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 <u>single</u> controller (**for all flight conditions**)
- "de-normalize" output (normalized fuel flow) and apply to engine

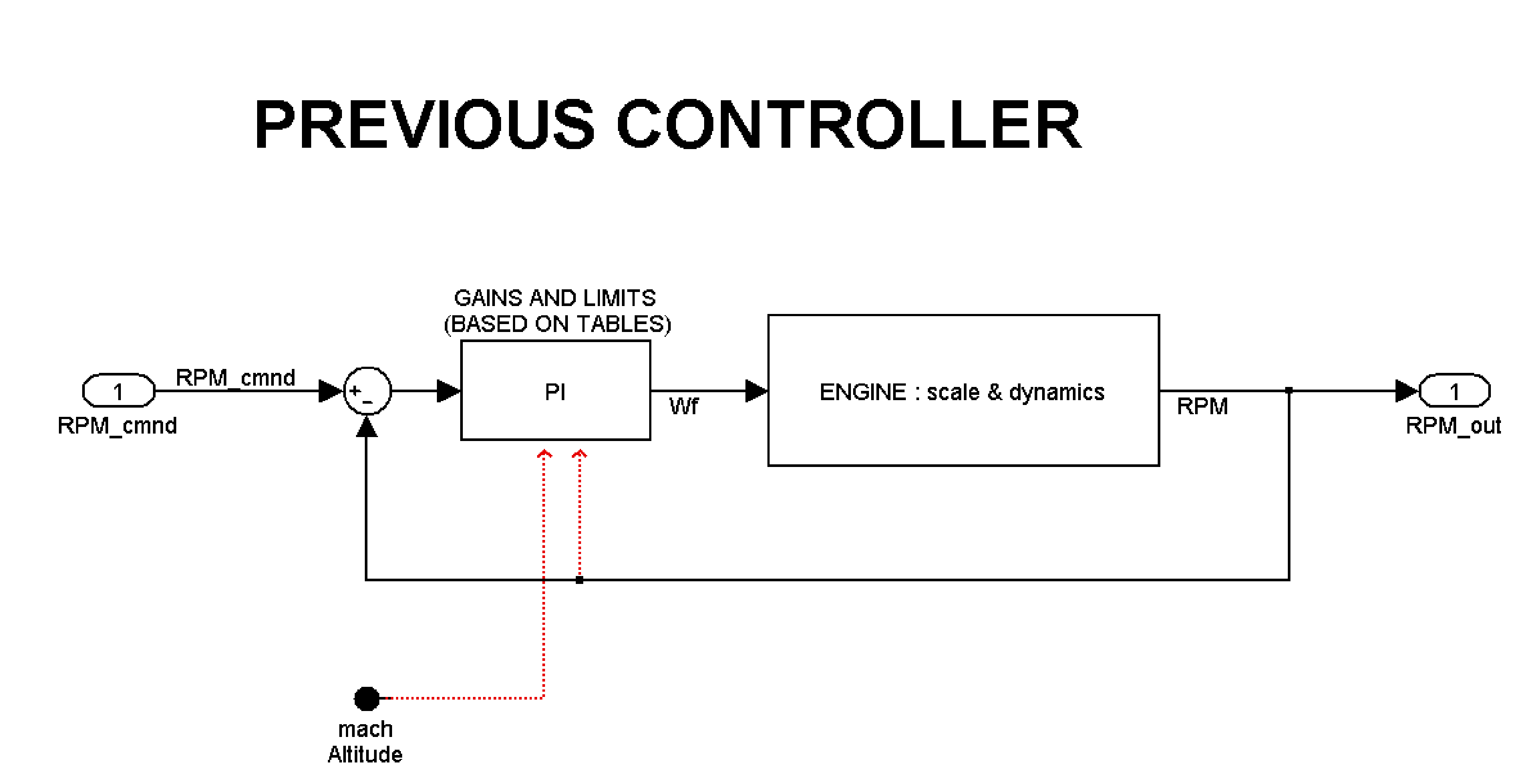
FEATURES:

