Application of the Tool for Turbine Engine Closed-loop Transient Analysis (TTECTrA) for Dynamic Systems Analysis

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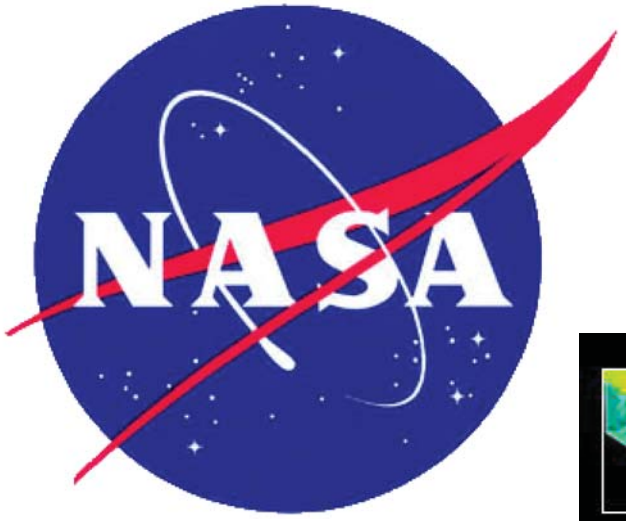
Acknowledgements



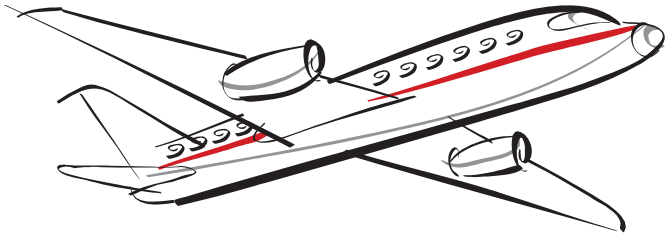
Thanks to the
NASA Fixed Wing Project
Systems Analysis & Integration
For funding this work

Outline

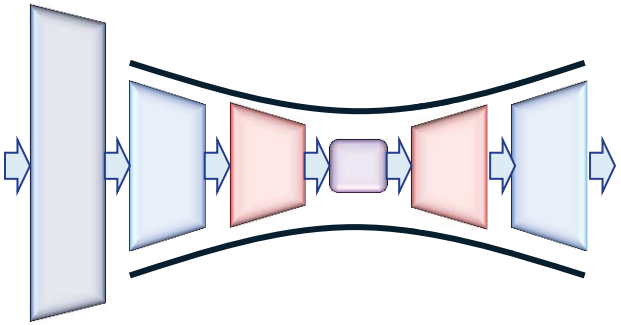
- Engine Design Process
- Dynamic Systems Analysis Concept
- Tool for Turbine Engine Closed-loop Transient Analysis (TTECTrA)
- Application with TTECTrA
- Summary
- Future Work

Engine Design Process

Systems Analysis

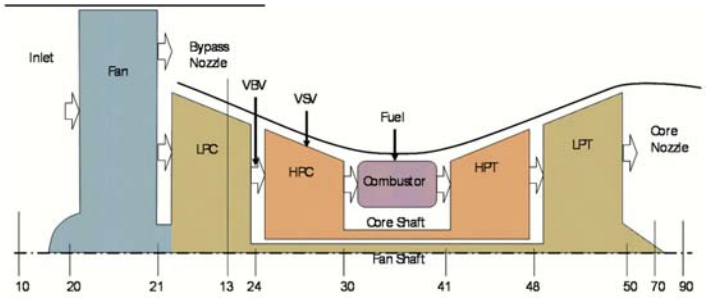


Optimize the system
(Airframe and Engine)



Configure the engine's components to meet the requirements

Define engine constraints (component efficiencies, speeds, temperatures, and operating margins)

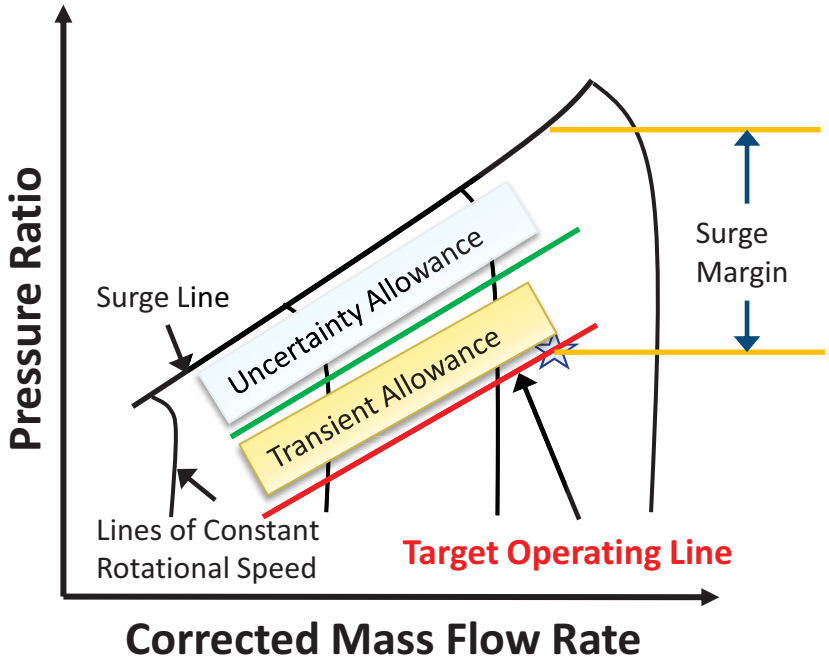


Build more detailed physics based models

Assess transient performance, etc.

