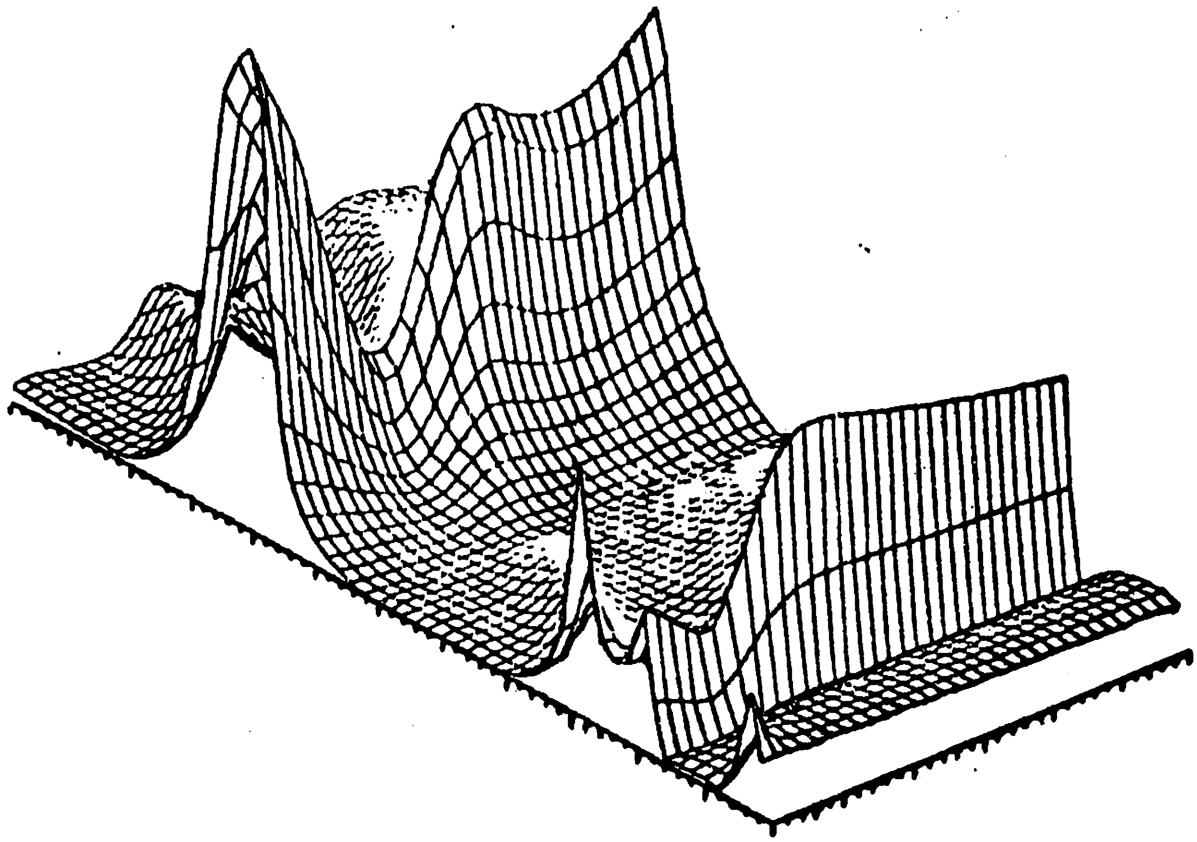
VERTICAL LIFT TECHNOLOGY REVIEW



FINAL REPORT

26 June 1980

The following assessment of Army Vertical Lift Technology, Missions and Management was conducted at the request of the Assistant Secretary of the Army for Research, Development and Acquisition. Terms of Reference for this action are reproduced in the Appendix. The study was completed in June 1980.

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1.0 SUMMARY AND CONCLUSIONS

1.1 Introduction

The Army Vertical Lift* program has been examined during this review with respect to the status of technology, mission opportunities, and management initiatives. Approximately fifty briefings were presented to the review group together with over a thousand pages of written material. Visits were made to the following installations:

- The Pentagon, Washington, DC, 5-6, February 1980
- U.S. Army Aviation Applied Technology Laboratory, Ft. Eustis, VA, 26 February 1980
- U.S. Army Aviation Research & Technology Structures Laboratory-NASA/Langley, Hampton, VA, 26 February 1980
- U.S. Army Aviation Research & Technology Propulsion Laboratory-NASA/Lewis, Cleveland, OH, 27 February 1980
- U.S. Army Aviation Research & Development Command, St. Louis, MO, 27 February 1980
- U. S. Army Aviation Research & Technology Headquarters and Aeromechanics Laboratory-NASA/Ames, Moffet Field, CA, 28 February 1980
- U.S. Army Aviation Flight Test Activity, Edwards AFB, CA, 29 February 1980
- U.S. Army Aviation Center, Ft. Rucker, AL, 6 March 1980

*"Vertical lift" as used herein refers to the class of aircraft which is capable of vertical take-off using lift generated from large rotating airfoils.

The following individuals from government agencies participated in the review:

- o Norman R. Augustine, Vice President, Technical Operations, Martin Marietta Aerospace - Review Chairman, member of the Air Force Scientific Advisory Board, the Navy Surface Ship Planning and Steering Group, and the Defense Science Board
- o Dr. Harvey R. Chaplin, Head, Aviation and Surface Effects Department, David W. Taylor Naval Ship Research and Development Center - Department of the Navy
- o Dr. Howard C. Curtiss, Jr., Professor, Department of Aerospace and Mechanical Sciences, Princeton University - member of the Army Science Board
- o Mr. Raymond M. Standahar, Staff Specialist for Propulsion, Office of the Under Secretary of Defense, Research and Engineering
- o Mr. John F. Ward, Manager, Low Speed Aircraft Office, NASA Headquarters, Washington, DC
- o Colonel John F. Zugschwert, Deputy for Aviation, Office of the Assistant Secretary of the Army (RDA) - Military Advisor
- o Lieutenant Colonel Norbert I. Patla, Department of the Army Systems Coordinator for Aeronautical Technology and Propulsion Systems, Office of the Deputy Chief of Staff, Research, Development and Acquisition - Assistant Military Advisor
- o Professor Robert G. Loewy, Institute Professor, School of Engineering, Rensselaer Polytechnic Institute - member of the Air Force Scientific Advisory Board and the NASA Aeronautics Advisory Council (Provided Comments)

The major contributions of:

- o Lieutenant General Allen Burdett - United States Army (Retired)
- o Mr. Charles W. Ellis, Vice President, Helicopter Development and Program Management, Boeing Vertol Company
- o Mr. John N. Kerr, Vice President, Engineering Research and Development, Hughes Helicopters
- o Mr. Robert R. Lynn, Senior Vice President, Research and Engineering, Bell Helicopter Textron

- Mr. William F. Paul, Senior Vice President, Engineering and Development, Sikorsky Aircraft

who provided the expert technical inputs from industry and the tactical community have been of immeasurable value in developing this report. The administrative assistance provided by Lieutenant Robert V. Walters, U.S. Marine Corps, Princeton University, and Mr. Edward J. Hanker, Jr., Princeton University, is also appreciated.

1.2 Overview

Progress in the vertical lift arena as applicable to Army missions has been substantial indeed during the past two decades, albeit not without problems. The NASA/Army relationship addressing this area is probably not excelled anywhere in the realm of interagency cooperation in terms of mutual support and efficiency. The effort to truly integrate the assets of these organizations has been highly successful; should be furthered; and has almost certainly been to the substantial benefit of both the Army and NASA. Moreover, in terms of overall accomplishment per dollar invested and in terms of organizational competence, the Army aviation activity would seem to rank with the best of the nation's military R&D activities.

The potential of vertical lift aviation with its high inherent mobility, particularly for a force which must expect to be required to fight outnumbered, has resulted in a major commitment of Army resources to aviation programs. The extent of this commitment is indicated in Figure 1, wherein the allocation of R&D and procurement funds to aviation programs among the three Military Departments is indicated. Also shown in the same figure is the relative aircraft inventory size of the respective Departments. It will be noted that the Army inventory still benefits from the major procurement programs of a decade ago, but the current level of spending for procurement, based on all available evidence, is inadequate to maintain the current force structure in the longer term.

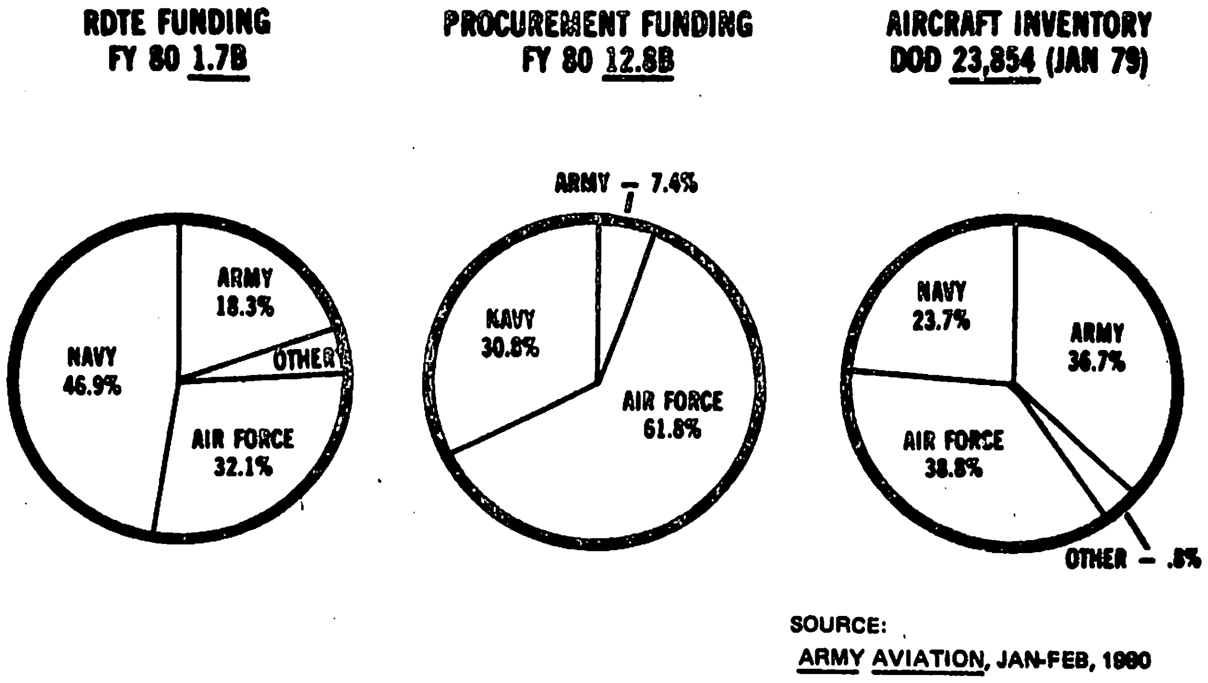


Figure 1 Military Aviation Perspective

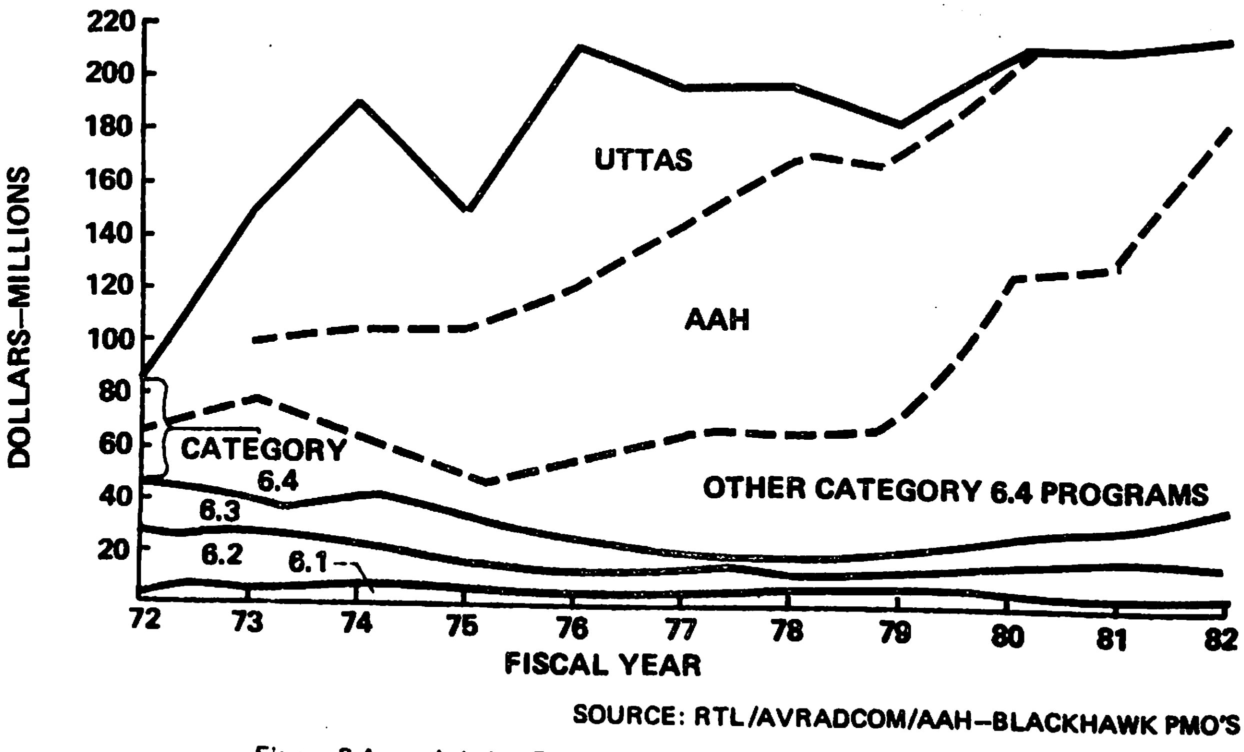


Figure. 2 Army Aviation Funding History (Constant FY72 $)

Figure 2 shows the recent funding history of the Army aviation program in constant FY72 dollars. It should be noted that once the Advanced Attack Helicopter R&D funding is completed, engineering development funding will address only component improvement and remotely piloted vehicles. By 1982 there will be no vertical lift program in engineering development. Technology base funding for aeronautics, both rotary wing and fixed wing, DoD and NASA, is shown in Figure 3. The support for rotary wing technology is relatively modest and has not grown in proportion to the overall effort in the aeronautics technical base.

The vertical lift growth trend in terms of rotary wing inventory size for the US and the USSR is summarized in Figure 4. Within this total inventory the Soviet Union holds a particularly significant advantage in the number of attack aircraft. It is clear that the US is not alone in counting heavily on vertical lift battlefield aircraft to make major contributions in future combat.

Although the US generally continues to enjoy a basic technology advantage in Army related vertical lift development activities, this advantage is unfortunately not fully exploited in its currently deployed equipment. This is due in large part to difficulties encountered in transitioning laboratory capabilities into operational equipment...a problem by no means peculiar to vertical lift aircraft. Efforts in Western allied nations of course represent a substantial contribution in the vertical lift area, although this same capability can have a corresponding deleterious effect on the US manufacturing base because of the highly competitive stature of these same firms in the worldwide commercial arena. As displayed in Figure 5, a number of the world's largest participants in rotary wing endeavors are today located in Europe. Foremost among these efforts in terms of size, and in many instances in terms of capability, is that of France.

