Operational Concept of the Integrated Helicopter Avionics System

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This paper briefly describes an effectiveness model derived to compare the value of various alternative avionics subsystem configurations in terms of performance and cost. The sensitivity of an operational model of a Marine expeditionary force to the parameters of avionics system effectiveness provide a measure of the avionics impact on the total force levels. The integrated helicopter avionics system (IHAS) provides independent all-weather point-to-point navigation, terrain avoidance, and station-keeping for assault helicopters/VTOL during amphibious operations and subsequent combat operations ashore. This mission is accomplished with an integrated avionics system employing advanced sensors, a digital computer central complex, and microelectronic integrated circuits. Highlights of the program include the concept of system integration, functional modularity in design with microelectronic integrated circuits, and built-in test equipment. The approach described in this paper is based on a normalized task analysis that should be general enough to have wide application.

THIS paper briefly describes a model for determining the effectiveness of an assault helicopter in the accomplishment of a particular mission, that of delivering cargo from an assault carrier to a landing zone. This description will be limited to evaluation of the avionics system, although the model is general enough to be applicable to the airframe and powerplants as well as to a variety of other missions. Of course, determination of system effectiveness is only one part of the yardstick one must use to compare alternate methods of accomplishing a mission. The other part is the resources available. This forces an additional comparison of the costs of alternate methods in terms of system cost of ownership and the number of systems required for the mission. The two principal factors that must be interplayed in selecting a system are configuration and cost. The system effectiveness of each configuration in terms of military capability is compared with cost of ownership to establish the best value of productivity vs cost of ownership. Figure 1 is a schematic illustration of the application of this concept in our IHAS analysis. The system effectiveness model was used to relate the measures of effectiveness (outputs) shown to various combinations of system characteristics, environment, and mission (inputs). Similarly, the cost model provides a relationship of total cost to the subsystem inputs, as shown. Outputs from these models were then parametrically combined to give values of cost effectiveness for the subsystem or system considered.

A specific example may best present the concept of this procedure. Let us examine a typical IHAS mission, the system capabilities, and the method of analysis used to determine system effectiveness of a particular IHAS system. The choice of the mission to be analyzed is constrained by several factors. It must be a typical military mission for the system being considered, the locale of the mission must be a likely one, and it must be the most stringent mission and environment that the system needs to satisfy. This will determine if differences in the performance of various system configurations are significant. In this case, the military objective was to establish a beachhead in Southeast Asia with an amphibious assault force and to consolidate the beachhead for future military operations. The mission assigned to the assault helicopters was to deliver four battalion landing teams to a specified landing zone at a specified time during the initial assault. The assumptions used in the systems effectiveness simulation model are shown in Table 1.

The general procedure for an amphibious assault using helicopters is shown in Fig. 2. Prior to the start of the assault, the helicopters are checked and spotted on the flight deck. They are loaded, given a final check, and then ordered to take off. The helicopters are vectored to the flight rendezvous point and to the wave rendezvous point, where the designated formations are made up. The wave then proceeds to the departure point, to the check points, and to the initial point. At this time, the wave breaks up into the landing formation, and each division proceeds to the landing zone and then to the landing site. The helicopters then land, discharge their troops or cargo, and take off to return to the LPH's. The same kind of forming and breakup of formations occurs as on entering. All during the flight, the helicopters are under the control of the Tactical Air Control Center (TACC) through a designated Helicopter Direction Center (HDC). The HDC function is executed by the Direct Air Support Center (DASC) when that facility is established ashore. In the vicinity of individual LPH's, control is delegated to local HDC's and in the vicinity of the LZ control, is shifted to a landing zone control party. The flight wave

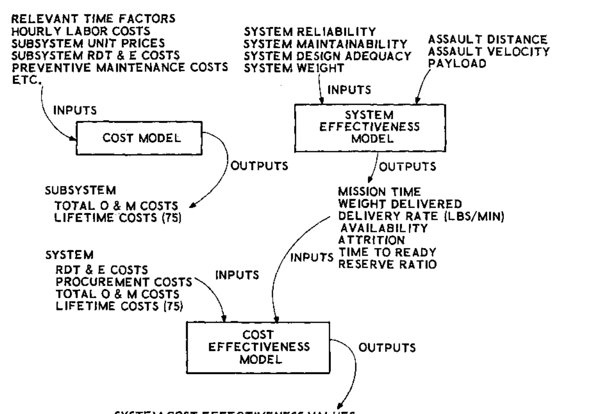

Fig. 1 Schematic of data flow for a cost effectiveness analysis.