- Engine normalization simplifies control system design for all control design approaches
- Only a simple PI example included in presentation

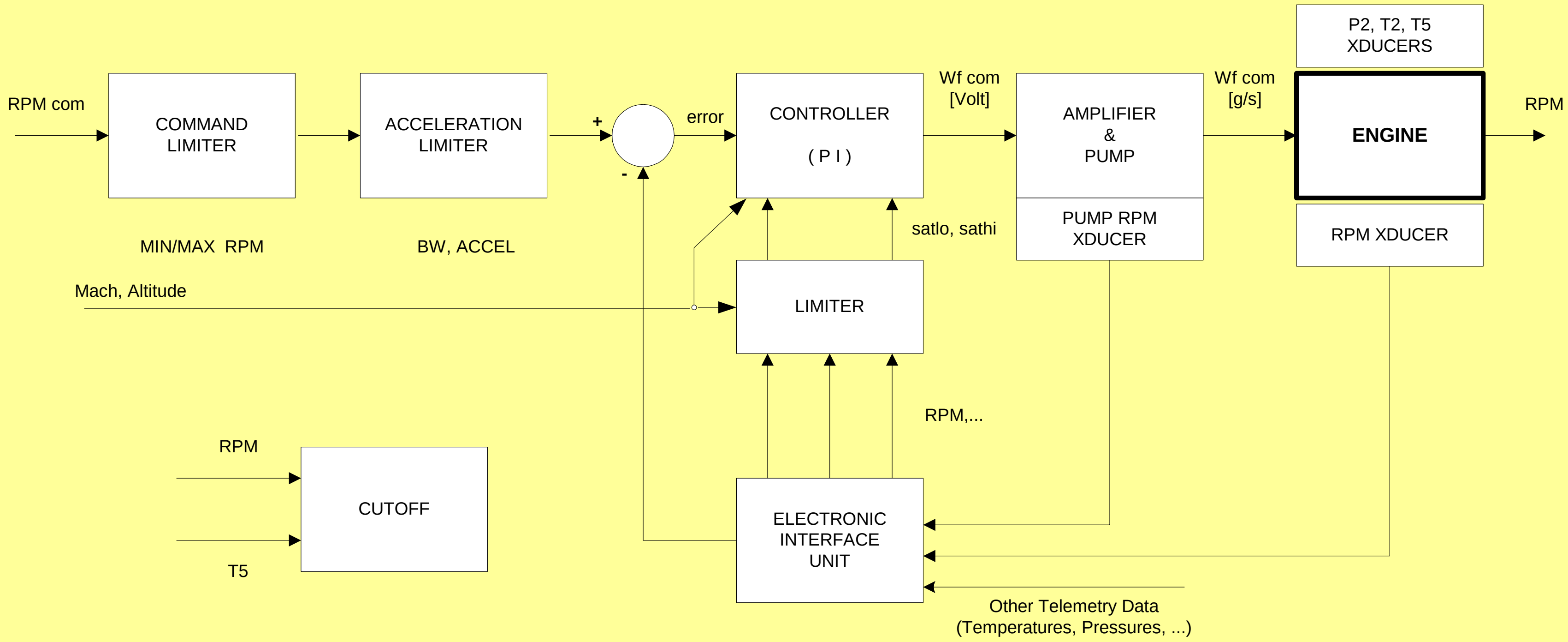
A PREVIOUS CONTROLLER(1/5)

