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

Asst. Prof. Beni Cukurel
Kobi Kadosh, Michael Palman

Turbo and Jet Engine Laboratory
Faculty of Aerospace Engineering
Technion - Israel Institute of Technology
Motivation

- Operational envelopes of UAVs expand into transonic speed range

- 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

- 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)

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Code Validation - Fixed Gear Turbofan

**NASA Quiet Fan B Map**

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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

Gear Ratios (In Percent of Nominal)

- 70%
- 80%
- 90%
- 100%
- 110%
- 120%

PR

Fan

PR

Compressor

PR

Turbine

PR

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

Effect on Bypass and Core

✓ Shift mechanism of fan operating line without effect on core performance
CVT Turbofan with Variable Nozzle

Variable Bypass Nozzle
Control mass flow through bypass without affecting core stream

Effect on Bypass and Core

- PR
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- \( \text{Fan} \)
- \( \text{Turbine} \)

- Shift mechanism of fan operating line without effect on core performance
CVT Turbofan with Variable Nozzle

Concept

CVT (Spreading) + 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

Compressor

Turbine
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!