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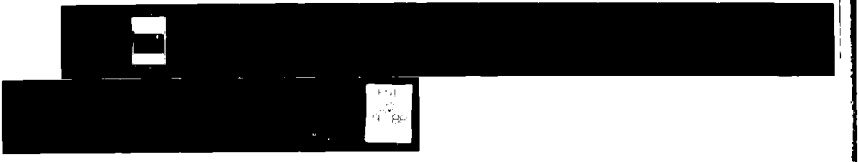

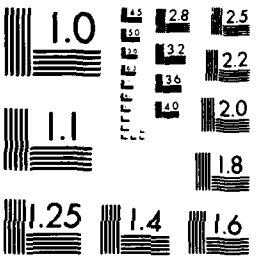

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AGARD ADVISORY REPORT No.243

Technical Evaluation Report on the Flight Mechanics Panel Symposium on Rotorcraft Design for Operations

AGARD-AR-243

NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Advisory Report No.243

TECHNICAL EVALUATION REPORT

on the

FLIGHT MECHANICS PANEL SYMPOSIUM

on

ROTORCRAFT DESIGN FOR OPERATIONS

by

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

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- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
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PREFACE

The expanding roles of the helicopter and the intensified threat perceived by its potential users have led to proposals for future rotorcraft with characteristics significantly different to existing types. The resulting rapid evolution of rotorcraft configurations, in response to user demands, now requires a translation into design criteria to permit the aerospace R&D community to provide appropriate and cost effective responses to these demands. The objective of this symposium was to explore the impact of operational needs on the evolution of rotorcraft design. The result will be to provide a review of the present status of rotorcraft design and to identify priorities and neglected topics. Three specific issues were central:

- The translation of operational mission requirements into design criteria
- The evaluation of techniques to incorporate user defined needs into the design and methods of test and verification
- The identification of design areas where unusual or new user needs are demanding special or radical features.

All papers were obtained by invitation.

The Conference Proceedings, commissioned by the AGARD Flight Mechanics Panel are published separately as AGARD CP 423.

* * *

Le rôle croissant de l'hélicoptère et de la menace, de plus en plus pressante, perçue par les utilisateurs potentiels ont conduit à la formulation de propositions pour des nouvelles voilures tournantes dont les caractéristiques seront très différentes de celles des modèles existants. En réponse aux demandes de l'utilisateur l'évolution rapide des configurations des voilures tournantes impose maintenant la traduction en critères d'étude, afin de permettre à la communauté de R et D aéronautique de fournir les réponses appropriées et le coût réel de ces exigences. Ce symposium avait pour objet de passer en revue l'état actuel de la conception des voilures tournantes et d'identifier les priorités et les omissions. Trois points spécifiques étaient au centre du problème:

- la traduction des exigences requises pour les missions opérationnelles en critères conceptuels
- l'évaluation des techniques pour tenir compte des besoins de l'utilisateur au niveau de la conception et des méthodes d'essais et de vérification
- l'identification des domaines d'étude où les besoins nouveaux ou inhabituels de l'utilisateur demandent des caractéristiques spéciales ou essentiellement différentes.

Toutes les communications ont été obtenues par voie d'invitation.

Le compte rendu du symposium demandé par la Commission Mécanique du Vol de l'AGARD est disponible de façon séparée, référence AGARD CP 423.

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A TECHNICAL EVALUATION REPORT FOR THE SYMPOSIUM ON "ROTORCRAFT DESIGN FOR OPERATIONS" (Amsterdam -The Netherlands,13-16 October1986)

by: Dott.-Ing. F. REINA
(Giovanni AGUSTA S.p.A.)
ITALY

1. INTRODUCTION

The 69th Symposium of The Flight Mechanics Panel on "Rotorcraft Design for operation" was held in Amsterdam from the 13th to 16th October 1986.
Attendance was 150.
The meeting subject was selected on the basis of the following rationale:

- -all nations face the evidence that defence programs tend to become fewer, more expensive, and are characterized by increasing technical risk.
- -Recent experience of mid-program difficulties indicate that a clear method to translate operational requirement in design criteria should be pursued and tentatively outlined.
- -Since most of the parameters affecting Life Cycle Cost (LCC) are decided upon during the preliminary design phases (feasibility + definition) it is at this stage that a severe cross check between requirement and design must be exercised.

