Advances in thermal model data exchange using open standards

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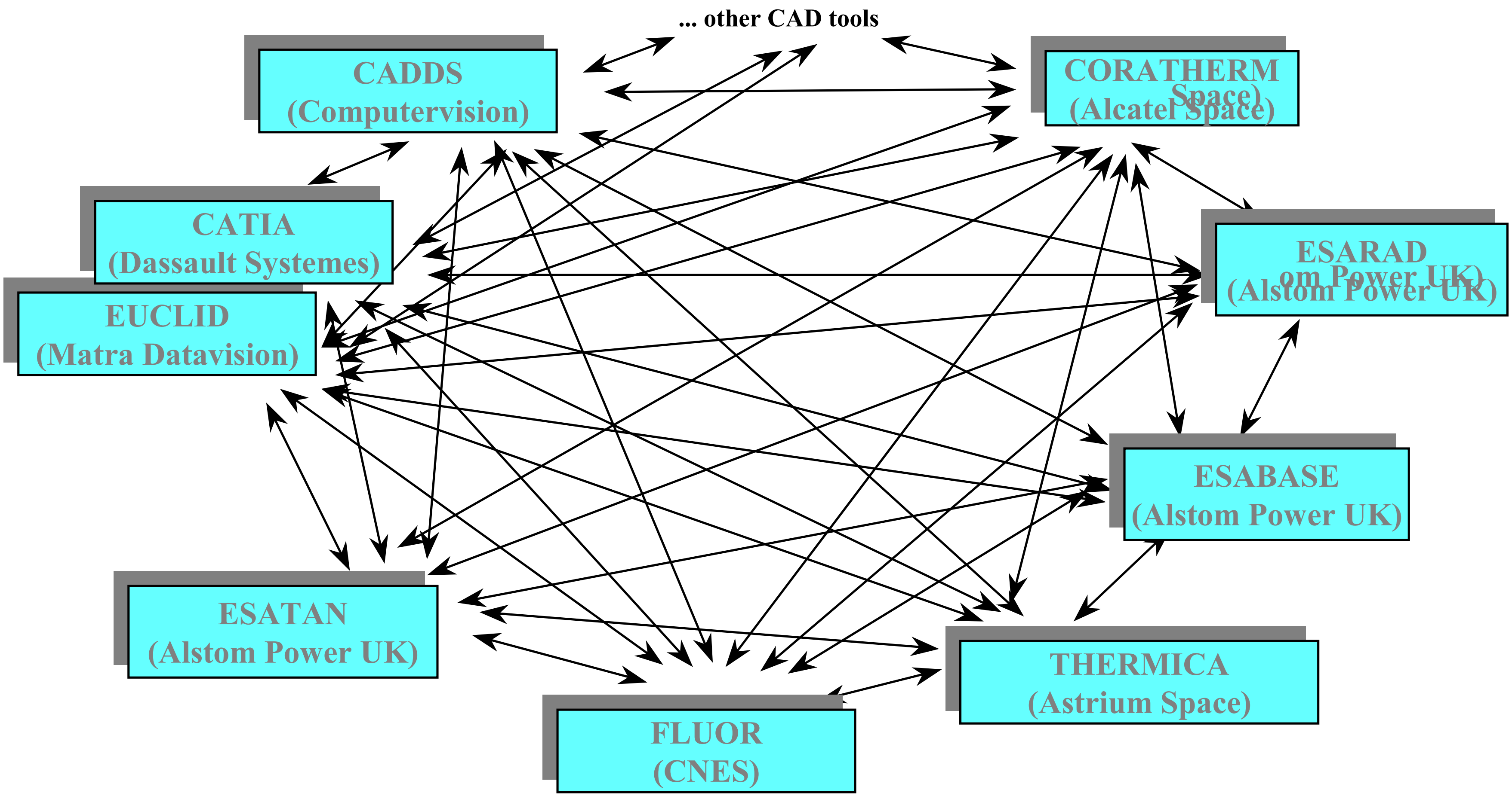
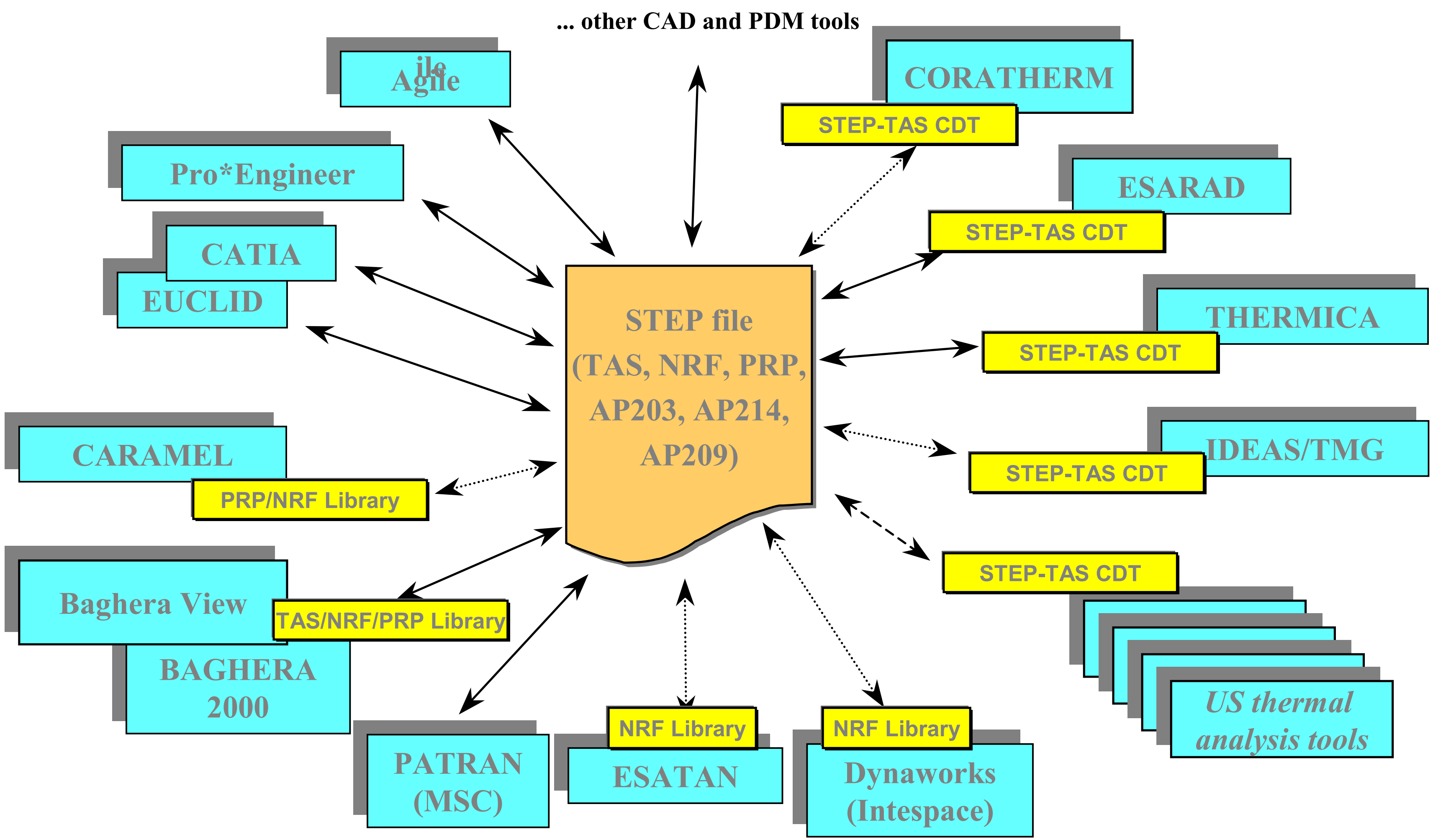
Background

- In more and more space projects - in particular international programmes - routine exchange of thermal analysis model data between different tools is necessary
- Conversion processes are inefficient
  - Mostly with direct point-to-point converters - costly to maintain
  - Supplemented with significant manual work
  - SI / US-English unit conversion a problem in itself
- Conversion processes are mostly informal
  - Not very reliable - no thorough validation - no certification
- Open standards are emerging: STEP, STEP-TAS, XML, XSL

