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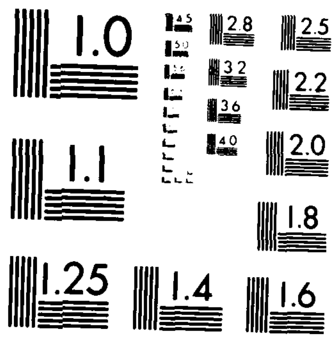

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AGARD ADVISORY REPORT No.208

Technical Evaluation Report on the Flight Mechanics Panel Symposium on Flight Test Techniques

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

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AGARD Advisory Report No.208

TECHNICAL EVALUATION REPORT

on the

FLIGHT MECHANICS PANEL SYMPOSIUM

on

FLIGHT TEST TECHNIQUES

by

Frederick N.Stoliker
Computer Sciences Corporation
Camarillo, California, USA

This Advisory Report was prepared at the request of the Flight Mechanics Panel of AGARD.

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TECHNICAL EVALUATION REPORT OF THE SYMPOSIUM ON "FLIGHT TEST TECHNIQUES"

(Lisbon, Portugal, 2-5 April 1984)

by

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1. INTRODUCTION

Symposia on the subject of flight testing and flight test techniques have been held every four years or so since the Flight Mechanics Panel was established. It was and is deemed necessary and vital that the AGARD flight test community meet regularly so that new information on flight test and instrumentation techniques could be disseminated to ensure that safe, timely, and efficient tests can be conducted.

The Flight Test Techniques Symposium in October 1976 primarily covered the "classical" flight test areas required for flight clearance of the basic air vehicles, their propulsion systems, and externally carried weapons; weapon development; and data acquisition and handling techniques. It was noted that rapid advances were being made in system/subsystem test and evaluation and recommended that a symposium be held to specifically cover this subject area plus the related areas of environmental testing and instrumentation capabilities. This lead to the Subsystem Testing and Flight Test Instrumentation Symposium in October 1980.

That symposium highlighted the diversity of problems and solutions in the field of system/subsystem testing. Subjects ranged from micro-miniaturized avionics to the 'heavy' engineering of landing gear and guns; from impact of climatic extremes to the elusive effects of electromagnetic radiation; and from test techniques and instrumentation facilities of sophisticated complexity to those of simple elegance.

Both of these symposia brought out the point that flight testing areas of concentration were shifting from the classical areas to that of system/subsystem testing. Systems were becoming far more complex and integrated as were the associated instrumentation and data handling capabilities, and there was increased willingness to invest in sophisticated facilities for ground testing. The need for a "global" view of testing emerged wherein major components must be treated as part of the whole system rather than as an isolated subsystems.

The rapidly advancing technologies of integrated flight and fire control, all-weather and night attack systems, digital multi-mode controls, wide field of view head-up displays, system/subsystem simulation, and rapidly increasing instrumentation acquisition, processing, and display capabilities led to the need for another symposium on Flight Test Techniques which was held in April 1984. The symposium was organized around three major subject areas: Performance and Flying Qualities (9 papers); Systems Testing (6 papers); and Instrumentation and Facilities (10 papers). The major points of these papers are covered in Sections 2 through 4 of this Technical Evaluation Report. A summary of the Round Table Discussion is contained in Section 5 while Conclusions and Recommendations are included in Sections 6 and 7, respectively.

2. PERFORMANCE AND FLYING QUALITIES

2.1 Store Drag

Determination of external store drag has been a continuing problem since the first store was hung on an aircraft. Obviously, the problems of determinating store drag have been compounded with the advent of variable geometry and/or multiple carriage racks being utilized. The multiple carriage has introduced interference effects between stores that are not readily or, often, accurately predictable.

The paper by Lutz and Matecki [reference 1] presents a technique for estimating single and multiple store drag building upon an earlier technique discussed by J.B. Berry during AGARD Lecture Series No. 67. Although the paper showed only flight test results, (restricted to the subsonic regime of the ALPHA-Jet test aircraft), the presenter noted that flight test results for static or quasi-static test conditions, in general, showed good agreement with predictions with some differences due to Reynolds Number effects and to model simplifications. The presentation, however, did note that there were some surprises in drag results as a result of unexpected flow around and through full and empty launchers and by mutual interference effects based on stores proximity to each other.

The prediction method shows promise of good comparison between estimated and flight test results, but further effort and study are required to define the estimation technique for interference effects between stores, launchers, pylon and wing.

2.2 High Angle of Attack

High angle of attack maneuvering presents the probability of encountering out of control conditions. These characteristics need to be evaluated and ways of avoiding and recovering from out of control conditions need to be evaluated in a safe and efficient manner.

McKay and Butcher [reference 2] presented data which demonstrated that a "fly-by-wire" control system can be effectively used to provide protection from departures and spins. Their paper noted the need for careful preplanning of all test missions, training of the flight and control room crews, use of real-time telemetry and positive response check lists - all items noted in the paper by Jones [reference 3].

Both papers noted the need for predictive studies such as wind-tunnel and pilot-in-the-loop simulations. Both also noted, either in the papers or the ensuing discussion, that there had been significant errors in wind-tunnel data and in simulations, but the errors did not negate the need for such data. In response to the question "do users find things that were not found in flight tests", Jones response was "not in the F-15 and the F-16".

Both stressed the need for a carefully structured test plan and program, but with flexibility to react to unanticipated test results. Jones noted the pre-test planning and safety reviews utilized at Edwards AFB. He also raised the very pertinent issue of providing test results to several different audiences in a format that would be usable to each.

2.3 Parameter Identification Techniques

Techniques for parameter identification have been in use for a number of years in a research environment. Only in the past ten to fifteen years, however, have these techniques been applied in a large scale fashion by test and evaluation organizations.

The paper by Breeman, Erkelens, Nieuwpoort [reference 4] sets forth an application of the Two-Step method developed in the Netherlands for determining performance and stability characteristics of a transport aircraft while using dynamic maneuvers. The Two-Step method starts by reconstructuring the aircraft flight path and then aerodynamic coefficients are determined using regression analysis techniques.

A research moving base simulator programmed with data from conventional flight tests and wind tunnel data was used to select maneuvers that could be readily flown by the pilot. The simulator was also used by pilots to practice the intended maneuvers.

It was noted that the on-board standard flight test instrumentation system had not been designed for dynamic flight testing, therefore, a laser strap-down inertial system was added to provide the necessary accuracy of measurements. It was further noted that engine manufacturer's data was used for thrust determination.

The authors noted that successful dynamic flight test techniques required an accurate instrumentation system, proven flight test maneuvers, and a sophisticated data processing and analysis software, and that use of a moving base simulator has great value in selecting maneuvers and in providing pilot training. The Two-Step method was stated to provide high quality parameter identification data with much less computer time being required in large part due to the interactive nature of the method.

In response to questions the authors noted that the Two-Step method had not yet been used in determining non-linear coefficients. A member of the audience noted that good results had been obtained in the lateral-directional axes by combining maneuvers. The authors stated that the pilots didn't like combined maneuvers and hence, they were not used. They considered making inputs through the aircraft flight control system, but didn't pursue this because the aircraft didn't have a high-gain system.

Perangelo and Waisanen [reference 5] noted that Grumman has been pursuing the implementation and evaluation of advanced parameter indentification software for use in flutter test data processing with the intent of having an on-line capability in the 1985 time frame.

