A Conceptual Performance Study on Integration of a Continuously Variable Speed Fan into a Micro Turbojet

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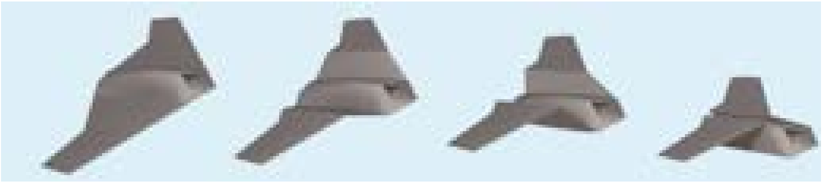
Motivation

- Operational envelopes of UAVs expand into transonic speed range



Lockheed Morphing UAV Concept

- Engine design process requires compromises in

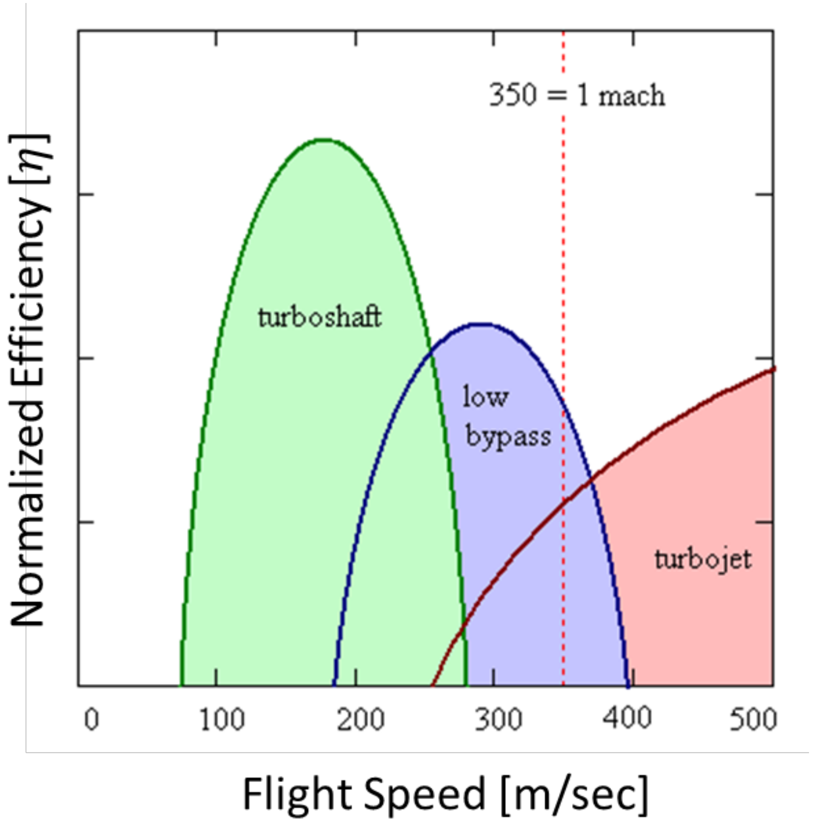
  □ Thrust □ Weight □ Fuel consumption

  □ Development budget □ Manufacturing cost

- Compromises are especially noticeable in microjet engine market, suffering
  - Restrained design costs
  - Low component efficiencies

Motivation

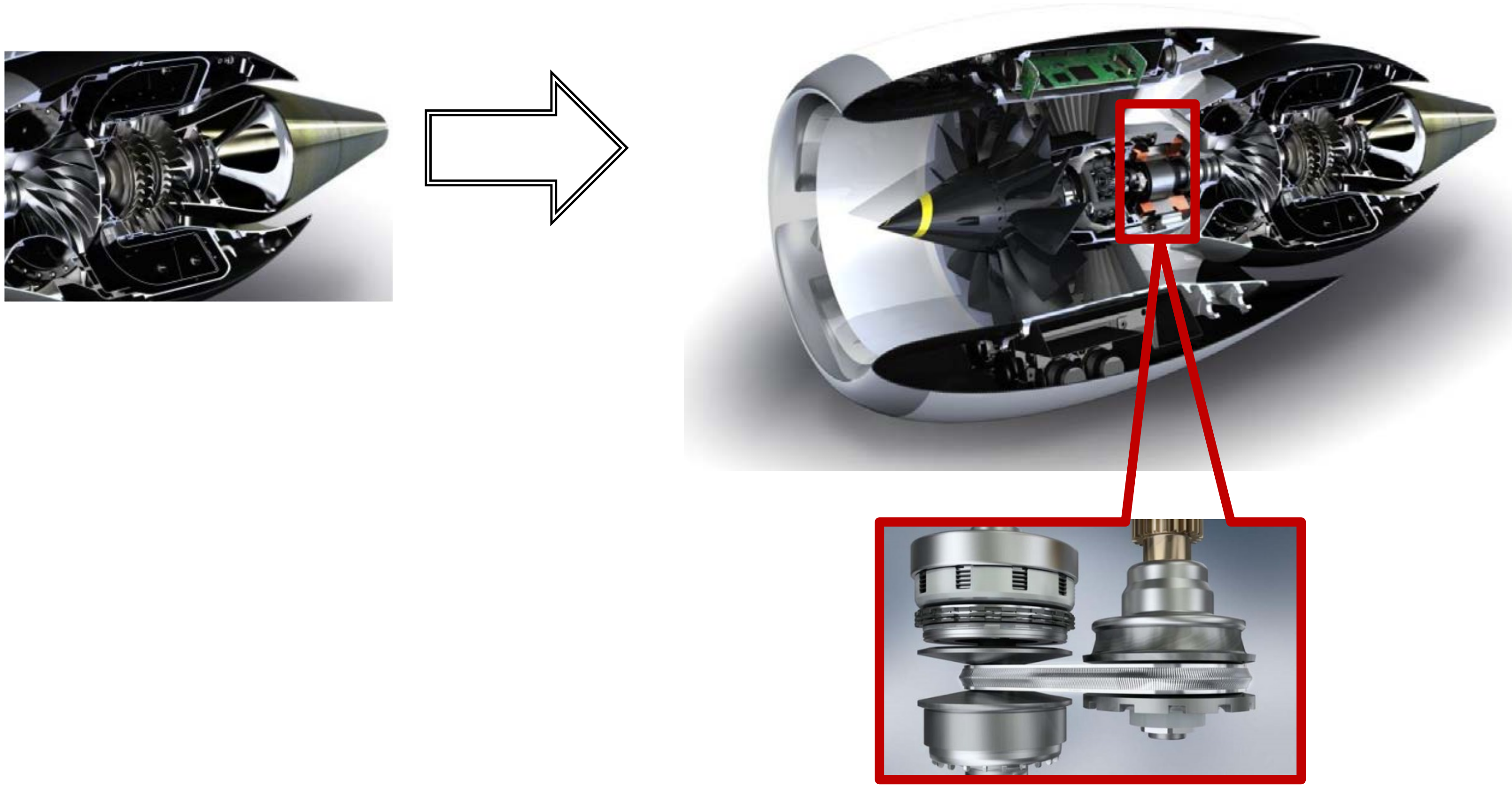
- Engine requirements for multiple operating points:
  - □ Low speed loitering □ High speed cruise flight
  - Impose conflicting design criteria



