LIFE CYCLE ANALYSIS OF A RADAR SYSTEM

by
Obie D. Reynolds III

Report submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

in

Systems Engineering

APPROVED:

Dean Benjamin S. Blanchard, Chairman

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Blacksburg, Virginia

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INTRODUCTION

The purpose of this paper is to demonstrate the application of the systems methodology with respect to the Navy's development of the AN/APG-71 radar system. As an essential factor in the overall effectiveness of the F-14 fighter, the radar system that this aircraft employs must be on the leading edge of technology. For the past two decades the radar system that performed that task was Hughes Corp.'s AWG-9 radar system. Although the AWG-9 was remarkable 25 years ago, its *analog* circuitry can no longer keep up with the signal processing loads that are demanded of it when one considers using many of the newer "smart" bombs that are available today. Consequently, the Navy's problem is that while the power and range of the AWG-9 radar system are adequate, the processing capability is severely limited, meaning that this system needs to be improved or replaced.

Performing a feasibility study, several alternative solutions are presented with the final recommendation that the best alternative was to radically modify the current radar system. The end result of this modification will be to digitalize the radar's receiver, master oscillator, analog signal conditioner, and data and signal processors. The power units, antenna, displays, and transmitter will remain essentially the same. This digitalization will increase the radar system's throughput more than six (6) times, not to mention gains in weight reduction, system reliability, and expandability for future functional growth.

Consistent with the systems methodology, once the problem has been clearly defined, and the most viable solution has been selected, a functional analysis is developed. It is important to note that the functional diagrams illustrate *what* has to be done, not *how* it is to be accomplished. The first step in this procedure is to define the system's requirements. These will include, among others, expected performance specifications, environmental constraints, effectiveness requirements, and support considerations.

Following the process outlined in the first level of the operational flow diagram, the next element is the design phase. Initially in this phase, a reliability and maintainability prediction analysis will be produced to determine if the proposed system will meet the required effectiveness specifications. Satisfied that the results are positive, the design phase continues by describing the software that drives the system and the hardware that makes up the system, as well as some of the basic functions of both software and hardware.

System life cycle tests are discussed next, followed by several production phase charts that include the program profile, program cost profile, support equipment/services procurement, and finally, a radar production schedule. The last block to be covered from the functional diagram concerns the system's distribution, or "sell-off" to the

Navy. An abbreviated synopsis of the quality conformance tests, or acceptance tests, is presented that might be used to accept or reject an installed radar system.

The last group of blocks on the functional diagram represents selections that could be made concerning the operation of the radar set. As an example of additional development of the functional diagram, block 12.0 is expanded to operational flow level 2. Further, block 12.2 of this second level will be extended to show a failed, or "no go" situation, and this will continue until maintenance levels one, two, and three are illustrated. Once the example problem is solved at maintenance level three, the diagram completes the loop by returning to the point of origin at operational level one. Note that *any* of the blocks in the functional diagram could have been expanded equally as well.

Advocating the systems methodology as outlined in Professor Blanchard's book, *Systems Engineering and Analysis*, each section emphasizes some aspect of the total life cycle of the subject matter. The difficulty of this particular report will be to sift through the mounds of available unclassified military specifications concerning radar systems and produce a report that is both an illustrative application of the systems process, and yet concise.

DEFINITION OF NEED

WHY THE NAVY NEEDS A SUPERIOR RADAR SYSTEM

Of all the various missions involving aircraft that the Navy is concerned with, the mission that is the most critical to the fleet and that captures the attention of the public the most often (e.g., the movie Top Gun) is that of "defending the fleet". It is vital that the Navy maintain complete control of the air space encompassing a battle group. To do this the Navy needs a superior fighter aircraft; one capable of defending the fleet against any potential threat directed at the fleet. Since the early 1970s, the aircraft series that has successfully fulfilled this mission is the F-14.

In service the F-14 has been a reasonably dependable and relatively trouble-free aircraft. As an integral part of the F-14's electronics suite, the AWG-9 radar system provided the greatest range and tracking ability of *any* airborne radar during the 70s and most of the 80s. However, other radar systems (some hostile) have continued to advance, and through not surpassing the AWG-9 in air-to-air capability, they have removed the overwhelming advantage the F-14 once enjoyed.

In a sentence, the problem is that while the power and range of the AWG-9 radar system are adequate, the processing capability is severely limited by today's standards. This is critical since most of the newer missiles depend on information that cannot be processed rapidly enough using analog technology. Further, the last decade has seen a dramatic increase in the sophistication of electronic counter measures, and only an advanced radar computer system has the ability to cope with this situation. This was demonstrated time and again in the "desert storm war", when hostile aircraft were repeatedly overwhelmed by the allied forces using superior electronic warfare techniques. That is, the inferior radar set was made inoperable by jamming or misinformation, and in effect, rendered useless. The final results of this electronic mismatch were so devastating that often, the Iraqi jets would simply flee, if they could, once they realized they had been detected by Allied radar.

By staying on the leading edge of aviation and weapons technology, the US Navy demonstrates to the world its ability and intentions to remain a viable force. Although the AWG-9 radar system has been upgraded many times over the last two decades, there are certain physical limits to the technological improvements that can be implemented in a 20 year old system. Consequently, several alternatives to improve or replace the current radar set have been or are being developed and considered: (1) once again upgrade the current AWG-9, (2) design a completely new radar system, or (3) radically modify (digitalize) the AWG-9.

FEASIBILITY STUDY

One of the central objectives of the feasibility study is to evaluate what alternative(s) might be acceptable to solve the problem defined, and then to suggest a direction to follow. Naturally, this presumes that a viable solution exists. The process to implement these decisions will be presented in the functional analysis, and then discussed throughout the remainder of this report.

Upgrade the AWG-9 Radar System

As previously mentioned, the problem is that the F-14's current radar system does not have the processing speed and capacity that it needs to implement many of the newer radar guided missiles, and to orchestrate a successful electronic warfare campaign. Although the current AWG-9 radar system has met and even exceeded it's original specifications, its 20 year old *analog* technology can not compete with the reliability and speed of digital electronics.

In an aircraft, weight and space are critical elements, and this places strict limitations on the radar's physical parameters. Consequently, it is not feasible to substantially expand the capability of the existing radar set without also increasing its size and weight beyond acceptable limits. Even if an upgraded radar set could be produced that met today's requirements, it is virtually certain that the upgraded radar would not be expandable enough to handle other weapon systems that are already being developed, and soon to begin field testing.

Finally, considering cost, while an upgrade would be the least expensive alternative, it will not provide the radar performance (if one is to stay on the forefront of technology) required by a modern fighter aircraft. To save 3 or possibly 4 million dollars, and then have a 60 million aircraft shot down due to an inadequate radar system, is not cost effective when other alternatives are available.

Design a completely new Radar System

New ideas in radar systems are constantly being developed. Implementation of the new technology within acceptable costs and time constraints is another matter. Some of the newer designs are radical to the extent that the aircraft itself will have to be completely redesigned (e.g., the advanced tactical fighter, or ATF). For example, the radar set's sensors are so integrated into the skin of the aircraft, that the new radar system can never be realistically considered as an "add-on" to an older aircraft and ever expect to reach its full potential.

Some estimates are that the Navy's version of a electronic scanning radar set will cost over 20 million per copy *after* research and development, and will not be available until the year 2005. A totally new design using current digital technology is feasible, but financially impractical when one considers that the life of the radar system, once it is in the field, may be as short as five years and probably no longer than ten years.

Modify the AWG-9 Radar System

The Navy knows *what* the radar set should do, it just needs the radar set to do it faster, more efficiently, more reliably, and if possible, reduce the weight and size of the radar while increasing the processing capability.

A highly successful Navy Technical Evaluation was completed by the Pacific Missile Test Center on a digitalized version of the F-14's AWG-9, referred to as the programmable signal processor (PSP). The final modifications were so extensive that the proposed new radar system would be renamed the AN/APG-71 radar set.

In addition to increasing the current AWG-9 weapon system performance, the AN/APG-71 radar set modifications would provide functional growth by utilizing standard computer processing digital interfaces and software programmable subsystems. The AN/APG-71 configuration would provide very large computer throughput and memory reserves.

The digital electronics would expand data processing, make controls and displays more flexible, provide more effective weapon management, and greatly decrease the cost of integrating new weapons and capabilities into the radar system in the future. Hardware and software configurations would emphasize commonality with the Navy/McDonnell Douglas *Hornet* and with the Navy/Grumman A-6E *Intruder* upgraded radar programs.

The proposed radar modification would ensure the F-14 *Phoenix* weapon system would continue to meet tomorrow's threat and have adequate growth potential to remain the most capable air-to-air weapon system in the world, well into the twenty-first century. The new radar (APG-71) could replace the current 26 unit AWG-9 with 14 units. Fewer parts, lower junction temperatures, and higher reliability components would guarantee a significant improvement in reliability. In addition, the digitalized radar system would incorporate the following additional changes: improved displays, a new low sidelobe array antenna, digital scan control, a new radar master oscillator and new receiver. Several of the AWG-9's units will either be retained or modified which greatly decreases the cost of such a substantial modification to the AWG-9 radar system.

Without question, the biggest radar performance gain would be from a major increase in radar processing capability. The radar data processor and signal processor memory and throughput would be an increase of more than six times the capability of the current AWG-9. The processing techniques developed by the PSP program would be implemented using gate array technology developed by Hughes Aircraft Company for the USAF F-15/APG-70(V) program. Use of this gate array technology in the AN/APG-71 would allow immediate development of advanced ECCM algorithms and provide for significant growth.

AN/APG-71 RADAR SYSTEM JUSTIFICATION

Once the alternatives have been identified, certain evaluation criteria have to be selected that hopefully will set one alternative apart as the best solution. For this case, it is important to note that certain factors are more essential than others, that is, the evaluation elements do not have equal weight, and so, an attempt will be made to rank these elements as objectively as possible, though it is recognized that eventually a subjective decision may have to be made as to what is the best higher-order system choice.

As shown in Table 1, the evaluation elements have been selected and then prioritized. Weights (1-10, with 10 being the highest) are attached to each element which reflect that element's importance in solving the stated problem. For example, the two predominant factors are performance (signal processing capability) and timeliness (when can the product be delivered). Next, each alternative has been evaluated (again, 1-10) as to how

TABLE 1

TRADE-OFF ANALYSIS

RANK	EVALUATION CRITERIA	WT	AWG-9 UPGRADE ST	AWG-9 UPGRADE LT	AWG-9 UPGRADE RATE	APG-71 SYSTEM ST	APG-71 SYSTEM LT	APG-71 SYSTEM RATE	NEW RADAR SET ST	NEW RADAR SET LT	NEW RADAR SET RATE
(1)	Performance (process capacity)	10	5	2	70	9	8	170	2	10	120
(2)	Timeliness (sys availability)	10	8	2	100	9	10	190	2	10	120
(3)	Functional Growth	8	2	1	24	9	9	144	2	10	96
(4)	Reliability/Maint	6	5	4	54	9	8	102	2	8	60
(5)	Power, range	5	9	3	60	9	8	85	2	8	50
(6)	Cost	3	9	3	36	6	6	36	1	2	9
(7)	Supportability	2	8	3	22	6	6	24	1	7	16
(8)	Commonality	2	5	2	14	8	7	30	2	7	18
	Rate totals				380			781			489

LEGEND:

WT — 10 is very important or very good, 5 is adequate, and 2 would signify poor

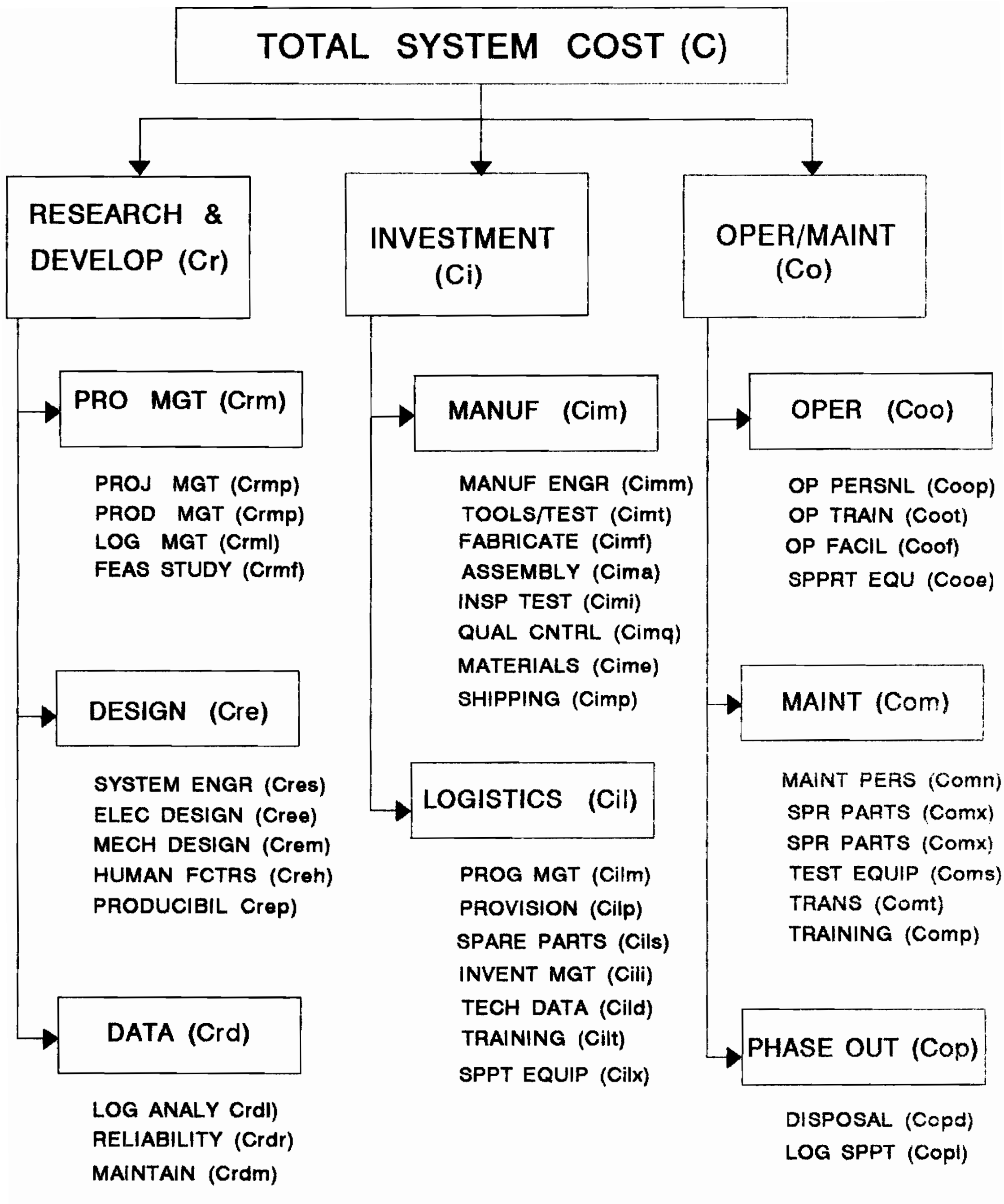
ST,LT — short term and long term, respectively

RATE — (ST + LT) x WT

it might fulfill each element's requirements. Finally, a decision is made as to which of the three feasible alternatives stands out from the rest.

