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A COMPARATIVE ANALYSIS OF TILT ROTOR AIRCRAFT VERSUS HELICOPTERS USING SIMULATOR RESULTS

by

Gregory K. Mislick

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Thesis Advisor: Dan C. Boger

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A Comparative Analysis of Tilt Rotor Aircraft Versus Helicopters Using Simulator Results

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I. INTRODUCTION

The United States Army's "Light Helicopter Experimental" (LHX) program has been at the forefront of concern for Army aviation officials during the past few years. Its purpose is to resolve how to best replace the Army's existing and aging light helicopter fleet. The program, however, has been plagued and inhibited by tight budgets, indecision over aircraft requirements, and other areas of concern. Past studies have helped to resolve some questions that have arisen, but have really only helped scratch the surface for the decision makers. The main concern is what type aircraft should be utilized. The secondary concern is whether it should be a single or dual piloted aircraft. From there, many other considerations originate such as cockpit design and the type of automated features that should be used.

Whether or not the LHX program continues or is ultimately dropped is still to be determined. Yet, regardless of what Army officials decide, many useful things have come from the studies conducted that should prove invaluable in later analyses and programs. These include: (1) benefits of helicopter versus tilt rotor, (2) benefits of one versus two-man airframe design, (3) benefits and workload savings of particular automated features, (4) what flight missions, flight maneuvers and mission segments cause operator overloads, (5) what transitions and/or procedures prove most difficult for a helicopter pilot when converting to the tilt rotor, (information that will hopefully be invaluable for the training command when the tilt rotor becomes operational), and (6) how to select pilots for further studies based on their past flying experiences.

This thesis will explore some of the options available to the U. S. Army, drawing ideas and suggestions from previous studies, using Operations Analysis procedures to draw new information from test data bases, analyzing ideas from an aviator survey and using experience gained from this writer's aviation past. A major portion of this study will deal with comparing the tilt rotor aircraft with conventional helicopters. Opinions and recommendations will be discussed.

II. BACKGROUND[1]

As previously stated, the immediate and most important concern for Army officials is the determination of what aircraft type the LHX should be. In search of answers, the Army, during the spring of 1987, turned to the RAND Corporation in Santa Monica, California, to ask for their help in solving this fast-approaching problem. On 30 June 1987, action began with key personnel from RAND's Army Arroyo Center visiting NASA Ames and the Army Aeroflightdynamics Directorate (AFDD) officials at the NASA Ames Research Center at Moffett Field, California. The means to assess the capabilities of various aircraft alternatives to perform the Army's aerial attack and scout missions were available there including manned helicopter and fixed-wing research simulators developed by Ames. Other areas of study were conducted on site at the RAND Corporation and included a force-on-force computer simulation (which analyzed unit and theater-level operational performance), cost and other pertinent decision factors.

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[1] The information in this section was excerpted from a RAND Corporation report (Veit, 1988, pp. vi-16) and a NASA Ames Research Center memorandum (Lewis, 1987, pp. 1-7) and edited by this author.

After extensive research, it was decided that three designs appeared to best satisfy the Army's tactical light helicopter aviation requirements. These requirements were based on current Army doctrine and specified the LHX to be lightweight, highly survivable, supportable, and affordable, while featuring state-of-the-art technologies and the ability to successfully execute all required missions (Hayner, U.S. Army, 1988). With these considerations in mind, the following three aircraft designs became the focus of this study: (1) a new and advanced conventional helicopter (yet to be built), (2) an upgraded version of the AH-64 Army Apache helicopter, and (3) the new tilt rotor aircraft offered by Bell-Boeing. Many considerations were involved, and included (1) cost, (2) engineering aspects, (3) maintainability, and (4) operational performance. One of the Army's restrictions required a maximum aircraft weight of approximately 10,000 pounds. RAND discovered, though, that a more mission capable aircraft weighing closer to 12,000 pounds was actually more cost-effective. They found that a 13% savings in weight translated into only a 3% savings in total incremental life cycle costs. Thus, RAND recommended that rather than focusing on the weight issue, the design should focus on mission performance, survivability, and cost (force size for fixed budget). (Veit, 1988, p. vii) As the result of intense analysis in these areas, the RAND Corporation's overall recommendation to the Army in November 1987 was to choose the advanced conventional helicopter over the other two alternatives as its LHX choice for the future of light helicopter operations. (Veit, 1988, p. vi) An additional reason was that the new airframe would furnish the Army with an air force capable of enduring well past the year 2000.

Another recommendation, though, was to build and refine a tilt rotor prototype suitable for their combat needs. During the analysis, the tilt rotor had proven its advantages in both range and speed as well as displaying interesting maneuverability capabilities. Despite its advantages, however, RAND did not feel that tilt rotor technology was sufficiently mature enough for a long range Army investment at this time. They also did not feel that the increased speed available in the tilt rotor was a significant operational advantage which, of course, is a subject open to debate.

Why should the tilt rotor be considered the airframe of the future, and why was it even considered in the RAND study? One of the reasons is the inherent limitations of the modern helicopter. To its credit, a helicopter has large rotary wings and its control system enables the operator to hover or fly at low airspeeds while maintaining good aerodynamic handling qualities, something impossible in a fixed-wing aircraft. However, its intrinsic design severely limits its attainment of high airspeeds. The limitations as speed increases are transonic problems due to the occurrence of shock waves, causing a high-Mach advancing blade while the retreating blade enters deeper stall conditions. This causes not only an increased need for required power, but also creates a loss of lift, induces high aircraft vibration levels, increases fuel requirements and decreases component service life due to high stress levels on them (Huber, 1986, pp. 1-2). Since this severely limits long-range missions, the helicopter falls short of desired military tactical requirements and the ideal answer/alternative appears to be provided by the tilt rotor. It offers the combined advantages of both the helicopter and the turboprop plane, capable of hovering and transporting troops into remote areas while flying at speeds and ranges over twice that of its rotary-winged counterpart. An in-depth discussion of the tilt rotor aircraft, including a brief history and future considerations, can be found in Appendix A.

The RAND objectives in the simulators were to identify direct discriminators between the two aircraft types when flown by pilots, determine measures for use in the force-on-force analysis, and to extend and refine the engineering analysis of maneuverability. In particular, RAND sought to answer (at least partially) these two questions:

(1) What are the flight performance differences between the tilt rotor and the conventional helicopter configurations, and

(2) What differences do they make in the ability of the aircraft to engage targets and evade the enemy air defense threat? (Veit, 1988, p. 1)

Though the tilt rotor actually outperformed (on the average) the helicopter in a larger number of maneuvers, it was not so overwhelmingly superior as to tip the scale in its favor for the final decision. RAND felt it was too risky for the Army to throw its whole future of rotary wing into an untried airframe, an opinion which the Army has agreed with thus far.

Other information, however, can be derived from this study in addition to that presented to the Army by the RAND Corporation, such as inter-aircraft differences during certain maneuvers, inter-pilot differences while considering past flight history, which maneuvers proved the most difficult to perform for helicopter pilots when transitioning to the tilt rotor, and which new technologies introduced in the tilt rotor caused the most initial difficulties. The following analysis using econometric procedures attempts to explore and answer these questions. To begin, a discussion of the simulator and methods used by the RAND Corporation to collect their data is presented.

A. THE SIMULATORS

Simulators were utilized to aid in the operational effectiveness and flight performance/evaluations of the LHX project. Utilizing a fixed base, single-piloted, interchangeable cab (ICAB) developed at NASA Ames, the two simulator cockpit mockups modelled the aerodynamics of each aircraft. The helicopter simulator was designed from a previously existing model known as ARMCOP. ARMCOP is a generic, ten degrees-of-freedom nonlinear mathematical model which has been expanded to represent some of the aerodynamic effects of low-speed, low altitude, and steeply descending flight (Lewis, 1987, p. 2). An advanced model was constructed for this study to represent the desired LHX helicopter design. The tilt rotor simulator was designed from a model developed by Bell Helicopter for the purpose of tilt rotor research on the XV-15. It is a full nonlinear mathematical model termed GTRSIM (for Generic Tilt Rotor Simulator); the version used was originally adapted for use as a model of the V-22 Osprey, but was configured for this study to represent an accepted LHX-type tilt rotor design (Lewis, 1987, p. 2). Thus, the hardware in the simulators remained nearly the same for each, while differences were brought about by the software utilized. Visual cues were identical and performance indicators (i.e., rate of climb, load-factor limit, side-slip limit, etc.) were similar in each model so as to preclude the possibility of immediately biasing the outcomes.

