# SYSTEM DESIGN APPROACH APPLIED TO THE DESIGN OF THE COMBAT SYSTEM FOR THE S&T UPDATE PROGRAMME

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ABSTRACT

The modification to the Combat System for the S&T Update Programme is a complex and difficult task. Structured analysis and design techniques, such as those developed for the SSN 20 programme, provide a powerful means of overcoming this complexity, and a means of influencing the constituent equipment design processes from a total system point of view. This article provides an illustration of how that influence has been achieved.

## Introduction

With the increasing pressure on the defence budget and the apparent reduction in the threat, the opportunities for major system developments using a 'clean sheet of paper' approach to meet MoD requirements are much diminished. As a result we are more likely to be involved in modifying and improving existing systems. Nevertheless, the need to ensure that the system so produced is coherent, and meets the requirement, remains of paramount importance and demands a disciplined and structured approach from the outset.

The S&T update (stage 3 and 4) Programme is such an example and consists of a collection of improvements, including new developments, to equipments and sub-systems of the SWIFTSURE and TRAFALGAR classes of submarines, with particular emphasis placed on the combat system. The Project Definition (PD) programme started in mid 1990 and completes in December 1993. An overview of the combat system design boundary, and the equipments which fall within it, is shown in (FIG. 1).

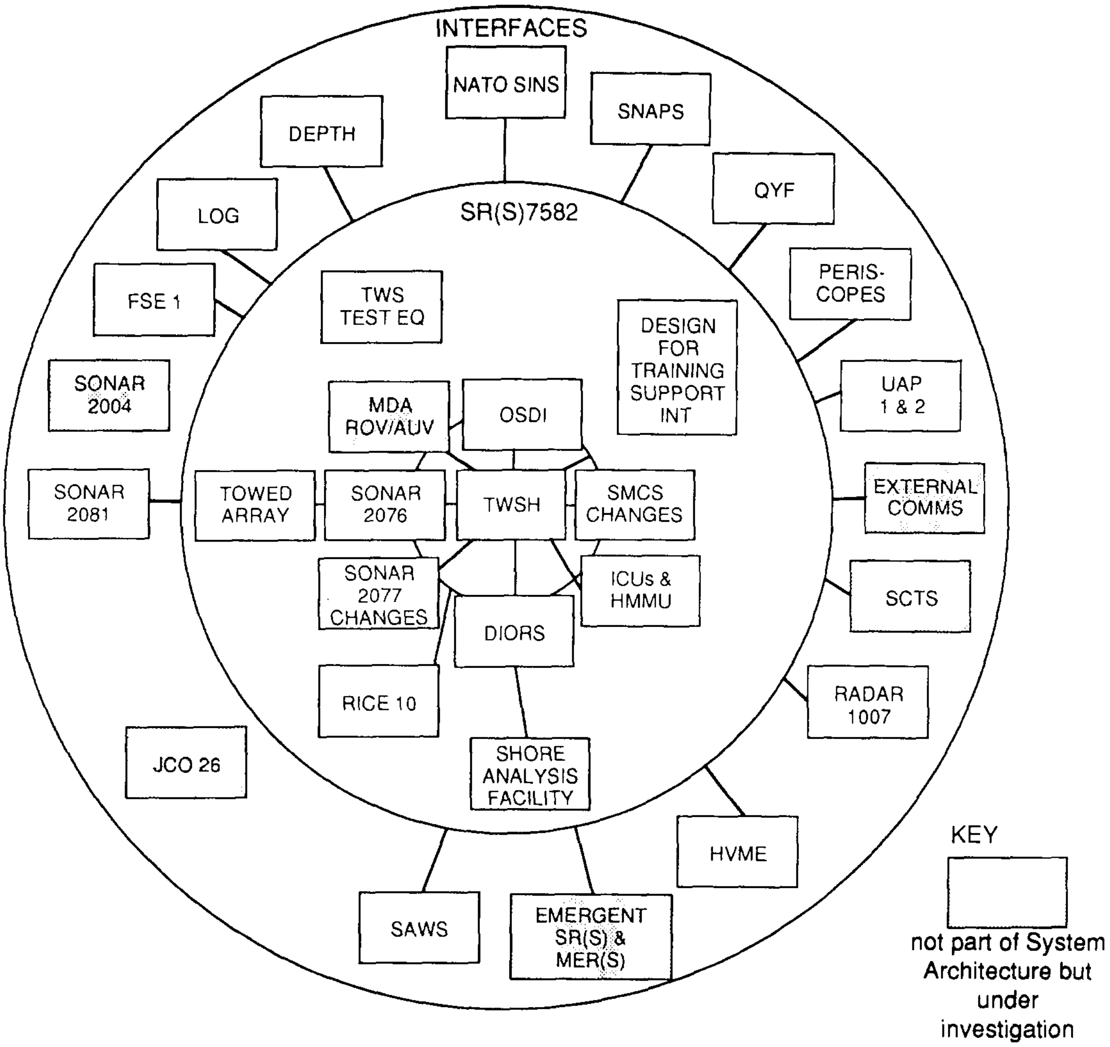


FIG. 1—TACTICAL WEAPON SYSTEM DESIGN BOUNDARY

AUV: Autonomous Underwater Vehicle
DIORS: Data Input Output Recording System
FSE: Frequency Standard Equipment
HMMU: Highway Vibration Monitoring Equipment
HVME: Hull Vibration Monitoring Equipment
ICUs: Interface Control Units
JCO: Special fit equipment
MDA: Mine Detection & Avoidance
MER(S): Minor Equipment Requirement (Sea)
OSDI: Own Ship Data Interface
QYF: a navigation equipment
RICE: Rationalized Internal Communications Equipment
ROV: Remote Operations Vehicle
SAWS: Submarine Acoustic Warfare System
SCTS: a Compass Transmission System
SINS: Ships Inertial Navigation System
SMCS: Submarine Control System
SNAPS: Submarine Navigation and Plotting System
SR(S): Staff Requirement (Sea)
TWSH: Tactical Weapon System Highway
UAP: Electronic support measures equipment

It is worth considering briefly the benefits that the adoption of the total system approach gives:

(*a*) It focuses attention on the important overall system issues.

(*b*) It replaces the intuitive approach with analytical methods such as model building and optimization techniques.

(*c*) Problems can be tackled in their correct order of importance as viewed from a total system perspective.

(*d*) Integration of the elements of the system is dealt with at the earliest opportunity, i.e. during design.