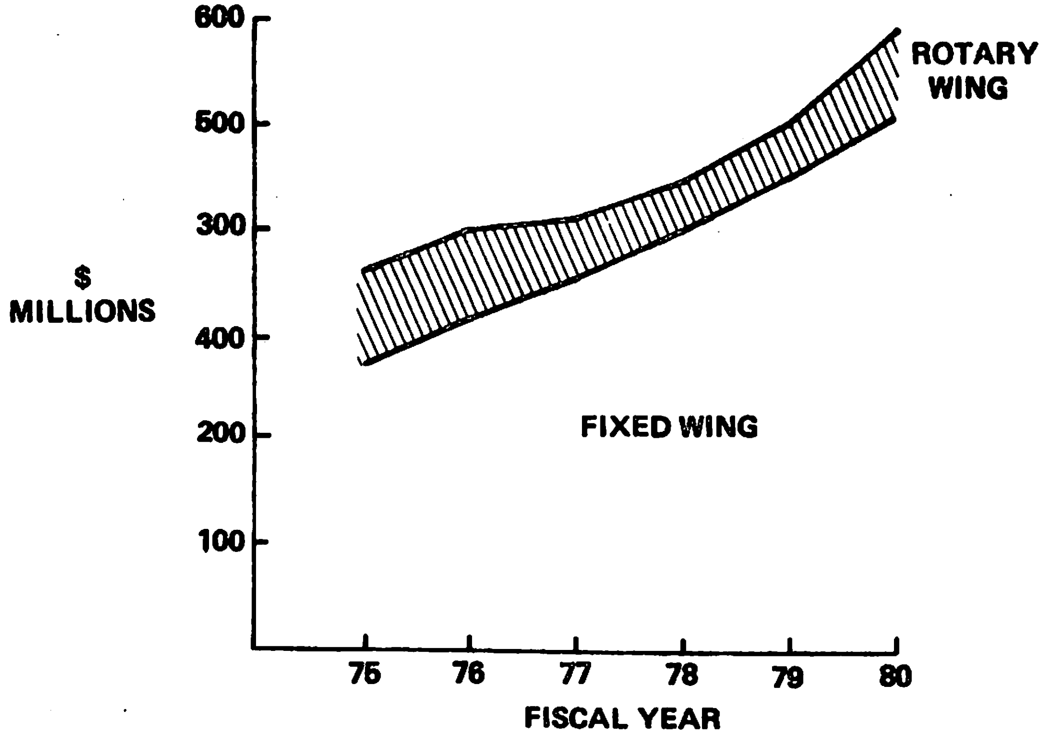


Figure 3. DoD And NASA Aeronautics Tech Base Funding

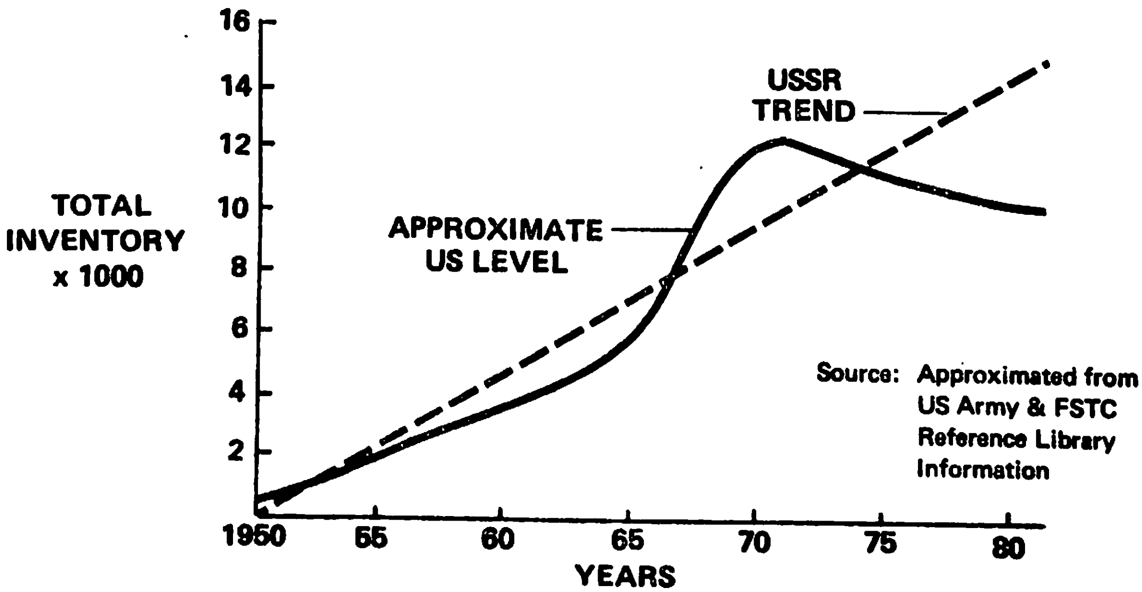


Figure 4. Rotary Wing Inventory (Military)

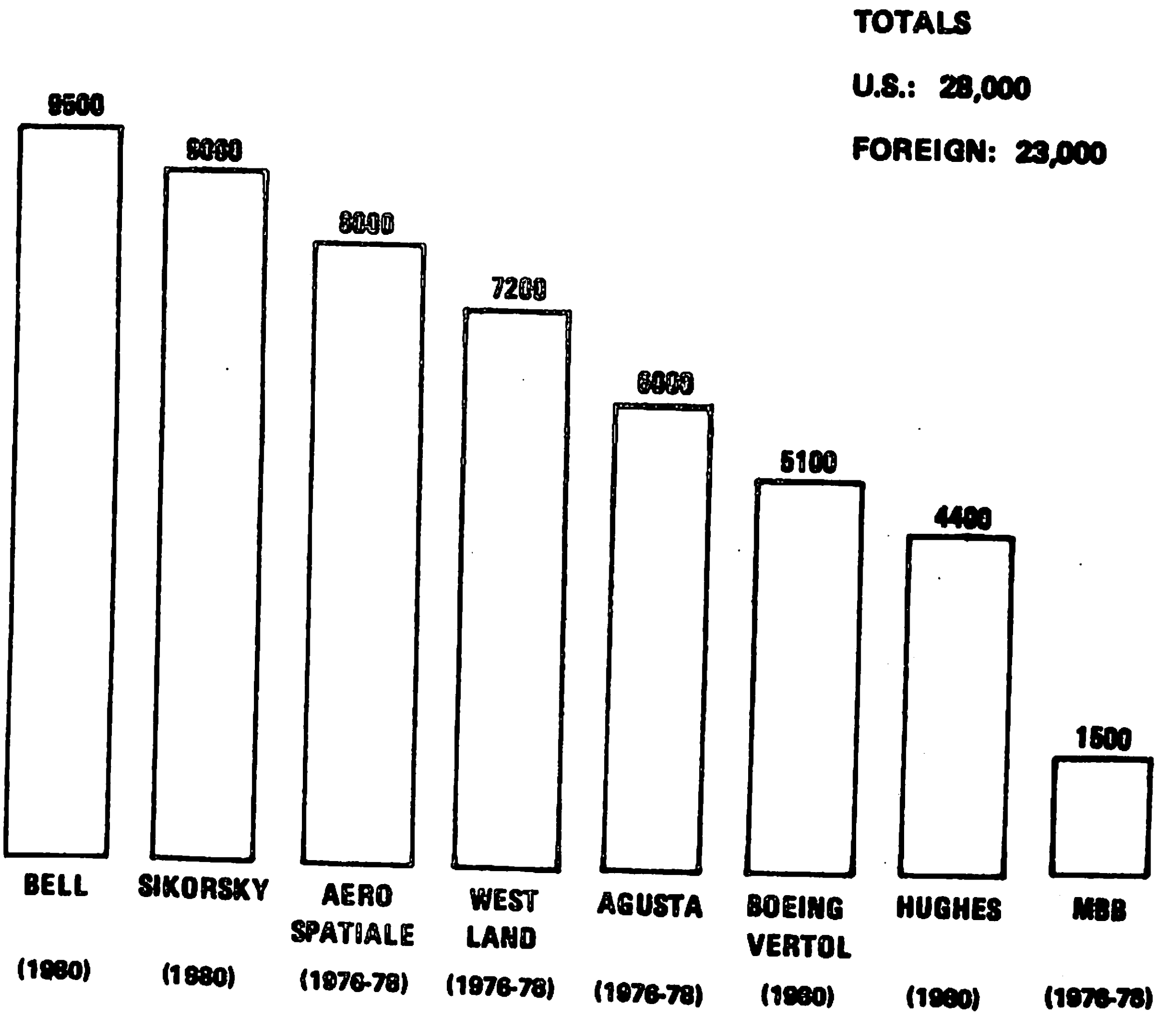


Figure 5. Helicopter Industry Status - Major Free World Helicopter Manufacturers Number of Employees

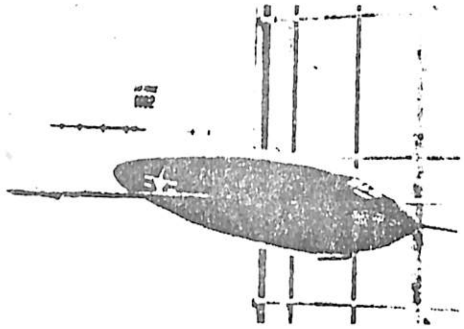
1.3 Problems Encountered in Development Activities

Virtually no Army vertical lift program in the last two decades has been altogether free from development problems, although the severity has varied greatly from instance to instance. Nonetheless, by virtue of highly determined efforts, two new systems of major capability are on the threshold of widespread use. The question as to how the problems might have been avoided in the first place or how they might be precluded in the future is, of course, of considerable interest. The specific difficulties confronted are not discussed in detail herein, but some of the underlying generic causes for the more significant problems are examined.

1.3.1 Maturity of Rotary Wing Aircraft

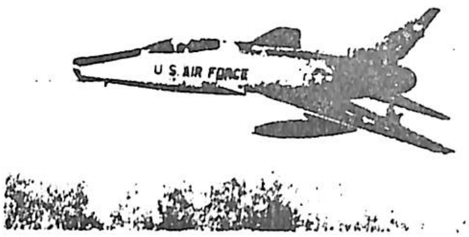
In order to appreciate fully the technical challenge of rotary wing development, as well as the design approaches attempted and sources of development problems, it is useful to recall that such machines are only now in their third generation, are some forty years behind fixed wing aircraft in terms of total flight experience, and have enjoyed but a small fraction of the development funds allocated to fixed wing aircraft. Consequently, rotary wing design is today nearly as much an art as it is a science. It has been said, not altogether incorrectly, that "the helicopter has not yet been fully invented." As shown in Figure 6, it is instructive in this regard to compare the introduction of the first armed "attack" helicopter with other accomplishments of aerospace technology which were its contemporaries. The relative technology level engendered in each of these systems as compared with the rotary wing example is striking. This observation is not intended to demean the achievements of the rotary wing community; quite the contrary. The comment is, however, intended to point out that in comparison to the state of the art of fixed wing aircraft, helicopters are only now leaving their infancy. Much remains to be done to reduce the extent of the

1947: FIRST SUPERSONIC FLIGHT



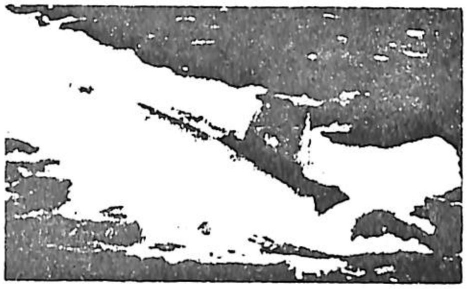
XS-1

1954: FIRST SUPERSONIC AIRPLANE OPERATIONAL



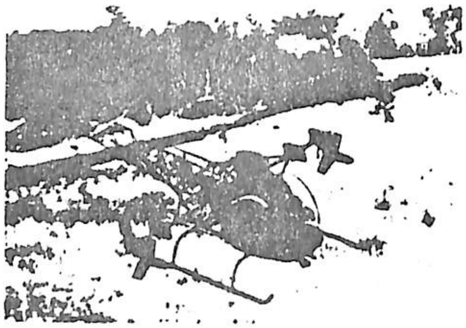
F-100

1960: FIRST FLEET BALLISTIC WEAPON SYSTEM DEPLOYED

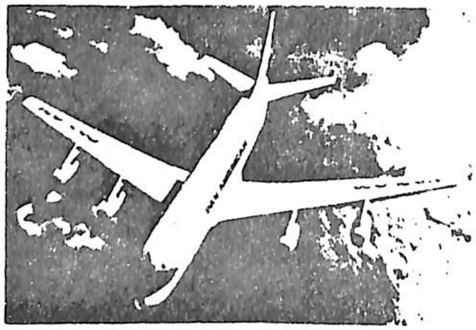


POLARIS

EARLY 60's: FIRST ATTACK HELICOPTER OPERATIONS

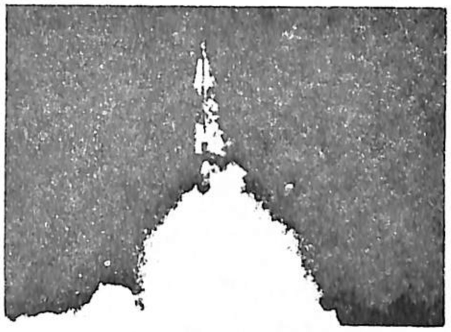


1954: FIRST U.S. COMMERCIAL JET FLIGHTS



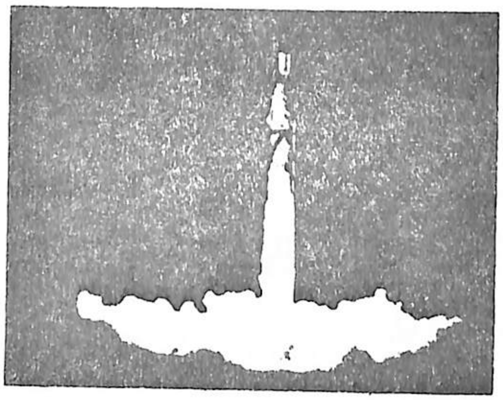
707

1959: FIRST ICBM ON STRATEGIC ALERT



ATLAS

1958: FIRST U.S. SPACECRAFT LAUNCHED INTO ORBIT



EXPLORER 1

Figure 6

design process which continues to fall into the category of "art." If there is any surprise as the result of rotary wing development in the past decade, it should probably be not that there have been problems, but rather that there have not been more problems.

1.3.2 Complexity of Rotary Wing Aircraft

There appears to be a natural tendency among many to view any machine that flies at a low subsonic speed and pulls only very low "g" levels as being, almost by definition, rather pedestrian in terms of technical content. This misconception is not important, of course, unless it results in an overstatement of requirements or an understatement of the resources required to insure success.