Background - Old situation
Exchange of thermal analysis models in Europe



Background - New emerging situation: Use of STEP / ISO 10303

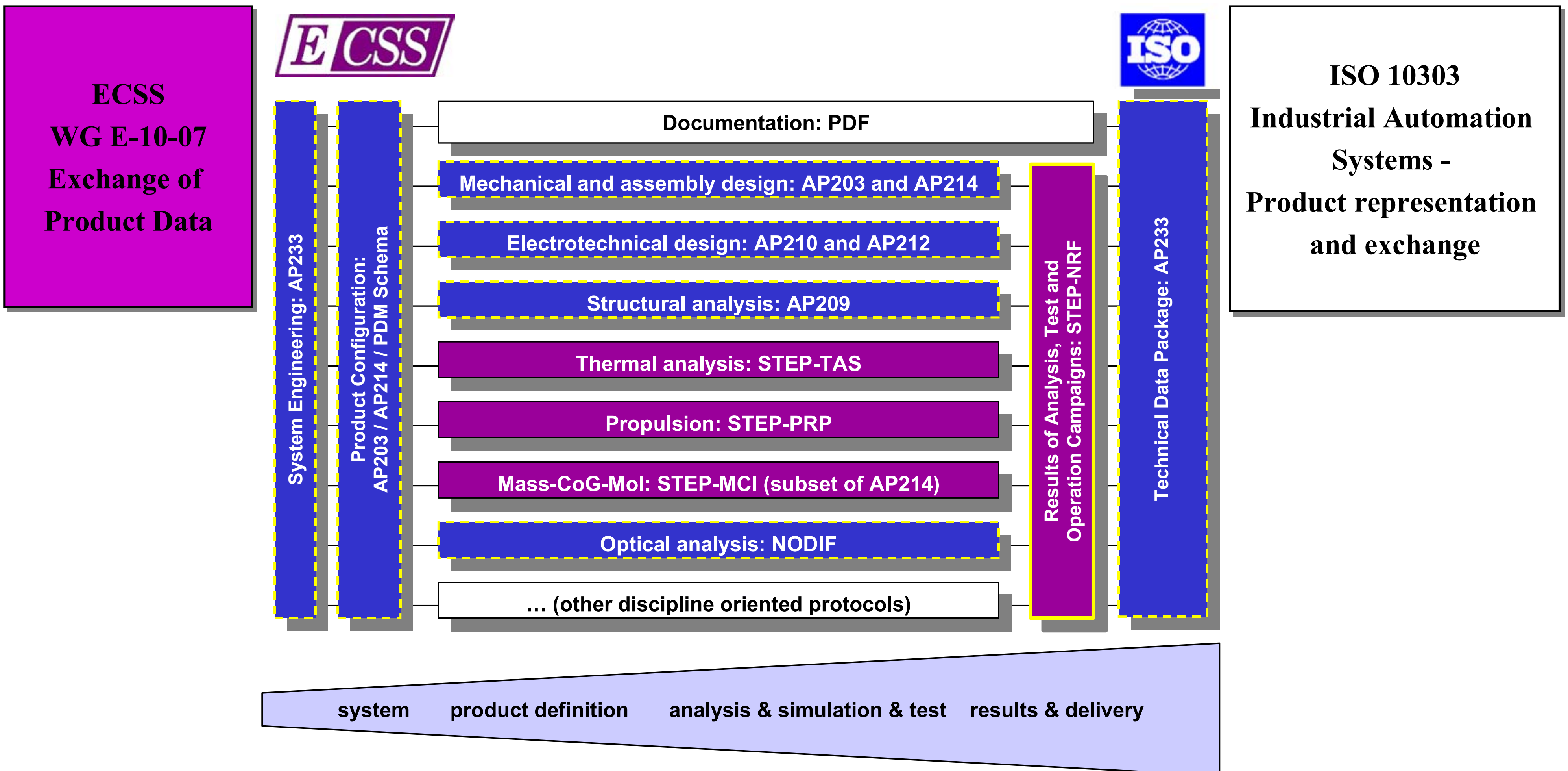


Objective of STEP / ISO 10303

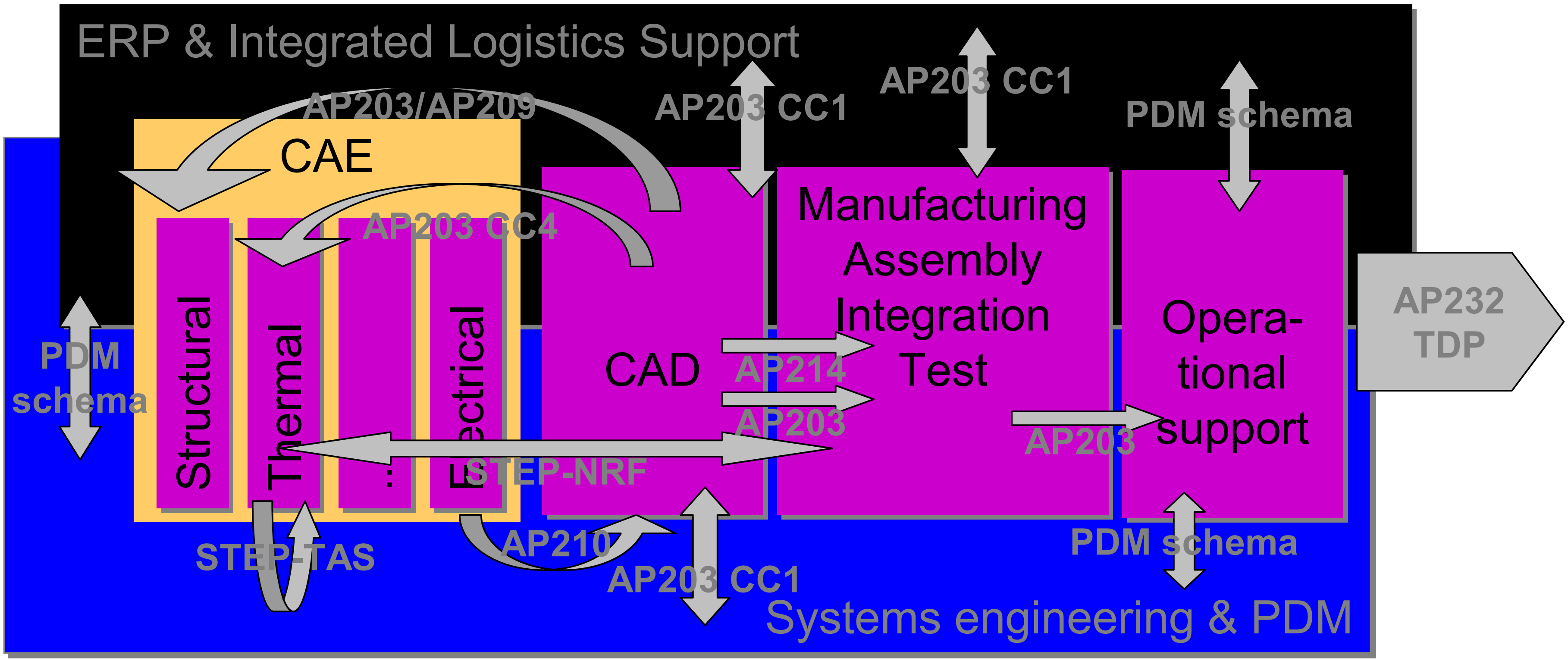
- STEP = STandard for the Exchange of Product model data = casual name for ISO 10303
- "ISO 10303 is an International Standard for the computer-interpretable representation and exchange of product data. The objective is to provide a mechanism that is capable of describing product data throughout the life cycle of a product, independent from any particular system. The nature of this description makes it suitable not only for neutral file exchange, but also as a basis for implementing and sharing product databases and archiving."

(From ISO 10303 Part 1)

The (Aero)Space STEP Protocols Map

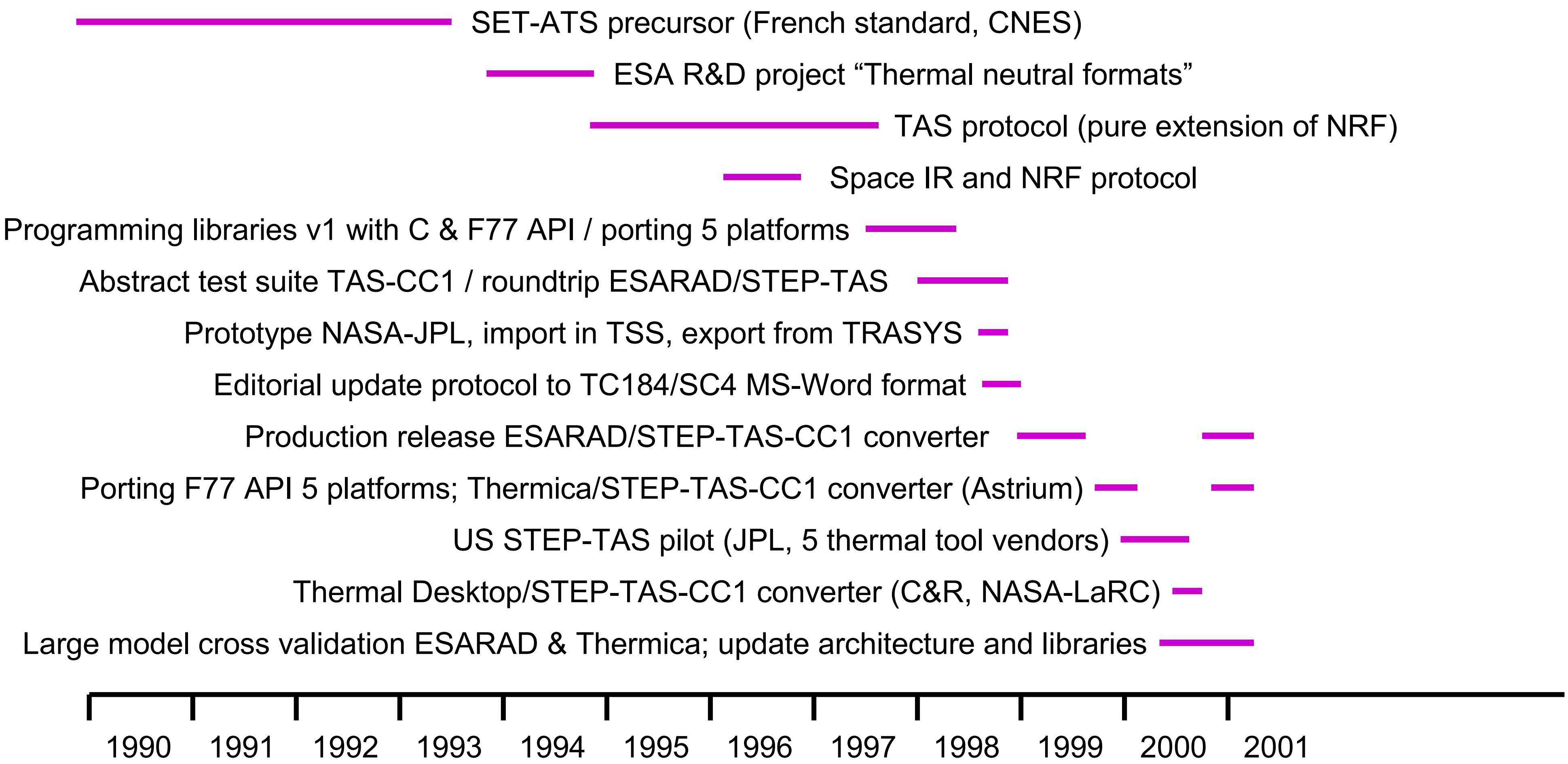


Disciplines in space projects
and examples of possible exchange



TAS = Thermal Analysis for Space
NRF = Network-model Results Format

Brief history TAS and NRF



STEP-TAS initial steps

- Initial steps taken
- Almost all tools / vendors on-board
  - Europe: ESARAD, THERMICA
  - US: Thermal Desktop/RADCAD, NEVADA, TSS, TRASYS, ATM, MSC-Patran, I-Deas TMG
- STEP-TAS converters in industrial release ESARAD and THERMICA (2000, 2001)
- Successful US pilot implementations in 2000

Update of STEP-TAS architecture

- Lessons learned from initial development and implementation
  - It takes too long …
    - To upgrade / correct the protocol or Converter Development Toolkit
    - To validate converter implementation
  - Web-based Implementors Forum is necessary
    - Including Converter Development Toolkit distribution
    - Problem reporting / tracking
    - Discussion Forum
    - Test suites / benchmarks