Presented as Preprint 64-785 at the AIAA Military Aircraft Systems and Technology Meeting, Washington, D. C., September 21–23, 1964; revision received April 2, 1965. This work was supported by the Bureau of Naval Weapons under the Project Definition Phase of the IHAS Program, Contract NOw63-046. The contributions of C. R. Johnson, J. D. Lawson, and our many conferees are gratefully acknowledged, as well as the able assistance from the Stanford Research Institute.

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leader has the responsibility of reporting to the control agency at rendezvous, departure, and initial points.

The avionics system that was used in the analysis can be broken down into several major subsystems,[2,3] which are described below:

1) Navigation subsystem: The function of the navigation subsystem is to permit the helicopter pilot to proceed accurately along his assigned approach or departure route in all weather conditions without the need for distracting manual or mental calculations. This subsystem operates in three modes. The primary mode is a doppler type, the second mode is an air mass/dead reckoning type, and the third mode uses a TACAN station to correct present position continuously. Position updating by visual means, radio, or TACAN is possible.

2) Station-keeping subsystem: The function of the station-keeping subsystem is to allow the helicopter pilot, under restricted visibility conditions, to maintain his correct station relative to other helicopters in the formation. The importance of the station-keeping function is threefold. Knowledge of the position of nearby helicopters increases safety of flight, station-keeping improves control of the relative landing times of helicopters, and station-keeping allows all helicopters to update their present position when any one obtains a navigation fix.

3) Terrain-following subsystem; The primary function of the terrain-following subsystem is to enable the helicopter to fly low and take advantage of natural terrain cover. This hides the location of the actual landing site and reduces the vulnerability of the helicopter to enemy fire. In addition, a terrain following radar makes possible automatic or manual terrain following under any visibility condition. The radar also has a ground-mapping capability that can be used as an aid to navigation.

Also integrated into the system are a computer central complex, automatic flight controls, an advanced cockpit display, and the normal communications and instrumentation subsystems.

The military task of the CH-53A was defined as the delivery of cargo or Marine personnel to the assault zone, and it must be at a rate commensurate with the axiom that to win you must get there "fustest with the mostest." Thus, military effectiveness for this aircraft is measured as a delivery capability in terms of pounds to be delivered to the assault zone

Table 1 Assumptions used in the systems effectiveness analysis environment

Low, ragged ceiling: transit primarily in 0 ceiling, 0 visibility; landing zone 200-ft ceiling, 0.25-naut-mile visibility
Flight path within range of one 57-mm gun site
Assault distance: 50 naut miles
Overwater distance: 40 naut miles
Mission requires two sorties
Mission altitude: minimum safe altitude to avoid enemy fire
Helicopter characteristics: CH-53A
Velocity: 150 knots
Payload of 8000 lb with present avionics weight
Load and unload times: 5 min
Operating from LPD's: 35 loads required
Maintenance and reliability
Premission avionics checks begin 10–12 hr before assault
Any failure of any subsystem means abort
Repairs that require more than two sorties are deferred until mission is complete
A constant failure rate is assumed for the system
Circular normal distributed repair times
Design adequacy
Navigation accuracy, station-keeping accuracy, and minimum safe flight altitude are primary system design measures
Helicopter assault simulation
Initial assault forces: 5500 men and 425 tons cargo
Ninety min allowed for assault from 50 naut miles
CH-53A allotted 10% of initial assault forces

