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Aerospace propulsion and related technology research

Prof Ryno Laubscher

Stellenbosch University - Faculty of Engineering
Industry showcase 2026

Research group - overview

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The TPM Group models integrated thermal systems, including propulsion and power cycles, using thermofluid network modelling, CFD, and machine learning.

- Develop software tools for system-wide, multiscale, multi-point simulation and design optimization.
- Perform component-level research and simulation of turbomachinery, combustors, and nozzles to inform system-level models.
- Conduct experimental testing of turbomachinery, combustors, and integrated engine performance to validate and extend the models.

TPM Group
THERMOFLUID PROCESS MODELLING
RESEARCH GROUP
@ STELLENBOSCH UNIVERSITY

Research partners/clients:

Solar Turbines
A Caterpillar Company

FLOWNEX®
SIMULATION ENVIRONMENT

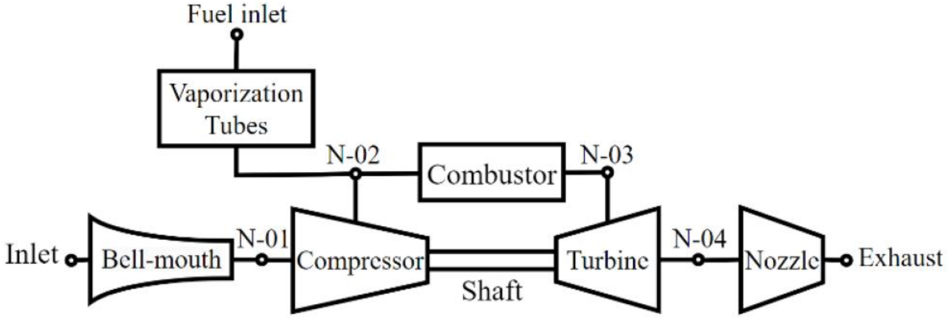
STRALER
AEROSPACE

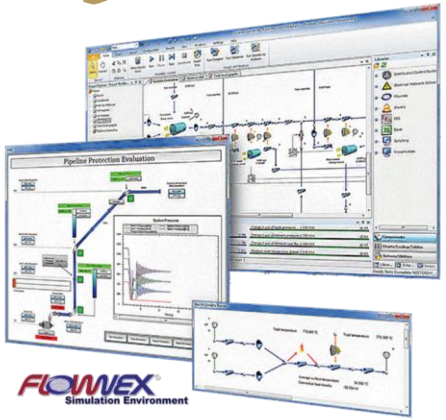
MK® AEROSPACE

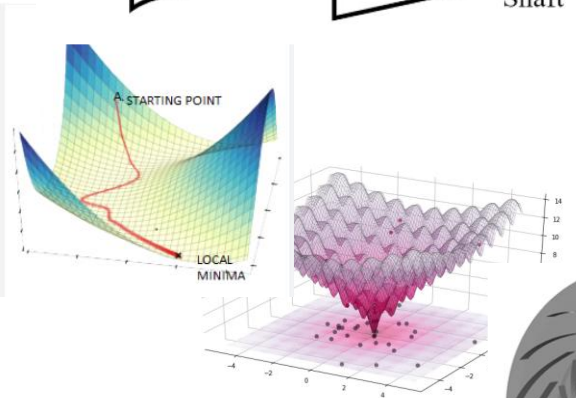
ASRI
Aerospace Systems
Research Institute

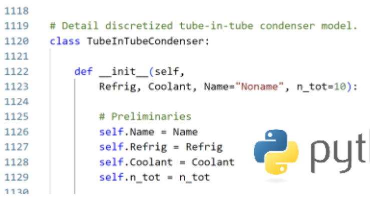
Research group capabilities and expertise

- **System modelling:** full engine cycles in Flownex SE and custom code (Python).
- **Control:** integrated control and thermofluid simulation in Flownex SE + MATLAB/Simulink.
- **CFD:** turbomachinery aerodynamics, combustion modelling and external flow simulations.
- **Experimental:** in-house rigs for compressors, combustors, and integrated engine performance.
- **ML & optimization:** PyTorch surrogates and design-space search across multi-point objectives.



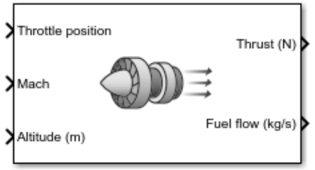


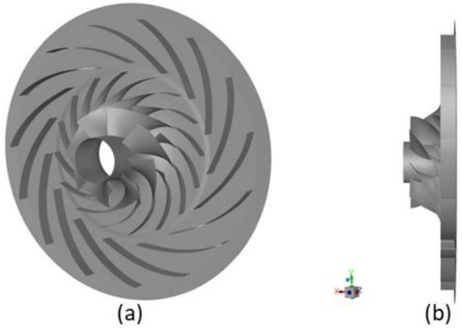


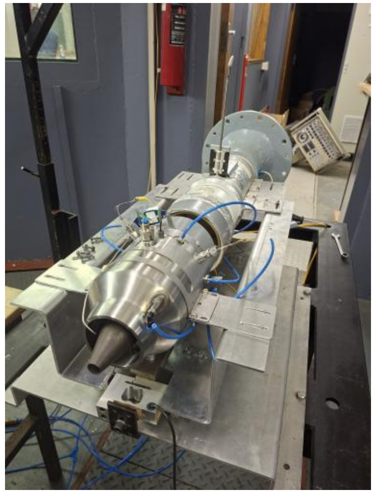


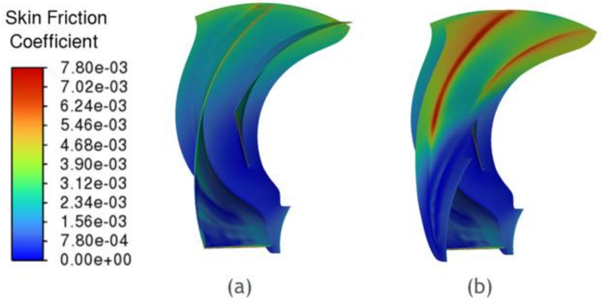
```python
# Detail discretized tube-in-tube condenser model.
class TubeInTubeCondenser:

    def __init__(self,
        Refrig, Coolant, Name="Noname", n_tot=10):

        # Preliminaries
        self.Name = Name
        self.Refrig = Refrig
        self.Coolant = Coolant
        self.n_tot = n_tot
```

