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by Network Analysis, Inc.

*Proven Software without Compromise*

# THERMICA Spacecraft Thermal Design System

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*Phone: 480-756-0512 Fax: 480-820-1991 email: sinda@sinda.com web: www.sinda.com*



## About Network Analysis

- 36 year history with SINDA
  - Associated with SINDA (CINDA) since 1963
  - Started selling and supporting a proprietary version of SINDA (now called SINDA/G) in 1982.
- Commercial & Govt. Customers Worldwide
  - UK, Europe, Japan/Asia, Israel, Argentina
  - NASA, JPL, Los Alamos, Argonne, NASDA, ISAS, CAS/CAST, CONAE, CONIDA, DRA
  - Provides experienced thermal engineer tech support, on-site training, comprehensive s/w maintenance program

- Staff
  – Highly experienced thermal engineers
  – Marketing, Sales professionals with engineering backgrounds

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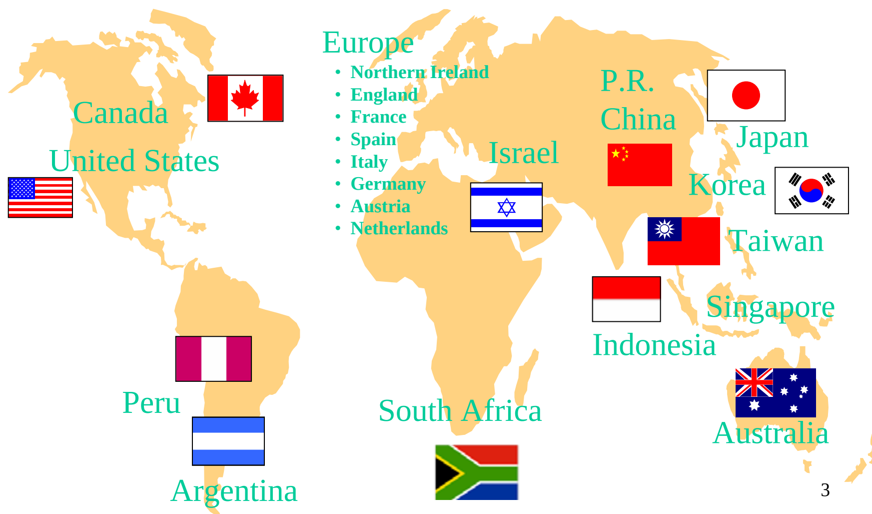
## SINDA/G - A World Wide Standard for Advanced Thermal Modeling

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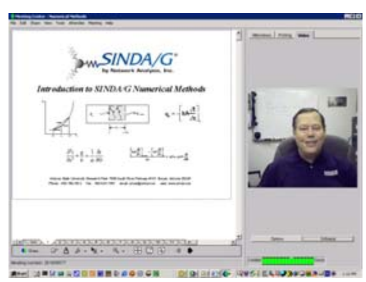
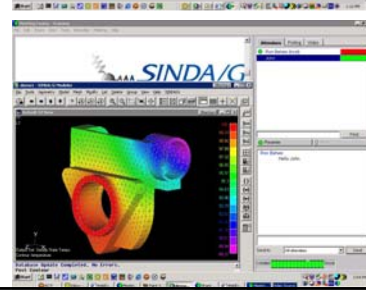
## Tech Support via Web Conferencing

- Anyone in conference can share documents, such as PowerPoint training slides or Word documents.
- Live video (not too useful, but at least we can wave and say hi!)
- Share an electronic whiteboard among all the participants (anyone may draw), or watch us draw on our wall sized whiteboard.
- Share any application, such as SINDA/G, SINDA/ATM, or THERMICA.
- Anyone in the conference can become the presenter and share their applications with us or even allow us to help fix problems in their models, or installation problems on their machine (with them watching of course!)
- Record both the computer screen and voice (both sides) in a movie that you can playback - pause - rewind and watch at your leisure.



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# The SYSTEMA Family of Spacecraft Design Tools

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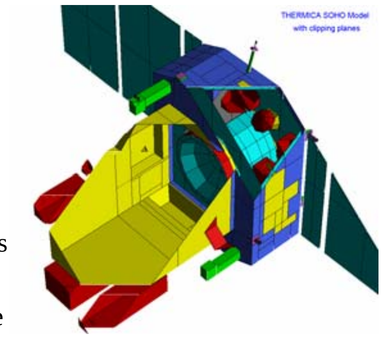
## Family of Spacecraft Design Tools

THERMICA is part of a comprehensive set of spacecraft design tools that use a common model for all analysis

- Thermica – comprehensive spacecraft-oriented modeling system
- Perturbation – Orbit perturbations due to the sun and planets effects
- Mass – monitors the mass and inertia of different entities
- Plume – Predicts dynamics effects, thermal flux and contamination on spacecraft
- Radiation Dose – computes the radiation dose received by electronic components
- Atomox – computes atomic oxygen flux and cumulated flux
- Contamination – computes surface contamination
- Maxsim – Used for EMC problems, RF analysis of antenna/structure interactions or antenna modelling.
- SMART2 – Space Mission Analysis Reference Tool) A tool for the modelling, the simulation and the analysis of low earth orbit observation missions.

# Thermica

- Geometry building using true geometric shapes and curved meshes
- Comprehensive mission planning with orbit maneuvers
- Ray-tracing thermal radiation and orbital heating involving specular diffuse and transparent surfaces
- Moving bodies, such as articulating solar panels and antennas, along with spacecraft maneuvers
- Creating a SINDA/G thermal model that can be launched and the results viewed graphically from within Thermica




# Mass

- Mass property generation of primitive shapes
- A listing of data showing current mass, the center of mass and principle moments of inertia for each system object
- Mass budget reporting, for a given system configuration, showing a detailed mass breakdown of each subsystem and of the overall system
- Static and dynamic balancing analysis
- Mass property analysis
- Mass sensitivity analysis

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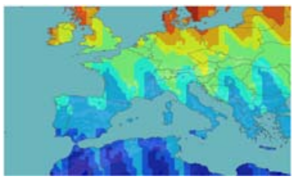
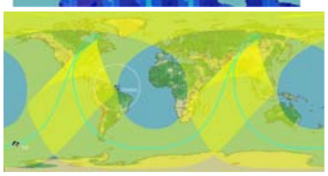
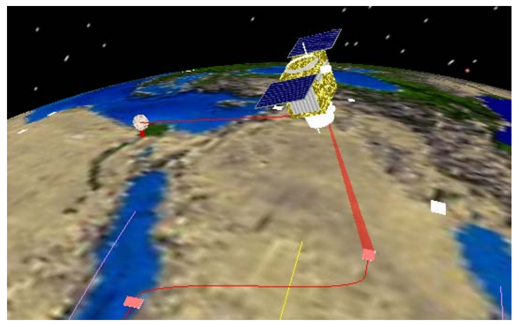
# SMART2

**SMART2** (Space Mission Analysis Reference Tool) is a computer tool for the modelling, the simulation and the analysis of low earth orbit observation missions.

**SMART2** include a satellite component (orbit characteristics, platform and instrument data), a ground component (characteristics of ground stations dedicated to command data uplink and images downlink: number, location, data on transmission and reception beams), as well as information about the Earth zones where analyses are to be performed (point targets, areas).







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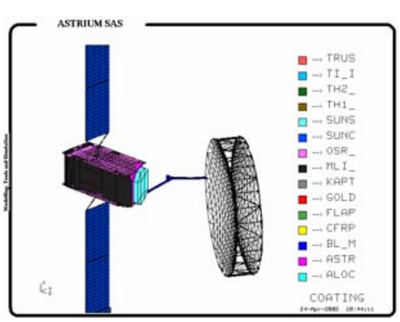
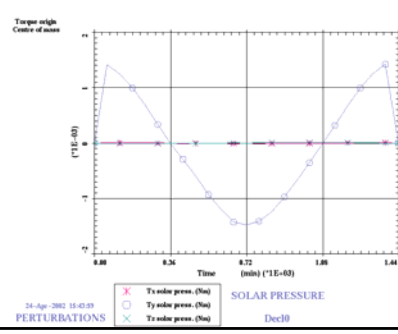
# Perturbation

- Gravity gradient - Gravitational perturbations mainly caused by non-spherical, non-uniform mass distribution of the Earth.
- Magnetic moment – Torque affects caused by the Earths magnetic field
- Air Drag – Air drag affects due to the Earth atmosphere
- Solar Radiation Pressure & Earth Radiation Pressure – Solar radiation pressure caused by light fluxes incident on the spacecraft, including albedo and Earth infrared pressure.

