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AGARD ADVISORY REPORT No.276

Technical Evaluation Report on the Guidance and Control Panel 48th Symposium on Advances in Techniques and Technologies for Air Vehicle Navigation and Guidance

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

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AGARD Advisory Report No.276

TECHNICAL EVALUATION REPORT

on the

GUIDANCE AND CONTROL PANEL

48th SYMPOSIUM

on

ADVANCES IN TECHNIQUES AND TECHNOLOGIES FOR AIR VEHICLE NAVIGATION AND GUIDANCE

by

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The Guidance and Control Panel 48th Symposium was held at the Instituto da Defesa Nacional in Lisbon, Portugal from 9th to 12th May, 1989. The papers were compiled as Conference Proceedings CP.455 and CP.455(S).

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- 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;
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PREFACE

In the 1990s and beyond, air vehicles will be designed on the basis of functionally integrated systems and the operation of such aircraft will also be highly integrated.

Past experience has clearly shown that interfacing classical sub-systems can introduce critical compromises in overall systems performance, availability, safety and cost.

Future systems will be designed and built by means of a new process where the physical characteristics of the resulting systems may not have any resemblance to today's subsystems or line-replaceable units.

The navigation and guidance aspects of future air vehicles cover a broad spectrum of important technical issues to meet the operational requirements with improved capability and increased survivability for reasonable costs. The systems increasingly depend upon the use of advanced sensor and signal processing techniques and particularly on software to provide the "intelligence" required for their functional performance.

This symposium was intended to deal with advances in techniques and technologies to design, build and test such navigation and guidance systems.

* * *

Dans les années 1990 et au-delà les véhicules aériens seront conçus sur la base de systèmes multi-fonctions et la mission de tels aéronefs sera aussi hautement coordonnée.

L'expérience acquise démontre que l'interconnexion des sous-systèmes classiques risque d'amener des compromis critiques en ce qui concerne les performance globales, la disponibilité, la sécurité et le coût des systèmes.

Les systèmes futurs seront conçus et construits au moyen de procédés nouveaux où les caractéristiques physiques des systèmes ne pourront avoir aucune ressemblance avec les sous-systèmes actuels qui sont remplaçables aux divers échelons de maintenance.

Les performances en navigation et en pilotage qui seront demandées aux aéronefs futurs afin de satisfaire aux besoins opérationnels, tout en assurant des capacités améliorées et un niveau de survivabilité plus élevé à des coûts raisonnables soulèvent bon nombre de questions techniques importantes dans des domaines divers. Les systèmes en question dépendent de plus en plus de la mise en oeuvre de techniques sophistiquées de détection et de traitement du signal et, en particulier, des logiciels qui fournissent "l'intelligence" nécessaire à leur fonctionnement.

Le symposium a examiné les progrès réalisés dans le domaine des techniques et des technologies demandées pour la conception, la réalisation et les essais de tels systèmes de navigation et pilotage.

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The Panel wishes to express its thanks to the Portuguese National Delegates to AGARD for the invitation to hold this meeting in their country and for the facilities and personnel which made the meeting possible.

Le Panel tient à remercier les Délégués Nationaux du Portugal près l'AGARD de leur invitation à tenir cette réunion dans leurs pays et de la mise à disposition de personnel et des installations nécessaires.

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TECHNICAL EVALUATION REPORT

by

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Cambridge, MA U.S.A.

EXECUTIVE SUMMARY

The 48th symposium of the AGARD Guidance and Control Panel (GCP) was convened in Lisbon, Portugal 9-12 May 1989. The symposium dealt with advances in techniques and technologies to design, build and test highly integrated navigation and guidance systems.

Papers covered a broad range of topics including terrain reference navigation, image processing, GPS, miniature inertial sensors, infra-red and millimeter wave radar as components of multisensor systems. A number of these papers reported the results of flight trials.

