Intelligent aero engines – modeling, control and diagnostics

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Outline of the presentation:

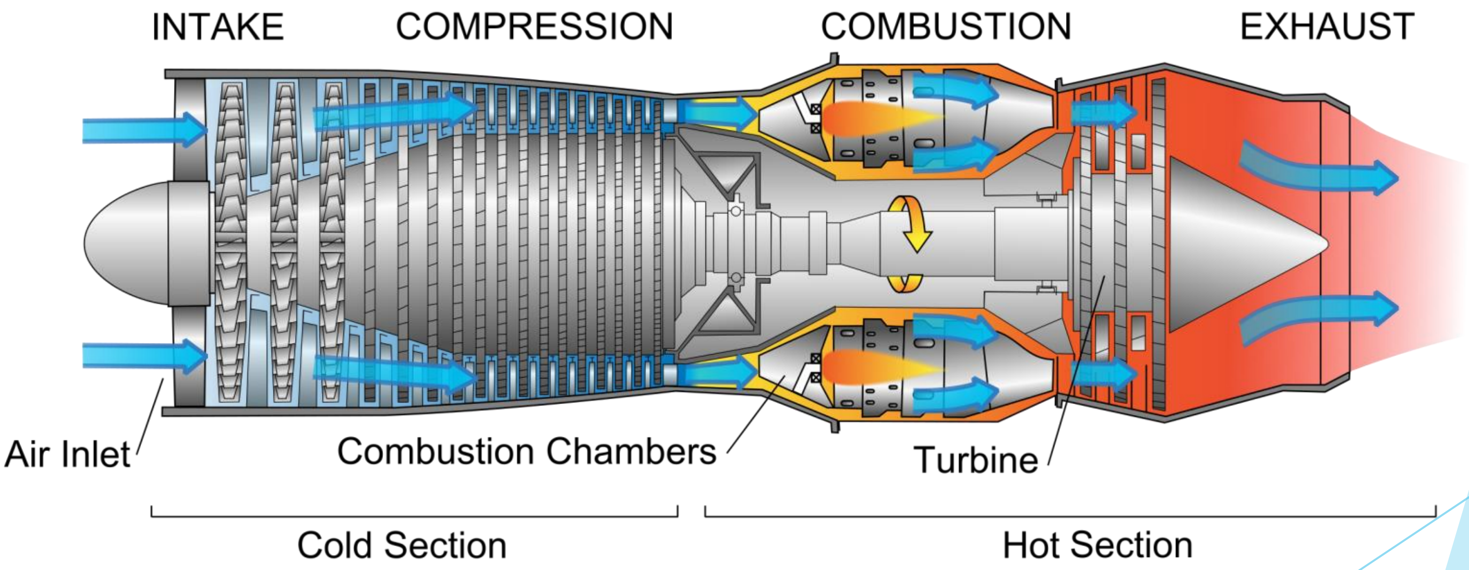
- Modern control of turbojet engines
- The methodology of intelligent situational control
- Application of situational control on small turbojet engines

Outline of the presentation

1. Turbojet engines, state of the art control systems
2. Advanced control algorithms for turbojet engines
3. Intelligent situational control of turbojet engines
4. Experimental results
5. Conclusion

Turbojet engines – principles of operation

- Turbojet engine is a complex system operating in a very broad spectrum of environments

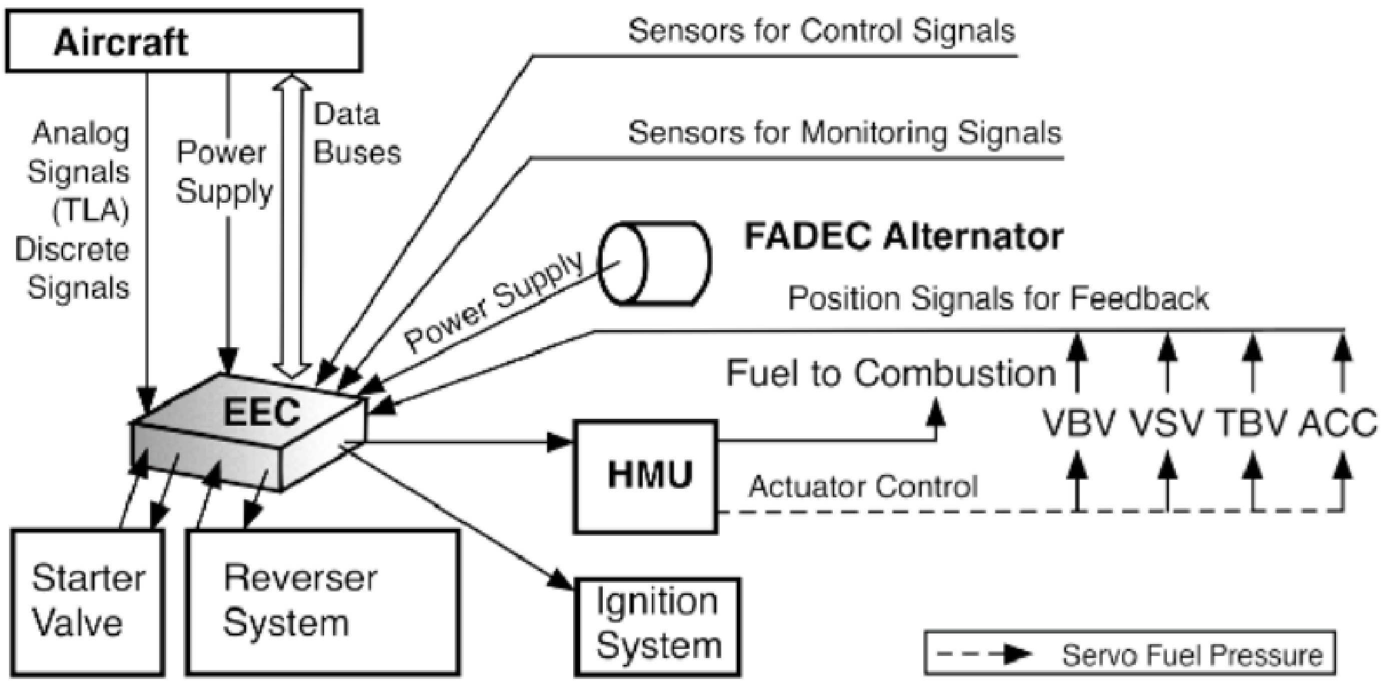


Turbojet engines – control systems

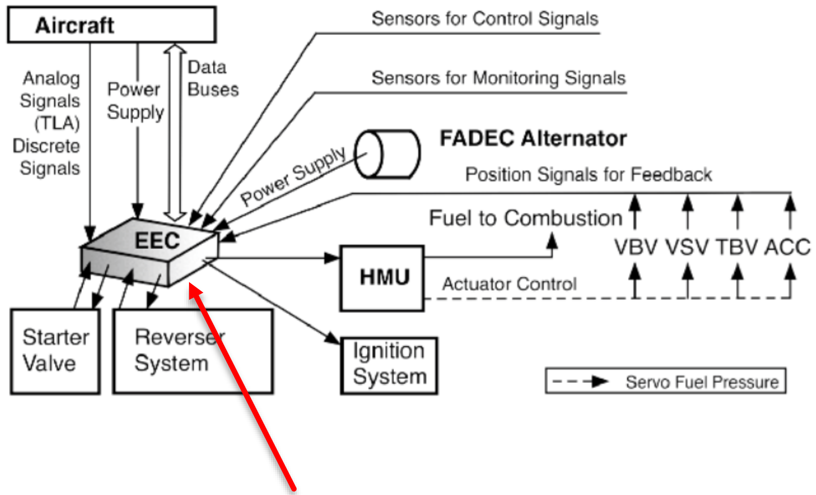
- The present digital engine control systems with full authority (**FADEC - Full Authority Digital Engine Control**) allow flying with aircraft without needing nearly any manipulation with the thrust lever by the pilot
- Basic properties and tasks solved by FADEC control system can be described as follows as compiled by the author from different literature resources:
  - Electronic engine thrust control
  - Electronic control of engine auxiliary systems
  - Diagnostics of the engine’s parameters
  - Engine start-up, restart and shutdown control
  - Health monitoring, engine condition management
  - Interface to aircraft control busses, engine and aircraft condition and management system (ECAM).

