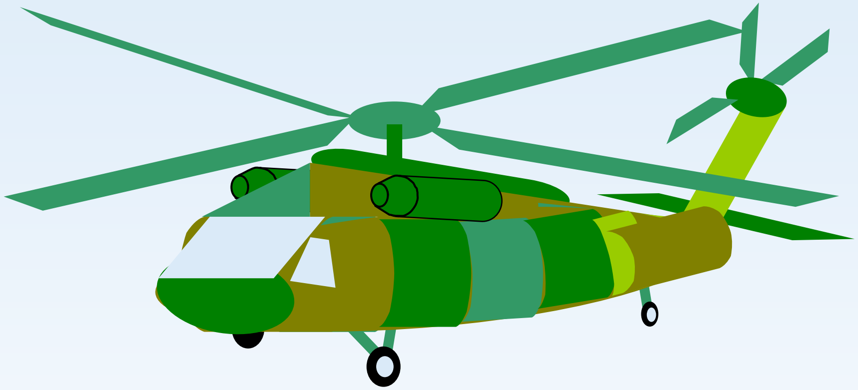
SRW/VARIABLE ROTOR SPEED CONTROL



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Outline of Presentation

- Overview of the Subsonic Rotary Wing Project
- Objective
- Background
- Variable Rotor Speed Discussion
- Sequential Shifting Control
- Example
- Automation of Shifting Procedure
- Conclusions/Issues/Future Work

Overview of the Subsonic Rotary Wing Project
Variable Rotor Speed Control
Flight Dynamics and Controls
This is part of a super integrated vehicle concept

- "Variable speed propulsion, without loss of efficiency and torque, is necessary to permit high-speed operation with reduced noise. Speed variations in excess of 50% will have a dramatic effect on reducing external noise while increasing rotorcraft performance." -- Fundamental Aeronautics Subsonic Rotary Wing Reference Document http://www.aeronautics.nasa.gov/nra_pdf/srw_icp_response_c1.pdf
- FY09 Milestone SRW.1.02.02: Engine/drive synchronized speed shifting control algorithms developed

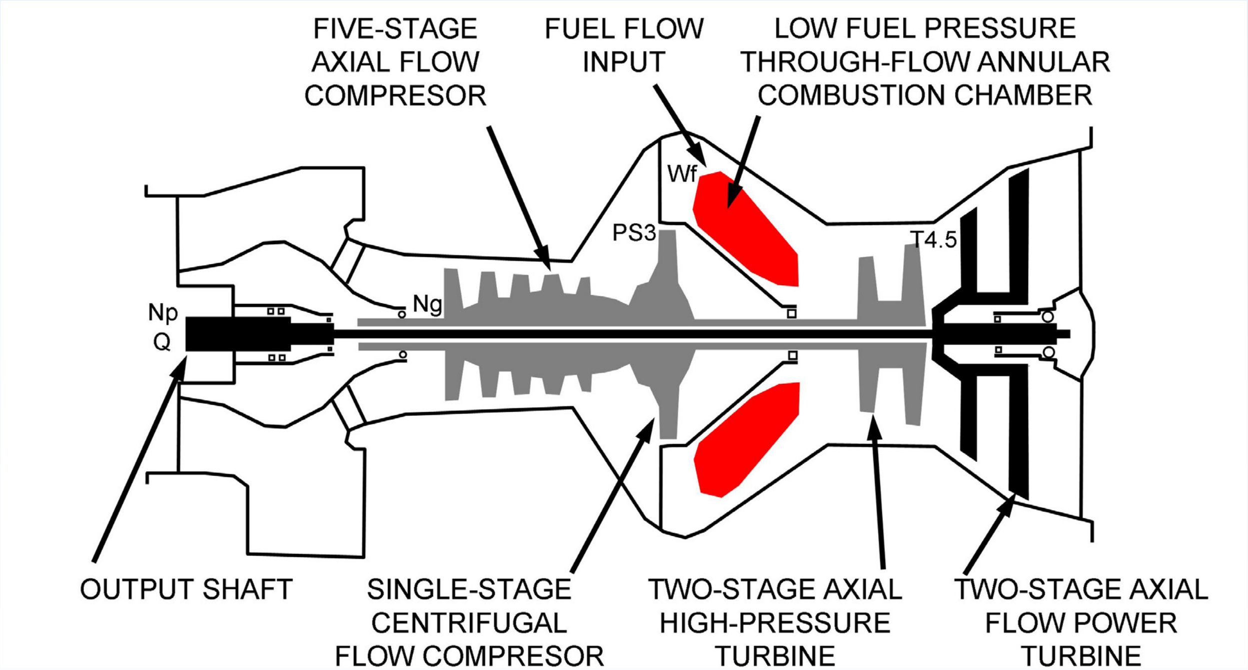
  Metric: Demonstrate control algorithms for 50% change in rotor speed working in simulation
- FY11 Milestone SRW.2.02.03: Synchronized rotor speed shifting