The systems approach is concerned with 'added value', i.e. the whole is more than just the sum of the parts. In addition, by addressing system aspects of the design at an early stage, problems of integration of the hardware, software, and the human element (human factors) will be much reduced. To take other than a system approach can result in 'value subtracted', and examples of this can be found in the history of the Sea Systems Controllerate, which has long and painful experience of troubled systems integration, and the reduction of this problem alone justifies the technique.

Over the last five years the MoD has gained much experience from the structured system design approach developed and adopted for the ill-fated SSN 20 programme, and a detailed description of the idealized system design life-cycle is given by Baker[1]. In particular DGSM/DCS SM staff have been responsible for developing and applying a computer-based system design tool, based on the YOURDON method, called the Integrated Modelling Environment (IME). Although the demise of the SSN 20 programme denied the IME the opportunity to exercise its full potential, the programme provided a wealth of experience in the 'top-down' approach to the design of a system as large and complex as a submarine combat system.

The use of structured methods in the system approach seeks to conquer the complexity of large systems by providing full visibility and consistency across all the system functions, and by partitioning them into sub-systems with identified, optimal, interfaces so that the system designer knows:

(*a*) How the functions trace to the statement of requirements. (It is this ability to identify which system functions satisfy specific statements of requirements which makes the stuctured design technique so powerful. In particular it ensures that functions are not duplicated and, more importantly, not omitted).

(*b*) How functions relate to each other.

(*c*) Where functions are performed.

It is also essential, particularly in the competitive procurement environment, to define and partition the system into procurable sub-systems at an early stage of the programme.

The approach to structured system design as outlined above is shown diagrammatically in (FIG. 2). The triangle shows the top-down decomposition of the requirement to a low level description of system functions, which can then be partitioned to describe the functionality of each of the sub-systems. In YOURDON terms this is known as the Physical or Implementation model which can then form the basis of procurement and management of the system design.

Having expounded the virtues of a system approach, it has to be declared that such an approach has not been adopted from the outset for the S&T Update Programme. However, this article explains how one has been 'grafted' on to the programme in order to ensure that the significant benefits of such an approach are realized.

## Background to the S&T Update Design

The S&T update programme has many of the characteristics of a traditional equipment process, having evolved from a purely sonar update aimed at exploiting the improvements in sonar performance identified in the SSN 20 and other sonar-related programmes. In particular the development of equipments and sub-systems which, collectively, will form the combat system is being managed by their respective procurement authorities, i.e.:

(*a*) Sonar 2076—DGUW/SMS.

