Status of STEP-TAS
(Thermal Analysis for Space)

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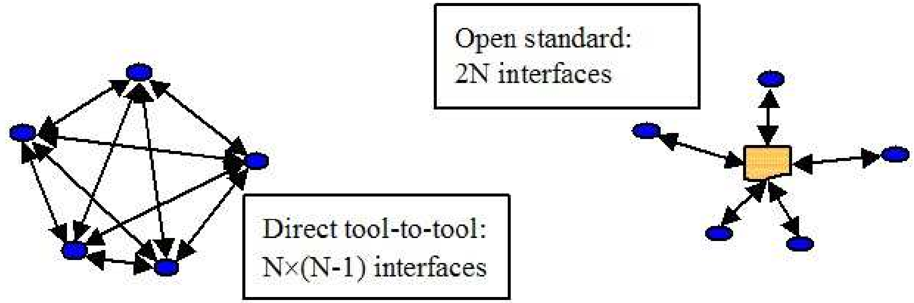
Topics

- 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

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

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

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

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*

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

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

STEP-TAS
Application Protocol
(*XHTML/PDF document*)
with EXPRESS schema
(extracted .exp file)

+

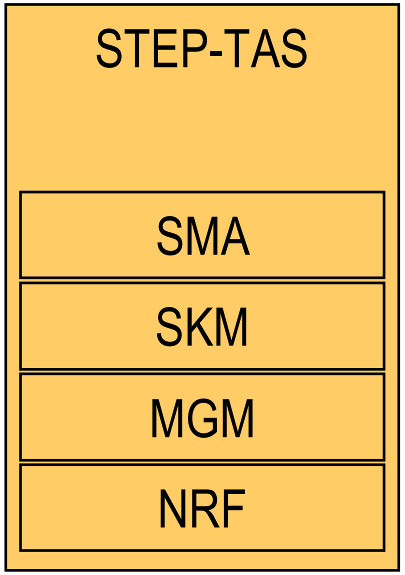
STEP-TAS
Run-time Loadable
Dictionary
(*ISO 10303-21 .stp file*)

Actually a STEP-TAS file itself

- 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

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



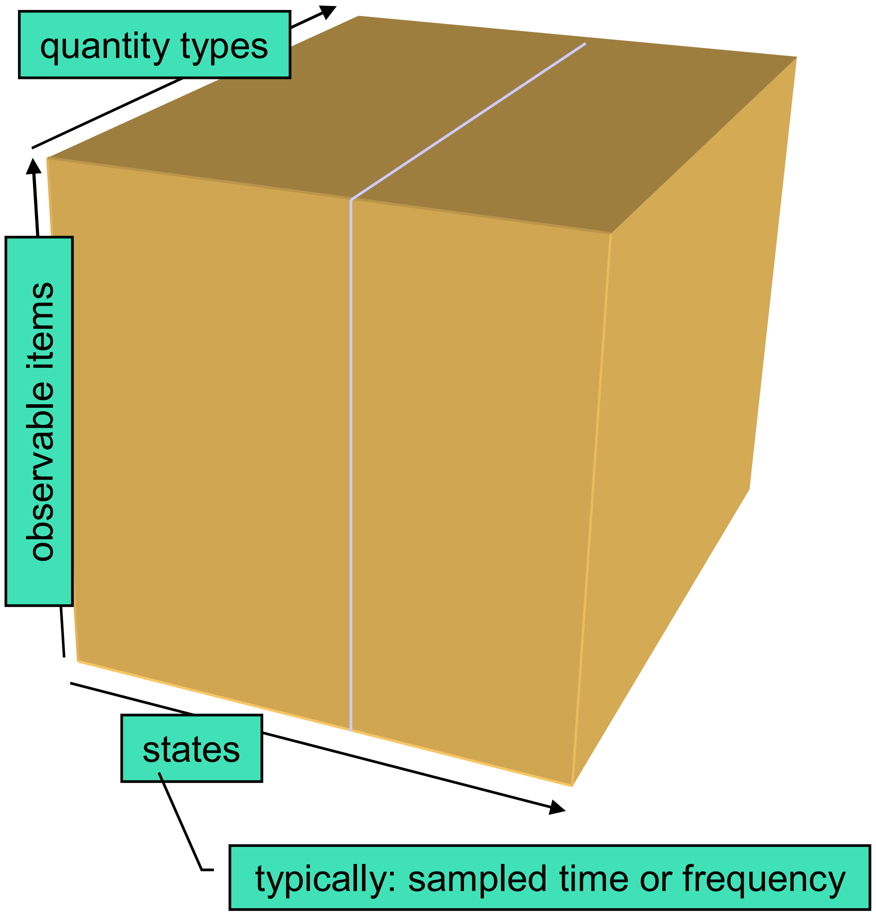
NRF Module (1)
(Network-model and Results Format)

