Effective Platform Designs for Medium Lift Helicopters

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ABSTRACT

This thesis demonstrates that the use of platform design for medium lift helicopters can provide opportunities for reduced time to market and faster return to service of helicopters through faster design generation and reduced planning requirements. Through historical review of the S70 helicopter and the derivatives of the basic model this thesis demonstrates that platform design methodologies address and minimize many of the difficulties associated with both the manufacture and post-deployment modification of the basic vehicle.

Platform designing is used in a large number of industries with the rotorcraft industry being an exception. Point designs to specific customer requirements have been the historical norm. Given the high non-recurring costs associated with the development and certification of new aircraft systems, there remains a tendency in the rotorcraft industry to prolong the timeframe in which a specific aircraft continues to be manufactured by a particular supplier. Furthermore, after these aircraft are fielded they tend to have useful lives that could exceed thirty years and in many cases long after the circumstances for the original requirement have been removed. Also, the embedded technologies within the aircraft continue to evolve after the aircraft is fielded. Changing requirements and roles sometime require that these newer technologies be incorporated into the aircraft. Due to the high value of these already fielded aircraft there is a tendency of the operators to modify the fielded aircraft to adapt to the new mission and role as opposed to procuring newer a aircraft with the newer technologies already installed.

This thesis concludes that through an understanding of the architecture of the air vehicle coupled with an assessment of the likely sections of that architecture that will change the enterprise is better positioned to respond to customer requirements with lower development investment. This thesis provides a review of the architecture of the S70A with particular attention to the instrument panel and allows for demonstration of protocols of platform designing. Various perspectives for assessing the architecture and maintaining the flexibility of the architecture are provided in the platform design context using the S70A helicopter as the central figure with the goal of providing a case study for reference during development of the next medium lift helicopter.

Thesis Supervisor: Dr. Daniel Frey
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Acknowledgments

Completing a work of this nature allows one to recognize the support systems in place both within and around. We, as SDM students, tend to rely heavily on these systems due to our age and position in life. Family, friends, fellow students, work associates and professors all fill roles that surround the student. I have found tremendous support from this circle during my experience. I regret its ending, but feel satisfied and fortunate that I was afforded this experience. To that end I wish to cite some of the people I have counted on.

First and foremost, my life partner deserves primary mention. Dawn has been tolerant, attentive and has provided insights that I would not have seen. The foundations set in our marriage have been tested during the last two years and I am proud to say we have weathered the tempest. Dawn, I love you.

The SDM cohort, specifically the people who started with me in January of 1997 remain key people in my life. I have learned and taken away many lessons from these people. These I will use for the rest of my life. The depth and richness of these relationships is like no other I have experienced. I thank you SDM '97. We were the first and are the best.

I wish to thank the original SDM program office. I regret that some of these people are not here to see this completion. I wish to thank my thesis advisor, Dr. Dan Frey. His guidance and energy through this effort has been tremendous and insightful. Thanks Frey.

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1 Introduction

The helicopter industry is increasingly seeing the life-span of its products being extended by modification and refit activities. As an example, the helicopter that now transports the U.S. President first flew in 1959 and will not be replaced until the year 2008. This means that the vehicle will be in service for almost fifty years before it is replaced. While this example is extreme considering the enormous maintenance costs associated with Marine Squadron One, it demonstrates that a helicopter could realistically be in service for many decades. So called Service Life Extension Programs or SLEPs are becoming an economical means of providing capable airframes with reasonable cost structures. In the commercial world, the "zero-time" refit of aircraft is providing fairly

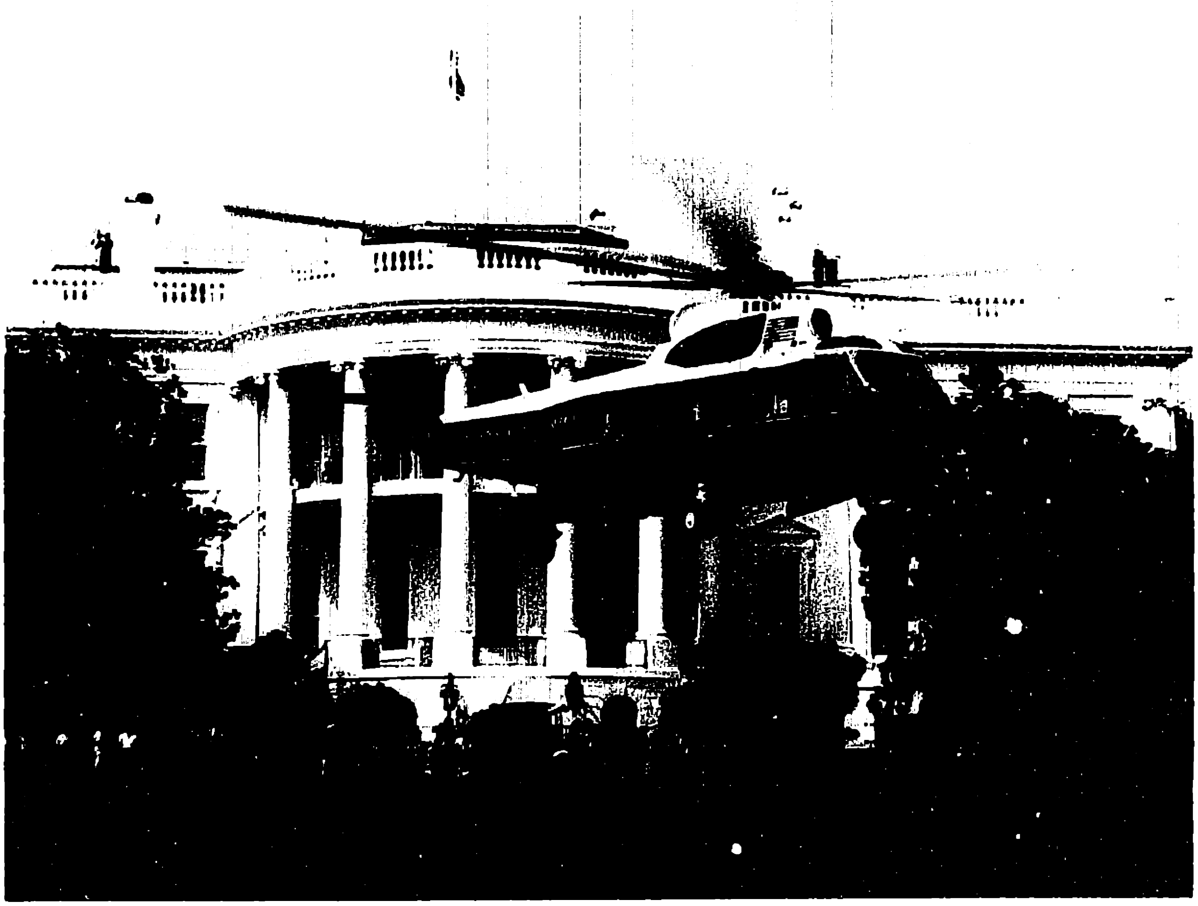

Figure 1 - Marine One (VH-3D)

rapid return to service capability in many areas of the industry from fire fighting to passenger service. The large inventories of spare parts for some models such as the Bell 412 allow for the appropriate levels of logistical support at modest cost to the user. This thesis looks to address what system architectural considerations should have been employed during the initial baseline design of the helicopter that would have made the resulting refit efforts we now see in the industry more cost effective with lower downtime requirements.

As is common knowledge today, the current reduction in military spending in the United States has forced traditional military contractors to seek non-traditional business segments of the market. Sikorsky Aircraft and its S70 model have not been spared from this phenomenon. The late eighties and early nineties were periods during which the defense sectors of the helicopter industry were permitted some growth on the taxpayer dollar. The shifting political realities have created a helicopter marketplace no longer based as heavily on the defense dollar. Parallel industries such as defense electronics and military fixed wing aircraft have seen mergers result from a need to consolidate against a shrinking market. To date this has not happened in the helicopter industry. There were four major manufacturers of helicopters prior to the end of the Cold War period and four still remain. They are; Bell, Boeing, McDonnell Douglas and Sikorsky. Some smaller helicopter manufacturers also remain such as Kaman and Robertson. Figure 2 broadly defines these helicopter manufacturers and their market segment. The question usually asked is if the defense dollar is not available, what is the replacement? To some degree there has been a market place shift from fewer, larger programs to more, smaller programs.

Manufacturer	Product Size	Market
Bell Helicopters	Small, Medium	Commercial, Defense
Boeing Helicopters	Medium, Heavy	Commercial, Defense
McDonnell Douglas Helicopters	Small, Medium	Commercial, Defense
Sikorsky Aircraft	Medium, Heavy	Commercial, Defense
Eurocopter	Small, Medium	Commercial, Defense
Agusta	Small, Medium	Commercial, Defense
Kaman	Small	Commercial
Robertson	Small	Commercial

Figure 2 - Current Helicopter Manufacturers

The more, smaller program environment creates the need for the derivative. The derivative helicopter has its basis in the primary product produced, but has some enhancements or specific customer required modifications. These changes allow the vehicle to be sold to the specific customer and are usually one of a kind helicopters. These enhancements generally include the integration of customer supplied or specified systems that are unique. In addition, there may be marketplace driven features which need to be incorporated. Past efforts in this type of business have led to specific design efforts for each configuration. This generally means that the non-recurring cost associated with the effort must be absorbed by the specific program. Given the defense industry contract compliance mindset, often the ability to transfer a common design effort over several programs of similar type is not permitted. This makes it more difficult to make a profit since the cost is amortized over a smaller number of aircraft.

Aside from the cost constraints placed on derivative work there also needs to be an accompanying mindset shift regarding the design / fabrication procedures employed. The DOD world has a large and unwieldy set of requirements that are often cumbersome at best. Oftentimes the commercial derivative customer has no need nor any desire to be the recipient of the volumes of documents normally associated with a DOD contract.

Therefore, the segments of the workforce normally associated with that phase of the business are no longer viewed as required to permit delivery of the product. This generally leads to two opportunities. The first is to re-train and re-assign these documentation producing personnel to efforts directly linked to the deliverable and the second is to remove these personnel from the workforce. Both approaches have benefits and drawbacks. The configuration of the workforce is key to derivative programs. The ability to have the appropriate skill sets available for discrete periods during the fairly short design efforts of derivative work remains a significant challenge. Ideally, there would be a sufficient population of derivative effort such that the design / fabrication personnel could be shifted from project to project. The timing of individual projects causes personnel to move between projects of different complexity at different times. This approach requires extremely strong central leadership to prevent islands of success and islands of failure. The thrust here is to permit the entire company to succeed and that means that a number of efforts need to be supported simultaneously which is again a departure from previous industry approaches.

Speed. If there is any one axis of review regarding product development and the role of platform designing upon it, speed provides many insights. Like an effective racing car, speed does not come from any single aspect, but the combination of many factors. Tires, power plant, aerodynamics and driver skill all play roles determining whether or not the team will be successful or not. A parallel case exists in the realm of product development. If speed again were to be used to define the axis of review, one would see that the product that arrived first to satisfy the customer's demand achieved some measure of success. Organizations that consistently arrive with their product first in the market place are rare and successful. However, it is the combination of technology, system architecture and managerial wit that permitted the product to be successful. These axes of review are not equally weighted. The technology available, the skill of the management and the flexibility of the system architecture don't all have the same impact on the success or failure of a new project. Controlling each in a predictable fashion may mean the difference between survival and prosperity as opposed to downsizing and acquisition.

Platform designing is not new. Many examples are available even during the most cursory of reviews. Platform design and the effective use of platforming protocols will however play an important role in determining just how quickly a product becomes available in the market place.

This work looks to the rotorcraft industry. There are currently four major producers of helicopters in the United States and several over-seas. Rotorcraft, helicopters if you will, still have many of the same systems that models conceived of in the 1920's. A large lifting main blade system coupled to some sort of anti-rotational smaller blade with the pilot and occupants fitted between. Compared to fixed wing aircraft which contain many categories and types of aircraft in large numbers, the market for helicopters is smaller and more diverse. Viable, commercial transport by helicopter remains a future possibility but is not currently available to all except those with the operating budgets of larger corporations. Helicopters remain difficult to maintain with some models taking more than eight maintenance hours for every flight hour. These and other major trends characterize the current helicopter industry. Success in this type of industry will be achieved by the most flexible supplier providing the right product at the right price within the right timeframe consisting of the right configuration.

These four customer driven requirements must be met by the successful helicopter manufacturer: product, price, timeframe and configuration.

- The product is what the market currently perceives it needs. If the enterprise does not provide a product that the market feels it requires, the Ford Edsel phenomenon of product and market mismatch has an opportunity to be recreated.

- The price is less than what the competition is asking for given the same capability.

- The timeframe is simple, now.

- The configuration speaks to what the customer really needs. Don't sell bells and whistles that are not required and will only provide dissatisfaction when they don't perform as advertised.

This work submits that platform design approaches can affect all four of these customer needs to some degree. It is this writer's experience as a team leader in development operations at Sikorsky that says any positive effect on a continuous basis to these four criteria will permit effective execution of the organizations business objectives in the long term. Platform design approaches permit flexible responses to market requirements on a timely basis. It is important to understand that not all markets have the same timeframe. It typically takes about 15 months to fabricate, assemble, acceptance test and flight test a basic S70 at Sikorsky Aircraft. Derivative aircraft, those with slightly different configurations will take upwards of 24 to 30 months to complete. The reason for this discussion now is to inform the reader of the types of timeframes involved in the development and delivery of helicopters. The writer however submits, and this thesis looks to demonstrate, that these timeframes can be shortened by effective deployment of platform design methodologies.

The scene having been set, this work looks to understand how platform design will effect the current situation to the better.

2 Thesis Statement

This thesis looks to describe the utility of platform approaches for the design and fabrication of the medium lift helicopter (MLH). This investigation will first examine a typical architecture for helicopters generally, then discuss the protocols of platform design and finally apply these protocols to a sub-system of a theoretical future MLH. Validation of the approach will be fully illustrated by addressing one specific sub-component of the defined architecture.

The method used to validate this thesis will be the review of a sub-system found previous derivative models of the S70A helicopter with the goal of identifying common features of that could be installed on the platform helicopter with a minimum of design and planning effort. The sub-system to be used will be the instrument panel of the aircraft. This method requires that the basic architecture of the helicopter be defined first. Once the helicopter architecture is defined the sub-components of that design that are common to the platform can be described along with the rationale as to why they are part of the platform. Given that the sub-component, the instrument panel, is part of the platform, a review of the forces affecting that instrument panel design is possible. Through this review, a rationale for positioning like and future sub-components into a platform framework is made along with a discussion of the potential benefits.

3 History of Air Vehicle Change

The U.S. aerospace industry has a history of large scale projects with budgets that exceed the GNP of some smaller nations in the world. As a subset of that industry, the domestic helicopter industry is no exception. Consider the AH-64 Apache attack helicopter. This vehicle has been in existence since the mid-1970's and is still fielded today. The helicopter program has responsibility for the expenditure of billions of dollars over the continuing course of its development and deployment. High military spending coupled with lack of off-shore competition permitted somewhat inefficient design and fabrication practices to flourish. Burdensome contracting procedures also created workload for the design / fabrication organization that may not have directly permitted an efficient product development process. Given the discrete program to program nature of the environment, point designs addressing specific customers and their needs were the norm. The aerospace industry has many examples of designs that were produced for a specific need in mind only to have the vehicle used for broader purposes other than its original mission.

The B-52 aircraft is riddled with cases of changing system installations and aircraft configurations. As its missions and roles changed, the design challenges required to met these evolving needs became increasingly complex. This is demonstrated by the change in role of the aircraft from a high altitude bomber into a nap-of-the-earth vehicle. This is a significant change in mission with many factors needing to be considered. The B52 was conceived of over forty years ago and is still in service today. Originally given the mission of high altitude nuclear bomber the B-52 now flies low-altitude conventional and nuclear missions. Additionally, the venerable aircraft has also been used to ferry both manned and unmanned systems to delivery altitude for scientific study as well as orbital insertion. Each of these new configurations of the B-52 needed to be conceived, designed, fabricated, integrated, installed, tested and delivered. Each time a new configuration needed to be developed, a specific organization was designed and designated to perform the work. This is a result of taking a point design for a specific need and re-configuring. While vision over forty years is easy in hind-sight, the issue of sub-optimizing a system due to the inherent constraints begs further review. Remember, this was an aircraft the had entire wing sections removed and replaced to fulfill the new envisioned mission role. This is about as severe a modification that a specific airframe can undergo.

Figure 3 - B-52 Aircraft

To further frame the discussion, a review of some numbers defining the operation of a typical helicopter provides some insight. The average life-span of an airframe being delivered today from Sikorsky Aircraft can exceed 20,000 hours of operation and be fielded for over twenty years. Just as the B-52 has changed roles during its fielded lifetime, so can a helicopter delivered today. The tools and methods used to address this demonstrated and historically referenced need can apply great leverage to the missions an aircraft can fly.

A platform design architecture is one such way to permit a host design the flexibility to incorporate changes later in the life of the product for a variety of reasons to produce a variant. The variant or derivative strives to meet the market needs without the incurred cost or time requirements of a completely new design. The aerospace industry is certainly not the only area where this phenomenon can be found. The auto industry is also full of examples of the manifestation of platform design. The interesting trade between the two industries is the life span of the product. The typical life of a good automobile design is probably less than five years. Yet, the automobile industry routinely uses platforms in its design approaches and the aerospace industry rarely uses platform design approaches. The platform design approach is subject to many design constraints, and the life of the product is probably one of the more important ones. This thesis will address many aspects of platform designs. This thesis will focus on medium lift helicopters (those up to 25,000 maximum gross weight). This focus allows for a tailored approach and implementation of the platform design tools discussed using a real world example.

4 Description of S70A Helicopter

4.1 Introduction

Sikorsky Aircraft's S70 helicopter was built in response to the U.S. Army rotary-winged aircraft program requirement referred to as Utility Tactical Transport Aircraft System (UTTAS). In short, the UTTAS program required a helicopter designed to perform missions such as troop transport, air cavalry and medical evacuation. The program also included standards for the helicopter's combat survivability, reliability and maintainability; and it went on to specify adverse weather and nighttime operational capabilities. Within the UTTAS program a specification for air transportability was included. This specification required that one UTTAS configured helicopter fit into a C-130 transport aircraft, two into a C-141 transport aircraft and six into a C-5 transport aircraft. This air transportability requirement has a large impact on the resulting configuration and overall dimensions of the S70 helicopter. The helicopter fuselage is approximately 51 feet long. When measured longitudinally from the foremost main rotor blade tip to the aft most tail rotor blade tip, the overall helicopter measures 65 feet long. Exclusive of the main rotor blades, the helicopter is approximately 14 feet wide and, without its tail rotor blades, it is approximately 12 feet high. The S70 helicopter has a basic structural design gross weight of 16, 938 pounds, and it has a maximum alternate gross weight of 22,000 pounds with some configurations reaching 23,500 pounds. The S70 helicopters cargo floor is designed for a capacity of 300 pounds per square inch. The volume of the cabin is 410 cubic feet. To facilitate air transportability, the horizontal tail, or stabilator, is removable and the vertical stabilizer, or tail rotor pylon, is foldable.

4.2 Airframe

The S70 helicopter airframe is divided into six structural sections. These are Cockpit (nose-section), Cabin (mid-fuselage), Main Rotor Pylon, Transition Section, Tail Cone and Tail Pylon. The cockpit accommodates the pilot and co-pilot, associated systems equipment and is entered through hinged, jettisonable crew doors on the left and right side of the aircraft. The cabin interconnects the cockpit and transition sections, has two crew member stations and a passenger / cargo compartment. The cabin is entered through aft-sliding passenger / cargo doors on each side of the helicopter. The transition section interconnecting the cabin and tail cone sections holds the fuel tanks and equipment stowage compartments. The transition section is reached from inside the passenger / cargo compartment or through an aft transition access panel on models so equipped. The main rotor pylon, attached to the upper cabin and transition section, is a protective aerodynamic cover that provides smooth airflow induction for cooling the helicopter major sub-system components. The tail cone connects the transition section and the tail rotor pylon, and also supports the tail rotor drive shaft and tail rotor pylon. The tail cone also encloses the tail rotor flight controls and contains the tail landing gear. The tail cone is reached from inside the rear passenger / cargo compartment, or from the outside through an aft transition access door for models so equipped. The tail rotor pylon is supported by and hinged to the tail cone. The tail rotor pylon supports the stabilator, intermediate and tail rotor gear boxes, connecting drive shafts, tail rotor assembly, and part of the flight controls. When the stabilator is removed or folded, as is the case with some models, the tail rotor pylon can also be folded and stowed next to the right side of the tail cone.

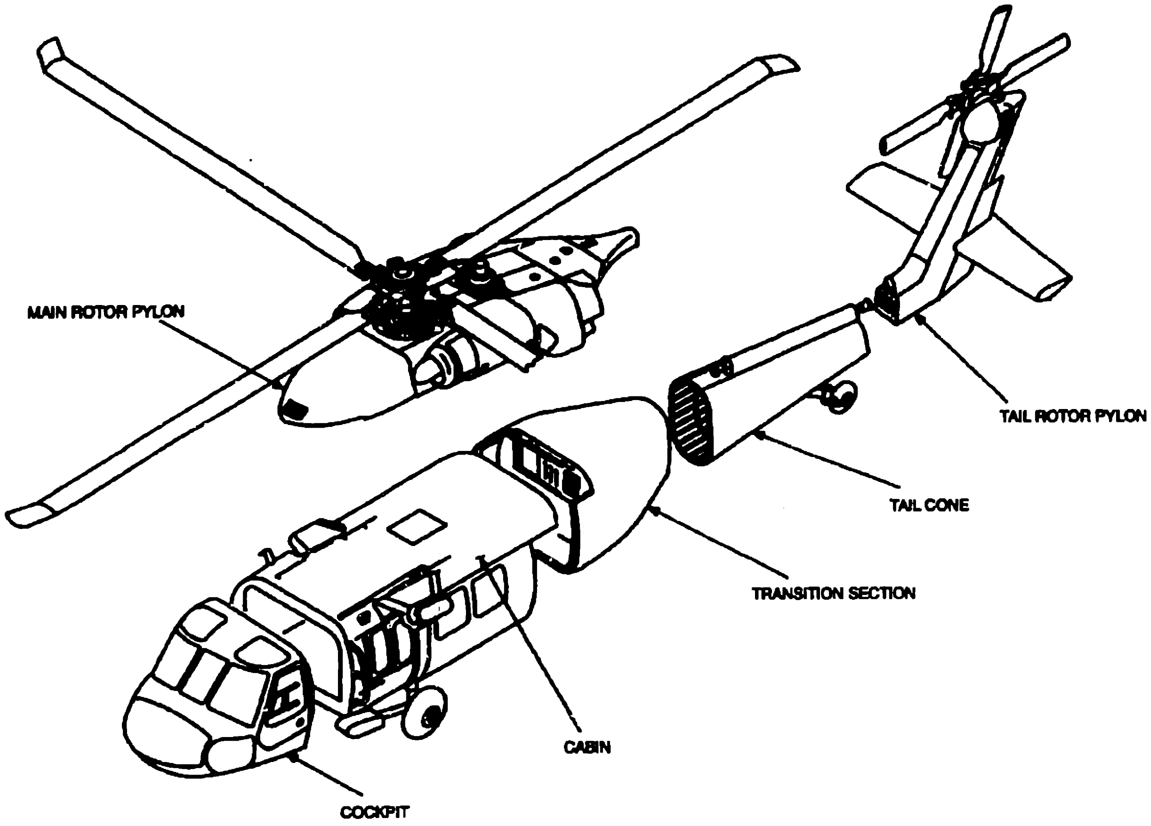

Figure 4 - Major Airframe Sections

4.3 Electrical

The S70 helicopter uses alternating current as prime electrical power. The electrical power system is supplied by three sources. This consists of primary AC power, auxiliary AC power and external AC power. Primary AC power is provide by two transmission driven independent generating systems each consisting of a brushless generator, generator control unit, current transformer, generator control switch, and a caution / advisory capsule. Auxiliary AC power is provided by a single APU driven generating system consisting of a brushless generator, generator control unit, current transformer, generator control switch and caution / advisory capsule. External AC power is supplied to the helicopter through and external power receptacle. It is controlled by an external power monitor, external power switch and a caution / advisory capsule. AC power is distributed to the helicopter busses from the generating systems and external AC source through a series of contactors and relays.