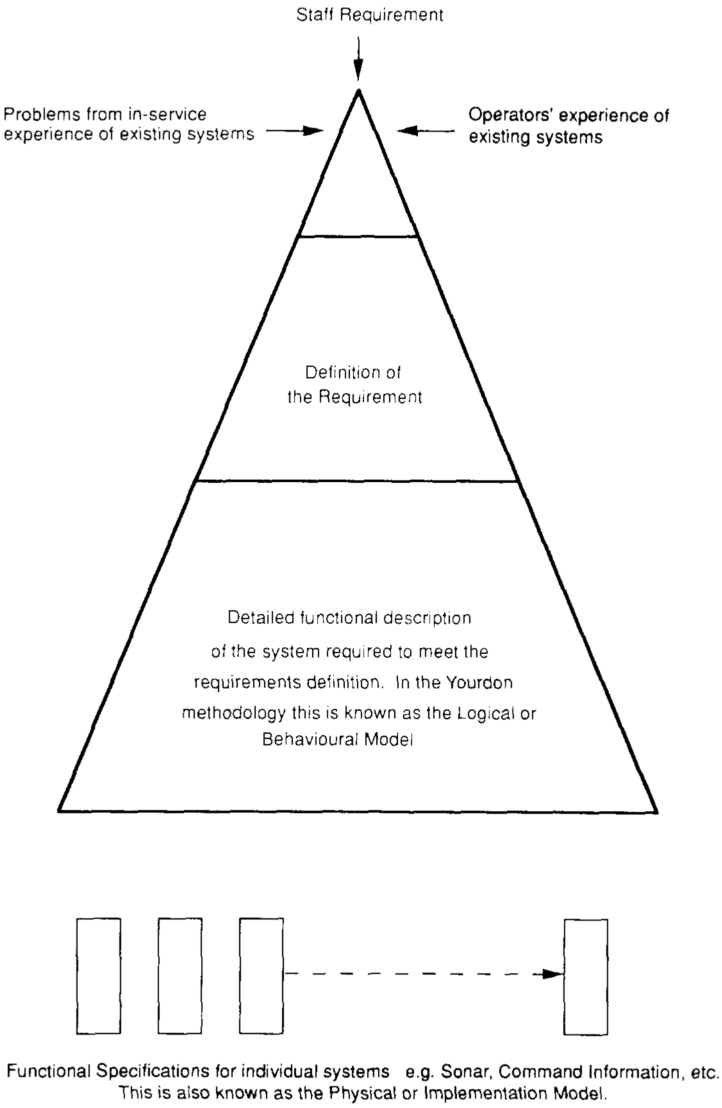


FIG. 2— THE STANDARD DESIGN PROCESS

(*b*) Submarine Command System (SMCS)—DGSM/AISM.
(*c*) Tactical Weapon System Highway (TWSH)—DGSM/AD CSDU.
(*d*) Submarine Acoustic Warfare System (SAWS)—DGUW/AD SCS.

The responsibility for co-ordinating the collection of equipments and sub-systems, of which the above is only a sample, into a coherent whole resides with DGSM/AD S&T. AD S&T is the system Design Authority who has the support of a Weapon System Integration Authority (WSIA) and the services of a system engineering cell within DGSM/AD CSDE to discharge this responsibility. The programme has four stages, but only the third and fourth stages are discussed in this article.

The principal aim of the S&T update system Design Authority is to bring the sub-system designs under system control. With such control the combat system equipments can enter their separate full development programmes with confidence that, when combined, they will integrate and operate with each other, and that the resultant combat system will achieve Fleet Weapon Acceptance.

Given that the programme has evolved from an equipment development to a combat system development programme, and that the system design is being led by the DGSM and DGUW equipment programmes, AD S&T was faced at the start of PD with the need to bring the equipment development programmes under the control of a system design process. This process may be considered to be convergent and (FIG. 3) shows diagrammatically how system design disciplines are applied, forcing the constituent equipments to converge to form an integrated system.

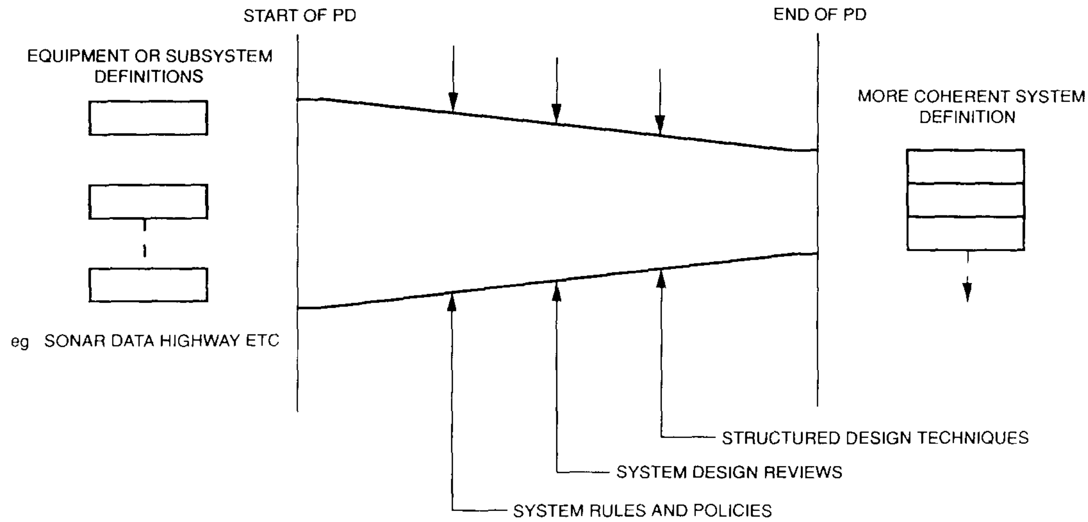


FIG. 3—DIAGRAMMATIC REPRESENTATION OF THE S & T UPDATE SYSTEM DESIGN PROCESS
PD: Project Definition

Very little system design work was done in the feasibility study phase and the system design produced was not considered to be robust. In addition, at that time it was considered desirable to give the sub-system contractors maximum flexibility to evolve their own solutions which, in hindsight, was at the expense of the system design approach. Therefore, at the commencement of PD, access to individual design processes, in addition to a means of creating a coherent system design from the collection of those equipments, was needed by AD S&T, if he were to have a chance of influencing their designs.

