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Investigation of Novel Thrust Parameters to Variable Geometry Turbojet Engines

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Introduction

Benefits of Turbofan Power Ratio (TPR)

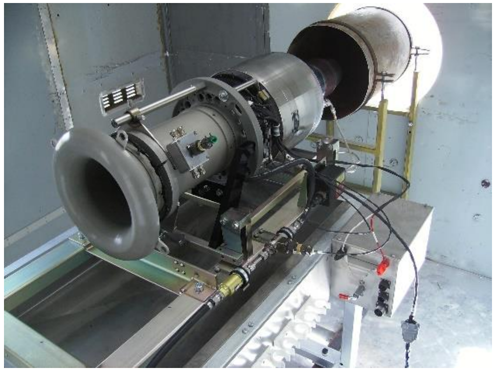
- Definition of TPR
- Comparison of TPR to other thrust parameters

Effect of variable nozzle on TPR

- Overview of TPR-to-thrust correlation
- Defining thrust by using TPR
- Introduction of Variable Nozzle Thrust Coefficient

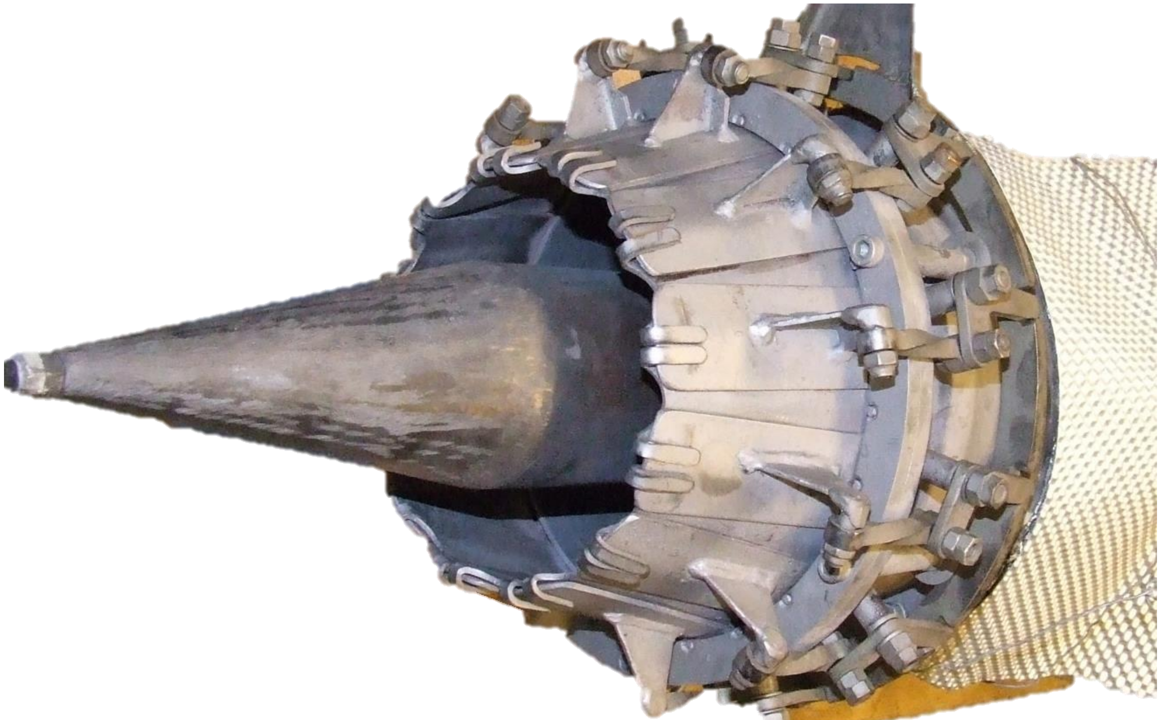
Conclusion

- **Goal of present investigation:** *investigate whether TPR can be used as thrust parameter in turbojets with variable exhaust nozzle and suggest*
- Turbojets are still used even if not widely spread
  - military Unmanned Aerial Vehicles (UAV's)
  - hobbyist radio controlled aircraft



- Their operating principle is very close to commercial engines like turbofans
  - Results obtained in turbojet research can be transferred to turbofans