4.4 Fuel System

The S70 helicopter has an on-board fuel system. The fuel system supplies fuel to both engines and to the auxiliary power unit, APU. The systems consists of a main fuel system, a fuel quantity system and a fuel low-level warning system. Fuel from both main tanks is drawn by suction from both main tanks to the hydro-mechanical unit, HMU and the engine driven fuel pumps. Fuel from the LHS or No. 1 fuel tanks is used to provide fuel to the APU. All fuel lines on the helicopter are self-sealing and have [illegible] sealing, breakaway-type valves. This prevents loss of fuel should lines be dam[illegible] valves separate from the rest of the fuel system. Helicopter refueling is accomplished by both pressure re-fueling using closed circuit adapters located on the left side of the helicopter in the transition section. Gravity refueling can also be accomplished from both sides of the helicopter using separate gravity re-fueling ports. No electrical power is required for either pressure or gravity refueling. The fuel system includes hi-level shut-off valves in each tank which actuate and close the pressure re-fueling valve when the tank is full. During pressure de-fueling a low-level shutoff actuates the pressure re-fueling valve when the tank become empty.

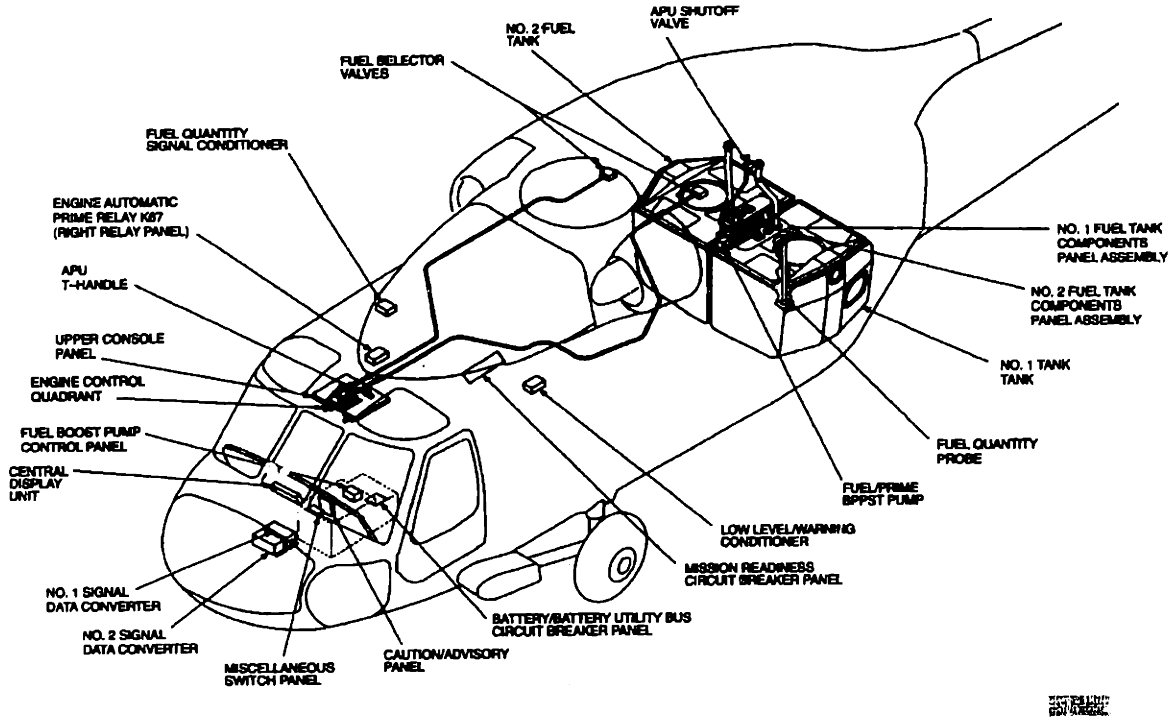

Figure 5 - Fuel System

4.5 Powerplant

Flight power for the S70 helicopter is provided by two General Electric 701C turbo-shaft gas turbine engines. The powerplant system consists of two de-mountable power packages containing the engine, engine control system, engine anti-icing system, engine over-speed protection system, engine speed trim system and indicating systems. These power packages are mounted one on each side of the main transmission. Interfacing between the engine and the helicopter are a pneumatic air starter, drive shaft assembly, engine mounts, tailpipe assembly, fuel and lubrication lines and wiring harnesses. The drive shaft assembly and a forward support tube connect the engine to the input gear box module of the main transmission. A shaft connected to the power turbine of the engine extends forward through the engine and into the input gearbox module to permit the transfer of mechanical energy from the engine to the main rotor transmission. Each engine is subsequently broken into four major sections. These are cold section, hot section, power turbine section and accessory section. Each engine also has bleed air capability to provide heated air for engine anti-icing, cockpit / cabin heating and cross-bleed engine starting.

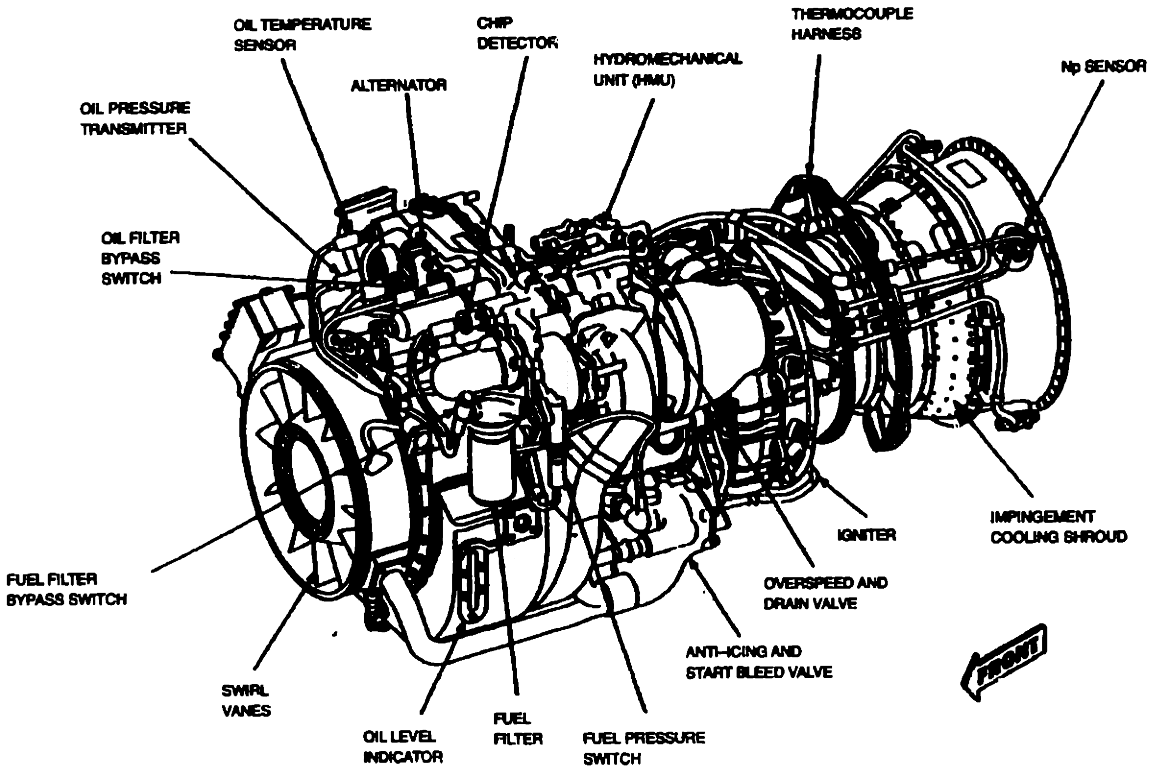

Figure 6 - Turboshaft Engine

4.6 Transmission System

The transmission system on the S70 helicopter carries the mechanical energy provided by the engines to the main and tail rotor systems. This system consists of the main transmission with oil cooler, intermediate gear box, tail gear box and interconnecting drive shafting. The transmission system has indicating systems for oil pressure and temperature which provide the flight crew with warnings for hot oil and low oil pressure as when as a chip detector system with fuss burn-off to provide warning of mechanical malfunction within the gearboxes. The main transmission drives the main rotor, tail rotor, main transmission oil cooler, No. 1 and No. 2 hydraulic pump modules, and the No.1 and No. 2 electrical generators. The main transmission is mounted on top of the cabin fuselage with a three-degree forward tilt. The transmission assembly is made up of five modules. These are; the main module, two input modules and two accessory modules. Modules housings are made of Magnesium and are covered with a special heat sensitive paint that will change color if the modules over heat. The main transmission assembly mounts and drives the main rotor head, changes the angle of drive from the engines, reduces engine rpm, and drives the oil cooler and tail rotor drive shaft. Both input and accessory modules are interchangeable with one another and can be replaced without removing any other main transmission modules. The accessory modules mount to and drive the generators and hydraulic pumps. If the aircraft is equipped with a rotor braking system, it will be mounted to the rear of the transmission between the main transmission housing and the oil cooler.

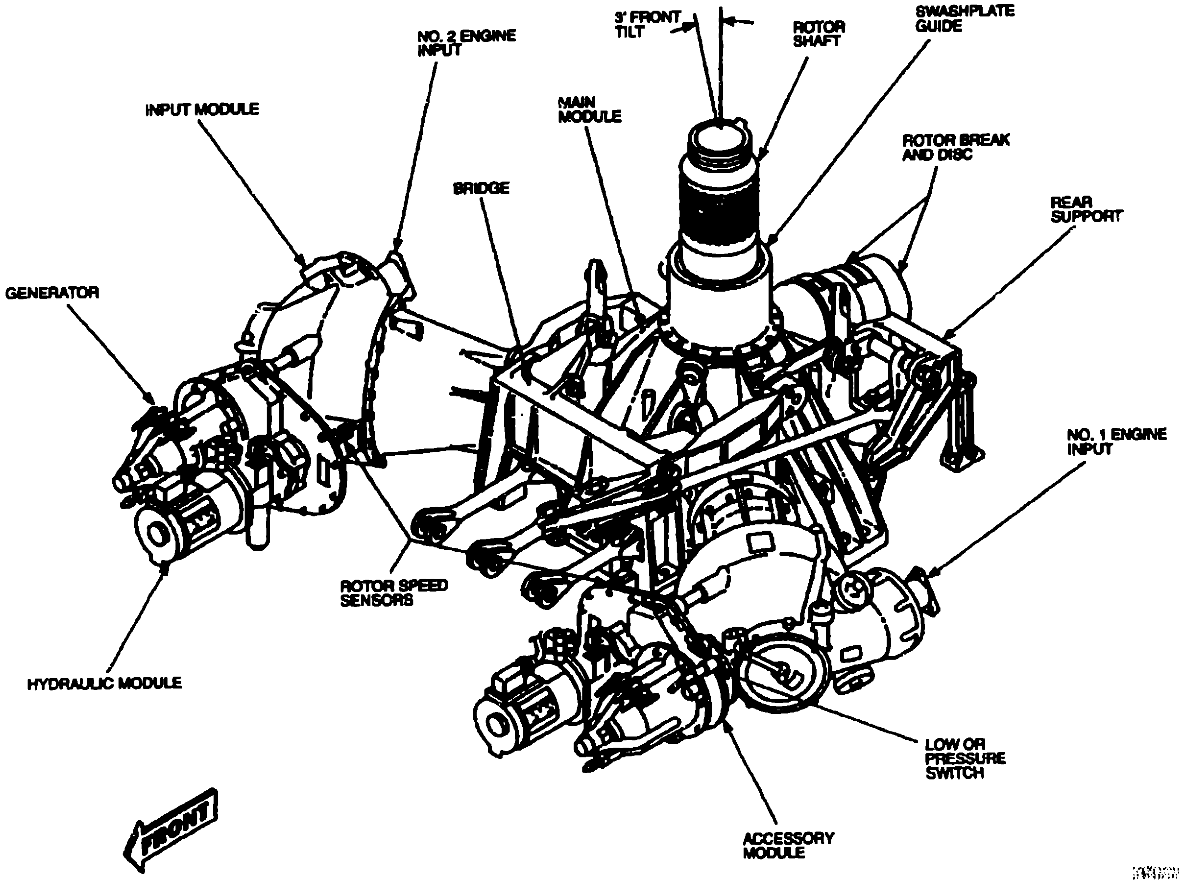

Figure 7 - Main Transmission

Aside from the main transmission two additional gearboxes provide mechanical energy from the main transmission to the tail rotor for helicopter directional control. These are the intermediate and tail gearboxes. The intermediate gearbox is constructed of three distinct Magnesium housings being input, center and output. The gearbox is mounted on the base of the tail rotor pylon and is designed to transmit torque to the tail gearbox. The intermediate gearbox also provides speed reduction and changes the angle of drive to permit interface with the drive shafting travelling up the forward face of the tail rotor pylon. The tail rotor gearbox is mounted on top of the tail rotor pylon and is also constructed of three magnesium housings. These are also called input, center and output. This gearbox furnishes reduction and changes the angle of drive 105 degrees to the tail rotor blade mounting flange. Lubrication of this gearbox as well as the intermediate gearbox is performed by a splash type approach. Additional systems mounted to the tail rotor gearbox are the tail rotor servo, aft quadrant, spring capsules and blade de-icing slip ring.

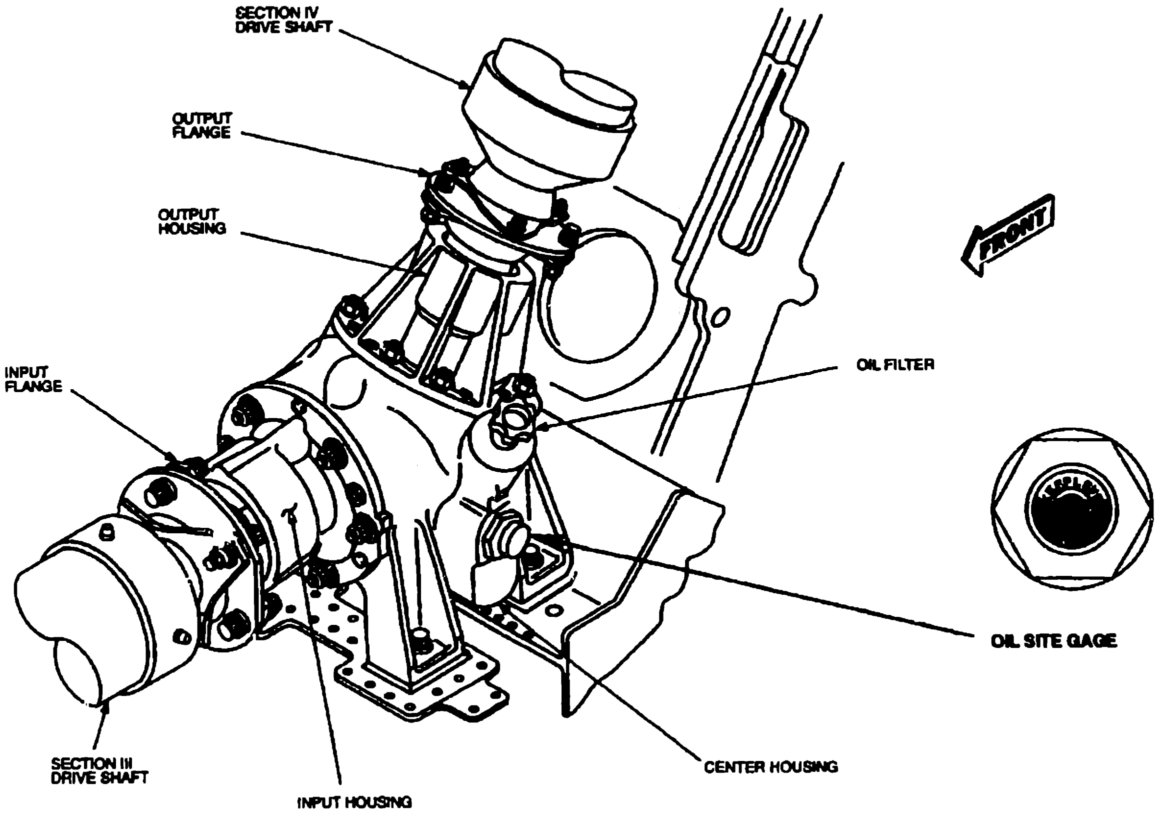

Figure 8 - Intermediate Gearbox

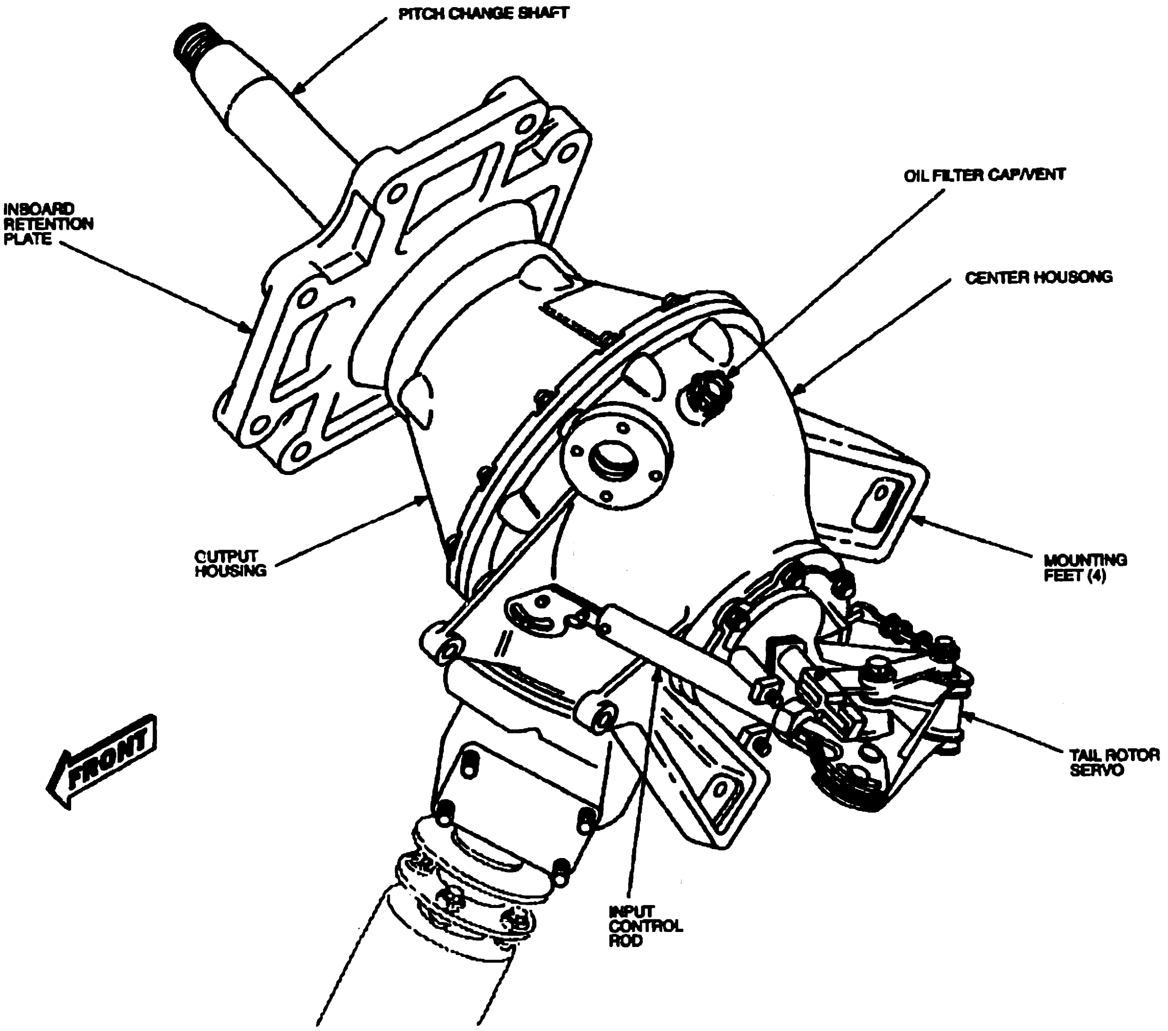

Figure 9 - Tail Rotor Gearbox

4.7 Rotor System

The rotor system is broken into two major areas. The first is the main rotor system and the second is the tail rotor system. Both systems consist of four blades to provide lift and directional control. The interface between the main blades and the transmission is accomplished by the main rotor head. The is also the case for the tail rotor blades using the tail rotor head.

The main rotor head transmits the movements of the flight controls to the four main rotor blades. The main rotor head turns in a counterclockwise direction. The head itself is supported by the main rotor shaft extension. The shaft extension is splined to the main transmission center shaft which drives the rotor head. The rotor head is supported at the top of the main rotor shaft extension by a series of pressure plates and cones interfacing with the upper and lower surfaces of the main rotor hub. The main rotor head also contains various vibration absorbing, main blade droop control and electrical features.

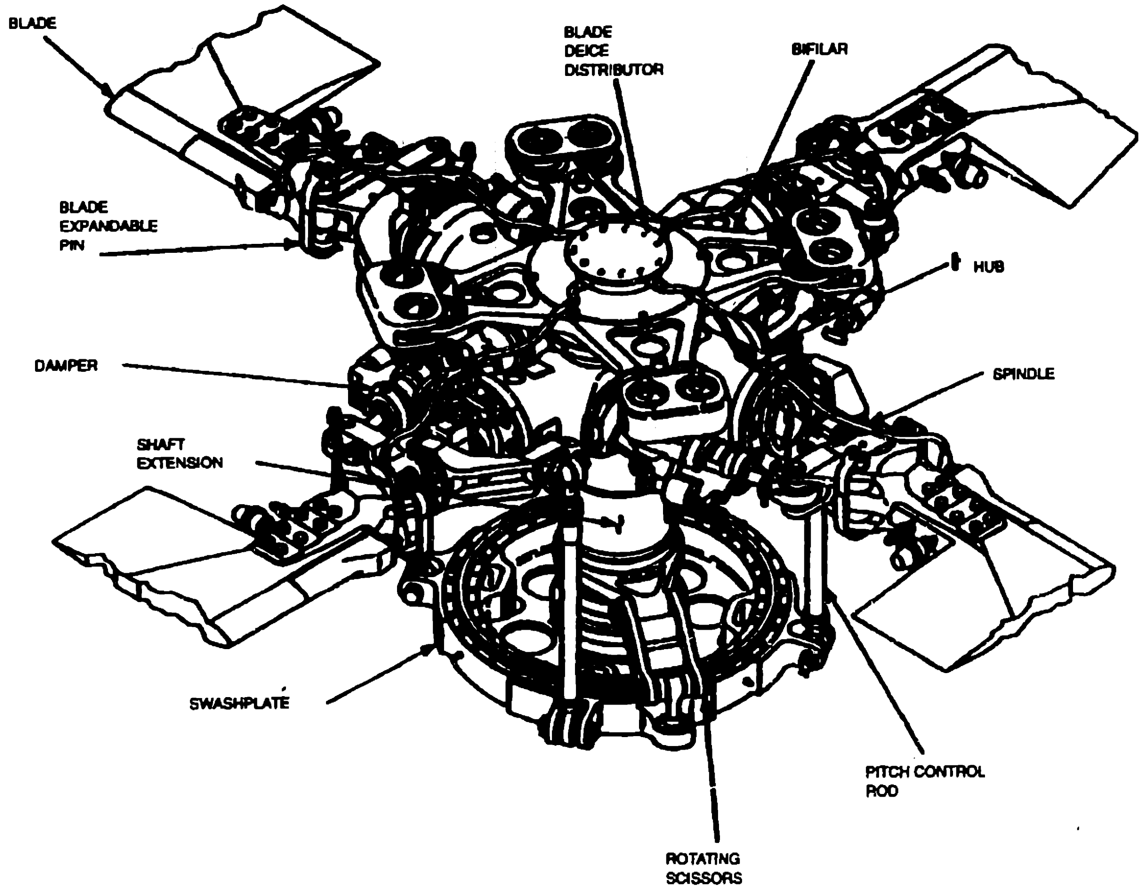

Figure 10 - Main Rotorhead

The four main rotor blades attached to the main rotor head provide primary lift for the air vehicle. Each main blade is constructed using a titanium spar with a honeycomb core and fiber glass skins and is approximately 24 feet long. Nickel and titanium abrasion strips area affixed to the blade leading edge to allow for operation in hostile environments without main blade damage. The tip of the main blade is a separate, removable assembly that permits access to the tip of the main blade and aerodynamic fairing. Original tip cap assemblies were made of Aluminum with current versions being of composite construction. An electric resistive heater mat is installed between the tip abrasion strip and a foam filler to allow for leading edge de-icing. The entire upper and lower skin surfaces of the main blade have wire mesh bonded onto the outermost surface to facilitate conductivity during lighting strike and static build-up. The internal titanium spar is pressurized with dry nitrogen to prevent environmental intrusion. A blade monitoring system is installed with indicators to alert operators of a loss of internal blade pressure. Each main rotor blade is both statically and dynamically balances to permit removal and replacement on an individual basis. Each blade has a built-in negative twist running from the root end to tip to permit equal distribution of lift across the entire length of the blade. Attachment to the main rotor head is accomplished through use of a titanium cuff that is mechanically fastened to the blade spar and attached to the rotor head through the use of expandable pins. Each blade also has two longitudinal balance stripes painted on the upper and lower surfaces to permit location of blade hoisting equipment during ground handling operations.