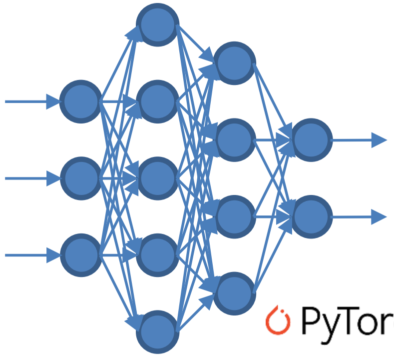
python™









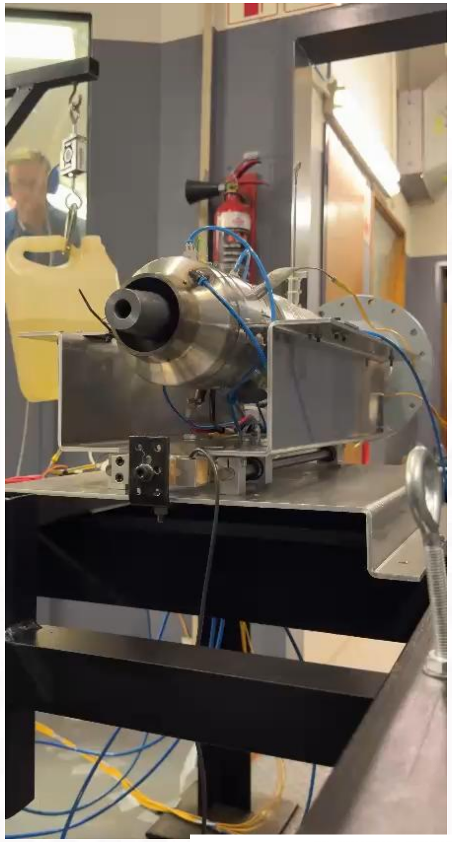


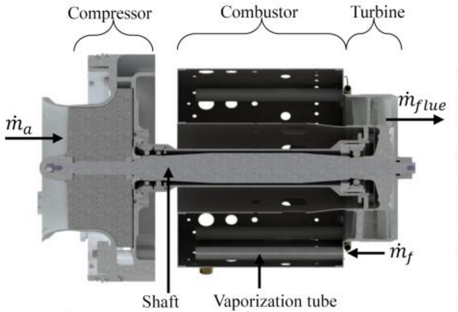
PyTorch

MGT experimental testing and model calibration

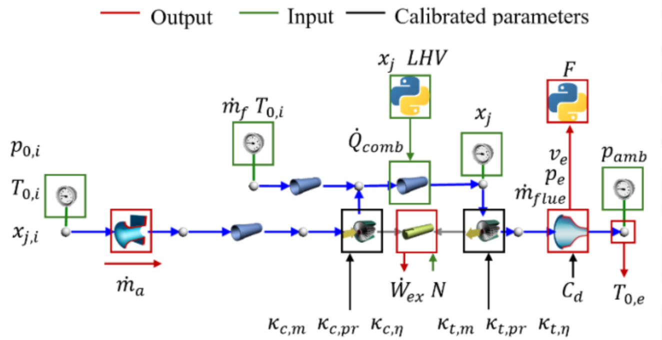
Case study: 250 N microjet gas turbine (MGT) — methodology applicable to larger aero and power-generation engines.

- **Motivation:** physical MGT testing for design and control development is costly calibrated 1D cycle models provide a fast, high-fidelity alternative.
- **Test rig:** 250 N kerosene-fuelled MGT instrumented for shaft speed, thrust, fuel/air flow, EGT, and exhaust gas composition.
- **Model:** physics-based steady-state thermofluid network in Flownex SE, built on mass, energy and compressible flow-momentum balances.
- **Calibration:** optimization-based tuning of combustion efficiency from exhaust composition, plus scaling of compressor and turbine maps against measured data.
- **Outcome:** calibrated model substantially improves predictive accuracy across thrust levels vs. the uncalibrated baseline.

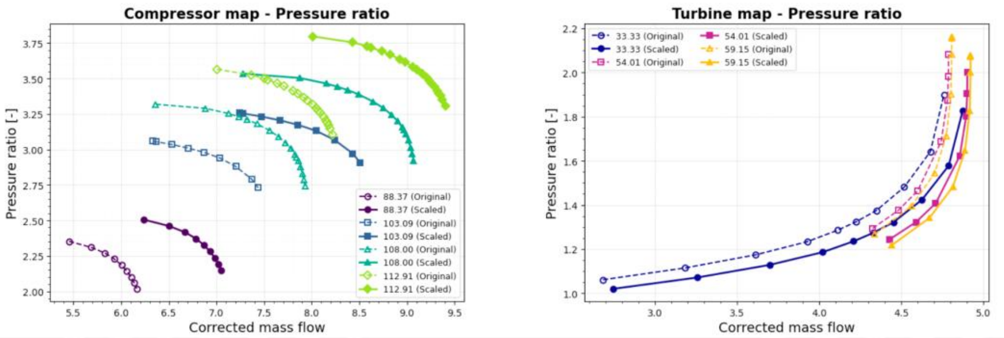




Layout of experimental microjet (MGT) engine



Simplified thermofluid network model of MGT for calibration

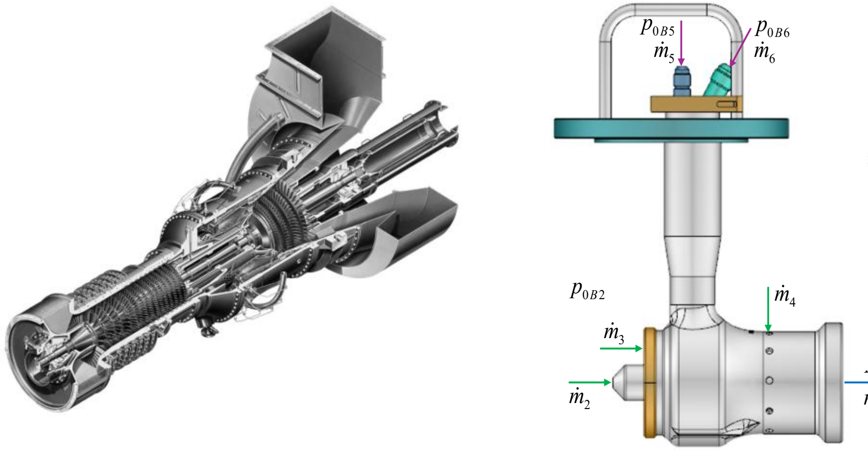


Calibrated compressor and turbine maps based on experimental measurements

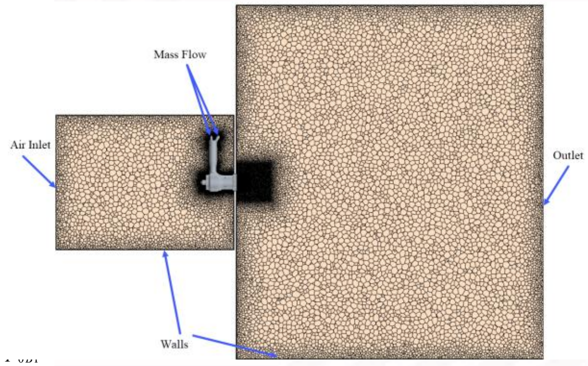
Gas turbine injector characterization

***Case study:** industrial DLE fuel injector (Solar Turbines) methodology directly transferable to aerospace injectors.*

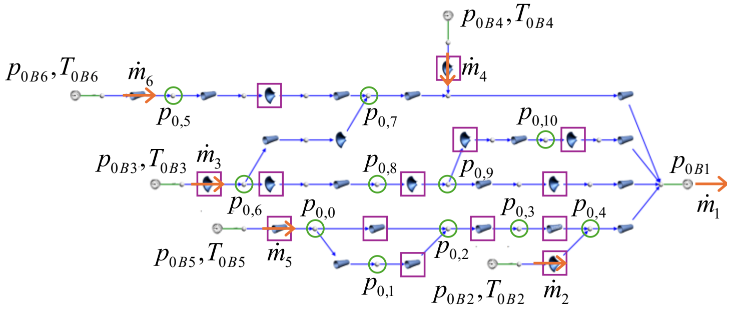
- **Motivation:** physical injector tests at engine pressures and temperatures are costly and difficult, OEMs need a fast, calibrated 1D surrogate for design and operational analysis.
- **Surrogate:** 1D Flownex SE network of the injector flow paths, three air inlets and two fuel inlets.
- **Reference data:** 3D RANS CFD at engine pressures and temperatures, mesh ~8M cells.
- **Calibration:** L-BFGS-B parameter identification tunes loss coefficients to match CFD mass flows and stagnation pressures.
- **Validation:** holds on unseen operating points and on physical cold-flow rig tests, same approach applies to aero-engine injectors.



