PAPER Nr.: 85

THE DEVELOPMENT OF AN ADVANCED INTEGRATED AVIONICS SYSTEM

BY

D. ROUGHTON

WESTLAND HELICOPTERS LIMITED
YEOVIL, SOMERSET, ENGLAND

FIFTEENTH EUROPEAN ROTORCRAFT FORUM

SEPTEMBER 12 - 15, 1989 AMSTERDAM

THE DEVELOPMENT OF AN ADVANCED INTEGRATED AVIONICS SYSTEM

BY

D. ROUGHTON

WESTLAND HELICOPTERS LIMITED,
YEOVIL, SOMERSET, ENGLAND

1. INTRODUCTION

Over the past twenty five years avionic systems have grown significantly in numbers, complexity and capability in response to the need to enhance the operational effectiveness of the helicopter.

In recent years advances in digital technology have enabled unprecedented levels of systems integration which has made it possible to accommodate this increased capability within the ever present constraints of weight and space presented by the air vehicle.

The development of these advanced integrated digital systems has represented a major engineering challenge to the helicopter manufacturer. The development cycle for the avionic systems is now equal to if not greater than the development cycle for the basic vehicle and it now takes between 7 and 10 years from initial go ahead to Interim Operational Clearance for the development of a major new project.

The need to manage the development process effectively has led to the development of new procedures, tools and techniques to ensure that the customer's operational requirements are met in a cost effective manner and the programme is achieved within cost and timescale.

This paper describes the major stages of the development process and draws on experience from a number of recent projects to identify some of the potential problem areas and the steps that can be taken to minimise their impact on the programme.

2. BACKGROUND

Avionic Systems have experienced a progressive evolution from the stand alone analogue systems of the 1960's to todays highly integrated digital systems.

This evolution has been made possible by the developments in the basic semiconductor technology.

The replacement of the thermionic valve by the transistor with its low weight, power consumption and heat dissipation led in the 1960's to a new generation of smaller, lighter avionic equipment.

The development of Medium Scale Integrated circuits and subsequent Large Scale Integrated circuits enabled the development of rugged lightweight digital computers suitable for airborne applications.

These rapidly found applications to handle the numerous computational tasks required in Air Data, Navigation and Weapon Aiming Systems, always the bete noire of analogue systems. The subsequent development of the microprocessor has led to the position where now almost every item of avionic equipment is digitally based.

The introduction of digital technology brought with it many benefits in reliability, repeatability and accuracy of calculations over its analogue predecessors but it brought with it its own problems - software.

Limitations in processor speed and memory capacity of the early computers and the immaturity of software development techniques meant many early projects failed to meet expectations.

Subsequent developments in hardware and in Software Engineering have now largely overcome these problems but software development remains one of the most critical aspects in the development of advanced avionic systems.

In parallel with these developments there has been significant developments in the operational capability of aircraft in response to the increasing sophistication of the perceived threat. This has led to the development of more and increasingly complex systems, multimode radars, electronic surveillance measures, infra-red sensors, sonars, advanced weapons etc.

The need to accommodate these systems within the constraints of weight and size and the need to maintain crew workload at an acceptable level has been the driving force towards high levels of systems integration.

This has been made possible by the introduction of the digital data bus which acts as a common link between all major digital systems. This permits all information generated within the system to be made available to all other users and hence avoids unnecessary duplication. It also enables the system control and the display of information to be rationalised, easing the constraints on space in the critical area of the cockpit and reducing crew workload.

The majority of military projects in the past decade have adopted the American Mil Std 1553 data bus standard for this application. This has resulted in almost all avionics equipments now being available with a Mil Std 1553 interface which considerably eases the problem of system integration. The result is the type of system architecture shown in Figure 1. This does not represent any specific project but is typical of an advanced integrated avionics architecture.

Although this type of system has very real advantages, it brings with it a number of new challenges for the system integrator, in system specification, design and development. With this ever increasing complexity of avionic systems there has been an attendant increase in system cost. The proportion of the unit flyaway cost of the helicopter attributable to avionics has grown progressively from about 10% in the sixties to over 50% for todays advanced vehicles. Successful systems integration is therefore vital to the success of the helicopter manufacturer.