The tail rotor head is canted and is attached to the tail rotor gearbox mounted on top of the tail rotor pylon. The pitch of the tail rotor system is accomplished through the actuation of an "X" shaped pitch change beam connected to a pitch shaft. As the beam rides up and down, the shaft a mechanical connection to the trailing edge of the tail rotor blade causes blade angle of attack changes. Additionally, since the tail rotor assembly is canted to the horizontal upwards of 400 pounds of lift is generated by the tail rotor disc. The canted feature also enhances ground clearance for both machinery and personnel.

Tail rotor blades are built around two graphite-epoxy composite spars crossing each other to form four blades. The airfoil is bonded to the graphite spar and is comprised of a honeycomb core with fiber glass skins similar to the main rotor blades. On the leading edge a polyurethane abrasion strip is mounted from root to mid-span with a nickel abrasion strip mounted from mid-span to tip. A resistive heater mat is sandwiched between the abrasion strip and a foam filler to facilitate de-icing. Wire mesh is bonded to the upper and lower skin surfaces to allow for conductivity and static wicking. Pitch changes are facilitated by a pair of elastomeric bearings at the root end of each airfoil as well as twisting the graphite spar.

4.8 Flight Control System

The flight control systems consists of collective, cyclic and directional control systems. Collective inputs control rotor system input torque and main blade pitch. Cyclic inputs control main blade disc position for forward, rearward and lateral helicopter movements. Directional control is facilitated by pedal inputs to the tail rotor system to provide main rotor torque reaction and azimuth. These systems use a series of push-pull rods, bellcranks, cables, pulleys and servos to transmit control movements from the cockpit to the main and tail rotor systems. The pilot, right hand side, and the co-pilot, left hand side, have dual controls. Automatic assistance is provided to the pilot and co-plot through the stability augmentation system, flight path stabilization system and trim control. Additional control is also provided by the stabilator system.

The stability augmentation system, SAS, is an analog systems with 5% control authority in pitch, roll and yaw. Using inputs from the stabilator system, attitude indicating system and the internal yaw rate gyro, the SAS amplifier derives SAS actuator control signals which are feed into the appropriate flight control path. Limited digital automatic flight control is also available. A digital automatic flight control system, AFCS, computer is mounted in the center console of the cockpit. Digital AFCS provides certain computer functions to the entire helicopter flight control system. The functions include SAS2, a 5% pitch, roll and yaw control stability system that is used in conjunction with SAS1 to provide dynamic stability. A trim system is available to hold controls at pre-selected positions through the use of various electro-mechanical and electro-hydramechanical servos. The flight path stabilization system provides 100% system authority at a limited rate through the trim servos to provide airspeed, pitch, roll and heading hold. The stabilator system is a dual channel, electro-mechanical system that moves the stabilator mounted on the tail rotor pylon. Aircraft sensors located throughout the airframe provide input to insure proper orientation of the stabilator for the flight regime. These include; air speed sensors, cabin accelerometers, pitch rate gyros, and collective stick position sensors. Actuation of the stabilator is accomplished through the use of a dual-stage, electrically controlled, hydraulically driven actuator. The actuator is mounted between the upper mid-span of the stabilator assembly and the aft spar of the tail rotor pylon.

4.9 Landing Gear

The S70A helicopter employs a three point landing system. Two main gear are attached to the cabin section of the airframe and a tail landing gear is attached to the aft bulkhead of the tailcone. The landing gear is designed for normal sink rates of up to nine feet per second and provides energy absorption in crash conditions up to 38 feet per second. The main gear assembly can be installed on either side of the aircraft. The main gear is comprised of a shock strut, drag beam and wheel / brake assembly. The shock strut is a vertical member made of a two-stage oleo designed to counter vertical loads during landing and ground maneuvering. The drag beam is a single machined aluminum forging that attaches to the stub wing under the crew door and the bottom of the shock strut. The drag beam is designed to counter drag loads and lateral loads during landing and ground maneuvers. The drag beam also has provision for attachment of the main landing gear wheel axle. The main landing gear wheel / brake assembly consists of a wheel, tire and hydraulic brake assembly. Wheel brakes are used to slow and stop the helicopter during ground maneuvering and well as control direction during taxi operations. Landing brakes are actuated by the foot pedals in the pilot and co-pilot foot wells and are capable of holding the helicopter on a 12 degree slope at design gross weight.

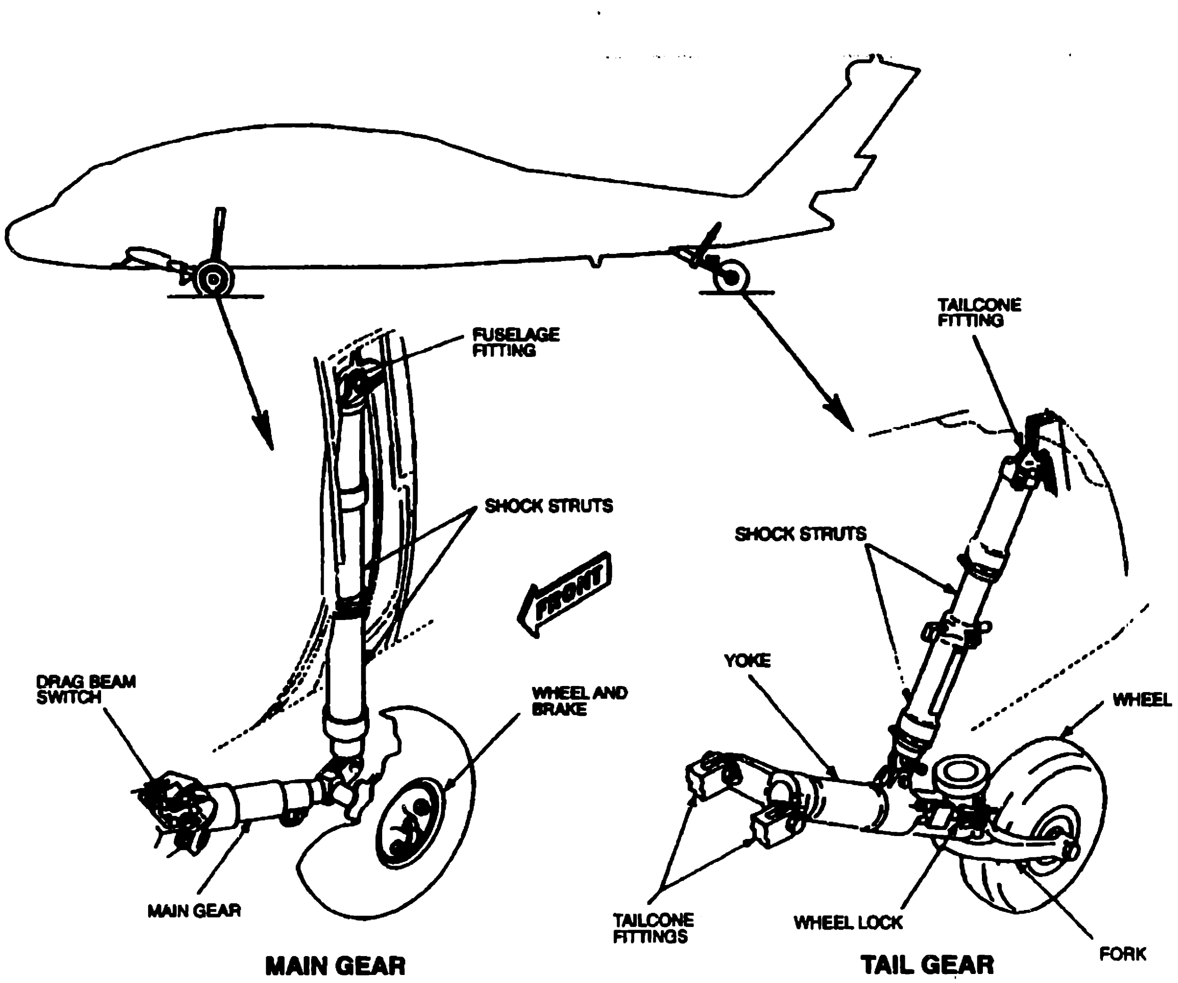

Figure 11 - Main and Tail Landing Gear

4.10 Derivatives

Currently, there are over 35 derivative models of the S70A helicopter. These derivative helicopters are more fully defined in Appendix 1.0.

Helicopter design has always had its roots in the defense industry. This heritage has led to point designs that have met specific goals of the immediate customer. This being the case, significant efforts have been devoted to expanding the mission capability of these vehicles. The helicopter most clearly meeting this point design expansion scenario is the Sikorsky S-70. This aircraft was designed and fielded to replace the UH-1. As an interesting aside, the UH-1 is also still supporting front line units with its first flight being almost forty years ago. The S-70 bears the UH-60 designation for its military role. Designed as a utility helicopter, the UH-60 now has over thirty-five derivative types and has been sold in over ninety countries. The transition from a U.S. Army utility helicopter to these many roles usually requires the launching of a specific design effort and its follow-on build cycle. Given the basic design was not done on a computer aided system, all interfaces to the basic structure may require engineering manpower to review "ink-on-mylar" designs. When commonality exists between deriva[illegible]signs. Then the effort proceeds somewhat more smoothly given the access to the electronic data developed during a previous effort. The UH-60 is touted as a rugged and reliable rotorcraft with multi-mission capability, however, this was not the original stimulus for its development. The need to access varied markets was the genesis of the derivative, not its baseline design. Depending on whether a vice-president is speaking or a design engineer, the merits of the UH-60 as a platform will be argued. There are non-recurring dollars associated with every derivative that is conceived by the company. This fact alone states quite clearly that the much touted platform does not meet the lower return on non-recurring expenditure that is facilitated by the readily reconfigurable nature of a platform system. A true platform would have minimal design / fabrication integration efforts to achieve a different configuration vehicle.

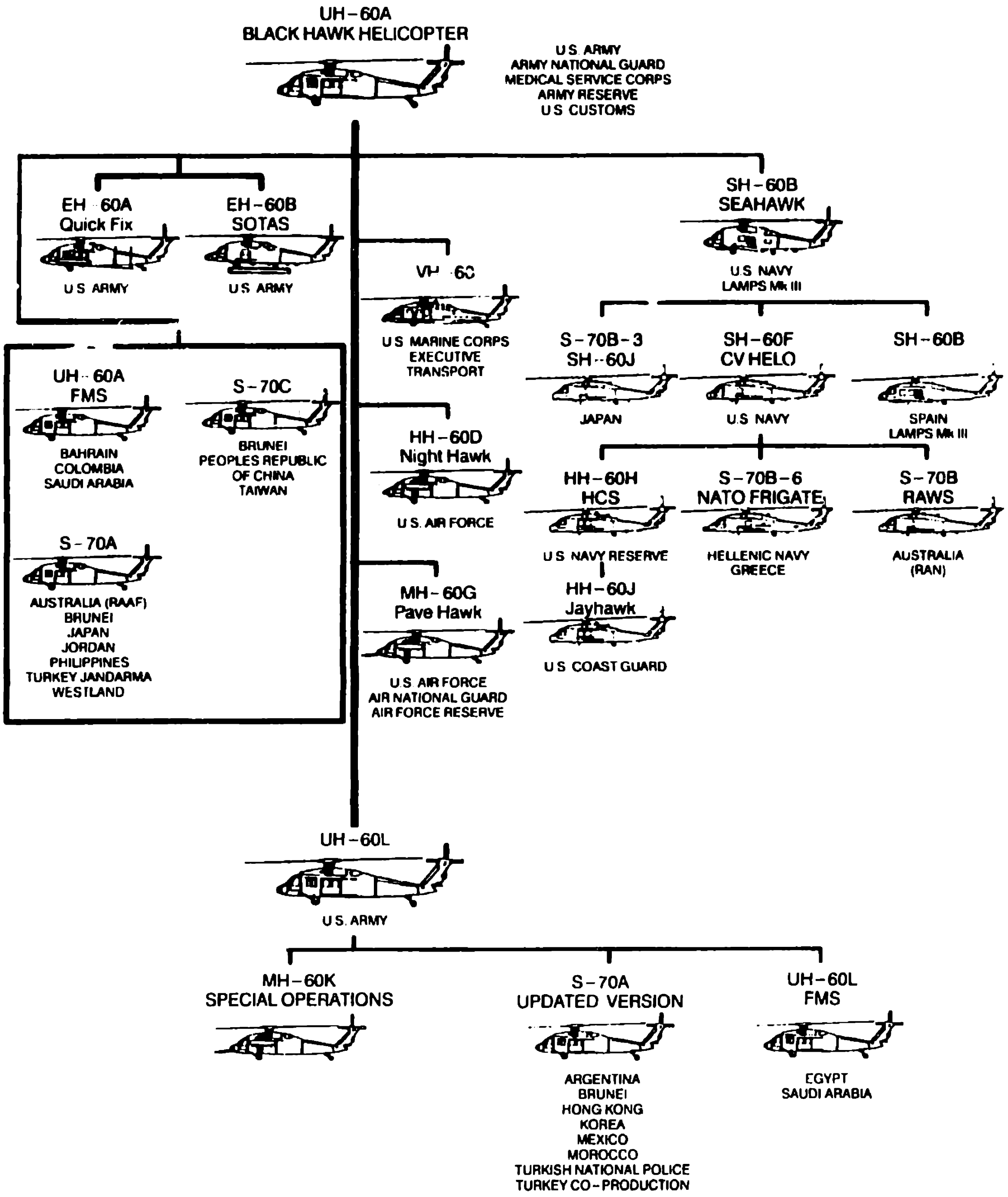

Figure 12 - UH-60 / S-70 Lineage

5 Description of S70A Architecture

5.1 Introduction

The emergence of the S70 derivative helicopter has occurred purely in response to marketplace demands. The S70 has its basis in the UH-60 delivered to the U.S. Army. Since the basic vehicle did not have the requirement for platform considerations, this transition from U.S. Army utility aircraft to a medium lift helicopter competing in the international market place is full of design challenges. The use of the platform theme for the UH-60 was more mission based as opposed to configuration based. The multi-mission role a utility helicopter may engage in could be troop transport, cargo movement, medical evacuation and VIP transport. As we move into defining the S70 as a platform we see quickly that the basic UH-60 vehicle does not fulfill the requirement due to system level reconfiguration requirements. This conversion from UH-60 to S70 is difficult at best. The S70 requirement has produced over 40 variations, see appendix 1.0. The challenge to respond to this diverse market stands as testimony to the innovative spirit resident at Sikorsky. Virtually every system, with the exception of the main dynamics, within the helicopter has been either replaced by a substitute or heavily modified in response to some customer requirement. The ability to integrate these changes more efficiently into the basic vehicle has remained a competitive disadvantage. While it is true that the basic vehicle had no platform or future growth requirement, the learning gained by identifying the specific affected areas of the helicopter architecture by this proliferation of derivative models serves to guide future design efforts for systems of these types.

5.2 S70A Configuration Table

The S70A Configuration Table, Appendix 2.0, is a representation of forty distinct models of the S70A helicopter produced by Sikorsky Aircraft Corporation. The purpose of the table is to define the type and magnitude of change from the basic UH-60 helicopter. As denoted earlier, the UH-60 started as a point design for a specific customer. For this reason, the basic aircraft is not described in the matrix, but only the change from the baseline vehicle. However, this design has been the basis for a number of other models of helicopter and is viewed as the starting point for all discussed S70 derivative models. The configuration table looks to identify and quantify the types of changes required to yield the specific derivative models. The basic UH-60 architecture is broken down into formal chunks to further isolate the locations within the architecture where change was made to satisfy specific customer requirements. Additionally, the matrix looks to identify the depth and complexity of the change to further bound the extent of the change to the basic vehicle defining the derivative.

5.3 S70A Architecture

There are many potential ways to define the architecture of the UH-60L helicopter This section looks to map the major sections of the vehicle into chunks that can act as place holders for various different type of specific systems performing the same role. As an example, the section entitled "communications equipment" can contain a broad range of different specific radio systems. These radio systems may operate on different frequencies, have different power requirements and may have different antenna mounting requirements. However, all these systems perform the same function. That function is to communicate using RF.

An additional point of discussion regarding the architecture of the UH-60 has to do with its intended customer. Remembering that the U.S. procurement process was a key defining force regarding how the system was portrayed to the DOD customer. The formal acquisition process was followed in this case. This effort starts with an informational request and terminates with a contract. All through this procedure, the architecture of the delivered system is discussed and defined. This pre-design activity constrains the design team almost from the beginning. Given that the architecture of a system is performed early in a system's life, perhaps the UH-60 architecture was never really defined by the manufacturer, but rather the by customer.

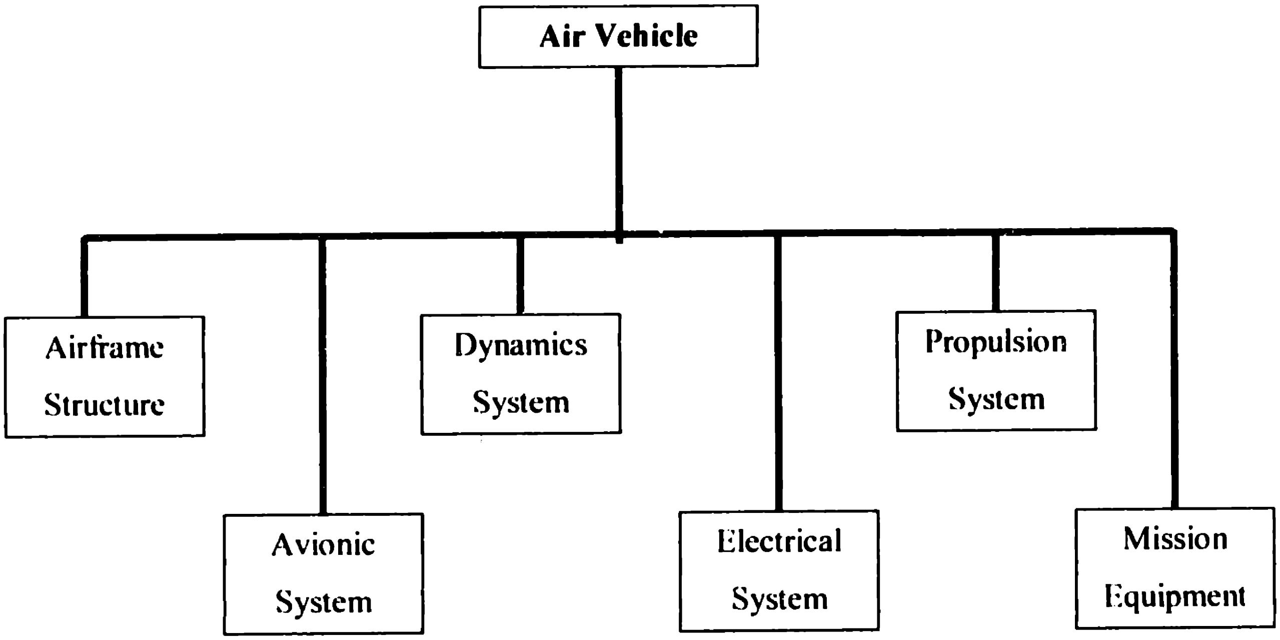

Figure 13 - S70A Architecture

Given this decomposition, below is listed the six major sub-sections of the aircraft followed by a brief description of each.

5.3.1 Structural System

The structural system for the helicopter is comprised of all the load bearing components on the vehicle. The structural system is further broken down into four major sub-sections. Any feature within the helicopter that bears a structural load either during flight or at rest can be inserted into one of the following categories.

5.3.1.1 Primary Airframe

The primary airframe structure is defined as those members of the airframe whose failure would result in the loss of the vehicle. Bulkheads, frames and butt-line beams are all components of the primary airframe structure. Typically, these pieces of structure are fairly heavy machined aluminum components with a large number of fastened interfaces to permit transfer of the carried structural loads along the appropriate distribution path. The primary airframe is comprised of five separate areas. These are cockpit, cabin, aft transition, tailcone and tail pylon. Together these sections when joined form the primary airframe system. Lower level interfaces called joinings are established between these five areas. The establishment of these interfaces and their configuration was mainly a function of producibility reviews of the structural design. Operator access, assembly tool needs and safety are some of the producibility constraints that were part of the interface definition for a joining. The current configuration for most of these interfaces requires much alignment tooling and fastener installation. Weight reduction, elimination of redundant structure and lower part count are all drivers that typically lead to this type of joining scheme. The converse is that more assembly time per unit is required and the opportunity to modify the joining is constrained due to the numerous structural interdependencies at the join. Significant changes to primary structural areas usually include doublers, high fastener counts and other structural components to allow for load distribution.

5.3.1.2 Secondary Airframe

The secondary airframe structure is the portion of the aircraft structural system that provides structural support for the non-flight critical features of the vehicle. Examples of secondary structure include the external aircraft skin, cabin and cockpit floors, and the cockpit windshield. Each of these type of components does bear a structural load, but its failure does not render the vehicle inoperative. The interesting feature of secondary structure is that it often has an opportunity to become primary structure or at least see an increase in its structural loading during modification. A secondary airframe component will reside within one of the five sections described in the primary area. There are some skin assemblies that will overlap a major join by one or two rows of fasteners, but these are the exception that make the rule. Secondary structure generally has fairly specific interfaces to the airframe. As an example, the windshield for the aircraft has these characteristics. It resides solely within the cockpit section and it interfaces along a compound curved surface with a large number of fasteners holding it in place. Another example of secondary structure is the cabin cargo door. The aircraft can fly with the door removed and it is also structurally capable of containing personnel and equipment within the cabin. The door is within the cabin section and interfaces along upper and lower door tracks specially designed for this door.

Secondary structure does become modular below the interface to the primary airframe section level. The cargo door can be highly modified as long as the interface to the remainder of the aircraft, the door tracks, are not affected. The windows within the door can be removed or modified or the door could be modified with external or internal storage systems. This third tier level provides much flexibility, if so required. As an example, given that many different missions can be performed by the vehicle this feature enhances the helicopter's ability to store equipment.