The cockpits themselves contained all of the essential displays and controls for flight. In addition, they utilized a HUD (Heads-Up Display), a convenient means for the pilot to monitor the flight gauges (i.e., airspeed and altitude indicators) without having to look inside the cockpit. This potentially improves flight safety while hopefully decreasing pilot workload.

Computer generated imagery was utilized and projected onto the windscreen. The three data bases--HAC, PYLON and CANYON--each presented pictorially a separate scenario. HAC was used most frequently and depicted a hilly region with hilltops from 100 to 1000 feet, and trees from 20 to 60 feet placed in critical positions according to the mission. PYLON was a runway scene, while CANYON depicted canyons and clearings. For a detailed and technical description of the simulators and their operation, see Lewis (1987, pp. 2-5).

Each pilot was allotted a minimum of two hours in the simulator to become familiar with the helicopter and tilt rotor configurations and its computer generated imagery before any data runs were recorded. In addition, each pilot flew five to seven trial runs per mission to completely familiarize himself with the requirements of that task beforehand.

B. MISSILE LAUNCH

Target engagements and SAM (surface-to-air missile) evasion were required maneuvers. The firing logic for both the tilt rotor and the helicopter were the same to ensure independent results. For missile launch, a clear line-of-sight (LOS) was necessary between the aircraft and the target. When this position was held for three seconds, the pilot received a tone in his headset indicating that he was free to launch his missile. Missile fly-out time was set to a constant thirteen seconds. During this period, the pilot was required to maintain LOS with the target until missile impact.

C. SAM FIRING

The sequence for SAM firing was initiated when a LOS occurred between the SAM site and the aircraft. Launching sequence was commenced when this LOS existed for twelve seconds. If this lock-on lasted three seconds longer, the SAM was launched. Time-of-flight to target was eleven seconds, and a successful evasion by the pilot was considered complete if the aircraft/SAM line-of-sight was interrupted for two seconds. Both lock-on and missile launching indicators were available in the aircraft to warn the pilot of the incoming danger. A hit by the SAM was indicated by a simulated large crack in the center windscreen of the cockpit.

D. PILOTS

A total of ten helicopter pilots were chosen for the analysis. Subjects included four Army pilots, four industry pilots, and two pilots from NASA Ames. All were currently in flying billets and were familiar with military flying doctrine and tactics. For individual history of employment and previous flight times, see Appendix B.

1. Army

All four Army pilots had experience in scout and/or attack (SCAT) model helicopters (OH-58 and AH-1, respectively). None had ever flown a tilt rotor or a tilt rotor simulator before. Consequently, they were afforded the opportunity to attend an intense four day course conducted by Bell Helicopters, receiving seven hours of XV-15 simulator time and two 1.5 hour flights in the XV-15 itself. Total helicopter time for the Army pilots ranged from a low of 800 hours to between 3100-5000 hours for the other three. Each Army pilot flew both the tilt rotor and the helicopter simulators during the analysis.

2. NASA Ames

These two pilots attended a shortened tilt rotor course which included one flight in the XV-15. Each had already flown 15-20 hours in the XV-15 and had tilt rotor simulator time (from NASA Ames) prior to this analysis. Their backgrounds included extensive military flying time (between 5000 and 5600 hours each) in both rotary-wing and fixed-wing aircraft. Each of these pilots also flew both the helicopter and the tilt rotor simulators in the analysis.

3. Industry

The two tilt rotor test pilots from Bell flew only the tilt rotor simulator, and the helicopter simulator was flown by two helicopter test pilots, one from Sikorsky Aircraft and the other from Boeing Vertol. All were also former military pilots with flight time ranging from 3000-4300 for the two helicopter test pilots, and from 7000-9500 for the two tilt rotor pilots. The latter two pilots were the only two with significant tilt rotor experience participating in this analysis (one had 350 hours, the other 500).

E. MISSIONS

In this analysis, there were a total of seventeen mission tasks which fell into two categories--maneuvering and engagement. The ten maneuvering tasks were used to examine possible differences between the two aircraft in certain flight regimes, while the seven engagement tasks were designed to simulate the final stages of typical LHX air-to-ground missions, including interaction with a target and SAM site. (Lewis, 1987, p. 7) Maneuvering tasks were designated by an "M" followed by the mission number, and the engagement tasks were designated by an "E" followed by the mission number (i.e., M3 for "maneuvering task mission 3", E4 for "engagement task mission 4"). A complete list of mission descriptions can be found in Appendix C.

III. DATA ANALYSIS

A. DATA

The data for this study were collected from the RAND Corporation for each of the seventeen mission tasks performed. After careful consideration, mission M2 was eliminated from this analysis due to a number of missing data points, too many to be able to successfully forecast the missing observations while keeping the data results "believable." Mission M8 was not utilized in the regression analysis due to its Measure of Effectiveness (MOE) being of a different criterion than the other sixteen, though its effects were considered qualitatively in the overall analysis. The major MOE for all remaining mission tasks was "time to maneuver" (measured in seconds) during the critical phase of each mission; this MOE was chosen since it is generally considered that the shorter the time in enemy territory or in a dangerous environment (especially with enemy SAM's available and active), the greater the chance for survival. Thus, the quicker the pilot can execute the maneuver during critical phases, the better.

The regression analysis performed in this thesis initially involved the basic model of one Dependent (Y)

Variable and five Independent (X) Variables:

Y-Variable (Dependent) -- Maneuver Time

X-Variable (Independent) X1--Helicopter Flight
(All X's Continuous) X2--Fixed Wing Flight Time
X3--Total Simulator Time
X4--Total Tilt Rotor Time
(Discrete) D1--Combat Experience

As previously stated, the dependent variable is that of maneuver time while the five independent variables involve data pertaining to the respective pilots' flight histories. The objective of the regression is to determine which independent variables have the most effect on mission performance. X1 and X2 are the amount of hours each pilot has logged in rotary and fixed-wing aircraft, respectively. X3 is the total amount of hours flown in both helicopter and fixed-wing simulators, and X4 is the total amount of simulator and actual time each pilot has flown in the tilt rotor aircraft (XV-15). The only discrete variable, D1, determines whether the pilot has had any combat experience.

There was a total of 480 dependent data points, eight for each run of the simulation (i.e., one per pilot per run) and thus sixteen total for the two tilt rotor runs and sixteen for the two helicopter runs encompassing each of the fifteen mission tasks analyzed. For clarification, the dependent data for each mission was presented in the manner shown in Table 1.

TABLE 1
FORMAT FOR DEPENDENT DATA SET

	MISSION NUMBER			
	TILT ROTOR		HELICOPTER	
	Run #1	Run #2	Run #1	Run #2
Pilot #1	(time)	(time)	(time)	(time)
Pilot #2	(time)	(time)	(time)	(time)
"				
Pilot #8	(time)	(time)	(time)	(time)

The total number of independent data points was fifty (50). Though technically time-series data, the sample was handled approximating that of a cross-section, since pilots made only two sequential runs. The time-series, therefore, is not long enough to allow estimation of any time-series parameters or meaningful calculation of any time-series statistics.

B. ANALYSIS AND RESULTS

The first step in the analysis was to determine whether the two tilt rotor runs and the two helicopter runs, of eight observations each, could be combined (pooled) within themselves in order to form a larger mission data base to analyze. This was accomplished by testing for structural change via the Chow Tests. This method (Johnston, 1984, p. 225) compares a calculated F-value with a tabled F-value. If the calculated F-value is less than the tabled, then the hypothesis that the regressions are the same cannot be hypothesis that the regressions are the same cannot be rejected. The equation used is:

$$H_0: B1=B2 \qquad F = \frac{(RSS1 - RSS3)/k}{RSS3/(n-2k)} \sim F(k,n-2k)$$

where RSS1 = Residual Sum of Squares (RSS) of Full Regression
RSS3 = Sum of RSS's from the 2 Separate Regressions
k = Number of Constraints on the Model
n = Total Number of Observations in the Combined Samples
B1 & B2 = Vectors of k Coefficients

For the tilt rotor data on Mission E1, the attempt to "pool" yielded the following:

RSS (1st run) = 11.22
RSS (2nd run) = 7.57
RSS3 = 11.22 + 7.57 = 18.79
RSS1 = 23.95
k = 5 and n = 16

Thus,

$$F = \frac{(23.95 - 18.79)/5}{18.79/(16 - 2*5)} = \underline{.3295} \text{ (calculated F-value)}$$

Tabled F-value for F(5,6) = $\underline{4.39}$ (at the .05 significance level) Since .3295 < 4.39, one cannot reject the hypothesis that the regressions are the same, and thus they can be pooled. Calculated F-values were found to be less than the tabled F-value for every set of mission data, and thus both the helicopter and tilt rotor mission data sets were pooled within themselves. This now provided fuller models of sixteen observations with which to conduct the analysis.

