Modeling Turboshaft Engines for the Revolutionary Vertical Lift Technology Project

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Purpose

High interest in Urban Air Mobility (UAM) / vertical-lift vehicles; critical need to understand requirements / capabilities.

The Revolutionary Vertical Lift Technology (RVLT) Project released a set of reference vehicles to support tools, operations and technology development within and outside NASA.

Proceed to next level of studies / analyses. Many turbine engine models not readily distributed / discussed. Develop representative performance and weight models to support vehicle sizing and mission analyses, as well as propulsion and power system modeling (650-7,500 hp / 485-5,600 kW engine class).

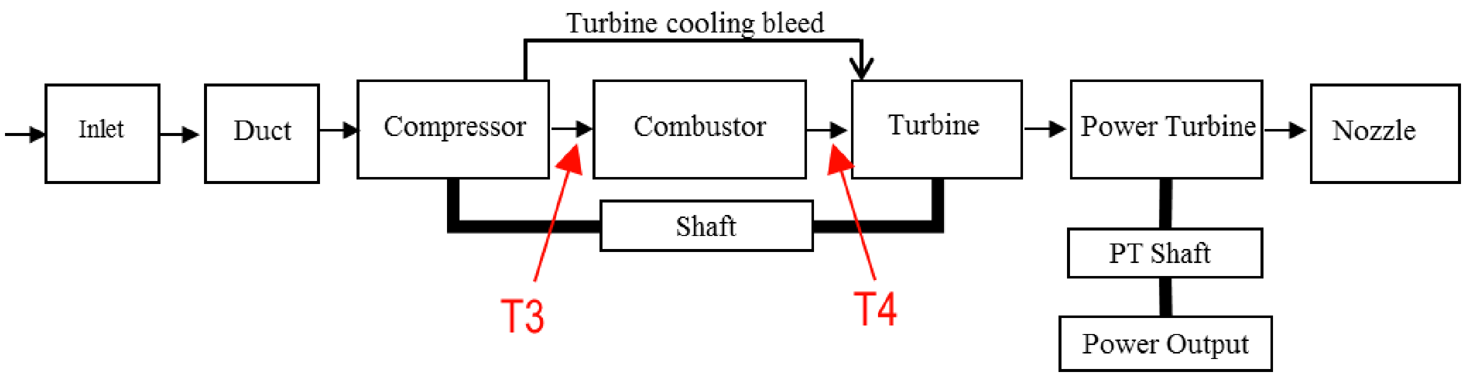
Outline

- Discuss gas turbine engine
  - Configurations, study variables
  - Component performance assumptions
  - Flowpath design layouts
- Gas turbine engine performance
  - 1 versus 2-spool core performance
  - Power-to-weight and Power Specific Fuel Consumption (PSFC) performance trend lines
- Vehicle sizing assuming advanced and current engine performance
- Summary
- Future efforts

Configurations and Variables: Gas Turbine Engine (Brayton cycle) Modeling

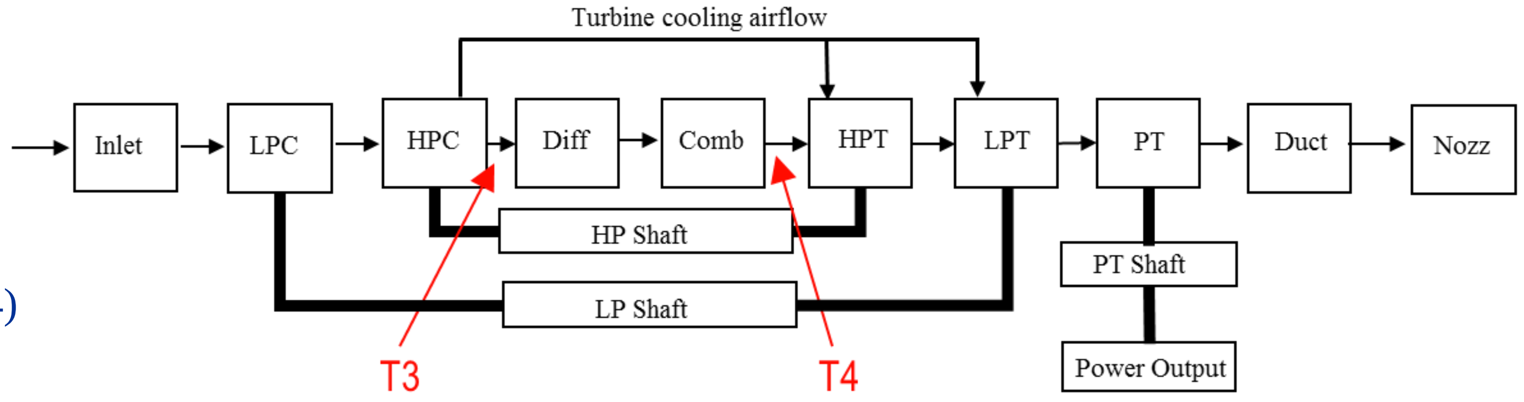
1-spool core turboshaft

(Airflow / HP, PR, T4)



