PROPULSION CONTROL AND CONTROL THEORY - A NEW RESEARCH FOCUS

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Aircraft propulsion system designs are increasing in complexity in order to achieve new levels of performance. The performance is being improved in terms of fuel efficiency, thrust-to-weight ratio, and such environmental factors as noise level and emissions. These improved turbine engine powerplants will have more inputs to be manipulated and more parameters to be measured. This fact is demonstrated by the chart of figure 1, which shows the increase in the number of controlled variables for various operational engines. As can be seen, this number has been increasing with time as engines have been improved.

Control systems for these more complex engines will be required to measure a greater number of variables more accurately and then act upon them in order to properly manipulate the multiplicity of inputs to the engine system. The control system, as a result, will be affected in two major areas: First, new rigorous and straightforward methods for designing acceptable control modes for the multiplicity of interacting inputs and outputs will be required. Second, the computational requirements of the new, more accurate control modes will require a digital electronic computing device instead of the present hydromechanical analog type of control computer. To address these two requirements, certain technology advances will be needed. This paper discusses these needs and the role that the NASA Lewis Research Center, as a Government research organization, will play in attacking certain of these needs.

TECHNOLOGY NEEDS

One of the technology needs is methodology for designing control modes for a process (turbine engine) that is both nonlinear and multivariable. Recent advances in analytical control theory offer possible solutions to this problem. In fact, the symposium of which this paper is a part was devoted to discussing how far we have progressed toward being able to rigorously design control laws for modern aircraft engines. Since a number of other papers address this issue quite adequately, no further comments on this multivariable control design problem are made herein. However, some extensions of the theory to satisfy needs beyond control mode selection are discussed later in this paper.

The requirement to replace the computation-limited hydromechanical analog controller being used today with a digital electronic control system is already being addressed in an evolutionary fashion. This is shown by the diagram of figure 2. The highly reliable hydromechanical controls used for relatively simple (from a control standpoint) engines are already being augmented by a supervisory digital electronic control. This arrangement is operational on the F100 turbofan engine used on the F-15 and F-16 military aircraft. Figure 3 is a cutaway view of this modern engine. The supervisory electronic control is used to trim the operation of the hydromechanical controller. Full performance is only achieved through the use of the supervisory functions. The supervisory control, which is mounted on the side of the engine, is vibration isolated and fuel cooled to enable it to survive in that hostile environment. Similar supervisory units will be used on the future fleet of Boeing 767 commercial aircraft.

The move to full-authority digital controls is being hampered by the reliability concerns surrounding electronic devices operating in the hostile engine environment. In fact, as shown in figure 2, full-authority digital electronic controls may first be used in conjunction with limited-authority hydromechanical backup controllers. Finally, as confidence increases, full-authority electronic controllers with electronic backup or redundancy schemes will come into use.

Figure 4 shows the quantitative levels of reliability concerned with propulsion control devices. Reliability here is measured as the mean time between failures (MTBF). Mature hydromechanical controllers on commercial engines now exhibit about 10 000 to 20 000 hours MTBF. The electronic supervisory control on the F100 engine, however, is down near 800 to 1200 hours MTBF. If this low figure is indicative of where the technology is for turbine-engine mounted electronics, a full-authority electronic control has significant technology needs before it can be accepted into operational service. The need for improvement is even more pronounced for a vertical-takeoff-and-landing (VTOL) aircraft. Flight control reliability requirements are usually an order of magnitude more stringent than those for the propulsion control of a multiengined aircraft. In the VTOL application the sophisticated powerplant will be an integral element of the flight control for the vertical mode of flight. Thus the required electronic propulsion controller will have to meet the same reliability requirements as the flight control (possibly greater than 10^6 hr). Achieving such high reliability with the propulsion control will definitely demand many technology advancements. The next sections describe the role the Lewis Research Center will play in this technology endeavor.

LEWIS PROPULSION CONTROL RESEARCH

The main thrust of the Lewis Research Center propulsion controls research activity then is to develop technology for enhancing the reliability of future aircraft powerplant control systems. In terms of our role as a Government research organization, we will identify the technology opportunities and then concentrate on those that are high risk but potentially offer a high payoff. These are the areas for which industry has difficulty justifying the expenditure of their own research funds. In these areas of opportunity we are talking about technology that would enter into service in the 1990's and beyond.

