Multi-Disciplinary Design Optimization

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Objectives and Outline

- Objectives
    - Brief overview of the multidisciplinary design and analysis research program for engine design
    - Design tools and design optimization using DAKOTA
- Outline
    - Program background and problem description
    - Variable cycle engine preliminary design
    - Design tools
    - DAKOTA optimization system
    - Demonstrations
    - Conclusions and discussion

Multidisciplinary Design Optimization

- *J* = Objective function
- ***x*** = Vector of design variables
- ***g*** = Vector of inequality constraints
- ***h*** = Vector of equality constraints
- $\boldsymbol{x}_{lb}$ and $\boldsymbol{x}_{ub}$ are lower and upper bounds on design variables

Multiple Disciplines

$$\text{find } x \text{ that minimizes } J(x) \text{ subject to } g(x) \leq 0,\ h(x) = 0, \text{ and } x_{lb} \leq x \leq x_{ub}$$

Multiobjective Design Optimization

- J_i = Objective functions
- $\boldsymbol{x}$ = Vector of design variables
- $\boldsymbol{g}$ = Vector of inequality constraints
- $\boldsymbol{h}$ = Vector of equality constraints
- $\boldsymbol{x}_{lb}$ and $\boldsymbol{x}_{ub}$ are lower and upper bounds on design variables

Multiple Objectives

$$\text{find } x \text{ that simultaneously minimizes } \left[J_1(x), J_2(x), \cdots, J_n(x)\right]$$

$$\text{subject to } g(x) \le 0,\ h(x) = 0, \text{ and } x_{lb} \le x \le x_{ub}$$

Multiobjective Design Optimization

- **Pareto solutions are those for which improvement in one objective can only occur when another objective is penalized**
- **The solution of a multiobjective problem is a possibly infinite set of Pareto points**
- **The Pareto front is a response surface in the design space containing Pareto points that constitute possible optimal solutions**

A design point in the objective space, J^* is Pareto optimal if there does not exist another feasible design objective vector, J, such that

$J_i \leq J_i^*$ for all $i \in \{1, 2, \ldots, n\}$, and $J_j \leq J_j^*$ for at least one $j \in \{1, 2, \ldots, n\}$

Multi-Disciplinary Analysis & Optimization

Description

- To assemble a working turbomachinery design system that is multi-fidelity, multi-disciplinary; driven by an optimizer to create Engine Systems ideally suited for particular missions
- To generate new integrated engine design system that will lead to improvements in efficiency, fuel burn, and reduction of green house gases
- To provide "industrial-quality" design & analysis tools for undergraduate education

Personnel

- Dr. Jeff Dalton (AVETEC Principal Investigator)
- Dr. Mark Turner (University of Cincinnati, Co-PI)
- Dr. Ian Halliwell (AVETEC)
- Dr. Tim Beach (AVETEC)
- Dr. John Reed (University of Toledo)
- Dr. Ananda Himansu (TAITECH)