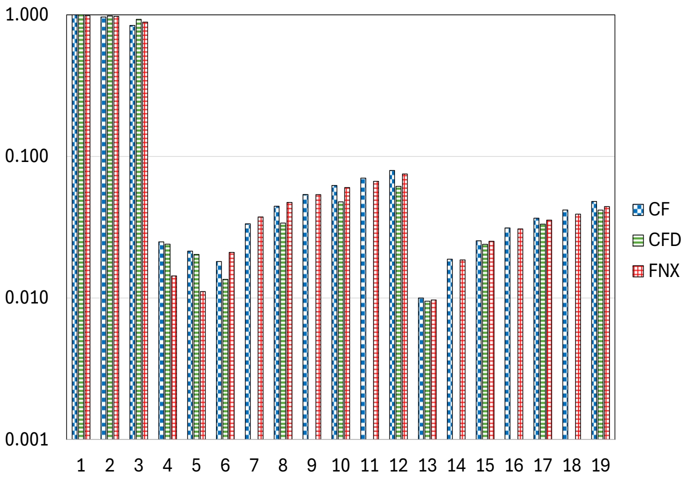
Large gas turbine and combustor fuel and air injector



Mesh of injector domain



Partial thermofluid network model of flow passages inside injector



Comparison between CFD, experimental (CF) and calibrated network model

In-house real gas thermofluid FV network solver for turbomachinery design and simulation

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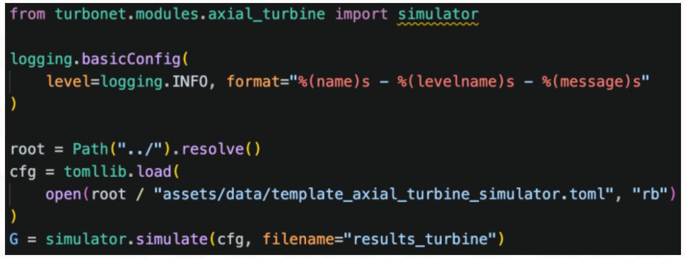
- ***turbonet***: in-house compressible real-gas 1D FV solver for full turbomachinery flow networks, applicable to air, sCO_2, and other real gases.
- **Novel formulation:** pseudo-advection momentum terms capture the polytropic compression path in a single increment per stage, pressure ratios within ~1% of measured data vs. up to 10% for conventional methods.
- **Application:** multi-stage axial turbine simulation and design optimization of a 400 N turbojet compressor.

turbonet

THERMOFLUID NETWORK MEAN LINE CODE
FOR TURBOMACHINERY

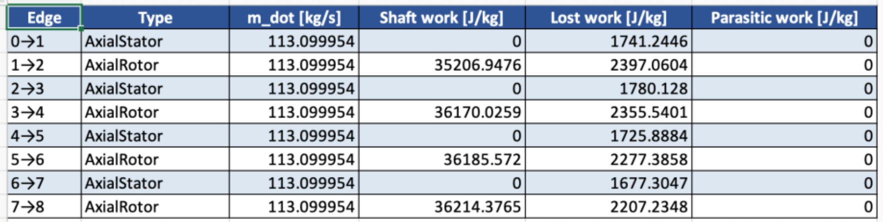


```python
from turbonet.modules.axial_turbine import simulator

logging.basicConfig(
    level=logging.INFO, format="%(name)s - %(levelname)s - %(message)s"
)

root = Path("../").resolve()
cfg = tomllib.load(
    open(root / "assets/data/template_axial_turbine_simulator.toml", "rb")
)
G = simulator.simulate(cfg, filename="results_turbine")
```

Simple function call to simulate 8-stage axial turbine



Edge	Type	m_dot [kg/s]	Shaft work [J/kg]	Lost work [J/kg]	Parasitic work [J/kg]
0→1	AxialStator	113.099954	0	1741.2446	0
1→2	AxialRotor	113.099954	35206.9476	2397.0604	0
2→3	AxialStator	113.099954	0	1780.128	0
3→4	AxialRotor	113.099954	36170.0259	2355.5401	0
4→5	AxialStator	113.099954	0	1725.8884	0
5→6	AxialRotor	113.099954	36185.572	2277.3858	0
6→7	AxialStator	113.099954	0	1677.3047	0
7→8	AxialRotor	113.099954	36214.3765	2207.2348	0

Selected output – shaft work and aerodynamic lost work per stage

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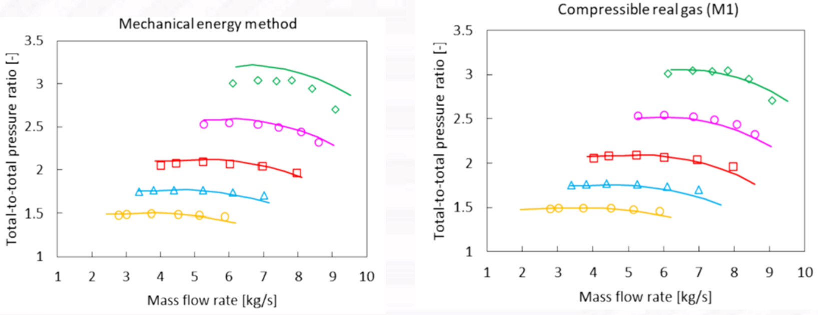
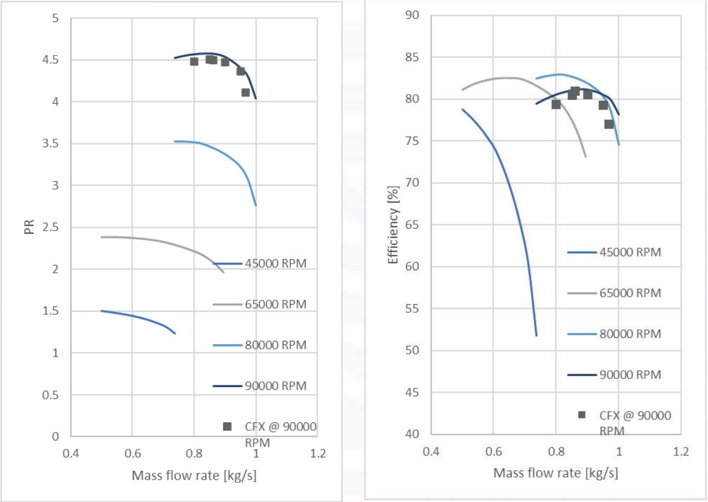
$$\int_{p}^{p_0} dp = \int_{h}^{h_0} \rho(p,h)dh$$

$$\frac{\partial p_0}{\partial x} + \frac{1}{2}\rho\frac{\partial u^2}{\partial x} - \frac{1}{2}\frac{\partial(\rho_s u^2)}{\partial x} = \frac{\partial p_{0,W}}{\partial x} - \frac{\partial p_{0,L}}{\partial x}$$