Successful system integration is a complex process requiring a fusion of sub-systems, air vehicle and crew to meet the operational requirements while obtaining an optimum balance of capability, operability, supportability and affordability.

Systems integration is always a compromise between these conflicting requirements and requires an iterative process of synthesis analysis, design, test and evaluation to achieve an effective solution.

3. THE AVIONIC SYSTEM DEVELOPMENT PROCESS

The major elements of the avionic system development process are shown in Figure 2. These elements can be grouped together into the three major phases of a programme, definition, design and development. Each of these phases will be discussed in more detail.

3.1 THE DEFINITION PHASE

This is perhaps the most critical phase of the whole programme. The cost involved is typically less than 5% of the total project cost but the decisions made at this time will establish 90% of the cost of the overall programme. In general the customer is not committed at this stage and there is often strong competition from other suppliers. There is considerable pressure to offer the maximum in capability at the minimum of cost.

The definition stage of the project takes the customer requirement and transforms it into the relevant system functional requirements. The functional requirements are then used to derive the system architecture, to allocate system function to units of hardware and to partition functions between hardware and software. This will lead ultimately to an architecture definition, equipment specification and a definition of the interface requirement between individual equipments.

This is normally an iterative process and will usually go through several stages of refinement before an acceptable compromise is established and the cost and timescales agreed with the customer.

The development of the systems architecture is essentially a creative process for which there are no hard and fast rules. Our typical architecture shows two buses, in some simple applications one could be sufficient, in others for reason of integrity, safety or bus loading three or more buses may be required. The integrated nature of the system gives a high degree of flexibility on where functions can be allocated in the system. Should the weapon firing computation be in the radar processor or in a dedicated weapon aiming computer? Should the Kalman filter for navigation data be in the inertial navigation equipment or on aircraft management computer? The definition process requires the resolution of a multitude of such issues.

Having established the basic architecture details of the data bus have to be defined, where are the bus controllers to reside, which types of traffic allowed by the

1553 standard are to be implemented, what data rates are required to minimise problems of data latency?

Once the basic design has been synthesized it must be analysed to ensure that all operational requirements can be met for both normal operation and under failure conditions and that requirements for reliability, availability etc can be met.

Throughout this phase attention must also be given to what is achievable with todays technology, what existing equipment can be used, what new developments are required, what are the risks and are they acceptable?

This represents just a few examples of tasks of the definition phase. For an advanced integrated system the magnitude of the task means it cannot be effectively managed and controlled by simple manual techniques.

This has led to the introduction of formal methods for the system definition.

A number of systems have been developed, based on the general principle of a structured 'top down' decomposition of requirements. Working progressively from system to sub-system to equipment levels with the definition of information flows, data attributes, transfer rates and interface details such as word formats being derived at each stage. The process is computer aided and includes automatic checking of the design for omissions and inconsistencies. The end result is a comprehensive, well documented, design data base which can be kept under strict configuration and change control. This data base can then be used to feed downstream activities such as the development of hardware and software specification with confidence that when the individual elements are brought together in an integrated system the desired objectives will be achieved.

Westland are now applying these techniques during the feasibility studies on the Light Attack Helicopter and they have been successfully used for fixed wing systems with considerable success (Ref. 1 & 2).

3.2 SYSTEM DESIGN

The next phase of the development is to turn the system definition into a detail design that will permit the procurement of hardware and software and the manufacture of the wiring and structural fittings required for its installation. This requires the preparation of detailed procurement specifications and Interface Control Documents for the placement of sub-contracts for equipment procurement and software development. It is essential that the design is frozen as early as possible in this phase and placed under tight configuration control to ensure that the design integrity is maintained and programme cost and timescales are achieved.

With highly integrated digital systems particular attention must be payed to establishing Electro Magnetic Compatibility (EMC) between systems. Digital systems are inherently more susceptible to electro magnetic interference than their analogue predecessors and an EMC policy must be established to control the emission and susceptibility of all equipment specified.