Although perhaps not widely recognized, the aerostructural complexities of a rotary wing vehicle are in fact enormous. Rotary wing vehicles regularly operate in difficult portions of the flight envelope which fixed wing aircraft tend to encounter only on a transient basis or not at all. For example, rotary wing aircraft regularly operate in unsteady flowfields, in ground effect, with near-sonic flow conditions on lifting surfaces and in a condition of static instability. There are complex and significant interactions between the lifting rotor and other components of the helicopter, particularly at low speeds, which are just beginning to be understood. Small and seemingly unimportant design changes can provide large changes in the vibration and stress levels encountered in flight as a result of the interactions. These effects all combine to make the development of rotary wing aircraft an extremely complex undertaking which should be initiated only with the due recognition of this fact and with the willingness to devote appropriate resources in order to control the inherent risks.

1.3.3 Development Approach for Rotary Wing Aircraft

The traditional practice in the development of rotary wing aircraft for the Army has been to minimize costs associated with the design process and, implicitly, to accept the consequences of unforeseen problems which tend to arise during flight test. The reasons for this approach undoubtedly stem mostly from a reluctance or inability to make R&D funding available early in development and to a lesser degree from the fact that analytical and experimental sub-scale/ground-test techniques associated with rotary wing aircraft have not yet reached maturity. As a result, design problems have been encountered in the flight test phase which, had they been identified in an earlier step of the development process, could have been corrected at much less cost in terms of both time and money.

Although there is certainly no fundamental law which demands that rotary wing and fixed wing aircraft engineers adhere to the same design practices and policies, or that they devote comparable resources to corresponding tasks, the disparity in the two fields of endeavor in these regards is nonetheless striking. Figure 7 indicates the number of wind tunnel hours devoted to the development of various aircraft systems. The modest useage of this important design tool in the case of rotary wing aircraft is evident. Wind tunnel wall effects and model complexity, of course, make testing particularly difficult for vertical lift systems, but neither these reasons nor the assertion that fixed wing military aircraft are more demanding technically or more sophisticated (if true at all) are very compelling when the cost of correcting basic defects during the flight test phase is considered. It is perhaps particularly significant that commercial fixed wing practice relies heavily on wind tunnel data...even despite the fact that the keystone of commercial practice is to avoid the edge of the state-of-the-art to the greatest extent practicable.

Similarly, the use of simulation in rotary wing development appears to be much less extensive than for fixed wing aircraft. Although in this instance the available quantitative evidence is more limited, Figure 8 does illustrate the general disparity in the use of moving-base simulators between fixed and rotary wing development programs. It is believed that the data in the sample are complete with respect to rotary

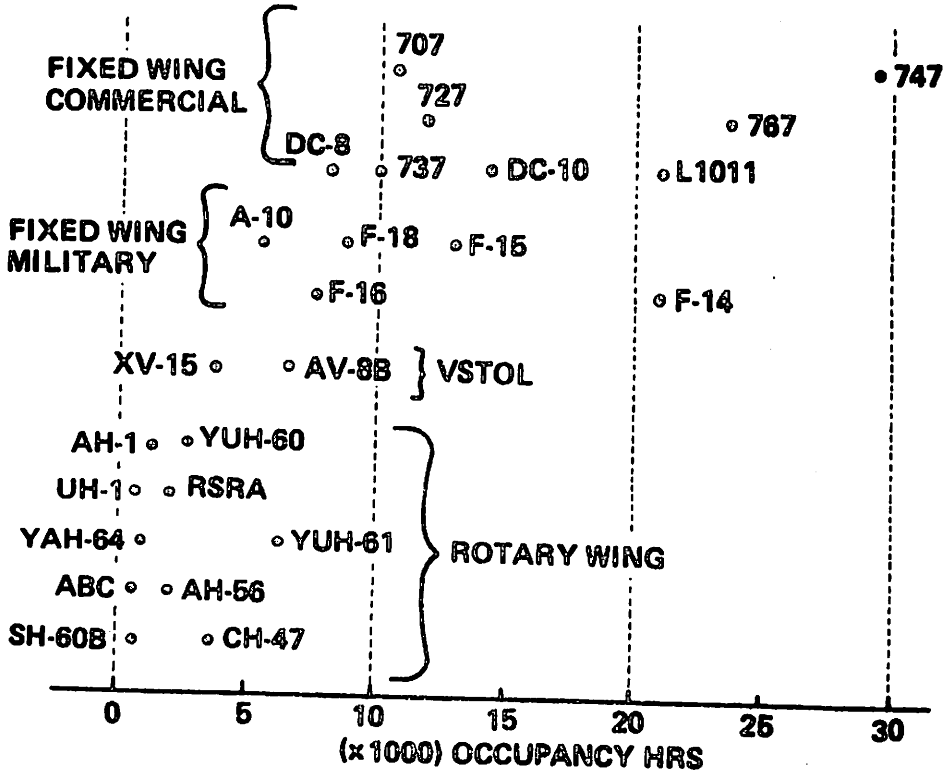


Figure 7. Comparison of Wind Tunnel Test Time

PROGRAM	AGENCY	OCCUPANCY IN SHIFT WEEKS
B1	USAF	28
AMST (YC14 & YC15)	USAF	42
F-5	USAF	12
F-111	USAF	1
F-15	USAF	27
F-16	USAF	14
A-10	USAF	3
ADV. FIGHTER DESIGNS	USAF	25
F-14	USN	64
F-18	USN	11
S-61	USN	3
AH-56	ARMY	0
HLH	ARMY	33
AAH	ARMY	10
UTTAS	ARMY	0
XV-15 TILT ROTOR	ARMY/NASA	60
CH-54	ARMY	18
RSRA	ARMY/NASA	8
ABC	ARMY	8
VTOL DESIGNS	ARMY	5
	TOTAL	372

INCLUDES NASA AMES/LANGLEY RESEARCH CENTER FACILITIES

PERIOD: 1972-79

SOURCE: RTL, NASA AMES/LANGLEY

Figure 8 Government Simulation Utilization wing developments, but highly incomplete with respect to fixed wing programs. That is, the differences are probably much more marked than the data suggest. It is perhaps indicative, although not necessarily improper, that most rotary wing manufacturers do not possess a wind tunnel and only one owns a moving-base simulator. Virtually all major fixed wing manufacturers possess one or more of both.

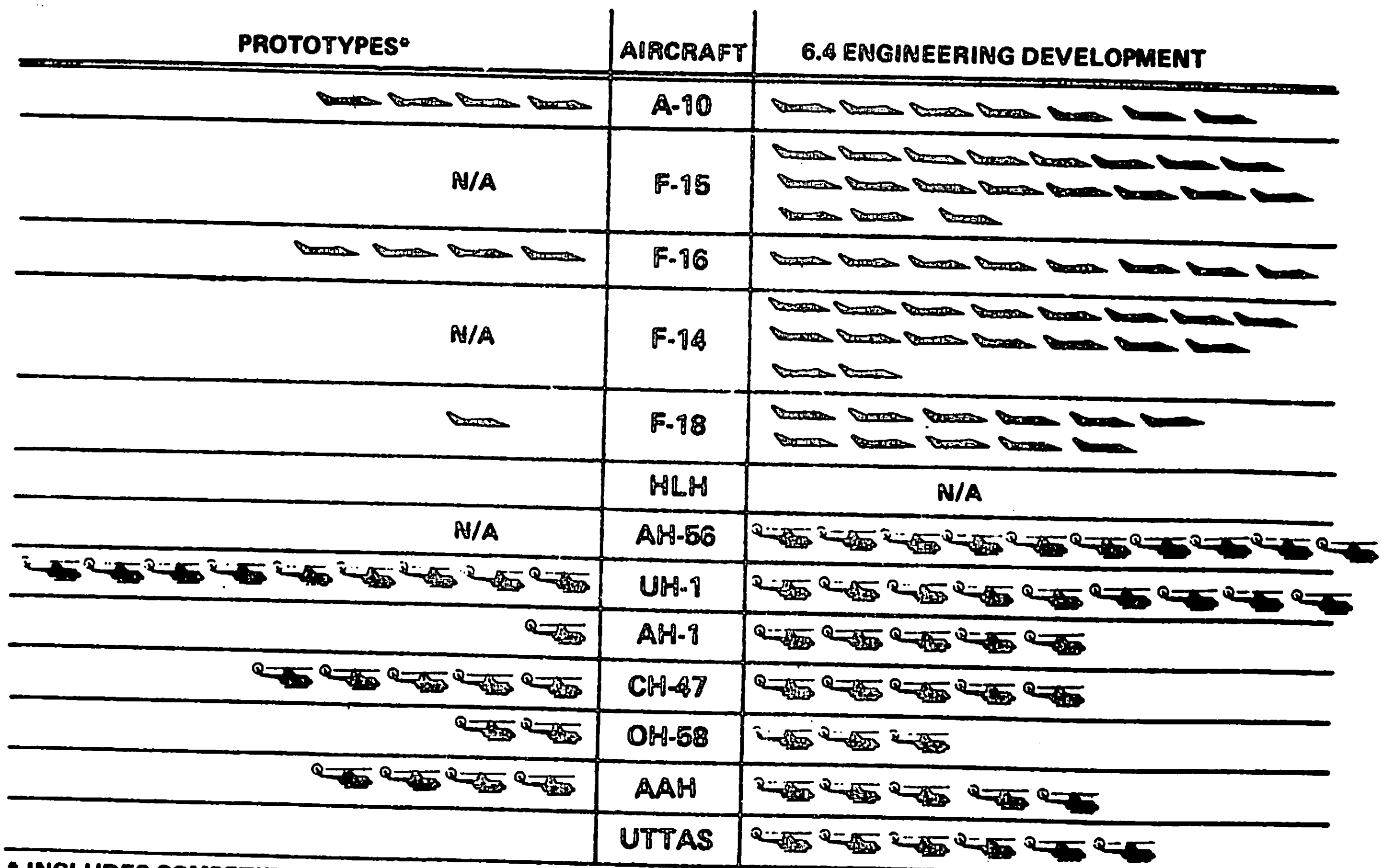
As noted above, these contrasts in wind tunnel and simulator usage are due in part to the inadequacy of current analytical and sub-scale techniques for vertical lift configurations, techniques which must be further developed. Also the indicated tendency to develop Army vertical lift aircraft "on a shoestring" somewhat inexplicably carries over into the flight phase. Figure 9, depicts this trend by showing the number of flight test prototypes procured for various programs.

The risks inherent in the above practices are exacerbated by the fact that helicopter developments have tended to come in "bunches" with long "dry spells" in between. As illustrated by Figure 10, another of these periods of inactivity now appears to be on the horizon. A consequence of this intermittency is that development resources are difficult to maintain: restructuring and relearning are then required.

This has been a problem in recent years in the fixed wing arena as well, but the past decade has observed the development of an F-14, F-15, F-16, F-18, A-10, S-3, etc., while only two rotary wing developments have been completed. While the need for a given number of development programs in support of operational requirements most assuredly cannot be asserted based on the present investigation, the impact of prolonged periods of inactivity in the development of any type of advanced hardware certainly can be; and it is highly adverse.

1.3.4 Some Lessons Learned

The inherent complexity of vertical lift machines, coupled with the immaturity of related design techniques, exacerbated by the practice of inadequate funding in the development process, has created the



* INCLUDES COMPETITIVE PROTOTYPES

Figure 9 Number of Research/Development Aircraft

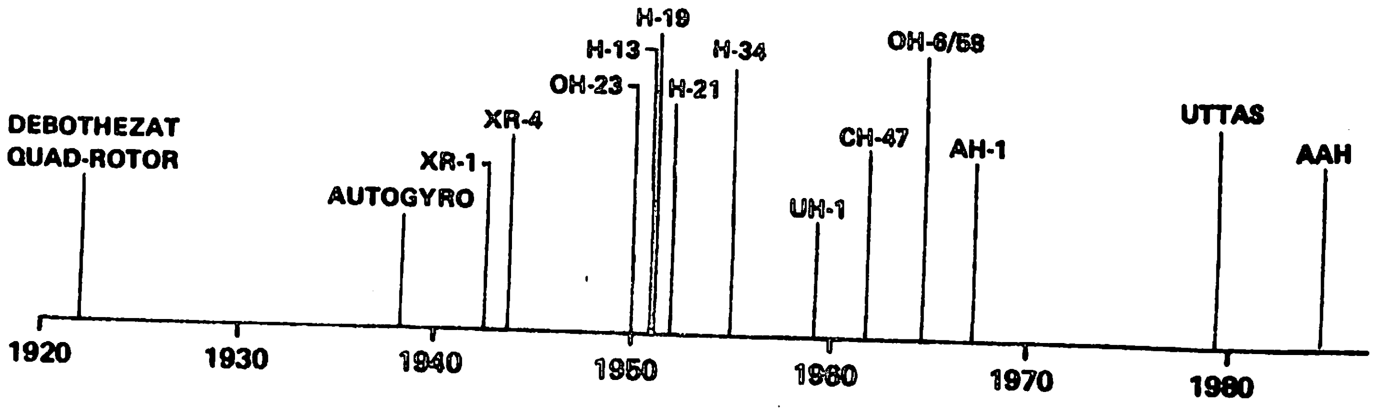


Figure 10. Timeline of U.S. Army Helicopter Development

(Representative sample of major programs) environment for technical problems to occur such as those experienced in recent developments. The fact that these developments seem to have been successfully completed generally attests to the skill of those involved. The fact that the problems occurred in the first place indicates that there must be a better approach. Figure 11 seeks to identify some of the principal lessons learned in this regard.

It is noteworthy that one technology which has plagued many of the fixed wing developments undertaken during the past two decades has in contrast been an area of enormous success in the Army vertical lift program. This is the field of propulsion, wherein the T700 engine has been a well considered, well executed endeavor virtually from start to finish. The reasons for this are quite evident; the Army funded over a period of many years a series of ground test activities that led to a highly mature engine being available at the time the aircraft on which it was to be used were themselves ready to fly. The message seems to be clear: cutting corners in the early technology and component development phases simply does not pay.

1.3.5 Other Observations

Two additional aspects of Army vertical lift endeavors appear worthy of note in the context of an overview. The first of these is the trend toward rapidly growing unit cost, a trend which far outstrips any likely growth in the defense budget. The inevitable consequence of this will be a diminishing inventory of aircraft, albeit comprised of individually superbly capable vehicles. The time would seem to be near at hand when requirements which demand "that last few percent" of performance may have to be foregone, and when advanced technology must be applied to increase numbers through reduced total ownership cost rather than to the search for greater performance. This has, of course, been accomplished to some modest degree already. However, Figure 12 shows the startling trend in unit cost growth of Army helicopters (a growth rate which, as it happens, exactly parallels the growth in cost of fixed wing aircraft).

