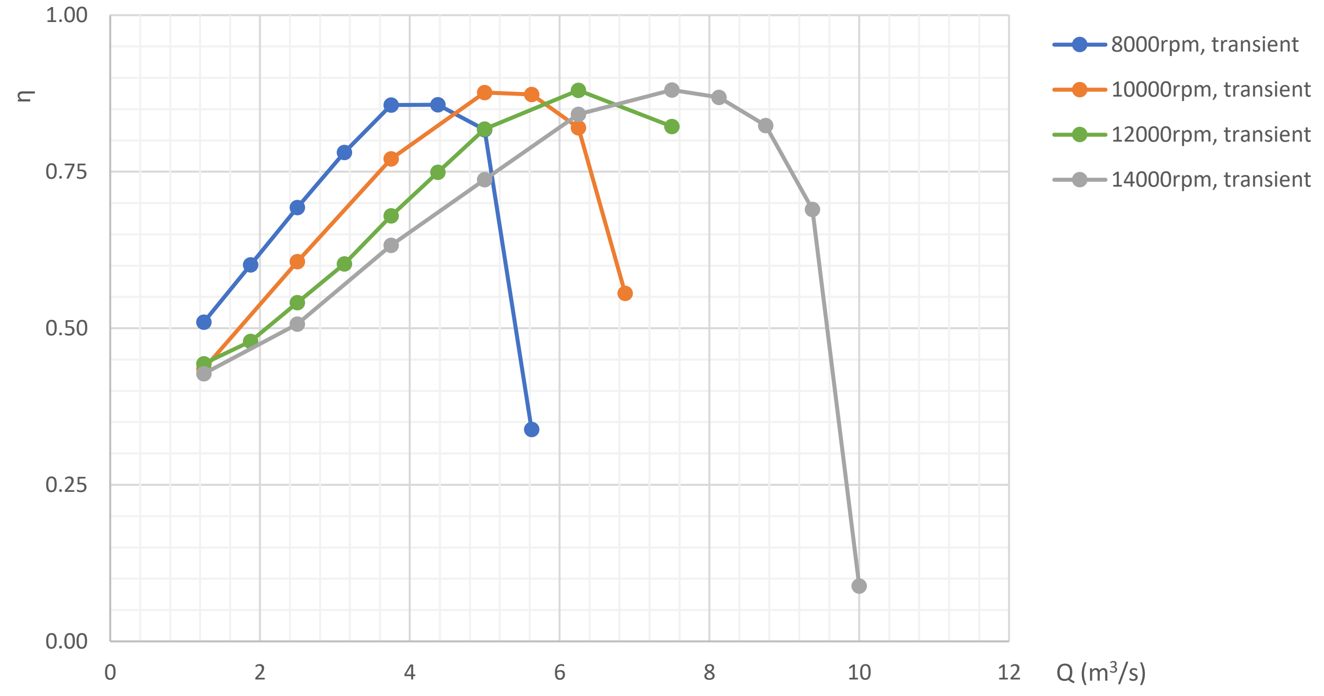


Figure M: Aerodynamic Efficiency, Impeller 2

About CFturbo

CFturbo (est. 2008) is headquartered in Dresden, Germany, with a major office in New York City, New York. The company is supported by a global network of distributors and has gained worldwide respect within the Turbomachinery community over the last ten years. CFturbo is dedicated to Turbomachinery design and related engineering services in design of rotating machinery, fluid flow, and heat transfer.

Our conceptual design software is the most user-friendly system available on the market—through its unrivaled, intuitive, and user-friendly design process, CFturbo software empowers every user, regardless of experience. The software can be used to design a variety of turbomachinery-related devices, including pumps, fans, blowers, compressors, turbines, stators, and volutes. CFturbo, Inc. offers a variety of Turbomachinery engineering services including aerodynamic and hydraulic designs, CFD and FEA simulation, rotating machinery optimization, mechanical design, prototyping, and testing. For more information, visit **cfturbo.com.**