LHX System Design for Improved Performance and Affordability

Gene R. Marner
Principal Research Scientist
U.S. Army Aviation Research
and Development Command (AVRADCOM)
St. Louis, Mo.

Richard R. Pruyn
Product Development Engineer
Boeing Vertol Company
Philadelphia, Pa.

A system design that can provide extraordinary avionics reliability for the LHX aircraft has been devised. This system includes self-healing components, functional and conventional redundancies, and reconfigurable features. There is little weight and cost increase over a conventional avionics installation since some components were eliminated and conventional redundancy was used only in selected situations. Supporting analyses show that LHX needs high reliability if it is to be affordable. New approaches are required since LHX must be more capable than present aircraft. More sensors, target-acquisition aids, and better navigation and communications systems are required. These systems must be effective in reducing crew workload. These systems must also be unusually reliable; with today's technology, they would cause an unacceptable failure rate and an impossible maintenance burden. The avionics architecture suggested for LHX has the potential for avoiding these drawbacks and, in fact, can provide increased utilization. When combined with the functional improvements furnished by the new sensors, the reliability of the LHX will provide high productivity.

Notation

ATR	= automatic target-recognition device
B.I.T.E.	= built-in test equipment
C^2	= command and control
FLIR	= forward-looking infrared imaging sensor
GPS	= global positioning system; navigation data from satellites
IFF/SIF	= identification, friend or foe/selective identification of friends
LHX	= the Army's new family of light helicopters for the 1990's and beyond; scout, light attack, and utility
LIDAR	= light radar; radar that operates at or near the frequency of visible light
MFK	= multifunction keyboard
MMW	= millimeter wave, wavelength of radar
MTBF	= mean time between failures (mission aborts)
MTI	= moving-target indication
PJH	= an acronym of acronyms; P is for precision in the PLRS, precision location and reference system; J is for joint in the JTIDS, joint tactical information and data system; H is for hybrid
PNVS	= pilot night-vision system
TADS	= target-acquisition and designating system, with optical and FLIR sensors and laser-ranging and -designating capability
TV	= television
VHSIC	= very high-speed integrated circuit

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Introduction

FEASTER and Borgman[1] reported in 1981 that concept formulation had started for a new family of light helicopters designated LHX. This paper reports some of the ongoing work of the concept formulation process.

Considerations of the composition of the current helicopter fleet, the nature of service life extension programs, and the planned procurement of new aircraft indicate that there will be considerable need for new light helicopters by the end of the century. Substantial numbers of affordable aircraft are needed. On the other hand, there are growing needs for improved performance and new capabilities. These seemingly conflicting needs place great demands on the concept formulation process. Approaches that we are using to deal with the performance-versus-affordability problem include the following: 1) Careful use of commonality to get the highest feasible production and logistics bases; 2) Design for large production runs; 3) Application of new technology to aircraft and subsytems in order to obtain better producibility and lower cost while still improving performance; 4) Design for high operational productivity; 5) Design for high survivability; 6) Minimization of aircraft weight and crew.

The concept formulation process has not yet progressed to the point that definitive affordability conclusions can be drawn. Some of the desired performance improvements will require considerable time for development, so that early cost estimates are difficult. However, there are some important synergistic effects in the design that improve the performance-affordability tradeoff. These include:

1) New sensors and increased automation that are needed for operation in more adverse weather also provide higher target-acquisition and attack rates, thus increasing productivity.

2) The new sensors and automation, together with flight control improvements, allow the aircraft to fly faster from the maintenance point to the battle area, which increases productivity.

3) Higher reliability needed to attain longer missions and self-deployment increases available flight time per day, thus further increasing productivity.

4) New sensors and automation which provide the higher target-acquisition and attack rates also provide shorter exposure times, thereby increasing survivability.

5) New sensors and automation needed for the reasons cited may make it possible to operate with a single crewmember, thus decreasing procurement and operational costs.

6) Target-acquisition and communication improvements will increase the effectiveness of external weapons systems, thus providing force multiplication.

As we progress in conceptual formulation, the benefits from design approaches and the synergistic effects are becoming more tangible and the possibility for achieving adequate levels of both performance and affordability becomes more likely.

Functions of the LHX Fleet

The LHX fleet will be called upon to perform a large number of battlefield functions. The fleet will generally fill the roles of armed scout, light attack, and light armed utility aircraft. Table 1 lists the functions that are under consideration and indicates the primary (P), secondary (S), and tertiary (T) importance of the functions to the three roles listed. It must be emphasized that these functions may be grouped into two to four aircraft types, probably with different names from those listed; for instance the armed scout and light attack may be combined into a single air cavalry vehicle.