PROGRAM	TECHNICAL PROBLEMS ENCOUNTERED	NATURE OF PROBLEM	PROBLEM SOLUTION	ACTIONS THAT MIGHT HAVE PREVENTED PROBLEM
HLH	LARGE GEAR/TRANSMISSION PERFORMANCE & RELIABILITY	SCALING OF EXISTING GEAR/TRANSMISSION TECHNOLOGY; INTRODUCTION OF NEW GEAR MATERIALS	ADDITIONAL TESTING AND NEW GEAR ANALYSIS	TECHNOLOGY PROGRAMS ON LARGE GEAR/TRANSMISSION INCLUDING ANALYSIS, EXPERIMENTS AND TESTING.
AH-56	MULTIPLE AEROELASTIC INSTABILITIES	LARGE NUMBER OF INTERACTIVE INSTABILITIES AND DIFFICULTY ASSOCIATED SOLVING THE TOTAL PROBLEM; INDIVIDUAL INSTABILITY PROBLEMS SOLVABLE.	MODIFIED CONTROL SYSTEM WHICH DE-COUPLED INSTABILITY PROBLEM	COMPREHENSIVE WIND TUNNEL AEROELASTIC TEST AND ANALYSIS ENCOMPASSING FULL FLIGHT SYSTEM, PRIOR TO FINAL DESIGN.
UH-60 "BLACKHAWK" (UTTAS)	1) HIGH STRUCTURAL LOADS IN TAIL/EMPENNAGE 2) LOW SPEED NOSE-UP ATTITUDE (EXTREME) 3) EXCESSIVE INTERFERENCE DRAG AND VIBRATIONS 4) EXCESSIVE PILOT WORK-LOAD AT LOW SPEED.	1,2) ROTOR DOWNWASH EFFECTS ON LARGE, FIXED HORIZONTAL TAIL 3) ROTOR/FUSELAGE INTERFERENCE 4) INADEQUATE RESPONSE OF FLUIDIC SAS UNDER ALL TEMPERATURE CONDITIONS.	1,2) CHANGE TO MOVEABLE "STABILATOR" 3) RAISE ROTOR 15 INCHES 4) INSTALL DUAL CHANNEL ELECTRONIC SAS	1) EMPHASIZE NEED FOR THOROUGH WIND TUNNEL TESTING WITH POWERED ROTOR MODELS PRIOR TO FLIGHT. 2) MINIMIZE VIBRATION FROM THE OUTSET BY THOROUGH ANALYSIS OF VIBRATORY MODES. 3) ANALYZE INTERFERENCE EFFECTS AS A FUNCTION OF ROTOR HEIGHT 4) ANALYZE PITCHING MOMENT AS A FUNCTION OF AIRSPEED & POWER 5) EXPLORE EFFECTS OF VARIABLE INCIDENCE AND LOCATION OF TAIL.
AH-64 (AAH)	1) HIGH STRUCTURAL LOADS IN TAIL/EMPENNAGE 2) EXCESSIVE PILOT EFFORT IN LEFT SIDEWARD FLIGHT 3) LOW SPEED SAS-OFF "WALLOWING" CHARACTERISTICS 4) EXTREME NOSE-UP ATTITUDE AT LOW SPEED 5) FAILURE TO MEET MAX VROC AND CRUISE SPEED SPECIFICATIONS	1) STRUCTURAL DYNAMICS OF "T" TAIL 1,4) ROTOR/FUSELAGE INTERFERENCE 2) TAIL ROTOR INTERFERENCE EFFECTS 3) UNKNOWN 5) AERODYNAMIC DEFICIENCIES	1,4) CHANGE TO LOW-MOUNTED, MOVEABLE STABILIZER 2) INCREASE DIAMETER OF TAIL ROTOR 3) DUAL-REDUNDANT DIRECTIONAL SAS (IF NECESSARY) INCREASE AERODYNAMIC EFFICIENCY BY MODIFYING MAIN ROTOR BLADE TIP CONFIGURATION, TAIL ROTOR GEOMETRY, AND DRAG REDUCTION DEVICES.	SAME AS UH-60 PLUS: 1) TEST (WIND TUNNEL) DESIGN OF TAIL ROTOR/EMPENNAGE 2) MAKE REALISTIC SAS-OFF SPECIFICATIONS ESPECIALLY WHEN REDUNCANT SAS'S ARE EMPLOYED.

Figure 11

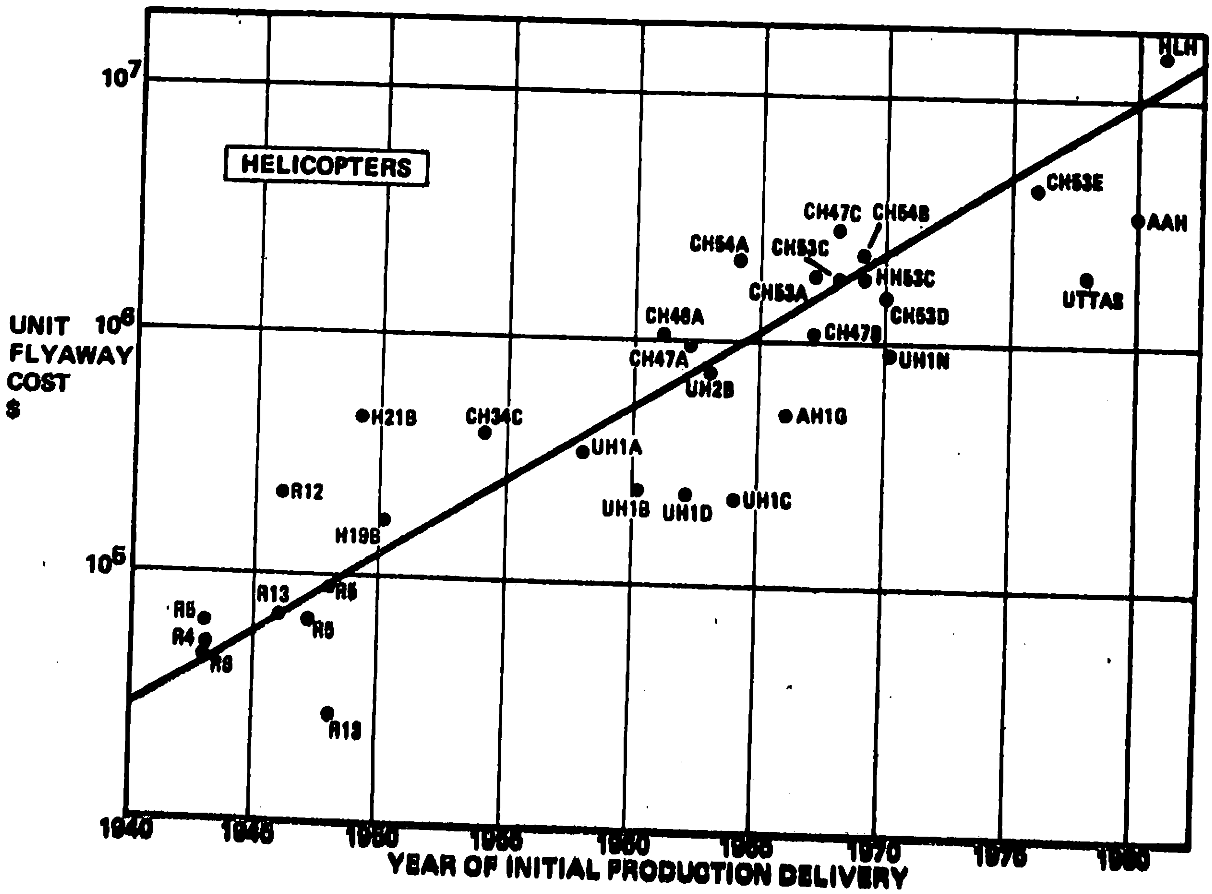


Figure 12. Unit Cost Increase With Time (1980 Estimated)

Turning to the second additional area of particular import; with the enormous gains recently made in payload lifting capability, target acquisition and weaponry, the element which now could threaten the basic viability of the modern vertical lift machine as used in military applications is the advancing technology of air defense; technology which has at least kept pace with the progress of aircraft design. The development of very long range second generation look down, shoot down airborne defenses, coupled with the proliferation of high precision, highly portable surface-to-air missiles, makes it clear that the matter of assuring survivability must receive a substantial share of attention in military vertical lift technology.

1.4 Recommendations

A number of individual recommendations are described in the following sections of this report. The more significant of these are summarized below, categorized into the three areas addressed in the panel's charter; (1) technology, (2) missions, and (3) management.

Ref.	Category	Recommendation
1	Technology	Establish a new program element and draw together an integrated program under a single manager to generate and verify mature vertical lift design techniques. This activity should include establishing comprehensive objectives as well as correlating and disseminating data obtained in flight with that from analysis and model tests. The end product should be a series of comprehensive design and development methodologies.
2	Technology	Fund engine developments at a continuing level of about $25M per year, initially focusing on the T700

Ref.	Category	Recommendation
		engine augmented power program and the Advanced Technology Demonstrator Engine development.
3	Technology	Concentrate technology funding on aeromechanics, propulsion, low observability, composites, flight controls, reliability enhancement and low cost design...possibly at the expense of further advancements in the ability to withstand damage.
4	Technology	Increase the funding of the 6.1, 6.2 and the high risk/high payoff 6.3A programs by at least 10 percent per year, even at the expense of development and production activities. It is from these areas that quantum jumps in capability will arise.
5	Technology	Focus 6.3A technology on configurations capable of high speed and long range in addition to good low speed agility.
6	Technology	Establish a specific line item to support the development and procurement of product improvement packages, particularly those which enhance reliability and maintainability.
7	Missions	Incorporate self-deployment as a design objective for future vertical lift machines whenever vehicle size makes strategic deployment by air unduly costly or otherwise impractical.

Ref.	Category	Recommendation
8	Missions	Provide a self-defense air-to-air capability for selected tactical helicopters. Do not, however, significantly compromise either design or doctrine associated with basic ground support missions in order to achieve this capability.
9	Missions	Initiate a feasibility study for a very low observable vertical lift aircraft...focusing on flying qualities only after observability has been minimized.
10	Missions	Introduce basic chemical/biological protection into current vertical lift systems, and make operation in chemical/biological environment a mandatory condition for all future aircraft. Care must be exercised, however, not to introduce overly complex systems which compromise basic mission capability.
11	Missions	Begin focusing the aviation program on a family of high speed, increased range vertical lift aircraft which still preserve good low speed agility. This appears to be feasible and appropriate. The current Tilt Rotor (XV-15) and Advancing Blade Concept (ABC) designs have demonstrated that the technology is available to provide strategic self-deployability, tactical battlefield versatility and support of missions demanding long range, low-level flight with terminal hover capability. (Off-shore and ship to shore requirements in many parts of the world also dictate support of this requirement.) Allow program

requirements to drive the selection of specific configurations.

Ref.	Category	Recommendation
12	Management	Allow more time and resources in the initial design phase of new systems for iterative analytical assessment, scale model testing, and design refinement. This time could be recovered in the pre-DSARC I/II and post-DSARC-III periods as now practiced.
13	Management	Support, through a highly visible Army program, the establishment of a small number of centers of excellence in rotary wing aircraft technology among respected US universities. Nuture this through a significantly expanded program of long-term research grants and invitational symposia.
14	Management	Assign young Army aviation officers to paired tours in the R&D and user communities. Increase the corresponding graduate education program in vertical lift technology in order to create a body of operator/technologists at least somewhat comparable in relative numbers to that today possessed by the Air Force and Navy. The recent support of the Army astronaut program sets an excellent example and could be a portion of this activity. Also, in conjunction with the support of educational institutions, assignment of aviation officers to institutions demonstrating a strong vertical lift program would be highly appropriate.

Ref.	Category	Recommendation
15	Management	Force an early down-selection of potential configurations which are to be candidates for the next generation of vertical lift systems. There is, of course, some risk that this will result in premature reduction of options, but it must be done for purposes of economy and to be sure that the competitive base is not undermined by each producer being associated with a single, different, highly specialized aircraft type.
16	Management	Institute at least two wide latitude, "Packard type" prototype programs to fill the oncoming gap in rotary wing development. The basic purpose in this is much the same as was the case when the F-16, F-17, F-18 and F-19 programs were initiated; i.e., the developmental base consisting of many capable individuals and key facilities represents a national asset which should be preserved...particularly when an abundance of promising design concepts is available. In the case of vertical lift aviation, these concepts will continue to evolve from the confluence of technologies relating to a high capability ASH -- a high cruise speed, long range vertical lift operational prototype; and possibly a heavy-lift machine.

Ref.	Category	Recommendation
17	Management	Construct, with the help of industry, an inventory of existing ongoing government management practices which tend to detract from program stability and the ability to accomplish desired objectives, and modify these practices to the greatest extent possible. It is considered that program turbulence is one of the greatest detriments which exist today to successful future research and development in the rotary wing field.
18	Management	The Army should maintain and disseminate a development problems record so that future developments can more readily avoid past difficulties.

Four items stand out in the near term that demand immediate attention and can provide the greatest payoff for the Army.

- o The rapidly expanding role of the helicopter in the activities of various governmental agencies and the civil sector, make it desirable that some one agency be designated the focal point for advancment of the state of the art in related technologies. The Army is probably the logical choice and should be provided the appropriate charter and funding to expand its existing base with support from other government agencies.

- o High speed and long range, previously played down in helicopter requirements, have become increasingly important for self-deployability and theater versatility. These attributes should be built into future programs. For the near term, modifications and kits for existing assets should be considered to achieve added speed and range.

- o Propulsion systems have been and will continue to be the very foundation for future vertical lift performance. The deterioration of emphasis on the Advanced Technology Demonstrator Engine should be reversed to provide for increased vertical lift capability.

- o Helicopter developments in the field of advanced composite materials will continue to be important. The development of airframe primary structure of composite materials is a current necessity and will contribute to the speed/range requirements addressed above as well as to RAM and survivability enhancement.

Some of the above actions call for significant additional funds (although many do not). The choice which is faced seems clear: either to pay now for the avoidance of future problems in vertical lift developments or to pay later, on a much larger scale, to correct those problems. The experience base in this regard seems, at least to this review group, highly compelling, particularly in view of the comparatively modest amount of funds required to make significant improvements early-on in a program. An alleviating factor is that many of the recommended actions, e.g., in composites, propulsion, RAM, human factors and survivability, have application to areas other than vertical lift, e.g., ground vehicles, so that the costs as well as the benefits can be shared to some degree.

In summary, in spite of obstacles and program shortcomings, the helicopter community is providing an important military capability. That capability, a "National Asset," has consisted of several generations of vehicles:

- The first generation was a family of 6-8 helicopter types.
- The second generation was down to 3 or 4.
- The third generation is two (AAH and Blackhawk).
- There are no plans for any fourth generation.
- There are no vertical lift machines programmed in the 6.4 area after FY82.

It appears that the U.S. may presently be at a vertical lift program crossroads; either to carry on a modest holding effort; or to move ahead to take advantage of the capabilities that lie beyond the current threshold. Any decision in this regard must of course be backed in the form of funding and the creation of a strong base of technology and design techniques.