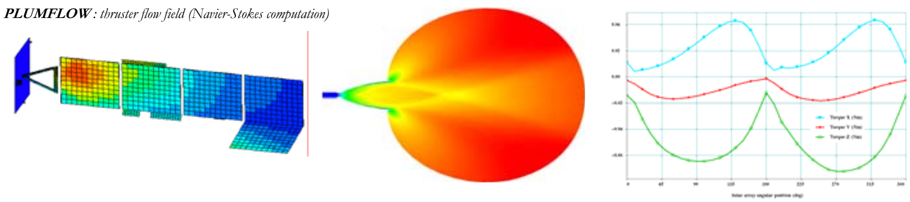


# Plume

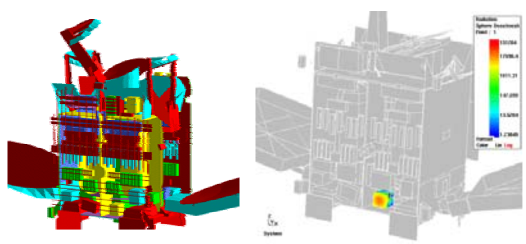
- Predicts dynamics effects, thermal flux and contamination on spacecraft
- Forces and torques of the gas plume producing dynamic perturbations and loss of thruster efficiency
- Analyzes thermal constraints due to the convective and radiative heat flux
- Analyzes the erosion caused by particles and the impingement of unburnt droplets

***PLUMFLOW**: thruster flow field (Navier-Stokes computation)*



# Radiation Dose

Uses Monte-Carlo ray tracing methods to determine radiation doses which results from incident flux of particles in space, mainly protons, and electrons which then propagate through the spacecraft material, generating secondary radiation (mainly X-rays) and depositing dose.



- Computes the radiation dose received by electronic components located within the spacecraft
- Accounts for the geometrical shielding and mission dose depth curve

| | RADIATIONS | | EQUIVALENT THICKNESS | |
|---|---|---|---|---|
| BOX FACE | RAD. DOSE (rad) | SOLID ANGLE (steradian) | TOT. EQU. THICK. (mm) | STRUC. EQU. THICK. (mm) |
| +X | 3468.1 | 2.09 | 7.91 | 7.91 |
| +Y | 1665.8 | 2.09 | 12.90 | 12.90 |
| +Z | 1394.9 | 2.09 | 15.67 | 15.67 |
| -X | 6410.7 | 2.09 | 6.56 | 6.56 |
| -Y | 83452.2 | 2.09 | 3.59 | 3.59 |
| -Z | 18871.8 | 2.09 | 5.04 | 5.04 |
| TOTAL | 115263.5 | 12.57 | 5.02 | .......... |

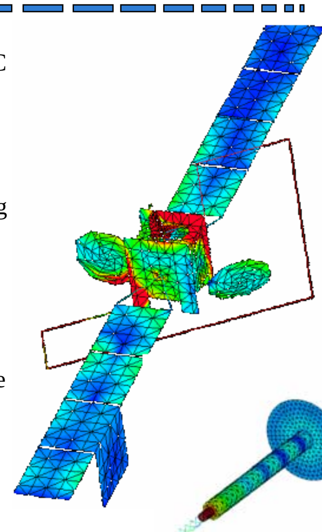
# Atomox

- Computes atomic flux and cumulated flux on spacecraft surfaces
- Evaluates the total surface erosion
- 3-D displays of flux, cumulated flux (fluence) and erosion on spacecraft surfaces.

# MAXSIM

**MAXSIM-F** is used for several types of applications : EMC problems, RF analysis of antenna/structure interactions or antenna modelling.  In the solving of the Maxwell's equations, four kinds of problem can be distinguished according to the time analysis (time varying or time harmonic) and also according to the type of space modelling in term of geometrical environment and boundary conditions.

**MAXSIM-F** is based on the Method of Moments in the frequency domain and is applied to surface geometries in 3D. **MAXSIM-T** is based on the Method of Moments in the time domain and is applied to surface geometries in 3D.



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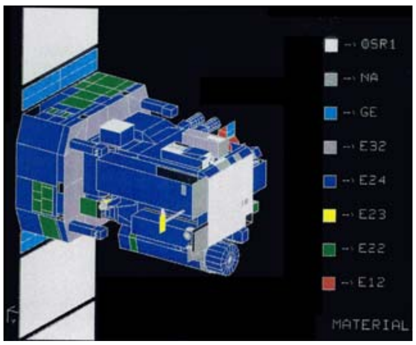
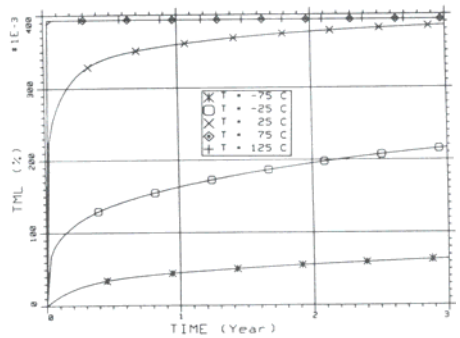
# Outgassing

- Computes surface contamination as a function of time – taking into account
  - Surface outgassing of contaminants
  - Surface re-emission kinetics
  - Ambient scattering
- Calculation is performed with a Monte-Carlo Ray-tracing method

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# Thermal Modeling Approaches

- Network (symbolic) Approach
  - Text based tools
  - Graphical tools
- Geometric
  - FEA meshing tools
  - Radiation shape tools

## Example of Network Approach

Typical detail of a hand build
Network or symbolic model

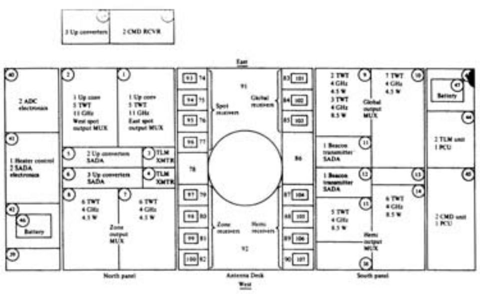


Figure 5.11 Nodal breakdown of the north and south panels and of the antenna deck of Intelsat V. (Courtesy of INTELSAT and FACC)

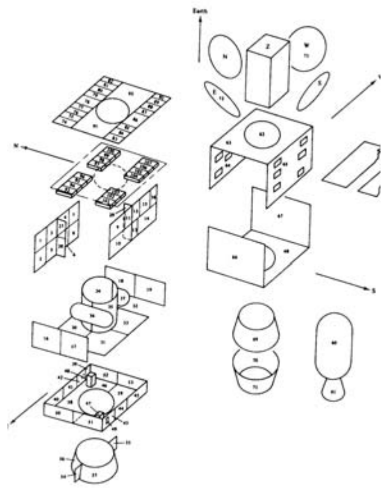
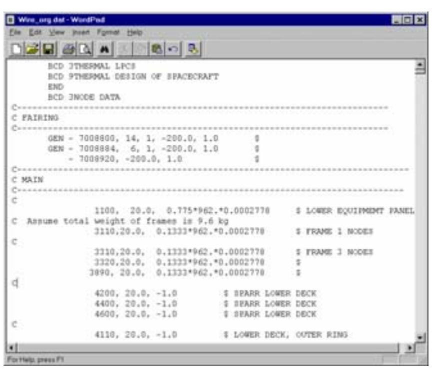


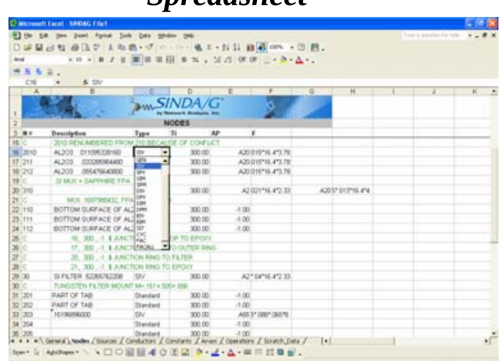
Figure 5.10 Thermal model of Intelsat V. (Courtesy of INTELSAT and FACC)