The authors noted that, before the availability of on-line digital and computer-aided analysis, flutter testing relied on manual and analog techniques. These methods were adequate for determining aeroelastic stability with clean signals that were not strongly coupled, but that these methods were degraded significantly in presence of turbulence or multimodal or highly damped response signals. In 1969, Grumman started developing a near-realtime capability for analyzing flutter response data using a linear-system difference-equation model of flutter dynamics and a least-squares equation-error identification algorithm. Development and refinement of this system continued through 1976 and concentrated on reducing algorithm susceptibility to noise effects and to analyzing data excited via random sources such as atmospheric turbulence. In 1981, Grumman initiated a program to develop a flutter test data analysis capability for both on-line and off-line support for the mid-eighties and beyond. This new capability is needed to support tests of aircraft tending toward the lightweight aerodynamic structures that will not easily accommodate traditional forced excitation devices. Also, an objective is to process data from randomly excited (shakerless) or poor-quality shaker data in a near real-time environment. The advanced parameter identification techniques being considered are the maximum likelihood (first generation) and extended Kalman filter techniques. These techniques are feasible only with the availability of high-speed computers since these techniques require a one to two orders of magnitude increase in computational capability when compared to the least-squares equation-error techniques.

It was noted that it is expected that the maximum likelihood method will have the advantages that one all-encompassing model is used for analysis and that since all available data in the measurement record is used, the need for windowing data has been eliminated. It was also noted that the goals of on-line data analysis are to improve safety and reduce program costs, and cost reduction is tied to reducing flight time and in minimizing the requirement for high quality shaker systems which are becoming more and more difficult to incorporate in the airframe.

During the question and answer period the authors noted that currently they are only looking at linear modeling and once having mastered that will look at non-linear situations. It was also noted that use of shakers will be reduced but that there is still a need for shakers/exciters, but it was stated that the projected techniques will provide optimal results whether or not a shaker is used. Elements of noise covariance could be obtained with the proposed methods, but since real data is not yet being used most efforts are exerted toward obtaining system stability.

2.4 Lift and Drag Determination

The battle to determine the lift and drag characteristics of each new airframe continues. Dynamic maneuvers are a means of reducing flight time required, but special preparation and techniques are required.

In reference 6, Knaus notes that a combination of steady-state and dynamic maneuvers resulted in high quality data that permitted accurate determination of the effects of aerodynamic modifications on lift and drag for the Tornado. Special attention was paid to the selection and calibration of the flight test instrumentation to provide high accuracy of static and total pressure, angles of attack and sideslip, 3-axis measures of acceleration, and engine parameters. Test data was telemetered to a ground station for real-time analysis. The test engines were calibrated on test stands and in the Altitude Test Facilities (ATF) at the National Gas Turbine Establishment (NGTE) at Pyestock, U.K. The engine instrumentation used in flight was the same as that used in the ATF.

During flight test a combination of steady state and dynamic maneuvers was used to improve data quality as well as to minimize flight test time. The author states that this combination of tests provided data that would take four to five times longer if only steady-state maneuvers were used. Further, he notes that dynamic maneuvers provide induced drag and zero-lift drag data in much greater quantity than steady-state maneuvers.

The author notes that there was good agreement between predicted and flight test data for all wing sweep conditions tested. His concluding remarks also noted that quality results and savings of flight time are obtainable only through special attention to pre-flight activities such as selection and calibration of flight-test instrumentation which is specifically tailored to the task, preparation of data reduction techniques, and careful calibration of engines.

In response to questions, Knaus noted that he had determined only total drag - not inflight thrust - and that angle of attack accuracy of 0.1 degree had been established by reference to the inertial platform during dynamic maneuvers.

2.5 Flight Testing a Digital Flight Control System

Modern computer technology is opening many options in the aeronautical sciences and, in particular, has provided the control systems designer an opportunity to tailor aircraft flying qualities.

In this paper [reference 7], Van Vliet spells out the modifications made to an F-16 aircraft in order to evaluate new flight control technologies, the implementation of a triplex digital fly-by-wire flight control system which operates asynchronously, implementation of an analog independent backup unit (IBU), the choices faced in incorporating these into the airframe, and their impact in flight testing.

The IBU had its own set of design and implementation problems caused by the necessity to be reliable, "simple", and independent of the digital system. One redesign was occasioned following an IBU flight test in the NT-33A Inflight Simulator. An interim fix was provided to give improved low speed aerodynamics, but resulted in a placard against supersonic flight until the IBU was redesigned. A number of issues were resolved relating to when the IBU was to be tested. The decision was made and implemented to test IBU as part of the envelope expansion.

Operation of the digital computers in the asynchronous mode was selected after an extensive trade off study. The asynchronous operation resulted in very fault tolerant operation.

Control laws were designed utilizing Linear Quadratic Synthesis (LQS). This resulted in gains being built into the system that were many times higher than equivalent gains in the F-16. These high gains proved to be a design deficiency and the gains had to be reduced.

The redundancy management system generally worked well, but had to be changed to be more compatible with the control laws. Among other changes, the "trip" level was changed from a constant 15% trip level to a variable trip level based on the rate of change of a specific output in its processor. Much of this harmonization was performed on a simulator.

The issue of how to complement various control modes was discussed as were the results of the various modes implemented and tested. Flight tests showed that mode purity was not as critical as anticipated; however, a little impurity in tasks requiring high accuracy such as aerial refueling or formation flying could make the pilot very nervous.

Many of the flight test results from the IBU and asynchronous digital control system differed from simulator predictions. This has raised a number of issues on the use of simulators to accurately represent a highly augmented fighter aircraft. The early and continued participation of the pilots in the design and simulation process, however, was felt to be beneficial.

During questioning, Van Vliet noted that the next generation IBU will be digital. EMP and EMI tests were performed at high level and the whole system seemed relatively immune. The asynchronous mode was chosen for its anticipated fault tolerance and the system seems to be very fault tolerant and is easily reset. He further noted that control harmony between stick, throttle and throttle twist was a problem and resulted in difficulty in tracking a "jinking" target. Fine corrections during side force operations were very difficult and tiring. Sideforce was ultimately held to 0.5g.

2.6 Clearing Aircraft for Operation After Runway Damage Repair

Recently there has been a flurry of test activity to determine aircraft capabilities when operated from runways that have been modified to simulate repair from damage. This presentation by Seidel [reference 8] details the test preparation, conduct and test results from operating a Tornado over a single AM-2 mat or over two AM-2 mats with different spacing.

The author noted that tests were planned in two phases. The first phase was conducted on a flat surface utilizing one or two mats under test conditions which were predicted to result in loads not to exceed 80% of limit loads. The second phase was to include reduced levels of repair quality. At the time of the Symposium, only phase 1 tests had been completed.

The test aircraft was a prototype Tornado which was heavily instrumented for aerodynamic tests. Additional instrumentation was added to measure landing gear behavior. Test data was recorded on-board and the PCM data was telemetered for quasi on-line evaluation.

A computer model existed prior to start of tests and was used to select test conditions and define initial pilot techniques. This model was updated using test results and provided excellent correlation of predicted and test results.

