A98-31693

ICAS-98-6,8,1

Maximising the Efficiency of the Structural Qualification Process

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Paper to be presented at ICAS 98,
The 21st Congress of The International Council of the Aeronautical Sciences

Abstract

BAe MA&A has demonstrated its commitment to improving the service to our customers by the development of Integrated Project Teams, dedicated to individual aircraft projects. In order to successfully implement these teams, we have had to analyse the design to manufacture process to enable the different disciplines to work efficiently together.

This paper focuses on how the Structures Discipline is evolving its Computing Facilities in support of engineering processes in order to meet the corporate requirement.

The challenges encountered and the solutions developed will be discussed, encompassing three related areas:

The Structural Qualification Process
Business Process Improvement (BPI) has been applied to Structural Qualification with Business Process Re-engineering (BPR) applied to the overall design process. The BPR process has lead to an increased requirement for engineers to have a 'broader knowledge' of aircraft design. The BPI process has addressed how the aims of BPR can be best achieved within the Structures discipline. The paper will describe the impact and implications of BPR and BPI on existing working practices; and how these changes have been incorporated into our strategy for Structures' computer system developments.

Automated Detail Stress Analysis
Considerable effort is being invested in improving the efficiency of existing analysis techniques and tools. There are two main threads to computing support for this development: Intuitive tools which promote ease of use; and the tailoring of tools to enable the overall structural qualification process. We are increasingly exploiting a number of 'intelligent' tools to lighten the engineers' load, using advanced computing technologies such as Heuristic KBS, Neural Networks, etc. The paper will describe systems which use the above technologies in support of general Structural Analysis, Fatigue Analysis and Onboard Loads Monitoring (OLM). The effect on the engineers' workload of these tools will be related to the ever increasing requirement for improved efficiency in the design process.

Data Control and Management
BAe MA&A is actively pursuing the customer requirement for a complete electronic product definition. The paper will describe Structures' Department support for this initiative in relation to the developing computer environment. In particular, the interfaces with other design disciplines will be described, since they provide key technology for the implementation of Integrated Project Teams.

The paper will conclude with a description of planned and proposed future developments.

21st ICAS Congress
13-18 September 1998
Melbourne, Australia

1. The Structural Qualification Process

1.1 The Objectives

British Aerospace has adopted new working practices in order to increase the overall efficiency of the design process. The primary aim of this procedure was to meet efficiency targets that are seen as essential for the business to compete in the World Aerospace Market. In summary, the aims were:

1. *To ensure adherence to schedule* - we must deliver to our customer on time.
2. *To minimise the design lifecycle* - to improve the response that we give to the customer on design issues.
3. *To maximise the efficiency of design processes* - to ensure that the business remains viable in a highly competitive market.

Objective 1 required changes in working practices across the whole of the company. In order to meet objective 1, however, objectives 2 and 3 had to be achieved by each of the design and manufacture disciplines.

This paper concentrates on how Structural Qualification has addressed the requirement to achieve objectives 2 and 3.

1.2 Re-organising the Business

The targets set for improvement were ambitious, and to meet them British Aerospace made significant investment in examining how we currently perform the overall design task. Existing procedures were examined to identify what changes could be made to increase the efficiency of the design process. This exercise was intended to embody Business Process Re-engineering (BPR).

In order to achieve objective 2, two main changes were planned. The first change was to look at how the various design processes interact. The second looked at improving the performance of each of the individual processes.

1.2.1 The Overall Design Process

Considering the global analysis, the existing design process followed a 'waterfall' lifecycle, whereby each stage required the previous process to have been completed. (Figure 1(a)). As a result of the analysis, the approach to design has been modified and compressed. Activities which were originally performed sequentially are now performed in parallel, carefully monitoring the availability and maturity of the design data. (Figure 1(b)).