Figure 5 shows the technology opportunities as we perceive them for enhancing the reliability of future propulsion control systems. As shown in the figure the major elements making up an advanced control fall into four categories: (1) sensors and actuators, (2) computer, (3) control modes and software, and (4) power sources. Power sources is an important area of technology needing advances. However, because of limited resources it is not being pursued by Lewis. The remaining three categories, however, each have activity being pursued by Lewis. A brief comment on each of the subcategories of figure 5 will be made, with heavier emphasis on those areas pertaining to some aspect of control theory or analytical methods.

In the sensor and actuator category, work is being pursued to minimize the problems associated with merging the real analog world that must be sensed and acted upon with the digital computations of the control. Sensors are being developed that will have outputs which can more easily be accepted by the digital computer, thus simplifying the interface complexity. In addition, the potential advantages of optical devices are being explored in hopes of operating more reliably in high electrical noise environments and/or in high-temperature situations.

In the computer category, a careful look is being taken at the potential that very large-scale, integrated (VLSI) circuit components have in enhancing reliability. The areas include the use of multiple processors either redundantly or in some modular reconfiguration scheme to achieve a fault-tolerant control computer. Also being pursued is the viability of optical computers as a possible candidate for the hostile engine environment. This, however, is a long-range technology that is not expected to mature for quite some time.

The category of control modes and software is most closely related to the items that were the central theme of the 1979 Propulsion Controls Symposium. As stated earlier a number of linear multivariable design techniques have been studied in relation to their applicability to the turbine engine control problem. These include both time domain and frequency domain approaches. Some have been extensively investigated, such as the linear quadratic regulator (LQR) approach used in the F100 MVCS program. Others have not been so exhaustively evaluated.

FUTURE LEWIS CONTROL THEORY RESEARCH

Future efforts in multivariable design sponsored by Lewis will concentrate on nonlinear design techniques. The intent is to avoid the somewhat tedious or cumbersome design methodology based strictly on linear techniques. Linear operating-point designs require some intelligent way to tie together a family of linear control designs based on a series of well-defined operating points. A nonlinear, multivariable methodology could simplify the control design task by requiring just one design or, at least, by minimizing the number of operating-point designs.

To make use of redundant or reconfigurable hardware architectures, reliable, fault-tolerant software algorithms must be studied. Along with that will be work on sensor-actuator failure detection, isolation, and accommodation algorithms. Success of this technology depends upon the inherent computational power of the computer to minimize the redundancy requirements on critical sensors and actuators.

Much of the failure accommodation work will be based on principles of system identification. Identification techniques permit the parameters of analytical models to be determined for the system being identified. These models can be identified from data obtained from experiments or from exercising a simulation of the process in question. Models are necessary to make use of rigorous control design procedures as well as to determine failures of system components. Effort will be directed toward improving the accuracy of identification techniques and enhancing the capability of identifying in real time. These improvements will allow for the future use of adaptive control strategies.

CONCLUDING REMARKS

In summary, then, it should be reiterated that there are a number of technology needs before reliable digital control of advanced aircraft powerplants can become a reality. A number of these needs are being pursued under Lewis Research Center direction. In the specific area of control theory research, emphasis is on simplified control design procedures and on software that will guarantee reliable operation even under conditions of component failures. This work will continue through a combination of university grants, contracts with industry, and in-house evaluations.