However there is no doubt that the biggest challenge thrown up by the integrated digital system is the effective control and management of software development.

Almost without exception early attempts at software development ran into major problem.

The magnitude of the software tasks was grossly underestimated, a problem that was exacerbated by limitations in processor speed and memory capacity and proved difficult to contain within cost and timescales.

Considerable progress has now been made in introducing sound engineering principles to the software development process.

Software development now follows a very similar path to hardware development with its own requirement specification and detail specifications for all elements of the software design. The software design is also more structured, assisted by the use of Higher Order Languages such as Pascal and Ada. This allows software to be functionally decomposed into manageable size modules which can be tightly specified developed and tested and then progressively integrated into the total system. Considerable progress has also been made in the development of the software support environment which provides the tools to manage the software development process.

Recent experience has given confidence that software development is now a much more predictable process, however, there can still be major problems. It is noted with interest that the US Air Force has announced postponement of the first flight of the C-17 transport aircraft by four months due to continuing development problems with the Mission Computer Software and Electronic Flight Control System (Ref. 3).

A major concern at this stage of the programme is to gain confidence in the design. The earlier that problems can be identified in the development cycle the better, as cost and timescale impacts will be minimised. The theoretical design will be subjected to a series of critical design reviews but it can be several years before there is actual aircraft hardware available to put the theory to the test.

To overcome this problem we increasingly make use of simulation facilities of varying degrees of sophistication with which to validate the design. These range from very simple facilities to assess display formats to a six degree of freedom flight simulator with complete emulation of all aircraft and mission systems. These provide invaluable tools with which to gain confidence in the design and an early opportunity to demonstrate the system to the customer to build his confidence that the end product will satisfy his requirements.

3.3 THE DEVELOPMENT PHASE

The development phase starts with the development of the individual equipments at the manufacturers. Individual equipments are tested by the airframe manufacturer to prove compliance with specification and then brought together with related equipments to be tested as major sub-systems before they are integrated and tested as part of the total system.

The integrated system is subjected to rigorous testing to prove its operation in all modes and reversionary states to the point where there is sufficient confidence to give approval for flight. This will be backed by the results of the Type Approval testing carried out by the equipment manufacturer which demonstrates that the equipment will continue to operate in the helicopter environment.

Subsequent flight testing will initially demonstrate the correct functioning of the system and then progressively collect the data necessary to demonstrate that the system performance complies with the specification requirements.

The above description makes the process sound very straight forward, in practice of course this is the time at which the real problems emerge. At each stage of testing problems may be discovered that will require engineering solutions to be found, new design work and modifications to equipment. Configuration control and effective Change Management Procedures are essential if the project is to be kept under control.

The number and magnitude of the problems at this stage will be a reflection of the quality of the initial design and specifications. It is important to flush out as many of the problems at the rig testing phase to prevent them carrying through to the Flight Test stage with the attendant impact on costs and risks.

For a major new project there is considerable benefit from carrying out the initial flight trials with an established airframe. Any new vehicle is likely to have its own development problems which can have a significant impact on the flight test time available for the system development.

A Sea King is currently being used for this purpose to develop the mission system for the EH101. This has proved very beneficial to the early development programme and has now logged several hundred hours of flight testing well in advance of what could be achieved by the definitive aircraft. This will significantly reduce the risk of integrating the mission system with the remainder of the EH101 avionic system.

4. KEY ISSUES

Over the past five years Westland Helicopters Limited have been responsible for the development of advanced integrated systems for Lynx, Sea King and the EH101 helicopter. The Sea King project development has now been completed satisfactorily. The Lynx programme is in the final stages of ground testing and the EH101 is just commencing flight testing. We are also actively involved in the System Studies for the Light Attack Helicopter. This has given a solid background of experience and the lessons learnt are being fed across to later projects.

From this experience we can identify a number of key areas which are vital to the successful development of an advanced integrated avionic system.

4.1 REQUIREMENT SPECIFICATION

One of the most fundamental concerns is the need to establish as early as possible in the programme an agreed requirement specification with the customer.