Although cost is not the critical driver, it may still prove beneficial to look more closely at a cost analysis. The cost breakdown structure is shown in Figure 1, followed by a life-cycle cost breakdown in Table 2, and finally, a cost comparison in Figure 2. Note that the AWG-9 radar system begins at a lower cost, but eventually surpasses the AN/APG-71 radar set when more time and effort (dollars) is invested continually trying to upgrade the aging system. Also, any scheme that combines an upgraded AWG-9 with a new radar set will inevitably cost more than the AN/APG-71 system. In any event, cost is not the driving factor (see Table 1.) since the AWG-9 set will not meet sustained performance expectations, and the newer radar system will not meet time requirements.

In short, of the three alternatives, the AN/APG-71 radar system is recommended as offering the best solution. The AWG-9 radar set is no longer state of the art, and any viable upgrade attempt, at any price, still would not allow the AWG-9 to perform fast enough to handle expected future data loads. While a completely new radar set could be developed exclusively for the F-14, it could not be implemented in a timely manner, thereby its cost could not be justified considering the short life time remaining for the F-14 series aircraft. The AN/APG-71, on the other hand, fully utilizes the transmitting power of the older AWG-9 while combining the signal processing capabilities of advanced digital electronics.



COST BREAKDOWN STRUCTURE

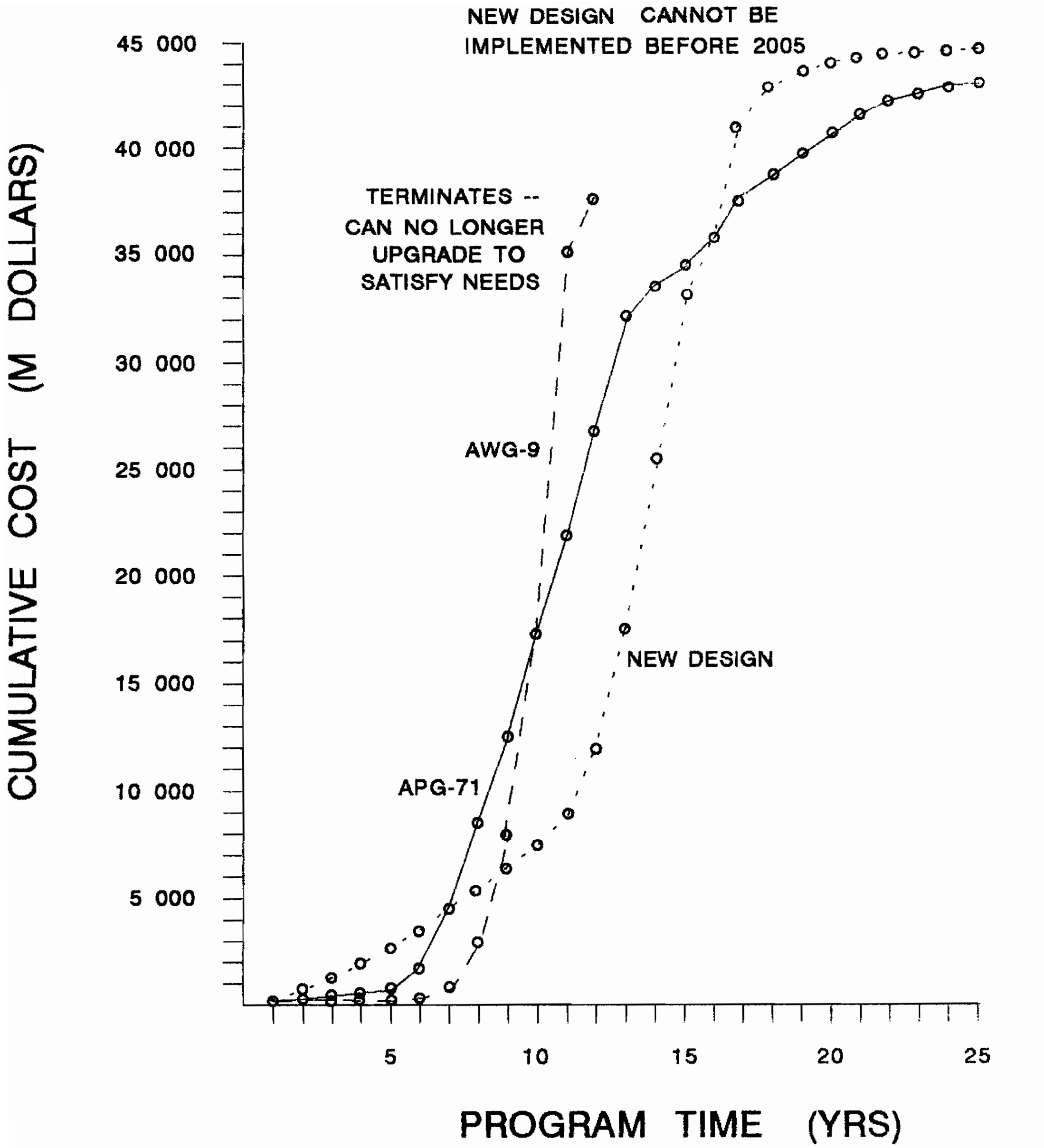
FIGURE 1.

TABLE 2

LIFE-CYCLE COST BREAKDOWN

COST CATEGORY	AWG-9 UPGRADE * PRESENT COST	APG-71 SYSTEM PRESENT COST	NEW RADAR SET PRESENT COST
Research & Development	.421	1.865	3.321
Project management	.187	.865	1.183
Design	.142	.717	1.092
Design Data	.092	.258	1.046
Investment	19,167.4	26,262.7	27,730.1
Manufacturing	13,814.3	17,585.8	18,652.9
Logistics	5,353.1	8,656.9	9,077.2
Operations and Maintenance	11,644.5	16,631.5	17,239.7
Operations	2,197.1	3,250.1	3,834.9
Maintenance	8,063.5	11,654.2	11,600.5
Phase Out	1,383.9	1,727.2	1,804.3
Totals	30,812.3	42,896.0	44,973.1

* Note that all costs are in millions



CUMULATIVE COST COMPARISON

FIGURE 2.

As an integral part of an advanced digital avionics suite, the AN/APG-71 radar would be an essential element of the F-14's weapons control. As was repeatedly demonstrated during the "Desert Storm" war, air superiority is achieved by possessing, maintaining, and successfully delivering technologically sophisticated ordinance, i.e., the so called "smart" bombs. Many of these weapons, e.g., Phoenix missiles, are guided to their targets by airborne radar. Clearly, a radar system that is the *first* to identify and "lock-on" to a potential threat, will have a substantially higher survival rate during a hostile encounter. For air-to-air combat, the APG-71 will have more overall capability than any other known airborne radar system in the world today. To stay on the "leading edge" of current weapons technology, the Navy needs the advanced digital processing capacity of the AN/APG-71 radar set. Overall, the radar system will be more reliable, easier to maintain, more durable, and it will win in every fighter scenario.

RADAR SYSTEM REQUIREMENTS

The problem has been clearly defined as needing a radar system with increased signal processing capability. The feasibility study indicates that the most reasonable solution for this problem, considering all restrictions, is to design and produce a modified version of the current F-14 radar system, which will be called the AN/APG-71. The functional diagrams that are shown in Figures 3 to 6 are an attempt to define not *how*, but rather *what* has to be done as part of the process in developing the AN/APG-71 radar system. The remainder of this report is an overview of an analysis of the functional diagrams.

DEFINITION OF SYSTEM REQUIREMENTS

Avoiding any detailed technical specifications which might be classified or considered to be sensitive material, the following statements try to focus on the direction that the design process should follow. Again, it should be restated that this system is replacing an older system that has been in service for over 20 years. The general requirements of the system (use, environment, etc.) are well established and will be the same.

<u>The primary mission</u> of the AN/APG-71 radar system is to provide surveillance and support for the F-14 weapon control system. This includes the surveying of a volume of air space or an area of land or sea surface to determine the presence of other objects and establish the position, motion, and threat potential of these objects. This must be conducted in all weather and in clear/clutter

and jamfree/ jamming environments. Provisions for search, detection, acquisition, track, target identification, target illumination, and missile communication must be made.

The system must accomplish the preceding mission statement with the newer digital signal processing components. The radar system should have fewer parts, have less weight, and process data at a much faster rate than the AWG-9. All pertinent detailed information can be found in the Navy's specification document SD-4690.

The *projected* total life cycle of the AN/APG-71 program is 25 years, with the first operational systems being needed in 1991. This includes the design and development phase through the production phase to the system disposal. The operational life of an individual radar set is difficult to ascertain. That is, the military *could* decide to maintain a specific system indefinitely (as support for a software simulator in a test lab, for example). On the other hand, the entire system series could be terminated after a few years, given the attitude swings of congress. Suffice it to say that at its inception, the AN/APG-71 program is considered to be a 25 year program.

The AN/APG-71 radar system will be used on the Grumman's F-14D (digital) fighter aircraft. This weapons system will be deployed on various carriers around the world and, due to the unusually "hard" landings and launchings, will have to be ruggardized. That is, the radar components must function in all positions (including upside down), must not be susceptible to vibrations or abrupt changes

