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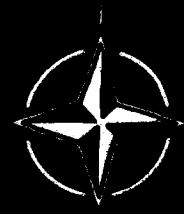
Technical Evaluation Report
on the
28th Guidance and Control Panel Symposium
on
Advances in Guidance and
Control Systems using
Digital Techniques

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 ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT
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AGARD Advisory Report No.148

6 TECHNICAL EVALUATION REPORT
 on the
~~28th~~ GUIDANCE AND CONTROL PANEL SYMPOSIUM (28th)
 on
ADVANCES IN GUIDANCE AND CONTROL SYSTEMS
USING DIGITAL TECHNIQUES.

by

10 Morris A. Ostgaard
 Air Force Flight Dynamics Laboratory
 USA

9 Advisory Report

11 Nov 79

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The 28th GCP Symposium was held in Ottawa, Canada, 8-11 May 1979. The program as presented at the Symposium is appended to this report. The complete compilation of papers has been published as Conference Proceedings CP-272.

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THE MISSION OF AGARD

The mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

- Exchanging of scientific and technical information;
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community.

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SUMMARY

The 28th Guidance and Control Symposium on "Advances in Guidance and Control Systems Using Digital Techniques" was considered extremely successful by virtue of the level of participation by the audience and the discussions and continued attendance for all the papers. The participants felt this meeting was timely in view of the emerging microprocessor technology and the emphasis placed upon guidance and control. They all encouraged a future meeting of this type within two or three years. The following represents a brief summary of the conclusions and recommendations resulting from audience comments and participation and technical assessment of the papers and the meeting.

CONCLUSIONS

The major conclusions derived from this meeting and the above technical evaluation are as follows:

1. There is a rapid emergence of digital processor application to guidance and control that represent integration opportunities heretofore unavailable in analog systems.

2. There appears to be a proliferation of microprocessor device application and architectures that, by themselves, limit potential for generalized application.

3. With the availability of more information from the data buss and the power of the computational capability, the multi-variable design techniques are offering significant potential for improving system performance and reducing equipment complexity.

4. There is a strong need for fundamental studies in functional architecture that can employ microprocessors and still retain standards that permit the application of emerging electronic technology without restructuring the total system.

RECOMMENDATIONS

Formation of a working group to address the areas of distributed microprocessor application to guidance and control systems with the objective of:

a. Definition of distributed systems architecture (functional, dynamic, static organization)

b. Derive standardization optimum on descriptions and nomenclature, and

c. Options/opportunities:

- Protocol
- Serial/parallel data transmissions
- Data Formatting
- Synchronous and asynchronous communication techniques.
- Hardware vs software redundancy
- Executives to applications software interface
- Standard HOL for executives
- Task oriented and medium level languages.

Instituting a lecture series on multi-variable analysis and design techniques.

EVALUATION REPORT

by

Morris A. Ostgaard

1. INTRODUCTION

The 28th Guidance and Control Panel Symposium on Advances in Guidance and Control Systems Using Digital Techniques was held at the Lester B. Pearson Building, Ottawa, Canada, from 8 to 11 May 1979. The Program Chairman for this meeting was Mr. Morris A. Ostgaard from the Air Force Flight Dynamics Laboratory. The program, as presented at the symposium, is appended to this report. The complete compilation of papers will be published as AGARD Conference Proceedings CP-272.

2. SYMPOSIUM THEME

The rapidly developing technologies in microprocessors, digital design techniques, and multifunctional use of sensors are demanding investigation of advances in guidance and control that can capitalize on these techniques. Also, because of the increasing constraints on cost, weight and volume, it becomes necessary to reassess the capabilities available from digital equipment and design techniques.

3. THE PURPOSE AND SCOPE

The purpose of this symposium was to provide a forum for international discussion on the subject of the application of advanced digital techniques to guidance and control systems. When one considers the computation capability available from the rapidly emerging digital processor technology, considerable increases in system performance can be achieved with substantial reduction in the equipment complement and support. Discussions were held after each paper unless similarity in subject by the different approaches suggested holding questions until both points of view were presented. These discussions quickly identified some of the critical issues and did open up some controversial areas. Although time was not sufficient to deal with all these controversial areas in detail, there was considerable discussion after the meetings and during breaks by the various authors and observers which were found to be extremely beneficial. In addition, there are, however, the traditional discussions that have been published and argued for years. This evaluation will discuss the concern from the viewpoints of use, operational issues and requirements, state-of-art, assessment of technology, identification of pacing technology, and critical needs for research and development, major challenges and trends; and finally, provide an assessment of the material presented and formulate recommendations for future action.

