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

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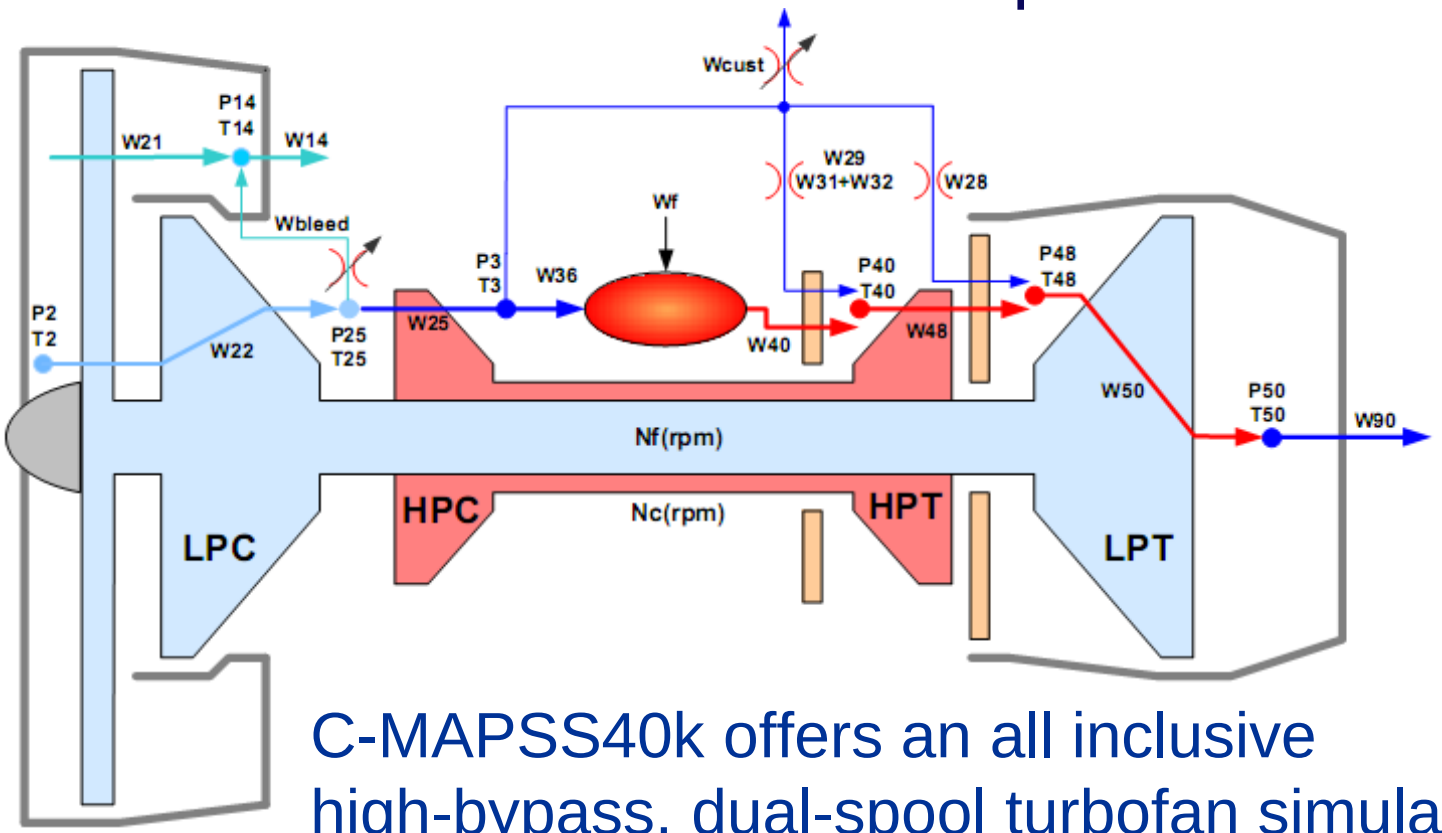
C-MAPSS40k Overview

- Simulation description
- Engine simulation
- Control system
- User features
- Recent updates
- Conclusion

