THE LATEST DEVELOPMENTS IN DESIGN DATA EXCHANGE: TOWARDS FULLY INTEGRATED AEROSPACE DESIGN ENVIRONMENTS

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Keywords: *design environments; systems engineering; standards; data exchange; data sharing; STEP*

Abstract

Aircraft continue to get more complex with each generation, in their structural design, their avionics and systems, and most importantly perhaps, in the increasingly close integration between these aspects. The aircraft development process, the skills brought to bear and its supporting tools and infrastructure also continue to grow in size and complexity. Evidence of the breadth of the systems engineering (SE) process can be seen in various manifestations as documented in standards such as IEEE-1220 (1994), EIA 632 and most recently the emerging ISO 15288. Note however that these capture only views of the generic systems engineering process, the real process used in aircraft developments is considerably more complex, and inevitably is complicated by commercial, political and company/cultural issues. The explosion of desk-top computerisation and internet-associated technologies has also opened up considerable possibilities in tool support for design definition, analysis, simulation and testing, leading to increased complexity in the aircraft design environment, with an increase in associated environment and integration problems.

However, recent developments in design data exchange, both in the structural design and the systems areas, promise significant improvements in the degree to which distributed design teams can produce the complex designs characteristically found within modern aircraft better, faster and cheaper. Particular emphasis will be placed on the developments of the European SEDRES projects, and the associated ISO "STEP" standard development AP-233.

SEDRES-2 is a European Commission Framework V co-funded project, a continuation of an earlier SEDRES-1 project, which has developed a draft data exchange standard to support the systems engineering domain. This emerging standard is based on "STEP", and will embrace the product definition aspects crucial to successful SE: product requirements, systems architectures, product functionality, allocation, traceability, and configuration management information. The standard will enable SE tools to exchange such information, and should be applicable to many industries. SEDRES-1 produced a number of prototype implementations, has demonstrated actual data exchange, and early results are confirming the potential business benefits anticipated.

STEP (ISO 10303) is the international standard for product data exchange, and is split up into a number of component parts, including a series of 'Application Protocols' or AP's, each covering a specific industry domain. SEDRES has spawned an activity at the ISO level, within STEP, called AP-233 "systems engineering data representation". AP-233 is building on top of the work of SEDRES and is aiming to produce the International Standard by 2002.

As well as describing the achievements of SEDRES, and the status of the AP-233 work, references will also be made to related work by the International Council on Systems Engineering and the relevance of other data exchange standards, such as XML.

1 Introduction

Pressures from all stakeholders – users, customers, shareholders – continue to drive for better products, delivered for less money in less time. As aircraft developments get ever more complex, an increasing number of organizations are actively involved in the design process, and a larger range of ever-more comprehensive design & analysis tools are used. Meanwhile the explosion of desk-top computer computerisation and internet-associated technologies has opened up considerable possibilities in tool support for design definition, analysis, simulation and testing, leading to increased complexity in the aircraft design environment. This itself has lead to an increase in the associated environment management and integration problems.

However, recent developments in design data exchange, both in structural design and the systems areas, promise significant improvements in the degree to which distributed design teams can produce the complex designs characteristically found within modern aircraft faster, cheaper, and to a higher quality. A European consortium has made substantial progress in developing the basis of a data exchange standard covering the systems engineering domain. This standard is being formalised as a component within the ISO standard 10303 'Standard for Exchange of Product model data', under an activity known as AP-233, "systems engineering data exchange". Other developments are pursing related areas, such as developing consistent models for product data management (PDM), and extending the data standards for areas such as engineering analysis.

Progress in these 'semantic level' standards are being paralleled by developments in the enabling internet technologies that can make data exchange and sharing happen in practice. These include shared object technologies such as CORBA (Common Object Request Broker Architecture) and the high-profile XML (Extensible Markup Language).