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

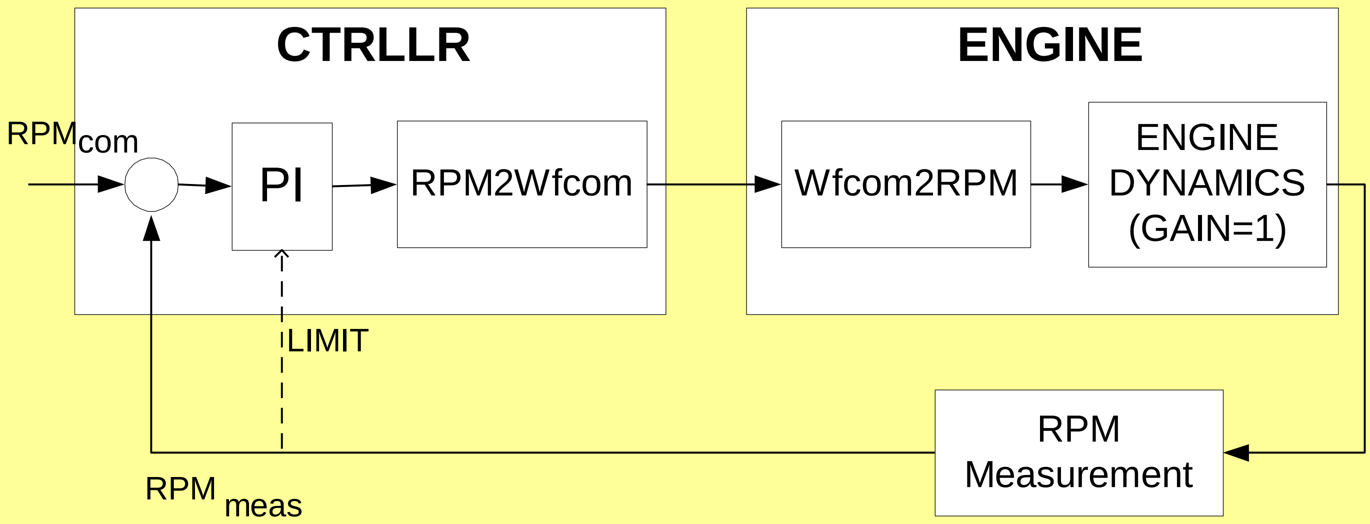
A PREVIOUS CONTROLLER(2/5)



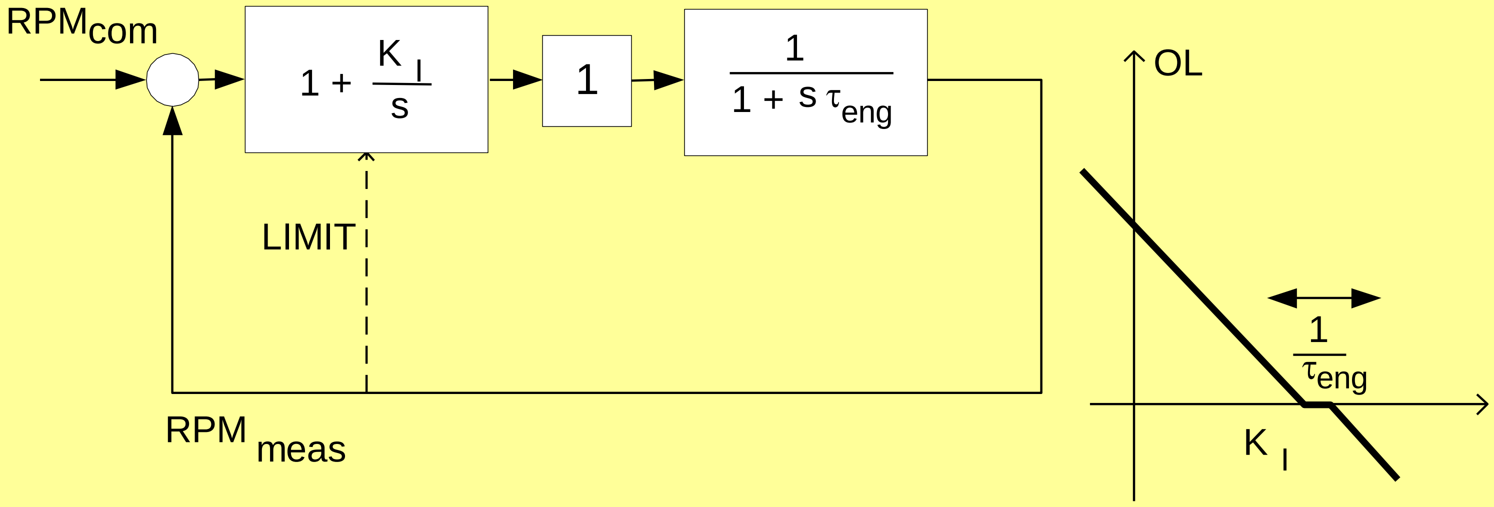
A PREVIOUS CONTROLLER(3/5)



