DEPLOYMENT OF STEP-TAS THERMAL MODEL EXCHANGE

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ABSTRACT

STEP-TAS is a draft open standard, developed by ESA, for the exchange of space thermal analysis models. TAS stands for *Thermal Analysis for Space* and STEP is the casual name for ISO 10303, the main global standard for the exchange of computer aided design and engineering analysis models.

What can be done with STEP-TAS today will be presented, including the TASverter tool that is freely distributed by ESA. TASverter now has a new full TRASYS interface (import and export), besides its known interfaces with the European tools ESARAD, THERMICA and CIGAL2. The TRASYS interface allows basic exchange with most US tools which is very useful for international space programs.

A new feature is storing analysis results into neutral STEP-TAS files, which now works for the ESATAN thermal network analyzer.

Furthermore the freely available software development kits to implement STEP-TAS interfaces in C++, C and Python will be shown, and last but not least the status of the formal standardization under ISO will be discussed.

INTRODUCTION AND BACKGROUND

The development of the STEP-TAS standard started a long time ago in 1995 as an initiative from the European Space Agency and supported by CNES (the French Space Agency). The need for an open neutral standard for the exchange has not changed over time. Reliable and easy-to-use exchange of electronic data is essential for efficient and cost-effective industrial product development processes. This is true for all disciplines involved in space product development and certainly also for space thermal engineering.

As illustrated in figure 1 below, for electronic data exchange between the native data formats of different software tools two basic approaches exist: (1) direct tool-to-tool converters, and (2) converters to and from an open, neutral standard format. Both approaches have advantages and disadvantages.

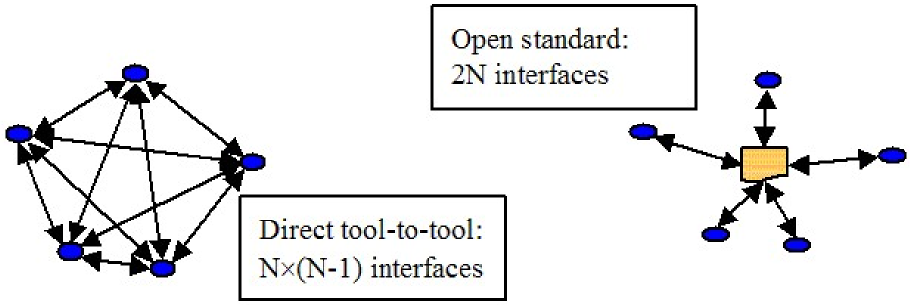

Figure 1: Data exchange interface options

As can be seen the direct tool-to-tool approach leads to many more interfaces to be developed and maintained. The pro's and con's of the two approaches are detailed hereafter.

Direct tool-to-tool data exchange has the following advantages:

- it can be implemented quickly;
- there is little loss of information when the capabilities of two tools match well;

and these disadvantages:

- developers need to know their own tool's format and the formats of all other tools involved; they only control only one side of the interface; this leads to many different versions and frequent updates of converters, and therefore complex configuration control and high maintenance cost;
- N x (N-1) interfaces are required for a full exchange capability between N tools;
- independent verification is difficult or impossible.

Data exchange via an open standard has the following advantages:

- developers need to know their own tool's format and the neutral format only; they control one side of the interface and have full access to the standard side;
- 2N interfaces are required for full exchange capability between N tools;
- it is suitable for long term data archiving;
- independent quality assurance and certification of interfaces is possible;
- independent test suites (in the open standard format) are possible;

and these disadvantages:

- it has a higher initial development cost;
- a longer development time is needed;
- a neutral standard needs to capture a "least common denominator" within an application domain, and consequently risks lagging behind on capabilities present in native data formats.

Taking all arguments into account there remains only one viable, long-term affordable option: data exchange via open standards. This argumentation holds for all application domains in all industrial sectors, which was also realized way back in 1984 in a number of European and US research projects and lead to the creation of the ISO "STEP" standard, formally designated as ISO 10303. Today in the aerospace industry, STEP standards are used primarily for the exchange of 3D CAD models and associated Product Data Management information: ISO 10303-203 "Application Protocol - Configuration Controlled 3D Designs of mechanical parts and assemblies" (also known as *STEP AP203*) and ISO 10303-214 "Application Protocol - Core data for automotive mechanical design processes" (also known as *STEP AP214*).