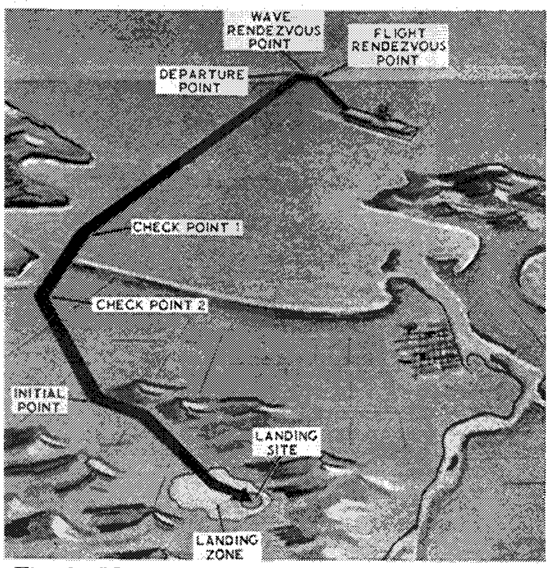

Fig. 2 Mission profile for amphibious assault.

in a specified time. Therefore, for the single aircraft, delivery rate in pounds per minute averaged over the duration of the required mission is the resultant measure of system effectiveness.

Once the measure of system effectiveness has been defined, one can begin the analysis. The sequence of operations for each helicopter to execute a sortie is divided into logical phases as follows: make-ready phase, takeoff and rendezvous phase, navigation phase, IP identification phase, terminal landing phase, and return to base phase.

The division of the IHAS mission into logical phases represents a step that should be taken for every systems effectiveness model. The phases should be selected in such a way that the requirements on the avionics system are constant throughout each phase. Each mission phase can then be analyzed separately. One output of this phase analysis should be a delineation of the states that describe the major results at the end of the phase. It may be noted, however, that the helicopter is likely to be called upon to fly different types of missions in different situations. One of these may pose the most stringent navigation requirements, another the most stringent requirements for terrain-following, etc. Our design must meet all of these requirements, as well as the somewhat arbitrary (typical) mission described herein. The mission in its totality must also be considered. The demands on a navigation subsystem may be different during the make-ready phase if initial alignment is requited than they will be during the navigation phase. However, neither phase may be neglected in evaluating the over-all worth of the subsystem.

Another necessary part of the mission analysis is a description of the sortie on a time line that records the occurrence of events and variable environment factors such as visibility, terrain, and formation status. The sortie description of Fig. 3 was used for the IHAS mission.

This time-line analysis can be related to the mission phases, and the interaction between the system and the environment can be determined for each phase. To describe this interaction, one defines what constitutes successful completion of the phase and devises a method that computes the probability that the system meets this requirement. To illustrate this point, consider the probability that the IHAS helicopter will not be lost to enemy action in the navigation from the first checkpoint to the IP. This probability is dependent upon the average minimum altitude of helicopter flight, the armament of the enemy, and the weather conditions. A study of these parameters will generate a relationship between the average minimum flight altitude and the probability that the helicopter is killed by enemy action.

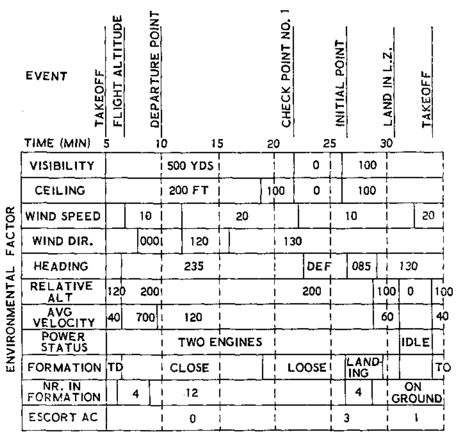

Fig. 3 Typical 1-hr sortie.

There are certain conditions in which the interaction can be best expressed in terms of a physical measurement that is of particular interest rather than in terms of a probability. In the IHAS mission, the element of time is of such great importance that the interaction between navigation accuracy and the mission was measured as the maximum increment of time to complete a sortie which would result from imperfect navigation.

Analysis of the mission in this manner leads one to recognize the system parameters that are of prime importance to the success of the mission. The measure of system effectiveness must be in terms of end use. It is best described in terms of an ability to accomplish a task and is generally defined as the probability that a system can successfully meet an operational demand within a given time and when operated under specified conditions.

Figure 4 is a diagram developed by the ARINC Research Corporation.[1] It shows the three components that combine to give system effectiveness: mission reliability, operational readiness, and design adequacy.

Mission reliability may be defined as the probability that, under stated conditions, the system will operate in the mode for which it was designed (i.e., with no malfunctions) for the duration of a mission, given that it was operating in this mode at the beginning of the mission.

