FINAL REPORT

Army Scientific Advisory Panel
Ad Hoc Group on

SIMULATION RESEARCH FACILITY REQUIREMENTS FOR NOE DAY-NIGHT VISUAL FLIGHT STUDIES

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SIMULATION RESEARCH FACILITY REQUIREMENTS FOR

NOE DAY-NIGHT VISUAL FLIGHT STUDIES

INTRODUCTION

This report examines the question of requirements for flight simulation within the U. S. Army, using ground based equipment for aviation research and development. Of particular interest is the impact of the NOE mission on future flight simulation requirements, however, broader aspects of the question are also considered. Ground based simulators range from comparatively simple devices used for pilot familiarization, to highly complex devices used for flying qualities research and air to air combat simulation. Although the Committee was primarily concerned with ground based simulation, in-flight simulation also plays an important role in the total simulation effort.

For fixed wing aircraft, simulation using ground based equipment is an integral part of the design process. During the past twenty years, the flying qualities aspect of fixed wing aircraft design has been converted from an empirical cut-and-try process to a rational design procedure through the use of simulators. Simulation has also been used effectively for rotary wing aircraft, however, the state of the art in helicopter flight simulation appears to be considerably behind the fixed wing aircraft.

At the outset it is important to distinguish among the various uses of simulators. The Committee was concerned with the use of simulators for research and development and not for training per se. The use of simulators in pilot training is an extremely valuable and cost effective portion of the training program. We do not question this, but are rather concerned with the use of simulators as a research and development tool.

We may identify four items as the output of research program using ground based simulators:

(a.) Improved Equipment Design.

(b.) Development of In-flight Procedures.

(c.) Development of Training Techniques.

(d.) Development of Aircrew Selection Procedures.

In this report, equipment design is restricted to mean consideration of the flight vehicle itself and various subsystems directly related to controlling and flying the vehicle, and thus, includes various sensors and displays which may be required for flight control as dictated by the mission and vehicle. In a gross sense, the problem of flying qualities design involves the study of tradeoffs between fully automatic flight with elaborate displays and the attendant complexity, cost, reliability and maintainability at one end of the scale, and the difficulties of accomplishing the mission with the basic vehicle at the other end.

The use of part-task simulators employed in the preliminary development of such items as new airborne weapons or electronics system are not considered. The limitations of part-task simulator studies must be properly understood with regard to their application to the total helicopter system and ultimately verified by more complete simulation. All of our discussions are related to the research and development aspects of simulation which clearly require a total man-in-the-loop systems approach.

The above four items are derived from two broad categories of research and development in which ground based flight simulation plays an essential role. These are:

1. Helicopter Flying Qualities. This is the category of equipment design and the interface with the human operator in its broadest sense. Essentially, research and development in the area of helicopter flying qualities is concerned with the determination of what is required to adapt the machine to the man and mission, or in other words, how to design the best machine from a flying qualities viewpoint to provide total mission capability. A wide range of topics are included such as: determination of the basic relationships between the control and response characteristics of a helicopter and the ability of the pilot to achieve a desired mission; development of new sensors and displays required for control of the helicopter in precision tasks along with an understanding of the tradeoffs between the complexity of the displays and the complexity of the pilot's task; understanding of the basic visual and motion cues employed by the human operator in flying the vehicle.

In addition, during the development of a specific helicopter, prior to first flight, a ground based simulator should be used for such items as determination of the optimum transfer functions between the control stick and the rotor controls and the evaluation of the safe flight envelope of the vehicle. This latter item is most difficult as it implies a complete knowledge of the dynamics and aerodynamics of the vehicle and implies therefore, the need for complete wind tunnel testing prior to first flight.

Design of new helicopters in the future must take the approach that a new development is not simply an R & D program for product imporvement of the helicopter with the view of the hardware, i.e., the helicopter and its instrumentation as given. The helicopter, its instrumentation, and the human operator must be considered an entity, with the human operator properly included in the helicopter flying qualities equation. The questions involved are much more complex than simply does the pilot like the vehicle.