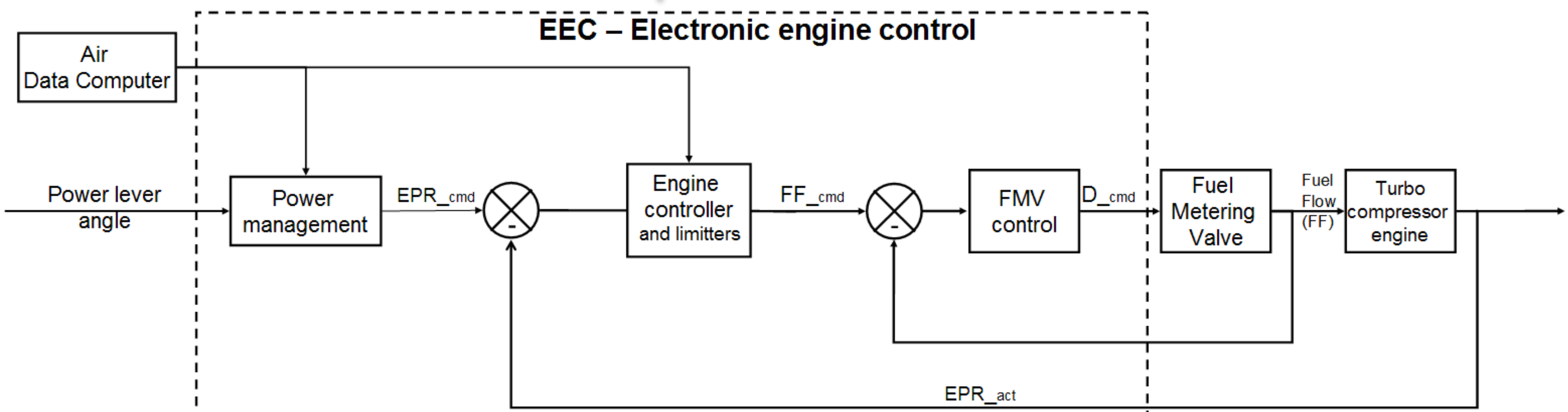
Turbojet engines – control systems

- Control algorithms of the EEC unit are proprietary to each engine; however the software usually contains the following main parts:
  - control software, with all control and limiting laws,
  - monitoring software used for diagnostics and engine health monitoring,
  - interface to aircraft systems.



Turbojet engines – control algorithms





EPR – Engine pressure ratio
FF- Fuel flow
FMV – Fuel Metering Valve

Turbojet engines – control algorithms

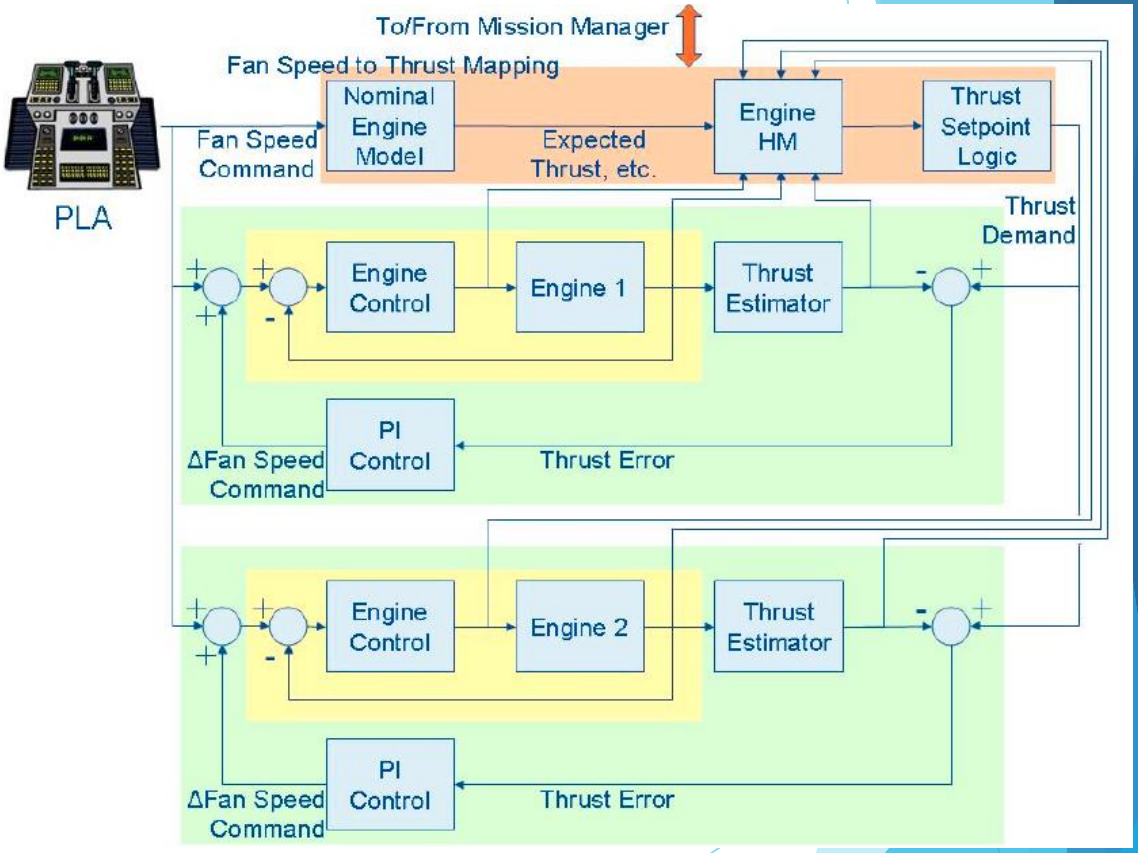
- All implemented algorithms need to be certified DO-178c (Software Considerations in Airborne Systems and Equipment Certification)
- Running on certified hardware RTOS systems with special considerations put on long running times
- This leads to the most simplistic control algorithms (PI controllers
  - P/PI controllers
  - Simple limitters
  - Scheduling algorithms
  - Direct inverse control

Advanced control of turbojet engines

Improvements of speed control by application of more advanced control algorithms (robust controllers, model predictive control, LQ, etc.)

New diagnostic methodologies based on intelligent algorithms (mainly neural networks)

Situational control as a framework methodology, which is modular



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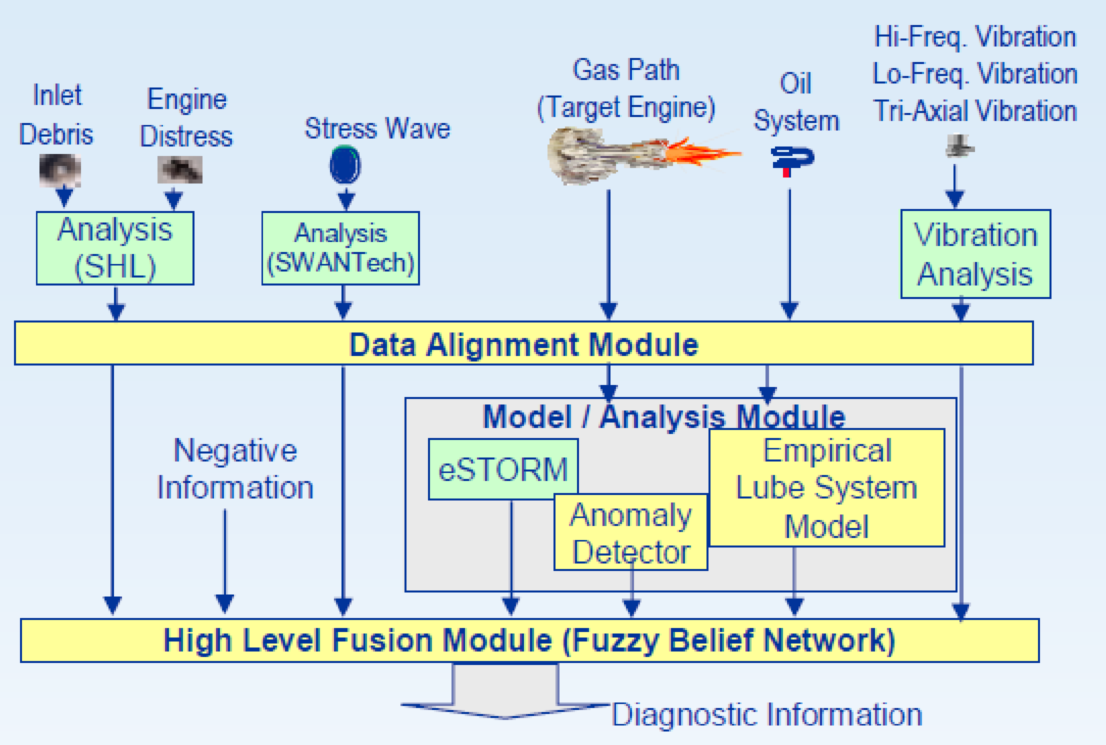
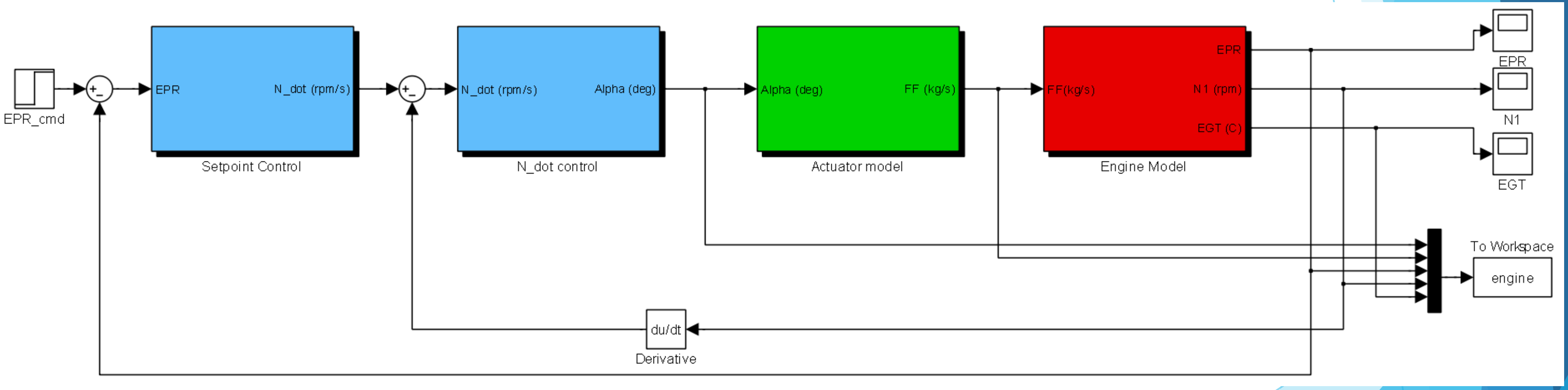