In the initial phases of the system definition flexibility is required to allow an acceptable compromise between capability, cost and timescale to be established. Once this has been established the requirement specification must be frozen and any changes should only be made when the full cost and timescale implications are understood and agreed by the customer. The specification must be made as definitive as possible including statements on facilities or functions that will not be provided where such decisions have been made. Without this there is no firm foundation for the remainder of the development exercise.

Although this may sound a statement of the obvious it is often one of the most difficult aspects to achieve.

4.2 SUB-CONTRACTORS

With the exception of the purchase of "off the shelf" equipment all other equipment suppliers should be dealt with as sub-contractors. The success of the programme is highly dependant on their performance and it is the prime contractors' responsibility to ensure that they achieve their objectives. The contractual terms and conditions should be aimed at gaining their total commitment to the programme including passing down any relevant penalty clauses in the main contract. The contract must also cover all of the work that is expected, not just the supply of equipment, but also all data requirements, documentation and support they will be expected to supply.

The sub-contractor must then be closely monitored for the duration of the contract. This requires regular design reviews to ensure not only that technical standards are being achieved but also that the programme is on cost and to timescale.

This should also include regular site visits to ensure that what is reported is consistent with what can be seen.

Without this attention to detail it is not unknown for deliveries to slip 6 months in the week before the equipment is due, despite favourable progress reports up to that time. This can have catastrophic consequences to the main programme.

4.3 SOFTWARE DEVELOPMENT

Despite significant improvements in the control and management of software with the introduction of structured languages and formal methods, software development remains one of the major risk areas. This is a particular problem when the software development is part of the sub-contrators responsibility. We continue to find equipment suppliers who adopt the methods and tools agreed as part of the contract failing to use them effectively. This is particularly true when the project standards differ from the standards normally used by the sub-contractor.

The consequence is that software development programmes need particular attention when monitoring sub-contractors. The general requirements previously described apply equally to software but particular attention needs to be given to the software quality assurance plan and its execution.

Experience has shown that when the going gets tough the first thing that suffers is the detailed testing. The inevitable consequence is that faults are discovered late in the programme when they are much more difficult and expensive to rectify.

4.4 DESIGN VALIDATION

The traditional tools for design validation described earlier require a significant development effort in their own right and take a considerable time to produce. There is therefore a long period once the system definition is complete before the design principles can be validated. In this intervening period the programme is at some risk. Better and more flexible tools are required to reduce this time. Research and Development effort is being applied in this area and we are currently examining the use of graphic work stations to develop cockpit displays and formats, modelling of 1553 data bus systems to analyse bus traffic and loading and the use of rapid prototyping systems for software development.

4.5 EQUIPMENT RELIABILITY

Reliability is perhaps the most neglected area during the development phase of a programme. This is not to say that considerable attention is not paid to reliability, but the focus of attention is generally aimed at meeting requirements for production standard equipment. Reliability is monitored during development to give early warning of potential problems.

Experience has shown that unreliability in development equipment can be a major disruption to the development programme and have a significant impact on customer confidence.

It is not obvious when a failure occurs whether it is an inherent design problem in the system, a design problem in the equipment or a random failure. A considerable amount of unscheduled effort is required to investigate every incident. This can cause particular embarrassment when the testing is being carried out in collaboration with the customer's representatives.

We are now paying much more attention to the quality of development standard equipment and increasingly reluctant to accept any concessions against the specified standard.

5. CONCLUDING REMARKS

The development of highly integrated digital systems has posed a major new challenge to the helicopter manufacturer. The successful execution of these programmes has required the acquisition of new skills and the development of new methods and tools.

As with the introduction of any new technology it has not all been plain sailing and no doubt mistakes have been made along the way. Many important lessons have been learnt and the experience used to the benefit of subsequent programmes.

However there are no indications that systems technology will remain static. The basic digital technology continues to make dramatic progress with more powerful microprocessors and higher density memories becoming available. Avionic systems will continue to exploit this technology to add yet more capability for a given weight and size and helicopter manufacturers will use these systems to maintain the competitive edge of their products. We can confidently expect systems integration to continue to throw out new and rewarding challenges.