  Metric: Demonstrate that speed-shifting control system can effect a 50% change in rotor speed

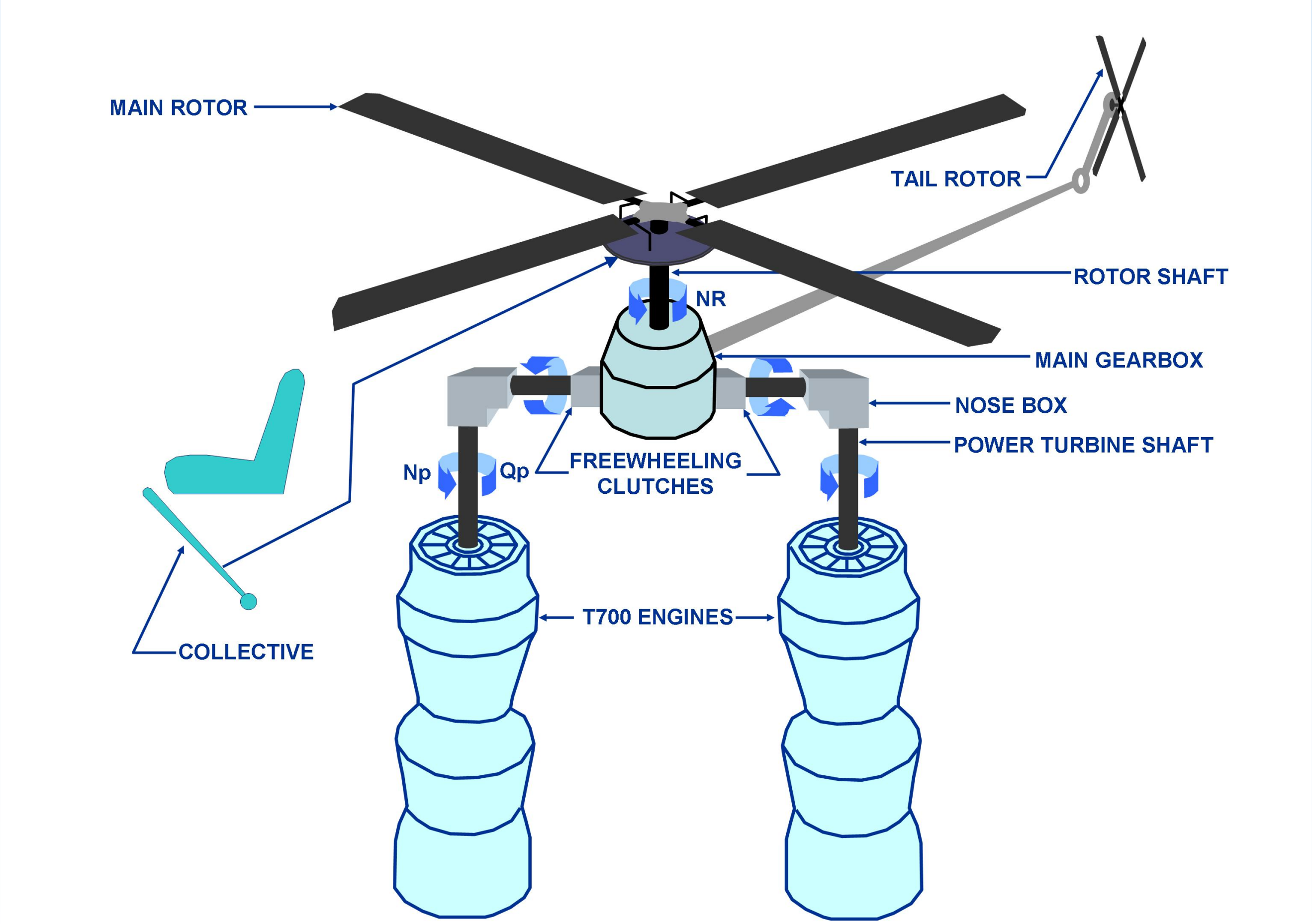
OBJECTIVE

- To develop a continuously variable rotor speed control
- First need to develop a method for continuously varying rotor speed

T700 ENGINE


FIVE-STAGE
AXIAL FLOW
COMPRESOR
FUEL FLOW
INPUT
LOW FUEL PRESSURE
THROUGH-FLOW ANNULAR
COMBUSTION CHAMBER
Wf
PS3
T4.5
Ng
Np
Q
OUTPUT SHAFT
SINGLE-STAGE
CENTRIFUGAL
FLOW COMPRESOR
TWO-STAGE AXIAL
HIGH-PRESSURE
TURBINE
TWO-STAGE AXIAL
FLOW POWER
TURBINE

T700 INSTALLATION



BENEFITS OF CONTINUOUSLY VARIABLE ROTOR SPEED

- Noise reduction
  - 15% rotor speed reduction can result in 5 dB noise-reduction
  - Tips of large rotor blades can exceed the speed of sound
- Agility
  - Enables time-optimal maneuvering

