

THERMAL NEUTRAL FORMAT BASED ON THE STEP TECHNOLOGY

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ABSTRACT

The exchange of models is one of the most serious problems currently encountered in the practice of spacecraft thermal analysis. Essentially, the problem originates in the diversity of computing environments that are used across different sites, and the consequent proliferation of native tool formats.

Furthermore, increasing pressure to reduce the development's life cycle time has originated a growing interest in the so-called spacecraft concurrent engineering. In this context, the realisation of the interdependencies between different disciplines and the proper communication between them become critical issues.

The use of a neutral format represents a step forward in addressing these problems. Such a means of communication is adopted by consensus. A neutral format is not directly tied to any specific tool and it is kept under stringent change control. Currently, most of the groups promoting exchange formats are contributing with their experience to STEP, the Standard for Exchange of Product Model Data, which is being developed under the auspices of the International Standards Organization (ISO 10303).

This paper presents the different efforts made in Europe to provide the spacecraft thermal analysis community with a Thermal Neutral Format (TNF) based on STEP. Following an introduction with some background information, the paper presents the characteristics of the STEP standard. Later, the first efforts to produce a STEP Spacecraft Thermal Application Protocol are described. Finally, the paper presents the currently harmonised European activities that follow up and extend earlier work on the area.

ABBREVIATIONS AND TERMS

AAM	Application Activity Model
AIM	Application Interpreted Model
ARM	Application Reference Model
ANSI	American National Standards Institute
AP	Application Protocol
ASCII	American Standard Code for Information Interchange

ATS	Application Thermique Spatiale
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CNES	Centre National d'Etudes Spatiales
ECLS	Environmental Control and Life Support
ESA	European Space Agency
* ESARAD	ESA's radiative analysis software
ESATAN	ESA's thermal network analyser
ESTEC	ESA's European Research and Technological Centre
FE	Finite Elements
FHTS	Fluid loop extension to ESATAN
FLUOR	CNES' Radiative Analysis Software
ICETAS	Integrated Communication Environment for Thermal Analysis
IGES	Initial Graphics Exchange System
IR	Integrated Resources
ISO	International Standards Organization
SDAI	Standard Data Access Interface
SET	Standard d'Exchange et Transfert
TAS	Thermal Analysis for Space AP
STEP	ISO's Standard for Exchange of Product Model Data
TMM	Thermal Mathematical Model
TNF	Thermal Neutral Format
VDA-FS	Verband Deutschen Automobil, Flaechen Schnittstelle
YC	ESTEC's Thermal Control and Life Support Division
YCV	YC's Analysis and Verification Section

THE THERMAL NEUTRAL FORMAT

Standardisation of the analysis tools

The standardisation of analysis procedures has become an essential requirement for the organisations operating in the European Space sector, due to the complexity found in large space projects involving international consortia of companies. This standardisation has most obviously materialised in the availability of a set of *de facto* standard tools which facilitate the interaction between the different parties involved in a project. Examples are the ESABASE (ref. [1]), ESATAN (ref. [2]), FHTS (ref. [2]), THERMICA (ref. [3]) and the recently released ESARAD (ref. [4]) tools.

An important consequence of this situation is that the tool's native formats have also been adopted as the *de facto* standards for exchange and archive of thermal models. This seemed quite convenient at a time when the number of tools was small and no obvious alternative was available. However, this approach is not satisfactory any longer. In fact, the use of native formats has serious and long reaching implications, which will be reviewed in the following sections.

The problem of exchange

The exchange of thermal models is currently posing a number of serious problems to the day-to-day practice of the spacecraft thermal analysis. Essentially, the problem originates in the diversity of computing environments adopted by different organisations, and the consequent proliferation of native tool formats. The situation can be even more troublesome for those organisations needing to maintain several environments to serve different requirements or customers.

Furthermore, the organisations often invest in the development of proprietary software, which is normally intended to serve purposes not adequately covered by the standard tools. These developments contribute to enhance the companies' competitiveness, by taking advantage of in-house expertise and skills. However, most of these tools introduce new exchangeability requirements, aggravating further the problem.

The concurrent engineering issue

A state-of-the-art analysis environment cannot overlook the need to provide proper communication means between the different teams involved in the spacecraft development. Indeed, spacecraft engineering is a true multidisciplinary process, in which the information follows complicated paths and different disciplines interact in non-trivial manners.