4. SYMPOSIUM PROGRAM

The program of this symposium was arranged in six specific sessions with a Roundtable Discussion at the end.

Session I, Functional Design Concepts, Trends, and Requirements, stressed the state of the art of digital processors and controls, the application of an avionics architecture to flight control system design, and finally, presented trends in digital data processing and system architecture.

Session II, Advances in Analytic and Design Techniques, included papers on the methodology of microprocessor networks for real-time functions, FORTRAN for avionics, the application of observer techniques for sensor failure detection and isolation, analytic techniques for automatic recovery after sensor failure, and the application of fiber optics for insuring high integrity digital guidance and control systems.

Session III, Advances in Digital System Design and Architecture to Insure High Integrity, stressed predominately techniques for insuring safety and integrity in guidance and control. This included papers on triplex digital fly-by-wire redundancy management, failure detection and isolation, integrated digital guidance and control systems, one solution to the use of logic and integration, techniques for redundancy management in inertial navigation systems, the application of hierarchical network for system design and the application of protection concepts for terrain following simplex digital systems.

Session IV, Data Processing and Computation Techniques, included papers on GPS updating of strap-down inertial systems, digital array signal processing techniques, on-line state estimation employing microprocessors, methods for strap down attitude determination and navigation with accelerometers and digital processing techniques in fire control radar.

Session V, *Software Design Validation Techniques Including Simulation*, covered areas such as an approach for validating digital flight control system software, validation of guidance and control software through real-time simulation, experience with a disciplined methodology for software development, experience with mini computer software for a remotely piloted helicopter and simulation use in development, and validation of HIMAT software.

Session VI, *Operational and System Development Experience*, included papers on federated microcomputer systems, missile guidance and control, ultra reliable computers designed for airborne and space applications, performance cost optimization of inertial measurement units using digital techniques, a high accuracy flight profile determining system and flight/fire control integration.

The main topic of the *Roundtable Discussions* was techniques for application of digital microprocessor techniques for insuring integrity and mission performance in a system concept.

5. TECHNICAL EVALUATION

Because of the scope and duration of the session, and the fact that it was classified, no notes could be taken during the presentation. It is extremely difficult for one person to assess and address all issues and concerns which were discussed. In an attempt to aid the evaluator in gathering necessary data and provide a consensus of the conferees, a "Reviewer's" form was developed which is attached as Appendix 2 of this report. This approach has been quite successful in providing many of the comments, observations, and assessments in the various technical areas of this report.

The *Keynote Address*, delivered by Mr. Bobyn, the AGARD National Delegate from Canada, stressed the importance and need for the application of digital techniques to guidance and control and the urgency to pursue technology in this area. This address was very well received by the participants and was discussed throughout the meeting. The address also stressed the urgency for cooperative research and development among NATO countries to reduce national costs by minimizing duplication and, also, to provide a medium for increasing standardization and interoperability of functions and equipment.

Session I covered conceptual ideas, studies, and philosophies dealing with integrated systems. Trends indicate future systems will be functionally integrated. However, questions arose as to how flight control integrity can be maintained in such a system. The first paper dealt with a state of the art survey of relevant aircraft technologies such as flight path management, control systems, crew station, integration methodologies, and device technology. The second paper presented a specific integration concept which is utilizing standardization for potential life-cycle costs improvements. The last paper discussed various methodologies for integrating systems and data processing techniques and stressed a need for architectural studies and standards to permit application of emerging computational capabilities and technologies without restructuring a system. The major emphasis suggested by this session was the importance of functional architectural studies and standards development.