Data Fusion Architecture

Advanced control of turbojet engines

- N_dot control algorithm with two loops:
  - Inner loop controls constant acceleration/deceleration in speed
  - The outer loop controls the required power state (setpoint)



Advanced control of turbojet engines

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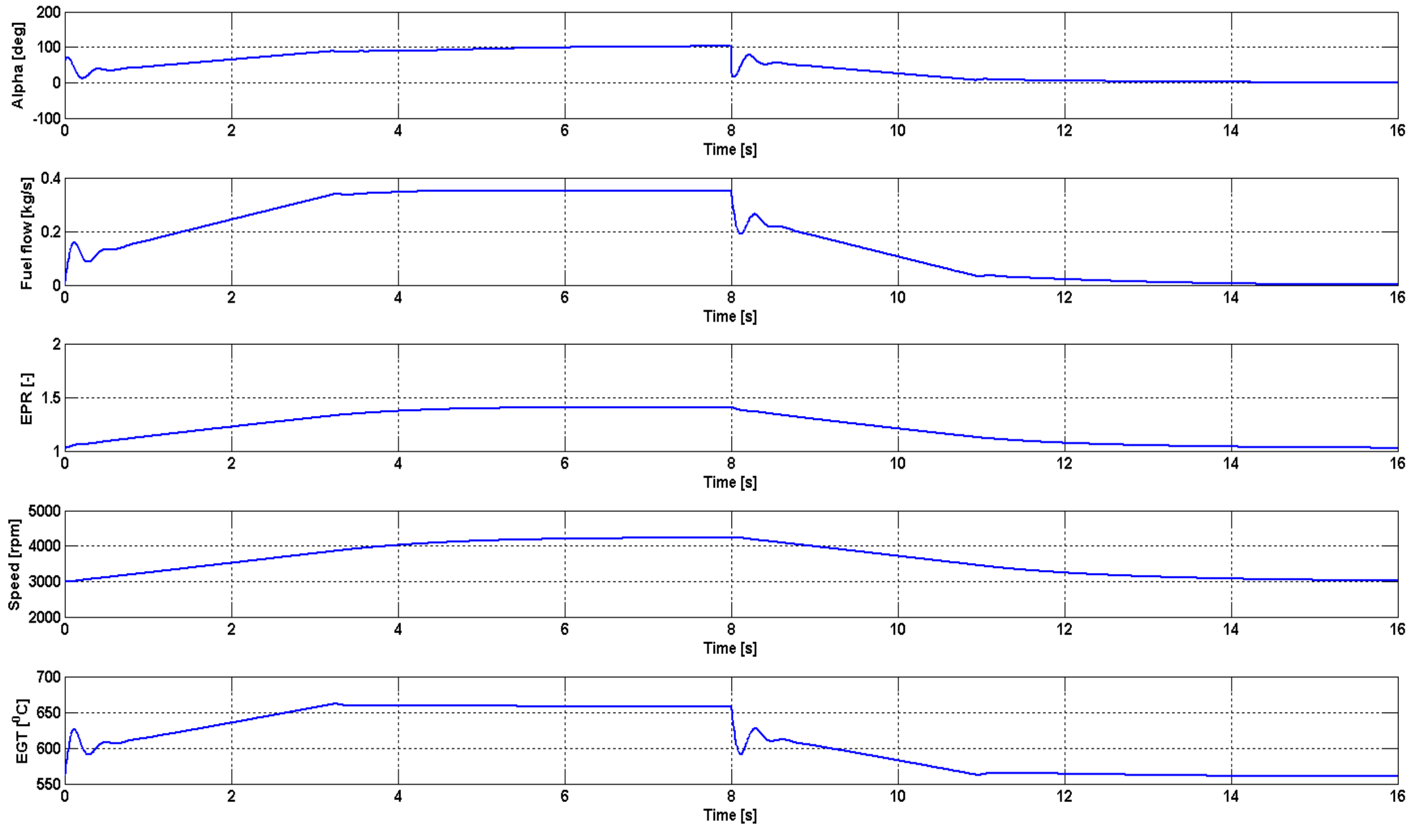
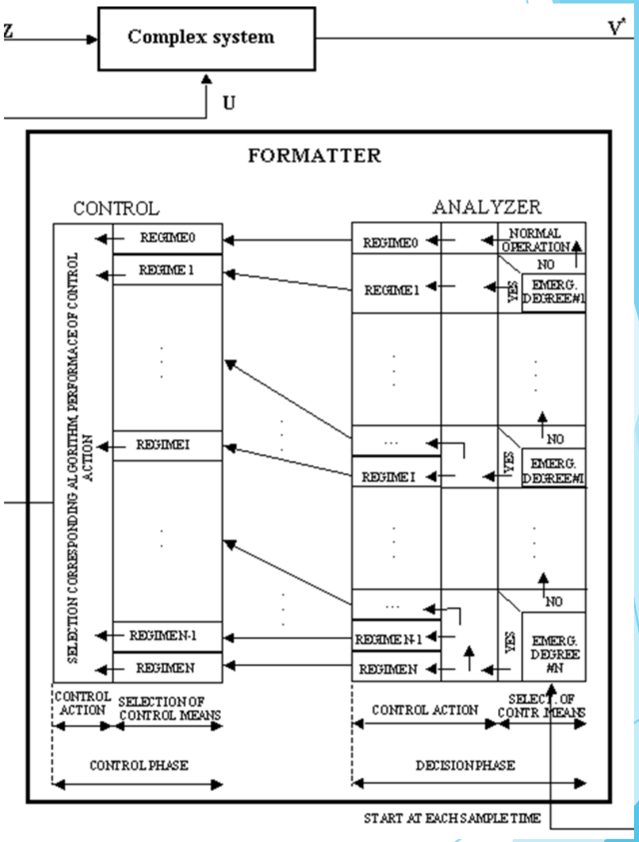


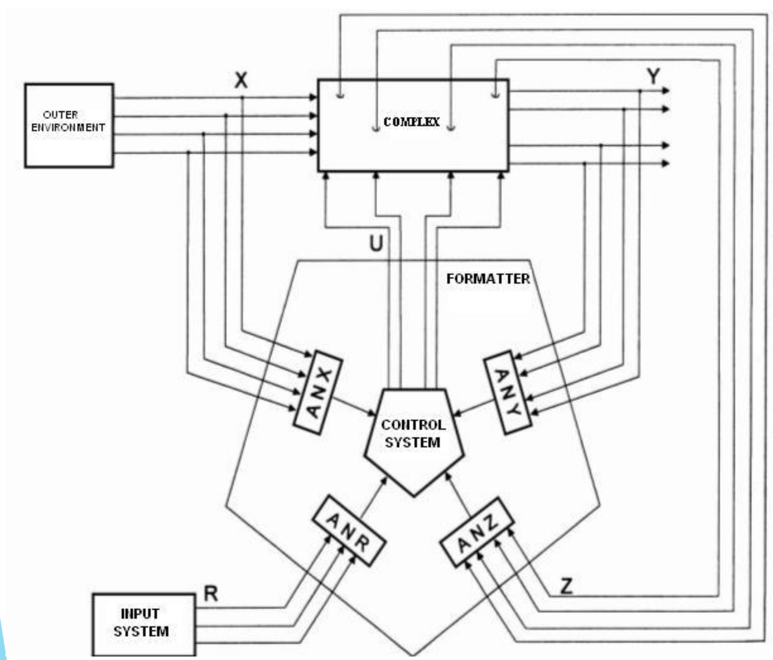
Situational control methodology

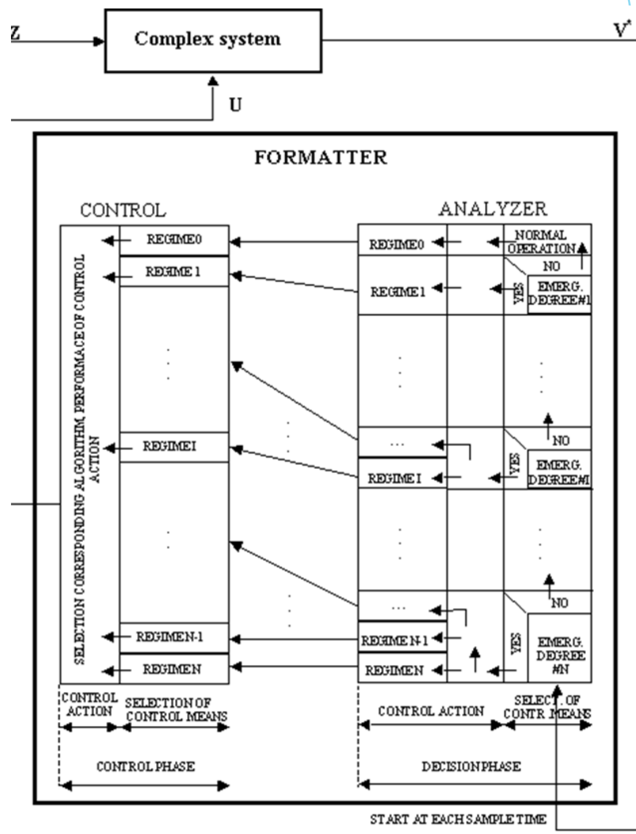
- Developed by professor Madarász, professor Spal and others
- Modular framework methodology, which is able to contain many methods for control of complex systems
- Specifically suitable at control during all operational states with emphasis on strategies during the atypical ones
- Naturally applied in many systems
- Can be also connected with event-based control.