## Obstacles to System Design

Part of the WSIA's work is to provide AD S&T with system design advice, and it was unfortunate that the contract was not placed until three months after the sonar contract. Gaining access to the equipment designs was the first major problem they experienced. The procurement programmes for those equipment which will form the system are largely competitive; Sonar 2076, TWSH and SAWS being the major sub-systems undergoing competitive PD studies. One of the effects of competition is to constrain severely the flow of information about competing sub-system designs to all interested parties, due to the need to protect this information until the bids are submitted by the contractors to the MoD; by which time it is too late to influence related, parallel, design programmes. An illustration of how this can adversely affect the system design process is shown as follows:

(*a*) The acoustic sensor input to the SAWS design is to be provided by Sonar 2076, possibly with some modifications.

(*b*) One of the two competing contractors involved in the SAWS PD studies is also carrying out the Sonar 2076 PD study, and the second SAWS PD contractor has close links with the second Sonar 2076 PD contractor.

(*c*) Neither contractor will allow the other access to design information about either their Sonar or SAWS designs. Hence each SAWS design team is only able to design with the knowledge of its own company's 2076 solution.

(*d*) For the system to be valid and for competition to be effective, the MoD needs to be assured that either SAWS design will work with either Sonar design. The lack of ready access to these designs frustrates that need. One could postulate that the lack of this assurance could constrain the MoD to only being able to place the SAWS contract with the successful Sonar 2076 contractor, which would defeat the objective of competition.

A further complication arose from the composition of the WSIA who, as mentioned, are responsible to AD S&T for, amongst other things, system design and engineering aspects of the design process. One of the companies in the WSIA consortia is also involved in the SAWS and Sonar 2076 PD studies. The result of this was to further frustrate the flow of information, in the early stages of PD, on the sonar and SAWS designs, jeopardizing the system engineering work being done by the WSIA.

The above is illustrative of the difficulties experienced by AD/S&T in exerting system control during the PD phase. To help in overcoming some of these difficulties and to provide support to the WSIA, SM841 has provided design assistance, particularly in the area of structured system design modelling work. This work, carried out under a tasking arrangement with AD S&T, is described in the following paragraphs. There is a considerable amount of valuable and similar system design work being done by the WSIA, who are AD S&T's main system design agent, but this is not discussed in this article.

## The Approach Taken

The high impact of changes downstream to the system design was highlighted during the feasibility study stage. Thus it was agreed that, as a parallel activity to the WSIA's system design work, the S&T update combat system would also be defined using the structured design techniques and tools developed for the SSN 20 programme. There were considered to be many advantages in this approach, not least of which was the reduction of risk, by virtue of having a second similar design technique providing an input to the process. In order to achieve this it was considered essential that the contractor doing this design and analysis work could not be a competitor of the other contractors involved in the programme, and as a result would have no commercial impediment to gaining access to the designs as they emerged.

Briefly, the technique used was as follows:

(*a*) Establish links with the designers of the equipment so that design information is provided as the design evolves.

(*b*) Transfer the designs into the analysis tool (described later) creating a system from the collection of equipments, utilizing the agreed interface definitions where available.

(*c*) Use the tool facilities to evaluate the system design (this is described in detail later).

(*d*) Report to the system Design Authority any system inconsistencies, resulting from the evaluation process needing resolution by Equipment and System Project Managers.

(*e*) Continue the process of updating the system design as changes are made, and re-evaluating as necessary.

(*f*) Use the technique as part of the sub-system PD study bids for Full Development Initial Production (FDIP) evaluation process.

It cannot be emphasized too strongly that the effectiveness of this process is dependent on the links that the system analyst has established with the equipment designers; the accuracy of the design information provided by the designers; and the timeliness of that information. The major point to note is that in carrying out this process the system Design Authority is not actually designing the system, but taking the designs of equipments as produced by the equipment contractors, creating a system from the collection of those equipments and evaluating that system for its coherency, adequacy, and its ability to meet the system requirements. It can be seen that, although it is not a top-down system design process, if the process described is done accurately and in a timely fashion it can be an effective means of controlling the emerging design from a system point of view.