2-spool core turboshaft

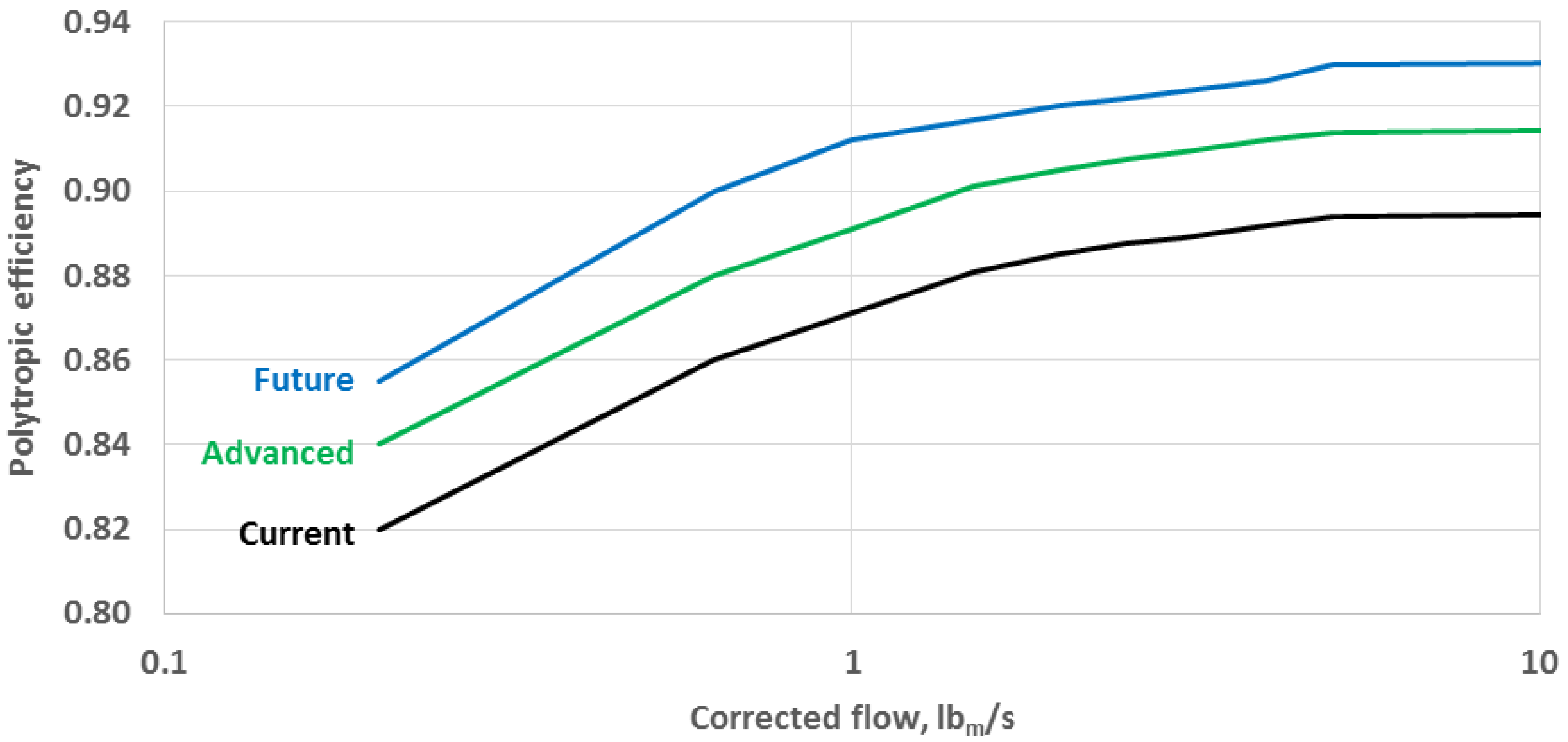
(Airflow / HP, PR each spool, T4)



LPC – low pressure compressor, HPC – high pressure compressor, Diff – diffuser, Comb – Combustor, HPT – high pressure turbine, LPT – low pressure turbine, PT – power turbine, Nozz – nozzle, HP – high pressure, LP – low pressure, PT – Power turbine,

More sophisticated core can enhance design and operational efficiency (example on later chart)

Turbomachinery Efficiency: Gas Turbine Engine (Brayton cycle) Modeling



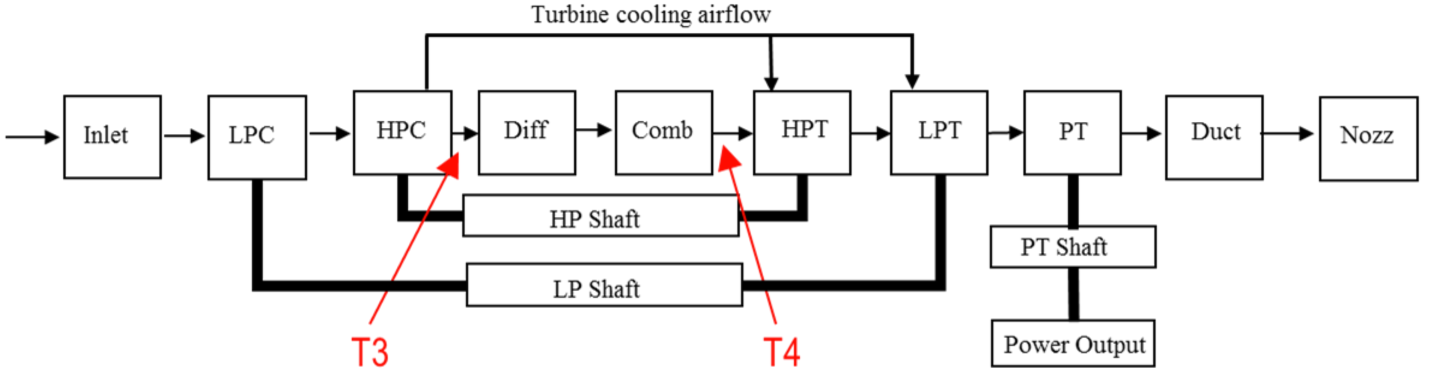
Notional curves for effect of blade size on turbomachinery efficiency