New method compared to current approach – cent. compressor

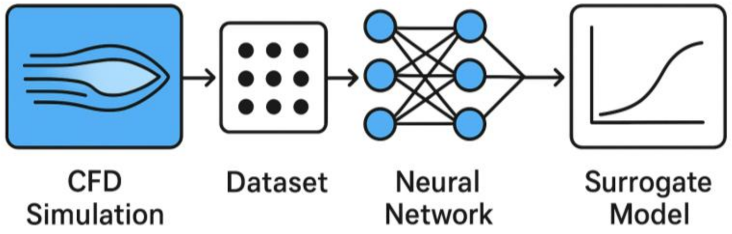


turbonet applied to the design and optimization of a 400N turbojet engine compressor – pressure ratio and efficiency maps

Generative learning applied to gas combustor

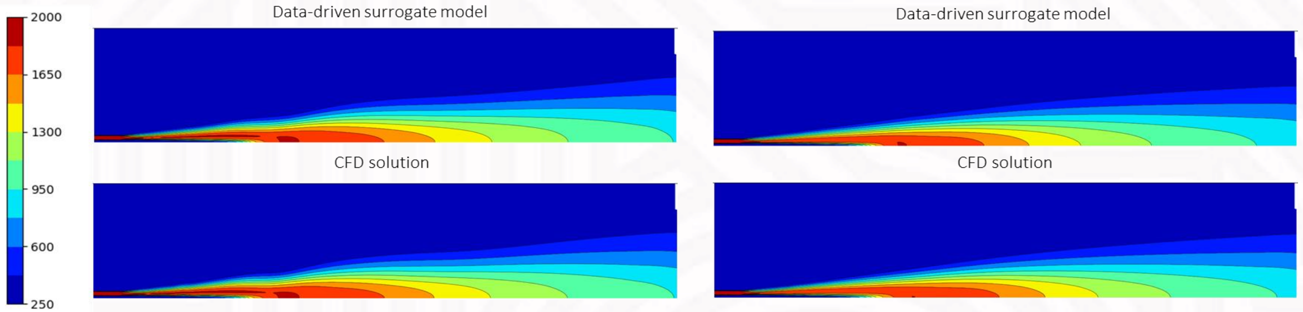
Case study: turbulent jet diffusion flame, methodology applicable to industrial combustors and gas turbine combustion chambers.

- **Motivation:** combustion CFD is too costly for real-time monitoring, control, or design-space exploration, a fast data-driven surrogate is needed.
- **Approach:** variational autoencoder compresses 2D CFD fields into a low-dimensional latent space; a deep neural network maps boundary conditions to that latent space.
- **Outputs:** cell-by-cell temperature, velocity, and species mass fractions (CO_2, H_2O, CO, O_2, CH_4, H_2) from high-level inputs.
- **Outcome:** 1.7% mean error on temperature, 7.1% on velocity, <0.3 %wt on species, fast enough for real-time use.



Typical work flow for surrogate modelling

Experimental setup of modelled flame



a) Random training data point

b) Random testing data point

Comparison between CFD (top) and AI model (bot) predictions for flame

Geometric deep learning for surrogate modelling in GT combustor pre-diffuser

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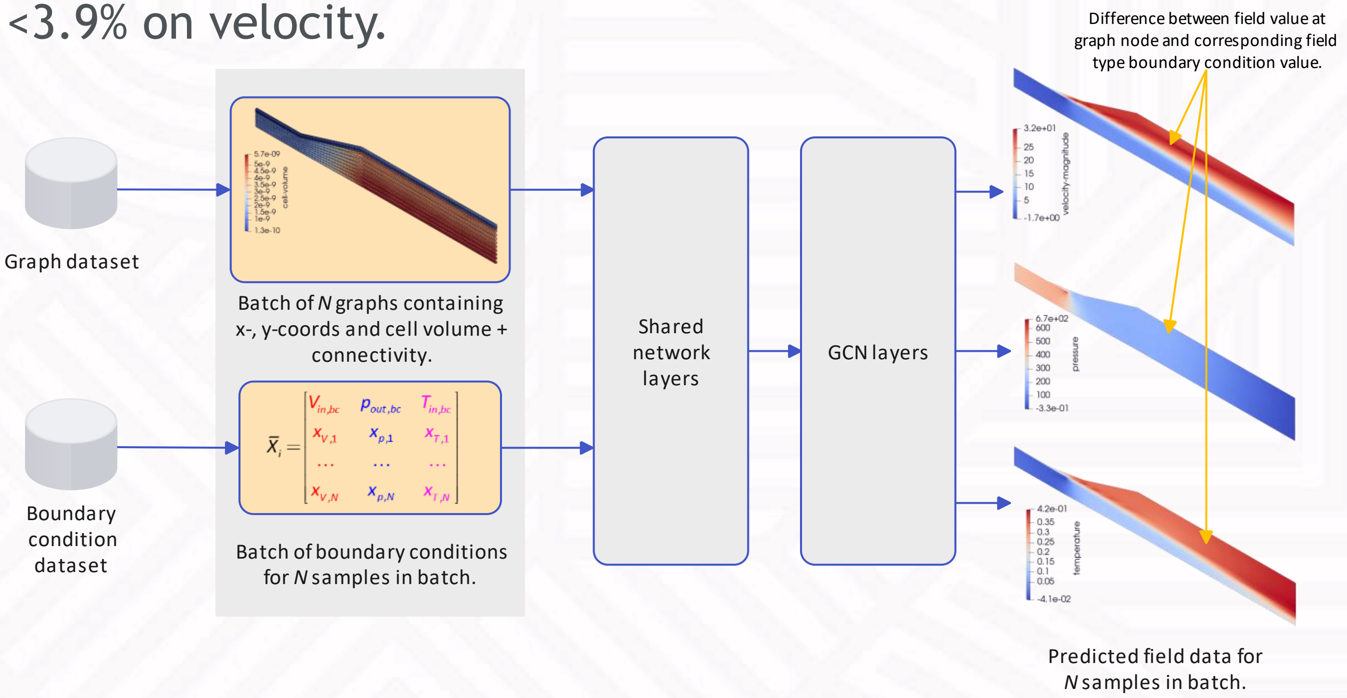
- **Motivation:** 3D combustor CFD is too expensive for design exploration, component-level surrogates plug into 1D system codes.
- **Approach:** spectral graph convolutional network trained on CFD across varied geometry and BCs, predicting 2D velocity, temperature and pressure fields.
- **Outcome:** normalized MAPE <1% on pressure and temperature, <3.9% on velocity.



Graph dataset

Batch of *N* graphs containing x-, y-coords and cell volume + connectivity.

Boundary condition dataset

$$\bar{X}_i = \begin{bmatrix} V_{in,bc} & p_{out,bc} & T_{in,bc} \\ x_{v,1} & x_{p,1} & x_{T,1} \\ \dots & \dots & \dots \\ x_{v,N} & x_{p,N} & x_{T,N} \end{bmatrix}$$

Batch of boundary conditions for *N* samples in batch.