The next step was to ensure that the mission data sets did not contain any built-in biases. Using the missions' residuals showed no discernible patterns, and the residuals probability plot for each set of mission data closely approximated that of a normal. A Kolmogorov-Smirnov test was also calculated to ensure that the samples came from a standard Normal distribution. The results show conclusively that the sample density function agrees very closely with the hypothesized density function at a significance level= .0087. Discovering no problems in that area, it was next necessary to check for heteroscedasticity amidst the mission data. Using the Goldfeld-Quandt test procedure (Johnston, 1984, p. 301), the sample calculation for Mission E1 in the tilt rotor simulator was as follows:

$$R = \frac{RSS2}{RSS1} \sim F[(n-c-2*k)/2,(n-c-2*k)/2]$$

where RSS1 = RSS from the Smaller of the Two Regressions
RSS2 = RSS from the Larger of the Two Regressions
n = Total Number of Observations in the Sample
c = Total Number of Central Values Omitted
k = Number of Constraints on the Model

The tilt rotor data from Mission E1 yielded the following:

RSS1 = .605 RSS2 = 4.80 n=16 c=4 k=5

$$R = \frac{4.80}{.605} = 7.934 \quad \text{(Calculated F-value)}$$

Tabled value for F[(16-4-2*5)/2,(16-4-2*5)/2] = F(1,1) = 161
(at the .05 significance level)

Thus, since 7.934 < 161, one cannot reject the assumption of homoscedasticity. This procedure was repeated for every mission data set. Calculated F-values were found to be significantly less than the tabled F-value in every mission, and thus one could not reject the assumption of homoscedasticity at the five percent level. With autocorrelation also not a factor, the mission data were felt to be bias-free and ready for model analysis.

One of the goals of this study was to discern any and all differences that may exist between the performance of the two aircraft types. Tilt rotor historical flight data is practically nonexistent due to the newness of the concept, especially in the area of operational environments, and simulators offer the major avenue to obtaining needed information. The first test, the purpose of which was to determine if there were in fact differences in aircraft performance, attempted to pool the data even further, utilizing again the Chow Test methods. Could the tilt rotor results be considered the same as that of the helicopter? The answer in the majority of cases was no. In the fifteen different missions, only five tests for structural change concluded that the performances of each type could be considered the same. Table 2 presents the results of these Chow tests.

TABLE 2
SUMMARY OF ATTEMPT TO POOL HELICOPTER WITH TILT ROTOR

Models which could not be pooled (Total -- 10)	Models which could be pooled (Total -- 5)
E1 E2 E3 E4 E6 E7 M1 M3 M6 M10	E5 M4 M5 M7 M9

The results show that 67% of the missions provided an obvious difference in performance between the two aircraft, while simultaneously controlling for diverse pilot experience levels. The majority of these models which could not be pooled could be categorized as "high maneuverability" missions, while the pooled models were generally more concerned with speed (i.e., slalom course and time to dash to a clearing). These are discussed on page 25 in the paragraph concerning inter-aircraft differences. Having pared the data and models as much as possible, the analysis was now focused on the remaining twenty-five mission data sets. Of these twenty-five regressions, five were for the pooled mission data samples and twenty for the non-pooled helicopter/tilt rotor mission data samples that were discussed above.

A check on the regression data from each mission provided the main gauge of performance. Each mission time was modelled against the five independent variables. If the model produced one or more variables with a significance level exceeding .15, only the variable with the largest significance level was dropped from the model.[2] A new regression was then calculated and again, the variable with the largest significance level exceeding .15 was dropped from the model. The "best fit" model was produced and recorded when the regression contained no variables with significance levels exceeding this .15 level. A summary of these "best fit" models is presented in Table 3.

This table shows a split in how well the models fit the missions. The original model containing the four continuous and one discrete variable produced ten "best fit" models (40% of the sample) with R-squared values exceeding .5, which shows a reasonably good model conformance. Six had models with R-squared values less than .3. The model producing the "best of all" fit was Mission E3 (helicopter) with an R-squared value of .864, while the model with the worst fit was Mission M4, where no combination of variables could produce any variable significance levels below .30.

The variable that was least significant to the models was X3, corresponding to total simulator time. It added a contribution in only eight of the twenty-five models, and five of these were negative correlations with the dependent variable. The variable most significant was X4, corresponding to

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[2] The value .15 is used as the cutoff standard since a regressed variable with a significance level exceeding this amount contributes little or nothing to the model.

TABLE 3
BEST FIT MODELS FOR EACH MISSION

ENGAGEMENT MISSIONS	MODEL (+ STANDARD ERROR BELOW EACH COEFFICIENT)
E-1 (H) R-SQ=.570	TIME= 1.290 - .00051*X2 + .00649*X3 + 2.0096*D1 (.9920) (.00021) (.00331) (.52737)
(T/R) R-SQ=.227	TIME= 6.13375 - .00033*X1 (.70343) (.000163)
E-2 (H) R-SQ=.769	TIME= 4.1564+.00112*X1+.02919*X3+.12313*X4-3.576*D1 (2.6316) (.00034) (.00736) (.02392) (.97909)
(T/R) R-SQ=.042	TIME= 6.55097 + .00036*X1 (1.9681) (.00046)
E-3 (H) R-SQ=.864	TIME= 13.096+.00099*X1+.00167*X2+.10349*X4-9.785*D1 (.9399) (.00029) (.00041) (.02084) (1.2275)
(T/R) R-SQ=.827	TIME= 9.2601+.00063*X2-.00533*X3-.00574*X4-2.216*D1 (.8931) (.00028) (.00289) (.00141) (.75949)
E-4 (H) R-SQ=.706	TIME= 16.799+.00169*X1-.00079*X2+.11486*X4-1.316*D1 (2.442) (.00076) (.00107) (.05416) (3.1894)
(T/R) R-SQ=.543	TIME= 15.403 + .00155*X1 - .01936*X4 - 2.5219*D1 (1.257) (.00048) (.00523) (1.2227)
E-5(POOL) R-SQ=.348	TIME= 16.259 + .00136*X1 - .00119*X2 - .01678*X4 (1.297) (.00043) (.00045) (.00559)
E-6 (H) R-SQ=.355	TIME= 1.631 + .00015*X2 - .60341*D1 (.1275) (.000087) (.22617)
(T/R) R-SQ=.742	TIME= 2.6877 - .00015*X1 + .00034*X2 - 1.7089*D1 (.3121) (.00007) (.00016) (.42674)
E-7 (H) R-SQ=.428	TIME= 23.989 + .00197*X2 (1.1429) (.00061)
(T/R) R-SQ=.352	TIME= 25.832 - .00069*X1 (2.3718) (.00055)

TABLE 3 (CONTINUED)

```
MANEUVERING
MISSIONS :  MODEL ( + STANDARD ERROR BELOW EACH COEFFICIENT)
---------:-------------------------------------------------------------
         :
M-1 (H)  :TIME= 5.9585 + .00166*X1 + .06613*X4
R-SQ=.612:      (1.4138)  (.00041)    (.02728)
         :
   (T/R) :TIME= 14.487 + .00139*X1 - .01907*X3 - .01166*X4
R-SQ=.814:      (1.1298)  (.00025)    (.00346)    (.00287)
         :
M-3 (H)  :TIME= 7.813 + .00123*X2 + .10769*X4 - 3.2428*D1
R-SQ=.479:      (1.045)  (.00069)    (.03384)    (1.9529)
         :
   (T/R) :TIME= 9.504 - .000052*X2 - .00218*X4 - .15611*D1
R-SQ=.110:      (.60249)  (.00041)    (.00196)    (1.0218)
         :
M-4(POOL):NO GOOD FIT COULD BE ACHIEVED
         :
M-5(POOL):TIME= 11.3687 + .00057*X1 - .00706*X4
R-SQ=.408:      (.40111)   (.00013)    (.00178)
         :
M-6 (H)  :TIME= 26.125 + .00091*X1 - .02949*X3 + .04002*X4
R-SQ=.663:      (3.350)   (.00039)    (.00936)    (.02744)
         :
   (T/R) :TIME= 23.315-.00121*X2-.01439*X3: 00485*X4+2.665*D1
R-SQ=.489:      (1.705) (.00054)  (.00552)  (.00268)  (1,4498)
         :
M-7(POOL):TIME=17.946-.00144*X2+.00865*X3-.00728*X4+3.5303*D1
R-SQ=.374:     (1.672) (.00047)  (.00562)  (.00325)  (1.1924)
         :
M-9(POOL):TIME= 104.015 - .03733*X3
R-SQ=.256:      (3.6351)   (.01162)
         :
M-10 (H) :TIME= 9.1615 + .0009*X1
R-SQ=.454:      (.8138)   (.00026)
         :
   (T/R) :TIME= 8.1193 + .00544*X4
R-SQ=.072:      (1.1255)   (.00519)
---------:-------------------------------------------------------------
```