6. REFERENCES

1) H.M. MALLEY, et. al., A Structured Approach to Weapon System Design. AGARD-CPP-417, April 1987.

2) W.E.R. Kellaway, Software Engineering for the British Aerospace "Experimental Aircraft Programme. AGARD-CPP-417, April 1987.

3) Anon. News Briefs - Aviation Week and Space Technology, August 28th 1989.

A TYPICAL ADVANCED INTEGRATED AVIONIC SYSTEM

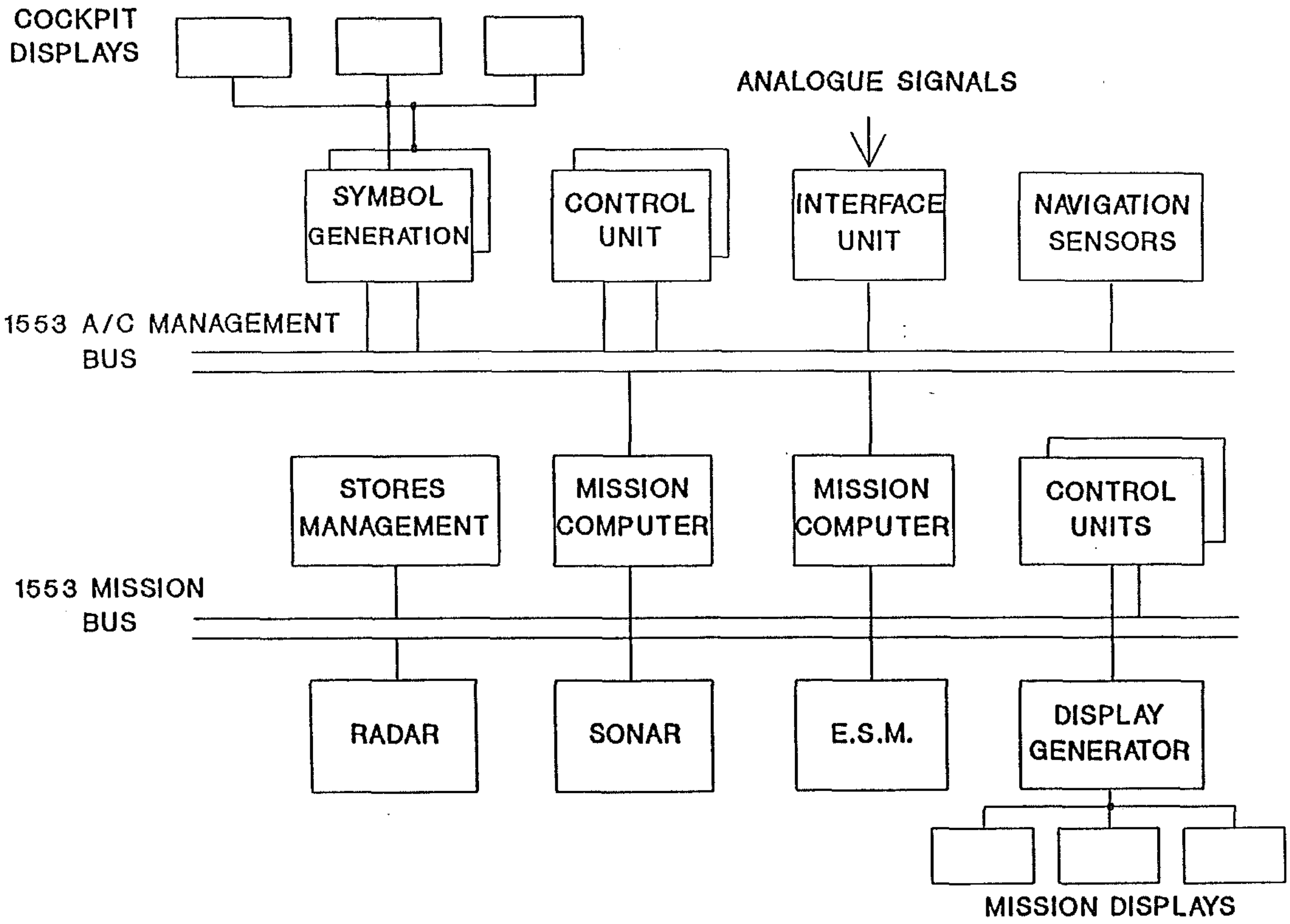
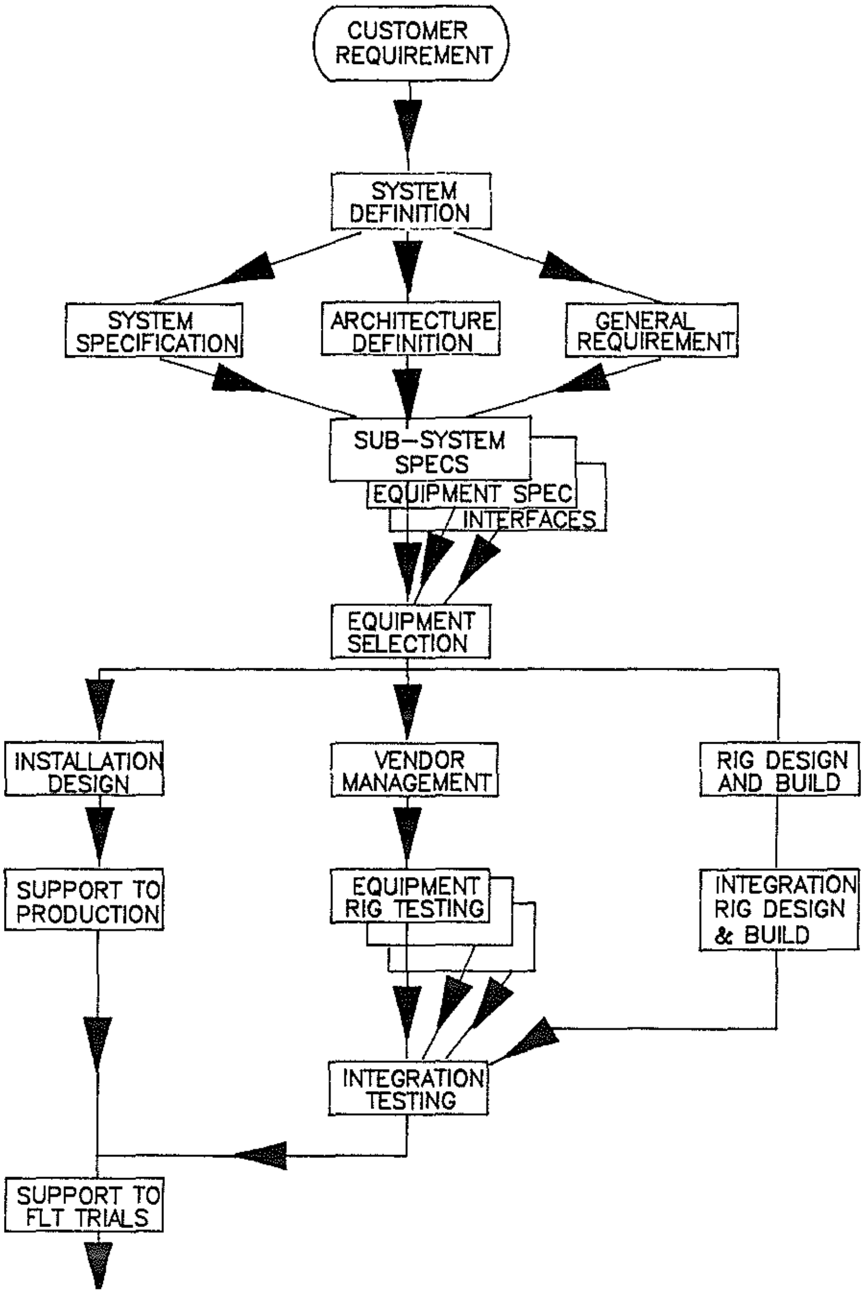


FIGURE 1



THE AVIONIC SYSTEM DEVELOPMENT PROCESS

FIGURE 2