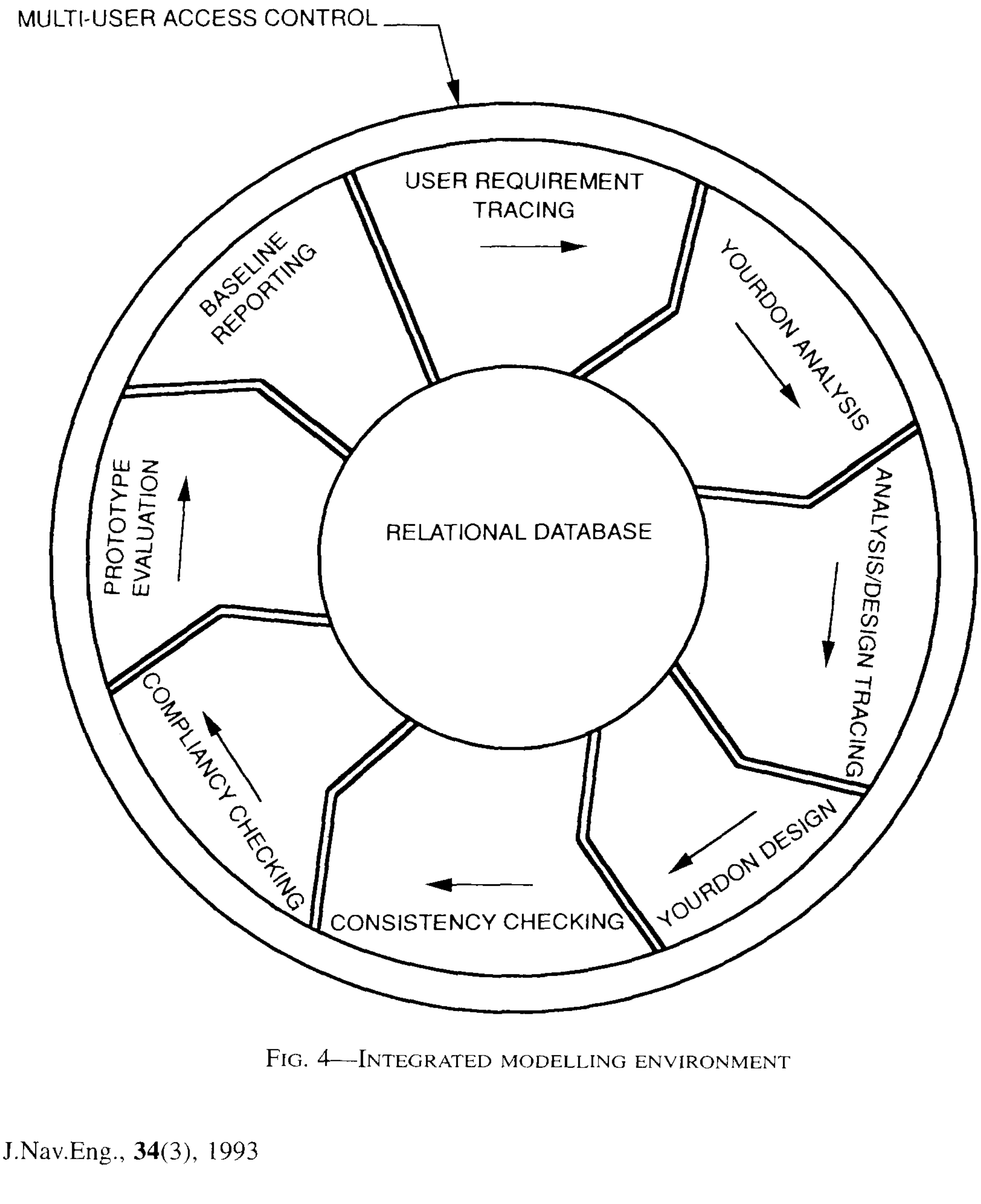


FIG. 4—INTEGRATED MODELLING ENVIRONMENT

## Overview of the System Design Tool Used

The particular tool used was the IME developed by VSEL under contract to the MoD as part of the SSN 20 design programme. This is a computer-based modelling tool which consists of an Oracle relational data base with associated structured analysis, graphics, and configuration control tools shown diagrammatically in (FIG. 4). The tool implements the YOURDON method in that it provides the analyst with facilities to create and analyse a design in a structured, graphical way. The facilities available and their application are briefly described later.

It must be noted here that the method and tool used are concerned only with the functional aspects of the design—i.e. what the system does and not how well it does it.

