FUTURE AIR FORCE AIRCRAFT PROPULSION CONTROL SYSTEMS -

THE EXTENDED SUMMARY PAPER

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Future military aircraft propulsion control systems will be full-authority, digital-electronic, microprocessor-base systems. By now, this should not surprise anyone, in fact, for someone who has been close to propulsion control development, this statement is widely accepted. I feel silly just writing it. If you were looking for a real grabber of an opening paragraph, I'm sorry.

The evidence in support of such a bold prediction is overwhelming. Currently and for the near-term future, propulsion system performance increases will be made through the exploitation of advanced variable geometry components. As shown in Figure 1, unless there is a breakthrough in component technology, performance increases will result in additional engine complexity. In other words, the control system will have to control more variables, more closely and faster than ever before. Hydromechanical control technology simply cannot compete against the performance benefits offered by electronics.

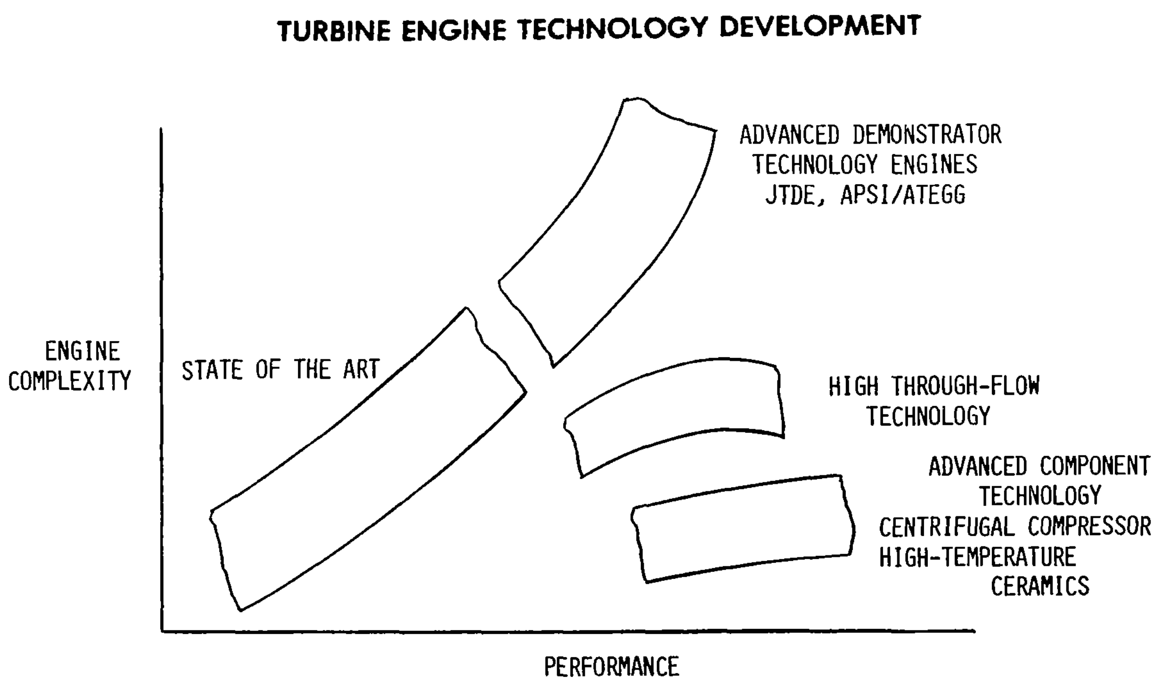

Figure 1

Now that the future has been defined, what should the Air Force's role be in the development of these systems? Clearly, we cannot expect to begin to develop new and better microprocessors and associated hardware. It is difficult just to keep up with the advances in computer technology. However, we can begin to plan for the day when microprocessor technology will permit the integrated control and management of the aircraft flight control, fire control and propulsion control systems and throw in maintenance and diagnostic information for free.

Therefore, in the Air Force Aero Propulsion Laboratory, we have concentrated on the development of control logic algorithms with every expectation that they will be put into workable software ultimately. We are confident that digital electronic controls systems will begin to really payoff when the full capability and power of the microprocessor is utilized. At the rate that microprocessor capability is expanding, we may never be able to use it all. However, our ultimate goal in the area of logic development is to be able to accomplish real-time, adaptive control of the aircraft propulsion system. For a propulsion system, this is a challenging problem for sure. The present pathway toward achieving this goal is the subject of the rest of this paper.

