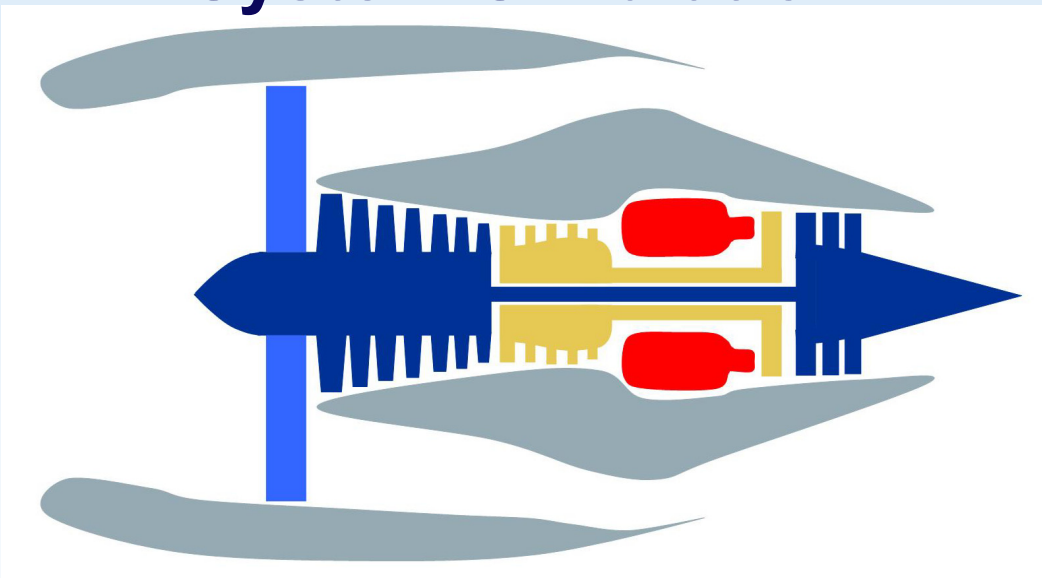
MAPSS/CMAPSS
Commercial Modular Aero-Propulsion System Simulation



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OUTLINE

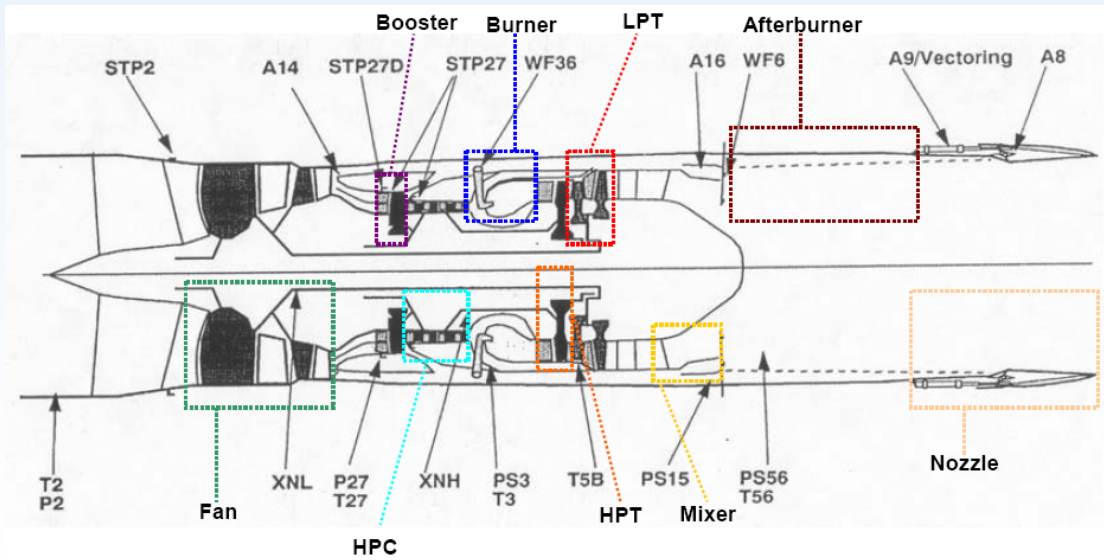
- MAPSS Concept
- Need for C-MAPSS
- C-MAPSS Features
- C-MAPSS Operation
- Deterioration and Fault Simulation
- Enhancements for Future Release
- Summary

The Modular Aero-Propulsion System Simulation (MAPSS) Concept

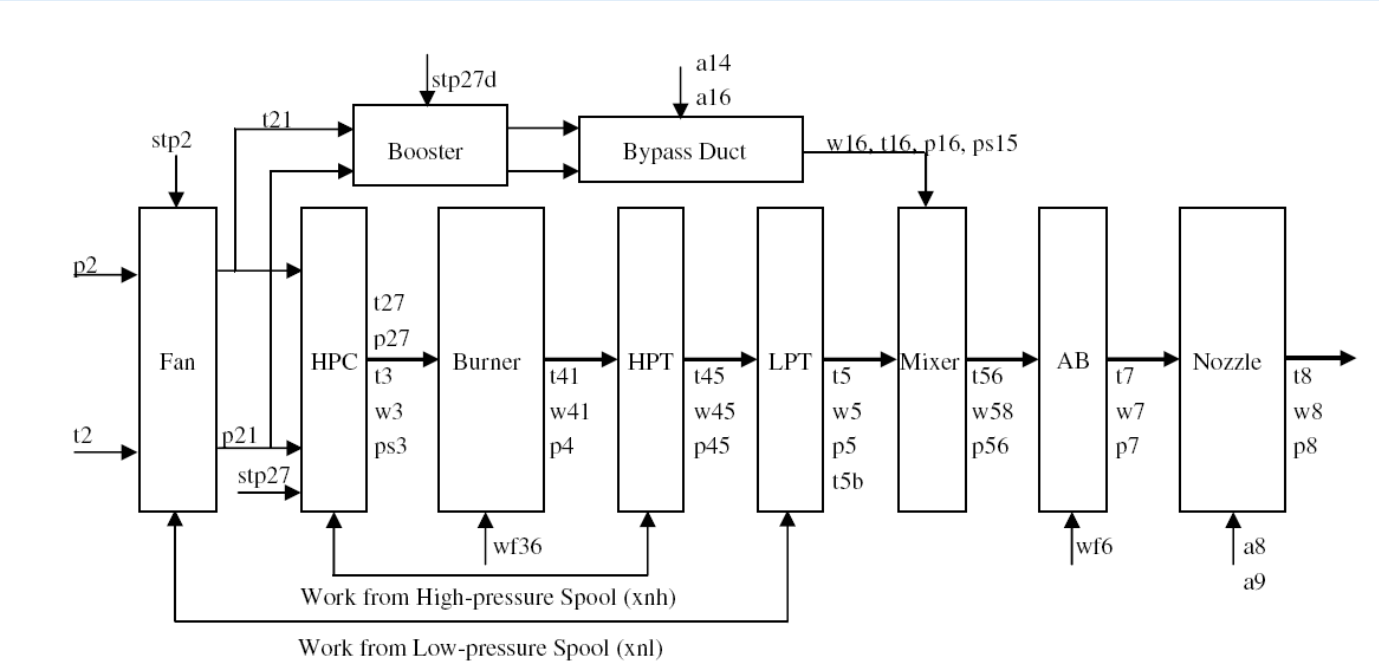
- MAPSS is a flexible turbofan engine simulation environment with easy access to health, control, and engine parameters through a graphical user interface
- MAPSS provides a graphical simulation environment in which to develop advanced control algorithms and quickly test them on a generic turbofan engine simulation
- MAPSS can generate state-space linear models, from which the user may create a piecewise linear controller
- MAPSS can run transient simulations which allows testing of the controller on a validated, and verified, generic engine model