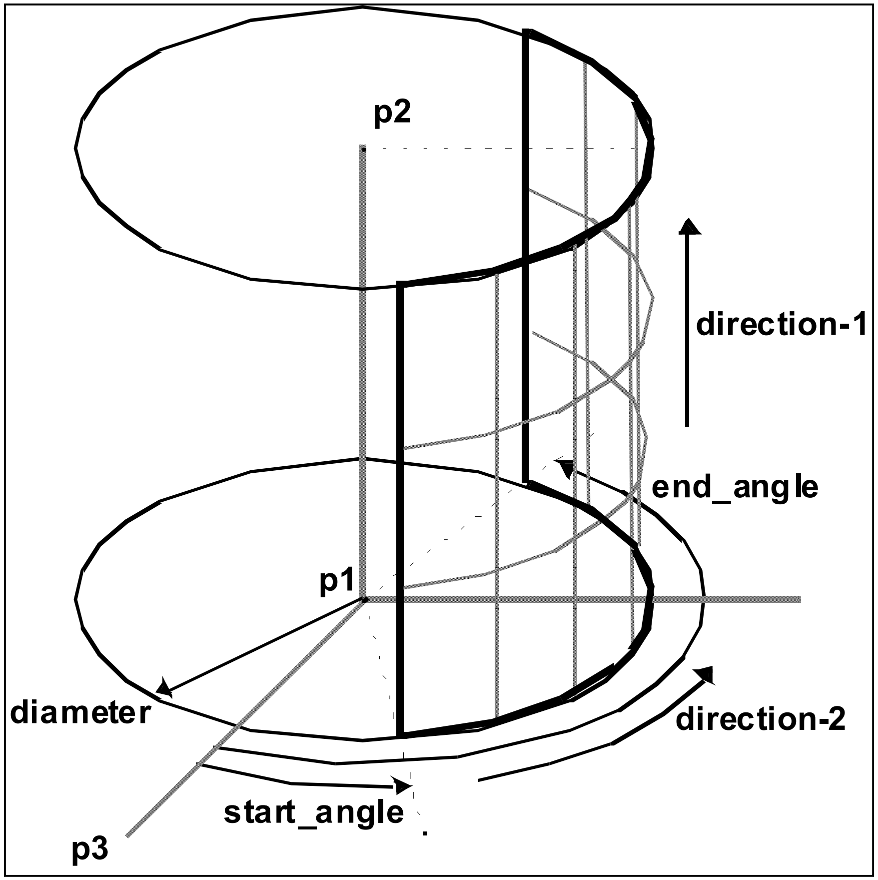
Main characteristics of STEP-TAS (1)

- Self contained, complete Application Protocol
  - AAM, ARM, Mapping Table, AIM, Express-G (586 pages)
  - Conforms to TC184/SC4 methods and guidelines
- Geometry defined as AP203 CC4 surfaces
- Thermal-radiative model faces added as associated features
  - Including possibility to support hierarchical submodel tree
  - Associated notional thickness, surface material and bulk material
  - Thermo-optical, thermo-physical properties for named material
  - Concept of material property environment (Part 45)
- Kinematic model conform STEP Part 105
  - for articulated rigid bodies (e.g. rotating solar arrays, gimballed antennas)

Main characteristics of STEP-TAS (2)

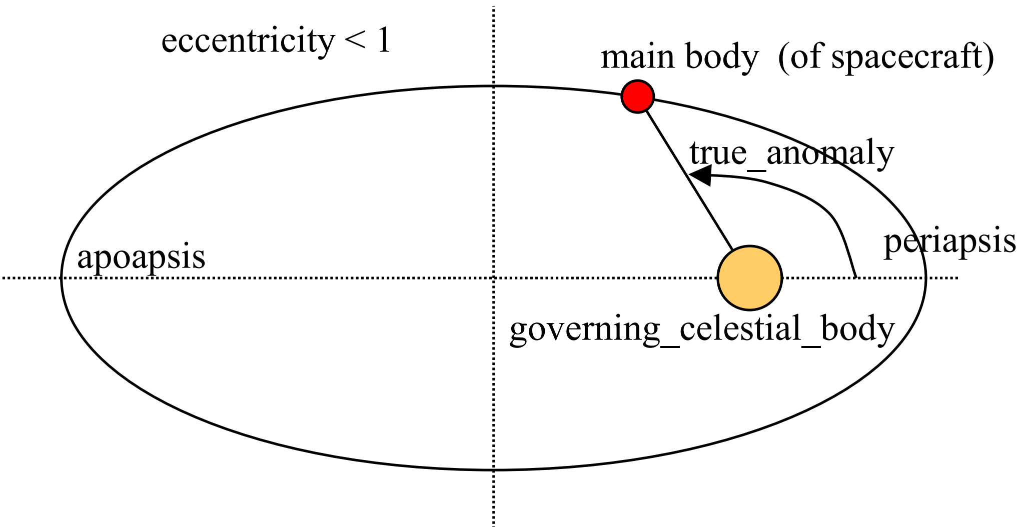
- Space mission aspects
  - orbit arc (Keplerian and discrete ephemeris)
  - space co-ordinate system, celestial bodies
  - orientation, general and named pointing, spinning, linear rotation rates
  - space thermal environment, including constant or lat/long dependent albedo / planetshine tables
- Boolean construction surfaces available for advanced tools
- STEP-TAS CC1 Abstract Test Suite
  - conform STEP Part 3xx series
  - test suite has been used in validation of TAS processors

STEP-TAS geometry and thermal-radiative models



- Shapes
  - Primitives: triangle, rectangle, quadrilateral, disc, cylinder, cone, sphere, paraboloid
  - Compound shapes
  - Shapes conform to AP203 CC4 non-manifold surfaces
- Thermal-radiative model
  - associates thermal-radiative faces with surface shapes
  - thermal mesh (uniform and non-uniform)
  - surface and bulk material properties by reference to material

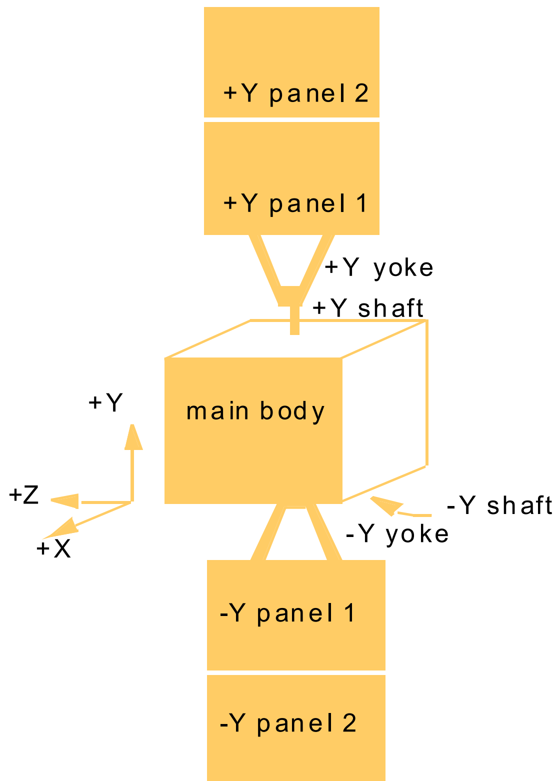
Illustration of basic
STEP-TAS Keplerian orbit definition



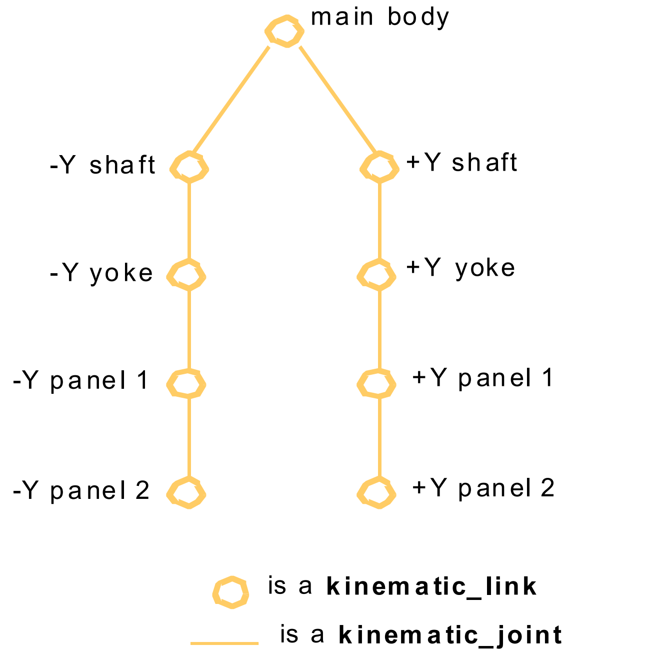

```
ENTITY keplerian_orbit_arc
    SUBTYPE OF (orbit_arc);
    kepler_parameters : kepler_parameter_set;
END_ENTITY;

ENTITY kepler_parameter_set;
  semi_major_axis : length_measure;
  eccentricity : REAL;
  inclination : plane_angle_measure;
  right_ascension_of_ascending_node :
    plane_angle_measure;
  argument_of_periapsis : plane_angle_measure;
  true_anomaly_at_start : plane_angle_measure;
WHERE
  wr1: semi_major_axis >= 0.0;
  wr2: eccentricity >= 0.0;
  wr3: (-180.0 < inclination) AND
       (inclination <= 180.0);
  wr4: (-360.0 < right_ascension_of_ascending_node)
    AND (right_ascension_of_ascending_node <=
    360.0);
  wr5: (0.0 <= argument_of_periapsis) AND
    (argument_of_periapsis < 360.0);
  wr6: (-360.0 < true_anomaly_at_start) AND
    (true_anomaly_at_start <= 360.0);
END_ENTITY;
```

STEP-TAS :
Product structure and kinematic



(a) Schematic shape model of a typical communications satellite with two fully deployed solar array wings



