NASA Technical Memorandum 78539

AVRADCOM Technical Report 78-56 (AM)

(NASA-TM-78539) COMPREHENSIVE HELICOPTER ANALYSIS: A STATE OF THE ART REVIEW (NASA) 18 p HC A02/MF A01 CSCL 01A

N79-12019

Unclas

G3/02 38831

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November 1978

NASA
National Aeronautics and Space Administration

United States Army
Aviation Research and Development Command

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COMPREHENSIVE HELICOPTER ANALYSES

A State of the Art Review

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SUMMARY

An assessment of the status of helicopter theory and analysis is presented. The technology level embodied in available design tools (computer programs) is examined, considering the problem areas of performance, loads and vibration, handling qualities and simulation, and aeroelastic stability. The effectiveness of the present analyses is discussed. The characteristics of the technology in the analyses are reviewed, including the aerodynamics technology, induced velocity and wake geometry, dynamics technology, and machine limitations.

INTRODUCTION

As an aid to both the selection of individual research topics and the formation of policy for research organizations, it is useful to periodically assess the status of the technology concerned. The development of helicopter theory and analysis is at a stage where such an assessment is appropriate: the first generation computer programs for helicopter analysis have reached maturity, the U.S. Army is about to embark on a project to develop a second generation analysis system, the latest generation of American civil and military helicopters are beyond the design stage and going into production, and NASA is planning a major expansion of its research concerning helicopters.

TECHNOLOGY IN PRESENT DESIGN TOOLS

Let us examine the technology level embodied in the design tools (meaning primarily computer programs for helicopter analysis) presently available to industry and government engineers. Such tools are the ultimate objective of helicopter analysis research and development projects. The programs will be assessed in terms of the most highly developed methods which can be found in present tools; besides allowing a comparison of the various programs available, this approach also serves to define the boundary between the technology which has reached the design process and that which is still in the research stage. This approach also naturally leads to a definition of the key technical areas requiring further research and development. The assessment presented here is based on references 1 to 17.*

Tables 1 to 4 outline the technology level in presently available computer programs for helicopter analysis. Four problem areas are considered: performance, loads and vibration, handling qualities and simulation, and aeroelastic stability. Such a division is not completely rigorous, but there are differences between these problems which influence the technology required to solve them. The performance and loads problems are generally concerned with steady or quasisteady operating conditions of the helicopter; while the handling qualities and aeroelastic stability problems are

*The assessment is also based on private communications with Kuczynski (Sikorsky Aircraft), Lemnios (Kaman Aerospace Corp.), and Walls (Boeing Vertol Co.), 1978.

concerned with transient or perturbed motions. The performance problem is concerned with the overall characteristics of the aircraft, while the loads and vibration problem is concerned with the detailed characteristics (this distinction is less valid for the solution techniques however, since a detailed model is required for a very accurate performance estimate). The handling qualities and simulation problem is concerned with the low frequency, rigid body helicopter motion, while the aeroelastic stability problem is concerned with the higher frequency, rotor motion (although in many situations the frequency separation is not large, and the two problems can be attacked with a single analysis). Tables 1 to 4 indicate, for a number of major computer programs, whether certain key capabilities are present or not.

OBSERVATIONS AND GENERALIZATIONS

How Good is the Present Technology?

Using the best helicopter analyses currently available, good correlation between the measured and predicted behavior is found for the general, overall quantities. The prediction of the detailed, specific quantities is often quite poor however. Predictions of quantities such as rotor performance or the mean and alternating loads are generally reliable provided a theoretical model appropriate to the problem is used, although this capability has been achieved only with considerable use of empirical models (for dynamic stall, three-dimensional flow effects, aerodynamic interference, and so on). However, such use of empiricism and approximations often leads to inaccurate prediction of detailed characteristics. A manufacturer's analyses tend to be most accurate when applied to aircraft of the type with which they are most familiar. Regretably, it is also true that analyses with lower technology than required for accurate predictions for a particular problem are used in many situations. The structural and inertial characteristics, and the aerodynamic environment of the rotary wing are very complex, and evidently considerable further development of the theoretical models is required before consistently reliable prediction of the aeroelastic behavior is possible.

The Technology Level is Not Uniform

It is evident from Tables 1 to 4 that the available technology is not uniformly utilized in current design tools, neither within a particular problem area nor within a particular organization. The things we know how to do now, accurately and efficiently, are not always done.