The first five functions are traditional. Armed reconnaissance is meant to imply more aggressive scouting and operation under higher threat conditions than current practice. The local-area security function implies good target acquisition and weapons suitable for defense against foot patrols and small mechanized units. The antiarmor function emphasizes capability against heavy armor but also includes medium armor. Target acquisition and handoff mean rapid and effective target search, detection, and location followed by rapid transmission of target data to external weapon systems, which may range from nearby attack helicopters to distant artillery. If the external weapon system is to be effective, the target location must be as accurate as possible. Current attack helicopters have considerable ability for air-defense suppression; we intend to improve this ability in the LHX, especially in the armed scout role.

Table 1 Functions of the LHX fleet

	Aircraft role		
LHX battlefield functions	Light attack	Armed scout	Light armed utility
1. Light utility functions	—	—	P
2. Command and control	—	S	P
3. Battlefield observation	S	P	P
4. Forward air control	—	P	P
5. Artillery adjustment	S	P	S
6. Armed reconnaissance	S	P	T
7. Local-area security	S	P	T
8. Antiarmor	P	S	—
9. Target acquisition and handoff	S	P	T
10. Air-defense suppression	S	P	T
11. Air-to-air engagement	S	P	T
12. Second-echelon attack	P	P	S
13. Long-leg tactical operation	P	P	P
14. Self-deployment	P	P	P

None of our current helicopters is designed for significant air-to-air combat, although it would not be surprising to see that capability developed in the future. It is important to provide optimized air-to-air capability in the LHX, especially in the armed scout role.

The next function, second-echelon attack, is not fully defined, nor do we know the scope of activities that will be practical. It may be feasible, if the armed reconnaissance, antiarmor, air-defense suppression, and air-to-air capabilities are high, to conduct rapid strikes on key second-echelon targets, probably in coordination with other weapons systems. The practicality of such tactics would depend on the density of enemy forces and the nature of the terrain. Again, the exact nature of long-leg tactical operation is not fully defined. The thought here is that tactical helicopters deployed to date have rather limited range in a full-up tactical configuration; it would seem sensible to extend the range in order to attain greater versatility. Finally, we are exploring the feasibility of self-deployment over transatlantic distances; this would add further versatility.

Performance Improvements

Candidates for performance improvement include speed, agility, range, endurance, mission reliability, adverse weather operation, target-acquisition and attack rates, productivity, survivability, and crew workload.

The aircraft is in the early stages of concept definition so that the requirements for speed and agility have not been defined. Several investigations are under way which are looking at various aspects to develop criteria for choosing design goals. One example is reported by Falco and Smith[2] in which the role of speed and agility in air-to-air engagements is treated.

The required range and endurance are also still to be determined. In order to proceed with the avionics concept tentative goals were selected for an effective mission mean time between failures (MTBF) of 100 hrs for the tactical configuration and 400 hrs for the ferry configuration. These goals would permit a probability of success of 96 percent for a 4-hr tactical mission and a 98-percent probability of success for an 8-hr ferry mission. These goals are both beyond the present state of the art but appear to be feasible for a new system.

The mission reliability of 100 hrs would permit scheduling of two 10-hr multisortie missions per day in which rearming, refueling, and even recrewing could be done at the edge of the battle zone. We will say more about this later.

It is important to be able to operate the aircraft in terrain flight efficiently and safely at a good crusing speed in heavy fog or rain, and to be able to acquire targets in heavy fog or moderate rain. This will require a navigation and target-acquisition radar. The combination of this radar and emerging technology for automatically analyzing TV and FLIR outputs will permit increases in target-acquisition and attack rates. It may be necessary to add a laser radar (LIDAR) for wire detection.

Since higher speed and higher mission reliability both give more time per day in the battlefield and since higher target-acquisition and attack rates produce more kills per unit time, the productivity should be increased by all of these factors. If survivability can be improved, the overall productivity would be further increased. Productivity goals have not yet been set, but it appears that an order-of-magnitude improvement over current practice may be feasible. With regard to survivability, it may not be practical in a light aircraft to improve the probability of survival, given a hit. It may be possible, however, through improvements in speed and agility, through increases in the target-acquisition and attack rates, and by reduction of physical size, to reduce the probability of incurring hits, thus improving survivability.

Improvements in electronic circuitry make it practical to reduce crew workload through higher levels of automation.

Improvements in sensors will be necessary to effect the desired performance increases. It appears that these various improvements, taken together, will permit the design of a semiautomatic total system which should have the desired characteristics, and should, in principle, be suitable for singleman operation. We do not yet know if practical displays and controls can be developed which will permit the total system to attain its ideal productivity with a single crewmember. The quality of operation of automatic target analysis, computer-generated map, and interactive voice controls, as well as the specific design of the other controls and displays, will be important in determining the ultimate performance.

The Role of Reliability in Aircraft Productivity

As previously mentioned, improvements in reliability are mportant to next-generation aircraft. There are several ·easons for this, including:

1) Desire for self-deployment;
2) Need for longer tactical missions;
3) Greater dependence on equipment when operating at iight and during adverse weather;
4) Desire to improve productivity.

The relationship of reliability to the first three reasons is :vident. In order to explore the relationship with productivity, ve will give consideration to the fourth.