Experience has indicated that during the preliminary design phase of a program, companies risk in mis-interpretations of the requirement and the Government procurement is vulnerable to over-sight of some characteristics of the proposed design which may later prove marginally acceptable.It must be considered that the mutual interference of requirement and design should be a two way exercise,with the design feeding back risk, time, cost implications for eventually re-define the requirement.
The passage from requirement statement to design specification definition is a critical program point because the users must resist the temptation to over-specify requirements and the industry the temptation to accept unrealistic commitments just to get the job and the program going.A method imposing severe two-way audits at this stage may avoid many problems later and could be more effective in avoiding unnecessary design efforts and the adoption of less than totally satisfactory designs. It is important to note that the concern for a continuous two way requirement / design interaction is not limited to the basic aircraft definition,but extends to cover the areas of avionic and mission system packages.
Once again it is the total requirement for the rotorcraft system which must be clearly understood by the designers and the total design definition which should be clearly visible to the users .With this rationale as background the FMP quite properly proposed papers offering contributions on:

- °° Operational Requirements
- °° Design and Testing
- °° New Programs

2. LIST OF PAPERS

SESSION I - OPERATIONAL REQUIREMENTS

(Session Chairmen : J-M. DUC,FR,& D.L.KEY,US)

1) Le dialogue "opérationnels-ingénieurs ":nécessité d'une concertation systématique entre constructeurs et utilisateurs pour la réalisation d'un hélicoptère de combat (Gen. G.BAFFELEUF,ALAT,FR)

2) The effect of operational requirements on LHX concept formulation (R.D. HUBBARD & R.L. TOMAINE, US Army AVSCOM,US)

3) Future civil operational requirements in North Sea oil support operations (F.F.J. SCHAPER, KLM Helicopter,NE)

SESSION II DESIGN AND TESTING

(SESSION Chairmen : H.MOOIj,NE & G.E.SACHS,GE)

4) Mission-oriented flying qualities criteria for helicopter design via inflight simulation (P.HAMEL, H.-J.PAUSDER & B.GMELIN,DFVLR,GE)

5) Investigation of vertical axis handling qualities ties for helicopter hover and NOE flight (S.BAILLIE & J.M.MORGAN,NAE,CA)

6) Handling qualities criteria for very low visibility rotorcraft NOE operations (R.H. HOH,Systems Technology,US)

7) MBB simulation facilities applied for rotorcraft research (P.KRAUSPE & H.BORCHERT,MBB,GE)

8) Simulateurs d'études pour Hélicoptères (M.D. JEROME,CEV,FR)

9) Modelling the XV-15 tilt-rotor aircraft dynamics by frequency and time domain identification techniques
(M.B.TISCHLER,Army Aeroflight Dynamic Div. J.KALETKA;DFVLR,GE)

10) Operational load measurements on service helicopters (SMP contribution)
(D.M.HOLFORD,RAE, UK)

11) The flight evaluation of an advanced engine display and monitoring system
(L.ADAMS,RAE,UK)

SESSION III SPECIAL TECHNOLOGIES
(Session Chairmen : L.M.B.C. CAMPOS,PO &
R.R.LYNN,US)

12) Controle actif des vibrations sur hélicoptére par commandes multicycliques auto-adaptives
(M.ACHACHE,Aerospatiale,FR, & M.GAUVRIT,CERT,FR)

13) Controlling the dynamic environment during NOE flight
(D.HALWES,Bell Helicopter Textron,US)

14) Minimisation of helicopter vibration through active control of structural response
(A.E.STAPLE & S.P.KING,Westand Helicopter,UK)

15) Impacts of rotor hub design criteria on the operational capabilities of rotorcraft system
(R.SCHINDLER & E.PFISTERER,IABG,GE)

16) Améliorations des performances du FENESTRON (Rotor de queue caréné pour hélicoptère)
(F.MORELLI & A.VUILLET,Aerospatiale,FR)

17) Rotorcraft design for the year 2000
(E.FRADENBURGH,Sikorsky UTC,US)

18) Helicopter (performance) management.Some ideas on system and hardware realization
(W.BENNER & R.DUSSMAN,Dornier,GE)

19) Fly-by-light- ADOCS flight demonstration program (GCP contribution)
(J. M.DAVIS & N.ALBION,Boeing Vertol ,US)

20) Conduite de tir hélicoptèere:Intéret d'une poursuite automatique de cibles
(B.CERUTTI,SFIM,FR)

SESSION IV NEW PROGRAMMES
(Session Chairmen :S.R.M. SINCLAIR,CA & A.A.WOODFIELD,UK)