- 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

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

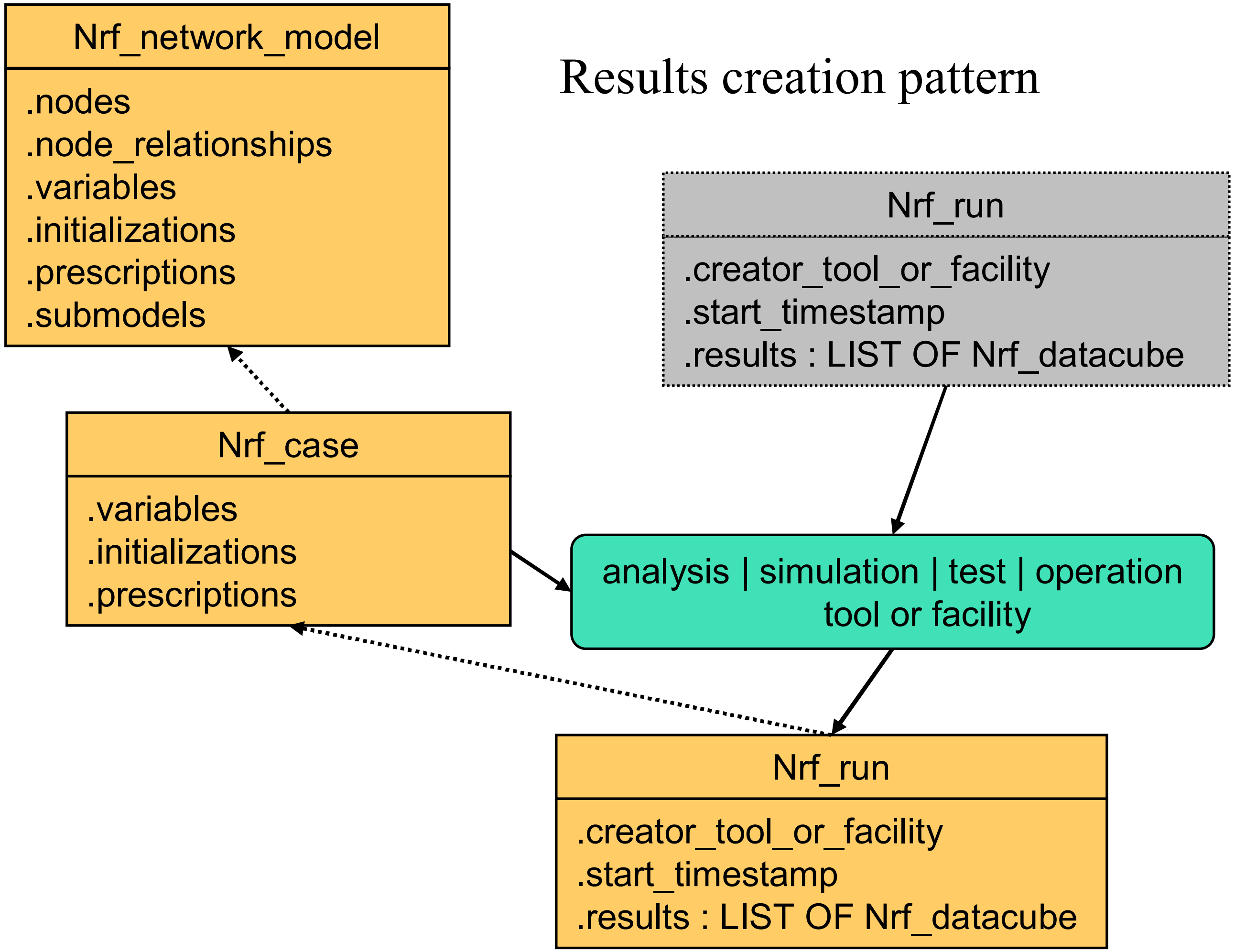
NRF Module (3) "Datacube"

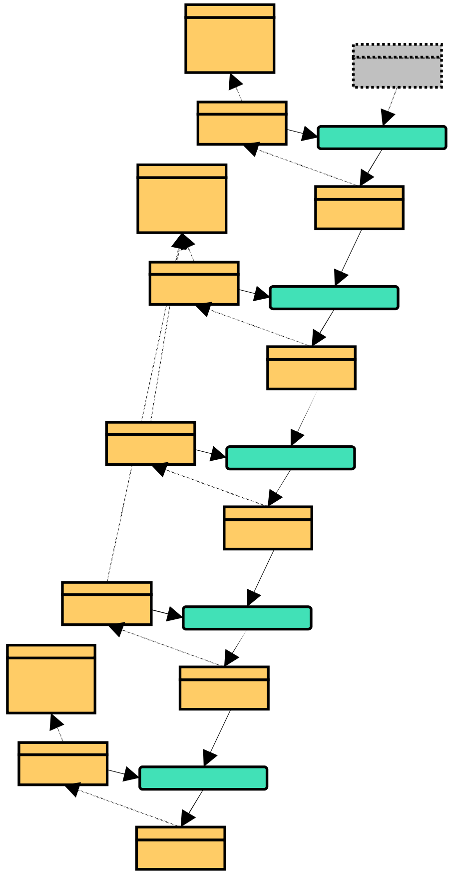


- Central NRF data structure to store large amount of results (or input values) is the so-called *datacube*
  - Each element of the *datacube* is a scalar or tensor property (= quantity value) for a specific combination of obervable_item, quantity_type, state
  - Designed for efficient storage and retrieval 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)

NRF Module (4)
"Chained results creation"