OPERATIONAL FLOW LEVEL 1

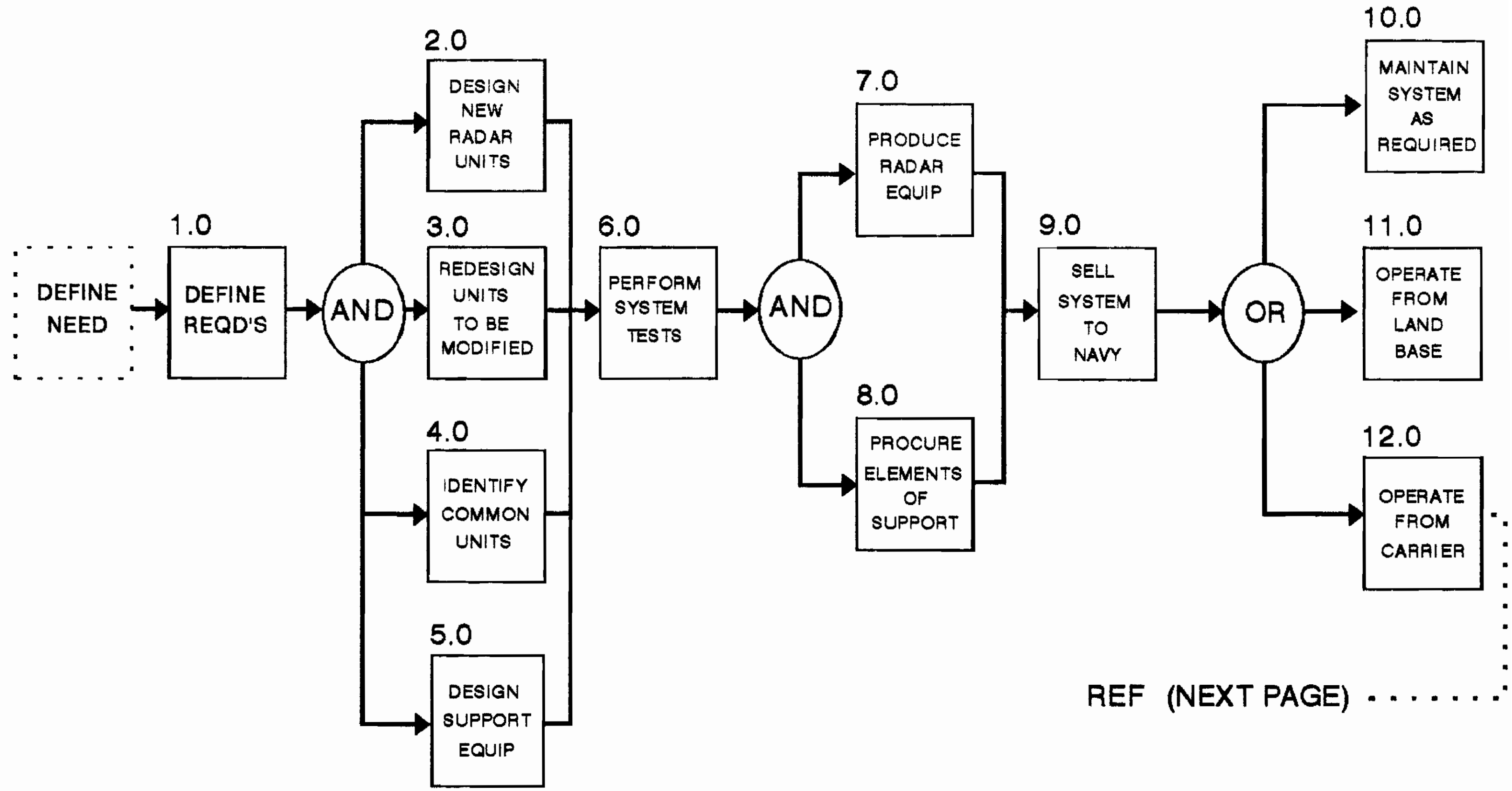


FIGURE 3. FUNCTIONAL DIAGRAM

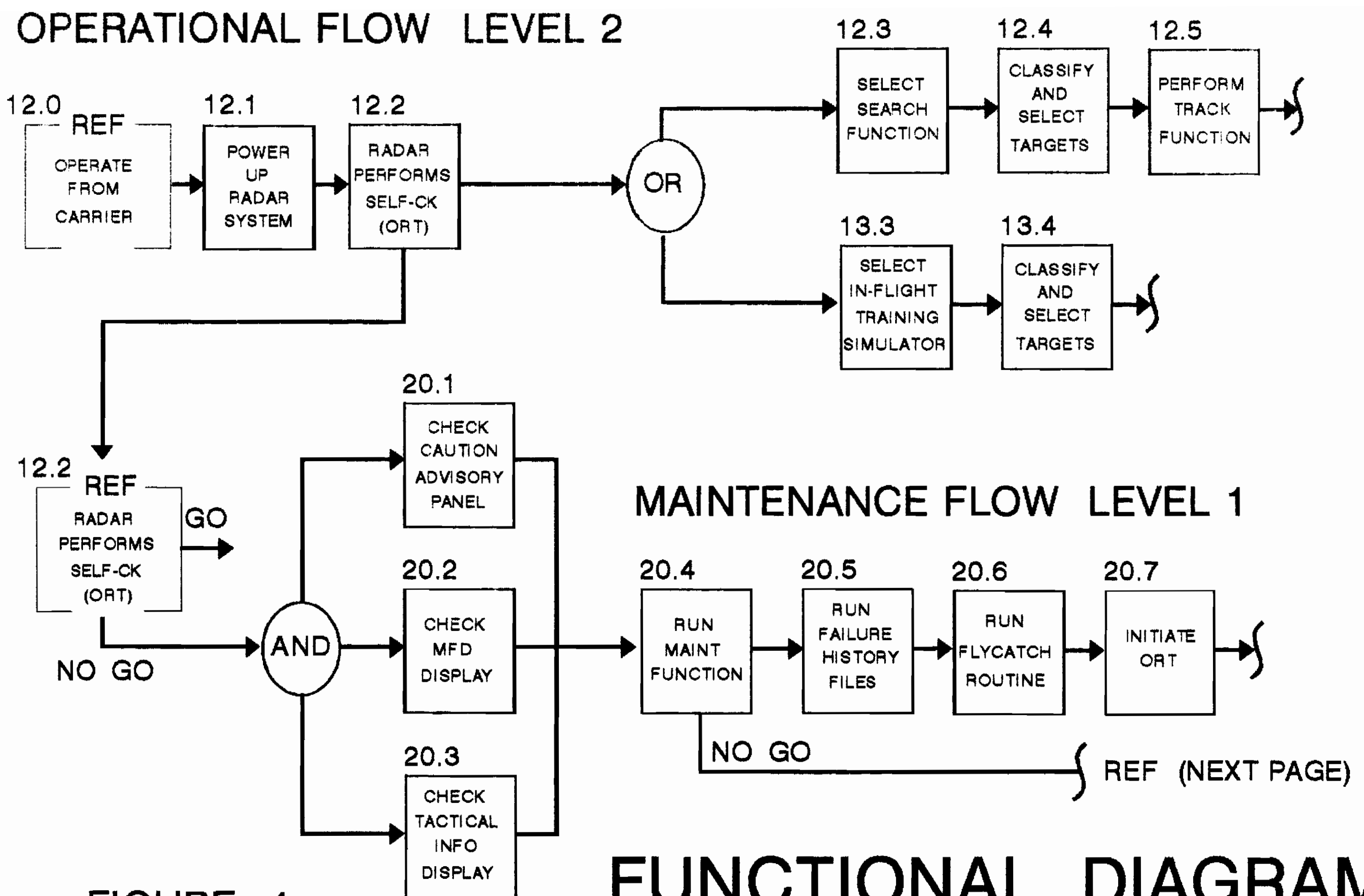


FIGURE 4.

FUNCTIONAL DIAGRAM
(CON'T)

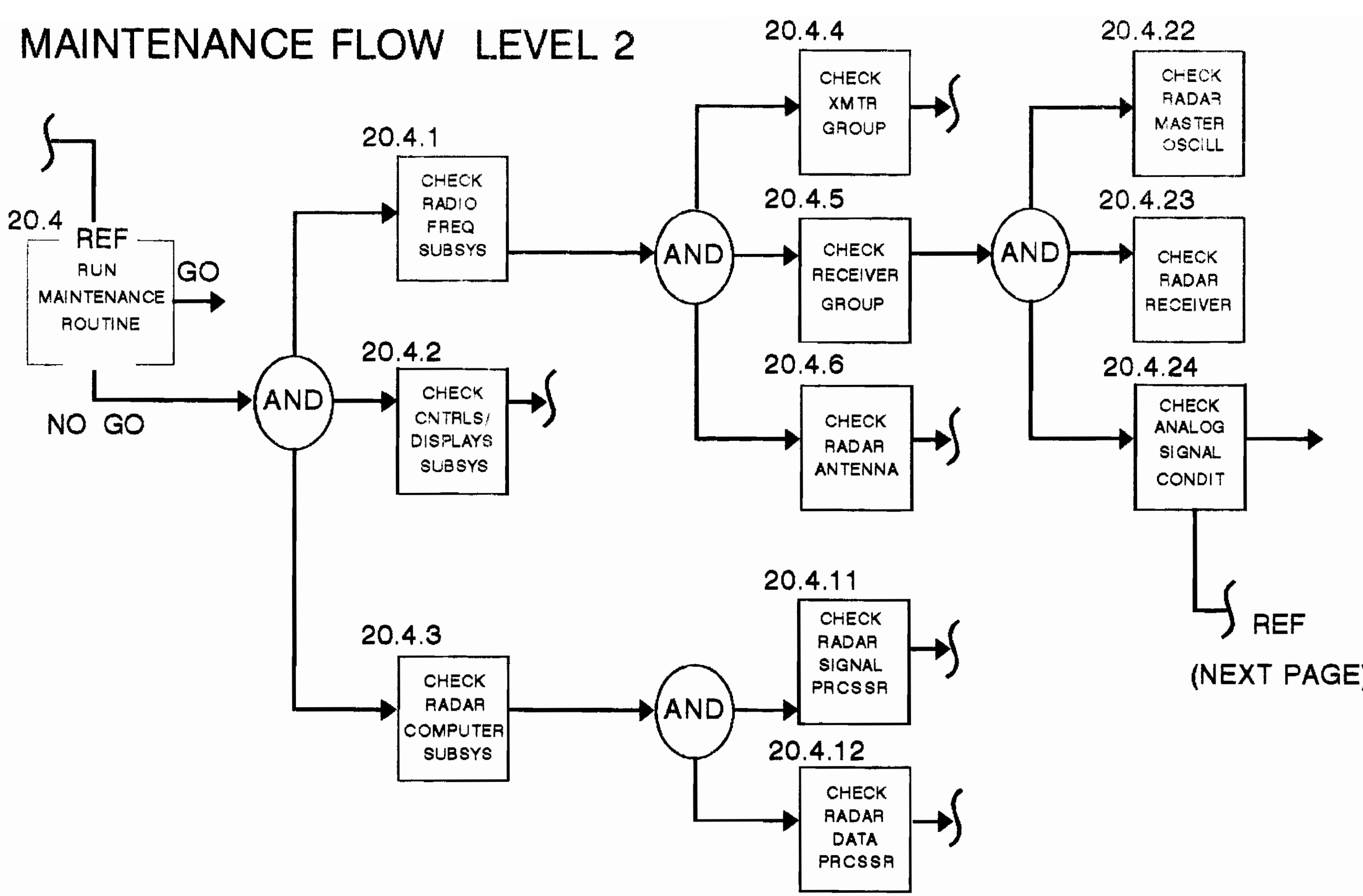


FIGURE 5. FUNCTIONAL DIAGRAM (CON'T)

MAINTENANCE FLOW LEVEL 3

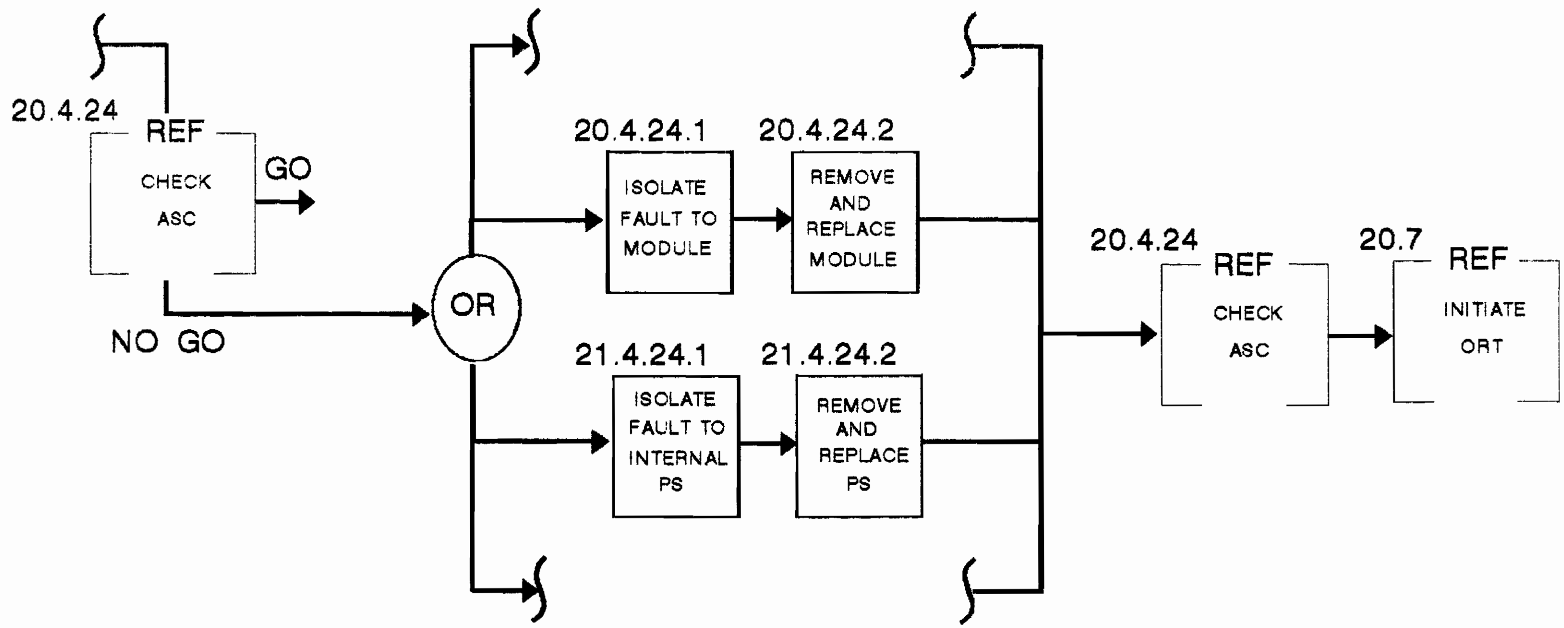


FIGURE 6. FUNCTIONAL DIAGRAM (CON'T)

in motion, acceleration, and direction. Further, it is expected that the radar set will be exposed to all extremes in global climate conditions, from hot and humid to cold and dry, with constant exposure to salt air.

The radar set will support the F-14 weapons system during surveillance missions, strike missions, in-flight training simulations, and air-to-air combat with hostile aircraft.

To increase reliability and maintainability effectiveness, the AN/APG-71 radar system must be capable of system level self checks (Built-In-Test, BIT) and component level self checks (Built-In-Self-Test, BIST). The radar system as installed in the airplane shall incorporate BIT and BIST features to provide a means of determining and displaying system status to the weapon replaceable assembly (WRA) level. The radar system BIT shall be capable of detecting 95% of all system faults and isolating those detected faults 95% of the time to a single WRA. In contrast, the avionics BIT shall be capable of detecting 85% of all systems.

Other effectiveness requirements concern the availability of the radar system, i.e., reliability/maintainability issues. The AN/APG-71 must conform to the Navy's *refly reliability* standard which is the probability that the aircraft's weapon system can be returned to full operating capability without corrective maintenance, other than minor O-Level unscheduled maintenance that can be performed in the forty (40) minute turn-around time between missions. Further, the mean flight hours between failures (MFHBF) should be no less than 2.3 hours.

The radar system must be supportable by standard Navy practices. Additional expertise where needed at the depot level will be procured by the Navy from Hughes Aircraft Corporation. Maintenance work performed on naval aircraft and associated equipment falls into one of three categories - Organizational, Intermediate, or Depot. These three categories are referred to as the three levels of maintenance and are frequently referred to in abbreviated form as "O", "I", or "D" level of maintenance.

Organizational maintenance is the lowest level of maintenance. It is performed by the squadrons on their aircraft, and involves such things as greasing, washing, inflating, inspecting, checking, troubleshooting and removing/replacing components or assemblies.

Intermediate maintenance, as the name implies, falls between organizational and depot level maintenance. This work is performed by an Aircraft Intermediate Maintenance Department (AIMD), sometimes referred to as an Intermediate Maintenance Activity (IMA). AIMDs typically support several squadrons and are located at Naval Air Stations, as well as on aircraft carriers. Work performed by the AIMD involves bench testing, some disassembly and replacement of failed parts, adjusting, etc.

The final, and highest level of maintenance, is the **Depot level**. Depot usually means a Naval Aviation Depot. Some depot level work, however, is performed by contractors. There is virtually no limit to what can be done at a NADEP. Work can be as simple as disassembling, cleaning.

reassembling, and repainting, or as involved as completely reproducing (manufacturing) replacement parts not readily available through the supply system and installing them by using specially designed support equipment.