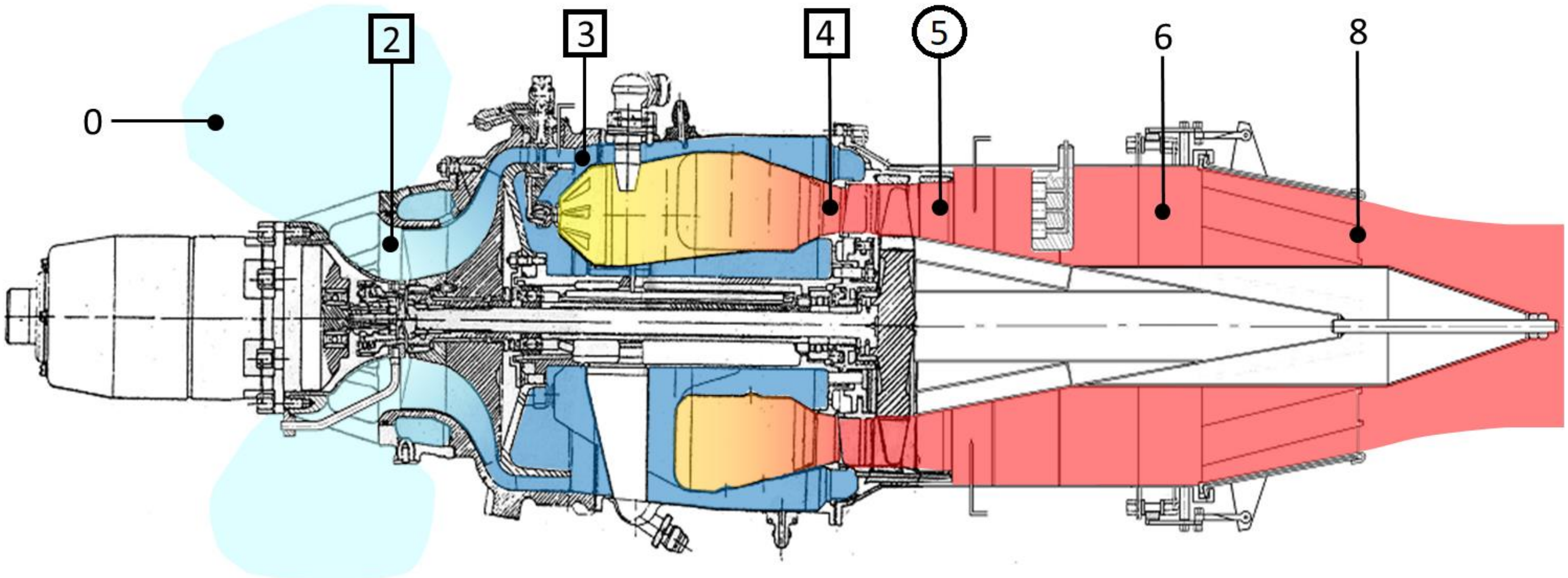
- **Variable nozzle** is not so common in civil aviation, however, the need for increased efficiency there are multiple recent investigations on variable fan duct nozzle