- Micro-turbojet engines:
  - Simple design
  - High levels of thrust
  - Poor fuel consumption - hindering range
- Conventional turbofan engines:
  - Greater propulsive efficiency
  - Augmented levels of thrust
  - Not suitable for high speed flight

Goal

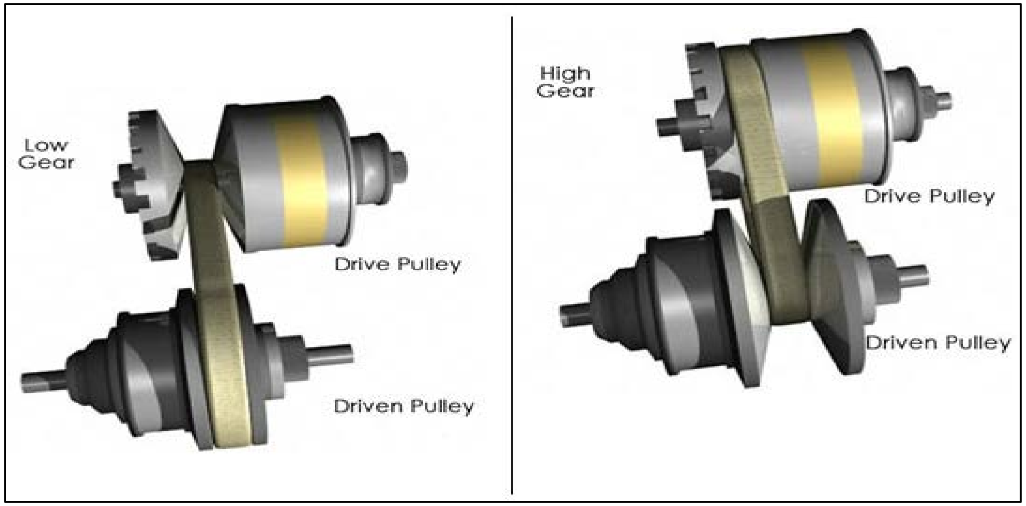
Variable cycle GT engine development which operates via integration of ***continuously variable speed fan*** into an existing micro-turbojet



Continuously Variable Transmission

Continuously Variable Transmission

- Non-discretely varies the transmission ratio between 2 boundaries.
- Can effectively achieve an infinite number of gear ratios.



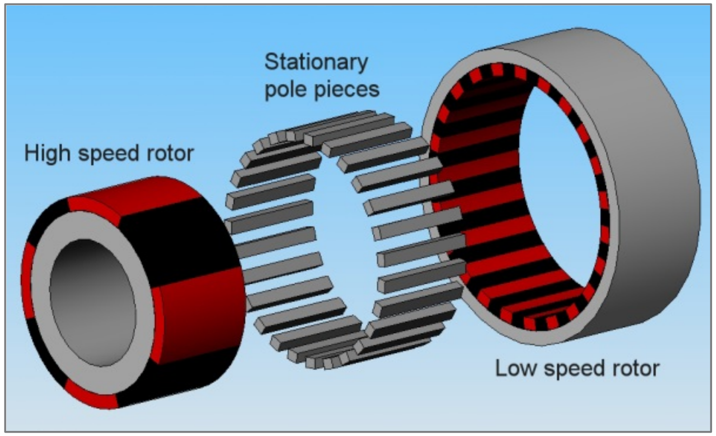
In Our Research

- Exploring the use of a CVT in turbomachinery applications

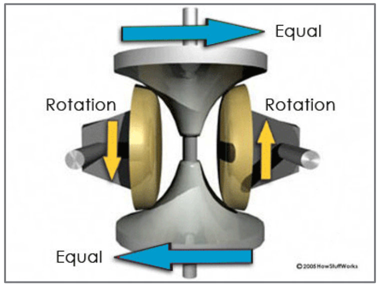
CVT Types

- Magnetic CVT

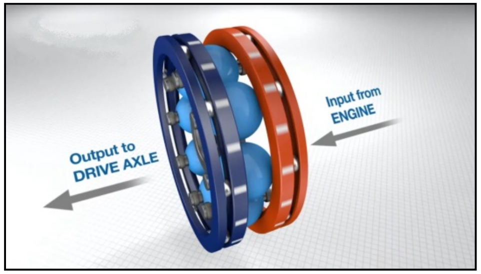
(similar to asynchronous generators)