Situational control methodology

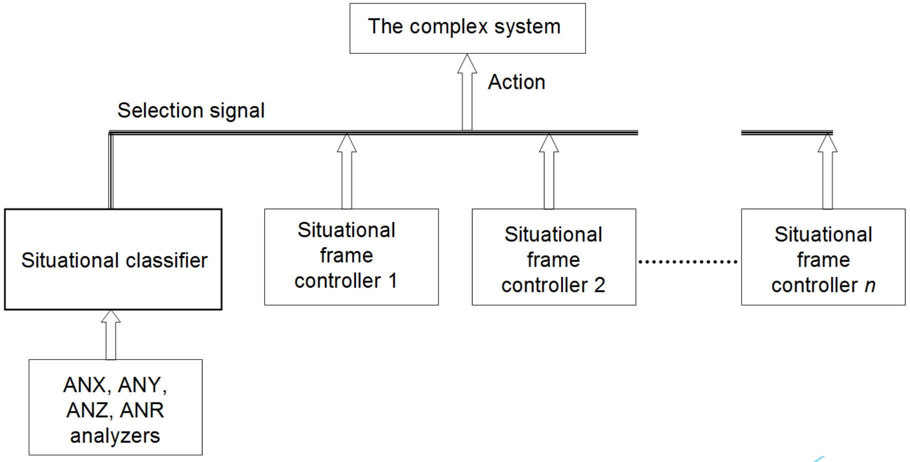
- Decision making phase and control phase
- Formatter is using all available data about environment, control, output and state variables.



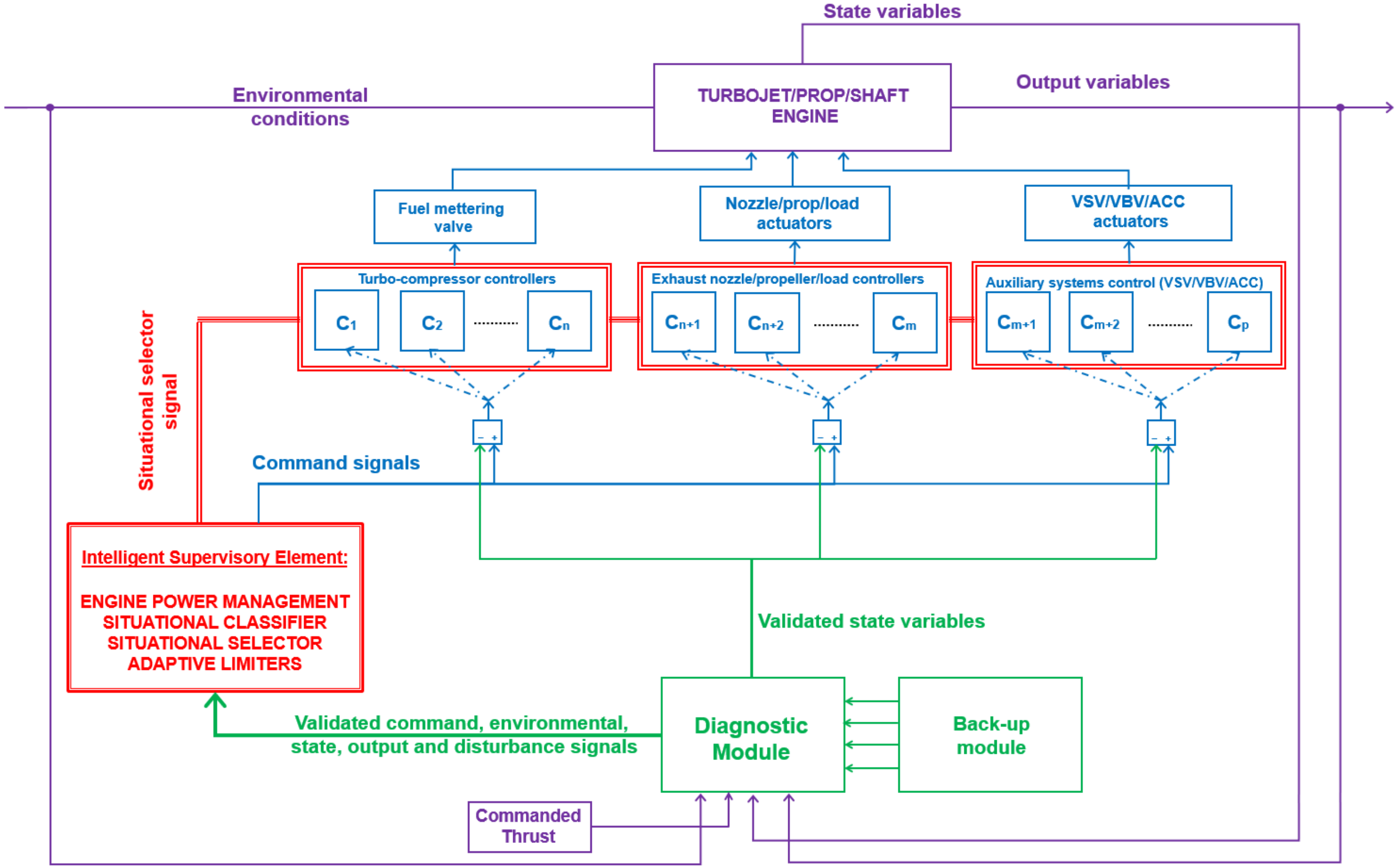


Intelligent situational control

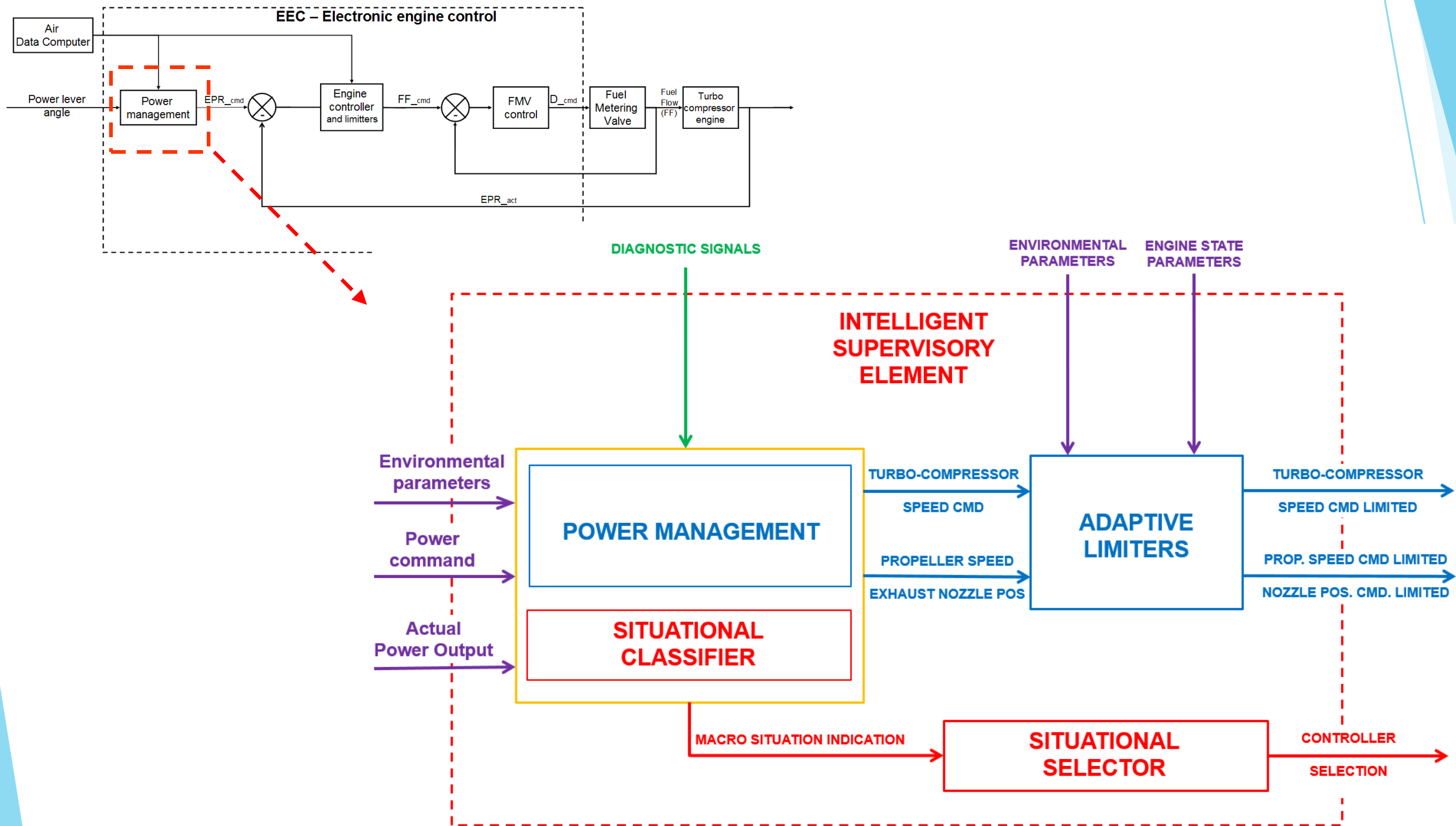
- Using intelligent algorithms in decision making (situational classification)
- Strong integration with diagnostic system (diagnostic system has an influence on decision making process as well as control algorithms)
- Selection of an optimal controller (control strategy) for each control situation
- Switch controllers intelligently without abrupt changes in the action hit without oscillations as with traditional limiters in engine control (temperature limiter example)