21) Development,testing and evaluation of a night vision goggle compatible Bo105DB for night low level operation
R.H. FRIEDERICY,Royal Neth.Army,NE

22) A129 advanced solution for meeting today's combat helicopter requirement
G.VIRTUANI,Agusta, IT

23) Apache for the battlefield of today and the 21st century
J.B. RORKE,McDonnell Douglas Helicopter,US

24) Mission de recherche et sauvetage - système SAR
M.RIOCHE,Aerospatiale,FR

25) The EH101 integrated project : a naval,utility and commercial helicopter system
P.ALLI & R.BALDASSARRINI,Agusta,IT

26) Influence of operational requirements on the design of the V-22 tilt-rotor-aircraft
B.BLAKE & T.GAFFEY,Boeing -Vertol Co,US

3. SUMMARY OF SYMPOSIUM PAPERS

1) The Operational Requirements Session.Paper 1)provided an excellent expression of the difficult task of defining a realistic requirement and highlighted the need for a continuous dialogue between operational experts and designers. Paper 2) provided details on the requirement definition process for the LHX, while paper 3) expressed a full range of civil requirements which presently are not adequately answered and for which more specific attention should be provided.

2) The Design and Testing Session has been characterized by papers assessing the efforts to provide advance evaluation of the designs via simulation (papers 4,5,7,8,9) .
These capabilities of realistic early identification of the most important design characteristic are indeed much needed for a safe development program launch.

The other three papers (6,10,11) propose:
- advanced criteria to quantify the degree of compliance with old ambitious requirements of NOE flight with reduced visual cues)
- Structural life prevision on the basis of complex fatigue monitoring system
-More efficient cockpit management via advanced displays for the propulsion system

3) The New Programs session provided direct experience from new programs which have completed their definition cycle and have reached various levels of operational verification.
Updated information on the AH64 Apache, the BO 105 for night low level operation and the Dauphin SAR system were presented as well as the A129 light Antitank helicopter which has just entered in production and the EH101 which shortly will take his first flight.

4. PRESENTATION DISCUSSION

SESSION 1 -OPERATIONAL REQUIREMENTS Starter with an outstanding contribution by Gen.G.Baffeleuf,ALAT,FR and was centered on the critical importance of the quality of the dialog between "Operatives" and " Engineers" within the military environment and in the military-industrial relationship.
The quality of this dialogue which is normally based on good person to person relationship must be improved,to become a more formal method of verification and promote a change of behaviour on both sides.
This dialogue must be a two way exercise and provide both parties with the information required to carry on the specific responsibilities which can be synthesised as follows:
-for the operational staff:
1)Appreciation and expressions of realistic requirement, avoiding to require impossible or unuseful capabilities but keeping a watchful eye on the future technical opportunities.
2)A timely launch of development programs to avoid unrealistic development time scales and immature fielding of equipment not completely developed or debugged.
For the engineers:
1)best adaptation of the new designs to the military requirement
2)effective cost and time estimations and control
3)correct schedule management
Finally the point of view of the ALAT on the attack helicopter design was outlined as follows:
-the "dedicated" helicopter alternative is preferred to the multifunction option:weight, size and detectability must be minimized to improve survivability on the battlefield and special emphasis must be placed on low detectability characteristic.
An immediate example of a disciplined method to translate operations requirement in design criteria has been provided by paper n.2) presented by Mr.R.Tomaine,U.S.Army AVSCOM.This paper addresses the concept formulation process of the US Army LHX (Scout & Light Attack plus Light Utility).

This process is supported by the wide experience of the US Army on helicopter development and although structured around a rather rigid scheme, in actual practice it is complemented by an intense dialogue (such as that suggested an paper 1) among AMC,TRADOC and Industry.

In this program extensive innovations are demanded by a challenging threat definition which includes ground based weapons, air-to-air and NBC components. Equally ambitiously the LCC (Life Cycle Cost) target appears to reduce the cost of ownership of the new LHX fleet by 40% over the cost of todays fleet of UH-I, HA-I, OH-6, OH -58.

Paper 1) and 2)stressed from two different aspects the point that the most careful attention must be focused on the requirement definition and on the preliminary design phases of any new rotorcraft development.The implication is that today's methodology to carry through these phases is not completely satisfactory and should be improved.

