Lessons Learned:
Apache Helicopter Development Program

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Contents

Lesson Learned 1. Don't over design – take risks but have a plan. ......................................................... 4
Lesson Learned 2. Design simplicity-- the keynote (R-10) ........................................................................ 4
Lesson Learned 3. Designed for easy maintenance .................................................................................. 5
Lesson Learned 4. Empennage configuration (you can be contractually correct, and technically wrong, and vice versa) ......................................................................................................................... 6
Lesson Learned 5. Cater to the customer, but not always .......................................................................... 7
Lesson Learned 6. How to conduct a design review .................................................................................. 8
Lesson Learned 7. IHADSS-- how to manage a higher risk program element ........................................... 9
Lesson Learned 8. Parasitic vs. integral armor ......................................................................................... 10
Lesson Learned 9. Good companies can, and occasionally do, design and build bad helicopters/airplanes 10
Lesson Learned 10. "Whether it's politics or pragmatism, you need more than a great product to win (and to keep it sold)" ........................................... 11
Lesson Learned 11. ""Team' Concept works (but don't give up the systems integration)" .......................... 12
Lesson Learned 12. Impact of continual government ............................................................................. 13

Background Documentation .................................................................................................................. 14
  THE OH-6A Light Observation Helicopter ........................................... 14
  Aircraft Weight .................................................................................. 15
  Projected Cost of Production ............................................................. 15
  Subcontract Management .................................................................. 16
  Weapons and Sightings Systems ......................................................... 17
  Cheyenne Cancellation ..................................................................... 19

Hughes' Relationship to Congress and the Military ............................................................................... 19
  Congressional Investigation of the Flying Boat Contract in 1947 20
  The Blowup at Hughes Aircraft in 1954 ........................................... 20
  Porter Hardy Congressional Investigation 1967 ................................. 21
List of Figures

Figure 1. Early concept drawing for the Phase I proposal submitted to the Army.................................5
Figure 2. Getting it right on the third try: The articulated horizontal stabilizer on a production aircraft..7
Figure 3. T-Tail during Phase 1 Flight Test ..........................................................................................7
Figure 4. IHADDS: Integrated Helmet and Display Sight System ......................................................9
Figure 5. Bell YAH-63 Program ........................................................................................................10
Figure 6. Bell YAH-63 in flight. Note T-tail, 2-bladed rotor, tricycle landing gear, and gun in front of the TADS/PNVS ........................................................................................................11
Figure 7. The YAH-64 Team of major subcontractors from across the country. ..............................13
Figure 8. Managing cost and schedule in the Design Department .....................................................14
Figure 9. OH-6A design: 4-bladed rotor, a static mast, and “crash worthiness” ...............................14
Figure 10. Weight Management .........................................................................................................15
Figure 11. Designed to Unit Production Cost .....................................................................................15
Figure 12. Major Subcontractor Management ..................................................................................16
Figure 13. Project TEAM Major Subcontractors ............................................................................16
Figure 14. Visibility in the dark, through fog and at long range. ......................................................17
Figure 15. Targeting the various weapons using the TADS/PNVS. ....................................................17
Figure 16. Armament Integration .......................................................................................................18
Figure 17. Ammunition, Missiles, Rockets and Fuel Stores Options ...............................................18
Figure 18. Department of Defense Opinion of Howard Hughes .........................................................19
Figure 19. The Spruce Goose ...........................................................................................................20
Figure 20. Hughes Scientists and Engineers found TRW .................................................................20
Figure 21. The Result of the Hughes OH-6A Congressional Investigation .......................................21
LESSON LEARNED 1. DON’T OVER DESIGN – TAKE RISKS BUT HAVE A PLAN.

Hughes’ design philosophy, previously applied to other helicopters and applied throughout the Phase I and Phase II programs is as follows:

1) Don’t over design (if you do, you may never find out you did, and even if you did find out, it’s probably too late/too expensive to redesign and take out the excess weight, cost, etc.).

2) Any design tradeoffs which appear attractive (lightweight, low-cost,) but which have attendant risk (performance, structural integrity, etc. etc.) should opt for the risk side, as long as
   
   A. You have a good contingency plan
   
   B. You have a way of deciding when the contingency plan must be executed in order to avoid overall program schedule impact.