(uses corrected flow, $W * \sqrt{\theta} / \delta$ as surrogate for blade size)

Compressors: exit flow   Turbines: entrance flow

(models presently have no limit on minimum corrected flow)

Flowpath shape / representation: Gas Turbine Engine (Brayton cycle) Modeling



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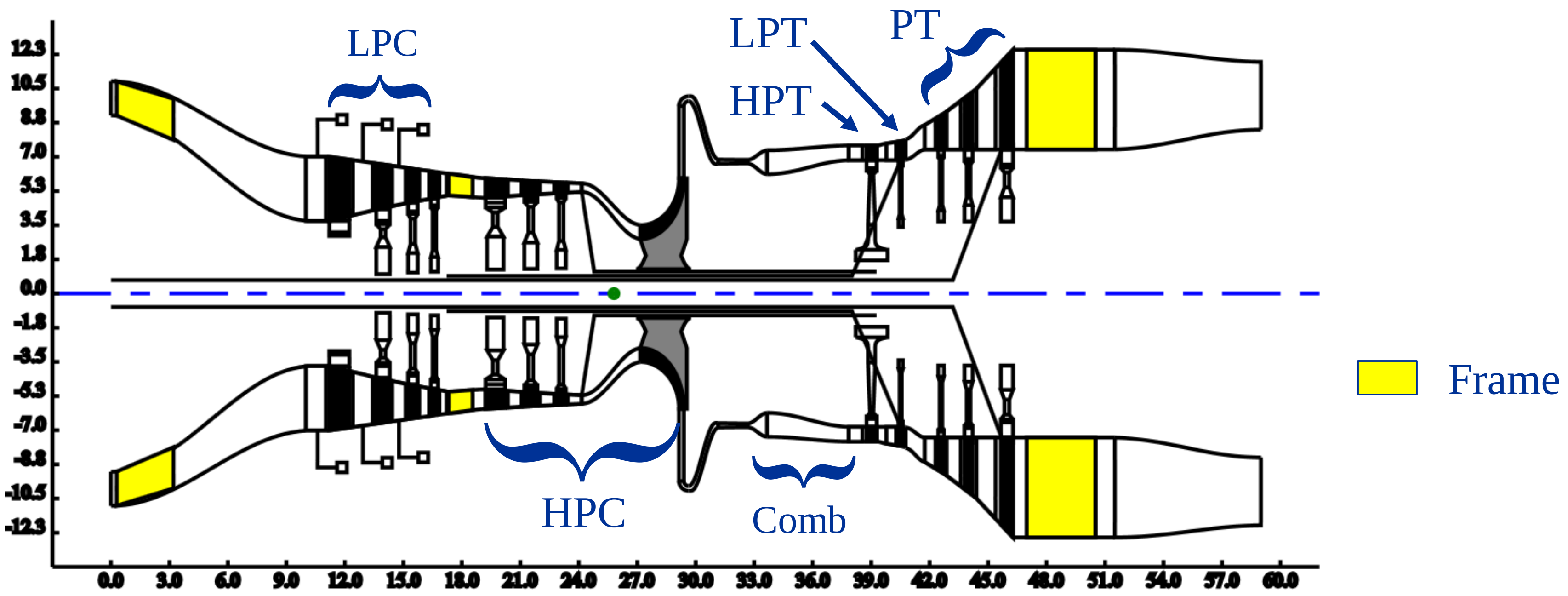
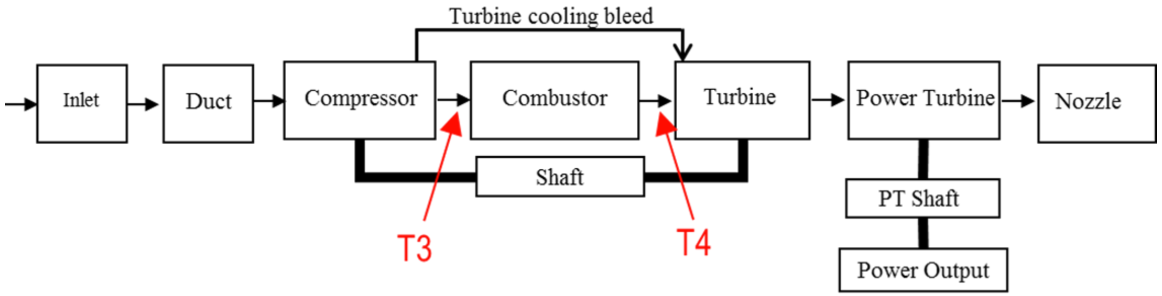
Numerical Propulsion System Simulation (NPSS) / Weight Analysis of Turbine Engines (WATE++)

