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

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Engineering, Sensing, Measuring and Distributed Technologies for Propulsion Systems Session
2014 Propulsion and Energy Forum
Cleveland, OH
July 28-30, 2014
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

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

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 Turbine Engine Closed-loop Transient Analysis (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

Desired Thrust

Set Point

Control Variable

Error

Σ

Set Point Controller

Nf Limiter

Nc Limiter

Ps30 Max Limiter

Accel Limiter

Min

Ps3Min Limiter

RU Limiter

Max

Actuator

Feedback

TTECTrA Control Architecture
TTECTrA

Set Point

Simulink

TTECTrA Controller
User’s Engine Model
simFromTTECTrA.m

MATLAB

TTECTrA: - Setpoint calculator
- Controller design
- Limiter design
- Verification simulations

controller

tSet Point Controller

Limit Controller

plant

loop gain

root locus

Control Variable

LM

Pre-Filter

Core acceleration limit

Set Point Controller

Corrected core speed

Corrected thrust

Frequency (rad/s)

Time, s

Phase

Gain

Corrected thrust

Frequency (rad/s)
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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrust Range</td>
<td>2.3 – 40k lbf</td>
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<tr>
<td>Bandwidth</td>
<td>1.75 Hz</td>
</tr>
<tr>
<td>Phase Margin</td>
<td>45 deg</td>
</tr>
<tr>
<td>Filter Bandwidth</td>
<td>10 Hz</td>
</tr>
<tr>
<td>Pre-Filter Bandwidth</td>
<td>10 Hz</td>
</tr>
<tr>
<td>Acceleration Limit</td>
<td>11%</td>
</tr>
<tr>
<td>Deceleration Limit</td>
<td>15%</td>
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</tbody>
</table>
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](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?