We start by defining the mission failure rate, λ_m, as the)perationally experienced rate of failure, where by failure we nean the development of some equipment condition which legrades operational capability below an acceptable level. It is iecessary, of course, to have monitoring equipment in the ircraft which senses equipment failures. Failures in this ionitoring equipment which degrade its operational apability below acceptable levels are included in λ_m. This ionitoring equipment will not be perfect. There are three ·ossible ways this equipment can fail. First, it can fail assively and not signal a false alarm or a real failure. econd, it can fail actively and give a false alarm. Such alarms ave operational consequences that are similar to true quipment failures, so we define the effective mission failure ite as

$$\lambda_{em} = (l + u)\lambda_m \tag{1}$$

here u is the mission unnecessary alarm ratio (that is, the iission unnecessary alarm rate expressed as a ratio to the iission failure rate). The third type of monitoring equipment nperfection is expressed by the mission missed-alarm ratio, l. Mission-critical failures that are undetected are quite ndesirable, since they result in flight with equipment graded below acceptable level, but with failure unknown to ie crew.

The equipment failures, unnecessary alarms, and missed arms result in three categories of undesirable time. In the rst, indicated failure causes the pilot to turn back to repair ie fault. In the second, an indicated mission failure is of such iture that the pilot elects to continue the flight. The ierational time after the indicated failure will, be definition, : at an unsatisfactory level of capability and therefore idesirable. The third case results when the aircraft continues operation after a mission affecting failure which is un-tected by the fault-monitoring system. It is desirable to sign the system and plan operations so that the sum of these ree undesired times is minimized. Defining a mission as a riod of operation between repair actions, it can be shown at with N planned missions of average duration T per day, th average out-of-service time, τ, per repair, and with an inimum abort strategy, the total undesirable time per day per rcraft is

$$T_u = NT^2\lambda_{em}(5/8 + m/2 + \tau/2T - \tau^2/6YT^2) \tag{2}$$

If we want to obtain maximum satisfactory operational time per day and also want to hold the probability of mission success at some desired level, $P_s(T)$, we will plan to schedule the aircraft for 24-hr usage for operations except for τ hrs maintenance between planned missions. The amount of satisfactory operational time per day would be

$$T_s = NT - T_u = (24 - N\tau) - T_u \tag{3}$$

subject to the condition

$$e^{-\lambda_{em}T} = P_S(T) \tag{4}$$

Time on the battlefield in satisfactory condition, T_{SB}, is

$$T_{SB} = T_s - 2NK \tag{5}$$

where K is the time of flight from the maintenance point to the battlefield. Figure 1 shows the satisfactory battlefield time as a function of the effective mission MTBF of the total aircraft $(1/\lambda_{em})$ based on the assumptions that m and u are 0.15, $P_S(T) = 0.9$, $K = 0.5$ hr and $\tau = 2$ hrs.

Specific design points are shown that permit the average mission duration to range from 2 hrs to 22 hrs. Note that if an effective mission MTBF of 95 hrs could be achieved, the operational time between maintenance could be 10 hrs and the satisfactory time in the battlefield would be 16.3 hrs. Current sophisticated rotary-wing aircraft fall into the general vicinity of the first case in which $T = 2$ hrs and the effective mission MTBF is 19 hrs. Satisfactory time in the battlefield would be 4.7 hrs. Since the productivity can be taken as proportional to the satisfactory time in the battlefield, the improvement from 19 to 95 hrs effective mission MTBF results in a productivity improvement of $16.3/4.7 = 3.5$.

Of course, it is not necessary to schedule aircraft usage in the manner just modeled. An additional benefit of the larger effective mission MTBF is the versatility to operate for any period between maintenance actions up to 10 hrs with a good probability of mission success.

Avionics Design Requirements

The LHX aircraft is required to perform present missions better and to perform new missions. The most demanding requirements are the following:

1) Capable of adverse-weather operation; must be able to fight in fog and in rain, day or night.

2) Target handoffs are to accomplished with the navigation system; a target at standoff range is to be in the narrow field of view of the optical target-acquisiton device when its position is given by a second LHX.

3) Secure voice and data communications are required.

This means that LHX must be more capable and sophisticated than present designs. Added sensors and automatic target recognizers must be developed to give this large increase in capability. Communications equipement is

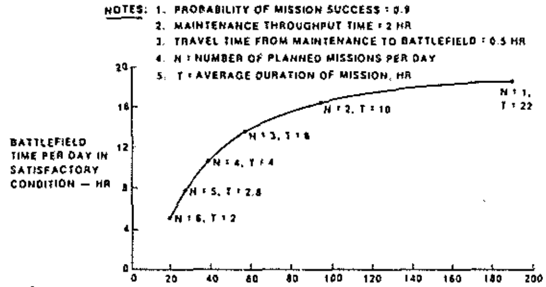

Fig. 1 Effect of mission reliability on possible utilization.

being developed to provide secure, covert voice and data transmissions to nearly every one in the field. In the cockpit, voice-actuated system controls and an automatic digital map system are needed to reduce complexity and pilot workload. A highly accurate navigation system is needed to reduce target handoff difficulties and target reacquisition time. Major efforts are needed to ensure that all this equipment is designed to be reliable.