Helicopter analysis development, particularly in industry, has usually been driven by a need to solve a specific problem, with limited time and resources available. The result is the present patchwork of computer programs. The government's approach to sponsored analysis development has also been a factor. The tendency has been to concentrate on extending existing programs, without recognizing that occasionally a completely new start is needed; and the emphasis in contracted work is on delivering a program, to the detriment of re-thinking approaches and thoroughly checking out the analyses. The coordination and long term commitment needed to develop a system of programs which consistently utilize the most advanced technology available has been lacking.

Furthermore, correlation and verification of a program are usually performed principally for the specific problem of immediate interest, and in contracted work often for only a few test cases. As a result, the present design tools incorporate a great deal of untested capability. In particular, the claims of applicability to all helicopter configurations or all rotor types (tables 1 to 4) have not been demonstrated in many cases. Experience has shown that an engineer wishing to use some one else's program, generally for a problem not quite the same as checked by the author, can count on spending considerable time in debugging and verification (although this is frustrating, it does lead to great familiarity with the program capabilities and limitations).

It must be pointed out that tables 1 to 4 only indicate what technical approaches are used in the various programs. Nothing is said about the level of sophistication of the models being used, which varies considerably. Another factor to consider is the ease with which a program can be used. Whether the programs involved in a calculation are completely and automatically coupled is one aspect, which is addressed in the tables; the convenience and appropriateness of the input and output are other important aspects.

Aerodynamics Technology

Helicopter aerodynamic theories are characterized by a heavy reliance on empirical techniques. Lifting line theory with two-dimensional airfoil data (as a function of angle-of-attack and Mach number) is almost universally used for the rotor blade aerodynamic loads. The better analyses incorporate approximate or semi-empirical corrections for the effects of dynamic stall, yawed flow, three-dimensional and compressible flow at the tip, and vortex/blade interactions. Empirical techniques are used either because existing aerodynamic theories are not able to handle the complex viscous and compressible flow of the rotor blade; or because a rigorous application of the theory leads to an impractical numerical problem.

Aerodynamic interference between the rotor and airframe is presently handled also by empirical or approximate techniques. Incorporation of an existing finite-element aerodynamic model of the airframe in the helicopter analysis is feasible (but it will be expensive). However, the flow field induced by the rotor at the airframe is very complex. Further development of the panelling methods to handle complex unsteady, separated flows will probably be needed before calculation of the airframe loads is accurate enough to justify the additional computation. Calculations of the airframe induced flow field at the rotor should be more successful.

Induced Velocity and Free Wake Geometry

Helicopter rotor nonuniform induced velocity calculations are well developed now, and may be routinely used for performance and loads problems. Uniform induced velocity is still used however, and can lead to significant errors which are avoidable with present technology. Note also that there are many differences in the wake models being used, so some of the nonuniform inflow calculations must also be used with caution.

A number of the programs can accept an input nonuniform inflow distribution. Such a capability is not very useful however since the induced velocity calculation must be coupled with the blade motion solution for reliable accuracy.

An inflow dynamics model is often needed in handling qualities and aeroelastic stability problems for accurate results. The rotor transient loads can produce significant induced velocity changes, but a nonuniform inflow calculation is not practical for a transient analysis. Approximate models for the inflow dynamics are available however, involving variations of the mean and linear induced velocity components with the rotor velocity and net hub reactions.

Free wake geometry calculations are fairly well developed, although not entirely verified, partly due to the scarcity of wake geometry data. Aspects such as tip vortex roll-up and detailed geometry near a blade need further work. Generally however, the rotary wing aerodynamic theory is not well enough developed to reasonably use an accurate wake geometry model. The free wake geometry tends to be much closer to the rotor disk than the rigid wake geometry; consequently the wake induced loads are increased. It is found however that the loads are over-predicted if viscous and three-dimensional flow effects are neglected. A combination of approximate lifting surface theory corrections and semi-empirical corrections for viscous flow effects is required for realistic use of the free wake geometry. Often it is more appropriate to use a rigid wake geometry and assume compensating errors.

Probably the most important advance in wake geometry information recently has been the development of empirical geometry models for hovering rotors from measured small-scale data. When properly tuned with the aerodynamic theory used, such prescribed wake geometries significantly improve the prediction of hover performance and loads. Development of a similar model for forward flight has not been attempted because of the additional parameters involved (forward speed and blade azimuth).