(b) The corresponding **kinematic_model** presented as a topological graph

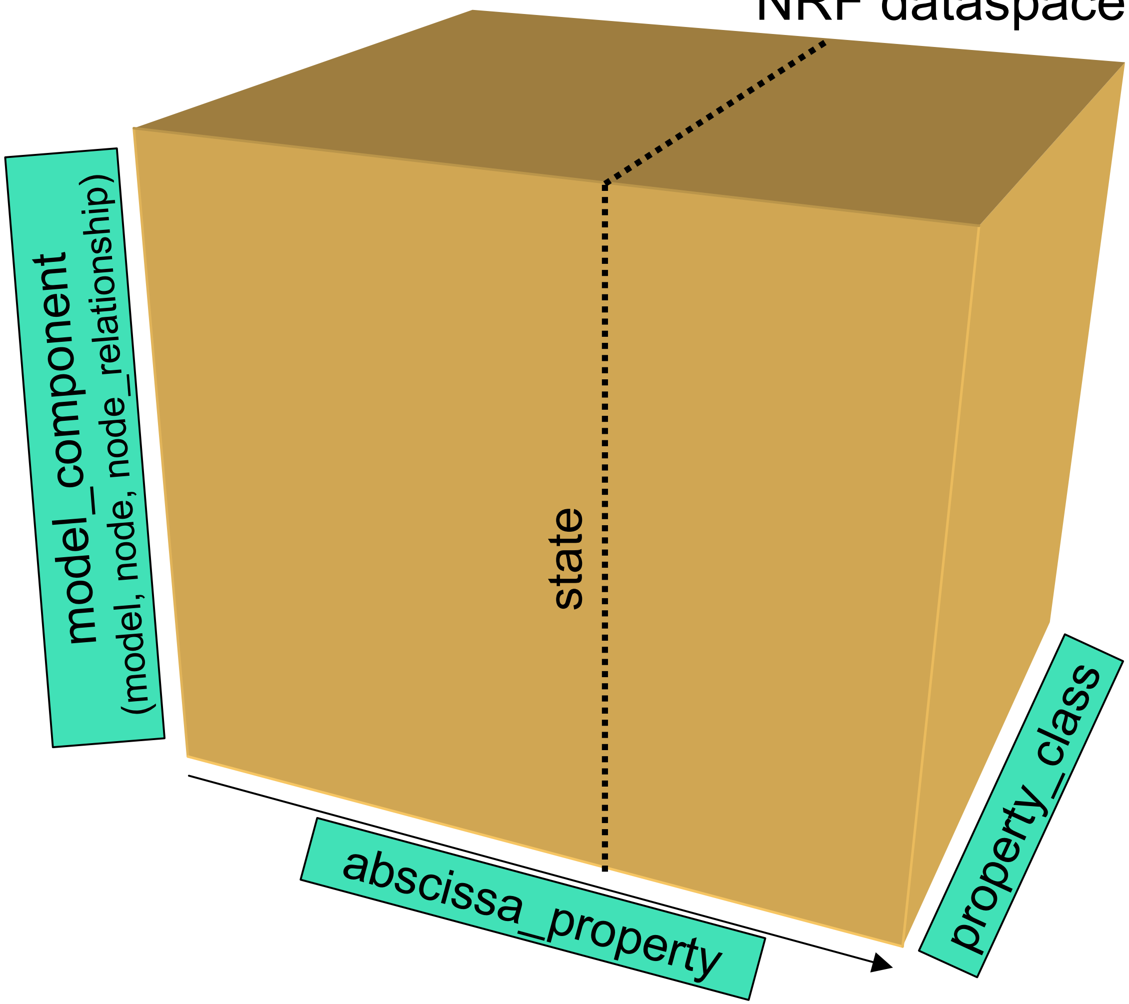
STEP-TAS Conformance Classes

	thermal-radiative model with basic geometry	kinematic model	constructive geometry	space mission aspects
CC-1	✓			
CC-2	✓	✓		
CC-3	✓		✓	
CC-4	✓	✓	✓	
CC-5	✓	✓		✓
CC-6	✓	✓	✓	✓

Main characteristics NRF (1)
Network-model Results Format

- Targets engineering-discipline independent exchange of bulk results data from analysis, test or operation
  - Representation of engineering objects by network models consisting of discrete nodes and node-relationships
  - Hierarchical tree of network models / submodels
  - Definition of properties
    - Quantitative, descriptive and functional properties
    - Scalar, vector and tensor property values
    - Property values only at discrete locations / discrete states
  - Full annotation of analysis / test / operation context
    - Campaign, case, phase, run
    - Facility/tool, environment, date and time, organisation, person, ...

Main characteristics NRF (2)
NRF dataspace

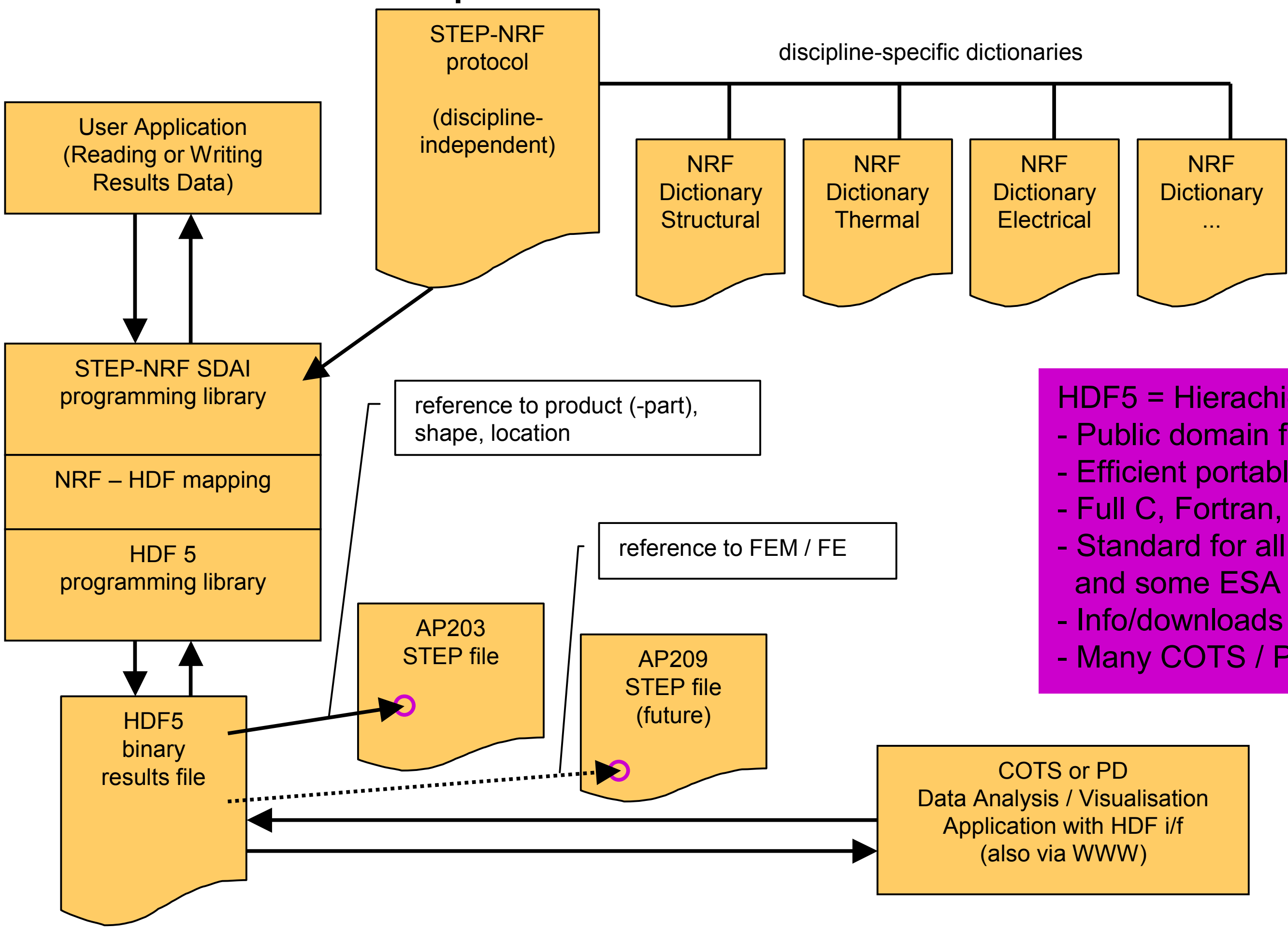


Each gridpoint in the 3D dataspace is a property value

Each can be scalar, vector, tensor

Data model and implementation designed to handle sparsely populated dataspace efficiently

Main characteristics NRF (3)
Proposed NRF/HDF architecture



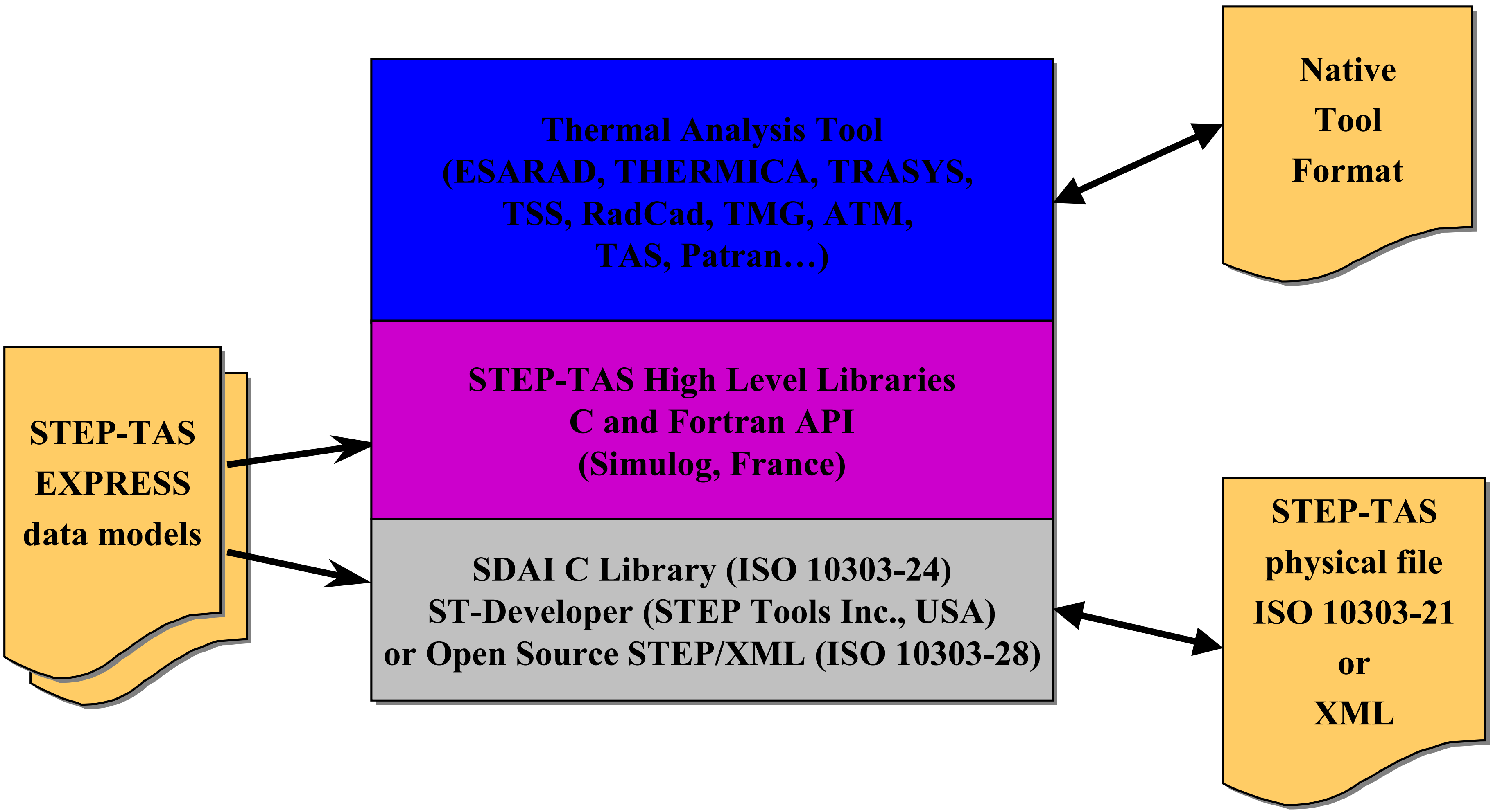
HDF5 is an efficient alternative for Part21 for large amounts of similar data

