#### Status of STEP-TAS (Thermal Analysis for Space)

Hans Peter de Koning (ESA/ESTEC, Noordwijk, The Netherlands)



# Topics

- Why an open data exchange standard?
- Short history of STEP-TAS development
- Overview of STEP-NRF and STEP-TAS standard
- STEP-TAS software
  - Available software development kits
  - TASverter
  - Additional developments
- Ongoing activities and outlook
  - Formalised standardization process with ISO
  - Industrial implementation



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# Why an open data exchange standard?

- Reliable easy-to-use data exchange is essential for efficient and cost-effective engineering
  - Certainly also for thermal engineering
  - Between different tools and with other engineering disciplines



- Direct tool-to-tool conversion versus conversion via neutral open standards
  - Both have advantages and disadvantages
  - Direct tool-to-tool can be implemented quickly, in particular when tools match well, but is difficult and expensive to maintain due to tool version and interface changes
  - Via open standard takes longer to develop and has higher up-front cost, but gives a stable long-term solution, with possibility for independent verification
  - In the end only exchange via open standards is reliable and sustainable in the long term



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## Why an open data exchange standard?

- Prescription of a single CAx tool (per discipline) in a space project is not effective ...
  - Project teams involve many partners and are often multi-national
  - Each partner organization should have the possibility to optimize its own processes
  - Some tool may be better at a certain system level than another
  - Supporting multiple tools within one organization is often too costly (licenses, training, etc.)
  - Competition between tool developers is healthy: promotes innovation and yields better tools
- ... therefore easy and reliable exchange of models is needed



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# What is STEP?

- STEP = Standard for the Exchange of Product model data = casual name for ISO 10303
  - Formal title: Industrial automation systems and integration Product data representation and exchange
  - Many parts/layers: generic resources and application protocols (APs)
  - Also: an architecture and methodology for product data exchange standards
  - Strict separation of data representation and presentation
  - Started in 1984, so predates XML, but XML encoding is possible (ISO 10303-28)
- Uses a formal data model definition language called EXPRESS (ISO 10303-11)
  - Defines data structure and rules (constraints) that data instances must fulfill



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#### ISO 10303 standards relevant to aerospace

- Most widely used existing STEP standards:
  - ISO 10303-203 Configuration controlled 3D designs of mechanical parts and assemblies
    - "AP203" Exchange of BRep models with PDM information available in most CAD tools
  - ISO 10303-214 Core data for automotive mechanical design processes
    - AP203 plus CSG CAD models, mechanisms/kinematics, links to analysis
- Others:
  - ISO 10303-210 Electronic assembly, interconnect and packaging design
  - ISO 10303-212 Electrotechnical design and installation
  - ISO 10303-239 Product life cycle support
- Under development:
  - ISO 10303-209 edition 2 Engineering analysis (was: Composite and metallic structural analysis and related design)
  - ISO 10303-233 Systems engineering



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# **Short history of STEP-TAS development**

1991-1993	Precursor: French SET-ATS standard – Some limited implementation in THERMICA and ESARAD				
1994	Initial ideas for STEP standard for exchange of thermal models (from ESA ICETAS study)				
1995-1997	Development of STEP-NRF and STEP-TAS version 1 Software library by Simulog (France) on top of ST-Developer toolkit by STEP Tools Inc. (USA)				
1998	Prototype implementations of STEP-TAS v1 in Europe and US				
1999	Implementation of STEP-TAS v1 in industrial releases of ESARAD, THERMICA and Thermal Desktop				
	Not successful: very slow, excessive memory usage and problems with large models				
2002-2006	Significant simplification of STEP-NRF and STEP-TAS at ESTEC				
	Development of pyExpress compiler/code generator to remove dependency on COTS toolkits				
	Development of TASverter in Python programming language using library generated by pyExpress Readers & writers for ESARAD, THERMICA and CIGAL2 – successfully used in industry from August 2003				
	Preparation of formal ECSS and ISO standardisation				
	Development of open source STEP development toolkit by University of Manchester (ESA contract)				
	Development of STEP-SPE (Space Environment analysis model exchange) extension of STEP-TAS (in progress)				
2006	Preparation of STEP-TAS v6.0 for formalisation under ISO				
	Full industrial implementation				



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#### STEP-TAS standard = protocol and dictionary TAS = Thermal Analysis for Space



- Application Protocol contains core data model formalized in an EXPRESS schema
- Run-time Loadable Dictionary contains pre-defined instances
  - Allows for backwards compatible extensions of standard without costly updates to protocol and implemented interface software