After 10 years of development, TRN is a mature technology capable of providing precise position over terrain. Passive terrain following and terrain collision avoidance using stored information are under development but are not yet mature systems. There is promise for improved navigational accuracy from passive imaging, however the technology has nowhere near the maturity of TRN while suffering the same limitation that it can only function over land.

The ultimate goal of a gyro on a chip appears feasible but has not yet been achieved. Millimeter wave radar offers some advantages over longer wavelengths for missile guidance and appears to be well suited to multisensor applications when teamed with passive infrared or optical seekers. Flight experience supports the argument that proper combinations of different sensors can improve tactical performance. The only hope for reducing the cost of multiple sensors is to have them built into the same box.

The development of new sensors has made an overwhelming amount of data available in the cockpit . The design of the cockpit interface to absorb the data and interact with the human pilot will be a difficult and expensive task. It would be appropriate to focus future meetings on this technical area.

The chief recommendation for future AGARD symposia is to put more emphasis on the operational advantages of new technology as weighed against their probable cost.

INTRODUCTION

The 48th symposium of the AGARD Guidance and Control Panel (GCP) was convened in Lisbon, Portugal 9-12 May 1989. The meeting was titled "Advances in Techniques and Technologies for Air Vehicle Navigation and Guidance". The Program Chairman was Mr. Uwe K. Krogmann of Bodenseewerk (GE). The Program Committee also included:

Mr. B. Chaillot	FR
Dr. H.Winter	GE
Prof. P. Sanz-Aranguez	SP
Mr. R. Dunn	UK
Prof. J. Sheperd	UK
Dr. J. Niemela	US
Dr. G. Schmidt	US

The theme of the meeting as established in the announcement was as follows:

In the 1990's and beyond, air vehicles will be designed on the basis of functionally integrated systems and operation of such aircraft will also be highly integrated. Past experience has clearly shown that interfacing classical subsystems can introduce critical compromises in overall systems performance, availability, safety and cost. Future systems will be designed and built by means of a new process where the physical characteristics of the resulting systems may not have any resemblance to today's subsystems or line-replaceable units. The navigation and guidance aspects of future air vehicles cover a broad spectrum of important technical issues to meet the operational requirements with improved capability and increased survivability for reasonable costs. The systems increasingly depend upon the use of advanced sensor and signal processing techniques and particularly on software to provide the intelligence required for their functional performance. This symposium is intended to deal with advances in techniques and technologies to design, build and test such navigation and guidance systems.

The keynote address was presented by Cor/Pilav Jose Armando Vizela Cardosa, Head of Operations Division, Portuguese Air Force Staff. He pointed out that the Warsaw Pact continues to develop advanced weapons despite the current efforts toward force reduction. He cautioned that NATO should avoid weaknesses in technology which would invite an outbreak of hostilities because of a perceived superiority. Nuclear disarmament will require improvements in the capabilities of conventional weapons, an arsenal where NATO is heavily outnumbered. He cited needs for aircraft with all-weather capability functioning without radio navigation aids where necessary in the face of massive electronic warfare capability on the part of the Warsaw Pact forces.

SESSION I: TERRAIN REFERENCE NAVIGATION METHODS

The first session consisted of three papers which described the current state of the art in terrain reference navigation in the UK and West Germany. The first paper (OXENHAM) discussed three British TRN systems whose maturity has been demonstrated in flight trials of high performance aircraft including F-16, Hunter and Tornado. These systems are TERPROM, SPARTAN and PENETRATE. Two promising new complimentary systems which work over flat terrain by recognizing ground features were also described. Scene matching (SMAC) compares an infra-red image with a stored map while Terrain Characteristic Matching (TCM) looks at the changes in the terrain's radar reflectivity to a conventional radar altimeter at 16 GHz. TCM has the potential to rival SMAC by providing high precision with an existing aircraft sensor.