This paper looks at the business and technical drivers for the desire for integrated design environments, explains the technology behind STEP, and outlines what has been achieved in the SEDRES-1 and AP233 activities. It looks at what SEDRES-2 intends to achieve and also summarises related activities. The objectives of the SEDRES project (SEDRES stands for Systems Engineering Data Representation and Exchange Standardisation) and its achievements are explained. The current status of the data model which is being extended by the AP-233 "systems engineering" activity will be described. Finally, future work in AP-233 and details of the work in the SEDRES-2 project will be outlined.

2 Drivers for integrated design environments

What are the business and technical drivers for the realisation of comprehensive product development environments? There are many, but arguably the most significant are the following:

1. To be able to form comprehensive environments largely from commercial off the shelf (COTS) design tools; aerospace companies do not see it as their core business to development systems engineering tools.
2. To realise an environment where engineers can get to the appropriate design information when and as they need it; in other works to create, access and interact with design information, regardless of in which tools this information may be stored.
3. To have a capability to manage design information in a coherent way, not in a tool specific way.
4. To do these things across the full lifecycle of the development.

These drivers lead to a number of strategies and approaches:

- A separation of the technologies that enable data to be transported and managed, frequently driven from the software and computer engineering domains, from semantic level models of design information, more appropriately driven from the appropriate industry domain. Examples of these two domains would be CORBA and STEP.

- A strong emphasis on open standards and neutral data exchange philosophies, such as STEP (explained in the next section).
- Developments in areas such as product data management, pursued in a tool-neutral way, such as work on the PDM Schema and PDM enablers.
- A holistic approach bringing together many parallel activities, where projects with a focus on different areas of the product lifecycle can achieve synergy (such as AP-233 and PLCS).

This paper concentrates on particular developments in STEP (SEDRES/AP-233), but includes explanation of other related work which contributes to the realisation of comprehensive design environments.

3 Neutral data exchange

What then is neutral data exchange, or more specifically standards-based neutral data exchange? The goal of achieving improved interoperability between design tools can be solved via a set of tool-to-tool exchange interfaces. However, a standards-based approach to design information exchange has a number of advantages, both to the organisations that use multiple design tools within a systems engineering process, but interestingly also to tool vendors. Figure 1 illustrates informally the contrast between pursuing a tool-to-tool interface approach and a standards-based approach to achieving improved interoperability, with a given set of tools[1].

From the potential need for the N(N-1) number of interfaces illustrated in the upper part of the figure, we move to the much more manageable situation of 2N potential interfaces. This means a smaller number of interfaces to develop and maintain, and increased flexibility in the use of the design tools.

Neutral design data exchange also opens up other opportunities. In addition to just achieving design data exchange via a standard format, that capability opens up the possibility to store design data in a tool-neutral format, which has particular significance, when one considers that operational life times of 40+ years are not uncommon for many systems engineering products. In addition, the abilities to pull subsets of design information from multiple design tools opens up the possibilities (with additional utilities) of performing consistency checking in a more comprehensive way than is possible with individual tools. It also makes it possible to gain 'views' of the design in ways that the existing design tool set cannot give.

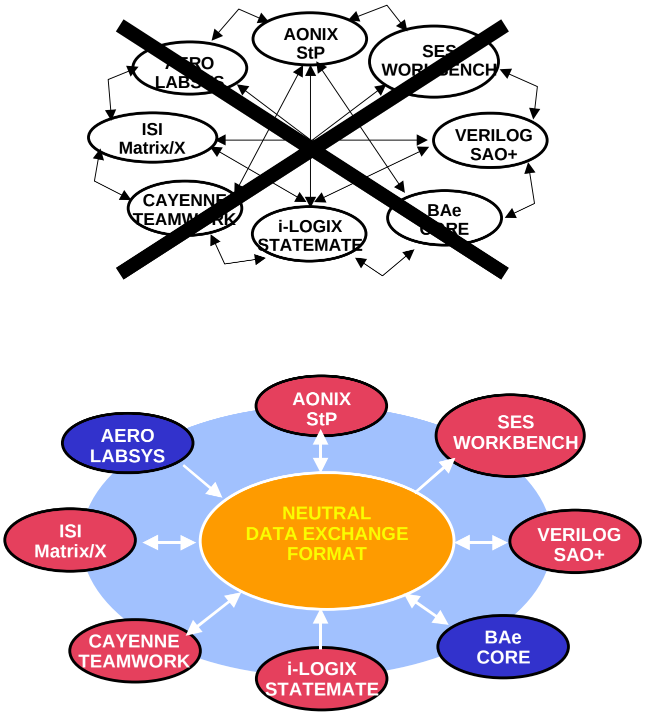

Figure 1: Advantages of standards-based exchange

The following sections explain how this vision of standards-based design data exchange is being realised, building on the work of the SEDRES project, through the related standardisation activity identified as AP-233, and most recently by the follow-on project SEDRES-2.