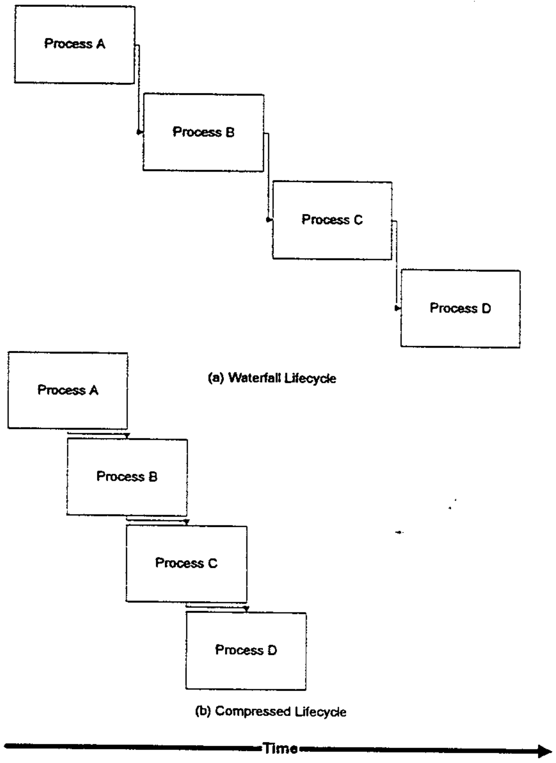

FIGURE 1
Design Lifecycles

To implement the compressed lifecycle model, radical changes were required to the organisational structure of technical design. Traditionally engineers had worked within departments with responsibility for their particular specialism (e.g. Structures, Design, Aerodynamics, etc.). The use of preliminary data required much greater co-ordination between the various disciplines. To achieve this, engineers were organised into project specific groups or Integrated Project Teams (IPTs). IPTs are multi-disciplinary, co-located groups who have overall design responsibility for a single major aircraft subassembly. (e.g. Forward Fuse IPT, Flying Surfaces IPT, etc.). This organisational structure was seen to benefit the company in many ways:

- The design team would have day-to-day contact with each other, improving communications across the project.
- It would promote understanding of the requirements of other specialisms within the design team.
- Targets for the work group would be more focused on the overall project requirements.
- The project focus would enable simplified accounting and give greater responsibility for the project profit plan to the IPT management.
- The management of resources would be simplified, i.e. The skill-set required for each project could be more clearly identified against the current stage in the design process.
- The structure would reflect the collaborative nature of the European Aerospace industry, with partner companies each holding responsibility for separate major subassemblies.

The proposed structure was successfully piloted in several areas of the Hawk design team. It has subsequently been implemented across all projects within the technical organisation. To retain the specialist skills of our engineers, the technical departments retained a core staff with responsibility for development of design methods; and Research was given 'Project' status to emphasise the importance of its position within the company.

1.2.2 Structural Qualification Efficiency

The above was the major development within the company to address the requirements of meeting objective 2. In order to meet objective 3 (improved efficiency) further work was required. Therefore each major design discipline (e.g. Structural Qualification) had a process owner allocated with the responsibility of ensuring efficient operation. The process owner was to ensure that the engineer has the right tools for the job, with access to the technologies required for producing a world class product. In-line with other technical disciplines, the Structural Qualification process had to be analysed for efficiency.