The second paper (GREY & DALE) was a detailed presentation on TERPROM and the extensive flight experience with that system. The navigation error was reported to be smaller than the map errors due to averaging. The need for flight experience to validate such systems was stressed. Cases of missing hill tops in the data base were reported. A new "silent" radar altimeter was mentioned whose power is varied with altitude. No data on its footprint was available, however, it is projected to be undetectable.

The third paper (EIBERT et al) described SPARTAN/ISS, an integration of the Intelligent Sensor System (ISS) which is a downward looking laser, with the previously described SPARTAN. Simulations have predicted greater accuracy than with either system operating alone, however the author was unable to say how the issue would be resolved when the two systems gave markedly different navigational positions.

From the presentations and the discussions it is clear that after 10 years of development TRN is a mature technology capable of providing precise position over terrain. Passive terrain following and terrain collision avoidance using stored information are under development but are not yet mature systems.

SESSION II: POSITIONING BY IMAGE PROCESSING OR GPS

This session included four papers on navigation by image processing and two on GPS. The first two papers considered systems where a dead-reckoning position is updated based on the time of crossing lines associated with roads, rivers, etc. MUEHLENFELD obtained a position error less than 8 m. in a simulation using a Kalman filter and a 75% line detection rate. PLUCHON et al predicted a 300 m. CEP for a stand-off weapon based on data obtained from the flight of a C22 drone.

The paper by CURET and MARAIS described a system which correlates a passive IR image with a stored model obtained from maps or satellite images. They predicted a match to within one or two pixels. Problems exist due to shadows, incomplete models and missing data.

An automatic landing system based on a video image of the runway was described by SCHELL & DICKMANNS. The sensors measure the angles which the camera makes with the aircraft and also track the horizon and runway edges. The concept has been demonstrated with a business-jet simulation that used linearized lateral and longitudinal modes.

A paper on Differential-GPS for landing approach guidance by JACOB & SCHAENZER described limited flight tests indicating potential category II precision. The test aircraft used an INS with a Kalman filter. The authors suggest that this configuration could be a substitute for MLS.

The last paper in the session (STOTTS et al) described the DARPA miniature GPS-based guidance package. The 2 watt miniature GPS has already been demonstrated. Concepts for a fiber-optic-gyro inertial system were outlined.

In summary there is promise for improved navigational accuracy from passive imaging, however the technology has nowhere near the maturity of TRN while suffering the same limitation that it can only function over land. The two systems relating to automatic landing are primarily applicable to civil aircraft operations although both are promising for that application. The miniature GPS is an impressive technical achievement however the gyro on a chip which is needed to complete the miniature guidance package still appears to be a long way from realization.

SESSION III: MISSION AND SENSOR MANAGEMENT

Because two papers had been withdrawn from this session the white paper delivered to the GCP two days earlier was repeated for the benefit of all the symposium participants. It consisted of a one hour tutorial on neural networks with illustrations from work at Naval Weapons Center, China Lake, California by the speaker, Dr. Andes. There was no written paper, however, the oral presentation was truly outstanding; one of the best observed by this reporter in his experience with AGARD. The message which came with this talk was one of optimism and caution for the potential of neural networks. Neural networks can learn and show considerable similarity to intelligent biological systems. However the number of neurons used for simple functions by the most primitive creatures is orders of magnitude greater than what has been built in the laboratory to date. The development of this field shows many of the characteristics that surfaced at the initiation of Artificial Intelligence, i.e., a lot of hype with few demonstrated accomplishments. It took a lot of time to realize that effective Knowledge Based Systems are large, complex, and take years to develop.

A paper titled "Advances In Navigation Support Systems Based On Operational Pilot's Heuristics" (DEBLON et al) gives an AI model of man-machine coupling. After four years of work there is no design yet for a pilot's assistant although an eventual simulation with real pilots in the loop is planned.

The paper by BUTLER & DUKE reports on the use of MUSE, a software IKBS toolkit in the development of a knowledge based flight status monitor. The use of the toolkit increased the speed by a factor of ten which was still ten times too slow for flight.