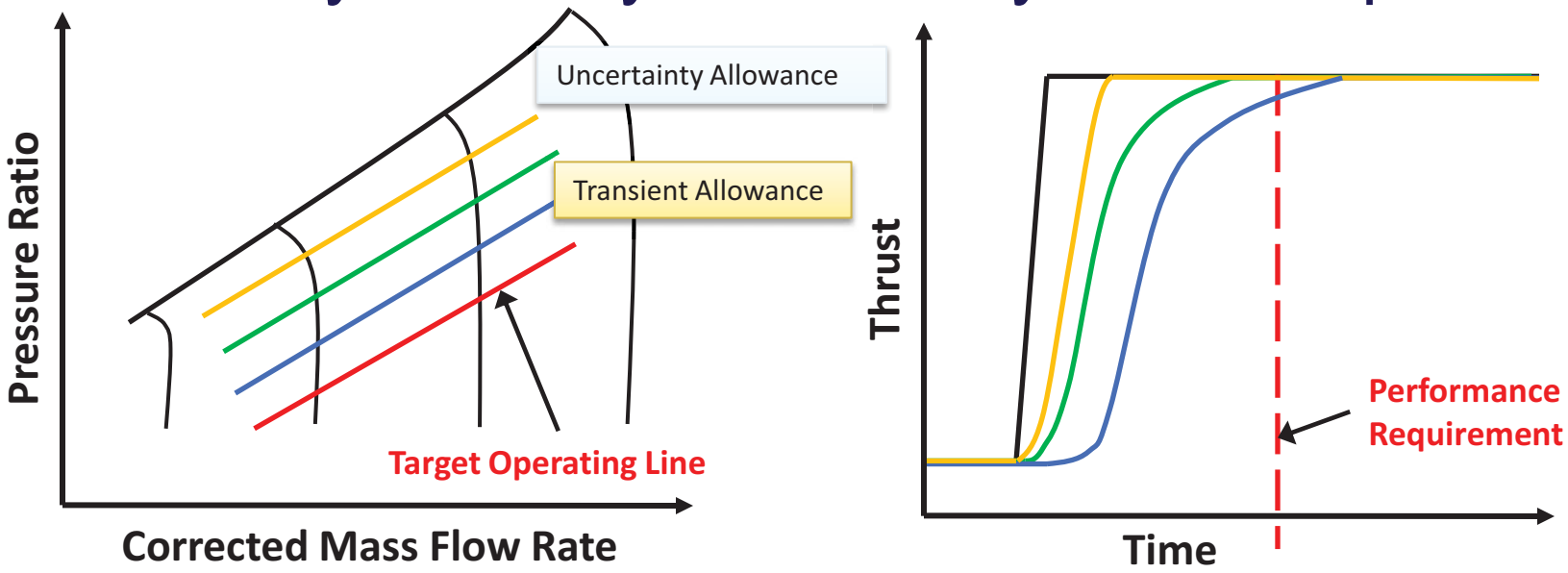
Compressor Surge Margin Constraint

- Surge Margin Constraint
  - Based on previous experience, designs, and generic rules of thumb
  - Target Operating Line
    - Most efficient operation while meeting design constraint.
  - Accounts for two different types of reductions
    - Uncertainty Allowance
      - mechanical imperfections, inlet distortion, engine degradation, etc.
    - Transient Allowance
      - occurs while transitioning from one point to another