MAPSS

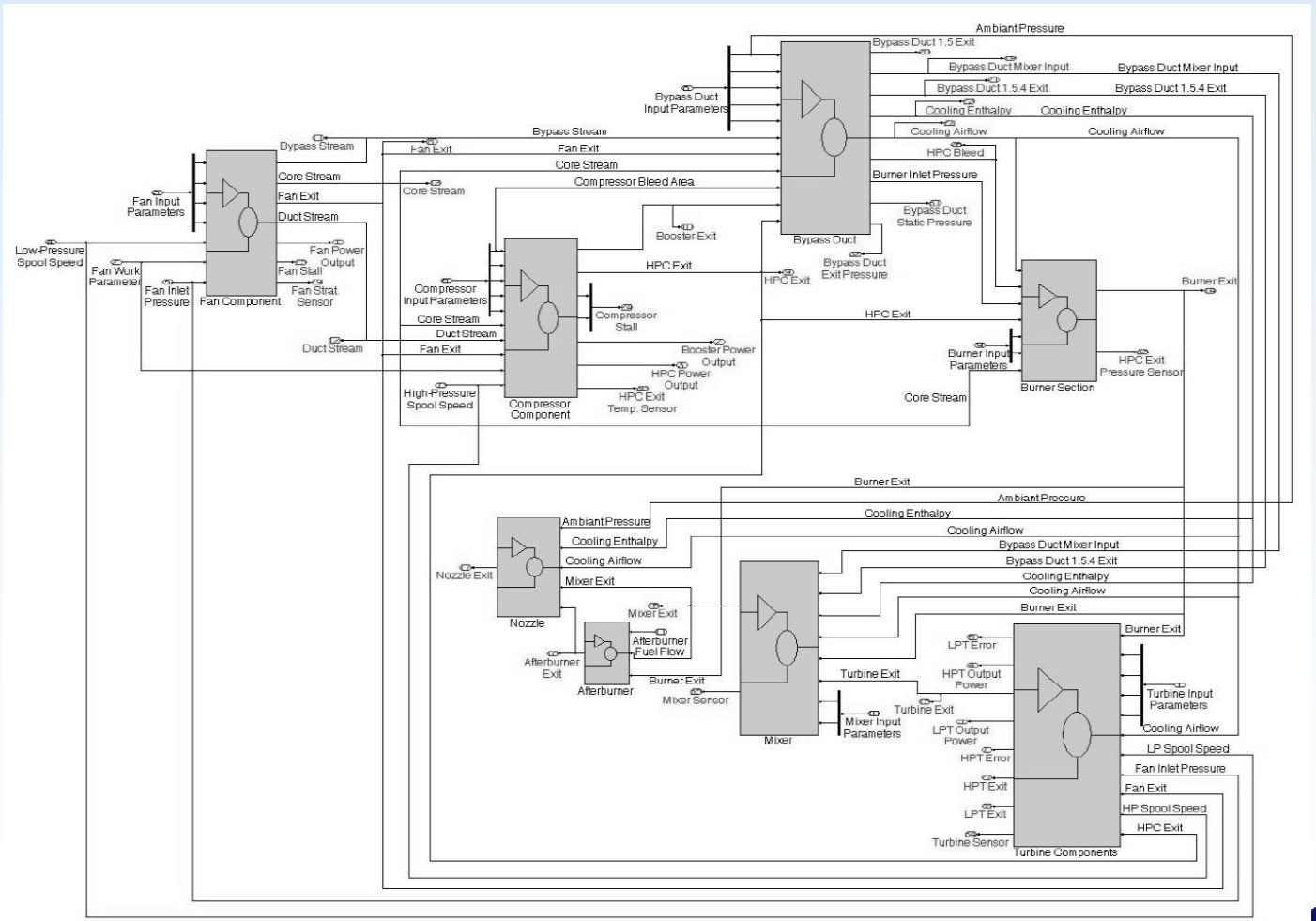
You may be familiar with the military low bypass version of MAPSS



It is a modular, component level model…



… written in Matlab/Simulink



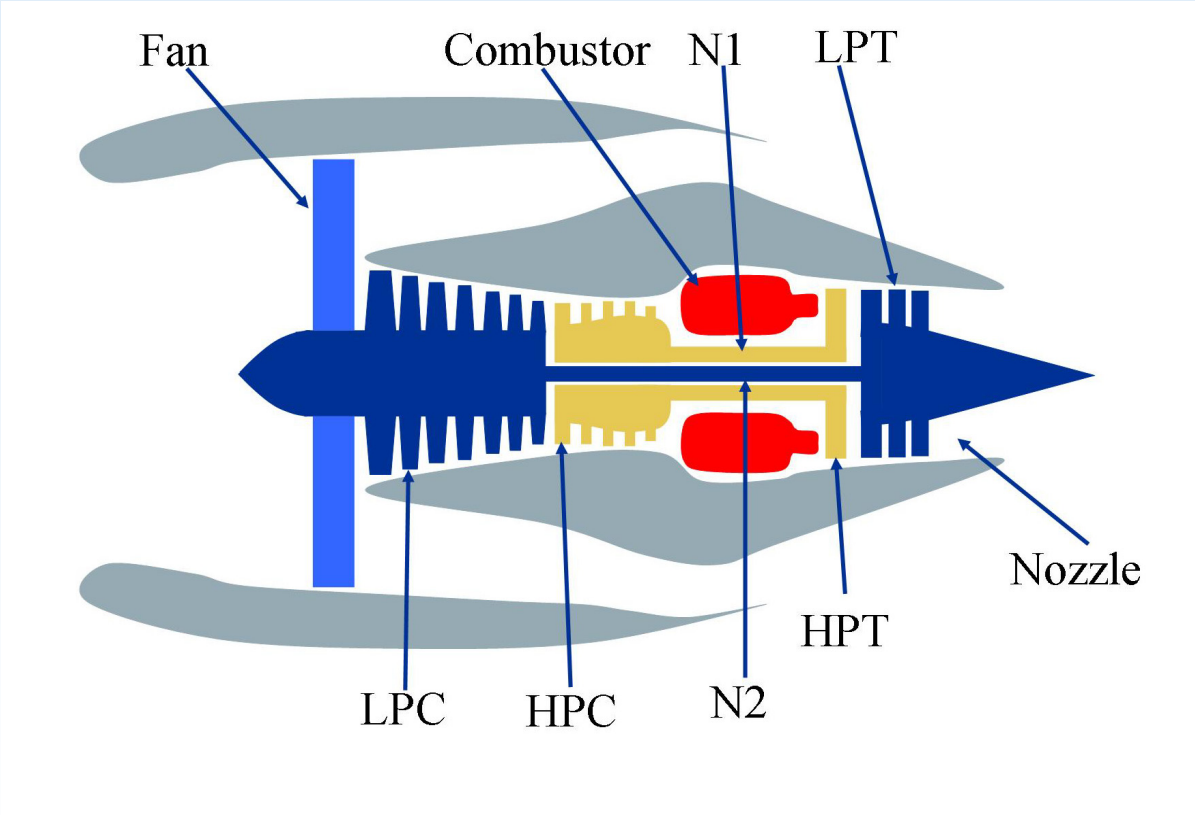
MAPSS AVAILABILITY

- Parker, Khary I., Guo, Ten-Heui, “Development of a Turbofan Engine Simulation in a Graphical Simulation Environment,” NASA TM-2003-212543, August 2003.
- Melcher, Kevin J., “The Modular Aero-Propulsion System Simulation (MAPSS) Users' Guide,” NASA TM-2004-212968, March 2004.
- MAPSS is available upon request from NASA's Software Repository through NASA GRC's Technology Transfer and Partnership Office. https://technology.grc.nasa.gov/software/SWInfo_form.asp?cat=Engineering%20Design%20and%20Analysis%20Codes&center=GRC&SwareKey=56