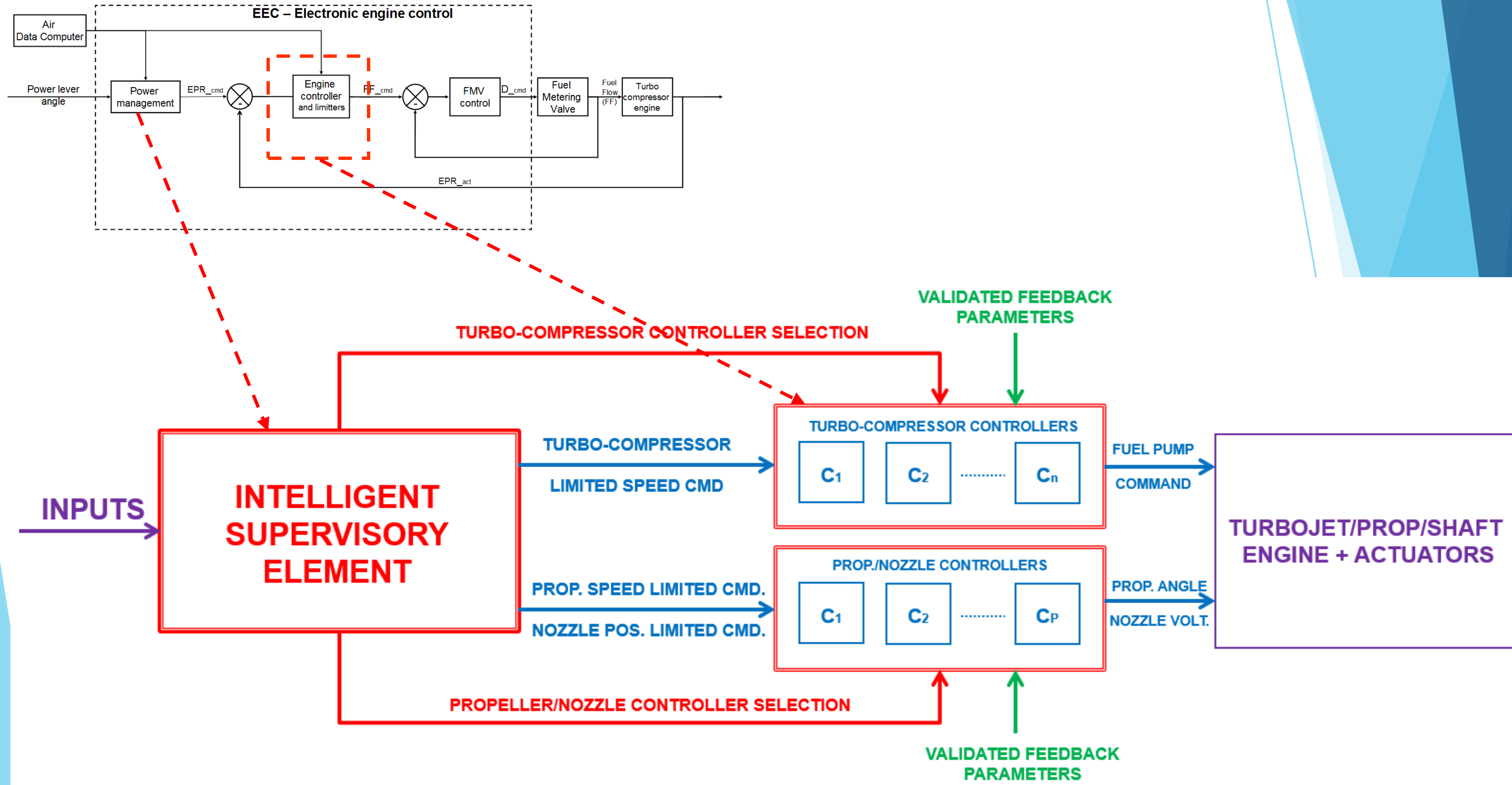
Intelligent situational control for turbojet engines



Situational control in turbojet engines – power management

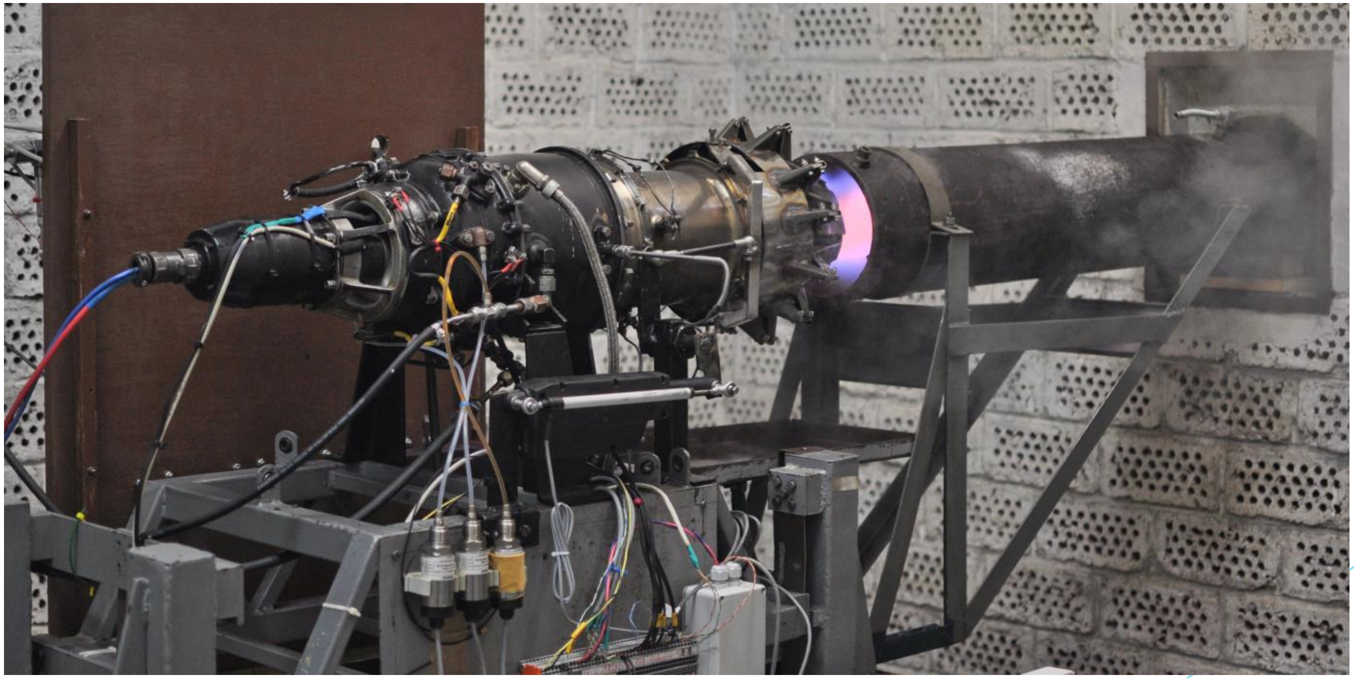


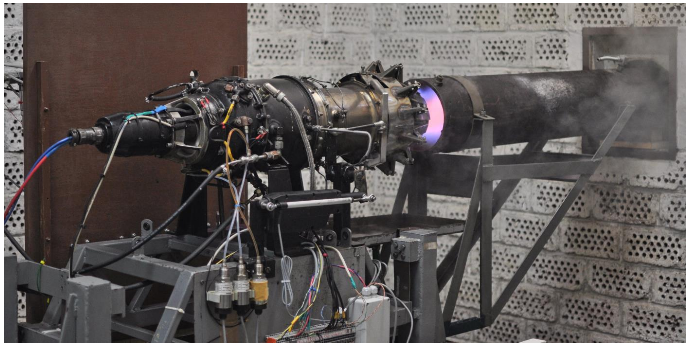
Intelligent situational control
EEC design