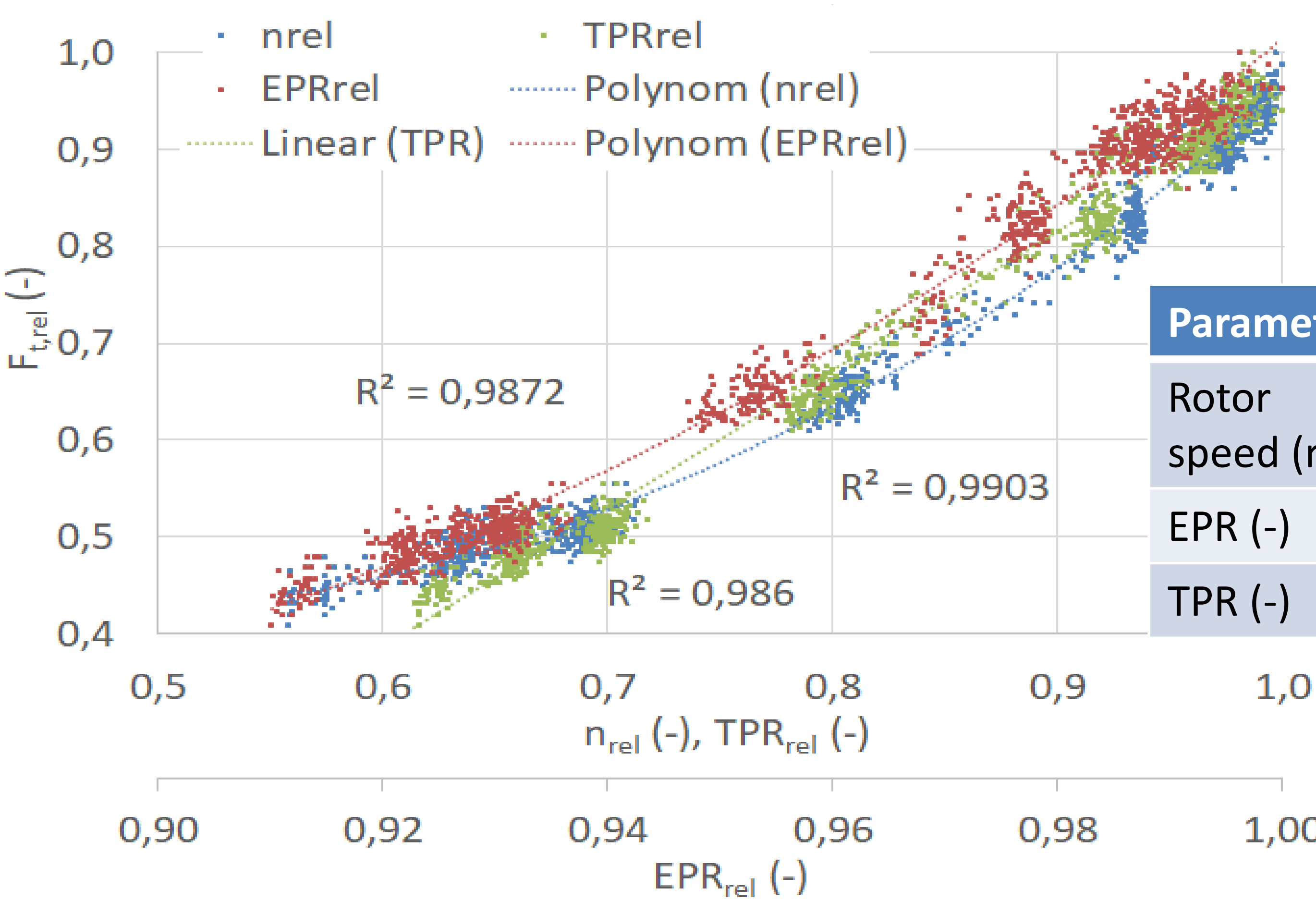
Variable exhaust nozzle of the investigated TKT-1 turbojet engine in minimum open condition.

Turbofan Power Ratio

- Is the product of compressor pressure ratio and square root of turbine temperature (inlet or outlet, both are applicable)
- $TPR = \frac{p_{3t}}{p_{2t}}\sqrt{\frac{T_{4t}}{T_{2t}}}$ or modified TPR: $TPR_{mod} = \frac{p_{3t}}{p_{2t}}\sqrt{\frac{T_{5t}}{T_{2t}}}$



- **Comparison of different thrust parameters (relative to respective maxima), $EPR = p_{5t}/p_{2t}$**