Examples of this design philosophy will be discussed on subsequent pages.

LESSON LEARNED 2. DESIGN SIMPLICITY-- THE KEYNOTE (R-10)

The basic configuration trade-offs of Phase I were as follows:

1) Crew member location/orientation (tandem, pilot front or pilot rear; side-by-side; staggered tandem).

2) Sighting system on nose or belly.

3) Gun nose or belly

4) Tricycle gear vs. tail dragger.

5) Drive system configuration (minimize number of gearboxes)

The tradeoffs followed the Hughes approach of design simplicity. By keeping the sighting system in the nose and the co-pilot/gunner in the front, the direct optical relay tube problem was minimized. By putting the gun on the belly between pilot and co-pilot stations, the feed chute length/mechanization difficulties were minimized (since the ammo storage must be at the center of gravity anyway).

Note that Bell chose the opposite approach with a pilot in the front, and ended up with two heavy, complicated items crossing each other; that is, the optical relay tube and the ammo feed system were long and had to cross each other, rather than being short and parallel as in the YAH-64. Note that
during the Phase I program, Bell and the Army made an effort to delete the requirement for direct optics. This would have reduced the above tradeoff differential between the Bell and Hughes designs. We got wind of this, wrote a quick 'white paper' which was apparently persuasive enough to prevent the elimination of the direct optics requirement, and we where thereby able to retain a distinct advantage which we calculated at the time was as much as 400 lbs.

We opted for the tail dragger for several reasons, including:

The pilot strongly favored a tail dragger design because it allows the pilot to use the tail gear in the NOE to seek out the ground and provide a positive reference point. From the engineering point of view, the tail dragger was also favored because of the simple geometry between the landing be gear and gun/sighting system (tail dragger legs stay out of the way of the sight and the gun). And a tail dragger provides better structural loading.

Having made all of the above correct decisions, we ended up with one additional gearbox by comparison with the YAH-63; the intermediate gearbox. This turned out to be a small price to pay; four out of five isn't bad.

![Very Early YAH-64 Design](image)

Figure 1. Early concept drawing for the Phase I proposal submitted to the Army

**LESSON LEARNED 3. DESIGNED FOR EASY MAINTENANCE**

We began Phase I with the objective of doing most of the maintenance while standing outside the aircraft. The upper deck mounted the APU, the ECS, etc., as well as the rotor support structure with the transmission. The large Kevlar access doors with a catwalk allowed the mechanic to stand on top of the aircraft to maintain the high maintenance items. For the avionics, the forward avionics bays allow most of the black boxes to be maintained while standing on the ground. During the evaluation, we always got high marks in maintenance and this approach served us well during the competition and will serve the aircraft well during its service life.
LESSON LEARNED 4. EMPENNAGE CONFIGURATION
(YOU CAN BE CONTRACTUALLY CORRECT, AND TECHNICALLY WRONG, AND VICE VERSA)

Following the basic Hughes design philosophy (Lesson Learned 1), we began with a fixed low tail, realizing that there was an attendant risk with regard to the possible effects of pitching moments incurred in low speed flight as the downwash from the main rotor blade passes over the low tail. Early in phase one, we quickly concluded that this would be a problem, and converted to a fixed "T" tail with the horizontal stabilizer mounted on the top of the vertical, reducing but not eliminating downwash induced pitching moments.

The aircraft flew in this way, successfully, throughout all of Phase I. Pitching moments were noticed, however, during the flyoff and evaluation by the Army pilots, it was my recollection (John Dendy) that the resulting pitching moments were not cited, nor were any related handling quality difficulties cited in the Army’s report as either a shortcoming or a deficiency.

Therefore, When Hughes won the flyoff and was awarded the Phase II contract, based on:

1) Best results in the flyoff as evidenced by the Army's report (which did not cite any related problems),

2) The system specification which described in detail the configuration of the aircraft, including the fact that it had a fixed "T" tail.

Hughes was not under any obligation to change the configuration and, in fact, would have to have government approval (and, therefore additional funding) to change the system specification.