TRENDS IN CONTROL COMPLEXITY

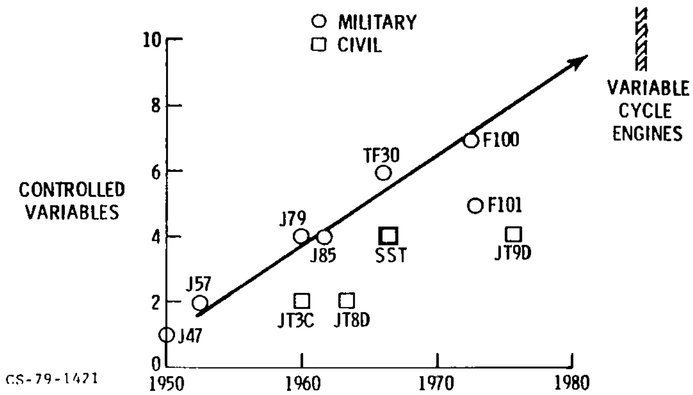

Figure 1

EVOLUTION OF ENGINE CONTROLS

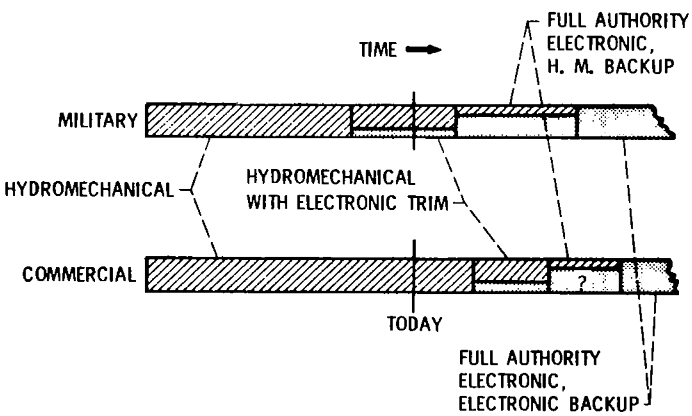

Figure 2

F100-PW-100 TURBOFAN ENGINE

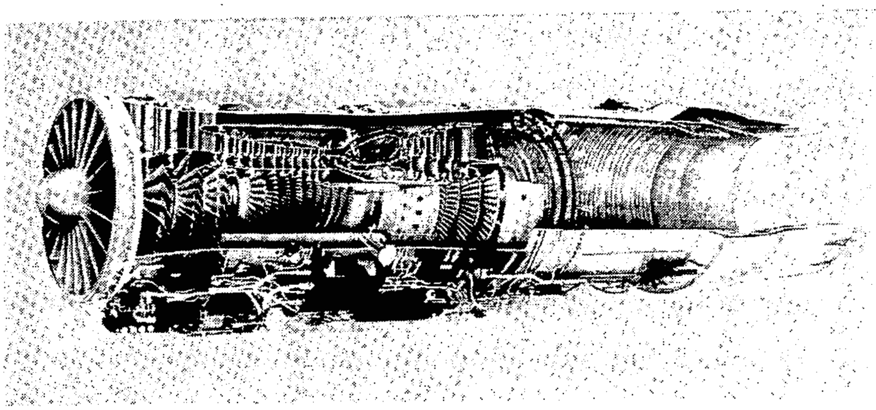

Figure 3

CONTROL SYSTEM RELIABILITY

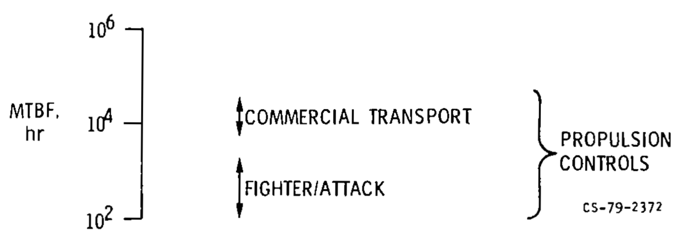

Figure 4

CATEGORIES OF TECHNOLOGY OPPORTUNITIES

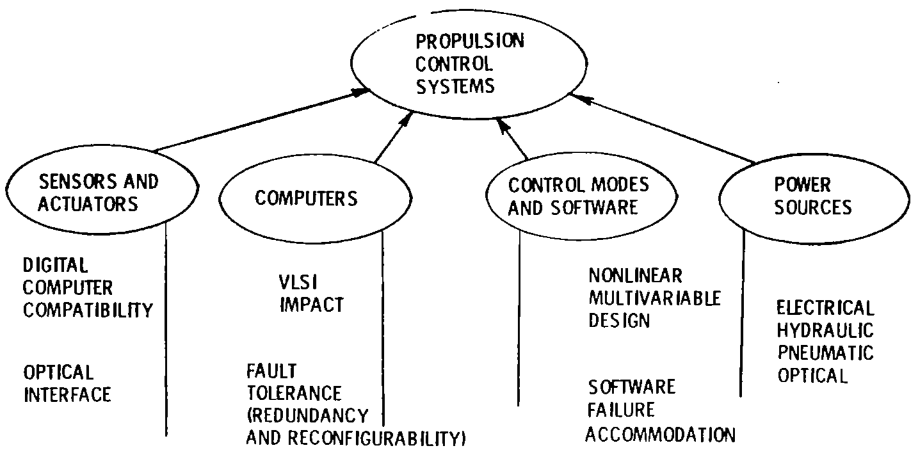

Figure 5