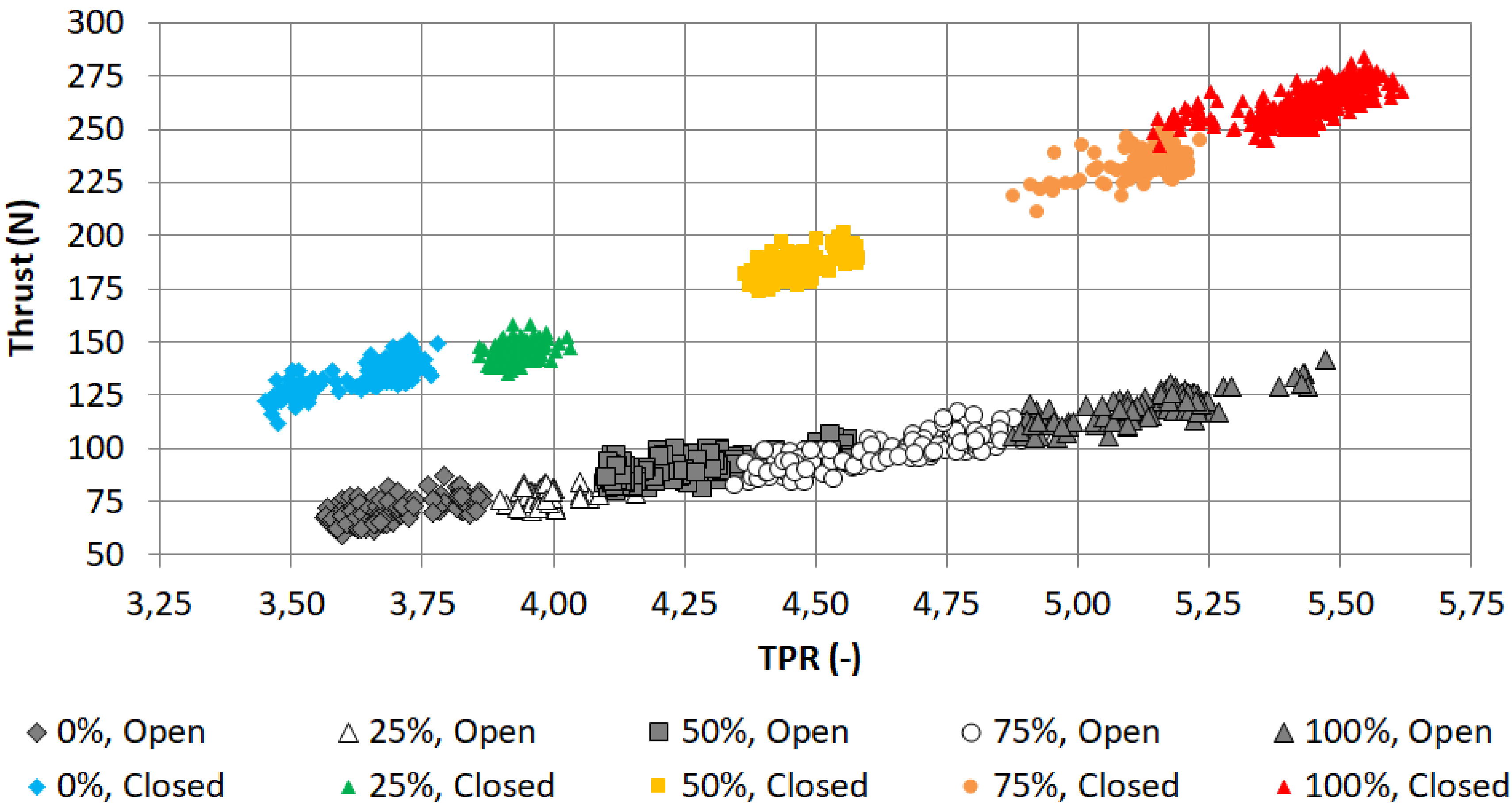


Parameter	Min.	Max.
Rotor speed (rpm)	37 889	47 917
EPR (-)	1.087	1.194
TPR (-)	3.450	5.619

➢ Comparison of different thrust parameters

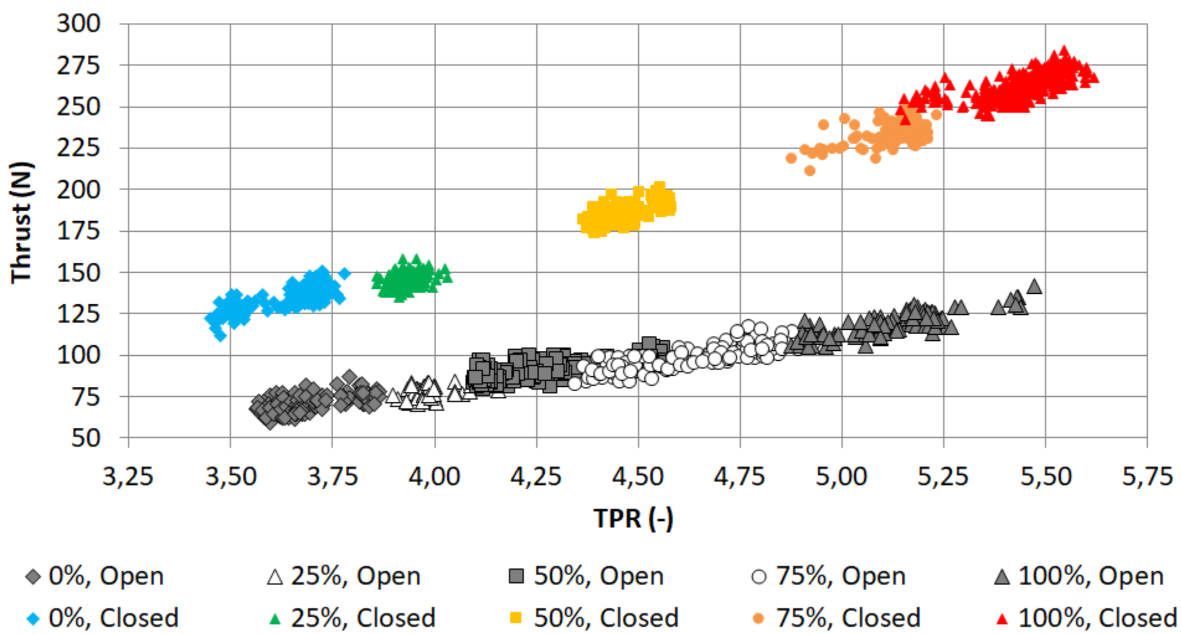
- EPR and TPR show linear correlation with thrust
- Rotor speed and TPR offer broad range
- Best choice (both linear and has sufficient range) is TPR