Simulation Description

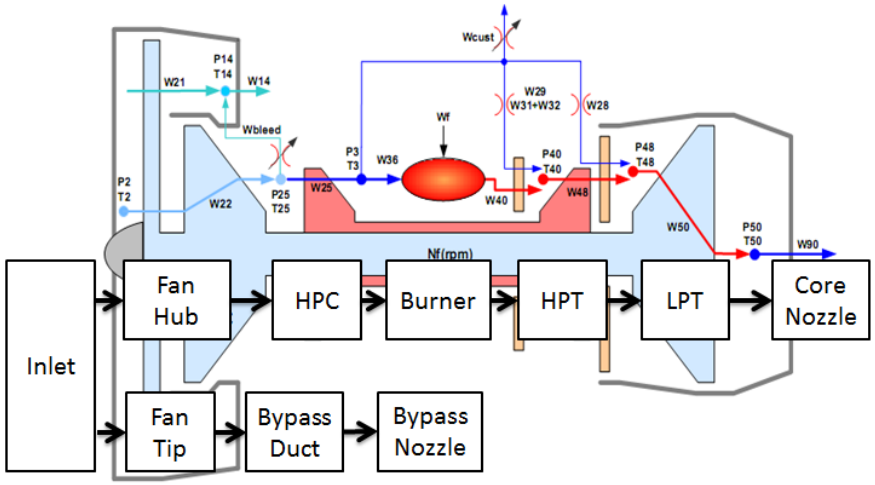


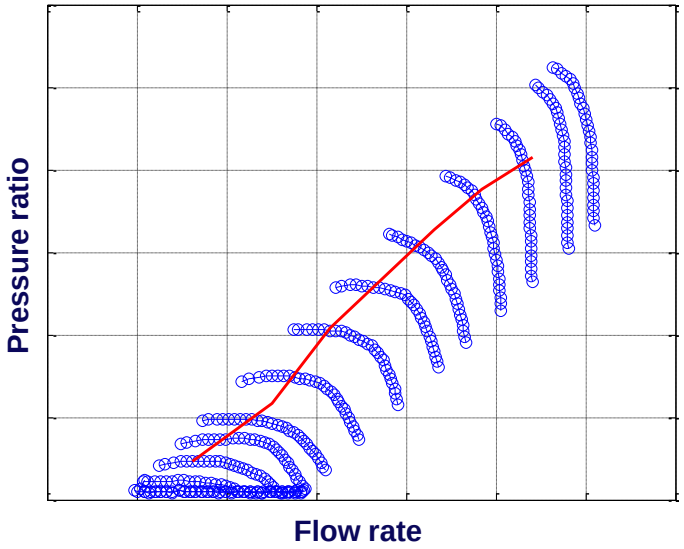
C-MAPSS40k offers an all inclusive high-bypass, dual-spool turbofan simulation

- 40,000-lb_f thrust class
- MATLAB/Simulink
- Steady state and dynamic operation
- Realistic control system

Engine Simulation

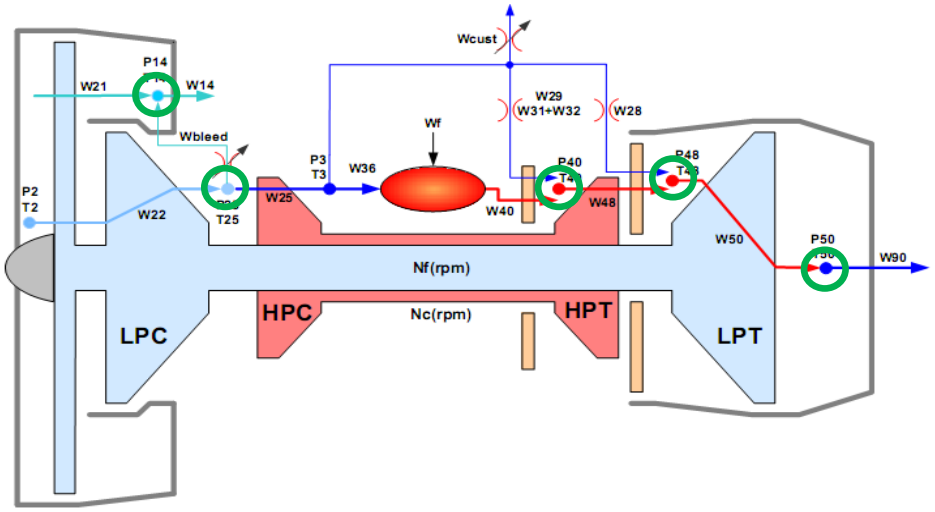
- Component-level modeling
- Physics-based
  - Aerothermodynamics
  - Performance maps
- Operates over wide range of environmental conditions
  - Mach, altitude, DTamb
- Faster than real-time
  - Components coded in C
  - Assembled in Simulink
  - Run via MATLAB
- Detailed stall margin model
- Engine health condition