HDF5 = Hierachical Data Format v5
- Public domain from NCSA
- Efficient portable binary storage format
- Full C, Fortran, Java libraries on >10 platforms
- Standard for all NASA EOS missions and some ESA earth observation
- Info/downloads at hdf.ncsa.uiuc.edu
- Many COTS / PD tools with HDF interface

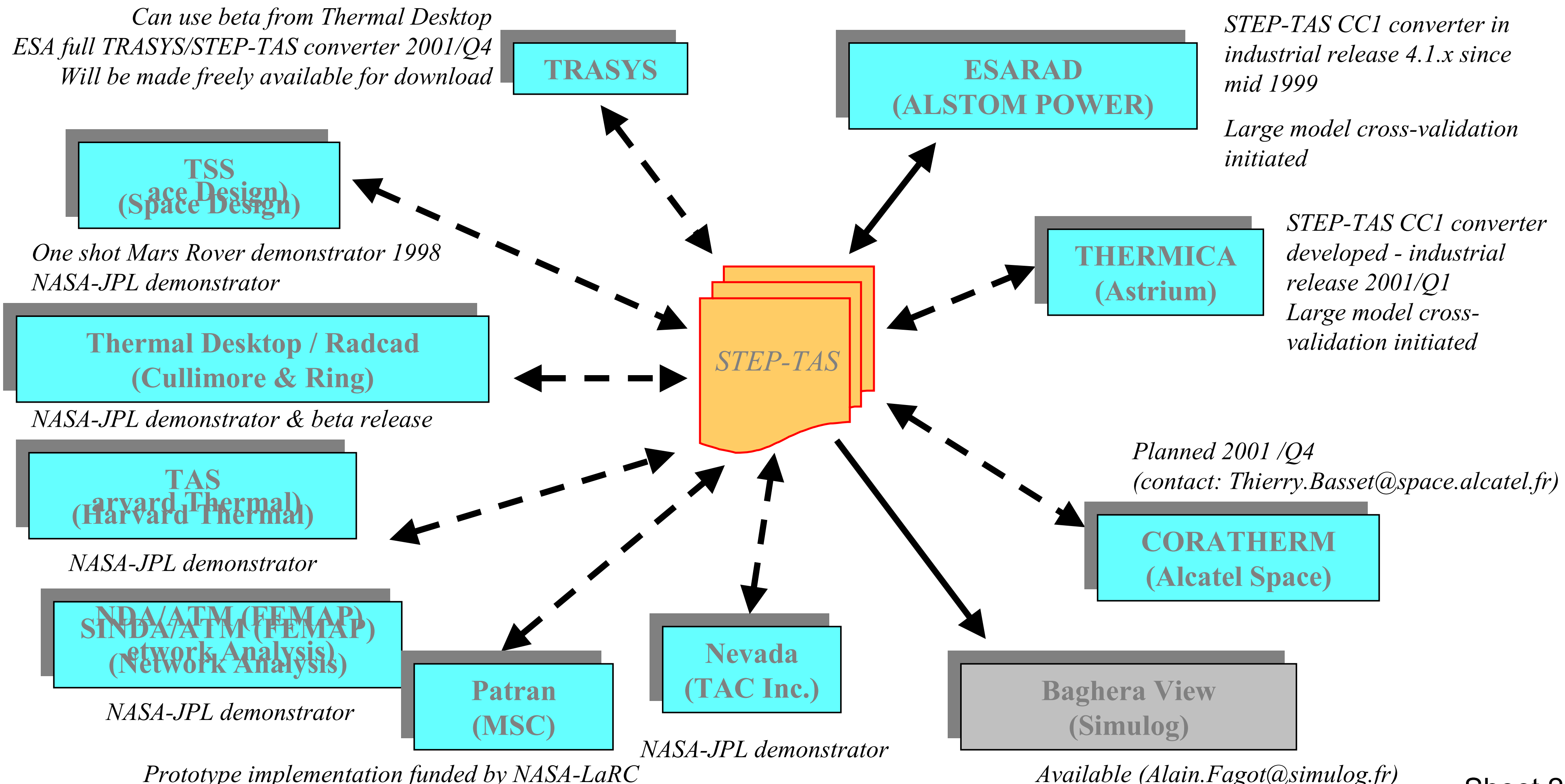
STEP-TAS CDT
Converter Development Toolkit

- High-level API (Application Programming Interface)
  - ARM concepts - close to thermal tools - hides STEP complexity
  - Full set of reading/writing functions in ANSI-C and F77
  - With documentation, examples and test suite
  - With Baghera-View to perform independent visual inspection
- Advantages:
  - Available to tool developers at nominal cost (from Simulog)
    - Platforms: Windows, Sun/Solaris, HP-UX, Compaq/Tru64, SGI/Irix
  - Enables to jumpstart converter implementation
  - Reduces converter validation / verification effort
  - All converters share reading/writing approach - increased reliability
  - Extensibility at affordable cost - e.g. add HDF or XML encoding

STEP-TAS Converter Architecture



The STEP-TAS roadmap - Sep 2001



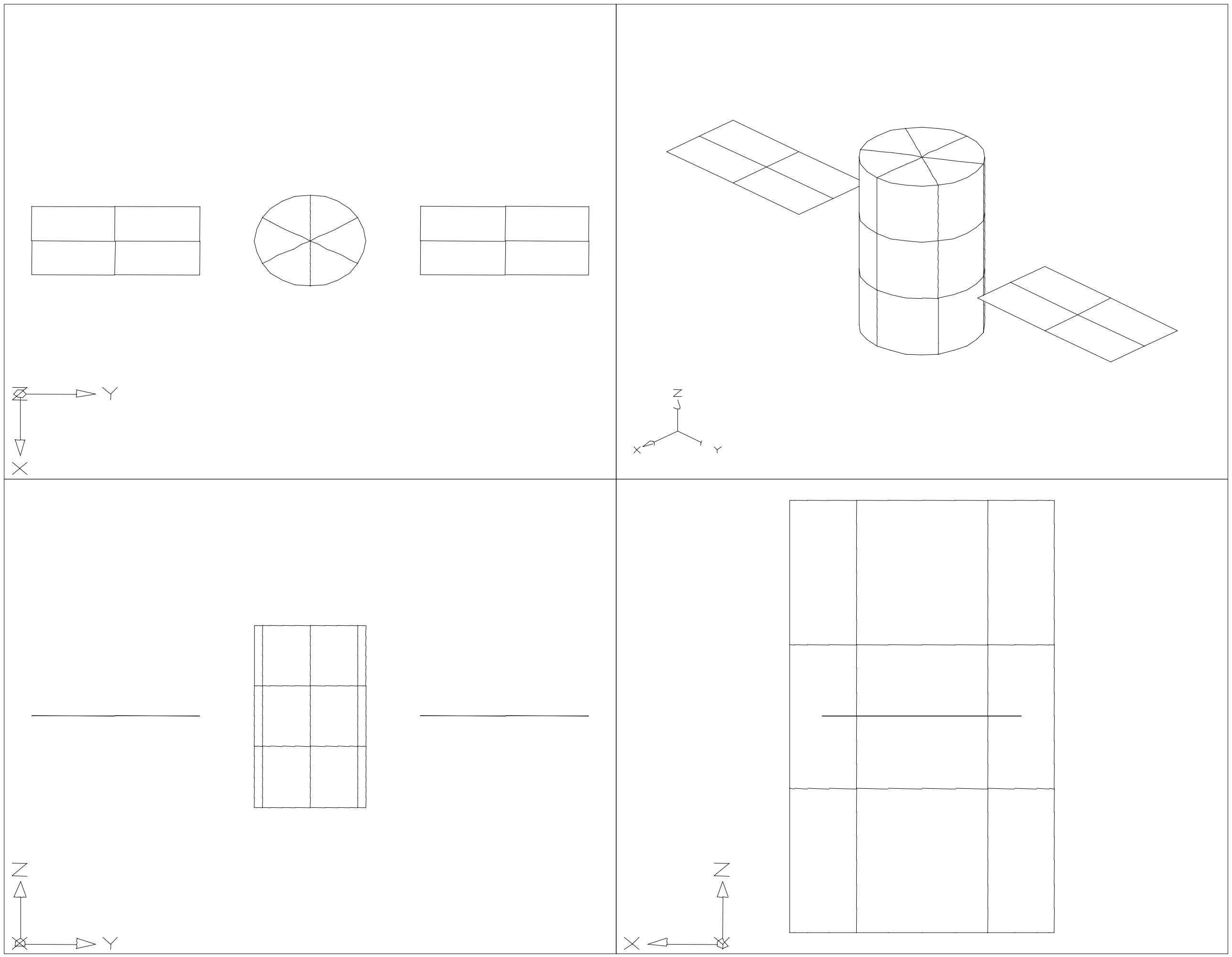
Status of STEP-TAS interfaces on European side