2. <u>In-Flight Procedures, Flight Training and Aircrew Selection</u>. This category encompasses the next three items noted above and is primarily concerned with the use of a simulator to explore what is necessary to adapt the man to the machine and the mission. That is, once the vehicle configuration and flight control system has been selected, the issue is how to train the human operator to obtain the most from his machine. Such questions as: how one selects from a population the particular group most readily adaptable to pilot training and; given a particular mission, what are the optimum normal and emergency in-flight procedures to follow to accomplish the various tasks associated with the mission, including controlling the machine, are involved. Additionally research is needed in workload measurement, relating it to optimum performance and how this performance is degraded by anxiety, lack of rest, etc.

These are two broad categories which require man-in-the-loop simulation which were of concern to the Committee. Another distinguishing feature of these two areas of reseach is the type of subject employed in the research. For research on flying qualities, it has been found that a small select group of highly trained engineering test pilots should be employed to develop flying qualities specifications, and in-flight procedures whereas, for flight training and aircrew selection research, a large number of subjects, representative of the average army aviator with varied backgrounds typical of those entering flight school are desired.

The critical question related to research and development using simulation in general is: how complex and sophisticated must the ground based simulator be to produce valid and meaningful results. The answer to this question is clearly a function of the objectives of the research as well as the task under consideration. It leads to a third category of research associated with simulator technology.

3. Simulation Techniques. This area involves the study of the requirements of complexity of the simulator itself as related to research and development, i.e., adapting the simulator to the problem. Four items are involved: a.) the human factors involved in effective pilot control of the machine and mission task accomplishment; b.) the degree of sophistication of the mathematical model of the helicopter; c.) the motion requirements of the simulator; d.) the fidelity of the visual scene. There is a lack of understanding of the human operator in relation to exactly what visual, aural, and motion cues are employed to fly a helicopter.

As a consequence there is a lack of quantitative data as to the necessary motion and visual cues which must be provided in a ground based simulator. Research on training techniques appears to require less simulator motion and a simpler mathematical model of the vehicle compared to flying qualities research.

DISCUSSION

1.) Helicopter Flying Qualities

The helicopter is notorious for its poor inherent handling characteristics. These characteristics deteriorate in low speed flight, just the region in which new tactical requirements for NOE are developing. New mission requirements of low altitude/low speed flight place an increased burden on the pilot, requiring him to perform many complex tasks simultaneously: obstacle avoidance; navigation; unusual tactical maneuvers, leave little time to deal with the problems of controlling a complex unstable system.

As a consequence there is a clear need for continuing research and development in helicopter handling qualities, to enable Army vehicles to perform satisfactorily many varied and complex missions. There is at present little research activity in the helicopter handling qualities field. The Army is the major user of helicopters and should be pursuing this important problem area vigorously. There has been a gap in the research and development in this field, clearly illustrated by the fact that the Military Specification for Helicopter Handling Qualities

(Mil-H 8501-A) is more than fifteen years old and clearly needs attention and revision. As a specific example, the last ten years has seen development of hingeless rotor helicopters with three to eight times the control effectiveness of articulated rotor helicopters. The handling qualities specifications are based on flight research done twenty years ago with articulated rotor helicopters with a much different range of control parameters.

In addition to the research gap, there are development needs associated with helicopter handling qualities.. The research will establish data to guide designers. However, once a tentative design is established, simulation provides program managers and contractors a method for "flying" the proposed helicopter with the man-in-the-loop for evaluation of competing designs, for making important economic trade-off decisions before construction starts, for test flight planning, and for product improvement. In this regard, the helicopter industry considerably lags the fixed-wing aircraft industry where manned flight simulators, like wind tunnels, are an integral part of the design process.

Wind tunnels, ground based simulators and in-flight simulation equipment are needed to conduct studies in this area. Wind tunnel data are required to insure that an accurate model of the vehicle aerodynamics is used in the simulation.