Paper 3) -presented by FFJ Schaper of KLM Helicopter,NE expressed a similar concern.Helicopter operators active on the offshore oil and gas support industry represent the largest group of civil users. Today they feel that the current rate of progress of the helicopter capabilities to meet their requirement is much to slow. Some unsatisfactory areas are cabin space safety, reliability, cockpit ergonomic and vibration. Again the recommendation is that, in future, the designers should try to harmonize basic military and civil requirements at early stages of the definition process. Unfortunately, while the EH 101 has represented a step in this direction, the LHX,NH90 and A129 utility design seem totally dominated by their military requirements.
Therefore three basic questions still stand:

1) Is the limited diffusion of civil helicopters the cause or the effect of the in-complete compliance of existing helicopters to the civil requirements?

2) Can a common civil requirement be expressed by a reasonable majority of the operators?

3) Can military and civil requirements be integrated to lead to a common basic design in which a balanced trade-off on capabilities will permit significant cost saving to both types of operators?

Session II - Design and Testing presented several papers on prediction and simulation technology.Clearly the possibility of precise prediction of the helicopter dynamic behaviour and of the cockpit /display effectiveness is a key factor in the process of Rotorcraft design for operation (see ref.4,5,6,7,8,9)and an essential tool in comparing, at an early stage, the requirements with design performance.

Paper 4 -by Hamel ,Pausder and Gmelin, reported on the advanced "in flight " simulator used by DFVLR in Germany to evaluate the flying qualities of future highly augmented rotorcrafts.This simulator is based on a BO 105 airframe modified with a full authority, simplex FBW system which provides the actuation function for a Model Following Control System(MFCS) which can be easily adapted to represent helicopters with different dynamic characteristics.It is felt that this technique is very promising because it allows the direct investigation of the basic handling characteristics at reduced cost, time and risks with a high degree of realism.

Paper 5 -by Baillie and Morgan provided a report on an experimental investigation of vertical axis handling qualities using an in-flight simulator at the National Aeronautical Establishment of Canada.The objective of this activity is to provide guidance for the future revision of MIL-8501A in the area of required heave damping levels and thrust -to-weight limits.

Paper 6 -by R.H. Hoh from Systems Technology Inc.US, also dealt with an experimental activity to support the revision of MIL-H-8501A in the area of handling qualities criteria for very low visibility rotorcraft NOE operations.The objectives of these experiments were to develop a criterion to account for degraded visual cues in defining the control and stabilization characteristics for the NOE environment.The conclusions are that micro texture visibility (spatial resolution) provides a higher VCR (Visual Cue Rating) than the field of view and that the proposed VCR method can be used to estimate satisfactorily the effectiveness of a display system.Helicopter attitude augmentation can be used to make up for display deficiencies, but it also results in loss of agility, so ultimately it is more effective to try to improve the visual cueing characteristics.

Papers 7 -by Krauspe & Borchert from MBB,GE and paper 8-byM. D. Jerome from CEV,FR, presented excellent informative details on the simulation facilities available at MBB and Aerospatiale to support rotorcraft design.The application of ground based real time flight simulators to support the feasibility,definition,specification and development phases requires high flexibility and realism.It is reported that the quality of available Hardware and Software is now adequate to pick up the challenge and is continuously improving.The total entity of the vehicle and its systems can now be evaluated as a unit providing a much needed opportunity to check the effectiveness of the design solution against the requirements in the early stages.

Paper 9 - by Tischler US and Kaletka, GE dealt with the problem of extracting from flight test data a predictive model of the XV-15 Tilt Rotor Aircraft hover dynamics (no augmentation).Two methods were used: frequency domain analysis and time-domain identification. Both methods were proven to have excellent predictive capabilities and a proposal for a coordinated parameter identification approach using both methods was presented.

Paper 10 - by D.M Holford, UK proposed the results of experimental research work carried out at RAE,Farborough on Operational Load Measurement.

The aim was to substantiate component fatigue lives on the basis of actual operational usage. This is a very attractive field of research in view of the target to obtain an " on condition" maintenance situation for critical parts for which unnecessary calendar replacement is particularly expensive in terms of cost and down-time of the aircraft.The way ahead is promising but does require that the on board instrumentation is capable of acquiring continuous, reliable data.Today the desired reliability is not yet obtained and the paper draws attention to problem areas that must be addressed in future, comprehensive fatigue monitoring system.

Papers 11,16,18,19,20 presented test results and analytical studies on critical helicopter subsystems which provide important contributions to the feasibility of new advanced solutions (such as safe single pilot operation for attack helicopter).