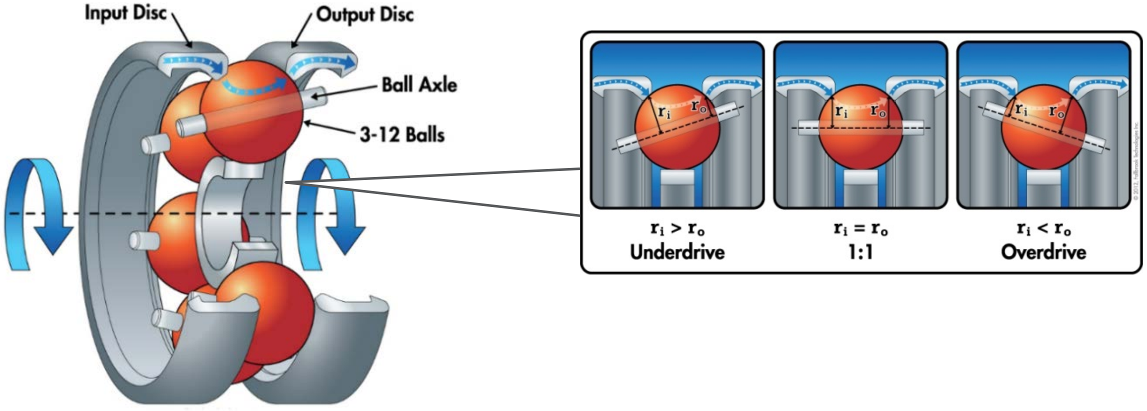


- Toroidal CVT



- Continuously variable planetary





CVT Turbofan Conversion Advantages

- Variable Bypass Ratio Cycle

□ *Enhanced performance (thrust)* □ *Higher efficiency*

- Independent Fan – Engine Core Operating Lines

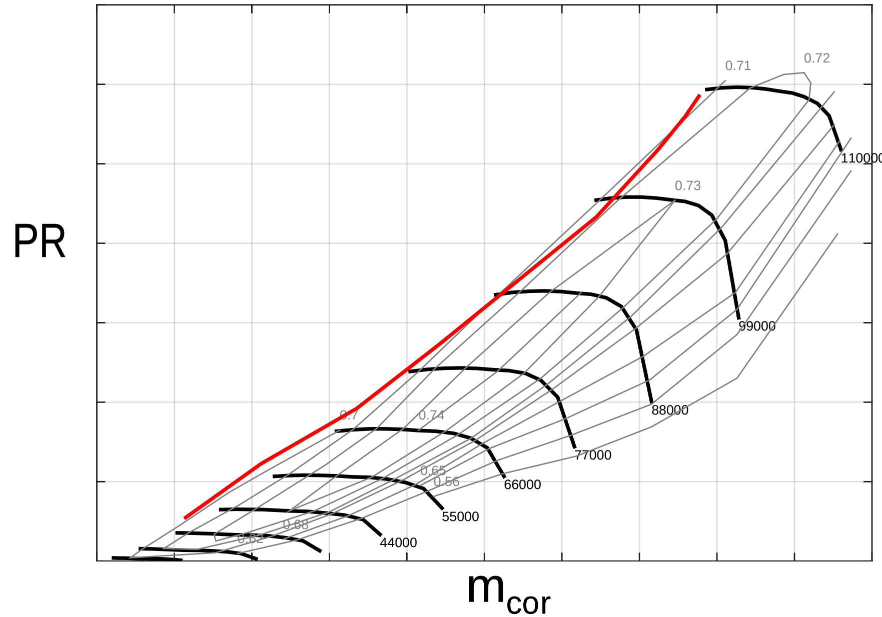
□ *Easy component matching* □ *Highest Possible Component Efficiency*

- Minimal changes to core stream

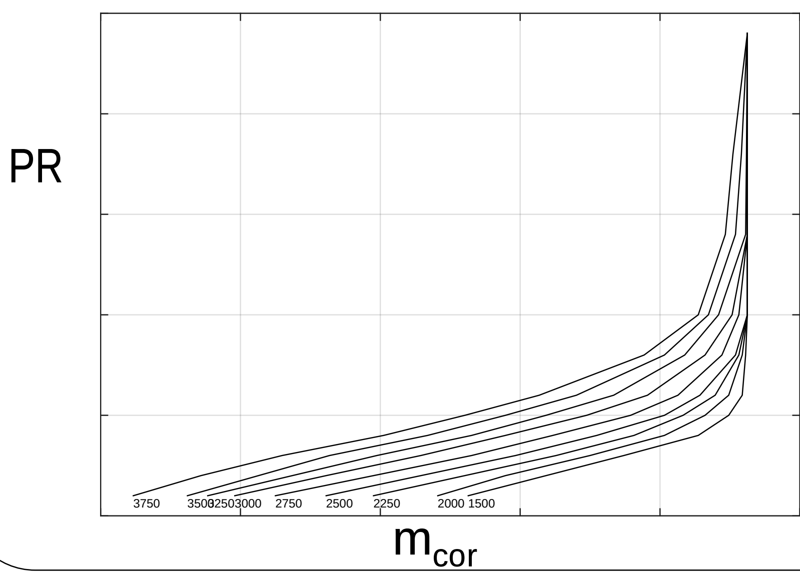
□ *Reduced development time and manufacturing cost*

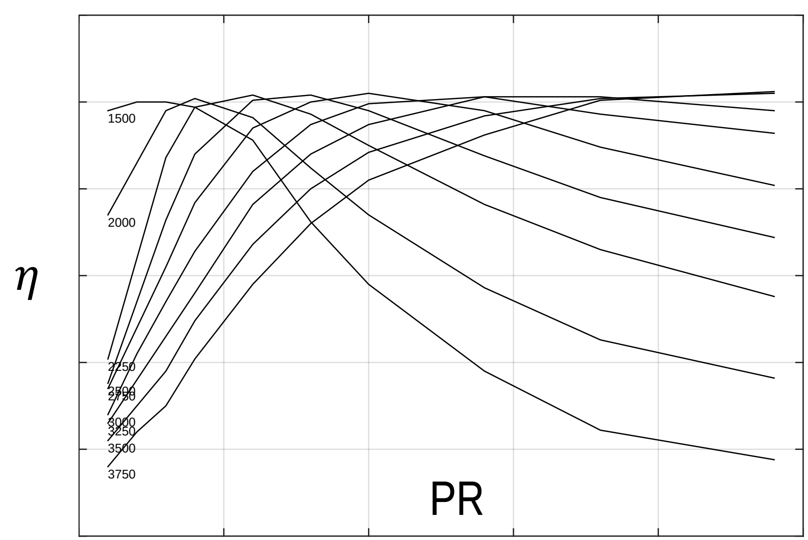
Turbojet Simulation

- Component Maps
  - Compressor:



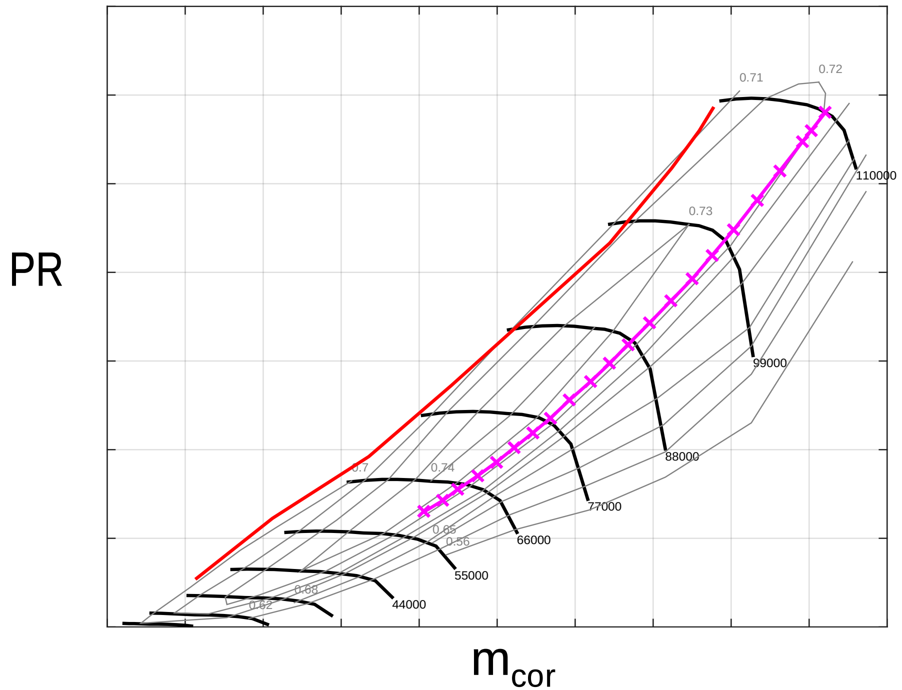
  - Turbine:





Code Validation - Turbojet

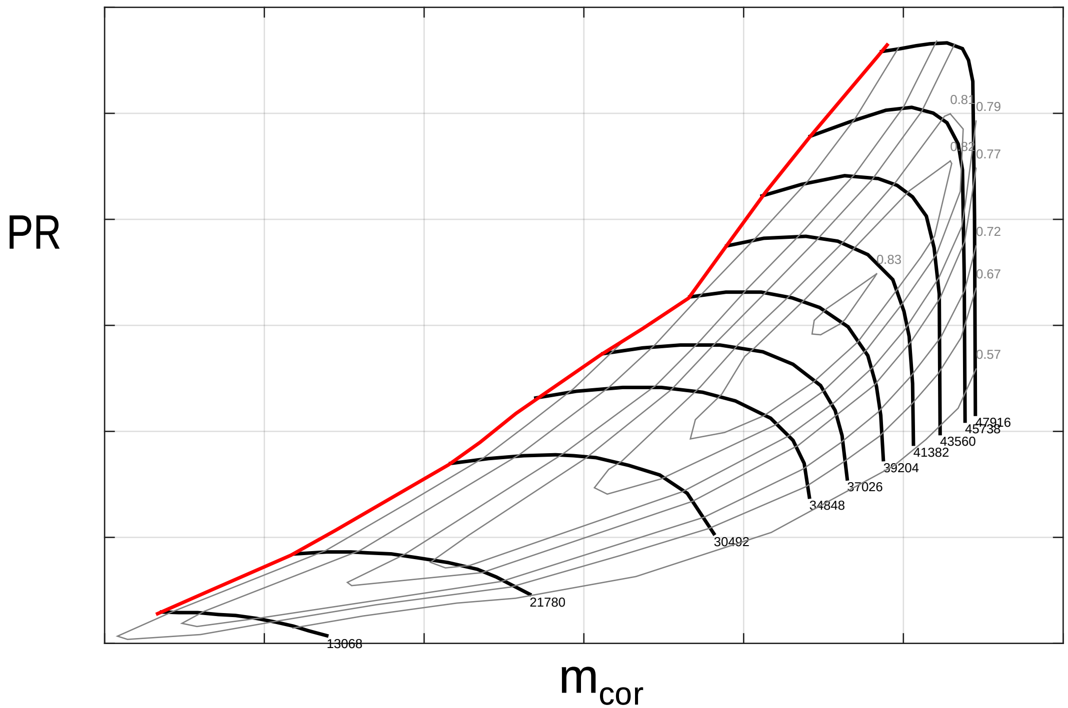
➢ Operating line (Alt.=0m, Mach=0)



Corr. RPM	Thrust [N]			Fuel Flow [kg/s]		
	Gasturb	Our Code	% Error	Gasturb	Our Code	% Error
108,500	220	216	1.8	0.00862	0.008294	3.8
97,650	160	155	3.1	0.00659	0.006295	4.5
86,800	110	108	1.8	0.00532	0.005032	5.5

Code Validation - Fixed Gear Turbofan

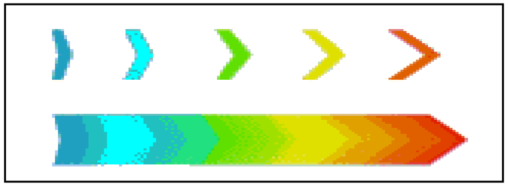
NASA Quiet Fan B Map



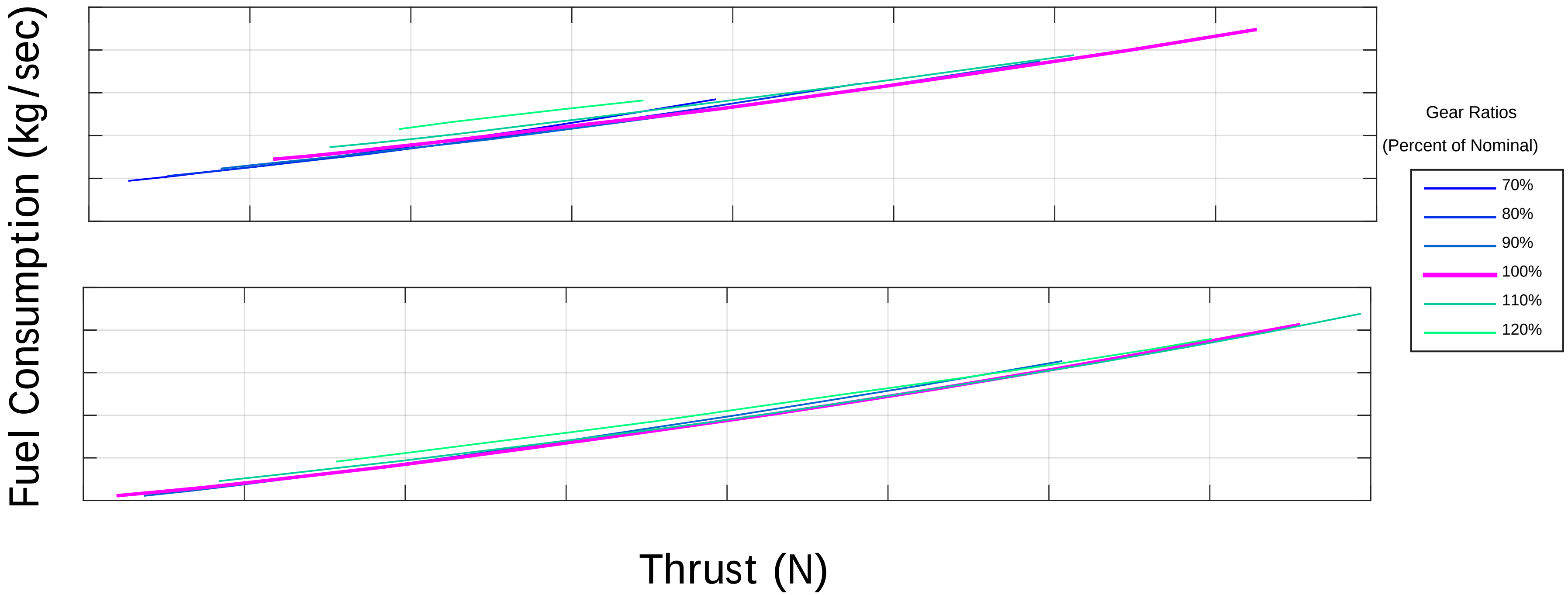
Corr. RPM	Thrust [N]			Fuel Flow [kg/s]		
	Gasturb	Our Code	% Error	Gasturb	Our Code	% Error
108,500	368	380	3.3	0.00989	0.01031	4.3
97,650	284	291	2.5	0.00788	0.00806	2.3
86,800	198	206	4.0	0.00617	0.00637	3.2