4 SEDRES-1

The European Commission co-funded project 20496, 'SEDRES', has made significant progress in producing a neutral data exchange standard based on STEP (Standard for the

[1] The tools listed here represent ones used in the SEDRES-1 project, and it is not intended to represent any endorsement of these tools.

Technical Exchange of Product Data, ISO-10303), embracing systems engineering design data. Co-funded by the European Commission and running from 1996 to March 1999, SEDRES was initiated by Aerospatiale (France), Alenia (Italy), the former British Aerospace (UK), DASA (Germany) and Saab (Sweden). Other contributors were the Universities of Loughborough (UK), Linkoping (Sweden), and the Australian Centre for Test & Evaluation.

The objectives of SEDRES were to produce:

A draft workable Systems Engineering data exchange standard;

Progress with this standard in the ISO forum;

A set of prototype data exchange tool interfaces for a number of tools & demonstrate;

A method of use, based on concurrent engineering & Integrated Product Development.

4.1 Achievements

By the time SEDRES completed in March 1999, it had achieved the majority of these objectives. It had:

produced three increasingly mature data exchange information models (successively known as SEDRES Capability/1, /2 and Final Proposal). The main building blocks of each version are illustrated in Figure 2;

produced prototype interfaces for several different Commercial Off the Shelf (COTS) tools used in systems engineering;

kicked off a healthy and vibrant parallel standardisation activity within the ISO STEP community [1], following a successful international ballot at the end of 1997, with 12 countries voting YES.

Details about the data models, the prototype interfaces and early evaluation results, have been reported in earlier papers [2, 3, 4, 5, 6].

5 Post SEDRES-1 Development

During 1999 the AP-233 data model has been extended further under supervision of the ISO working group. The main contributions originate from the SEDEX project performed at Linköping University and from European research project 28916 'KARE'. The main focus of contributions have not been to extend the scope of AP-233 but to improve the capabilities of the data model further. Improvements are especially in the areas of systems architecture, functional behaviour representation, configuration management and property representation. The relationships to object oriented analysis and design methods has also been investigated.

6 SEDRES/A-233 Model Philosophy & scope

6.1 Model Philosophy

The basic philosophy behind the SEDRES data models has been:

To focus on semantic-level rather than document level information;

To embrace a significant subset of the entire systems engineering domain;

To adopt a STEP style of modelling (although Capability/1 and /2 models only approximate to a strict STEP style);

To avoid being design tool specific;

To avoid prescribing any specific systems engineering process, but cogniscent of standards such as EIA 632 [7];

To support a concept that is termed 're-use', having part of a design which is defined once but appears in multiple contexts (analogous to use of a software subroutine or object several times within a large software product).

6.2 Model elements

The main elements of each model version appear in figure 2, and are summarised in the following paragraphs.

6.2.1 Systems architecture

This provides an entity to represent the system (or systems), to which other model elements can be related and covers relationships between systems, as well as definition of lifecycle, mode or stakeholder views on a system.

6.2.2 Requirements

Requirements covers structured or unstructured requirement statements, be they functional, architectural, operational aspects or system properties (safety or legislative requirements, performance, cost, etc.); relationships to requirements are also covered.

6.2.3 Functional

Functional comprises entities to model the system functions, functional hierachy, flows between functions, and the functional context.

6.2.4 Behaviour

The behaviour area embraces detailed timing, sequencing and event-based behaviour. These include: data driven behaviour specifications; finite state machine concepts; a procedural or functional chain approach; a synchronous behavioural model. A 'black box' or 'stimulus-response' form is also being considered.