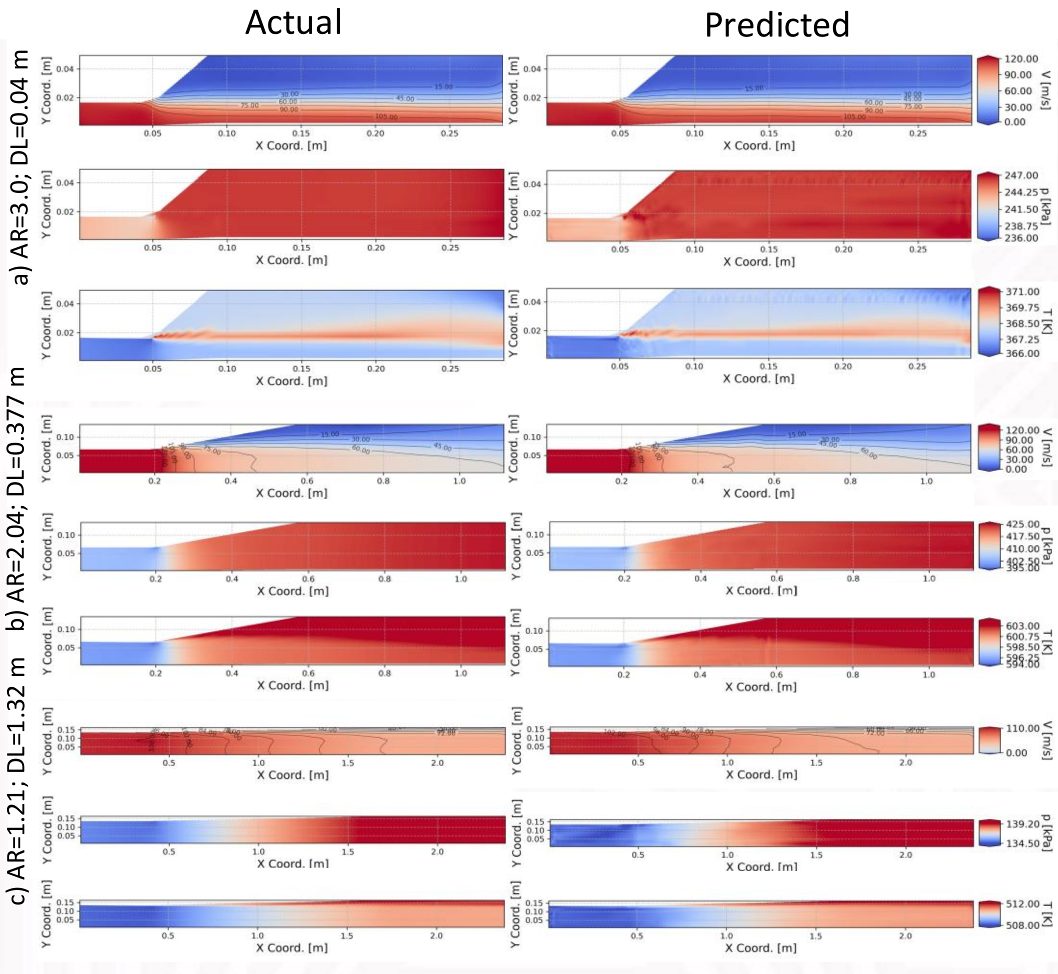
Shared network layers

GCN layers

Difference between field value at graph node and corresponding field type boundary condition value.

Predicted field data for *N* samples in batch.

Architecture of shared-layer GCN surrogate model



Comparison between CFD and GCN predicted quantities

Redesign of MGT cross-over diffuser for efficiency improvements

- **Motivation:** existing cross-over diffuser on the CAT205 engine incurred a significant total-pressure loss, limiting compressor stage efficiency and overall thrust.
- **Modification:** replaced the radial compressor stage with a mixed-flow compressor and redesigned cross-over diffuser to recover the pressure loss.
- **Manufacture:** compressor and diffuser stages produced by Venter Consulting (Pretoria); engine assembled in-house.
- **Test results:** (MGT test bench, 115 000 rpm):
  - Thrust: 220 N → 247 N (+12%)
  - TSFC: 69.4 → 61.7 g/(kN·s) (−11%)
- **Next:** further upgrade with a splitter multi-vane cross-over diffuser.

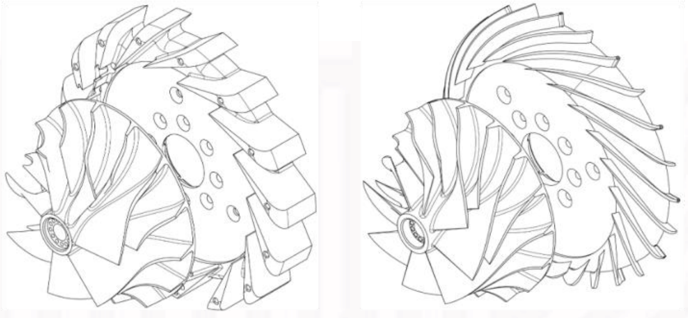
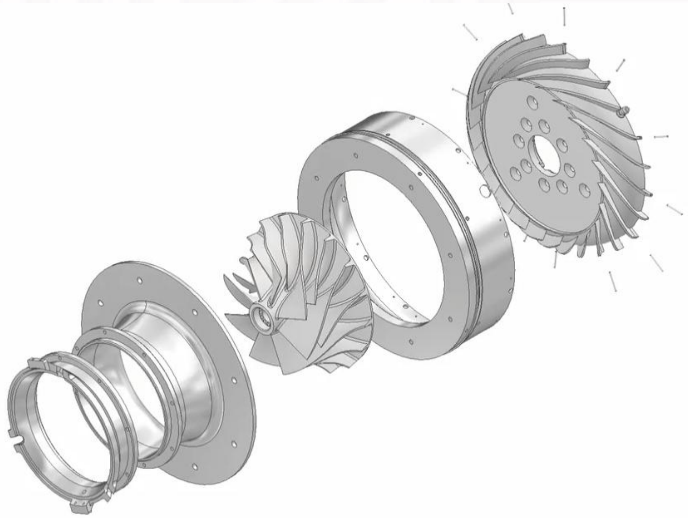


Figure 7: Current Compressor in CAT250TJ

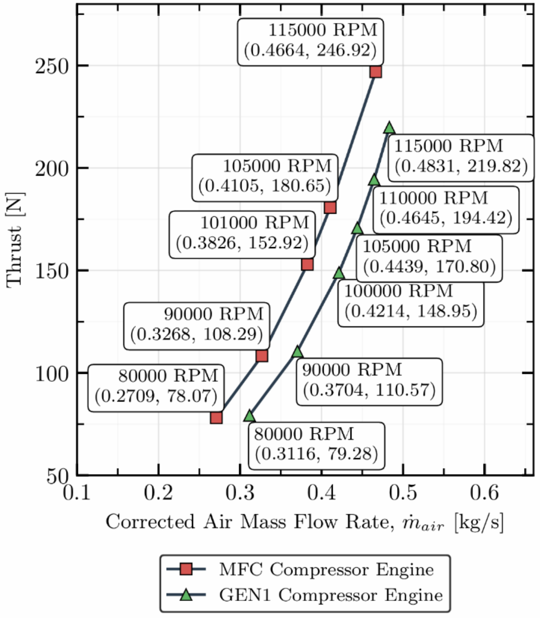
Figure 8: Proposed Compressor Upgrade for CAT250TJ