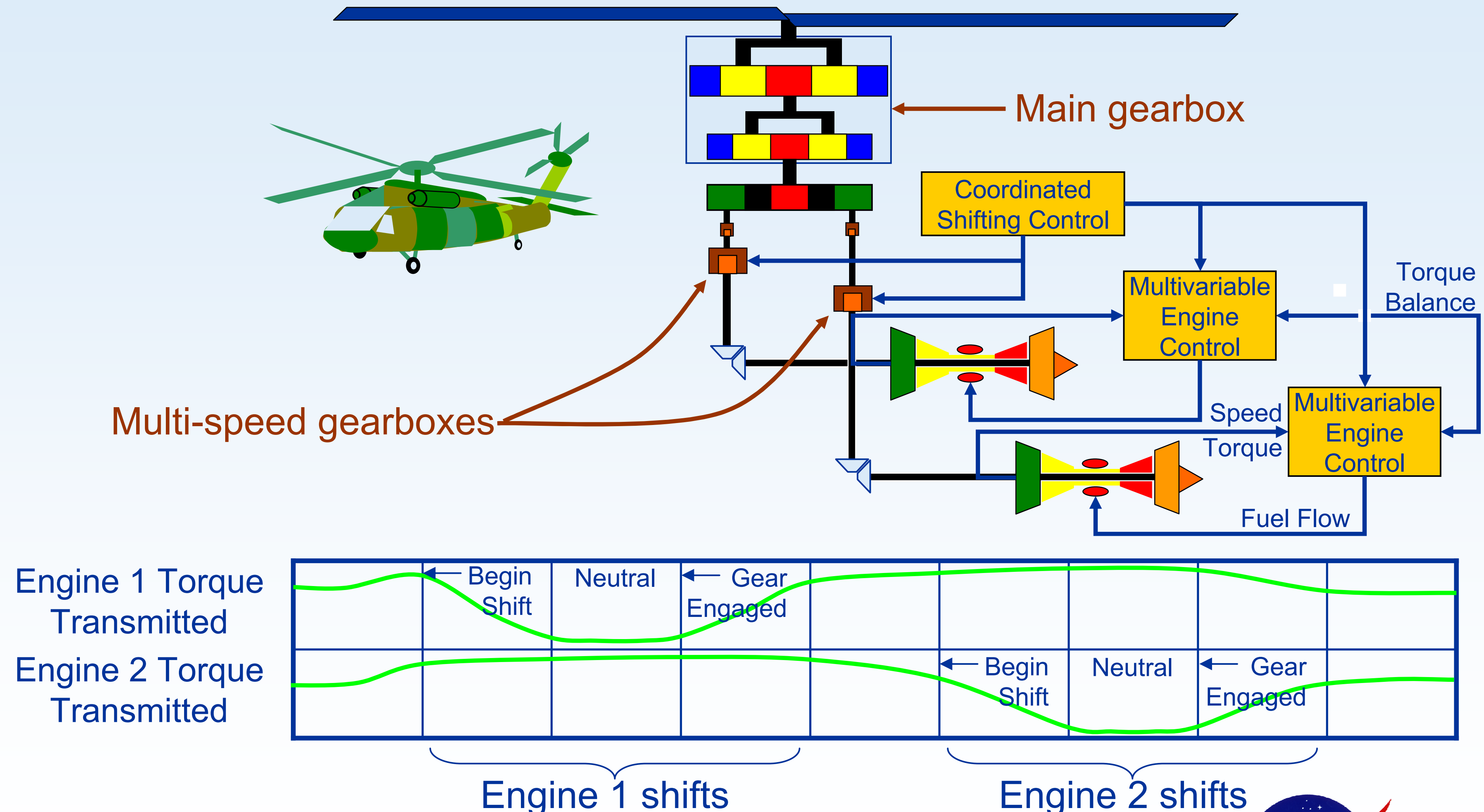
APPROACHES TO CONTINUOUSLY VARIABLE ROTOR SPEED

- Power Turbine Speed Variation
  - Speed variation is restricted to a maximum of about 15% because of fuel efficiency and stall margin considerations
- Continuously Variable Transmission
  - Usually traction drive or friction drive, they are relatively large and heavy, and their efficiency and reliability are poor compared to gearboxes.
- Two Speed/Multi-speed
  - Shifting from one speed to another could cause a momentary loss of output power
  - Large power changes can damage the transmission or drive train

VARIABLE ROTOR SPEED CONTROL REQUIREMENTS

- 100%-50% speed range
- Power turbine speed variation limited to about 15%
- Continuous torque must be applied to the rotor