Session II provided a review of analytical techniques for use in detecting and isolating failures in systems, some techniques for integrating system, and the application of a Higher Order Language (HOL) for avionics systems. The first paper considered the partitioning of system functions using microprocessors with the capabilities for increasing reliability, maintainability with reduced costs. The use of FORTRAN as an interim higher order language was considered in the second paper. Because of its widespread usage, a compiler was developed so that it would provide a low cost HOL until the new standard HOL is applied. The next two papers dealt with observer system and Kalman filter approaches for isolating sensor failures in a flight control system, and techniques for automatic recovery. Since fiber optics are being recognized as an effective means for reducing electro-magnetic effects and increasing data bandwidth, the last paper discussed the factors to be considered in the practical application of fiber optics for interconnecting elements of an active control system. This session emphasized the role of computation capability that permits application of analytic methods and software to enhance integrity with minimum on-board equipment complexity.

Session III dealt primarily with system architectural and redundancy methods for assuring high system integrity. The first paper presented results of work accomplished on a CCV, triplex digital fly-by-wire system. The system cross-straps sensors and stresses control law reconfiguration for enhanced safety and points out that the computer self test confidence level must be improved to achieve higher levels of reliability. The next two papers considered system and functional techniques for increasing system reliability. The use of a redundant strapdown for space application was next considered. Skewed sensors are employed, with a two-dimensional parity vector method for detecting soft failures. The next paper discusses a hierarchical architecture approach for interconnecting system elements. A topologically structured global network is established which allows alternate transmission paths. Subsystems are connected with a 10 cal star structured bussing arrangement. The last paper of the session considered the use of dissimilar redundancy for increasing the confidence of failure detection in terrain following systems. Besides the built-in test, an independent monitor is included to interrogate the radar sensors. This session showed that analog systems are rapidly being replaced by digital systems due to the inherent compatibility of digital systems to other mission systems and the provision for ease of inter-coupling that permits access

to other information and data. It stressed, however, the need to examine more powerful techniques to insure integrity and the importance of proper functional architectural structuring.

Session IV covered, primarily, the application of computational techniques to guidance and navigation systems. A GPS/Strapdown inertial system simulation was discussed using a high order Kalman filter, (45-49 states). However, its order must be substantially reduced to permit real time operation. The second paper considered the application of spatial filtering and beam forming techniques for increasing the resolution and accuracy of microwave landing systems employing a reduced size and complex antenna array. The third paper discussed methods of strap-down attitude estimation and navigation in the accelerometers, an interesting paper detailing a Kalman approach for using linear and angular accelerometers for an inertial system mechanization. In the discussion period, it was considered that the more conventional use of gyros in place of the angular accelerometers might be easier to mechanize, especially for higher quality systems. The remaining two papers were much more oriented toward consideration of actual hardware mechanizations. The paper, "Digital Array Signal Processing Techniques Applied to Guidance and Navigation", dealt with a portable microwave landing system which had achieved an excellent capability. The other paper, "Digital Signal Processing Techniques in a Monopulse Tracking Radar", was most notable for its extreme practicality and flexibility in laying out the requirements for a special-purpose signal processor. The major discussion centered on strap-down systems and the application of high order filtering techniques to achieve the desired accuracy with reduced equipment complexity and cost. This was also evident in the discussion on attitude estimation and navigation using accelerometers and computers in place of gyros. This emphasized and stressed a need for investigating the emerging capabilities of computation and data processing using microprocessors to reduce on-board equipment complexity.

Session V provided a review of techniques for validating software. The first paper discussed an integrated philosophy for validating software and discusses a strategy which should be employed by the software team. The second paper relates simulation experiences in validating the software for tactical missiles. The procedure runs from open loop testing through closed loop testing with the system subjected to representative actual signals. Comparisons are then made to similar data and then to flight test data. The final paper also discussed validation techniques applied to actual system developments. Because of the numerous paths in a software routine, limited coverage is all that can be accomplished; thus, realistic approaches must be derived to assure system integrity. The intense interest in software validation was very evident and indicated the need for renewed emphasis on new approaches to software development that can reduce the intensive efforts required in software validation.