Design Approach and Philosophy

The stringent demands of the LHX missions make it obvious that the conventional approach to new helicopter system design was not good enough. A design was required that emphasized reliability from the start. The avionics represent a large fraction of the aircraft cost, so the use of conventional redundancy must be limited. The more innovative approaches, including self-healing concepts, functional redundancy, and reconfigurable architecture, were explored and used where applicable. Analysis of the resulting design shows that is exceeds the reliability design goals.

Self-Healing

In our definition of the self-healing concept, as shown in Fig. 2, there are a number of systems, any one of which can perform the desired function. Each system includes built-in test equipment (B.I.T.E.) and associated logic to disable the system if it fails to satisfy the B.I.T.E. test. A control function is provided that lets System A perform unless it is disabled, and, in this case, it enables a second system to perform. This part of the concept applies for self-healing at the component or at the subcomponent (chip) level.

For self-healing at the component, or black box, level it is advantageous for the pilot to be able to switch back and forth and judge between the performance of the systems. This allows the pilot to isolate failures that may be undetectable by the B.I.T.E. Detected failure warnings are only displayed to the pilot if both systems fail. All failures are shown on the maintenance display for repair at the next scheduled maintenance action.

The self-healing concept is in use today. An example is the thrust-management system that is in the Boeing 757 and 767 aircraft. This thrust-management system has two processors acting as System A and System B (Fig. 2). This configuration may not be required in the future, since it is anticipated that processors will be self-healing at the subcomponent level, resulting in a component MTBF of 50,000 hrs.

Functional Redundancy

In certain conditions, some subsystems duplicate some of the functions of other subsystems. This functional redundancy can be used to increase mission reliability. An example of this is the use of the target-acquisition devices to update the navigation system if the GPS fails. This could not be done routinely since it will increase pilot workload, but it is a workaround that can provide adequate navigational accuracy.

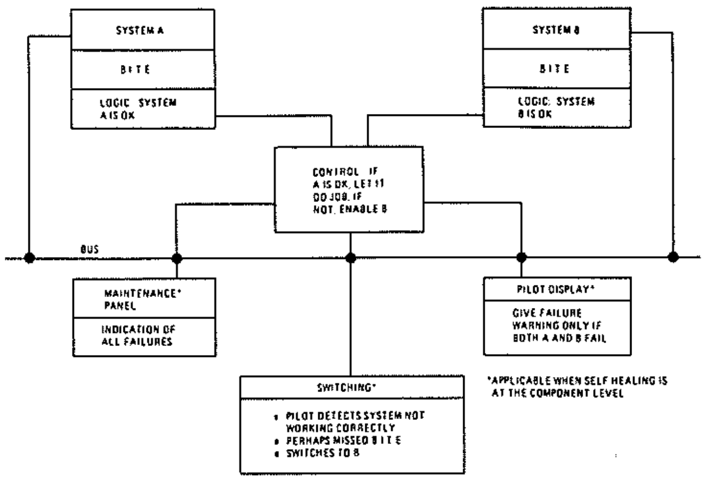

Fig. 2 Schematic of self-healing concept

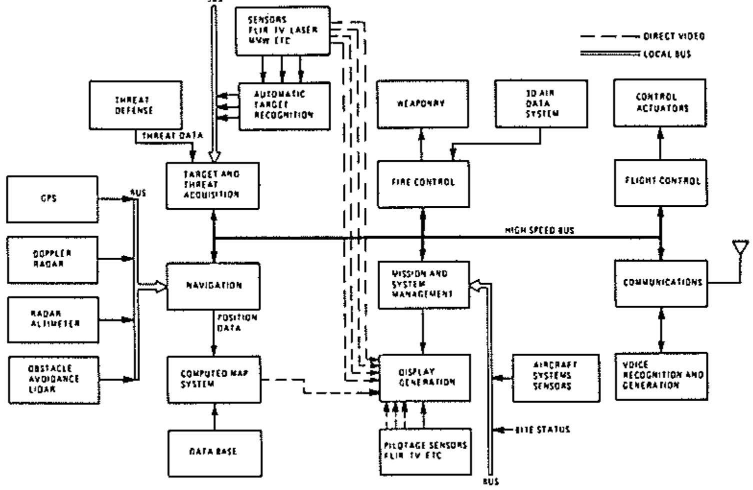

Fig. 3 Schematic of avionics suite.

Most of the functional redundancies are in the target-acquisition and navigation systems.