Operational readiness is the probability that, at any point in time, the system is either operating satisfactorily or ready to be placed in operation on demand when used under stated conditions. This must include a stated allowable warning time. Thus, calendar time is the basis for computation of operational readiness. (This is not the traditional Navy meaning of operational readiness. However, it has been generally accepted for use in this context by those working in the analysis field for the Navy.)

Design adequacy is the probability that the system will successfully accomplish its mission, given that the system is operating within design specifications.

This division of system effectiveness into measurable parts is useful, but it does not show how to incorporate cost or force structure. In Fig. 5, mission definition provides a standard for system effectiveness and leads to a sortie functional analysis. This analysis details the tasks that must be accomplished and leads to the system specification. That the state of the art influences the specification is also shown. The sortie analysis is an input for specifying the standard of performance desired in the computation of design adequacy. Similarly, mission definition provides standards for mission reliability and operational readiness through the utilization required for satisfactory operations.

Cost per system is influenced by configuration and the state of the art. The system effectiveness output, productivity, is compared with the cost output investment to provide the desired measure, cost effectiveness.

In Fig. 6, the diagram is expanded further to show that system effectiveness matched against the operational requirement leads to a force structure. Then, the force structure can be matched against the requirement to establish the measure of operational effectiveness. The force structure and the cost per system provide inputs that determine cost per force. This, combined with operational effectiveness, gives another measure of value, the cost effectiveness to the force as a whole. Further expansion of the diagram can show the details of determining systems cost and can take into account the effect of enemy action but would lead to a diagram too complicated for presentation here. The effect of enemy action can be taken into account as another factor, attrition, which influences force structure, whereas costs can be broken into standard categories such as those shown in Fig. 7.

It is important to note that the cost-effectiveness ratio gives productivity in terms of military value (i.e., ability to produce in a shooting war). Cost, however, is peacetime cost (i.e., the cost to procure and support the capability over a projected peaceful lifetime). Properly done, programs using this criterion seem to be the best way to prosecute the cold war, in that resources applied in this manner tend to give a best capability over the long haul.

With these insights, it is now possible to proceed to the task of specifying pertinent measures of cost effectiveness for the various levels that could be controlled by an industrial organization. In planning operations, the major problem is to compare competitive weapons systems that may be significantly different in character (e.g., bombers and missiles for delivery of warheads). Such comparison can be done only by specifying a desired end result and working backward to determine what each weapon system would require to perform this task. In this approach, a specific military task is chosen for accomplishment. Then, the cost of the force needed to accomplish this is calculated for each configuration proposed. These task normalized costs are costs to do a particular task. Obviously, the least expensive is the best choice by the cost effectiveness criterion.

Figure 8 shows this in concept. Starting at the desired operational effectiveness, one first works back through an error analysis to establish the number of shots needed to obtain the number of hits required. For IHAS, this would be

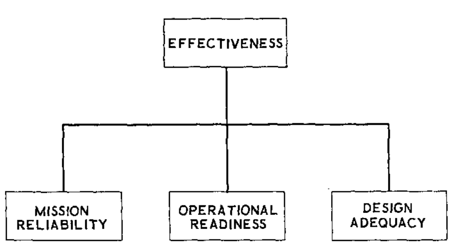

Fig. 4 Main variables associated with system effectiveness.

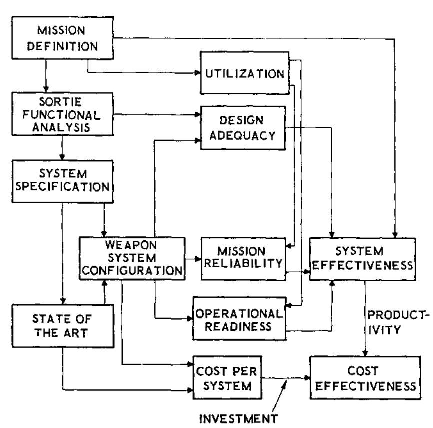

Fig. 5 Avionics cost effectiveness.