As expected, critical loads were approached only as a result of multiple mat traverses. Pilot technique did affect loads during braking or thrust reverser usage, but changes to techniques minimized these effects.

An unexpected result from these trials was the effect of runway surface characteristics. After some unexpected test results, a runway survey showed an area, just ahead of the second mat, that varied from 3.5 cm below runway average to 1.5 cm above average in a span of 15 meters. After relocating the mats, test results showed good agreement with predictions.

In response to a question regarding ability to predict weights at which an aircraft could operate from a damaged/repaired runway, the author stated that clearance could be provided over roughness equal to two AM-2 mats, but that thrust reverser use would have to be limited.

3. SYSTEMS TESTING

3.1 Evaluating Aircraft as Receivers During Air-to-Air Refueling

During 1982, the U.K. experienced a large stimulus to increase the air-to-air refueling capability of a large portion of the Royal Air Force. In this paper [reference 9] Bradley sets forth some of handling and performance tests required to clear aircraft as receivers. Also included are some results of aircraft that were qualified as receivers, particularly large transport aircraft.

The author described the characteristics of the probe and drogue system in use. He then provided a description of a typical refueling maneuver and described the typical changes in handling qualities, performance, buffet and noise than can occur. Pilot technique was also briefly described, including optimum positioning after drogue contact. The process whereby the clearance for refueling was conducted was noted, as was the importance of a chase aircraft for obtaining a video record in case any unexpected behavior warranted further analysis.

The author noted that, at this time, the assessment of handling qualities during air-to-air refueling is almost exclusively a qualitative assessment by the receiver pilot. Engineering quantifications usually serve only to explain why the pilots find handling easy or difficult.

Trials indicated that all aircraft types evaluated have the potential to be receivers, but that some had difficulty behind certain tankers. In general, large aircraft do not perform well as receivers when attempting refueling behind a wing-mounted pod. No significant handling problems due to asymmetric thrust of multi-engined receivers were noted, however, the refueling envelope is significantly reduced. Also, it appeared that engine operations of receiver aircraft were not particularly affected by the disturbed airflow environment.

The use of "tobogganning" or maintaining a rate of descent during refueling has allowed refueling of aircraft that otherwise had insufficient performance. The disadvantage here is the need to regain altitude and the possibility of encountering turbulence or clouds.

There were concerns raised about the effects on fatigue life of airframes while operating in the increased turbulence during refueling. However, no quantitative data has yet been obtained.

During the question period, Bradley noted that corners were cut and risks were taken, but not during flight. Also he noted that use of instrumented aircraft didn't decrease flying time, but did increase confidence in the data. Instrumentation was often not available to assess performance and handling qualities, but the fuel system was always instrumented.

Bradley stated that he was not aware of quantitative methods to provide "read-across" clearances for receiver aircraft. He felt that read-across clearances for "fast jets" could be accomplished with some confidence, but that large aircraft are more difficult to clear with confidence.

In response to a question on reducing drogue drag by redesign, Bradley noted that there are certain minimum drags required to assure drogue engagement. He noted it would be desirable to have the drogue fly lower in relation to the tanker to reduce turbulence, but was not aware of any design efforts to do so.

3.2 Evaluation of Navigation Equipment

The evaluation of the accuracy of navigation systems is becoming ever more difficult because of the relative accuracy of the systems to be tested. This paper by Smith and Stokes [reference 10] sets forth the history of systems developed at the Royal Aircraft Establishment (RAE) for the assessment of navigation accuracy, sets forth the use of Kalman filter techniques and usages, and provides some typical test results.

Accuracy requirements became ever more stringent from the mid-1950's until the late 1970's when it became necessary to know position with 10s of yards. This accuracy was required to assess the effects of flight maneuvers on the accuracy of the INS under operational conditions.

The authors trace the development of the RAE system noting how various data sources were utilized, what the source errors were, and how source errors were taken into account. As systems became more complex, Kalman filtering techniques were developed to ease the automation of the process of obtaining reference positions. There follows an explanation of the advantages and assumptions relating to Kalman filtering techniques. An important item of note is that use of Kalman filtering requires a detailed knowledge of the characteristics of the individual sensors.

The RAE system uses preprocessing of data from individual sensors to reduce the total computing task and to simplify software design. This preprocessing makes it possible to use a relatively simple set of error sources for the Kalman Filter state vector with considerable benefits in terms of reduced computation.

The authors note that because maximum accuracy of data is not required until after the flight the Filter is run backward with respect to time to produce a new set of estimates of Inertial Navigator errors. Then, the two versions can be merged to give a single best estimate based on all available data.

The lessons learned are that the Kalman Filter approach does work and its use is justified even in the face of the detailed knowledge required of the individual sensors, and that if Integrated Navigation techniques are to be applied widely individual equipments need to undergo flight testing to produce more pertinent data.

3.3 Autopilot Performance Evaluation

The use of test rigs/iron birds in preparing for and evaluating the results of flight tests has been increasing rapidly. In this paper [reference 11], Carabelli and Pellissero, note how a test rig was used to support Tornado autopilot system performance evaluations, note lessons learned, and to tell of a future use of a test rig.

The test aircraft was instrumented to gather autopilot data by tapping into the interface in the analog section. This particular data was required to evaluate system dropouts. As sometimes happens, the instrumentation tap caused some problems which required extensive investigation.

An extensive ground based data acquisition and computing facility was utilized which permitted real-time display and quasi real-time data analysis. The system allowed parallel processing of data from previous flights for comparison and analysis purposes.

A real-time simulation capability also existed which used flight hardware in the loop in order to reproduce real behavior of the system. Case was also exercised to ensure that wiring was configured as closely as possible to that in the aircraft. The simulation was validated using predicted and flight test data and was used for software confidence testing as well as duplicating in-flight occurrences and for training.

Lessons learned included: software can always be affected by human errors which sometimes require sophisticated and expensive validation tests to uncover errors; in spite of expectations software changes are not easy to perform correctly; test rigs offered quick and productive means to uncover the source of errors; people must always be reminded that test safety is paramount; and test engineers must become more conversant with design engineering and, where possibly both the test and design disciplines must learn to share and understand mathematical modeling and flight simulation.

New facilities tailored to the needs of the AM-X aircraft development are being developed utilizing the lessons learned from Tornado evaluations.

The authors responded to questions noting that they could not predict "rig" time to flight time for the AM-X based on Tornado experience, and that the Tornado simulation results were quite good because simulation based on predicted data had been updated with flight test results.

3.4 Assessing Pilot Workload In Flight

Over the years there have been many attempts to find ways to measure pilot workload during flight. Most of these efforts have not had success. As Roscoe notes in reference 12, there are two broad conceptual groups into which most workload definitions fall - the "input load" which is related to the demands of the flight tasks and the "operator effort" which is associated with the response to the tasks. Roscoe has chosen to direct his attempts to measure workload to operator effort.

Roscoe notes that many physiological variables were considered for monitoring as a measure of pilot workload. Since the method of choice had to be non-intrusive as well as compatible with flight safety, heart rate was chosen as the measurand. Heart rate, speech and various aircraft parameters are recorded on magnetic tape. Subsequently mean heart rates for 30 second periods are plotted vs time.

Initially, pilot opinions of workload were provided in a relatively unstructured descriptive manner in an attempt to equate workload to heart rate. After much trial and error a "Pilot Workload Rating Scale" has been developed which has proven useful to the pilots in assessing workload.

