EVALUATION OF AN EFFECTIVE ENGINE COMPRESSOR MAP USING DATA ACQUISITION DURING TRANSIENT OPERATION

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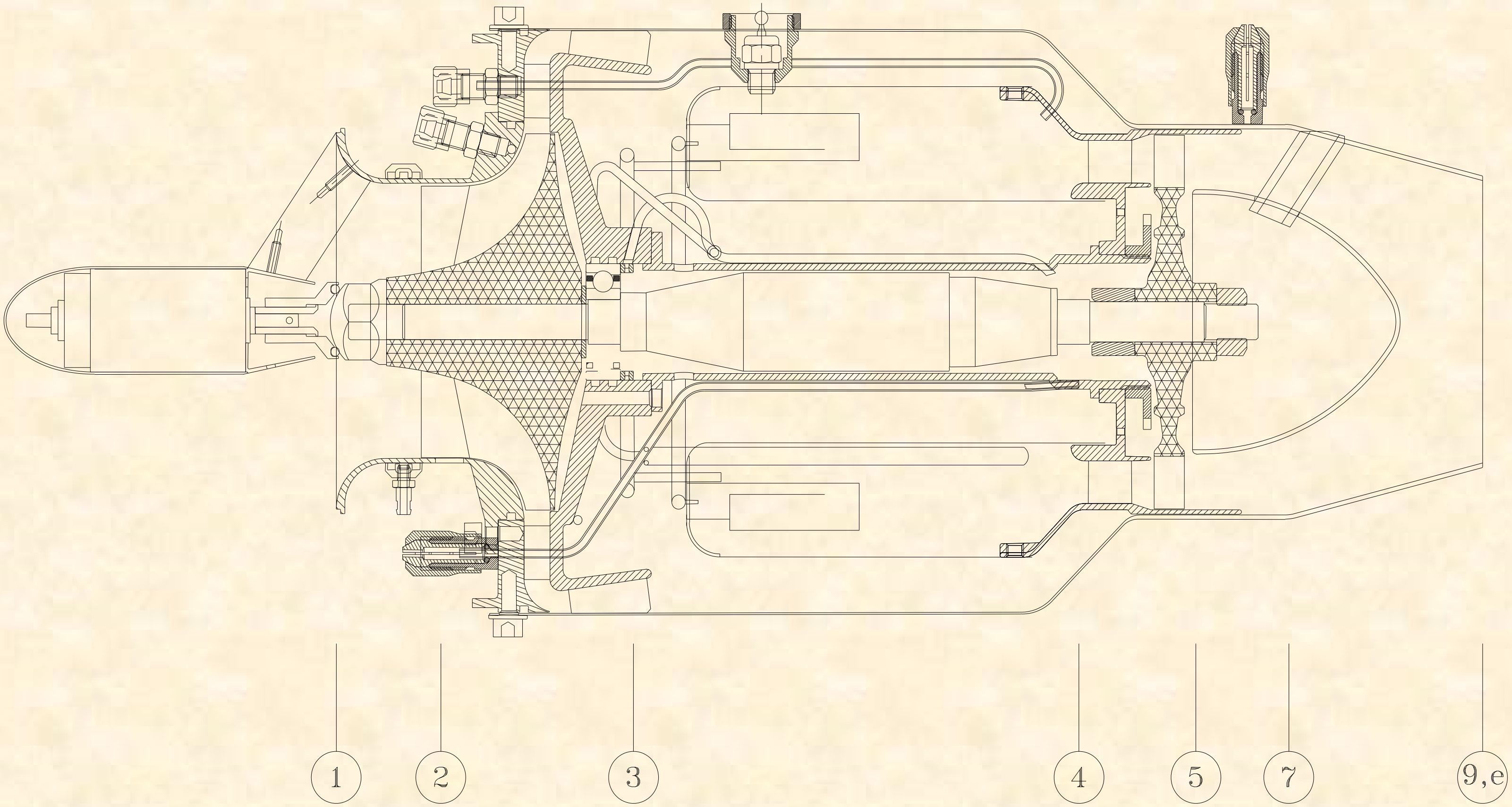
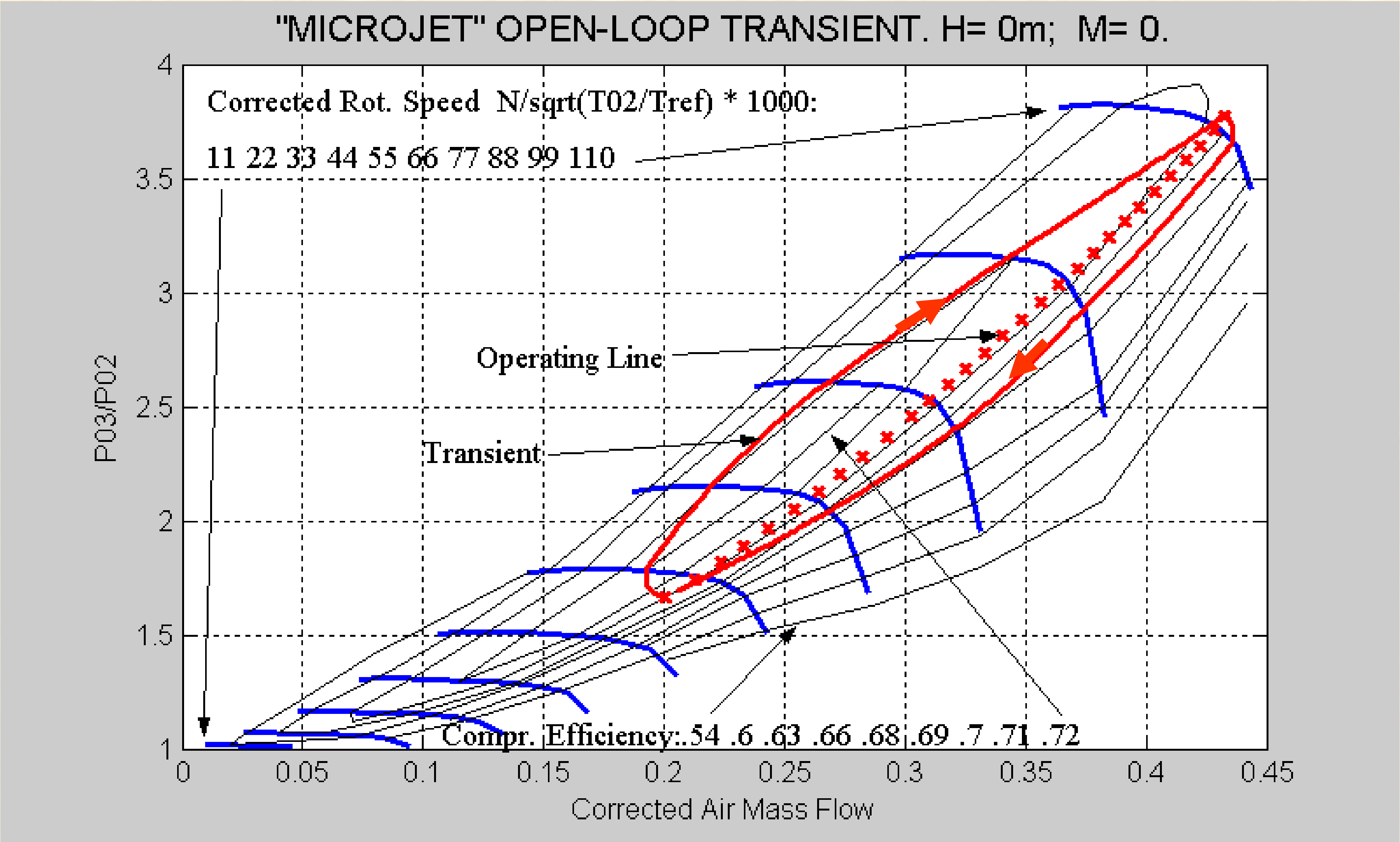
Engine Stations