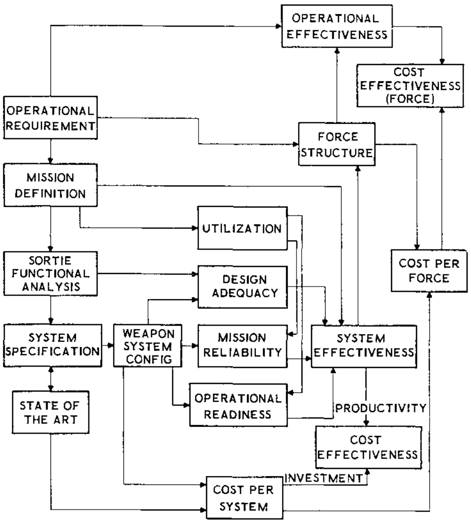

Fig. 6 Cost effectiveness at force level.

landings completed vs landings attempted. This number is then raised by an attrition analysis that determines the number of starts required for the number of shots or number of landings. This number, in turn, is magnified by additional inefficiencies associated with the number that must be deployed to get the desired number of starts. Some will be in the wrong place; others will be tied up in training, and so forth. Additional inefficiencies will be added by the inefficiencies of the procurement cycle, leading to a yet larger force. Poorly located bases, bad design or technical limitations, etc., can take away from the effectiveness of the total force. When the entire force is then determined, the cost of each of the elements is figured, and the summation is called the task normalized cost. This normalization can be carried out at any level within a projected operational force.

Let us now return to our typical amphibious assault mission. Analysis of the mission in the manner previously described leads one to recognize the system parameters that are of prime importance to the success of the mission. The major influences on system effectiveness will be 1) design adequacy as represented by ability to navigate accurately, ability to avoid losses due to enemy action, and command and control quality as represented by the communications and data processing subsystems; 2) mission reliability as reflected by minimized aborts due to equipment or human failure; 3) operational readiness as influenced by minimum loss of sorties due to reliability and maintainability factors; and 4) load-tarrying capability as influenced by the weight of the syscem configuration.

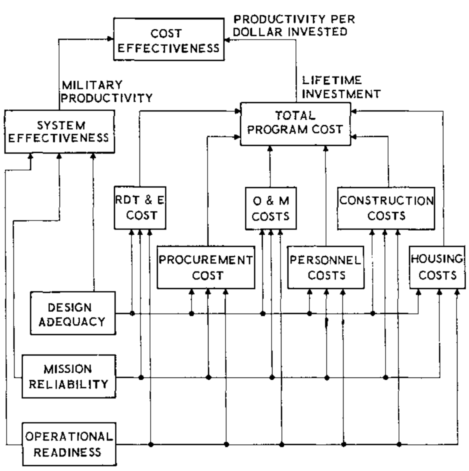

Fig. 7 Avionics system cost-effectiveness model.

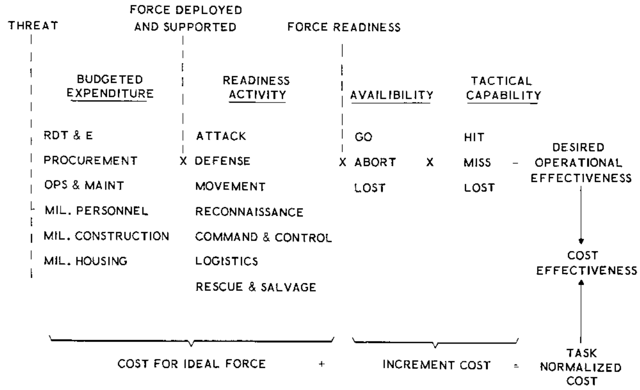

Fig. 8 Force structure projection.

The method of accounting for these factors is the mission phase analysis. When each phase has been analyzed, the resulting probability distributions can be combined and inserted in a simplified mission model such as that shown in Fig. 9. Also, the delta times caused by navigation errors, judgment errors, enemy action, etc., can be combined and placed in the model. The model is then used to calculate cargo delivery rates for the various system configurations. Next, the force structure is determined and the cost of ownership calculated. Finally, the task normalized costs of the configurations are compared to determine which is best.

