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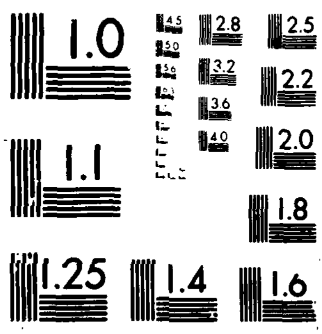

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AGARD Advisory Report No.152

TECHNICAL EVALUATION REPORT

on the

PROPULSION AND ENERGETICS PANEL 54th (A) MEETING

on

ADVANCED CONTROL SYSTEMS FOR AIRCRAFT POWERPLANTS

by

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Stanford, California, USA

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This Advisory Report was prepared at the request of the Propulsion and Energetics Panel of AGARD.

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TECHNICAL EVALUATION REPORT

by

J.David Powell

1. INTRODUCTION

The advancing technology of digital computers and the increasing complexity of aircraft powerplants have led to an increased activity in related control system research and development. Accordingly, the 54th(A) Specialists' Meeting of the Propulsion and Energetics Panel was focussed on this area. The subjects highlighted included development experience from recent applications, techniques of implementation, transducers, microprocessor applications, optimum control strategies, redundancy management and advanced digital control concepts.

The meeting was divided into four sessions of technical papers and concluded with a round table discussion. Authors represented five different countries and came from industry, government sponsored organizations and universities.

2. SESSION CONTENT

Overview

The general nature of the papers presented is summarized in Table I. A very large fraction of the papers were applications oriented and either discussed specific control applications or, based on the authors' experience with several applications, discussed general concepts of control implementations on aircraft powerplants. Five of the nineteen papers contained quantitative experimental data on some aspect of the topic being discussed and these papers are indicated in the Table as "Experimental". Four of the nineteen papers contained some kind of theoretical development, one on sensor concepts[6], one on intake characteristics[11], and two on control law generation methods[10,12]. Of these last two, one[12] described a new control system design method and carried it through to an implementation with experimental data demonstrating performance.

In keeping with the theme of the meeting, most of the control systems discussed were implemented (or were to be implemented) using digital hardware. In about half the papers, the digital aspects of the control were the primary topics discussed. Some of these[8,9,17] discussed the use of 8-bit microprocessors in the implementation and generally agreed that these devices are capable of performing the control tasks for aircraft powerplants. The conclusions from Justice's paper[9] sums it up well:

> All the experimental results to date during the various engine trials and development tests point to the wider acceptance of microprocessor controllers for stringent control requirements. The initial concern whether the microprocessor could meet the performance goals, especially the 8-bit family such as the INTEL 8080/8085, has now been dispelled. Furthermore, the sensitivity of digital circuitry to the harsh RFI and EMC environments has not been seen as a problem. Current designs have satisfied MIL-STD-461A and MIL-STD-704A tests whilst the packaging and environmental aspects are relatively straightforward.
>
> The "on-engine" microprocessor controller that replaces its hydromechanical equivalent is now available with competative price, weight and reliability factors. Performance, growth and flexibility have now been proven to be significantly greater than the analogue counterpart which leaves the engine and airframe manufacturer wide scope for system improvements.

Another aspect of electronic control, digital or analog, which was discussed by over half the papers was that of redundancy or fault detection. It appeared from the papers that there is no unanimity on how much redundancy is required for adequate system safety nor is there agreement on how to structure the redundancy and fault detection for best system reliability.

Session I

All papers discussed specific control system applications. Paper No.1, by W.Mitchell, described a digital controller for the Space Shuttle including the hardware vibration isolation and thermal design. He concluded that one of the reasons they were able to complete the development on schedule was because the system was digital and could be changed easily.

Paper No.2, by J.McNamara, E.Roberts and C.Legge, described a Concorde demonstration project of a digital controller for comparison with the current analog system. The digital system performed all the functions of the analog and has been operating successfully on seven different engines. The presentation concluded by predicting that the next SST engines would be controlled by microprocessors.