The author discusses a number of examples of assessing workload using heart rate and related pilot assessments where this approach seems to provide a good correlation. One of the keys in the success has been in getting pilots to provide a workload assessment for the 30-second period prior to the time when they were asked for the assessment.

The concept of "arousal", although not based on solid experimental evidence, has proven useful in describing the relationship between workload and heart rate.

In response to questions the author made the following points:

- There is no apparent hang-over or carry-over of heart rate from one task to another.
- There is an initial relationship between reponse in a simulator and flight test, but pilots readily adapted to the simulator and heart rates would hardly rise.
- There does not appear to be any clear relationship between risk and heart rate.
- It is very hard to find a relationship between heart rate and very short-term workload.
- Heart rate tends to be a good indicator of workload regardless of the experience level of the pilot.
- Observors noted errors that occurred, but unless pilots became aware of the errors, heart rate was not affected.
- Higher heart rate does not always equate to higher workload. The higher rate could reflect a higher arousal state.

3.5 Avionic System Testing

The sophistication and complexity of modern aircraft-especially those with large integrated avionics systems - are creating severe problems for the flight test community. How does one adequately test and evaluate all of the system capabilities in a safe, efficient and timely fashion?

In his paper [reference 13], Cruce notes an approach taken in support of the F/A-18. As stated the F/A-18 represented a quantum increase in sophistication and complexity over previous aircraft tested at the Naval Air Test Center.

A simulation was prepared and used to reduce the amount of flight test time required. The simulation was based upon the MIL-STD-1553 multiplex bus architecture. An actual fire control computer was integrated into the simulation and was attached directly to the data bus. The avionics subsystems were modeled on general purpose computers that were connected to the data bus through special purpose interfaces. The simulation was driven by software that simulated the external environment of the aircraft, i.e., air-frame dynamics, earth, atmosphere, and targets. In this fashion the operation of the fire control computer in the laboratory is made to match the fire control computer in the aircraft during flight. Once the match is achieved, the simulation is used to evaluate software performance in each of the mission computers. Examples of the type of laboratory tests conducted are contained in the paper.

It is proposed to expand this simulation testing to include hardware systems such as the stores management set. In one case the simulation was connected directly to the aircraft multiplex data bus and models of avionics systems that were active in the air-craft were removed from the simulation. This allowed evaluation of the stores management set in the airplane as well as the production configured weapon racks and weapon suspen-sion hardware.

The author notes that increased use will be made of this type of simulation testing as airborne weapon systems continue to increase in complexity. Also, it was stated that this simulation may be the only way to evaluate off-nominal conditions such as computer or actuator failures.

During the question period, the author noted that failures were not injected into the simulation during this test period, but he anticipated this would be done in 6-9 months. He also stated that there was no real air-to-air equipment in the laboratory set-up - just math models - but they anticipated integrating this equipment into the simulation in the near future.

The Nimrod MR MK 2 weapon system represents a large step forward in Anti-Submarine Warfare (ASW) capability. Means were required to determine not only how accurately systems and sensors work, but also the best way to use the total systems as a fighting machine. In reference 14, Dutton sets forth the planning for and the use of various facilities for conducting the Nimrod performance.

The Nimrod is a complex, digital computer based weapon system. The early trials had shown that the aircraft's systems were safe to operate, and that the equipment provided sensible data. The next step was to conduct trials which would measure the performance of the aircraft in as near an operational environment as possible. These weapons trials were viewed not as a one-time event, but rather as an on-going require-ment. This recognition, therefore, flavored the way instrumentation and data processing systems were established.

The integrated Nimrod weapon system is made up of four complex data systems that are each under the control of a host software program. There is no overall control by a single software program. This posed the potential problem that a fault could be rooted in one system, but would show up on another system. In addition, the programs in each of the four sub-systems is updated as required and not at the same time.

The instrumentation system used to gather on-board data included the operational data recorders, a special test system, hand-held tape recorders, hand-held cameras, and video recorders. Much of the special instrumentation was requied to ensure highly accurate time synchronization between the aircraft systems, the recording systems, and the range data. The timing accuracy was selected early-on as 0.1 seconds for reasons of space positioning accuracy. This was a serendipitous decision since it happened to equal the tactical computer system cycle time.

Range information provided the space positioning data required for the Nimrod and its targets. However, special airborne photographic techniques were required to provide accurate sonobuoy tracking.

Because of the amount of data to be gathered and analyzed it was obvious that an automated data analysis system based on a digital computer was required. The data analy-sis facilities were fashioned to permit the replay of data as well as to provide merged, processed data for review. The period of two years prior to the trials provided the opportunity to prepare programs for merging, sifting, and smoothing of data. A database format was chosen for the trials data. The use of database format permitted rapid and easy access to the large amounts of data gathered.

The author noted that future trials are already being planned. He set forth the types of tests and the facilities which will be used along with rationale for using those facilities. He also noted that a new microprocessor controlled trials instrumentation system is being developed. The system will generate 1600 bit-per-inch computer compatible tapes in flight such that analysis can start immediately after landing. It is expected that this system can be fitted to a trials aircraft in a few days.

The techniques used during the trials were generally considered successful and future trial programs are drawing heavily upon the experience gained.

In response to questions, Dutton noted that in an operational environment, all operations would have to be done in relation to the drifting sonobuoys rather than to some fixed earth station. He felt that use of the GPS NAVSTAR would be very useful to future trials in solving navigational problems. He noted that it would have been very useful to have system math models available prior to the trials; however, since all error modes couldn't be anticipated, math models had to await determination of system error distributions.

The proposed integration of diffraction optics head up display (HUD) to the F-16 and A-10 posed equally difficult tasks to the evaluators and integrators. Wurfel [reference 16] sets forth a description of the HUDs tested, tests conducted, the problem encountered, and provides recommendations for system modifications and future testing.

Evaluations of various avionic systems applicable to the night attack mission verified the effectiveness of some of these systems and confirmed the importance of a HUD. The ability to overlay flight and weapons information on a wide angle electro-optical video presentation and provide that information to a pilot on a HUD was determined to provide a significant advantage for conducting effective night operations. A decision was made to build wide field-of-view (WFOV) HUDs for the F-16 and A-10 aircraft and to conduct appropriate tests. (Integrated systems level performance evaluation was not part of these assessments). Test objectives were to verify that WFOV HUDs were functionally equivalent to the production HUDs and to provide an evaluation of the HUDs video raster capability.

In addition to modifications to incorporate the WFOV HUD, the F-16 was modified to carry an instrumentation package for recording MIL-STD-1553B data traffic and an airborne video tape recorder (AVTR) to record video and audio information. The A-10 was also modified to incorporate the WFOV HUD, a cockpit television sensor (CTVS), and AVTR.

A Head Up Display Rating Scale was developed specifically for these HUD evaluations. This scale proved valuable in providing an objective indication of how the users perceived the WFOV HUD.