FUTURE PROPULSION CONTROL

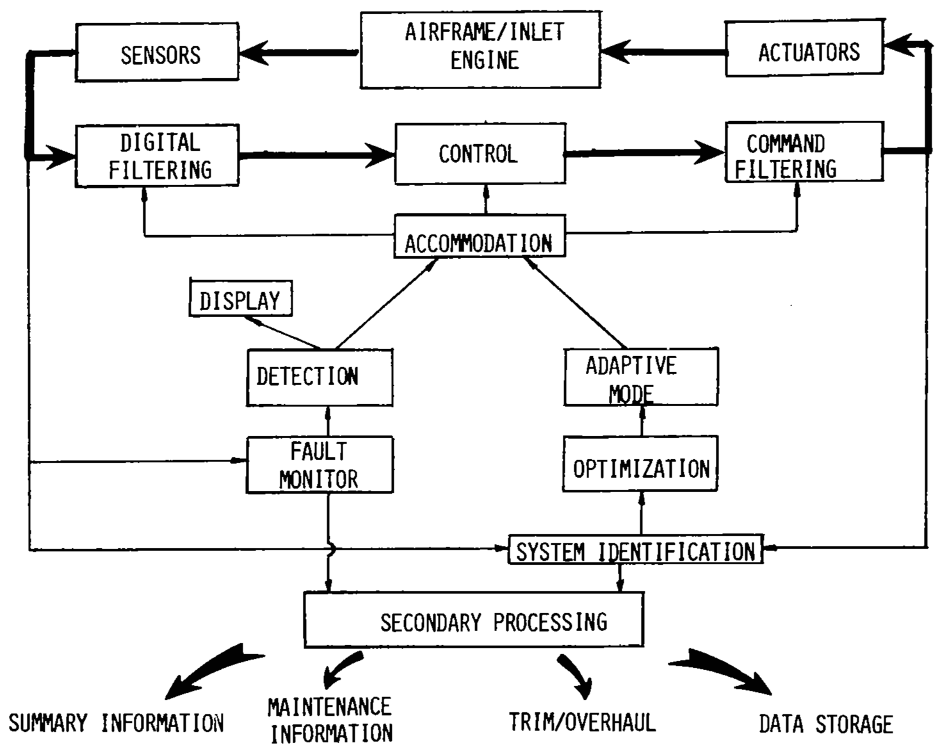

Figure 2

A schematic of the propulsion system control and information management system is shown in Figure 2. Single, closed-loop control of the engine is shown in dark lines. The dark lines indicate which part of the control and information management function can be done real time with current state-of-the-art hardware and software technology. In our current activities, we are developing basic control logic algorithms based on linear quadratic synthesis techniques and various schemes based on filter theory for sensor failure detection and accommodation and to a limited extent actuator failure detection and accommodation. At this point in time, actuator failure accommodation consists of a reversion to an independent back-up control system. Just how to accommodate an actuator failure without seriously degrading engine performance by way of reconfiguring the control law to account for the loss of controllability is an attractive and needed research area.

Our current planned research activities include an increasing emphasis on the development of real-time system identification techniques. It is obvious to us that this is an extremely important and vital area that will enable us to develop a real-time adaptive control. Research in this area has been ongoing with the initial emphasis on identification of aircraft handling qualities. Research in developing real-time identification methods has begun.

With the knowledge of the engine's current operating characteristics, adaptive control techniques can be implemented. Such a scheme would involve on-line optimization based on continuous observations of engine operating parameters. Adjustments to the control logic would then be made.

System identification methods may also be used for engine diagnostics. The technique would isolate a faulty engine component or sensor based on comparisons of observed engine behavior with nominal engine behavior. The results of such an analysis could be used to trim up or adjust for the loss in performance by way of an adjustment to the control logic. A sensor failure, for example, would result in the reconstruction of that measurement in the signal conditioning logic so it would continue to operate without any perceivable change in performance. In any event, the results would be saved and used later for maintenance purposes.

As shown in the figure, the development of a control and diagnostics capability is a logical evolution of such an approach. Unfortunately, the prevailing opinion of Government and industry is that the integration of control and diagnostics is revolutionary, not evolutionary. In an industry where change is both painful and slow, it would appear easier to reduce the national debt. Despite the internal and political resistance, which is great, technical advancements and a carefully orchistrated effort on the part of the Government agencies who sponsor research in this area may just pull it off.