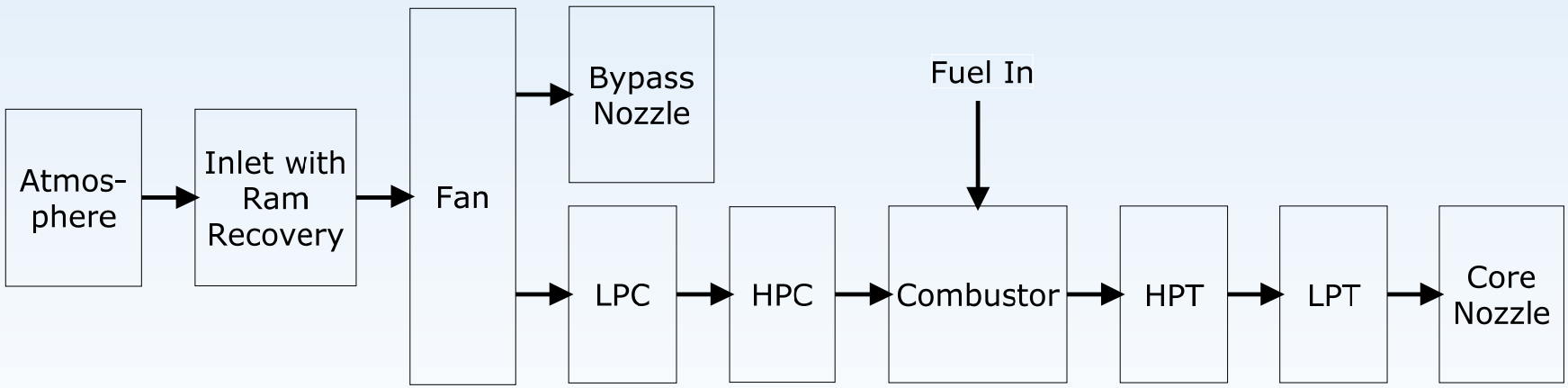
C-MAPSS Relationship to IRAC

- C-MAPSS is a large (~90K lbs of thrust) commercial turbofan engine simulation with a FADEC-like controller
- C-MAPSS is being developed under IRAC
- C-MAPSS provides a realistic test bed on which to modify controller limits to determine Enhanced Operation/Risk tradeoffs

The Commercial Modular Aero-Propulsion System Simulation (C-MAPSS)

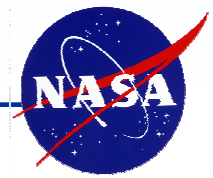


Is a modular high bypass component level model, also written in Matlab/Simulink



Important Features of C-MAPSS

- C-MAPSS simulates a large high-bypass turbofan engine with 90K lbs peak thrust
- Contains an atmospheric model allowing full envelope operation
- Runs faster than real time
- Is GUI driven
- Automatically generates linear engine models at user-specified operating points
- Has the ability to compare generated linear model to original non-linear model



Important Features of C-MAPSS

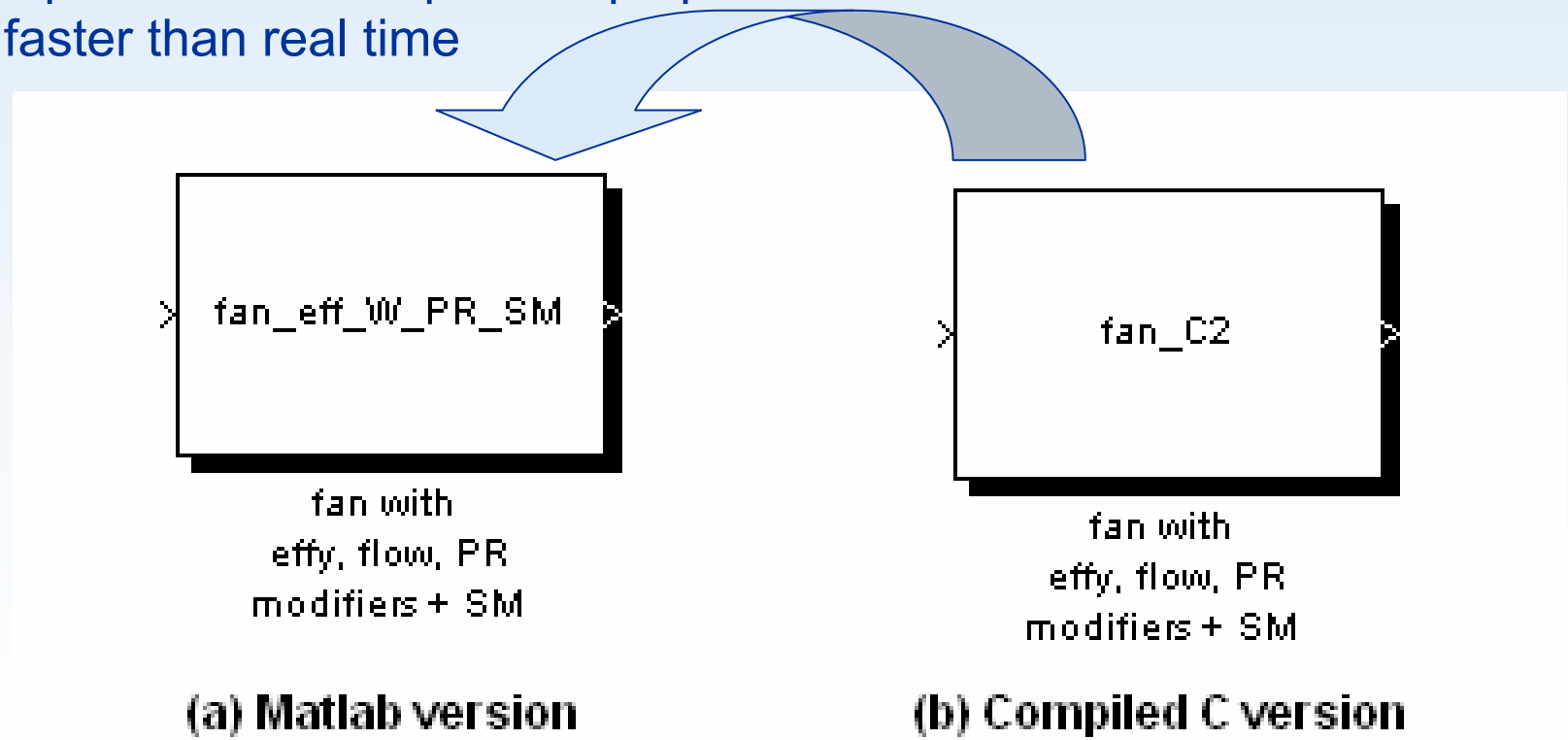
- Has a realistic FADEC-like controller
- Has a Control Design GUI to facilitate the development of point controllers
- Provides access to pertinent variables for control and diagnostics
- Enables the implementation and evaluation of user-developed algorithms
- Can simulate deterioration and faults