Paper No.3, by W.Bender, described a production digital controller concurrently with development of the engine itself. They predicted that such concurrent development would enhance the engine improvements made possible by digital control.

Paper No.5, by M.Arnaud, J.Gonzales and B.Secher, described an advanced application of analog electronics to the control of very small turbines.

Session II

Paper No.6, by G.Davies, emphasized the importance of measuring quantities that are most directly related to that required for control. Specifically, he advocated and described a direct pressure ratio measurement in place of conventional pressure transducers.

Paper No.7, by H.Holzem, described the benefits of using a combination of pulse modulation and binary grading for direct digital control of fuel metering.

Paper No.8, by J.Collin, discussed the application of microprocessors to military aircraft engine control and concluded that microprocessors will become more common and would promote innovations in future engine designs.

Paper No.9, by N.Justice, also discussed microprocessor applications to turbine control. The paper contained a detailed comparison of several computers as background to their specific selection and covered a wide range of experience in microprocessor application. He concluded by predicting wider acceptance of these types of controllers.

Paper No.10, by C.Skira, R.DeHoff and E.Hall, demonstrated the use of modern optimal control methods to arrive at a digital controller for the F100 turbofan, an engine with multiple control actuators and interacting control loops. The resulting controller was extensively evaluated on a hybrid simulation and on an altitude test facility and found to deliver excellent control.

Paper No.11, by D.Dini, reviewed the factors influencing variable geometry inlet design. Special emphasis was given to the control design requirements by the large variations in flight régime encountered by fighter aircraft.

Session III

Paper No.12, by C.Barrouil, described an analytical method for the generation of optimal fuel flow and exit area control laws.

Paper No.13, by K.Bauerfeind, discussed "Mode Control", a concept aimed at determining the correct trim for all engine operating conditions so as to avoid compromises and non-optimal operation. The controllers are now being implemented in digital hardware for flight evaluation.

Paper No.14, by E.Eccles, E.Simons and J.Evans, discussed dual redundancy concepts for full authority electronic engine control. The discussion was substantiated by several examples of engine design experience.

Paper No.15, by J.Tchavdarov, describes the engine control on the A300 Airbus engines and discusses the control configurations that are being considered for future airbus engines.

Paper No.16, by C.Casci, F.Monlevecchi and B.Abbiati describes their controls research experience on automotive engines. The systems studied were microprocessor control of fuel delivery systems, they concluded that closed-loop engine control methods show good promise.

Session IV

Paper No.17, by R.Powell and M.Joby, showed how the control industry is approaching general purpose control and that common modules can cover a range of applications both in hardware and software.

Paper No.18, by G.Dahl and H.Drtil, points out the advantages of digital control over hydromechanical and analog technology. However, the paper also pointed out that further benefits will be obtained when sensors and actuators are also digitized.

Paper No.19, by M.Perks and T.Morton, discussed the desirability of designing the engine digital controller as an integral part of all the turbine accessories. It concluded with the message: Digital Control is attractive for what else can it do – not simply for what existing control technology it can replace (albeit better).

3. ROUND TABLE DISCUSSION

The round table participants were:

Prof. E.E.Covert, MIT, USA, Chairman
Dr J.Dunham, NGTE, UK
Mr W.Kaemmer, VDO, Germany
Mr C.A.Bentz, AFAPL, USA
Mr J.M.Collin, SNECMA, France

Dr Dunham opened the discussion by bringing out the lack of consensus on the level and type of redundancy that is required for electronic engine control. Other questions that he pointed out had not been answered were: (a) where should the electronics be located (engine or airframe) and should it be centralized or distributed; (b) what is the role of high level languages vs assembly languages; (c) what is the role of modern multivariable control techniques vs the classical single loop design method? Dr Dunham's overall feeling about the meeting was that there had been a lot of qualitative papers but not as many quantitative results as he would have liked. This feeling is substantiated by Table I, which shows that 5 out of the 19 papers (marked experimental) contained quantitative experimental results.

Mr Kaemmer also felt the control computer vs several modular processors (distributed system) question remained unanswered. In addition, he felt the questions of sensor availability and accuracy were vital to continued advance in electronic control and that the man-machine interface should continue to be addressed.