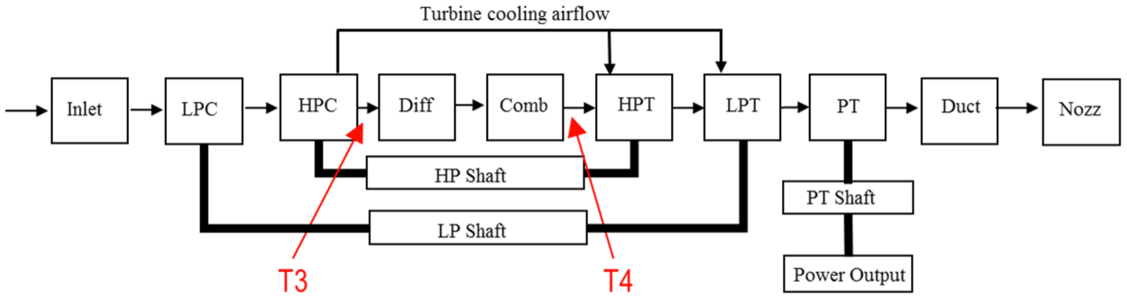
FATE Technology 7,500 hp engine



Performance: 1 versus 2 spool core: Gas Turbine Engine (Brayton cycle)



1-spool core turboshaft



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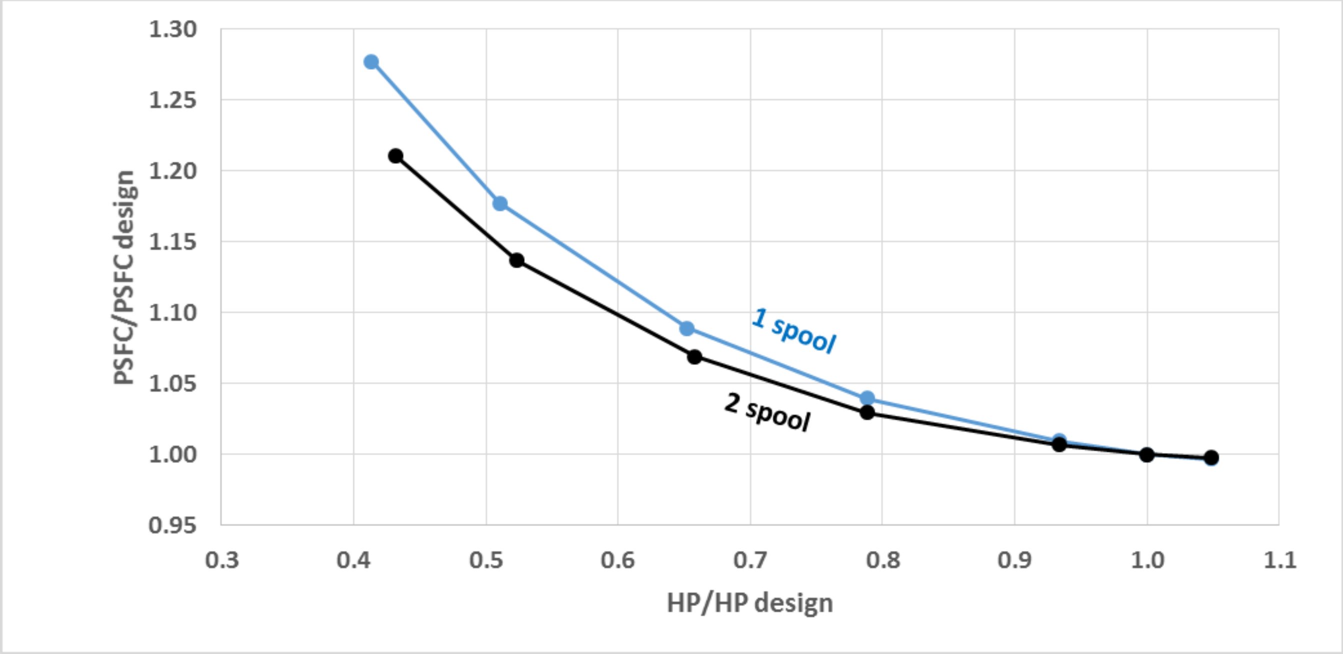
2-spool core turboshaft

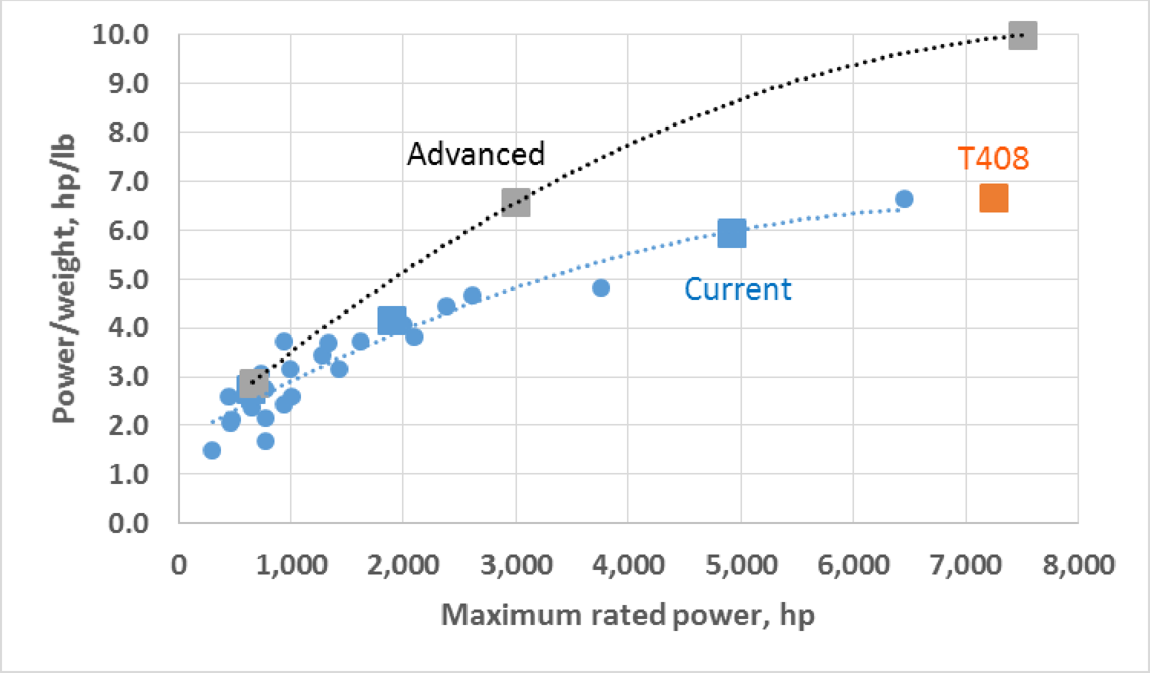
More sophisticated engine configuration yields some efficiency improvement at part power. But choice will depend on vehicles, mission requirements, etc.