Details of engine and ambient models

- modeling done primarily via Simulink S-functions that consist of Matlab code
- major components are: ambient, fan, LPC, HPC, burner & HPT, LPT, and control system
- has subsystems for
  - Atmospheric model
    - altitudes from sea level to 40,000 feet
    - Mach numbers from 0 to 0.90
    - ambient temperatures from -60 ºF to 103 ºF.
  - output variables
  - health-parameter inputs
  - algebraic-loop solver
  - shaft acceleration and speed
  - TRA to corrected-fan speed
- can use DLL files (compiled C code) for fast execution or interpretive Matlab code that can be modified by user

Conversion of Some Matlab Code to C Code Provides Faster Operation

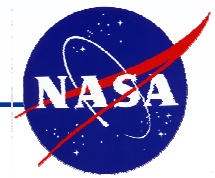
Using C code rather than Matlab for component models speeds up operation to faster than real time



Commanded Inputs and Outputs

- Commanded Inputs
  - Fuel Flow
  - Other actuators such as bleeds and variable stator vanes are considered to be operating on their schedules
- Outputs
  - 27 output variables accessible for diagnostics and control
  - Many other internal variables available as well

General Operation

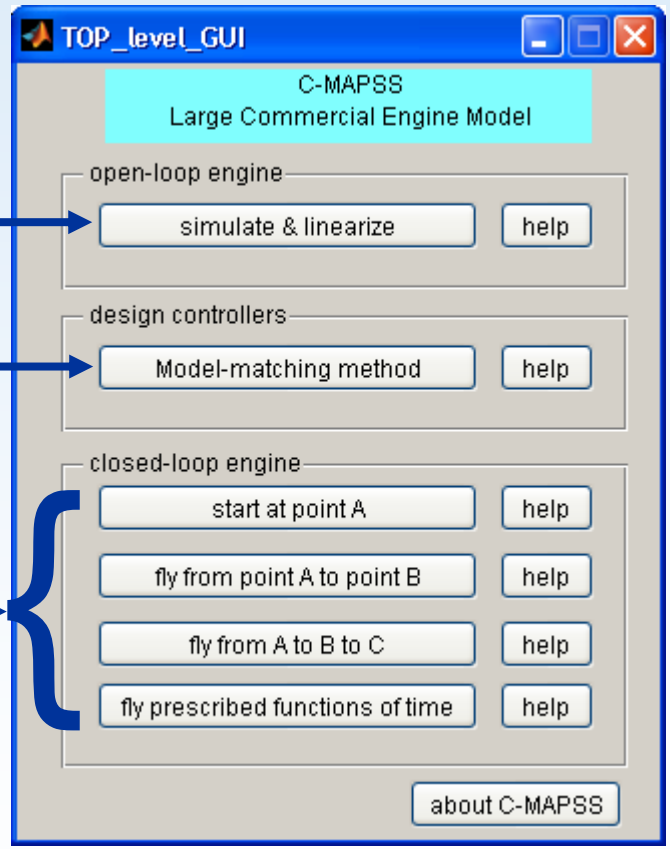


C-MAPSS is GUI-Driven for Ease of Operation
Top-Level GUI

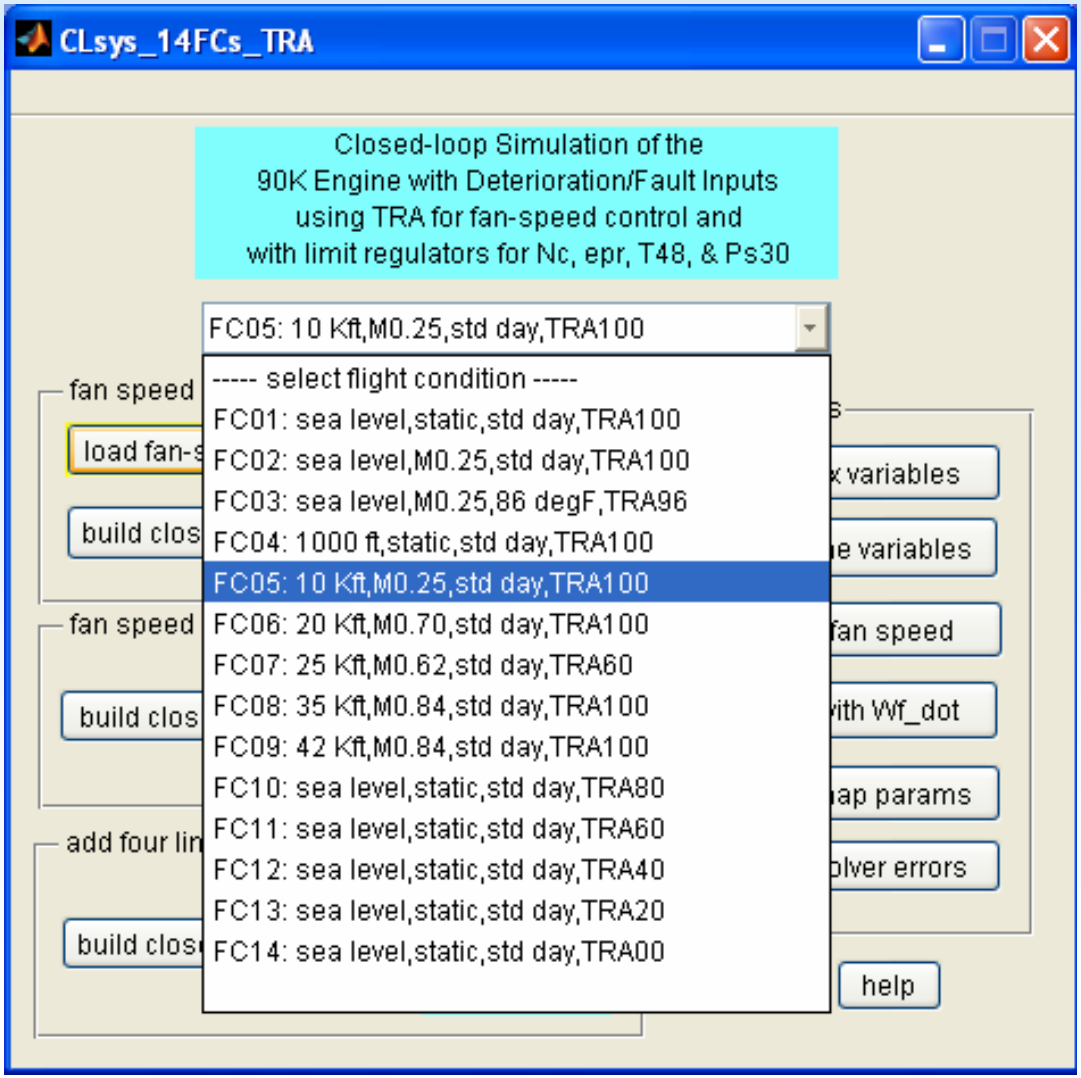
Allows open-loop engine to be simulated and linear models generated