2.0 TECHNOLOGY

2.1 Introduction

The following section addresses the technology of vertical flight, principally that of rotorcraft. First, the existing capability in the U.S. and abroad in each of the basic technical areas is reviewed. The important areas, their effects, the potential for improvement, and the consequences of that improvement are noted. Additionally, applicability of current and planned Army programs is noted and comments are given. For the most part, the Army's listing of technical areas in the 1979 Army Aviation RDT&E Plan is used as an outline, although several areas in that document which are not considered critical to this review are omitted. As a part of the review of current capability and potential, the synergism associated with advancements in all of the technology areas taken in concert is discussed, and comments are made regarding VTOL configurations other than the helicopter. Second, with the status of technology defined, several technology related issues are discussed:

- o The anticipated operational capabilities that could be provided by vertical lift technology efforts (thus offering a counter perspective to that of Chapter 3.0, which addresses possible future capabilities from the perspective of requirements.)
- o The location of the technical base
- o The thrust of future technology efforts for near and far term payoff
- o Development risk.

The third and final part of this chapter summarizes the key recommended actions that the Army should undertake to improve the technology base in the vertical lift field and, consequently, the Army's and other Services' operational capability.

2.2 Current Technological Capability, Potential, and Needs

2.2.1 Aeromechanics (Aerodynamics, Dynamics, Flight Controls, Acoustics)

Aeromechanics is central in its importance to future progress in rotorcraft. Current analytical and experimental procedures are limited primarily because of the incompletely defined nature of the unsteady flow fields of rotors in the presence of fuselages through a very wide angle-of-attack range, and the extremely complex, usually non-linear, multi-frequency structural dynamic interactions. In addition, there is a lack of confidence in small scale experimental investigations due to inadequate model/full scale correlation efforts. The U.S. helicopter industry has developed a much broader and deeper aeromechanics technology base than either foreign industry or the USSR. However, many of the foreign manufacturers appear to have the ability to assimilate technology and to convert it more quickly into hardware. This is believed to be due in part to the "supportive" relationship that the foreign companies have with their governments, as contrasted to the arm's length relationship in this country brought about by the US competitive structure.

For values of thrust coefficient and advance ratio typical of contemporary U.S. helicopters, power required can be predicted at best to ±3% in hover and ±5% at cruise speed. External noise estimates are within 3 to 10db for 3000 to 40,000 pound helicopters, respectively. Conventional rotorcraft weights are predictable within 3%.

Stability and control predictions appear to be of acceptable accuracy except for operating conditions at high advance ratios and thrust coefficients and the higher angle-of-attack ranges. Nap-of-the earth (NOE) handling qualities are predictable except for the interaction effects of the fuselage and main and tail rotors at low flight speeds over and close to the ground. (Unfortunately both of these areas of limited accuracy are important parts of the operating envelope.) As yet, specific agility requirements are not defined.

Reliable methods for fuselage vibration and oscillatory structural loading predictions, especially for the higher frequencies, are not available. Small changes to existing components may cause significant changes in vibration level which are not predictable. Mechanical devices have been invented which attenuate the vibration to acceptable levels throughout most of the flight envelope with a small weight penalty, and the science/art of helicopter design has provided reasonable approaches to estimating structural loading.

Invention is an important part of vertical lift technology--a part that is too often ignored in planning development activities. Future planning should include the promotion and fostering of invention and innovation, and R&D efforts should be structured to take advantage of these aspects when they occur.

Aeromechanics problems encountered during the development of the third generation of rotorcraft can in most instances be traced directly to limitations in methodology, the lack of understanding of the possible problems, an inadequate experimental base, and limited design team experience. The methodology at the beginning of the 70's was considerably less advanced than even that noted above. Additionally, ambitious specification of requirements and a lack of full understanding of the consequences of those requirements contributed to the problems encountered. Further, within the competitive environment which was established, substantive discussions of technical risks were rare, and little or no time was allowed for design iteration or significant design support tests.

The potential for improvement and significant payoff therefrom is great. For instance, it is projected that the same relative gain in hover performance achieved for third generation helicopters can be realized in the next generation. This means payload gains of as much as 25% over the new rotorcraft now entering the inventory may be obtained. Simultaneously, increased understanding of aeromechanics problems will reduce the risks associated with future rotorcraft development.

Greatly improved values of the benchmark aerodynamic efficiency parameter, lift/drag (L/D), are achievable for the helicopter. Alternate approaches to vertical flight, furthermore, have been demonstrated which promise to double current rotorcraft productivity, reduce fuel consumption by half, and provide range capability consistent with true overseas self-deployment.

Advanced flight controls work sponsored by all Services has made the U.S. the leader in that field. Benefits include reduced pilot workload and increased rotorcraft safety, survivability (ballistic tolerance, nuclear tolerance, agility), and performance. Active controls technology applied to the rotor has shown the potential for reducing rotor dynamic loads and aircraft vibration. The work of NASA and the Army in this area has been outstanding, with French contributions also being significant. U.S. industry is now moving into fly-by-wire control and eventually will employ fly-by-light. In connection with the latter, the Advanced Digital Optical Control System (ADOCS) program is a step toward integrating state of the art flight control technology. The program will culminate in a 25 hour flight test demonstration to establish feasibility and substantiate significant benefits for safety, survivability, RAM and cost/weight reduction.

The 1979 U.S. Army RDT&E plan clearly recognizes the opportunities in aeromechanics and contains an excellent program. Budgetary support of this plan is, of course, the pivotal issue. Following are additional thoughts and comments:

o The Government, with industry, should assess the accuracy of current aeromechanic tools, including wind tunnels and simulation, to force realism into future rotorcraft specifications and minimize overzealous marketing.

o The Government should develop an aeromechanics data base including wind tunnel, flight, and simulation data for Army helicopters for the purpose of correlation. Available data may be used in part and the project should not depend only upon flight programs planned for the distant future, but should exploit existing aircraft and models to the maximum practicable extent.

o The NASA/Army should develop a new family of rotorcraft airfoils using in-house resources.

o The Second Generation Comprehensive Helicopter Analysis System Program (2GCHAS) should be aimed at improving the understanding of the physics underlying rotorcraft phenomena before undertaking a more advanced effort. Advanced analytical models and improved test and evaluation methods should be developed with careful validation of each step.

o There is concern about the productivity (research per dollar) of the Rotor Systems Research Aircraft (RSRA). The baseline flight testing is slow and a well defined program leading to meaningful research results is needed.

o The Army should define (and establish) a requirement for agility.

o Analytic models of the rotor wake require substantial further improvement, especially for very low and very high advance ratios. Development of more efficient and economical algorithms is also required to attain broader practical utility.

o The detailed evaluation of the rotor wake by laser velocimeter is important and should be continued. However, it will to be a slow and laborious process and is fundamentally limited to giving time-averaged values. The velocimeter work should be augmented by flow visualization efforts from which an approach to the time variant nature of the rotor wake could be defined.

o The design time allowed for new rotorcraft development should be increased significantly, allowing time for iteration based on design support test results. This does not mean that the pre-development program approval process should be extended.

o The Army should maintain and disseminate a development problems record so that future developments can more readily avoid past difficulties.

2.2.2 Propulsion

2.2.2.1 Power Plant - Progress in engine development will be reflected as a benefit to direct operating costs, fuel requirements, payload, reliability and maintainability, infrared signature and noise. Its overall importance ranks at least equal with aeromechanics. From the specific standpoint of offering potential improvement to rotorcraft performance, the power plant ranks first.

Power plants contemplated for a new aircraft should be developed well ahead of the planned aircraft since they require much greater leadtimes than the airframe. This was accomplished in a most exemplary manner for the third generation helicopter in the case of the 1500 SHP T700 engine. This program has provided the U.S. with a superior advanced technology engine in its size class.

There is today a need for a smaller engine to power the Light Helicopter (LHX) family, currently in Army planning. The existing Advanced Technology Demonstrator Engine (ATDE ~800 SHP) program fills this need. Current funding, however, seriously limits progress on the program.

For mid-size rotary wing aircraft, ten horsepower of engine ouput is roughly equivalent to 100 lbs. of helicopter lift. One hundred horsepower could translate to 1000 lbs. of additional lift--a major gain indeed. The Soviet Union has embraced the philosophy of emphasizing engine growth rather than airframe sophistication; a tradeoff which seems appropriate in view of the typical sensitivity factors governing such choices. It is thus recommended that the T700-701, T700 booster and the 800 HP (ATDE) engine programs be fully funded.

Similarly, there are future requirements for higher power advanced engines. The Modern Technology Engine (MTE ~4000-5000 HP) offers promise as a needed T55/T64 replacement for a medium lift helicopter or a large advanced VTOL configuration and, together with the Allison T701 (8000 HP) developed for the Heavy Lift Helicopter, should still be considered a potential engine for future Army and DOD vehicles. Development of these engines should be completed as soon as possible.

A lesser size power plant (300 to 400 HP) should be investigated in a multi-service role for powering future cruise missiles, APU's, and small helicopters. Further, if one-engine-inoperative requirements become more important, as might well happen with the increasingly more costly mission equipment aboard smaller helicopters, triple engine installations may be a superior answer to a possible one-engine-out hover requirement, and the small engine may find use there.

It is believed that U.S. engine technology is generally superior to that of foreign industry; however, such a conclusion may simply be the consequence of lack of experience with the engines of even our allies. Based on the statistics that can be obtained, the French Turbomeca Arriel and Makila power plants are very competitive with U.S. engines as is the English Rolls Royce Gem IV engine.

Current modern technology power plants have pressure ratios of about 16, giving high efficiency at turbine temperatures around 2300°F. Turbine shaft speeds up to 20,000 to 40,000 RPM have been shown to be practicable for helicopter power plants. Continued research in materials and cooling to allow higher temperature operation, combined with continued exploration of higher shaft speeds, offers continued promise for still lower weight and lower fuel consumption power plants. But there is a new factor in the equation now--fuel shortages and attendant costs.

In the past, the power plant development drive has been directed equally toward simplicity for reduced maintenance and lower initial cost, low fuel consumption, and low engine weight. Because of the fuel shortage, it is time to reconsider approaches that have been cast off earlier because of increased complexity. Regeneration (recuperator) may be a viable approach in the reasonably near term to reduce fuel use. This is especially true for an application requiring infrared suppression.

Variable geometry schemes offer considerable promise in reducing partial power fuel requirements. Research in these areas should be initiated or accelerated. Additionally, alternate and low grade fuel capability should be sought. Similarly, the Army should move as quickly as possible to electronic fuel controls which would reduce fleet operating costs through a reduction of fuel consumption and maintenance requirements. The adaptive digital fuel control design study should be followed promptly by advanced control law development and flight demonstration hardware.

In summary, within the engine area, specific recommendations are:

- o Continue development of the T700 booster engine to provide growth essential for the third generation helicopters.
- o Carry the ATDE through its development phase so that a modern engine will be available for the next generation helicopter.
- o Expand R&D in areas which will minimize fuel requirements on both existing and new aircraft.
- o Initiate R&D on convertible powerplants (such as the convertible fan/shaft engine) that are suitable for high performance configurations.

2.2.2.2 Transmission - The mechanical gear-driven transmission will remain unchallenged as the best solution for transferring power from engine to rotor for the foreseeble future (except possibly for very heavy lift helicopters). The combined transmission component development programs of the Army and NASA are well conceived and managed, and no change is recommended.

Currently, the U.S. technology in this area appears to be well ahead of foreign competition, both allied and Soviet, with lighter weight per stage per horsepower and superior special features such as fly-dry and ballistic survivability.

Transmission weight reduction of 15 to 20 percent is predicted over the next five years with improved ballistic survivability, better efficiency, lower noise, and increased time between overhauls. Unit costs will increase slightly, however, and with the probability of higher engine shaft speeds the importance of transmission research will grow. Emphasis on reliability improvements and diagnostic systems can have a significant impact on operating costs and effectiveness.

2.2.3 Structures (Airframe and Rotor)

With metallic airframe design having reached a plateau of maturity, the future thrust will be in application of advanced composites first to secondary and subsequently to primary airframe structures. Weight savings of approximately 20 percent of the replaced structure are indicated and production cost reductions of around 15 percent are forecast, the latter primarily because of lower labor content. The elimination of the catastrophic failure modes of monolithic metallic primary structures, such as rotor hubs and blades, is equally important.

U.S. industry, after initially trailing behind West Germany and France, has taken the lead in composite rotor blade technology through introduction of mechanized manufacturing methods capable of high output rates. This achievement, coupled with the application of advanced aerodynamic design, makes the U.S. the current leader in rotor blade design and production.

Application of composites to secondary structures is rapidly expanding even today. Principal materials used are glass, graphite, and Kevlar in epoxy matrices. In this area, U.S. and European technology--principally France's Aerospatiale--are roughly equal, while the Soviet Union lags behind.

Composite material usage in primary airframe structure is slow in coming for several reasons, including the lack of reliable failure criteria for parts with complex loading, uncertain production costs, the lack of service experience, undeveloped inspection techniques, low design allowables because of very conservative environmental degradation requirements, and lack of experienced design personnel.

The Army's Advanced Composites Airframe Program (ACAP) is an important step in bringing composite technology to primary airframe structures and is fully endorsed. It will do much for training of personnel, developing better manufacturing methods, reducing source material lead times, and improving design-approaches.

In a similar manner, the Integrated Technology Rotor Program (ITRP) is considered to be an important undertaking. It may be too ambitious, however. More consideration should be given to reducing the number of variables or unknowns per test and to conducting more tests.

The Army structures programs stressing the development of hardware are endorsed as important and useful work. However, it is believed that they could be modified and, if necessary, reduced in scope so that other needed work might also be funded, including:

o The development of comprehensive structural design guide data through a government/industry program. This effort should include development of unified materials specifications for composites.

o The establishment of a vigorous program to develop substitute materials (composites, ceramics) for scarce metals such as cobalt, tungsten, molybdenum, chromium, and others. A <u>viable</u> strategic materials bank needs to be established.

o The development of improved fatigue life prediction methodology for composites and bonded structures as well as metals. Current methods yield life expectancy predictions varying by over two orders of magnitude.

2.2.4 Army Aircraft Reliability/Availability/Maintainability (RAM)

Army aircraft systems' peacetime RAM performance compared with commercial users, on the surface, would appear to be poor. When investigated further, it can be determined that a better gage of RAM than operational readiness rates (military ~75%; apparent commercial rates ≈95%) is flying hours per airframe. The commercial industry rate of approximately 100 hours/airframe/month closely parallels the Army performance in combat in Vietnam and currently demonstrated at the Aviation School. Recent logistics studies also indicates that to fly aircraft less than about 30 hours per month considerably increases maintenance manhours per flight hour. While currently averaging about 18 hours per airframe per month, the Army operational readiness rate of 75% should be considered generally good especially when comparing its lack of the single mission requirement environment and the stability of dedicated crews and maintenance personnel enjoyed by commercial operators. Projected combat utilization rates should be achievable under current plans. However, the third generation helicopters, the Blackhawk and AAH should have (as the Blackhawk is currently demonstrating) an order of magnitude better maintenance manhours to flight hour ratio than previous generation equipment. The RAMLOG data and research programs of the Army laboratories are beginning to make contributions to improve RAM assessment techniques during the aircraft design phase.