Numerous problems were encountered with HUD capabilities. These are discussed in the paper. Two interesting problems, however, deserve attention. On the F-16, a dual [illegible] problem was encountered. After extensive investigation, it was determined that this result was caused not by the HUD, but by the decollimation effect of the canopy. This effect could well have been uncovered by planned ground tests that were deferred because of pressures to start flying. The second problem was related to pilot comments that the eye motion box was too restrictive. After conducting an eye position study, it was determined that for the F-16 the actual eye position was well forward of the specification value used for HUD design. The same problem was noted but to a lesser degree in the A-10. These problems are both to be considered in subsequent HUD modifications, but both point out the need for meticulous attention to detail during system and test preparations.

4. INSTRUMENTATION AND FACILITIES

4.1 In-Flight Antenna Pattern Determination

As the airborne capabilities and complexity both increase, there is a resultant need to provide an improved - and evermore complex - ground support capability.

In their paper [reference 17], Bothe and Klein provide a description of the DFVLR system that was designed and constructed to determine both airborne antenna radiation patterns and characteristics of the receivers to support Electronic Support Measurement (ESM) and Electronic Countermeasures (ECM) systems. Also included is a description of system use and test techniques. Representative test results are presented.

The overall system consists of a ground emitter subsystem used to illuminate the target, the data acquisition, transmission and processing subsystem which provides quick-look and processed data, and an on-board receiving subsystem which detects the signals received by the target antennas.

The illuminating subsystem is slaved to the automatic tracking system which also receives telemetry (TM) data from the aircraft under test. A TV monitoring system is mounted on the telemetry antenna to provide visual confimation of tracking the correct aircraft. The TM data is available for quick look and, along with ground station derived data and timing data, are tape recorded for off-line evaluation.

The authors noted that it takes two to three weeks to fly tests and two to three months to get the processed data when performing a calibration from UHF to 18 Gigahertz. They also noted that their tests had not been affected by topographic layers because of the short distances (from 10 to 40 kilometers) involved. They responded that it would be possible to acquire their data as a result of piggy-backing on other tests, but preferred to use dedicated missions.

4.2 Test Techniques for Determining Structural Loads of Externally Carried Stores

The necessity to measure the loads on the aircraft caused by externally carried stores is becoming more critical with the advent of the variable geometry aircraft and with the proliferation of stores that must be carried. Bertolina et al [reference 18] have provided a description of the overall Tornado stores flight test program including instrumentation and calibration procedures, flight test techniques, and presentation of test results obtained to date.

This particular series of tests was driven by the revised FRG and Italian Air Force requirement to carry MW-1, NATO, and conventional stores without changing adapters and ERUs for the different configurations. The changed requirement led to revised ERUs and fuselage pylons and, consequently, new tests.

The test Tornado had been previously used for loads measurements and hence, had a full complement of loads instrumentation. The aircraft also had full standard instrumentation to record aircraft configuration, flight parameters, aircraft response parameters, and control surface positions. Extensive additional instrumentation was added to measure loads generated on the store racks. A detailed review of this latter instrumentation is provided in the reference. In order to prevent/minimize output drift due to ambient temperature changes, strain gage bending bridges were used wherever possible in lieu of shear bridges. Cross influence on strain gage output, if evident, were compensated by computer processing.

Calibrations of rack instrumentation was done both off-aircraft in a laboratory and on-aircraft with the aircraft fixed on a support frame. The on-aircraft calibration data was recorded using the flight test signal conditioning and tape recorder.

Flight tests were conducted using quasi-static or slowly changing dynamic maneuvers. A "standard maneuver" was performed near the beginning and end of each flight to provide a quality assurance check of the data obtained. Real-time monitoring via a telemetry link was used when approaching hazardous test conditions, to provide quick-look data analysis, and to accelerate test conduct.

A universal software package was prepared for data processing. Modules were selected and activated for specific test conditions utilized. Data was processed and compared to wind-tunnel information.

Even though tests were not yet completed, the authors felt that initial test results confirm the reliability of the course chosen.

4.3 Real-time Monitoring and Control of Flight Testing

Real-time monitoring and control of flight testing has been a long-time goal. The advent of telemetry and large scale computers and specialized software have made this goal a reality in specially equipped facilities.

In reference 19, Scherrer presents a detailed description of the real-time support facilities at Istre. There is a wide divergence in the level of use of facilities. For example there are a number of flights which are flown in an autonomous mode - little or no support from the real-time center - whereas missile tests and high angle of attack tests require a large amount of interchange. This demonstrates that facility must be modular and flexible. Space positioning data as well as telemetry data are available.

The Flight Test Command Post (CIGALE) was established to provide real-time data monitoring for safety of flight and for data quality. In 1977, real-time data processing capability was added. Color CRTs are used for some data presentations while black and white CRTs are used for tabular data presentation. The present data processing system is based on mini-computers which are to be replaced with SEL 32/87s.

During his presentation [reference 20], Costard detailed the flight test data acquisition and data reduction system operated by Avions M. Dassault-Breguet Aviation. A movie was shown which dramatically demonstrated some of the uses of the system. This system is currently supporting 13 different types of aircraft in various states of development.

The real-time acquisition and reduction of telemetered data enhances flight safety, provides support to the pilot in monitoring tests, reduces data processing time, permits monitoring of aircraft and instrumentation systems, and allows integration of the ground test team. The result is enhanced safety, reduced flight time, and reduced turnaround between flights.

The movie demonstrated the use of the real-time system to support high angle of attack and spin testing. The near real-time graphics display of maneuvering aircraft was most interesting.

Other flight test support capabilities were set forth in the paper and the accompanying figures.

During the combined question and answer period, Scherrer noted that the CRT displays are variable and programmable. The display can be frozen and/or a replay can be conducted. The CRTs are updated at 16 frames per record for graphics and 1 frame per second for tabular data. A hard copy can be obtained of any display. The configuration for any given control room can be established automatically. He further noted that two different tests can be supported simultaneously.

Costard noted that analog displays are presented in real-time and that digital displays are true values. The aircraft manufacturer works with CEV/Istre in developing new capabilities and, where reasonable, use the equipment of the Center. He further noted that the cinetheodolite data used in displays do not contain corrections for tracking errors, but that 75 percent of data is acceptable (±1.5) meters in X, Y, and Z). The equations used for real-time conversion to engineering units in real-time are accurate enough such that reconversion to engineering units is not required for batch processing.

In his presentation [reference 21], Dinkel presents a history of the real-time systems used to support Grumman flight testing. He described the Automated Telemetry System (ATS) which incorporated on-line processing, the up-grades made to the ATS to provide a second-generation capability, and then describes the New Display and Control System (NDCS) which is expected to be operational in 1986.

Dinkel noted that use of the ATS improved testing efficiency, enhanced productivity, accelerated turnaround between flights, and enhanced flight safety. The system monitored and displayed limit violations as they occurred.

The second generation ATS resulted from the incorporation of a new software operating system. The new software permitted enhanced computational capabilities (which included ability to look up data from tabulated files), permitted deferred processing which still supplied near real-time answers, provided increased core storage for analysis programs, provided ability to create output files, and permitted intermaneuver data processing. This enhancement was designed to provide answers during the flight which previously had been available only in the batch processing mode.

The NDCS is being designed to improve support for systems flight testing, to provide better quality and quantity of answers to the flight test engineer, and to eliminate single points of failure. The system will have a great deal of modularity to permit selective upgrade of the computers used and/or permit addition of equipment to increase data flow. A complete description of the NDCS is contained in the paper.