So, the company was, to the best of my recollection (John Dendy), contractually correct and protected relative to the "T" tail configuration; however, we knew all along that the design produced pitching moments during flight at low air speeds, as mentioned above. The designers prepared some layouts of alternative approaches, including a low mounted articulated/automatically controlled horizontal stabilizer, as was implemented on the Sikorsky UTTAS/UH-60. However, no additional activity was required and there was plenty of other work to be done. So in the middle of Phase II, when the Army began to realize that at the low-to-moderate speeds at which the helicopter flies NOE, the handling qualities caused by the "T" tail were a real operational problem. This became a major issue.

While it became a contractual/political/funding issue, it was really not much of a technical one. Upon being directed to do so, the solution was relatively simple; Hughes approached Hamilton Standard (who had done the work for Sikorsky) and purchase the electronic box to drive the actuator to drive the newly relocated horizontal stabilizer. Hamilton Standard had a good handle on the control laws necessary to minimize pitching moments (collective/cyclic/airspeed parametric control), and the program went on its successful way.
Figure 2. Getting it right on the third try: The articulated horizontal stabilizer on a production aircraft.

Figure 3. T-Tail during Phase 1 Flight Test

LESSON LEARNED 5. CATER TO THE CUSTOMER, BUT NOT ALWAYS

As always, it is necessary to learn what the customer thinks is important and to apply his own technology where appropriate. There are several examples of doing this on the AH-64, including the power generation/distribution system (generation and usage of hydraulic, electrical, pressurized air power). The Army had done a recent study, written a report and we followed their recommendations because we agreed with them. There are many such examples.
An example of not caving to the pressure had to do with stability augmentation. One of the laboratories had spent a lot of money and time developing fluidic stability augmentation techniques (this was popular ten to fifteen years ago). We were under great pressure to use these techniques but resisted, and, in fact, ultimately had to refuse, not because of a "not invented here" attitude, or other prejudices, but simply because the proponents (laboratory and manufacturer) could not satisfactorily answer questions related to the thermal shift of their fluidic sensors.

Note that the Sikorsky UH-60 came under severe criticism in the Army's "Vertical Lift Technology Review" report issued in 1980 for severe thermal shift problems with the fluidic augmentation system. Therefore this was a case of standing our ground for good technical reasons, despite customer pressure.

An example of caving to a laboratories approach which we did not really agree with, is as follows: an Phase II the Fort Monmouth people who were on the AH-64 design review team wanted to implement some symbology for IHADSS and the heads-down display which was identical to that which they had developed for the past five years in different laboratory, simulator, and airborne experiments. We, at Hughes, disagreed (and still disagree) with the complex symbology which the Army wanted to implement (specifically in the fact that they should separate symbols for acceleration, velocity and displacement for a hovering maneuver). We tried to simplify the symbology, but quickly found out that keeping the customer happy, and staying within budget and schedule was still very much the "art of the possible and" and stopped arguing.

Pragmatism was at work. The effect of a bad (fluidic) stability augmentation system would have damaged us because it would have been very obvious to the pilot. The effect of having an unnecessarily complex symbology would be less difficult for us because the whole subject was so new to the pilots that the engineers were still "driving the train". Further, we were already in Phase II and no longer had to beat Bell.

As it stands, in my opinion at least, the symbology is still overly complex and engineering change proposals should be generated at the appropriate time.

LESSON LEARNED 6. HOW TO CONDUCT A DESIGN REVIEW

With approximately 100 Army people (aviators, maintainers, technologists from all walks of life, bureaucrats, and scientists) showing up every couple of months for a design review, this became a management challenge.

It didn't take long to develop the following successful approach.

1. Get them all together in one room early. Tell them what the agenda is, tell them that you will provide all information and make any person available to them.

2. Turn them loose in a big room with experts sitting at tables designated by discipline (try to be parallel to the way the customer is organized), and backed up with several file cabinets full of drawings, test results, samples, etc.