- Until now a fixed nozzle was considered, the figure below indicates the effect of variable nozzle on TPR



- **This figure evidently shows that the nozzle strongly affects thrust output at the same TPR values, i.e.**

- **<u>TPR is not immediately useable in engines with variable nozzle</u>**



- **If one wishes to create a similar parameter, which is a measure of thrust but without the influence of the nozzle area, the thrust must be defined by the TPR and coefficients that are functions of nozzle opening γ_N:**

$$T = a(\gamma_N) \cdot TPR + b(\gamma_N)$$

- **Based on the measurement, the coefficients can be summarized as follows:**

Parameter	a (N/TPR)	b (N)
Open nozzle	33.3	-49.88
Closed nozzle	75.0	-137.5

- **Then, as next step the $a(\gamma_N)$ and $b(\gamma_N)$ functions can be determined, by taking $\gamma_N = 0.5$ for closed and $\gamma_N = 1$ for the opened configuration (these numbers reflect the cross-sectional area relative to the maximum):**

$$a(\gamma_N) = \underbrace{\frac{a|_{\gamma_N=1} - a|_{\gamma_N=0.5}}{0.5}}_{f}\gamma_N + a\Big|_{\gamma_N=0} \qquad b(\gamma_N) = \underbrace{\frac{b|_{\gamma_N=1} - b|_{\gamma_N=0.5}}{0.5}}_{g}\gamma_N + b\Big|_{\gamma_N=0}$$

Parameter	$a\big\vert_{\gamma_N=0}$	$b\big\vert_{\gamma_N=0}$	***f***	***g***
Value	116.7	-226	-83.4	-176
Unit	N / TPR	N	N / TPR / γ	N / γ