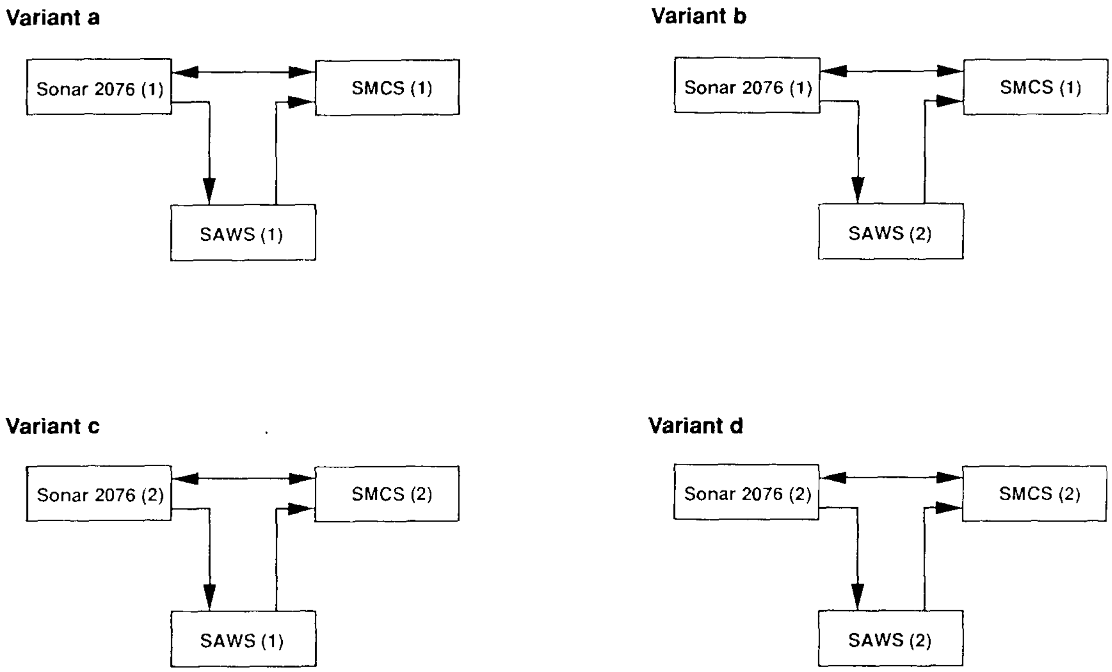


FIG. 5—OVERVIEW OF COMBAT SYSTEM DESIGN VARIANTS STUDIED. INTERFACES ARE SHOWN IN BASIC SIMPLIFIED FORM

SAWS: Submarine Acoustic Warfare System
SMCS: Submarine Command System

## The Application of the IME to the S&T Update Design

As described, the first action was to gain access to the designs of the sub-systems and equipment being produced in the separate but related PD studies. These were largely the two competing Sonar 2076 designs: the SMCS design, which of necessity consisted of separate designs to take account of each of the sonar designs; and the two competing SAWS designs. (By designs is meant the sub-system definitions resulting from the PD studies which form the basis for full development). These three sub-systems were considered to be the major contributors to the combat system functions being developed as part of the S&T update, and the highest risk areas. Commercial confidentiality agreements were obtained between the contractors for these sub-systems and the system analysts, VSEL combat systems, allowing them access to the design information. In addition liaision meetings were held where points of clarification were discussed.

The second activity was to build the model of the system variants using the information provided by the sub-system designers. The number of variants captured in the model is shown diagrammatically in (FIG. 5). At this stage it was necessary to gain the agreement of the sub-system designers that their designs had been correctly interpreted and represented within the tool. This was most important as the analyst's interpretation, if in error, could adversely influence the choice of a competing contractor's sub-system design from a system engineering perspective.

Having built the IME representation of the system, the facilities within the tool were used to evaluate the 'integrity' of the system. In particular the consistency at the interfaces between the sub-systems was examined, as was the functional definition at the boundaries.

## The Evaluation Process

There were six individual criteria used for evaluating the integrity of the system. These were:

(*a*) Data Flow Diagram (DFD) evaluation.

(*b*) Data Dictionary evaluation.

(*c*) Process Description evaluation.

(*d*) System Structure.

(*e*) Trace to the requirements.

(*f*) SMCS changes.

Whilst the average reader will not be familiar with the YOURDON method and associated jargon, the following few simple pointers should be adequate to provide a basic understanding of the technique reported here. In simple terms systems are essentially hierarchical and can be defined in terms of the functions they perform, and the data they require in order to perform those functions. The structured design technique is a rigorous process and the tool used automatically forces the designer using it to address the details of the design. Essential components of the technique are the DFDs which, collectively, represent the essential work that the system does. Data Dictionaries and Process Descriptions are textual entries within the model describing the functions and data flows within the system. (FIG. 6) shows diagrammatically the heirarchical reltionship of the components of the system, in the form of DFDs, and how that system is decomposed to the level of detail required.

Evaluation against the first three assessment criteria is carried out automatically by the tool, and specifically determines the rigour applied to the design definition by considering the detail of the functions, and the data flows, throughout the system with the objective of establishing coherency, without which the system would not be complete.

*DFD Evaluation*—This activity examines overall system coherency by establishing whether all data flows have a source and destination for the data. If there are any unsatisfied data flows, or functions without a data input, then these will be found. Such inconsistencies are 'system issues' to be resolved.

*Data Dictionary Evaluation*—This activity examines the consistency of the data flows between functions. In effect this validates that the source and sink functions are respectively transmitting and receiving the same clearly definable piece of information.