BERTON et al reported on the use of a real-time expert system for the monitoring of a Kalman filter. The behavior of the filter under a variety of conditions was translated into rules which changed elements of the filter in response to its performance. The system worked well in an orbital navigation application.

PERDZOCK et al described their experience using the ADA language for the redundancy management of a multifunction inertial reference system.

In summary the message which came out of this session is that software can be extremely expensive in terms of both time and money. One has to be careful to appreciate the exact costs and benefits of the newer fields such as knowledge based systems and neural networks. Be cautious against being oversold on capabilities. Realize the limitations on speed, failure modes, and development time. One of the major challenges is the development of the training algorithms that allow neural networks to learn.

SESSION IV: NEW TECHNIQUES AND ALGORITHMS

This session contained six papers that were for the most part unrelated to one another. The first paper in this session (FOSSARD & UZAN) was a mathematical study of trajectory optimization using a forced singular perturbation methodology. This method

separates the motion into slow and fast modes. While there are a number of difficulties in its application the author reported that he was able to achieve greater range with the singular perturbation method.

The second paper (REICHERT & BERTON) described a real-time expert system using image correlation to estimate satellite orbital elements. The expert system allows correlation to a precision of a single pixel. The results with SPOT images show the superiority of this approach relative to more classical techniques. There is confidence that the two minute process time can be reduced. This was a very good paper and provided an example where an expert system proved very effective.

The third paper (HALL & KOHOUT) reported on the development of a reusable software module to provide the navigation function for mission specific missiles. The idea is that an engineer would be able to go to a library of software chips, put them into his system and get expected results. The audience was clearly dubious about putting the idea into practise as the presenter was unable to answer questions which were raised about library support, proprietary software, and international use.

The fourth paper (FLEMING et al) investigated the feasibility of using a parallel processing transputer-based network in an autopilot control law for the longitudinal axis. The work was in support of a large hardware effort at RAE Bedford. Execution time was found to be reduced substantially as the number of processors increased. The system is presently awaiting flight test.

The fifth paper (DAVIS & BIRNBAUM) described an approach to multisensor data fusion in naval surveillance aircraft. The data consisted of radar, infrared, ESM, and acoustic. Preliminary performance results based on simulation were reported. Demonstration on a P-3 aircraft is planned in the near future.

The last paper (PATUREL) described an approach to the computation of low airspeed in helicopters using inertial measurements of attitude and acceleration together with control deflection information. The calculation was based on a linear model of the vehicle. Flight test showed accuracies in the range of a meter per second with a band width of about five Hertz.

SESSION V: SENSOR TECHNOLOGY

This session consisted of six papers on sensors split between inertial, radar and infrared. The first and third papers (DAVIDOFF et al) described laser gyro and solid-state, vibrating-beam accelerometer technology advances in the ballistic missile field. The second paper (ELWELL & KELLY) reported on progress at Draper Laboratory to produce a softball size inertial package costing about $8000 in production. The design uses a resonant fiber-optic gyro and a quartz resonator accelerometer. Elements of the design have been tested in the laboratory and the authors are optimistic that the goal of one knot drift can be achieved with this approach.

The fourth paper (NICHOLLS) proposed a millimeter wave guidance system developed at Marconi as a candidate sensor for a stand-off weapon system. A movie was shown which demonstrated its tracking performance capability. It was claimed that novel hardware elements had made it cost effective.

The following paper (MIDAVAINE et al) described a dual mode system which used a millimeter wave seeker together with infrared. The application was for fire and forget missiles against tanks. Field measurements indicate that the combination has considerable potential.

The last paper (LIANG & DIFILIPPO) reported on the development and testing of an airborne synthetic aperture radar motion compensation system. A strapdown system on the radar was kept in continuous alignment with a master platform. There was no discussion as the authors were unable to attend the meeting.