5.3.1.3 Fairings and Enclosures

The fairings and enclosures section of the airframe structure systems is made up of all the various access panels, covers and fairing assemblies added to the airframe to protect components from the environment, improve its appearance, and provide for better aerodynamic performance. This type of structure typically does not carry any significant load other than its own weight and attachment requirements. This type of airframe is usually highly shaped and may require significant tooling to fabricate. This dichotomy of structural insignificance and manufacturing cost significance leads the design team to try to reuse the component as much as possible throughout the design. An example of this type of structure would be the small fairings used to cover the shock strut for the landing gear. This composite fairing is made of kevlar with graphite-epoxy stiffening bands. It is highly shaped and has a long manufacturing lead time.

5.3.1.4 Interiors

The interiors section of the airframe perform the cosmetic role of covering the wiring and other system interconnects. Interiors are also used to absorb sound and protect flight critical systems, such as control rods, from damage or ingestion of foreign objects. Interior configurations range in complexity from the utilitarian to the ornate depending of the customers needs and the mission to be performed.

5.3.2 Dynamic System

The dynamic system of the helicopter architecture can be quickly defined by identifying the rotating parts on the aircraft. The very essence of helicopter flight is accomplished through the generation of lift through rotation about an axis. This action replaces translation of the entire vehicle through the air for lift creation as is common in fixed wing. All the lift and control of helicopter flight is created by rotating either an airfoil, shaft or gear. The dynamic system within the aircraft tends to be one of the most complicated. Below are listed three broad categories that can be used to further describe the overall dynamic system on-board the vehicle.

5.3.2.1 Rotor System

The rotor system for the helicopter consists of the main and tail rotors or blades. The S70 has four main blades and two, two-sided tail rotor blades that create four airfoil surfaces. The rotor system essentially interfaces with the rest of the helicopter through the gearbox mountings for the tail blades and the rotor head for the main blades. The close coupling of the blades to the remainder of the helicopter does not permit much of a modular or distinct interface for the blades, but given the complexity of blade manufacture and the assets needed to design a blade, an interface of convenience is established here. In other words, the necessary configuration of the interface requires that the structure of the helicopter accommodate the rotor system. In strict terms this means that the attachment of the rotor system to the aircraft may not be an interface at all since both sides of the attachment remain fixed. This does not fall within the strict definition of interface since most interfaces are two sided with some flexibility to change one side or the other without affecting the integrity of the interface.

Another consideration of the architectural significance of the rotor system is the enormous resources needed to design and build a rotor system for a helicopter of this type. This overwhelming cost will likely skew the architectural context and drive system change around the rotor system design space as opposed to through the design space for the rotor system. As a percentage of the overall vehicle the rotor system may make up more than forty percent of the cost. Certainly, as a business entity, the company needs to apply its assets as required to ensure profitability. Effective understanding of the architecture of the delivered product will enable appropriate targeting of product capability to market.

5.3.2.2 Drive Train

While the entire set of components used to drive the main and tail rotors could be called the drive train, the following architectural definition will not include all these components. The drive train from an architectural perspective is the collection of components that connect the gear boxes to one another. This collection consists all the drive shafting between the main and intermediate gearboxes and then from the intermediate to the tail rotor pylon gearboxes. The basis of this portion of the architecture are the ground aluminum shafts that transmit the mechanical energy from gearbox to gearbox. Couplings at the terminations of these shafts allow for alignment and backlash control.

5.3.2.3 Gearboxes

The three major gearboxes within the rotor system interface within the architecture to perform two major functions. These are to transfer the mechanical energy from the power plants to the blade system and to transfer the force from the blades to the airframe. This dual requirement configures the individual gearboxes to be efficient in housing the gears themselves and also maintaining good structural continuity. Alignment of the input and output shafting for the gearboxes tends to be tightly specified. This is due to the nature of the gear trains within the box and the various angles and bevels of each specific gear. Gear cutting and shaping is a long lead design and manufacturing process. Even subtle changes in gear geometry can be costly with regard to tooling and qualification requirements. Generally speaking, once the design has been established for a gearbox, it generally stays fixed unless fielding identifies any specific failure mode that must be corrected or a major upgrade program in undertaken. Gearboxes are another architectural element that tend to have a one-way interface. The structural interface tends to be fixed and tooled to close tolerances. This permits efficient transfer of structural loads through tight coupling. The internal assembly tends to be fixed due to its need be maintain input and output angles and axes for energy transfer.

5.3.3 Electrical System

The electrical system for the aircraft tends to be broken into three chunks. These are; generation, distribution and lighting. These three chunks allow for interface and power supply to all components. The lighting aspect tends to fall into the electrical system basically due to its limited functionality and view that lights are end users of electrical power only, require no signal and perform no signal processing.

5.3.3.1 Electrical Generation System

Electrical power generation for the S70A is performed by two generators mounted to the forward input modules of the main gearbox. A specified output shaft within the accessory case is used to drive the generators. The mounting of the generators is facilitated by six bolts holding the generator which is cantilevered off of the accessory case. Three heavy gauge wires connect to terminal lugs on the generator to transfer the electrical energy to the power distribution boxes. The need to mount the generators near available energy for rotation of the armature and the need to be able to connect to the remainder of the electrical system drives the interface requirements for the electrical generator. These devices are usually designed and qualified to the interface specified by the overall vehicle architecture through extensive testing programs. Generators are made almost exclusively by firms specializing in their design and manufacture.

5.3.3.2 Electrical Distribution System

The distribution of electrical energy throughout the helicopter is performed by routing bundled wire harnesses within the airframe. Consideration of the requirement to maintain separation of the various types of wire harnesses due to the electromagnetic fields generated during current and signal transport causes power, signal and grounding wires and harnesses to be routed differently. Additionally, clamping frequency, proximity to flight controls, required bend radii and other physical constraints must be considered. Architecturally, the electrical distribution system is quite flexible with regard to change of both configuration and capability. Wire bundles are naturally adaptive to change and can be split or clustered as required. Also, remote circuit breaker panels, junction boxes and various types of relays allow for the distribution of signal and power in accord with mission requirements. A remaining concern with the distribution system is the upper bound of available power. The two generators on-board the S70 helicopter each generate 23.8 kW of power. Should mission requirements exceed this available amount of power electrical load shedding protocols must be followed. This would mean that various non-essential systems would have to be shut-down to prevent draining of power. An example in which the architecture of the distribution system would be critical would be cold start at night of the helicopter in arctic conditions after an icing event. Here, all on-board de-icing systems would be employed and internal heating and required avionics systems would be activated. This combination of systems could easily outstrip the available power. Here, the pilot or co-pilot would then shut-down systems such as secondary communications and navigation equipment to permit power to necessary equipment.

5.3.3.3 Lighting System

The lighting systems on-board the S70 can be divided into two broad categories. These are internal lighting and external lighting. These two types of lighting systems are affected strongly by the mission requirements of the aircraft. Civilian operations tend to have one set of criteria while military operations (especially those perform in clandestined operations) tend to have another. While lighting requirements are primarily influenced by night operations, the need to illuminate either flight instruments, external features of the helicopter, or a desired location below the helicopter are all performed by the helicopter lighting system. Architecturally, the lighting system must provide the required illumination, attach in a structurally appropriate manner, and interface with the power system of the helicopter. Secondary requirements are that the system be compatible with night vision systems and infrared viewing systems. The interface for lighting systems can be modified to a fairly high degree. Internal lighting generally consists of instrument illumination and interior lighting. Instrument lighting is usually facilitated by illuminated bezels or backlit panels. These lighting bezels are generally provided by the supplier of the instrument. Interior lighting however may be a different issue. Lighting sources are available for integration, but their attachment and use are a function of the vehicle assembler. Here, the interface to the remainder of the architecture needs to be designed and fabricated on a case by case basis. For example, interior lighting needed in a medical interior requires the attachment of a controllable overhead lighting array. This array needs to be attached to withstand internal cabin crash loads as well as perform the needed function of lighting patients being transported.

5.3.4 Avionic System

The avionic system of the helicopter is further decomposed into three sub-systems. These are communication, navigation, and aircraft survivability equipment. The primary means of grouping these systems together is the ability to process signals. Communication, navigation, and survivability equipment all receive data, process the data, and display the data to the operator.

5.3.4.1 Communication Equipment

Generally speaking, the communication equipment on-board the S70 is for voice transmission. Both secure and non-secure verbal communications are facilitated by the communication portion of the avionic system. Many different types of radios using multiple bandwidths can be installed in the helicopter depending on the customers requirements and the mission. These communication systems may be simple VHF radios or sophisticated satellite communication systems. Also, UHF, HF, and Marine Band radios can be installed. Generally, the communication systems will also interface with the intercom system on the aircraft to permit personnel other than pilot and co-pilot access to external communications. Navigation equipment systems will usually include an antenna, signal processing unit, and a controller / display. It is typical for the S70 to have five or more different communications systems on the aircraft with some redundant systems.

5.3.4.2 Navigation Equipment

The navigation equipment on-board the S70 supplies the pilot with needed data to help him maintain controlled movement of the helicopter in a desired direction. Navigational aids ranging from simple non-directional beacons to global position systems are acquired and updated by equipment mounted on the helicopter. Generally, a navigation system, like a communication system, will include an antenna, display and a processing unit. It is typical for the S70 to have seven or more navigation systems on board the helicopter. Architecturally, interoperability is the primary concern regarding navigation equipment. Given the relatively small size of a helicopter, the number of emitters and receivers located within a confined volume and the power available to these systems, there is a need to assess the operating characteristics of each system with the other systems also in operation. This verification is usually performed during the ground acceptance phase of the program. Prior to the actual placing of the antennas on the aircraft, an antenna arrangement drawing is created to ensure proper antenna positioning based on electromagnetic theory.

5.3.4.3 Aircraft Survivability Equipment

Aircraft Survivability Equipment or (ASE) are systems on-board the aircraft used to detect and confuse potential threats to the aircraft. These threats include fire control radar, laser designation devices and infrared seeking missiles. Typically, ASE is comprised of multiple systems mounted on the aircraft each performing a specific task or function. In a similar sense to the other avionic equipment, ASE will consist of an antenna, control head or display and a processing unit. The antennas will be mounted on the aircraft skin to provide maximum coverage for the specified task. The display will be mounted in the cockpit on either the center console or the instrument panel. The processor will be mounted in a suitable avionics bay, as required. Not all aircraft configurations get the same level of ASE installation. Some configurations will only receive the minimum level of equipment as denoted by the contract. This may be due to export license considerations or the possibility that the customer prefers to install his own equipment. In the latter case, only the provisions for the system may be installed. Given the sensitive nature of ASE is terms of security classification significant elaboration on these systems is not appropriate in this work.

5.3.5 Propulsion System

The architecture of the S70 propulsion system is related to all systems and sub-systems required to turn the main and tail rotors in order to achieve controlled flight. These system must behave in a coordinated fashion due to the high degree of coupling in the flight of a helicopter. Inputs in any of the three axis of flight; roll, pitch and yaw will affect the remaining two. Below the propulsion system are four major chunks. These are; engines, fuel system, flight controls and environmental system.

5.3.5.1 Engines

The S70 helicopter has two engines. These are mounted on the upper deck, above The cabin section. The engines themselves are self-contained turbo-shaft gas turbines and are capable of being installed on either the right hand or left hand sides of the aircraft. Interfaces to the remainder of the air vehicle consist of structural attachments, fuel lines, bleed air lines, air intake ducting and exhaust ducting. The fuel line is a single connection from the fuel system. It contains the necessary coaxial valves to prevent fuel spillage during line rupture. The structural attachment of the engines is accomplished through the use of attachment rods and separable hardware for upper attachment of the engines and engine mounts on the upper deck of the aircraft for lower attachment. The bleed air line is a single formed steel tube that attaches to the compressor section of the engine. Finally, the intake and exhaust ducting is wrapped around the engine. This ducting is actually part of the airframe, but interfaces to the engine to facilitate smooth airflow.

5.3.5.2 Fuel System

The fuel system is within the propulsion system due to the need to provide the gas turbines with fuel. While the fuel system could have its own architectural section based on its complexity, however, there is no reason to have a fuel system except to support the propulsion system. Therefore, the fuel system is subject to second tier placement with the architecture. At the fuel system level there are three major chunks. These are fuel storage, fuel transport and fuel control. Fuel storage is facilitated by the fuel cells mounted in the aft transition of the aircraft. Fuel transport is made by the various fuel lines, pumps and valves within the systems. Fuel control is the collection of gauges, measuring probes and displays on-board the aircraft.

5.3.5.3 Flight Controls

The flight control system within the propulsion system directs the mechanical energy created by the propulsion system to allow for directed flight of the helicopter. The architecture of the flight control system can be cleaved into two major sections. These are main rotor control and tail rotor control. The flight control system for the main rotor is comprised of cyclic and collective sticks that are mechanically connected to the rotorhead of the aircraft. The flight control system for the tail rotor consists of pedals on the forward cockpit floor are mechanically connected to the tail rotor. Additionally, both systems have automatic stabilization and control systems available that simply control the system similar to the pilot or co-pilot through electro-mechanical inputs to the system using servo motors.

5.3.5.4 Environmental Control System

The environmental system is also part of the propulsion system due to the requirement for either pressurized air or heated air or both as a basic environmental system need. Heating of the occupied spaces of the helicopter is accomplished by drawing bleed air off of the compressor sections of the engines. This hot compressed air is mixed with ambient air to provide the desired temperature and air flow to the occupants. Bleed air can also be used to run the air conditioning system to provide cooler air to the occupants if desired. Finally, should there be a requirement for an on-board oxygen generation system or OBOGS, bleed air can be tapped to source of high pressure air to be filtered for that system.

5.3.6 Mission Equipment

Mission equipment is the final piece of the S70 architecture. Generally speaking mission equipment are all the systems directly used to perform certain operational missions. Mission equipment may not be installed on the aircraft all the time. As an example, an infant incubator is a piece of mission equipment. The necessary interfaces for power and structural attach must be on the helicopter, but the device itself may not be required for the mission at hand. Therefore, the incubator can be stored at the base of operations. Mission equipment can be a fairly exhaustive list of requirements that need to be considered. The important issues affecting the architecture of the aircraft are the composition of this equipment on the aircraft at any given time and the interface requirements. This may lead to a variety of configurations for the aircraft and attendant tables describing the layout of the equipment for a given mission. Generally, the mission equipment, due to its removable nature, is mounted around all other systems.

6 Current Design Approaches for S70A Derivatives

6.1 Introduction

To date, over forty derivative models of the S70 helicopter have been contracted, designed, produced and fielded. These aircraft are in service all over the globe. In order to effectively facilitate the unique configuration requirements for these aircraft Sikorsky Aircraft has traditionally relied upon product teams formed for the delivery of the specific derivative model contracted. The criteria for establishing these teams was based on the need to address specific and unique features of the selected model. Price, quantity of delivered aircraft and program schedule were not normally the primary factors associated with the formation of a program team. The basis for this type of approach was largely due to the need to manufacture the aircraft in the same environment i.e. factory in which similar aircraft of common configuration are also being made. This need to manage the manufacture of a derivative aircraft in a more intensive fashion on the shop floor is a major discussion point of this work. Descriptions from the organizational and technical perspectives will permit further definition of the current derivative aircraft process and allow for linkage to a proposed platform derivative process.

6.2 Organizational Perspective

The contemporary approach to designing and building medium lift helicopters at Sikorsky Aircraft includes unique and distinct design and planning activities associated with the particular derivative model that is currently under contract. The design and planning activity required as each derivative model is contracted are effected as discrete programs. Additionally, due to sequencing of the different emerging efforts this activity is not always accomplished by the same team of personnel. As a result, the engineering data produced during these different programs is contained to the specific model and the team assigned. The result is that there is little transfer of engineering data between the different teams executing these different programs. Organizationally, the derivative team was originally controlled by program management. This scheme was replaced by separate integrated project teams. After integrated project teams, development operations emerged as the organizational structure used to run derivative programs. However, the next generation of derivative aircraft will be run within the platform teams currently being established at Sikorsky.

6.2.1 Program Management Scheme (Pre-1989)

The program management scheme originally used to run derivative teams was the way that initial derivative contracts were executed from an organizational point of view. Here, a program manager would establish schedules and budgets from distribution. Schedules were predicated on signed contract documents that determined the customers needs as matched with delivery profiles. After meeting with the program manager, the finance department would then allocate the appropriate charging mechanisms for cost tracking. Functional departments would receive the program work authorization documents and begin work. These functional departments would also track and

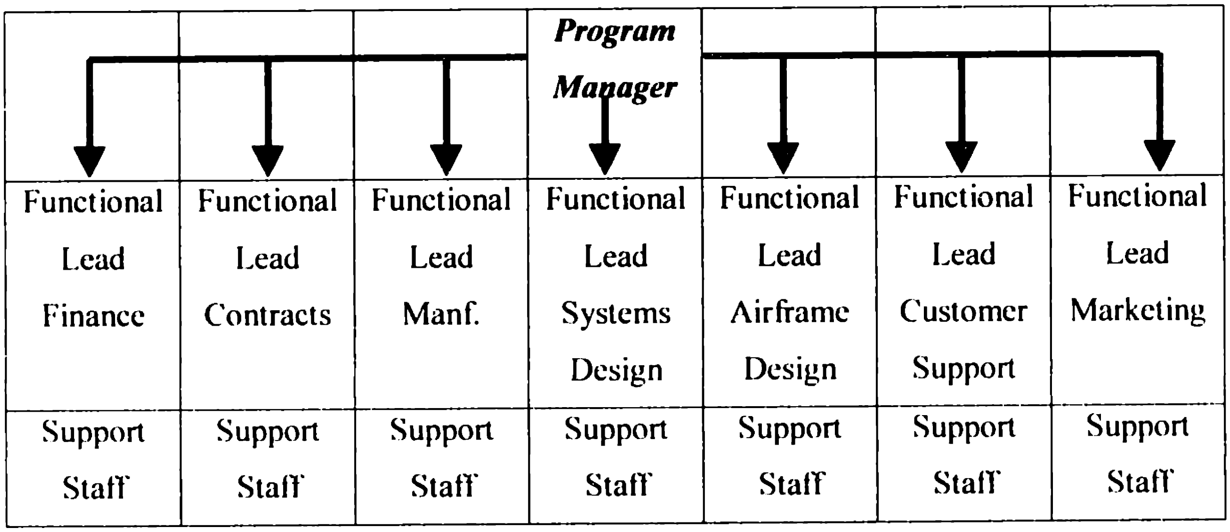

Figure 14 - Functional Organization Scheme

allocate the budget within their own departments. For instance, manufacturing engineering would have a budget group with all of manufacturing engineering whose purpose was to track and control budgets distributed to the department by various contracts. Formal meetings were the means by which important and day to day issues were communicated. Schedules and costs were segmented along functional lines and controlled by the functional manager assigned. As an example, the planning and tooling budget for manufacturing engineering would be controlled by a manufacturing engineering manager. The individual would staff and control the salary and hourly expenditure to perform the required manufacturing engineering tasks. Managers would manage to the assigned intra-department budget numbers. Typically, budget under-runs were reallocated to those functions in over-run conditions. This was the domain of the program manager depending upon the state of the program. Typical inter-departmental communications were along the lines of non-delivery or non-performance of upstream or downstream functions. Short-term goals included spending within profile and meeting program milestones. Longer term goals were not clearly defined at the department level except through broad schedule milestones such as hangar delivery dates, first flight and customer acceptance.

This organizational approach segmented the team along budget and schedule allocations. Typically, those departments upstream in the design / development process were not sensitized to the effects downstream caused by missed dates or poor quality. Usually, the design team had already expended its allocated budget even before the aircraft had been delivered to the hangar. Thus, development issues found during assembly and test required searching out the responsible individual, who was likely assigned to another effort and breaking him free to aid in diagnosing the issue discovered. For example, if an avionics box interfered with a piece of airframe structure, both the appropriate airframe and electrical design engineering personnel were sought. Then, a negotiation would take place as to the responsible party, then additional budget needed to be allocated, then the current workload of the assigned engineer needed to be deferred and work could begin. All the while, operations personnel are building the aircraft around this technical difficulty. While isolated issues during fabrication are not tremendous concerns, cumulative effects of many integration issues such as this could cause schedule slip. While marketplace changes required quicker design and manufacturing cycle times, the program management scheme was basically a legacy of prior business climates. Individuals worked hard within the above scheme and their efforts should not be belittled.

6.2.2 Integrated Project Team (1989-1995)

The integrated project team (IPD) scheme emerged in response to the perceived lack of performance of the program approach. The IPD consisted of assigned personnel that may or may not be co-located from all the required functional departments. These teams usually had set meeting times and personnel assigned typically only to support the current effort. IPDs were traditionally run by a program manager or operations manager. The IPD did execute the assigned programs faster simply due to easier communication and a single assigned project focus. Simply put, everybody was working on the same aircraft and could usually get up from their assigned workplace and walk over to the person that needed to be contacted for whatever reason. Individuals assigned to team were usually not given any particular training regarding the team structure or dynamics. This was usually a learned skill after being on the team for some period of time. Additionally, team members still reported to their home departments for basic job skills and performance reviews. The only day-to-day direction was supplied by the IPT leadership. As a team member, the individual was expected to be competent in his or her field and be able to performed assigned tasks. However, the resultant split reporting organization structure for individual team members proved too powerful a force against team cohesion. This was because individual performance assessments were still held by the functional organizations while the individuals daily workload was controlled by another manager. This lack of connectivity to the home organization supervisory structure led to individuals to communicating with supervisors not assigned to the IPD. This led to individuals working in an inconsistent fashion with the requirements of the team. The reasoning was simple. If performance was not based upon day-to-day performance, the individual was forced to rely on the stand-off direction of functional supervision to achieve favorable performance ratings and merit increases. Today, IPTs still exist at Sikorsky with the balance of these fundamental concerns still not addressed.

6.2.3 Development Operations (1995-1998)

The development operations scheme emerged as a response to the need to consolidate the team into a single department entity. Additionally, the need to have available experienced personnel assigned also become apparent. The original vision for the Development Operation included performance review responsibility. The development operation approach required the establishment of an entirely new department within the company. In a downsizing environment this proved to be extremely challenging from a justification point of view. The essence of the development operations approach was the use of a core team made of individuals who have been transferred from all the functional departments needed to execute a derivative program. The core members have the responsibility of providing the necessary skills to perform the program while also seeking additional manpower from the functional departments on an as needed basis. Core members all report to the director of development operations and have the same department number. In this scheme, the project in jointly controlled by a team leader and the program manager. The team leader's role is to insure internal cost and schedule requirements are maintained. The program managers role in to provide customer interface and any other activities external to the company.

6.2.4 Platform Teams (1998 and Beyond)

The platform team scheme is the current organizational approach at Sikorsky. Here, entire teams are collocated with all functional capabilities resident within the team. The teams are broken along helicopter model lines. As an example there is a platform team for the UH-60/S70A helicopter. This team handles all contracts for the helicopter irregardless of the customer, configuration or quantity of aircraft delivered. Both production and derivative configurations are handled by the team. Individuals assigned to the team are reviewed and rated by the platform team leader. This approach allows for total integration of the effort from proposal to delivery and after sale support. Team leaders are selected by the platform leader to perform individual aircraft builds as contracted.

All the various schemes for organizing the team to allow for a derivative aircraft program rotate about common themes. The team must be able to communicate the issues associated with the aircraft program as well as use the learnings from program to program as the team encounters like problems on different aircraft.

Effective Dates	Type of Organization	Characteristics	Strengths	Opportunities
Pre-1989	Program Management	Hierarchical, Vertical Integration	Strong Functional Skills Maintained	Slow Response Time
1989-1995	Integrated Project Team	Diverse, Project Focused	Fast Information Flow	Team Training Requirements
1995-1998	Development Operations	Small, Cross-Functional	Multi-Disciplinary	Poor Interface to Enterprise
1998-Beyond	Platform Teams	Full Model Responsibility	Knowledge Retention	Multi-Project Skills Required

Figure 15 - Organizational Schemes

6.3 Technical Perspective

Aside from the organizational issues associated with derivative programs there are fundamental issues with the basic vehicle. The helicopter itself was never designed to fully fulfill the role of a platform. Certain utility features permit the installation of additional systems, but these installations usually require structural and systems modifications to the vehicle to facilitate their functioning. These systems may also operate at less than optimal due to installation constraints. An example is the installation of search lights onto the aircraft that cannot be moved through their complete available axis of rotation due to interference with the airframe structure, ground clearance or electro-magnetic compatibility. There are many other customer driven systems installations that would available to the market place had the basic vehicle utilized a platform design approach.