Objectives:

Development of an Inverse Engine Model (without Compressor Map) for:

- Evaluation of the Effective Compressor Map
- Jet Engine Control



$$\dot{m}_{2,corr} = \frac{\dot{m}_{a,c} \cdot \sqrt{\frac{T_{02}}{T_{ref}}}}{\frac{P_{02}}{P_{ref}}}; \quad N_{2,corr} = \frac{N}{\sqrt{\frac{T_{02}}{T_{ref}}}}; \quad \eta_C = \frac{\left(\frac{P_{03}}{P_{02}}\right)^{\frac{\gamma_{a,c}-1}{\gamma_{a,c}}} - 1}{\frac{T_{03}}{T_{02}} - 1} \Rightarrow$$

Required parameters:

$N, \dot{m}_{a,c}, T_{02}, T_{03}, P_{02}, P_{03}, \gamma_{a,c}(\bar{T}_{2,3})$;

$N, T_{05}, \dot{m}_f, H, M$ *are measured*

Conventional Model of Single-Spool Engine

(Equation Examples)

Compressor:

$$\left(\frac{P_{03}}{P_{02}}\right) \text{vs.}\ \dot{m}_{2,corr}; \quad N_{2,corr} - \text{parameter}$$

$$\left(\frac{P_{03}}{P_{02}}\right) \text{vs.}\ \dot{m}_{2,corr}; \quad \eta_c - \text{parameter}$$

Turbine:

$$\dot{m}_{4,corr}\ \text{vs.} \left(\frac{P_{04}}{P_{05}}\right), \quad N_{4,corr} = \text{parameter}$$

$$\eta_t\ \text{vs.} \left(\frac{P_{04}}{P_{05}}\right), \quad N_{4,corr} = \text{parameter}$$