STEP-TAS builds on the STEP data exchange technology and addresses the industrial need for a stable, long term solution for efficient and reliable exchange of space thermal analysis models and results as well as space thermal test results. Such a data exchange solution is very much needed for the following reasons:

- the thermal control engineering of spacecraft and other space-related equipment requires extensive computer-supported analyses and tests;
- in typical space projects many companies and/or institutions work together as a consortium in customer / supplier relationships, working at different levels of detail, but finally producing one integrated product; this is even more true in cooperative international space programs;
- the consortium members are often located at different sites, which may be geographically far apart;
- the consortium members often use different analysis tools and/or different computer platforms, and it is often unfeasible to standardize on one tool (or toolset) per project because of the required investments in licenses and training;
- many projects and organizations need an open long term archiving format for space thermal analysis models and results, because they cannot (or do not want) to depend on software tool vendors to provide them with tools that can still correctly read models and results a number of years after their creation.

The initial versions of the STEP-TAS protocol were finished in 1998 together with prototype implementations of import and export processors for ESARAD. It was recognized early on, that for its acceptance and implementation by the thermal analysis tool vendors it was necessary to provide an easy and efficient way to implement the protocol. Therefore, ESA funded Simulog (France) to create a STEP-TAS converter development kit.

From 1997 up to now, a lot of effort was spent to publicize the existence and possible applications of STEP-TAS worldwide, outside Europe in particular among NASA and US thermal analysis tool vendors. This has succeeded quite well, with the result that NASA has joined the STEP-TAS standardization, and that prototype STEP-TAS (Conformance Class 1, initial 1998 release of STEP-TAS) converters were implemented to some extent for virtually all known space thermal analysis tools:

- ESARAD (Alstom Aerospace UK and ESA)
- THERMICA (Astrium SAS)
- Thermal Desktop / RadCad (Cullimore & Ring Technologies)
- Advanced Thermal Modeller / Femap (Network Analysis) – limited prototype
- NEVADA (TAC) – limited prototype
- TSS (Space Design) – limited prototype
- TAS (Harvard Thermal) – limited prototype
- PATRAN (MSC)

- IMOS (NASA-JPL, in-house tool) – prototype
- I-DEAS/TMG and FEMAP/TMG (UGS and Maya Heat Transfer Technology) – initiated prototyping
- CORATHERM / CIGAL2 (Alenia Alcatel Space Cannes, in-house tool)

Most of the US prototype implementations have been sponsored by NASA-JPL or NASA-LaRC.

However, although there was some utilization of STEP-TAS interfaces, the architecture and implementation of the STEP-TAS development kit prior to 2002 showed unfortunately to be insufficient for full industrial use: it was too slow and unable to handle larger models. The extendibility of the kit was limited and the maintenance cost was considered too high for further development.

As an intermediate solution (period of September 2002 to August 2003) ESA/ESTEC carried out an initial in-house development of an EXPRESS compiler and code generator. This tool, called *pyExpress*, is implemented in the Python programming language. It supports EXPRESS (ISO 10303-11) to the extent needed for the STEP-TAS protocol. This approach turned out to be very successful due to its easy extendibility and quick adaptability to changes in the STEP-TAS protocol. The only issue is that the Python code is not ideal for very large datasets (hundreds of MB, GB), because Python is a dynamic, interpreted scripting language, with an inherently lower performance than static compiled languages such a C and C++.

In order to resolve this and to obtain a full ISO 10303-11 compliant compiler and code generator, the Agency contracted Manchester Informatics Ltd. and the University of Manchester to develop a new open source EXPRESS Software Development Kit that builds on the best of *pyExpress* and the University of Manchester's earlier Jex (Java-Express) tool. The new tool is called *expressik* and will generate early-binding C++, late-binding C and early-binding Python libraries from any EXPRESS schema.
The capabilities of *expressik* are:

- Scanning and parsing of a short or long form EXPRESS schema into a fully resolved abstract syntax tree (AST) representation in the form of a Java API that can be traversed following the 'visitor pattern'.
- C++ code generator back-end, which generates an early-binding C++ class library corresponding to the given EXPRESS schema.
- Python code generator back-end, which generates a Python class library corresponding to the given EXPRESS schema.
- C code generator back-end, which generated a late-binding C API conforming to ISO 10303-24.

Both *pyExpress* and *expressik* also contain runtime libraries that implement an EXPRESS repository handler and all built-in EXPRESS datatypes, functions and procedures as well as ISO 10303-21 (Part 21) STEP file reader and writer modules. The runtime libraries are to be used in conjunction with the generated libraries in order to enable implementation of applications that create and process datasets conforming to the given EXPRESS schema.