6.2.5 Configuration Management

This covers the concepts needed to manage and control the different design items, including: authorship and ownership, authorisation, work management, development process reference, item versions, product variants, item maturity through the product's lifecycle. This will build on the STEP Product Data Management (PDM) Schema work.

6.2.6 Graphics (Visual presentation)

This covers concepts such as diagram object shape, connections, and placement within the diagram, supporting transfer of the visual layout of SE notations such as: data flow diagrams, statecharts, functional flow block diagrams.

6.2.7 Properties

This covers representation of numerical calculated, assessed or measured attributes of systems, physical elements or functions. Examples include cost, weight and execution time.

6.2.8 Physical Architecture

This area covers a simple node-&-link type approach for capturing architectures, where the node-elements and connect-elements are instantiated for different technology elements. This generic approach enables the data model to support physical component topologies (interconnections without details of physical placement) for a variety of basic implementation technologies. Allocation from functions to architectural components is also supported.

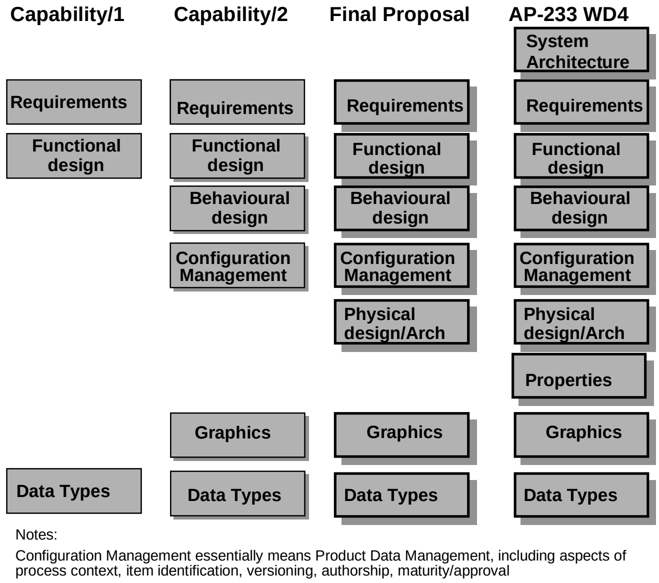

Figure 2: Evolution and elements of SEDRES data model

6.2.9 Data Types

Data types includes: strings, dates, bound (for instance Day-of-Month [1..31]) and unbound number types, compound data types or aggregations. This area will be aligned with the existing data type building blocks available within the existing STEP architecture.

The final data model from SEDRES-1 is described in more detail in [4, 5]. The current 4^{th} Working Draft is described in [8].

7 STEP & AP-233

STEP is the shorthand name for ISO standard 10303, "Standard for the Technical Exchange of Product data" [1]. STEP is briefly described in [4], a more complete overview and history is available in [9], and more information is available at a number of sources (for instance, in the web site www.ukcic.org/). The advantages of basing a design data exchange standard for systems engineering on the STEP technology have been described in [4]. Each of the main data transfer standards for different application domains are called Application Protocols, hence the term AP-233.

Any person or organisation can contribute to the technical discussions within AP-233 provided they can fund their attendance at the international meetings, however voting at the ballot stages for ISO standards is always organised on a country basis. The AP-233 working group has many active participants, including organisations from the countries in the SEDRES consortium, organisations such as NASA and Lockheed Martin from the USA, and active participation from Australia.

8 Future Work & AP-233 Development

8.1 AP-233 Development

Throughout 1999 much effort in the ISO working group was directed towards reaching consensus on the scope of AP-233. Remaining work is to complete or start work in the following areas:

The textual Requirements document communicating the scope of AP-233;

The STEP-style process model, or AAM (Application Activity Model);

The refined data model, or Application Reference Model (ARM); this is essentially a data model expressed using terminology to which practicing systems engineering should be familiar;

The creation of the integrated data exchange model, the Application Interpreted Model (AIM); the AIM 'interprets' the ARM using a number of existing STEP building blocks and becomes directly implementable;

Conformance level statement and Abstract Test Suite (ATS). The former defines a tool interface testing framework, while the ATS contains details of individual test cases for testing interfaces.