Current (left) and modified (right) compressor assembly

Manufactured impeller and cross-over diffuser



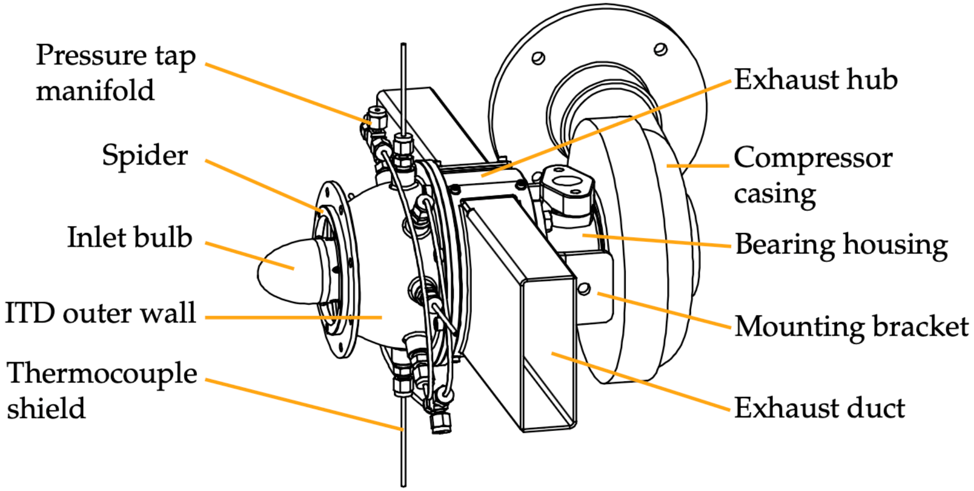
Assembly process of modified compressor



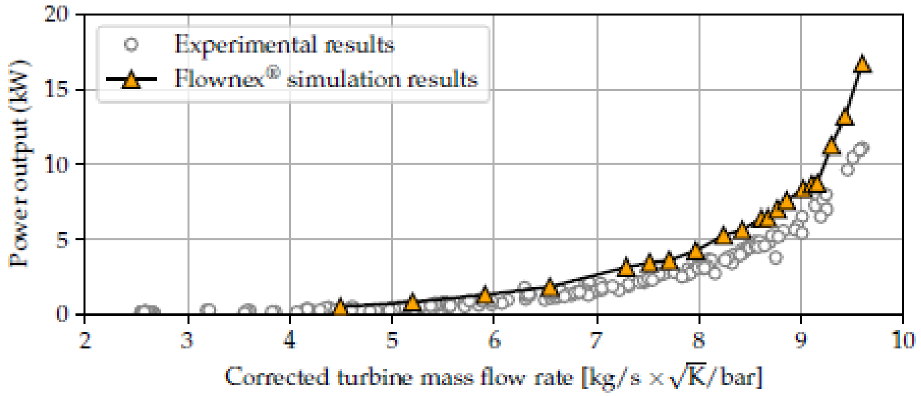
Comparison between old and new MGT assembly

Micro turboprop development

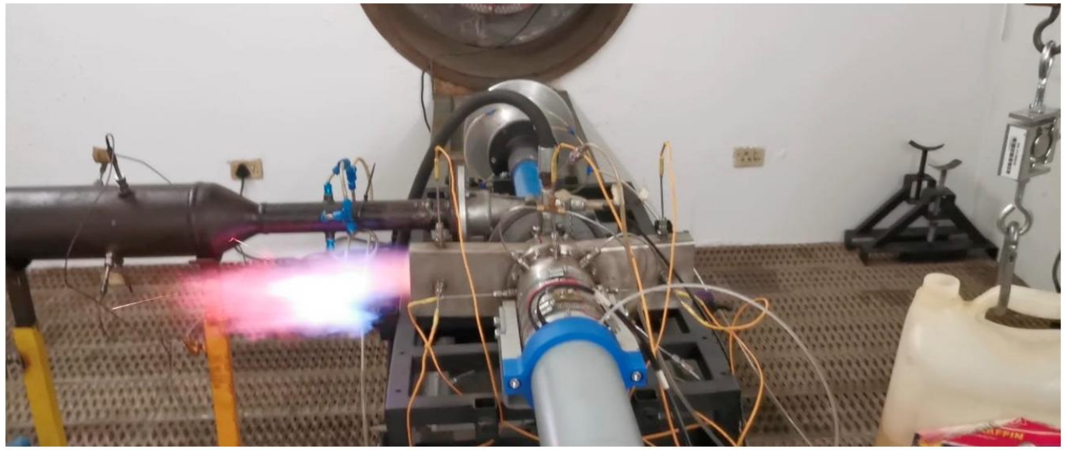
- **Motivation:** conversion of 250N microjet to a 30 kW micro turboprop for helicopter propulsion.
- **Modification:** designed new drive turbine stage, design shaft layout and modified exhaust gas system. Develop integrated process model using turbine maps generated using CFD modelling.
- **Test results:** Only 11 kW produced, due to damage to new turbine. Preliminary results positive.



Assembly of new power turbine



Predicted vs. experimental power output from new turbine

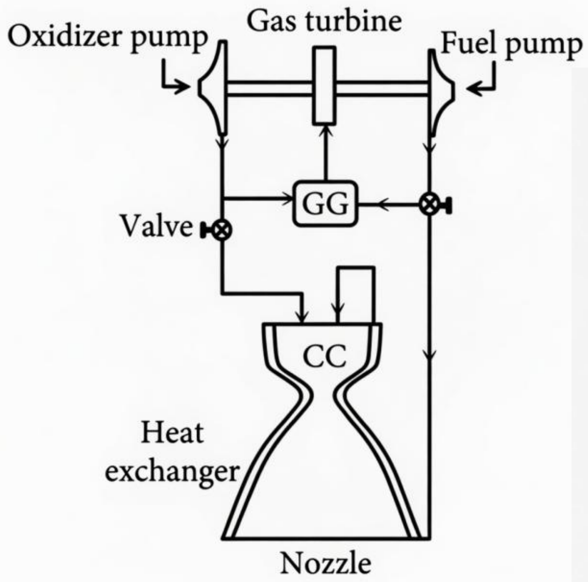


Experimental testing of turbine

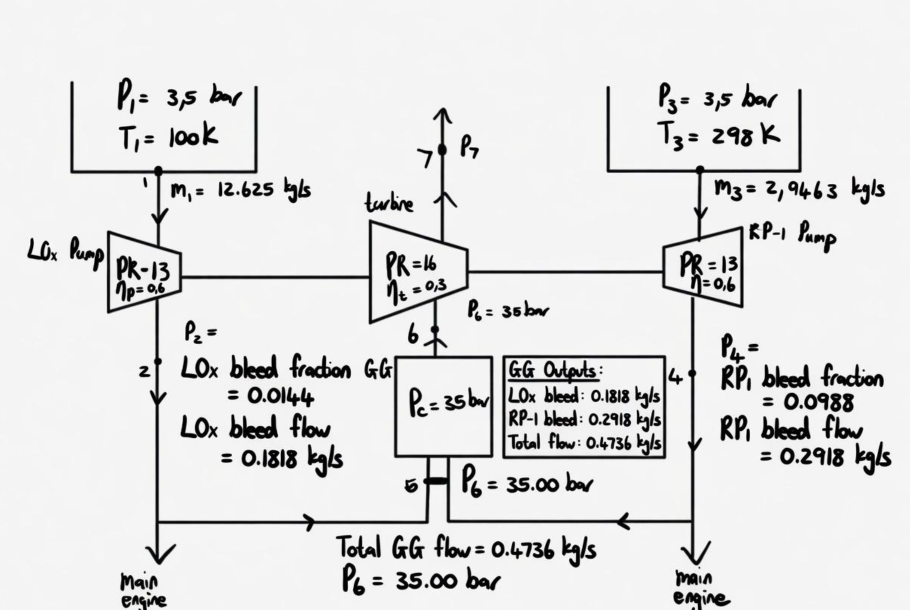
LOx/kerosene combustor development for ASRI SAFFIRE

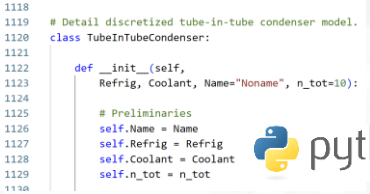
Development of Lox/kerosene gas generator (GG) for rocket turbopump system.