Uncertainty Allowance	11%
Transient Allowance	12%
Total	**23%**

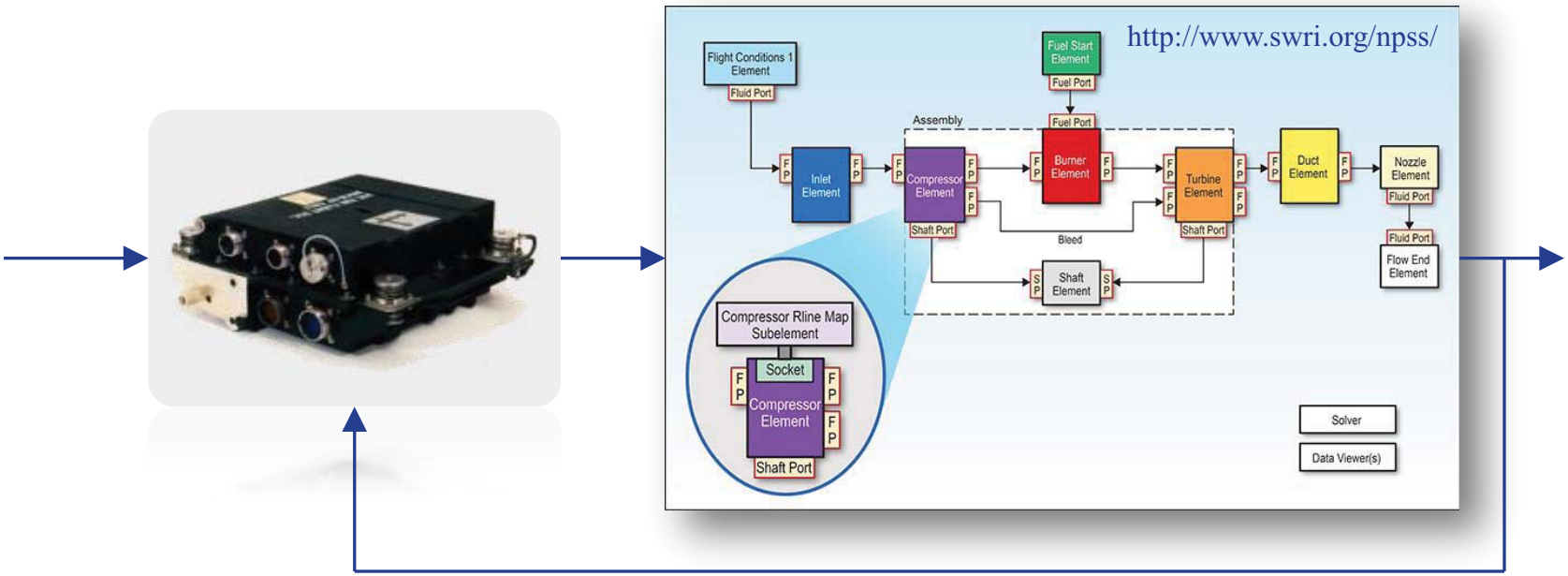
Dynamic Systems Analysis Concept



- Decrease Transient Allowance / Increase Uncertainty Allowance
  - Uncertainty allowance is greater than needed / Poor performance
- Increase Transient Allowance / Decrease Uncertainty Allowance
  - Uncertainty allowance is less than required / Good performance

Better defining margins/constraints may allow a more efficient design while still meeting performance requirements

Dynamic Systems Analysis Concept

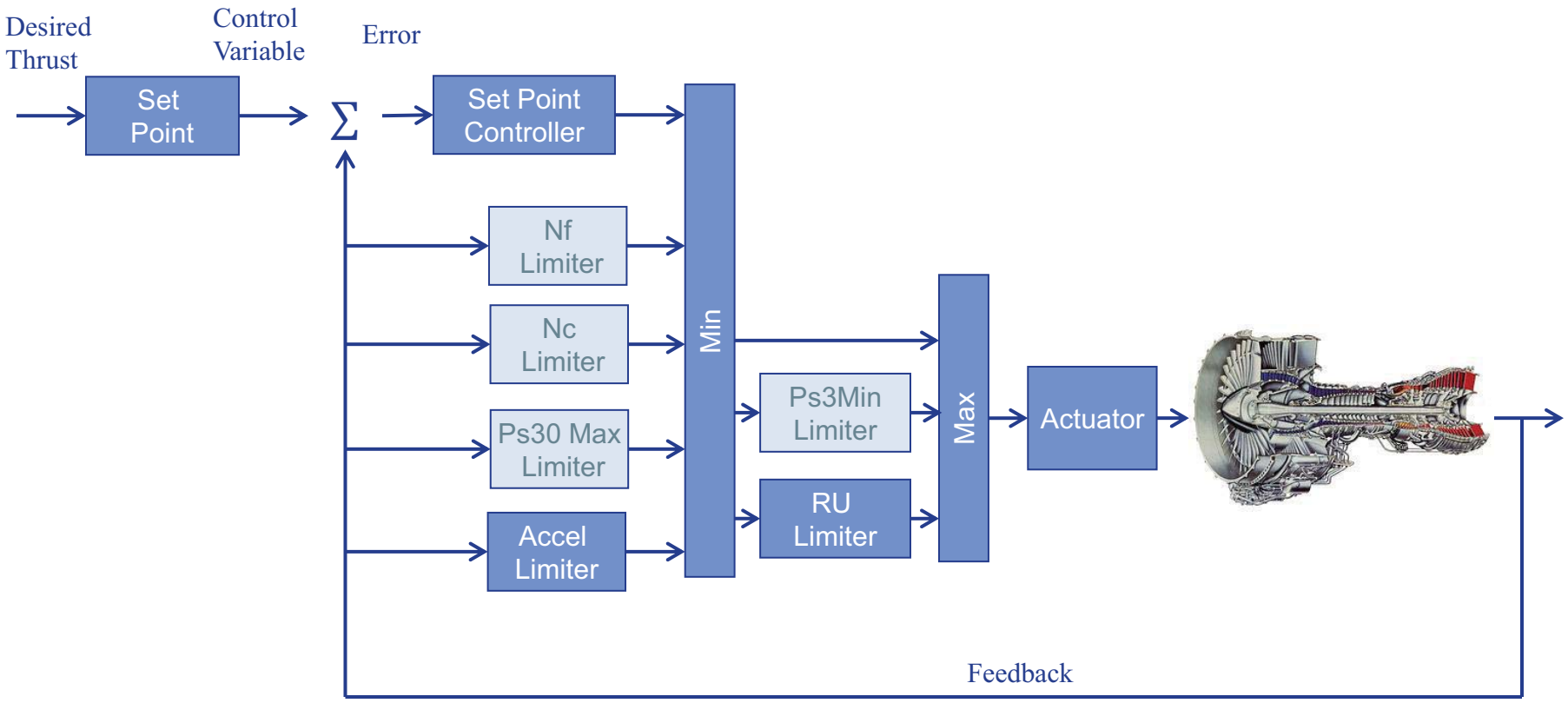


- Systems analysis is performed using steady-state data usually generated from NPSS.
- To more accurately define the margins, the impact of the **closed loop controller** has to be accounted for.

