A NORMALIZED CONTROL SYSTEM FOR A TURBOJET ENGINE

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APPROACH:

- Normalization of fuel flow and RPM
  - correction for altitude, mach, DISA, and linearization
- Normalize Measurements
- Design single controller (for all flight conditions)
- "de-normalize" output (normalized fuel flow) and apply to engine
FEATURES:

- Engine normalization simplifies control system design for all control design approaches
- Only a simple PI example included in presentation
A PREVIOUS CONTROLLER (1/5)

- GAIN SCHEDULING (Mach, Altitude, RPM)
- Requires Tables – extensive testing for modeling and verification
- Limited use of knowledge of the physical engine behavior
A PREVIOUS CONTROLLER (2/5)

PREVIOUS CONTROLLER

- **GAINS AND LIMITS (BASED ON TABLES)**
- **ENGINE: scale & dynamics**
- **mach**
- **Altitude**

Block diagram showing connections between input and output variables in the previous control system for a turbojet engine.
A PREVIOUS CONTROLLER (3/5)

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A PREVIOUS CONTROLLER(4/5)

[Diagram showing a control system with blocks labeled CTRLLR, PI, RPM2Wfcom, Wfcom2RPM, ENGINE DYNAMICS (GAIN=1), and RPM Measurement. The system includes signals for RPM_com, RPM_meas, and a limit.]
A PREVIOUS CONTROLLER (5/5)

\[
\begin{align*}
\text{RPM}_{\text{com}} & \rightarrow 1 + \frac{K_1}{s} & \rightarrow 1 & \rightarrow \frac{1}{1 + s \tau_{\text{eng}}} \\
\text{LIMIT} & & & \\
\rightarrow & & & \rightarrow \text{OL}
\end{align*}
\]
THE NORMALIZED CONTROLLER

- **T0** = 288.15
- **TISA** = T0 - 0.0065 * Alt
- **Tamb** = TISA + DISA
- **Beta** = 1 + (Mach^2) / 5
- **Ttot** = Tamb * Beta
- **Delta** = ((TISA / T0)^5.256) * Beta^3.5
- **Theta** = Ttot / T0
- **RPM** = RPM / Sqrt(Theta)
- **Wf** = Wf / (Delta * Sqrt(Theta))
THE CONCEPT:

red: physical normalization (valid for all engines);
cyan: Engine-dependent blocks (note: only 2 different types)
yell: PI parameters, per individual controller requirement (BW, Disturbance Rejection, ...).
FEATURES (1/2):

- Gain is practically constant and unity over RPM, altitude, mach and DISA
- A single gain P and Fuel Flow limits can be designed.
- Other Controller designs (not PI) also simplified (no, or less, envelope dependence)
FEATURES (2/2):

- Integral Gain I is dependent on engine *dynamics*.
- A mach-Altitude-RPM table may be used (as in the Present Solution).
- Alternately a model of Corrected Tau can be explored.

FUEL LIMITER:

**OBJECTIVES:**

Avoid surge, stall, over-temperature, blowout

**DESIGN:**

In normalized controller !!

**IMPLEMENTATION (PI case):**

Include anti-windup
SIMULATION RESULTS (1/2):

![Graphs showing RPM C.L. Step response: Full envelope with various normalized time and normalized envelope for Mach, Alt, and DeltaISA: -100 -> 100 [%].]
SIMULATION RESULTS (2/2):

(Increased gain !!)

**COMPRESSOR MAP.** $M=0\,\% ; H=0\,\% ; DISA=0[K]$;

**RPM C.L. Step response:** $M=0\,\% ; H=0\,\% ; DISA=0[K]$;

**Corrected Air Mass Flow \[%\]**

**Pressure Ratio: $P_{03}/P_{02}$ \[%\]**

**Corrected RPM \[%\]**

**Surge Line**

**Steady-State Line**

**SM = 5\% Line**

**Normalized time**

**Sat-High**

**Sat-Low**

**Wf-Tag**
BENEFITS of the APPROACH:

- good physical basis for design
- simple controller - *single design*
- simple limiter - *single design*
- easier testability - *fewer envelope points*
- simpler transportability of the controller to other engines
THANK YOU

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