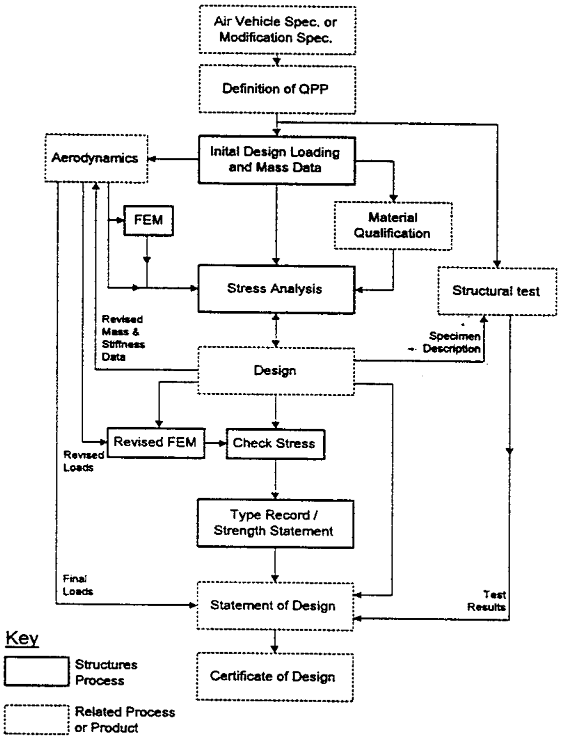

FIGURE 2
The Basic Structural Qualification Procedure

Figure 2 outlines the basic Structural Qualification process required for an aircraft (omitting Fatigue Analysis, Mass Control, etc. for clarity). It indicates the level of detail at which design has been analysed. From Figure 2, it is apparent that the Structural Qualification contains two significant processes which are repeated for every aircraft project. Initial calculations based on early design data produce both a Finite Element Model (FEM) and a set of Stress Calculations. When the design matures both the FEM and stress calculations are repeated with revised data, supplied by the supporting processes. Further, in the case of the introduction of a new variant of an existing aircraft, the current calculations would find further use. Clearly this provided an opportunity to increase efficiency and to reduce the Design Lifecycle, meeting the requirements of both Objectives 2 and 3.

The problem was then how to minimise the duplicated effort within the process and improve the engineer's performance without compromising the quality of his work. The obvious solution would be to computerise as much of the task as possible so that the duplicated parts of the process could be repeated (semi) automatically. The Structural Engineer would then be free to consider further aspects of the design, adding quality and meeting the independence requirement of the check-stress process of the Structural Qualification procedure. Paragraph 2 discusses the development of a computer based solution of the problem. Additional factors which influenced the development are now discussed.

1.3 Changing Working Environment

The described developments have had a profound impact on the day-to-day activities for the Structural Engineer.

Traditionally, there was a well defined interface with other technical disciplines. The Structures Engineer would be supplied data at defined stages of the design process. Working within Multi-Disciplinary teams has lead to a softening of this interface, which requires the individual to have greater awareness of the maturity of the data that he is being required to use. Management of this data and defining the data sources could potentially impose a major burden on the project engineer.

At the same time, other technical areas are developing improved working practices which will enable them to achieve their own efficiency targets. In the majority of cases, this has been achieved by the utilisation of computer based design tools. Consequently the Structures Engineer is expected to be able to utilise data created by such methods where his work requires it, where (traditionally) information was provided in written form. This is further complicated since the use of computers has lead to an exponential increase in the amount of data being presented. (Would it be true to say that Cognitive Overload is no-longer confined to combat pilots?).

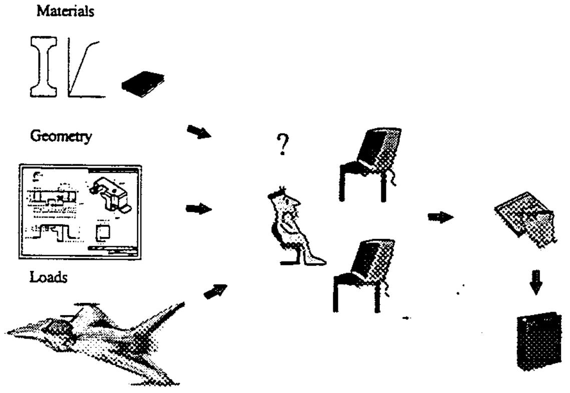

FIGURE 3
The IPT Structural Engineer?

Systems are presented on a variety of computing platforms which all operate differently. Existing working practices would have required the engineer to assimilate all of this data to perform (hand) calculations which would eventually be presented as the Strength Statement for the aircraft type.