Intelligent situational control - implementation

- **iSTC-21v engine** – own design developed from 2004 – MPM-20 engine,
- Static thrust 300-500 N, variable exhaust nozzle (two degrees of freedom)
- Intelligent engine, prototyping of new control algorithms
- Situational control, integrated diagnostic/control systems





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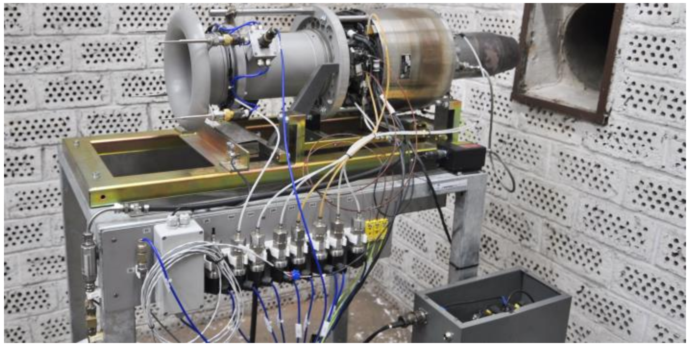
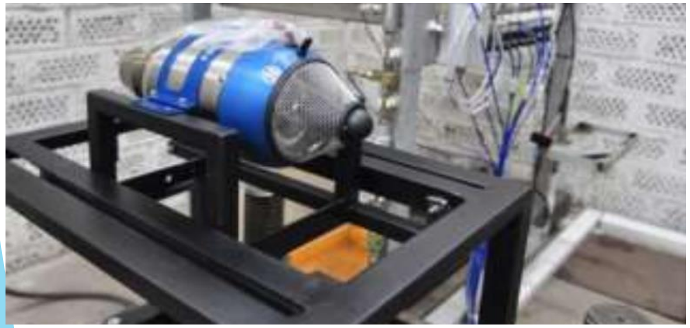
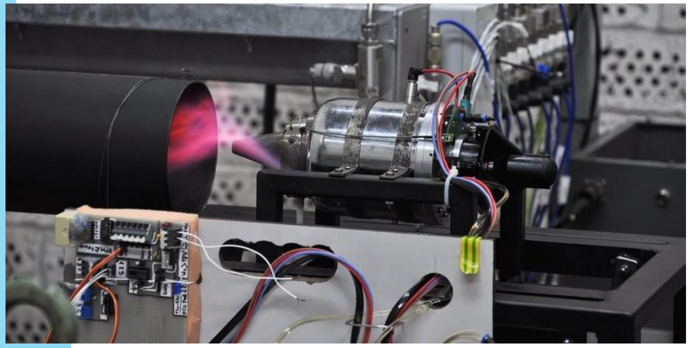


- **TJ-100 engine**, FADEC controlled, digital DAQ
- Static thrust 1000 N
- Serves as standard
- Research of dynamic engine properties



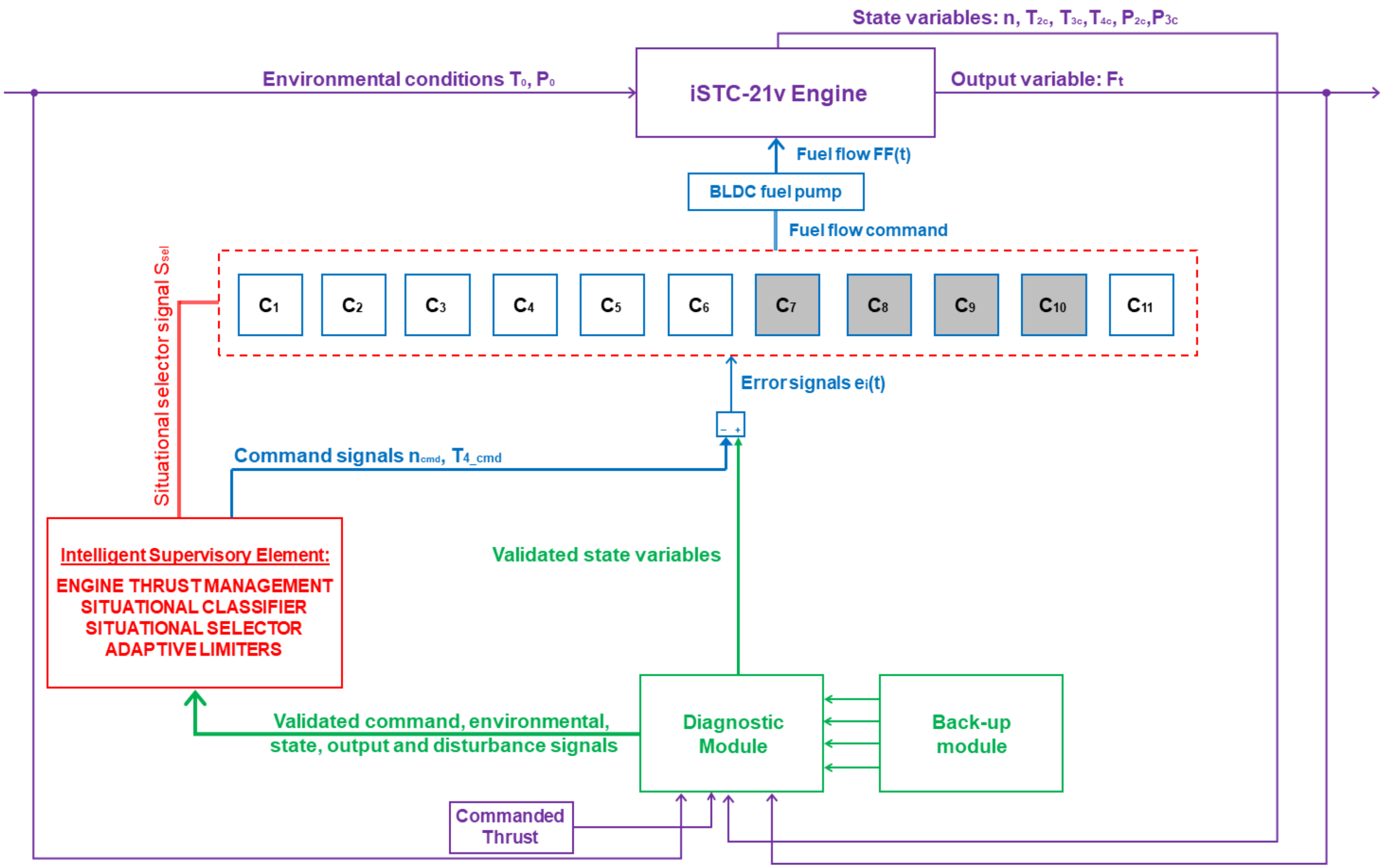
- **TJ-20 engine**, FADEC controlled, digital DAQ
- Static thrust 200 N
- Students’ projects, diagnostics, modeling
- KEGA project, cooperation with PBS



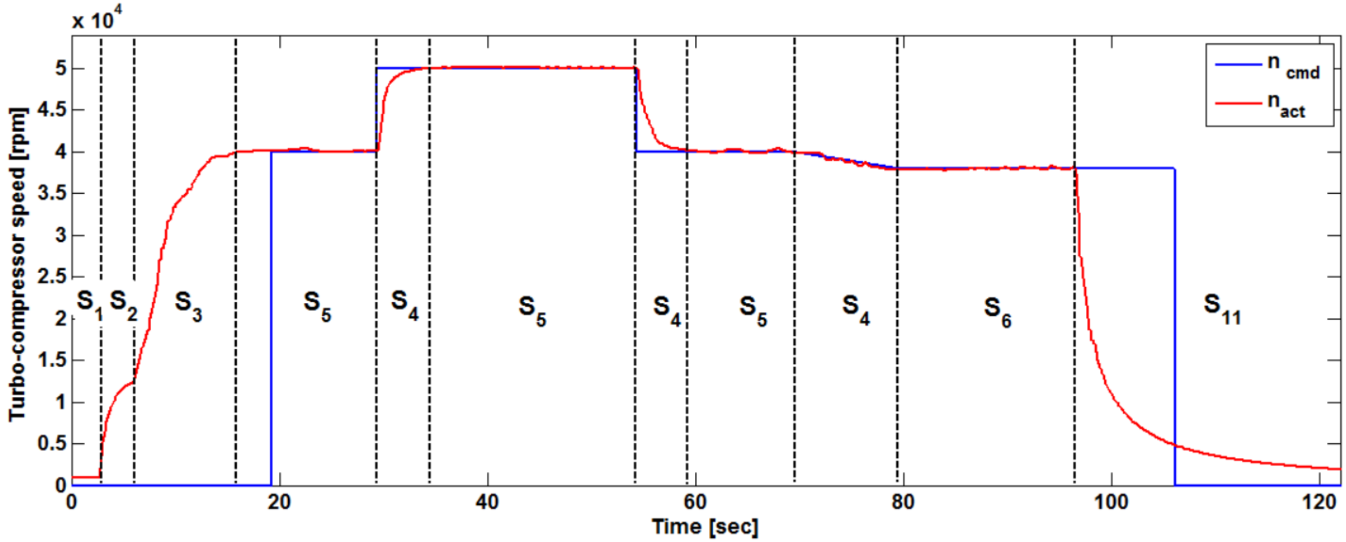
- **JetCAT-P80** engine, FADEC controlled, digital DAQ
- Static thrust 80 N
- Students’ projects, intelligent control
- Cooperation with Honeywell