Tool for **T**urbine **E**ngine **C**losed-loop **Tr**ansient **A**nalysis (**TTECTrA**)

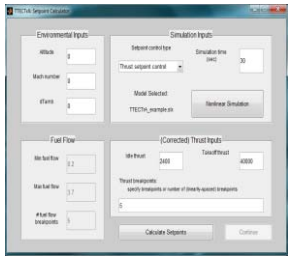
- **Provide an estimate of the closed-loop transient performance/capability of a conceptual engine design.**
- Capable of automatically designing a controller for transient operation (subset of full controller).
- Easily integrates with a users engine model in the MATLAB®/Simulink® Environment.
- Requirements:
  - MATLAB/Simulink (Release R2012b or later) with Control Systems Toolbox® Version 9.4 (R2012b)
  - Engine model compatible with Simulink
  - State space model

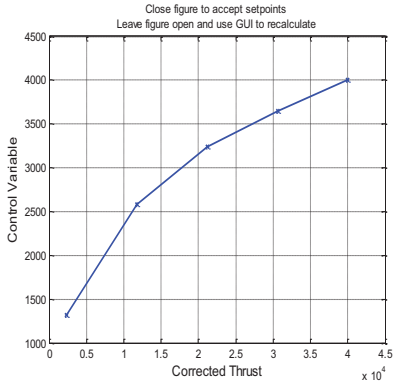
TTECTrA Control Architecture



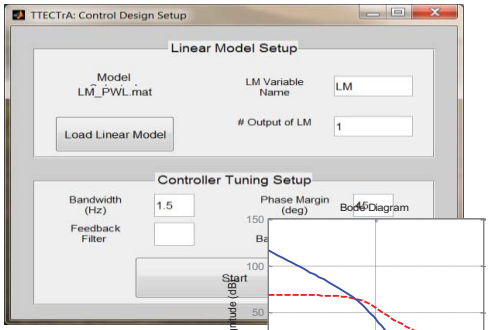
TTECTrA

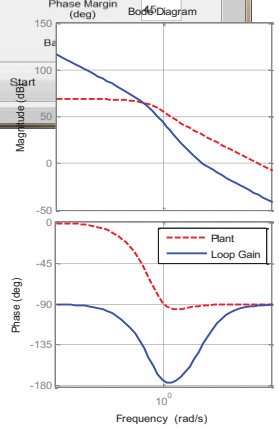
Set Point