Results creation pattern





Chaining results creation

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

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

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

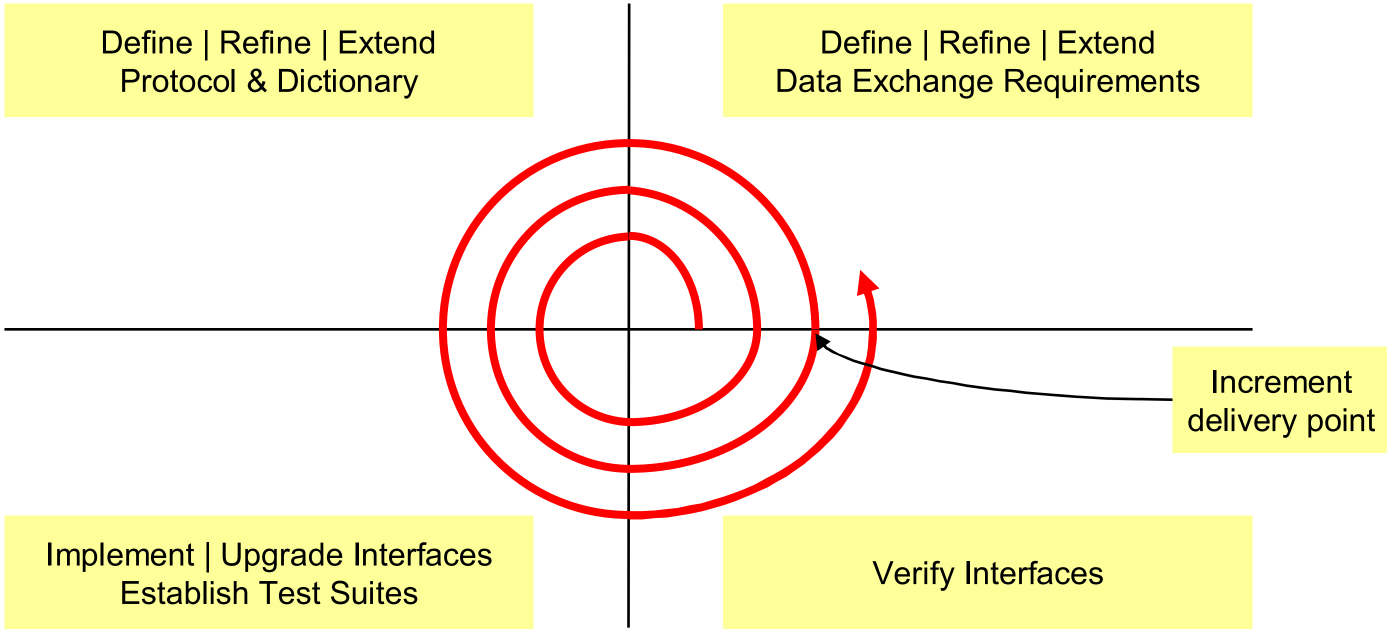
Scope of STEP-TAS

- 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

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

Iterative, incremental development scheme



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

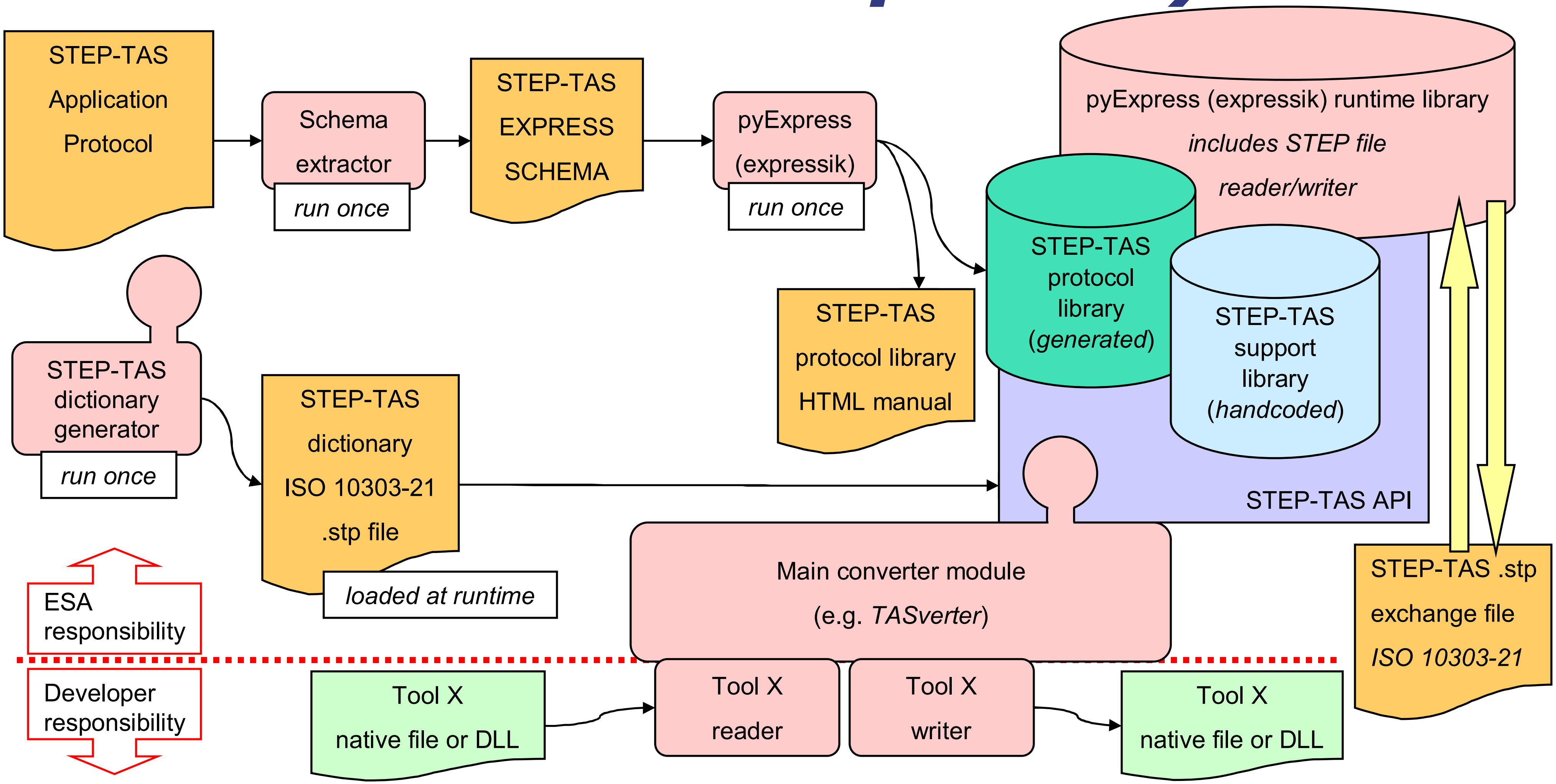
STEP-TAS software (1)