Nozzle:

$$\dot{m}_{7,corr} = \dot{m}_{7,corr,theor} \cdot C_D$$

$$\dot{m}_{7,corr,theor} = \sqrt{2 \cdot \eta_n \cdot C_p \cdot \left[1 - \left(\frac{1}{\left(\frac{P_{07}}{P_a}\right)}\right)^{\frac{\gamma_g - 1}{\gamma_g}}\right]} \cdot \frac{A_e}{R} \cdot \frac{1}{\left(\frac{P_{07}}{P_a}\right)} \cdot \frac{1}{1 - \eta_n \left[1 - \left(\frac{1}{\left(\frac{P_{07}}{P_a}\right)}\right)^{\frac{\gamma_g - 1}{\gamma_g}}\right]}$$

Power Balance:

$$Cp_{gt} \cdot \dot{m}_g \cdot (T_{04} - T_{05}) \cdot \eta_m = Cp_{ac} \cdot \dot{m}_a \cdot (T_{03} - T_{02}) + altpower + \frac{dE}{dt}$$

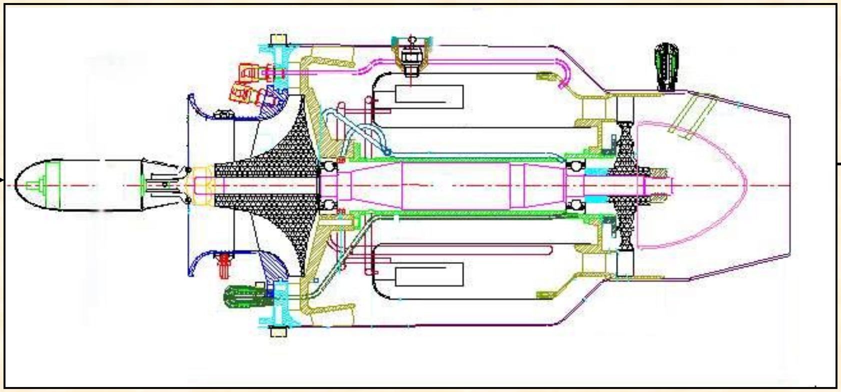
$$E = \frac{J \cdot N^2 \cdot \pi^2}{1800}$$

Conventional Dynamic Engine Model

for Real-Time Simulation

Command:

$N_{cor}(t)$



Measured output vs. time:

$H, M, \dot{m}_f, N, T_{05}$

$H, M, \dot{m}_f(t)$

Initial Conditional

Conventional Engine Model

(Using Compressor/Turbine/Nozzle Maps)

$N(t), \dot{m}_a(t)$

$T_{02}(t)...T_{07}(t)$

$P_{02}(t)...P_{07}(t)$

η_C, η_t

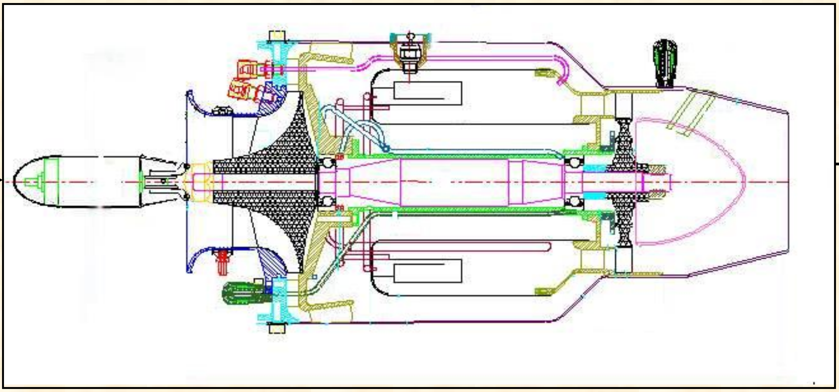
$SM(t), \varphi(t)$

Disadvantages: a) slow solution, b) accumulation of integration error

Evaluation of Effective Engine Compressor Map Using Inverse Engine TN-Model (Turbine/Nozzle Maps Only)

Command:

$N_{cor}(t)$



Measured Output:

$H(t), M(t),$

$\dot{m}_f(t), N(t), T_{05}(t)$

Compr. Parameters

$\frac{P_{03}}{P_{02}}(t), \dot{m}_{a,corr}(t),$

$N_{corr}(t), \eta_c(t),$

$\dot{m}_a(t), \eta_t,$

$T_{02}(t) \ldots T_{04}(t),$

$P_{02}(t) \ldots P_{07}(t),$

$SM(t), \varphi(t).$

$H(t), M(t), \dot{m}_f(t)$

$N(t), T_{05}(t)$

Inverse Engine TN -Model

(Using Turbine/Nozzle Maps Only)