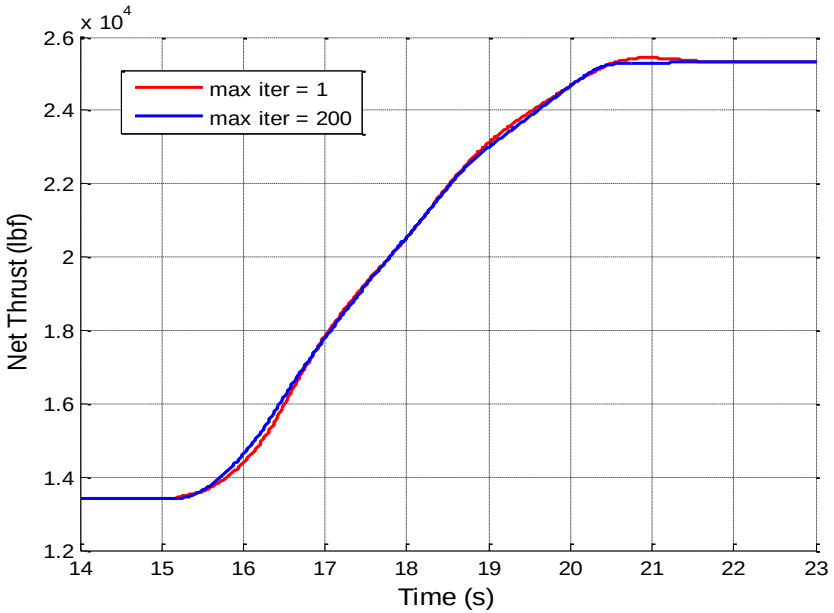


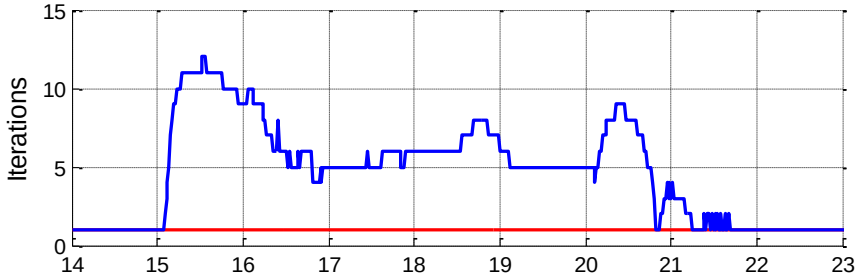


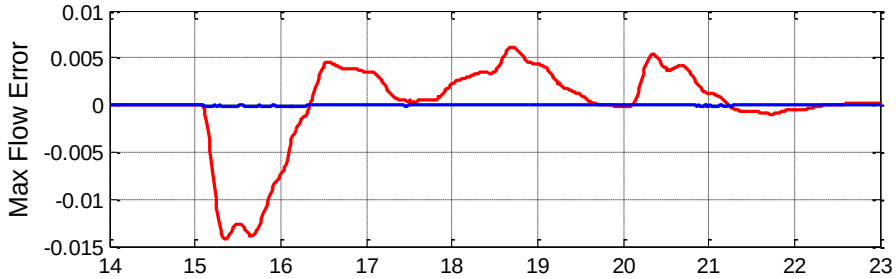
Engine Simulation

- Dynamics
  - Nonlinear dynamical system with spool speeds as state variables
- Flow continuity
  - Iterate to ensure conservation of mass and energy at each time step
  - Realistic transient performance