Reconfigurable Architecture Features

Our definition of a reconfigurable architecture feature is the use in a degraded mode of the remaining working components to substitute for a failed component. For example, the doppler navigator could measure radar altitude, at least in a degraded mode. The obstacle-avoidance LIDAR could also be used to measure radar altitude. It is these kinds of reconfigurations of components and their uses that we have defined as reconfigurable architecture features. If a primary sensor fails, the reconfigurable component is commanded to go into a degraded mode to prevent an unacceptable solution.

When this study started, we believed that the likely application of this concept would be to use processors that could be reprogrammed so they could fill in for a higher priority processor that had failed. That concept probably is viable, but with the coming very-high-speed integrated-circuit (VHSIC) self-healing processors it is unnecessary.

System Design

The suggested LHX system design incorporates self-healing components, some reconfigurable architectural features, and numerous functional redundancies in a structure of individual units working together. The functional diagram, Fig. 3, shows the interactions of the major functions. Some systems include a local data bus where there are numerous sensors to control. Television-like imagery is transmitted directly to the display-generation subsystem.

As presently envisioned, the design consists of six basic functional units, each with a dedicated processor. A high-speed data bus interconnects these processors so that all basic data can reside in a central memeory. This central-memory function ensures that at the start of each computing cycle, all calculations proceed from the same basic inputs.

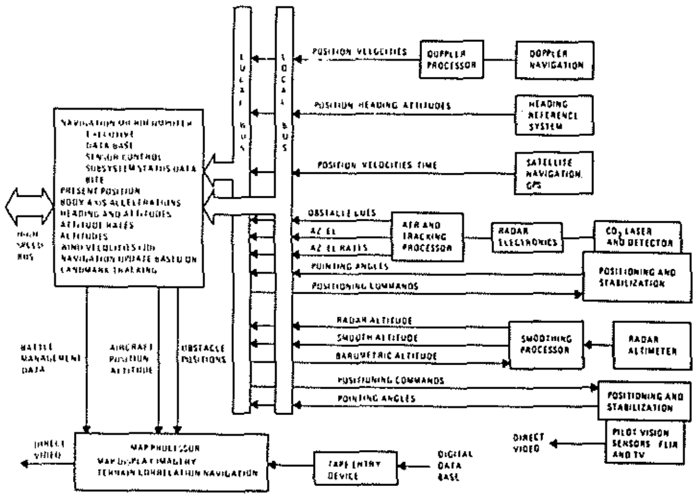

Fig. 4 Schematic of navigation subsystem.

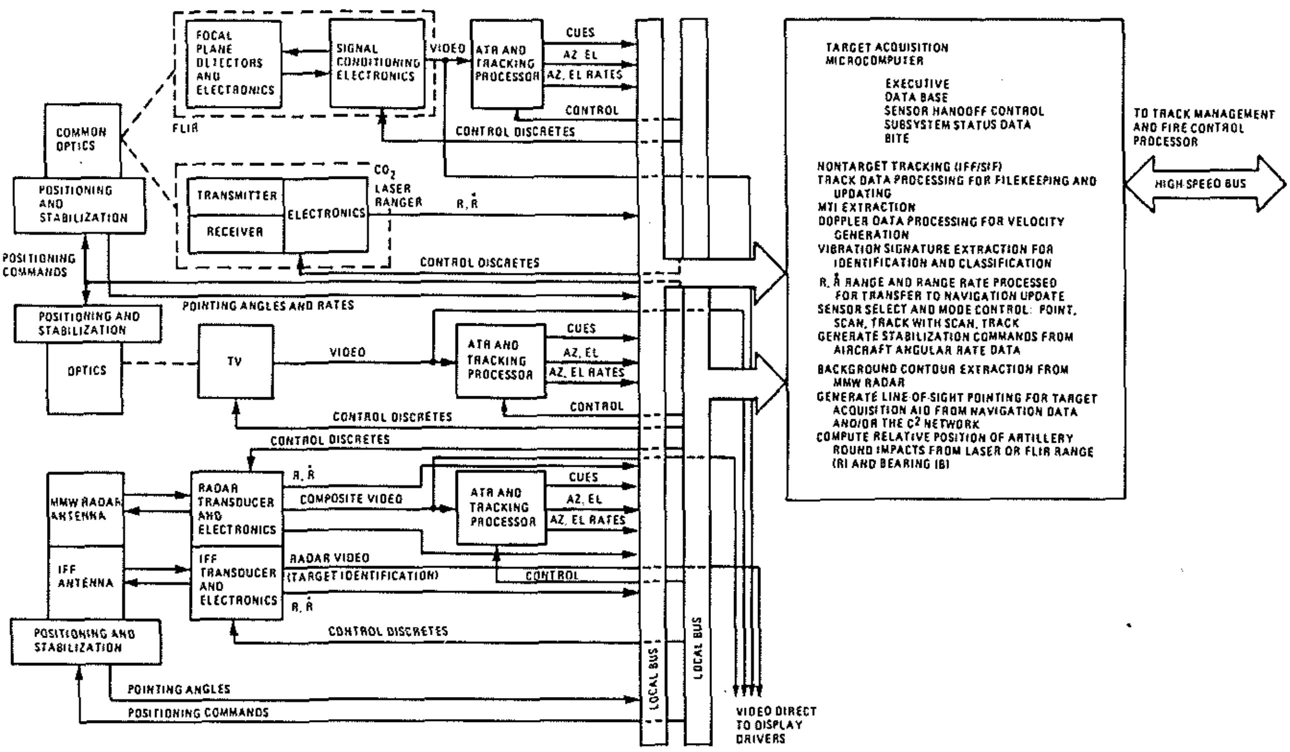

Fig. 5 Schematic of target-acquisition subsystem.