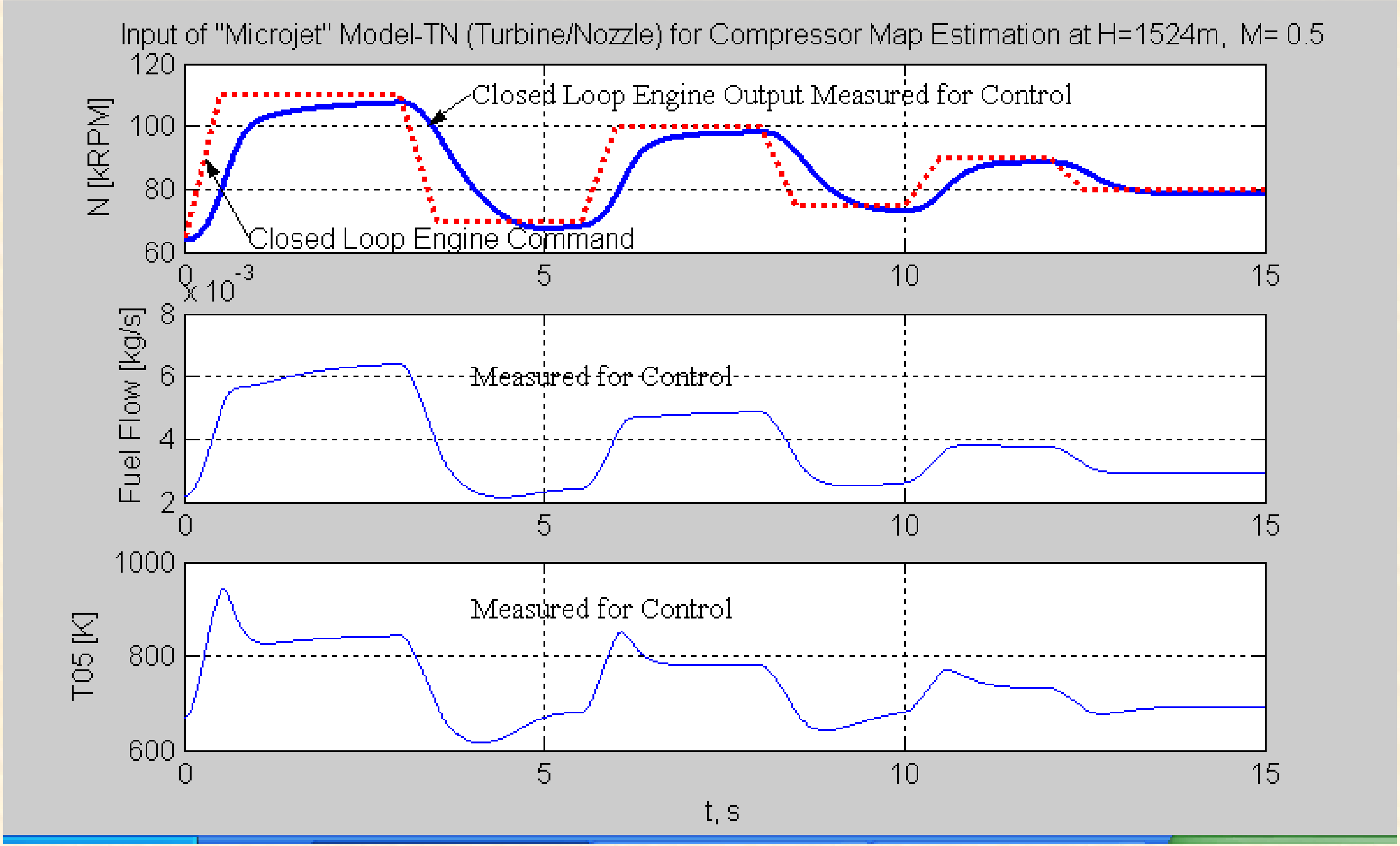
$\left(\frac{P_{03}}{P_{02}}\right)$ vs. $(\dot{m}_{2,corr}, N_{2,corr})$