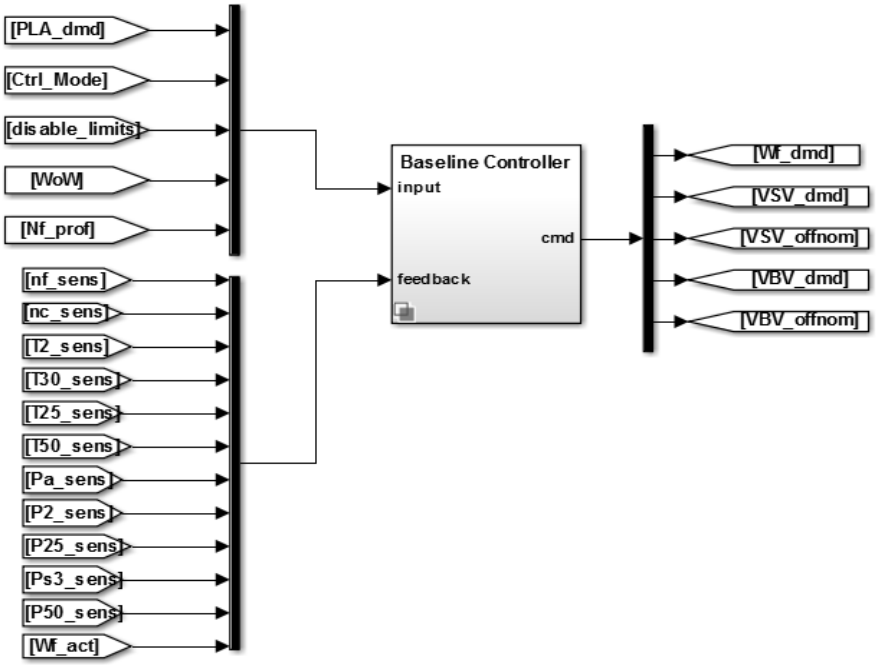




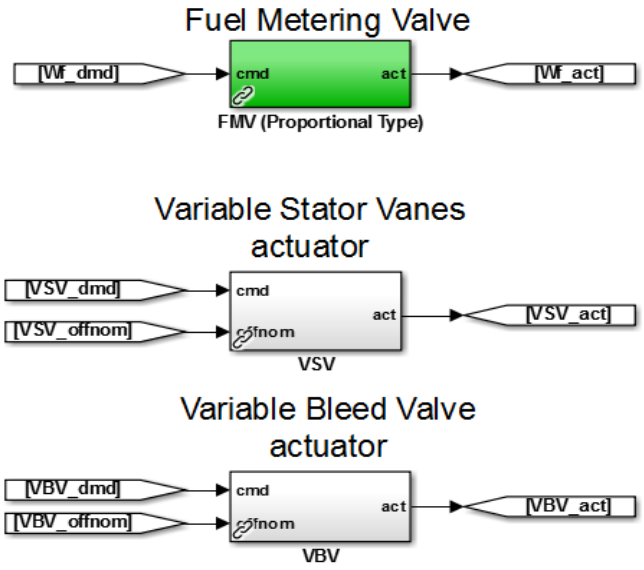
Control System

- Representative of industry standard
- Controls engine based on throttle input
- Calculates fuel flow, variable stator vane position (VSV), variable bleed valve position (VBV)
- Uses typically sensed engine outputs
- Simulates actuator/sensor dynamics