Figure 3 illustrates the problems for every engineer. The proliferation of computer methods will in themselves improve the efficiency of individual design processes, but will fail to deliver objective 3 if the interfaces between the disciplines are not also addressed. The practical outcome of such a failure would be that the Structures Engineer on an IPT (for example) would be continually managing his sources of information and learning new computer operating systems to access data, rather than spending his time adding value to the product by applying thought to his engineering tasks. (This would also be true for engineers within other disciplines who require access to Structures' data) Automated interfaces were, therefore, a further requirement for the development of the computerised system, in addition to the company-wide developments discussed in paragraph 3.

The above are, therefore, the drivers for the development of a new and improved computer based working environment for the Structural Engineer.

2. Automated Detail Stress Analysis

2.1 A Short History of Engineering Software

The use of Computer Technology in support of engineering is, in itself, nothing new. Therefore, in order to provide process improvements for the engineer, more consideration is required to how the engineer uses computerised methods than ever before.

In order to fully understand the current situation, it is worth considering the history of the processes used by the Structures Engineer in relation to the use of computers:

Due to the nature of an engineer's tasks, engineering has (and still does) provide one of the most challenging uses of computer technology. In the early years, 'Engineering Computing' was limited to numerically intensive tasks. There are still, no doubt, Structural Engineers working who were involved in writing Finite Difference programs from scratch, assembling the required matrices by hand. As computing technology advanced, however, these early, usually single use programs were gradually replaced by more general, commercial Finite Element programs. At this stage, engineers moved from writing individual FEA solutions to provision of individual tools, covering specific areas of Structural Design. Typically each engineer would have a small suite of programs geared to his own particular needs. (Indeed this is still common practice among subcontract engineers, who use 'Psion' scale devices for basic programs wherever they work.) Before long, companies were assembling sets of these programs under more general headings to provide 'approved' suites of corporate 'Stressing Systems'. If someone came up with a new or improved method, then it was added to the set.

2.2 Lessons Learned

The following are some of the more pertinent observations which were concluded about the existing computer stressing suites of software which were available at the time:

Few of the existing programs had given thought to good (software) design practice. Many programs had simple, command line style data input, with specific data requirements according to the method employed. Usually the results of the program would be provided in tabular form suitable for output to basic line-printers or terminal screens. This was no surprise since development of better user interfaces would have required considerable time and effort to develop, which fell outside of the remit of the job. Only major systems (usually related to FEA) had developed more intuitive interface designs, and then usually when in conjunction with commercial CAE software.

Often, within 'suites' of software, much of the code would be duplicated, for example material data input would be written into each of the individual programs. Additionally, a suite would contain numerous similar programs, each dealing with specific instances of the same problem. (For Example: Consider the number of permutations when dealing with a buckling program).

The usual method of development in these cases would be to develop a program to deal with the basic case (e.g. Buckling of a flat isotropic plate under uni-axial compression), then developing further programs which increased in complexity. (e.g. bucking of a curved composite plate under combined loading). Few of the available programs would read data directly from external sources of information, requiring work by the Structures Engineer to enter the data manually.

The number of data file types created by a suite of software was directly proportional to the number of programs the suite contains. This could potentially cause confusion for the user when confronted with an unfamiliar file type.

Code was written in FORTRAN with some (older) code written in BASIC and some (newer) in 'C'. Nearly all of the code was written for large computing platforms, ranging from IBM and VAX Mainframes to newer Unix servers; presumably to ensure that the required raw computing power would be available.

With the exception of FEA, programs provided a basic level of automation of the tasks that traditionally the engineer would have to perform by hand.

In practice, the engineer would use hand calculations to generate data for the appropriate program, manually enter the data, then use the results of 'the program in subsequent calculations, often modifying the results to fit their particular design case.

The above was the area identified in paragraph 1.2.2 as the target for potential improvement of efficiency for the Structural Design Process. Therefore any new system would have to allow the engineer access to standard calculations, but with the flexibility to modify the calculation process to suit individual design solutions.