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### STEP-TAS protocol (as updated per v5.3, June 2006)

- STEP-TAS protocol consists of 4 modules
  - NRF Network-model and Results Format
  - MGM Meshed Geometric Model
  - SKM Space Kinematic Model
  - SMA Space Mission Aspects
- · Each module adds features on top of the preceding one





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## NRF Module (1) (Network-model and Results Format)

- Generic foundation module, independent of any specific engineering discipline
- Identification and naming of objects
- Persons and organizations, responsibility or approval roles
- Date and time
- Quantities and units (all defined in dictionary)
  - scalar quantities: physical (magnitude or multitude), enumeration, string-valued
  - tensor quantities of any rank
  - SI units (ISO 31) and binary data units (IEC 60027-2)
  - non-SI units with explicit conversion factors and offsets (from NIST SP 811)
  - extended but simplified version of ISO 10303-41 measure\_schema
  - supports nominal values, uncertainty margins, uncertainty probability distribution
- Parametric value expressions



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## NRF Module (2) (Network-model and Results Format)

- Network-model representation using discrete nodes and relationships between the nodes
  - allows infinitely deep hierarchical breakdown of model into submodels
- Analysis, simulation, test or operation cases and runs with results
  - a run is the execution of model + case combination
- Hierarchical product or system breakdown structure, and relation to discrete network-model
- Materials and material properties
  - including material property environment



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#### NRF Module (3) "Datacube"



- Central NRF data structure to store large amount of results (or input values) is the so-called *datacube* 
  - Each element of the *datacube* is a scalar or tensor property (= quantity value) for a specific combination of obervable\_item, quantity\_type, state
  - Designed for efficient storage and retrieval of massive amounts of structured data
  - Separation of real valued and integer valued quantities stored as two flat lists
    - Enumeration and String quantities are mapped to integer index values
    - Convenience functions provide reshaping flat lists into multidimensional arrays (maps well into HDF5 API capabilities)

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#### NRF Module (4) "Chained results creation"



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### MGM Module (Meshed Geometric Model)

- Meshed geometric model for analysis purposes based on primitive mathematical shapes
  - supports thin shells with notional thickness and face activity
  - supports primitive solids
  - compound shapes hierarchically composed of primitive or lower level compound shapes
  - coordinate transformations at any level of nesting
  - boolean cut operations (surface cut with solid)
  - provisions for explicit numerical tolerancing
  - assignment of network-nodes corresponding to faces
  - presentational colour
  - parametric definition of point coordinates, shape dimensions, transformation parameters possible



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## SKM Module (Space Kinematic Model)

- Rigid body kinematics specified on MGM meshed geometric model
  - kinematic joint between a contained shape and its parent (compound) shape
  - per joint up to six degrees of freedom
    - a maximum of three sliding and three revolute degrees of freedom
  - optional end-stops per degree of freedom
    - constrains range for sliding or rotation



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## SMA Module (Space Mission Aspects)

- Aspects of a space mission relevant to thermal and space environment effects analysis
  - space mission analysis case
  - space coordinate system and pointing directions in space
  - orbit arcs, defined by keplerian parameter set or general ephemeris
  - identification of celestial body
  - space environment parameters (e.g. sun radiation temperature, deep space temperature)
  - kinematic articulations on SKM rigid body kinematics model
    - explicit articulation as a function of mission elapsed time
    - implicit articulation through desired primary and secondary pointing directions in the applicable space coordinate system
    - fast spinning (fast with respect to some response time, e.g. thermal)
  - named events and association with orbit arc positions or mission elapsed time
  - defined for thermal and space environment effects, but extendible for other engineering disciplines



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# **Scope of STEP-TAS**

- Thermal-radiative/conductive models and results
  - geometry, material properties, kinematics, orbit/attitude, space environment, mission timeline
  - computed results (e.g. radiative couplings, linear conductors, fluxes)
  - target tools: ESARAD, THERMICA, CIGAL2, RADCAD, TMG, TSS, TRASYS, ...
- Thermal network models and results
  - thermal network model and analysis case, optional 1D hydraulic network
  - optional inclusion of user-defined logic
  - analysis predictions (e.g. time series of temperatures, powers)
  - target tools: ESATAN/FHTS, SINDA-G, SINDA/FLUINT, TMG, ...
- Thermal test models and results
  - test environment and run identification
  - sensors/channels with observed quantities/units, optionally with location in geometric model
  - measurements



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# **STEP-TAS Conformance Classes**

- A STEP-TAS-compliant converter must implement one or more of the following:
  - 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



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#### Iterative, incremental development scheme