CVT Geared Turbofan

- Discrete gears + Interpolation ⟶ CVT model



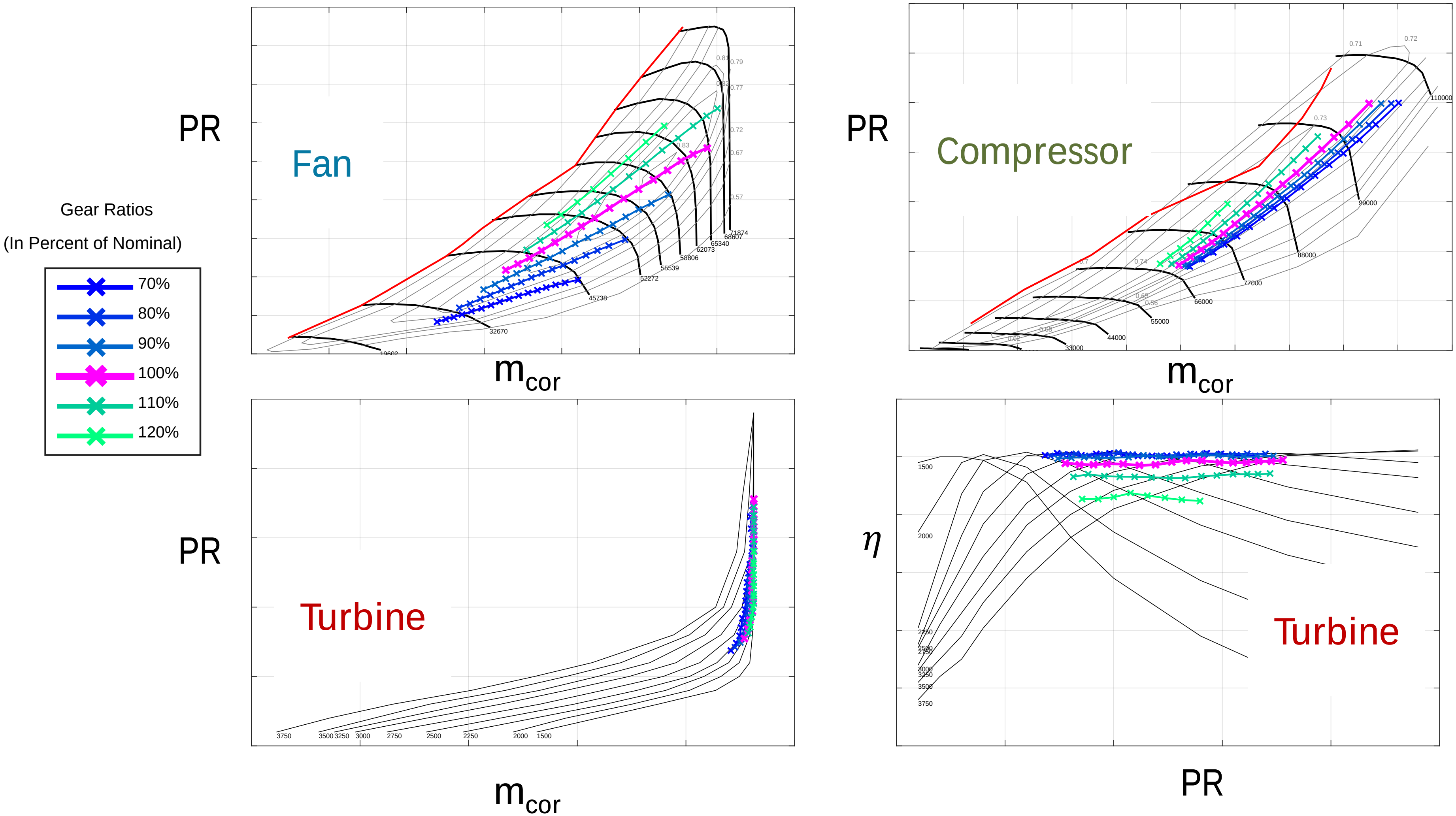
Gear Ratio Effect



- ✓ For Ma < 0.7 : Nominal Design gear ratio always exhibits the best fuel consumption
- ✓ CVT only beneficial for Transonic Ma?