tilt rotor time; it was contained in fifteen of the models and eight times was a positive contributor. This is intuitive when considering the complexity of transitioning to a new aircraft concept. Immediately following (in level of significance), was variable X1 (helicopter flight time), found in fourteen of the "best fit" models. Eleven of these were positive correlations, which was the most of any variable. Both D1 (combat experience) and X2 (fixed-wing flight time) were involved in the model fit 48% of the time (in 12 of 25 models). Ten of the D1 variables were negatively correlated, while X2 was split evenly (six for each) between positive and negative contributions to the dependent variable. No independent variable was found overwhelmingly more often in either the helicopter or tilt rotor missions "best fit". The model that occurred most often (6 of 25) was simply C + X1. Summarizing these findings, it is seen that helicopter and tilt rotor flight times were the two most positively significant independent variables to this type of flight simulation. For future studies, then, these pilot backgrounds should possibly be considered as most appealing when attempting to choose amongst a variety of candidates. Total simulator flight time was the least significant. Combat experience was a negative contributor in terms of the performance measure in 83.3% of the models in which it was found.

In terms of inter-aircraft differences, a few trends from the regressions were noted, which coincide with some of the findings by the RAND Corporation. While neither the tilt rotor nor the helicopter proved superior in every case, Table 3 shows that certain missions did show a distinct advantage to one or the other. The tilt rotor performed better in maneuvers requiring hard, maximum effort turns, as in Missions E7 and M10, and in maneuvers requiring firing at targets in depressed positions (Missions E2 and E3). The helicopter was faster in maneuvers requiring quick lateral movements and rapid hover-up/hover-down procedures, as in the times it was necessary to escape missile lock-on by the enemy (i.e., Missions M1, E1, and E6). Rapid hover maneuvers would be inhibited in the tilt rotor partly because of the increased drag on the airframe caused by the wings. There was no discernible difference in the accelerations to 120 knots (since the tilt rotor and helicopter data from Mission M5 could be pooled); this result would most likely have been changed in the tilt rotor's favor if a greater airspeed had been desired. However, the NASA Ames simulator was unable to accurately model proper power and rotor limitations above that airspeed, and thus missions were tailored accordingly.

Taking the point of airspeed one step further, it is the one major advantage of the tilt rotor over the helicopter that is not shown by the data. In the scenarios offered here, speed did not prove extremely important, but in battle situations, it is _essential_. "Speed is life" is a popular and legitimate fixed-wing community saying. Whether flying off the ship or going inland from the beach, speed (1) enhances the ability to surprise the enemy, (2) reduces enemy reaction time, (3) increases sortie production, and (4) increases survivability in today's modern battlefield. Due to its over-the-horizon launching ability, ship protection will be enhanced as well. Maybe even more importantly, U. S. Marine Corps Colonel W. R. Gage wrote that the tilt rotor would provide greater tactical flexibility and give the United States the advantage of modern technology to ensure that U.S. weapons systems are superior, in quality if not in quantity, to those of the enemy. (Gage, 1984, p. 1) The tilt rotor certainly should warrant some consideration in future tactical acquisitions, if not in the LHX program itself.

Finally, inter-pilot differences were examined. Did the Army pilots perform better in the combat scenarios, or did the tilt rotor experience of the industry pilots influence the better performances in their direction? Analysis began by immediately combining the two runs for each mission due to the limited number of observations available. The eight observations for the four Army pilots per mission were then modelled against the five independent variables as before. Initial regressions found that both the X4 and D1 variables were linear combinations of other independent variables and had to be eliminated. Thus, the model became the eight observations of the dependent variable versus the three independent variables X1, X2, and X3. Identical procedures were performed for the industry pilots.

For the helicopter model, this method proved to be plausible. Chow test F-tests were calculated, this time to determine whether the Army pilots' helicopter performance was significantly different than the industry pilots' performance in this study. Of the fifteen missions, only mission M9 (the slalom course) had a calculated F-test greater than the tabled F-value (46.06 > 9.28). The mission data set for M9 could _not_ be pooled and thus was the only helicopter mission to reveal a flight performance difference between the pilot communities. A close look at the raw data shows that, surprisingly, the _industry_ pilots performed this maneuver more proficiently with a lower mean completion time! Due to the tactical nature of the maneuver and recalling the flying requirements in their present professional duties, expectations would lead to the opposite conclusion.

The tilt rotor model, however, was not as satisfactory. Due to the structure of the flight history data, X4 and D1 were again linear combinations of the other independent variables and thus could not be included in the model. This is unfortunate because the results would be more meaningful if tilt rotor performance could be modelled as a function of tilt rotor experience. Instead, the independent variables were again X1, X2 and X3, modelling tilt rotor time against helicopter, fixed-wing, and total simulator flight time. The resultant regressions also produced only one mission whose data could not be pooled (F-test 9.57 > 9.28). Mission E2 (engaging a 12 degree depressed target and evading through the pass) was performed significantly faster in the tilt rotor by the Army pilots which again is a big surprise, since the industry pilots had notably more tilt rotor flight experience and would be expected to excel in that arena. Overall, however, the performances of the Army and industry pilots were not significantly different. Further studies into individual performances might show that some pilots performed better than others, but as a community, the abilities were reasonably the same.

IV. QUESTIONNAIRE AND RESPONSES

In addition to analyzing the raw data for information, questionnaires were sent to the ten pilots who had participated in the RAND study. Replies, either via the survey or by telephone, were received from nine of them, the tenth pilot being unavailable in the Far East. A copy is presented in Appendix D. The questionnaire was broken down into the following areas:

- Flight History
- Comments About the Simulator Used
- Hardest Mechanical Differences to Transition to When Converting From a Helicopter to the Tilt Rotor
- Hardest Maneuvers to Master in the Tilt Rotor
- Comments About the Study and Tilt Rotor
- What Automation the LHX Needs Most
- Should the LHX/Tilt Rotor be a One or Two-Man Airframe

The first five areas, along with comments by the pilots, will now be discussed in order. The final two are incorporated into Chapter V.

A. FLIGHT HISTORY

This information was utilized as the needed data for the regression analysis independent variables.

B. COMMENTS ABOUT THE SIMULATOR USED

A simulator is a useful tool. It creates a means by which to compare two models, providing a reasonable environment for a generic flight simulation. The importance of this section is to ascertain what areas of simulator flying can be considered most and least accurate in terms of data collection. When trying to assimilate simulator data to that of the real aircraft, certain ideas where variability may occur must be kept in mind. Some data points can prove to be exaggerated due to inconsistencies or limitations in the simulator. This section focuses on where the pilots felt that weaknesses or inconsistencies occurred and what biases should possibly be considered when contemplating the simulator results.

In general, the simulator was considered adequate in its flying performance by all the pilots, with the mean rating just over five on a scale of one to ten. The limited field-of-view (LFOV) did, however, affect their flying abilities, especially in the severe-type maneuvers such as high-speed low-level turns, quick stops, and low-speed Nap-of-the-Earth (NOE)[3] tasks. The tilt rotor was less affected by this due

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[3] NOE is low-level (less than 50 feet AGL) terrain flying where the pilot flies via the contours of the earth. It is one of the most demanding environments in which to operate due to aircraft speed and the close proximity to obstacles and the ground. Quick stops are precise maneuvers that involve decelerating to a hover while maintaining constant

to its ability to maintain a more level body attitude during acceleration or deceleration, just one of the new aerodynamic advantages introduced by the tilt rotor due to the nacelles' ability to tilt forward. Table 5 presents evidence of this in Mission M6 (a forward quick stop)--the regressions show that the aircraft types are significantly different, with the raw data indicating tilt rotor times and maximum pitch angles significantly less than those of the helicopter. Helicopter performance in mission E4 was also adversely affected by the LFOV. Since the optimal path (in this particular maneuver) was to maintain terrain height in order to avoid radar detection, terrain visual cues would be obscured if aggressive accelerations were flown during egress. (Lewis, 1987, p. 10) Maneuver times again were significantly less in the tilt rotor.