Other areas to be considered regarding support logistics is the repair support equipment and personnel. Almost all of the components of the newer radar system can be tested on existing Navy Automatic Test Equipment (ATE). However, there still remains a requirement to rewrite many of the test program sets (TPS), which are the software programs that drive the hardware. In addition, service manuals will have to be published that address the various new components and test sets, and training will have to be developed and provided for all service personnel associated with the radar system. Finally, spare systems will be at a premium since the cost of a complete system with piece part reserves will run over $10 million. Nevertheless, the initial program will attempt to supply approximately 1.5 radar systems for every F-14D aircraft.

The disposal of the system should not present any unusual problems. After the year 2001, the radar sets will no longer be produced. By that time, the Navy expects to be well into the production of its next generation of aircraft fighters, i.e., its version of the ATF. In effect the F-14's will be removed from service by attrition for approximately ten years. The corresponding affected radar sets will be cannibalized as required, with "good" parts returned to the supply system to support the remaining operational sets in service. During the final disposal phase, the remaining complete radar sets will be used in various training situations, e.g., schools for electronics technicians. There are no hazardous materials to contend with, and there are no environmental concerns other than the disposal of scrap metal.

One additional item that deserves attention is the System Engineering Management Plan (SEMP). A program of this size needs to establish strict guidelines up front to coordinate efforts between the major parties, that is, between NAVAIR (the ultimate user of the product), Grumman (the primary contractor to build the F-14) and Hughes Aircraft Company (the principal designer and producer of the radar system). Hughes has proven the viability of the AWG-9 modification and will serve as a subcontractor to Grumman to design, develop and qualify the AN/APG-71 radar for the F-14D.

SYSTEM DESIGN

It has been established that what the Navy needs is a radar system with significant increases in signal processing capabilities. Adhering to the process flow depicted in the first figure of the functional diagrams, the general requirements were defined, and will now be followed by the design phase. There are many constraints that restrict what the designer can do since the radar system will be fitted into essentially the same compartments that the older system vacates. Recall that the primary goal is to digitalize certain key elements with the intent of improving data processing speed, reducing weight, and increasing the reliability of the system.

RELIABILITY/MAINTAINABILITY ANALYSIS

Before full scale development of a prototype begins, a reliability prediction and maintainability analysis should be performed to determine if the proposed digital version will satisfy the Navy's *refly reliability* standard and the MFHBF requirements.

One method used to predict the radar set's reliability/maintainability will be to incorporate established military standards. For example, items that are common between new electronics devices and older devices, can be studied by examining the maintenance history of these older units from the military's 3M data. The failure rate of new components has to be predicted using other mathematical methods coupled with actual trial tests.

until a more extensive history file from the field can be developed.

To illustrate, a common technique for estimating the failure rate of specific components is the US Department of Defense MIL-HDBK-217 standards. In each version of the standard, the objective has been to develop a model for the failure rate of electronic components using experimental data obtained by analyzing the failures of actual devices. Shown below is a model and some of the more important parameters that are used in calculating (predicting) the constant failure rate (cfr) of an integrated circuit.

$$cfr = \pi_L \pi_Q (C_1 \pi_T + C_2 \pi_E) \pi_P \quad \text{failures per million hours}$$

where π_L is a *learning* factor, π_Q is a *quality* factor, π_T is a *temperature* factor, π_E is an *environmental* factor, π_P is a *pin* factor, and C_1 and C_2 are *complexity* factors.

Once a failure rate has been assigned to a discrete component and/or circuit card, then an analysis is made of a higher assembly which might contain two, three, or hundreds of the rated subcomponents. Using standard techniques, each subassembly, or to use the military terminology, each shop replaceable assembly (SRA) is assigned its own failure rate, and in turn the next higher assembly, or weapon replaceable assembly (WRA), is likewise evaluated. Once a group of WRAs are rated (e.g., the radar set) a final prediction can be made to see if this total system will satisfy the original design specifications. If the prediction is acceptable, then a history will be maintained to determine if the reliability analysis is valid.

RELIABILITY AND MAINTAINABILITY (R/M) PREDICTION ANALYSIS

The baseline radar set specified in F-14 Specification (SD-561-3), was used as the reference configuration for the APG-71 hardware prediction analysis. This R/M data showed an average MFHBF for these radar sets to be 2.35 hours. The data from the R/M Prediction Analysis is given in Table 3. Note that there *are* line items that are not listed in Table 3 due to the sensitive or classified nature of the item. The table is meant to be a representation of typical values only.

Estimates of the R/M parameters were provided by the Navy or, where not available, estimates of these R/M parameters were obtained from 3M data of similar units. Certain ratios (e.g., the conversion ratio for the AN/APG-71 is 2.7) are employed to reduce the supplier's MTBF prediction to a MFHBF. These ratios are based on 3M data compiled for F-14A units (1989, Blocks 105-130). Where supplier MFHBMA and MFHBR were not available, estimates of these values were made using the same ratio between these values and the MFHBF as shown in 3M data for similar units. In addition all MFHBF, MFHBR, and MFHBMA are considered to be unit operational hours compared to mission hours (duty cycle) in factoring the MTBF down to a MFHBF, etc.

There is no redundancy of the major components of the radar set. A *series* mathematical model for the AN/APG-71 is used as the basis for performing all R/M predictions. That is, the AN/APG-71 model is considered a serial string of all units, and the radar system is a serial string within the F-14D model. This is depicted in Figure 7.

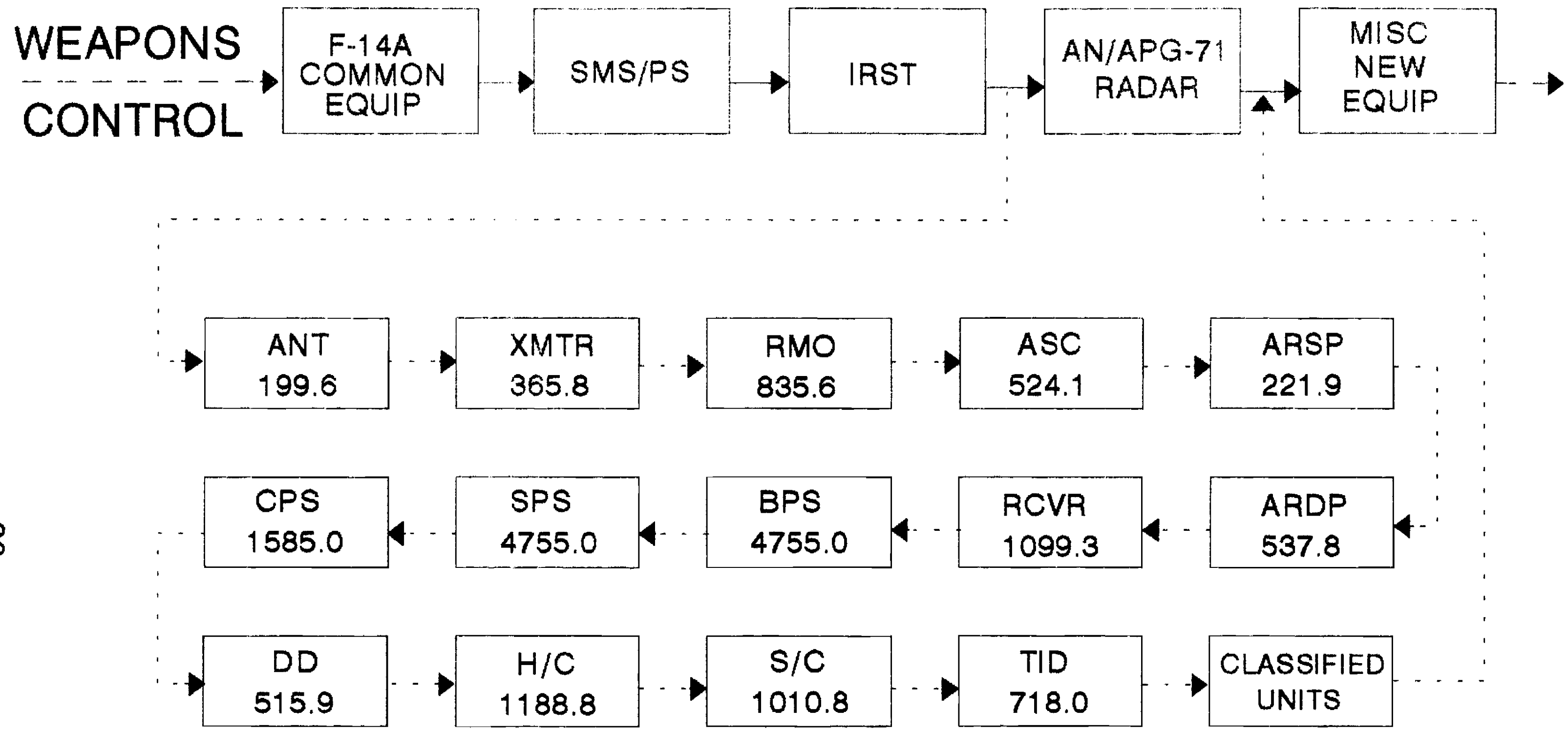
TABLE 3

RELIABILITY AND MAINTAINABILITY PREDICTION ANALYSIS

EQUIPMENT	ORGANIZATIONAL			INTERMEDIATE			
NOMENCLATURE	MFHBMA	MTTR	MMH/FHR	MFHBR	MTTR	MMH/FHR	MFHBF
AWG9 MSLE CONT	3170.0	1.77	0.00156	9510.0	6.00	0.00158	9510.0
WAVEGUIDE (1)	1902.0	1.43	0.00221	3170.0	20.90	0.03428	2377.5
WAVEGUIDE (2)	9510.0	3.00	0.00095	****.*	0.00	0.00000	00.0
RADAR XMTR	172.9	2.44	0.03528	317.0	7.89	0.11200	365.8
WAVEGUIDE (3)	3170.0	7.17	0.00679	3170.0	20.20	0.05416	3170.0
PWR SPPLY(1KV)	1358.6	1.49	0.00230	4755.0	7.50	0.00899	4755.0
PWR SUPPLY	951.0	2.27	0.00525	1902.0	5.06	0.01117	1585.0
PWR SUP SLENOD	3170.0	3.27	0.00289	3170.0	5.90	0.01117	4755.0
WAVEGUIDE	1902.0	0.80	0.00084	****.*	6.90	0.00000	9510.0
MOAT WAVEGUIDE	3170.0	1.50	0.00095	9510.0	2.75	0.00246	9510.0
CABLE	9510.0	4.30	0.00090	****.*	79.90	0.00005	24405.0
CONT DISPLAY	4755.0	1.00	0.00063	****.*	1.50	0.00000	18156.0
TID	117.4	1.41	0.02522	306.8	5.06	0.05773	718.0
AUX SUBSYS	3170.0	7.57	0.00716	****.*	0.00	0.00000	9510.0
EQUIP RACK	2377.0	18.50	0.01634	****.*	0.00	0.00000	9510.0
HAND CONTROL	396.3	0.81	0.00409	1188.8	2.80	0.00872	1188.8
SENS DISP	333.2	1.20	0.00792	1132.5	4.12	0.00618	1010.8
RADAR OSC	488.5	2.10	0.00903	489.8	5.48	0.01678	835.6
RECEIVER	417.1	2.04	0.01076	418.8	4.70	0.01683	1099.3
ANTENNA	118.2	2.69	0.05917	141.5	6.34	0.05825	199.6
ARSP	152.9	1.65	0.02158	153.0	6.73	0.10997	221.9
ARDP	177.1	1.86	0.02416	177.0	3.80	0.03435	537.8
ASC	440.0	2.07	0.01035	441.1	4.54	0.01441	524.1
DD	352.5	1.47	0.00834	353.0	5.92	0.02851	515.9

LEGEND:

MFHBMA	mean flight hours between maintenance actions
MTTR	mean time to repair
MMH/FHR	maintenance man hours per flight hours
MFHBR	mean flight hours between repairs
MFHBF	mean flight hours between failures



RELIABILITY MODEL

Figure 7.

Based on this type of analysis, the predicted AN/APG-71 R/M parameters have been calculated and are compared to the requirements as follows:

parameter	requirement	prediction
MFHBF	**2.30 hours**	**2.35 hours**
MMH/FH (O-level)	5.10	5.035
MMH/FH (I-level)	5.30	5.232

SOFTWARE ANALYSIS

One of the essential elements in the definition of requirements is the effectiveness requirement that the system contain the ability to test itself. This feature has to be incorporated in the design phase, but is also considered as part of the overall system tests. First, a prediction will be made of the BIT detection effectiveness, then an overview of what the self-tests are expected to do is given.

Percent-BIT Detection

Total aircraft as well as the total radar set's % BIT detection is defined as the sum of unit %BITs times their removal rates divided by the sum of the unit removal rates, where removal rate equals 1/MFHBR. The removal rate instead of the failure rate was used to take into account false alarms.

%BIT Detection		
Equipment	Requirement	Prediction
Radar (old & new WRAs)	**95%**	**98.3%**
F-14D Aircraft (avionics)	85%	86.3%

AN/APG-71 RADAR SYSTEM BIT DESCRIPTION

Although the AN/APG-71 will maintain its own independent self-check system, it will work in conjunction with the overall avionics OBC system.

Built-In Test (BIT)

The BIT and Calibration functions should evaluate the operational capability of the radar using system hardware, firmware and software. The radar system hardware supplies the required input stimuli to the BIT function to execute system tests and calibrations.

BIT should perform the following four functions:

1. Detect radar system faults.
2. Isolate faults to the malfunctioned Weapon Replaceable Assembly (WRA).
3. Advise the RIO of system malfunctions during tactical operation.
4. Calibrate radar system components and system operation to optimize system performance.

BIT will be comprised of three major test categories: Operational Readiness Test (ORT), Initiated BIT (IBIT), and Continuous Monitor (CM).