6.3.1 Current Derivative Structural Design

The structural design activity for derivative aircraft generally centers around the need to physically attach a modification to the airframe. Safety considerations are a primary requirement that must be addressed here. Crash loads, in-flight dynamic performance, and environmental tolerance are also significant considerations during this process. Given the development of technology since the inception of the basic airframe, the needed structural provisions for the modification often require the addition of structure to the aircraft. This addition of structure may range in complexity from simple sheet metal clips and brackets to highly shaped composite components. The ability for the basic UH-60 to accommodate these structural changes usually requires some form of structural analysis to verify that the integrity of the vehicle has not been altered in any adverse way. This two-fold requirement of part design and verification generally requires two design personnel to complete the task. One person will be from airframe design and the other from stress engineering. During significant modification efforts, some iteration may occur between the design and stress analysis communities to ensure that basic performance criteria of the vehicle are maintained.

6.3.2 Current Derivative Electrical Design

The electrical design activity common to the derivative aircraft program again relies upon the basic UH-60L design for it starting point. Changes to the basic configuration are identified from the aircraft specification. The electrical design will encompass the need to get electrical energy to the avionic, lighting, and mission equipment. Analysis of the change in electrical loading is required to ensure electrical generation capabilities onboard the aircraft are capable of supplying the additional equipment installed. Wiring schematics, harness routing, and equipment mounting drawings are all deliverables from the electrical design activity. Typically, during the fabrication phase of the initial aircraft of a unique configuration, additional electrical design support will be required by the operations community fabricating the aircraft. Also, schedule and cost constraints may cause the design to lack the usual fidelity seen in full production programs. Higher than normal capability is usually required from the design engineer doing the electrical design on a derivative aircraft given the need to have full understanding of the basic aircraft.

6.3.3 Current Derivative Avionic Design

The avionic design activity common to a derivative aircraft program is in many ways the center of the modification design effort. It is the avionic systems on-board the helicopter that often directly drive the changes needed in other portions of the aircraft architecture. This is a basic response to the most rapidly evolving section of the aerospace industry in general. Basic airframe shapes and vehicle configurations have essentially remained intact since the early 1950's. However, changes in the electronic industry as a whole have created secondary effects in the avionics industry. Higher processing power, lower power requirements and smaller packaging have enabled more capability within smaller volumes. This permits greater mission capability and a greater amount of information to become available to the operator. While there are mechanical similarities between the electrical design function and the avionic design function, a major difference between the two is in the operation of the aircraft. The avionic engineer deals with the electronic systems on-board the helicopter once the systems have been installed and powered. Here, the avionics engineer will write and assist in performing acceptance tests during the initial install, ground testing and flight testing phases. This includes the engineer being on-board the aircraft during ground runs and initial flights. Given the non-uniform nature of the derivative aircraft specification, procedures may have to be altered in real time to address any discrepancies identified during this initial testing of the aircraft systems.

6.3.4 Current Derivative Missions Systems Design

The design activity associated with the mission systems requirements for the derivative aircraft centers around the customer's need to perform certain missions. Often the customer has a wide array of missions that need to be supported by the aircraft. This being the case, the integration of various systems on-board the aircraft becomes the basic challenge for the mission systems engineer. An example of this type of integration conflict would be in the installation of an internal rescue hoist and medical interior. Here, both systems are looking to occupy the same section of the cabin floor. Modification to one of the two items, either the medial interior floor or the rescue hoist mounting provisions, must be made. While this example may sound trivial, the issue remains central when logistical support and spares / repairs need to be obtained. Unique equipment out in the field remains a significant cost driver over the entire vehicle useful life.

6.4 Business / Financial Perspective

Derivative aircraft manufacture can be profitable. While the quantity of actual aircraft fielded may be lower, the margin per aircraft may be higher. This is usually due to the uniqueness of the configuration as well as the tailored nature of the helicopter towards specific customer requirements. Often the initial proposal to a customer will not be completely comprehensive with regard to the final delivered configuration. The final configuration will be determined after across the table discussions with the buyer have occurred. The reasoning here is that often the derivative customer will have certain key technologies that he needs integrated into the aircraft that may not be completely known to the derivative aircraft team. The customer needs to understand the complexities associated with these integrative issues as well as any trade-offs in performance of the selected combinations of systems. An example here may be the installation of a FLIR and a searchlight in the same location on the aircraft. The field-of-view for either system may be hampered if the two systems are located to close together as dictated by a customer requirement. That requirement may be that the aircraft must look symmetrical with regard to externally mounted features or there may be certain ground clearance issues in the operational environment of the customer.

7 Discussion of Platform Design

7.1 Introduction

A platform is a type of product architecture. Product architecture is the scheme by which the function of a product is allocated to physical components [Ulrich, 1995]. There are many different types of product architectures available to define and describe a product or system. Integral, bussed, modular and slot [Ulrich, 1995] are all types of product architectures. This work looks to focus on platform architectures only. There are several reasons why the larger discussion of product architectures must be only referenced in this work. Because product architectures may not be limited to the physical form of the delivered system to the user and additional effort to bound the system is required. This is so because the architecture may include the environment within which the system is used and the associated interfaces. This work looks to address the intra-system aspects of the helicopter with the vehicle itself being the limit of the system as described in chapter 5.0. This will provide a rigorous framework within which platform designs can be more fully described by recognizing this one type of architecture within a possibility of many.

Within this thesis the architecture of a helicopter has been referred to often. The discussion will now focus on platform designs as an architectural scheme. A platform design is similar in many ways to a bussed type of product architecture. A bus architecture permits a variety of different types of components to be installed onto the bus using the same type of interface [Eppinger-Ulrich, 1995]. A major difference between the bus architecture and the platform architecture is in the definition of this interface. While a bus design will enforce that the interface to the bus be common at all locations. The platform design is not as rigid in the definition of the interface. While there must be a defined interface to fully exploit the benefits of the platform, it need not be identical for all interfaces within the architecture. In fact, the interface may not even be resident within the system when originally fabricated, only fully understood and capable of being deployed when needed. The primary reason for this difference lies is the frequency of need to reconfigure the system [Clark-Henderson, 1990]. A true bussed design may require reconfiguration of the system very frequently, while the platform architecture tends not to have this requirement. Platform designed systems tend to remain in mostly the same configuration for their entire useful lives with discrete pieces of the system being changed. Platform designed systems also tend to serve the same purpose for their entire useful life. In the case of helicopters, avionic systems may be upgraded for an aircraft, but most likely it will perform the same mission e.g. search and rescue, cargo or troop transport. The interface for the specific added features tends to be more of a design and manufacturing pathway as opposed to a readily modified system attribute. In other words, there is a fully defined interface, but the interface is defined by engineering data as opposed to a physical entity. It is important to note two major thrusts that could originate from this point of view. Over time, a system could be modified after fielded or a new system could developed using pieces of existing designs. Both the modification scheme and the new hybrid scheme are facilitated by platform design approaches. Whether either or both schemes are used is a function of company strategy. The point being that this design approach could add an addition degree of freedom while formulating that strategy.

7.2 Why Platform Design in the Helicopter Industry?

The aerospace industry today continues to be subject to the economic, political and technical realities of a shrinking market. The non-recurring costs of developing new helicopter systems continues to rise and will do so for the foreseeable future. System complexity is the main driver of cost growth [Lundqvist et. al., 1996]. As systems increase in complexity design integration becomes more challenging requiring more highly skilled personnel. The types of equipment being integrated into the helicopter are more costly due to higher functionality. Finally, macroeconomic factors such as inflation and exchange rates also affect the cost structure, especially in international sales.

Politically, shrinking defense budgets have reduced the available capital being spent on aerospace products both domestically and abroad. Political factors may also require that long term joint ventures or offset agreements be established as part of the aircraft contract. Technically, the lead-time needed to integrate and certify new aircraft systems has increased simply due to the higher complexity of these systems. Coupled with this increased design lead time will be an increase in the manufacturing assembly and test lead time. Here, the integrative nature of the helicopter needs to be verified over a wider array of test protocol. It simply takes longer to perform more of these types of tasks. While there are other perspectives that have an affect on the industry, these three provide a good starting point for the platform design discussion.

The economic perspective probably contains the most persuasive argument for the implementation of a platform design approach. A major feature of platform designing includes the re-designation of exiting designs for newer models. For new designs, the new-used hybrid scheme permits re-use of systems and sub-systems already designed and fielded. While this may not be a completely off-the-shelf design protocol, significant cost reductions could be realized by this approach. For fielded aircraft, the ability to re-configure a fielded aircraft provides the opportunity for product renewal at some point and the opportunity for additional revenues to be generated by the original helicopter OEM or designate. Given the length of time that these types of aircraft remain in the field, there is a strong possibility for modification after fielding.

The political perspective ties to the economic to some degree, but a large weighting can given to the current industry trend of consolidation and cross-country joint ventures. The ability to cleave a design through the use of platform designs facilitates transfer of design and manufacturing data to permit the spreading of cost across many organizations more efficiently and effectively. The design and manufacture of sub-components could be performed remotely and integrated elsewhere. While this integrated supply chain approach is not new in consumer goods, it is still in its infancy in the aerospace industry. A major hurdle that must be overcome is the need to protect propriety information and intellectual property. A well partitioned design will allow for the needed compartmentalization as well as interface control which will reduce the potential exposure to intellectual property loss. This political view also stems from the need to communicate across cultural, time-zone and language barriers as well. If a design is well executed, it will communicate itself to a large degree as opposed to needing continuous translation by the creator. It is this translation feature that can be very costly. In other words, dispatching pieces of the design team to remote locate to enable a partner to manufacture a portion of the needed design is both undesirable and costly.

The technical perspective is the major theme of this paper. However, here it is important to remember the safety, reliability and performance are measures that are applied to helicopter designs. Safety of air vehicles is a function of use. The more a system is used, the better the understanding of its capabilities and limitations. Re-use of existing systems allows for greater understanding of any safety related concerns quicker in the design process based on the fact that there is data available about its use. The same holds true for reliability and performance. Additionally, coupled with safety is the need to certify to the appropriate agency the airworthiness of the vehicle against an accepted set of standards. Certification of a system already deployed is faster and more cost effective than certification of a system that is completely new.

An important caution here. The goal of platform design is to maximize available technology not stifle development of newer technologies. All technologies were new at some time. Truly effective platforms can adapt to these newer technologies and continue to be effective [Clark-Wheelwright, 1992]. However, the innovation road is uncertain and unpredictable. In conservative businesses such as helicopter manufacture it may be a more successful approach for the enterprise to creatively blend current and accepted technologies as opposed to untried and unproven technologies. Platform design schemes facilitate this.

7.3 Incremental and Radical Change

Another important factor regarding the use of platform design approaches stems from the product life cycle and patterns of innovation. These factors are time based as opposed to the above factors which are policy based. Time based factors are often difficult to quantify because they are based on projections of the future. The business case to satisfy questions regarding how a product life cycle will evolve and what patterns of innovation will emerge is a function of a vision into the future. The linkage to platform design is fairly straightforward. In the case of product life cycle, more flexibility to address future customer expectations is available. In the case of patterns of innovation, the ability to dip into the available, changing technology stream becomes easier for the enterprise. Each perspective requires additional elaboration.

"In this environment (well defined markets) innovation is typically incremental…" [Abernathy-Utterback, 1978]. To a large degree, the market for most aerospace vehicles has been well defined for several years. Air vehicle designs have been of like configurations since the World War Two era. The last radical change to take place was the introduction of jet transport aircraft (e.g. the Boeing 707). This being the case, the realm of innovation is narrowed from radical to incremental improvements. Incremental improvements are distinct changes in the sub-systems of the aircraft. For example, material changes will affect the structural system of the aircraft. Changing from metallic construction to composite construction illustrates this. While the basic geometry and shape of the vehicle remains largely the same, the method of part fabrication and aircraft assembly will be substantially different. Further, the aircraft may see increased range and higher payload capability due to the decrease in structural weight.

Changing technology also represents a future challenge to the air vehicle. When an air vehicle architecture is determined, the types and levels of available technology are known. It is fundamental to any industry that technology will change over time. This change in technology will not only affect the way that the vehicle functions but also the way it is designed and the way that it is built. Again, flexibility to address this change affords the enterprise the opportunity to incorporate this newer technology. An example here is the incorporation of global positioning systems for navigation illustrated in the following section.

7.3.1 GPS Incorporation into S70A Helicopter

The integration of global positioning navigation systems (GPS) onto the S70A helicopter illustrates many aspects of platform design. When the basic UH-60 aircraft was fielded there was no reliable method of navigation via satellite signal. The emergence of reliable satellite navigation occurred well after several thousand helicopters had already been fielded. The technology to navigate via satellite signal was attractive enough that several operators expressed their desire to have the system installed on their aircraft. Furthermore, new aircraft sales also required that a GPS be part of the basic configuration of the aircraft. The original S70A, however, had no provision for this type of system because it was not part of the basic helicopter.

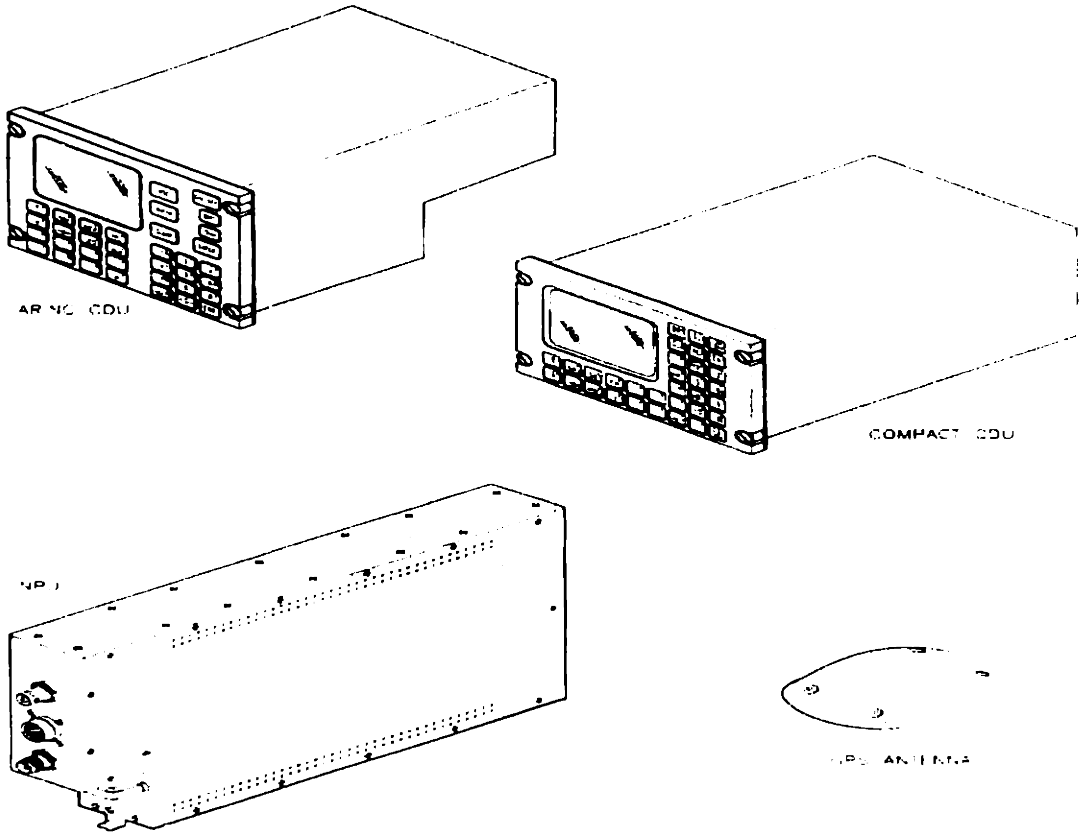

Figure 16 - GPS System Components

There are three basic components associated with a GPS; the display, the processor and the antenna. Wiring for power and coaxial cable for signal provide the needed interconnectivity for system operation. The display will visually relate to the operator the position of the aircraft and the condition of the system. Data displayed will include items such as; the time, number of satellites acquired and ground speed of the aircraft. The display is usually located on the center console inside the cockpit. The processor is the device which converts the signal received into electrical and signal data needed to operate the display. The processor is usually mounted remotely in an avionic bay on the aircraft. Signal wire from the antenna and power supply wire harnessing are routed though the airframe to the processor. In turn, a wire harness runs from the processor to the display. The antenna for the GPS is mounted on an external surface on the aircraft. A skin penetration is required to mount the antenna and facilitate the coaxial cable run from the antenna to the processor.

In general, a GPS system can fall into two broad systems categories. These are integrated and dead-ended systems. An integrated system will interface will other aircraft systems to provide navigational data. For instance, a moving map display may take navigation data from to the GPS to automatically update the position of the helicopter as displayed to the pilot. Dead-ended systems are not interfaced with other systems. The GPS data is displayed on a control panel. This may be latitude and longitude of the aircraft or grid coordinates or some other operator selected means of describing the position of the aircraft. The data is not used elsewhere.

Given this general understanding of a GPS, the task at hand became integrating the system onto the helicopter for both new and fielded aircraft. The matrix below describes the ease with which a GPS could be incorporated given the type of system and the type of aircraft. A discussion of each cell on the matrix has its own issues that need to be addressed.

	New Aircraft	**Fielded Aircraft**
Integrated	Difficult	Extremely Difficult
Non-Integrated	Easy	Moderate

Figure 17 - GPS Installation Difficulty Matrix

The installation of an integrated GPS on a new aircraft is difficult due to external constraints. The architecture of the interfacing systems generally do not use the current state of the art. This means that items such as interfacing software may need to be revised using legacy software code to allow communication with other on-board systems. This reverse engineering can be time consuming and costly.

The difficulty experienced at the new aircraft node for integrated systems is even more pronounced at the fielded aircraft node. The major complication here is that subsequent modifications may have been performed on the aircraft that affected the interface after the aircraft was fielded. Often there is little or no documentation associated with these follow-on modifications. This tends to lead to an extended checkout period once the system has been physically installed on the aircraft.

The installation of a non-integrated GPS on a new aircraft is easiest node on the matrix. Here, physical space is the only constraint. Once locations for the major components is identified, the interconnecting wiring is run. At that point, the system is completely installed.

As expected, the installation of a GPS on a fielded aircraft is similar to that of a new installation with one major exception. That is, new locations must be found and wire routing paths accessed. Once this has been accomplished and the system is supplied with power, the installation is complete and checkout can begin.

The GPS installation scenario is typical of a non-platform design approach. It has all the elements of a point design being modified to enable the incorporation of a newer technology. All the subsequent decisions that need to be made after the acceptance of GPS technology are required only due to the fact that the organization did not use the platform design thought process. The decisions about integrated as opposed to non-integrated and new as opposed to fielded could all have been decided months and maybe years prior to actual customer demand. Yet, in retrospect the organization did not perform poorly, it just performed with a limited time horizon.

7.4 Successful Platform Designs

"The platform approach to product development dramatically reduces manufacturing costs and provides significant economies of scale in the procurement of components and materials." [Lehnerd-Meyer, 1997]

7.4.1 Product Change

Product change, as denoted by the GPS story in section 7.3.1, is a fundamental need that is fulfilled through the use of platform designs. Whether the need is to develop a different product from the factory or alter it after it has been fielded, this can be accomplished with less total effort if a platform architecture is used as opposed to unique "point" design. Product change can take many forms. These include upgrade, ad-ons, adaptation, wear, consumption and flexibility in use [Ishii and Martin, 1997]. Remembering that product change usually includes some functional change relative to the previous model, it is the platform architecture that permits this efficiently [Sanderson-Uzumeri, 1995]. Otherwise, basic systems within the product would have to be re-developed to perform similar functions already available through the platform.

7.4.2 Change Complexity

The characterization and quantification of product change determines a true measurement of platform design effectiveness. The measurement of change complexity can be made from many perspectives. These perspectives may be as simple as part count addition, number of aircraft systems affected, or overall life-cycle cost change for the aircraft. The complexity of change when compared to the ease of incorporation has the potential to gage the effectiveness of the overall platform design. Like complexity, ease of incorporation also needs to be measured. Potential measures of ease of incorporation may be design engineering man-hours required, aircraft assembly hours or total out of service time for the aircraft. For instance, if minor configuration changes cannot be easily inserted into the aircraft configuration, the baseline platform design may not be fulfilling its intended need. Conversely, if complex product change can be readily incorporated, then the system design would be considered a good platform.

While change complexity remains a difficult concept to gage, ease of incorporation measures all seem to gravitate towards a common measure of time. Design hours, fabrication schedule and aircraft out of service periods all can be translated into temporal units.

7.4.3 Interface Levels

One perspective regarding platform designs could center about interface complexity. Remembering that a system architecture may be viewed as discrete building blocks and the interfaces between them. To a large degree, it is within individual blocks of an architecture that change can manifest itself. Associated with the change of individual blocks are the interfaces that the blocks make with the rest of the system. The understanding and complexity of these interfaces affect the ease with which changes can be made to the individual blocks within the architecture. Accurate control and mapping of all interfaces enables quick understanding of the magnitude of the proposed change.

To draw relation to the GPS example the system itself could be a block with the structural and electrical interfaces being described. Another opportunity to describe the interfaces could be based on the mounting of the discrete components and the structural and electrical interfaces involved. For example, the antenna for the system needs to be structurally mounted to the aircraft skin and a coaxial cable needs to be run from the antenna to the processing unit. The antenna could be viewed as a block of the architecture with the structural and electrical requirements being the interface. The characteristics of the structural interface could be further described and weighted in terms of complexity. For instance, the antenna has four nutplate locations that need to be installed on the skin to affix the antenna to the aircraft. There is also a need to ensure electrical bonding of the antenna to the electrical ground plane of the aircraft. These are two key characteristics of the structural interface. While these are fairly simple to describe and could carry a lower complexity weighting, an understanding of this interface is essential should future change be required. This interface mapping could be performed for all systems and provide insight to the design team as to the locations within the helicopter architecture that may be likely to change.

7.4.4 Assessment Perspectives

An effective platform design needs to be assessed along many axes. Many of these views are not necessarily a consideration for the immediate design task at hand. This situation moves the decision making role from the individual designing to that of the program lead designer and program manager. The reason for this transfer of responsibility is simply one of visibility. The component designer has a sufficient number of constraints on his particular task that will only serve to hinder the complete understanding needed for the platform aspects of the design to be fully exploited.

The other two axes of consideration for effective assessment of the platform design have some temporal quality. Since the primary focus is on the future of the helicopter, there is a need to understand the future uses of the vehicle. The questions that need to be asked and answered include the integration of newer technology, its method of manufacture and the costs associated with its integration into the vehicle manufacture and use.