Dinkel in response to questions commented that another factor in the upgrade was that present equipment was running out of life. He noted that Grumman is building their own system to support both on-site and off-site tests and that data from remote sites will be brought back to Grumman via satellite link.

The NDCS will incorporate a Hyperchannel which is a commercial product to permit high speed communications between different types of computers. There will be two Hyperchannels available to permit parallel operations and avoid a single point of failure.

The set-up time is minimal because all software is available and selectable. The system turn-around time between non-similar aircraft is about one-half hour.

The training of engineers to use the system has not been a problem for Grumman because of the limited types of aircraft supported.

TSPI data is not presented at the ATS stations. Aircraft position is tracked by another person in a different building.

Dinkel stated that the ATS has improved flight safety by providing limit checks and assistance in monitoring critical parameters during emergencies or spin testing.

4.4 Airspeed and Windshear Measurements

A perennial problem in flight testing has been measurement of static pressure, speed and flow direction, and turbulence. The usual sensors can only measure air conditions at their location on the aircraft, and this local airflow has been disturbed by the presence of the aircraft. Woodfield and Vaughn [reference 22] describe the use of an airborne Laser True Airspeed System (LATAS), include examples of measurements from the various trials, and give some projections for possible uses of an extended system.

The LATAS which is a CO_2 CW laser Doppler system has been developed and tested by RAE and RSRE since about 1970. The present system was specified in 1978. The same optics are used for both transmitter and receiver. The beam waist (the narrowest portion of the converging-diverging beam) from which the strongest signals are received can be set at distances up to about 300 meters ahead of the output lens.

The Doppler signals from the LATAS are not affected by heavy rain or by dense clouds or fog unless visability drops to less than 50m. The infra-red beams are unaffected by smoke and hazes even though visibility at optical wavelengths may be reduced.

The LATAS system has needed adjustments only after removing the laser, and laser removal has been a rare event. The Germanium window in the nose of the aircraft shows no sign of damage after 3.5 years of flying including flights through soft hail.

The LATAS system is considered totally safe in flight. Only when both the target and the aircraft are stationary is there a need for safety precautions to protect personnel.

Good correlation has been obtained between LATAS results and the calibrated aircraft systems. Some scattering of comparative results is apparent, but this is the result of turbulence changes with time and because the aircraft does not precisely fly into the area measured by LATAS.

A number of potential future uses of LATAS are set forth in the paper.

During the question period, the author noted that the LATAS has been calibrated for backscatter, but gaps do exist and, at present, they can't guarantee the system will operate under all conditions of backscatter. Heavy rain has not caused distortion; however, you can encounter distortion in clouds if visibility decreases to less than 50m. The turbulence/windshear ahead of the aircraft can be measured at a sample rate of 20 per second.

Measurement of direction of windshear cannot be accomplished with a single beam unless conical scanning is used. With conical scan, 3-axis response up to 10 Hertz could be achieved. Using conical scanning and a one-half cone from 15 to 30 degrees, you could measure transverse elements of windshear. (Conical scanning has not been used in this particular aircraft, but reportedly has been flown with "considerable" success).

The optics head weighs approximately 35 pounds and the "rear-end system" weighs about 30 pounds. The power consumption of 200 watts is about equally divided between the laser itself and the heater mat.

4.5 Time-Space-Position Information (TSPI)

Obtaining cost effective, accurate time-space-position information (TSPI) has been a continuing problem as aircraft flew higher and faster and now fly fast and low over terrain of varying types and as more participants were added to the test scenario. It was always potentially possible to add more radars, cinetheodolites, laser trackers, or other TSPI determining systems, but it was usually not economically feasible to do so. New systems have enhanced the ability to gather more accurate data, often with less effort and less cost.

The advent of the NAVSTAR Global Positioning System (GPS) offered a possible solution to the range TSPI dilemma. This paper [reference 23] by George and McConnell summarizes a U.S. Tri-Service study to evaluate GPS application areas, identify and analyze technical issues, evaluate GPS application areas, identify and analyze technical issues, and recommend cost and mission-effective applications.

GPS offers a major opportunity for fielding a standardized TSPI system on ranges that would provide precise and uniform tracking accuracy to an unlimited number of test articles operating between the earth's surface and low earth orbit. Telemetry data link upgrades and additional data handling systems would have to be procured but these costs could probably be off-set by avoiding investments in other high cost TSPI systems. There are, however, some significant GPS performance issues such as data quality and data continuity to be resolved before potential benefits can be realized.

GPS can meet most test requirements and can offer better performance than many conventional (non-GPS) systems. (Test accuracy requirements are detailed in the paper). Also, there are indications that the overall cost savings to the U.S. Department of Defense (DoD) can exceed $300 million over 20 years and could approach $1 billion. (It is noted that the "Land Training and OT&E" range is the only generic range which does not favor GPS over non-GPS systems).

During questioning the author stated that it is expected that, unless there is a wartime emergency, there should not be a problem of usage by the ranges. He noted that it would be very useful to have "band" antennas developed for pods but in the meantime, use of normal "belly" and "back" GPS antennas was being studied.

It was noted that the P code normally provides better accuracy and is less sensitive to multi-path effects, but that C/A code provides better velocity information. System accuracies have been pretty well verified by range data even though the data is relatively limited.

The GPS uses an earth-centered rotating reference system. If targets are in another reference system, the 1972 DoD reference system would probably be used.

Another approach to obtaining TSPI data is set forth in reference 24. In his presentation, Lincoln notes that most of the TSPI gathered by Boeing Flight Test is at altitudes from 0 to 1000 meters and in areas from two to ten kilometers in length. Aircraft mounted forward-looking cameras (the Airplane Position and Altitude Camera System (APACS) were successfully used to obtain TSPI data, but were limited to altitudes up to 100 meters. Use was limited to areas where accurately surveyed runway lights were available. The down-looking camera, used primarily in support of noise testing, had a practical altitude limitation of 20 to 1000 meters, but required that accurately surveyed targets be available when runway lights were not available. Both camera systems required extensive range set up prior to testing and considerable post-test data processing.

Because of the time and expense associated with noise testing, real-time data and pilot guidance information became a priority item during the planning for 767 airplane certification. It was determined that a microwave based system would meet the criteria and such a system, designated the Microwave Airplane Position System (MAPS) was built for Boeing in 1981. The MAPS transponders are located on the ground, but the interrogator unit and data processing equipment are carried in the test aircraft. Further detail is contained in the reference.

Acceptance tests of the MAPS showed that at altitudes above 50 meters, MAPS data agreed within 2 meters of APACS and downward looking camera data at least 95 percent of the time. Below 50 meters, data accuracy was constrained by the geometric dilution of precision inherent in geometrical sytems and by the practical limit on the number of ground transponders deployed. As soon as acceptance tests defined the limits of the initial MAPS system, a study was initiated to determine means to extend the test regime to ground level using other data as inputs.

Alternate sources of altitude data available on test airplanes are pressure altitude, radar altitude and inertial reference unit (IRU) altitude. Each source was evaluated to determine how they could/would be included in MAPS. After MAPS has established an accurate time history of altitude, pressure altitude is used to establish altitude changes below the MAPS flight regime, radar altitude is used to provide accurate altitude over a runway, while IRU vertical speed is used at all times. These data are input to the MAPS linearized Kalman filter as appropriate and the filter provides position output with respect to a fixed coordinate system. With these inputs, the system is referred to as Extended MAPS.