Mr Bentz was very positive on the advantages of digital control, but cautioned that we must have patience. He pointed out that it takes 15 years to develop an aircraft and that it may take that long to change over from hydromechanical to digital. There is time required to look for a highly reliable methodology and to perform the hardware and software redundancy tradeoffs required to arrive at the best solution. The ultimate payoff would be increased versatility using digital control.

Mr Collin's primary concern was the difficulty in using high-level languages to its fullest potential and to adequately test it.

Professor Covert remarked on the excellent qualities of digital control in terms of its high-speed and failure tolerance and that the ultimate payoff will be a life increase and more reliable performance. He then opened the discussion to the floor.

Mr Griffiths, Smith Industries, UK, remarked that there seemed to be a lack of projects through which digital controls could achieve production status.

Mr Stitt of Marconi Avionics, UK, asked why there is not more digital engine control being brought in on a retro fit basis so as to obtain its advantages. Dr Bentz answered that it was too expensive.

Mr Davies of Plessey Aerospace, UK, asked whether we will have the courage to take full advantage of digital control by running nearer the surge line. Mr Bentz answered that all engines are being designed with digital control in mind. The issue is whether the systems can withstand the environment within a reasonable cost. In reply to Professor Covert he confirmed he meant closed-loop control. Dr Dunham agreed but pointed out that this presented the very difficult problem of detecting incipient surge.

Mr Evans of Smith Industries, UK, asked if the reliability of compilers could not be considered analogous to the accuracy of parts made on numerically controlled milling machines. Mr Collin commented that it was a difficult question to answer but that compilers were a problem for any end use.

Mr Hawes of Bendix, Canada, asked about the effect of the environment on reliability. He thought that going to fuselage mounting would increase interface problems and asked whether we should stay with the mil-spec approach or let manufacturers design equipment to live in the existing environment. Professor Covert answered that the latter seemed like a good idea and that he felt it was important to duplicate the environment in the laboratory.

Prof. Lo, DFVLR, Germany, remarked that digital control configurations may require special engine design considerations. Mr Bentz responded that single loop classical design may cause stability problems due to the increasing difficulty in accounting for the cross coupling. The solution is to use multivariable control methods.

4. CONCLUSIONS

The meeting successfully addressed the topics that it intended to focus on. The primary conclusions that emerged from the sessions and panel discussion are:

1. Digital technology (and particularly the microprocessor) is here to stay. It not only matches what can be done by hydromechanical or analog control, but also adds great flexibility to perform tasks not previously possible.

2. There is *no* consensus on the level and type of redundancy that is required for electronic engine control.

3. There is some question as to when and where high-level programming languages should be used.

4. Modern multivariable control design methods, although successful in their limited applications, are not in widespread use and their role is still questioned by some.

TABLE I

General Categories and Topics Discussed

		Implementation Technique							Paper Content				Topics Covered			
No.	Authors (Speakers Underlined)	Analog Electronics	Hydro Mechanical	Fluidic	Digital	Digital Packaging	Software	Computer Comparisons	Theoretical	Optimal	Experimental	Application	Sensors	Actuators	Redundancy or Fault Detection	Authors' Nationality
1	Mitchell				X	X						X	X	X	X	US
2	McNamara, Roberts, Legge				X	X	X					X	X	X	X	UK
3	Bender				X	X						X	X	X	X	GE
4	Cording, O'Keefe				X	X	X					X				US
5	Arnaud, Gonzales, Secher	X	X		*							X	X	X		FR
6	Davies	X		X					X		X		X			UK
7	Holzem		X		X						X			X		GE
8	Collin				X		X					X			X	FR
9	Justice				X		X	X				X		X	X	UK
10	Skira, DeHoff, Hall				X				X	X	X				X	US
11	Dini				*				X			X		X		IT
12	Barrouil								X	X						FR
13	Bauerfeind	X			*					X		X				GE
14	Eccles, Simons, Evans	X	X		X						X	X	X	X	X	UK
15	Tchavdarov	X	X									X				FR
16	Casci, Montevecchi, Abbiati				X						X		X	X		IT
17	Powell, Joby		X		X		X					X	X		X	UK
18	Dahl, Drtil				X							X			X	GE
19	Perks, Morton				X							X			X	UK

* Will Be

REFERENCES – Conference Papers

1. Mitchell, W.T. — *Space Shuttle Main Engine Digital Controller.* NASA George C.Marshall Space Flight Center, US.

2. McNamara, J., Roberts, E., Legge, C.G. — *Experimental Full Authority Digital Engine Control on Concorde.* Rolls-Royce Ltd, UK.