- **Motivation:** Support of ASRI 27.6 kN rocket engine development.
- **Challenge:** Combustion of high-pressure liquid oxygen and kerosene.
- **Objectives:** Perform preliminary system sizing. Design co-axial swirl/shear injectors and perform cold-flow tests to identify injection patterns.
- **Progress:** Developed real gas system model in Python used to identify GG input conditions and determine bleed fractions.
- **Next phase:** Combustor modelling incorporating equilibrium dense real gas combustion.



Schematic of rocket motor drive system





```

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        # Preliminaries
        self.Name = Name
        self.Refrig = Refrig
        self.Coolant = Coolant
        self.n_tot = n_tot
```
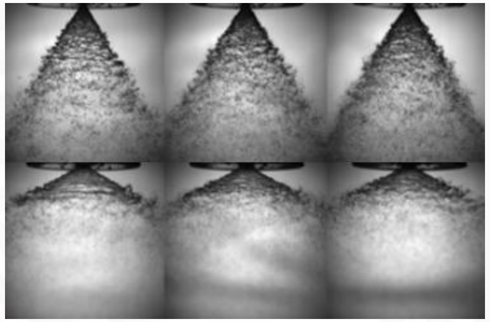

PFD of rocket drive system showing code results



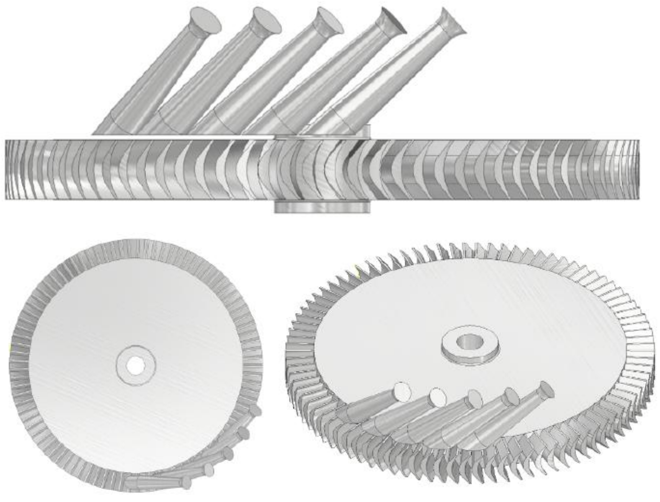
Shadowgraph imaging of LOx spray patterns (Yoon and Ahn, 2018)

LOx/kerosene combustor development for ASRI SAFFIRE

Development of partial admission turbine for driving turbo and fuel pumps

Motivation: Support of ASRI 27.6 kN rocket engine development.

- **Challenge:** Size partial admission turbine that delivers 85 kW.
- **Objectives:** Develop mean line simulation of partial admission turbine and validate design using CFD simulation.
- **Results:** Mean line design and CFD not in agreement, further investigation required. Output that CFD predicts is 94 kW.
- **Next phase:** Design optimization and investigation into possible testing.



CAD model of partial admission turnine

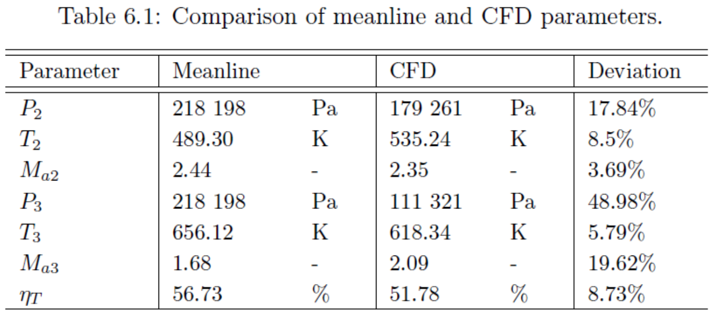
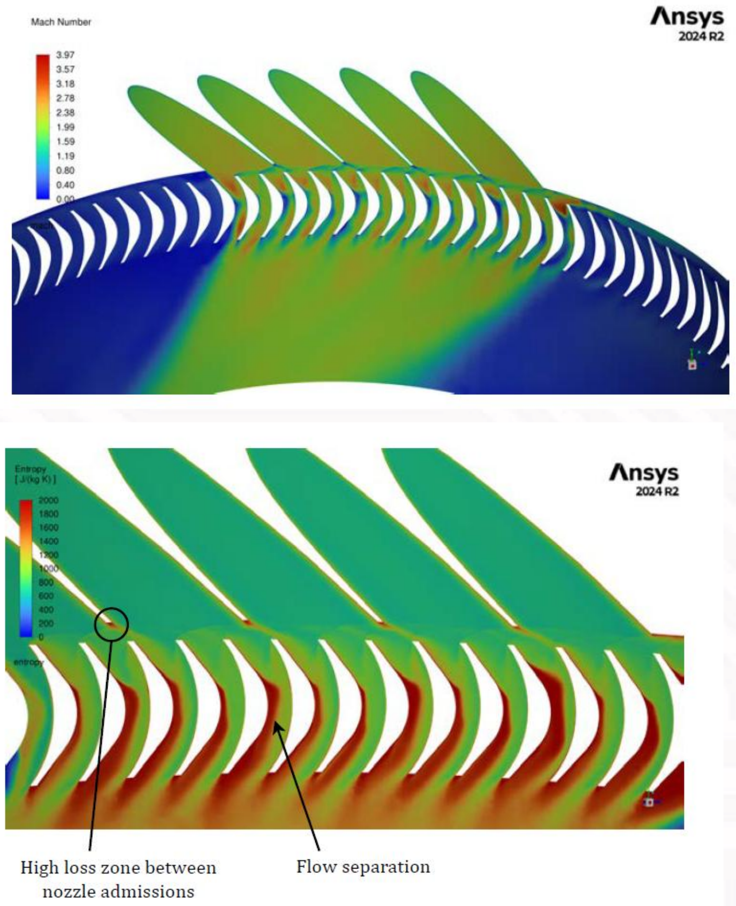


Table 6.1: Comparison of meanline and CFD parameters.