We have discussed the information required about the environment from the viewpoint of its end use, but at no point has there been a statement that says that an environmental model is composed of item 1, item 2, etc. Delineations of what is and what is not a part of an environmental model are fraught with the dangers of incompleteness, oversimplification, and misunderstanding. Nonetheless, it is suggested here that an environmental model is composed of the sources of information discussed, the information derived therefrom, and the relationship between the information and its end use in reliability, maintainability, and design adequacy analysis.

Table 2 summarizes the environmental model. The sources of information are to the left of the table, the ultimate use of the information is at the top of the table, and the information itself is the entry in the table. For instance, a list of the environmental factors that influence reliability is contained in the column in Table 2 under the heading of "Reliability." The information that describes the mission will be found in the row of Table 2 which is labeled "Mission definition." Obviously, Table 2 is not all-inclusive, but it does show the type, level of detail, and relationship of the data involved in an environmental model. It also suggests a means of relating the system effectiveness to our initial assumptions. In this manner, we may achieve an analysis of the sensitivity of the results to environment, airframe characteristics, system design, maintenance, and reliability, as well as mission objectives.

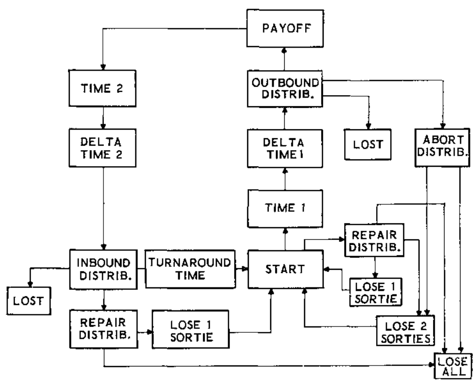

Fig. 9 Simplified mission model.

Table 2 Summary of environmental model

			Design adequacy (pure performance)			
	Reliability	Maintainability	Navigation function	Attrition reduction function	Communications function	Stability and control function
Scenario Time period Geography Forces Objective of force Orders of battle	Nuclear radiation? Dust and sand Salt atmosphere Fungus	Facilities available Repair shops Spare parts storage Other system demands on facilities Resupply Base of operation Repair space limitations	Initial position accuracy Initial heading accuracy	Enemy defense (number, location and effectiveness) Small arms Anti-aircraft artillery (optical and radar controlled) Surface-to-air missiles Interceptors Electronic countermeasures Day or night operation	Interfaces with existing tactical data systems Frequency allocations Electronic countermeasures by enemy Interference possibilities	
Mission definition Specific objective Scheme of maneuver Description of sortie	Time of operation Operational demand	Time isolated from maintenance Turnaround times Abort procedures Priorities of repair	Checkpoint Visibility Accuracy Marked by beacon Numbers and locations Flight variables Velocity Altitude Heading changes Formation effects Distance: over water, over land	Other aircraft present in formation, escort, other Geography about flight path Cliffs, trees, manmade obstacles	Altitudes of receivers and transmitters Terrain masking Distances of communications Command and control considerations within formation, with ground elements, base External automatic control of vehicle requirements	Altitudes, time of flight Formation requirements Landing and takeoff area constraints
Standard operating procedure Operational Maintenance		What is repaired at each maintenance level Throw-away vs repair Personnel Training	Electromagnetic emission control External aids germinated	Altitude limitations Velocity limitations	Emergency procedures Identification friend or foe Reporting procedures Electromagnetic emission control	Fuel reserves required Power setting limits Bank and turn limits
Vehicle description	Shock Vibration	Inflight repair possibilities		Vulnerable area Radar cross section Altitude limit	Antenna placement Acoustic noise Electromagnetic noise	Equations of motion Aerodynamic data Center of gravity travel Maximum accelerations
Meteorological data	Temperature Humidity Pressure	Weather effects on repair facility	Visibility Ceiling Precipitation	Visibility Ceiling Precipitation Temperature	Fading Atmospheric noise Precipitation	Wind profile Direction Average speed Gust velocity Gust accelerations

Realistic cost and system effectiveness models must be devised so that the resultant comparison between alternate methods of accomplishing a mission will be meaningful. We have attempted to define the problem areas in terms of system functions, technical feasibility, and predicted capability and to derive a relationship between the system design parameters and those system functions that constitute the major variables affecting system effectiveness. The approach to problem definition just described is based on a normalized task analysis and may have application to other military requirements.

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