From the presentations and the discussion it is clear that while inertial sensors represent a very mature technology there continue to be steady advances that improve on size, weight, cost and performance. The ultimate goal of a gyro on a chip appears feasible but has not yet been achieved. Millimeter wave radar offers some advantages over longer wavelengths for missile guidance and appears to be well suited to multisensor applications when teamed with passive infrared or optical seekers.

SESSION VI: SYSTEMS APPLICATIONS

The final session contained four papers, three on systems and one substitute paper on the topic of Session I. The paper by MARKOV et al reported on the development, simulation, testbed aircraft trials and proof-of-concept flight trials of the Canadian ROBOT-X, maneuvering aerial target system. In addition to fulfilling a number of aerial target roles, the vehicle provides an advanced flying laboratory with which a number of sensor, hardware and software guidance and control problems can be investigated.

The next paper (BAIRD et al) described the terrain-aided navigation and target acquisition system on the AFTI/F-16. Navigation accuracy was very similar to the UK results reported in the first session. Accuracy was independent of the algorithms, but strongly dependent on the maps and worse than expected in the mountains where the maps turned out to be poor. TRN has an advantage over active ranging where the accuracy depends on the range slope. There are plans to direct the weapons delivery pull-up using knowledge of the terrain after the ground-collision warning feature has been developed.

The third paper (DITZLER & SUTTON) reported on the Fighter/Attack Avionics Target Demonstration (F/AATD) multisensor tracking system. The tracking algorithm was the same as that described earlier in the paper by Davis. The sensors included radar, ESM and FLIR. As might be expected the radar gives better range, the FLIR gives better angle. The multisystem is much less sensitive to foresight errors relative to single sensor. There remains a fundamental difficulty in making one to one target associations when there are multiple targets and one sensor cannot resolve them. Relative to radar alone the multisensor system had a 2-3 times higher false alarm rate, a 30 - 40% better probability of detection, and a 3-5 times longer maximum track length. It was concluded that the multisensor system gave a tactically significant improvement.

The final paper of the meeting was an oral presentation on the MBB LATAN, an advanced TRN system which has been tested extensively in the Tornado. It is expected to grow to include synthetic view and obstacle warning. The talk was substituted for a cancelled paper and augmented the papers of Session I on the same subject.

ROUND TABLE DISCUSSION

The chairman of the symposium presided over the closing discussion which was initiated by comments from panel members Dr. John Niemela US, Richard Starling UK, Jean Moraud FR, and Dr. George Schmidt US. The comments like the conference were over a broad focus.

There was a general feeling that while the technology was meeting the technical requirements, there is a widening gap between the costs and the funds available. Some future production decisions will depend on whether there is sufficient technology gain to justify a pre-established fixed price. Sensor integration which was a major topic of the meeting, may be too expensive to justify. This idea prompted some heated discussion on questions such as "If we have IR on board do we need radar?" and "Is it necessary to have both TRN and GPS?" The consensus on this issue was that there are strong advantages to redundancy and it is dangerous to put all one's eggs in the same basket. Some cost advantage could be gained by manufacturing complementary systems in the same box.

Several points were made on the TRN vs. GPS controversy. TRN won't work over water and GPS is not self-contained. Both will give comparable accuracy for targeting. Differential GPS for use by the military was rejected on the grounds that it defeats the P-code and exposes your position through the transmitter. The improved accuracy is academic. TRN provides stored information on the lay of the land. The GPS receiving antenna will make a good reflector which is inappropriate for stealth.

There was a complaint that the keynote address identified the threat and the need while the papers did not relate to the theme of the keynote. It was requested that future meetings pay more attention to the operational aspects which drive the need for the technology and justify its probable cost. Military leaders would like to know specifically what operational advantage is likely to result from the technology gains which are reported.