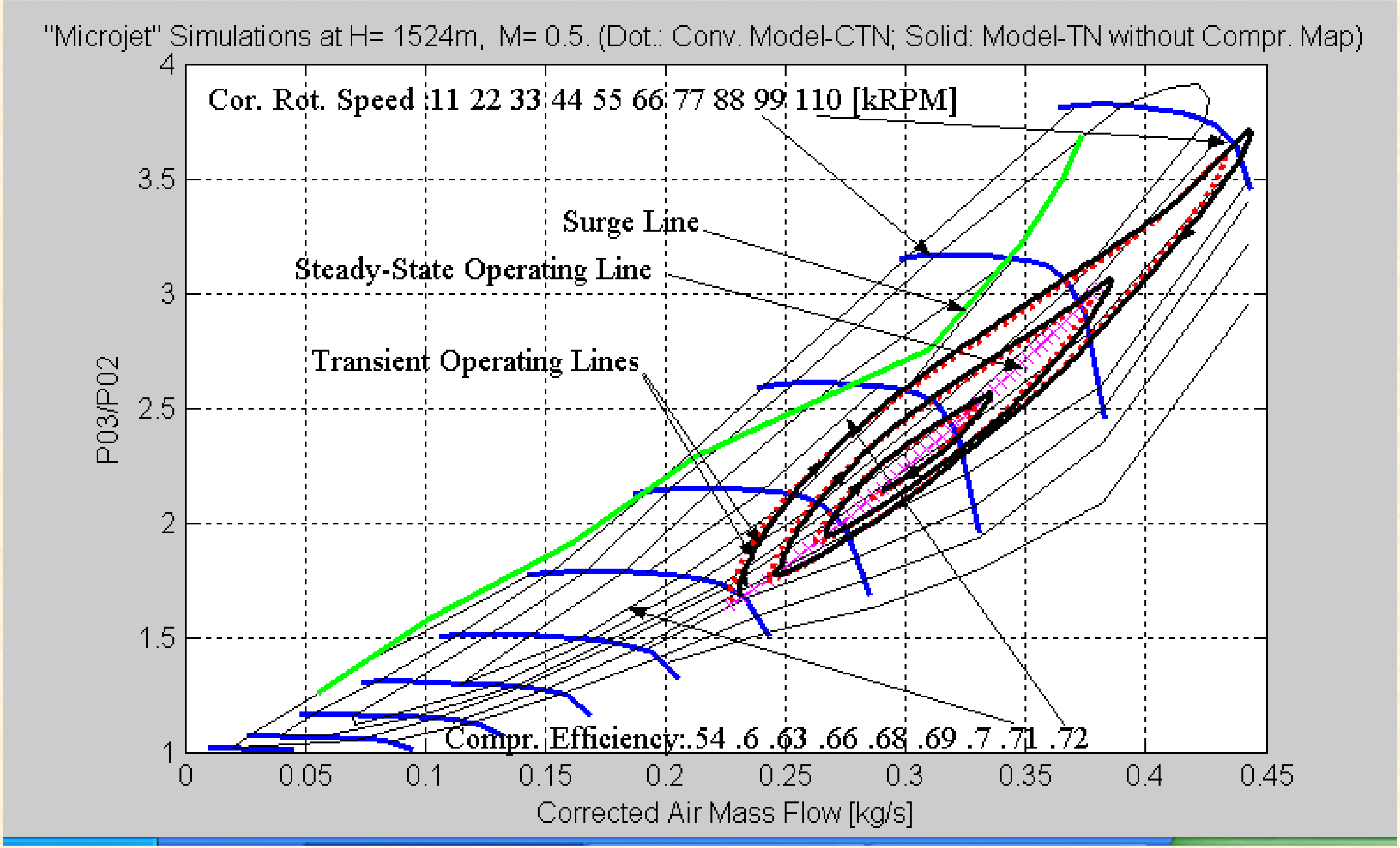
$\left(\frac{P_{03}}{P_{02}}\right)$ vs. $(\dot{m}_{2,corr}, \eta_c)$