The helicopter industry neither has the facilities nor the continuing need and resources to separately develop and operate the required facilities. NASA and the Army have jointly undertaken to provide the facilities and research programs needed for the rational design of helicopters. The 40 x 80 wind tunnel at Ames is being reconfigured and repowered specifically to provide for on the ground testing of new rotor dynamics systems and full scale rotary wing machines. Coupling the results of theory, 4- x 80 wind tunnel tests and, RSRA flight tests, moving base simulator studies, together, offers the promise of more rapid, safer approach to the understanding of rotary wing flight phenomena than has been present heretofor.

2.) <u>Training and Aircrew Selection</u>

This is an equally important area for continuing research using ground based simulation equipment. As the mission becomes more complex, better definition of aircrew selection procedures are required. The question of simulator sophistication required for safe and economic training is a difficult one. Questions to be answered range from what hardware is necessary, such that, the subject "believes" he is actually flying an aircraft and not just sitting on the ground, to how elaborately do the aerodynamics and dynamics of the vehicle have to be modeled. Research in this area does not appear to need the sophisticated ground equipment which is required for flying qualities research and development.

However, we do not thoroughly understand what individual human factors and combinations of these factors need to be understood in developing NOE flight proficiency. Simulator development is ahead of understanding the behavioral factors involved in effective safe aviator performance in the NOE day and night environment. Until we clearly understand the individual skills and interactions between those skills required of the pilot, it is unlikely effective training simulators can be developed.

NOE pilot training requirements and methods are not known today because we do not yet know what human factors are critical to effective, safe piloting in the NOE environment. These factors may well be the traditional ones, although research will be required to establish them.

3.) Simulator Research

There is also a need for research on simulation techniques associated with helicopter flight. This should be a continuing program coupled to the other two, to investigate the degree of sophistication required in the areas of mathematical modelling, motion requirements, and visual scene fidelity as related to the mission and task. The most difficult topic associated specifically with NOE flight is the degree of fidelity required for the visual scene to obtain valid results. In-flight simulation is desirable to verify the results of research on simulation techniques.

The need to quantify the human factors parameters is an essential one impinging on all three of these areas. We do not know whether it is actually necessary to duplicate, as closely as possible, real NOE flight conditions in simulators for pilot training. The questions of what skills, how developed, and how much transferability takes place from simulator to actual flight performance are unanswered.

In general, it appears that past studies have treated the man and the machine separately with too little consideration of their combined roles in a man-machine system. Helicopter handling qualities studies are conducted by aeronautical engineers to adapt the machine to the man, and ground-based and in-flight simulators offer a method to expand the data base by systematic research. Training studies are conducted by psychologists to optimize the adaptation of the man to the helicopter. Training simulators are one tool in the adaptation, and a larger data base should be obtained to understand their proper design and impact on the total training program.

Ground based simulation of NOE flight raises a number of questions which are considered in detail below.

a.) Dynamic Modelling of the Helicopter - Requirements in general appear to be different for research related to training as compared to that in handling qualities and vehicle dynamics. Simulation of vehicle dynamics for handling qualities research appears to require more sophisticated equipment than for training. As of the present, it appears that a very complex mathematical model is necessary to represent the helicopter for handling qualities research as compared to the fixed wing airplane, and as a consequence considerably more sophisticated computing equipment is required. This is particularly true if the mathematical model includes blade motion dynamics as is required if the ground based simulator is used for exploration in flight boundaries of the vehicle, owing to the fact that the computation must be done in real time for realistic flight simulation.

There is little substantiation of the degree of sophistication required for modelling the helicopter as compared to the state of the art for fixed-wing aircraft since considerably less simulation research has been conducted. In addition, there does not exist for the helicopter the backlog of aerodynamic data and correlation with flight test necessary to insure that the computer model faithfully represents the helicopter. There are modelling questions not only in low speed flight, as encountered in NOE mission, where there is a lack of basic aerodynamic data but throughout the flight regime of the helicopter.