CVT Geared Turbofan

Operating Lines for Different Gear Ratios

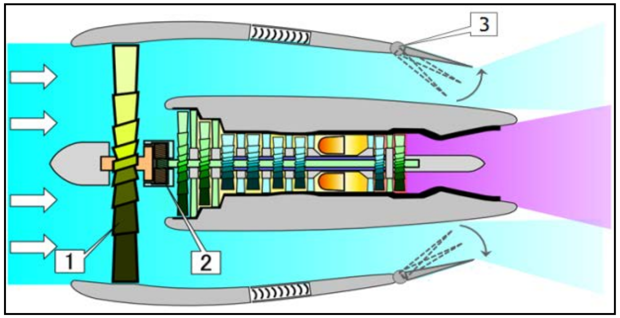


✓ Spreading Motion ➔ Need to further decouple the fan operation from the core

CVT Turbofan with Variable Nozzle

Variable Bypass Nozzle

Control mass flow through bypass without affecting core stream

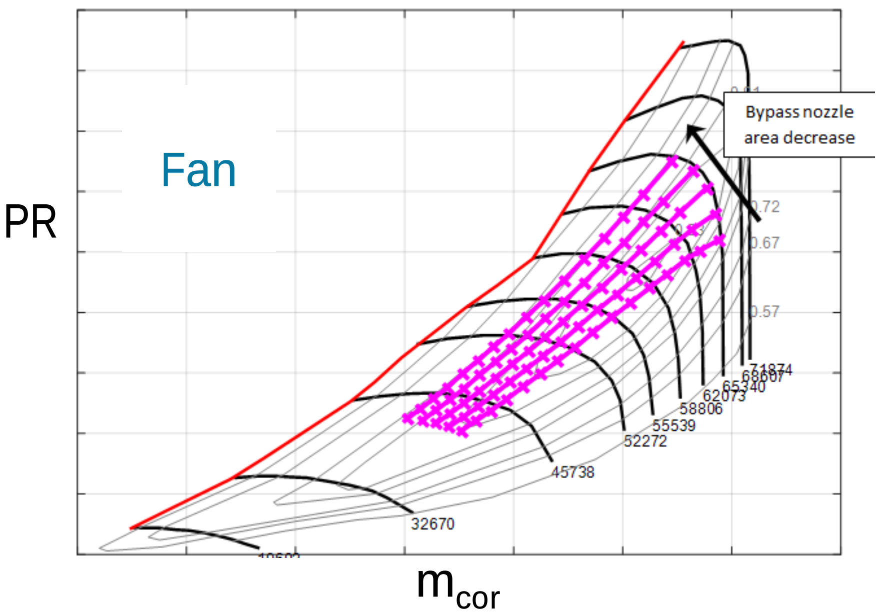


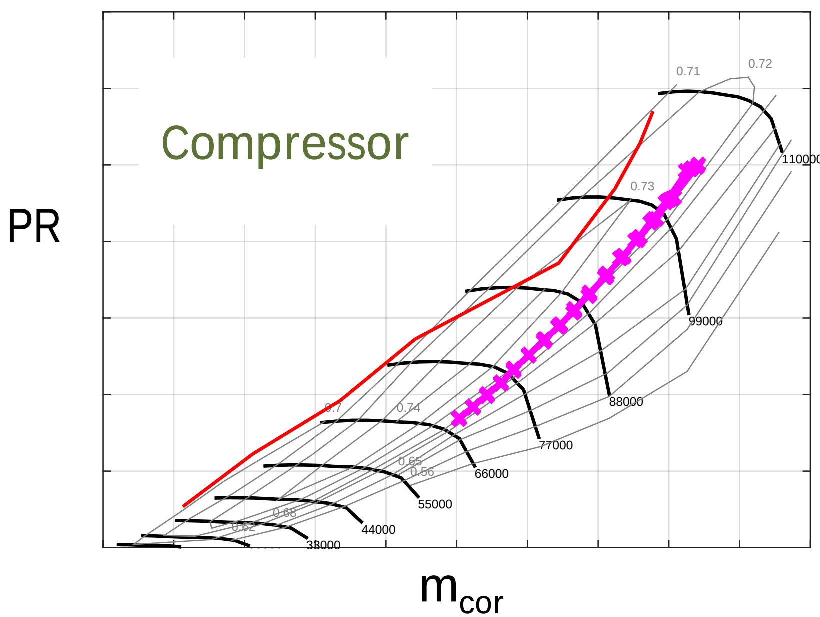
1 - Fan

2 - CVT gearbox

3 - Variable bypass nozzle

Effect on Bypass and Core





✓ Shift mechanism of fan operating line without effect on core performance

CVT Turbofan with Variable Nozzle

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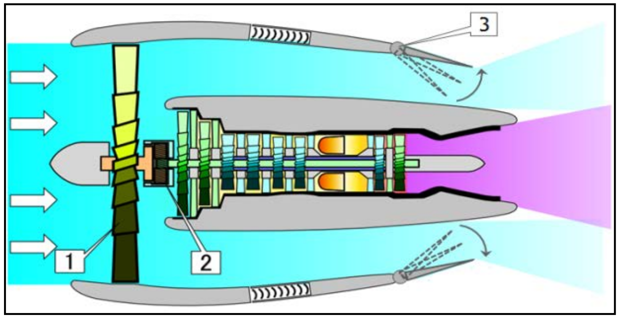
Control mass flow through bypass without affecting core stream



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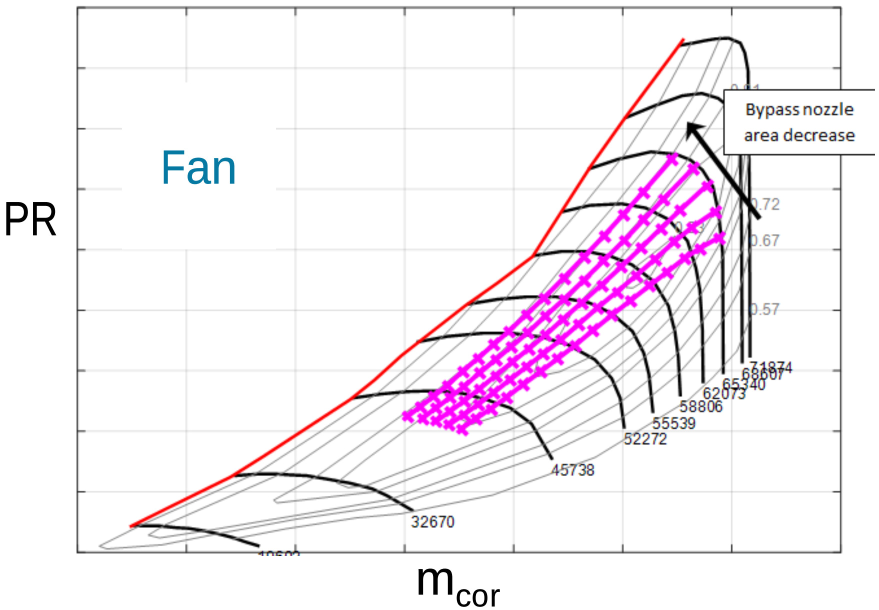

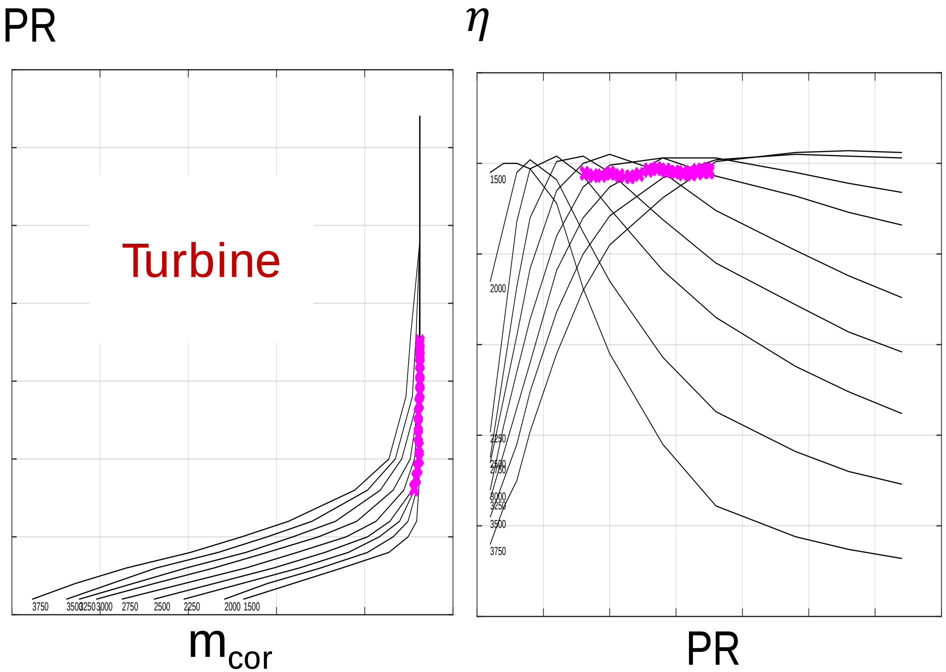

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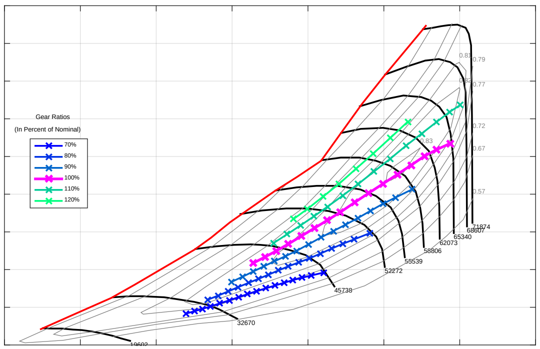
CVT Turbofan with Variable Nozzle

Concept

CVT (Spreading)



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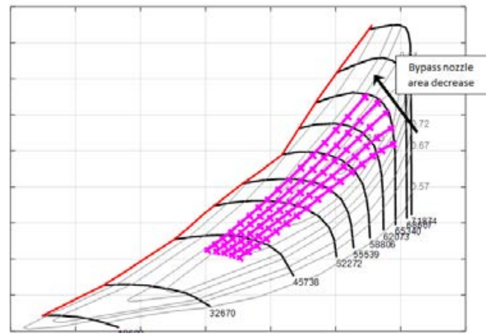
Var. Bypass (Fanning)