- ESARAD (ALSTOM POWER, ESA)
  - CC1 bi-directional interface in industrial release since mid 1999
- THERMICA (Astrium/Toulouse)
  - CC1 bi-directional interface in industrial release since 2001/Q1
- Large model cross-validation ESARAD / THERMICA
  - Currently in progress
  - Thousands of thermal-radiative faces
  - Resolving performance / memory management issues
  - Import of models is slow - still issues with reliability
- Coratherm (Alcatel Space)
  - Converter development expected to start 2001/Q4

Status of STEP-TAS interfaces on US side

- Bi-directional demonstrator development funded by NASA-JPL
  - 2000-Q1/Q3 on limited scope by 5 vendors:
    - Thermal Desktop (Cullimore and Ring Inc.)
    - TSS (Space Design)
    - TAS (Harvard Thermal)
    - SINDA-G/ATM (Network Analysis Inc.)
    - Nevada (TAC Inc.)
- Bi-directional converter development funded by NASA-LaRC
  - Thermal Desktop (C&R) - beta released 2000-Q3/Q4
  - MSC/Patran - currently in progress
  - Using STEP-TAS converter development toolkit from Simulog
- Cross validation US tools / European tools being planned

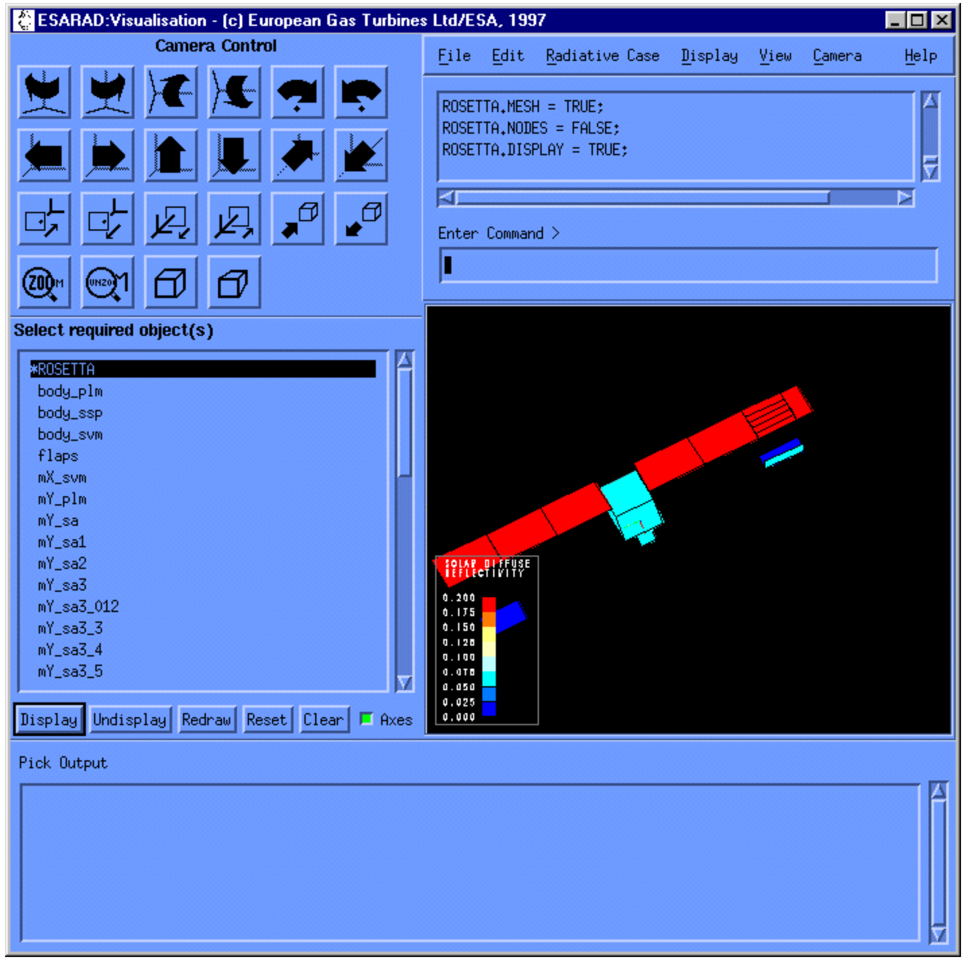
NASA-JPL STEP-TAS Demonstrator



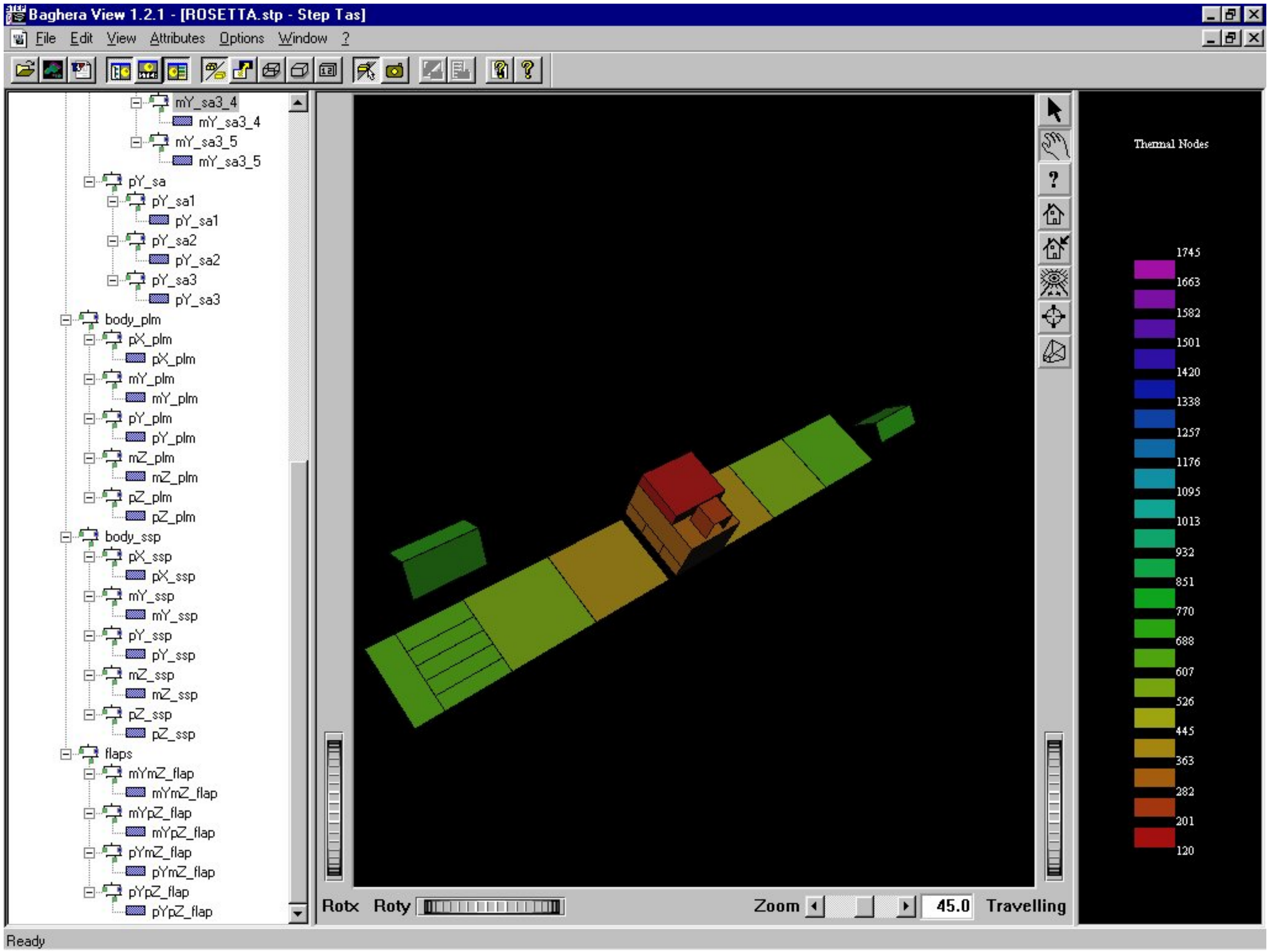
- A feasibility and familiarisation study
- Objective: to develop a limited bi-directional STEP-TAS prototype converter