Dynamics Technology

Helicopter dynamics theories are characterized by the requirement to treat many different rotor and helicopter configurations. Usually a new configuration requires the development of a new set of equations of motion; the hingeless rotor in particular has been the subject of numerous investigations recently. A new problem or new configuration often will require consideration of additional degrees of freedom in the rotor or in the airframe. As a result, the existing design tools incorporate a very wide range of dynamics models (meaning equations of motion, including inertial and structural forces and external aerodynamics loads); it is doubtful if any two programs use exactly the same model. Such a situation naturally leads to questions (or arguments) over which model is correct. Since all of the models are approximations, this question can only be answered by comparing to the real world (experimental data), subject to a precise definition of the system it is intended to model.
Many helicopters and rotors being investigated now require complex, nonlinear dynamics models, which greatly complicates the tasks of developing and verifying the theories. Often the development of dynamics models have followed rather than preceded the problems. The theories are used first to define and find cures for difficulties rather than to predict them. The models are then used for prediction until a configuration is encountered which introduces new problems outside the current model. An attempt to anticipate all dynamics problems in the model development is admirable, but inevitably impossible. What is also required therefore is the flexibility to rapidly adapt or extend the models to cover new problems.

Machine Limitations

A general rule is that for a computer program to be useful at the design stage, or in any application other than its own development, it should have a running time less than 10 or 15 minutes. As computers have improved, helicopter analyses have always encountered this limit. Presently nonuniform inflow for steady state flight presents no computation time problem. A free wake geometry computation is practical only if a great deal of effort is put into developing economical solution procedures; a straight-forward integration of the wake induced velocity until convergence is achieved is unacceptable. Time domain integration of the nonlinear, rotor and airframe transient response (for such problems as stability and control characteristics, maneuver loads, or aeroelastic stability) is marginally feasible; including nonuniform inflow in such an analysis is beyond present capability. Computation time limitations generally preclude the use of lifting surface theory for rotary wings, except for the hover condition or for model problems to be used in the complete solution. Applications of panelling techniques to calculations of the airframe aerodynamics will also encounter computation time difficulties, since even the hover problem is unsteady.

Helicopter real-time simulations are particularly limited by hardware capabilities rather than by the status of theory development. An evaluation of the net rotor forces and moments (or stability derivatives) in all operating conditions requires a detailed consideration of the rotor blade forces and motion. The direct approach involves time domain integration of both the airframe and rotor motions. With this approach present cycle time limitations require the use of a very simple rotor model. This approach is not entirely appropriate however: the limitation arises from the high frequency dynamics, but it is the low frequency dynamics which are of interest. Work on numerical techniques for problems with two time scales, on minimal helicopter rotor models appropriate to low frequency dynamics, and on special purpose digital or hybrid computers to solve the rotor equations will eventually remove this hardware constraint from helicopter simulations.

CONCLUDING REMARKS

A high level of technology is available for use in the design of helicopters; many sophisticated analyses have been developed in industry and government. It is also true however that the capability to analyze and design helicopters would be greatly improved by a full, uniform application of the existing technology. The heavy reliance in present analyses on approximate and semi-empirical methods means that there is also much to be gained by pursuing investigations of the fundamental problems in helicopter aerodynamics, dynamics, and structures, as well as the development of practical, economical procedures for applying the solutions to comprehensive analyses.

REFERENCES

1. Alexander, H.R., et al., "V/STOL Dynamics and Aeroelastic Rotor-Airframe Technology," AFFDL TR 72-40, January 1973

2. Anderson, W.D., Connor, F., Kretsinger, P., and Reaser, J.S., "REXOR Rotorcraft Simulation Model," USAAMRDL TR 76-28, July 1976

3. Arcidiacono, P.J., and Carlson, R.G., "Helicopter Rotor Loads Prediction," AGARD Conference Proceedings No. 122, March 1973

4. Bennett, R.L., "Rotor System Design and Evaluation Using a General Purpose Helicopter Flight Simulation Program," AGARD Conference Proceedings No. 122, March 1973

5. Bielawa, R.L., "Aeroelastic Analysis for Helicopter Rotor Blades with Time-Variable, Nonlinear Structural Twist and Multiple Structural Redundancy," NASA CR 2638, 1976

6. Carlson, R.M., and Kerr, R.W., "Integrated Rotor/Body Loads Prediction," AGARD Conference Proceedings No. 122, March 1973