3. That is, never say no to request. Give them more data more and people than they could possibly hope for.

4. Make thousands of chit forms available to them. Be generous.

5. Structure that chit form so that it is clear which part of the helicopter they are critiquing, what their problem is, and have a place for them to sign, show the organization, and most importantly, a place for the Hughes representative in that area to also sign (not to indicate that he agrees or disagrees with the chit, but that he has had the opportunity to discuss the concern with the customer and that they have communicated as much as is feasible in the matter).
6. Collect all chits at a designated time (there were always several hundred), have an all night review with a designated Army team and a Hughes representative. The Army team is first tasked to throw out the redundant chits, and then the silly ones. Then the Hughes/Army team captains review the remaining chits and classify them into ‘Hughes problems’ or ‘Government problems’ (recognizing that many concerns are from field people who don’t know what the spec requires.) Don’t let them go home with more than a few unclassified chits.

In summary, that everyone have the opportunity to criticize, be generous with information and people, make the customers speak with one voice, reach quick agreement on who has what actions, and get on with the job.

LESSON LEARNED 7. IHADSS-- HOW TO MANAGE A HIGHER RISK PROGRAM ELEMENT

The Integrated Helmet and Display Sight System (IHADDS) coordinates sensor and targeting systems with the pilot’s head movements. The computer displays flight information and targeting data through images projected on to a small transparent screen attached to the pilot’s helmet.

Figure 4. IHADDS: Integrated Helmet and Display Sight System

Throughout the Phase I program, the Hughes design employed panel mounted (heads down) display for FLIR and flight symbology. When we receive the RFP for Phase II (remember that Bell and Hughes were still competing), the Army RFP ask that the competitors do a tradeoff between heads-up and heads-down display.

Normally, this is a good approach. That is, let the customer tell you what he would like to accomplish, but not how to accomplish it. In this particular case, however, the Army had recently done quite a bit of flight testing with panel-mounted heads-up displays and had not yet released the report. Hughes took the Army on directly, and demanded that the Army make a selection and change the RFP, telling Bell and Hughes which way to propose.

As background, recognize that the panel-mounted display was low the risk approach, and yet we felt that the heads up display, while high risk, was the better ultimate decision, yet, we did not feel it fair for the Army to ask industry to do the tradeoff without sharing the test results.

We were successful in persuading the Army to change the RFP to specify a heads-up display.

We then, in our proposal, proposed a special subprogram within the program, in which a tightly managed team, comprised of Hughes, Hughes’ selected supplier, and an Army assistant project manager, would manage this program very tightly with special monthly meetings and individual
internal progress reports. As described in Lesson Learned 1, we developed a contingency plan. Including the criteria upon which the contingency plan would have to be executed in order to avoid a program impact. The contingency plan was a fallback position to a panel-mounted display. However despite the fact that this was without a doubt the highest risk element of the Phase II program, the IHADSS was very successful and the contingency plan did not have to be executed.

LESSON LEARNED 8. PARASITIC VS. INTEGRAL ARMOR

I’m not sure that this is a Lesson Learned, but is an observation that was a genuine concern during Phase I and Phase II as to warrant serious thought. The subject is integral armor vs. parasitic armor.

Generally, integral armor results in a lower weight impact. Look what happens when the threat changes or even when our understanding of the threat changes? To redesign the integral armor is major. Parasitic armor can be more readily replaced with upgraded; it can even be discarded when the threat becomes undefeatable. Further, how about the relative replacement cost of parasitic vs. integral armor when slightly damaged by the specified round? (Something that no one talks about much is that the specs requires only that the round be defeated, not that the service life be unaffected.)

Considering the fact that the AH-64 came in remarkably under weight, and that we still need to get the cost out of the airplane, I have recommended that we go back and build hydraulic actuators of conventional materials instead of TSR Steel, and use parasitic armor instead (this will result in a weight increase, possible maintenance difficulties, but should greatly reduce the cost).

LESSON LEARNED 9. GOOD COMPANIES CAN, AND OCCASIONALLY DO, DESIGN AND BUILD BAD HELICOPTERS/AIRPLANES

From a taxpayer's viewpoint, the flyoff program, while expensive, was beneficial. Without the flyoff program, Bell would have won. Without a flyoff, Boeing-Vertol might well have won UTTAS. In each flyoff there was a clear winner and a clear loser, too good helicopters and two not so good ones. Yet, the results would have been different without a flyoff.