- NASA Contract: NNC07CB61C

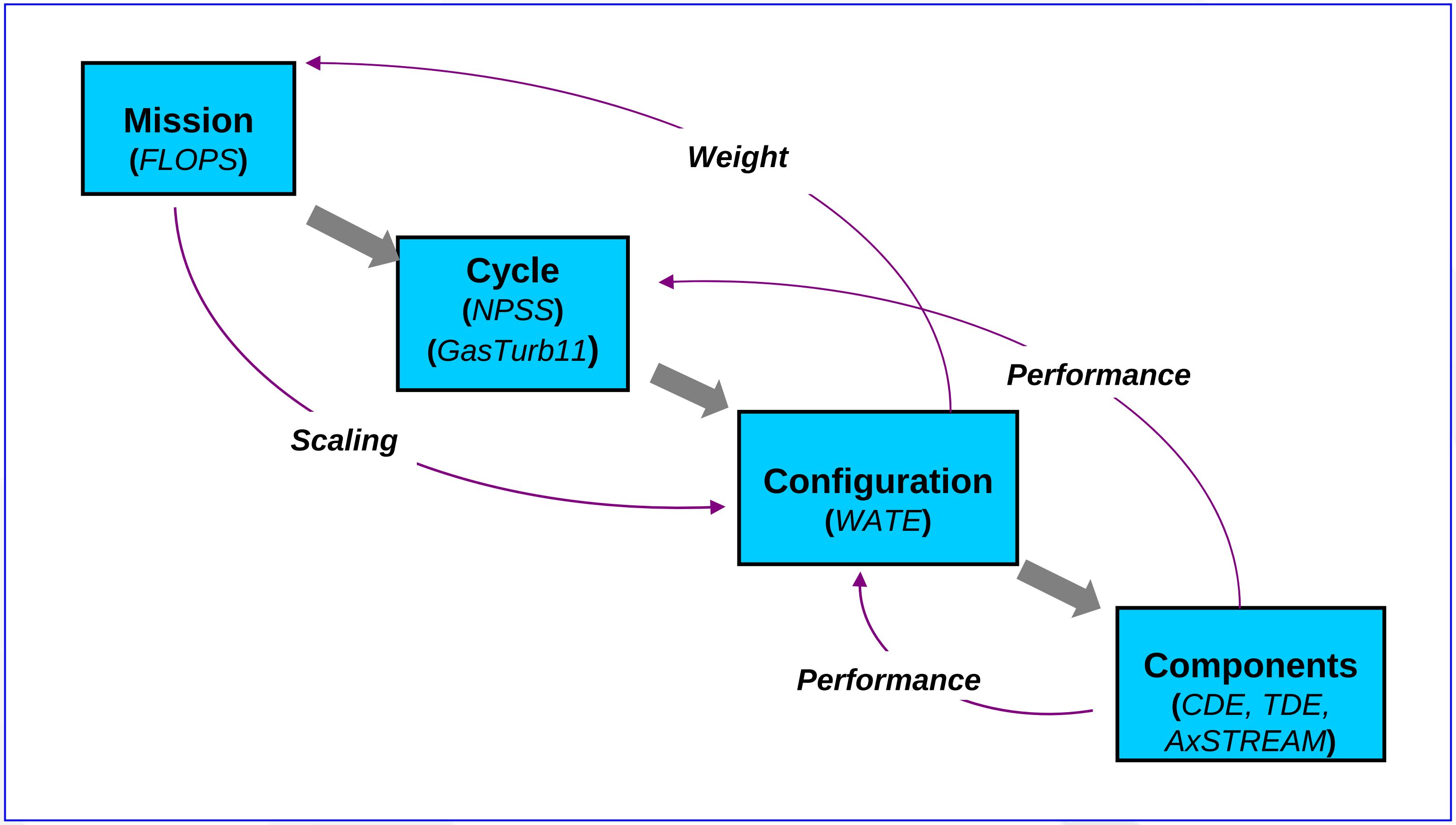
Technical Approach

- A subsonic Variable Cycle Engine, relevant to the NASA Subsonic Fixed-Wing Program, is used as a vehicle for the proposed effort
- The results of initial design studies using *GasTurb*, are transferred to *NPSS & ANOPP* for subsequent development, mission analysis and noise prediction
- High-fidelity multidisciplinary simulation is performed on selected components; associated codes are integrated into the NPSS environment
- UC Design Suite used for geometry modeling
- High fidelity CFD studies to validate designs