Examples of STEP-TAS exchanges

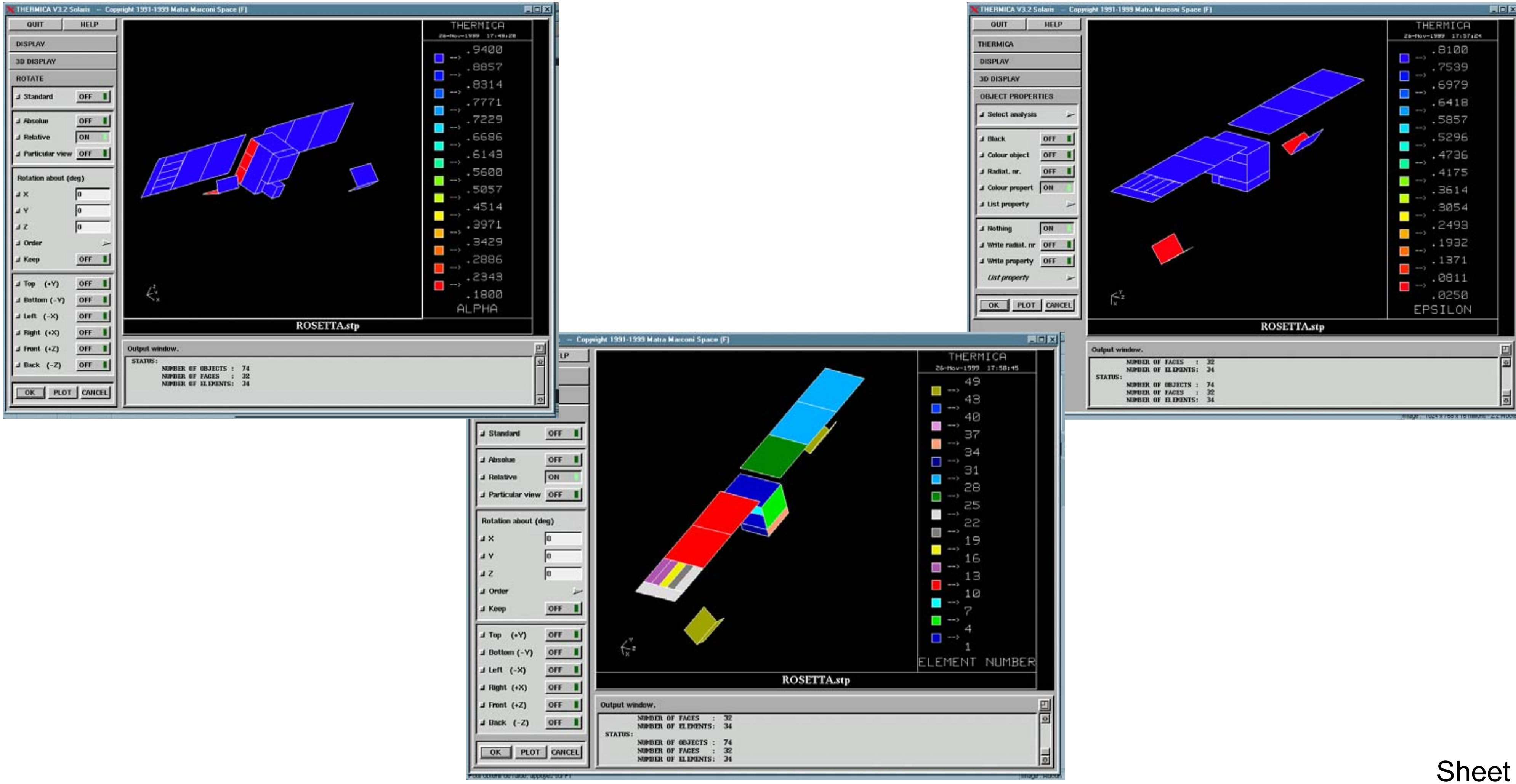
ROSETTA in ESARAD



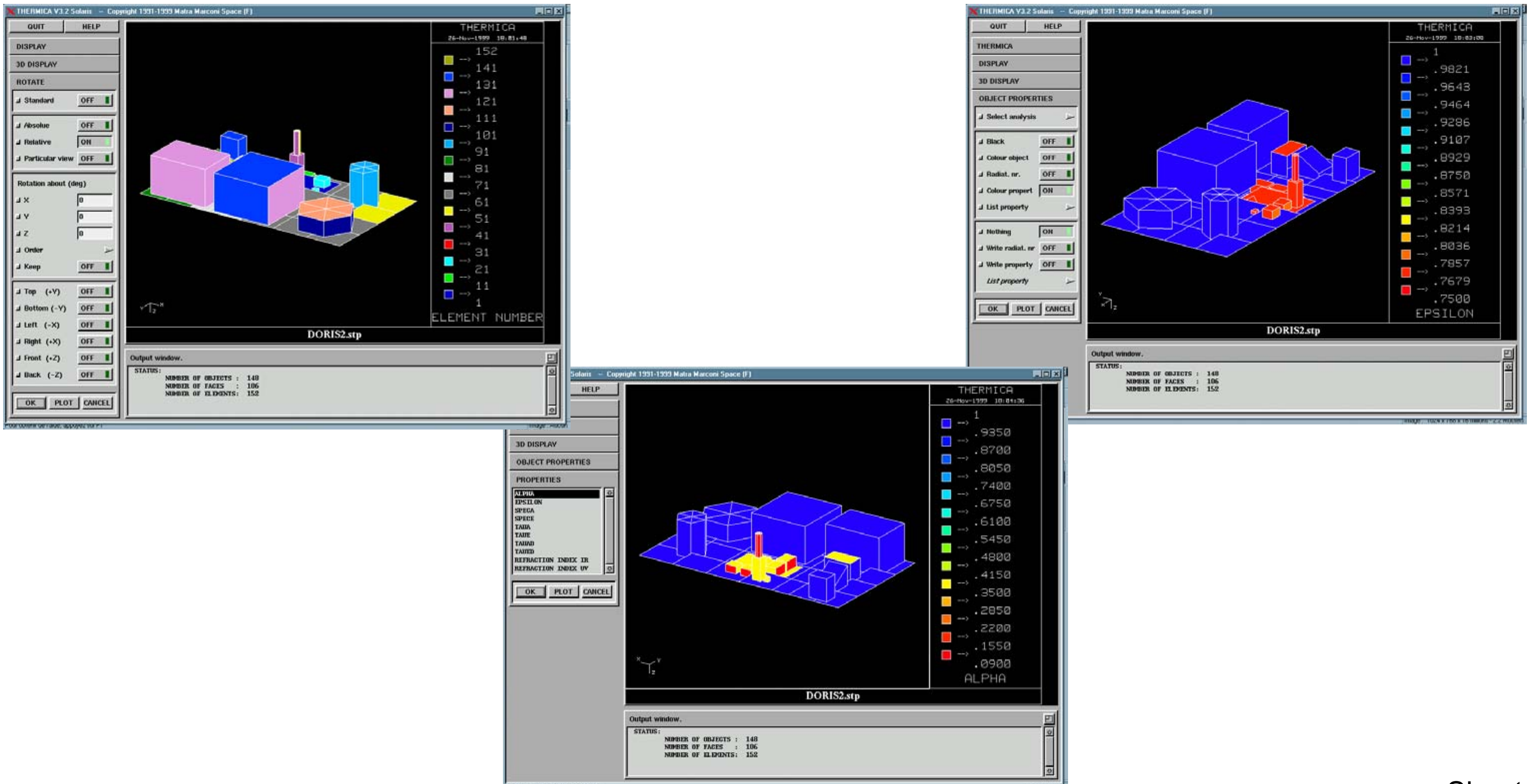
ROSETTA in Baghera View



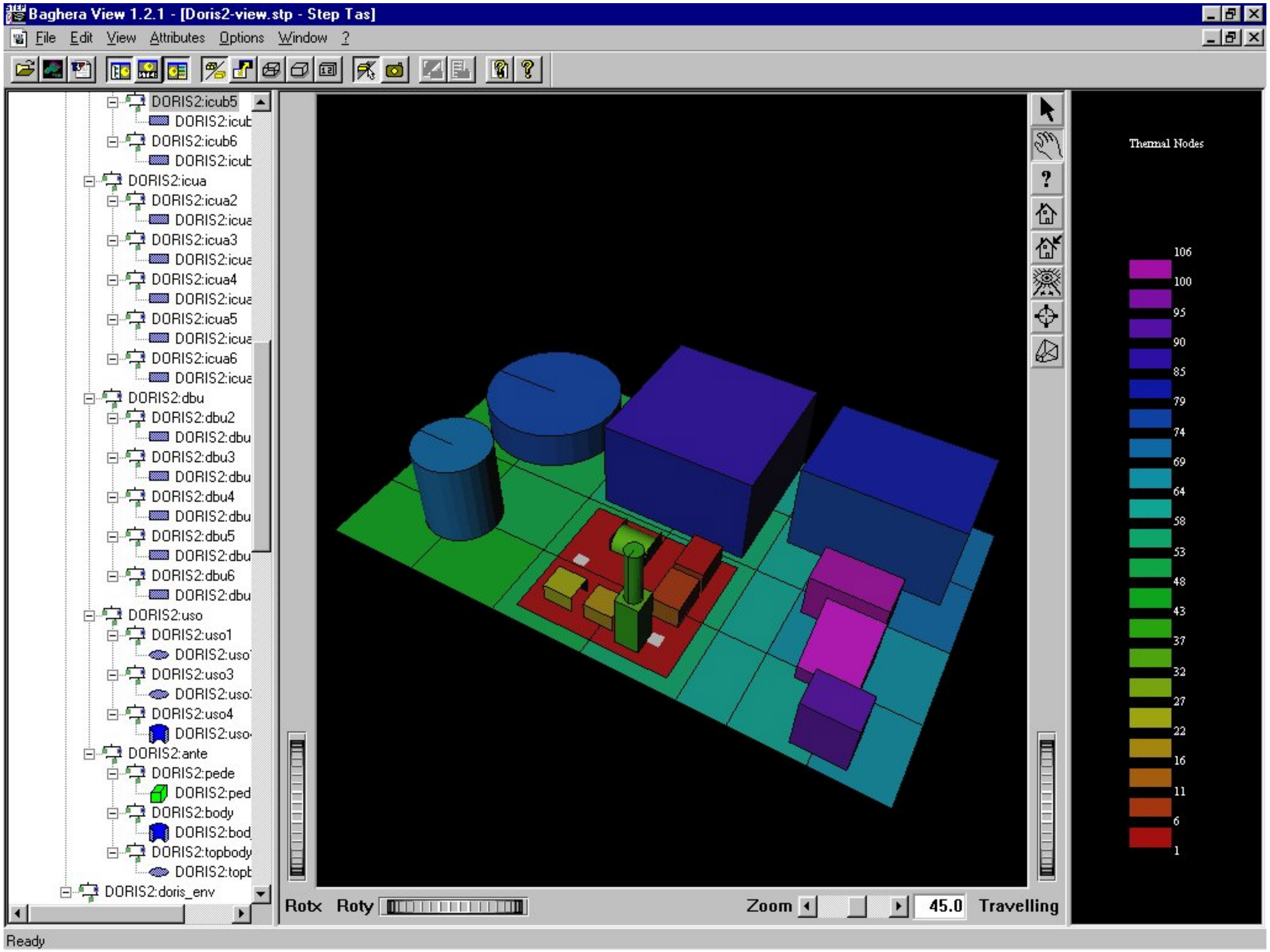
ROSETTA in THERMICA



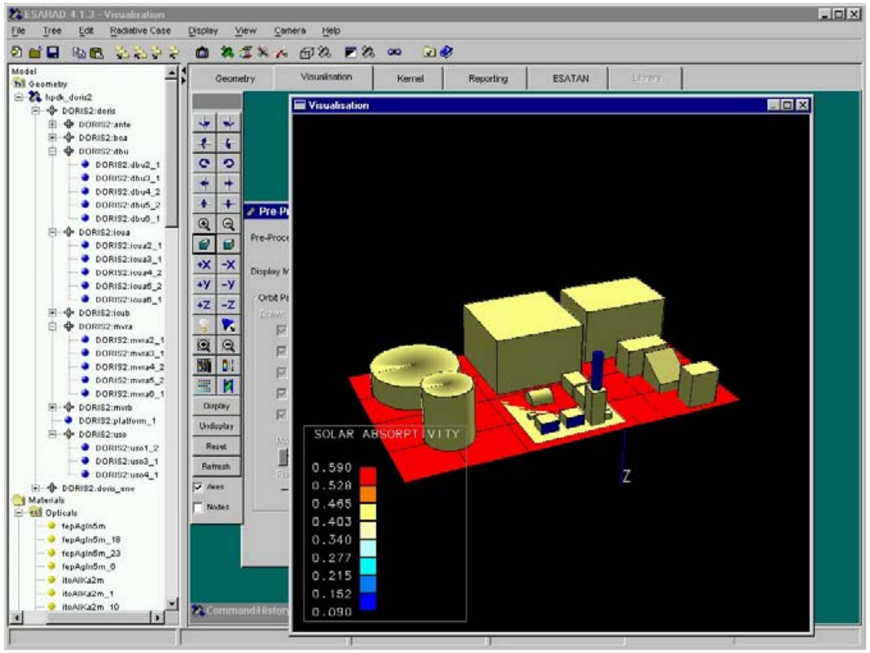
Doris in THERMICA

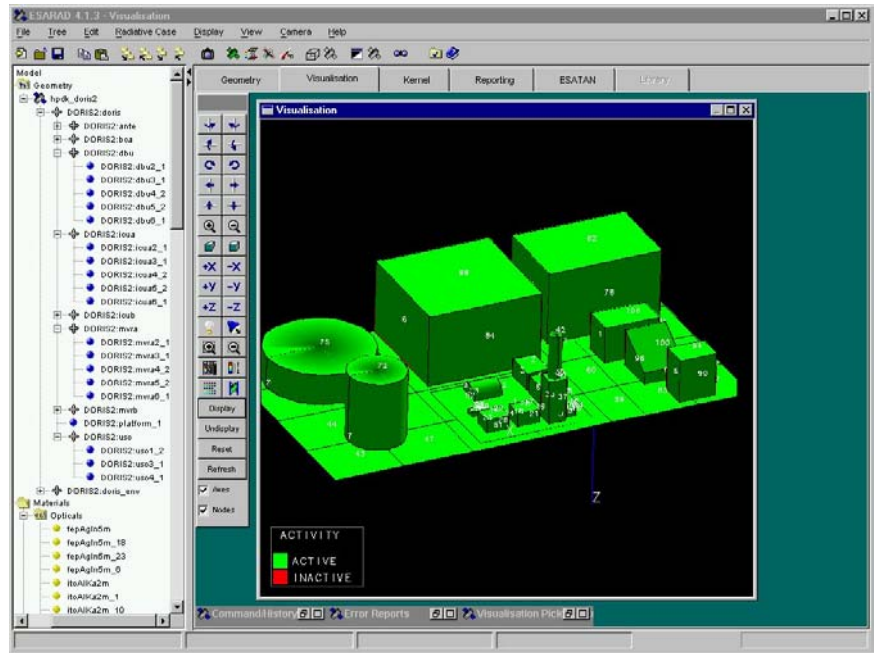


Doris in Baghera-View

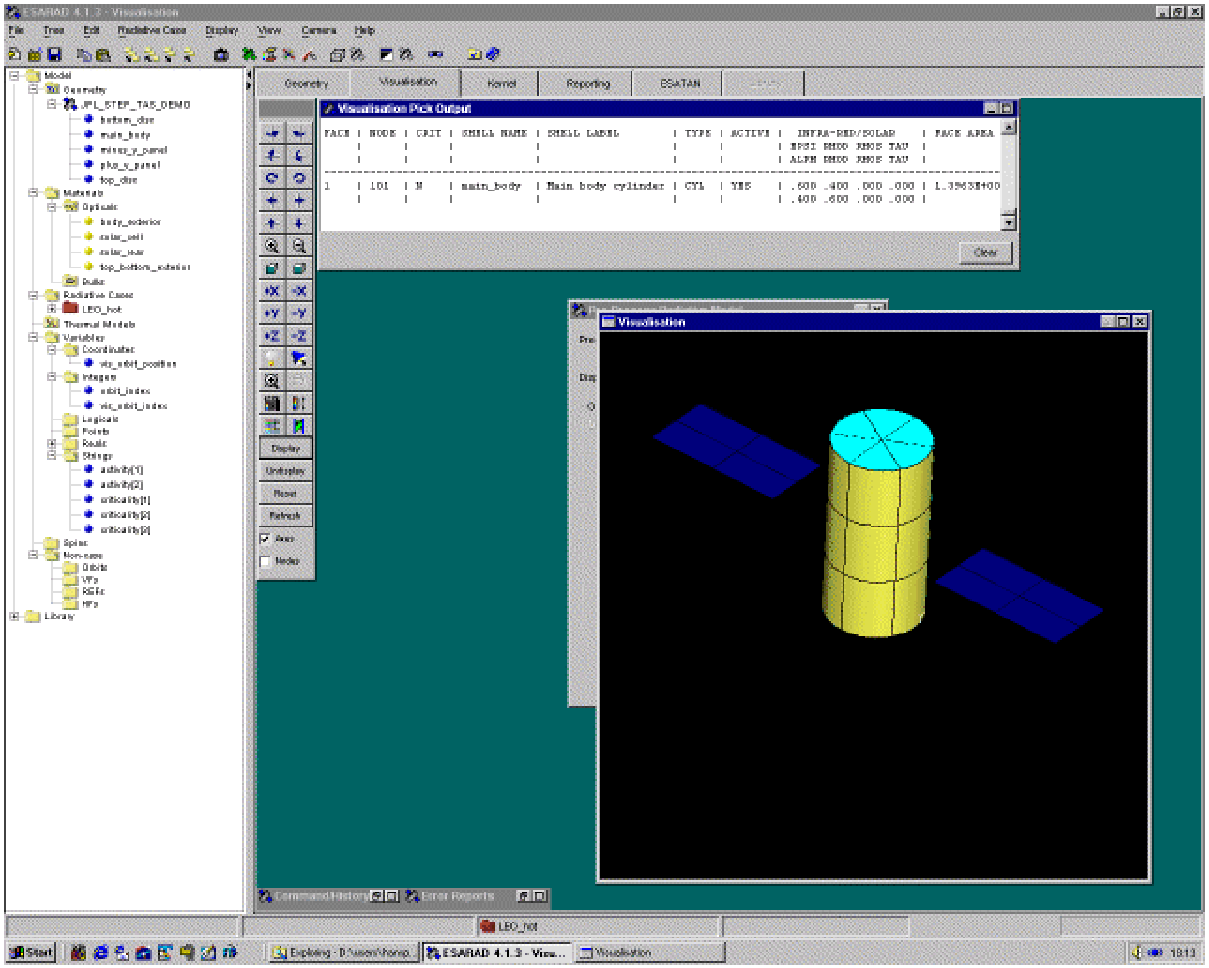


DORIS in ESARAD





NASA-JPL demonstrator in ESARAD




```
ISO-10303-21;
HEADER;
...
#109=TYPE_QUALIFIER('diffuse');
#110=TYPE_QUALIFIER('infra_red');
#111=ATR_PROPERTY_NAME('transmittanc
    e');
#112=ATR_PROPERTY_QUANTITATIVE(#111,
    .SYMMETRICAL.);
#113=ATR_PROPERTY_USAGE(#71,#112,#11
    4);
#114=ATR_PROPERTY_MEANING((#109,#110
    ));
#115=SI_UNIT(*,$,.METRE.);
#116=SI_UNIT(*,$,.DEGREE_CELSIUS.);
#117=GLOBAL_UNIT_ASSIGNED_CONTEXT(''
    ,'',(#115,#116));
#118=GLOBAL_UNCERTAINTY_ASSIGNED_CON
    TEXT('','',(#119,#120));
#119=UNCERTAINTY_MEASURE_WITH_UNIT(L
    ENGTH_MEASURE(1.E-008),#115,
...
```

Details available at ftp://ftp.estec.esa.nl/pub/yc/step/JPL_STEP_TAS_DEMO/index.htm

Lessons learned

- Iterative, incremental development necessary
  - Can not get things right in one go …
- High level programming library very useful
  - Greatly reduces converter development effort
  - Speeds up standard penetration & increases exchange reliability
  - Chosen API close to old SET-ATS interface needs reconsideration
- Continuous resource / funding level is needed
  - To meet vendor expectations by providing timely support and library updates resolving SPRs
- Communication must be improved
  - Start a 'STEP-TAS implementors forum'

Road Ahead (1)

- Web-based collaboration on further development:
  STEP-TAS Implementors' Forum
  - ftp://ftp.estec.esa.nl/pub/step-tas/index.html as a start