Controller

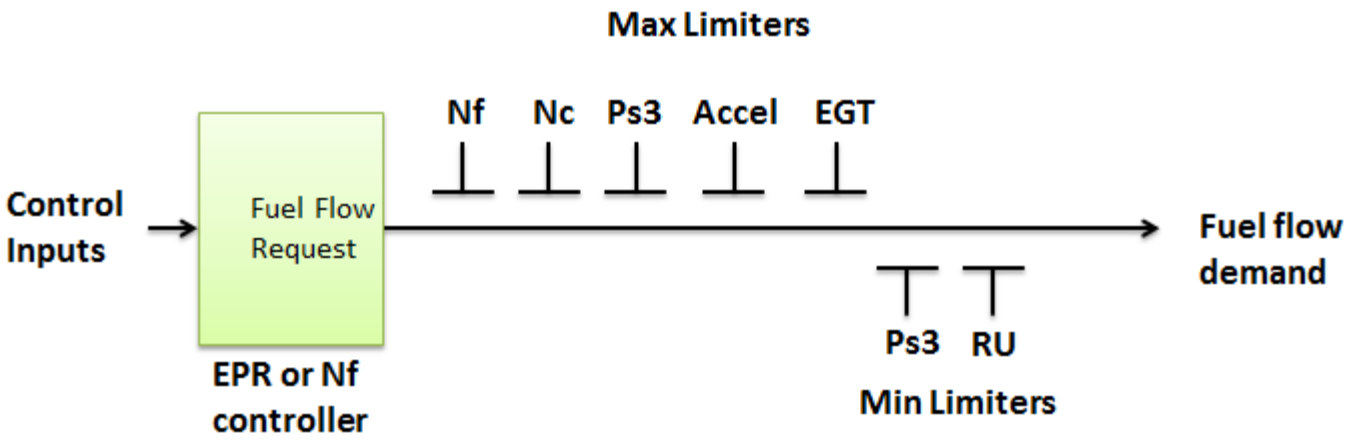


Actuator Models



Control System

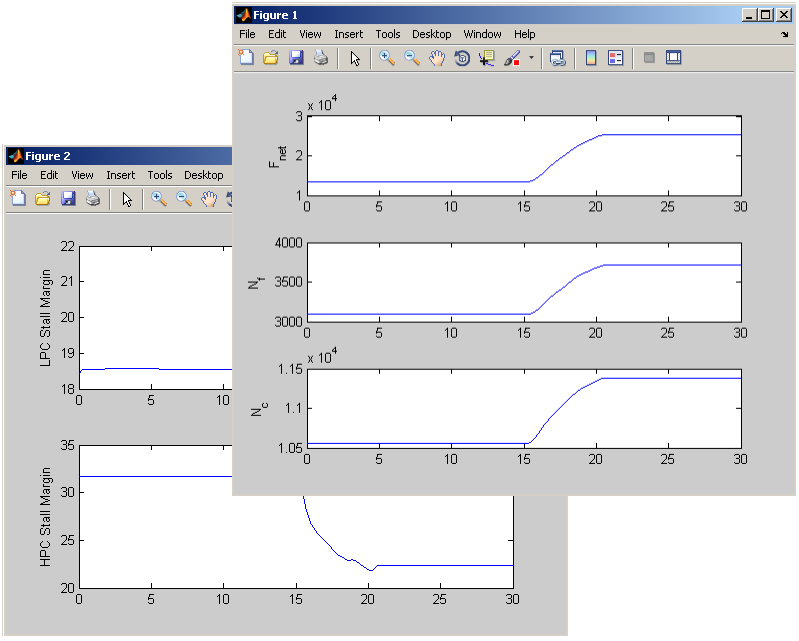
- VSV, VBV are scheduled on sensed engine parameters
- Fuel: gain-scheduled PI feedback control on EPR/Nf with protection logic