From the standpoint of the disciplines of reliability and maintainability and their consideration during design, the U.S. appears to be a free world leader. The exact relative reliability of our military rotorcraft compared to foreign machines is not known, but a subjective comparison based on commercial helicopters indicates that our aircraft are probably superior for a given degree of performance capability. The Army has unquestionably recognized the importance of reliability and maintainability; however, funding frequently stops short of the actual correcting of defined problems...essentially making the RAM effort an academic exercise. Similarly, funding for extensive reliability testing is often not forthcoming. It is recommended that future vertical lift developments incorporate well defined, adequately funded, up-front RAM programs; that RAM research receive more concentrated attention in the Army's RDT&E planning; that increased component environmental tests be conducted; and that special attention be given to providing a continuing, sound reliability and maintainability effort, including a corrective action program for current inventory aircraft in order to assure adequate operational readiness.

Modern microelectronics can provide significant improvements in rotorcraft diagnostics and systems monitoring. Exploration of these techniques can potentially lead to significant gains in maintainability, reliability, safety, and utilization.

2.2.5 Survivability

Battlefield survivability is an extremely complex subject involving a great number of tradeoffs. In past years survivability efforts focused on ballistic tolerance to small arms fire. Engineering solutions for the 7.62mm threat were found quickly, and as a result a strong effort was developed to find protection against higher caliber threats. Some excellent results have been obtained, such as powder panels for fuel cell protection against high-explosive incendiary projectiles. These panels give the equivalent protection of parasitic armor with less than one-tenth of the weight. R&D work in this area is still producing payoffs and should be focused on seeking nonparasitic solutions. In this particular area of survivability the US clearly leads the world.

A concern in the important area of survivability is the possible specification of excessive, perhaps unbalanced requirements. It will not be possible to protect aircraft against hits from all types of weapons and a foremost goal must be to avoid hits in the first place. Overspecification of ballistic survivability will only make avoiding hits that much more difficult by reducing agility, observability, and other possible defensive means. If threat requirements are excessive, the system costs may limit the number of aircraft that can be fielded. In the carnage of a future battlefield where little can survive indefinitely, it may be necessary to increase force numbers, and this may in turn dictate a simpler, lower cost, even less ballistically tolerant aircraft. As threat calibers increase and missiles play a grater role, it appears that the priority given to still further gains in ballistic tolerance should decrease.

It must be recognized that in a competitive atmosphere the specification of "desired" values often becomes "required" in the minds of the competitors. Nice-to-have or slightly beyond the state of the art features have no place in Engineering Development program quotation requests.

The U.S. lags the USSR in other areas of survivability such as chemical, biological and radiation protection; possibly dangerously so. There are also unanswered questions regarding protection against laser weapons. This situation needs to be addressed on an urgent basis. Chemical and biological protection, at least, should be considered for current aircraft, and radiation protection requirements defined and applied to selected helicopters. CBR must be applied to all new developments to the extent practicable.

Additional work is needed relating to hit avoidance. As noted previously, the term "agility" needs to be defined and requirements developed. Pilot workload in nap-of-the-earth flight, control response, and warning systems should be evaluated as to their effect on battlefield survivability. Also, the standardized survivability evaluation method being considered by the Joint Technical Coordinating Group for Aircraft Survivability should be accelerated. One area of survivability which appears to be receiving too little attention is that of further reductions in observability, particularly with regard to radar frequency signature. A "zero base" design to minimize observability would appear to be worthy of investigation.

2.2.6 Crashworthiness

Crashworthiness of rotorcraft involves numerous interrelated factors such as the crash environment, injury mechanisms, airframe structure, landing gear, rotors, fuel system, seats, and emergency evacuation. The U.S. Army Aeromedical Research Laboratory and Safety Center at Fort Rucker and the other Army laboratories working in the field have done excellent past work and currently have ongoing R&D in the area of defining the crash environment and injury mechanisms. Crashworthiness R&D directed toward the airframe structure and landing gear should continue to be emphasized, especially with the increasing use of composite materials in primary structures. Current and planned crashworthiness technology work is of excellent quality and is fully endorsed; although it too must be viewed in the same context as discussed for survivability features.

The Army developed the "Aircraft Crash Survival Design Guide" and the associated MIL-STD-1290, Crashworthiness Requirements, that cover all aspects of aircraft crashworthiness design. These documents are used as a basis for rotorcraft crashworthiness standards throughout the world. Without question, the U.S. leads the world in this area, and many crashworthiness improvements fostered by the Army are beginning to find their way into commercial helicopters.

As with survivability, there is a concern that crashworthiness requirements are, or will become, excessive and possibly limit superior approaches to enhancing overall occupant probability of survival and mission accomplishment. An example is the trade-off between the vertical sink speed design requirement and the helicopter's autorotation performance. It might be better to provide additional rotor inertia to reduce the touch-down sink rate, rather than designing for very high sink rates, letting the aircraft crash, and relying on structural energy attenuation to give the desired level of survivability. Also, there are concerns that in some cases the consequences of requirements which are deeply intertwined with design details such as crashworthiness are not fully known before they are specified. As mentioned earlier in the sub-section on Survivability, the total growth of the aircraft resulting from all of the requirements might increase system cost to the point where this country cannot field an adequate force or, alternately, lead to an actual decrease in probability of crew survivability for a given degree of mission accomplishment.

2.2.7 Aviation Electronics

Advances in microelectronics and in the use of digital techniques have made avionics equipment lighter, more flexible, more reliable, and less costly in production for a given capability. Additional major advancements are expected in the near future. In these areas the U.S. leads foreign industry, both European and Soviet.

2.2.7.1 Digital Avionics Integration -The use of digital integration techniques in the form of MIL-STD-1553 multiplex buses is a well established technology in use on a number of aircraft. In recent years the requirements for more sophisticated avionics have created large wire bundles throughout the aircraft that are a major maintenance liability and, in addition, are vulnerable to battle damage. Also, advanced avionics features have produced a cockpit cluttered with dedicated subsystems, controls and displays, resulting in excessive workload for the crew. Multiplexing, as exemplified by the Integrated Avionics Control System (IACS) and Digitally Integrated Avionics System (DIAS) programs, has the potential to reduce weight, increase reliability and battle damage tolerance, accept system changes with only minor software changes, and provide significant growth potential. This is an area of great potential which should lead to a revolution in cockpit design, improving the processing capability in the cockpit and reducing the workload of the crew. Development work in this area should be afforded increased priority and funding.

The current Army RDT&E plan indicates a period of investigation and development of advanced avionics technology from 1980 to 1984. Actually, this technology is already well established and with the effort planned could be applied to deployed Army aircraft by the 1985 timeframe. Much of the gain associated with multiplexing could be realized by 1985 and plans should be made to do so. The AAH exemplifies the value and methodology of multiplexing.

2.2.7.2 Sensors -Advances in the various sensor technologies show the potential for providing Army aviation with the capability to operate day/night/adverse weather in nap-of-the-earth conditions during the next decade. Common module Forward Looking Infrared devices (FLIRS) are providing improved target acquisition/navigation ability at night and in fog, smoke, and haze. Millimeter wave radar has the capability to provide more nearly true all-weather operation later in the decade. CO_2 laser developments show promise in providing obstacle warning and augmented FLIR operation. Hybrid multispectral sensor mixes such as FLIR/CO_2-laser and millimeter wave radar show great promise for accomplishing tactical nap-of-the-earth operations. Also, millimeter wave radar and infrared detectors show promise for air-to-air target acquisition consistent with current missile and gun ranges.

Improved radios are in development to provide reliable communications under nap-of-the-earth conditions. This effort should be afforded high priority. What is now needed is a secure tactical data link. It should be noted that a viable data link must function in multiple communication nets.

Other avionics associated with target acquisition and weapon delivery show equally promising advancements but are not within the scope of the current investigation. These devices must, however, be carefully integrated with other cockpit functions if the crew workload is not to become excessive.

2.2.7.3 Countermeasures -The threat environment on the mid-to high-intensity battlefield has become more sophisticated and dense to the point of making today's countermeasures equipment only marginally effective. Radar warning system capability must be expanded to detect and identify millimeter wave and monopulse trackers as well as continuous wave and pulse doppler radars. Jammers must also be developed or adapted to counter these threats. Laser threat warning systems may be needed in some instances as may be a passive missile launch detector. Further, an effort needs to be initiated to define the best means of displaying data and controlling countermeasures in the cockpit.

In the area of countermeasures, there are RDT&E efforts and identified development efforts running through FY89 to counter threats that already exist today. It is recommended that these programs be accelerated in order to meet current needs. In these efforts a proper balance must be sought between inherent survivability and self-protection "black boxes", which recognizes both the characteristics of the threat and the relative limitations of the two alternatives for survivability.

2.2.8 Technology Integration

Improvements in each of the vertical lift technology areas above are significant in their own measure. The synergistic effect of combining them is, however, potentially even greater. Studies show that to accomplish a given mission, the gross weight of a typical modern helicopter could be reduced by perhaps 30 percent and the fuel required reduced by 40 percent if advanced technology were applied throughout. Engine recuperation, if added without increasing drag, could lower gross weight by another 2 percent and reduce the fuel required to less than 50 percent. Typically, the improvement due to an advanced power plant on an existing vehicle is the most significant product improvement step which is readily taken.

These major improvements in vehicle performance coupled with reduced fuel consumption will help control costs so that greatly expanded use of rotorcraft can potentially occur, thus providing a much improved operational capability. New rotorcraft will also feature improved safety, RAM, and mission capability; achieved through advancements in aircraft performance and, where relevant, target acquisition capability, and weaponry.

2.2.9 Configurations

The preceding sections have indicated major technology gains which will lead to increased operational performance of rotorcraft. While these gains are impressive, some of the most striking performance improvements (i.e., speed, range, and productivity) can be achieved through development of fundamentally new configurations. These are not seen as replacing the helicopter--rather as providing a new dimension in vertical lift.

Over the past 25 years, a number of configurations have been investigated through analyses, wind tunnel testing and experimental flight. In 1969, a compound helicopter was flown to speeds in excess of 270 knots. A major lesson learned was that the cruise efficiency was relatively low with an equivalent lift-to-drag ratio less than 4, caused to a great extent by the drag of the rotor hub. This problem is inherent in high speed configurations which maintain conventional vertical shaft orientation of the rotor. Since the rotor hub can contribute up to 40 percent of the flat plate drag area of a single rotor helicopter, it is extremely difficult to achieve high speed efficiency. Hence, the high speed of the compound aircraft can only be used for a short time as, for instance, to give a high speed, short range dash capability. Its long-range cruise speed and lift-to-drag are little better than those of the more conventional helicopter.

An alternate rotorcraft configuration, which maintains the low disk loading hover efficiency of a helicopter and converts to a low drag configuration for high speed flight, is the tiltrotor. This concept offers superior range and productivity because its high speed lift-to-drag ratio may be in the order of 10 to 12. The present program with the XV-15 should be extended to include an evaluation of its operational characteristics and the related cost effectiveness of specific applications. The X-wing concept, being explored by DARPA, also provides an important alternative configuration with good low speed characteristics. Similarly the Advancing Blade Concept (ABC) would appear to offer performance advantages. These latter concepts should also be pursued to evaluate their desirable operational characteristics. However, a selection made among all the viable candidates at the earliest supportable time is recommended in order to permit a focusing of resources. One other consideration which appears to warrant greatly increased attention is the configuration of a helicopter specifically for the purpose of low observability...radar, infrared, optical (visual) and acoustic. A program in this regard should be considered for initiation and given funding priority in keeping with the previous discussion on the changing emphasis needed in the area of survivability.

With respect to alternative types of VTOL aircraft, the Army should establish a long term development strategy which defines what needs to be accomplished during any particular mission, the priority to be assigned to various missions, the approximate development schedule, and the other factors of key importance in establishing a new development program. This is necessary to permit focusing the limited resources available and to allow the competitive process to select the appropriate configuration. For example, if a quick response, low hovering time "fighter" aircraft is needed, then the deflected thrust or lift fan aircraft should be pursued--not for a few months at a time, but with the same kind of dedication that developed the Harrier. If high hover efficiency is paramount and 150 knots is truly the maximum speed that is needed, then the machine to carry into development and to which to apply the advanced technology is the conventional helicopter. If a combination of dash speed (200 - 250Kn) and hover efficiency is needed, then a compound configuration such as the ABC is attractive. If high cruise speed (250 - 400 Kn), hover efficiency, and long range are needed, then the tiltrotor and X-Wing configurations come to the fore.

Commitment must be made. Partial support of many systems is the same as no decision and a disservice to all. Further, allocating resources over a wide variety of different configurations, each specialized to a given contractor, may result in decreased competition when the selection of a preferred configuration is finally made. By and large, sufficient information will soon be available to make decisions in this regard and this should in fact be done.

SUMMARY OF RECOMMENDED ACTIONS (TECHNOLOGY

This paragraph summarizes the key recommendations for specific actions in the technology area as addressed in this section. Their implementation will improve this country's base in vertical lift technology and the Army's operational capability. The recommendations are:

- o Place heavy emphasis when allocating R&D funds on efforts which foster invention and innovation. Structure developmental efforts to maximize these when they occur.

- o Use the undocumented experimental prototype approach as the initial phase of development when it makes sense in terms of the technical risks being taken and the capability gains potentially achievable.

- *o Maintain a current assessment of the accuracy of aeromechanical tools including methodology, wind tunnels, and simulators. Correlation with flight is essential and requires establishment of a program directed at this specific purpose, providing, in effect, a data bank of analysis/model test flight design methodologies.

- o Encourage the development of a "national" facility for helicopter icing studies, either under NASA or FAA NAFEC. The capability is urgently needed yet no one service or company can afford the construction of an adequate facility.

- o Define and establish a requirement for agility.

- *o Re-emphasize and broaden rotor wake studies.

- o Commit to achieving high speed and high lift-to-drag ratios without sacrificing nap-of-the-earth agility.

- o Increase design time and encourage test design iteration in the initial definition phase without an increase in overall development time prior to operational availability.

o Maintain and provide all development contractors with a record of past development problems and their solutions.

o Develop the T700 growth engine.

o Complete the development of the Advanced Technology Demonstrator Engine.

o Expand power plant R&D in areas to reduce fuel consumption.

*o Develop comprehensive composite structures guide, including unified materials specifications.

o Develop substitute materials for scarce metals or establish a strategic materials bank.

o Develop improved fatigue life prediction methodology verified by testing.

o Fund RAM programs up-front for new developments, placing emphasis on designing for reliability and on environmental test and correction of deficiencies encountered.

o Set up a specific funding line item to support continuing corrective reliability and maintainability action for current inventory helicopters.

o Guard against excessive requirements in all areas, especially in crashworthiness and survivability.

o Evaluate and correct, on an urgent basis, CBR protection of current and planned aircraft. Make a practical level of CBR protection a requirement in new designs.

o Accelerate obstacle and weapon warning R&D.