SEQUENTIAL SHIFTING CONTROL



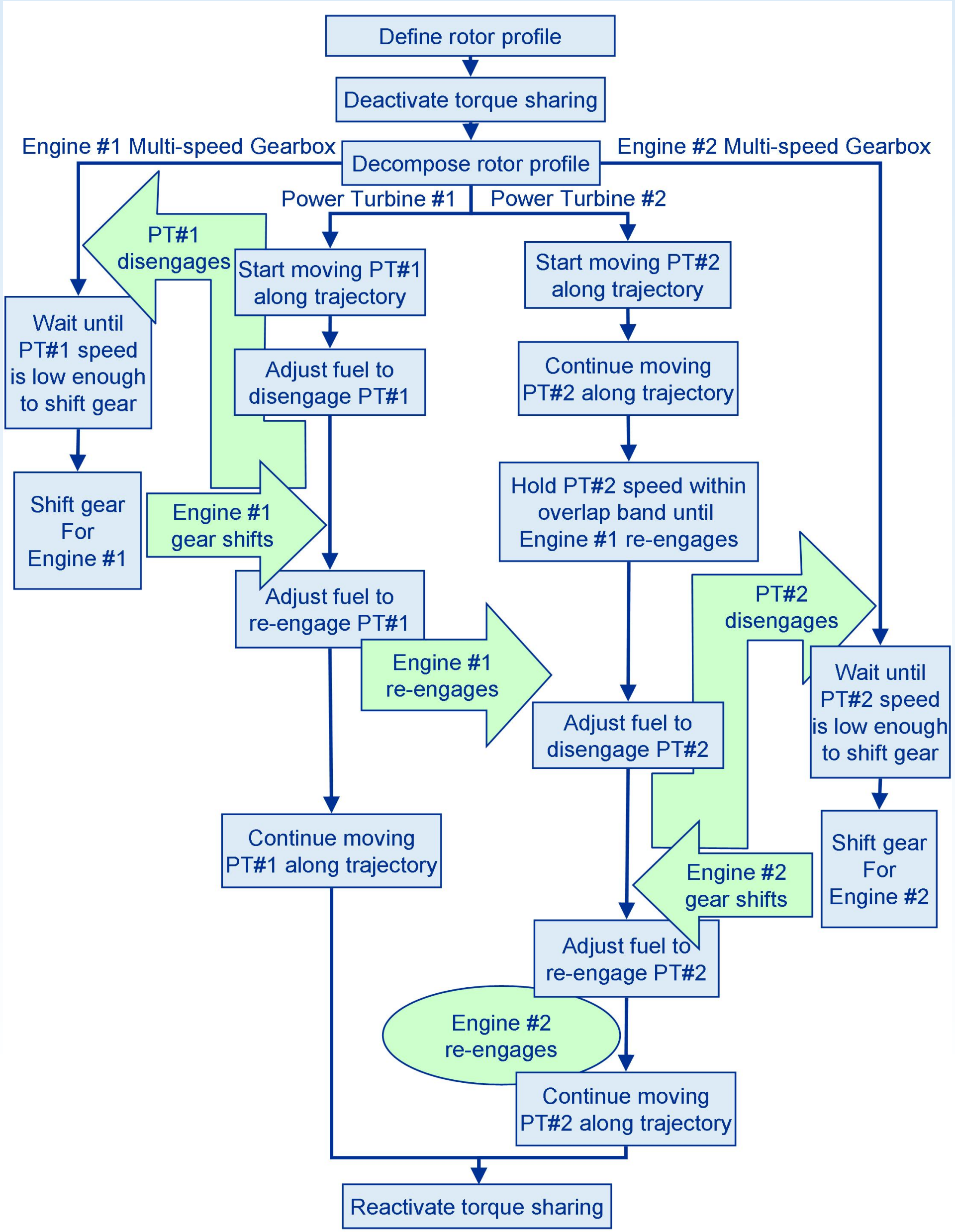
SPEED RANGES FOR 100%-50% VARIATION

Multi-speed gearbox gear ratios and corresponding rotor speed ranges

Range	Gear Ratio	Lowest Speed	Highest Speed
1	1.0	92.5%	107.5%
2	0.87	80%	93.5
3	0.75	69%	81%
4	0.65	60%	70%
5	0.57	53%	61%
6	0.50	46%	54%

- Power turbine speed variation about 15%
- Speed bands overlap about 1% for “hand off”