- 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

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

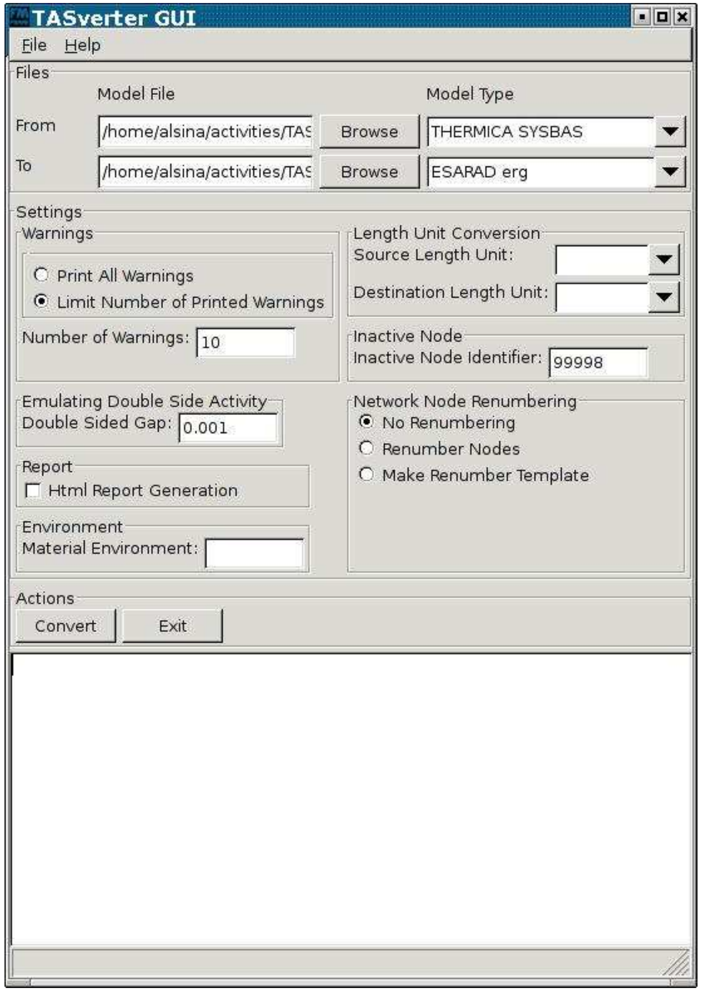
STEP-TAS converter architecture with areas of responsibility

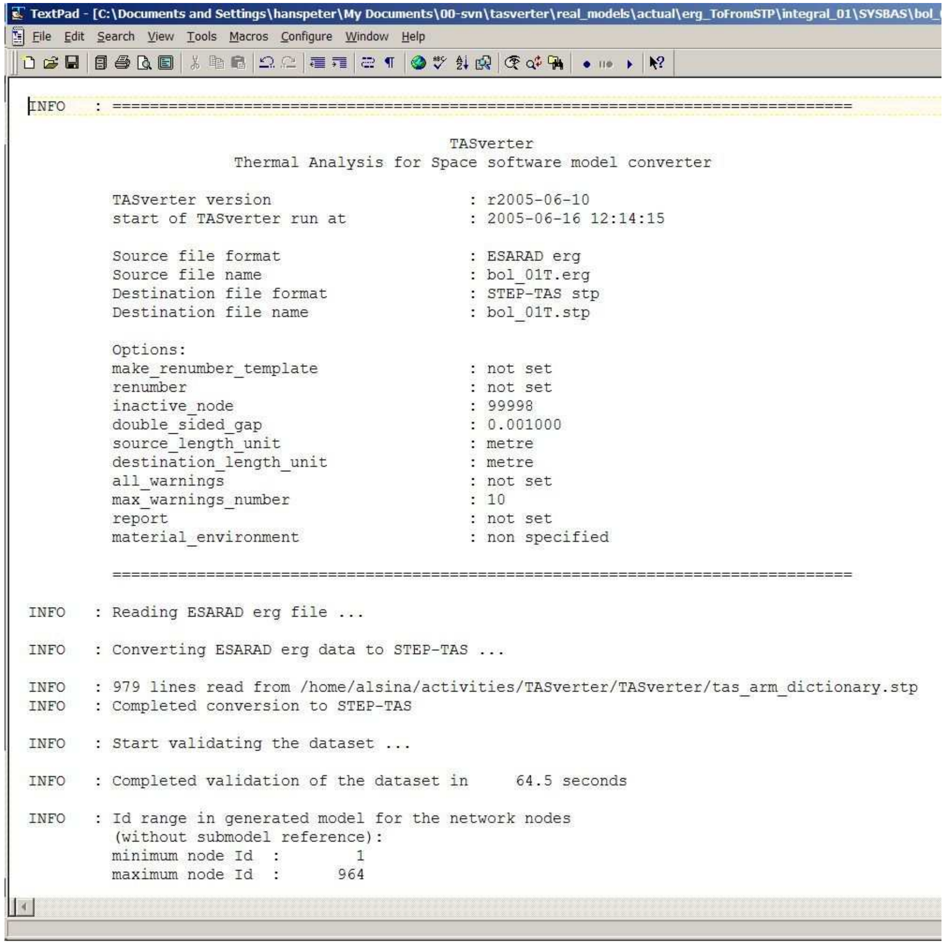


STEP-TAS Testsuite

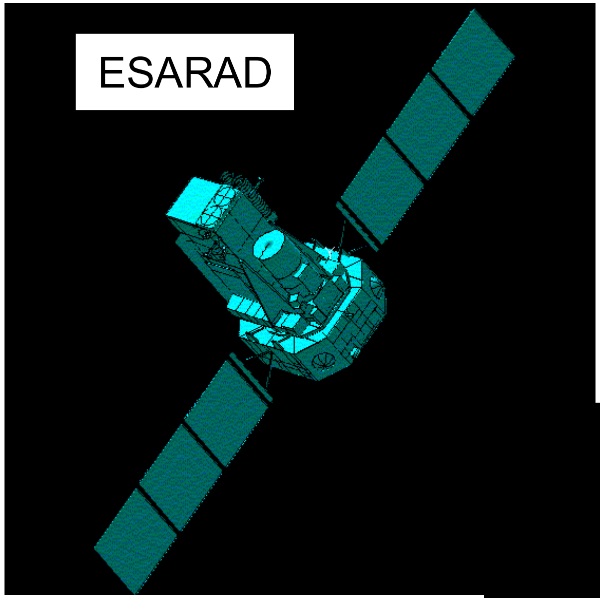
- Approximately 500 small test cases
- 28 real full size thermal-radiative models
- Fully automated test run environment
- Used for regression testing