Traditionally, each discipline's analysis has been performed in an uncoupled way, in an attempt to isolate their particularities and thus to simplify the assumptions and methods used for each of them. However, two main developments have radically changed in the last years the context in which the analysis takes place:

- the advances made in terms of computing power have allowed to perform more and more complex analysis in a shorter time. Furthermore, this evolution has enabled the development of tools that model and analyse the physical problems with fewer simplifications and restrictions.
- more and more complex missions impose requirements which cannot be achieved by performing uncoupled disciplinary analysis.

With these ideas in mind, there is an increasing trend to acknowledge the interdependencies between design and analysis and to integrate them within a tightly coupled process. This approach also encourages the concurrent analysis of several physical problems through the use of common models, procedures and tools. The final objectives are those of streamlining the flow of information and of increasing the efficiency and the capabilities of the design and analysis processes, while rationalising the resources used.

Two issues are particularly important in this context. Firstly, a good communication between the CAD world and the analysis environment has become an essential requirement. Indeed, although the flow of information between disciplines depends on several organisational issues, the initial stage is typically the acquisition of configurational data from the project source, which in general is a CAD system. Secondly, proper communication to commercial finite element (FE) packages is more and more important. The continuous evolution of these tools in the last years makes them very attractive to both managers and engineers. FE packages provide a framework which can be used to integrate individual discipline tools to yield the desired multidisciplinary analysis capability. Although finite differences remains the method of choice in spacecraft thermal analysis, the drive towards concurrent engineering is likely to foster the use of FE tools in the future.

The problem of archive

The exchangeability requirements can be extended quite naturally to the archive and retrieval of analysis models and results. After all, one can consider archiving as an exchange across time. Indeed, an archived model might not run properly when retrieved because of the evolution of the tool and the incompatibility between different versions. An extreme case, but not unlikely given the typically long duration of the space projects, would arise when the tools once used in a project are not available (or supported) any more.

A further reason making the case for stable archive means is the need to perform occasional emergency analysis campaigns to cope with spacecraft operation modes that follow unexpected events or failures. Under the urgency of these situations, costly modifications to the archived models are simply not acceptable.

The need for a neutral format

It is clear that the use of native formats as a means of exchange brings about serious problems. For instance:

- their use encourages the proliferation of tool-to-tool interfaces. Obviously this is not the most efficient way to exchange data between a given number of software packages.
- native formats are intrinsically unstable, i. e. they evolve with time. Therefore, the software interfaces that read/write native formats have to be constantly updated in order to keep up with new versions of the tools.
- the interface developers need to have a complete, updated description of the two formats being interfaced. This might be a problem if, as usual, the interface developers are not in control (at least one) of the formats. This fact increases the chances of software interfaces lagging behind the evolution of the tools, or simply being obsolete.
- organisations may have to develop different interfaces to satisfy each major customer's requirements. The extra costs incurred by this practice are frequently absorbed by the customer.

The use of a neutral format overcomes these serious problems. Such an approach is adopted by consensus as a means of exchange and archive. A neutral format does not depend on any specific tool and it is kept under stringent change control. The neutral format system consists not only of the description of the data intended to be exchanged or archived, but also of a formalism describing the means for exchange or archive and of the interfaces to other formats.

According to ref. [5], a Thermal Neutral Format (TNF) shall fulfil the following requirements:

- the TNF shall ultimately support the domain relevant to all the software tools used to perform thermal analysis.
- the interfaces in both directions (TNF to native format and vice versa) shall preserve the integrity of the information being exchanged or archived.
- the TNF shall be flexible enough to allow its extension without modification of the existing features.
- the TNF shall allow the selective treatment of the data. That is, each interface shall be able to process only the data relevant to the interface.
- the TNF shall be portable across systems and sites.

A TNF should also benefit of a large scope. Indeed, a widely spread standard formalism should be used to support the data exchanged or archived, simply because commercial CAD/CAE and FE tools are more likely to include built-in interfaces to internationally accepted standard formats. The development of a specific formalism for the TNF would not only waste efforts but also limit its immediate scope of application.

Finally, it is important to notice that were a TNF available, the development of interfaces to and from the TNF would normally be left to the tool developers themselves. This would likely give better chances to have interfaces up-to-date to the last tool versions.

Initiatives in the field of Thermal Model exchange and archive

Although the problems described in the previous sections have been around for a long time, the development of a TNF, based on a broad consensus within the European Space Industry, has not been attempted until recently. However, a number of initiatives were born with the intention to address the problems in one way or another.