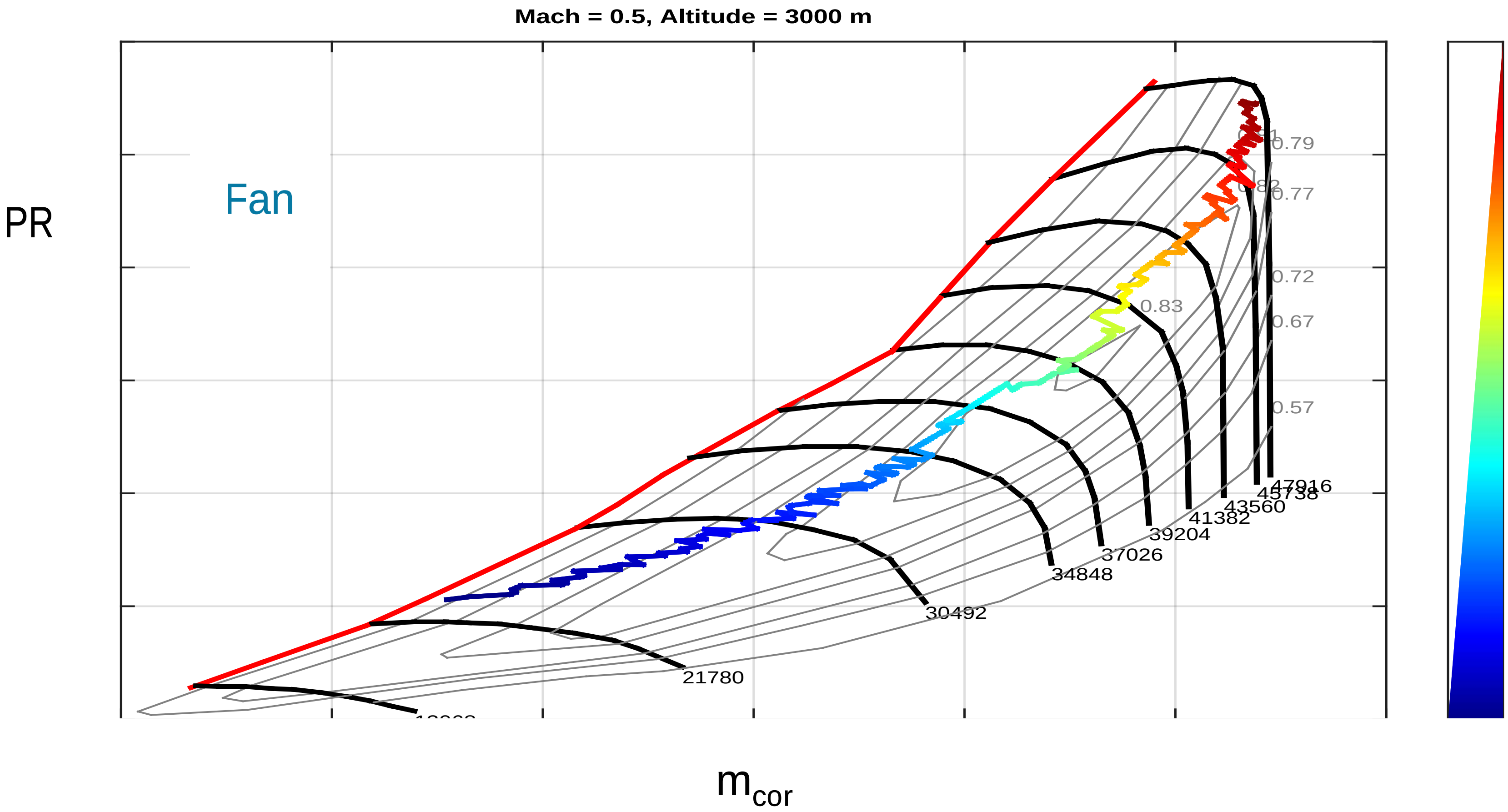


= **Operating Line Anywhere on Fan Map**

Investigation

- Select flight condition
- Select a large band of gear ratios, nozzle positions, and core RPMs
- Examine Thrust vs. Fuel at each combination
- Select gear, nozzle position, RPM with least Fuel per Thrust

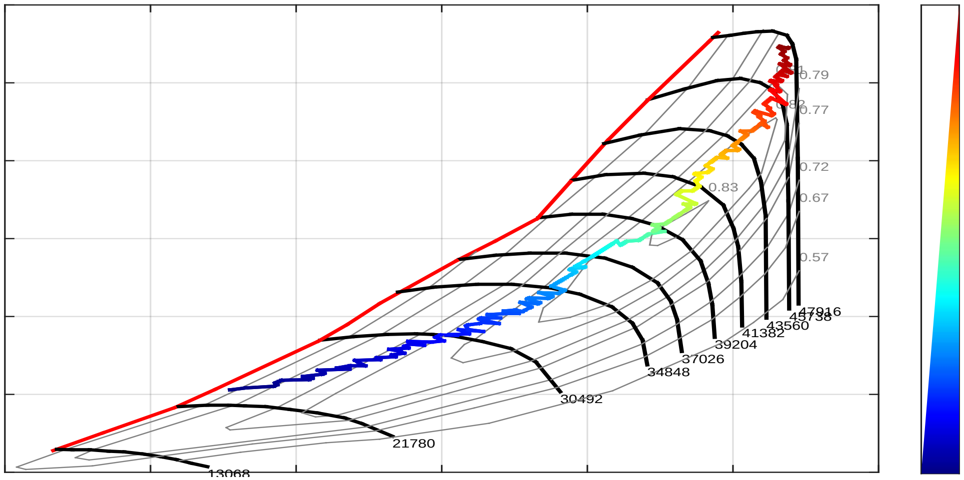
CVT Turbofan with Variable Nozzle

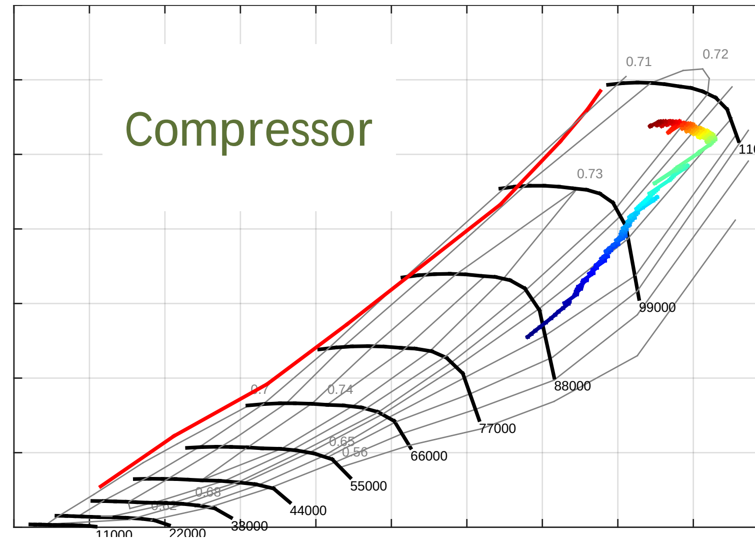


- ✓ Always operating on the most efficient point on the fan map
- ✓ No operability issues (running out of the map)
- ✓ Easy to scale and integrate existing fan designs