Enables user-specified controllers to be developed for linear point models

Simulates operation around the flight envelope under closed-loop control



Popup menu for selecting pre-defined initial flight condition

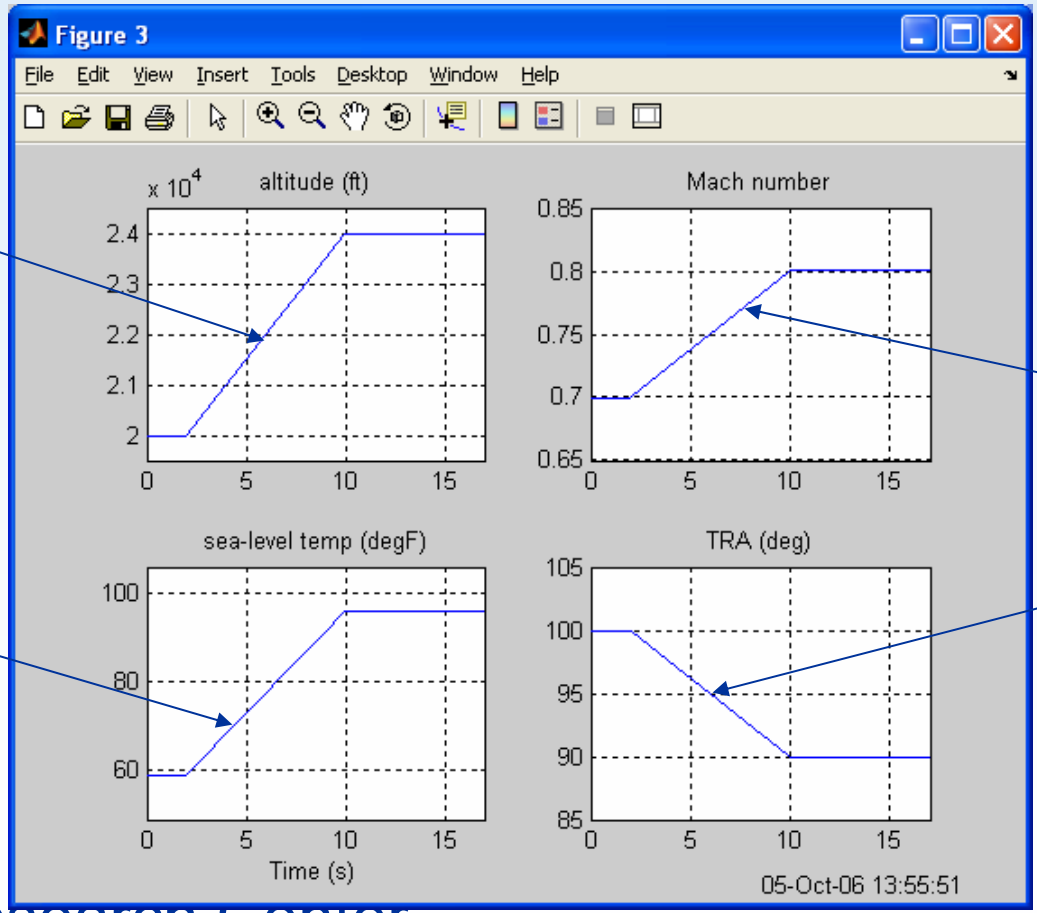


User can create new flight conditions and add them to the menu

User can specify changes in altitude, Mach number, sea-level temperature, and TRA

user-specified flight condition: start at flight condition 06 (20,000 ft, Mach 0.70, 59 degF, TRA100) go to 24,000 ft, Mach 0.80, 96 degF, TRA90