As previously commented, native formats were typically exchanged between sites. The Thermal Mathematical Models (TMM) exchanged by means of ESATAN input decks are a clear example of this approach. As the need to exchange geometry-based models grew, the requirement for a new format became obvious. For that purpose, the ESABASE[4] language started to be used. Although ESABASE is basically a system engineering package, its input language provides a means to define analysis-tool-independent models. Furthermore, the ESABASE framework includes translators to several radiative and thermal packages. However, the ESABASE language depends itself on the evolution of the ESABASE software, and it has a rather limited scope.

Another ESA's initiative, ICETAS (ref. [6][7]), was not originally an effort to provide solutions to the problems of exchange and archive. Rather, it addressed the issue of integration of thermal software tools. Nevertheless, as work on ICETAS progressed these aspects became very relevant. Furthermore, the project produced a description of the complete set of data required to perform Spacecraft Thermal Analysis, as well as their interrelationships. This information is clearly very relevant to the development of a TNF.

The SET-ATS protocol

An important initiative has recently been undertaken by CNES, the French Space Agency, in order to provide a TNF based on the French standard SET. CNES have developed the "Application Thermique Spatiale" (ATS) Application Protocol to address the spacecraft thermal analysis exchange and archive requirements.

The first version of the protocol (ref. [8]) provided support for three major categories of entities:

- geometrical entities extracted from a set of primitive shapes, which are meshed and have thermo-optical properties attached to their faces. These entities can be assembled to build hierarchical models containing multiple occurrences of sub-models.
- results of calculations (processing) associated to geometric or thermal nodes.
- an entity containing the data needed to characterise the orbit.

In addition to these categories, the "neutral file header" and "neutral file summary" entities define the required additional information (origin, date of issue ...) for exchange and archive purposes.

Following a first implementation and test, a second version (ref. [9]) has extended the original protocol to improve the support for:

- orbit and kinematic extensions. Orbital data locate the satellite, considering it as a point in space (its centre of mass). Kinematics data give the attitude of the satellite and its moving parts with respect to the planet and the Sun.
- geometrical features. The set of elementary surfaces has been extended to take into account boolean operations and high-level shapes. The boolean operations (union and difference) can be used to generate complex geometry by combining elementary surfaces. High-level shapes, which have an associated type (e. g., box, cylinder ...), allow the easy manipulation of collections of elementary surfaces.
- language features such as comments, numbering and labelling, mainly introduced for man-machine interface purposes.

With this extended support, the new version aims to cover the main capabilities of the FLUOR, THERMICA ESABASE and ESARAD radiative analysis software.

The ATS protocol is based in the data and mechanisms defined in the SET Z68-300 standard, which is implemented in a large number of CAD/CAE software packages and used extensively in the European Aircraft Industry. The protocol, which covers some domain specific requirements, makes use of a subset of the generic entities available in the SET language. Moreover, some items of information, not covered by the SET standard, required the addition of new blocks and sub-blocks which can only be used by an interface that recognizes their format and semantics. Consequently, a correct SET-ATS interface will generate a SET physical file syntactically compliant to the SET standard. A standard SET interface will read these files, although it will be unable to interpret the parts of the information specific to the ATS protocol.

THE STEP STANDARD

Description of the standard

Work on communication standards between CAD/CAE systems has been under way since the beginning of the eighties, resulting in the development of several exchange formats like IGES, VDA-FS or the above mentioned SET. Currently, most of the groups promoting these exchange formats are contributing with their experience to STEP[10], the Standard for Exchange of Product Model Data, which is being developed under the auspices of the International Standards Organization (ISO 10303).

STEP was first proposed in 1984, with the intention to provide a worldwide standard supporting the complete representation of a product throughout its life cycle. STEP is different to other exchange formats in that rather than only providing rules to format a defined set of data, it is also supplying a methodology to formally describe the data and to implement the format. Furthermore, conformance testing to the standard is an integral part of STEP. From this point of view, STEP goes beyond the concept standing behind other exchange standards, by providing a standardised methodology to define application-specific product data standards. Other advantages with respect to existing standards are:

- because of the broad international consensus built around it, STEP is likely to meet the requirements set by many different applications.
- STEP establishes a separation between the logical design of the data and the physical implementation.
- the use of a formal language removes ambiguity and enables a rigorous conformance testing. Furthermore, automatic software generation from the EXPRESS specification becomes possible.