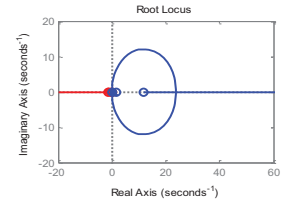


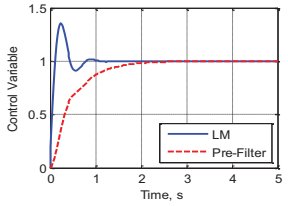


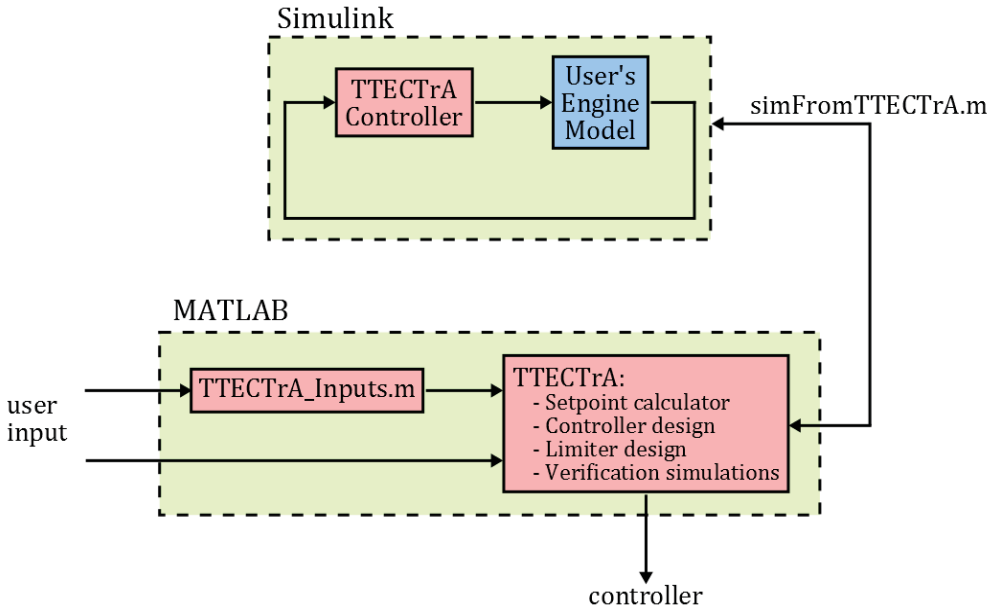
Set Point Controller



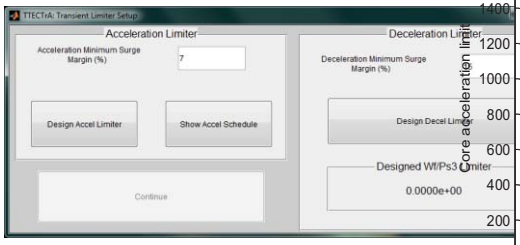


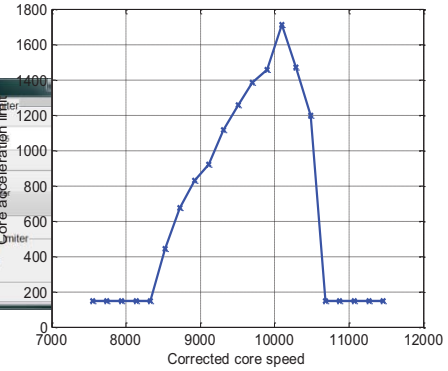






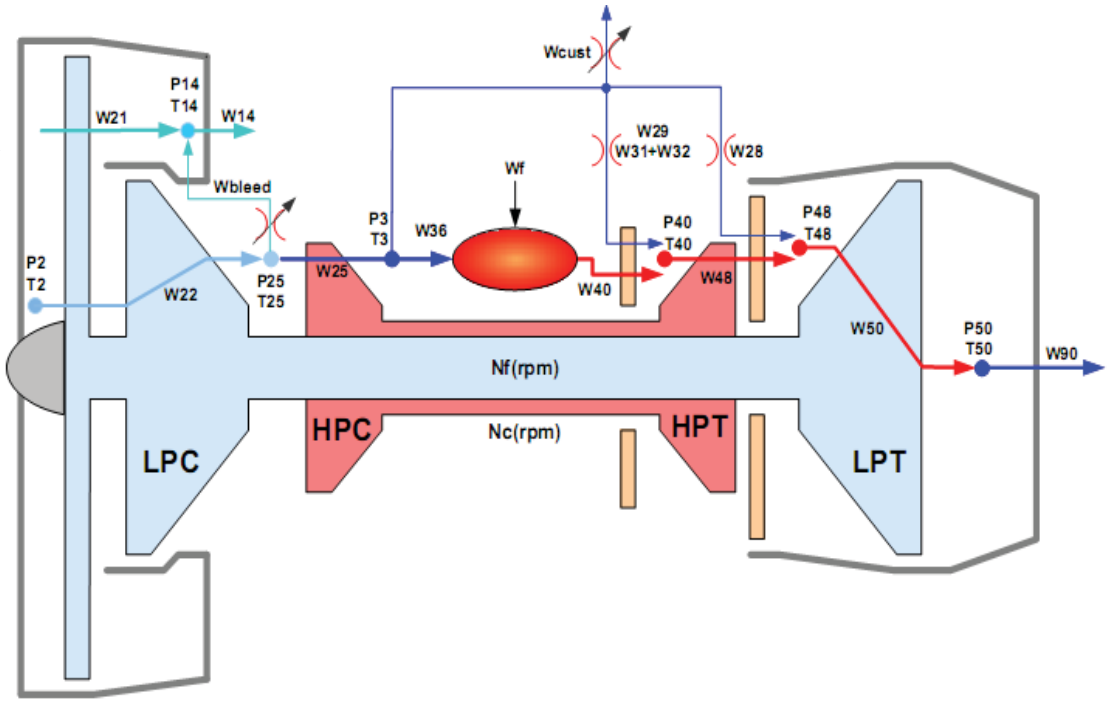
Limit Controller



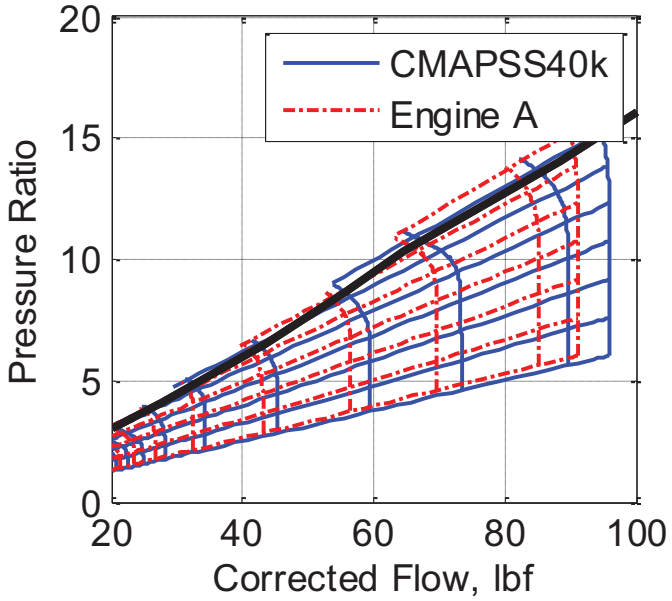


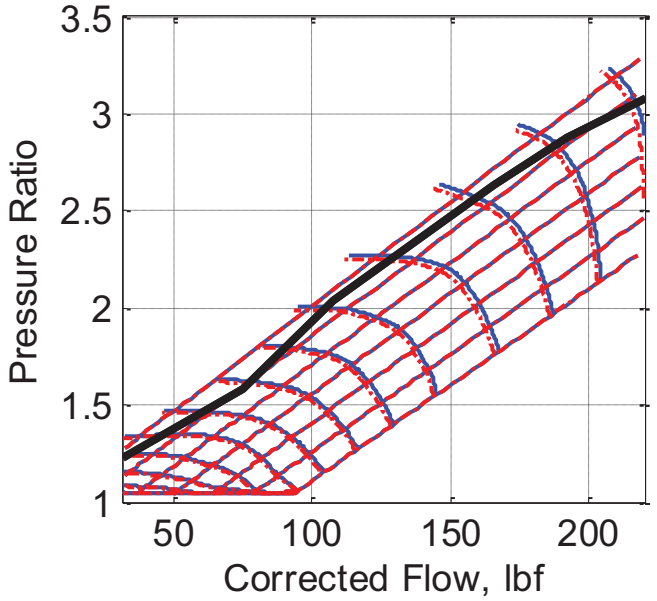
Commercial Modular Aero-Propulsion System Simulation 40,000 (C-MAPSS40k)

- 40,000 lb Thrust class high bypass turbofan engine simulation
- MATLAB/Simulink environment
- Publicly available to US Citizens
- Realistic controller
- Realistic surge margin calculations

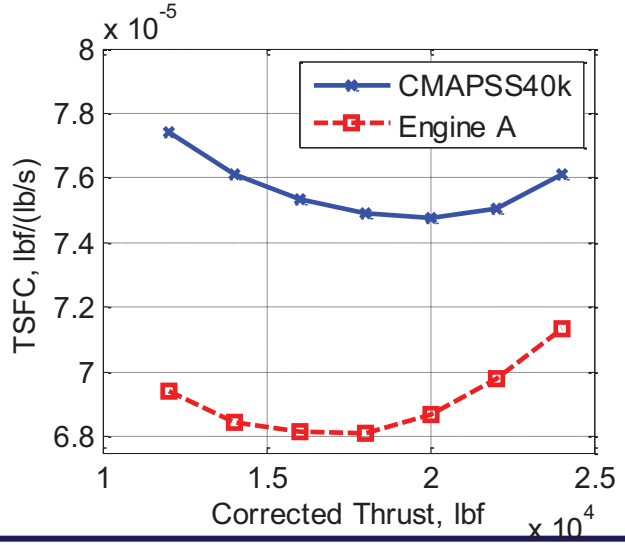


TTECTrA Application





- Compare CMAPSS40k to a Scaled version (Engine A) which is more fuel efficient (Lower TSFC)