REACTION OF THE SYMPOSIUM PARTICIPANTS

About 40 standard questionnaires were received from the participants. Overall the meeting was rated as good or better by 95% of the respondents. The meeting was rated very good or excellent by 40%. A 70% majority felt that most of the papers met the published objectives of the meeting. A 60% majority said that about half the papers selected were of personal interest to them. A 90% majority said the general level of the papers was satisfactory. A 60% majority found most of the speakers effective in presenting their topics. Two complaints were received that there was insufficient time for discussion. Twenty percent of the responses had criticisms concerned with language or meeting organization. These are summarized below.

There were several requests for a list of participants. It would be reasonable to prepare this before the meeting since all attendees have indicated their intention to participate in advance. Suggest only one or two major hotels so that participants will be brought together for interaction outside the normal meeting hours. Detailed maps including bus routes would be more useful if available before the conference to facilitate navigation to the hotel and meeting site. Discourage papers which exhibit more advertising than technical content. Encourage presentation by the major author who is capable of responding to questions. All authors should provide written copies of their papers. Classified papers should have an unclassified summary for distribution at the meeting.

There were numerous comments about the excellent work done by the translators, but also several criticisms of the translation process. The booth needs to be isolated from the audience as it is very distracting to hear the presentation and the translation simultaneously. English participants requested that perhaps complicated slides could be displayed in English when the paper was presented in French since only the spoken word is translated. The session chairmen and the speakers should be provided with headphones so they do not have to leave the podium to receive questions. Presentations are far better when they are not read from a prepared text, despite the request for one from the translators. Speaking slowly and distinctly is far better for both the audience and the translators than a rapid reading of a prepared text.

CONCLUSIONS AND RECOMMENDATIONS

From the presentations and the discussions it is clear that after 10 years of development TRN is a mature technology capable of providing precise position over terrain. Passive terrain following and terrain collision avoidance using stored information are under development but are not yet mature systems. There is promise for improved navigational accuracy from passive imaging, however the technology has nowhere near the maturity of TRN while suffering the same limitation that it can only function over land.

Guidance and control software can be extremely expensive in terms of both time and money. One has to be careful to appreciate the exact costs and benefits of the newer fields such as knowledge based systems and neural networks. There are several examples of both success and failure. Be cautious against being oversold on capabilities. Realize the limitations on speed, failure modes, and development time. Reusable software has admirable goals for economy, but the case has not yet been made convincing. One of the major challenges for neural networks is the development of the training algorithms that cause the systems to learn. This is probably an appropriate topic for a future working group.

While inertial sensors represent a very mature technology there continue to be steady advances that improve on size, weight, cost and performance. The ultimate goal of a gyro on a chip appears feasible but has not yet been achieved. Millimeter wave radar offers some advantages over longer wavelengths for missile guidance and appears to be well suited to multisensor applications when teamed with passive infrared or optical seekers. Flight experience supports the argument that proper combinations of different sensors can improve tactical performance. The only hope for reducing the cost of multiple sensors is to have them built into the same box.

The development of new sensors has made an overwhelming amount of data available in the cockpit . The design of the cockpit interface to absorb the data and interact with the human pilot will be a difficult and expensive task. It would be appropriate to focus future meetings on this technical area. Future meetings should also pay more attention to the operational aspects which drive the need for the technology and justify its probable cost. Military leaders would like to know specifically what operational advantage is likely to result from the technology gains which are reported on at the AGARD symposia. This is the chief recommendation, namely to put more emphasis on the cost and operational advantage of the technology.

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14. Abstract

Evaluation Report on the Guidance and Control Panel 48th Symposium on "Advances in Techniques and Technologies for Air Vehicle Navigation and Guidance" held at the Instituto da Defesa Nacional in Lisbon, Portugal from 9th to 12th May, 1989.

Papers were presented covering the following headings: Terrain reference navigation methods; Positioning by image processing or GPS; Mission and sensor management; New techniques and algorithms; Sensor technology; Systems applications.

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