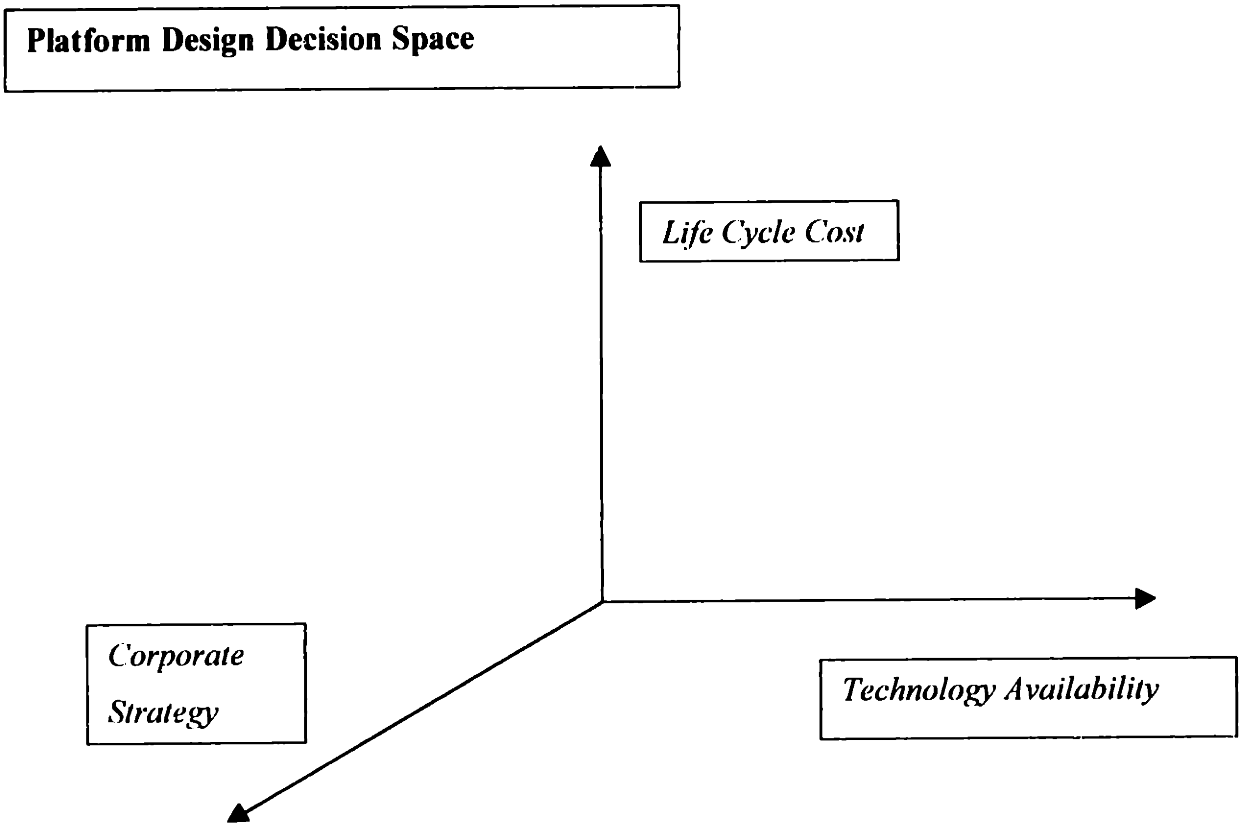

Figure 18 - Platform Design Space

One axis of consideration is the emergence of technology that will directly affect the design of the vehicle. The understanding of this technology infusion and the ease with which it can be accommodated by the baseline design is core to any effective platform design. The S70 line of Sikorsky helicopters has been subject to numerous technology changes. These changes are mostly in the avionics area. While technology has permitted some discrete structural changes and some vehicle performance enhancements, these are far outweighed by the changes made in the avionics realm. The main reason for the infusion of technology is the secondary effects of a competitive market place. In other words, in order to compete, the technology offered elsewhere in the market place must also be available in the S70. To have the S70 incapable of integrating this needed technology creates disadvantages from the customer's point of view. It also forces other features of the helicopter to be more heavily scrutinized when the entire vehicle is considered by a potential customer.

Another axis of consideration for effective platform design is the overall manufacturing capability strategy the company is determined to pursue. A design that incorporates features that are not consistent with the internal or external manufacturing capabilities, both current and planned, will cause difficulties during future fabrication of the vehicle [Robertson and Ulrich, 1998]. Here, as is the case with the technology axis, there is a time dependent portion of the analysis.

For most large companies, the manufacturing strategy of the organization evolves over time. Often the configuration of the manufacturing side of an enterprise when a platform design is conceived will not remain the same over the life of the platform. Certainly, the outsourcing of components that make-up the design is a manufacturing consideration. The need to understand how newer installed systems are to be manufactured and installed is required regardless of where they are fabricated. The enterprise has the opportunity to relieve internal organizations of the more typical types of manufacturing requirements through outsourcing. This permits an internal focus on newer technologies as the demand for these technologies to support the platform is required.

The last axis of consideration is life-cycle cost. Life-cycle cost needs to be understood from two perspectives in the case of platform design. The first is the cost associated with the activities prior to delivery of the vehicle to the customer. The second is the cost associated with the activities while the vehicle is in service with the user.

The optimization of this space would include a low life-cycle cost product within the strategic vision of the enterprise while taking advantage of emerging technology. While this may be posed as the ideal case, it is important to make these type of frame work assessments to enable discussion within the team as to the direction the platform is taking overall. The design space is discussed below.

7.4.4.1 Life Cycle Cost / Technological Availability

A comparison of the life cycle cost and the technology available could be framed in terms of technology maturity. The newer the technology being incorporated into the design, the higher the life cycle cost [Arend, 1985]. Therefore, a trade study between the overall maturity of the technology being incorporated into the design and the expected life cycle to maintain that technology is helpful to describe the cost impact to the user of the helicopters maintenance.

7.4.4.2 Life Cycle Cost / Corporate Strategy – Capability

A comparison of the life cycle cost and the corporate strategy and capability describes how long the enterprise will be associated with its product after the product has been fielded. If the company will be required to support the aircraft after deployment, the life cycle cost will be of concern. If there is revenue to be gained by the sales of spare parts and technical support there may be a different view of the life cycle cost. However, both reviews allow the organization a comparison based on its internal strategy and the need to address both short and long term commitments to fielded aircraft.

7.4.4.3 Technology Availability / Corporate Strategy - Capability

The comparison between technology availability and corporate strategy will determine whether or not the product will be using newer technologies or established technologies. A review of the user community, the internal organization and the suppliers of this newer technology will frame the speed of adoption for the incorporation of the technology [Benton. 1995]

7.4.5 Platform Threshold Concept

The concept of the platform threshold is based on the ability of a platform design to facilitate change within tolerance levels determined by the enterprise. This ability is based largely on the enterprise's ability to make significant change to the aircraft within constraints defined by the company. The below schematic is a review of the types of systems that would be affected. Generally speaking it is more difficult and costly to change systems that have a rigorous testing and certification processes. The threshold may change over time, but identifies the pieces of the helicopter architecture that may be modified over time. Items identified above the threshold line will not be modified and will remain as part of the platform. Items below the line will be modified and as not considered part of the platform.

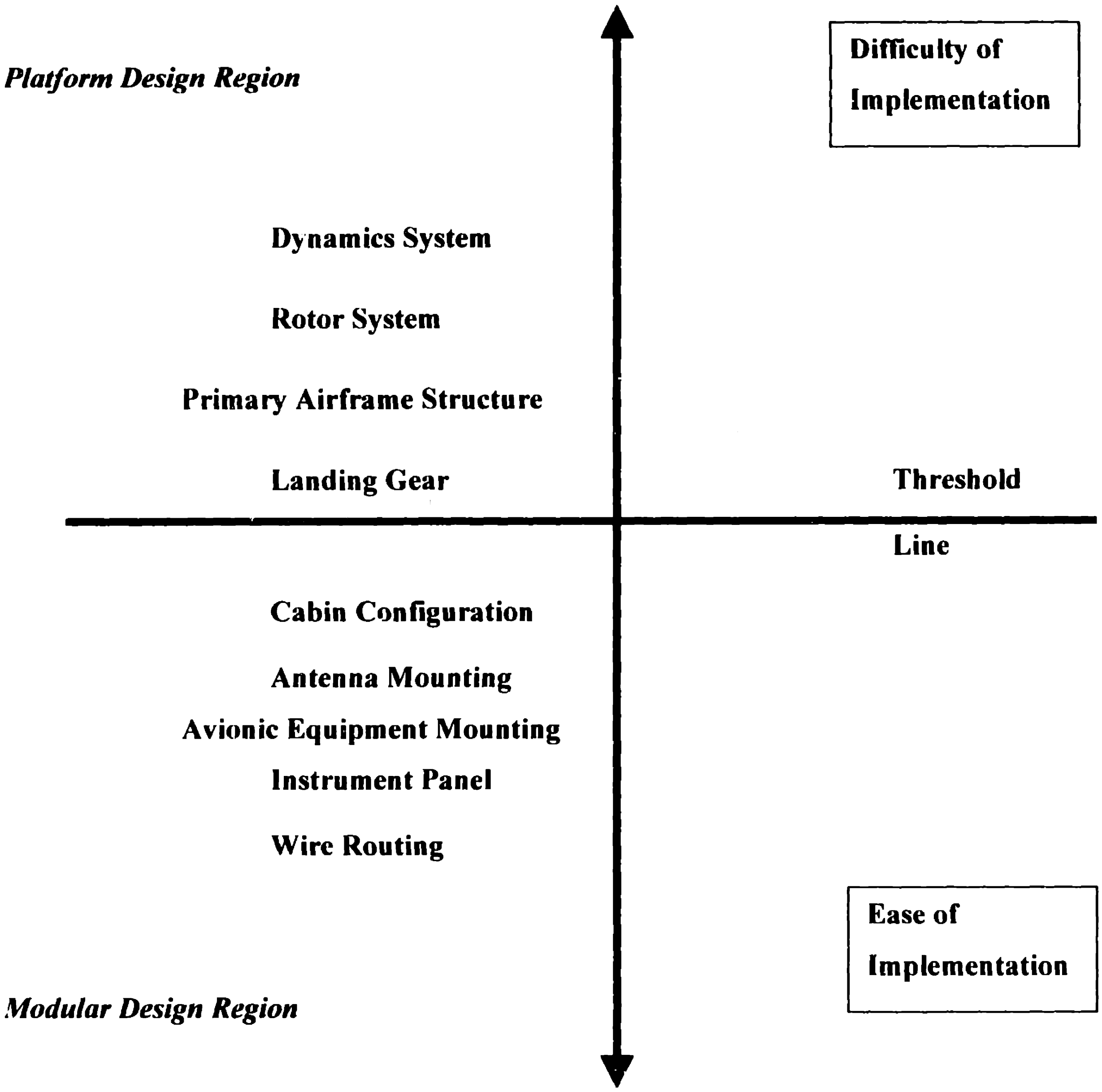

Figure 19 - Platform Threshold Scheme

8 Application of Platform Design

8.1 Introduction

To more fully understand the application of a platform design approach, it is necessary to illustrate its implementation. Its application across the entire helicopter system would encompass many different systems on-board the aircraft and would likely take volumes of text and take much time to fully develop. For purposes of this work, a focus on the cockpit with specific emphasis on the instrument panel will provide an adequate example of the platform design approach.

The reasons behind using this particular portion of the aircraft architecture to demonstrate the platform approached are two-fold. The first is that there is significant change in the design of this portion of the aircraft. Each operator has specific missions and requirements for the aircraft. This causes specific instrument panel configurations to be developed for each customer. The required mix of aircraft and mission data must be readily available to ensure that the aircraft is operated safely and efficiently. Secondly, the interfaces to the rest of the aircraft are fairly straightforward from both a systems and structural point of view.

The electrical connections from the actual instruments mounted to the instrument panel are facilitated by a short harness from the instrument to a disconnect bracket just forward or behind the instrument panel. This permits assembly of the unit including the "stuffing" of the panel off of the aircraft in parallel with its overall manufacture. A separate instrument panel harness is manufactured to allow for this modular feature. Structurally, the instrument panel is mounted to the aircraft through the use of separable fasteners and nutplates. Attachment is made at two outboard locations, two inboard locations and at the interface to the center console. These are all done through this nutplate and bolt arrangement.

Given this quick and simple interface, the balance of the change related to the instrument panel occurs from two major perspectives. The first is the arrangement of the units on the panel itself and the second is the installation of the needed power supplies, pre and post processors and the mounting of any needed external antennas. For purposes of this work architectural requirements outside or beyond the described electrical and structural interface will be recognized, but not fully explored from an architectural point of view. This actually reinforces the platform design approach since fully understood interfaces will actually support further the implementation of platform thinking. Clearly defined interfaces will be expanded upon later in this chapter.

8.2 Instrument Panels – General

The instrument panel (IP) on the S70A helicopter is the direct means by which flight information is visually communicated to the pilot and co-pilot. All relevant data to safely conduct the required mission is displayed by the components mounted on the IP. Also the information regarding the operating parameters of the flight systems such as the engines, the altitude and heading of the aircraft and the caution / advisory warning systems are displayed on the IP. Additionally, secondary systems such as selected navigation source, FLIR displays and radar imagery will also be available from displays mounted on the IP. Occasionally, communication controls will also be mounted on the IP as well as aircraft survivability equipment (ASE). The IP is the means by which the majority of the information that the operator needs to perform the mission is transmitted either visually or aurally.

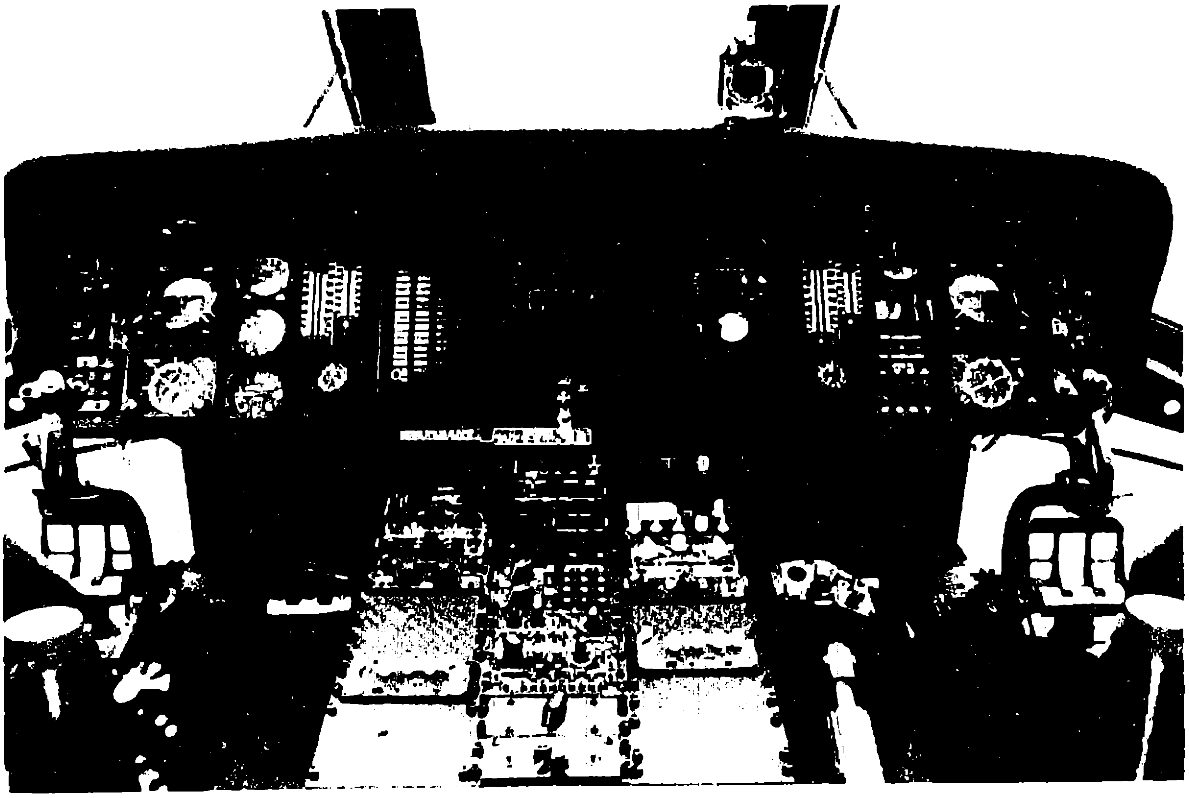

Figure 20 - S70 Instrument Panel

8.3 Instrument Panel Design

At Sikorsky Aircraft, instrument panel design is performed by an electrical design engineer. This design activity is usually in response to a negotiated instrument panel configuration resulting from customer interface. The result of these conversations with the customer is usually the gross design decisions regarding IP layout and general component positioning. The design activity at this point will focus on dimensioning the panel, ensuring proper structural mounting has been facilitated, proper ventilation and thermal considerations have been made and that no interferences exists between the units mounted. The electrical designer will interface with the appropriate functional engineering disciplines to verify the necessary requirements are met. This will include structural engineering, manufacturing engineering and materials engineering. Structural engineering will provide the necessary analysis of the performance of the design and its ability to bear the required loads throughout the flight regime. Manufacturing engineering will provide the necessary data regarding the manufacturing scheme and any producibility issues regarding the fabrication of the individual and assembled components. Materials engineering will address any processing issues that might arise affecting the temper of the material or the finishing of the components for corrosion prevention. Additionally, human factors are needed to certify that the design does not violate any man-machine interface protocols. Lighting reviews are also performed to check that lighting balance and interoperability with night vision systems is accomplished as required.

The units that require mounting are subject to a number of criteria during the design process. The displays themselves as selected by the customer may be large and occupy a large amount of available space on the panel. An example of this may be a radar display that is 10 inches wide that needs to be readable by both cockpit occupants. Here, the display will occupy a central location on the panel. This mounting configuration may cause other instruments to be placed in less than optimal locations. Typically, the back-up flight instruments are most directly affected given their secondary function.

8.4 Instrument Panel Variation

Instrument panels vary broadly. Most individual models have their own corresponding instrument panel configuration. Generally, customers look for maximum utility within the IP design with as little mounting space remaining as possible. The instrument panel of the current S70A helicopter has two distinct varieties. One is 58 inches wide and the other is 60.75 inches wide. However, there are other types of variation that can be seen in instrument panel designs over time. The basis for review of this variation can be seen by studying one type of instrument, the chronometer

8.4.1 Chronometer Variation

A study of five instrument panels designed and produced around the same time frame help to illustrate the type of variation that can occur even over a relatively short period of time. Here, five different instrument panels were reviewed. The location of the chronometer (clock) for each panel was determined as well as other mounting features. Six basic features of the installation were reviewed. These included; Butt-line location, Horizontal location, shape, mounting, type of clock and number of functions the clock could perform.

The butt-line location of the clock is the location relative to the centerline of the aircraft. This is normally denoted as right hand side or left hand side. Since the clock is mounted at the same butt-line on both sides of the instrument panel only one number denoting location is entered in the table. This is the number of inches the chronometer is displaced from the aircraft center line.

The horizontal location of the clock is the vertical position relative to the instrument panel horizontal center line. Due to the fact that instrument panels are inclined during installation, only a foreshortened view is available after installation. The use of an instrument panel related feature enable true views of the horizontal location. The horizontal location also has a plus or minus sign in front of the number. Negative numbers indicate a position below the centerline and positive numbers indicate a position above the centerline.

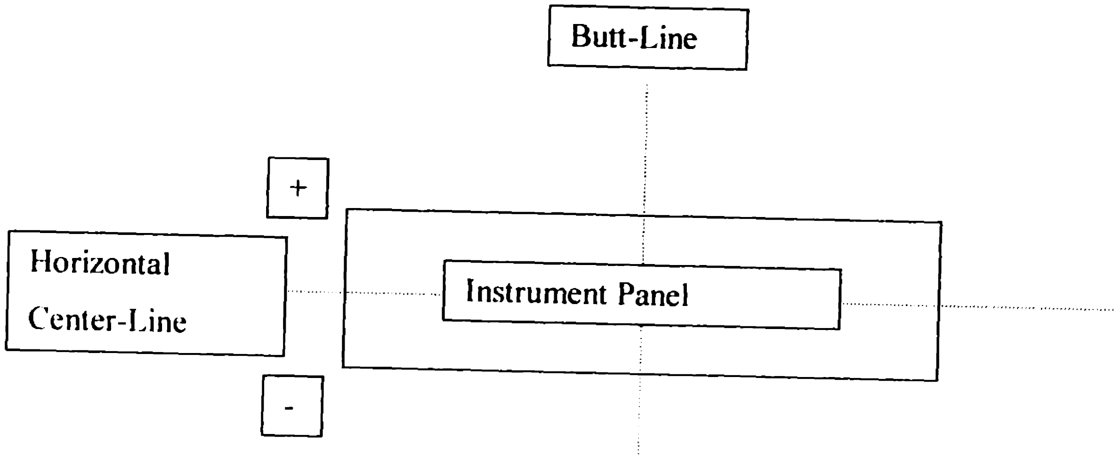

Figure 21 - Instrument Panel Location Map

The shape column of the table addresses the general profile of the mounted unit. This feature directly affects the type of cutout needed on the instrument panel. The mounting of the unit can be accomplished from either the rear or the front of the panel. Here again, the cutout required in the panel as well as the means of installing the mounting hardware needs to be considered. The last two column address the unit type and functionality. Given that these design were performed at nearly the same time the type and functionality are similar, but not quite the same.

Case	Butt-Line Location (Inches)	Horizontal Location (Inches)	Shape	Mounting	Type	No. of Functions
One	26.00	-2.00	Round	Rear	Digital	6
Two	32.00	+1.00	Square	Front	Digital	3
Three	26.00	-3.00	Square	Front	Digital	3
Four	26.00	-2.00	Square	Front	Digital	3
Five	27.00	-2.00	Round	Rear	Digital	6

Figure 22 - Chronometer Installations

Based on the representation in the above table some immediate observations can be made. The first conclusion is that no two units are mounted in the same location and that within these five cases no two system installations in terms of interface to the instrument panel were the same. There are similar features, but no identical cases. The second observation that can be made is that different units are being installed to perform the same role in the aircraft. These units have different interface requirements.

Given the variety evident in this brief review of a single basic instrument, one can imagine the variety that could be experienced over a longer period of time of a large population of instruments.

8.5 Instrument Panel Fabrication

Instrument panels themselves are generally of welded, sheetmetal construction. This approach allows for structural support of the large number of instruments. Some mounted equipment on the instrument panel may weigh over thirty pounds. Given that occupant safety during a crash is a critical design feature for the cockpit area, a metallic assembly provides the greatest margins when load bearing is assessed. The panels themselves facilitate many different configurations given the state of the art in both sheetmetal router and punch press technology. Also, the low cost of the raw materials involved and their ready availability make this approach attractive. Panels are typically punched, formed and welded to net shape in a fairly short period of time, usually about one week. The panel is then finished and painted and nutplate provisions are installed to allow for fastening of the individual units onto the panel. The final operation performed is the bonding of rubber guards and plastic grommeting. The panel is then identified with a part number and stocked until required.

8.6 Instrument Panel Assembly

Instrument panel assembly consists primarily of the "stuffing" of the instruments onto the instrument panel. Here, the components are mechanically attached to the panel. In most cases the components have captured hardware on the individual units that must engage mounting provisions on the instrument panel. Some components will require addition support structure which is installed as part of the overall component installation. This additional structure is usually installed with separable, i.e. nut and bolt, hardware. In addition to mounting the units, various placards and nameplates are adhered to the panel as well. The wiring harness that connects the individual units to the instrument panel disconnect bracket is also installed during instrument panel assembly.

8.7 Instrument Panel Integration and Test

For the most part, integrated test of the instrument panel does not occur until the assembly is installed in the aircraft. The reasoning behind this approach stems from the requirement to have the entire air vehicle and all its systems available and powered. It is technically possible to create a test bench that would simulate an entire aircraft. However, given the variety and high frequency of change, the bench would have to be made from an open architecture capable of adapting to the changing instrument panels as the customer requirements change. Additionally, there is the need to understand what parameters would be tested and under what circumstances. The likelihood that the entire spectrum of operations and their individual utility could be tested on a bench could also be debated given the large number of combinations of situations that normally occur during helicopter operations and the environment within which that operation occurs.