2.3 Requirements for the New System

In order to progress a new standard, a number of decisions were made at an early stage:

1. An intuitive interface would be required, which would add value to the documentation and understanding to the user.
2. A mechanism would be provided to ensure that data could be transferred between individual methods with minimal requirement for the engineer to manually manipulate and input data.
3. Each method developed would consider the highest possible level of complexity first. Therefore more basic cases would be automatically covered as simplifications.
4. The system produced would be the first step to replacing the existing (paper) Technical Standards Manuals with an authoritative, computer based, approved set of methods.
5. The complete system would create one type of data file, which the system is responsible for interpreting the contents of the file.
6. The system would be developed to maximise re-use of code and methods to minimise the amount of work required. (e.g. only one material data input module)
7. PCs have now developed to a level where many engineering calculations can be performed within an acceptable response time. It was decided that the user interface to the new system would be PC based.

8. To minimise the workload, maximum use would be made of commercial software and software components.
9. The software would be developed using state-of-the-art C++ and windows technology.

An ambitious target was set for the first release of the system to cover the basic techniques which are used day-to-day by IPT Structural Engineers, including:

- Engineering Data: Selection of Basic Material Data from Corporate Data Sources,

- 2D Stress / Strain: Laminate Property Determination and Section Properties. Determination of Forces and Reactions in user defined reference frames, Principal / Von Mises Stresses, etc.

- Beams and Struts: Frameworks, Buckling & Compression, etc.

- Panel / Plate instability: All materials, edge conditions, plasticity, etc.

- Joints: Boltgroups / Lug Analysis etc.

2.4 The Development Process

Work commenced in 1995 on the production of such a system.

It became clear at an early stage that the skill set required for the production of the system would lie outside that normally required for Structural Engineers. Skills in PC development techniques, particularly in windows environment programming were priority items.

A team was assembled consisting of both engineering method specialists and experienced engineering / mathematical programmers. In order to make maximum use of the skills of the team, a new working practice was developed.

The method specialists were supplied with mathematical software which was used to develop the company approved standards. On completion of a method, the computer model of the analysis was supplied to the programmers as the specification for coding. This was significant, since the live specification document enable the programmers to test the code against known, independently generated values greatly increasing the confidence in the final product.

2.5 The CITS System

Computer Integrated Technical Standards (CITS) is the result of the described developments. For the first time within British Aerospace Structures, a significant development of PC software has been put into use.

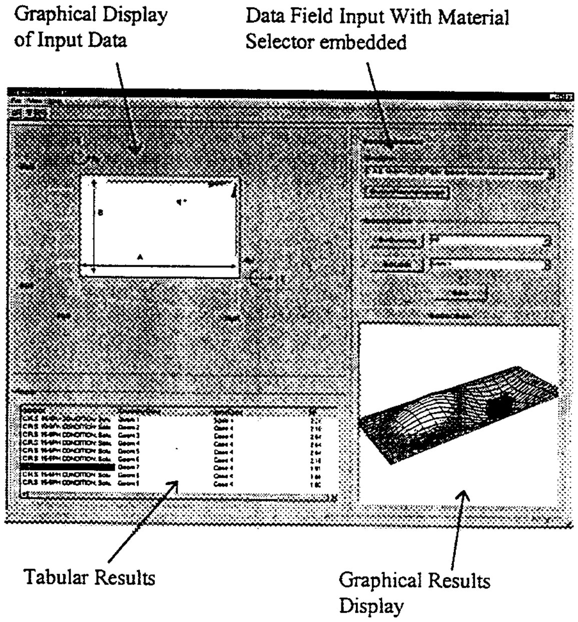

FIGURE 4
Panel Buckling Method

The developed interface (Figure 4) has given the engineer a working environment that is both intuitive (looks the same as standard PC software) and easy to understand from an engineering point of view.

The system comprises two operating levels, backed up by theoretical and practical help systems.