altitude goes from 20,000 to 24,000 feet

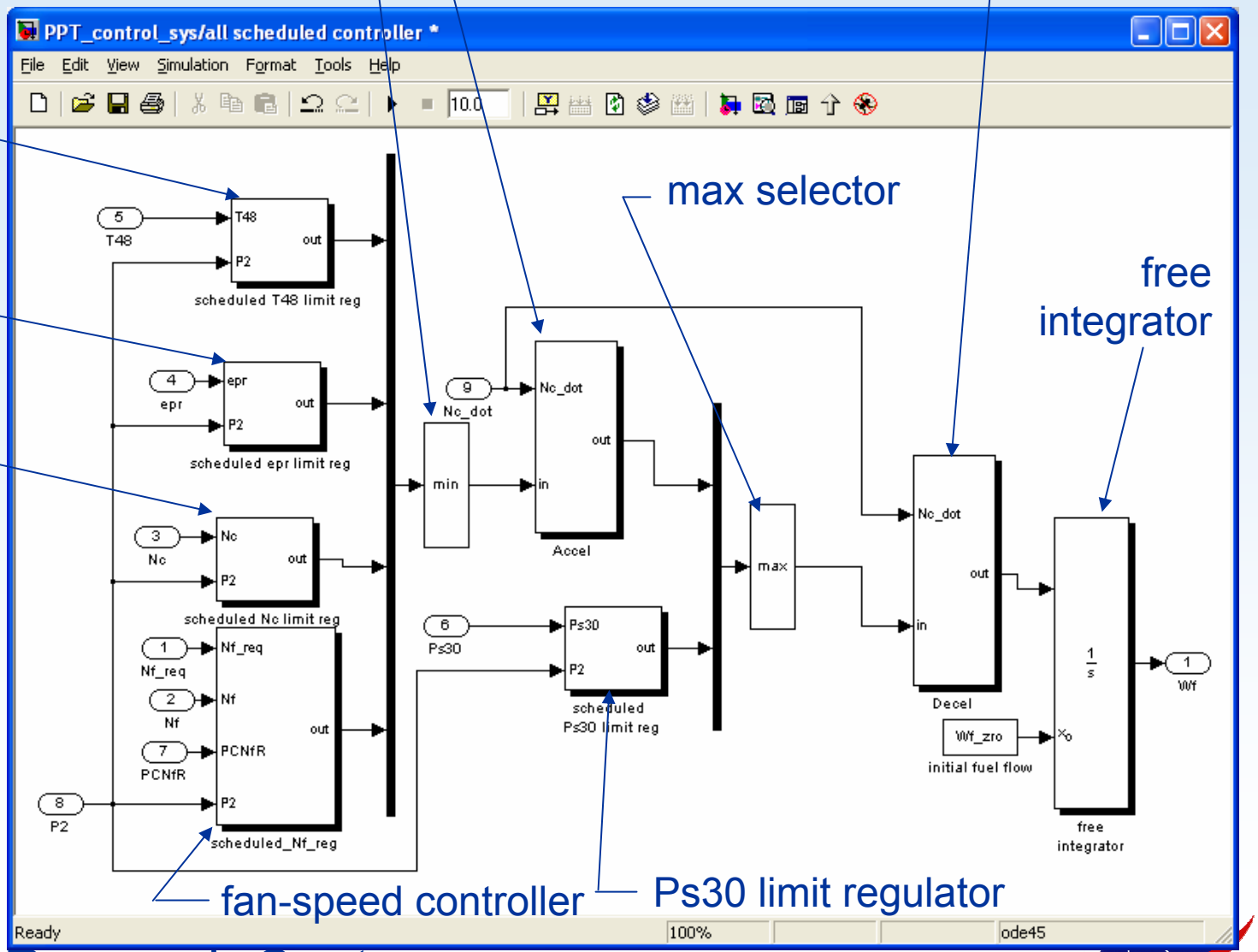


Mach number goes from 0.70 to 0.80

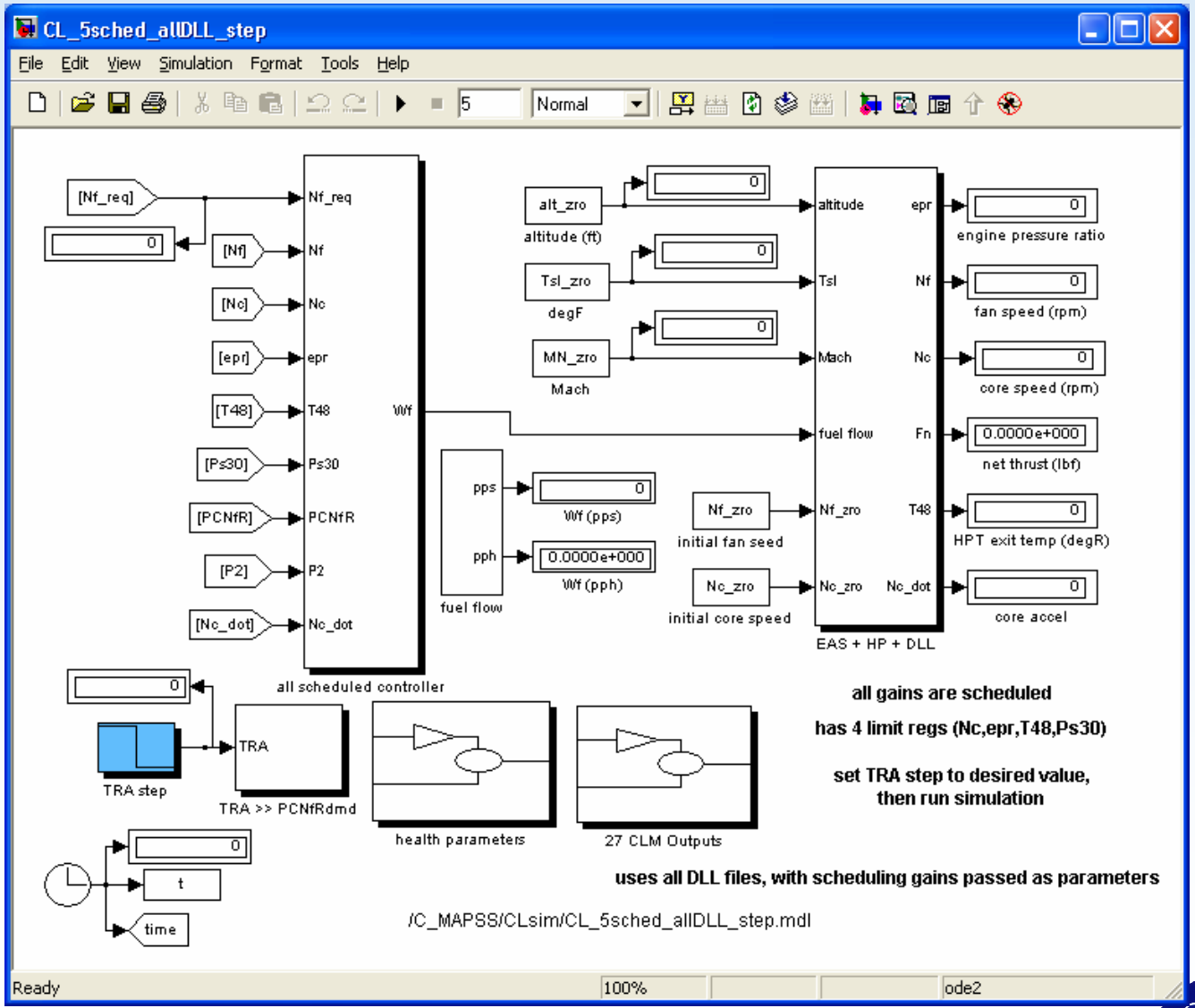
sea-level temperature goes from 59 to 96 degF

TRA goes from 100 to 90 deg

C-MAPSS has a Realistic FADEC-like Controller



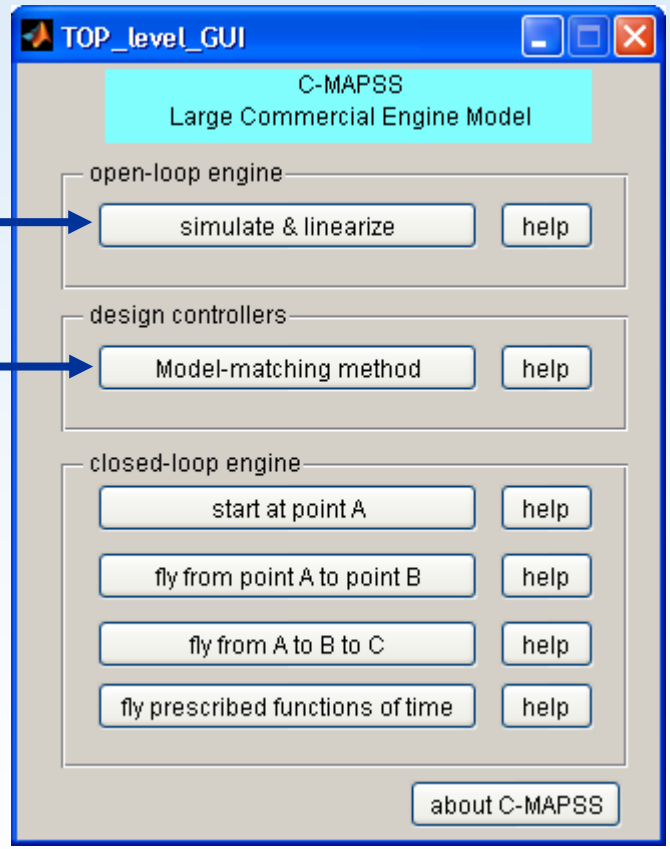
Full Envelope Closed-Loop Nonlinear Simulation



Linear Model Generation and Control Design

Allows open-loop engine to be simulated and linear models generated

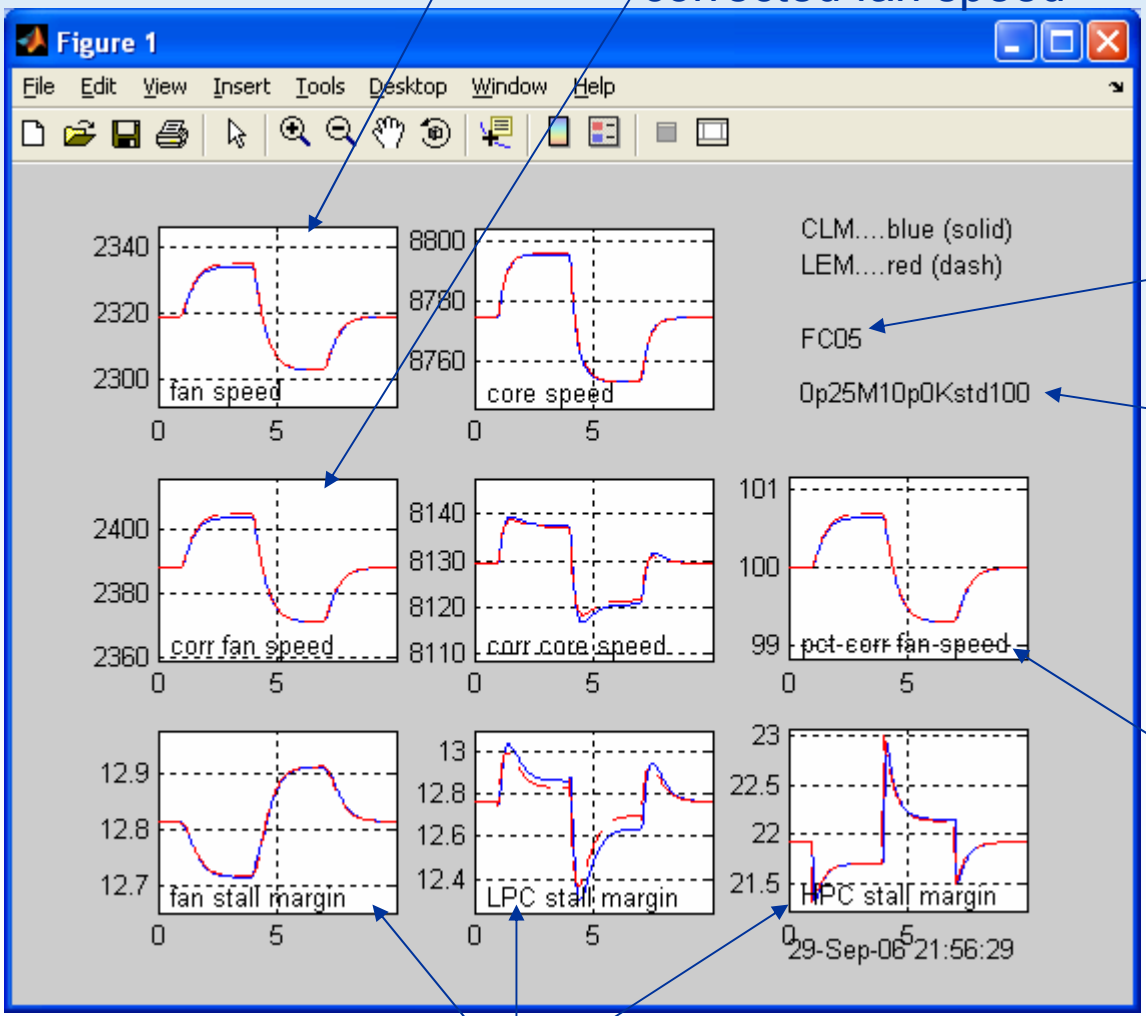
Enables user-specified controllers to be developed for linear point models