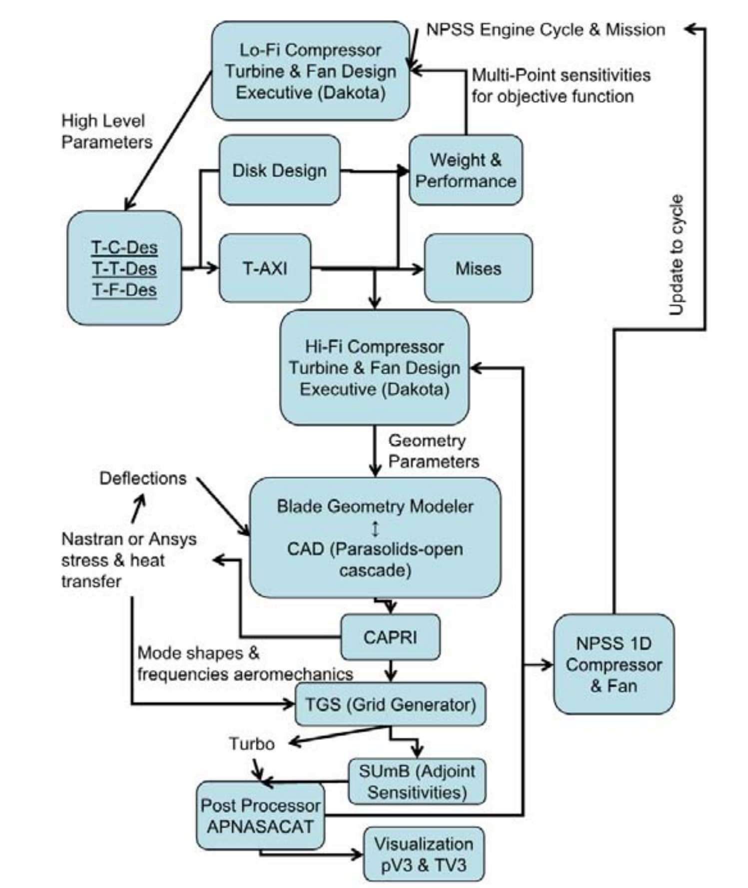
Approach and Schedule

- Year 1: DAKOTA scripts to perform elementary trust region optimization.
- Year 2: DAKOTA scripts to perform Surrogate-Based Optimization on high-fidelity engine component simulation
- Year 3: Final report detailing selection of design parameters and performance of optimizer, together with performance of improved design. DAKOTA scripts that perform the optimization.

Design Process and Trade-Offs



MDAO Process Flow



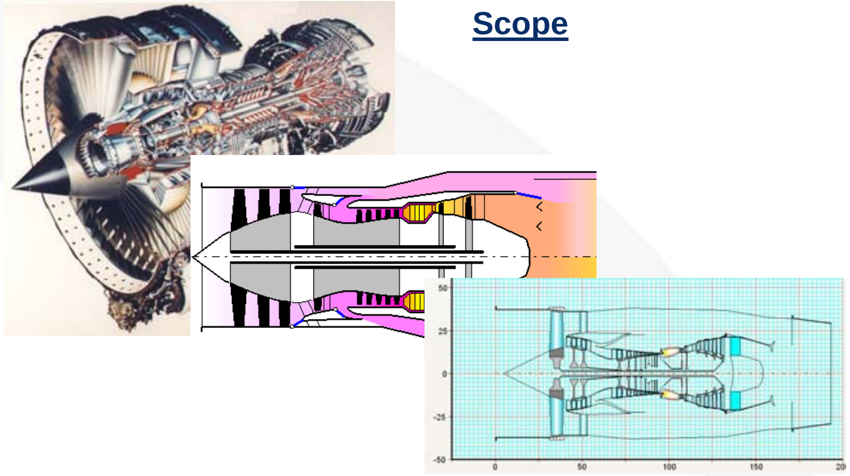
- Multidisciplinary
  - Aircraft mission
  - Noise generation
  - Blade geometry
  - Disk geometry
  - Engine cycle
  - Materials
- Multiobjective
  - Minimize weight
  - Minimize noise
  - Minimize SFC
  - Maximize efficiency
- Multifidelity
  - 0-D parametric
  - 1-D centerline
  - 3-DFlow physics

Variable Cycle Engines for Subsonic Transport (Air Force)

Description

- Fuel savings rank very high in VAATE program
- This may be achieved by improving the sfc of engines in **subsonic transport aircraft**
- Variable Cycle architecture provides additional means of achieving significant fuel burn advantages
- Increased fuel costs now justify the consideration of VCEs for application to subsonic propulsion systems
- A systems trade study & mission analysis is proposed to identify viable VCE architectures & quantify benefits