Operational Readiness Test (ORT) is performed automatically as part of the radar power up sequence. The purpose of ORT is to validate to a high level of confidence that the radar set will perform satisfactorily during a mission. The radar is tested using both Built-In Self Tests (BIST), and System Tests (BIT). Self Tests are self contained and independent of support equipment and external signals. Application of power to a component (ARDP, RMO, ASC and ANT), or a command from the ARDP initiates the self-test function. Faults are declared to the ARDP by the unit after a test has been repeated and failed three times (faults occurring less than three times are stored in the Intermittent History Matrix). System tests check specific system features and capabilities requiring communication between individual boxes.

Initiated BIT (IBIT) may be performed either airborne or on the ground when initiated by the operator while in the BIT category.

Continuous Monitor (CM) is automatically initiated upon entry into a tactical mode. CM periodically monitors and evaluates the operational status of key radar system parameters (overheats, power, etc.) as a background task.

Maintenance Readout Routine. This display results from accumulated CM, CMD OBC, and test panel initiated BIT. Failure data is stored in MCS memory, and made available through the MCS interface with the display system. This display is selected by pressing the FAULT pushbutton on the MFD. MCS failure history files will then be interrogated, and the results displayed on the operator's MFD.

Cooperative Support Software (CSS) Functions. CSS function (trap, block address, and flycatcher) extract memory information from compatible processors and make it available for MFD display and storage in a designated location.

The radar's software is important not only for fault isolation but especially for maintainability of the individual radar units (BIST) and also for the interface between these units (BIT). In addition, the software is ultimately the vehicle that directs the actions of the radar system. Depending on the ordnance and mission of the aircraft (i.e., intercept, patrol, strike) the instruction sets for a particular mission are loaded into the mission computers while the aircraft is on the ground. The mission computers then instruct and interact with the radar data processor to tell the radar system what it wants the radar to do. Once airborne, the mission computers continuously update the radar system with crucial information concerning the aircraft's vector location, altitude, speed, etc. The information received from the mission computers has to be as near perfect as possible; even if erroneous data is received from the mission computers, the radar system will still perform as well as it can based on the information provided to it from outside sources. Consequently the software is critical to the reliability of the radar's mission, as well as being essential for the maintenance of the radar's hardware, hardware interrelationship, and hardware interface with other avionics.

RADAR SYSTEM PROTOTYPE DESCRIPTION

The preliminary AN/APG-71 radar system design will consist of thirty-six (36) higher assembly components, or units, of which twenty (20) are existing AN/AWG-9 units, four (4) are AN/AWG-9 modified units, and twelve (12) are new. Many of the existing units are items such as waveguides and holding fixtures, which are not being replaced. The major carry-over units are the transmitter group and the tactical information display (TID). The essential new units are the computer subsystem and the receiver group. What follows is a brief description of what the radar system groups and subgroups should be, and some of the basic functions. A block diagram of the radar system and its relationship to other avionics systems is shown in Figure 8.

The AN/APG-71 system shall be divided into 3 subsystems defined as follows:

(1) **Radio Frequency (RF) Subsystem**

(2) **Computer Subsystem**

(3) **Controls and Displays Subsystem**

(1) <u>**Radio Frequency Subsystem**</u>

The RF Subsystem shall consist of the following:

Transmitter (XMTR) Group

Receiver Group

Radar Antenna

Transmitter Group

The XMTR Group shall consist of the following WRAs:

Radar Transmitter

Collector Power Supply (CPS)

Beam Power Supply (BPS)

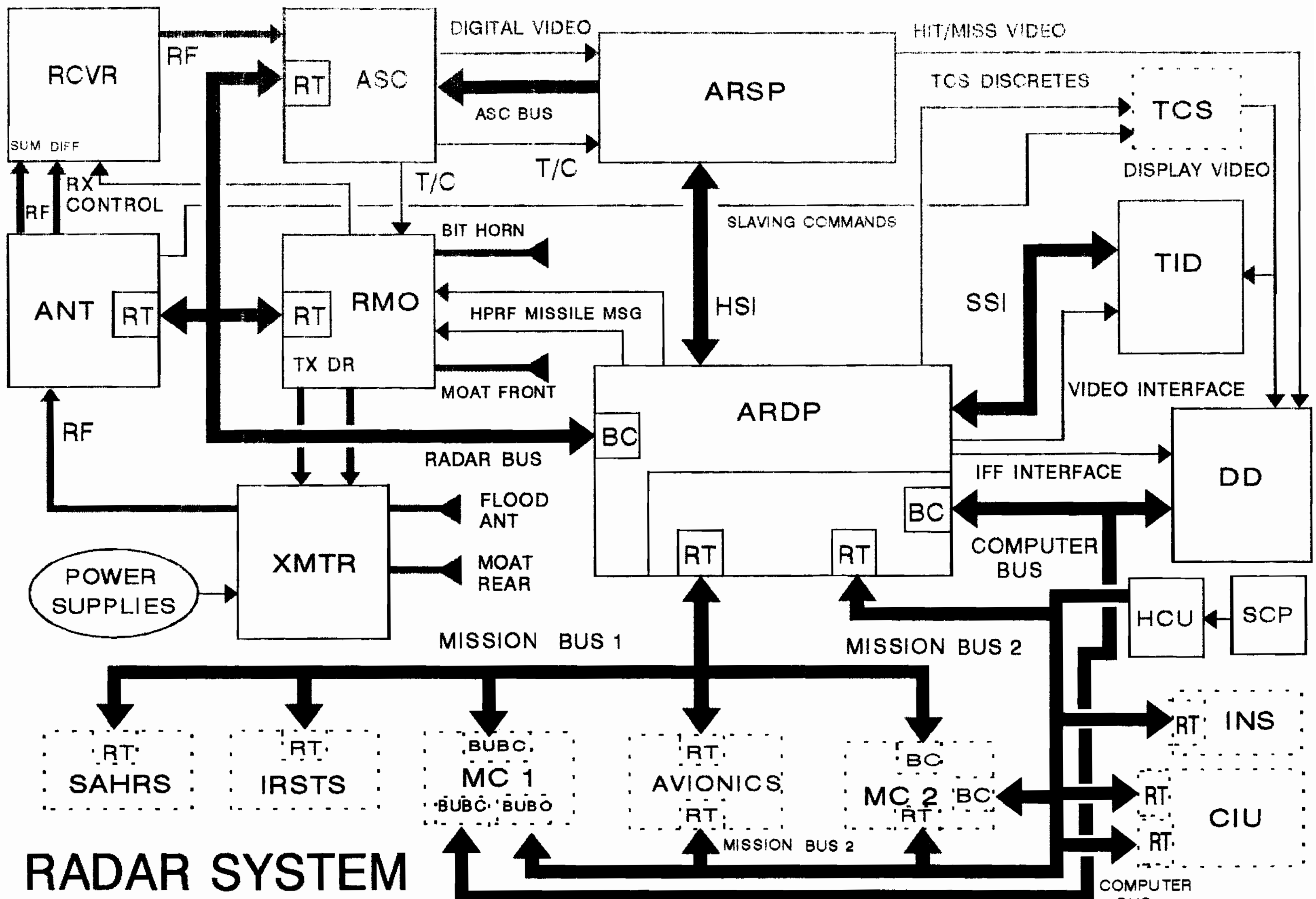
Solenoid Power Supply (SPS)

The radar transmitter will contain a pulsed power amplifier and a Continuous Wave (CW) power amplifier. The pulsed power amplifier shall receive a low power RF signal from the Radar Master Oscillator (RMO) and amplify it. This amplified signal shall be gated by the transmitter gate signal from the Analog Signal Conditioner (ASC) and sent to the radar antenna for broadcast. The pulsed power amplifier shall be used for pulse doppler and pulse radar operation as well as for data link messages for missile support. The CW RF signal shall be used for CW target illumination for a CW guided missile. The transmitter group shall receive command discretes from the ARDP program and send back status discretes to the ARDP program for BIT purposes. The transmitter shall also receive a grid gating signal from the ASC.

The CPS shall be a floating unregulated power supply whose negative terminal is connected to the cathode of the pulsed power amplifier and the positive terminal to the collector of the pulsed power amplifier.

The BPS shall be a direct current voltage-regulated supply that is connected between the cathode and the body of the pulsed power amplifier. This power supply shall also provide the beam power for the CW power amplifier when CW illumination is required.

The SPS shall be a remote sensing current-regulated unit that provides the excitation current for the pulsed power amplifier focusing electromagnet.



RADAR SYSTEM
Figure 8.

Receiver Group

The receiver group shall be composed of the following WRAs:

Radar Master Oscillator (RMO)
Radar Receiver (RCVR)
Analog Signal Conditioner (ASC)

The RMO shall provide X band transmitter drive signals for the CW and pulsed power amplifiers of the transmitter. The RMO shall also provide an X band local oscillator (LO) to the receiver. The CW drive signal can be any one of six selectable carrier frequencies with frequency modulation to provide coding for the CW guided missiles. The pulsed power amplifier drive signal and its corresponding LO signal shall be generated using a frequency synthesizer with the capability of rapidly changing carrier frequencies. Depending upon the system mode, the signals can be frequency modulated to perform frequency modulation ranging in High PRF (HPRF) PD operation, and a chirp pulse for Low PRF (LPRF) pulse compression operation. The commands necessary to select these various options shall come from the ARDP program through the MIL-STD-1553B Radar Multiplexed (RMX) bus. Missile message commands from the ARDP program shall arrive over discrete lines. Timing signals for the sequencing of the operation shall come from the ASC.

The radar receiver shall be a dual channel receiver with the capability of low noise amplification and dual down conversion to IF. The receiver shall amplify the two channel RF energy from the antenna and convert it to an intermediate frequency (IF) for use in the ASC. During STT operation the receiver shall combine the two received channels by using a quadrature combiner. During LPRF pulse compression operation, the receiver shall compress the input chirp pulse in both channels. The receiver blanking signal from the RMO shall be used to protect the receiver while the transmitter is on.

The ASC shall provide the signal conversion necessary to transform the IF signal from the receiver into the digital format required for processing by the ARSP program. Two IF inputs shall be supplied to the ASC: a main/sum IF channel and guard/difference IF channel. Analog slewable central band and main lobe clutter filters shall be provided and positioned by commands from the ARDP program. These filters can also be bypassed on command from the ARDP program. The ASC shall receive digital automatic gain control commands from the ARSP program so that signal power will be kept within the dynamic range of the analog-to-digital (A/D) converter. Upon conversion to video, each IF channel is converted to its inphase (I) and quadrature (Q) components. These video signals shall be filtered by one of 16 video filters selected by the ARDP program before being A/D sampled. Also included in the ASC is the timing and control function. The timing and control command information shall be generated by the ARDP program. The ASC shall use this information to generate timing signals for the rest of the radar system. All ARDP generated ASC control commands, including the Timing and Control (T&C) commands, shall be transmitted to the ASC via High Speed Interface (HSI) to the ARSP and then from the ARSP to the ASC over the ASC bus. This transmission shall require ARSP program cooperation. The primary ASC software function shall be to perform Built-In Self Test (BIST). A secondary function shall be the handling of microprocessor interrupts and tactical interrupts for functions which require the use of the ASC internal digital BIT. Finally, the microprocessor software shall provide for handling an RS232 interrupt for Special Test Equipment (STE).

The Radar Antenna

The radar antenna shall be compose of four antennas: a sidelobe planar array, an IFF array, a null horn, and a guard horn all mounted on a two-axis gimbal system. The primary function of the radar antenna shall be to directionally propagate RF signals from the transmitter and direct RF signals which are incident on it to the receiver. At the antenna pedestal a two channel waveguide (main/sum and guard/diff) shall be available for routing to the radar receiver. The pointing of the antenna shall be performed by hydraulic actuators that are powered by a self-contained hydraulic power supply and controlled by a digital controller. The antenna controller shall accept scan and pointing commands from the ARDP and shall compute the analog drive commands for the antenna hydraulics. The antenna controller in return shall send the space and aircraft stabilized antenna position to the ARDP program.

(2) **Computer Subsystem**

The computer subsystem shall be composed of two WRAs:

Advanced Radar Signal Processor (ARSP)

Advanced Radar Data Processor (ARDP)

The ARSP shall be a special purpose digital signal processing computer. It shall consist of four processing elements, a MIL-STD-1750A architecture array controller, working program and bulk storage memories, and interface hardware. The ARSP program shall accept digital data from the ASC and then process the data to extract information on the signal content. The ARSP program shall enhance weak target signals and perform thresholding to provide detection decisions. Selected data shall be sent to the ARDP program for use in target tracking, raid assessment, and target identification functions. Detected video data shall be formatted and sent to the DD for display to the RIO. The ARSP program shall receive ASC timing and control commands from the ARDP program, which are forwarded to the ASC, and signal processing command control information from the ARDP program.

The ARDP shall be a general purpose digital computer consisting of two MIL-STD-1750A architecture CPUs, program and working memories, and interface hardware. The role assigned to the ARDP program shall be the control of the radar system and other peripherals, and interfacing with the operator and other F-14D avionics systems. The processing of the radar signal content information shall include observation processing, sampled data tracking, and closed loop tracking. These functions shall be organized to perform the required processing appropriate for the particular system mode and waveform. The resulting track information shall be displayed to the RIO and sent to the MC2 program for use in its weapon control functions. The ARDP shall perform the control functions for the AN/APG-71. In this role it shall generate the appropriate commands to implement each of the radar modes, and it shall correlate the radar information with information from other peripheral equipment.

(3) <u>Controls and Displays Subsystem</u>

The C&D subsystem shall provide the RIO with the required visual displays, controls, and indicators necessary to interface with the AN/APG-71 . The C&D subsystem shall consist of the following WRAs:

Sensor Control Panel (SCP)
Digital Display (DD)
Hand Control Unit (HCU)
Tactical Info Display (TID)

SUPPORT EQUIPMENT

Concerning the design of support equipment; as mentioned in the previous section on requirements, virtually all of the test equipment can be obtained using existing Navy ATE where available, and supplementing the remainder with commercially available products. However, as was also pointed out, new test programs will have to be written, especially in the case of the digital units. Most of the old radar components and all of the new radar components will have extensive Built-in-tests (BIT) and Built-in-self-tests (BIST). Consequently, the majority of the software's job will be to exercise self test abilities and record the results. There *will* be a hardware requirement, however, for new interface devices, cable assemblies, cooling oil adapters, and other related interface connections between the test unit and the test equipment.