  - Will use sourceforge.net open source software development set-up for distribution of documentation and code, bug tracking, configuration control, test suite(s) - start 2001/Q4
  - E-mail tech support
- Take European / US collaboration to a next stage
  - Action ESA and NASA together with Simulog
  - Clarify/establish intellectual property rights and support

Road Ahead (2)

- Trade-off for best ‘Return on Investment’ next 5 years
  - Appropriate level of formal publishing (ISO, ESA and NASA)
  - Much simplified ARM based exchange
  - Start support of XML physical file (STEP part 28)
  - Upgrade high level API to support all STEP-TAS constructs
    - e.g. submodelling, non-uniform meshing and node numbering
- Upgrade STEP-TAS Converter Development Toolkit
  - Resolve all reported issues / bugs
  - Use open source software approach
- Upgrade converter options
  - Consistently support length unit selection / conversion

Road Ahead (3)

- TRASYS/STEP-TAS-CC1 bi-directional converter
  - Stand-alone tool by Simulog on ESA funding
  - Will be made available freely
- Upgrade BagheraView capabilities
  - By Simulog sponsored by CNES
  - Release v1.3 beta ready 5-Sep-2001 (supports Windows 2000)
- Revive NRF developments
  - HDF5 binding (co-operation with EDF, NCSA and others)
  - Assess links with Engineering Analysis modules, ISO 10303-50
  - Pilot web-based remote consultation of structural test results

Acknowledgements

- STEP-TAS and STEP-NRF were developed under ESA contract by an industrial consortium consisting of
  - Simulog (F, prime)
  - Fokker Space (NL)
  - Association GOSET (F)
  - Epsilon Ingénierie (F)
  - Alstom Power (UK)
- Special acknowledgement to Georg Siebes of NASA-JPL who is and has been the driving force for the development and acceptance of STEP-TAS in the US