*Process Description Evaluation*—This activity evaluates the integrity of all the functions within the system. Essentially it ensures that all the input data flows to a function are required by the function, and that the function is capable of generating all the output data flows.

*System Structure*—This analysis considers the level of information provided by the equipment designer and takes advantage of the hierarchical nature of systems. If the information provided is sparse in particular areas of the design then this can be an indicator of the risk associated with that part of the design, and hence the overall design process.

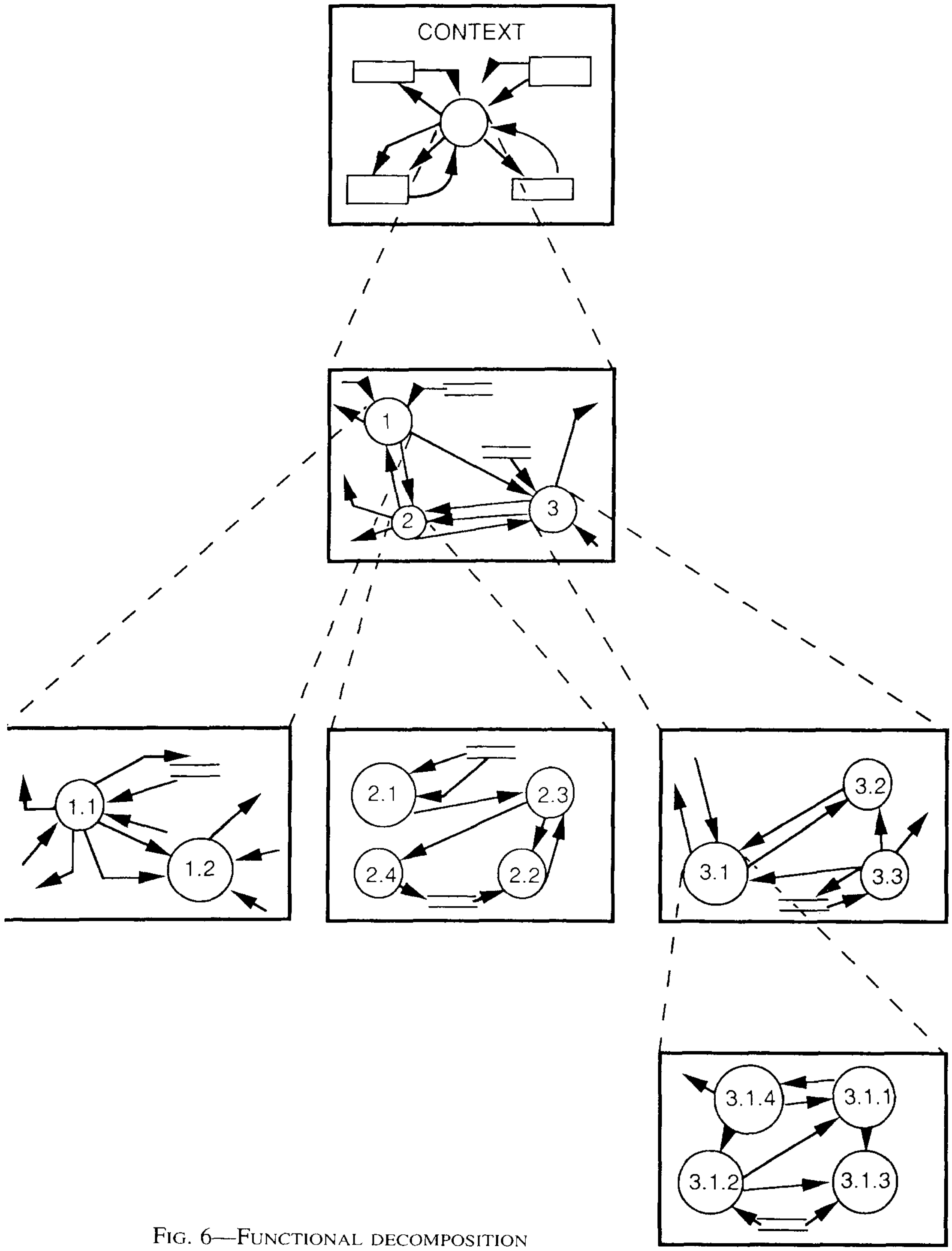


FIG. 6—FUNCTIONAL DECOMPOSITION

*Trace To The Requirements Statements*—This activity traces all the functions carried out by the system to specific statements in the requirements data base. It identifies areas of the design where functionality is provided, and not required, and functionality required and not provided. This can have a useful by-product as, at times, we in the PE are required to provide assurance that there is no 'gold plating' in our design work. This trace technique provides a powerful means of demonstrating the economy of our designs.

*SMCS Changes Required*—This is an evaluation process specific to the S&T Update Programme. As the SMCS design changes are dependent on the sonar design, it is necessary to have a view of the number and magnitude of those changes required by each competing sonar design. The system Design Authority has adopted a policy which requires the changes to SMCS to be kept to a minimum level, and this particular evaluation process quantifies those changes for each sonar solution. (It is worthy of note here that SMCS is being developed under a separate SR(S) and only the changes to that basic design are covered by the S&T update programme). The magnitude of the changes to SMCS will form an important part of the Sonar 2076 tender assessment process.