At the time of writing (May 2000) there is substantial progress on the first three items above, with the 4th Working Draft of the ARM reaching maturity. Development of the last two items will be initiated in the SEDRES-2 project with the aim to produce the first Committee Draft during 2001. Other materials will also be produced, leading up to an International Standard in 2002

8.2 SEDRES-2: Consortium & objectives.

The existing SEDRES-1 partners have succeeded in getting a follow-on project, SEDRES-2, in operation with an extended consortium. Additional partners are: Eurostep Ltd (UK), a specialist consultancy company focusing in the area of standards, information management and technology, active in several areas of STEP; Technical University of Clausthal (Germany), with experience of engineering design, data management, advanced computer-aided information systems and again active in ISO STEP standardisation activities; SIA (Societa Italiana Avionica; Italy), a systems & software engineering company experienced in the design of real time control systems. These participants strengthen the consortium as the data model is further extended, validated and taken through the later stages of the ISO process.

The objective of SEDRES-2 is set against the ultimate concept of achieving a distributed environment supporting systems engineering (SE), and building on the results of the SEDRES-1 project. SEDRES-2 aims to extend the data model against the remaining key SE technical areas and refined approach on product data management, and to evaluate resulting data exchange, via practical demonstration and industrial case studies, ultimately across several industry sectors. Important aspects of the project are:

- the work is complementary to the AP-233 work;
- the technical data scope is extended over that covered in SEDRES-1, including architecture, object orientation, selected system properties and design trade study aspects;
- development work will produce an extended set of prototype tool interfaces;
- some work will involve investigating shared design repositories, rather than simply data exchange;

*8.2.1 The start-up of SEDRES.*network

A component of SEDRES-2 is to realise the concept of SEDRES.*network*. SEDRES.*network* is a proactive organisation to maintain a generic systems engineering view of AP-233 across a mix of stakeholders, including: partners involved in industry sectors other than aerospace, embracing (potentially) automotive, rail transport, telecommunications, & process industries; design tool vendors; the ISO community.

SEDRES.*network* has start-up funding only within the currently funded SEDRES-2, however there is the intention to submit proposals for additional funding to support the full vision of SEDRES.*network.*

8.2.2 Timeframe, Validation Scenarios, prototyping

The SEDRES-2 project started in January 2000, and is initially planned to run over 18 months, with broadly three phases:

1st semester	Requirements refinement, Validation Scenario definition, data modelling, technology scoping
2nd semester	Interface development, validation environment development, testing, evaluation preparation
3rd semester	Validation scenario execution, evaluation, final report

The project will define two Validation Scenarios (VS's), one aircraft related and the other tackling the space domain.They will be representative of a real design and an industrial organisation working collaboratively and concurrently. The concept of the VS is crucial to ensuring both the refined requirements on AP-233 can be related to a real situation, and that a vehicle exists for doing a meaningful evaluation of the SEDRES/AP-233 data exchange capability.

Both validation scenarios are defined by the following features:

- the application context,
- the phases and activities of the system engineering process being addressed,
- the technical data handled,
- the system engineering environment used in the scenario (tools & infrastructure),
- the evaluation requirement, and
- the success criteria regarding the performance of this Validation Scenario.

The data modelling activities will refine existing work, and create appropriate new elements corresponding to the technical data scope identified earlier.

The prototyping activities will produce one or both interfaces for many different tools used to support SE activities, and in general will embrace the data coverage appropriate to that particular tool. At the time of writing the exact set of tools that will be used for prototyping is not decided, but it is likely to involve (in additional to internal tools) many of the following commercially available tools: Cradle, DOORS, MATRIXx, RDD-100, SCADE, SES-Workbench, Software-through-Pictures, Statemate, Teamwork.