STEP consists basically of a series of components (called parts in the STEP terminology). Each of the parts are published separately, to help coping with their different degree of maturity. The main parts are:

- the EXPRESS[11] language, developed on purpose for STEP. EXPRESS is a formal information modelling language used when describing the STEP entities, with the intention to ensure consistency and avoid ambiguity.
- resource information models defining the basis for the development of application standards. The so-called Integrated Resources (IR) are in fact the basic building blocks used to define the application standards. They provide a unique representation of each element of information used within STEP. These resources can be either Generic Resources, i.e. of potential use for any type of application, or Application Resources, valid only for specific applications. The EXPRESS language is used to define the IR.
- Application Protocols (AP), which are the actual application-oriented standards that end-users will take for their exchange and integration needs. The APs are logically self-contained and complete.
- implementation methods supporting the data models provided by STEP.
- strict conformance testing procedures and tools to control and to certify compliance to STEP APs.

Therefore, the EXPRESS language is used in the definition of the Integrated Resources, from which the Application Protocols are derived (these can also use directly EXPRESS). A STEP implementation is produced when an Implementation Form is chosen. This implementation can be tested for conformance to the standard using the STEP-supplied methodology.

STEP is also to play a role in the issue of integration. Indeed, there are several possible implementation forms of the STEP standard. Today, the only implementation in place is the physical transfer file, but work is progressing in the definition of the Standard Data Access Interface (SDAI), which will introduce a software layer representing an abstract, "EXPRESS" view of the data to be transferred or stored. The SDAI will provide in practice interfaces to both relational and object STEP databases.

STEP Application Protocols

As mentioned previously, STEP provides a standardised methodology to develop protocols oriented to specific fields of application. The development of a particular AP stems from the specification of the scope and the information requirements of the AP. This is achieved by means of the Application Activity Model (AAM), which describes the processes, information flows and functional requirements of the application. The AAM helps to understand the nature of the activities and the role of the product data in the field of application. The AAM is included as an informative annex to the AP.

A more detailed Application Reference Model (ARM) specifies the information requirements and constraints of the AP, in terms of the so-called Units of Functionality. These units contain information about the entities, attributes and relationships that determine a given concept within the ARM. Although the ARM is defined by means of a formal data description language, application-specific terminology is used in this model. The ARM is also appended as an informative annex to the AP.

After the ARM is defined, the Application Interpreted Model (AIM) specify the manner in which the Integrated Resources can be used to satisfy the AP requirements. The resource constructs can be used directly, or refined depending on the application requirements.

Finally, the APs shall include the conformance requirements to be satisfied by any implementation claiming to support the AP. Such an implementation is tested by performing a conformance test based on a set of abstract test cases.

STEP and the TNF

Several fundamental STEP parts are already available either as International Standard or Draft International Standard. These parts include the EXPRESS language, the Physical File Exchange Structure, the conformance testing methodology, some Integrated Resources and some Application Protocols. A significant number of other IR and AP are being developed, with many of them close to achieve a stable state.

Certainly, the transition from current exchange standards to STEP will take some time. Nevertheless, enough progress has been achieved to appreciate the relevance of the STEP technology to the development of a TNF. Indeed, STEP is an obvious candidate for the TNF, because in addition to its intrinsic advantages as product data standard, it fulfils the basic requirements for a TNF:

- it is a neutral format that satisfies the needs for stability and tool-independence.
- its broad scope will allow immediate communication to the CAD and FE worlds.

In summary, STEP provides an excellent methodology to develop a Spacecraft Thermal Application Protocol. For the first time ever, the thermal analysis community might have the possibility to use a TNF tailored to its needs, but at the same time enjoying the character of full international standard.

DEVELOPMENT OF THE STEP THERMAL AP

CNES' STEP-ATS Application Protocol

Based on the experience gained in the production of SET-ATS, CNES undertook the development of an application protocol using the technology and methods developed for STEP (ref. [12]).

This application protocol was developed in conformance to the rules put forward in the "Guidelines document for development of STEP protocols". However, the complete process of Integration and Qualification imposed by ISO on the 10303 Parts was not followed. In particular, the Application Activity Model was not produced. On the other hand, the application protocol was developed by using, as far as possible, resources defined in ISO 10303. However, due to the fact that STEP is still in evolution, some of the required resources are not yet available in the standard. Therefore, these specific resources had to be produced in order to meet the application requirements. With these limitations in mind, the STEP protocol was defined to match the user requirements associated to the first version of the SET-ATS protocol.

The first stage of the development consisted in the specification of the information requirements in terms of units of functionality, application objects and application assertions. This stage defines the product data as viewed by the application users. The models are specified to have a tree structure including occurrences of sub-models. Any sub-model can also contain surface data representing a part of the geometry. Information related to the meshing and to the physical properties of each face is attached to the surfaces. Moreover, the protocol supports the transfer of the data needed for the orbit determination and the results of the thermal analysis. Finally, it includes the information related to the management of the exchanged models (designer, creation date, entity labels, colour for possible graphical display, grouping of entities into cells ...)