Every pilot felt that they flew more aggressively in the simulator than in the real aircraft and the data supports this view. This was explained by one aviator to be "due to lack of motion feedback provided by simulators", and another "due to lack of visual cues which generally force the pilot to achieve greater rates and displacements before control feedback is noted." NASA Ames noted that in this study,

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altitude. The usual tendency is to gain altitude, known as "ballooning".

pilots were occasionally found to be at a 45-to-60 degree nose-down attitude when safety-of-flight considerations in a real aircraft would generally require a maximum of 30-to-45 degree nose displacement. However, exceeding these limits is easy to do since simulators will not break if the maximum G-limit is exceeded. Also, the loss of peripheral vision due to LFOV limits one's situational awareness of both attitude and obstacles in many situations. Detrimental effects on depth perception is a big problem, too.

C. HARDEST MECHANICAL DIFFICULTIES TO TRANSITION TO WHEN CONVERTING FROM A HELICOPTER TO A TILT ROTOR

With the advent of the V-22 Osprey into the operational fleet expected to occur in 1991, it will be crucial for those individuals tasked with providing instructions to future Osprey pilots to be aware of the areas of flight that will prove most difficult during the transition period. Certainly it will depend on the pilots' background as to what may be the hardest--an experienced helicopter pilot will have different problem areas than, say, a Harrier pilot or a "nugget" pilot fresh out of flight school. Thus, background should be the main quantifier for the areas in which to expect the least and most difficulties. Careful consideration of these problem areas could greatly decrease safety problems and accident rates, while simultaneously speeding pilot transition completion time and increasing his technical knowledge of this state-of-the-art aircraft. The following paragraphs discuss the areas that the ten helicopter pilots in the RAND study found the most difficult during their transition.

While no single transitional domain was unanimously considered the most difficult, three problem areas were continually addressed. They were (1) nacelle operations (including the conversion corridor), (2) the Lateral Translation Mode (LTM) and, (3) the "throttle versus collective" concept. The third point, though not a problem in _this_ study, will be discussed because it was noted by nearly every pilot, and its possible effect on the Osprey was regarded as a major cause of concern. All agreed that the problems were more mental than physical, and that mastering the new systems was just a function of the time spent in the aircraft. Therefore, none of the transitions were felt to be overwhelming. It was reported that it was difficult, though, getting used to operating the nacelles, using them to gain forward airspeed (or hover in reverse) while maintaining the same pitch attitude, when the pilot had extensive flight experience in helicopters. In that regime, flying in a level attitude while accelerating simply is not natural, since normally the nose of the aircraft would be well below the horizon. New thought processes and motor skills are unquestionably required. Expanding further, the "conversion corridor" deals with converting from helicopter to fixed-wing mode and will be awkward for all pilots, regardless of their background, since no other aircraft offers this concept. Where to stop tilting the nacelles in the 0 to 90 degree range-of-motion for a desired attitude and airspeed will certainly take practice. Pilots with fixed-wing backgrounds may initially have more difficulty here due to unfamiliarity at airspeeds below 80 knots. Also, the LTM's will certainly require practice, but is a useful system. Its function, operated by a simple conical momentary position switch, is to help one fly laterally with more ease and little stick movement by readjusting the cant of the rotor blades while maintaining a level aircraft attitude. Practice should help the pilots easily integrate this into their flying fundamentals. With the importance of these systems and the number of times they are used in flight, these switches should be conveniently configured on the collective/power lever for reduced pilot workload.

The largest problem, though, and this depends on what communities the Osprey pilots are from, may be caused by the new throttle in the V-22. If the pilots are former Harrier pilots (since this throttle system is used in AV-8's), it will feel natural, though hovering for long periods of time as required by the Osprey mission may not. Harrier pilots wanting to convert to a slower and less maneuverable aircraft appears to be a doubtful proposition, however. If the pilots are recent flight school graduates, they can be taught the new system and be comfortable with it from the start. The negative aspect of this, though, is that they have had no operational experience in the fleet. Finally, since the Osprey is performing a helicopter mission--it's just doing the mission faster due to its speed--and is projected to replace many types of helicopters, it seems logical to pool the pilots from the helicopter community. Concerning pilots with a helicopter background, however, initial problems with the throttle configuration will invariably occur. Helicopters utilize a collective which, in basic terms, is raised when an altitude increase is required, and lowered for an altitude decrease. With considerations toward human factors, this is intuitively logical and correct. The throttle configuration, however, is basically the opposite of the collective, and may prove extremely difficult to transition to. The problems will occur, unfortunately, when instinctive actions are necessary (as in an emergency situation) and pilots unconsciously revert to the original collective mode of operation. For obvious safety reasons, emphasis in this area cannot be overstressed by the training commands. The only other major difference that was noted by the pilots was the difference in thrust responses of the two aircraft, to which they became adjusted after initial practice flights. In terms of all other human factors considerations, each pilot felt that all controls and displays were generally optimally located.

D. HARDEST MANEUVERS TO MASTER IN THE TILT ROTOR

As in the previous section, this information will be important to those instructors teaching new Osprey pilots how to fly while in the training squadrons, and will hopefully give them an idea as to (1) where to expect the most problems and (2) where to be the most safety-conscious.

The two specific aircraft flight performance maneuvers that were felt to cause the most initial problems were (1) stabilizing at a specified airspeed and (2) altitude control. Due to this, performing quick stops were very difficult because of the tendency to "balloon" (gain a lot of altitude) during the execution. Mission M6 again can be seen to support this. Operationally, NOE flight was seen to be the hardest to execute. This is because the aircraft response is sluggish compared to the helicopter, and "tweaking" the nacelles forward or back to keep a constant attitude is difficult to master. The tilt rotor is not as maneuverable in low altitude regimes (as in valleys) and is made primarily for a "dash and leave" type of scenario. This can explain why the data in Mission M9 (the slalom course) could be pooled (which suggests that the results are about the same).

The tilt rotor would be expected to negotiate the course faster than the helicopter because of its speed superiority, but is only equal to its counterpart in this mission due to the greater inherent maneuverability of the helicopter and the comparative sluggishness of the tilt rotor in the roll and yaw axes. One of the greatest advantages evident in the tilt rotor, however, was felt to be its ability to fire at a depressed or elevated target while simultaneously flying rearward, a maneuver aerodynamically impossible in a helicopter (since nose down to fire in a helicopter implies forward airspeed and thus movement toward the target). Though performing this maneuver is initially difficult due to its uniqueness, this tilt rotor advantage is significant in that it severely decreases escape time, thus increasing survivability. This tactic was observed in Missions E2 and E3 and is summarized in Table 4. Note the large differences in Evasive Maneuver (EM) times. This difference is due to the airspeed when the evasive maneuver began. As can be seen, the tilt rotor aircraft is nearly hovering in Mission E2 and actually flying rearward in Mission E3 at EM time, and thus in essence is already beginning his escape. The differences in all airspeeds here are very significant for survival purposes, and it is here that the tilt rotor is felt to be far superior to the helicopter. This point was noted not only by the pilots but by RAND (Veit, 1988, p. 57) as well.

TABLE 4
TILT ROTOR AND HELICOPTER COMPARISON IN TASKS E2 AND E3

Maneuver	Helicopter	Tilt Rotor
	E2/E3	E2/E3
Change in fwd airspeed from target acquisition to firing (in knots)	41.0/34.7	0.3/-15.9
Airspeed at EM (in knots)	46.7/43.9	8.9/-7.9
Time from start of EM to breaking target LOS (in seconds)	15.9/14.1	7.9/6.8

Other maneuvers such as acceleration and deceleration, pitch attitude, pedal turns and yaw control were discussed. All were felt to be equally challenging and would require some transition time, but were generally not overly demanding.

E. COMMENTS ABOUT THE TILT ROTOR AND SIMULATOR

This section presents general opinions of the pilots pertaining to the study and to the tilt rotor aircraft.

Overall, the pilots were very favorable in their attitudes toward the tilt rotor aircraft. This is significant because the sample includes industry pilots who came from aeronautical corporations who compete with Bell, and who had initial skepticism as to the capabilities of the tilt rotor. On the negative side, all did note the XV-15's sluggishness in the roll and yaw axes. One pilot likened its performance characteristics to "a large barbell" in these axes. This is due to the heavy weight of the engines, transmissions, rotors and hydraulics on the wingtips producing high inertia about the longitudinal and vertical axes. Other than that, though, all comments were positive. They felt that the tilt rotor was more stable in a hover than the helicopter and was equal to the turboprop in its flying characteristics when in the airplane mode. The tilt rotor aircraft also cannot be stalled "power on", which alleviates that worry during transition. All felt that the tilt rotor must have a Heads Up Display (HUD) in the cockpit for workload management, and that both the nacelle tilt switch and the LTM control switch should be placed on the collective/power lever for ease of use. All also felt that the tilt rotor took much too long to decelerate from the airplane mode airspeed to the helicopter mode airspeed which necessitated the addition of a speed brake. The V-22 has already adopted this conception.