The selection of the self-healing components, reconfigurable features, and functional redundancies has resulted in a design that reduces the mission abort rate by a factor of more than 30 compared to a similar system designed with today's technology and approaches. These features can almost eliminate the need for avionics maintenance during critical periods of combat, which will greatly improve the operational effectiveness of the LHX above that of present helicopters.

Navigation

The navigation subsystem is designed to provide highly accurate aircraft position for target handoff. This system also provides aircraft attitude and velocity, obstacle-avoidance radar data, pilot night-vision data, and imagery for the map display. The functional interactions of this subsystem are illustrated in Fig. 4. Functional redundancy is provided in sensing position from the doppler navigator, the intertial attitude and heading reference system, and the Global Positioning System (GPS). Kalman filtering of the resulting data will provide highly accurate position data for rapid target location and handoff. The heading reference system is the only source of aircraft attitude data, so it should consist of multiple redundant sensors in a self-healing configuration.

The obstacle-avoidance LIDAR scans the flight path of the aircraft. Target-recognizing algorithms of the LIDAR would process the radar returns to find obstacles. Range, bearing, and obstacle classification data would be sent to the display subsystem for presentation to the pilot with the aid of computer-generated images of the obstacles. In a backup mode, this radar could also be reconfigured to scan downward to determine radar altitude if the radar altimeter fails.

Target Acquisition

The target-acquisition subsystem provides millimeter-wave radar in functional redundancy with optical and infrared systems. As illustrated in Fig. 5, each of these sensors is expected to have a target recognizer and tracking processor. The target-acquisition computer will control the sensors and compare the sensor outputs. The sensor output imagery will be sent to the display-generation subsystem by direct video links.

There is also the desire to expand the night and adverse-weather flight capability by time-sharing the target-acquisition millimeter-wave radar. Initial work suggests it may be possible to use such a radar to generate terrain elevation profiles at various ranges as well as obstacle classification, range, elevation, and bearing. These data could be combined with computer-generated imagery so as to have the terrain information needed for nap-of-the-earth (NOE) flight. The tactical effectiveness of the aircraft would be greatly improved by this capability; this concept will be explored further.

Communications

The suggested LHX design provides highly automated communications with radios that can provide reliable covert operations in the NOE environment. Voice-recognition devices and automation are provided to help the pilot cope with the expansion of the available modes of communication. The voice-recognition system is also expected to perform many of the switching functions in the cockpit. Conventional redundancy is included in the voice-recognition system to ensure that these switching functions be performed. Voice actuation of switching functions can significantly improve reliability and reduce aircraft acquisition costs by reducing cockpit complexity. Crew workload is also reduced.

The other aspect of the communications automation is the use of preselected bands, channels, and frequencies that are called with pilot voice recognition. Radio monitoring would be automated. The monitoring system could give the pilot all messages directed to him in a prioritized order.

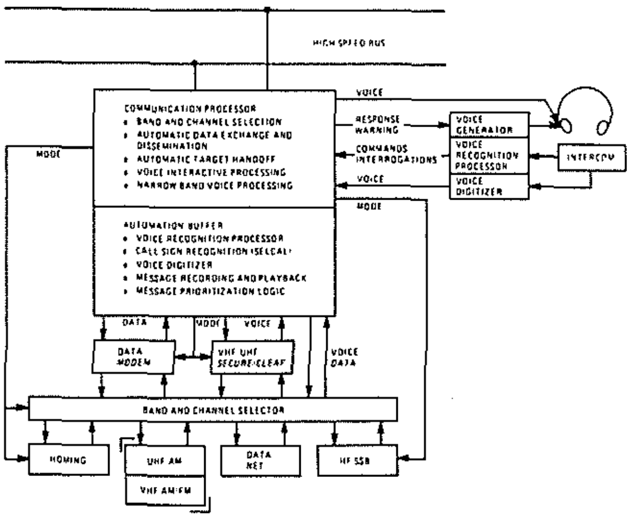

Fig. 6 Schematic of communcations subsystem.