Paper 11- by L.Adams , RAE,UK reported an experimental results from an advanced engine display and monitoring system.The final aim was to allow the pilot to concentrate his attention outside the aircraft while maintaining or improving his safety margin, thus achieving an optimization of mission effectiveness.

Exploiting a balanced use of available technical solutions, such as integrated colour display and synthetic voice outputs it was demonstrated that engine and transmission data other than rotor torque and r.p.m. can be suppressed and provided to the pilot only when really needed.
A similar experience has been presented by paper 18 by Benner and Dussman ,Dornier,GE which covered the more general issue of total helicopter performance management.
Mission planning on the ground and mission management in flight could be integrated to obtain the best effectiveness of the helicopter usage.An advanced cockpit philosophy has been tested to demonstrate that through proper display design and task allocation it was possible to extend the helicopter's utilization to its limits and exploit its full performance potential. This feasibility has been established, but additional efforts, mostly in the sensor accuracy,are still necessary.

Paper 20- by B. Cerutti SFIM,FR presented a backyround view of the rationale behind the requirement of an automatic target tracking capability for helicopter use.Gunnery workload reduction and the improvement of accuracy and stability of the line of sight were obtainable.A possible technical solution for the tracking algorithm has been presented in concept.

Paper 19 -by Davis and Albion ,Boeing Vertol,US presented an advanced and very important experimental activity on flight-by-light technology carried out at Boeing Vertol on a UH-60 Black Hawk helicopter.
Weight, safety, reliability and maintainability advantages have been claimed over the conventional flight controls of the reference aircraft.The functional flexibility to adapt this system to advanced side-arm controllers and optimized control laws makes this system an essential building block for new rotorcraft design such as LHX.The recent Boeing Vertol experiments and flight experience confirm the feasibility of the solution and the availability of the technology both at component and system level.

Paper 21 -by R. H. Friedercy , Royal Neth Army,NE provided a complete and clear history of development,testing and evaluation of a night vision goggle compatible BO105DB for night low level operation.
This extensive flight test activity carried out by the Netherlands Air Force confirmed the feasibility of the concept provided a specific avionic package was added to the basic IFR configuration.The package includes a new cockpit layout with NVG compatible "blue lighting",installation of a Doppler Navigation System with map reader, a Tacan, a Radar Altimeter and a three axis stabilization system.The evaluation of 4 NVG alternatives resulted in the selection of a modified version of the BM8043 NVG's (3rd generation ITT's).

A group of papers (n. 12,13,14) dealt with different approaches to the objective of vibration minimization.This goal has been, and still is, extremely important as vibrations level today constitutes the first limit to improvement of basic operational capabilities such as speed and stability.

Paper 12 -by Mr .Achache , Aerospatiale,FR presented the results obtained by Aerospatiale through the active higher harmonic control approach to vibration reduction.In this case high speed,low authority actuators drive the flight control links to the main rotor swashplate generating loads to the rotor in opposition to the loads from rotor which cause the vibrations.
The control system described is based on a autoadaptative principle ', which the control law parameters are variable and minimize the vibration level by an evolutionary configuration.The experimental work started with simulation studies and was concluded by actual test flights on a SA 349 Gazelle.
Three different types of algorithms were evaluated and the effectiveness of the system has been demonstrated throughout the helicopter flight envelope.
This approach appears to be extremely interesting because the impact on the aircraft is limited to the flight controls and avionic subsystems.Therefore adaptation of the active control concept to a range of helicopters configurations is feasible.
The final result was to reduce cabin vibrations to well below the level obtained by passive devices.

A completely different approach was presented in paper 13 by DR Halwes , Bell Helicopter Textron,US.
On a Bell model 206 LM the main transmission has been isolated from the airframe by a six degrees of freedom passive arrangement based on six "LIVE" links (Liquid Inertia Vibration Eliminator).This passive system,called TRIS (Total Rotor Isolation System) has demonstrated a capability to reduce main rotor induced vibration to below the 0,04 g level, having isolated over 95% of the loads generated by the main rotor. In addition, the TRIS installation has demonstrated a significant improvement in helicopter flying qualities to a point where artificial stability augmentation is no longer required.
The most significant advantages over the Bell 206 baseline isolation system was obtained at lower speeds (< 50 kts) where the main rotor was the dominant vibration source.The weight penalty is estimated to be less than 1% of the max gross weight for the 206 LM helicopter.The movements of the pylon (typically 3/4" displacement and 2,5°torsion) probably limit this solution which is therefore most suited for light helicopters.
Paper 14 -by Staples & King ,Westland Helicopter,UK, proposed an additional alternative to the two previous methods of vibration reduction which was based on Active Control of Structural Response (ACSR).
In this approach high frequency forces are super-posed on the dominant vibratory forces in a active manner within the helicopter structure.In the case of the Westland WG 30