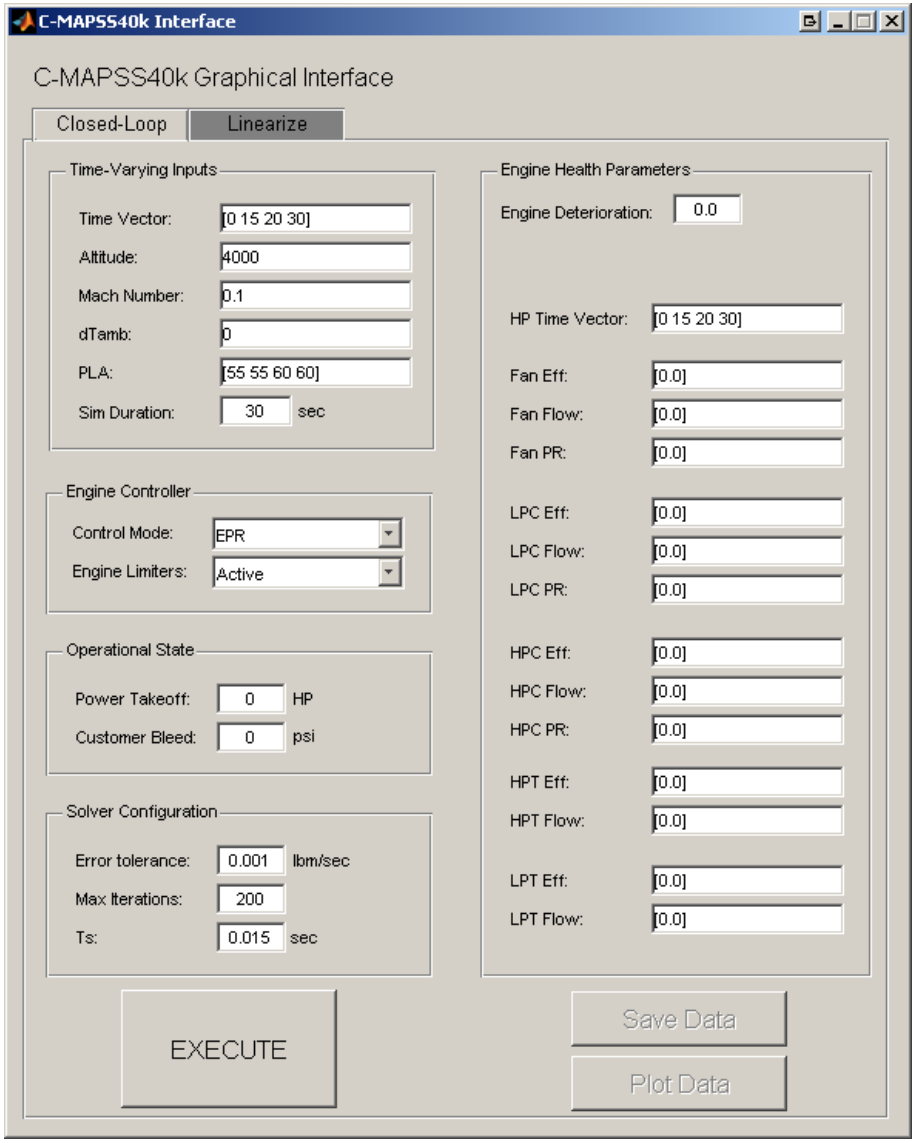


Protection Logic Architecture representative of Industry Standard

User Features: Graphical Interface

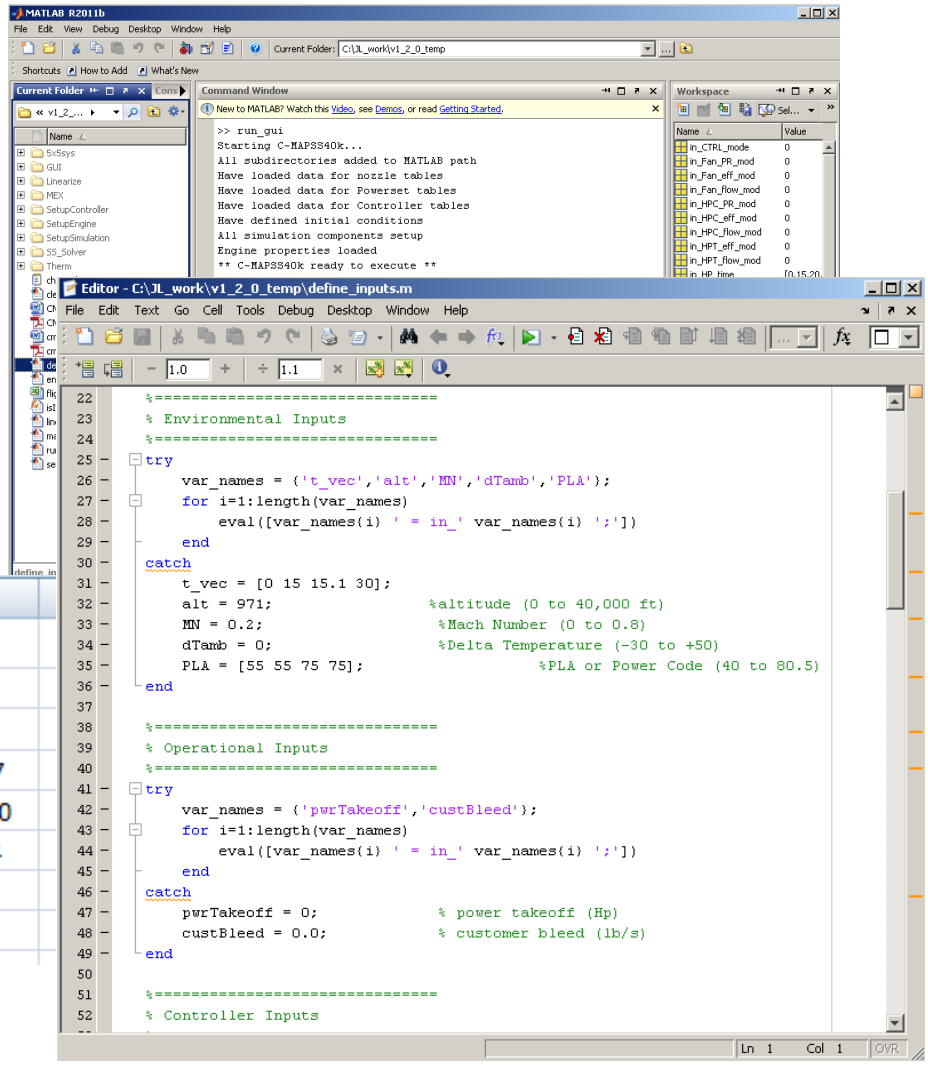
- Environmental & throttle inputs
- Control settings
- Simulation settings
- Engine health settings
- Plot & save data