A PREVIOUS CONTROLLER(4/5)



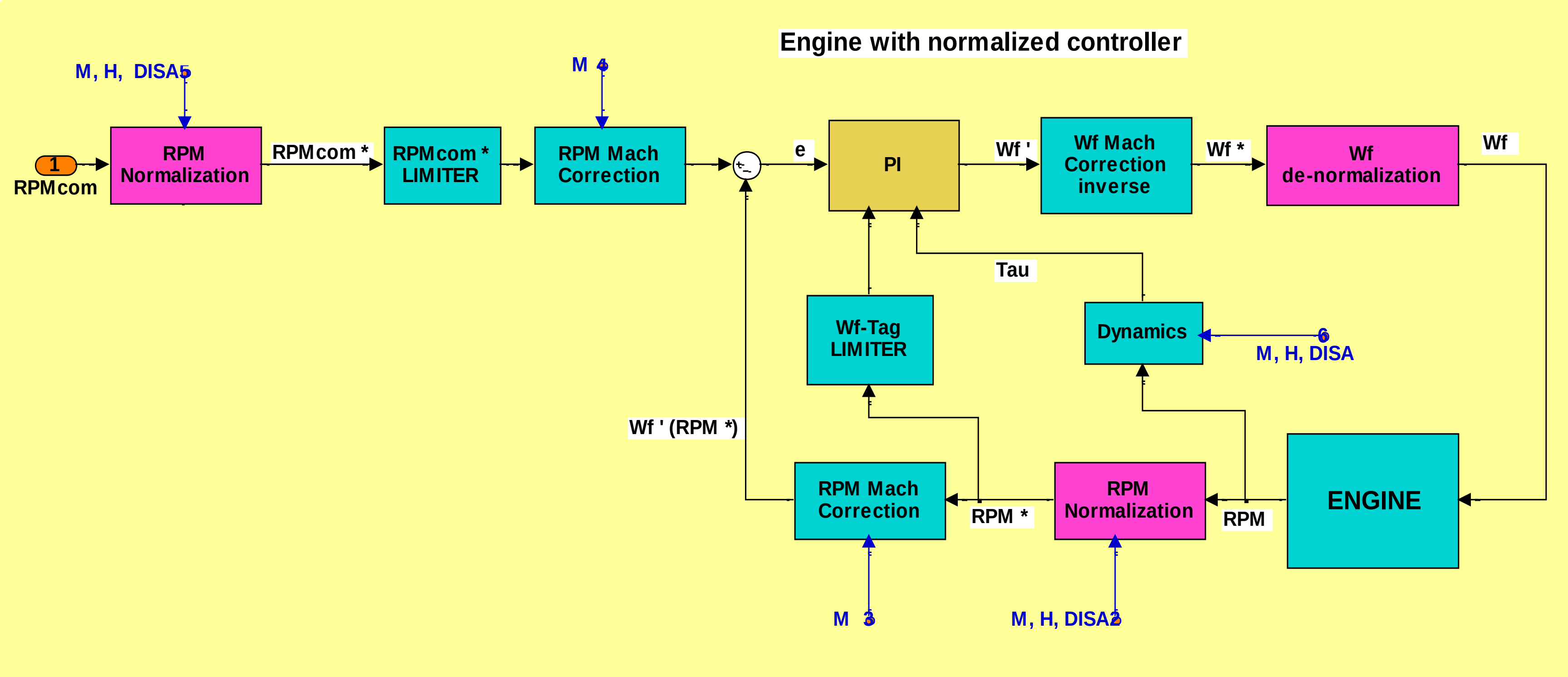
A PREVIOUS CONTROLLER(5/5)



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**
- **= Ptot/P0**
- **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.
  - Otto, E.W. and Taylor, B.L, "Dynamics of a Turbojet Engine Considered as a Quasi-Static System," NACA TR 1011, 1951.