## Network Approach Using a Text Based Tool

***The Text Editor***



***Spreadsheet***



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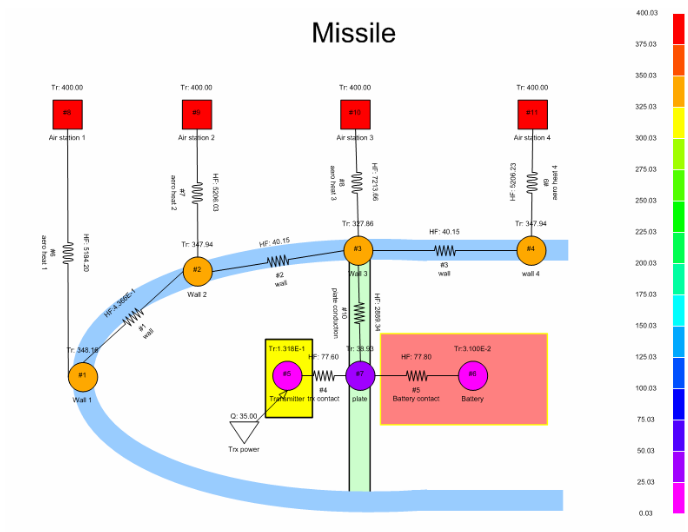
## Network Approach Using a Graphical Approach

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## Thermal Modeling Approaches

- Network (symbolic) Approach
  - Text based tools
  - Graphical tools
- Geometric
  - FEA meshing tools
  - Radiation shape tools

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# Geometric Model Builders

- FEA Meshing Based Modelers
  - Create 3D solids geometry or import from CAD and divide geometry into finite elements using a mesher.
  - These model builders are general purpose and are frequently used by many different analyzers (thermal, structural, CFD).
- Radiation Shape Based Modelers
  - Create model using several geometric shapes that are supported by the thermal radiation code.
  - These model builders are usually tied to one thermal radiation code, and will not easily work with another.

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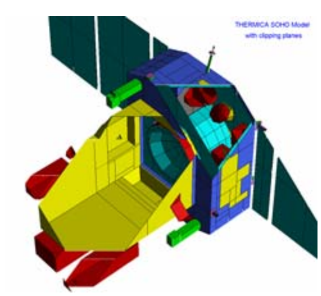
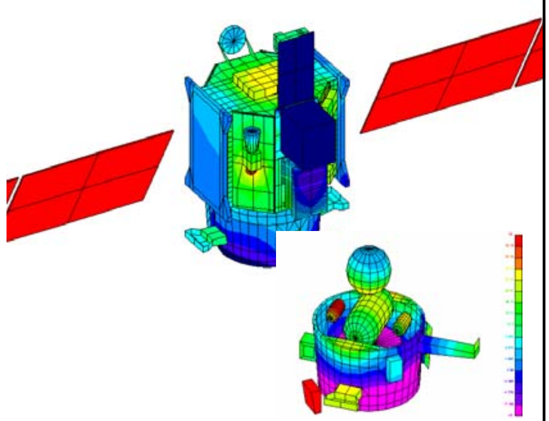
# Two General Types of Geometric Model Builders for SINDA/G

Shaped Based
Model Builder




FEA Meshing Based
Model Builder



## Commercially Available Geometric Modelers for *SINDA/G*

| Shape Model Builder | Meshing Model Builder |
|---|---|
| THERMICA | SINDA/ATM (based on FEMAP) |
| TSS | SINDA 3/D |
| ESARAD | PATRAN using P/Thermal |
| NEVADA (SPARKS) | PATRAN – SINDA/G (3rd qtr 2003) |
| Thermal Desktop | I-DEAS/TMG |
| | MSC/NASTRAN for Windows (Based on FEMAP) |

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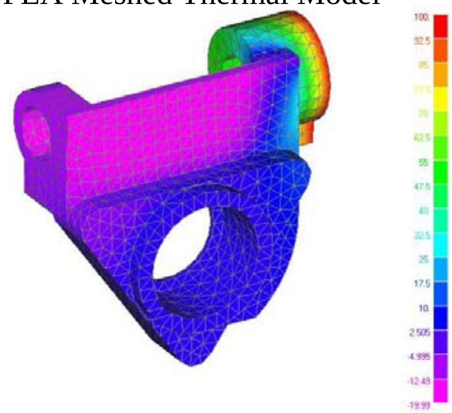
## Advantages & Disadvantages of the Two Types of Geometric Model Builders

- FEA Meshers
  - Good connection to CAD
  - Good connection to FEA structural/fluid programs
  - Flat plat connection to radiation/orbital heating programs
  - Usually use corner node method
  - Models solids, orthotropic materials and laminate materials
- Shape based Model builders
  - Poor connection to CAD
  - Poor connection to FEA programs
  - Excellent-full shape) connection to radiation/orbital heating programs
  - Usually element node method, but can be either
  - Usually not models surfaces only with isotropic plates

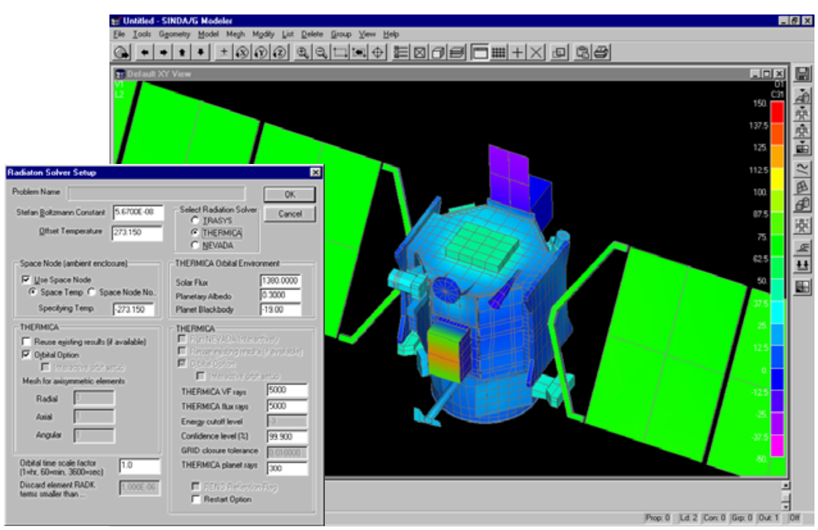
# FEA Meshing Based Tools

CAD Model

FEA Meshed Thermal Model




# SINDA/ATM Model are Independent of Radiation Code

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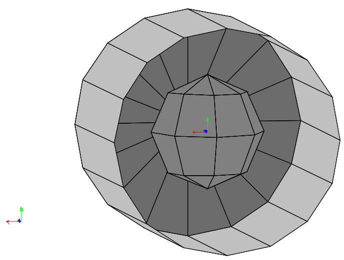
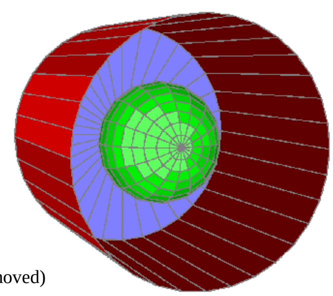
## Radiation Surfaces Created by Graphical Modelers

FEA Mesher
SINDA/3D

Shaped Based Modeler
(THERMICA)





(end disk removed)

Hydrazine Tank Modeled with
112 Flat Plates

Hydrazine Tank Modeled with
4 True Geometric Surfaces

Produces 6000+ radiation conductors

Produces 6 radiation conductors

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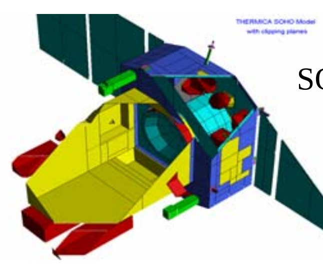
## Typical Detail Level of Thermal Model