Scope



Technical Benefits

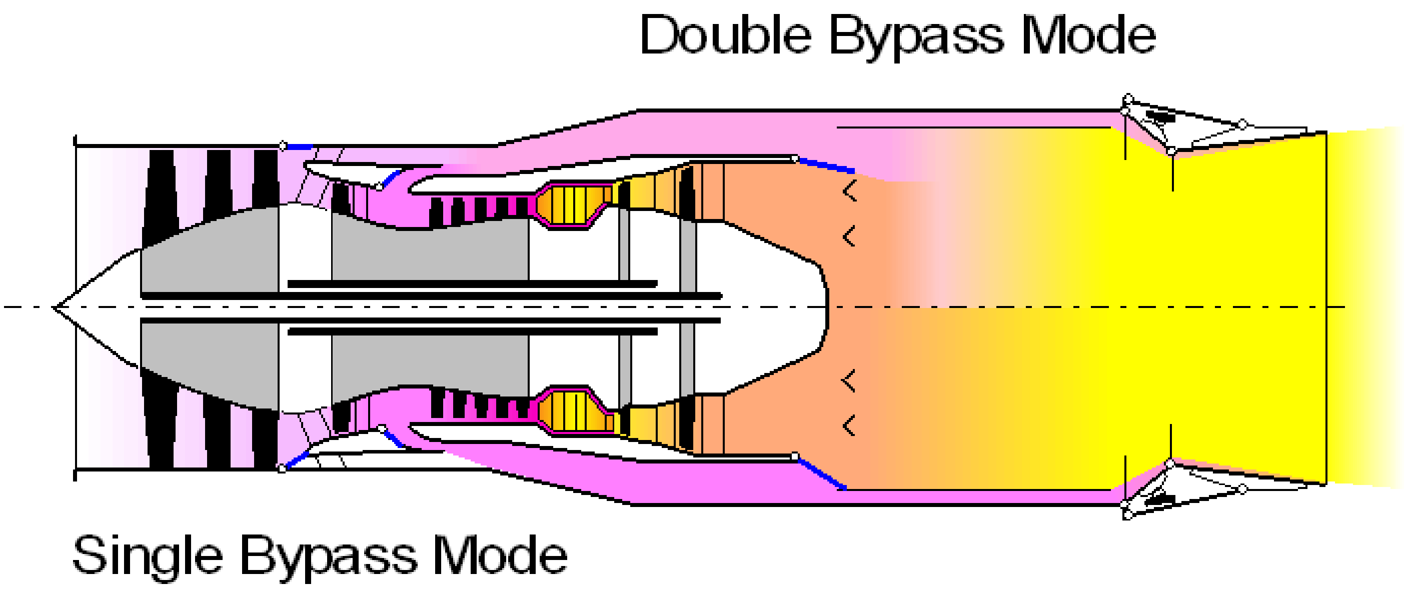
- Optimization of engine cycle at each point in its mission
- Recommendations for operability
- Quantification of cost vs. weight vs. sfc to produce minimum fuel burn, improved life & safety
- Low noise at take-off
- Low emissions throughout mission

Approach and Schedule

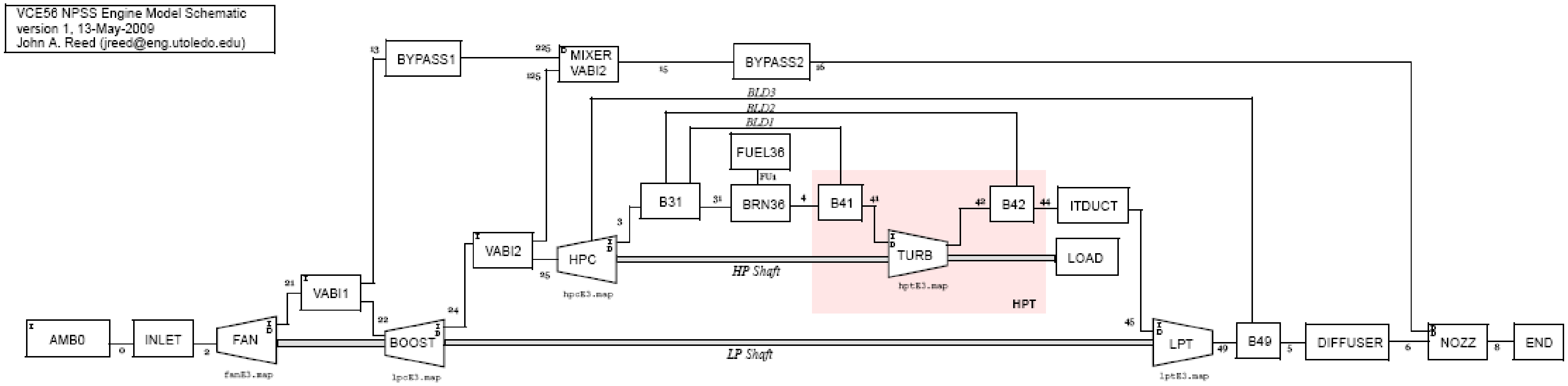
- **Conventional Turbofan Variables**
  - FPR, BPR, OPR, T_{41}
- **Additional VCE Variables for Optimized Performance**
  - Second BPR
  - Variable Booster on HP and/or LP spool
  - Adjustable/variable Speed Ratio
  - Variable % Cooling Air