these forces are generated by active elastomeric isolators placed between the Main Gear Box "raft" and the cabin roof.
The active isolators are capable of a movement of 0,5 mm.This system has been fully defined through extensive research studies and has shown significant potential for vibration reduction. Control algorithms have been fully developed and a demonstrator program is now underway based in Westland 30 series 100 helicopter.Flight trials are expected to begin later this year ('86).

The final three papers of section 3 on Special Technologies (15,16,17) offered a very good update on general configuration issues on the main rotor,the tail rotor and on the complete rotorcraft.

Paper 15 -by R.Schndler and E.Pfisterer , IABG,GE,presented a comprehensive summary of the development history of main rotor heads. Several existing configurations (approx 13) have been developed at different times to meet differing needs of the users and are described in this paper.
Future rotor system will be required to provide: high manouvrability,uncritical stability behaviour and low vibration level.These functional performances must be complemented by life-cycle cost and logistic improvements.Bearingless rotors probably present the most promising configuration for light and medium helicopters.

Paper 16 -by F.Morelli and A. Vuillet ,Aerospatiale,FR, presented recent analytical and experimental development of the fan -in-fin (fenestron) configuration of the antitorque system. This configuration was originally developed to improve the safety in case of external collisions,but with continuous improvements it has now reached a performance figure of merit which compares favourably with advanced four bladed conventional tail rotors.The latest performance improvements are obtained with optimized airfoils and stator blades in the diffuser.This newest configuration allows a reduction of the shroud width which results in drag savings in forward flight without hover performance penalty.
Generally speaking and in consideration of performance as well as safety,reliability,detectability and vulnerability this configuration may presently be considered as the best anti-torque system for light and medium size helicopters.

Paper 17- by E. A. Fradenburgh ,Sikorsky U.T.C., US, examined some of the rotorcraft concepts that can offer higher speeds than pure helicopter,including the compound helicopter,ABC,tilt-rotor,X-wing and stowed rotor configurations. All of these are potentially practical aircraft.Economic considerations seem to dictate that the pure helicopter is here to stay, since higher speed rotorcraft are not as cost-effective at short ranges.The heavy lift requirement (30 tons typical) is also examined with the conclusion that a super-large helicopter is unaffordable.A more cost effective solution is to use the twin-lift technique to transport the occasional extra-heavy load.

The final groups papers (22,23,24,25,26) reported valuable,hands -on experience on new programs at different stages of development.

Paper 22 -By Virtuani,C.A.G.Agusta, It, provided a detailed overview of the development process of the A129 antitank helicopter and of its advanced technical solutions to meet its operational requirement. Key points of this design are :
-advanced technology subsystems
-extremely high level of integration
These concepts have been applied to the vehicle design as well as to the mission package and avionic architecture and lead to a very flexible and efficient total weapon system which obtained a significant cost effectiveness by keeping weight and dimensions within strict limits.(The helicopter mission weight for the Italian Army is 2850 kg).This design has just transitioned to production after having been tested on 5 prototypes (two of which fully mission equipped).

Paper 23 -by J.B. Rorke -MDHC, US -was a very illuminating presentation on the verification of the performance of a very innovative design after 5 years of production .The Ah-64 Apache helicopter was developed in the '70 as a complete antitank system capable of day,night and adverse weather operation.This was an extensive technical effort which was largely successful and resulted fielding, in 1983, a very advanced attack helicopter providing an antitank effectiveness never before achieved.However in 1986 changes emerged in operational requirements, in the threat and in the available technology, which lead to the identification of a list of possible technology updates which would provide further enhancements to the system mission effectiveness. While the US Army is currently evaluating the relative value of the available options, it has been recognized that the area offering the largest payoff in terms of future growth capability and effectiveness enhancement is that of avionics,controls and displays.The precise definition and evaluation of the possible new avionic solutions will need accurate methods and tools such as simulation,hot bench and flight validation. Previous papers during this symposium have indicated that these methods and tools are indeed available and capable of providing an affordable and reliable basis for an update program.