- o Establish long-term program planning strategy for new and replacement systems that can serve on a focus for VTOL technology development.

In addition to the above, the panel endorses the following major Army R&T programs that are discussed in the text, in some cases modified as noted.

- o Army Advanced Digital/Optical Control System
- o 2GCHAS
- *o Advanced Composite Airframe
- *o Integrated Technology Rotor
- o Crashworthiness Technology
- *o Army/NASA Transmission Work

*Note: These items support similar recommendations contained in "An Evaluation of NASA's Program for Advancing Rotorcraft technology," National Academy of Science, 1978.

3.0 MISSIONS

3.1 Introduction

The threat in Central Europe clearly indicates a need to defend against numerically superior armored and air forces. However, this mission does not, in itself, establish sufficiently broad criteria to judge the needs for vertical lift capabilities. The so-called "Fulda Gap Syndrome" may have a stifling effect on the realization of many beneficial technical advances, particularly as regards nap-of-the-earth flight, high speed, and sensors and weapons for battlefields that are less dense in targets and threats than Central Europe.

3.2 Emerging Air-to-Air Requirement

Soviet military forces have adopted and expanded on the U.S. Army's vertical lift tactical mobility and fire support concepts demonstrated in Vietnam. As a result, the Soviet Union is now producing large quantities of troop assault, fire support, and anti-armor helicopters, most possessing a degree of air-to-air capability against other helicopters. The latter is in the form of the existing guns and as a secondary mission for anti-tank missiles. The HIND-D assault helicopter, being the most sophisticated weapons platform of the Soviet helicopter inventory, can be expected to be employed against both ground and air (helicopter) targets. This poses a relatively new, yet critical threat to vertical lift aircraft survival and effectiveness. In addition, Soviet helicopter platforms of themselves represent a capability which would have to be neutralized in a conflict. A concerted effort should be made to address the near term potential requirement for vertical lift air-to-air capability and to develop tactics and weapons to provide an air-to-air self-defense capability for current U.S. helicopters.

It would be most unfortunate, however, if air-to-air capability became the end in itself for a specific helicopter design. It would seem that to be most useful the helicopter must continue to function primarily as an integral part of the combined arms team. This will become clearer as the air-to-air role for vertical lift evolves.

3.3 Survivability

The increasingly dynamic nature of the mid-intensity battlefield, together with already observed threat growth trends, can be expected to radically influence the provision for survivability in the design of new systems.

Soviet forces have been responding to U.S. doctrine by increasing both their ground based and airborne anti-air capability. They have fielded the ZSU-23 and anti-aircraft missiles in large numbers and are developing advanced weapons, radars, and other sensors. They have also placed emphasis on electronic warfare systems. Potential threats further into the future may include high energy lasers. Soviet doctrine and equipment already stress operations with nuclear, biological, and chemical weapons. Both future new aircraft programs and product improvements to the existing fleet will have to address these threats.

Aircraft loss probability is the product of detectability, hit probability, and vulnerability. Vertical lift aircraft design has in the past tended to emphasize vulnerability as the dominant component. In the future, the severity of projected threats, as well as the dynamic nature of the battlefield, will dictate mission requirements that emphasize non-detectability and mission equipment and tactics to reduce detectability, avoid threats, establish favorable engagement conditions (e.g., greater stand-off range), and reduce exposure. The next generation of Army vertical lift systems should be expected to depend less for their survivability on withstanding hits and more on fighting from a distance, avoiding detection, and being the first to launch weapons in an engagement. The soon to be released results of the TASVAL experiments conducted at Fort Hunter, Liggett, California in the summer of 1979, pitting helicopter and fixed wing close air support aircraft against a postulated Soviet air defense threat, should provide further insight for this area.

3.4 Importance of Speed and Range

Since current Army doctrine emphasizes nap-of-the-earth techniques, there might appear to be a limit to the advantages gained from increased speed. Further, the NOE concept has proven to be an excellent tactic against existing air defense systems. However, these tactics may not on their own be effective against armed helicopters and advanced radar systems particularly when employed in high altitude aircraft platforms. Additionally, the fielding of Soviet attack helicopters in large numbers in the next five years, coupled with the possibilities of encounters in areas of little, if any, masking could significantly reduce the effectiveness of NOE tactics.

Furthermore, scenarios can be postulated that require the ability to redeploy rapidly to weak points in the defensive system or to exploit offensive breakthroughs. Additionally, long range lateral deployment is necessary both now and in the future. These scenarios dictate a desire for flight speeds and ranges significantly in excess of the capability of current Army helicopters.

Thus, future Army aircraft will have to be able to adjust tactics to meet new threat and mission demands. There is, therefore, a need for continued efforts to improve the agility and handling qualities within the nap-of-the-earth environment and at the same time provide expansion of current flight capabilities, particularly in the area of higher speed and greater range. Several on-going programs (Tilt-Rotor and the ABC) and past work involving the compound helicopter have demonstrated increased speed, range, maneuverability and other attributes. These may offer to the Army the combined advantages of helicopters and fixed wing aircraft.

3.5 Self-Deployment

An urgent need exists for current and proposed vertical lift vehicles to self-deploy from continental United States to Europe and on into other areas of the world. Rapid self-deployment capabilities on a global scale are currently inadequate, and should be emphasized in the planning requirements of current and proposed vertical lift vehicles. With existing rotor craft this will probably have to be done with increased tankage. In the future improved engines and higher L/D configurations are expected to yield significantly improved specific ranges (miles per gallon) and thus contribute to the rapid self-deployment over long distances of many vertical lift aircraft in the inventory. Self-deployability will, of course, also avoid the severe design compromises involved in achieving air transportability in C-141 or similar aircraft, in addition to permitting more effective and timely tactical operations.

3.6 Noise and Vibration

Considerable achievements have been accomplished in reducing the high noise levels and vibration associated with rotorcraft. Further improvements are needed to reduce the adverse effects of these phenomena on crew performance and RAM.

3.7 Impacts on Tactics and Doctrine

The present Army system of determining tactical doctrine and thereby having the user define new requirements as a basis for system development appears to have a major potential flaw. Today, the user bases a requirement on the capability perceived to be possible. For example, if the user believes that speed and attendant long range are not possible in vertical lift aircraft, the perception becomes self-fulfilling through constrained requirements. An accurate yet decisive challenge of currently accepted doctrine, tactics and approaches must be attempted. The user community must be made more aware of existing and attainable technical capabilities and must continue to be brought closer together with the technical community in a more synergistic manner. Prototyping modern systems is one way to demonstrate technology opportunities and achieve user community involvement; but only if the prototype program includes this purpose.

3.8 Mission Analytical Capability

The nature of the threat, environment and missions will necessitate improvement in the methods used by the Army and industry to assess mission effectiveness. Analytical models must incorporate projected threats and missions, considering in detail such factors as detectability, aircraft agility, engagement conditions, air-to-air encounters, aircraft survivability equipment and other electronic support measures. Such models must, as but one area of improvement, evolve from the current emphasis on single-shot kill probability to consideration of round-to round interdependence and the interactive effects of multiple hits.

3.9 Next Aviation Program - ASH?

The Advanced Scout Helicopter (ASH) may well be the next opportunity for the Army to incorporate the concepts discussed in this report. ASH could be an aircraft that can perform its mission in the postulated high threat environment during day/night and adverse weather. While existing aircraft can be configured for an ASH mission and subsequently armed for air-to-air engagements, they were not designed with optimum handling qualities, performance, and agility required for these specified missions. Any new development aircraft concept for this mission could involve a small, agile, highly capable and affordable airframe with appropriate battlefield survivability characteristics; and must be fielded in adequate numbers.

The ASH could be the first of a potential Light Helicopter (LHX) family, with attack versions to follow. The potential production quantities of such an aircraft, plus the technology gains needed to accomplish the ASH mission against the postulated threat, would appear to warrant a competitive prototyping program embodying advanced technology concepts.

Another area for the utilization of advanced vertical lift capabilities, is the Heavy Lift Helicopter. To this point priorities for funding, have been the source of difficulty, although the need for such an aircraft is generally recognized. If enough users, military and civil, worldwide, can be found and the costs of the HLH program shared over a wide enough customer base, available funding and priorities may be put into sufficient balance to pursue a full scale program. Growing requirements for battlefield mobility and logistics and growing dependence on containerized transportation make this capability of increasing importance in both NATO and Rapid Deployment Force operations. Completion of the engine transmission effort by NASA is seen as the first step of such a program.

The increased efficiencies promised by the present tilt rotor demonstrator, the advancing blade concept and X-wing aircraft, point the way to new vertical lift capabilities with possibilities for still new mission concepts.

4.0 Management

4.1 Introduction

This review of the management aspects of Army aviation technology considers the objectives of the Army aviation R&D program, the general status of the technology against these objectives, and the location, characteristics, and shortcomings of the Army's technology base. It also provides several recommendations for improving the management (and hence the effectiveness) of this base.

4.2 Technology Objectives and Current Capabilities

Any review of the management of the vertical lift technology base must consider the objectives for which this technology base is maintained and the demonstrated capabilities in each element of the base. It is postulated that the Army's aviation technology base is maintained to achieve the following four objectives:

1. To provide the technical skills and capabilities to efficiently, effectively and rapidly develop products to meet the Army's aviation needs.

2. To provide the technical options for improving the capabilities of the Army's existing aviation resources.

3. To provide advanced technology choice for replacing current Army aviation resources with vehicles having better, more effective, and/or less costly ways of meeting Army aviation needs.

4. To guard against technological surprise by any potential adversary and to create new aviation weapon system capabilities offering quantum increases in cost effectiveness or the capability to perform altogether new missions.

This examination of the management of the Army's aviation technology base considers its ability to meet the above objectives and recommends those management changes the Army should consider to improve the technology base and its use.

With respect to objective one, the provision of technical capabilities for successful product development activities, the record of problems encountered in recent major aviation programs has shown that the opportunity exists for improvment. This should include the ability to proceed directly from initial design to production qualification and delivery without significant redesign and retest, and shortened overall schedule, and confidence levels allowing some degree of concurrent qualification and production to be achieved without significant cost risk.

In terms of objective two, the lack of an across-the-board, coordinated strategy and pre-planned funding of product improvement has helped create the long development and qualification lead times of today's product improvement programs, wherein the requirements for new design features are frequently updated before a production design is reached in order that the fielded configuration be "the best." A healthy technology base, combined with an appropriate development strategy for progressive system updating should enable a more rapid, more efficient and less costly way of maintaining effective aviation systems which can satisfactorily carry out their assigned missions. Achievement of such a capability is hampered by the lack of a clear Army aviation system acquisition strategy which incorporates from the outset a progressive improvement philosophy. This is not to suggest that there have not been any notable successes in this area, but it does appear that much more could be accomplished.

To meet objective three requires that the technology base provide demonstrated technology options which can be employed to meet new threats or provide alternate methods of meeting existing threats. Such alternate methods might provide lower cost ways of achieving a given capability, might permit the development of more effective military tactics, or might avoid limitations imposed by existing systems. A strong user/developer/technologist synergistic interaction is usually required to bring such options to full fruition. The Army currently appears to suffer from inhibitions related to such synergism, and as a consequence there is a lack of balance in fully developing and exploiting its technology base related to this objective. The most notable manifestation of this situation is the lack of any new aviation development programs recognized, supported and funded as the army plan for aviation development in the next 5 to 10 years.

Objective four, to guard against technological surprise and to provide quantum gains in capability, demands focus of attention on fundamental research of a high risk nature...the type which truly does offer the potential of quantum gains and not merely modest improvements. Attendant to this type of undertaking must be the willingness of the entire materiel management system to accept occasional failure in this type of activity. The concern exists that the current system of management scrutiny, from the Congress on down, may discourage taking high payoff technical risks in the 6.1, 6.2 and 6.3A programs.

It is fully understood that the reason for some of the shortfalls in the aviation management area lies in forces outside of the aviation system itself, e.g., where other tradeoffs must be considered. It is also appreciated that current budget constraints dictate numerous program adjustments and the Army aviation management structure is responding to these pressures. However, these "facts of life" and their effects must be accommodated.

4.3 Problems in Managing the Technology Base

4.3.1 General

A direct result of the relative newness of rotary wing technology and low level of investment in comparison with fixed wing practice is that the analytical and developmental tools (such as the wind tunnel), which are considered to be essential components of fixed wing development, are only beginning to be extensively employed in the design of rotary wing vehicles. These tools allow fixed wing airplane system design and system integration to proceed with relatively low risk. Commercial fixed wing aircraft are typically certified in parallel with initial production, such that deliveries can proceed immediately upon certification. This level of concurrency could, if available to rotary wing aircraft, substantially reduce development schedules and costs. Such an approach for the rotorcraft will only be possible when the technical tools are developed and proven to a level comparable to the fixed wing aircraft and when the state of the art is not unduly stressed in Engineering Development. The present status of technology development does not approach this level of maturity, a reality which should have a profound effect on the management approach to rotary wing activities today and in the future.

4.3.2 Industry

The U.S. rotary wing industry today is in a relatively healthy condition. The Blackhawk, Advanced Attack Helicopter, Chinook Modernization, and Cobra programs currently provide a solid military production base. Expanding commercial helicopter programs are accounting for an increasing portion of the total business base of the industry. Technology levels have developed to the point where reliable rotary wing vehicles can be built to operate with acceptable operating costs, performance, safety and component life. As has already been discussed, however, these vehicles do generally require extensive experimental flight test development and problem correction, with resulting unfavorable effects on schedule, development cost, and risk.

From an Army aviation viewpoint, however, the industry lacks the impetus of firm mid and long range plans for additional military modernization and new aircraft development. Such plans, well conceived and stably funded, thoroughly understood by the industrial participants and supported by the government with continuity, contribute significantly to the effectiveness and creativity of technology development programs by instilling the proper blend of competitive pressure, schedule demands, and synergistic industry/Army efforts. The relatively long term program structure and stability demonstrated in the 1960's and 1970's with the T700 engine, UTTAS, AAH and CH-47 Modernization programs is lacking today. This is considered to be a serious detriment to continued growth of the Army's rotorcraft technology base.

The above condition is aggravated by the extremely long periods which have been allowed to occur between program approval of a technology effort and actual contract placement. Typical flow times of 12 to 18 months for such processes significantly reduce the beneficial effects of combining government funds with industry programs to produce maximum technological benefits. The current process reduces the pace of technological development and tends to cause industrial technology to gravitate away from military rotorcraft requirements.

4.3.3 U.S. Army

A review of the program planning of this activity indicates that major Army emphasis tends to be placed on the achievement of relatively near-term hardware system improvements, to the detriment of both the development of improved analytical and test "tools" and the development of more advanced longer term technologies and capabilities. A large factor in this emphasis is the degree of influence exercised by the Army "user" over research priorities. "User" in this context does not refer to TRADOC alone but to the entire user community in the field as well as at staff agencies. While the necessity for user involvement in overall research program planning is self-evident, the degree of that influence on the basic technology program may be so great as to not be in the best interests of a vital and effective vertical lift technology base.