The information requirements are specified in terms of:

- Units of Functionality that allow the classification of the application objects into coherent groups such as geometry, thermo-optical properties or model structure.
- application objects such as surface type, mesh characteristics and orbit parameters. These objects are atomic elements that embody a unique application concept and contain attributes specifying the data elements of the object.
- application assertions that specify the relationships among application objects. For instance, “meshing of a Thermal_face is defined by one Mesh_characteristics”, “a Mesh_characteristics applies to one Thermal_face” or “a Thermal_face has at most one Mesh_characteristics”

A graphical representation, using the EXPRESS-G notation, describes the structure and constraints of these application requirements (see Figure 1).

Following the definition of the information requirements, the Application Interpreted Model was then produced to specify the references to the STEP Integrated Resources. For each Unit of Functionality and application object, the so-called Mapping Table shows the correspondence between the information requirements and one or several AIM resource constructs.

Finally, the AIM’s EXPRESS annotated listing was produced to present the complete listing of the types, entities and rules necessary to fully specify the AP.

It is important to note that the move from SET to STEP does not only represent a change in the neutral file physical format but also demands the evolution of the requirements (or at least of the way to take them into account). As a matter of fact, STEP promotes the concept of product whereas SET deals mainly with geometrical models. Although the STEP AP development process is more complex, the possible scope of the AP is much broader. Furthermore, it encourages an approach which is consistent with data representation requirements appearing in other stages of the spacecraft design.

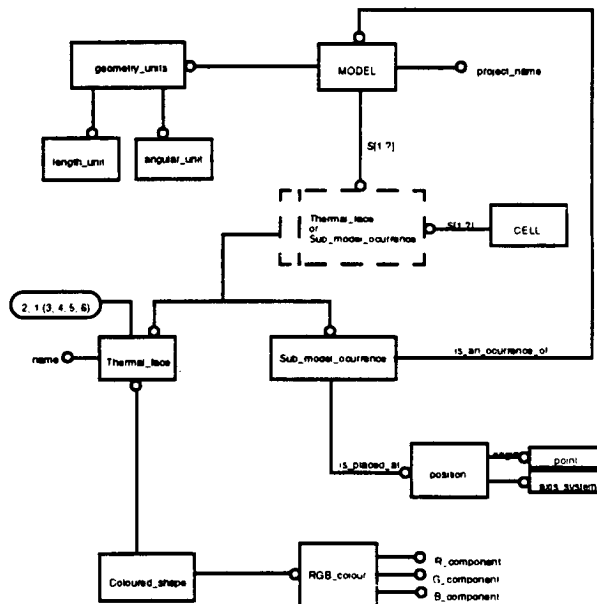


FIGURE 1. EXPRESS-G diagram presenting the information related to the Model_structure unit of functionality

Thermal Analysis for Space AP

The independent efforts undertaken by CNES and ESA in 1993 had similar timing and objectives, since both intended to produce a STEP Application Protocol for Spacecraft Thermal Analysis. Thus, it seemed reasonable to start a harmonisation process in order to reduce the chances of duplicating work. Furthermore, it seemed sensible to rationalise the efforts by making an efficient use of the knowledge gained by both CNES and ESA in the matter.

This harmonisation was fully achieved in early 1994 in the form of an activity to develop an Application Protocol on Thermal Analysis for Space (STEP-TAS). Previous experience coming from the STEP-ATS and the ICETAS projects was directly fed into the new project.

The harmonised work set off with the fundamental objectives of:

- merging the domain information models developed independently by CNES and ESA. Consensus in the Application Activity and Application Reference Models will result from this merge.
- extending the AIM developed by CNES to support a subset of the domain information requirements mentioned above.
- demonstrating the exchange of thermal models via STEP files. For that purpose a prototype facility is being developed to communicate FLUOR and ESARAD.

Results produced in the first stage of the harmonised effort are expected towards the end of 1994.

CONCLUSIONS

The concept of neutral file contributes in a very significant way to streamline the exchange of information, as proved by the development and use of the SET-ATS protocol. Modern product data technology, commonly associated to STEP, ensures the development of non-ambiguous domain-specific protocols which provide solutions not only to the information exchange problems but also to the integration of applications. However, the matter of successfully introducing a TNF in the spacecraft thermal analysis community remains largely a problem of consensus. Currently, a harmonised effort CNES/ESA is under way to provide a unique description of the information requirements in this domain. If an agreement is reached on the suitability of this logical description, the STEP technology is ready to produce an implementation of the TNF.

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