TTECTrA Application

- Design controllers using TTECTrA and same inputs
- Simulate a burst and chop thrust profile and observe the following outputs:
  - Thrust – acceleration time
  - HPC Surge Margin – minimum surge margin
  - LPC Surge Margin – minimum surge margin

TTECTrA Inputs

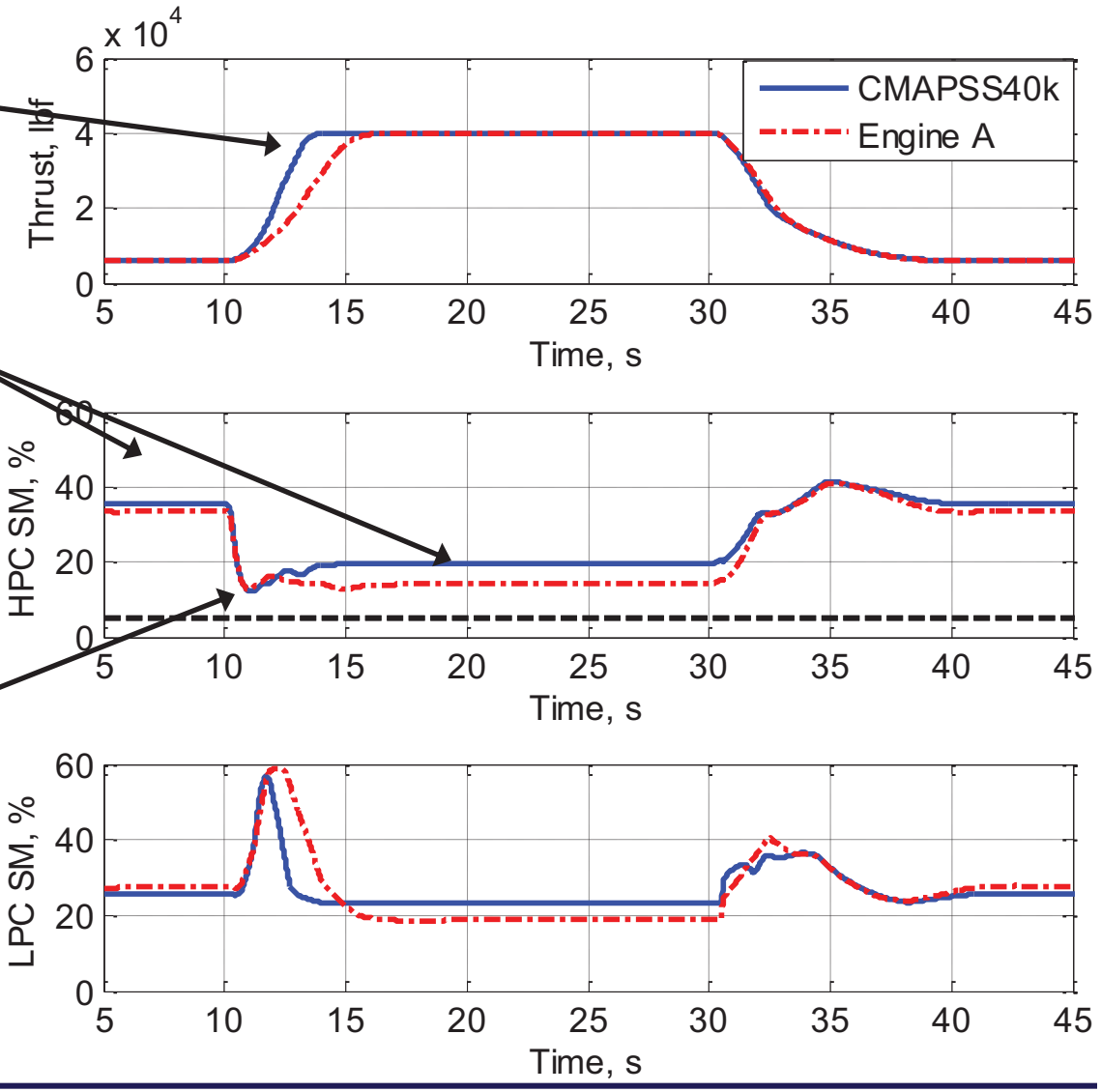
Parameter	Value
Thrust Range	2.3 – 40k lbf
Bandwidth	1.75 Hz
Phase Margin	45 deg
Filter Bandwidth	10 Hz
Pre-Filter Bandwidth	10 Hz
Acceleration Limit	11%
Deceleration Limit	15%

Engine Design Comparison

Engine A has a slower response time than CMAPSS40k

Engine A has a lower surge margin in steady-state

Both have same minimum surge margin due to acceleration limiters being designed for same minimum surge margin