8.8 Technology Impacts on Design

There are many influences that may require a design to be changed. One of the primary forces causing a design to be changed is technological change. Given the timeframe of the concept through disposal process, there is ample opportunity for the design of an instrument panel to be affected by technological evolution. In conjunction with technological change are the relative rates of change of technology when view along different technology paths. As an example, the rate of technological evolution affecting the processing and finishing of the actual metal instrument panel is different from the processing power being embedded into discrete pieces of avionic equipment that will be subsequently mounted onto that panel. Therefore, there may be a need to change the geometry of the instrument panel, but not the method by which the metal panel itself is manufactured. This mismatch of technological improvement rates causes the incorporation of the newer technological to be constrained in some fashion. It could be further stated that the number of constraints caused by latent technological effects needs to minimized. It could also be stated that there is an upper bound at which the number of constraints outweighs the feasibility of revising the design.

In the case of the instrument panel, the geometry is fairly flexible. This permits a wide variety of components to be placed on the instrument panel in a large number of configurations. Therefore, the impact of changing technology for the individual components is not as severe as would be imagined at first glance. However, if that technological change required a radical departure from the current structural interface to the panel, there may be secondary effects that would need to be considered.

8.8.1 Types of Technological Change Affecting Instrument Panels

To more clearly define the type of changes that could affect the instrument panel's design, a brief discussion on the types of technological change is in order. The avionics mounted on the instrument panel are electrical devices receiving signal and creating a visual representation to the user. Technologies driving this activity include; power consumption, visual display and electronic packaging.

Power consumption is the means by which electrical energy facilitates the signal to visual representations. Two immediate considerations are relevant regarding power consumption. The first is that the heat generated by this function must be minimized. Excess heat in the cockpit environment will cause the occupants to become uncomfortable. Excess heat may also flow to nearby mounted equipment which may affect the function and service life and demand that additional cooling and ventilation be supplied to the compartment. The second immediate concern regarding power consumption is the amount of power required. Given that there is a fixed amount of power available on the aircraft at any given time, the ability to minimize consumption during a mission is imperative in order to create flexibility for on-board equipment use.

Visual display technology is the means by which the operator is presented with the needed information. Primary factors affecting display technology include; lighting conditions, off-angle viewing and robustness. Lighting conditions include the operation in adverse weather and night vision conditions. The need to balance and control all illumination sources within the cockpit is a requirement for safe operation of the helicopter. This prevents the operator from being distracted. As display technology changes from mechanical to cathode ray to liquid crystal the need to accurately control the intensity of the display is facilitated by different means. The platformed instrument panel must be able to account for this lighting balance need.

Electronic packaging also affects the instrument panel configuration. As components are required to perform more tasks, the size of the component itself may grow. In the past, avionic components mounted within the aircraft had a number of different units associated with the installed system. This may have included; a power supply, a pre- or post-processor and a display. Today, these formally separate units are now integrated into a single box. This results is a larger unit be mounted on the instrument panel with higher degrees of complexity where a smaller unit was placed in the past. While miniaturization is the driver to this phenomenon, the short term effect is the need to mount larger units and the issues associated with that installation. Larger units have size and weight considerations that need to be considered to permit appropriate mounting on the instrument panel.

8.9 Technology for Platforming an Instrument Panel

8.9.1 Technology Review

Since technology change will ultimately affect the instrument panel platform, an understanding of changes within the core technologies that support that design must be continuously updated. This review will allow for an understanding of the needed changes to the platform if a customer requests that particular technology in the delivered helicopter. To a large degree, a technology review also permits an early indication of whether or not the platform is nearing the end of its useful life. A recording of the frequency of technology changes that cannot be incorporated into the design is one such indicator. If the number of unsupportable technologies sharply rises, the platform may need to be comprehensively reviewed. Technology reviews also can identify trends in investment by suppliers. Remembering that suppliers also interface with the market and provide aircraft operators with data on current investments being made in research and development. This activity by suppliers may channel helicopter operators towards certain expectations regarding emerging technologies and their application. Another benefit of technology reviews is an understanding of where the rate of technological change is the largest. It is efficient for the platform team to understand these areas of focus to prepare the platform for incorporation or modification. Finally, it is important to remember that the platform can also be modified after the helicopter has been fielded. It is not uncommon for older helicopters to be modified after they have been in service for a number of years. A technology review should also include an aspect that addresses already fielded craft for upgrade.

8.9.2 Decision Tree Retention

The retention of decisions made in the past allow for future users of the design to understand the reasons why certain protocols were chosen as the design evolved. Design and planning teams need to be flexible enough to respond to current requirements, but also need insight into the rationale used by past teams working on similar projects. This insight prevents duplication of effort over time as well as enhanced organizational learning. For the most part, design and planning tools remain relatively constant over the life a design. While it is true that information technology has materially affected the way that the design and planning is performed, the underlying assumptions have not changed. The design is still broken from vehicle to major assembly to sub-assembly to detail level. Each level has its own requirements and needs to be developed along a prescribed path that allows for design data to be transferred both up and down the architecture. This process includes a myriad of decisions that need to be made. Oftentimes the rationale of the design is lost with only the result remaining. It is the capable organization that not only remembers the result, but also the context and reason why certain courses of action were taken. The ability to retain this needed data will eliminate redundant activity and cultivate an environment that uses organizational history as a learning tool [Rogers, 1994]. There are many data management systems available to the design organization. These include product data management, materials requirements planning and engineering resource planning. Through selective and appropriate use of information technology, the decisions made about a product platform can be retained.

8.9.3 Market Requirements

Assessing market requirements is also a valuable tool in determining the forces affecting the platform design. Here, customer expectations, both present and future, can be matched against the platform capability to determine if there is opportunity to incorporate these requirements into the design. Market requirements an be gathered from a number of sources. Current operators could be polled to understand how the aircraft is being used and what future expansion or modifications could be envisioned. Suppliers of avionic equipment could be contacted to understand what parts of the industry are ordering what types of equipment. Finally, complimentary industries need to be observed to understand if parallel situations are occurring in industries using like technology.

8.9.4 Interface Characterization and Mapping

As described in the previous chapter, the characterization of the interfaces within the platform also provides insight into the architectures ability to be modified. In the case of the instrument panel, an interface map could be created around the individual units mounted on the panel itself. The individual unit's structural and electrical interface characteristics could be identified and given a complexity weighting. As an example, the Horizontal Situation Indicator (HSI) has four captive screws that engage four (4) nutplates installed on the IP. Some HSI's also have mounting trays that extend from the backside of the IP with shock pin receptacles to provide appropriate structural mounting. This structural interface needs to be considered should follow-on design modifications be required or should new designs include this piece of equipment. Electrically, the HSI has a single electrical connector that provides lighting, power and signals to the unit. This connector is part of the instrument panel harness that connects all the units of the IP to the instrument panel disconnect bracket. Given the close relationship between the panel configuration and the instrument panel harness, there is some cause and effect regarding the interface. In other words, during the definition of the IP platform, a concurrent activity is needed to review the harness that will connect all the units and the IP disconnect bracket. It is also important to note there is a hierarchy involved with this platform mapping. The location of the instruments on the panel takes precedence over the IP harness design. Unit location on the panel is driven by factors such as viewing angle, customer preference and operation criteria. The IP harness is then developed based on this review and the selected positioning of the units on the IP.

9 Conclusions

The platform design approach to products with strong tendency to change is a way for an enterprise to maximize the potential of its precious design and planning resources. Product change can occur prior to deliver of the system or after the system is in use. The approach also allows for multiple derivatives of a basic model to be efficiently modified to address specific customer needs. Within the context of the helicopter industry all of the above is applicable.

Aircraft have long lives. Some can be fielded for more than thirty years. The missions and roles that aircraft perform may change over its life-span. This change in missions and roles will require that newly manufactured aircraft be configured differently from its predecessors and that already fielded aircraft be modified to incorporate the required changes. The ability of the aircraft to address these changing requirements is strongly influenced by its architecture. Imbedded within the aircraft's architecture are various technologies. These different technologies evolve over time at different rates. Therefore some parts of the aircraft architecture are more susceptible to change than others due to the frequency of change of the embedded technology. As discussed, structural technologies with aircraft evolve at a slower rate than avionic technologies. This lead to the avionic portion of the architecture being more likely to experience change than the structural portion of the technology of the architecture over time. The platform approach to designing the aircraft architecture allows the enterprise to address this technology evolution mismatch.

Platform design is not solely assessed along the design perspective. The enterprise strategy, organization of its resources and an understanding of the related technologies also needs to be considered. Platform thinking affects the product for its entire life from concept to abandonment. Platform design is also strongly linked to past actions affecting the design and the need to retain the context of the decisions that caused those actions. This knowledge retention allows for past experiences to be relayed to newer team members and management.

There are a number of actions that need to be considered during platform design. The first is a universally accepted architecture of the product. The organization must review the product similar to Chapter 5 of this thesis. This permits accurate communication of the design intent and also provides a foundation for subsequent change. The second is an understanding of the forces external to the architecture that will provide impetus to change it. While the majority of this force will be technologically based, other factors may affect the architecture such as supplier base, business climate i.e. merger and acquisition and others. The third action is to prepare the architecture for change based upon the understanding of the first two actions. This preparation includes understanding the interfaces of the individual chunks of the architecture and the means by which the affected chunk is integrated with the whole system.

The instrument panel of the S70A helicopter allows for demonstration of the platform approach. The instrument panel assembly is subject to much variation with the air vehicle system and can be platformed. The technologies affecting the instrument panel require that it contain a variety of different pieces of equipment for any specific model of helicopter. The interface of the instrument panel permits fixed points of attachment for both structural and electrical systems. The maintenance over time of these fixed interfaces accommodates multiple configurations of the instrument panel. Given the high degree of change of the units within the instrument panel, this partition of the assembly with the aircraft platform allows flexibility to address these evolving needs.

The benefits of platform design are many. A strong link between the architecture and the organization results due to the in-depth understanding required. An opportunity to respond faster to evolving market needs due to continuous assessment of the forces affecting the architecture ahead of actual requirements. A strong link between organization and product strategies results due to the co-destiny of both. Finally, strong customer links result due to the continuous review of operator requirements and the potential incorporation of those requirements into the architecture.

10 References

[Abernathy-Utterback, 1978]
Patterns of Industrial Innovation
William J. Abernathy, Professor of Business Administration, Harvard University
James M. Utterback, Center for Policy Alternatives
Innovation / Technology Review

[Allen-Sauvageau-Joyner, 1994]
Reusable Launch Vehicle Design Flexibility
B. D. Allen, Thiokol Corporation
D. R. Sauvageau, Thiokol Corporation
C. R. Joyner, Pratt & Whitney
AIAA 94-4499
AIAA Space Programs and Technologies Conference, September 27-29, 1994
American Institute of Aeronautics and Astronautics

[Arend, 1985]
Design-to-Cost of a Heavy-Lift Reusable Ballistic Launcher for Leo Missions
H. Arend, Technical University of Berlin, Aerospace Institute
IAF-85-481
International Astronautical Federation, 36th Congress, Stockholm Sweden October 1985
American Institute of Aeronautics and Astronautics

[Barnes-Lyon, 1993]
Time-Dependent Properties of Particleboard Decking in Flexure
D. E. Lyon, Mississippi State University
H. M. Barnes, Mississippi State University
Forest Products Journal, Vol. 28, Issue 12, pgs. 28 – 33

[Benton, 1995]
Rockwell's Reusable Launch Vehicle Concept – Design for Low Risk and High Operability
Mark G. Benton, Sr., Rockwell Space Systems Division
AIAA-95-3857
AIAA 1995 Space Programs and Technologies Conference, September 26-28, 1995
American Institute of Aeronautics and Astronautics

[Clark-Henderson, 1990]
Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms.
Rebecca M. Henderson, Massachusetts Institute of Technology
Kim B. Clark, Harvard University
Administrative Science Quarterly, Vol. 35, No. 1, March 1990, pgs. 9 – 30

[Clark-Wheelwright, 1992]
Creating Project Plans to Focus Product Development
Steven C. Wheelwright, Harvard Business School
Kim B. Clark, Harvard Business School
Harvard Business Review, Vol. 72, No. 2, March/April 1992, pgs. 70 – 82

[Eppinger, 1997]
A Planning Method for Integration of Large-Scale Engineering Systems
Steven D. Eppinger, MIT Sloan School of Management
International Conference on Engineering Design 1997
Tampere, August 19-21, 1997

[Eppinger-Pimmler, 1994]
Integration Analysis of Product Decompositions
Thomas U. Pimmler, Massachusetts Institute of Technology
Steven D. Eppinger, Massachusetts Institute of Technology
DE-Vol. 68
Design Theory and Methodology – DTM 1994
American Society of Mechanical Engineers, 1994

[Eppinger-Ulrich, 1995]
Product Design and Development
Karl T. Ulrich, Massachusetts Institute of Technology
Steven D. Eppinger, Massachusetts Institute of Technology
McGraw – Hill, Inc., New York, New York 10020, 1995

[Erens-Verulst, 1997]
Architectures in Product Families
Freek Erens, Eindhoven University of Technology
Karel Verulst, Phillips Medical Systems
Computers in Industry, Vol. 33, No. 2,3, September 1997, pgs. 165 – 178

[Fredriksson, 1994]
Holistic Systems Engineering in Product Development
Billy Fredriksson, Vice-President of Engineering and Technical Director, Saab Military Aircraft
Griffin

[Hamada, 1984]
Development of Welded I-Beam with Corrugated Web
Masami Hamada, Superintendent, Kashima Steel Works
The Sumitomo Search No. 29, November 1984

[Ishii-Martin, 1997]
Design for Variety: Development of Complexity Indices and Design Charts
Mark V. Martin, Department of Mechanical Engineering, Stanford University
Kosuke Ishii, Department of Mechanical Engineering, Stanford University
DETC97 / DFM-4359

[Jaquith et al., 1993]
Modular Engine Room Design and Construction for Strategic Sealift Ships
Peter E. Jaquith et al., National Steel and Shipbuilding Company (NASSO)
Journal of Ship Production, Vol. 12, Issue No. 4, pgs. 230 – 243

[Jolliff, 1994]
Modular Ship Design Concepts
CDR. James V. Jolliff, USN
Naval Engineers Journal, October 1994

[Koopman, 1995]
A Taxonomy of Decomposition Strategies based on Structures, Behaviors and Goals
Phillip J. Koopman, Jr., United Technologies Research Center
DE-Vol. 83
1995 Design Engineering Technical Conferences, Volume 2
American Society of Mechanical Engineers, 1995

[Lehnerd-Meyer, 1997]
The Power of Product Platforms – Building Value and Cost Leadership
Marc H. Meyer, Northeastern University & MIT Sloan School of Management
Alvin P. Lehnerd, Northeastern University & MIT Sloan School of Management
The Free Press, New York, New York 10020, 1997

[Lucas, 1971]
New Methods Make Housing Units Solids as Box Beams
Edward R. Lucas
Wood and Wood Products, Vol. 76, Issue 10, October 1971, pgs. 32 – 35

[Lundqvist-Sundgren-Trygg, 1996]
Remodularization of a Product Line: Adding Complexity to Project Management
Mats Lundqvist, Chalmers University of Technology
Niklas Sundgren, Chalmers University of Technology
Lars Trygg, Chalmers University of Technology
The Journal of Product Innovation, Vol. 13, No. 4, July 1996, pgs. 311 – 324

[Maropoulos, 1995]
A Novel Process Planning Architecture for Product-Based Manufacture
P.G. Maropoulos, School of Engineering, University of Durham
Proceedings of the Institution of Mechanical Engineers, Part B:
Journal of Engineering Manufacture, Vol. 209, 1995, pgs. 267 – 276

[McGhee, 1996]
3KSES Design, Development and Construction
G. Douglas McGhee, Vice-President and Program Manager, Rohr Marine, Inc.

[Meyer-Terzakian-Utterback, 1997]
Metrics for Managing Research and Development in the Context of the Product Family
Marc H. Meyer, Northeastern University
Peter Terzakian, Northeastern University
James M. Utterback, Massachusetts Institute of Technology
Management Science, Vol. 43, No. 1, January 1997, pgs. 88 - 111

[Nation, 1982]
A Modular Approach to Electronic Instrument Cluster Design
Thomas C. Nation, Ford Motor Co., Electrical and Electronics Division
SAE Technical Paper Series, No. 820110
International Congress and Exposition, Detroit, Michigan, February 22-26, 1982
Society of Automotive Engineers

[Rechtin, 1991]
Systems Architecting – Creating & Building Complex Systems
Eberhardt Rechtin, University of Southern California – Los Angeles
Prentice Hall P T R, Englewood Cliffs, New Jersey 07632, 1991

[Robertson-Ulrich, 1998]
Planning for Product Platforms
David Robertson, Vice-President Global Market Development, Baan Company
Karl Ulrich, Associate Professor, The Wharton School, University of Pennsylvania
Sloan Management Review, Volume 39, Number 4, Summer 1998, pgs. 19-31

[Rogers, 1994]
Product Information Management: Using an "Intellectual Inventory"
Danny Rogers, Paragon Communications (UK) Ltd., London
Industrial Management and Data Systems, Vol. 94, No. 1, 1994, pgs. 19 – 22

[Ross, 1977]
Structured Analysis (SA): A Language for Communicating Ideas
Douglas T. Ross
IEEE Transactions on Software Engineering, Vol. SE-3, No. 1, January 1977

[Ross-Schoman, 1977]
Structured Analysis for Requirements Definition
Douglas T. Ross
Kenneth E. Schoman, Jr., Manager of Systems Definition and Engineer, SofTech, Inc
IEEE Transactions on Software Engineering, Vol. SE-3, No. 1, January 1977

[Sanderson-Uzumeri, 1995]
Managing Product Families: The Case of the Sony Walkman
Susan Sanderson, School of Management, Renssalaer Polytechnic Institute
Mustafa Uzumeri, Department of Management, College of Business, Auburn University
Research Policy 24 (September 1995) pgs. 761 - 782

[Stanley et. Al., 1991]
Conceptual Design of a Next-Generation, Fully Reusable Manned Launch System
Douglas O. Stanley, NASA Langley Research Center, Hampton VA.
Theodore A. Talay, NASA Langley Research Center, Hampton VA.
Roger A. Lepsch, NASA Langley Research Center, Hampton VA.
W. Douglas Morris, NASA Langley Research Center, Hampton VA.
Kathryn E. Wurster, NASA Langley Research Center, Hampton VA.
AIAA-91-0537
29th Aerospace Sciences Meeting, January 7-10, 1991
American Institute of Aeronautics and Astronautics

[Ulrich, 1995]
The Role of Product Architecture in the Manufacturing Firm
Karl Ulrich, MIT – Sloan School of Management
Research Policy 24 (May 1995) pgs. 419 – 440

11 Appendix 1.0 – Listing of UH-60 / S70 Helicopter Models

Model Designation	Nomenclature	Mission	Customer
EH-60	Quick Fix	Electronic Warfare	U.S. Government
K70A-2	Korea Kits	Utility	Government of Korea
MH-60K	SOA	Special Operation	U.S. Government
S-70A-1	Saudi Blackhawk	Utility	Gov't of Saudi Arabia
S-70A-1L	Saudi Med-Evac	Med-Evac	Gov't of Saudi Arabia
S70A-1V	Saudi VIP	VIP Transport	Gov't of Saudi Arabia
S-70A-11	Jordan	Utility / VIP Transport	Government of Jordan
S-70A-12	Japanese Blackhawk	Utility / SAR	Government of Japan
S-70A-14	Brunei #2	VIP Transport	Government of Brunei
S-70A-16	Westland	Utility	Various
S-70A-17	Turkey Blackhawk	Utility	Government of Turkey
S-70A-18	Korea Co-Production	Utility	Government of Korea
S-70A-20	Thailand	Utility	Government of Thailand
S-70A-21	Egypt VIP Blackhawk	VIP Transport	Government of Egypt
S-70A-22	Korean Blackhawk	Utility	Government of Korea
S-70A-5	BH	Utility	U.S. Government
S-70A-9	R.A.A.F.	Utility / SAR	Gov't of Australia
S-70C-1A	Taiwan	Utility	Government of Taiwan
S-70C-2	PRC	Utility	Republic of China
S-70C-5	Brunei #1	VIP Transport	Government of Brunei
S-70A-6	ROCAF	Utility / SAR	Republic of China
S70A-17C	Turkish National Police	Utility	Government of Turkey
S70A-24	Mexico VIP	VIP Transport	Government of Mexico
S70A-24A	Mexico Utility	Utility	Government of Mexico
S70A-25	Morocco 8-Passenger	Utility	Government of Morocco
S70A-26	Morocco 12-Passenger	Utility / Troop Transport	Government of Morocco
S70A-27	Hong Kong	Utility / SAR	Government Hong Kong
S70A-28	Turkey Utility	Utility	Government of Turkey
S70A-28E	Turkey Utility-STD	Utility	Government of Turkey
S70A-29	Brunei VVIP	VIP Transport	Government of Brunei
S70A-30	Argentina	Utility	Gov't Argentina
S70A-33	Brunei SAR	Utility / SAR	Government of Brunei
S70A-34	Malaysia VIP	VIP Transport	Gov't of Malaysia
S70A-36	Brazil Utility	Utility	Government of Brazil
S70A-37	Firehawk	Fire Fighting	U.S. Government
S70A-38	Norway	Utility / SAR	Government of Norway
S70A-41	Venezuela	Utility	Government of Venezuela
S70A-50	Israel FMS Utility	Utility	Government of Israel
UH-60A	U.S. Army Blackhawk	Utility	U.S. Government
UH-60L	U.S. Army Growth Blackhawk		U.S. Government
UH60USAF	U.S. Air Force	Combat SAR	U.S. Government
VH-60	U.S. Marines	Presidential Transport	U.S. Government

12 Appendix 2.0 – UH-60 / S70 Helicopter Configurations

The following five pages describe the types and variations of installed equipment on both the S-70 aircraft and the UH-60 aircraft.