Paper 24 - by S. Rioche ,Aerospatiale,FR. -Described the most advanced search and rescue mission package now available for helicopter use This system optimized the SAR mission effectiveness of the AS Dauphine helicopter providing the following automatic functions:
°trajectory stabilization during the search pattern flight and the approach manouver;

°hove hold during the rescue operation
°cockpit management control of four colour multifunction CRT displays.
Once again a difficult and demanding mission has been made more reliable with the optimization of the man-machine interface and by reducing the operators work load .

Paper 25- by P.Alli, R.Baldassarrini, and others from Agusta, It, reported on the development of the Anglo-Italian EH101 "Integrated" program .This design, was faced with the challenge of the requirement of two Navies for a medium size ASW helicopter, the military requirement for an utility vehicle and the commercial requirement for a passenger transport.The approach has been to work for an early integration of the three requirements and to aim for a common design which would satisfy the integrated requirement while relegating to secondary,developments the task of generating the national and special -to-role variants.It is unique to this program that the integrated solution has been considered from the early stages of the design, providing the maximum freedom in the technical solutions.

The paper (presented by Mr.G.Marzorati) provided specific data on the reduction of the non- recurring costs, comparing the costs of dedicated developments to the costs of the integrated program.
A figure of 60% cost- saving was claimed,while the overall capabilities of the helicopter,often driven by the most demanding requirement, appear to be exceptionally advanced. The weight has been kept lower than the average trend by a factor of 7,5% (naval) or 14% (civil).

Paper 26- by B.Blake ,(Boeing Vertol) and T.Gaffey (BHT)from U.S. exposed the influence of operational requirements on the design of the V-22 Tilt Rotor Aircraft.In this case the requirements are both exceptionally innovative and demanding.Beside the unique requirement for high speed, altitude and range the military needs have imposed a significant challenge to the development of this aircraft. The specific needs were:
1)ship board compatibility, 2)rear ramp loading, 3)manouvrability, 4)wing and rotor folding.
This innovative configuration has posed significant new tradeoff problems during the preliminary design phase. This applies to the mission requirements (assault troop transport,long range deployment) as well as the subsystem design solutions.
A synthetic description has been provided of the results obtained in the areas of aircraft efficiency, handling qualities, crashworthiness, component life monitoring and maintainability characteristics.

5. ROUND TABLE DISCUSSION

1)A round table discussion was held at the conclusion of the presentations of the scheduled papers.
Four topics were selected among the issues of more general interest raised during the question and answer period which followed each paper and were assigned to round table speakers as follow:

1.1) Mr.R.HOH :
Feasibility of Single Pilot Helicopter Operation

1.2) LT.Col.A.PARRINI
Multirole vs. dedicated helicopter

1.3) Mr.M.RIOCHE
Military vs civil requirements compatibility

1.4) Mr.R.LYNN
New Developments on Rotorcraft configuration

2) Single Pilot Operation Feasibility . The feasibility of single pilot helicopter operation is not being questioned any more. It is commonly accepted that provided sufficient time and money availability this capability can be achieved with the technology now available. Difficulties have to be expected however in the area of quantitative measurement of pilot's work load in a difficult environment such as nap of earth anti-tank missions where the psychological effect of being alone may increase significantly the operation difficulties. In general, methods for quantitative assessment of human engineering parameters are still somewhat obscure and a resistance to structured experiments is common.Therefore a more concentrated effort in this area is needed and recommended.
Additional comments were added to the speaker statement:

Mr.R.L. Tomaine confirmed that single pilot operation is still a requirement for LHX and that a dicision will be taken on the base of an experimental comparisons of the single vs two pilot configuration.

Mr.Bauer of NL Navy pointed out that proper training will play a most important role in the success of single pilot operation.On the ASW Lynx the Dutch navy operates with

single pilot and a navigator since six years on the basis of intensive flight and simulator training.

Bob Lynn expressed a concern on the fact tnat single pilot operation for complex missions (i.e. LHX) may increase complexity and cost of the avionic package to an unacceptable level.

3) Dedicated vs multirole helicopters . The contradictory situation of having the US, which have a large quantitative requirement seeking a priori design commonality; while the European Nations with smaller quantities are seeking the dedicated solution was mentioned in the opening remarks by Prof.Campos.
Colonel Parrini expressed the view that dedicated helicopters are required for the most specialized missions, such as antitank attack, while commonality is possible on utility-type mission such as transport on SAR.
Mr.Tomaine pointed out that commonality may range from a common drive-system to the entire basic helicopter configuration. In the LHX case only the drive system may be common to the utility, attack and scout versions. The advantages of commonality should be assessed by specific considerations and not on general terms.
R.Lynn mentioned that the quantitative inferiority of NATO helicopter must be compensated by qualitative superiority; therefore the dedicated helicopter design optimized for the most demanding missions is mandatory.