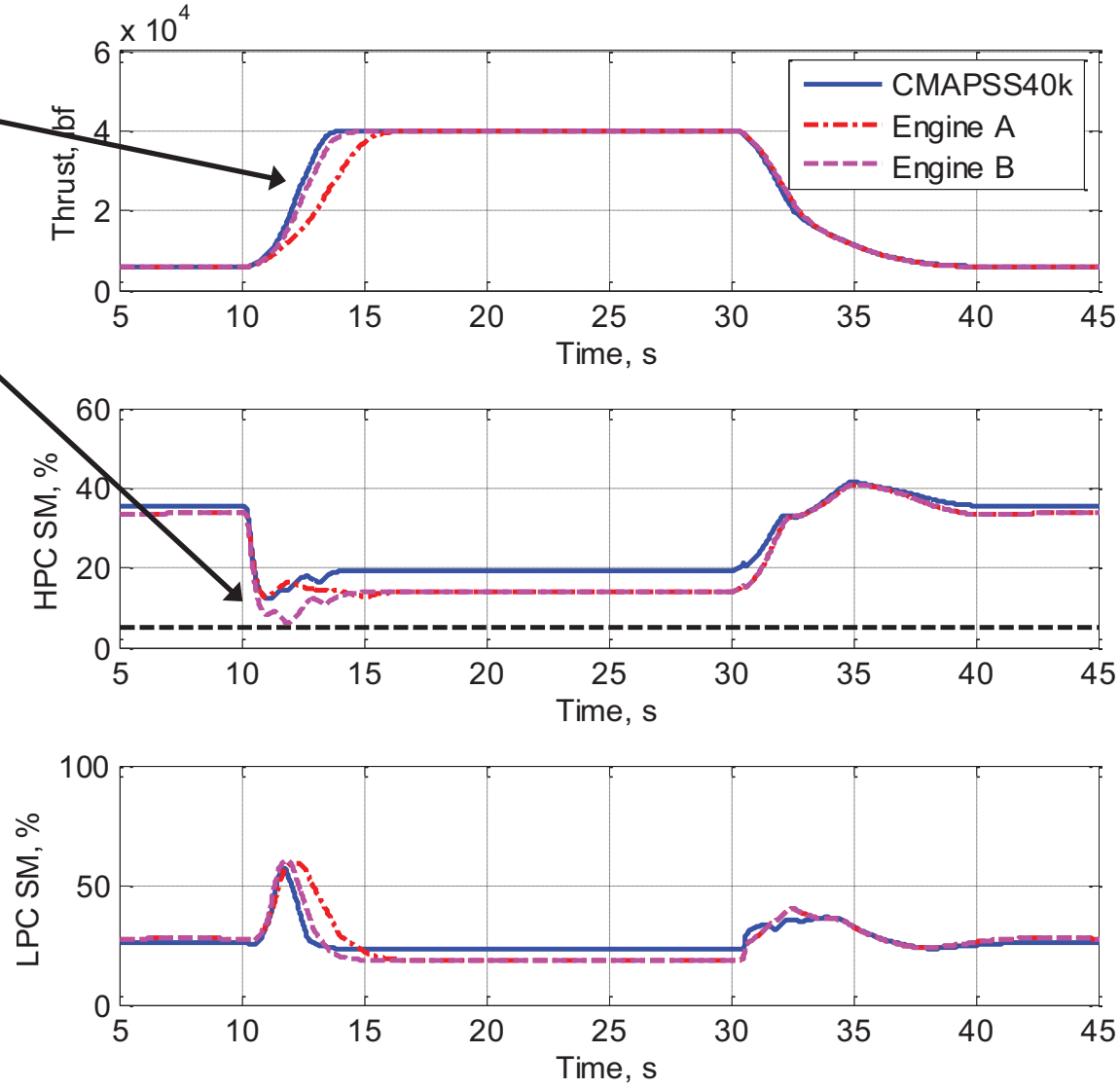


Engine Design Comparison

Lower minimum surge margin increase performance

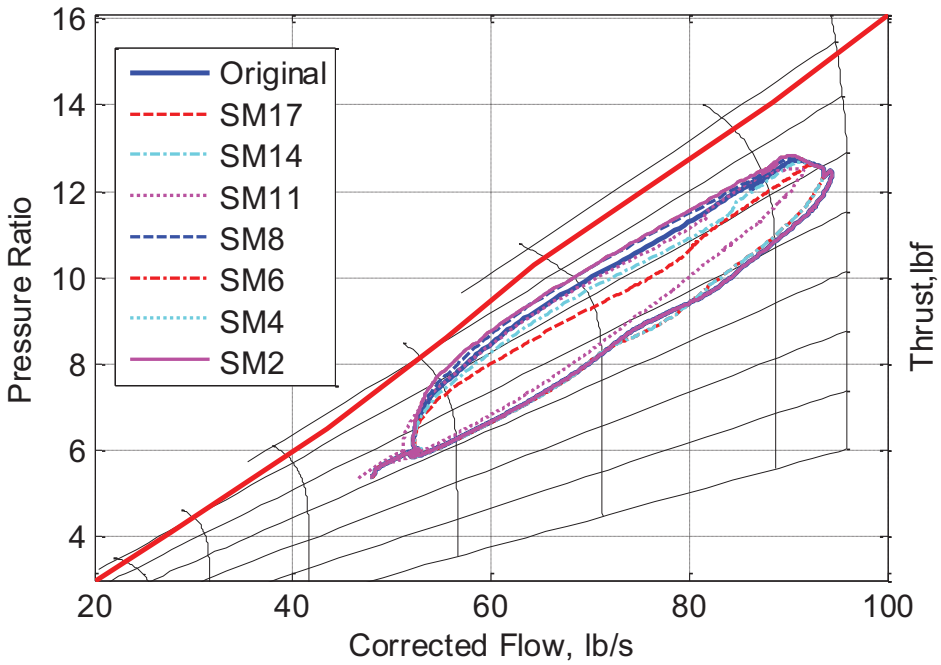
Redesign acceleration limiter to have lower minimum HPC surge margin (Engine B)