S-70/UH-60 CONFIGURATIONS

CONFIGURATION	PROPOSAL	CONTRACT	CONTRACT	DELIV	VERBAL	DELIVERED	CONT	PROP	DEL	PD	CONT	SOR	PROP	PROP	PROP	PROP	CONT	PD	PROP	PD	PROP	PROP	PD	PROP	PROP	PROP
	MALYS MLH	BRUNEI 8	MALAYSIA	Brunei 84	JORDAN	Egypt	Brunei	Kuwait	HK 83	Brazil	UH-60Q	CANADA	USN	HELLENIC CG	BRUNEI MSH	PORTUGAL	BRUNEI	ROCAF	INDONESIA	ISRAEL	SINGAPORE	SINGAPORE	TURKEY	TURKEY	MALAYSIA	THAILAND
JULY 2, 1997 REV 5	CSAR	S-70A-29 VVIP	S-70A-34 VVIP	S-70A-29 VVIP	VIP	S-70A-21 VIP	S-70A-33 MLH/SAR	Multi	S-70A-24 Util	S-70A-36 Util	Medevac	SAR	CH-60	S-70A	S-70A ATTACK SAR	S-70A SAR/CSAR & SIFICAP	S-70A-29 VVIP	S-70C-6 SAR	UTILITY	S-70A-50 UTILITY	S-70A MSH	S-70B MSH	S-70B SAR	S-70A ATAK	S-70B SAR	UTILITY NOTE 1
Type of Contract																										
Commercial	X	X	X	X	X		X		X	X		X		X	X		X	X	X		X	X		X	X	
FMS						X		X					X													
Military											X			X	X	X										
Method of Certification																										
Military (FMS)								X			X		X							X						
FAA		X	X	X	X	X						X		X					X							X
QAB	X						X	X	X	X					X	X	X	X			X	X	X	X	X	
Mission Management Systems																										
SIKORSKY COLLINS CORE CDNU-800							X	X					X													
COLLINS CDNU-900															X	X					X (2)	X (2)	X (2)	X (2)	X (2)	
UNS-1B MMMS		X	X	X	X												X									
Canadian Marconi (CMA-2082)											X	X														
BASE UH-60L WITH AN/ASN-128 DPLR									X	X																
UNS-1C	X													X				X	X							X
Flight Directors																										
Sikorsky AFCS Coupled Flight Dir					X							X		X	X	X	X		X		X	X	X	X	X	
Honeywell Dual Flight Director FD-706	X	X	X	X			X							X	X		X	X	X		X	X	X	X	X	X
UH-60L CIS						X	X	X	X	X	X									X						
UH-60L CIS Integrated into LCD EFIS								X				X														
Radio Management																										
Primus II Com/Nav Radio Mgmt Sys					X																					
Mil-Std-1553 Integrated Nav Radios								X			X	X			X						X	X	X	X	X	
Mil-Std-1553 Integrated Comm Radios											X	X			X						X	X	X	X	X	
Stand Alone Comm Radios	X	X	X	X		X	X	X	X	X				X		X	X	X	X	X						X
Cockpit Displays																										
UH-60L Instruments*						X			X	X	X									X						
Expanded (MH-60G) Caut/Adv. Panel	X	X	X	X	X		X						X	X		X	X	X	X							X
LCD MFD/Caut Adv Panel/FLIR Disply								X			competed	X			X						X	X	X w/o Caut Adv panel	X	X	
LCD EFIS								X							X						X	X	X	X	X	
EFIS EDZ-756 Display/Controls	X	X	X	X	X		X							X		X	X	X	X							X
Standby Instruments	X	X	XX	X	X		X	X				X				X			X				X			
Honeywell FR Dir. Display/Controls				X																						
Single CCU	X	X					X										X	X	X							X
Dual CDU											X	X		X	X	X					X	X	X	X	X	
Remote Readout Units (for Comm)								X																		
UNS-1X Control/Display		X	X	X	X									X			X	X	X							X
Single FLIR Display	X						X							X			X	X					X			X
Dual FLIR Display (LCD)											X	X			X						X	X		X	X	
Dedicated Weather Radar Display			X	X	X				X																	
Stormscope Display					X						X															
Dual Rad Alt Display	X	X	X	X	X	X	X	X	X	X	X			X	X		X	?	X		X	X	X	X	X	?
Millibar Barometric Altimeter									X					X	X		X	X					X			X
DME-42 Indicator		X	X	X				X	X					X			X									
DME KDM-706A Indicator								X				X			X						X	X			X	
DME Indicator (Primus II)					X																					
RMI Indicator						X																	X			
* UH-60L displays include HSI's,																										
VSI's, Airspeed Indicators, Bar Alts,																										
Vert Vel. Indicators, Cau/Adv Panel,																										
Mode Select Panels, CIS Panel																										
Communications:																										
ARC-186 VHF AM									X	X										X						
ARC-186 VHF AM -1553 Comp																										
ARC-186 VHF FM		X	X	X					X	X							X									
ARC-186 VHF FM -1553 Comp																										
ARC-186 VHF AM/FM Conversion									X	X																
3rd ARC-186									X																	
VHF-22B VHF/AM Radios (2)		X	X	X													X									
TRC 9600 VHF-FM																										
Primus II Radio Comm System					X																					
ARC-164 UHF AM		X	X	X												X	X									
ARC-164 UHF w/ HQ I																				X						
ARC-164 UHF w/ HQ I -1553 Comp																										
ARC-164 UHF w/ HQ II									X	X																

S-70/UH-60 CONFIGURATIONS

CONFIGURATION	PROPOSAL	CONTRACT	CONTRACT	DELIV	VERBAL	DELIVERED	CONT	PROP	DEL	PD	CONT	BOR	PROP	PROP	PROP	PROP	CONT	PD	PROP	PD	PROP	PROP	PD	PROP	PROP	PROP
	MALYS MLH	BRUNEI 6	MALAYSIA	Brunei #4	JORDAN	Egypt	Brunei	Kuwait	HK #3	Brazil	UH-60Q	CANADA	USN	HELLENIC CG	BRUNEI MSH	PORTUGAL	BRUNEI	ROCAF	INDONESIA	ISRAEL	SINGAPORE	SINGAPORE	TURKEY	TURKEY	MALAYSIA	THAILAND
JULY 2, 1997 REV 5	CSAR	S-70A-29 VVIP	S-70A-34 VVIP	S-70A-29 VVIP	VIP	S-70A-21 VIP	S-70A-33 MLH/SAR	Multi	S-70A-24 Util	S-70A-36 Util	Medevac	SAR	CH-60	S-70A	S-70A ATTACK SAR	S-70A SAR/CSAR & SIFICAP	S-70A-29 VVIP	S-70C-6 SAR	UTILITY	S-70A-50 UTILITY	S-70A MSH	S-70B MSH	S-70B SAR	S-70A ATAK	S-70B SAR	UTILITY NOTE 1
ARC-164 UHF w/ HQ II -1553 Comp											X															
ARC-164 UHF w/ Quick Fox					X																					
ARC-182 VHF/UHF FM/AM (2)	X					X	X							X				X		ONE ONLY W/ CHELTON						
ARC-182 Encryption (RACAL MA4777)							X																			
ARC-182 VHF/UHF -1553 Comp																										
ARC-210 VHF/UHF FM/AM (2)	X							X					X	OPTION												X
ARC-210 VHF/UHF FM/AM -1553 Comp												X									X	X	X	X	X	
ARC-201(VE) INTNL SINCGARS								OPT																		
ARC-201D SINCGARS (2) -1553 Comp											X DUAL				X											
AN/ARC-222 VHF-AM/FM											X					2										
VHF-22B																			X							
AN/ARC-880																				X						
KING 985 VHF/UHF FM																				X						
KY-28/58/75 Provisions						X			X	X	X		X	X	X	X										
IDM MODEM											X															
Rohde Schwartz SECOS 610 UHF								X																	X	
ARC-190 HF Radio						X																				
ARC-217 (HF-9000)	X		X		X		X			X				X		X		X		W/ALE						X
ARC-217 (HF-9000) -1553 Comp												X			X						X	X	X		X	
HF Radio Struc Prov								X																		
HF-9100			X																							
Data Msg Term for HF-9000							X														X	X	X		X	
SELCAL capability for HF-9000					X											X										
ARC-220 HF Radio																										
ARC-220 WITH 1553 CDU AND KYK-100											X															
Dual RACAL Cougarnet UHF Radios							X								X											
Dual RACAL Jaguar VHF FM Radios																										
Motorola Spectra VHF-FM w/ Encrypt.					X																					
RT-138 VHF FM Hi Band																										
ICS C-11746											X	X	X		X	X					X	X	X	X	X	
ICS C-6533						X	X	X	X	X				X				X		X						X
ICS A301-61/B	X	X	X	X	X												X		X							
Baker Page/Chime		X	X	X	X	X											X									
APX-100 IFF/Xponder	X				X	P	X	X	X	X	X	X	X	X	X	W/KIT1A				X	X	X	X	X	X	
APX-101																		X								X
TDR-90 Xponder		X	X	X													X		X							
Cellular Phone Provisions		X	X	X	X	X																				
Navigation:																										
VOR/ILS ARN-123									X																	
VOR/ILS ARN-147						X	X			X								X		X						X
VOR/ILS ARN-147 -1553 COMP								X			X		X		X						X	X		X	X	
Dual VOR/ILS ARN-147 -1553 COMP												X											X			
VIR-32 VOR/ILS (2)	X	X	X	X										X		1	X		X							
LF/ADF ARN 89									X																	
LF/ADF ARN 149							X			X								X								X
LF/ADF ARN 149 -1553 COMP								X			X	X	X		X						X		X			
ADF-60 LF/ADF	X	X		X		X								X			X		X							
Primus II Radio Nav System					X																					
ASN-128 Doppler						X														X						
ASN-128B Doppler w/ GPS						X					X															
CMA-2012 DOPPLER												X														
ASN-137 Doppler (-1553)		X	X	X	X		X	X									X									
ASN-157 Doppler	X													X		X		X	OPTIONAL							X
ASN-157 Doppler (-1553)															X						X					
AN/APN-217(V)6 DOPPLER																						X	X	X	X	
TACAN ARN-118						X							X													
TACAN ARN-153							X									OPTION		X								X
TACAN ARN-153 -1553 COMP											X	X	X								X		X	X		
MAGR GPS (-1553)	X						X																			
TNL 8100 GPS										X																
INS SNU-84-1																										
INS/GPS LN100G or H764G								X				X			100G	100G					X	X	X	X	X	
GPS-1200 (UNS-1X)	X				X													X	X							X
GPS-1000 (UNS-1X)		X	X	X									X	X			X									
Garmin GPS-150																										
VLF Omega UNC-764 (UNS-1B)		X	X	X																						
TRIMBLE 2100																				X						
TASMAN P CODE GPS														X												
DF 301E Direction Finder					X	X	X	X							X					X	X	X	X	X	X	
MDF-124F VHF/UHF SAR DF	X											X		X		X		X								X
DME-42	X	X	X	X					X				X	X			X									
DME KING 706A								X							X						X(1553)	X(1553)			X(1553)	
Dual DME KING 706A												X														

S-70/UH-60 CONFIGURATIONS

CONFIGURATION	PROPOSAL	CONTRACT	CONTRACT	DELIV	VERBAL	DELIVERED	CONT	PROP	DEL	PD	CONT	SOR	PROP	PROP	PROP	PROP	CONT	PD	PROP	PD	PROP	PROP	PD	PROP	PROP	PROP
	MALYS MLH	BRUNEI 6	MALAYSIA	Brunei 94	JORDAN	Egypt	Brunei	Kuwait	HK 93	Brazil	UH-60Q	CANADA	USN	HELLENIC CO	BRUNEI MSH	PORTUGAL	BRUNEI	ROCAF	INDONESIA	ISRAEL	SINGAPORE	SINGAPORE	TURKEY	TURKEY	MALAYSIA	THAILAND
JULY 2, 1997 REV 5	CSAR	S-70A-29 VVIP	S-70A-34 VVIP	S-70A-29 VVIP	VIP	S-70A-21 VIP	S-70A-33 MLH/SAR	Multi	S-70A-24 Util	S-70A-36 Util	Medevac	SAR	CH-60	S-70A	S-70A ATTACK SAR	S-70A SAR/CSAR & SIFICAP	S-70A-29 VVIP	S-70C-6 SAR	UTILITY	S-70A-50 UTILITY	S-70A MSH	S-70B MSH	S-70B SAR	S-70A ATAK	S-70B SAR	UTILITY NOTE 1
Dual AHRS LCR-92	X	X	X	X	X									X	X	X	X	X	X							X
ASN-43 Compass						X	X	X	X	X	X										X	X	X	X	X	
Radar Altimeter APN-194																						W/ RAWS DUAL	X	X	W/ RAWS DUAL	
Radar Altimeter APN-209	X	X	X	X	X	X	X	X	X	X								X		W/ RAWS						X
Radar Altimeter APN-209F (RAWS)											X		X													
Dual AA-300 RADALT (SAR)	X				X							X		X	X	X	X		X		W/ RAWS					
Penny/Giles Air Data Computers (2)	X	X	X	X	X		X	X						X	X	X	X	X	X		X	X	X	X	X	X
Voice Warning																					X	X			X	
Mission																										
SH-60 AFCS	X	X	X	X			X	X							X		X	X								X
Coupled Flight Director (SAR Package)					X							X		X	X		X		X		X	X	X		X	
UH60L ASE Provisions		X	X	X	X	X	X	X	X	X	X		X			X				X						
Pulse Radar Jammer																										
CW JAMMER ALQ-144													X							X						
LASER WARNING AVR-2																AVR-2A OPTION										
ALE-47 Chaff/Flare																X							X			
AN/ALQ-144(V)5					CP											X										
AN/ALQ-162 CW JAMMER					CP								X													
AN/ALQ-144(V)1 IRCM													X										X	X		
RADAR WARNING AN/APR-39A(V)1													X													
RADAR WARNING AN/APR-39A(V)2					CP																					
ALISRA SPS-20 RADAR WARNING																				X						
LITTON ASPIS RDR WARNING & JAMMINC													X													
MISSILE WARNING AAR-47																										
ALQ-156 Missile Warning Provisions					CP																					
AAR-54 Missile Warning																X										
LWS-250 LASER WARNING								X																		
M-130 Tracor Dispenser													X													
XM-130 DUAL DISPENSER																				X						
ESM LR 100															X	X					X	X	X		X	
Weather Radar Primus-500																										
Weather Radar Primus-700			X				X	X						X				X								X
Weather Radar Primus-701	X	X		X								X				SAR/CSAR	X									
Weather Radar RDR-1400C									X			X														
WEATHER RADAR RDR-1400D											X	X														
DATA NAV III			X	X																						
CMS-400 "HEAD UP" CHECKLIST																	X									
WX-1000 Stormscope					X						X															
APS-143 SEARCH RADAR																							X		X	
RDR-1500B W/CALEDONIA TRACKER																SIFICAP										
TI SEAVU RADAR															X						X	X				
AAQ-22 FLIR	X	X					X							X												
AAQ-22 FLIR VCR Recorder							X										X	X								X
AAQ-22 FLIR VCR Recorder&Tracker																X										
AAQ-22 FLIR -1553 Comp											COMPETED	X														
AAS-44 FLIR/Desig/RF								X																		
AAS-44 FLIR/Desig/RF - 1553															X						X		X	X	X	
AAQ-22 FLIR -1553 Comp/Desig/RF																										
AAQ16D Aesop FLIR																										
ARS-6 PLS NON-BUSSED											X							X								X
Base Ten Weapons Control								X							X									?		
GEC MONOHUD								X																X		
ANVIS HUD					X			X												X	(PROV)			X		
DL-902 Data Loader							X	X			X	X	X													
DR-200 DATA LOADER															X						X	X	X	X	X	
DIGI-MAP DISPLAY															X		X									
Cockpit Voice/Data Recorder																										
Ext. Hyd. Rescue Hoist	X						X	X	X			X	X	X	X	X		X	X		X	X	X		X	X
Ext. Elec. Rescue Hoist											COMPETED									X						
INTERNAL ELEC HOIST 600#'s																		X								
Backup ELECTRIC HOIST (300#'s)																X										
SX-16 Nightsun Searchlight									X			X		X		X		X								
External Loud Hailer System							X	X						X	X	SIFICAP		X								
FASTROPE									X																	
Dukane DK100 Sonic Locator							X					X		X												
TechTest 503 ELT																X										
EBC-302HM ELT	X	X	X	X	X	X	X	X				X		X	X		X	X	X		X	X		X	X	X
POINT ELT																				X						
Six Man Pole and Strap Litters							X	X	X			X	X	X		SAR		X			X					X
.50 Cal Machine Gun Mts							X	X																X		

S-70/UH-60 CONFIGURATIONS

CONFIGURATION	PROPOSAL	CONTRACT	CONTRACT	DELIV	VERBAL	DELIVERED	CONT	PROP	DEL	PD	CONT	SOR	PROP	PROP	PROP	PROP	CONT	PD	PROP	PD	PROP	PROP	PD	PROP	PROP	PROP
	MALYS MLH	BRUNEI 5	MALAYSIA	Brunei 84	JORDAN	Egypt	Brunei	Kuwait	HK 83	Brazil	UH-60Q	CANADA	USN	HELLENIC CG	BRUNEI MSH	PORTUGAL	BRUNEI	ROCAF	INDONESIA	ISRAEL	SINGAPORE	SINGAPORE	TURKEY	TURKEY	MALAYSIA	THAILAND
JULY 2, 1997 REV 5	CSAR	S-70A-29 VVIP	S-70A-34 VVIP	S-70A-29 VVIP	VIP	S-70A-21 VIP	S-70A-33 MLH/SAR	Multi	S-70A-24 Util	S-70A-36 Util	Medevac	SAR	CH-60	S-70A	S-70A ATTACK SAR	S-70A SAR/CSAR & SIFICAP	S-70A-29 VVIP	S-70C-6 SAR	UTILITY	S-70A-50 UTILITY	S-70A MSH	S-70B MSH	S-70B SAR	S-70A ATAK	S-70B SAR	UTILITY NOTE 1
Air Conditioner				X	X	X		X				OPT														
Air Conditioning w/ ETS (pump reloc.)																										
63K BTU Air cond w comb 50K heater		X	X								X						X	X								
6 MAN ELECTRO/MECH LITTER SYSTEM											X															
Airframe:																										
20 Seats	X						X		X								X									
International Gearbox	X	X	X	X	X	X	X	X	X	X		X				X		X	X	X	X	X	X		X	X
Rotor Brake	X	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Intnl Tailcone w/ Trans. access door	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X			X		X
External Mirrors																										
Side Skin Beef-up	X	X	X	X	X	X	X	X			X	X		STD	STD	X		X		ECP 533 LOT 21	X			X		X
Folding Stabilator													X													
Rapid Fold Tail Pylon													X									X	X		X	
Electric Folding Rotor Head													X									X	X		X	
Seahawk Doors (jett. windows)											x	X	X									X	X		X	
Plug Doors		X	X	X	X	X																				
Plug Windows		X	X	X	X	X																				
Skinned over gunners windows											x															
Bubble windows on doors											X	X														
Bubble window cabin											X	X				2										
Long Fixed Step						X																				
Electric Step		X	X	X	X																					
Blank Floors		X	X	X	X	X																				
M/Tail Blade Erosion Protection								X																		
4 BAG FLOATATION															X	X					X					
FAA 6 BAG FLOATATION														X			X	X								
Interiors																	X									
Utility	X						X	X	X	X			X		X			X								X
Medical evacuation interior											X	X		X												
8 Place with Four Captain's Chairs				X	X	X																				
8 Place with 125 Gal Tank																										
8 Place with Side Facing Seats			X																							
7 Place		X															X					X			X	
12 Place																				X	X					
VVIP Cockpit		X		X	X												X									
SAR/CSAR CONFIG														15 SEAT		X					X	X	X		X	
Propulsion:																										
Aerial Refueling Probe																STRUCT.PR OV.										
Internal 117 Gal. Tank																										
HIFR													X			X							X			
Fuel Dump												X	X			X										
ETS - WINGS												X								IN COUNTRY						
ETS - PROVISIONS												X														
ETS - WINGS (BLEED AIR)			X											X												
ETS - PROVISIONS (BLEED AIR)																										
ESSS - WINGS	X	X					X		X		X				X	X		X			X			X		
ESSS - PROVISIONS	X						X	X	X		X															
ESSS - VIP PROVISIONS		X		X	X												X									
ERFS - (ESSS W/ ETS PUMP PACKAGE)																X										
230 GAL TANK ETS																				X				X		
230 GAL TANK ESSS/ETS (BLEED AIR)	X	X	X				X		X					X	X		X	X			X					
250 GALLON TANKS												X				4										
125 Int Aux Tank																										
REFUELING PROBE/PROVISIONS																				X						
APU Exhaust Deflectors			X	X	X	X																				
APU IPS								X																		
Fuel Drain Collector			X	X	X	X																				
EAPS								X																		
Armament																										
70 mm Rockets Launcher								X																		
Giat 20 mm Cannon								X																		
T-100 Sighting System								X																		
BEI Mark 4 Gun Rocket Control								X																		
Base-10 Gun/Rocket Control																								?		
ERU 1216 Ejector Racks								X													X	X	X	X	X	
Hellfire Capability															X						X	X	X	X	X	
Hellfire Wiring Provisions																					X	X	X	X	X	
HELLFIRE 299 Launcher															x						X	X	X	X	X	
TORPEDOES																						X	X		X	
PENGUIN																							X		X	
NOTE: CHECK FOR REVISION STATUS IF																										
MORE THAN ONE WEEK OLD																										
NOTES:																										

S-70/UH-60 CONFIGURATIONS

CONFIGURATION	PROPOSAL	CONTRACT	CONTRACT	DELIV	VERBAL	DELIVERED	CONT	PROP	DEL.	PD	CONT	SOR	PROP	PROP	PROP	PROP	CONT	PD	PROP	PD	PROP	PROP	PD	PROP	PROP	PROP
	MALYS MLH	BRUNEI 8	MALAYSIA	Brunei 94	JORDAN	Egypt	Brunei	Kuwait	HK 93	Brazil	UH-60Q	CANADA	USN	HELLENIC CO	BRUNEI MSH	PORTUGAL	BRUNEI	ROCAF	INDONESIA	ISRAEL	SINGAPORE	SINGAPORE	TURKEY	TURKEY	MALAYSIA	THAILAND
JULY 2, 1997 REV 5	CSAR	S-70A-29 VVIP	S-70A-34 VVIP	S-70A-29 VVIP	VIP	S-70A-21 VIP	S-70A-33 MLH/SAR	Multi	S-70A-24 Util	S-70A-36 Util	Medevac	SAR	CH-60	S-70A	S-70A ATTACK SAR	S-70A SAR/CSAR & SIFICAP	S-70A-29 VVIP	S-70C-6 SAR	UTILITY	S-70A-60 UTILITY	S-70A MSH	S-70B MSH	S-70B SAR	S-70A ATAK	S-70B SAR	UTILITY NOTE:1
1. DUE TO THE LACK OF TIME, DMC II HAS DECIDED TO GO OUT WITH A ROCAF SIMILAR CONFIGURATION. THIS IS NOT THE SAME CONFIGURATION AS APPROVED BY ACT.																										

13 Appendix 3.0 – Definitions

13.1 Introduction

In order to prevent any confusion regarding description of the various systems on-board the aircraft it is prudent to briefly define the words that will be used in this work.

13.1.1 Derivative Helicopter

A derivative helicopter is best described as a helicopter very similar to an existing, delivered helicopter with some changes that do not materially change the appearance or performance of the air vehicle. These changes typically are along the line of discrete avionic systems changes, cabin configuration changes or cosmetic alterations. A derivative helicopter will also usually include the installation of components not usually installed in the basic vehicle that enhance the performance of the systems already in the basic vehicle.

13.1.2 Helicopter Avionic System

The avionic system of a medium lift helicopter encompasses all the systems used to communicate, navigate, electronically protect and electronically control the helicopter as it performs its mission. These systems in of themselves do not usually prevent the helicopter from flying, but do materially affect the way in which it is operated

13.1.3 Helicopter Electrical System

The electrical system of a medium lift helicopter generates and distributes the electrical energy to the components needed to operate the aircraft. This system includes the aircraft auxiliary power unit, generators, junction boxes and circuit breakers. Failure of this system can result in loss of the vehicle, depending on the severity and type of components affected.

13.1.4 Helicopter Propulsion System

The helicopter propulsion system centers around those components consuming and storing fuel during their operation. These items include the aircraft engines, auxiliary power units and any main or secondary fuel tanks. The propulsion system also extends to the systems directly interfacing with the above described items. These systems are the bleed air system, fuel management system and the engine start systems. One other popular description of the aircraft propulsion system is that if a liquid is moved by the system such as air, fuel or water then it is part of the aircraft propulsion system.

13.1.5 Helicopter Structure

The helicopter structure is comprised of all the physical elements of the air vehicle used to carry both the static and dynamic loads induced into the helicopter during both ground and flight operations. Aside from the obvious framing and skin assemblies common to semi-monoque airframe design, other physical features of the vehicle will also be required to carry structural loads. These items include the seating available for both the crew and passengers, the housings for the drive-train and the floor system in the vehicle. In addition, certain features of the vehicle are loading only during specific conditions such as crash and high 'g' maneuvering. This requires an understanding of the full performance envelope of the vehicle

13.1.6 Modular Design

A modular design used for medium lift helicopter is a design, fabrication and integration protocol that permits installation of a variety of systems of similar function into the same location on the airframe without significant alterations to the baseline vehicle. An example of this type of design approach would be the installation of a forward looking infra-red system. Here, a variety of different type of FLIR's could be installed in the same location with the require provisions already in place on the basic vehicle. Thus, the FLIR designs are modular to the platform.

13.1.7 Platform Design

The platform design of a medium lift helicopter is the method by which basic helicopter functions are inherent in a host vehicle with the ability of the design to accommodate modification to fulfill specific needs. A platform design for a medium lift helicopter can be described along many axis. These axis include; cost, design lead-time, manufacturing lead-time and frequency of re-use. Certainly one of the primary reasons why platform approaches are used is to drive down the design / planning non-recurring costs associated with the development and tooling of new helicopter systems and their integration. However, the ability to re-use design data is of considerable importance given the ability to transfer a design across different form of the basic configuration with a minimum of effort.