The first operating level is where the engineer works at the data level. This is in-line with more traditional programs where the user is required to enter numerical values to calculate results, which were presented in tabular format. The second operating level is the graphical input and feedback mechanisms employed. The engineer is able to visualise the data, via graphical input and displays of results. As the data changes, so do the graphs displaying the results of the user's changes, thus understanding is greatly improved.

The help systems comprise on-line 'live' documents which enable the user to examine the mathematics and detailed descriptions of the operation requirements for the system. The 'live' documents can have values inserted to test the engineer's understanding. The descriptive part maps the theory to the input required by the program.

2.6 Related Software Developments

In addition to CITS, British Aerospace has instigated the development of PC software at various universities in the areas of Knowledge Based Systems (KBS or Heuristics) and Artificial Intelligence (AI or Neural Networks) programming. These technologies are being examined to determine applicability as a part of the overall CITS system.

Current activities include a program to evaluate Fatigue Stress Factors for various design features, utilising KBS to determine appropriate parameters in cases where (traditionally) engineering judgement would have been used; additionally, a design configuration optimisation' tool which is intended for use in the concept and preliminary definition phases of the design procedure is being researched.

Neural networks are being investigated for use with Onboard Loads Monitoring data, to replace the existing manual data cleansing tasks. The software developed has the capability to remove 'spikes' from the data, based on the learning process of neural nets.

These emerging technologies are adding value to structural design. They show potential to limit mundane procedural aspects of the process and to apply specialist knowledge routinely, for all engineers involved in structural qualification.

3. Data Control and Management

3.1 Electronic Product Definition

In common with industry trends, British Aerospace customers are now requiring us to maintain complete electronic definitions of our designs. We have committed to this requirement on several recent projects. British Aerospace were, therefore, required to determine suitable tools and methods to achieve this aim.

3.2 The PIE System

A corporate project has been underway to address the electronic product definition requirement. The product of this development is the Product Information Environment (PIE). Structures activities have supported this development by the use of the described computing systems. Calculations which have traditionally been stored in paper format can now be kept as part of the electronic definition using CITS. This, however, has only been part of the problem.

By quantitative measures, the most significant data for Structural Calculations is that produced by Finite Element Analysis.

The problem that this presents is primarily the quantity of data involved. An average FE analysis produces about 2Gb of Data. Whereas - in some other disciplines - file sizes generally are about 10Mb (e.g. CAD datafiles). This has provided a major challenge to support the Structures Data, which is required for the working life of the aircraft.