SYSTEM TESTS

SYSTEM LIFE CYCLE TESTING

As an integral part of the total life cycle process, good test planning should accompany every phase. Proven components of the radar systems, i.e., carry-overs, will need far fewer initial tests when compared with the newly designed digital units. As the point of system integration nears, clever testing strategy becomes critical, since this will be the ideal opportunity to capture "weak" or fatal areas in overall system operation. Referring to Professor Blanchard's book *Systems Engineering and Analysis*, the following figure shown (Figure 9), and the testing types discussed are defined in section six of said book.

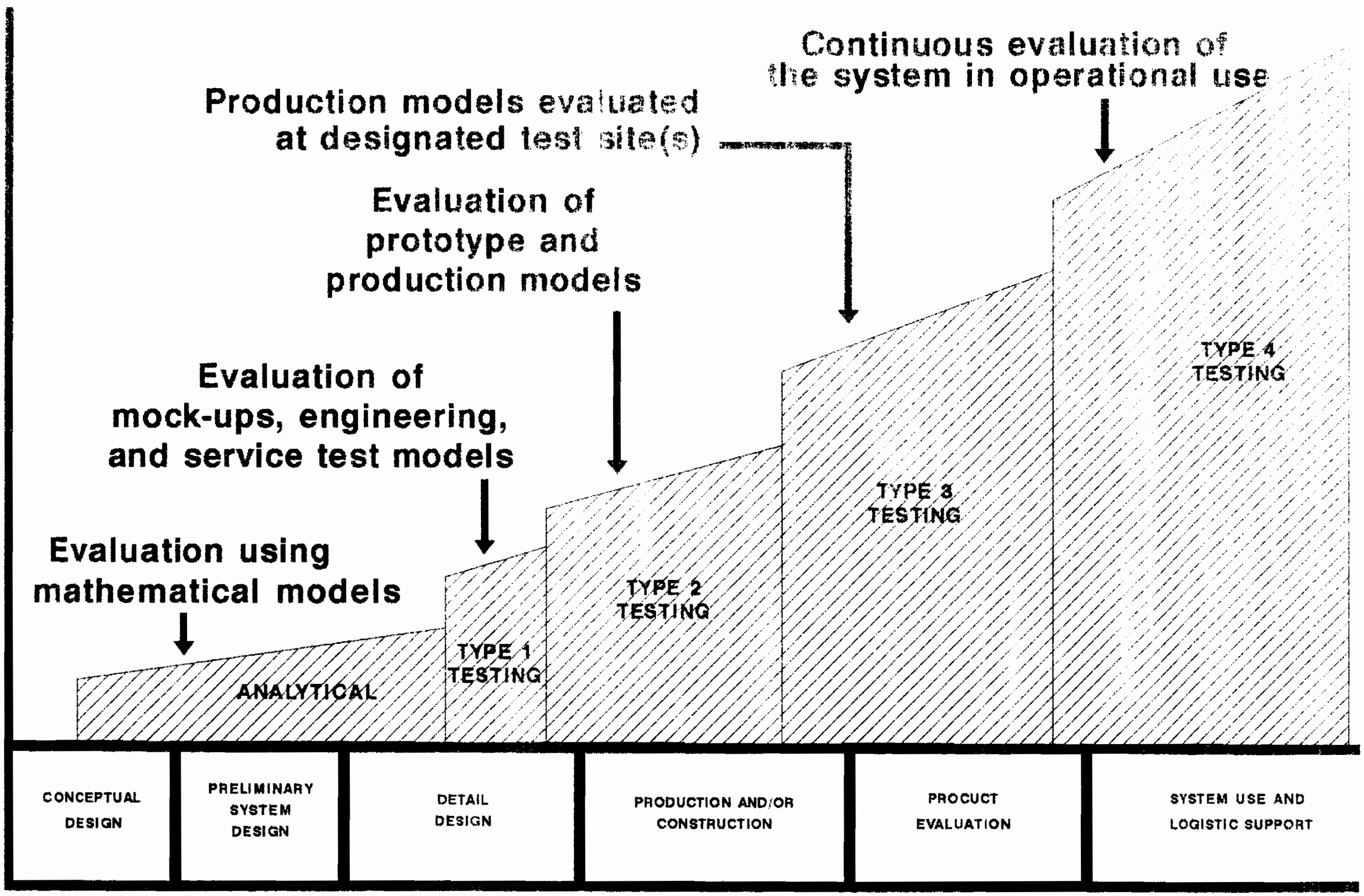
Type I Testing

As described in the text, R&D, or early design development, is not directly applicable to the AN/APG-71 radar system as a whole, but rather to certain key components that constitute a large portion of the total system. To elaborate, the AN/APG-71 is a highly sophisticated system that has emerged from 20 years of evolution since the initial AWG-9 (which *did* have many years of Research and Design Development). Naturally, more R&D effort was done on the newer digital subsystems (e.g., ASC), and their interaction with older, but proven subsystems (e.g., the power supplies), and this is where type I testing will occur.

Type II Testing

When the radar prototype has been successfully realized, detailed system tests and demonstrations should be performed before going into a full production phase. The AN/APG-71 will undergo many type two system tests. These will include formal tests conducted by NAVAIR to verify that the radar system will conform to design specifications (SD-4690) established by and agreed to by all parties. In addition, these performance specifications will address most of the elements contained in the final quality conformance testing (acceptance tests) of the manufactured product, such as validation of reliability/maintainability issues, support equipment compatibility, and environmental concerns.

For example, one key element to be tested is the self-tests, BIT and BIST, that have been designed into the radar system. Although this may sound peculiar (i.e., testing the tests) it should be remembered that these self-tests are an integral, *permanent* hardware and software feature designed into the system with the central purpose of improving the effectiveness of the system by increasing the reliability, while certainly being a major factor in the maintainability of the radar set. In any event, the point is that these self-tests, and the software that drives them, have to be validated along with all of the other hardware system tests.



LIFE CYCLE TESTS

Figure 9.

Type III Testing

These tests occur after the beginning of production and involve the total operational structure of the system including support test equipment, the maintenance framework, spares inventory, and all other areas of logistic support. While it might be said that the type II tests were on the entire radar system in a laboratory environment, the type III tests will be in the field under actual operating conditions. Once the radar set has proven itself on a consistent basis, the total weapons system (F-14) will be "sold" to the Navy via a whole series of acceptance tests. These acceptance tests, or quality conformance tests, will check all facets of the radar system during actual flight conditions. The AN/APG-71 radar system will have to pass the same formal tests and demonstrations required of any new aircraft subsystem procured by the Navy.

Type IV Testing

The Navy has maintained extensive records via periodic testing and regular maintenance data on the F-14 and all of its subsystems for several decades, and will continue to do the same for the F-14D, and correspondingly, the AN/APG-71 radar system.

SYSTEM IMPLEMENTATION

Just after the actual feasibility study, representatives of the F-14 program office in the Naval Air System Command indicated a desire to conduct a program wherein almost all F-14A and F-14A+ aircraft produced by Grumman would be inducted into a comprehensive remanufacturing program and converted into an equivalent "D" (for digital) production configuration. As the planning study progressed, the conversion program was defined as approximately 550 aircraft representing all production configurations from Block 70 through Block 155. Consequently, 550 represents the baseline number of fully operational AN/APG-71 radar sets that will be needed.

NOTE: these projection figures are no longer true due to severe cutbacks in military spending; however, these were the original estimates, and they are the numbers that will be used for the AN/APG-71 cost profile.

PROGRAM PLAN

The program plan is difficult to produce in "textbook" form since it is complicated by the initial "R&D phase", and the final "Phase-Down". There has been essentially no R&D on the AN/APG-71 itself as a complete system since the majority of research and development was performed on earlier versions of this radar series by HAC, and this expense was spread out over each series' respective life-cycle cost program. The phase-down is difficult since it is virtually impossible to determine when a replacement for the AN/APG-71 will occur, given the wide-swinging

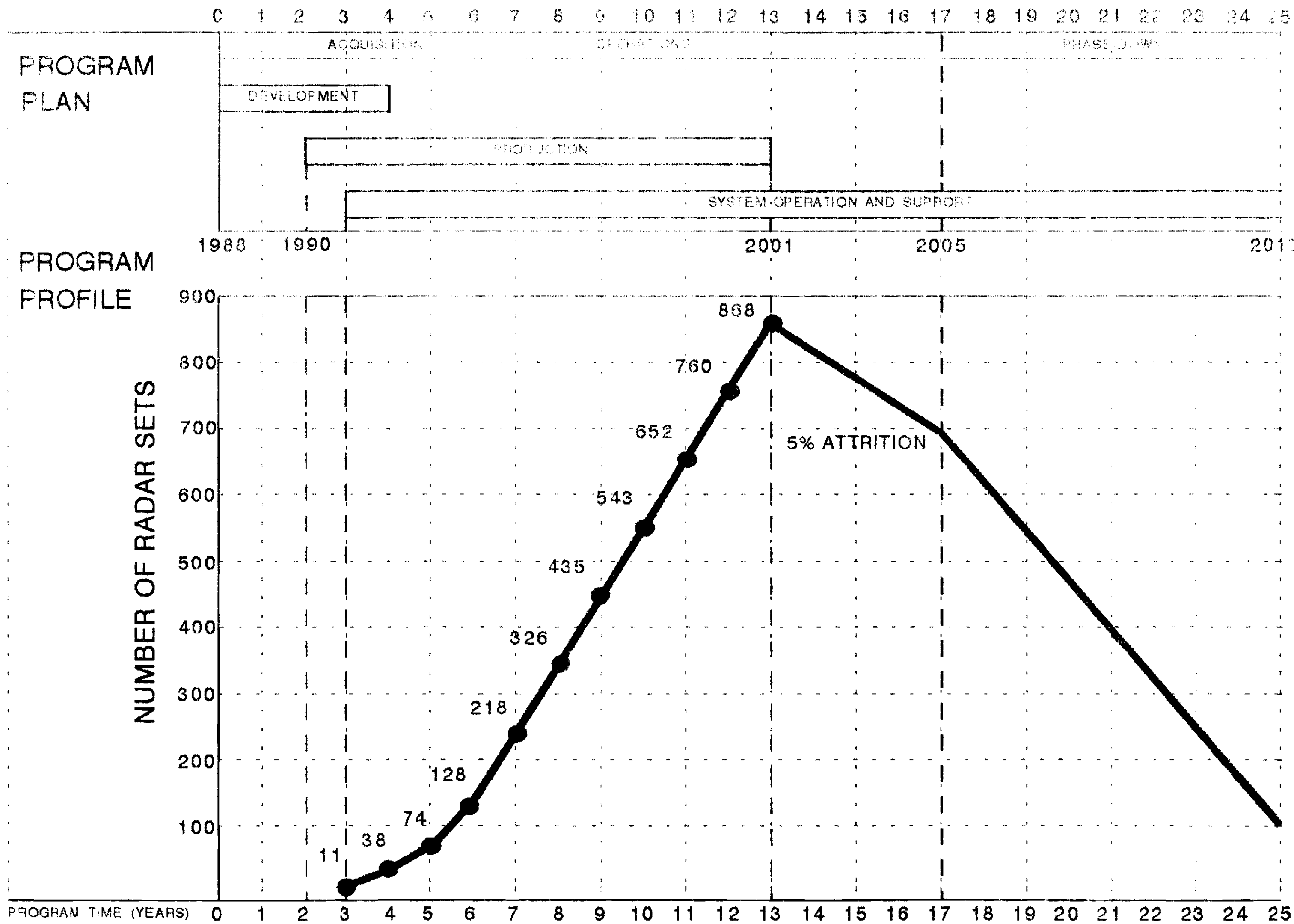


Figure 10. PROGRAM PROFILE

moods of our congress toward defense spending and the unpredictable climate of world politics. (Actually, the AN/APG-73 has already been introduced, wherein a "new" transmitter and "new" power supplies will be incorporated into the existing AN/APG-71 system.) Nevertheless, at this writing, the Navy's version of an advanced tactical fighter (ATF) is tentatively scheduled to be deployed around the year 2005, and this will include a radar system that is totally electronic, i.e., no mechanically moving parts in the forward antenna. Assuming a 5-year buildup (of the ATF), and then another 5 years for full replacement, the phase-down period for the AN/APG-71 could be as long as 14 years.

PROGRAM PROFILE

The procurement rates are as shown. There is an initial buildup of approximately 5 years at which point production of the AN/APG-71 will level out at 109 radar sets per year. Subsequent lots are expected to remain at 109 sets per year until at least 853 radar sets are available. Delivery of the last APG-71 to the fleet will occur in the year 2001. Each F-14D(R) aircraft represents an order for 1.5 APG-71 radar systems from HAC. There are very few spare systems in supply due to cost and backlog of orders.