User Features: Script/Command Line

- MATLAB command line
- MATLAB scripts
- MS Excel input profile generation

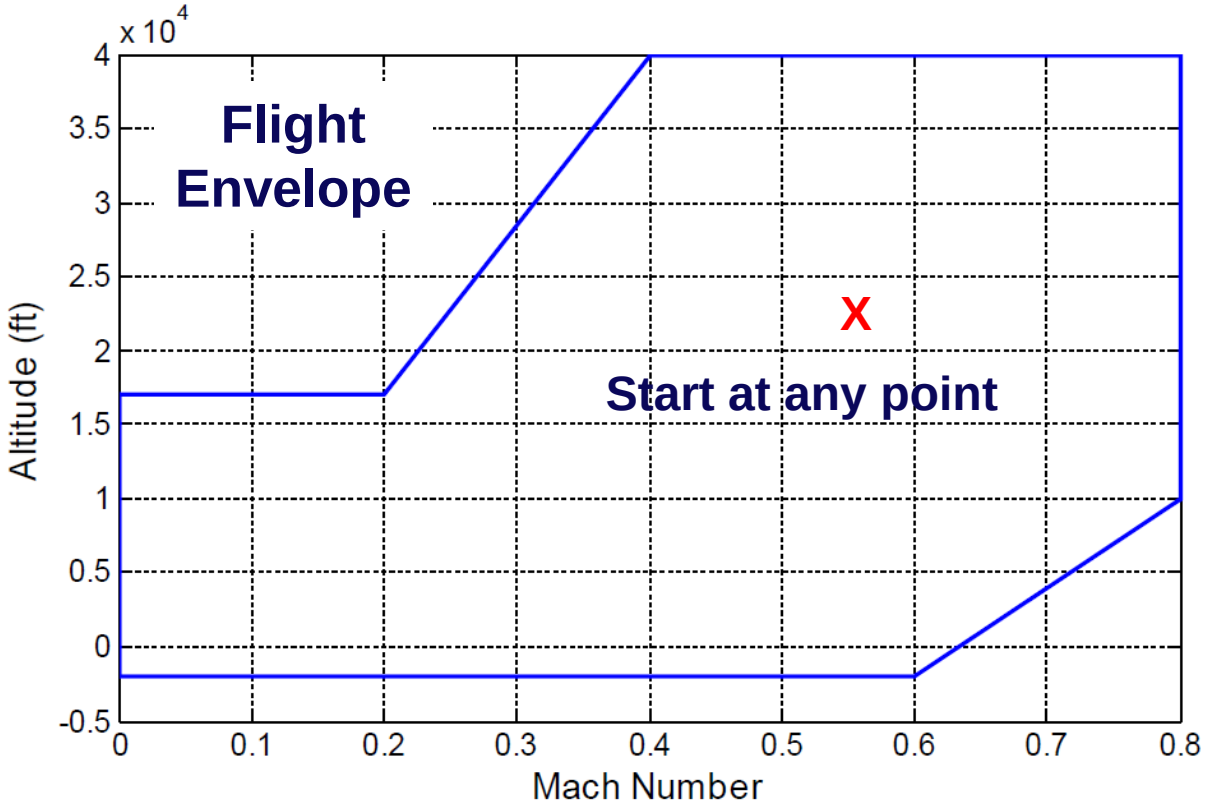


	A	B	C	D	E	F
1	**C-MAPSS40k Input Flight Profile**					
2						
3	**Environmental Inputs**					
4	Time Vector (sec)	0	10	15	135	137
5	Altitude (ft)	971	971	971	6000	6000
6	Mach Number	0	0	0.15	0.4	0.4
7	dTamb (deg F)	0	0	0	0	0
8	PLA (deg)	40	40	78	78	73

User Features: Steady-State Solver

- Steady-state engine model calculates the initial conditions for any point in flight envelope before simulation run