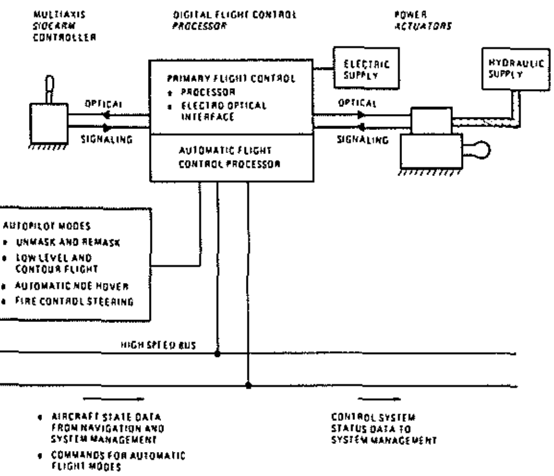

Fig. 7 Schematic of flight control subsystem.

Communication reliability is a key issue since it has a major influence on mission effectiveness. As shown in the schematic, Fig. 6, redundant radios for voice communications as well as various digital data links are provided.

Flight Controls

The flight control subsystem under consideration for LHX is the Army's advanced digital-optical control system (ADOCS) augmented with some automatic flight modes. Figure 7 is a second-level schematic of the subsystem. This system provides triplexed pairs of the primary flight control path functions to ensure that a high level of flight safety is achieved. Fiber-optic signaling eliminates possible electrical interferences and increases the available bandwidth. The bandwidth available at optical frequencies greatly eases the scheduling of data on a multiplex bus. There is no firm requirement for this capability at this time, but it may be of value for systems that require rapidly changing data.

Mission and System Management

A second-level schematic of the mission and system management system is shown in Fig. 8. The mission management processor will assist the pilot in mission planning and data exchanges. In the scout-attack configuration provisions for attack plannning, particularly for the attack team leader role, are included. Data management includes target handoff from the LHX to other combined arms units

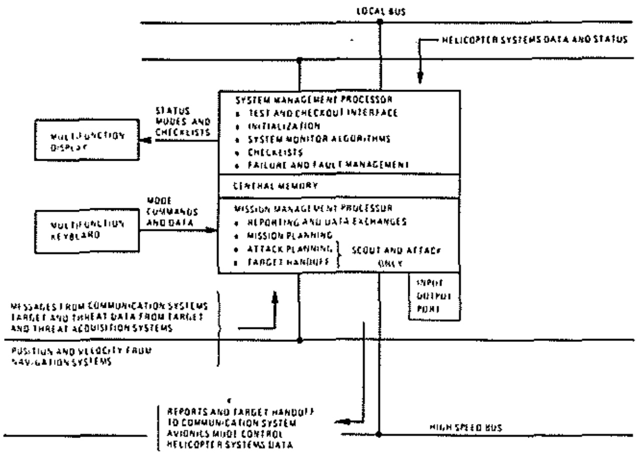

Fig. 8 Schematic of mission and system management.

Table 2 Reliability summary for self-healing architecture

System	Failures per million hours: Maintenance	Failures per million hours: Mission
Mission and system management	798	86
Communications	5,286	20
Flight controls (including hydraulics and actuators)	756	356
Navigation	8,437	80
Fire control	428	28
Threat defense	4,317	8
Target acquisition	11,187	20
Total	31,309	587

Table 3 Contributions of remaining mission-critical components

Status	Component	Mission failure rate per million hours: Each	Total	Percent of total
Reliable components	Processors (6)	20	120	20
	Display drivers (2)	20	40	7
	Switches (2)	8	16	3
	Miscellaneous	—	1	—
Relatively unreliable components	Flight control	—	—	59
	Actuators	—	246	—
	Hydraulics	—	68	—
	System monitor	—	30	—
	Disk/tape entry	—	66	11
Total			587	

and to the LHX from high-level battlefield surveillance systems. Data-processing aids are provided so that these data are not overwhelming to the pilot. These data can include targets that are threatening and nonthreats, ground and air, moving and stationary, quiet and emitting, live and dead, as well as the usual target classifications and quantities.

The system management processor provides the pilot with system status on a by-exception-only basis. The pilot can access all of the system status data through this processor, but routine status information given will be minimal.

Mission Reliability Predicted for LHX Design

Reliability of the latest design iteration is summarized in Table 2. The failure rate of 587 failures per million hrs is equivalent to a mission mean time between failures of 1,703 hrs. The equivalent value for systems with today's technology is about 50 hrs.

Key features that provide this high reliability are the millimeter-wave radar that is functionally redundant to the visual and infrared target-acquisition devices and the use of VHSIC technology in all processing devices. VHSIC technology provides the small, low-cost subcomponents that allow use of the self-healing concepts at the chip level. Table 3 shows the components that contribute to the failure rate of the latest design. The VHSIC processors and display drivers contribute 27 percent, so the design is somewhat sensitive to the ability of this technology to meet its goals. Our caclulations are based on a failure rate for these components that is 3 times the design goal for VHSIC processors to accommodate the Army aircraft field environment.