As for the study itself, one pilot felt that even the actual flight experience he had was not enough for him to operate at a maximum effective level in the LHX--there is just too much to do to stay abreast of the continually changing situation. They unanimously felt that the RAND Corporation had conducted a meaningful and professional study and were glad to be a part of it. Cockpit designs and the automation provided were adequate indicators of what should be provided by the LHX.

The next two sections of the questionnaire dealt with answering the issues of "what automation the LHX needs most" and "should the LHX be a one or two-man airframe." The following chapter deals specifically with these questions and contains pilot opinions.

V. ONE-MAN VERSUS TWO-MAN CONFIGURATION

The second most important question to be analyzed before production of the LHX commences, after aircraft type, is whether the aircraft will be developed with a one or two-seat configuration. The Army is interested in a single seat model because it offers the following potential benefits: (1) a more compact size which increases maneuverability and survivability, (2) a decrease in required manpower, and (3) lower costing in all areas, including training, manpower, production, operating and life cycle costs. These desires can be found as factors in most programs and are obviously appealing and feasible ways to save money. The aircraft will be lighter with only one pilot (the projection is approximately 15%) and more maneuverable, thus performance should be better. However, consider the mission of the LHX. It has a primary role as an anti-armor weapon system that must be able to execute combat missions in any weather, day or night. The pilot must be able to reconnoiter and contact enemy elements, hand-off targets to other scout/attack elements, help select firing positions, and engage enemy targets, in addition to flying the aircraft. These tasks require that the pilot supervise or control the following: (1) data management and transfer systems, (2) flight control, navigation, guidance and communication systems, (3) target acquisition and designation systems, (4) weapon systems, (5) threat identification system and (6) electronic countermeasure (ECM) systems (Hickman, 1985, p. 3). Can a single pilot effectively perform with that workload? Add to all this the likelihood of executing these while flying at tree-top level utilizing Nap-of-the-Earth (NOE) techniques in all weather conditions while avoiding obstacles and probable enemy fire. (Hickman, 1985, p. 3) The stress of combat and fatigue after days of continuous flying can only further degrade performance. Can one man handle it all?

To help deal with this workload problem, the Army is planning to equip the LHX with highly automated subsystems. A partial list includes: (1) an increased number of sensors and target acquisition aids, (2) improved navigation and communication systems, (3) advanced crew station design, (4) improved flight controls, and (5) extraordinary avionics reliability, self-healing components, functional redundancies and reconfigurable features (Aldrich, 1984, p. 13). Though the advanced systems will cost more than present ones, Army officials feel high system reliability and single crew operation will eventually make them cost effective. Their pervasive feeling is that a single pilot will be able to handle the LHX and its multi-purpose role effectively with all of the increased automation. This, then, demands that two areas be explored at this point: the two-seat aircraft configuration, and the workload now placed on the pilot with this advanced automation. These now follow in order.

History has shown, with concepts dating as far back as the two-man foxhole, that soldiers fight more aggressively and effectively as a team (Hickman, 1985, p. 38). This is not to imply, though, that a two-seat aircraft does not have disadvantages. The obvious negative is that weight is increased, thus reducing maneuverability, range, climb rate, speed and service ceiling, while increasing fuel consumption. Life cycle costs are also higher, and required manpower is doubled with two pilots. These are certainly areas that require consideration when approaching program development. But despite its disadvantages, a two seat configuration can be the more beneficial and most studies recommend it.

First, statistics from the Naval Safety Center in Norfolk, Virginia, show that a two-seat F-4 has a lifetime mishap rate of 2.77 (per 100,000 hours) versus 4.79 for the single seat F-8; the twin seat A-6 has only a 1.52 mishap rate versus 2.66 for the single seat A-7. Plus, only five of the A-6 mishaps were due to pilot error, while 41 pilot error mishaps occurred in the A-7 (Hickman, 1985, p. 32). Regarding the above data, it was found that pilot error usually occurred because the pilot's attention was focused elsewhere. He failed to perceive an emergency situation approaching or occurring, and was consequently slow or late in reacting to proper procedures. This type of problem is severely diminished in a two-pilot situation, where the second crewman relieves the first pilot from a number of duties, thus reducing his workload and allowing him to concentrate more on flying the aircraft. Though this data pertains to fixed-wing aircraft, it is hard to imagine the added safety factor of a second crewman not holding for the rotary-winged environment as well. As for cost--if just one aircraft is saved in a flight of five due to the second pilot sighting an enemy threat or an unsafe condition, then he has successfully helped "pay" for all life cycle costs that would have been incurred due to the extra seat (Hickman, 1985, p. 39). This implies that a two-seater *can* be more cost-effective from the aspect of flight safety, and is even more so during combat (vs. peacetime) situations. It is also safe to assume that the probability of survival will increase with experience level. Thus, an inexperienced pilot teamed with an experienced aviator in a dual-configured aircraft would have a greater chance for survival than if he were alone in a single seat aircraft.

Realizing that there are major trade-offs involved, the U.S. Army has conducted numerous studies on this subject. One of these such studies occurred in July 1983 at Fort Rucker, Alabama. The Army Research Institute (ARI) Field

Unit was tasked to (1) evaluate the feasibility of single-pilot LHX mission performance, and (2) help identify the automation that would be most beneficial in mission accomplishment (Aldrich, 1984, p. 3). Twenty-nine representative LHX scout and attack mission segments were devised and analyzed for excessive workload, with the workload components broken down into four areas: visual, auditory, cognitive, and psychomotor. A chart (Aldrich, 1984, p. 18) detailing all workload activities analyzed can be found in Appendix E. Table 5 presents the results detailing where the workload overloads occurred (Aldrich, 1984, p. 48). As can be seen, the single pilot configuration produced 263 overload conditions, while two-pilot configurations produced only 43, 83.6% less. Another result was that 40 of the 43 overloads in the two-pilot crew were experienced by the copilot. This makes sense when it is realized that the pilot handles the flight controls while the copilot performs the support and mission functions. Further results concerning the one-pilot configuration included: (1) no auditory overloads, (2) 1.5 more visual overloads than cognitive, and (3) greater than 2.5 times as many psychomotor overloads than visual. Thus, overloads were _not_ distributed equally over the four workload components (Aldrich, 1984, p. 50). For the two-pilot configuration, overloads decreased greatly and were equally distributed over three of the workload

TABLE 5
FREQUENCY OF OVERLOAD CONDITIONS BY MISSION SEGMENTS

Segment	TITLE	NUMBER OF OVERLOAD CONDITIONS	
		1-CREWMEMBER	2-CREWMEMBERS
	RECONNAISSANCE PHASE		
1	Bomb Damage Assessment	5	0
2	Evade Radar Lock-On	3	1
3	Reconnaissance, General	14	3
4	Record Sightings	10	2
5	Tactical Movement	21	3
6	Transmit Report, Digital	4	0
	TARGET SERVICE, GROUND		
7	Acquisition, Auto Search	12	3
8	Acquisition, From Laser Cueing	2	1
9	Adjustments, Area Weapons, Digital	4	1
10	Adjustments, Area Weapons, Voice	3	1
11	Designate for PGM	12	7
12	Engagement, Air to Ground, Autonomous, Lock on After Launch	15	1
13	Engagement, Ground Target, Autonomous, Lock on Before Launch	18	5
14	Engagement, Ground Target, Remote Designation	8	0
15	Engagement, Soft Targets, Cannon Fire, Hover	7	0
16	Engagement, Soft Targets, FFAR, Direct	8	0
17	Handoff, Ground Target, Digital	5	0
18	Handoff, Ground Target, Voice	7	0
19	Handoff Target, Laser Cueing	5	0
20	Holding Checks	11	0
21	Overwatch	11	0
22	Receive Handoff, Voice	2	0
23	Team Coordination	11	3
	TARGET SERVICE, AIR-TO-AIR		
24	Acquisition, Free Search	19	7
25	Engagement From Masked Position	14	0
26	Engagement, Running Fire, Cannon	3	0
27	Engagement, Running Fire, Missile	4	0
28	Handoff Aerial Threat, Voice	12	2
29	Receive Handoff, Voice	13	3
	TOTAL OVERLOAD CONDITIONS	263	43

components (visual, cognitive, and psychomotor), but again, no auditory overloads occurred. From the one-pilot configuration to the dual, visual overloads decreased 70%, cognitive decreased 69%, and psychomotor dropped 93% (Aldrich, 1984, p. 52). Also observe from Table 5 that many overloads in the one-man design no longer exist in the dual design. More importantly, it can be seen that the majority of the overloads could possibly be eliminated by providing automated flight control and target acquisition systems, since only segments 2 and 26 do not require at least one of these (Aldrich, 1984, p. 67). The ARI summary ultimately found that the two-seat LHX was overwhelmingly preferred. Many of these tasks in the two-piloted scenario (14 of 29) could be performed without overload and without the help of automation, and only three pilot tasks caused overloads without automation. It is evident that <u>with</u> automation, performance would improve even more. The results here are also helpful in gaining an appreciation of what areas of automation are needed most if a one-seat configuration is indeed pursued.