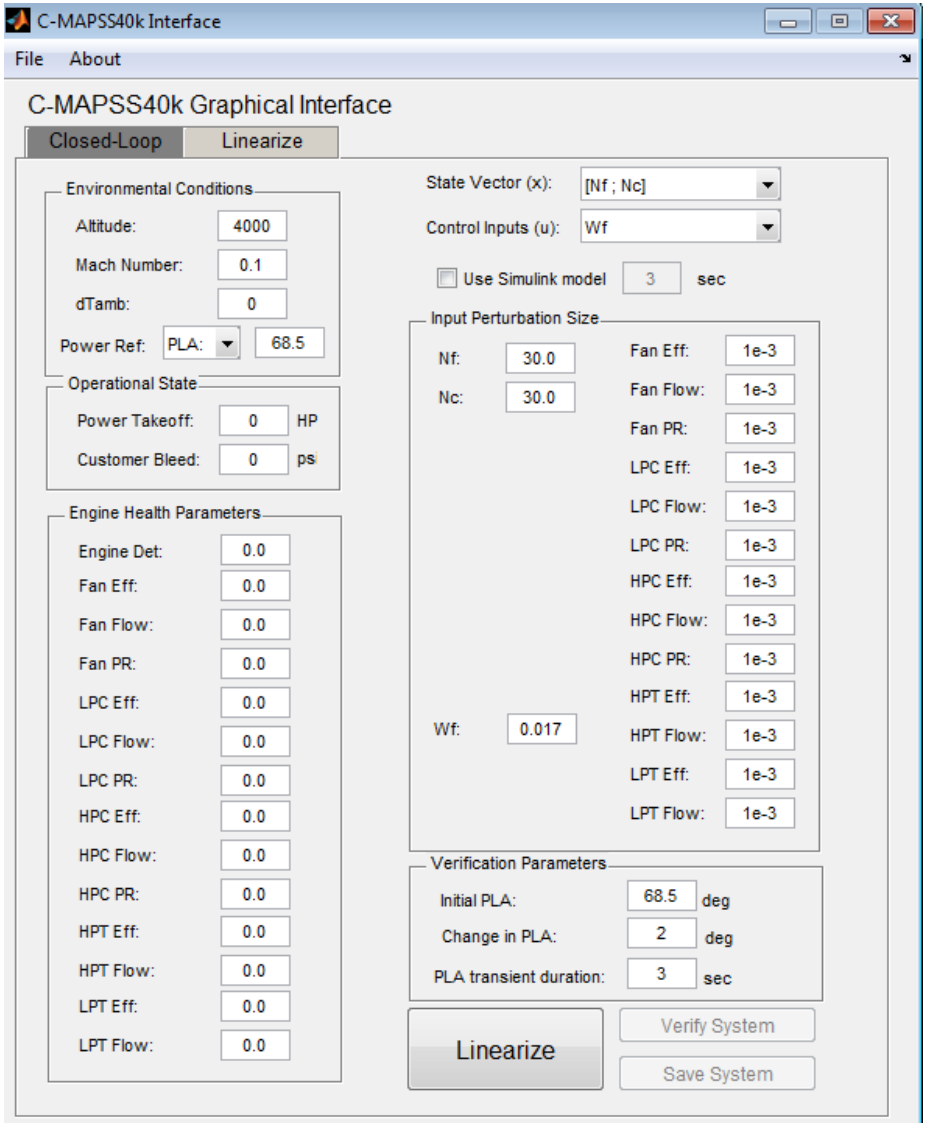
- Faster and more elegant than “flying” to desired starting point from a known initial flight condition



User Features: Linear Models

$$\dot{x} = Ax + Bu + Lh$$
$$y = Cx + Du + Mh$$

- Generate linear models about any equilibrium point (i.e., flight condition)
- Specify flight/health condition
- Specify state/input variable vectors
- Verify and save linear model



Major Updates

- Controller input realism
  - Adjusted control logic to be based exclusively on typical sensed parameters and control inputs
- Adjusted PLA to Fuel flow request mapping
  - Ground idle speeds (Nf and Nc) reflect more realistic levels
  - Increased linear relationship between PLA and Thrust
- Fuel flow limiter updates
  - Added an EGT limiter to the controller
  - Updated Ps3max, Nfmax, and Accel Limiters to be more realistic
- Linear model Power Reference
  - Added feature to allow a user to linearize the engine about a specified set point type: Nc, Nf, or PLA.
- Off-nominal variable stator vane positions
  - Updated off nominal VSV effects to be more realistic in its effect on stall margin and engine performance

Summary

- Simulation of 40,000-lb_f class, high-bypass, dual-spool turbofan engine
- Physics-based, component-level model
- Faster than real-time
- Realistic control system
- Graphical/command-line user interfaces
- Linear model generation

Related NASA Publications

- Csank, Jeffrey, May, Ryan D., Litt, Jonathan S., and Guo, Ten-Huei, "Control Design for a Generic Commercial Aircraft Engine," AIAA-2010-6629, 46th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Nashville, TN, July 25-28, 2010, also NASA/TM—2010-216811, October 2010.
- May, Ryan D., Csank, Jeffrey, Lavelle, T. M., Litt, Jonathan S., and Guo, Ten-Huei, "A High-Fidelity Simulation of a Generic Commercial Aircraft Engine and Controller," AIAA-2010-6630, 46th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Nashville, TN, July 25-28, 2010, also NASA/TM—2010-216810, October 2010.

Available for download from the NASA Software Repository

- *Software availability limited to U.S. citizens due to export control regulations*

https://sr.grc.nasa.gov/public/project/77/