4) Compatibility of military and civil requirements as basic design drives . The issue has been raised both with regard to the possibility to meet both requirement by a new design and to the capability to provide a satisfactory adaptation of an original military or civil design to a later application in the other field.
Mr.Rioche provided as an example of successful evolution the history of A.S.Dauphin from his civil origin to maritime and then military antitank applications.
Mr.Fradenburgh indicated that in the case of the UH-60 Black Hawk (which obtained a limited civil certification) the air transportability requirement,which is typically military, forced a limit in cabin height which is not satisfactory for the civil users and cannot be economically corrected. Similarly the development of armament kits to allow weapons firing from a utility helicopter was successfully achieved but with no intention to substitute the dedicated attack helicopter.
Mr.Schaper finally suggested that the Governments may introduce a specific requirement to meet some basic civil characteristic in the requirement list for new military helicopters as a mean to force a better use of tax payer money and to obtain in general a more cost effective design on a common competition basis.

5) New Development of Helicopters Mr.R.Lynn gave a clear summary of the realistic possibility of development of the helicopter conventional configuration. It is admitted that the maximum speed limit for conventional helicopters is in the range of 200kts for large machines and 170kts for small ones. Nevertheless the relative importance of speed vs autorotation and hover capability still makes the conventional configuration more attractive than alternatives such as the compound helicopter. If speed is an absolutely important parameter then the tilt wing configuration becomes convenient mostly if it can be associated to high altitude flight profiles. Much can still be done to improve rotorcraft by careful use of advanced technologies. The total contribution of minor advances in individual technologies such as aerodynamics, dynamics, materials, power plants and electronics may lead to reducing weight and cost by a factor of two while obtaining increases in safety and productivity by an even higher factor.
In a medium term a significant commercial business opportunity for rotorcraft appears to be offered by the aerospace congestion due to the fixed wing airplanes traffic growth. This congestion can certainly be alleviated by innovative use of advanced rotorcrafts.

6. CONCLUSION

The symposium was extremely successful both for the quality of the papers which were presented and for the importance of the subjects which were properly tuned to real problems of helicopter design development. Specifically:

-The availability of realistic simulation of the critical design characteristics of the entire helicopter system has been discussed both as a requirement and as a feasible technical achievement.

-The costs and difficulties in developing flexible and convincing simulators are very high, therefore exchange of information on this subject is extremely important and useful.

-Advanced Technical solutions have been presented for new problems as well as for old ones.

-Some problems are :NOE night flying,cockpit integration, mission management, target tracking and the effective measurement of operational loads to obtain safe on-condition maintenance,.

-The most significant of the old challenges are vibration reduction, and the identification of improved main rotor and tail rotor configurations.In these areas opportunities for improvements have been actively pursued and a free exchange of informations can be seen as a very valuable contribution to the helicopter technology progress.

7. RECOMMENDATIONS

1) The identification of a viable and proven method to translate operational requirements into design targets and to verify the satisfactory level of design results is clearly needed by the military experts as well as by the engineers. It is strongly recommended that such method is extracted from the latest experiences on helicopter developments and tested on new programs.

2) As system simulators appear to be a key tool in this verification, the exchange of information on these facilities and agreements on shared use of existing ones should be encouraged

3) Helicopter vibration reduction is still a challenge for all manufacturers.Several innovative solutions have been developed to the experimental stage.The exchange of information on achieved test results and support for the on- going programs should be encouraged both at industrial and government level.

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14. Abstract

The expanding roles of the helicopter and the intensified threat perceived by its potential users have led to proposals for future rotorcraft with characteristics significantly different to existing types. The resulting rapid evolution of rotorcraft configurations, in response to user demands, now requires a translation into design criteria to permit the aerospace R & D community to provide appropriate and cost effective responses to these demands. The objective of this symposium was to explore the impact of operational need on the evolution of rotorcraft design and to identify priorities and neglected topics. Three specific issues were central:

- The translation of operational mission requirements into design criteria
- The evaluation of techniques to incorporate user defined needs into the design and methods of test and verification
- The identification of design areas where unusual or new user needs are demanding special or radical features.

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