Such a system, when implemented, would involve several microprocessors working together in parallel being monitored by a master control or supervisory computer. Such a concept of a distributed, microprocessor-based control system is shown in Figure 3. What looks like a system designer's nightmare will have to be another area of intense research activity. The microprocessor is breaking down the conventional divisions between software and hardware —

LARGE-SCALE CONTROL DISTRIBUTED SYSTEMS

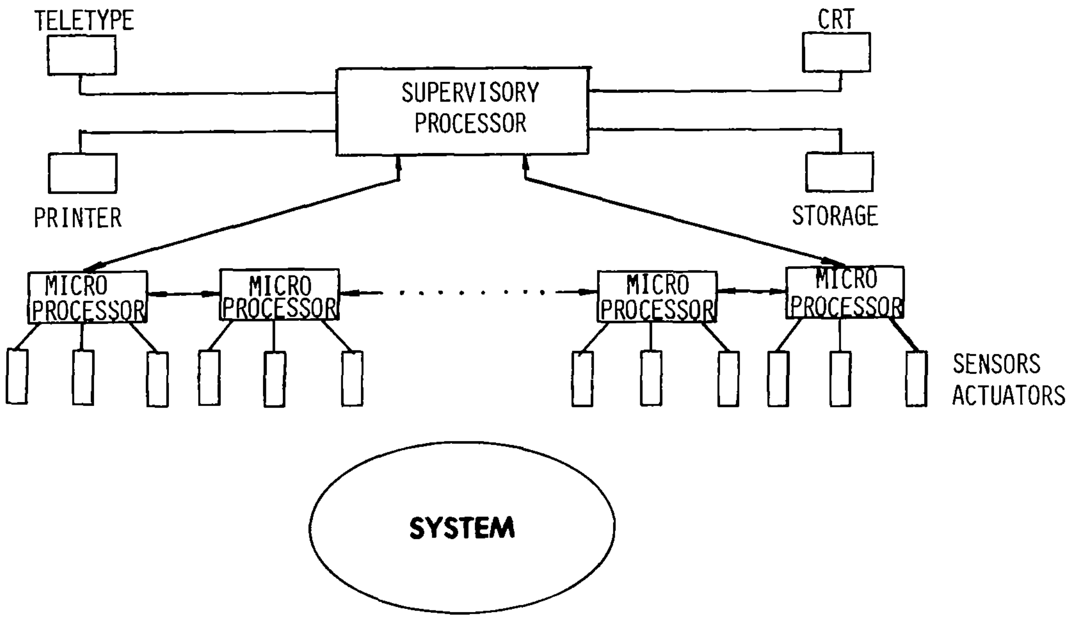

Figure 3

the new definition is firmware. Control design engineers will by necessity become electronics engineers.

Fortunately, aircraft propulsion systems will not lead the way, already energy-minded industries involved in process control are utilizing microprocessors to optimize system efficiency and save energy costs. However, the engine control problem is unique and will require more foresight, greater imagination and more coordination on the part of Government and industry alike. Greater emphasis will be placed on concept demonstration and validation. A large ongoing commitment in terms of facilities and test beds within the Government is vital to the successful implementation of the concepts presented in this paper.

In conclusion, we in the Air Force have defined the problem and proposed an outline of an approach to accomplishing a real-time, adaptive control and diagnostic information system. Such a task requires further research in several areas. These are listed below in Table I. Some areas have been the focal point of generic development activity and the investigation of how these techniques may be applied to the propulsion control problem remains to be investigated. In some areas, such as linear quadratic synthesis and multivariable frequency methods for control logic development, applications to the propulsion control problem have been investigated. In other areas, basic research is needed. In any event, a coordinated research effort on the part of the Air Force, NASA, and the Navy is needed.

TABLE I. - AREAS OF FUTURE RESEARCH

- Systems Modeling
- System Identification
- Multivariable Control
  - Frequency Domain
  - Time Domain
  - Discrete-Time Control
- Stochastic Control
- Distributed Systems
- Hierarchical Control
- System Reliability/Integrity
- Filtering/Estimation
- Failure Accommodation
  - Fault Detection
  - Fault Isolation
- Adaptive Control/Optimization
  - Performance Seeking
  - Real-Time Optimization