Sometime during the Phase I program, approximately two or three months before the first flights of the YAH-64 and the YAH-63, Congress was putting a lot of pressure on the Army to reduce the cost of the AAH program.

Figure 5. Bell YAH-63 Program
Because of this, the Army technical community wrote a report in answer to the question "if we were to shut off the competition in picking a winner today based on the lab results, technical reports, and design reviews held to date, who would you pick?"

The Army's reply was an unequivocal "Bell". This report was released not too long before first flight. We have been told that on the day that the Army got the two airplanes for their flight evaluation, that was not one doubt in anyone’s mind that the YAH-64 was far, far superior to the YAH-63. That is, that there was one clear winner and one clear loser.

Flyoffs are expensive but necessary

**LESSON LEARNED 10. "WHETHER IT'S POLITICS OR PRAGMATISM, YOU NEED MORE THAN A GREAT PRODUCT TO WIN (AND TO KEEP IT SOLD)"

The only reason Hughes was picked as one of the two winners for the Phase I competition, was Sikorsky and Boeing-Vertol were already selected to compete in the flyoff for the UTTAS. In the Army's mind at the time, Bell was the only other major helicopter company around, and was clearly the favored supplier of the AAH. Hughes was selected as a dark horse only to keep Bell honest.

We were ideal for that purpose, since as a result of our design approach we tend to develop "non-parametric" products. We were seen as a dark horse which could be eliminated at any time because of our orthodoxy. In fact, one of our greatest difficulties in the early part of Phase I was our inability to persuade the customer that our aircraft would be as lightweight as it was (this, notwithstanding our demonstrated experience on the OH-6A).

The statement has been made that we did not win this program, but that Bell lost it. This was probably true. It is probable that if the two competing helicopters had been more or less equivalent, we would not have stood a chance for many reasons, including the fact that Bell was better facilitated; also there were many people in the government who were still distressed at Hughes because of the pricing episode of the OH-6A, and further, the general feeling was that the company that builds the Cobra could do the best job on the AAH.

The fact is, Bell's entry was not a very good one. This in no way means that ours was not a great helicopter. It is. The AH-64a will lead to the AH-64B, C, D and Z: and will become a classic like the F-4 AND C-130, and will be in production for four decades. (Remember this was written by John Dendy in 1985)
When the draft RFP was received in mid 1972, Hughes Helicopters assets and technologies were extremely limited. There were maybe a total of 40 engineers in the entire helicopter side of the business. We were particularly limited in electronics, avionics, weaponization, fire control, and flight control skills, having always depended on Hughes Aircraft company for anything more complicated than a radio.

This became a problem having to boot-strap ourselves into a competitive position by forming a team of major potential suppliers (Teledyne, Sperry, Bendix, etc.); these organizations competed for the privilege of competing. Once we selected them, they wrote major sections of the proposal and once we won the job, they, of course, usually spent five years or more of their development cycle before receiving any kind of profit. Not only did we leverage our technical base, but also financial and political bases. The remarkable fact is that most of the original team members are still on the helicopter, and, of course, it has paid off for them, as well as for Hughes.

Another remarkable fact is that despite limited skills in many of the subsystems that are on the aircraft, we did not relinquish the systems integration or systems management responsibilities. We wrote specifications, we managed the procurement (virtually all of this done by the engineering department since there was little or no subcontract management capability in the company at that time).