It is essential to keep in mind that these evaluation techniques are carried out on information provided by the equipment and sub-system designers. Therefore if inconsistencies are found it is relatively easy for the designers to confirm whether there is an error in the design, or an error in the interpretation of the design by the system analyst. If it is the former, and the design is modified as a result, then the process has made an effective contribution to that design.

## Progress to Date

Having identified the overall process in some detail it is worthwhile looking at progress that has been made so far, bearing in mind that the application of this technique is only worthwhile if it actually influences the design process. Two separate system models based on the two competing sonar designs emanating from PD, together with the corresponding SMCS changes, have been created. These have been subjected to the system analysis described above and the results will be the subject of a formal report to be issued shortly. Due to reasons outside the scope of this article the Sonar 2076 programme is to go through a 're-bid' exercise, and the resultant designs offered, if changed, will once again be analysed on the lines above, and this will contribute to the tender assessment process. The results of this work will form a major part of the influence that the system Design Authority brings to bear on the design process.

The same system models have been used to identify and analyse the system aspects of the competing SAWS PD study designs, see FIG. 5. The SAWS designs could have a major impact on both the Sonar and SMCS designs regardless of which sonar design is chosen to go forward into full development. In addition the MoD project needs to know whether each SAWS design will work with either Sonar 2076 design. To establish this the model has been used to identify the information required from the sonar and SMCS sub-systems by each SAWS design to determine whether that information exists within those as currently defined. In this way confidence can be gained that either sonar solution will satisfy either SAWS solution, and if not, take action to ensure that any deficiences identified are remedied before the MoD is committed to contract. The magnitude of the changes to SMCS will contribute to the overall cost of the programme and therefore will form an important part of the Sonar 2076 tender assessment process.

## Conclusions

System integration, traditionally a costly affair, is now being carried out at the earliest possible stage in the programme, i.e. during the design stage. Although the design of the elements of the system prior to PD has not been driven by a system design methodology, such a methodology has been applied as far as is possible and as a result confidence has been gained in system integration in that it has been thoroughly addressed during the PD stage.

A system dimension has been added to the analysis of the sub-system competitive procurement process. Major influence is being exerted by system engineers in the tender assessment process using the technique described.

A barrier to competition, in the form of a restricted flow of information on competitive designs (SAWS and sonar), has been overcome ensuring that the benefits of competitive procurement are not lost.

## Future Application of the Approach

The models developed are currently being considered as a means of assessing the inter-operability between the sonar and SMCS, which has been declared as a major risk area in the programme. By identifying and quantifying the detailed functions (man and machine) that contribute to the exchange of data between the Sonar 2076 and SMCS sub-systems, and stimulating the sonar with a realistic high intensity scenario, measurements can be made of the capability of the crew to cope with all the man-functions that are required during the scenario. This will provide a 'first pass' measure of the inter-operability of the system, and it will also allow an asessment of whether the split of functions between man and machine is optimum.

Having established the representative system design in the model, evaluation of the effects of change within sub-systems on the overall system can be carried out. This will include the ability to cope with the emergence of new requirements and changes to those existing. Thus a valuable mechanism for the management of change throughout the remainder of the programme is provided. Further, it is essential, procurement strategy permitting, to carry out progressive evaluation of the sonar, SAWS, and SMCS designs as they progress through full development, providing a system dimension to that process as necessary.

## Lessons Learned

As with all human endeavour the design process could be improved, and it is fair to say that if we were to do it again it would not necessarily be done in this way. The lessons learned merely reinforce the need for a system approach using structured and disciplined techniques from the outset. The following are a few specific items for consideration and are by no means exhaustive:

(*a*) The system design should lead the sub-system designs.

(*b*) Given the complexity of ship's equipments, sub-system designers should be forced to adopt structured system design techniques and preferably should have a proven track record in their application.

(*c*) There must be no commercial impediment to the information on the designs, being carried out at sub-system level, being made available to the designers and analysts operating at system level.

(*d*) Information on the sub-system designs should be provided in a suitable, preferably standard, format for system analysis, and timely enough to influence, and be influenced by, the system design process.

(*e*) Competition has many benefits but in this case it has frustrated the attempts to provide a system dimension to the design process. Therefore, with competition dominating the procurement strategy, it is essential that access to and protection of design information is established and enshrined within all associated contracts.

## Acknowledgements

I am deeply grateful to those whose work has contributed to the creation of this article, particularly in the combat system design and S&T update community. In particular my thanks are due to Mike Hoskin and Ray Charlton whose comments have been invaluable.

*References*

1. Baker, L. H: Combat system design developments; *Journal of Naval Engineering*, vol 32, no. 3 Dec. 1990, pp. 458–513.