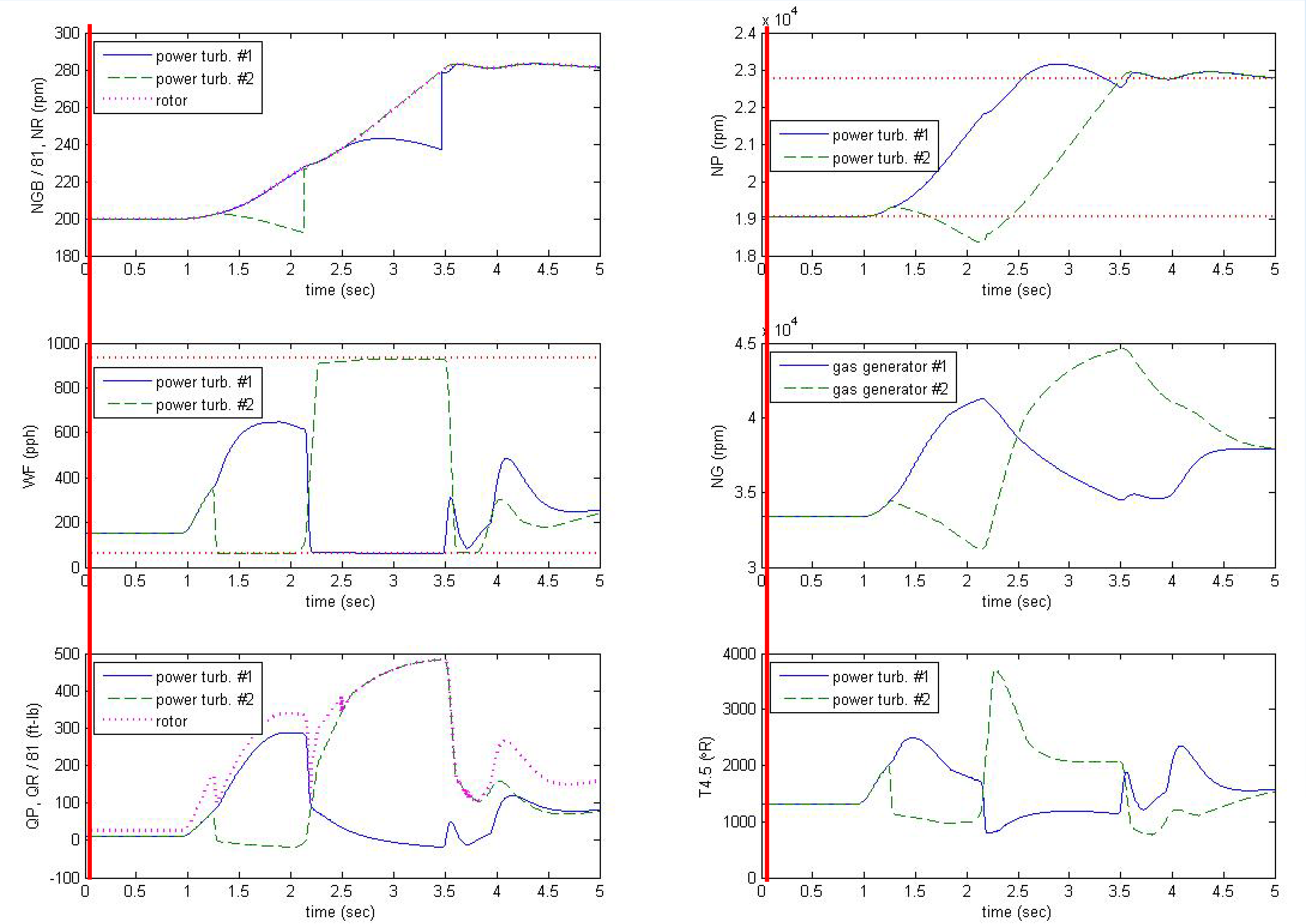
LOGICAL FLOW DIAGRAM OF SSC



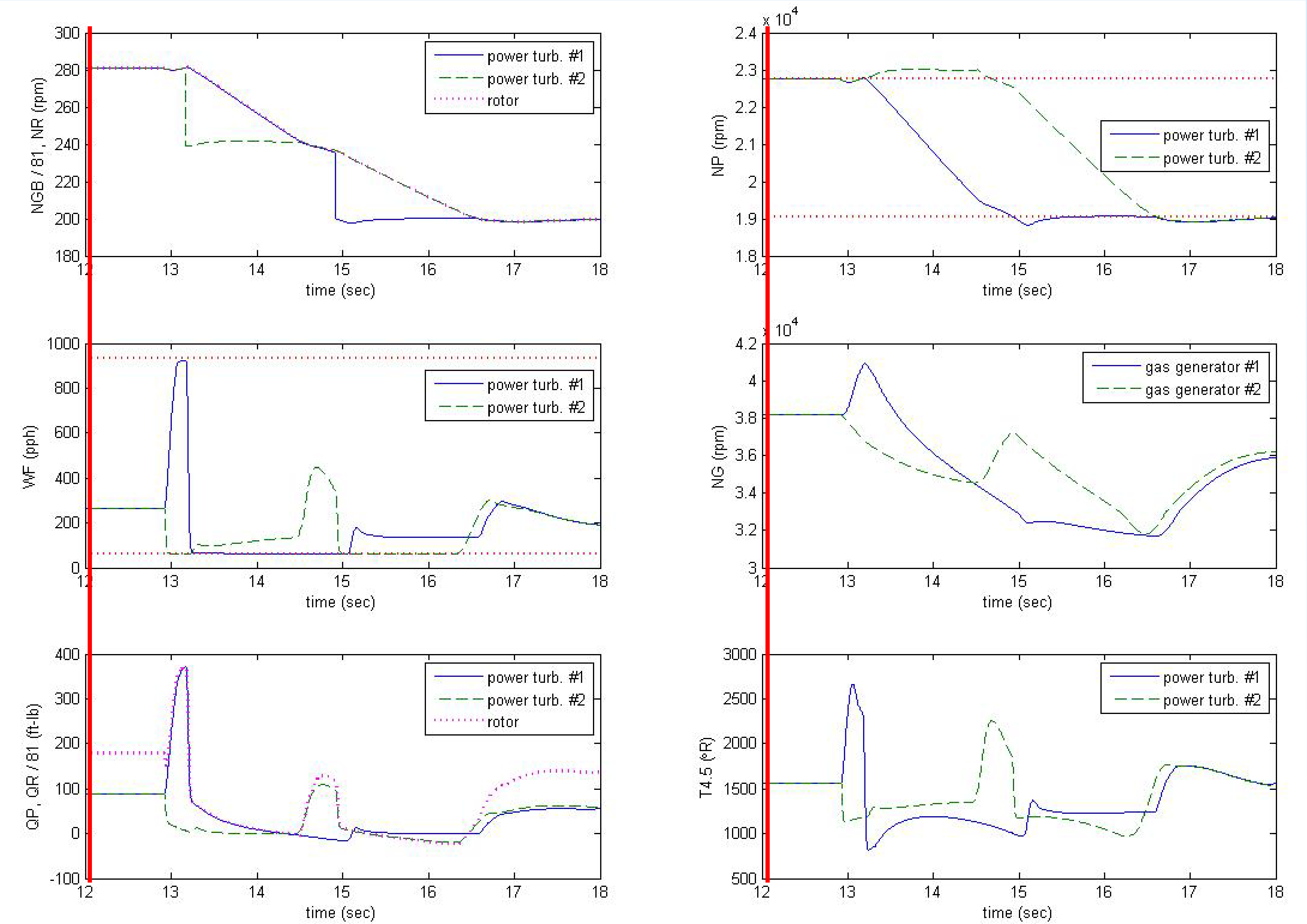
EXAMPLE

- Simplified Simulation
  - Two T700 piecewise linear engine models
  - Dynamometer rotor load model
  - Gear shifting is ideal and instantaneous
  - Shafts are rigid
  - Freewheeling clutches disengage when the rotor begins to drive the power turbine shaft, they re-engage when speed matches the gearbox speed