#### Currently with STEP-TAS at increment (version) 6.0rc1 (April 2007)



# STEP-TAS software (1)

- Developers need supporting software to implement STEP-TAS interfaces efficiently
- Python libraries generated by pyExpress (ESA)
  - Used and validated in TASverter and CIGAL/STEP-TAS interface by Alcatel Alenia Space
  - Available as open source from ESA to implementers
- expressik EXPRESS compiler/code generator (University of Manchester & ESA)
  - Implemented in Java Open back-end API to create new code generators
  - Generates C++ and C libraries for any EXPRESS (ed. 1 or 2) SCHEMA
  - Prototype re-implementation of TAS support module and THERMICA VIF reader succeeded
  - Will be made available as open source from ESA (licence finally available May/June 2007)
- TASverter (ESA) last release March 2007 free download https://exchange.esa.int
  - Converts thermal-radiative models between ESARAD, THERMICA, TRASYS, TAS v5.2 .stp
  - Export of ESATAN model snapshot and results data implemented, used for testing ESATAP
  - Patran .SES and results export and NASTRAN (TRI, QUAD) import



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# STEP-TAS software (2)

- ESATAP Thermal Analysis Post-processor (Silogic, DOREA, Alcatel Alenia Space, ESA)
  - Development in progress
  - Initial post-processing of ESATAN to STEP-TAS results export works
- HDF5 exchange file implementation of STEP-TAS (DOREA, ESA)
  - First phase completed April 2006 with working prototype
  - Second industrialization phase started April 2007
- BagheraView (CSTB, CNES)
  - Independent STEP-TAS viewer released April 2006 for STEP-TAS v5.2
- AP203/AP214 CAD to STEP-TAS conversion (Hanop, CSTB, ESA)
  - Triangulated meshing of complex shapes works (using OpenCascade)
  - Automatic simplification of CAD to thermal analysis geometry works



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#### STEP-TAS converter architecture with areas of responsibility



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# **STEP-TAS Testsuite**

- Approximately 500 small test cases
- 28 real full size thermal-radiative models
- Fully automated test run environment
- Used for regression testing



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#### STEP-TAS real model conversion gallery TASverter GUI and log

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#### STEP-TAS gallery Integral





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#### STEP-TAS gallery METOP stowed solar array





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#### STEP-TAS gallery Study model

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# **Ongoing activities and outlook**

- Formalised standardization with ISO
- IITAS Industrial implementation (hand-over from ESA to tool vendors)
  - ESARAD, THERMICA, CIGAL2
  - In progress since January 2007
- NASA SBIR sponsored project with Cullimore & Ring In progress
  - Initial STEP-TAS interface for Thermal Desktop
- CSA sponsored project with Maya Heat Transfer Technologies Being prepared
  - STEP-TAS interface for TMG
- ECSS (European Coordination for Space Standardization)
  - ETM-10-23 Engineering database
  - ETM-10-25 Design model data exchange (CDF)



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# Formalised standardization with ISO

- 2005: STEP-NRF and STEP-TAS were approved as ECSS new work items with intention to go directly for ISO standardization
- June 2006: Informal presentation at ISO TC184 / SC4 meeting in Toulouse (France)
  - Result: STEP-TAS can be harvested in fast-track as so-called "externally developed specification"
  - Will probably become an ISO "Technical Specification" (TS)
- June 2006: Completion of version 5.3 of STEP-TAS protocol and modules
- May/June 2007: Completion of version 6.0 of STEP-TAS protocol and modules
  - Submission of STEP-TAS protocol and modules to ISO for review
- 2007 Q2/Q3/Q4 (TBC): ISO review/ballot/release as ISO TS
- 2006 2007: Continued development of HDF5 encoding of EXPRESS driven data with ISO TC184 / SC4 working group (generic, not restricted to thermal analysis)



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#### STEP-TAS / TASverter team at ESA tasverter (at) thermal.esa.int

- Simon Appel
- Duncan Gibson
- Harrie Rooijackers
- James Etchells
- Hans Peter de Koning



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# References

- STEP-NRF and STEP-TAS
   <u>http://mechanical-engineering.esa.int/thermal/tools</u>
   Look for "Standards"
- TASverter <u>https://exchange.esa.int/thermal/tools</u> Look for "TASverter", free download after simple name/e-mail-address registration
- ISO TC 184 / SC 4 standardization committee (a.o. STEP standards) <u>http://www.tc184-sc4.org</u>
- European Cooperation for Space Standardization
   <a href="http://www.ecss.nl">http://www.ecss.nl</a>



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