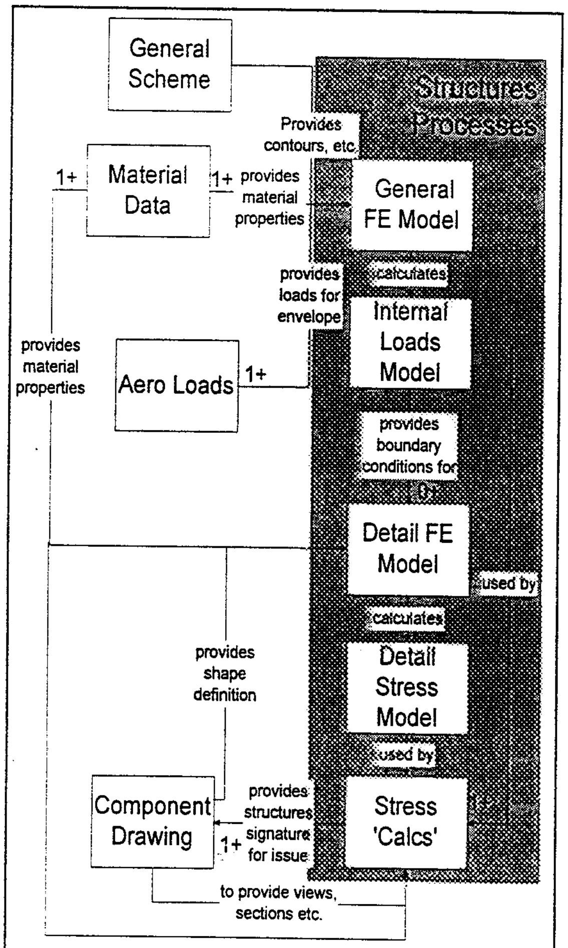

FIGURE 5
Structures Main Data Interfaces

Additionally, this is complicated since Structural calculations have a complex interaction with related data. Figure 5 illustrates this problem. The basic product of the Structural Qualification process is the Strength Statement. This document is compiled from the stress calculations (See Figure 2)

The problem this presents is that in order to maintain the traceability of data throughout the design process, there are many links from the stress calculations to related data. Whereas generally, for example, a CAD model will have a 1:1 relationship with associated data, stress data will have many dependencies.

A further complication arises because each specific instance of a structural calculation will have a unique relationship with associated data. i.e.: a stress 'calc' could refer to one or several CAD models, many load cases and one or several material property sets. General FEA models will refer to one master geometry model but many materials and load cases. This scenario does not fit well with the available data management tools which assume consistent data relationships in their data models. Structures have therefore been working in conjunction with the PIE support team to effect this requirement.

4. Planned Developments / Future Work

4.1 Process Definition

The analysis of the design process for efficiency is and will be an ongoing task. It is therefore important that Structures software developments are kept flexible to accommodate any required changes.

The principal aid to achieving flexibility is the new approach to software design in Structures. Object Oriented codes enable quick and simple modification of existing software to meet new methods of working and new developments within related processes such as Aerodynamics and Design.

4.2 Automated Detail Stress Analysis

Computer Integrated Technical Standards are now in general use by structural engineers.

Planned developments will provide both additional functionality and improved workflow for the engineer. Interfaces are being developed which will enable CITS items to import, for example, CAD attribute data for use in the Structural Calculations. This will be achieved by reinforcing the use of standards such as OLE, DCOM and CORBA where appropriate to the tools being developed.

It is planned to incorporate advanced computing technology such as KBS and Neural Nets in the definition of methods in the CITS system. The aim is to both enhance the quality of the engineers work and to remove the requirement to perform mundane or repetitive analyses.

The long-term aim is that all structural methods will be available as CITS items, utilising commercial software wherever possible. (For Example FEA software).

Further, investigations are ongoing to evaluate if the CITS framework could be utilised in other, similar, design processes such as Aerodynamics.

4.3 Data Management

Structures will continue to support developments in data management tools.

Having achieved traceability and control of the engineering data, the next task is to provide support for the overall design process as it relates to Structures. In outline, when the designer completes a CAD model, the PIE system will automatically forward the event to the Structures engineer (and other interested parties) for analysis of the design. When complete, the component will be electronically 'signed off' and passed on for the next qualification process.

5. Conclusions

British Aerospace now has the necessary structure to support the objectives described in paragraph 1.

The Technical Directorate has made a step change in its processes and procedures as a first stage to achieving adherence to schedule (Objective 1).

The Structures Discipline have supported the objectives at various levels:

To reduce the design lifecycle (Objective 2), process improvements have been identified. The efficient use of design data has been addressed and the interfaces between technical disciplines improved. Computer based tools have been developed which minimise mundane and repetative design tasks.

To increase the efficiency of Structural Design, (Objective 3), tools have been developed that aid the engineer on production of quality designs. Research on 'intelligent' software is at an advanced stage in several areas which will reduce the workload on the engineer.

British Aerospace has recognised that improved efficiency is a continuous process. Therefore, the described developments will be integral to future develolpments within the company.

6. Acknowledgements

The Author would like to thank British Aerospace Ltd for their permission and co-operation in publishing this paper.

The Author acknowledges the work performed by the CITS development team, the BPR team and the PIE development team; all based at British Aerospace's site at Warton, Lancashire, England.