Extended MAPS was verified by use of simulations and comparative tests against the TSPI systems previously mentioned. The Extended MAPS is useful from the ground level to the design altitude of a transponder array. Simulation data agreed with the flight data and, therefore, can be used to study either MAPS or Extended MAPS usages. Extended MAPS altitude data is considered accurate within one meter 90 percent of the time. Future uses of MAPS that do not need as large a transponder array are under consideration.

During questioning, Lincoln noted that MAPS could be used on any aircraft that could accommodate the bulky equipment. It had been used on the 757 and 737 and use was planned for the 767. Accuracy of the system requires carefully surveyed concrete monuments, but ground set-up then only requires placing the transponder on the monument. Each Transponder contains its own power supply thus minimizing set-up. MAPS uses a maximum of eleven transponders. A minimum of three transponders is required for a position solution, but responses from eight transponders are desired. Multipath had not been a problem to date.

It was noted that the IRU was the "poorest" of the three additional altitude sources investigated to augment MAPS.

4.6 Aircraft Instrumentation

Just as aircraft systems have become more complex, so have the airborne instumentation systems become more complex. In addition the need for real-time data presentation plus the increasing costs of flight test time have challenged the ingenuity of the instrumentation engineers.

In reference 25, Karmann and Gandert describe a versatile test and calibration system - General Integrated Multipupose Inflight Calibration System (GIMICS) - that will be incorporated into the flight test instrumentation system. The GIMICS is to be operable in 1985 to support the Advanced Technology Testing Aircraft System (ATTAS) that will be flown at the DFVLR in Braunschweig. MBB-VFW and DFVLR are cooperating in the development of the ATTAS In-flight Simulator which will be based on the VFW 614 aircraft. ATTAS will incorporate a dual fail-passive redundancy concept which will permit computer-controlled take-off, landing and high speed flight in the simulation mode. The GIMICS is described in detail in the reference.

GIMICS itself contains as an integral part a complete test and calibration system which permits signal input - and response - measurement under computer control at different points in the measurement system. GIMICS also includes the calibration center that is built-in to each signal conditioning unit, and is connected to the Test and Calibration System via the calibration bus. Using the calibration center each signal conditioning unit can be calibrated in the stand-alone mode. The sum of all errors lying on the calibration path for each center is less than 0.15 percent of FSD in the temperature range from - 25°C to 65°C.

The components of signal conditioning and PCM are distributed throughout the aircraft, but the Test and Calibration System is concentrated at an operating panel for the measurement system operator. The graphic display provides a quick-look capability for the test and calibration functions. The GIMICS modular and integrated concept results in optimum transparency in the ATTAS hardware and software.

During the question period, Karman noted that although all the transducers are calibrated in the laboratory there are many calibration loops in the system. It was noted that the GIMICS will degrade reliability somewhat, but there is only one critical relay and a highly reliable relay has been selected and used. Only linear calibrations are performed on the aircraft. Non-linear calibrations must be perfomed on the ground. Airborne dynamic calibrations are accomplished in a non-critical flight regime. Inputs from INS or radio-navigation systems that are in IRIG format can input to the PCM system. The maximum power required for GIMICS is 1.5 to 2.0 kilowatts.

In his paper [reference 26], Bever describes the Airborne Instumentation Computer System (AICS). AICS was developed to satisfy the need for a system capable of interfacing special digital systems to pulse code modulation (PCM) systems, as well as providing on-board engineering calculations and display.

AICS design was driven by the need for a compact system that could be easily modified to satisfy changing instrumentation requirements. The capability for real-time data reduction was highly desired to improve flight safety, to reduce flight test time, and to reduce post-flight data reduction tasks. Simplicity and flexibility of design as well as equipment serviceability also influenced the AICS design.

The STD bus (designed by the Pro-Log Corporation at Monterey, California) was found to meet design goals. This bus was designed to work with 8-bit microprocessors and an 8-bit processor was felt to be adequate for most of the known flight test applications.

No specific commercially available card satisfied the requirements to contain the basic general purpose computer and the standard input-output circuitry. It was also determined that an arithmetic or floating point processor was required. Therefore, it was decided to build this board in-house.

A standard enclosure was built to contain 3 wire-wrap prototype cards or 6 printed circuit cards. Standard connectors, however, were not used and it was left for each project to decide the desired type of connector.

Two boards were designed to interface the AICS to a remote multiplexer digitizer unit (RMDU) telemetry PCM system. One board contains the memory accessible by the PCM system while the other board contains the direct memory access (DMA) controller that the PCM uses to interrogate the PCM memory.

A voice output board was designed to interface the processor to a speech synthesizer via the STD bus. This board uses a phoneme speech synthesizer having 64 different phonemes.

The software system was designed and tailored to meet flight test instrumentation needs. Design requirements included low overhead, non-volatile memory, simplicity and optimum use of hardware. Coding was performed in assembly language.

Exhaustive environmental tests have not yet been conducted; however, one version of AICS has met NASA process specification 21-2, curve A for vibration (±2g from 32-500 Hz).

A number of successful applications of AICS are incorporated in the paper. Planned enhancements are also discussed.

In the question period, Bever stated that AICS was designed to provide a flexible interface for two very short lead-time projects. The design tried to include flexibility for other future use. AICS does have some limited ability to take data from an ARINC 429 bus and put it into a data stream; however, the full capability to do this is unknown.

5. ROUND TABLE DISCUSSION

(No attempt has been made to ascribe comments, questions, or answers to any specific individual. The purpose here is to provide a summary of the round table discussion and the comments that were provided by Symposium attendees).

Round Table Participants:

- Mr. A.D. Phillips, USA
- Mr. T.B. Saunders, UK
- Prof. L.M.B.C. Campos, PO
- Dr. P. Hamel, FRG
- Dr. D.L. Kohlman, USA
- Mr. J.T.M. van Doorn, NE
- Mr. J.F. Renaudie, FR

The discussion was opened by the Chairman who stated that there had been a radical - an almost exponential - change in flight testing in recent times. The classical approaches to flight testing are also changing as are the aircraft. Aircraft are becoming much more oriented to digital electronics and this in turn is driving the way tests are planned and conducted. There is much more time spent in test preparation than in flight testing itself.

It was noted that many of the papers reflected the trend to bigger and better real-time computing facilities. The introduction of big computers in the 1970s could and did force changes in flight test management and resulted in increased productivity and efficiencies. In an attempt to stimulate discussion, the question was raised as to whether one could get rid of the big computers and still retain the efficiencies introduced.

In general, the concensus was that real-time processing using a large computational capability is here to stay. It would be extremely difficult to remove the computer and retain the efficiencies that had been realized. In addition, the increases in computational capability, at less and less cost for the hardware, are making it more and more feasible to perform bench testing of systems in simulations thus saving flight time and improving flight safety.

It was noted that the investment in real-time computational capabilities and in simulations is quite analogous to what is occurring in the manufacturing industries. An increased investment in flight test "tools" can and does improve the productivity of the people - and the test aircraft - involved.

The question was raised as to whether we are gathering data because its needed or because we can collect it. The operator of one real-time facility noted that only 25 percent of the data gathered has been looked at - in a post-flight mode - within 12 months of the date it was gathered. The further question was raised as to how to control the people who ask for data and then don't use it.