Some Preliminary Results

VCE: GasTurb Generic Model of a Variable Cycle Engine (2)

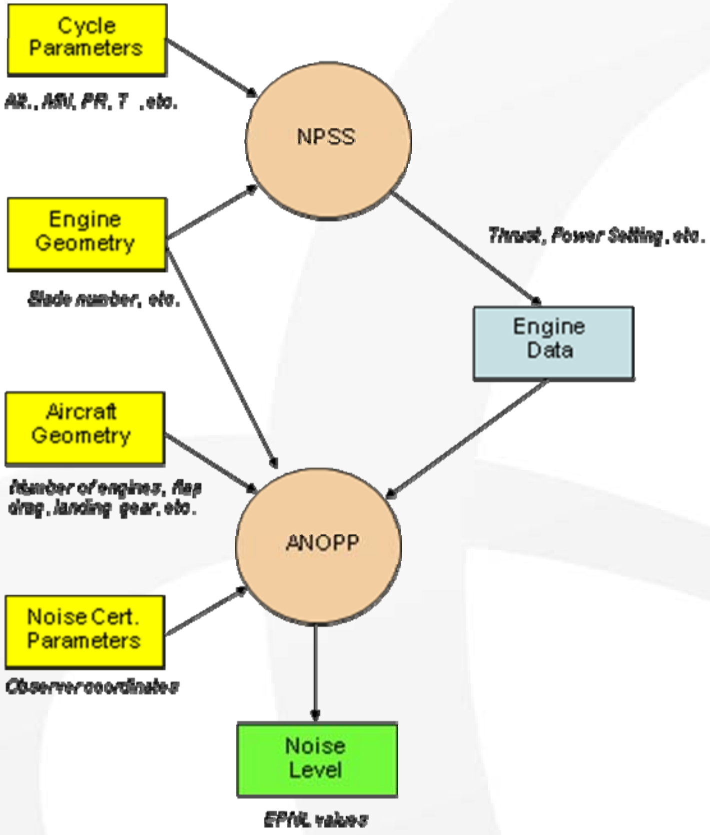


Variable Cycle Engine NPSS Model



	Double Bypass (Takeoff)	Single Bypass (Cruise)
VABI1	Open ind_BPR is active	Closed ind_BPR is not active BPR = 0
VABI2	Open ind_BPR is active	Open ind_BPR is active
MIXERVABI2	dep_errPs is active	dep_errPs is not active

NPSS/ANOPP Integration



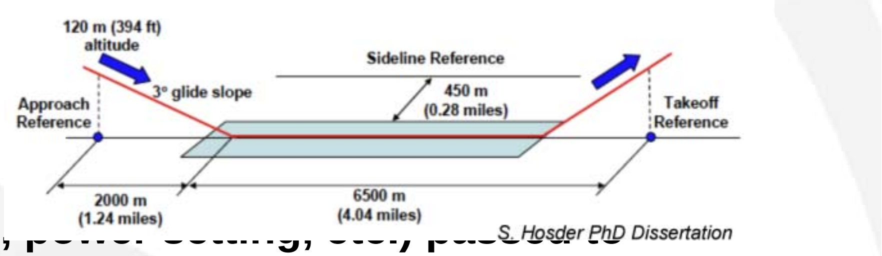
- **NPSS Interpreted components write ANOPP input files based on engine cycle parameters**
- **NPSS runs evaluate design for take off/ascent and cruise**
- **DAKOTA optimization loop will be generated to wrap the NPSS/ANOPP runs**