FUEL LIMITER:

- **OBJECTIVES:**

  Avoid surge, stall, over-temperature, blowout

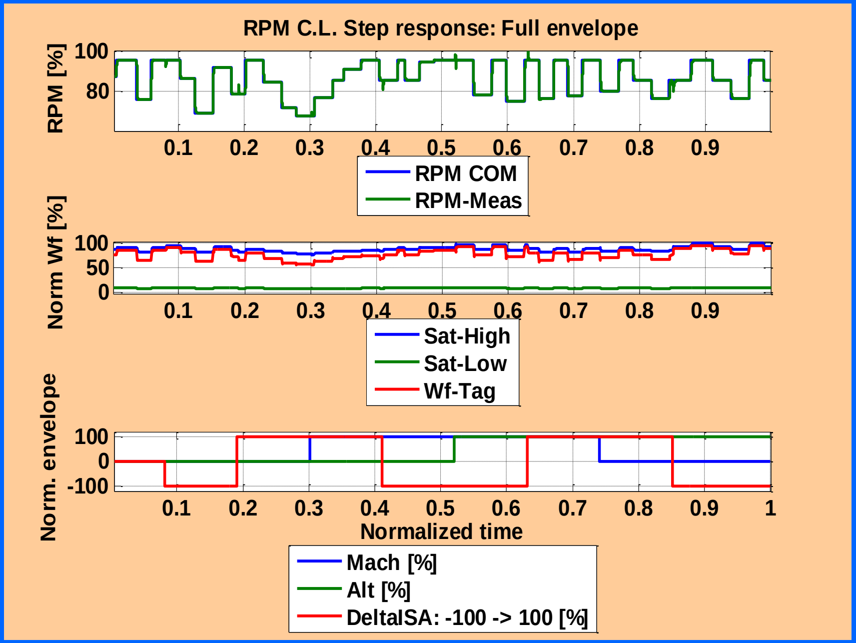
- **DESIGN:**

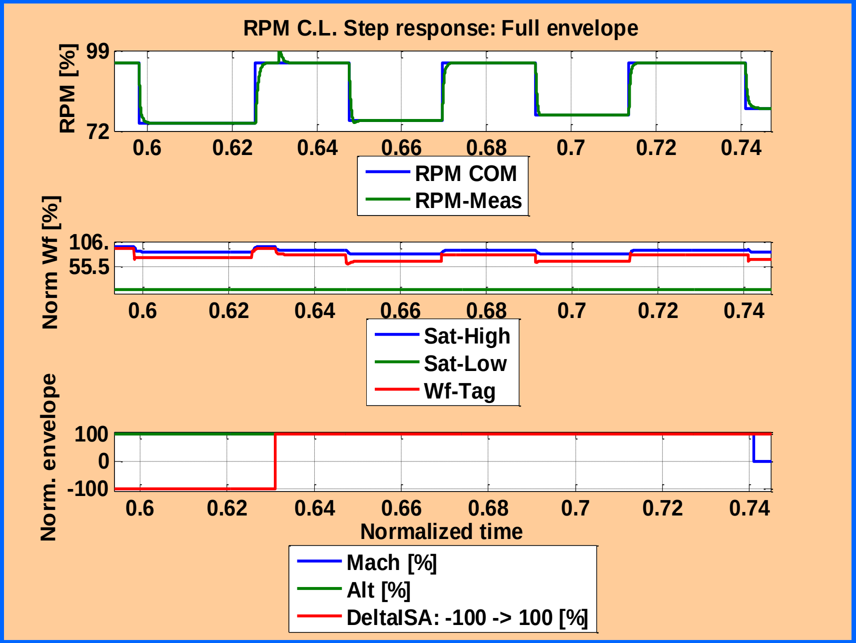
  In normalized controller !!