Parameter	Meanline		CFD		Deviation
P_2	218 198	Pa	179 261	Pa	17.84%
T_2	489.30	K	535.24	K	8.5%
M_{a2}	2.44	-	2.35	-	3.69%
P_3	218 198	Pa	111 321	Pa	48.98%
T_3	656.12	K	618.34	K	5.79%
M_{a3}	1.68	-	2.09	-	19.62%
η_T	56.73	%	51.78	%	8.73%

Comparison between CFD and mean line simulation results



CFD simulation results for Ma (top) and entropy (bot)

Real gas axial turbine optimization study using *turbonet*

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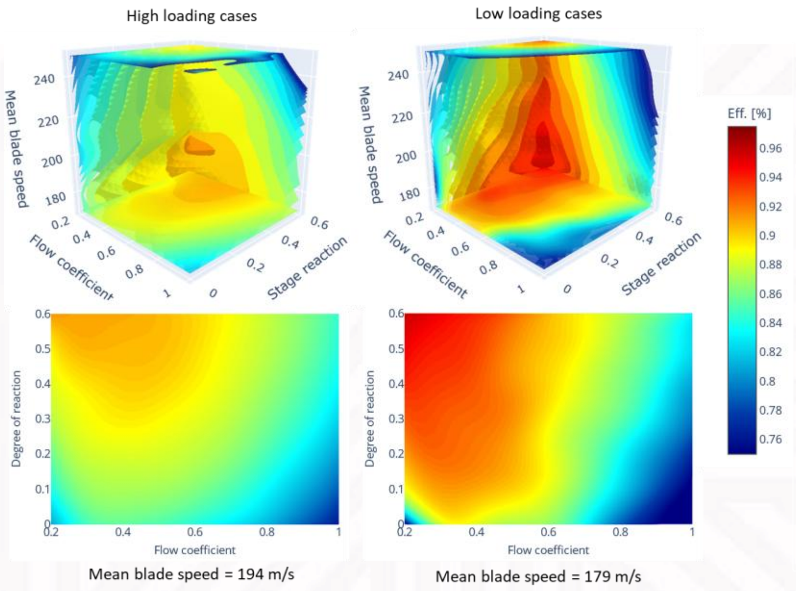
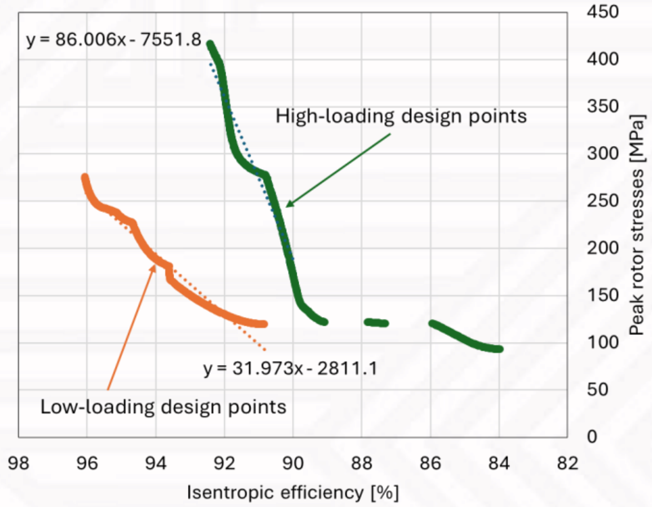
Case study: high- and low-pressure axial turbines mean-line + CFD + DoE workflow.

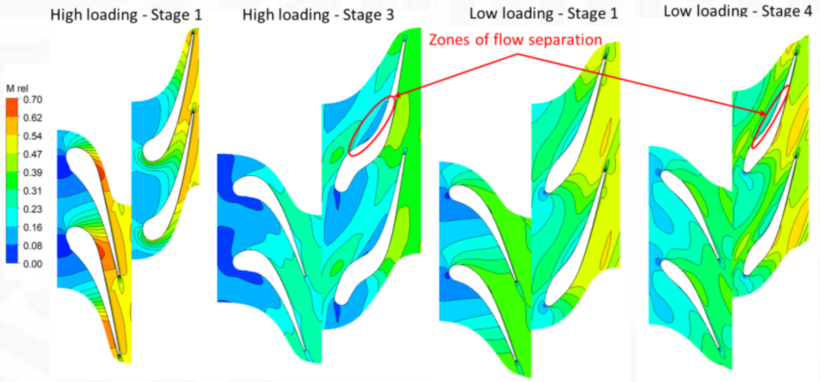
- **Motivation:** turbine efficiency drives both sCO_2 plant economics and aero-engine SFC — small efficiency gains translate to large system-level savings.
- **Approach:** in-house mean-line code (*turbonet*) validated against CFD, then used to sweep stage loading, flow coefficient and reaction over a design-of-experiments grid.
- **Outcome:** Pareto fronts for high- and low-loading designs trading efficiency against peak rotor stress — optimal designs give up ~3% efficiency for a 29% drop in stress.



Design of experiments data for varying design conditions



Pareto fronts for low- and high-loading HPT optimized designs



CFD modelling of selected designs

Turbine stage and loading	Pressure ratio,	Total-to-total isentropic efficiency,
HPT high loading	1.68 (1.75)	90.9% (89.7%)
HPT low loading	1.7 (1.75)	93.7% (91.3%)
LPT high loading	1.69 (1.75)	94.1% (92.6%)
LPT low loading	1.73 (1.75)	95.1% (94.4%)

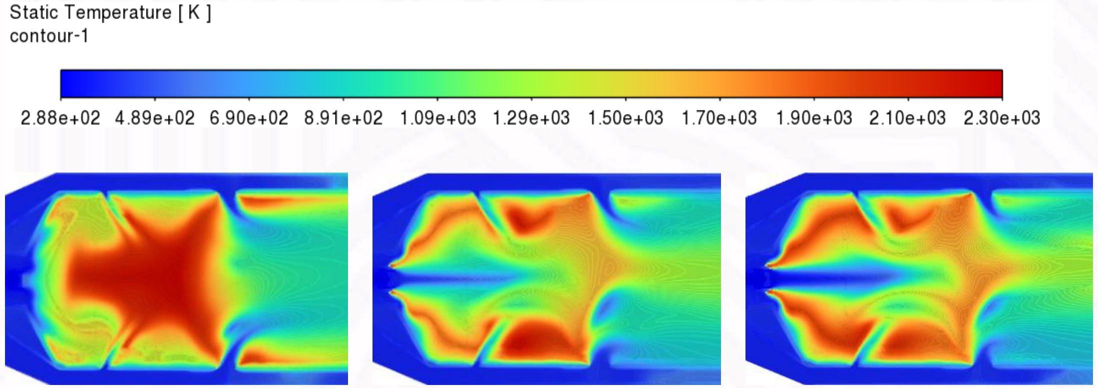
Comparison between CFD and *turbonet* results

H2 gas turbine combustor research

Case study: investigation into H2-hydrocarbon blended combustion effects on gas turbine cycle

- **Motivation:** H2/SAF blends as a path to low-carbon flight. Combustor redesign for H2 blends relevant to aerospace.
- **Approach:** Use of CFD modelling of combustor, integrated process model of entire gas turbine and experimental data to investigate influence of H2 addition of system performance.
- **Experimental setup:** Currently exhaust gas from drive turbine is not utilized as thrust but fed through a load compressor.
- **Outcome:** CFD and integrated process modelling complete, propane-firing performed, currently commissioning H2 fuel system. Co-firing experiments to take place with next 2-3 weeks.

Power generation gas turbine test setup



CFD simulation results of propane and H_2 co-firing

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Thank you
Enkosi
Dankie

Photo by Stefan Els