Regarding the analysis to follow, it should be noted that actual costs are "sensitive" and difficult to obtain. Consequently, although the total system cost is reasonably accurate, many "grand assumptions" have been made concerning individual items (There are 81 line items that make up the complete radar set.). Suffice it to say that a complete set (including spare parts) will come in at

FIGURE 11. COST BREAKDOWN

PROGRAM TIME (YRS)

(INFLATED DOLLARS, MILLIONS)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	TOTAL COST
RESEARCH & DEVELOPMENT (Cr)																										
Crmp	.06	.07	.08	.08																						.219
Crmm	.03	.03	.04	.05																						.156
Crmi	.03	.04	.04	.06																						.159
Crmf	.10	.11	.05	...																						.261
Crm	.22	.25	.21	.19																						.665
Cres	.05	.05	.06	.07																						.222
Cree	...	.05	.05	.06																						.161
Crem	...	.05	.06	.06																						.166
Creh	...	.04	.05	...																						.082
Crep	...	.04	.04	...																						.086
Cre	.05	.23	.26	.19																						.717
Crdi	...	.04	.04	...																						.061
Crdr	...	.04	.05	...																						.089
Crdm	...	.03	.05	...																						.087
Crd	...	.12	.14	...																						.258
Cr	.27	.54	.61	.37																						1.641
INVESTMENT (Ci)																										
Cimm			1.2	9.5	17.2	36.9	79.5	108.4	115.5	120.6	127.7	134.8	141.9													886.2
Cimt			1.7	9.3	24.5	52.7	113.5	152.0	161.2	172.0	182.4	192.6	202.7													1,265.9
Cimf			2.4	13.2	35.0	17.3	182.2	217.2	231.2	246.2	260.6	275.1	289.6													1,808.5
Cima			4.9	27.1	71.5	153.7	330.9	443.5	472.9	502.4	531.9	561.4	590.9													3,690.9
Ciml			3.5	18.9	50.1	107.8	231.7	310.0	330.9	351.7	372.3	392.9	413.7													2,583.6
Cimo			1.9	10.6	28.0	60.0	129.8	173.6	185.4	197.0	208.6	220.6	231.8													1,447.4
Cime			7.1	38.7	102.2	219.5	472.8	633.2	675.5	717.8	759.8	802.0	844.3													5,272.7
Cimp			0.8	4.5	12.0	25.6	55.6	74.5	78.5	83.4	88.4	94.3	99.3													620.3
Cim			23.5	128.9	340.5	701.7	1576.7	2110.8	2251.7	2392.5	2532.6	2673.4	2814.2													17,575.8
Ciim			0.9	4.1	14.5	31.1	67.1	89.9	95.8	101.9	107.8	113.8	119.8													
Ciip			0.6	3.8	8.7	18.7	40.2	53.9	57.5	61.1	64.7	68.3	71.9													448.7
Cis			4.6	25.4	[illegible]	144.2	310.5	415.9	443.6	471.4	498.8	526.7	554.4													3,462.8
Cil			0.4	1.4	7.6	11.2	36.2	48.6	51.7	54.9	58.2	61.4	64.7													403.9
Cild			0.5	2.3	5.2	16.8	24.1	32.3	34.5	37.7	38.8	40.9	43.1													269.3
Cilt			2.8	15.9	40.2	86.5	186.3	249.5	266.2	282.8	299.4	316.0	332.7													2,077.7
Cilx			1.7	9.2	24.1	51.9	111.8	149.7	159.7	169.7	179.6	189.6	199.6													1,246.6
Cii			11.5	63.8	167.7	360.4	778.3	1009.7	1109.1	1178.4	1247.4	1318.7	1386.1													8,656.9
Ci			35.0	192.5	308.2	1092.7	2352.3	3150.5	3360.8	3570.9	3780.0	3990.1	4200.3													26,262.7
OPERATIONS & MAINTENANCE (Co)																										
Coop				0.4	2.2	4.2	10.8	19.2	25.7	27.4	29.2	30.9	32.6	34.3	37.7	41.5	45.8	38.1	29.2	20.7	15.0	10.8	6.7	4.7	2.5	468.0
Coot				0.6	3.4	6.2	18.5	28.8	38.6	41.2	43.7	46.3	48.9	51.5	56.6	62.3	68.5	57.2	42.2	30.8	22.5	16.3	10.1	8.2	3.7	702.1
Coof				1.1	6.2	11.5	30.5	53.4	71.4	76.2	81.0	85.7	90.5	95.3	104.8	115.3	126.8	105.9	78.2	57.4	41.7	30.0	18.7	11.4	6.9	1,300.0
Cooe				0.7	3.8	6.9	18.3	32.0	42.9	45.7	48.6	51.4	54.3	57.2	62.9	69.2	76.1	63.8	46.9	34.4	25.0	18.0	11.2	6.8	4.1	760.0
Coo				2.8	15.6	28.8	76.2	133.4	178.6	190.6	202.5	214.3	226.2	238.2	261.8	288.2	316.9	264.9	195.6	143.5	104.9	75.1	46.7	28.8	17.2	3,250.1
Comm				1.4	7.6	20.2	43.3	93.4	125.0	133.4	141.7	150.0	158.4	166.7	184.0	201.7	221.9	198.7	158.8	127.9	102.2	91.8	57.3	40.1	28.1	2,447.4
Comx				2.0	10.9	28.8	61.9	133.4	178.6	190.6	202.5	214.3	226.2	238.2	262.9	288.2	317.0	285.3	228.2	182.8	146.1	116.9	81.8	57.2	40.1	3,496.3
Coms				1.0	5.3	14.1	30.9	65.4	87.9	93.4	99.2	105.0	110.9	116.7	128.8	141.2	155.3	139.8	111.8	89.5	71.6	57.3	40.1	28.1	19.8	1,713.2
Comt				0.6	4.3	9.8	21.2	15.7	61.3	65.4	69.4	73.5	77.6	81.7	90.2	98.8	108.7	97.8	76.3	62.6	50.1	40.1	28.1	19.6	13.7	1,199.2
Comp				0.7	3.7	6.9	14.9	32.0	42.9	45.8	48.6	51.5	54.3	57.2	63.1	69.2	76.1	66.5	54.8	46.8	35.1	28.1	19.8	13.7	9.6	839.5
Comf				0.3	1.8	11.3	10.4	52.3	70.1	74.9	77.8	84.1	88.7	93.4	103.1	113.0	124.3	111.9	89.5	71.8	57.3	45.8	32.1	22.4	15.7	1,371.1
Camd				0.5	2.6	4.8	24.3	22.4	30.0	32.1	34.0	36.0	38.0	40.0	41.2	48.4	53.3	47.9	38.4	30.7	24.5	19.6	13.7	9.6	6.7	587.6
Cam				6.7	36.3	98.0	208.4	444.6	595.4	635.2	674.9	714.4	754.1	793.9	873.3	980.5	1056.7	950.9	760.8	608.8	486.9	399.5	272.7	190.6	133.6	11,654.2
Copd				...	...	...	...	...	15.3	18.3	21.7	22.8	28.1	30.6	39.3	43.2	54.4	57.0	58.7	52.8	52.2	49.0	38.6	29.3	24.1	643.0
Copl				...	...	...	12.3	57.2	61.3	65.4	66.1	66.9	67.2	77.5	72.9	80.3	81.5	85.6	71.7	64.6	52.2	45.8	31.5	23.9	16.0	1,084.2
Cop				...	...	...	12.3	57.2	76.6	81.7	88.8	91.9	98.9	102.1	112.3	123.5	135.9	142.6	130.4	117.4	104.4	91.8	70.1	53.2	40.1	1,727.2
Co				9.5	51.9	137.2	294.9	635.1	850.6	907.4	964.1	1,020.8	1,077.9	1,134.1	1,247.9	1,372.2	1,509.5	1,358.5	1,086.8	889.4	695.0	558.4	389.5	272.6	180.6	16,631.5

TOTAL SYSTEM COST ALLOCATION C

TOTAL COST (INFL DLRS, MILLIONS)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13
DESIGN	0.3	0.6	0.7	0.4	...	...	...	...	...	...	...	...	...
INVESTMENT	...	...	35.0	192.5	508.2	1092.1	2552.3	3150.5	3360.6	3570.9	3780.0	3990.1	4200.3
OPER/MAINT	...	...	...	9.5	51.9	137.2	294.9	635.1	850.8	907.4	964.1	1020.6	1077.3
TOTAL COST	0.3	0.6	35.7	202.4	560.1	1229.3	2847.2	3785.6	4211.4	4478.3	4744.1	5010.7	5227.6

Year	14	15	16	17	18	19	20	21	22	23	24	25	TOTAL COST (INFL DLRS, MILLIONS)
DESIGN	...	...	...	...	...	...	...	...	...	...	...	...	1.8
INVESTMENT	...	...	...	...	...	...	...	...	...	...	...	...	26,262.7
OPER/MAINT	1134.1	1247.5	1372.2	1509.5	1358.5	1088.8	869.4	695.6	556.4	389.5	272.6	190.8	16,631.5
TOTAL COST	1134.1	1247.5	1372.2	1509.5	1358.5	1088.8	869.4	695.6	556.4	389.5	272.6	190.8	42,896.0

COST PROFILE

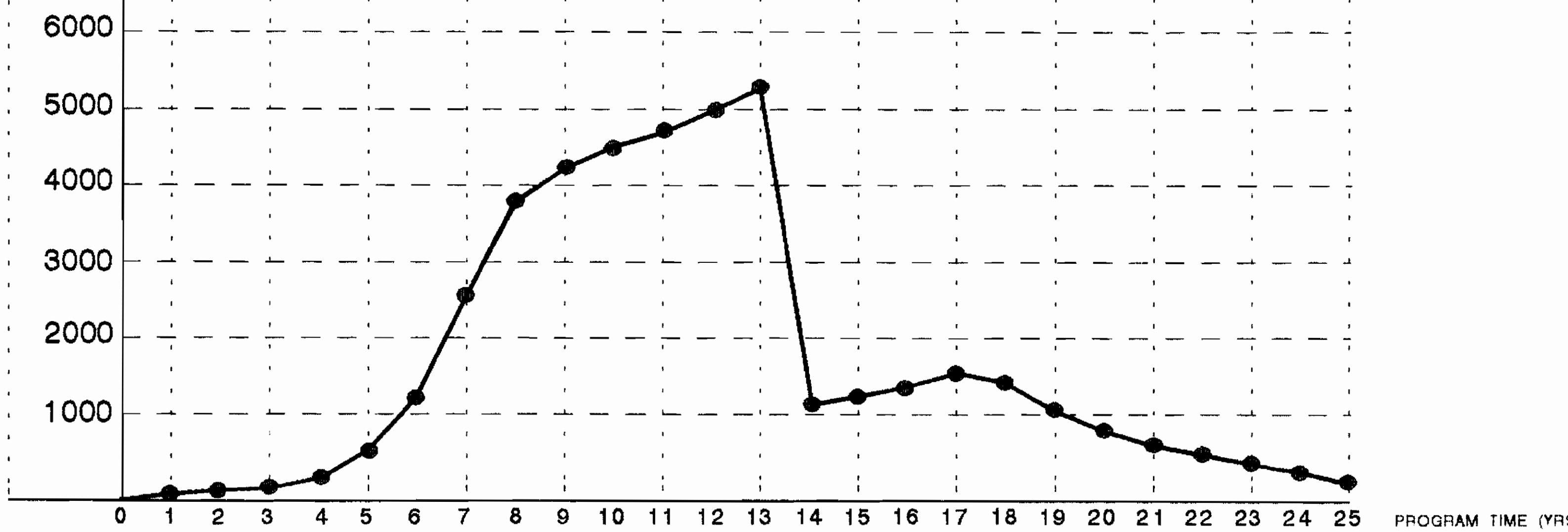


FIGURE 12. COST PROFILE

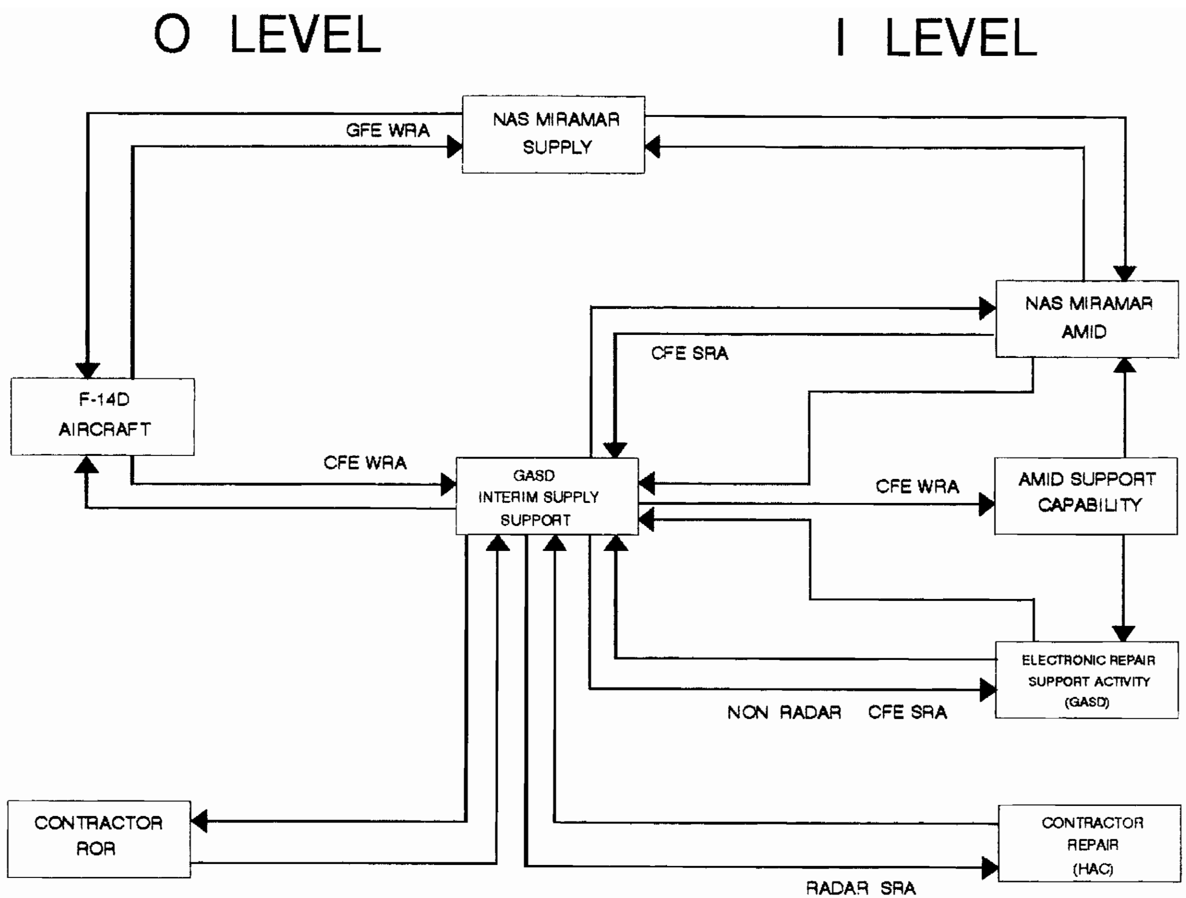
about $11.2M. Costs are based on inflated dollars (6%). In any event, the structure and methodology should be correct as it relates to this project.