What made it work

1. We were fair, never misrepresenting the situation, either too optimistically or too pessimistically.
2. We were tough. We literally gave the CEO’s of these team members a written report card every month showing their performance, both good and bad of their part of the action.
3. Most importantly, we knew what we were doing. We very carefully developed the system architecture early on and while not having the people assets to execute much of the work in-house, we very tightly monitored the suppliers work. Whenever problems arose, we work the problems as if they were our problems while always maintaining the distinction of whose contractual responsibility it was to fix the problem, we maintained a team spirit regarding the practical approach to the situation.
4. We threw parties for the team members, lavishly and enthusiastically, thereby maintaining an up-front appearance of success and confidence (then we gave them their report cards). We insisted that the CEOs attend these events, insuring high visibility/priority for the AAH program back at the supplier’s plants.
LESSON LEARNED 12. IMPACT OF CONTINUAL GOVERNMENT

Throughout the Phase I and Phase II programs, as a result of both internal and external funding, technical, and political forces, the program was continually undergoing reprogramming (adjustment of the funding and schedule). In my rough estimation, this reprogramming resulted in a 40% reduction in the effective use of the core people who really get the job done. Due to this continual reprogramming, the actual task of developing the helicopter frequently took second priority.

The program was managed on the C/SC system for which we could write an entire book lessons learned. However, in synopsis:

1. A system like C/SC which measures value is essential to any well managed program.

2. The very detailed and dogmatic approach to C/SC is probably due to the fact that DoD learned a long time ago it cannot distinguish between unethical and unprofessionally managed programs, without having this vast amount of detail and control especially the virtual inability to execute changes in the plan.

One of the most difficult rules to abide by was at the C/SC managers are the real managers. DoD clearly did not want, for good reason, a cadre of specialists controlling the C/SC paper and simply making him look good while real work is unaffected by the C/SC management process.
From DOD's point of view, this was understandable. From the supplier's point of view, if you tie the very complicated change process to the fact that the core people are the individuals who have to deal most closely with the C/SC paper, then throw in the third element of continual re-programming for whatever reason, then you have a virtual disaster on your hands, causing the real development of the helicopter to almost stop in its tracks every time the program has to get re-scheduled or re-budgeted; this in turn causes another probable re-progranmming downstream.

**BACKGROUND DOCUMENTATION**

**THE OH-6A Light Observation Helicopter**

![OH-6A Helicopter](image)

**Figure 9. OH-6A design: 4-bladed rotor, a static mast, and “crash worthiness”**
Aircraft Weight

Aircraft Weight Status

![Weight Management Graph]

Figure 10. Weight Management

Projected Cost of Production

Design To Unit Production Cost

![Designed to Unit Production Cost Graph]

Figure 11. Designed to Unit Production Cost
Subcontract Management

Hughes Helicopters will employ a computerized communication system called Project TEAM during Phase 2. This system will link each major subcontractor to the YAH-64 TEAM Data Base. The system will be used to periodically report Cost, Schedule, and Change Control data. Each major subcontractor will use a small terminal to access his portion of the TEAM Data Base. Only Hughes Helicopters will be able to access the entire data base.

Figure 12. Major Subcontractor Management

Figure 13. Project TEAM Major Subcontractors
Weapons and Sightings Systems

**TADS & PNVS**

**Figure 14.** Visibility in the dark, through fog and at long range.

**Figure 15.** Targeting the various weapons using the TADS/PNVS.
Figure 16. Armament Integration

Figure 17. Ammunition, Missiles, Rockets and Fuel Stores Options
Cheyenne Cancellation

Lockheed’s Cheyenne Helicopter Program – Canceled

HUGHES’ RELATIONSHIP TO CONGRESS AND THE MILITARY

Hobby Shop

Army Air Corps Memo January 26, 1942 - It’s a Hobby

It is the opinion of this office that this plant is a hobby of the management and that the present project now being engineered is a waste of time and that the facilities, both in engineering personnel and equipment, are not being used to the full advantage in this emergency . . . . The Air Corps should discontinue any further aircraft projects with this organization.

Senate War Hearings, p. 24485

Figure 18. Department of Defense Opinion of Howard Hughes
Congressional Investigation of the Flying Boat Contract in 1947

Figure 19. The Spruce Goose

The Blowup at Hughes Aircraft in 1954

The Hughes Aircraft plant, now almost wholly devoted to electronics, is situated on some 1,200 acres at Culver City, on the outskirts of Los Angeles, two miles from the sea. It employs 15,000 workers.

Figure 20. Hughes Scientists and Engineers found TRW
Porter Hardy Congressional Investigation 1967

Figure 21. The Result of the Hughes OH-6A Congressional Investigation