3. Bender, W. — *The Secondary Power System Control Unit, an Electronic Subsystem in the Panavia Tornado.* VDO, LuftfahrtgeräteWerk, Germany.

4. Cording, R.W., O'Keefe, F.J. — *Concurrent Development and Test of a Digital Electronic Controller with an Advanced Variable Cycle Engine.* Bendix Energy Controls Division, US.

5. Arnaud, F., Gonzales, J., Secher, B. — *Nouveau Système de Commande de Débit de Carburant pour Petites Turbomachines.* Sociéte Microturbo, France.

6. Davies, G.E. — *Transducers for Engine Control Systems.* Plessey Aerospace Ltd, UK.

7. Holzem, H. — *A Combined Parallel Digital and Pulse Modulated Fuel Metering System.* Pierburg Luftfahrtgeräte Union GmbH, Germany.

8. Collin, J.M., Gaj, B. — *Application des Microprocesseurs à la Régulation des Moteurs d'Avions Militaires.* ELECMA (SNECMA), France.

9. Justice, N.A. — *The Design Concept and Experimental Results using the INTEL 8080/8085 Microprocessor.* Hawker Siddeley Dynamics Engineering Ltd, UK.

10. Skira, C.A., DeHoff, R.L., Hall, W.E., Jr — *Design, Evaluation, and Test of an Electronic Multivariable Control for the F100 Turbofan Engine.* Systems Control, AFAPL/WPAFB, US.

11. Dini, D., Lazzeretti, R. — *Engine Intake Control Design for Advanced Fighter Aircraft.* University of Pisa, Italy.

12. Barrouil, C. — *Détermination des Lois Optimales de Montée en Regime d'un Turboréacteur.* ONERA/CERT, France.

13. Bauerfeind, K. — *A Flexible Control Concept for Military Aircraft Engines.* MTU München GmbH, Germany.

14. Eccles, E.S., Simons, E.D., Evans, J.F.O. — *Redundancy Concepts in Full Authority Electronic Engine Control – Particularly Dual Redundancy.* Dowty and Smiths Industries Controls Ltd, UK.

15. Tchavdarov, J-C. — *Conduite des Moteurs de la Nouvelle Famille Airbus.* SNI Aérospatiale, France.

16. Casci, C., Montevecchi, F.M., Abbiati, B. — *Control of Alternative Engines by Microcomputer Systems.* Politecnico di Milano, Italy.

17. Joby, M.J., Powell, R.D. — *A Unified Digital Approach to the Control of a Diverse Range of Engines.* Lucas Aerospace Ltd, UK.

18. Dahl, G., Drtil, H. — *Advantages of the Digital Technology for the Realization of Engine Control Systems.* Bodensee werk Gerätetechnik GmbH, Germany.

19. Perks, M.P., Morton, T.G. — *The Digital Control System as Part of an Integrated Accessory Fit for Future Engines.* Rolls Royce Ltd, UK.

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14. Abstract

This Technical Evaluation Report on the Propulsion and Energetics 54th (A) Specialists' Meeting on Advanced Control Systems for Aircraft Powerplants contains a survey on the nineteen papers presented, and of the discussions which followed each paper, as well as of the concluding Round Table Session. Conclusions are drawn.

The papers presented at the meeting together with the discussions are published as AGARD Conference Proceedings No.274 – Advanced Control Systems for Aircraft Powerplants.

This Advisory Report was prepared at the request of the Propulsion and Energetics Panel of AGARD.

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