There is a significant reliability benefit from the use of voice controls. We believe that the system can be designed with few switches: perhaps only an enable switch for weapons firing and a switch for counter-measures. We estimate that with conventional technology, the LHX would require about 200 switches and knobs; the UH-60 has 174 such controls. As shown in Table 3, each switch has a failure rate of 8 per million hours, so 200 switches would triple our total failure rate. The two switches contribute only 3 percent of our total failures.

Note in Table 3 that 59 percent of the mission failure rate is contributed by the flight control system; this is mostly due to the flight control actuators and hydraulics. These mechanical components need to be redesigned for improved mission reliability.

The disk/tape entry device contributes the remaining 11 percent of the design failure rate. This is a rather complex mechanical device that probably cannot be developed to have fewer than the 66 failures per million hours shown in Table 3. This relatively low failure rate does not seem to justify

Table 4 Summary of approaches used to get mission reliability

Approach	Navigation	Threat definition	Target acquisition	Fire control	Flight control	Communication	Mission and System management
Conventional redundancy	Clocks				Triplex systems	Voice controls	Avionics bus
Functional redundancy	Landmark processing for GPS	TADS for threat detectors	MMW radar for TADS			HF for PJH	MFK for voice Display substitutions
	Display substitutions	PJH and TADS for IFF	Voice controls for tracking handle				
Reconfigurable components	Lidar for radar altimeter TADS for PNVS						
Self-healing	Attitude heading reference processors (2)		Processor	Processor	System monitor processor	Processor	Processor

providing conventional redundancy, but if the cost of this device is low enough, it should be considered.

As shown in Table 4, most of the improvement in reliability has been achieved by functional redundancy, reconfigurable components, and self-healing. These cause the least increase in cost and weight. We have only included five conventional redundancies: the triple systems needed for safety of flight of the flight controls; the critical voice controls; the multifunction radios; the clocks; and the avionics busses. Current multifunction radio technology indicates that the cost and weight of a dual system is a good trade. Electronic clocks are low in cost and weight are a good trade with the projected failure rate. Electronic clocks are low in cost and weight and if they are not redundant there would be an increase in the total failure rate of about 30 percent, so this redundancy is also a good trade.

One-Man Operation

The LHX avionics design provides the automation needed so that a single man can efficiently perform the design missions. Design of the system has been based on a workload analysis. The validity of this analysis has been investigated in a piloted flight and target-acquisition simulation. This work has shown that for one-man operation automation is required in automatic target recognition, automatic communication, digital map generation, and in intelligent mission data and systems monitoring. The pilot's efficiency will be increased by the provision of advanced flight controls and a large-field-of-view integrated display.

While the design for a single pilot is desired for affordability, it appears that the developing technology can provide improved effectiveness with the high level of automation that makes one-man operation possible. The automatic systems must be developed to increase the effectiveness of LHX regardless of the number of crewmen.

Affordabilty

Design of the LHX avionics has been a system-engineering approach to determine what features provide the required performance with the best possible reliability that can be achieved with small increases in cost. This system design is based on technology that could be produced in the 1990's. The resulting design concept provides the following cost-reduction features:

1) Simplification to eliminate from the cockpit almost all of the expensive-to-install switches, knobs, and associated wiring;

2) A properly partitioned architecture to divide the software into less expensive, more understandable, and more easily validated and maintained packages;

3) Division of the systems also provides a secondary effect of allowing use of industry-specific know-how on specific equipment.

LHX will have a low cost due to its large production base. Furthermore, some part of the LHX avionics package can be applicable to other Army aircraft and it can be retrofitted into the existing fleet. This applicabilty ensures a large production potential and should result in affordable unit costs and enough development funds to assure that highly reliable units are produced. It is estimated that the resulting volume will reduce unit costs to 30 percent of the cost of systems procured in quantities typical of other helicopters.

Conclusions

1) A highly capable avionics system for the LHX has been designed to have a mission reliability of 1,700 hours MTBF, well in excess of the design goal of 300 hours. Functional redundancy, self-healing components, and reconfigurable architecture can provide this reliability without a significant increase in cost or weight.

2) Achievement of the reliability found to be possible in this study can provide a large increase in the effectiveness of the LHX. A threefold increase in flight utilization is possible with today's maintenance resources.

3) Developments needed to attain this reliability include very-high-speed integrated-circuit (VHSIC) technology and various component developments. Components needed for mission reliability include voice-actuated controls, millimeter-wave radar, a self-healing heading-attitude reference, and a reconfigurable obstacle-avoidance LIDAR.

4) The sensors needed for better performance, when combined with control and display innovations, provide the potential for single crew operation. Component developments needed for one-man operation also include automatic target recognition, automatic communication, digital map generation, and an intelligent systems monitor.

5) Improvements in speed, functional performance, and reliability can provide an order-of-magnitude increase in productivity compared with the current fleets.

6) When combined with production economics the increase in productivity of LHX should provide a practical level of affordability.

References

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