Mission Model

- Airbus A320 aircraft for used mission analysis
  - VCE56 designed to match CFM56-5C2 engine specifications, which are used on A320
- A320 model is developed entirely in NPSS
  - Aerodynamic performance data (drag, lift, etc.) from the BADA (Base of Aircraft DAta) Aircraft Performance Model
  - Aircraft climb/cruise/descent performance predicted using Total Energy Method
  - Takeoff performance modeled using standard aircraft model
- Aircraft trajectory is calculated from best-practices for contant-speed, reduced-thrust takeoff and climb, to constant Mach number cruise
- Mission analysis based on short to medium haul flights
- Total fuel burned during all flight segments is tracked

Noise Model

- Aircraft noise levels modeled using NASA Aircraft NOise Prediction Program (ANOPP)
- Computes Effective Perceived Noise Level (EPNL)
  - Measure of the subjective effect of aircraft noise on human beings
  - Measured from location on ground and time-integrated to give single value
- Currently only modeling noise during takeoff/climb
- ANOPP execution controlled by NPSS “run script”
- VCE56 cycle parameters (thrust, power setting, etc.) passed to ANOPP along with engine and aircraft geometry, and noise certification parameters
- EPNL value parsed from ANOPP output file and returned to DAKOTA



S. Hosder PhD Dissertation

Optimization

- Use DAKOTA (Design Analysis Kit for Optimization and Terascale Applications) to perform multi-point optimization of VCE56 performance
- DAKOTA controls NPSS VCE56/mission simulations
- Calculates Pareto front of designs to minimize 2 design parameters:
  - mission fuel burn (currently includes takeoff, climb and cruise)
  - Effective Perceived Noise Level (EPNL) for takeoff & climb
  - Done by varying VCE Bypass Ratio (BPR), subjected to mission profile (defined by airspeed/Mach number schedule, thrust settings)
- DAKOTA also used to optimize VCE56 Booster component design using both 1D and 3D fidelity models

Features of DAKOTA

- Department of Energy code under development by Sandia National Laboratories
- Designed for very large scale optimization problems
- Parallel and scalable to DOE High Performance Computing Clusters
- Accommodates multiple types of optimization and analysis
  - Parameter study methods
  - Design of simulation experiments
  - Uncertainty quantification
  - Nonlinear least squares parameter estimation
  - Non-gradient based (evolutionary) optimization algorithms

Disk and Blade Optimization

T-AXI Disk

V 2.5

Part of the T-AXI suite
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Choose Resolution: 1280x800 (Recommended)