} Compressor Map

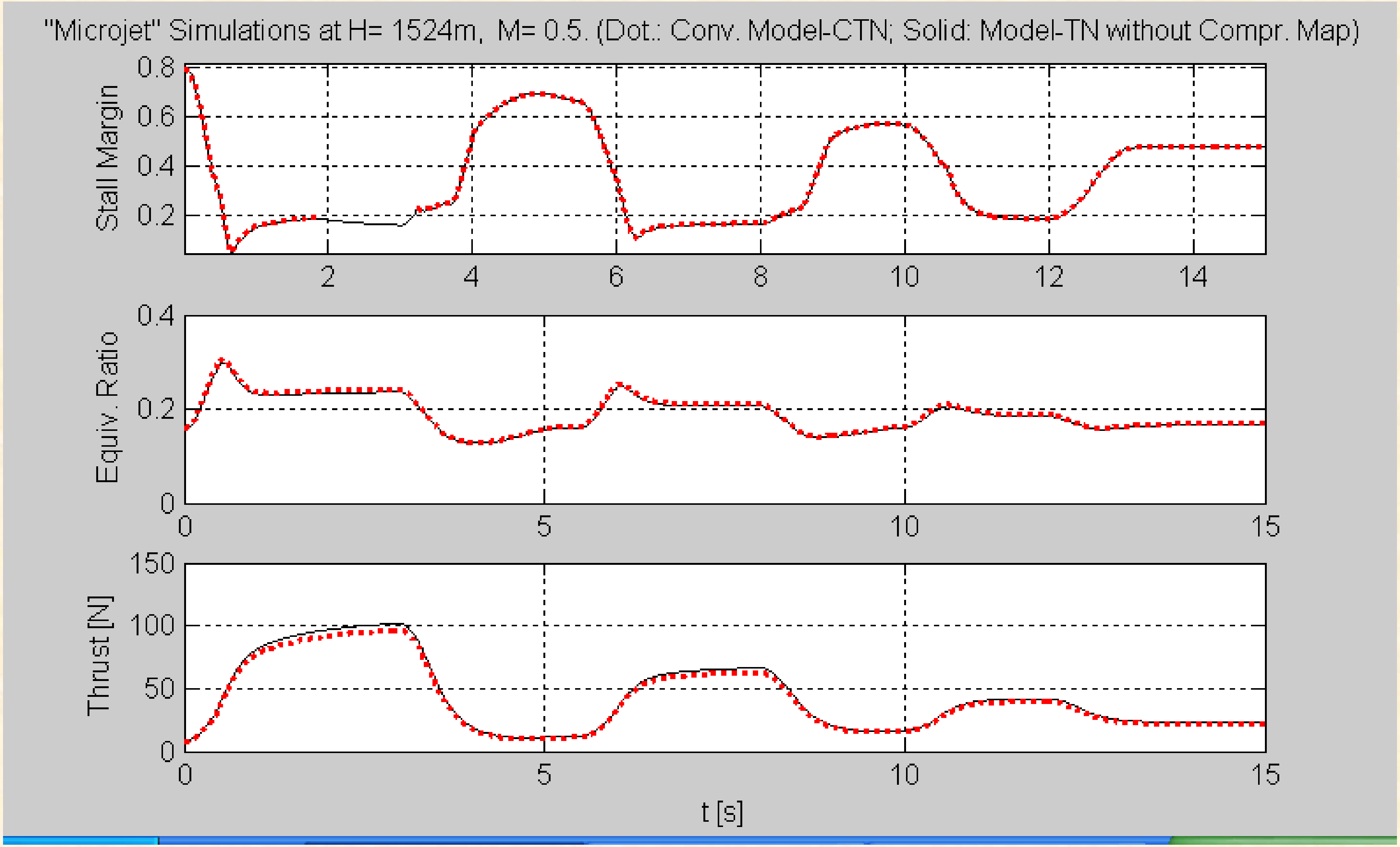
Initial Conditional

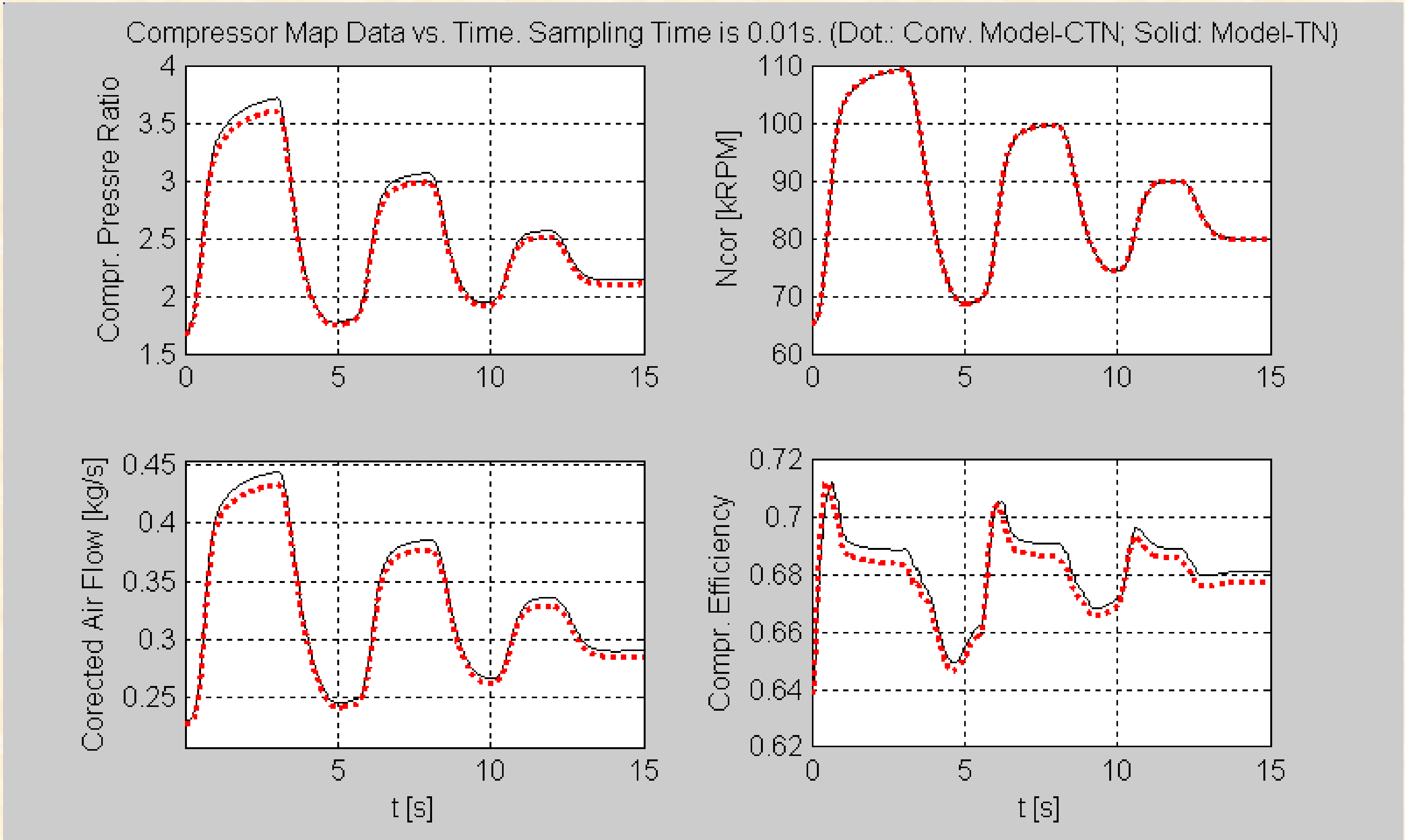
$$Cp_{gt} \cdot \dot{m}_g \cdot (T_{04} - T_{05}) \cdot \eta_m = Cp_{ac} \cdot \dot{m}_a \cdot (T_{03} - T_{02}) + altpower + \frac{dE(t)}{dt}, \quad E = \frac{J \cdot N^2 \cdot \pi^2}{1800}$$