EXAMPLE
SHIFT UP TO HIGH GEAR



EXAMPLE
SHIFT DOWN FROM HIGH GEAR



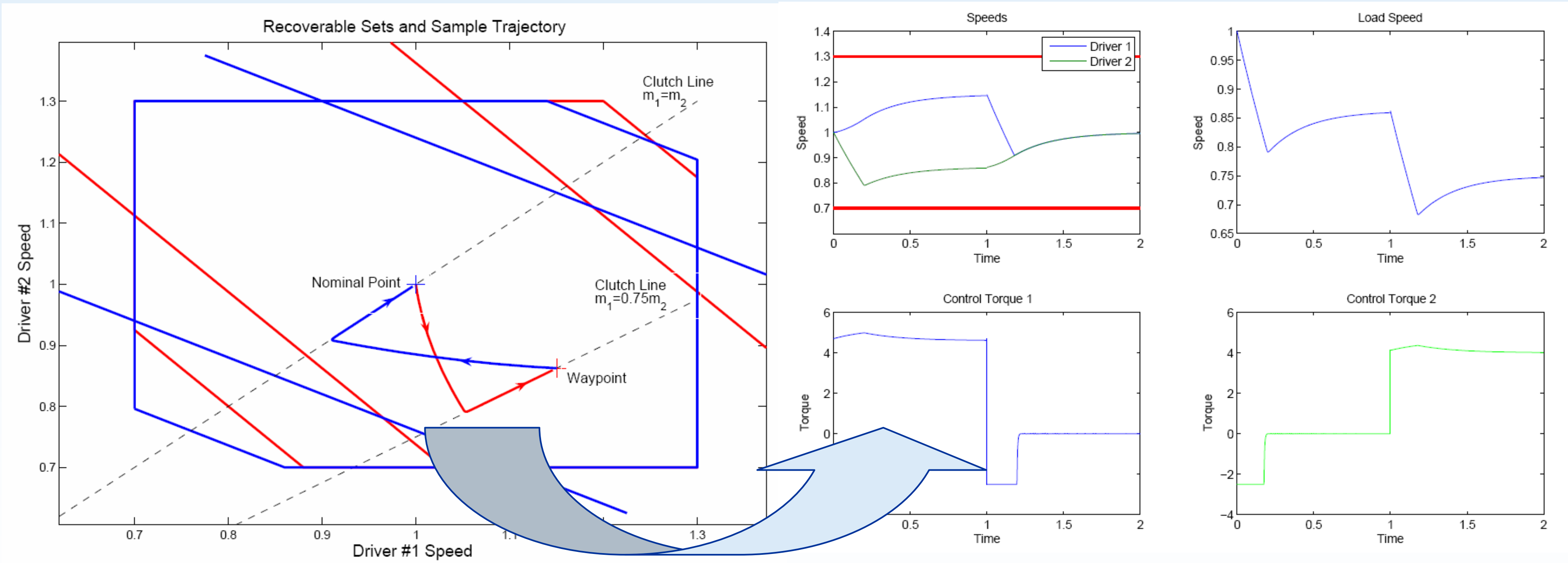
Coordinated Approach to SSC

- Examples were “open-loop” and hand tuned
- Need a way to coordinate all of the activity
- Coordination will be “closed loop” and will effectively “automate” the switching procedure
- Preliminary work using a coordinated variable-structure control approach (a variation of sliding mode control) is promising

Variable Structure Control Preliminary Results

Constraints and Trajectories

Time Responses



CONCLUSIONS

- Proof of concept of a sequential shifting control for continuously variable rotor speed was demonstrated for a simplified linear simulation
- Rotor speed and rotor torque variation were relatively smooth
- The benefits of such a system include noise reduction and improved agility
- Initial automation of shifting concept demonstrated

ISSUES

- Gearbox weight
- Example used linear models, how well is off-nominal performance captured by these models? What happens to Stall margin? SFC?
- Available power for shifting to high gear, accounting for the effect of engine deterioration, ambient temperature, and engine controller limits
- Vehicle integration-related such as torque changes and yawing induced by sudden sequenced gear shifts, the impact of related tail rotor speed changes, and the effect of the large power changes on the transmission

FUTURE WORK

- Improve model fidelity
- Integrate component models to evaluate effect of shifting on vehicle
- Continue to investigate automation of shifting

These are collaboration opportunities

REFERENCES

- Litt, J.S., Edwards, J.M., DeCastro, J.A., "A Sequential Shifting Algorithm for Variable Rotor Speed Control," AHS 63rd Forum, Virginia Beach, VA, May 1-3, 2007, NASA/TM-2007-214842.