Intelligent situational control

- Situational control implementation on iSTC-21v
- Diagnostics + control = increased safety



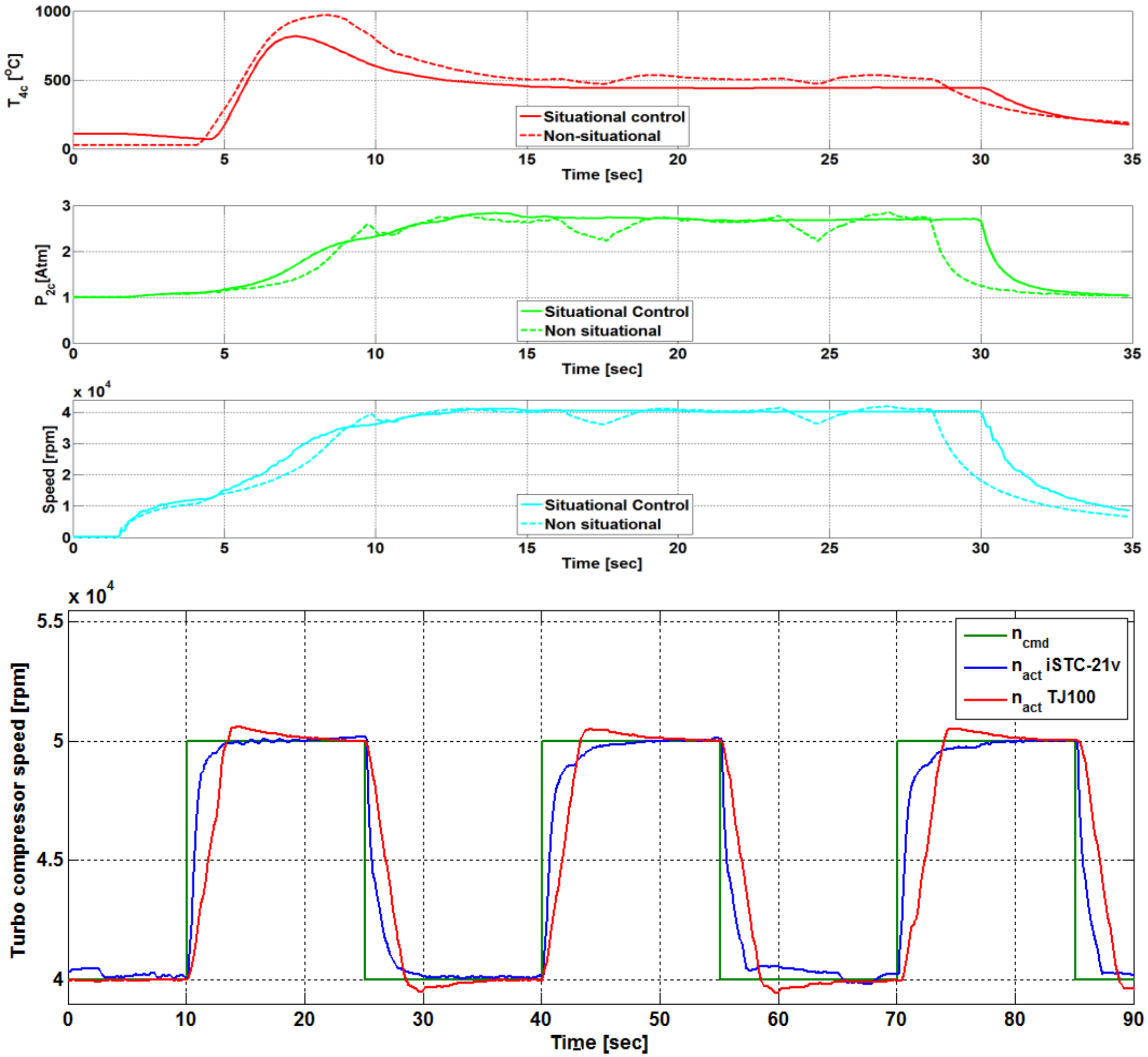
Implemented situational controllers



Situation	Strategy	Controller
S_1	Pre-start control	C_1
S_2	Launch control	C_2
S_3	Ignition control	C_3
S_4	Acceleration/deceleration	C_4
S_5	Stable operation of the engine	C_5
S_6	Idle control	C_6
S_7	Compressor stall	C_7
S_8	Turbo-compressor over speed	C_8
S_9	Turbine overheat	C_9
S_{10}	Unspecific degraded mode of operation	C_{10}
S_{11}	Engine shut-down	C_{11}

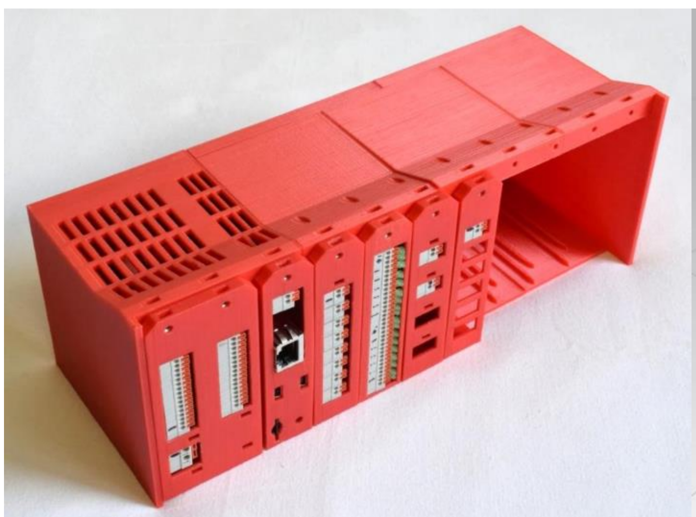
Intelligent situational control

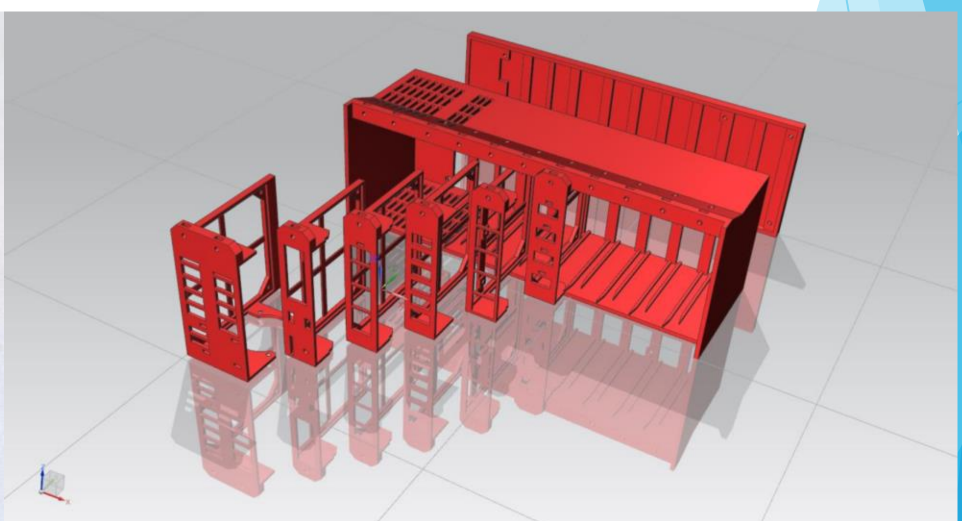
- Intelligent FADEC results (iSTC-21v vs. TJ-100):



Intelligent situational control

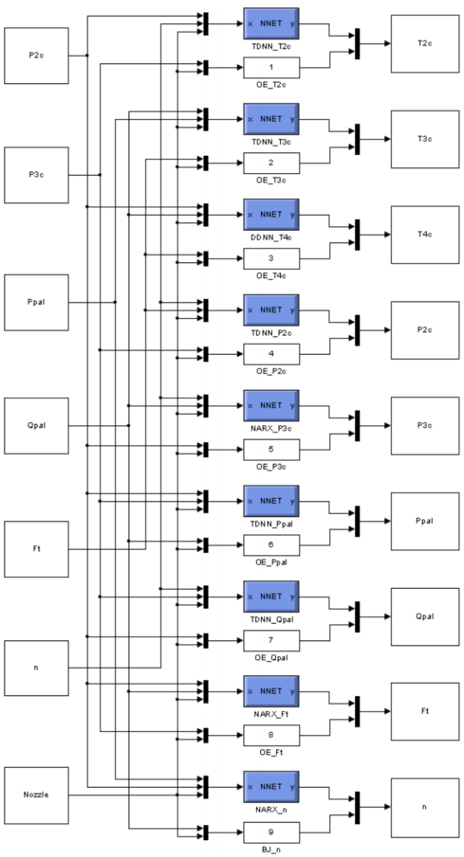
- Solved and practically tested:
  - Switching of situational frames and controllers
  - Integration of diagnostic module into control (diagnostics operates together with control)
  - In fully digital environment with application of embedded controllers
  - Comparable or even better efficiency than the TJ-100 engine
  - Perspective intelligent FADEC design using embedded micro controllers and a modular platform