Using *pyExpress* ESA/ESTEC have developed *TASverter,* a model conversion tool using a the STEP-TAS draft standard for the exchange of space thermal analysis models and results.

TASverter is freely made available by ESA from:

http://mechanical-engineering.esa.int/thermal/tools

and currently supports converting models to and from the main European thermal-radiative analysis tools: ESARAD, THERMICA and CIGAL2.

Since 2003 six releases of *TASverter* have been published – the last one in June 2005 – and the tool has been used quite extensively in European space industry on many real projects. During the development the STEP-TAS protocol has been scrutinized, made more robust and simplified as much possible. Also a large test suite has been build up containing around 400 unit testcases and more than 30 real models.

This brings us to the current status in which we have a solid draft standard that has been proven in industrial practice in Europe and for which free implementation support software is available. It is now time to realize the original ambition of a world-wide open standard for the exchange of space thermal models. There a formalization process with ISO has been started.

OVERVIEW OF THE STEP-TAS STANDARD

The STEP-TAS standard actually consists of a *protocol* (formal data model) containing four main modules:

- NRF: Network-model and Results Format
- MGM: Meshed Geometric Model
- SKM: Space Kinematic Model
- SMA: Space Mission Aspects

and a runtime loadable *dictionary* of predefined *terms* (or *instances* in object-oriented software engineering terminology).

The NRF module is a generic engineering discipline independent foundation module, providing definitions to capture:

- identification and naming of objects
- persons and organizations
- date and time
- quantities and units, including the representation of scalar and tensor quantities of any rank, and of numerical (physical) as well as string valued quantities
- parametrics
- network-model representation of engineering objects using discrete nodes and relationships between the nodes
- analysis, simulation, test or operation cases
- analysis, simulation, test or operation runs with results
- simple hierarchical product or system structure, and their relation with discrete network-model representations

- materials and material properties

The STEP-NRF module can be used as a stand-alone protocol.

The MGM module contains the definitions for:
- meshed geometric models for analysis purposes based on primitive mathematical shapes (thin shells and solids) with face activity
- hierarchical composition of primitive shapes into compound shapes
- coordinate transformations at any level of nesting
- limited boolean cut operations
- provisions for explicit numerical tolerancing

The SKM module contains the definitions for:
- rigid body kinematics specified on a MGM meshed geometric model with up to six degrees of freedom joints (up to a maximum of three sliding and three revolute degrees of freedom)
- end stops per degree of freedom

The SMA module contains the definitions for:
- space mission analysis case
- space coordinate system
- pointing direction in space
- orbit arcs, defined by keplerian parameter set or general ephemeris
- identification of celestial body
- kinematic articulation, prescribed explicitly as a function of elapsed time, or implicitly through desired primary and secondary pointing directions in the applicable space coordinate system

The runtime loadable dictionary allows extension of the terms needed for the standard in a backwards-compatible way. Loading the dictionary is very fast so that it does not impede the overall model conversion time. The dictionary can be published on the Internet so that real-time updates to the latest version are possible.

A STEP standard can be configured with so-called conformance classes which specify a necessary subset of the standard that an implementer has to implement in order to claim compliance with the standard. For STEP-TAS the following conformance classes are specified:
- CC1: Thermal radiation and conduction model defined by shell geometry.
- CC2: CC1 plus kinematic model.
- CC3: CC1 plus constructive geometry.
- CC4: CC3 plus kinematic model.
- CC5: CC1 plus space mission aspects.
- CC6: CC4 plus space mission aspects.
- CC7: Results for thermal radiation and conduction model.
- CC8: Thermal lumped parameter model without user-defined logic.
- CC9: CC8 plus results.

- CC10: Thermal lumped parameter model with user-defined logic.
- CC11: CC10 plus results;
- CC12: Thermal test or operation model with results.

Current implementations have focused on classes CC1 and CC3.

STEP-TAS CONVERTER TOOL ARCHITECTURE

The architecture for a STEP-TAS compliant model converter is shown in figure 2.