8.2.3 Evaluation

The implementation of a SEDRES-like capability for model data exchange brings with it major implications for the way system engineering can be carried out, including human and business aspects. The evaluation area will build on the existing achievements within SEDRES-1 and other projects, especially in the user-system evaluation area. There will be an emphasis on business efficiency measures with respect to team working and quality of life factors, a process involving both evaluators and industrial partners.

The evaluation approach is structured in 5 main steps:

- the definition of the evaluation objectives,
- the set-up of the evaluation process,
- the integration of the evaluation environment,
- the evaluation during the performance of the Validation Scenarios,
- the exploitation of the results against the evaluation objectives.

It should therefore be possible to gain insight and potentially quantifiable results into the effectiveness with which SEDRES/AP233 supports the individual systems engineering activities that involve design data exchange, and into the wider team work and quality of life factors.

8.3 AP-233 Status Summary

AP-233 is now at a point where it is refining the technical details and reaching industrial concensus. The emphasis on effort to achieving industrial adoption must now be extended beyond the technical, to the business and market aspects of adoption. In the authors view there is no doubt that a neutral systems engineering standard can be made to work, and will provide significant opportunities and benefits.

9 Related work & standards

Part of the AP-233 & SEDRES work is to relate it to other areas of STEP development, and to other relevant data and process standards & projects. This section looks at these related areas of work.

9.1 Process standards

Over recent years a number of systems engineering process standards have emerged. These have included [10], and more recently ANSI/EIA-632-1998 [9] and the emerging ISO/IEC 15288 (now going through CD2 stage). Due to the significance of these process standards to systems engineering, the AP-233 work will attempt to ensure its data exchange approach is supportive of such process views, where possible.

9.2 STEP parts

ISO 10303 is actually a family of standards, covering many aspects of product definition, currently largely focussing on structural product definition (for instance, Bill of Materials parts explosion and geometry definition) and manufacturing (for instance, NC machining or sheet metal forming details). The working group will liaise with groups developing related standards, such as STEP AP210: Electronic Assembly, Interconnect and packaging Design; AP214: Core Data for Automotive Mechanical Design Processes and AP203: Configuration Controlled 3D design of Mechanical Parts and Assemblies. Several of these parts of STEP, for instance AP203, are already mature and in production use within major organisations.

9.3 PDM Schema work and modularisation

It has always been the intention that the component parts of STEP would interoperate, since it was recognised that any one organisation would need to make use of two or more Application Protocols to support its business operations. In recent years, a process to improve the very architecture of STEP has been pursued. This work has dual aims, partly to increase interoperability, and partly to reduce the costs of developing STEP interfaces by adopting a philosophy that would enable software implementation modules to match the very data modules that would make up Application Protocols.

Due to the ubiquitous relevance of product data management (PDM) issues to data exchange, the PDM area has acted as a focus for this development, and has lead to the development of the STEP PDM Schema. More information about the status of this development is available at www.pdesinc.com.

9.4 Engineering analysis

In addition to work in various Application Protocols, as described in the earlier section, there is also work contributing to other potential STEP models in the area of engineering analysis. Traditionally this work has focussed on the types of engineering analysis centred around finite element approaches, such as those used to support stress analysis, electromagnetic analysis and computational fluid dynamics. However, this work will continue to be more comprehensive, and its very significance to systems engineering prompts the need for SEDRES/AP-233 to achieve a degree of consistency with the work.

9.5 INCOSE

INCOSE is the International Council on Systems Engineering (see wwww.incose.org). It is the leading professional organisation worldwide representing the systems engineering discipline, has over 3000 members and Chapters in many countries. INCOSE has a structure of Technical Committees and Working Groups progressing many areas of the subject, several with particular relevance to SEDRES/AP-233, including the Tools Integration and Interoperability Working Group (TIWG), and the Model Driven Systems Design working group. The TIWG is itself producing a statement of requirements for an Integrated Systems Engineering Environment (ISEE), and the emerging AP-233 would be one of the key enabling standards that would make such a concept realisable.

An illustration of the INCOSE thinking on integrated systems environments is shown by Figure 3, from a draft of their TIWG document "A Concept Of Operations For An Integrated Systems Engineering Environment". The good correspondence between the INCOSE view and the emerging AP-233 is somewhat masked when the content of figures 3 and 2 are compared, since this view is organised functionally, while the view in figure 2 is organised along data-centred lines.