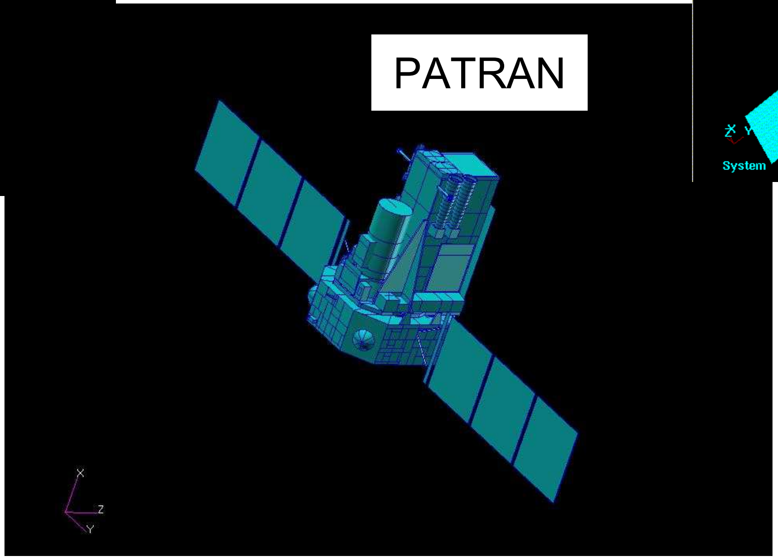
STEP-TAS real model conversion gallery
TASverter GUI and log