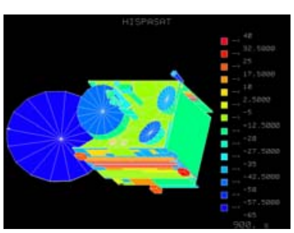
Hispasat

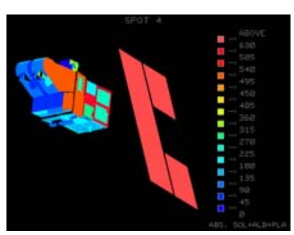


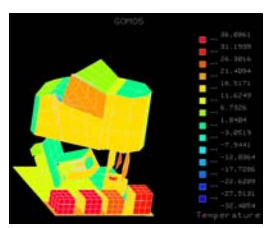
SOHO

SPOT 4

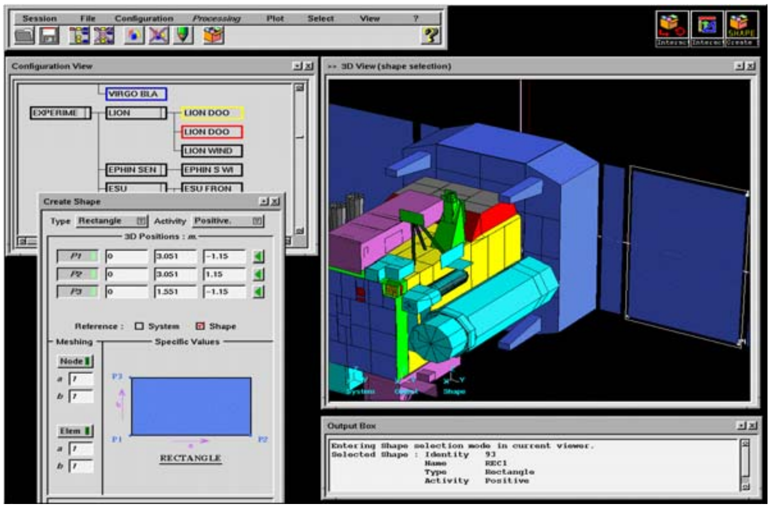
GOMOS





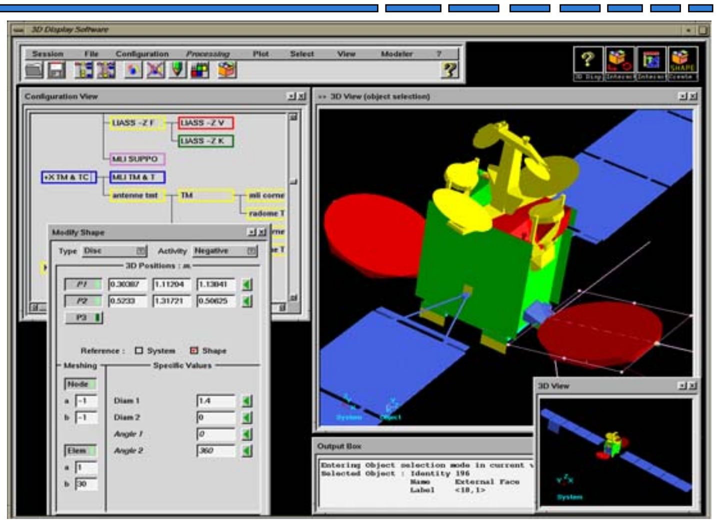


## THERMICA-SINDA/G



•SOHO Spacecraft

## THERMICA-SINDA/G



•MMS Telecom Spacecraft

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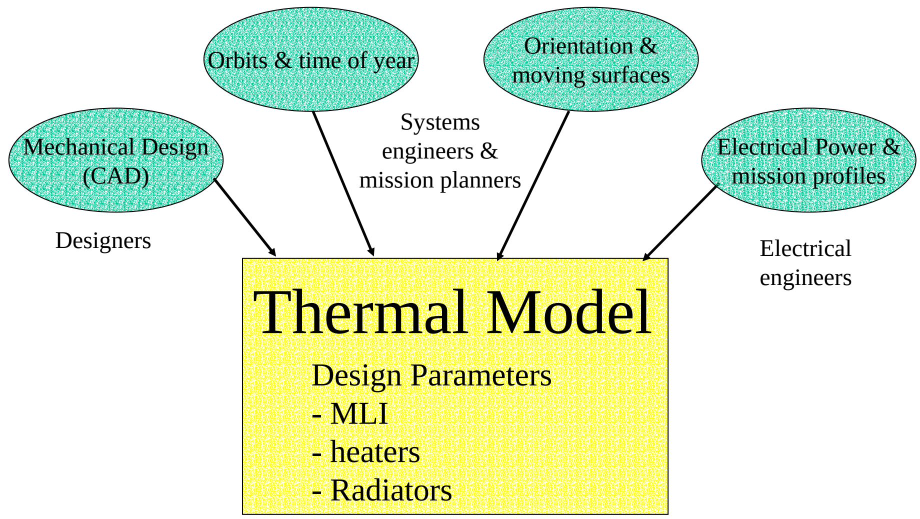
## Required Inputs for Spacecraft Thermal Design

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## Spacecraft Thermal Design Process

- Spacecraft Model building
  - Geometry
  - Thermal protection
- Mission Planning
  - Orbits
  - Orientations, maneuvers and moving bodies
- Thermal Model Generation
  - Thermal Radiation and Orbital Heating
  - Powers
  - Computation of Temperatures
- Results Postprocessing

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# Physical Model Building Phase

- Geometry building
- Material library
- Hierarchical assembly of parts
- Automatic generation of nodes and conductors

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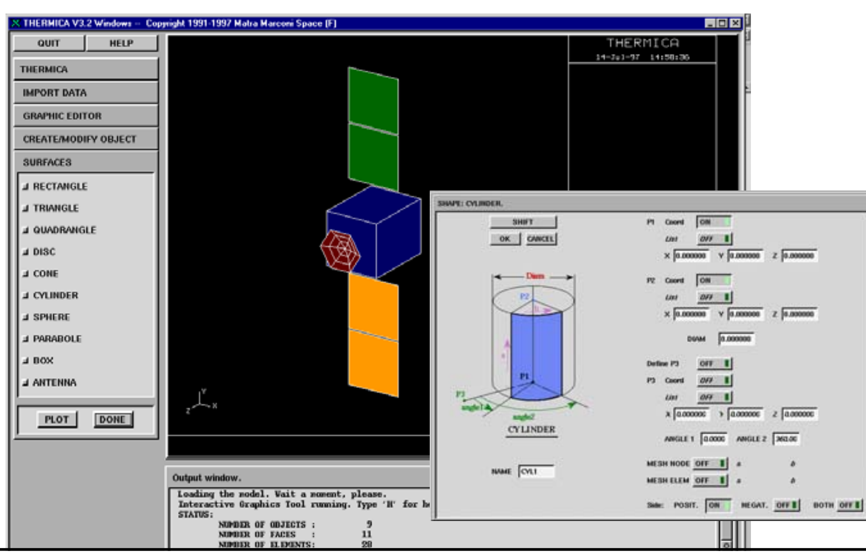
# Geometry Building



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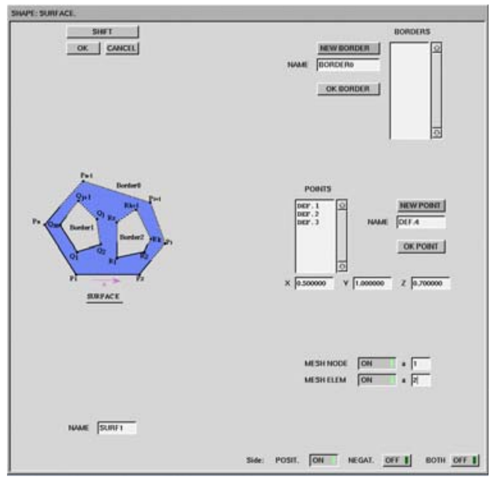
# Shapes

- RECTANGLE
- TRIANGLE
- QUADRANGLE
- DISC
- CONE
- CYLINDER
- SPHERE
- PARABOLE
- BOX, BOXCG
- BEAM
- NODE
- ANTENNA
- SURFACE
- HYPERBOLOID
- ELLIPSOID
- REVOL
- PRISM