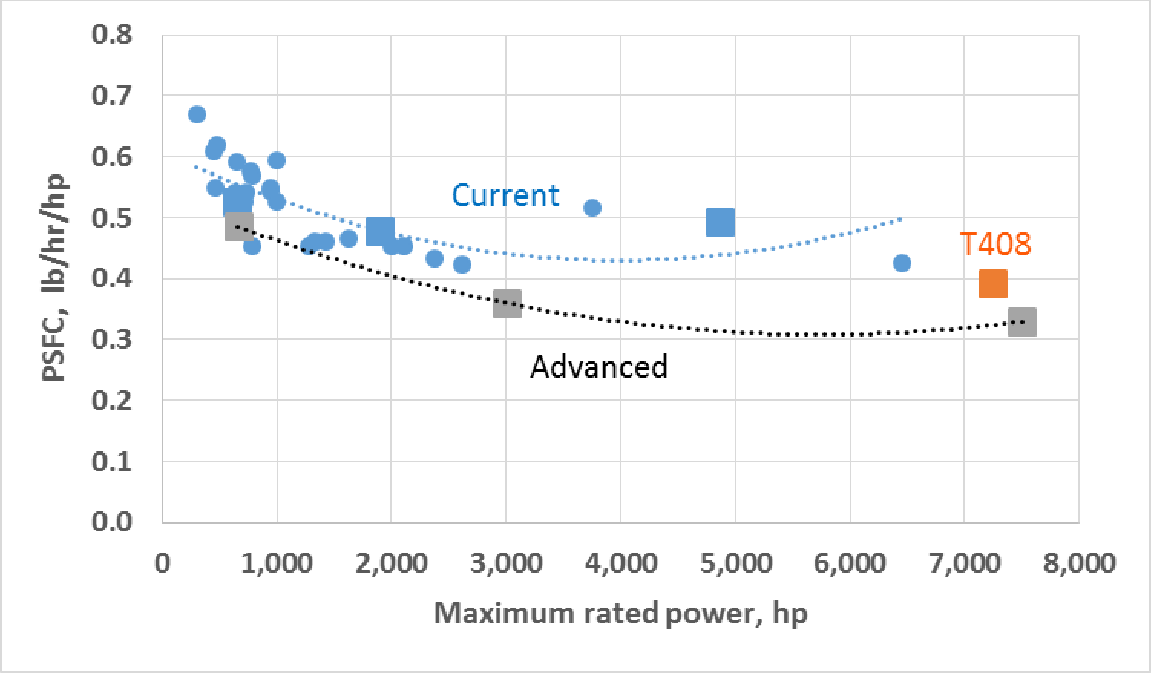
2-spool could have better design Power specific fuel consumption (PSFC)



Performance Trend lines: Gas Turbine Engine (Brayton cycle)

Square markers are modeled engines





PSFC = Power specific fuel consumption

New, advanced engines are realizing some significant improvements at larger sizes / power.

Lower performance gains at smaller sizes from size effects / losses.

Vehicle Sizing: Advanced vs. Current gas turbine engines

Turboelectric versions of vehicles, modeled in NASA Design and Analysis of Rotorcraft (NDARC)

Vehicle	Tiltwing			Lift+cruise		
Engine Technology	Current	Advanced	difference	Current	Advanced	difference
Design Gross Weight, lb	15,470	13,350	-14 %	6,650	5,970	-10 %
Engine power, hp	5,190	4,570	-12 %	1,220	1,220	-
Engine weight, lb	900	570	-37 %	370	260	-30 %
PSFC, hp/(lb/h)	0.380	0.325	-14 %	0.597	0.360	-40 %
Fuel, lb	2,500	1,910	-24 %	295	170	-42 %

Advanced engines enable significant vehicle sizing benefits.

Summary

- Gas turbine modeling methodology and assumptions were developed for current and advanced technology engines to support tools, operations and technology development within and outside NASA.
- Engine models complement RVLT vehicles developed and released last year. Can support multidisciplinary design and analysis (MDAO) as well as more detailed hybrid or turboelectric systems for electric propulsion and power studies.
- Advanced gas turbine engine performance and weight can realize significant improvements in fuel efficiency and engine weight, especially at higher horsepower classes.
- Improved engine performance can be used to reduce vehicle size while maintaining mission capability.