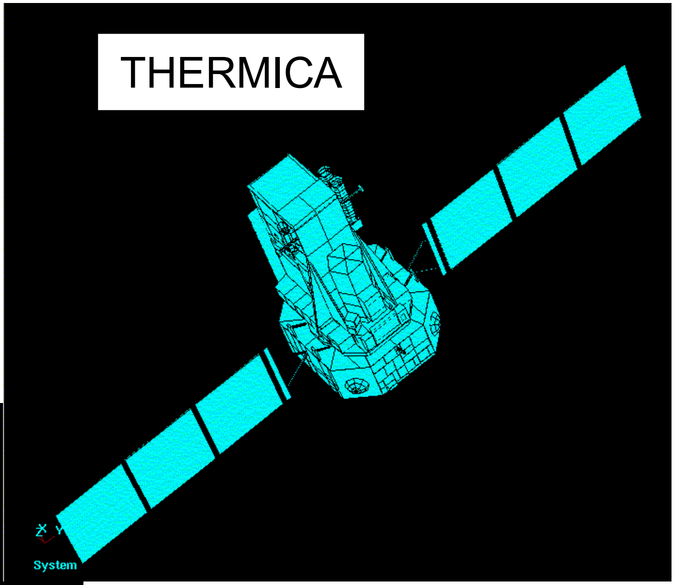




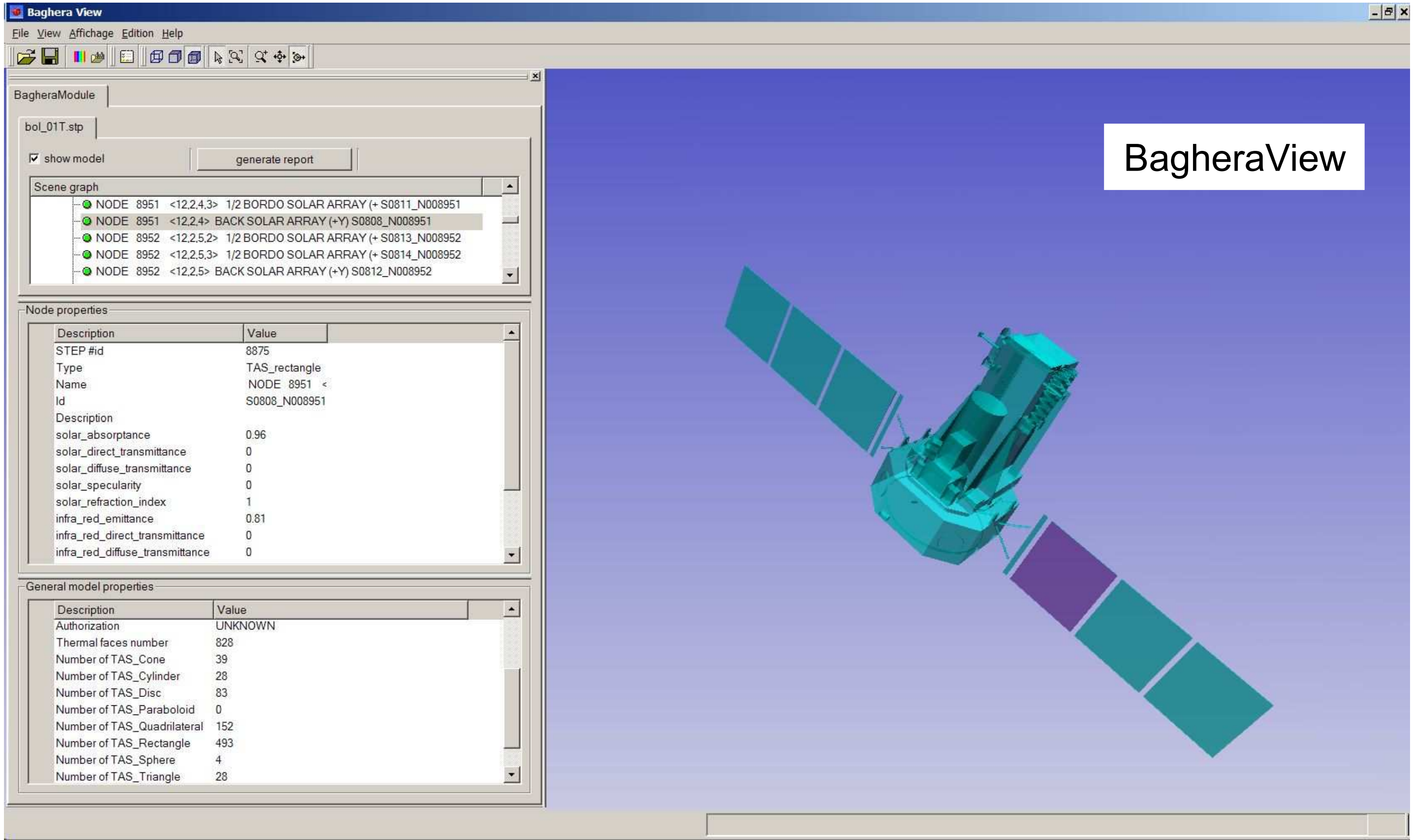
STEP-TAS gallery
Integral



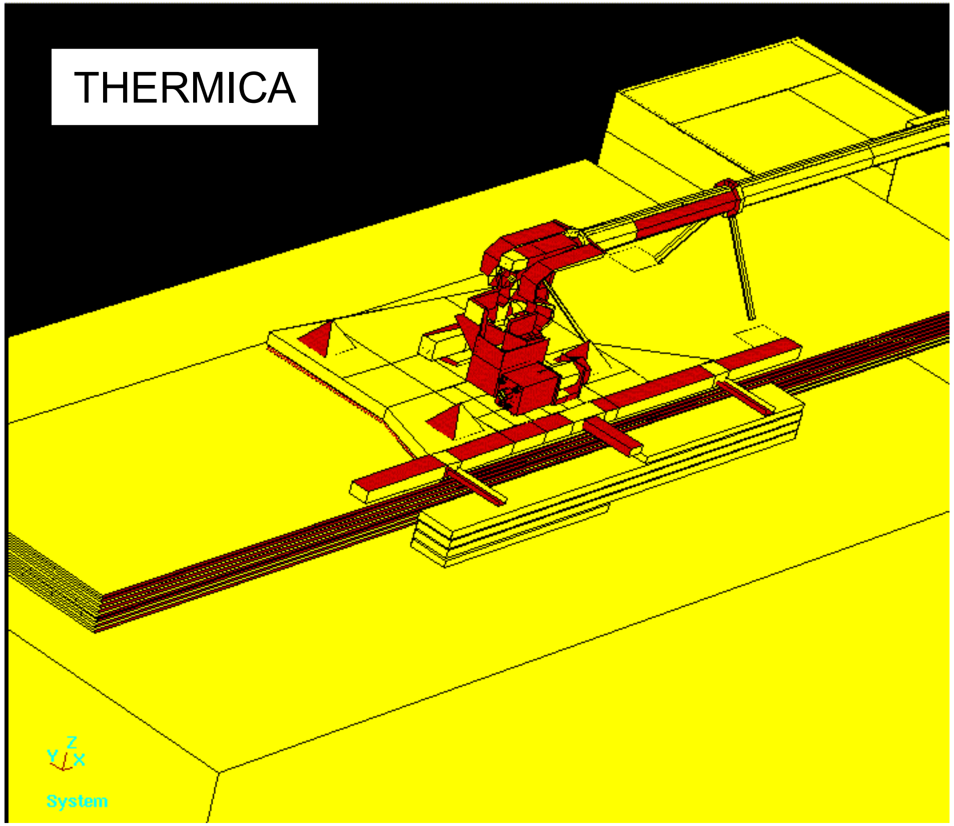


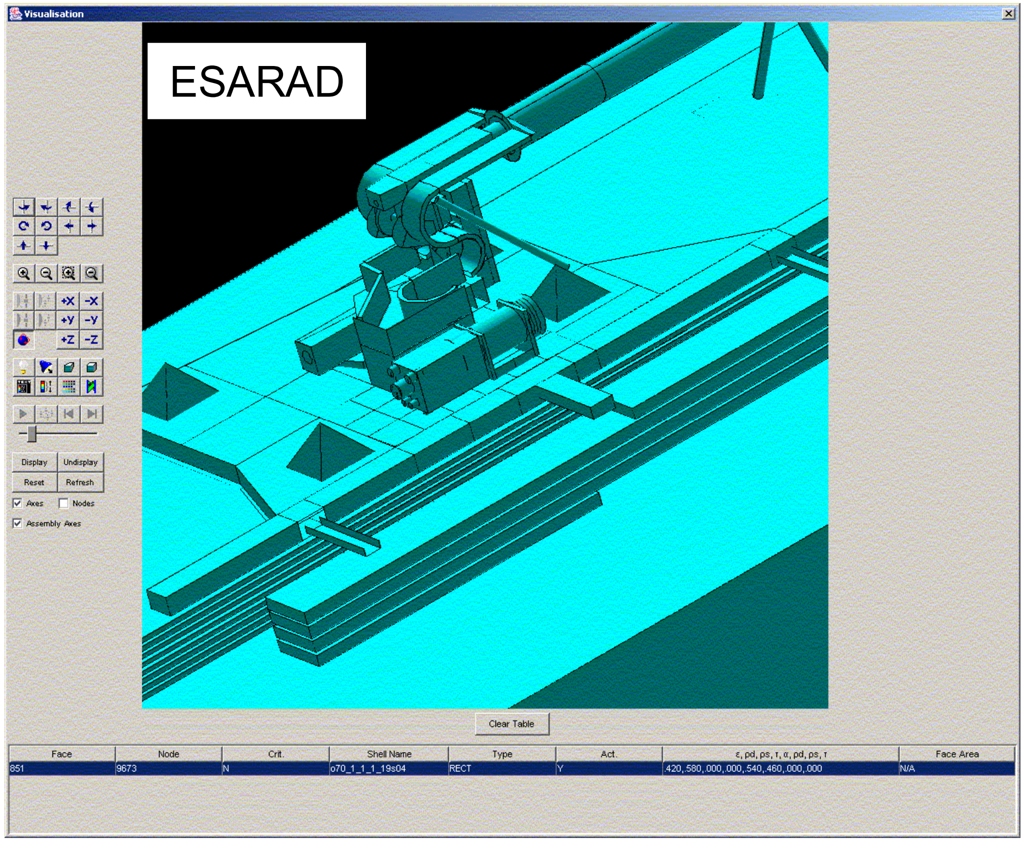


STEP-TAS gallery
Integral

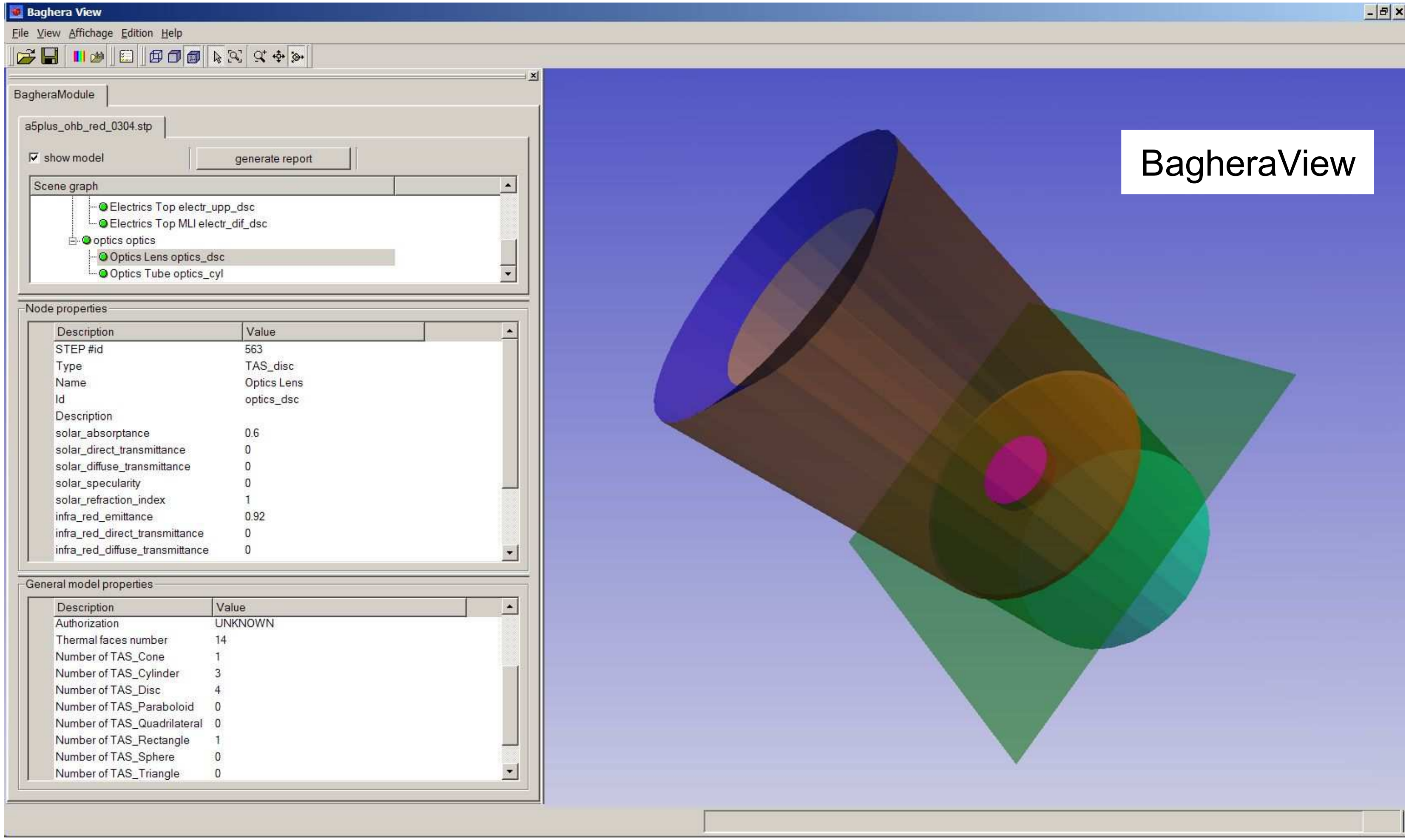