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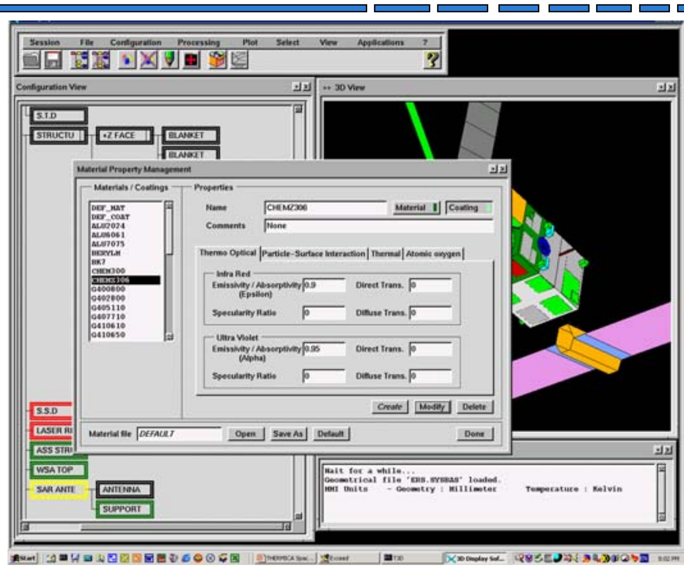
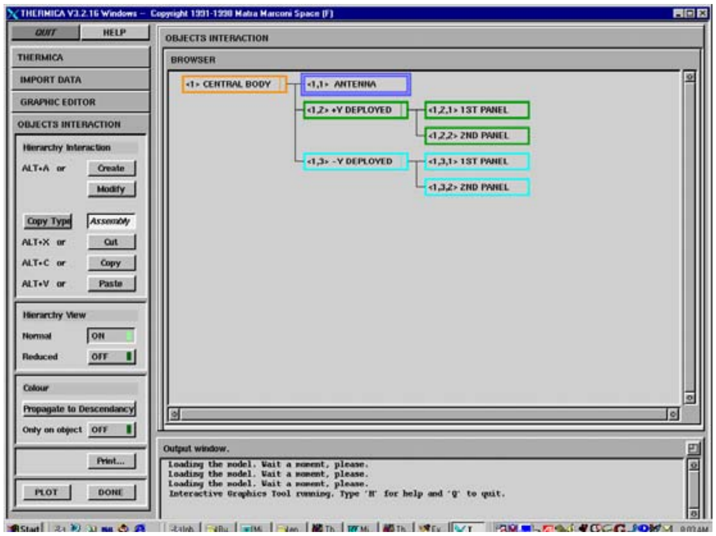
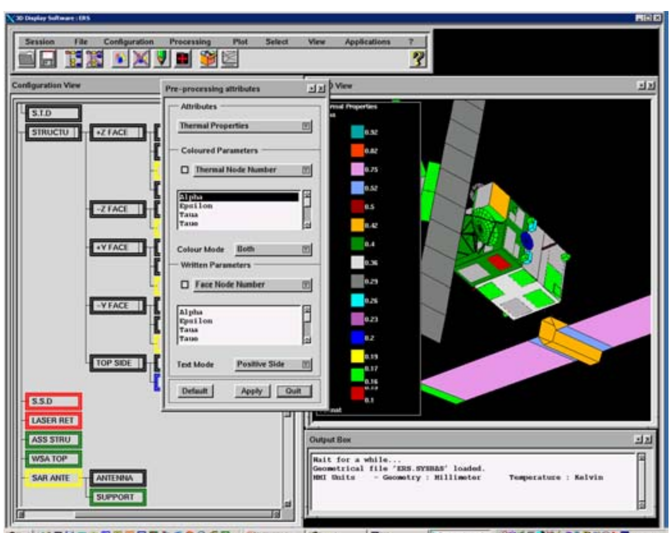
# Material Library



## Hierarchical Assembly of Parts




## Color Code by Material Properties



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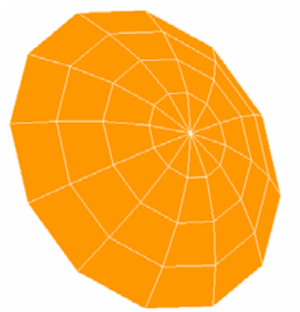
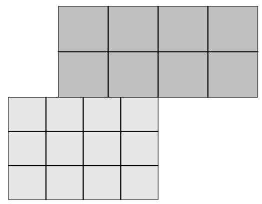
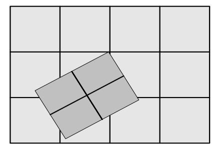
## Automatic Generation of Nodes and Conductors



Define mesh of objects



Edge to edge contact



Surface to surface contact

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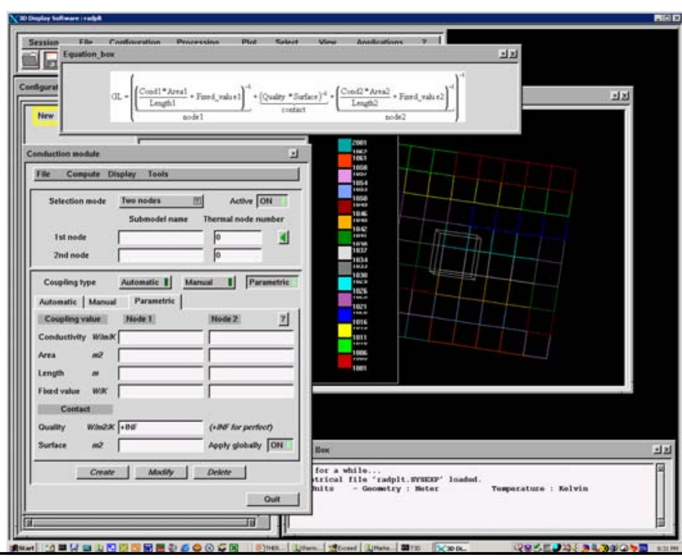
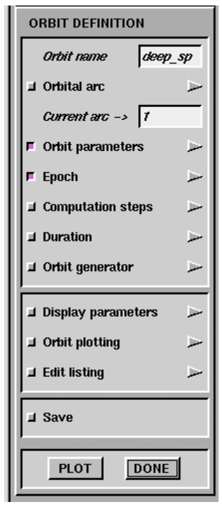
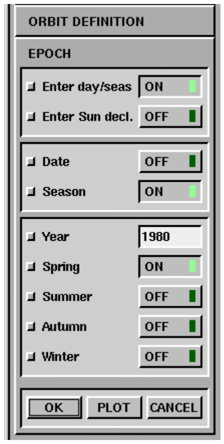
## Automatic Generation of Nodes and Conductors

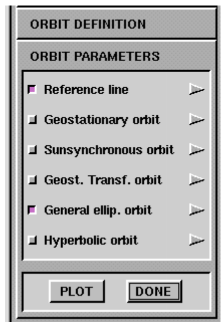


# Orbit Definition

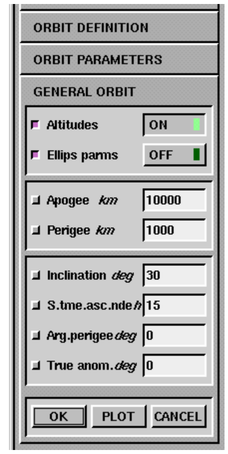



Date or Season



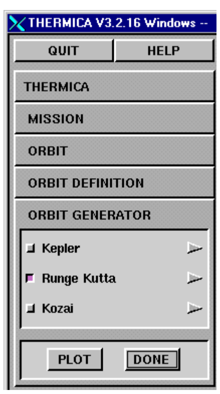

Orbit Types

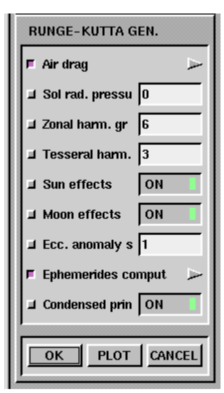


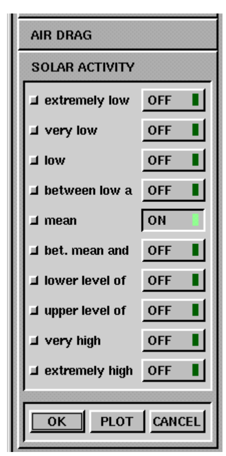

General Orbit Type

Main Orbit Definition Menu

# Full Features Orbital Modeling



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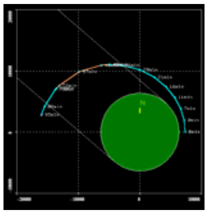
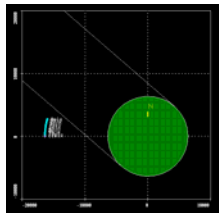
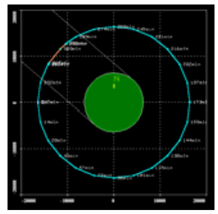
## Complex Orbits and are Graphically Setup and Displayed