Future efforts

- Some model cleanup still necessary:
  - Some additional model documentation (within models and overall).
  - Update and organize some variable names.
  - Verify and document release approval.
- Some additional models already requested
  - Models specifically sized for the RVLT reference vehicles (200, 1300 and 5000 hp).
  - Also improve trend line performance within and outside 650-7,500 hp range
- Help integrate models into more-detailed propulsion and power models
  - Multi-disciplinary analysis and optimization (MDAO) studies
  - Hybrid (parallel or serial) or turboelectric systems; steady-state and transient modeling (support thermal management studies).

Acknowledgments

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Revolutionary Vertical Lift Technology (RVLT) Project

Questions?

Backup Slides

Engine size and performance parameters

Maximum rated hp, Sea level, ISA	650	660	1,895	3,000	4,916	7,248	7,500
Technology	Current	Advanced	Current	Advanced	Current	Mid	Advanced
PSFC, lb/hr/hp	0.526	0.485	0.476	0.360	0.494	0.394	0.330
Airflow, lb/s	4.8	4.1	11.8	14.6	28.1	35.7	28.1
Overall pressure ratio	9	9	17.7	25.2	9.3	20	30
Comp. exit corrected flow, lbm/s	0.8	0.65	0.9	0.9	4.4	2.5	1.6
Compressor layout (A=axial, C=centrifugal)	1C	1C	5A + 1C	6A + 1C	7A + 1C	5A + 1C	4A / 3A + 1C
Turbine stages	1 + 1	1 + 1	2 + 2	2 + 3	2 + 2	2 + 3	1 + 1 + 3
Diameter in	16	16	17	16.4	24	27	25
Length, in	28	28	45	47	46.5	58	59
Weight, lb	238	229	458	457	830	1085	750
Power/weight, hp/lb	2.7	2.9	4.1	6.6	5.9	6.7	10

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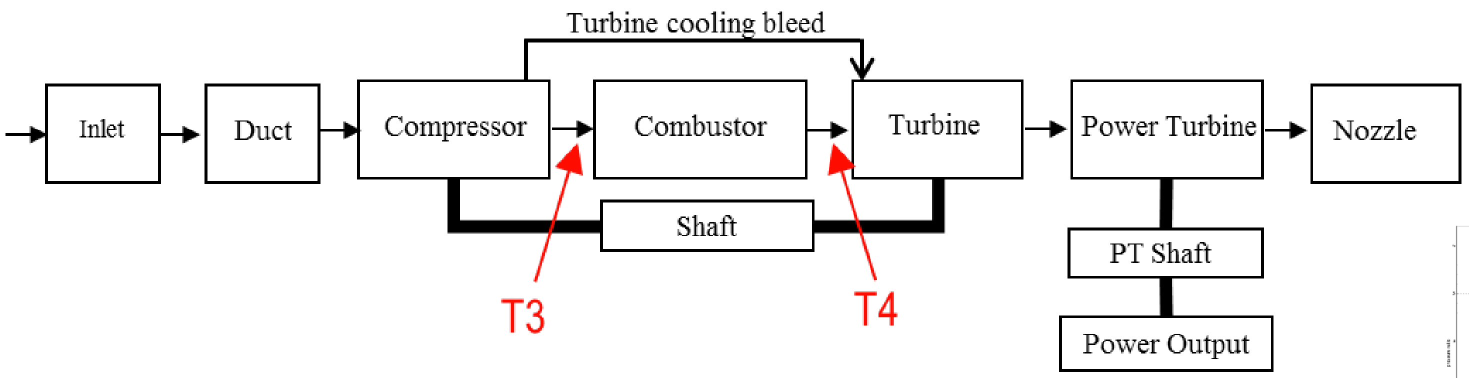