Simulate Linear Engine Model and engine with same doublet input for comparison

physical fan speed

corrected fan speed



blue = engine
red = Linear Engine Model

flight condition 05

10,000 feet

Mach 0.25

Standard day

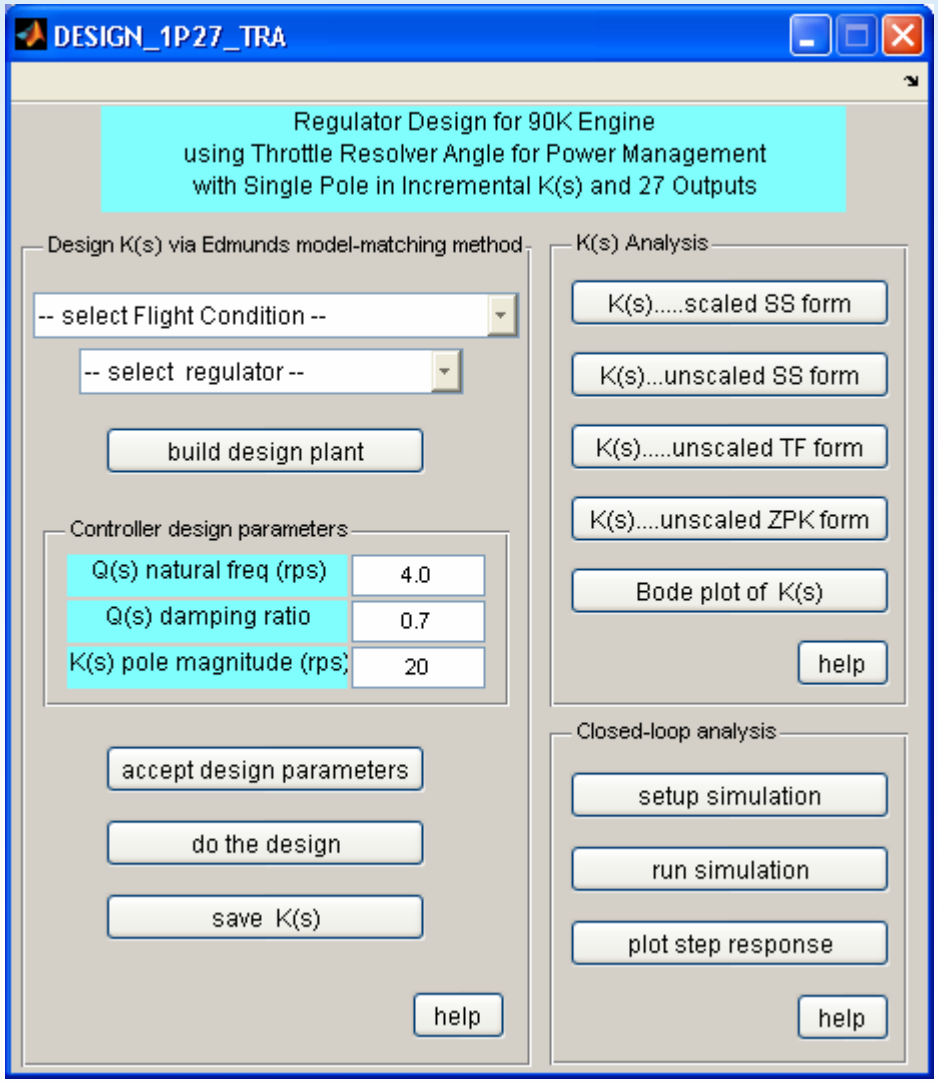
PCNfR = 100%

percent corrected fan speed

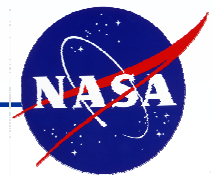
stall margins

Controller Point Design GUI

User-specified closed-loop response characteristics. Designs fan speed and limit regulators



Deterioration and Fault Simulation



Deterioration and Faults are Implemented the Same Way

- Modification of Health Parameters is used to simulate Faults and Deterioration
- Faults occur abruptly, usually in one component
- Deterioration occurs slowly, generally in all components
- Health parameters in C-MAPSS:

  fan efficiency modifier, fan flow modifier, fan pressure-ratio modifier

  LPC efficiency modifier, LPC flow modifier, LPC pressure-ratio modifier

  HPC efficiency modifier, HPC flow modifier, HPC pressure-ratio modifier

  HPT efficiency modifier, HPT flow modifier

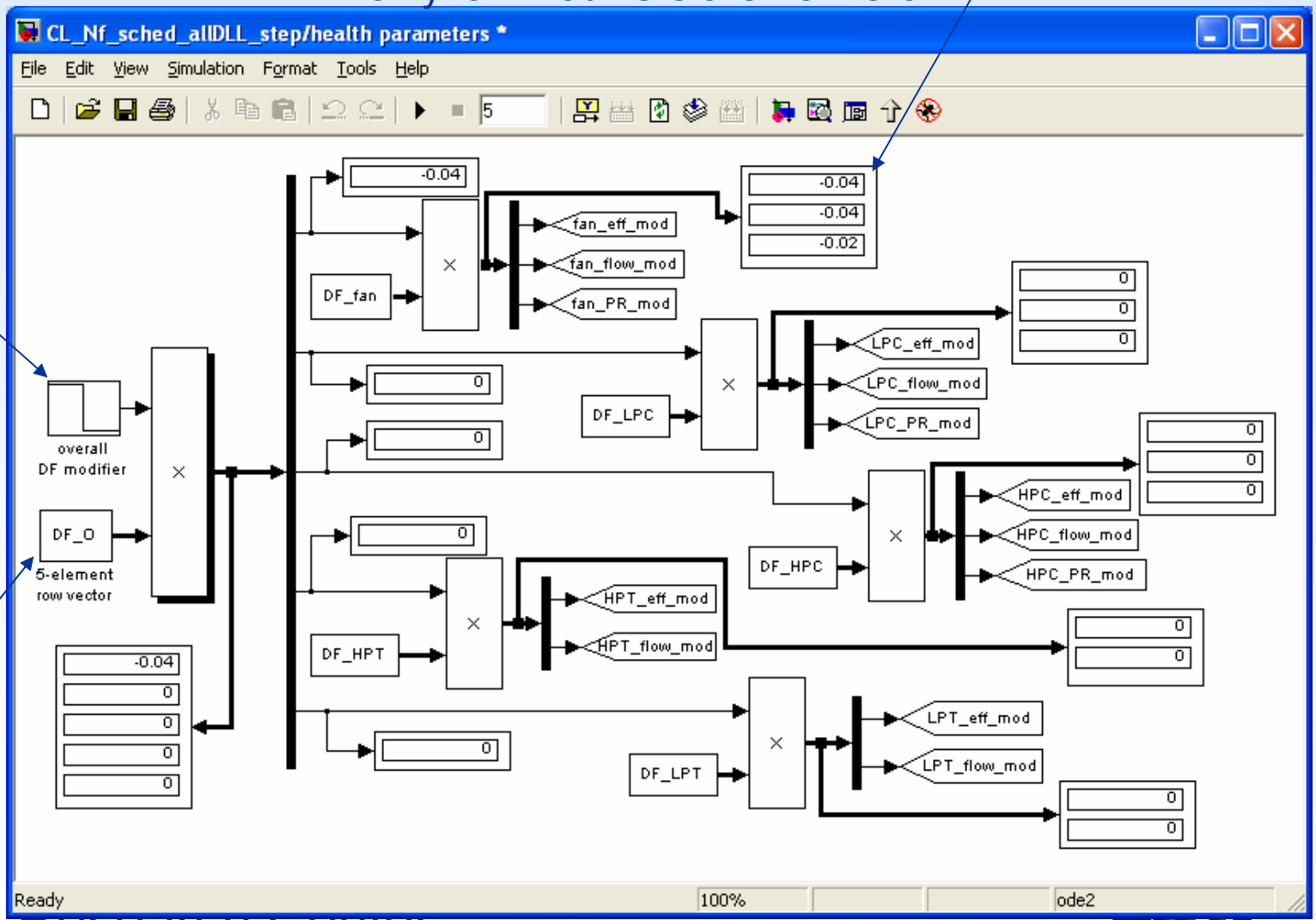
  LPT efficiency modifier, HPT flow modifier