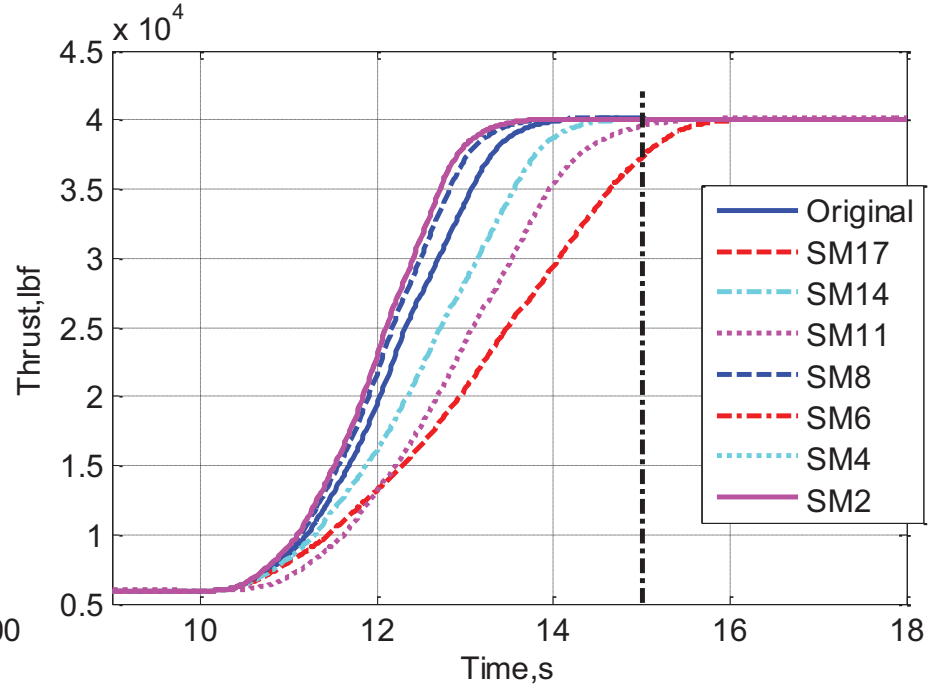
Modify the acceleration limiter for various surge margin limits and observe response time.



Engine Design Comparison

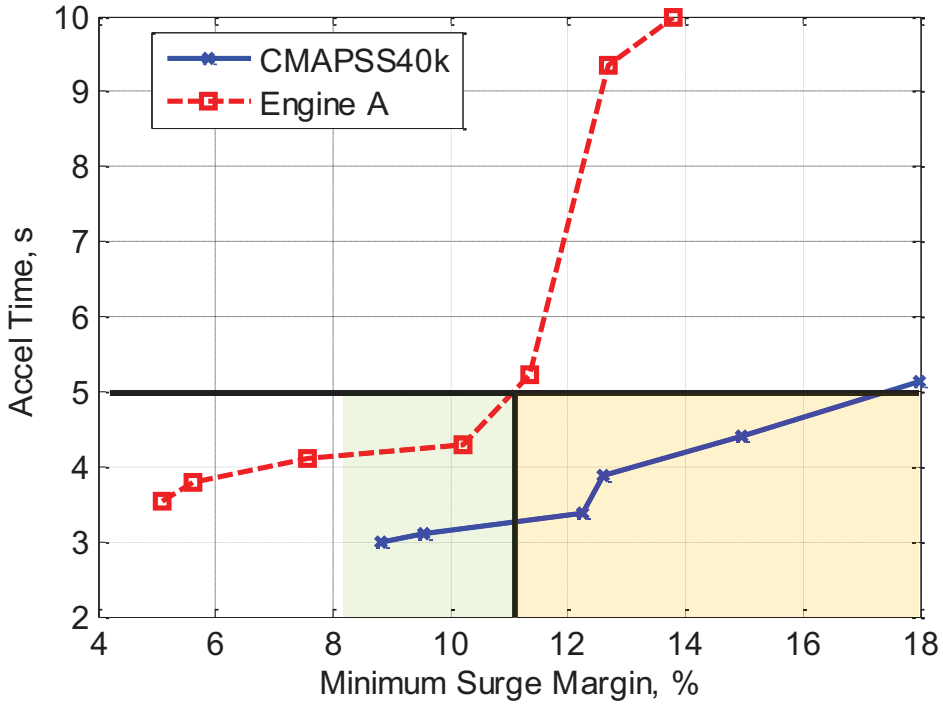
CMAPSS40k





Evaluation Tool

- Transient performance requirement (5 seconds)
- Initial surge margin requirement (11%)
- Reduce surge margin requirement (8%)



Identify overly conservative margin and perhaps reduce the target operating line by this extra margin.

Summary

- Dynamic Systems Analysis Goal
  - Better defining the transient operation of the engine early in the design phase may allow moving the operating line and impact the design by increasing efficiency
- Tool for Turbine Engine Closed-loop Transient Analysis (TTECTrA)
  - Provides an estimate of the transient operation
- Evaluation Tool
  - Compares performance (acceleration time) and operability (surge margin)
  - Capable of identifying designs that are capable of meeting transient performance requirements.
  - Identify overly conservative margin and perhaps reduce the target operating line by this extra margin.

TTECTrA Status

- TTECTrA is publicly available
  - https://github.com/nasa/TTECTrA/releases

Future Work

- Developing an automated version of TTECTrA and plan to release early 2015
- Developing version of TTECTrA for integration with an NPSS through a Simulink S-function
- Developing process for incorporating dynamic systems analysis with current systems analysis method
- Investigate other engine architectures

Thank you

Questions?