Another study, this one by the U.S. Air Force, evaluated five different crewstation configurations and mission equipment packages utilizing a previously proven technique known as SWAT (Subjective Workload Assessment Technique) (Hickman, 1985, p. 6). The success of this technique occurs by allowing the experience and knowledge of the operational pilots used to aid in determining the optimal crewstation design. The mission task analysis began with a review of 24 LHX mission profiles to determine the critical mission segments that have the greatest impact on aviator workload (Hickman, 1985, p. 8) Within each of these mission profiles, twenty-nine mission segments were chosen for analysis, with six of these segments selected as critical points at which to collect workload estimates. These six were: (1) reconnaissance, (2) pre-Forward Line of Troops (FLOT), (3) FLOT penetration, (4) approach to battle position, (5) air-to-ground target acquisition and engagement, and (6) air-to-air target acquisition and engagement (Hickman, 1985, p. 9). The subjects were Army pilots with varying backgrounds and experience levels to judge personal workload requirements. In addition, interviews with operational pilots from the four major services were conducted to gain further insight of crewstation configuration as well as the equipment and technologies to be utilized. Again, workload components were broken down into visual, auditory, cognitive and psychomotor. The first analysis was completed without automation, the second with automation, and the results were as follows: For the one-man/no automation aircraft, the pilots experienced overloads in all twenty-nine segments, while the two-man/no automation aircraft produced fifteen overloads, a 48.3% drop; on the fully automated analysis, no overloads were identified in the two-man crew, while two overloads occurred in the single seat aircraft in the critical segments of "air-to-ground target engagement" and "reconnaissance".

Once again, the summary was the same. Single crewmembers will experience overloads during critical segments, with a second crewmember eliminating them in a fully automated system. With less-than-full automation, crew overloads can be expected to increase (Hickman, 1985, p. 8). Another important outcome was that workload was greatly reduced when a wide field-of-vision was present in cockpit design. Thus, a wide field-of-vision (90-120 degrees) should be considered critical in either the one _or_ two-man design, since it improves target acquisition by improving accuracy and decreasing acquisition time. This correlates well with Chapter IV, Section B findings, where limited field-of-vision affected the quick stops and NOE flight maneuvers, and high-speed low-level turns.

What are the pilots' opinions? From the survey of the RAND study participants, all were unanimous in their support for a two-seat LHX due to workload reduction. In the words of one, "Two brains are four times better than one, and four eyes are sixteen times better than two!" Another felt that two were needed due to advanced system requirements and since workload is higher with the "high tech" glass cockpits. A few did feel, however, that with some extremely state-of-the-art systems, it may very well be possible to build a single seat version that could be effective. While some tasks did prove overwhelming for one pilot, other tasks were an "overkill" with two. Discovering this "ideal" model, if one exists, is one of the Army's main goals with its present testing for the LHX, to find if it is indeed operationally feasible. It is also possible that projected population demographics and escalating training costs will actually dictate a migration to this type configuration in the not-too-distant future. Since the second crewmember in tactical operations is primarily required to navigate while the pilot flies, automatic navigation and waypoint steering systems may help eliminate their need. The pilot's main requirement would then be to operate the weapons systems. This implies that today's challenge is to develop adequate warning and weapons systems to both protect the aircraft and to perform the targeting tasks for the pilot. An abbreviated list of other pilots' inputs, many of which support the findings of the above studies, have helped determine that the following functions are critical in a fully automated system: (1) voice interactive systems, (2) automatic navigation, (3) automatic target detection, acquisition, tracking and recognition, (4) automatic threat analysis and management, (5) terrain follow/terrain avoidance, (6) integrated fire, flight, flight engine and flight path controls, (7) a wide field of-vision and (8) artificial intelligence concepts. If it turns out that the LHX is a tilt rotor, it will be further enhanced by the automatic flaps, conversion corridor protection and automatic RPM governing systems that the Osprey will possess. These all will certainly help the aircraft survivability. A major question, though, is whether these above-desired technologies will be mature enough in the time frame desired by the U.S. Army to be incorporated into the LHX to help reduce crew workload. Voice interactive systems, for one, are important but are currently incapable of the large vocabulary needed to be integrated fully into mission accomplishment. What systems will or will not be available to be utilized will play a major role in the Army's ultimate decision on the LHX. Maintainability of these systems will also be a factor, as it will require highly-skilled maintenance personnel to keep abreast of this new technology. This, of course, increases already high training and personnel costs as well.

VI. CONCLUSIONS

It should be clear that there are a myriad of considerations necessary in procuring a system such as the LHX. These decisions are tedious and necessarily time-consuming; however, as the process is extended, the useful life of the existing light helicopter fleet continues to diminish. Many choices, as discussed within this thesis, are available for the LHX in terms of airframe types, cockpit configuration, design, and automation. High acquisition costs will, as usual, be a major factor in the ultimate decision, as the force size per fixed budget is optimized. The tilt rotor, though ruled out by initial studies, possibly should still be considered as a candidate, as the success of the XV-15 has removed significant uncertainty by proving the tilt rotor concept. The V-22 Osprey is much too large for the LHX mission, but a scaled-down model, one the size of the XV-15, may be feasible. The data from the RAND Corporation study revealed that the tilt rotor performed better in the missions requiring (1) hard, maximum effort turns and (2) firing at elevated or depressed targets. The helicopter, in turn, has the advantage in lateral movements and quick hover up/hover down maneuvers, such as when trying to escape missile lock-on. The U.S. Army must take the advantages and disadvantages of each aircraft, plus the expected enemy threat beyond the year 2000, into account when reviewing the desired tasks of the LHX to best assess the characteristics needed to perform and survive the LHX mission.

The views brought forth in this thesis hope to provoke ideas regarding what should or should not be considered not only for the LHX but for future aviation acquisitions as well, plus the benefits and disadvantages that they impose. The helicopter pilot opinions disclosed within this thesis offered that particular group's views regarding what issues they felt were most important. These views may be significantly different from another cross-section of pilots. Pilot opinion conclusions pertaining to which systems and maneuvers were most difficult for helicopter pilots' attempting a tilt rotor transition were clear and distinct, while the differences in performance by pilot communities were found to be negligible.

APPENDIX A

THE TILT ROTOR

The Bell-Boeing Tilt Rotor aircraft (being produced as a team effort) has been designated a multi-mission/multi-service program that is scheduled to be operationally introduced to the fleet in the early 1990's. It is an extremely versatile airframe that has given high hopes to procurement personnel in many aviation programs, and can arguably be considered the most advanced technological breakthrough in the aviation field in decades. The advantages of the program is its reduced research and development costs due to joint efforts amongst the services, and the Bell-Boeing team effort which has exploited a broader technology base for its design (Gage, 1984, p. 15). Its original conception actually occurred over thirty years ago when Bell Helicopter tested the XV-3 (a tilt rotor of sorts) back in 1955. Despite some serious aeroelastic stability problems (it came apart during a wind tunnel test!), the program provided great promise for the future. In the late 1960's, engineers felt that they had solved the XV-3 instability problems, and after funding approval, Bell (under contract to NASA Ames) commenced development of the XV-15. Its first successful flight, in 1977, "proved the concept" of the tilt rotor and has opened the door for the production and design of the V-22 Osprey. It is important to note, though, that the XV-15 is not a prototype for the Osprey--in fact, it was constructed primarily from "off-the-shelf" technology. Thus, very little of this hardware will be present in the Osprey upon its completion.