In reply it was noted that the very existence of a real-time capability tends to force one to use data now rather than at a later date. However, it was agreed that later use of data (where real-time computation is used) usually depends on something unexpected or unusual occurring. Up until that point, it is usually agreed too much data has been gathered - then we discover that we have gathered too little data of the wrong kind.

As in past symposia concern was expressed that where large computational facilities exist the test engineer could easily lose track of the physics of the problem. We must be careful not to be lost in the beauty of answers to 12 decimal places. We must remember where the true quality of the data lies and not just enthralled with the speed or precision of calculation. We must ensure that we're not getting bad data in real time rather than in two or three weeks. The need to critically and logically question test results must be continually brought to our attention and to the attention of our cohorts.

During the 1960s there was some thought that computers could replace wind tunnels, but today we are building bigger and better wind tunnels. Should we as flight testers now be concerned that the new and evermore sophisticated simulators will replace flight testing?

The general concensus is that simulation complements rather than replaces flight test and that a good balance is being reached between wind tunnels, simulations, and flight test, especially for fixed wing aircraft. In many cases the simulation is used to plan the flight tests. The simulator is then up-dated with flight test results so that further tests can be planned and executed.

It was noted that for fixed-wing transport aircraft that flight certification takes about one year while rotary-wing aircraft certification takes about three years. It was stated that a large part of this time difference was probably caused by the lack of suitable wind-tunnel data and consequently, lack of good simulations. New emphasis is being directed in a joint US-Canadian venture, at reducing this time, to approximately one year. Parameter identification is well done for fixed wing aircraft, but much remains to be done in both math modeling and parameter identification for rotary-wing vehicles. A simulation to accurately portray nap of the earth flying was stated to be one of the most pressing needs for military rotary-wing aircraft development.

The issues of the pilot's role in flight testing and the safety of the pilot/test crew were raised as concerns because little had been specifically brought out in the formal presentations. A number of people disagreed that pilot/crew safety or flight safety were not being given adequate attention. Even though not specifically mentioned in presentation, safety is a paramount issue. It was noted that safety is heavily stressed during planning and test conduct, and this is reflected in the safety records of the various test activities. Both simulation and real-time data have contributed to this record.

It was interesting to note the diversity of ways in which real-time data review is carried out. For their large transport aircraft, Boeing places the computational capability and the data reviewers on-board the aircraft. Large amounts of post-flight batch processing is still accomplished, but limits to the amount of data an engineer can accumulate is controlled by not providing space for data storage. Most fighter/attack aircraft telemeter large amounts of data to the computational facility for real-time computation, display, and analysis - using batch processing only as required. For their rotary-wing aircraft, Bell uses real-time telemetry for safety, but records most data on-board the aircraft for post-flight analysis. Bell felt flight safety was enhanced by limiting the amount of real-time data that was available.

It was noted that flight testing has indeed changed character in the recent past. Even though there is a continuing need for the "classical" flight test techniques, the airframe and propulsion system are becoming a much smaller part of the flight test. More time and emphasis needs to be placed upon improved ways to evaluate the integrated avionics systems that are becoming more and more prevalent.

6. CONCLUSIONS

The prime purpose of this Symposium was to share information on flight test and instrumentation techniques amongst the AGARD community. That goal was very well met and there was a consensus on a number of items such as:

- Real-time data analysis and presentation are maturing capabilities that are an accepted part of the flight test communities "tools".
- Simulation of aircraft performance, handling qualities, and systems are rapidly becoming routine "tools" in preparation for and during conduct of flight test.
- "Classical" flight tests such as performance, handling qualities, structure and flutter, and propulsion system integration are still important and vital; however, classical flight tests are relatively less of the total flight test as aircraft are becoming more oriented to integrated digital electronic systems.
- Classical approaches to testing flying qualities/handling qualities against military specifications may no longer be a valid criteria in the world of active control technology. Pilot comments on how good or bad the airplane handles may be a better criteria than hard quantitative numbers when aircraft qualities can be drastically changed through software.
- There is much more integration of ground and flight testing and this trend will accelerate.
- Wind-tunnel tests, simulations, and flight tests are now more than ever complementary rather than competing techniques. Each will certainly compete for the limited financial resources available, but choices of resource allocation must be made on the basis of where each best performs its role in a complementary sense.
- More time and emphasis needs to be devoted to find improved ways to evaluate integrated avionics systems.
- The integration of wind-tunnel and flight test data, use of simulations, and use of real-time data capabilities has improved flight safety especially when the pilot is involved with the development and use of the simulation.
- Much more time and manhours are expended in preparing for flight tests than are expended in actual test conduct.
- The use of pilot rating scales has done much to bring objectivity to such diverse fields as pilot workload assessment and evaluating head-up displays.
- Use of Kalman filtering techniques is becoming very widespread in flight testing. The price that you must pay for using Kalman techniques is in obtaining detailed knowledge of a system and its error sources, but the result is much better, convergent data.
- Parameter identification techniques now appear to be well in-hand for fixed-wing aircraft, but much work remains to be done for rotary-wing aircraft.
- There is a continuing concern that engineers may lose track of the physics and the real purpose of prediction, comparison and flight testing as capabilities to perform these functions become evermore sophisticated.
- There is a continuing trend to using inertial systems as a source of flight test data.
- The use of microcomputers as an interface between aircraft and instrumentation signal conditioning units is a useful approach.
- Satellite-based TSPI systems have potential for use in providing precise and uniform tracking for an unlimited number of vehicles. Long-term equipment investment and maintenance costs can be minimized by using the GPS system.
- The use of lasers to measure airspeed and windshear is a capability that now appears feasible for test purposes.

7. RECOMMENDATIONS

The first recommendation, not surprisingly, is that there should be Flight Test Techniques Symposia held on a regular basis. Four years between gatherings of the AGARD flight test comminity, however, may be too long a period of time because of the accelerating change in the flight test techniques of systems/subsystems, particularly the integrated digital avionics systems.

Therefore, the second recommendation is that consideration be given to establishing specialist meetings between the Flight Test Techniques Symposia for those who are involved with integration, instrumentation, and test of digital avionics.

The following recommendations are of lesser importance than the first two and are listed below in the order of descending priority.

- Attention must be directed to finding innovative means to simulate and evaluate new avionics systems more easily and more quickly.

- More attention must be given to providing parameter identification techniques for rotary-wing aircraft.

- Attention must be given to means and criteria for evaluating flying qualities/stability and control for aircraft that do, or will, incorporate active control technology.

- Since ground and flight tests are becoming more and more integrated, means such as AGARD symposia or lecture series on ground and flight test correlation should be established to increase the contact between ground and flight test personnel. Instrumentation engineers should be included in such activities as active participants.

- Means should be found to ensure that new engineers who are maturing in a sophisticated computation environment do not lose track of the physics of their tasks.

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4. J.H. Breeman, L.J.J. Erkelene and A.M.H. Nieuwpoort. Determination of Performance and Stability Characteristics from Dynamic Manoeuvres with a Transport Aircraft Using Parameter Identification.

5. H.J. Perangelo and P.R. Waisanen. Application of Advanced Parameter Identification Methods for Flight Flutter Data Analysis with Comparison to Current Techniques.

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