CVT Turbofan with Variable Nozzle

PR





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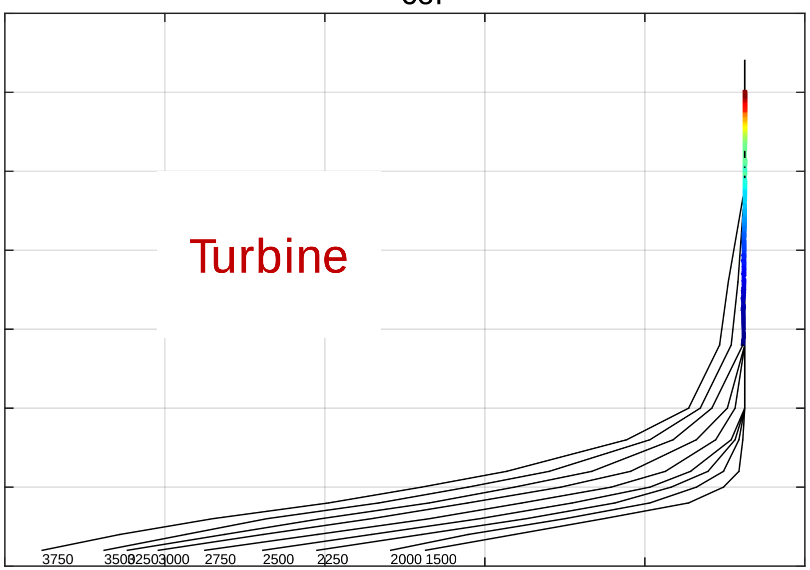

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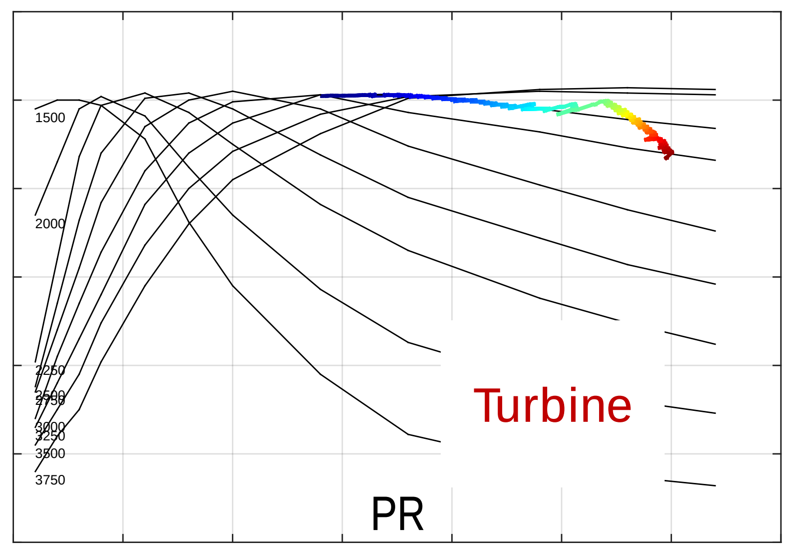
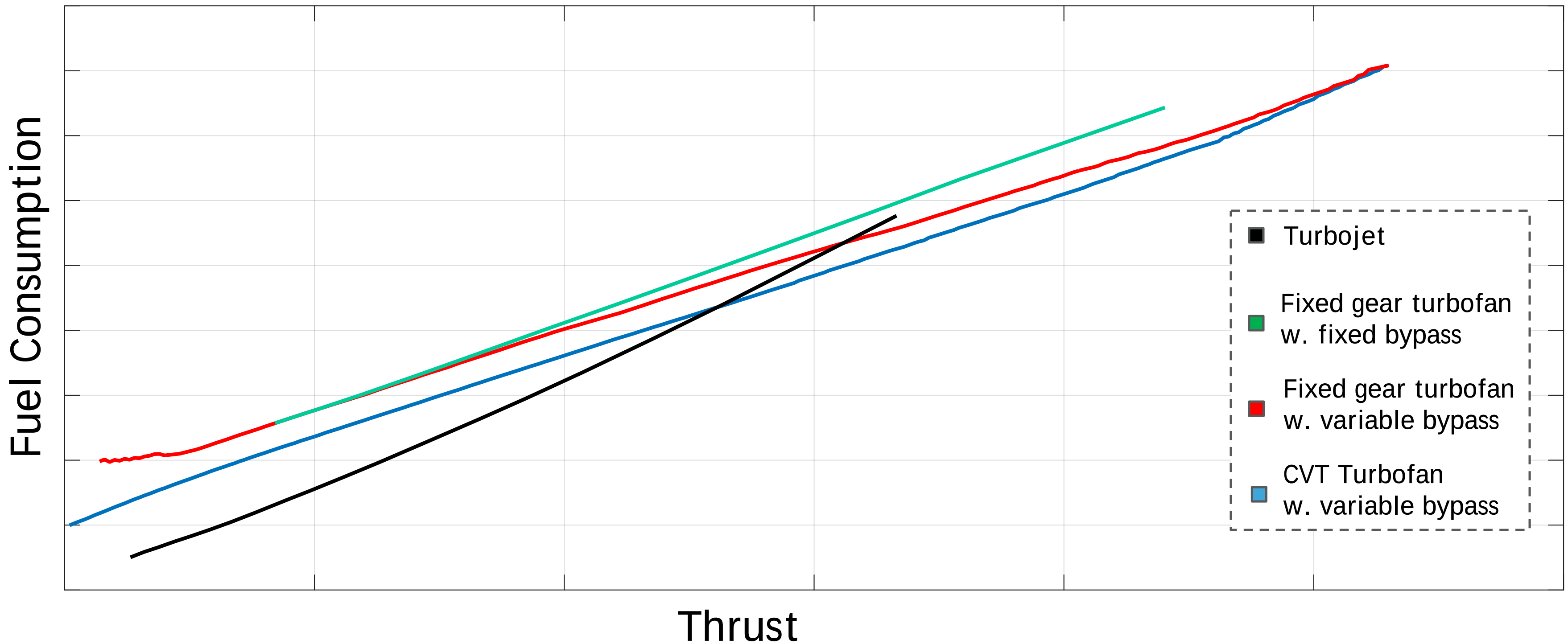


PR

Efficiency of Various Configurations

For Typical Subsonic Flight Conditions



Fan: • Stability Issues • Under matching, thrust increase ~35 % • Fuel consumption increase ~30%

Variable bypass: • Good operability ➔ thrust increase ~20% • Poor fuel consumption persists

CVT with variable bypass: • Reduction in fuel consumption ~20%

✓ Enables operation at Transonic and Supersonic Flight (not modeled here)

Conclusions and Future Work

Thermodynamic analysis of ***Variable cycle micro-GT*** engine development

Integration of **continuously variable speed fan** and **variable bypass nozzle** :

□ Enhanced Thrust □ Higher Efficiency □ Augmented Operability

Implications

- Cost effective engine that can perform multiple roles.
- Make use of readily available turbojet platform
- Longer range/More payload

Future Work

- Thrust versus weight considerations
- Simulation of Operation at Transonic Flight Conditions
- Modeling of larger engines
- Complete Flight Mission Modeling
- Laboratory experimentation

Thank you for your time!