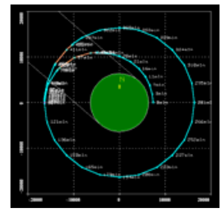
Arc #1



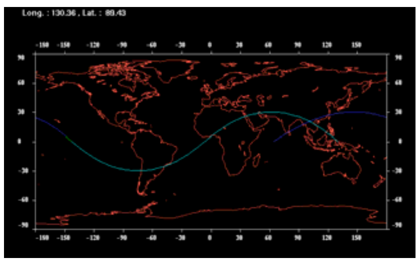
Arc #2

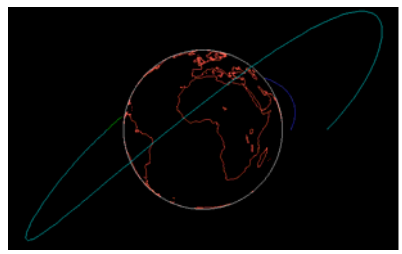


Arc #3



Combination of 3 Arcs





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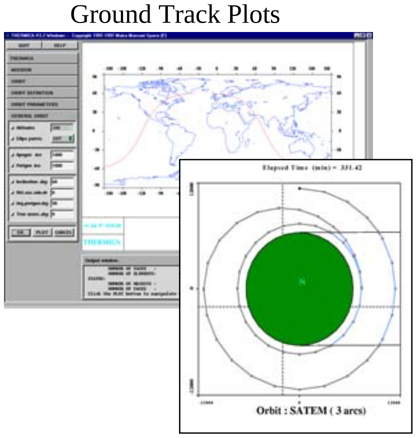
## Radiation Shape Model Builders Orientated Towards Spacecraft Thermal Design

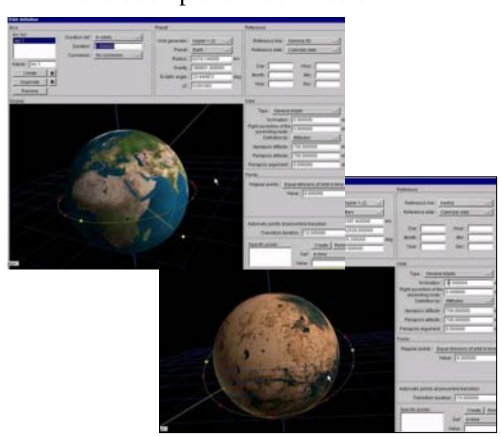
Example of mission planning screens from THERMICA

Ground Track Plots

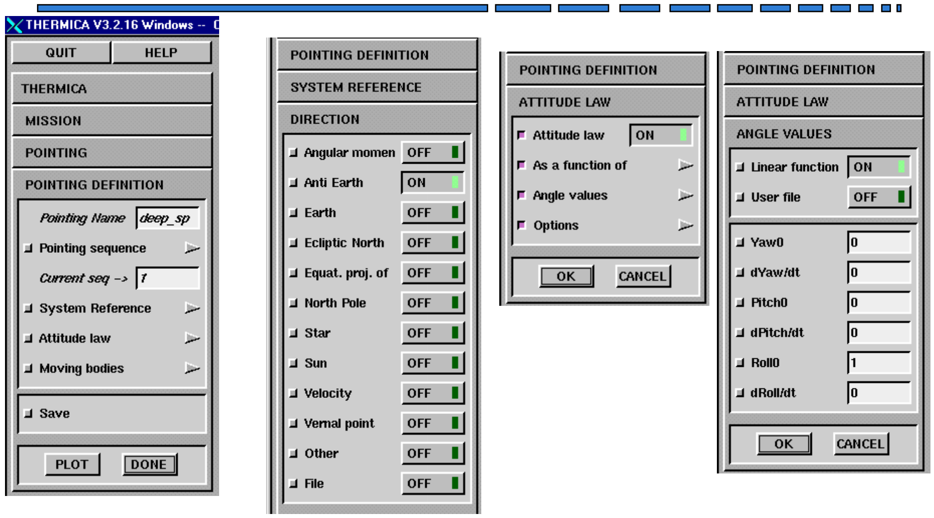
Orbit setup and visualization



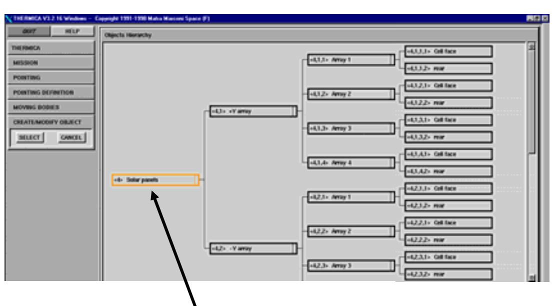

2D Orbital Plots



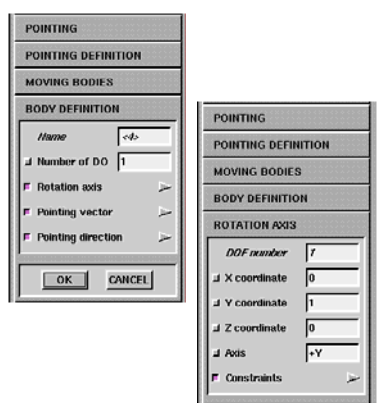
## Pointing, Moving Bodies and Orbit Maneuvering




## Moving Bodies



**Select a part from the assembly tree, and all connected parts move with it.**




**Define Number of DOF, rotation axis, constraints and pointing vectors**

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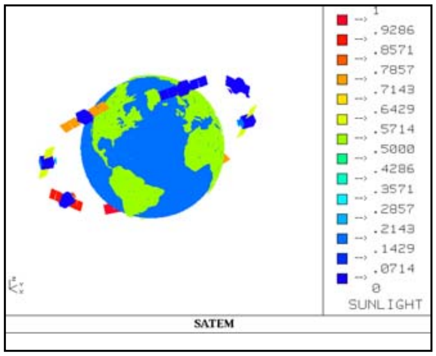
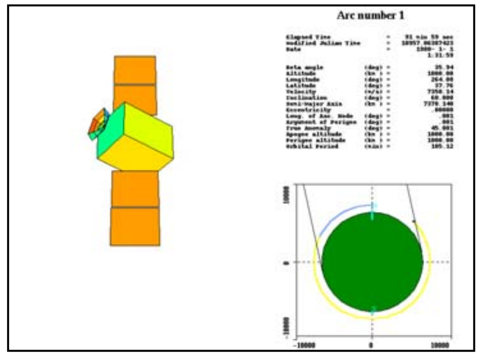
# Visual Verification with Plots and Animations