Engineering-wise, the tilt rotor aircraft has two three-bladed proprotors mounted onto wingtip engine nacelles, giving the appearance of "a fixed-wing aircraft with helicopter rotors." These nacelles operate from angles of 0 degrees (the horizontal position in front of the wings) to a 95 degree position, 5 degrees past the vertical configuration. Basic operation is such that the aircraft takes off vertically much like a helicopter with the rotors/nacelles in the 90 degree position. There is a limit to how fast the aircraft can fly in this configuration (thus the limitation in the conventional helicopter), so the nacelles "tilt" forward to the horizontal position, or may be stopped anywhere in between. This area "in between" is known as the conversion corridor, the conversion from the 90 degree vertical "helicopter" position to the 0 degree full-forward "airplane" position. The 95 degree position is provided to enable the tilt rotor to fly backwards in much the same manner as a helicopter. The usual fixed-wing control surfaces (i.e., flaps, ailerons) are operable, but ineffective, at low airspeeds.

Hopes for the future of the Osprey have been so high that three of the four major services plan to acquire a total of 657 of these tilt rotor aircraft to replace existing rotary and fixed-wing platforms. They will be used to perform the following missions:

U.S. Marine Corps--Medium Amphibious Assault while replacing the workhouse CH-46 (medium assault helicopter) and the CH-53A/D. One of the Marines' primary missions is rapid movement of ground troops, which is suited perfectly to the tilt rotor's vertical takeoff and landing capabilities and its forward flight speed and range. The Marine Corps plans to purchase 552 aircraft;

Navy--Combat Search and Rescue (SAR), Special Warfare, and Fleet Logistics Support Missions. Purchase amount is fifty (50) aircraft to replace the HH-3;

Air Force--Long-Range Placement and Special Operations. Plans are to procure fifty-five (55) aircraft to replace the HH-53 and HH-60.

The fourth major service, the U.S. Army, had desired to acquire 231 Ospreys as well, but recently dropped these plans due to budgetary considerations.

The capabilities of the V-22 Osprey will include inflight refueling to drastically improve mission range, and an advanced "Fly-by-Wire" flight control system, utilizing "lessons learned" from the F/A-18 for cost, weight and safety considerations. Approximate performance specifications will include:

- Cruise Speed--250 knots
- Maximum Speed--300 knots
- Range--500 nautical miles
- Payload--24 fully equipped combat troops
- Altitude--30,000 feet

There are still gaps in the knowledge of the aerodynamic aspects of the tilt rotor (such as complete flowfield effects of the rotors and the downloading effect it has on the wings), but no major problems have been discovered or foreseen. Testing of all aspects of the aircraft continues daily at NASA Ames to reduce the inherent risk involved with the production of a new aircraft design.

APPENDIX B

PILOT FLIGHT HISTORY ENTERING RAND STUDY (in hours)

ARMY

NAME	HELICOPTER	FIXED WING	SIMULATOR	TILT ROTOR ACT + SIM)
PILOT #1	5000	3300	300	10
PILOT #2	800	100	225	10
PILOT #3	3100	15	355	10
PILOT #4	2700	600	320	10

INDUSTRY

PILOT #5 (Bell Helicopter-Tilt Rotor Only)	5000	2000	200	350
PILOT #6 (Bell Helicopter-Tilt Rotor Only)	8000	1500	510	500
PILOT #7 (Sikorsky Aircraft-Helicopter Only)	3546	750	250	0
PILOT #8 (Boeing Vertol-Helicopter Only)	1700	1300	280	60

NASA AMES

PILOT #9	1500	3500	386	11
PILOT #10	3990	1600	210	45

APPENDIX C

MISSION DESCRIPTIONS

Engagement Mission Tasks

- E-1 Bob up, fire, bob down
- E-2 Engage 12 degree depressed target, evade thru pass
- E-3 Engage 8 degree depressed target, evade thru pass
- E-4 Bob up, fire, forward dash to clearing
- E-5 Bob up, fire, lateral dash to clearing
- E-6 Lateral unmask, fire, lateral mask
- E-7 Fire in transit, dash to clearing

Maneuver Mission Tasks

- M-1 Lateral acceleration and pedal turn
- M-2 Near zero-G pedal turn
- M-3 Depressed rocket firing
- M-4 Elevated rocket firing
- M-5 Forward dash
- M-6 Forward quick stop
- M-7 Cruise and quick mask
- M-8 Lateral hugh speed jinking
- M-9 Slalom and missile fire
- M-10 Return to target and fire rockets

APPENDIX D

THESIS QUESTIONNAIRE

NAME: ORGANIZATION:

FLIGHT HISTORY: (Input in Hours)	Helicopter Flight Time	____________
	Fixed Wing Flight Time	____________
	Total Simulator Time-- Helo	____________
	-- Fixed Wing	____________
	Tilt Rotor Time: Actual	____________
	Simulator	____________

1. a) What was your overall impression of the simulator used at NASA/Ames for the RAND study? (Circle one)

1	2	3	4	5	6	7	8	9	10
Bad									Good

b) Did one simulator have a more realistic feel than the other? If so, which one and why? Do you feel that the simulator field-of-view limited or affected your flying abilities in any maneuvers? If so, which ones?

2. With respect to your background in helicopters:

a) What were the most difficult transitions in switching to the tilt rotor? Which components were most difficult to "master", or the most confusing to understand? Use the following list as an aid:

TRANSITION DIFFERENCES	RANK ORDER OF DIFFICULTY
Different thrust response	
Nacelles	
Lateral Translation Mode (LTM)	
Greater Pilot-Induced Oscillations	

Please add others you feel are pertinent, please.

b) Which capabilities did you utilize the best? the least/worst?

c) With the understanding that tilt rotor experience was generally limited before the RAND study, do you feel you successfully flew the tilt rotor to a reasonably maximal effectiveness, or did you find yourself tending to fly it like a helicopter? Please explain.

3. Which type of maneuvers were most difficult? (Rank if possible, using 1 as the hardest, 2 as next hardest, etc.)

Acceleration ______
Deceleration ______
Pedal turns ______
Yaw control ______
Turns ______
Stabilizing at an airspeed ______
Using aft nacelles to decel ______
Maintaining pitch attitude ______
Altitude control ______
Scheduling of wing flaps ______

List any others you felt were significant, whether easy or hard.

4. Do you feel you flew more aggressively in the simulator than you do in real flight? (circle one) Yes/No

This next section deals loosely with Human Factors, which can be described as "keeping the operator (pilot) of the aircraft and his physical capabilities and limitations in mind when designing the cockpit." In the context of the RAND study, I realize that the cockpits were only skeletal in nature and not designed with human factors in mind. Thus, please answer only with the major systems in mind. You can base your answers either on the real aircraft or the simulators, but please specify which you are describing.

5. How would you compare the tilt rotor cockpit set-up with that of a helicopter? What seems "out of place"? What systems/ switches seem to have had human factors considerations performed in the design phase? Which do not? What would you change and where would you put it? (Or is the set-up fine as is?) Do you feel this "discrepancy" (for those,if any, noted) affected your overall performance in the RAND study?

6. With respect to the new systems that the tilt rotor provides, is the cockpit "too busy"? Does the added complexity of these systems "wash out" the positive effects that they are supposed to provide? What automated systems do you feel the LHX needs most to reduce pilot workload?

7. Was target acquisition different in the two simulators? If so, which was easiest?

8. Do you advocate a single- or dual-piloted tilt rotor aircraft? How about in the LHX, assuming it turns out <u>not</u> to be a tilt rotor aircraft? Why?

APPENDIX E

WORKLOAD COMPONENTS

VISUAL

1-- Monitor, Scan, Survey
2-- Detect Movement, Change in Size, Brightness
3-- Trace, Follow, Track
4-- Align, Aim, Orient On
5-- Discriminate Symbols, Numbers, Words
6-- Discriminate Based on Multiple Aspects

AUDITORY

1-- Detect Occurrence of Sound, Tone, etc.
2-- Detect Change in Amplitude, Pulse Rate, Pitch
3-- Comprehend Semantic Content of Message
4-- Discriminate Sounds on the Basis of Signal Pattern Pitch, Pulse Rate, Amplitude

COGNITIVE

1-- Automatic (Simple Association)
2-- Sign/Signal Recognition
3-- Alternative Selection
4-- Encoding/Decoding, Recall
5-- Formulation of Plans (Projecting Action Sequence, etc.)
6-- Evaluation (Consider Several Aspects in Reaching Judgement)
7-- Estimation, Calculation, Conversion

PSYCHOMOTOR

1-- Discrete Actuation (Button, Toggle, Trigger)
2-- Discrete Adjustive (Variable Dial, etc.)
3-- Speech Using Prescribed Format
4-- Continuous Adjustive (Flight Controls, Sensor Control, etc.)
5-- Manipulative (Handling Objects, Maps, etc.)
6-- Symbolic Production (Writing)
7-- Serial Discrete Manipulation (Keyboard Entries)

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