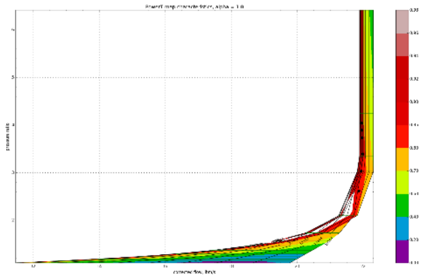

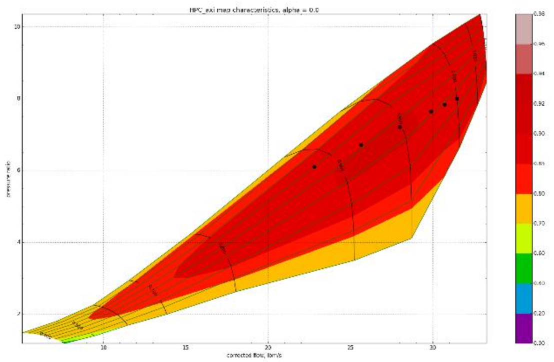

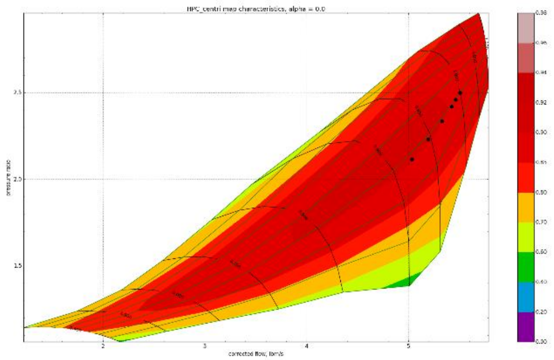

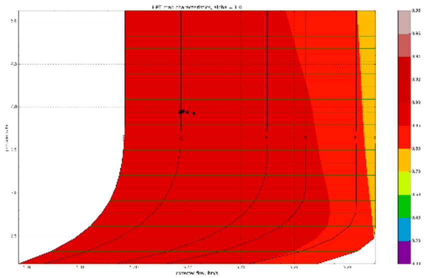

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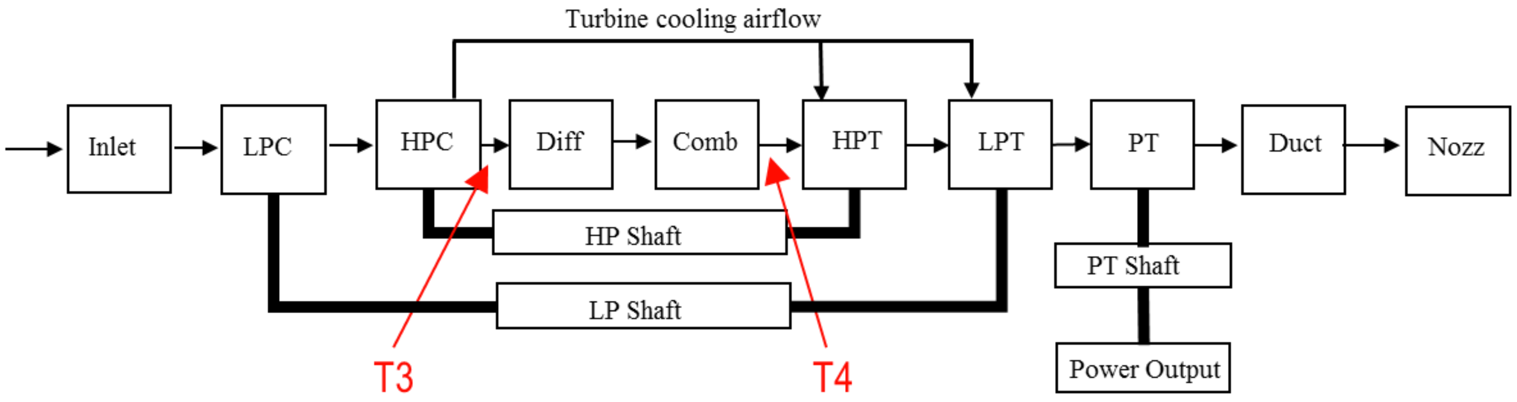

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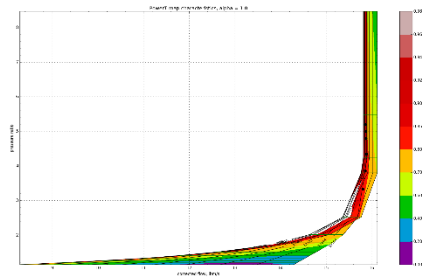