Orbital & Orientation 3D Plots




Shadowing & Orientation Animated Plots

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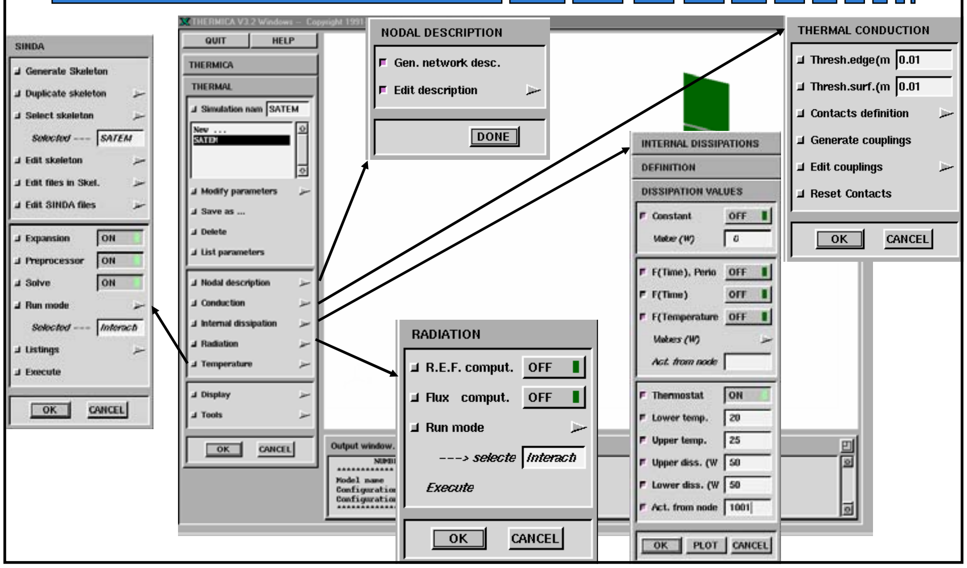
# Thermal Model Generation



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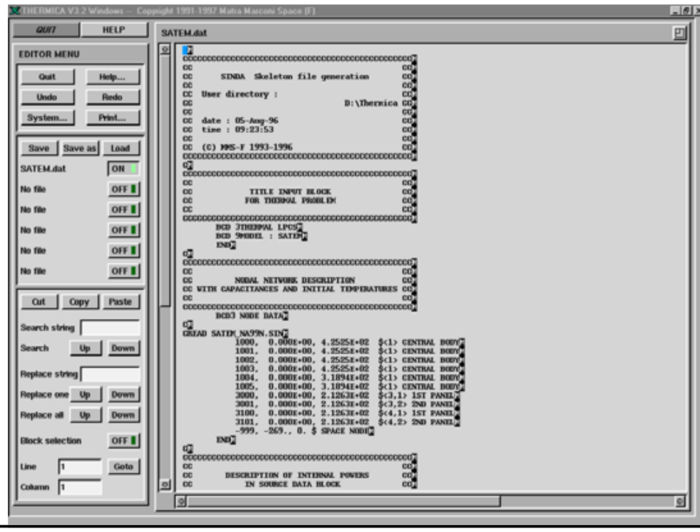
## Documented SINDA/G File Built-in Editor and Ability to use Skeleton files

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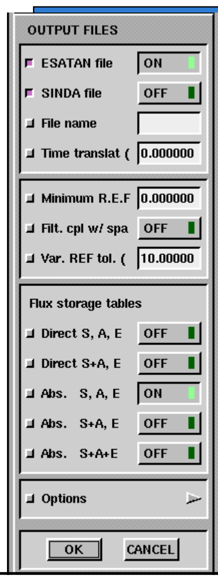
## SINDA/G or ESATAN

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            A= 3.0000E+00, ALP=   .250, EPS=   .810;
   D 1001 = '<1> CENTRAL BODY / BOX1', T=  0.000E+00, C= 4.2525E+02,
            A= 3.0000E+00, ALP=   .250, EPS=   .810;
   D 1002 = '<1> CENTRAL BODY / BOX1', T=  0.000E+00, C= 4.2525E+02,
            A= 3.0000E+00, ALP=   .250, EPS=   .810;
   D 1003 = '<1> CENTRAL BODY / BOX1', T=  0.000E+00, C= 4.2525E+02,
            A= 3.0000E+00, ALP=   .250, EPS=   .810;
   D 1004 = '<1> CENTRAL BODY / BOX1', T=  0.000E+00, C= 3.1894E+02,
            A= 2.2500E+00, ALP=   .250, EPS=   .810;
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            A= 2.2500E+00, ALP=   .250, EPS=   .810;
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   D 3000 = '<1,2,1> 1ST PANEL / REC1', T=  0.000E+00, C= 2.1263E+02,
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            A= 4.5000E+00, ALP=   .845, EPS=   .860;
   D 3101 = '<1,3,2> 2ND PANEL / REC1', T=  0.000E+00, C= 2.1263E+02,
            A= 4.5000E+00, ALP=   .845, EPS=   .860;
   B  999 = 'SPACE', T= -269;

       BCD 3NODE DATA
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           1001,  0.000E+00, 4.2525E+02  $<1> CENTRAL BODY / BOX1
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           1004,  0.000E+00, 3.1894E+02  $<1> CENTRAL BODY / BOX1
           1005,  0.000E+00, 3.1894E+02  $<1> CENTRAL BODY / BOX1
           2000,  0.000E+00, 6.3379E+03  $<1,1> ANTENNA / PARA1
           3000,  0.000E+00, 2.1263E+02  $<1,2,1> 1ST PANEL / REC1
           3001,  0.000E+00, 2.1263E+02  $<1,2,2> 2ND PANEL / REC1
           3100,  0.000E+00, 2.1263E+02  $<1,3,1> 1ST PANEL / REC1
           3101,  0.000E+00, 2.1263E+02  $<1,3,2> 2ND PANEL / REC1
           -999, -269., 0. $ SPACE NODE
```

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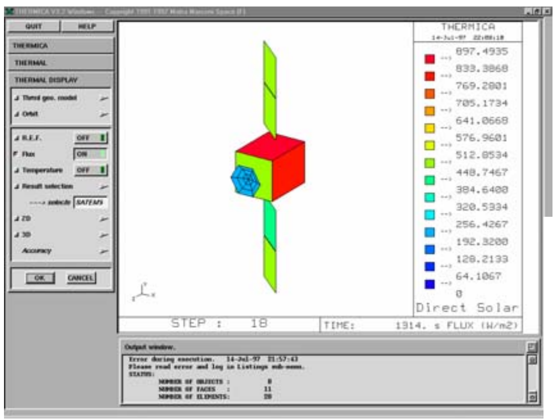
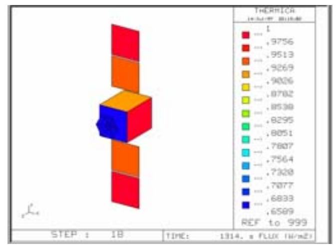
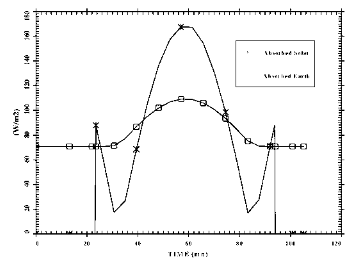
# Thermal Results Postprocessing







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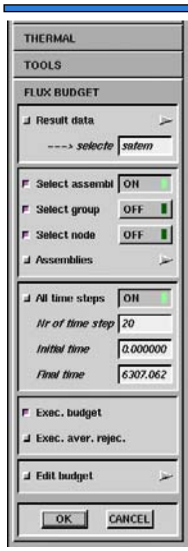
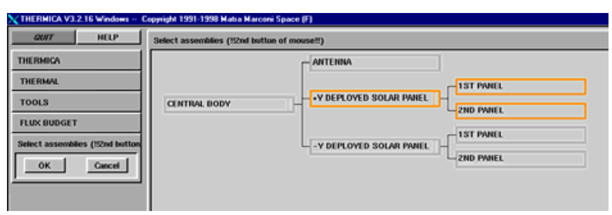
# Flux Budget Report




Sink Temperature Computation to facilitate interfacing

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## Transient Flux Budget Report on Entire Spacecraft