NAS MIRAMAR SUPPORT SITE ACTIVATION

To provide for the support effort, the Navy initiated the Support Site Activation Plan to provide site activation and managerial personnel with an integrated activation plan for the orderly introduction of support elements associated with the F-14D weapon system. A proposed contractor operated Electronic Repair Support Activity (ERSA), is intended to provide interim Shop Replaceable Assembly (SRA) support until the Navy develops organic SRA test/repair capability.

In short, site activation at NAS Miramar CA, is a joint Navy/Grumman effort. The Navy has overall responsibility for the activation effort. The Naval Air Station is responsible for providing Intermediate and Organizational level spaces, warehousing, and administrative space requirements as identified in this Site Activation Plan. Depot level support will be procured from Hughes by a specific contract.

Figure 13. illustrates the Organizational and Intermediate level facilities required to support the APG-71 at NAS Miramar. Due to the high degree of commonality between the AWG-9 and the AN/APG-71, most of the facilities currently in place at NAS Miramar are adequate to support the APG71.



MIRAMAR MAINTENANCE SUPPORT

Figure 13.

Organizational Level Support Equipment

Some new and modified portable test sets and mechanical support equipment will be required at the organizational level of maintenance. One example is the Loader Verifier Test Set (LVTS). This test set enables loading and verification of the following 1553B compatible programmable memories:

- Data Entry Keyboard Indicator
- Armament Computer
- Advanced Radar Data Processor
- Converter Interface Unit
- Sensor Control Unit
- Tactical Threat Warning Computer
- Mission Computer
- Infrared Search and Track System

The LVTS is required at both the "O" and "I" levels for loading and verifying programmable memories.

Intermediate Level Support Equipment

A representative list of some of the typical Automatic Test Equipment (ATE) required for testing new or modified WRA's of the AN/APG-71 are:

-- CAT IIID AN/USM-429(V1)

-- RADCOM/RIU AN/USM-467 & OQ-354/ISM467

-- Avionics Test Set (ATS) AN/USM-470(V2)

-- Grumman Automatic Cable Tester (GACT)

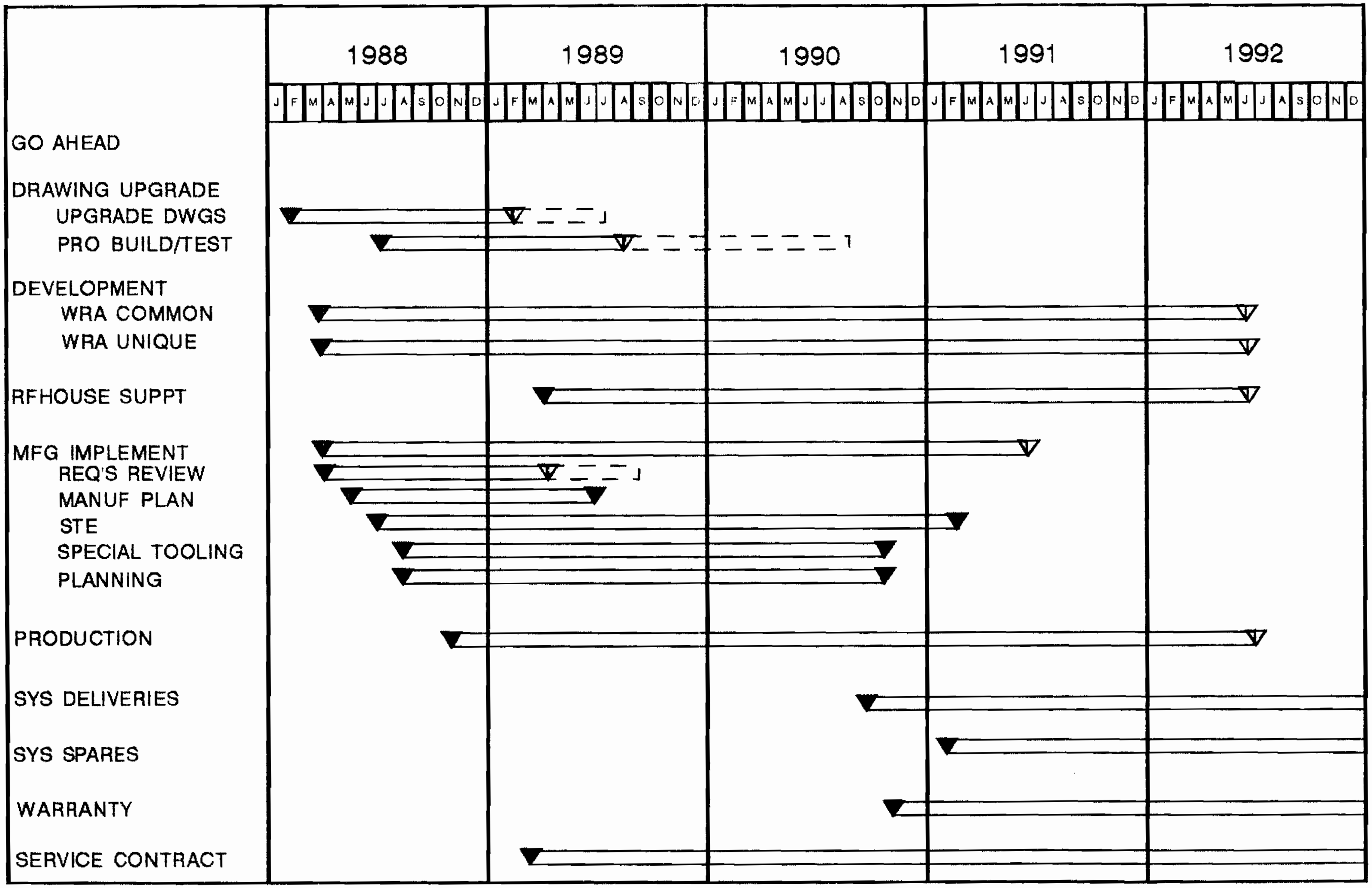
The Navy already owns and operates this test gear. The new requirement will be for software to drive the ATE, and interface devices and cables to connect the unit-under-test to the tester.

Test Program Set (TPS) Requirements Intermediate level FSD Support Equipment is being provided to NAS in support of the CFE WRA's in the FSD aircraft at PMTC OPEVAL. They include Test Program Sets (TPS's) and Ancillary Equipment per WRA utilizing the ATE machines listed above.

NATOPS manuals and some organizational data manuals have been ordered and should be completed by site activation. Production versions of the remaining organizational pubs, plus Intermediate Level and Support Equipment manuals, are currently being produced.

Summary

In Figure 14, projected start/stop times for various supporting concurrent activities are shown together in one milestone chart. Although an elementary observation, please note that as can be seen, many of the subprojects will overlap, which emphasizes the need for the timely coordination of all line items to realize the successful completion of the final product. Two of the entries on the chart that may need additional clarification are the "roofhouse support" and the "service contract" lines. The roofhouse is similar to a lab arrangement where the total system is operational and available for experimental or developmental work. The key difference is that the roofhouse radar system will be capable of transmitting, i.e., full power radiation, where normally this is not possible in the lab environment. The service contract involves factory representatives that will be available to assist the Navy on-site during initial calibration, installation, or any host of problems that inevitably are associated with a new system.



RADAR PRODUCTION SCHEDULE

Figure 14.

SYSTEM DISTRIBUTION

After the first complete radar system has been produced and installed, and all provisions to support the radar set have been implemented, the subcontractor (Hughes) of the radar set, in coordination with the prime contractor (Grumman) will attempt to "sell" the final product, i.e., the F-14, to the end user (the Navy). The Navy, in turn will initiate an entire battery of acceptance tests, which will verify specifications established during the design phase.

QUALITY CONFORMANCE TEST

The quality conformance tests shall determine that the reliability and maintainability of the Aircraft Weapon Systems offered for acceptance under a regular production contract are equal to or better than the reliability criteria.

Each Aircraft Weapon System submitted for acceptance shall be subjected to two flights (and corresponding checkouts of the radar system) in accordance with SD-561-3. As each uncensored quality conformance flight is completed, the data shall be recorded, and the accumulated data (from 40 flights) will be evaluated against the acceptance criteria of Tables 4 and 5. If the R/M values are not met, an analysis of the data and a recommended course of corrective action shall be proposed to the procuring activity within 90 days. The refly reliability standard requirements are based on a 2.3 mean flight hours between failure with at least an 80 percent confidence level.

A censored flight is a flight in which the validity of the results is questionable. A censored flight or an excluded flight as defined shall not be used in determining compliance with requirements. A flight may be censored when the "no-test" definition of MIL-STD-757 is applicable. However, if the number of censored flights exceeded 20%, the quantitative requirements of Tables 4 and 5 have not been met.

Maintenance shall not be conducted during flight except when necessary to restore the Aircraft Weapon System to a minimum acceptable condition as specified for crew safety or as permitted by established Navy operator maintenance procedures. All maintenance between flights shall be accomplished in accordance with established Navy maintenance procedures. All peripheral equipment such as common Navy line and shop test and support equipment plus any special support equipment used during the test shall consist of common line and shop test and support equipment and special support equipment normally used with the radar system.

TABLE 4.
QUANTITIVE RELIABILITY ACCEPTANCE CRITERIA

Flights	D	F
40 to 59	40	32
60 or more	40	31

NOTES:
1 D is the number of uncensored flights in the data base.
2 F is the cumulative number of flights that generate corrective maintenance work that shall not be exceeded to meet the reliability requirement. Minor O-Level maintenance that can be performed in the forty (40) minute turn-around time that does not result in an I-Level item processed is excluded from the calculations.

TABLE 5.

QUANTITIVE MAINTAINABILITY ACCEPTANCE CRITERIA

Requirements	Number of flights	
	40 - 59	60 plus
1. Median corrective maintenance downtime at the "O" Level to restore the system to full operational capability shall not be greater than...	2.6 hrs	2.4 hrs
2. Direct corrective maintenance per flight hour for the system at the "O" level shall not be greater than..	5.5 hrs	5.2 hrs

TEST MISSIONS

The test mission shall begin with the Aircraft Weapon System in the condition of full operating capability after satisfactory completion of a preflight inspection and an operational readiness test. The test mission profile shall be similar to the phases identified below. A detailed test plan further identifying the test mission phases shall be submitted 6 months prior to the start of testing. The AN/APG-71 radar system must function successfully as an integral part of the total aircraft acceptance tests.

Once the aircraft has successfully taken off, and reaches cruise altitude, the AN/APG-71 radar system will be tested. This phase of the acceptance testing shall last the length of time it takes to complete the following phase elements, usually 1.0 to 2.0 hours.

-- Perform all functions necessary to test target detection and tracking,
-- Perform all functions necessary to simulate successful AIM-54 launch,
-- Perform all functions necessary to simulate successful AIM-9 launch,
-- Exercise defensive electronic counter-measures functions,
-- Exercise TCS identification and tracking functions,
-- Perform all functions necessary to control gunnery and bombing runs.
-- Post Landing. Record significant data observed during the radar system testing.

CONCLUSION

The objective of this report was to employ the "systems" methodology for solving a complex problem, in particular, to illustrate the approach used to design a replacement for an aging airborne radar system. The AWG-9 radar set had served the Navy's F-14 admirably for more than twenty years, but there are physical limits to the quantity of data and processing speed that the radar set's analog technology can ever hope to execute, and these slower rates are unacceptable by today's standards.

Once the problem was clearly defined, a feasibility study was performed to see what viable solutions might be available. Although an upgraded version of the AWG-9 would be the least expensive, it would only marginally satisfy the data processing requirements, and certainly would not be capable of any future expansion for some of the more sophisticated missile systems already envisioned. A completely new radar system, by far the most costly avenue, could not be developed and manufactured in a timely manner. Consequently, cost was not the critical factor in either of the first two alternatives since the first alternative could not produce the desired radar set, and the second alternative could not deliver the desired radar set when it was needed. The third option was to digitalize the signal processing components of the AWG-9 radar set, while retaining those assets that generate and control the radar's power. This last alternative was selected as the recommended solution, and the proposed radar set was renamed the AN/APG-71 radar system. Designing and building this radar system will solve the problem stated, that is, the AN/APG-71 will maintain the power and range of the older system, and it will increase the signal processing throughput more than six (6) times. Also note that the digitalized system will require fewer components, for better reliability and maintainability, and will have far greater capacity for expansion, i.e., making it readily adaptable for advanced electronic warfare algorithms, and provide for significant growth.

Following the systems methodology, functional diagrams of the operational flow of the radar set were developed, with the emphasis on *what* was to be done, not on *how* to do it. One example of the functional diagram's possibilities was given by expanding one block to the second operational level, and then continuing by exploring a potential malfunction to three levels of maintenance. The functional diagrams help to solidify the direction that the process should follow from the initial "definition of requirements" stage to final distribution of the product.

One point to be made is that the design process is not a simple, step-by-step procedure that can always be followed in a logically progressive manner. The life cycle analysis is an iterative process that depends on continuous feedback from all the key elements to arrive at an optimal system design. For instance, it might be observed during the procurement phase of the functional analysis that potential support equipment needed to test the components as designed was readily available from the Navy's current assets. With this information, the software engineer can write the self-test programs to accommodate the tester, rather than to "re-invent the wheel" by requesting new test gear.

The primary intent of this report was to show that the radar system in question was not the end result of an action-reaction evolutionary development. Rather, a methodical approach was applied to design a supportable state-of-the-art radar system in the most cost effective and efficient manner. As the department of defence continues to downsize through the remainder of this century, it will become increasingly important for the military to choose and fund its projects wisely. Systems engineering provides a vehicle for accomplishing these ends.

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