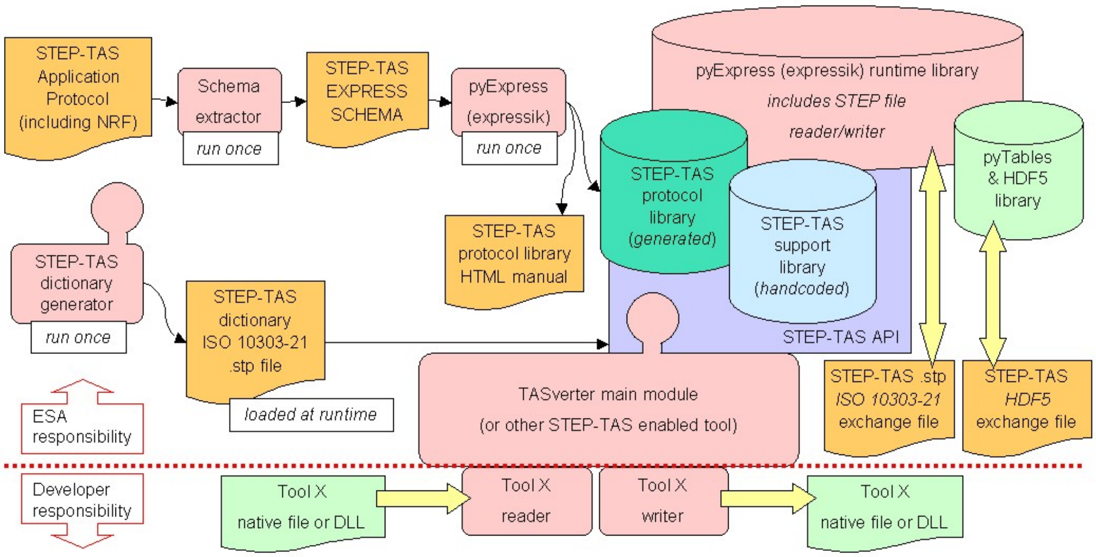

Figure 2: STEP-TAS converter architecture (for TASverter)

The diagram shows also areas of responsibility for ESA and tool developers. ESA coordinates the protocol and dictionary definition, and provides the software libraries that are needed for efficient implementation of the standard. The tool developers are responsible for the implementation of reader/writer (export/import) interfaces that map tool native data structures onto STEP-TAS structures and vice-versa.

The diagram also show two neutral exchange file formats that are provided by the runtime library:

- the ISO 10303-21 or the .stp "stepfile", an ASCII text encoding of a STEP protocol compliant dataset, and,
- the HDF5 file, an efficient binary portable file, in the HDF version 5 public domain format specified by the US National Center for Supercomputing Applications

The .stp file format is fully implemented and used in all TASverter releases. The HDF5 interface is experimental and still under development. The HDF5 format is very promising for very large datasets containing hundreds of MB or several GB of analysis results data.

EXAMPLE EXCHANGES

Below a number of successful exchanges are presented of actual space thermal models. All exchanges were performed with TASverter. TASverter can be run both in GUI or command line mode. Figure 3 is a screenshot of the TASverter GUI, which also shows that during a conversion the length unit can be changed, the material property environment can be set and thermal nodes can be renumbered.