- **IMPLEMENTATION (PI case):**

  Include anti-windup

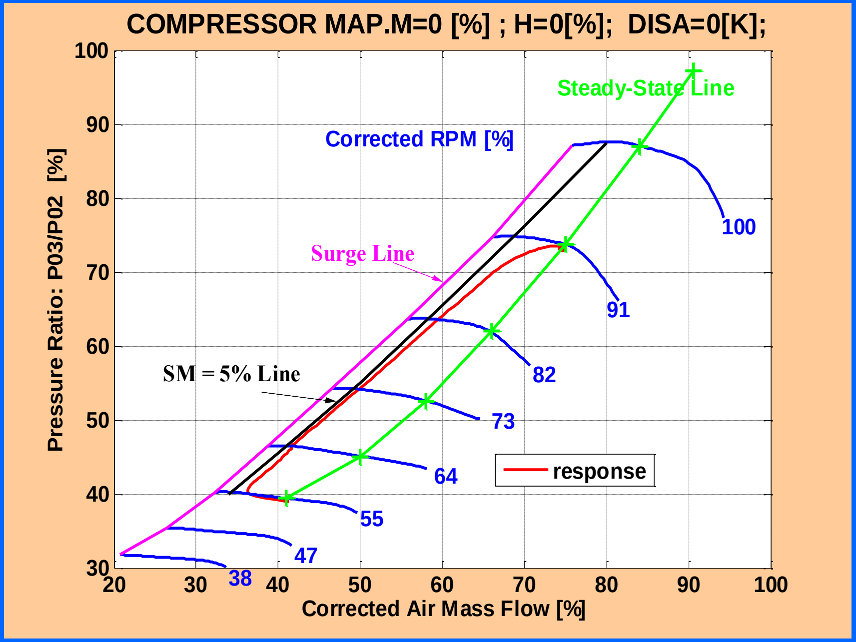
SIMULATION RESULTS (1/2):

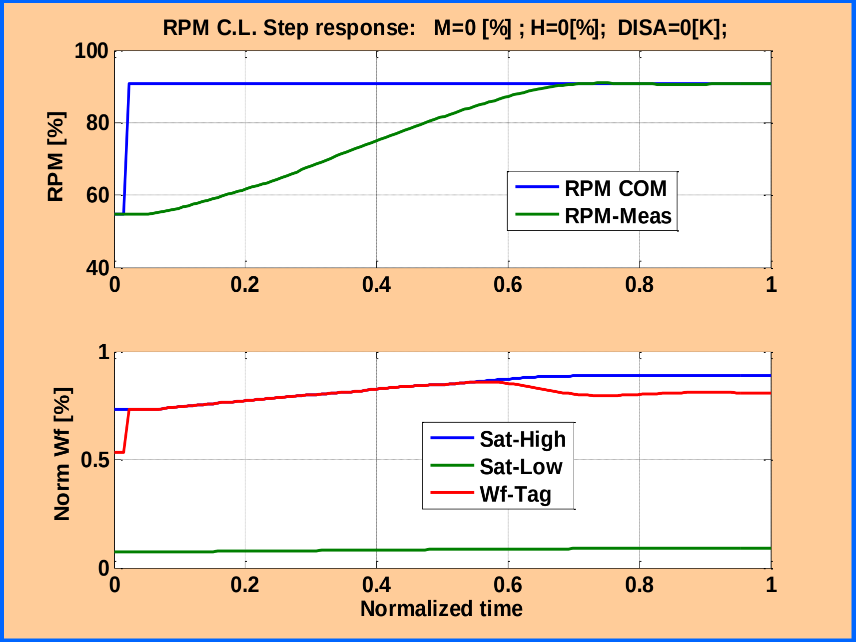




SIMULATION RESULTS (2/2):

(Increased gain !!)





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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