Input of "Microjet" Model-TN (Turbine/Nozzle) for Compressor Map Estimation at H=1524m, M= 0.5
N [kRPM]
Closed Loop Engine Output Measured for Control
Closed Loop Engine Command
x 10^-3
Fuel Flow [kg/s]
Measured for Control
T05 [K]
Measured for Control
t, s



$$\frac{\text{CPU time using the conventional open loop model}}{\text{CPU time using the TN - model}} = 5$$


"Microjet" Simulations at H= 1524m, M= 0.5. (Dot.: Conv. Model-CTN; Solid: Model-TN without Compr. Map)
Stall Margin
0.8
0.6
0.4
0.2
2
4
6
8
10
12
14
Equiv. Ratio
0.4
0.2
0
0
5
10
15
Thrust [N]
150
100
50
0
0
5
10
15
t [s]



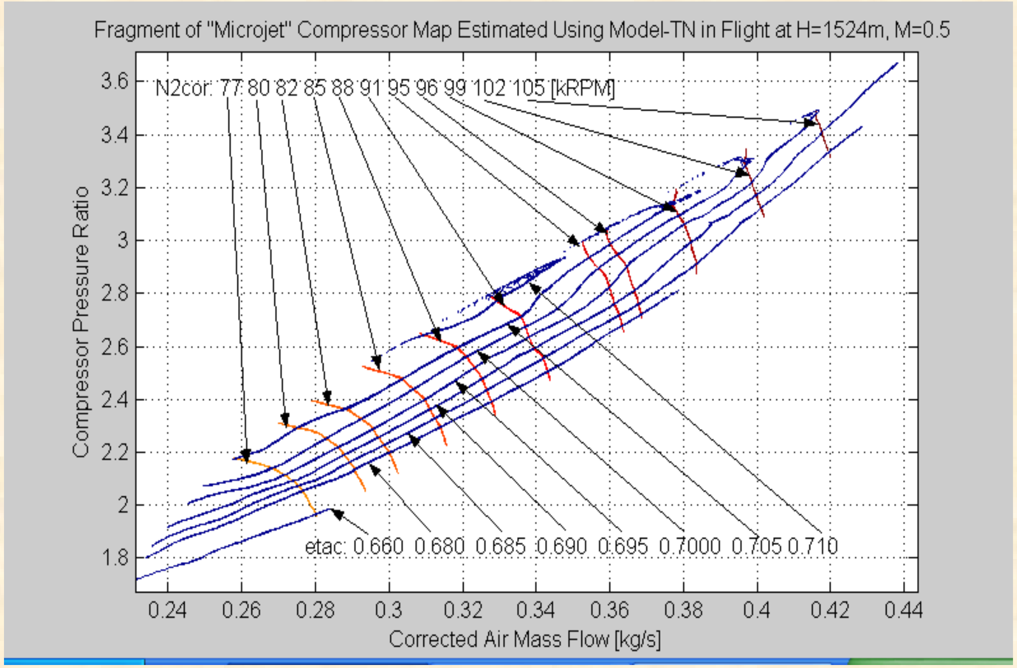
Compressor Map Data Matrix: 1500X4

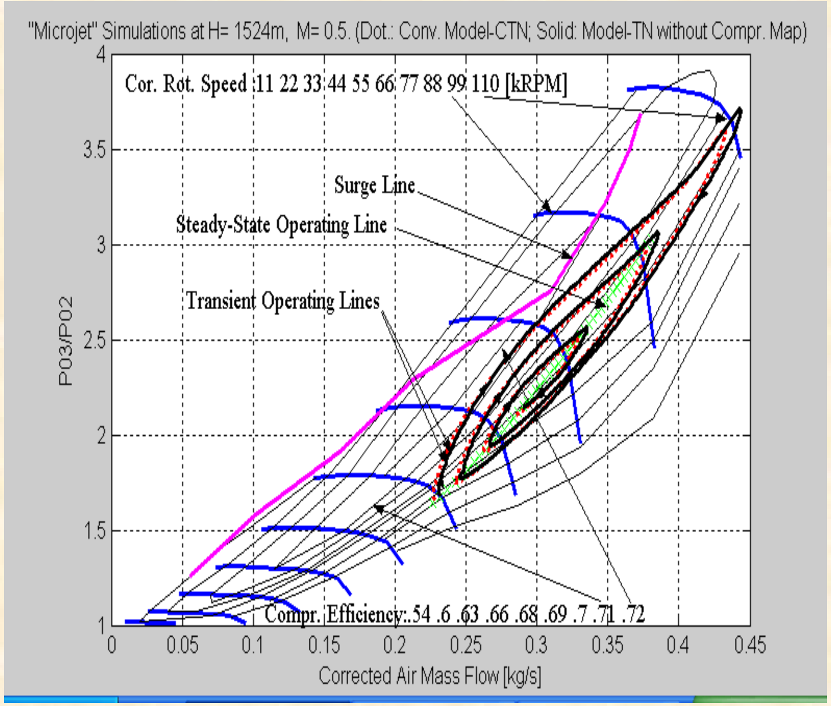
Compressor Map Data Matrix (1500X4):