T-AXI Blade V1.8.1

T-AXI BLADE

V 1.8

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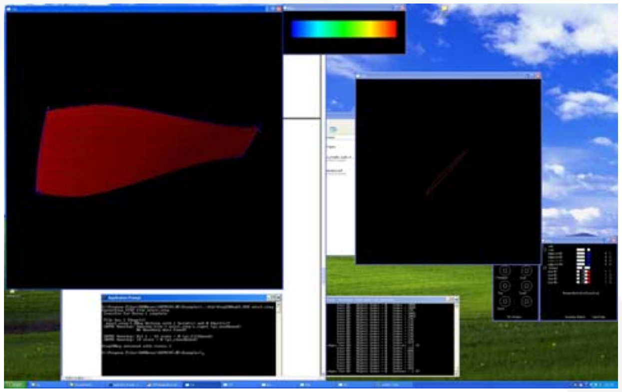
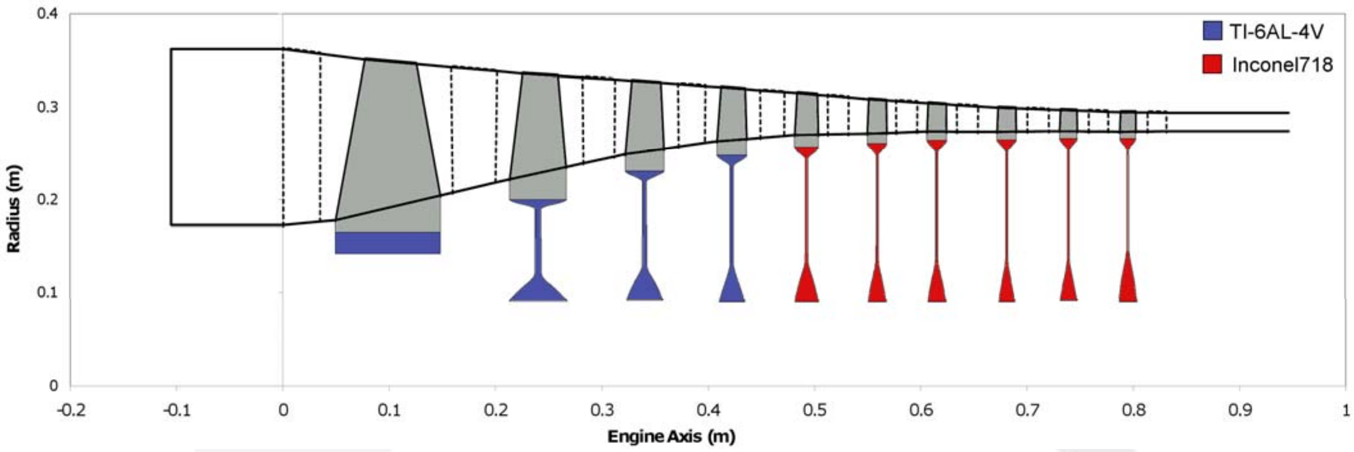
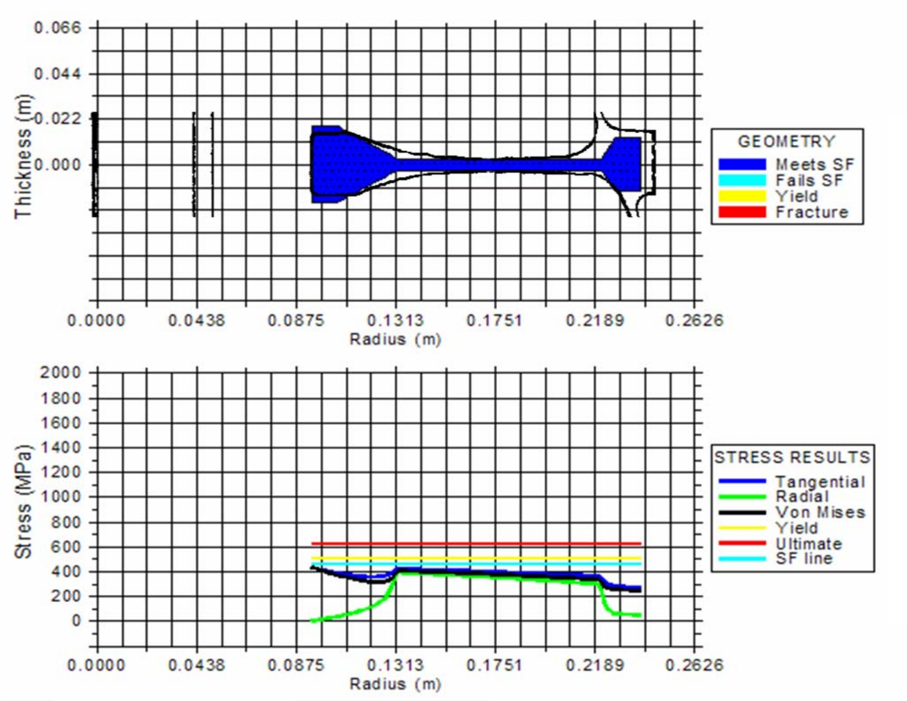
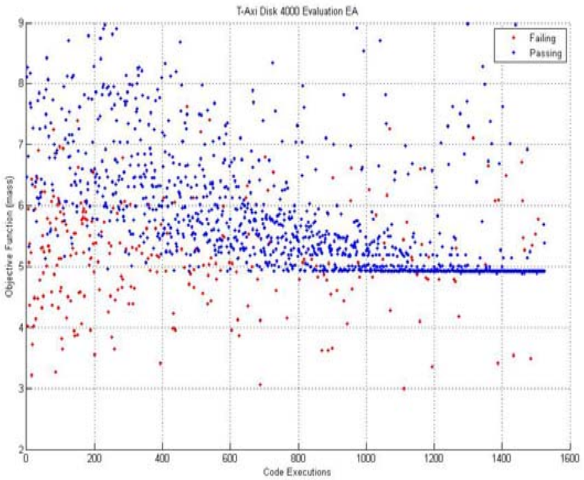
Build 1





Disk Optimization Example





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  - MDAO Project Co-PI
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- David Gutzwiller (University of Cincinnati)
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