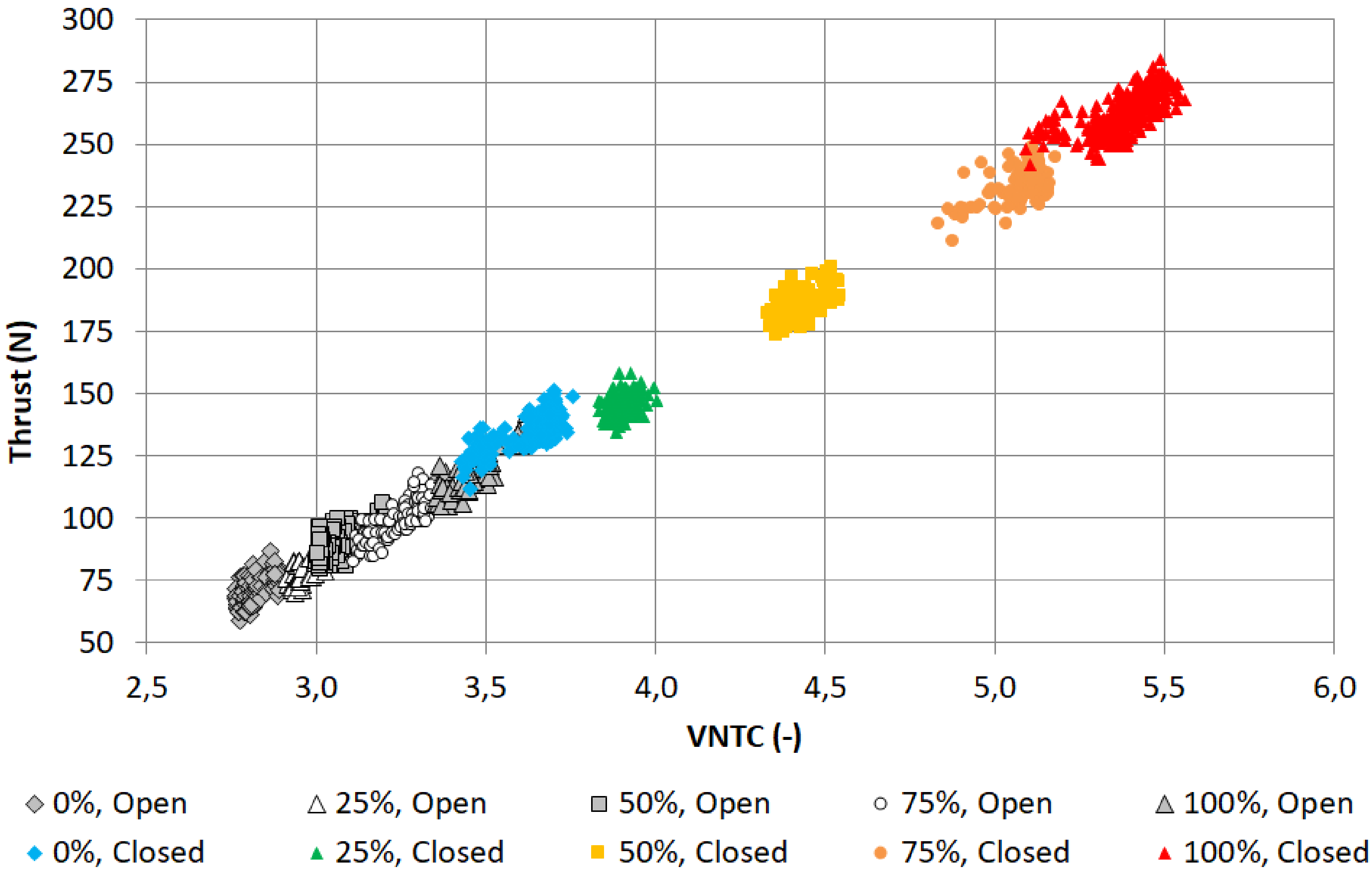
- **Conversion of TPR into an equivalent value at various nozzle openings can be achieved by the following formula called Variable Nozzle Thrust Coefficient (VNTC):**

$$VNTC = \frac{a|_{\gamma_N,act} \cdot TPR_{act} + b|_{\gamma_N,act} - b|_{\gamma_N,closed}}{a|_{\gamma_N,closed}}$$

- **Or, if one substitutes directly the original thermodynamic parameters that compose TPR the VNTC can be obtained as:**

$$VNTC = \frac{a|_{\gamma_N,act} \cdot \frac{p_{3t}}{p_{2t}}\sqrt{\frac{T_{5t}}{T_{2t}}} + b|_{\gamma_N,act} - b|_{\gamma_N,closed}}{a|_{\gamma_N,closed}}$$

➢ **If one plots the thrust output against VNTC, an entirely linear correlation is the result over the whole operating range of the engine:**



- **Goals that have been reached:**
  - ✓ *The author has conducted measurements and identified the benefits of TPR over conventional Engine Pressure Ratio or rotor speed*
  - ✓ *The measurements showed that raw TPR cannot be used evidently to determine thrust if the nozzle is variable*
  - ✓ *The author has established the correlation between thrust and TPR at different nozzle openings*
  - ✓ *A novel thrust parameter Variable Nozzle Thrust Coefficient has been developed that is based on TPR but allows a single linear correlation to thrust over the entire operating range of the engine*

CONCLUSION

- **Possible further development:**

  - *The measurement has been carried out in a reduced range → the overall range of the engine should be mapped*

  - *During the original measurement, only two extreme nozzle conditions (opened and closed) have been assessed → intermediate nozzle positions should be involved to provide an increased accuracy model in the future*

  - *The method should be validated on turbofan engines as the recent trends show an increased interest in variable fan nozzle configurations*

Thank you for your kind attention!