Session VI dealt with experiences in operational systems and systems under development. The first paper presented a federated architecture for missile guidance and control using microprocessors. This type of architecture provides an inherent flexibility for reconfiguring the missile for a broad spectrum of missions. The next paper described the characteristics of a processor which is microprogrammable, by a detailed error and reconfiguration capability that can be reconfigured for a specific application. A system was then described which allows alignment of the inertial system aboard aircraft carriers. It employs optical alignment with data transmitted by radio. The next paper discusses the use of groundbased LED illuminator and on-board photo diode detectors to accurately update the position of an aircraft on an overfly. The system has application to evaluate the performance of ILS/MLS systems. The final paper of the conference considered the integration of flight control and fire control systems. Coupling of the systems will provide improvements in weapon delivery and potentials for increased accuracy. Again, the major emphasis was placed upon the need for functional architectural studies that can permit the application of multi-variable design and implementation approaches which will insure system integrity and still allow the desired performance capability.

Roundtable Discussion. The question put forth to the Roundtable Members and the audience was, "How can integrity and performance be assured in advanced guidance and control systems employing digital techniques?":

Should the system be partitioned into flight critical and non flight critical functions?, or

Should integrity be placed in the architecture and data buss? How does architecture impact the application of multi-variable (multi-input, multi-output) designs?

This Roundtable Discussion generated tremendous enthusiasm and comments and revealed the controversy that exists over partition vs overall architectural approaches. The general consensus was that an architectural approach has significantly more potential and would be compatible with the application of multi-variable design concepts. The need for a working group in this area was suggested as one approach to achieve a functional architecture and a potential standard that could be used by all NATO countries.

6. CONCLUSIONS

The major conclusions derived from this meeting and the above technical evaluation are as follows:

6.1 There is a rapid emergence of digital processor application to guidance and control that represent integration opportunities heretofore unavailable in analog systems.

6.2 There appears to be a proliferation of microprocessor device application and architectures that, by themselves, limit potential for generalized application.

6.3 With the availability of more information from the data buss and the power of the computational capability, the multi-variable design techniques are offering significant potential for improving system performance and reducing equipment complexity.

6.4 There is a strong need for fundamental studies in functional architecture that can employ microprocessors and still retain standards that permit the application of emerging electronic technology without restructuring the total system.

7. RECOMMENDATIONS

7.1 Formation of a working group to address the areas of distributed microprocessor application to guidance and control systems with the objective of:

a. Definition of distributed systems architecture (functional, dynamic, static organization)

b. Derive standardization optimum on descriptions and nomenclature, and

c. Options/opportunities:

Protocol

Serial/parallel data transmissions

Data Formatting

Synchronous and asynchronous communication techniques.

Hardware vs software redundancy

Executives to applications software interface

Standard HOL for executives

Task oriented and medium level languages.

7.2 Instituting a lecture series on multi-variable analysis and design techniques.

ANNEX

GENERAL COMMENTS

1. SELECTION OF PAPERS

Over 68 abstracts were received in response that called for papers, some of which were received too late for consideration at the meeting of the program committee. The committee had a difficult task in selecting approximately 29 papers which were considered to be the optimal number for a 4-day symposium, and was obliged to reject a large number of the abstracts submitted. The objectives were to provide a selection of high quality papers for each of the sessions that would fit well within the theme of the meeting and give a good impression of the range of interest and quality of work in the countries participating. In a few cases, it was found possible to combine a small number of individual proposals into a joint paper. The distribution of papers per country is shown below:

3	Canada
7	France
3	Germany
1	Italy
1	Netherlands
4	UK
10	US

Attendance: The total number of participants was 152 including panel members. The National distribution was:

Belgium 1; Canada 32; France 22; Germany 21;
Italy 5; Netherlands 7; United Kingdom 25; US 37;

NATO Organizations 3.

2. LOCAL ARRANGEMENTS:

The symposium was held in the Lester B. Pearson Building. The facilities were unanimously recognized as the best ever offered for a GCP meeting. Canadian Host Coordinator, Mr. K. A. Peebles, is to be congratulated for his support and on the thoroughness and the success of the arrangements. Mr. Bobyn, Canadian National Delegate, presented the opening address. Participants were entertained at an official reception in the Lester B. Pearson Building. A technical tour was also conducted through the Canadian Defence Research Establishment, Ottawa.