We applaud the program at Ames to repower the 40 x 80 ft wind tunnel to provide the capability of measuring the parameters needed for high fidelity simulation of helicopter flight characteristics, both within and outside the normal performance envelope. Only through controlled measurement can the modelling of helicopter aerodynamics be made as reliable as that of fixed wing machines. The combination of reliable wind tunnel data and RSRA flight test data with reliable simulation offers promise of an early and substantial advance in helicopter design for safety of flight and reasonable handling qualities.

b.) Ground Based Simulator Motion Requirements - The fundamental question here is how much simulator motion is required, such that, valid experimental studies can be carried out in ground based simulator. Less motion is probably required for training research than for helicopter flying qualities however, exactly how much motion is required is not clear owing to our lack of understanding of the human factors. Close coordination between ground based simulation and in-flight simulation in a variable stability helicopter is necessary to develop answers to this question. This issue again is related to the entire flight regime of the helicopter.

c.) Visual Scene Fidelity - This is a most difficult area in which the requirements are particularly critical with respect to simulation of the NOE mission. For other helicopter missions not involving operation close to the ground, scene fidelity does not appear to be a problem. As of the present, the best state of the art appears to be represented by a ground board/T.V. camera system. It would appear that in the future, computer generated imagery will provide the ultimate system. It presently appears that visual scene fidelity requirements for NOE mission simulation are beyond the state of the art.

Understanding of the simulator requirements with respect to items b.) and c.) require close coordination among aeronautical engineers and psychologists.

d.) Human Factors Involved in Effective Pilot Performance - The Army needs to insure that the right questions with respect to the human elements involved in pilot task accomplishments are being asked before specific research designs are implemented and simulator capacity developed to answer these questions.

Thorough studies of the physical reaction time, muscle-eye coordination, perceptual, auditory and mental coordination of all sensory inputs which is then translated into pilot actions must be made. This also includes examination of what outside-the-aircraft cues are required and how much time the pilot spends "in" and "out of" the cockpit.

Based on these studies, man-machine design of new helicopters can be improved; modification of existing helicopters and training of pilots for all weather NOE flight would be better understood so as to keep the flying task within the human capabilities of pilots.

PRESENT ARMY CAPABILITIES

The Army presently has a small staff concerned with various aspects of helicopter handling qualities research at the two AMRDL Directorates at Ames and Langley Research Centers. In addition, there is staff at ARI concerned with training research.

At the AMRDL Directorates, the staff has access to some of the required facilities for research and development using ground based simulators. NASA Ames has extensive moving base simulation facilities, and a unique capability for wind tunnel testing of rotary wing machines in the 40 x 80 tunnel. The combination of wind tunnel tests, RSRA flight tests, and ground based simulation represents a powerful approach to radical improvements in rotary wing handling qualities. NASA Langley has less in the way of moving base equipment, but larger computational facilities associated with simulation at present. There is in-flight simulation effort at NASA Langley, and in addition, the RSRA program provides the ability to obtain experimental data on rotor dynamics and aerodynamics from full scale in-flight measurements.

ARI has a well qualified staff located at Fort Rucker and has access to training simulators which at present probably do not provide sufficient flexibility to conduct training research. USAARL has been doing and is doing superior work on the human in the helicopter environment.

CONCLUSIONS AND RECOMMENDATIONS

1.) It is recommended that the Army place increased emphasis on research and development in helicopter flying qualities using both ground based and in-flight simulation.

Most previous helicopter research and development has treated the dynamics of the vehicle and its control system independently and without enough consideration of its real place as a subsystem in a larger man-machine system. Ground based and in-flight simulators offer the opportunity to look at the total man-machine system, both for research to guide vehicle design and for development projects when optimizing decisions in vehicle construction. The use of simulators for fixed-wing handling qualities research is firmly established, and, in fixed-wing development, they are now an integral part of the design process. They should become an integral part of the helicopter design process.

2.) It is recommended steps be taken by AVSCOM to coordinate the activities of various agencies and laboratories within the Army concerned with helicopter flight simulation.

Coordination is necessary to obtain the maximum benefit from various simulation studies, to insure the total systems approach is taken in the design of the helicopter and its flying qualities.