```
+-----------------------------------------------------------------------------+
|                                                                             |
|                           Flux budget analysis                              |
|                                                                             |
+-----------------------------------------------------------------------------+
+-------------------------------------+---------------------------------------+
|                                     |                                       |
| Budget on assembly or group         | CENTRAL BODY                          |
|                                     |                                       |
+-------------------------------------+---------------------------------------+
| Time                                | 0.0000E+00 min                        |
+-------------------------------------+---------------------------------------+
| Area                                | 3.4597E+01 m2                         |
| Equivalent emissivity               | 8.8955E-01                            |
| Thermal rejection                   |      .0000 W/m2                       |
| Mean radiative temperature          |     14.214 C                          |
| Ambient temperature                 |   -133.255 C                          |
| Thermal node temperature extremes   | [ -174.352 C ,    86.520 C ]          |
|                          at present | [  -65.152 C ,    48.688 C ]          |
|                                     |                                       |
+--------------------------+----------+----------+------+----------+----------+
|        Exchange with     | In. flux | Out. flux|   %  | Radiation|Conduction|
+--------------------------+----------+----------+------+----------+----------+
|                          |          |          |      |          |          |
|Sun + Alb. + IR           |1.1128E+04|          | 99.11|          |          |
|Internal dissip.          |1.0000E+02|          |   .89|          |          |
|CENTRAL BODY
|                          |          |          |      |          |          |
|Space                     |          |1.1228E+04|100.00|-1.123E+04|          |
|1ST PANEL
|2ND PANEL                 |          |5.1962E-01|   .00|          |          |
|ANTENNA
|2ND PANEL                 |          |5.0000E-01|   .00|          |          |
|Other assemblies          |          |2.4245E-01|   .00|          |          |
|-Y DEPLOYED SOLAR PANELS
|1ST PANEL
|+Y DEPLOYED SOLAR PANELS |          |1.0000E-01|   .00|          |          |
|                          |          |          |      |          |          |
|   -Cp.dT/dt              |          |          |      |          |          |
+--------------------------+----------+----------+------+----------+----------+
|   Total                  |1.1228E+04|1.1228E+04|100.00|-1.123E+04|-2.682E-07|
+--------------------------+----------+----------+------+----------+----------+
```

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## Orbit Average Flux Budget Report on +Y Deployed Solar Panel

```
+-----------------------------------------------------------------------------+
|                                                                             |
|                           Flux budget analysis                              |
|                                                                             |
+-----------------------------------------------------------------------------+
|                                                                             |
| Results from file   : satem.NTP                                             |
| Type of computation : Average rejection budget for                          |
|                     : assemblies or nodes group                             |
| Comp. date & time   : 24-Feb-99 at 11:21:17                                 |
|                                                                             |
+-----------------------------------------------------------------------------+
+-------------------------------------+---------------------------------------+
|                                     |                                       |
| Budget on assembly or group         | +Y DEPLOYED SOLAR PANELS              |
|                                     |                                       |
+-------------------------------------+---------------------------------------+
| Area                                |  9.0000E+00 m2                        |
| Equivalent emissivity               |  8.63E-01                             |
| Average thermal rejection           |  6.91E+00 W/m2                        |
| Average rejected flux               |  6.22E+01 W                           |
+-------------------------------------+---------------------------------------+
+-------------------------------------+---------------------------------------+
|                                     |                                       |
| Budget on assembly or group         | 1ST PANEL                            |
|
+-------------------------------------+---------------------------------------+
| Area                                |  0.0000E+00 m2                        |
| Equivalent emissivity               |  0.00E+00                             |
| Average thermal rejection           |  0.00E+00 W/m2                        |
| Average rejected flux               |  0.00E+00 W                           |
+-------------------------------------+---------------------------------------+
+-------------------------------------+---------------------------------------+
|                                     |                                       |
| Budget on assembly or group         | 2ND PANEL                             |
|                                     |                                       |
+-------------------------------------+---------------------------------------+
| Area                                |  0.0000E+00 m2                        |
| Equivalent emissivity               |  0.00E+00                             |
| Average thermal rejection           |  0.00E+00 W/m2                        |
| Average rejected flux               |  0.00E+00 W                           |
+-------------------------------------+---------------------------------------+
```

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# *THERMICA User Experience*

## *Lessons Learned*

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## Lessons Learned by Major Spacecraft Company

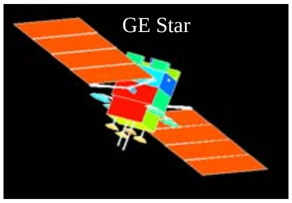
- Five to Ten Times More Product Produced (time wise) - Compared to other tools that were previously used
- Multi-discipline Design Support – provides insight on CONOPS, Star Tracker Viewing, Solar Collection
- Very Responsive To Proposal Activities
- Set New Standards For Quality & Timeliness
- Fifteen Major Satellite Programs Supported in Last 18 Months. (Teledesic, Ellipso, @Contact, Discoverer II, ReFly, GPS II F, Mars Sample Return, GE*, etc.)
- Easy to learn – requires no formal training budget
- Runs on a PC – eliminates costly Unix workstations

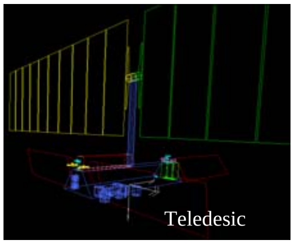
## Successful Use of THERMICA at a Major Aerospace Company

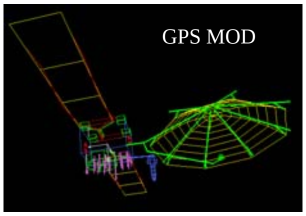
- A user friendly interface and easy to use geometry model building tools allow for rapid design concept model generation
- This permits thermal considerations to have an impact on the system design, mission planning and the concept of operations
- Key trades are also performed early on to produce a more optimal design
- THERMICA was used successfully on 14 different programs in the last two years and 4 major contracts were awarded as a result
- All this was accomplished by two analyst, demonstrating a productivity increase of more than 5 times greater than previously experienced

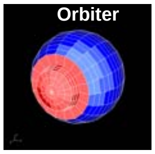
## THERMICA Permits Rapid Generation of Complex Thermal Models

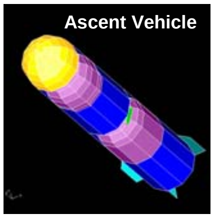
**These Models were built in 3 to 5 Days**

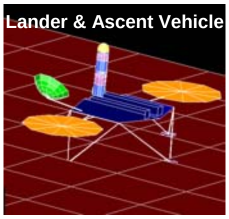


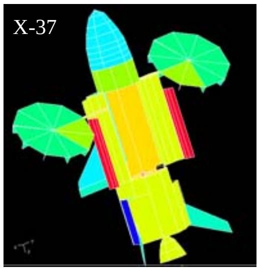




Mars Sample Return Mission

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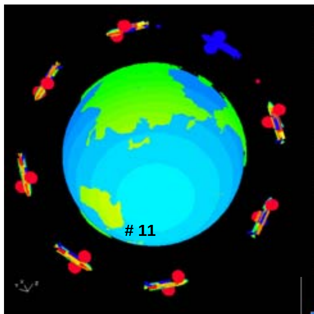
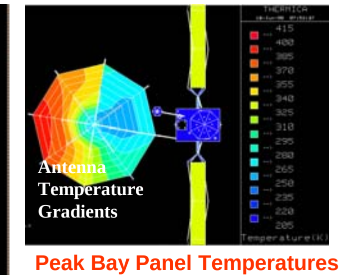
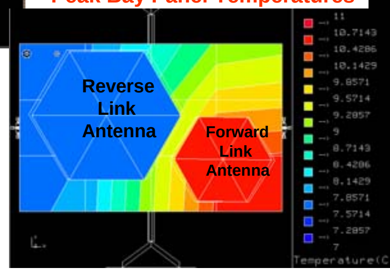
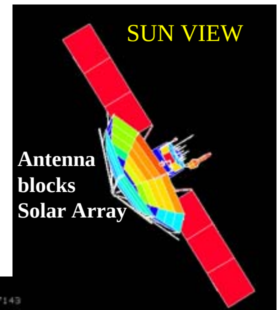
THERMICA Was Used for Problem Solving, Trades and Mission Planning




CONOPS for Min Radiator Heat Load And Max Solar Energy Collection

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# Summary of the THERMICA System

- Incorporates graphical model building with mathematical surfaces not just flat plates.
- Specular and diffuse radiation modeling.
- Complex spacecrafts can be modeled using a hierarchical assembly of parts.
- Numerous 2D, 3D and 3D animations are available to visualize almost input or calculated parameter.
- Design changes such as orbits, orientations, radiator sizes, powers, heater locations, can be easily made and the results displayed graphically.
- Software available for Windows 95/NT and most Unix workstations.