Health-parameter subsystem for 4% fault in fan only

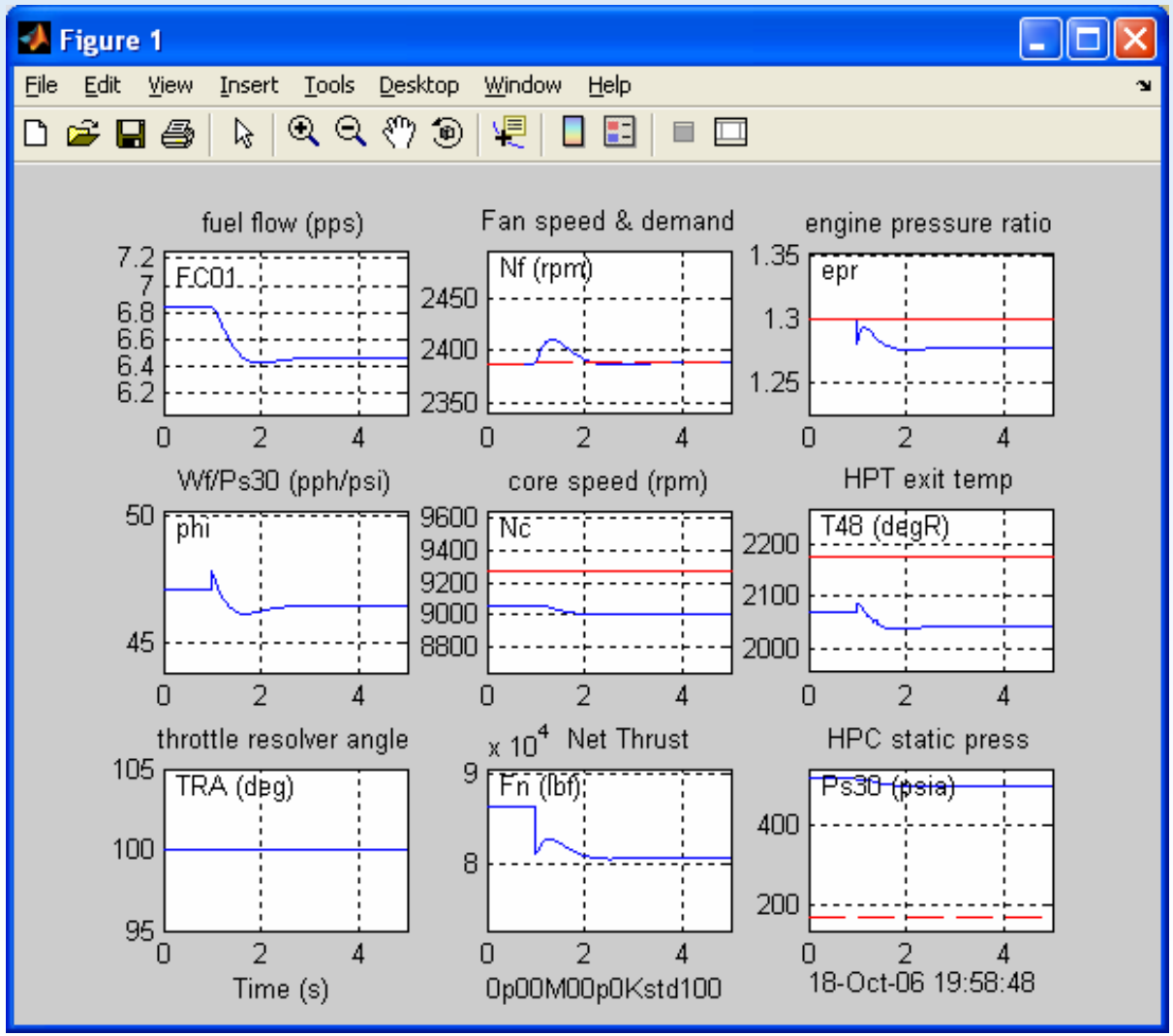
only fan modifiers are nonzero

step of -0.04
at t = 1 s

[1 0 0 0 0]



Response to 4% fan fault at t = 1 sec with fan speed controlled



C-MAPSS AVAILABILITY

- The first version of C-MAPSS is complete and the Users' Guide is published.
- Some paperwork still must be completed before C-MAPSS is released publicly
- Official release will be as soon as possible
- Check our Branch website
  http://www.grc.nasa.gov/WWW/cdtb/facilities/mapss.html

C-MAPSS Enhancements for Future Release

- Usability
  - Improve initialization scheme: Trim simulation at user-specified thrust level, deterioration, and environmental conditions rather than pre-stored operating points
- Model fidelity
  - Add fuel metering valve (FMV) dynamics
  - Add Sensor Dynamics
  - Add combustion delay
  - Add effect of Variable Stator Vanes (modify compressor maps away from schedule)
  - Add effect of Variable Bleed Valve
  - Add Reynolds Number effects: high altitude operation
- Operation
  - Incorporate redesigned controller based on additional sensor and actuator dynamics
- PLANNED UPGRADE TO BE RELEASED BY JULY 2008

Summary

- MAPSS and C-MAPSS can be used for the development and validation of control and diagnostic algorithms
- Both have easy-to-use graphical environments
- C-MAPSS is a new high-bypass commercial engine simulation with a realistic controller
- C-MAPSS runs faster than real time
- MAPSS and C-MAPSS are both available through NASA (check our branch website)

REFERENCES

- Frederick, Dean K., DeCastro, Jonathan A., Litt, Jonathan S. “C-MAPSS User’s Guide for the Commercial Modular Aero-Propulsion System Simulation (C-MAPSS),” NASA TM-2007-215026, October 2007.