7. Gabel, R., "Current Loads Technology for Helicopter Rotors," AGARD Conference Proceedings No. 122, March 1973

8. Johnson, W., "Aeroelsatic Analysis for Rotorcraft in Flight or in a Wind Tunnel," NASA TN D-8515, July 1977

9. Johnston, R.A., and Cassarino, S.J., "Aeroelastic Rotor Stability Analysis," USAAMRDL TR 75-40, January 1976

10. Landgrebe, A.J., and Egolf, T.A., "Rotorcraft Wake Analysis for the Prediction of Induced Velocities," USAAMRDL TR 75-45, January 1976

11. Landgrebe, A.J., Moffitt, R.C., and Clark, D.R., "Aerodynamic Technology for Advanced Rotorcraft," Journal of the American Helicopter Society, April-July 1977

12. Lemnios, A.Z., "Rotary Wing Design Technology," AGARD Conference Proceedings No. 122, March 1973

13. McLarty, T.T., Van Gaasbeek, J.R., and Hsieh, P.Y., "Rotorcraft Flight Simulation with Coupled Rotor Aeroelastic Stability Analysis," USAAMRDL TR 76-41, May 1977

14. Reaser, J.S., "Rotorcraft Linear Simulation Model," NASA CR 152079, January 1978

15. Sadler, S.G., "Main Rotor Free Wake Geometry Effects on Blade Air Loads and Response for Helicopters in Steady Maneuvers," NASA CR 2110 and NASA CR 2111, September 1972

16. Scully, M.P., "Computation of Helicopter Rotor Wake Geometry and its Influence on Rotor Harmonic Airloads," MIT ASRL TR 178-1, March 1975

17. Sutton, L.R., "Documentation of Helicopter Aeroelastic Stability Analysis Computer Program," USARTL TR 77-52, December 1977

Table 1. Technology level in helicopter performance analyses.

	Computer Programs										
	A1	A2	B1	B2	C1	C2	D1	G1	G2	G3	H1
All helicopter configurations	■		■								
All rotor types	■		■	■	■		■	■			
Helicopter trimmed	■	c	c	c	c	■	■	c	c	c	c
Elastic airframe motion	a						a				
Complete blade motion	■		e	■	e		e	■			
Inflow dynamics							■				
Dynamic stall	■		■	■			■	■			■
Nonuniform inflow			■	■				d	■	■	■
Free wake geometry								d	■		■
Aerodynamic interference	■			■			■	d			
Programs completely coupled	b	■	■		b	■	■		■		

Key To The Tables

□	feature not available
■	some level of capability present
(a)	shaft or pylon elastic motion only
(b)	needs blade mode shapes
(c)	partial trim
(d)	available from separate program
(e)	not quite

Table 2. Technology level in helicopter vibration and loads analyses.

Computer Programs

	A1	B1	C1	D1	E	F1	G1	G4	H1
All helicopter configurations	■	■							
All rotor types	■	■	■	■	■		■		
Helicopter trimmed	■	c	c	■	■		c		c
Elastic airframe motion	a			a					
Complete blade motion	■	e	e	e	■		■	■	
Inflow dynamics				■					
Dynamic stall	■	■		■			■		■
Nonuniform inflow		■				■	d	■	■
Free wake geometry						■	d		■
Aerodynamic interference	■			■	■		d		
Programs completely coupled	b	■		■				■	

(see Table 1 for key)

Table 3. Technology level in helicopter handling qualities analyses.

	Computer Programs						
	A1	C3	D1	D2	E	G5	H2
All helicopter configurations	■					■	■
All rotor types	■		■	■	■		■
Helicopter trimmed	■	c	■	c	■	■	■
Elastic airframe motion	a		a				■
Complete blade motion	■		e	■	■		■
Inflow dynamics			■			■	■
Dynamic stall	■		■				
Nonuniform inflow							
Free wake geometry							
Aerodynamic interference	■		■		■		■
Programs completely coupled	b		■	■		■	■

(see Table 1 for key)

Table 4. Technology level in helicopter aeroelastic stability analyses.

	Computer Programs						
	B3	D1	E	F2	G6	G7	H2
All helicopter configurations	■						■
All rotor types	■	■	■	■	■	■	■
Helicopter trimmed		■	■			c	■
Elastic airframe motion	■	a		■	■		■
Complete blade motion	■	e	■	■	■	■	■
Inflow dynamics		■					■
Dynamic stall		■					
Nonuniform inflow							
Free wake geometry							
Aerodynamic interference		■	■				■
Programs completely coupled	b	■		■		b	■

(see Table 1 for key)