There appears to be a strong requirement for better coordination among the groups (AMRDL Ames, AMRDL Langley, USAARL, ARI and HEL) concerned with various aspects of helicopter flight simulation, to insure that the machine is not being over emphasized with respect to the man and vice versa.

3.) The development of a flying qualities simulator as proposed by AMRDL is highly desirable and should be fully supported. Its development and use should result in significant payoff in terms of increased helicopter capabilities.

It is essential to pursue research and development in flying qualities, and the primary question is the most timely and cost-effective way to attain the goal of improving the ease with which a helicopter pilot can accomplish his mission. Increased use should be made of existing ground-based and in-flight simulators available to the Army. However, these simulators do not appear to meet all the technical requirements for helicopter simulation or the time requirements for Army Product Manager and Contractor support, so an expansion in capabilities is required.

There was not general agreement within the Committee with respect to the fact that present simulators do not appear to meet the technical requirements for simulation research. Lack of human operator data makes if difficult to quantify the simulator requirements. However, if a new six-degree-of-freedom moving base simulator such as proposed by AMRDL is built, it should be with the understanding that this facility is national in character with NASA and the other military services sharing the burden of owning and operating the facility.

4.) It is not clear that the complexity and sophistication of the Visual Flight Research Facility, proposed by ARI, is required to conduct the research proposed. Alternatives to this device should be considered for research into visual fidelity.

While the Committee recognizes the advantages of conducting human factors studies in an environment that includes a simulation of the machine, the design of a simulator visual system to attain scene fidelity is expensive and technologically risky. Further studies should be made of the equipment required to conduct these studies and of the risks associated with equipment development.

5.) The modest increase in flexibility of an existing training simulator for research on training proposed by ARI at Fort Rucker should be supported.

Existing Army helicopter training simulators have been used successfully in training aviators. However, further study using these simulators can be conducted to optimize their design and their use in the training program. The results of such research can not only improve the cost-effectiveness of existing training programs, it would also influence the design of simulators and training programs for future Army vehicles.

Terms of Reference
Ad Hoc Working Group On

Simulation Research Facility Requirements for
NOE Day-Night Visual
Flight Studies

23 May 1975

1. Introduction. Reference: AMRDL Report, Subject: A Technical Assessment of U.S. Army Flight Simulation Capability and Requirements for Aviation Research and Development.

Through the 1960's, the application of simulation to the design and development of conventional aircraft became routine. The increasing complexity of aircraft and their systems made it necessary to use simulation as a design tool. This has further been forced by the Army's demand for greatly expanded mission capability. The current threat will require operation at very low altitude, in daylight and darkness and in all weather conditions. This means that flying qualities will have to be improved greatly so that the aviator has capacity left over to operate all aids that are necessary for performing his mission. There is a need to study all the interrelated elements: the human pilot; the flight control system; the displays and vision aids; navigation and guidance equipment; weapons systems; and the ever changing environment. Ground-based simulation is the only way to systematically investigate all the trade-offs; it will allow these trade-offs to be studied before hardware is developed, in safety on the ground. The Army needs a coordinated plan to be responsive to the training and R&D simulation requirements.

2. Terms of Reference.

a. Ad Hoc Working Group review the reference prior to being briefed on the completed study prepared by AMRDL.

b. Does the Army have an existing research facility or one now in the process of construction to meet the requirements of the behavioral aviation research program for which the VFRF is intended?

c. Are there any specific plans and specifications for a research facility elsewhere in the Army which satisfy the requirements for visual flight research at NOE altitude, particularly at night?

d. What is the primary research goal of the research facilities proposed by the Army (e.g., training research, flight control, helicopter development, sensors, visual perception)?

e. What would be the cost of proposed research facilities?

f. What are the trade-offs between a general versus that of a highly specialized facility?

g. Is it necessary to faithfully simulate all possible helicopter parameters to conduct meaningful research in a specific problem area such as visual perception?

h. Is a general purpose research simulator needed and practical from a cost and complexity viewpoint for specific research in NOE visual and behavioral problems?

i. Does the Army have a qualified staff, related field research and other qualifying experience for visual and behavioral research?

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23 May 75

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