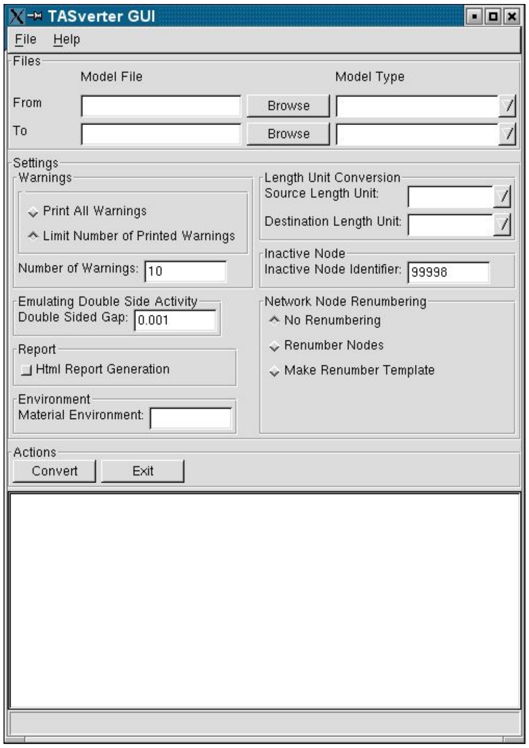

Figure 3: TASverter GUI screenshot

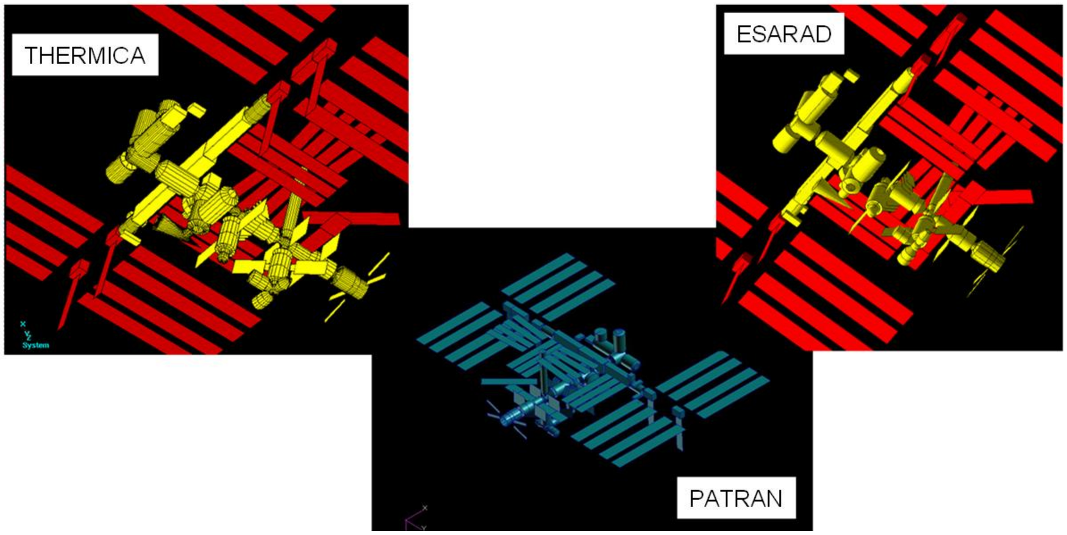

Figure 4: Conversion of ISS thermal interface model

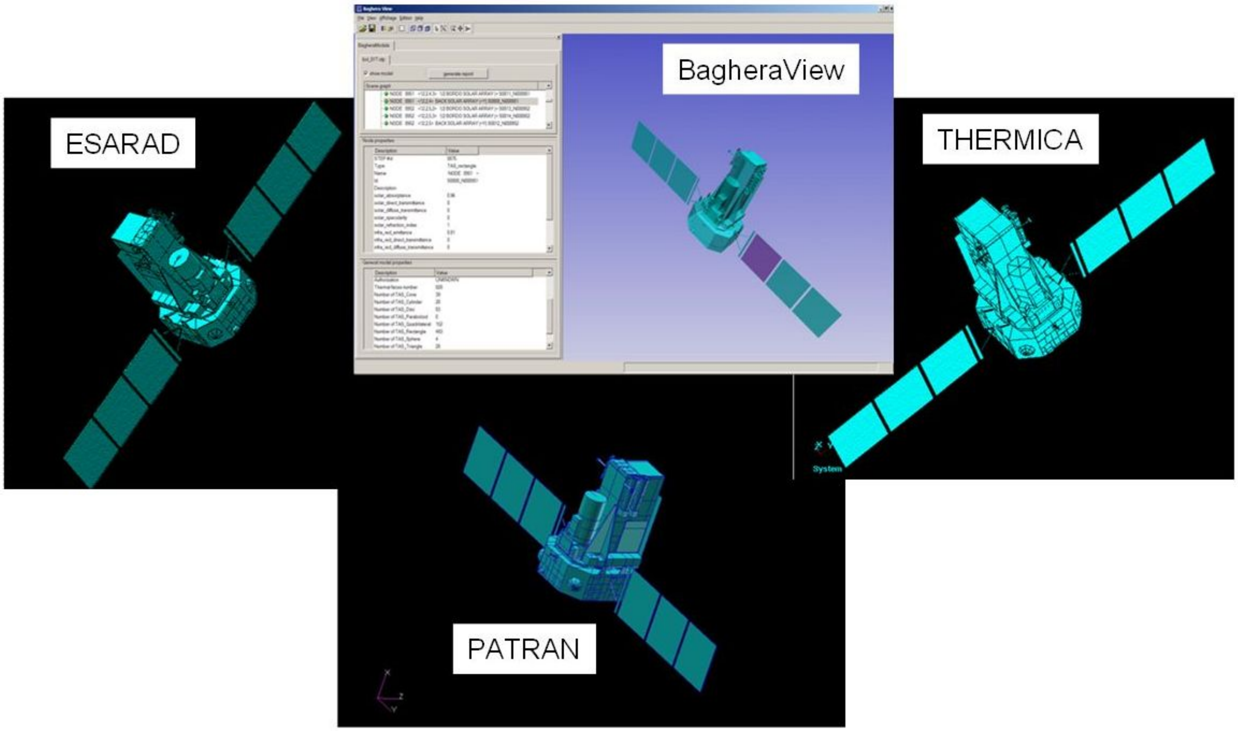

Figure 5: Conversion of Integral spacecraft thermal model

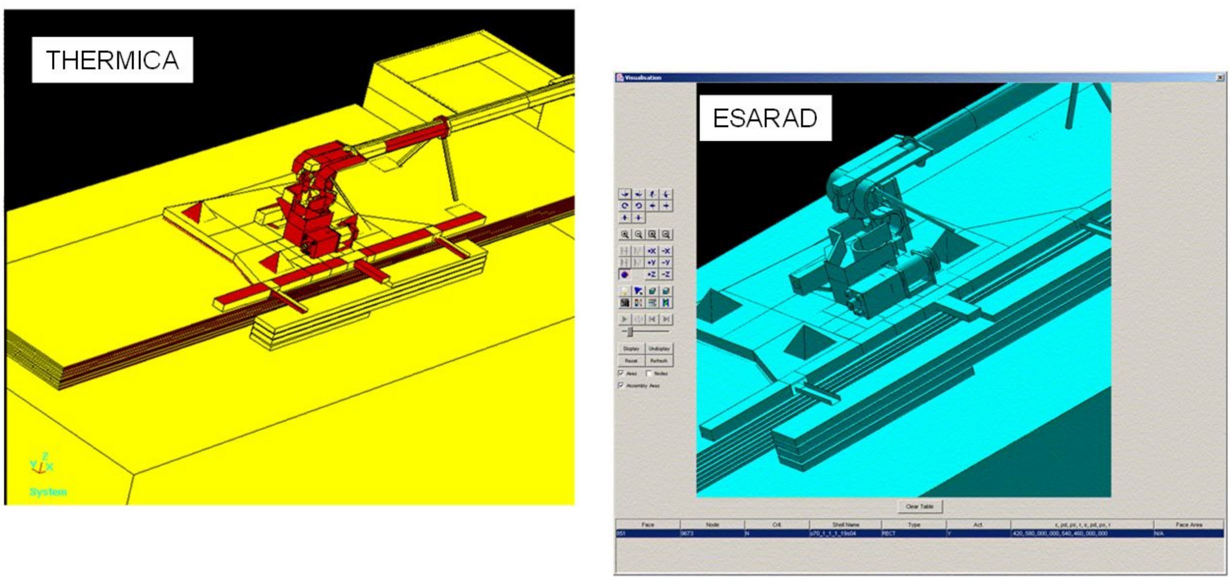

Figure 6: Conversion of METOP spacecraft thermal model (stowed solar array detail)

ONGOING DEVELOPMENTS AND OUTLOOK

Currently the development version of TASverter also supports the conversion of a full set of results from ESATAN (which is the European thermal network analyzer equivalent to SINDA). This STEP-TAS results file is used in the development of ESATAP, a STEP-NRF/TAS based post processing toolkit. The STEP-TAS results file is also used in prototyping and benchmarking HDF5 encodings in order to do performance analysis. Results are very promising and have been reported in [STEP-TAS-HDF5].

The last public release of STEP-TAS was version 5.2 in June 2005. Currently version 5.3 is being completed which is the final version of the protocol and dictionary before going into formalization with ISO. The formalization procedures have been established with ISO TC184 / SC4 the international standardization subcommittee that is in charge of the development and publication of STEP standards, and is expected to start in September 2006. Active participation in the balloting process is sought of non-European representatives of the space thermal analysis domain, in order to create a truly international standard.

The new *expressik* EXPRESS software interface kit is almost ready to be released as open source software and will allow the creation of efficient and effective implementation libraries in C and C++, in addition to the already existing possibilities using the Python language.

In addition ESA is sponsoring the development of a sister standard for space environment and effects analysis called STEP-SPE, which targets exchange of analysis models for contamination, micro-meteorites and debris, atomic oxygen, particle radiation, etc. The initial development is expected to last well into 2007. STEP-SPE will re-use as much as possible from STEP-TAS.

CONCLUSIONS

The main conclusion is that – finally – the STEP-TAS standard is mature, has been thoroughly validated in industrial practice and is now ready for formalization under ISO, and further international deployment, thereby making cooperation in the domain of space thermal analysis more easy and reliable.

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