APPENDIX I

FINAL PROGRAM

ADVANCES IN GUIDANCE AND CONTROL SYSTEMS USING DIGITAL TECHNIQUES
Ottawa, Canada, 8-11 May 1979

OPENING CEREMONIES

OPENING ADDRESS by Mr. E. J. Bobyn, NDHQ, Canadian National Delegate to AGARD

KEYNOTE ADDRESS by Mr. E. J. Bobyn, NDHQ, Canadian National Delegate to AGARD

SESSION I - FUNCTIONAL DESIGN CONCEPTS, TRENDS, AND REQUIREMENTS

Chairman: Mr. Morris A. Ostgaard, USA

- o State-of-the-Art for Digital Avionics and Controls, 1978 , by R. K. Smyth, Milco International, Inc., USA
- o A Flight Control System Using the DAIS Architecture, by A. P. DeThomas, R. A. Hendrix, AF Flight Dynamics Laboratory, USA
- o Trends in Digital Data Processing and System Architecture, by A. A. Callaway, Royal Aircraft Establishment, UK

SESSION II - ADVANCES IN ANALYTICAL AND DESIGN TECHNIQUES

Chairman: Mr. Uwe Krogmann, Germany

- o A Methodology of Design Multimicroprocessors Network for Real Time Functions in Avionics, by J. F. le Maitre, J. Gillon, R. Mampey, CERT/DERA, France; and P. Romand, Aleonard et de Moment, Societe Crouzet, France
- o Fortran for Avionics, by A. J. Maher, Singer Kearfott Division, USA
- o An Observer System for Sensor Failure Detection and Isolation in Digital Flight Control System, by N. Stuckenberg, DFVLR, Inst f Flugfuehrung, Germany
- o Automatic Recovery after Sensors Failure On Board, by M. J. Pelegrin, M. Labarrere, M. Pircher, ONERA, France
- o Recent Advances in Fiber Optics for High Integrity Digital Control Systems, by R. P. G. Collinson, Marconi Avionics Limited, UK

SESSION III - ADVANCES IN DIGITAL SYSTEM DESIGN AND ARCHITECTURE TO ASSURE HIGH INTEGRITY

Chairman: Ing. General Marc J. Pelegrin, France

- o Redundancy Management Considerations for a Control Configured Fighter Aircraft Triplex Digital Fly-By-Wire Flight Control System, by J. H. Watson, G. S. Gurley, J. M. Railey, General Dynamics, USA
- o Failure Detection, Isolation and Indication in Highly Integrated Digital Guidance and Control Systems, by W. J. Kubbat, Messerschmitt-Boelkow-Blohm GmbH, Germany
- o L'integrite des Logiciels Embarques: une solution, by G. Germain, Electronique Marcel Dassault, France
- o A redundant Inertial Navigation System for Interim Upper Stage (IUS), by R. Baum, Hamilton Standard, Farmington CT, USA; G.E. Morrison, The Boeing Aerospace Company, USA, and R. C. Peters, Aerospace Corporation, USA
- o Definition of the Hierarchical Network for Aggressive Environment (RHEA), by M. Buis, J. C. Laprie, J. Marco, D. R. Powell, Laboratoire d'Automatique et d'Analyse des Systemes, France
- o Protection of a Simplex Digital Computer for Terrain Following, by G. T. Shanks, Royal Aircraft Establishment, UK

SESSION IV - DATA PROCESSING AND COMPUTATION TECHNIQUES

Chairman: Mr. William F. Ball, USA

- o Development of Aiding GPS/Strapdown Inertial Navigation System, by D. F. Liang, Defence Research Establishment, Ottawa, Ontario, Canada; D. B. Reid, Philip A. Lapp Limited, Ottawa, Ontario, Canada; R. H. Johnson, SandS Software Limited, Ottawa, Ontario, Canada; B. G. Fletcher, Defence Research Establishment, Ottawa, Ontario, Canada
- o Digital Array Signal Processing Techniques Applied to Guidance and Navigation, by S. Bloch, Standard Elektrik Lorenz (ITT), Germany