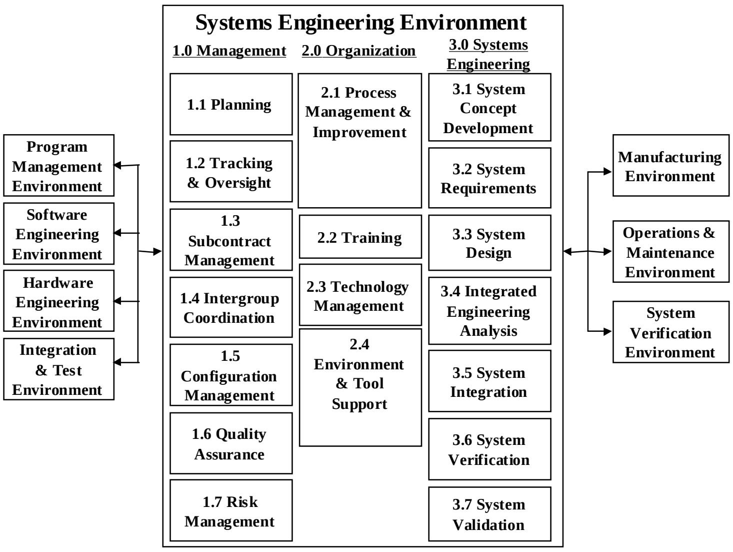

Figure 3: Notional architecture of Integrated Systems Engineering Environment (with acknowledgements to INCOSE TIWG).

Formal liaison has been established between AP-233 and INCOSE at an organisational level, with an agreement between ISO SC4/TC184, the Committee overseeing the AP-233 development, and an INCOSE individual (Dr David Oliver) in place to oversee the liaison. The fruits of this liaison have already been seen, with a successful INCOSE-organised AP-233 review workshop taking place in early May 2000 providing useful review comments to the AP-233 development.

9.6 PLCS

PLCS stands for Product Life Cycle Support. The PLCS project is aiming to produce a standard to facilitate the definition and exchange of design and support data focussed on the through-life support of a product (see www.plcs.com). The work of SEDRES/AP-233 and PLCS are both being done within a STEP modelling context, and are complementary in the areas of a product lifecycle on which they concentrate. Formal liaison exists between the SEDRES-2 project and PLCS to ensure that they are consistent and will interoperate. Several organisations are partners in both projects.

9.7 CORBA & XML

In addition to the application-domain semantic standards such as those within STEP and PLCS, there are also integration technology standards that are progressing with direct relevance.
CORBA, or Common Object Request Broker Architecture, is the Object Management Group's (OMG, see www.omg.com) standard for enabling the vendor-independent storage and exchange of software objects across platforms and technologies. This standard continues to mature, with a number of commercial and public domain implementations now available.
XML, or eXtensible Markup Language, is another standard of relevance to the vision of systems development environments. XML is really a meta-standard, a standard for building standards. Already a number of specialist applications have been developed in areas such as mathematics and chemistry. XML at some point is likely to be replacement for Part-21, the flat-file data exchange encoding standard within STEP, and would be applicable to all STEP developments, including AP-233.

10 CONCLUSIONS

This paper has provided a summary of the need for a comprehensive systems engineering data exchange standard, and given a view of how such a standard is an enabler for a longer term vision. It has reported the objectives and achievements of the SEDRES-1 project. It has given a view of the progress and intentions within the AP-233 development. It has explained the objectives and approach of the follow-on project, SEDRES-2. It has pointed to many other areas of related work, and to related standards that, together with AP-233, will enable the vision of the future aircraft development environments to become a reality.

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Acknowledgements

The SEDRES-1 and SEDRES-2 projects are funded jointly by the participating industrial partner companies and the European Commission. The financial support from the Swedish National Board for Industrial and Technical Development (NUTEK) is also gratefully acknowledged. The author gratefully acknowledge the hard work of the other project participants.

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