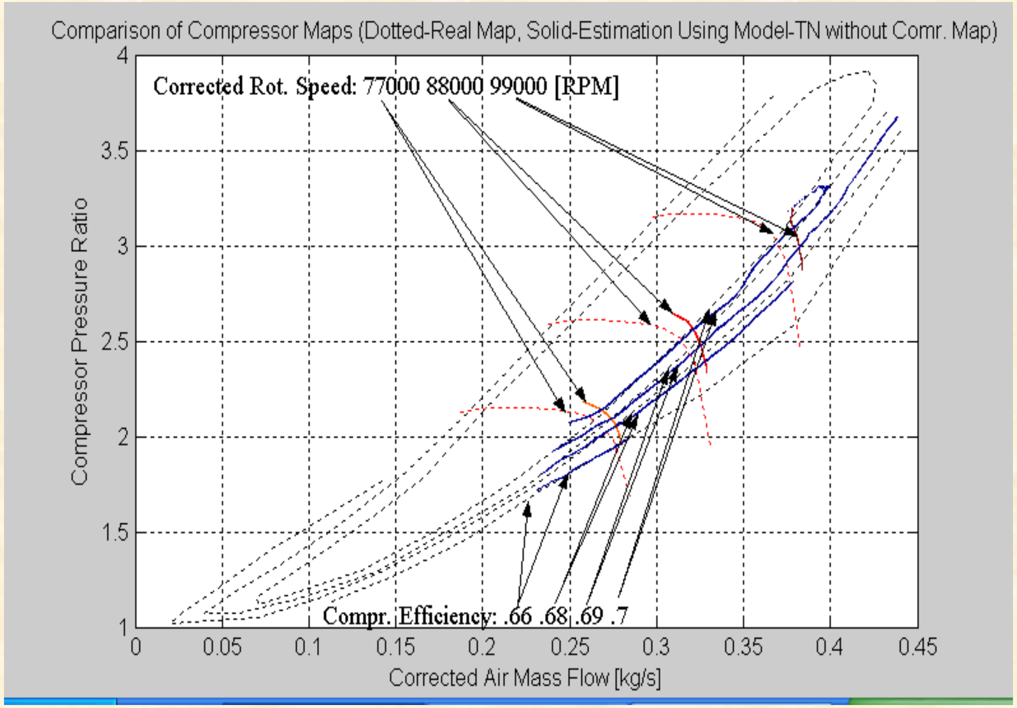
$$\frac{P_{03}}{P_{02}}(t), \dot{m}_{a,corr}(t),$$

$$N_{corr}(t), \eta_c(t)$$

$\Rightarrow$







Conclusions

1. The novel method is proposed for evaluation of the effective compressor map during on-line transient operation using the inverse engine model for data processing.

2. The advantages of the method :

   a) The evaluated compressor map precision increases because acquisition data increase by factor of hundreds in the transient operation;

   b) Duration of the engine tests decreases significantly (some tens seconds only);

   c) **Low cost**

3. The inverse jet engine model may be used both for effective maps evaluation and for engine control. CPU time decreases by a factor of 5 in comparison with the conventional model.

THE END