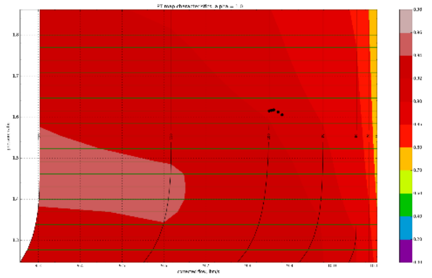

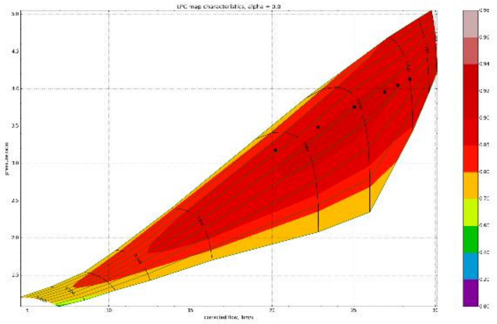

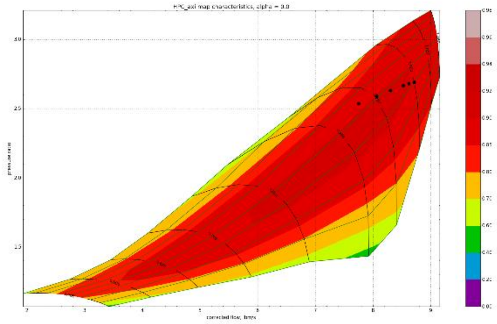

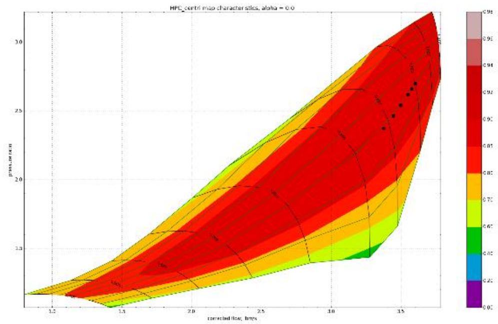

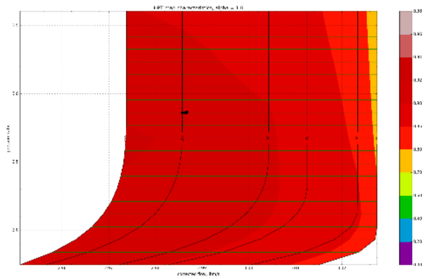

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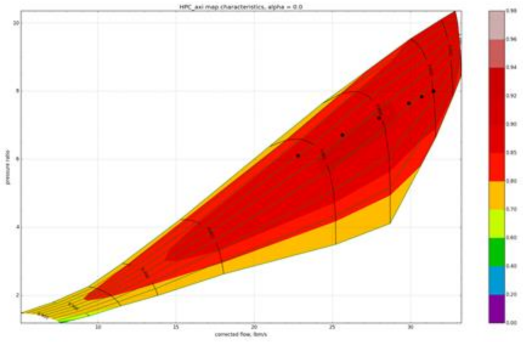
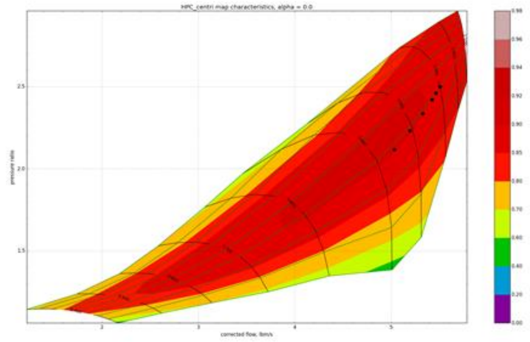
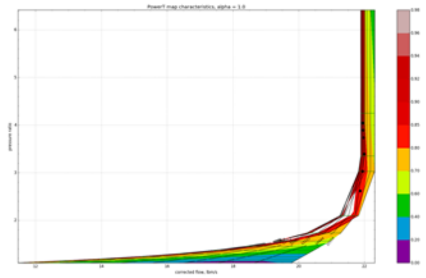
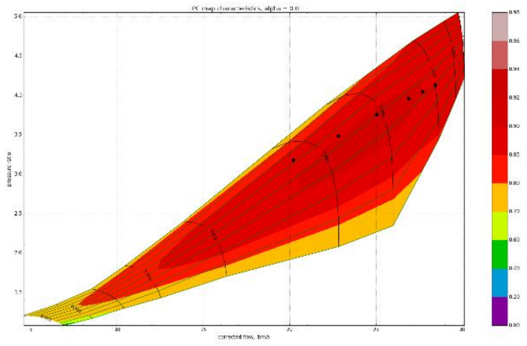


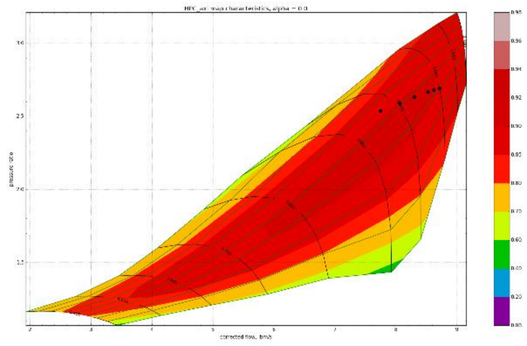


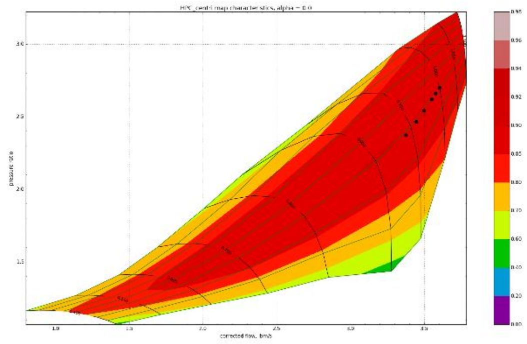


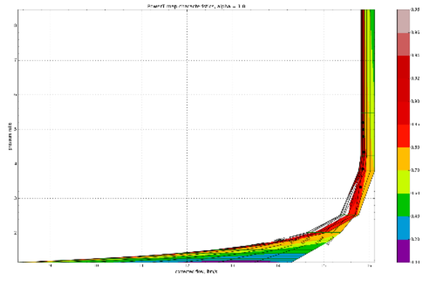
1-spool ↑

2-spool ↓









ABSTRACT

Turboshaft engine performance and weight models were developed to support conceptual propulsion and vehicle mission design in support of the National Aeronautics and Space Administration's (NASA) Aeronautics Mission Research Directorate's (ARMD) Revolutionary Vertical Lift Technology (RVLT) Project. These models were developed using open data sources, assuming current and advanced technology levels, and range from 650 to 7,500 shaft output horsepower (485 to 5,600 kW). Documenting the methodology, assumptions, and resulting performance realizes important benefits for NASA and the aviation community. NASA concept vehicle efforts using these propulsion models can more readily shared among the government, industry and university community as common baselines to support current and future work. Assessing the benefits of advanced technologies and new configurations can be facilitated using these models, which helps guide technology investment. As the various modeling conceptual vehicle and mission analysis environments advance, these models can be used directly for broader systems analysis studies, including optimization within the propulsion model itself. To perform this effort, the turboshaft engine is briefly discussed, highlighting the specific components and their expected performance characteristics over the power range and technology levels considered. Engine configurations will also be discussed as they will vary based on power output and assumed technology level. Engine performance, such as airflow, power output and weight will be reported, noting trends that are important for system studies. The effect of advanced propulsion technologies on RVLT concept vehicles are also reported. Finally, potential future propulsion modeling work will be proposed.

END