- o Microcomputer-Based On-Line State Estimation with Applications to Satellites, by N. K. Sinha, S. Y. Law, Department of Electrical Engineering, McMaster University, Ontario, Canada; R. Mamen, Communications Research Centre, Ottawa, Ontario, Canada
- o Methods for Strap Down Attitude Determination and Navigation with Accelerometers, by R. P. Offereins, J. J. L. Tiernego, Twente University of Technology, Netherlands
- o Digital Signal Processing Techniques in a Monopulse Fire Control System, by U. Fazio, F. Ambrosioni, C. de Bonis, Contraves Italiana SpA, Italy

SESSION V - SOFTWARE DESIGN VALIDATION TECHNIQUES INCLUDING SIMULATION

Chairman: Mr. K. A. Peebles, Canada

- o An Assessment of and Approach to the Validation of Digital Flight Control Systems, by D. B. Mulcare, W. G. Ness, Lockheed-Georgia Co, USA
- o Validation of Guidance and Control Software Through Real Time Simulation, by R. G. Baldwin, J. P. Smith, W. C. Morton, Raytheon Company, USA
- o Logiciel Avionique, Experiences Pratique d'une Methodologie, by J. Perin, Electronique Marcel Dassault, France
- o Experience in Producing Minicomputer Software for the Ground Station of a Remotely Piloted Helicopter, by J. P. Webby, P. Wescott, M. Tucker, H. Smith, Westland Helicopter Limited, UK
- o Simulation Use in the Development and Validation of HIMAT Flight Software, by A. Myers, NASA-Dryden Flight Research Center, USA

SESSION VI - OPERATIONAL AND SYSTEM DEVELOPMENT EXPERIENCE

Chairman: Mr. John L. Hollington, UK

- o Federated Microcomputer Systems for On-Board Missile Guidance and Control, by F. J. Langley, Raytheon Company; D. S. Siegel, Office of Naval Research; and R. E. Wehman, Naval Surface Weapons Center; and W. F. Savage, USA
- o COPRA - The New Line of Ultra-Reliable Computers COPRA Designed for Airborne and Space Applications), by C. Meraud, F. Browaeys, Sagem, Osny, France
- o ALIDADE - A Successful Performance-at-Cost Optimization of Aircraft INU Carrier Alignment Using Recent Digital Techniques, and Technology, by L. Camberlein, J. Paccard, M. de Cremiers, Sagem, Osny, France
- o A High-Accuracy Flight Profile Determining System, by P. R. Vousden, P. J. Gollop, Litton Systems Canada Limited, Ontario, Canada
- o Integration of Flight and Fire Control, by R. Huber, AF Flight Dynamics Laboratory, USA

ROUNDTABLE DISCUSSION

CLOSING CEREMONIES

APPENDIX II

(EVALUATION FORM)

COMMENTS ON AGARD GCP SYMPOSIUM
Ottawa, Canada, 8-11 May 1979

TO ALL ATTENDEES

Considerable time and effort was expended by a number of countries in the organization and hosting of this symposium. As a result, the Program Committee Chairman is obligated to prepare an evaluation report. To aid him in preparing a timely, meaningful report, and since we have assembled here leading technical experts in the field, we solicit any feedback or comments you may desire to submit. These may be handwritten notes, and anonymous. If you have any questions, please contact the AGARD staff, the Program or Panel Chairman.

The following are typical examples of areas in which observations, comments and assessments are desired:

(a) General observations

1. Quality, and relevance of papers, sessions and questions;
2. Did papers support the theme?
3. Did symposium live up to your expectations?

(b) Technical observations

Views on operational use and requirements;
Assessment of technology (State-of-the-Art);
Views on pacing technology or critical need for R&D;
What do you see as major challenges and trends?
Views on systems integration aspects;
What area or problems are unresolved?

(c) Suggested improvements for symposium (new or special topics, procedures for enrolment, authors' instructions, logistics, etc.).

Please write your comments overleaf and hand them in
to the Authors' Desk before the end of the symposium.
Thank you for your contribution and cooperation.

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13. Keywords/Descriptors Digital techniques High integrity Failure detection Strap-down Digital flight controls			
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