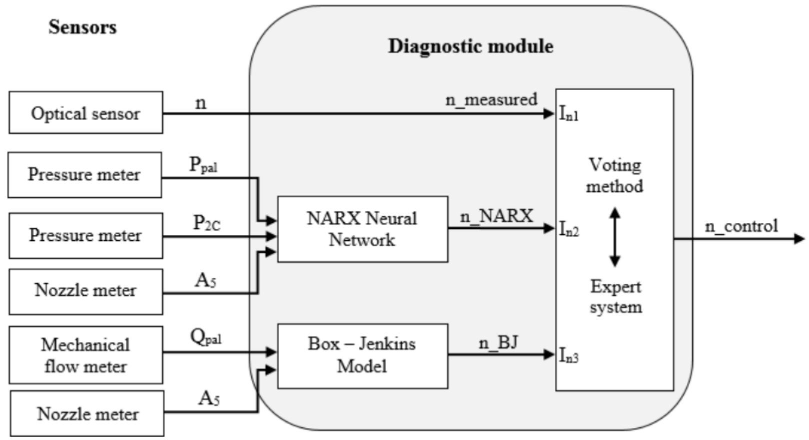


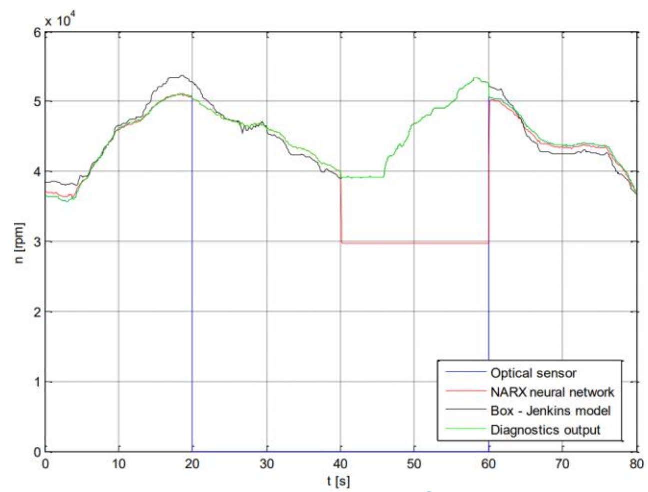


Intelligent diagnostics

- Multiple model-based intelligent diagnostics module:

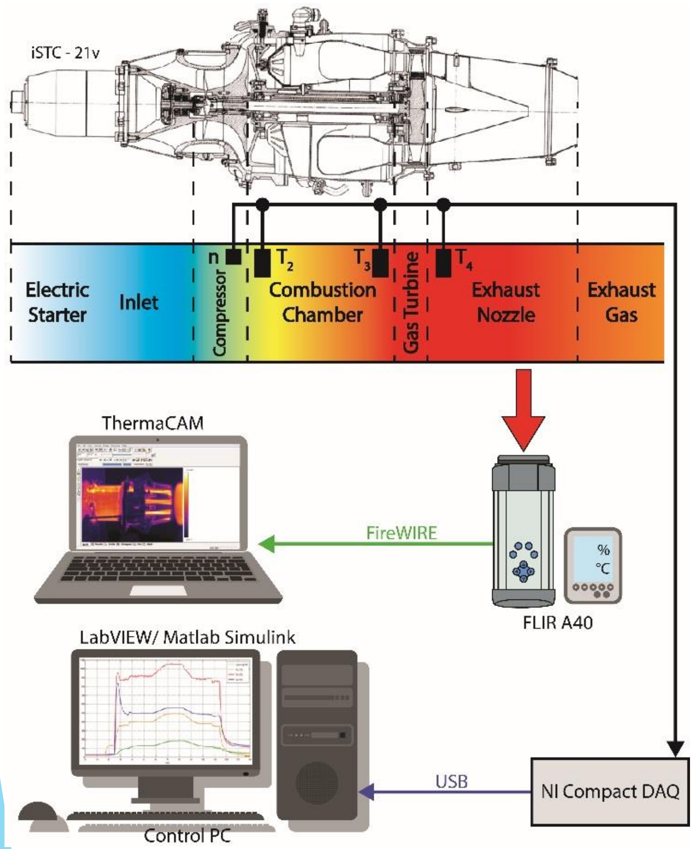


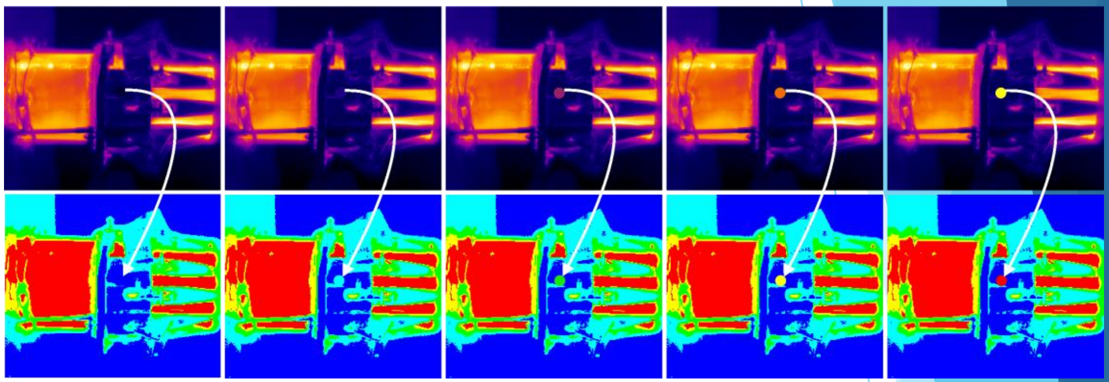


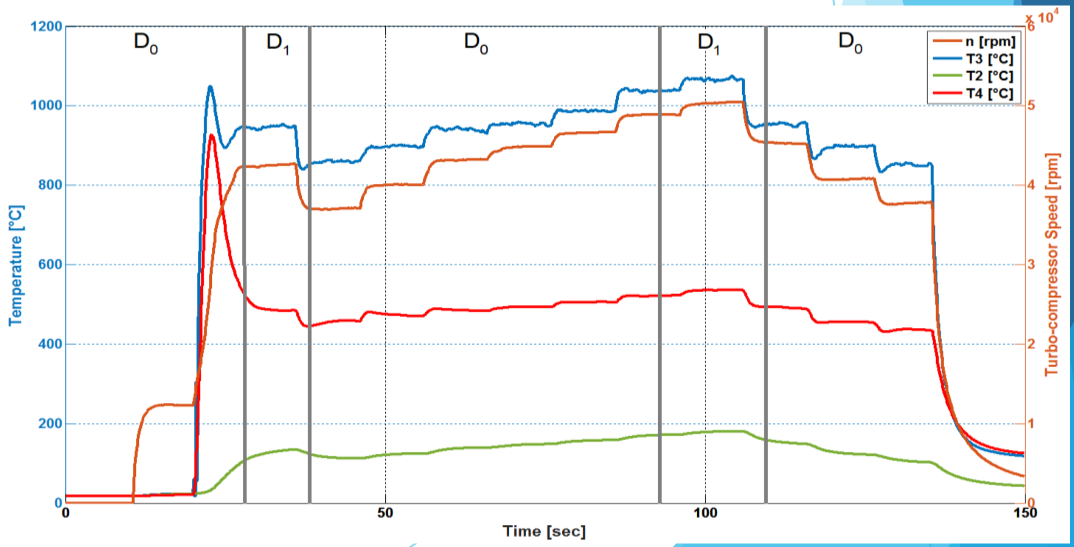


Intelligent diagnostics

- Thermovision based diagnostics – self organizing maps:







Conclusion – future research

- The future lies in efficient - green and safe transportation
- Intelligent situational control algorithms have the potential to increase safety and efficiency of operation of turbojet engines and other complex systems
- The methodology has been tested and applied on a small iSTC-21v engine
- The challenge lies in making the methodology compatible with DO-178c
- Situational control methodology is modular and usable for control of other complex systems
- Research is aimed at less rigid control system architectures with cooperating controllers / morphing structures / bag of controllers using new robust intelligent algorithms with reinforcement learning

Conclusion – socio-economic impact

- Improving the safety of operation of turbojet engines results in safer transportation
- Increase in efficiency of jet engines by development of intelligent control systems brings economic savings and improves life of jet engines (lower stress during different regimes of operation)
- Sustainable aviation fuels testing and development resulting in lower emissions decreases ecological impacts of aviation transport on environment
- Small turbojet engines can be used in unmanned systems or even for specialized personal transporters, which can be important in different tasks like rescue, firefighting, etc.
- Small turbine engines can be employed as power generating units in more electric aircraft
- Intelligent aero engines represent the future of aviation propulsion by being safe, ecological and efficient

Conclusion – cooperation

- Development of innovative control strategies for complex/large scale systems
- Development of methodologies from the area of computational cybernetics (deep neural networks, hybrid algorithms)
- Research and development of cost effective electronic control systems and smart sensors
- Research and development of efficient aircraft propulsion systems using alternative/sustainable fuels
- Research in the area of intelligent diagnostic and systems for complex/large scale systems
- Research in the area of predictive maintenance, sensor fusion
- Development and applications of micro turbojet engines for unmanned aerial vehicles
- Research of rapid prototyping technologies using hardware and software in the loop systems

Thank you for your attention