STEP-TAS gallery
METOP stowed solar array

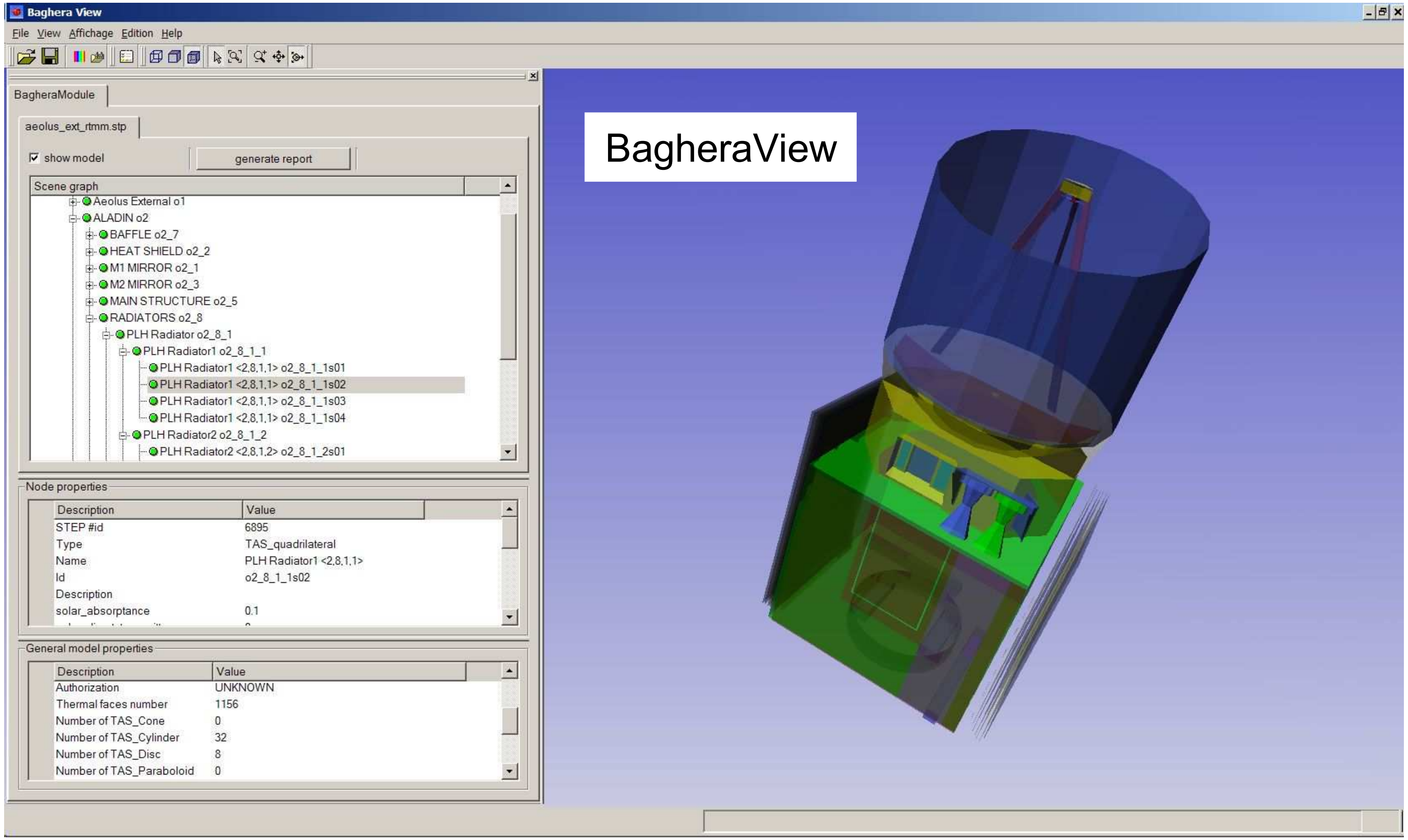




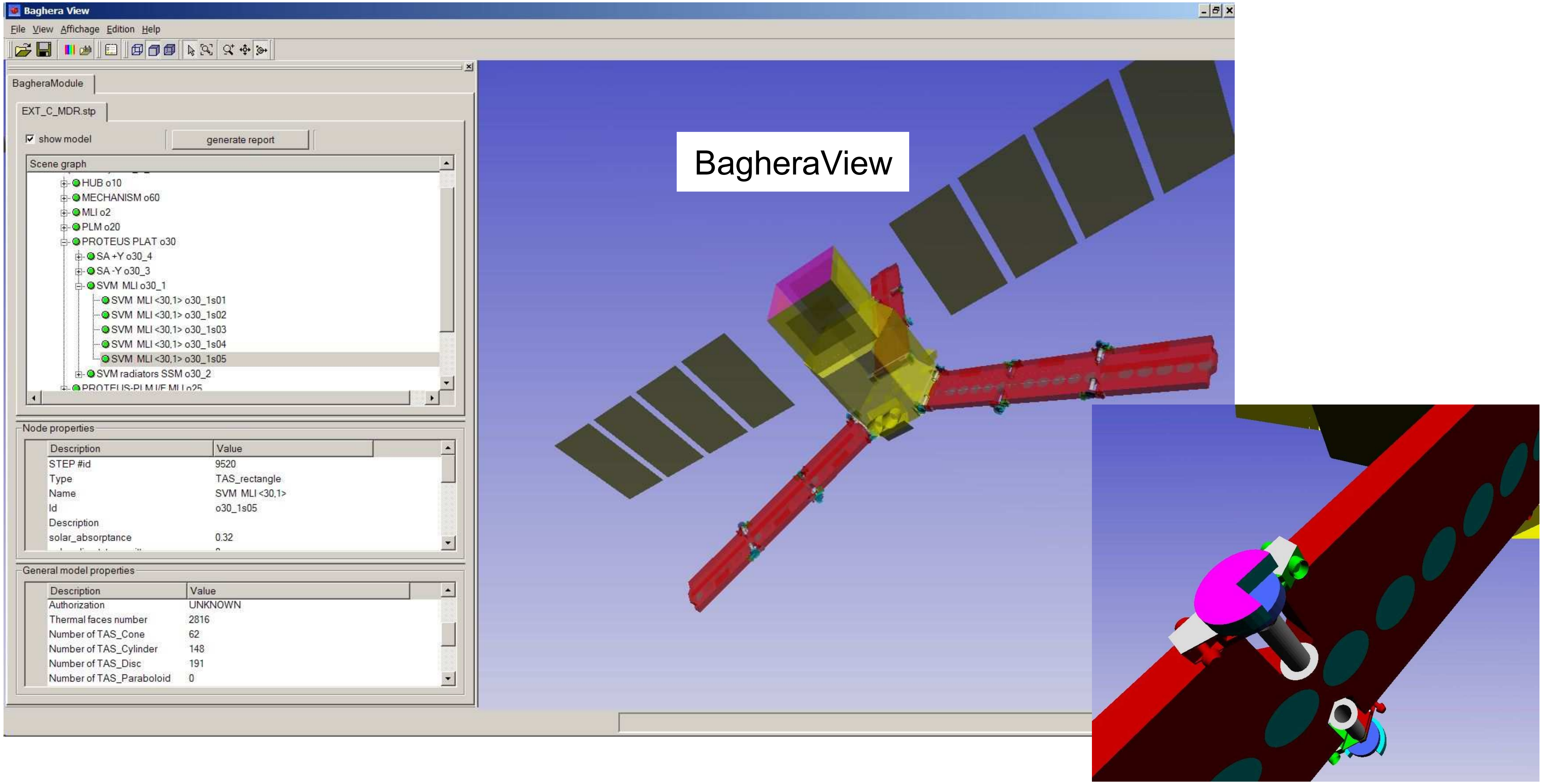
STEP-TAS gallery
Study model



STEP-TAS gallery
Aeolus (stowed)



STEP-TAS gallery
SMOS



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)

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)

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

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

References

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