The diminution of the Army's research efforts in the area of aircraft design and system integration and aircraft technology demonstration is of particular concern; two areas which traditionally have been pursued by the Applied Technology Laboratory at Fort Eustis. The ABC, RSRA and XV-15 have been demonstrated with no current visible place in the field for employment. No new similar programs with the exception of ACAP are on the horizon. Increased attention to this part of the Army aviation laboratory mission will be of long term benefit to Army aviation.

The development strategy used on the T700 engine and initiated on the ATDE 800 HP engine program has been very successful in providing new engine technology in a qualified engine suitable for application in new rotorcraft products. These strategies recognize the necessity of adequate technology development, demonstration, and advanced prototyping prior to commitment for aircraft engineering development. The gas turbine engine has generally less complex operating aerodynamics and dynamics than the helicopter itself, yet the development strategy pursued by the engine community has been shown to be necessary to have a successful engine development that does not pace or retard the total system schedule. Continuation of this kind of engine development strategy can be very beneficial to Army aviation and its continued selective transfer to airframe development could have corresponding payoffs.

Application of new technologies to the solution of Army Aviation problems require the synergistic actions and reactions of the technologist, the developer, and the user. Considerable attention is paid to the development of a formal interaction between the technology staff and the developer staff, largely through joint task assignments on critical programs. The system set up for user participation in this interaction is very complex. The assignment of young, company grade, aviation officers to the laboratory and development areas is substantially below available personnel slots and far below practices in the Air Force and Navy, probably due to the Army-wide shortage of aviators and aviation oriented officers. The lack of routine, rotating assignments of such officers to the user community and then the technology/developer community substantially reduces the opportunity for achieving the desired blending of technology and tactics so necessary to exploit advancing technology.

This blending requires a day in, day out iterative endeavor over long periods of time to build the personal knowledge and relationship that makes the synergism possible. It is also required if technological opportunities are not to be missed and, equally important, if engineering development effort is to be focused on practical solutions - suitability of which only a user can assesss.

Army/NASA/industry coordination has generally maintained an effective technical interchange. Shortage of funds, particularly in the 6.1 and

6.2 categories, has caused some tendency for government in-house concentration of efforts in these categories. This, coupled with the lack of new long term Army Aviation programs jeopardizes the industrial priorities on Army technology problems. Competitive pressures tend to create communication barriers which reduce the effectiveness of industry/Army cooperation. Once the benefits of competition have been obtained in a given program, those barriers should be taken down rapidly and lessons learned disseminated to all.

4.3.4 U. S. Navy

A potential source of augmentation for the U.S. military technology base in vertical lift is the U.S. Navy. While Navy resources are considerably smaller than Army resources in this area, valuable knowledge and talent does exist. Little evidence is available to indicate that truly effective cooperative effort between Army and Navy rotary wing technologists is in effect today at the technology level.

4.3.5 Academia

Colleges and universities which offer training and research in the vertical lift disciplines are very limited in number, especially in comparison with the total number of institutions offering programs in aerospace engineering. Research is an essential component of graduate education in any engineering field. Funding commitments on a long term basis are essential to the conduct of viable experimental research especially in the rotary wing field. Complex apparatus, instrumentation and models in addition to a high level of professional staff support, are required to conduct meaningful research in the vertical lift field and such capabilities cannot be built up or sustained in universities today without long term financial commitments. Relatively modest levels of sustained funding would permit updating equipment and apparatus and continued training of graduate students in the few universities that presently engage in rotary wing research, as well as to encourage other university researchers to enter the field. The lack of such a commitment has contributed to the general lack of focus for rotary wing research in universities. The leverage and impact of modest levels of sustained funding to universities in the rotary wing field will be great in an area of technology vital to the Army.

4.3-6 Foreign Resource

Foreign organizations (in allied countries) offer a limited source of vertical lift technology although such technology is often of high quality. These organizations generally benefit more from U.S. technology than does U.S. industry, in part because of a more agressive foreign government sponsorship of foreign industrial organizations and a greater commercial orientation. This foreign government support extends from experimental development to international marketing support, and in some cases provides the foreign company with more and earlier market opportunities to apply new technology. Since aerospace military exports are a vital part of the economic plan among governments of most rotary wing producers, and since such activities on a military level are generally discouraged by current U.S. policy, U.S. encouragement of foreign technology exchange may actually contribute to a decline in the market potential for U.S. industry and thereby reduce its mobilization base. There are, obviously, many tradeoff factors which must be included in any decision to exchange technology with foreign nations; however, the latter should be at least one consideration.

4.4 Recommended U.S. Army Technology Management Actions

4.4.1 Objectives for Development Tools & Strategies

A concensus concerning the objectives and parameters for improving available technology tools and development strategies needs to be established between the Army developer, NASA and Army laboratories, and U.S. industry. Such a concensus is needed to insure that proper goals and milestones can be identified against which the limited available resources can proceed toward the development of the necessary "tools". Joint Army/NASA/industry/university working groups, at appropriate management levels, offer one way of reaching such a consensus.

With a clear agreement on objectives, a set of plans with milestones for development of technology tools should be established addressing the attainment of these objectives. Care is required to insure the proper balance of funds and management emphasis on such tasks vis-a-vis the more glamorous aspects of advanced hardware and configuration technology. Such plans should emphasize the development of effective new methods for analysis and wind tunnel, bench and flight testing, and the correlation of the results therefrom.

Development strategies should be similarly created and proven. For example, helicopter programs now span about eight years from request for proposal to the initial operational capability. Increasing lead times for strategic materials, growing regulations, and increasing sophistication of systems and subsystems will tend to worsen this situation unless measures are taken to reverse the trend. Concurrency provides one lever to shorten the system acquisition cycle. Yet, increasing concurrency often raises the risk of greater cost or outright failure. The risks associated with concurrency are greatest when development programs are stretched to the edge of the state of the art to meet stated mission requirements and when a basic technology foundation has not been established.

Some of the specific considerations the Committee would suggest are:

- Revision of vehicle engineering development schedules to allow adequate time for design trades and wind tunnel testing, and the application of other technology "tools" prior to vehicle commitment to construction.

- In conjunction with the above, measured reduction of "heel-to-toe" program scheduling after commitment to reduce total development time and cost.

- Careful balancing between the advantages of competitive development and single source development. The former may be appropriate in high risk, high payoff areas where documentation and Army management attention may be reduced; the latter may make more funds and time available to improve overall system quality. The Army should carefully review past results on the UTTAS and AAH.

as well as recent Air Force and Navy programs, to better assist future selection among the alternatives for any given set of conditions.

- A review of Army approaches to system specification to insure that requirements are not unnecessarily restrictive nor beyond the existing industrial technology capability. This is essential to insure that resources are expended only in necessary areas, and that judgments are made against proper criteria during development programs.

- Development and implementation of "Packard" type prototype development programs.

- Provide full and adequate funding for all programs that are initiated. Programs of lesser priority which cannot demand such resouces should simply not be initiated.

4.4.2 Technology Focus for Product Improvements and Advanced Products

The user/developer/technologist interface should stimulate creativity and encourage effective interchange of knowledge. Specific considerations should be:

- An increase in people interchanges, with particular emphasis on long term career development of young aviation officers who can transfer knowledge between the laboratory, the developer and the user. Such career officers should be carefully nurtured to provide the nucleus around which new capabilities, technologies, and military requirements can coalesce to create the Army aviation managers of tomorrow.

- A reevaluation of the user's leverage on the direction of Army basic (6.1, 6.2 and possibly 6.3A) technology efforts, to take best advantage of available knowledge within the user, development, technology, and industrial communities.

- o An increase in the day to day interactive role of the developer with the user in the establishment of new Engineering Development programs.

- o Creation of a clear focal point and responsibility at a single geographical location for advanced concept development within the laboratory/developer complex, including strong user participation. This requires the allocation of an appropriate portion of the Army's aviation R&D resources to support this activity.

As already noted, an important part of improving the utility of the Army's aviation technology is the interrelating of technology to military potential and military threat. Some form of autonomous single point of aviation proponency, once provided by the Director of Army Aviation, could significantly improve the current user/developer/technologist interface.

Of major importance in improving the Army's use of aviation technology to better perform its missions is the establishment of stable, funded plans for new or improved aviation systems. In the product improvement area, the Army should establish product improvement as an important element of each system's long term plan. This will require that new systems be initially planned to be compatible with a building block, progressive improvement approach. Objectives should be established for product improvement steps, and specific funding should be set aside in advance for such improvements. The developer, because of intimate knowledge of the hardware to be improved, should have a heavy responsibility for seizing the opportunities provided by new technology in carrying out such a step by step approach to improve system capabilities.

Long term objectives for new systems need to be similarly established to serve as a focal point for technology development. Greater interactive user input to the developer's "5 year plan" could assist in this area.

4.4.3 Foster Stability and Growth of Technology Base

The important contribution of the academic world to vertical lift technology as its source of human resources should be nurtured by an aggressive program of research grants and R&D contracts to Universities. This should be paralleled by an active effort to create a few vertical lift education centers of excellence. Long term commitments should be provided in such activity. Young Army aviation career officers should be encouraged to seek graduate education at these institutions so that they can take advantage of the learning opportunities created by such research. Current Army research funding in the vertical lift area is very low.

Program continuity and long term planning on the part of the Army will encourage an expanded IR&D activity in industry. That in conjunction with providing a more responsive R&D contracting process would allow a better coupling between industry's ideas and development of those ideas. Packard-type initiatives may provide a useful way of sustaining the Army aviation technology focus during the period of low Engineering Development activity which will inevitably follow the recent burst of new system developments.

In the foreign technology area, careful consideration must be given to the competitive status of U.S. and foreign vertical lift producers. U.S. industry relies for much of its business base on international markets where it meets heavy government subsidized competition from the foreign producers. Aggressive technology transfer could seriously impact the U.S. industrial base by eliminating our current technology advantages. On the other hand such exchanges should be weighed against the possibility of significant military capability increases or changes made in U.S. government support of U.S. industry's international sales efforts. The Army will probably be best served in this area if it allows normal industry to industry agreements to evolve and avoids interjecting itself into the development of such agreements <u>insofar as is consistent</u> with national security objectives.

4.5 Summary

The "track record" of the management of Army aviation materiel development, in spite of the various technical difficulties, has on balance been extremely successful. The first generation reciprocating engine machines proved military worth. The second generation turbine powered fleet led the way for widespread commercial acceptance of the helicopter. With technology still in relative infancy, the third generation of much greater capability is now being fielded.

It would appear that at this time, fully realizing the management activities necessary to mature the technology along with the technology demonstration presently available (Tilt-Rotor, ABC, ATDE, ACAP etc) to provide a greater capability than ever before realized, an opportunity of major proportions exists. The apparent missing ingredient is an agreed upon and funded management plan to harness the potential.

APPENDIX—TERMS OF REFERENCE

DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY
WASHINGTON, D.C. 20310

15 JAN 1980

MEMORANDUM FOR MR. ~~NORMAN~~ Norm. R. AUGUSTINE, CHAIRMAN, VERTICAL LIFT TECHNOLOGY AD HOC SUB-GROUP

SUBJECT: Terms of Reference

BACKGROUND: The first successful helicopter flights were demonstrated during World War II. During the Korean War all three Services, led by the Army, successfully utilized the helicopter in combat. Up to that time it appears that industry led in pushing helicopter/vertical lift technology. The relatively inefficient, delicate, reciprocating engine powered helicopters were gaining military acceptability. In the mid-late fifties the Army initiated major R&D efforts toward fielding a second generation, efficient, durable, safe, turbine powered helicopter fleet. The Vietnam Conflict provided the "proving ground" for those second generation helicopters followed by general universal capability acceptance.

Army R&D efforts have now pushed into the third technological generation of helicopters with the tough, rugged, combat survivable AAH, BLACKHAWK, CH-47D modernized CHINOOK as well as the Heavy Lift Helicopter and Small Advanced Scout Helicopter. We have recently realized much greater, safer acceptance where, in the past few years, civil helicopter operators outnumbered military. The US helicopter technological base is primarily identified by the Army facilities colocated with NASA at Ames, Langley and Lewis. The US civil technical base has emerged as the four current helicopter manufacturers: Bell, Sikorsky, Boeing/Vertol and Hughes. NASA has initiated some helicopter R&D efforts.

Where, during the 1960's, the US emerged as a world leader in the development, production and utilization of vertical lift/helicopters, other countries were fast to learn and move forward. The USSR has fielded a formidable helicopter combat capability. It is advised that Agusta (Italy) manufactures one in ten helicopters in the world today. Aerospatiale (France) has been fielding a new model helicopter per year. It does not appear that the US has retained a technological superiority in this field.

SUBJECT: Terms of Reference

The major capability that the helicopter has provided the Army, and that has been so attractive to the civil sector, is a safe mobility capability and responsiveness which is not limited by roads, bridges, forests, hills/mountains, etc. It is also a vehicle that can operate under the same climatological conditions as ground units, yet not be restricted by the non-availability of long runways and aviation facilities. That capability is not limited in a technological sense to helicopters but should be considered open to any vertical lift device.

Although it is apparent that helicopter/vertical lift technology has advanced by great measures over the past 20 to 30 years, recent problems in developmental programs have indicated the possible lack of a solid technical base from which to expand or provide a credible basis to defend ongoing advanced technology helicopter programs. Two examples are:

Initial acceptance of the main rotor mounted almost against the fuselage, later required to be elevated approximately two feet on both the BLACKHAWK and the Advanced Helicopter programs.

One major technical change in the horizontal stabilizer of the BLACKHAWK and two major changes in the same area of the AAH, both ending in a "stabilator" approach after considerable program adjustment.

<u>TERMS OF REFERENCE</u>: The Army has programmed a considerable amount of its combat capability directly related to helicopters/vertical lift machines and fully appreciates the advanced capabilities these systems provide on the battlefield of the future.

In this regard I would appreciate you chairing a group of approximately ten individuals to provide me a report by the end of June 1980 that addresses the following issues:

1. <u>Technology Requirements</u>
   What are the operational capabilities that should be provided by the vertical lift technology efforts of the next five years?

2. <u>Existing Technical Capabilities</u>
   What is the status of the existing technical base in the US that relates to vertical lift technology?

SUBJECT: Terms of Reference

Where does this technology base exist?

What is the US status in this technical area as related to foreign efforts?

3. Future Technology Thrust
What technical areas should be pursued to preclude recurrence of technical problems as encountered in the BLACKHAWK and AAH programs?

What technologies should be pursued in the near term to insure that future advances in vertical lift will be available for the Army, i.e., fan-in-wing, etc.?

4. Management of Technology Efforts
Where should vertical lift technology proponency be focused, i.e., government (agencies), industry, etc.? How fostered?

Is the capability of the structure presently existing within the Army adequate to pursue vertical lift technology of the future?

How can the ability of the US to benefit from foreign vertical lift technology efforts be improved, i.e., competitive-cooperative efforts, etc.?

Percy
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