Appendix M

Insight HP3
Thermal Modelling with Thermal Desktop

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Abstract

The Heat-Flow and Physical Properties Probe (HP3) is an instrument package built by Deutsches Zentrum für Luft- und Raumfahrt (DLR) as a part of NASA-JPL Insight Mission (The Interior Exploration Using Seismic Investigations, Geodesy, and Heat Transport) which will investigate the interior structure and processes of Mars. The mission will be launched on a Type I trajectory to Mars in March of 2016.
The main subsystems of HP3 includes:

- Hammering mechanism , the Mole that penetrates below the Martian surface
- Support structure that houses the Mole prior to ground penetration
- Radiometer mounted on the lander
- Back-end electronics in the lander thermal enclosure

The thermal analysis and design of the HP3 Instrument for the landed phase of the mission have been performed by Active Space Technologies GmbH using Thermal Desktop and Sinda/Fluint. In the scope of the thermal analysis and design activities, the detailed thermal and geometrical models of each subsystem as well as the integrated models are created. Being composed of subsystems which are permanently mounted on the lander, deployed on the Mars surface after landing and deployed into the Martian soil, different external thermal environments are defined for each subsystem for the different phases of the mission, including the mars heating environment modelling. The detailed models are integrated on the simplified lander model and the reduced models of the subsystems are also created to be integrated into the detailed lander model.
The features of Thermal Desktop used for the different stages of the HP3 instrument thermal modelling and analysis process are presented:

- General features;
- Generation of thermal models;
- Integration of geometrical and thermal models
- Planet heating environment modelling;
- Post-processing;
- Data exchange.

Insight HP3
Thermal Modelling with Thermal Desktop

European Space Thermal Analysis Workshop 2014

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Asli Gencosmanoglu

14-15 October 2014

Estec, Nordwijk - The Netherlands

making space a global endeavour

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ActiveSpace Technologies GmbH

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HP3

The Heat-Flow and Physical Properties Probe (HP3) :

- Instrument package built by DLR as a part of NASA-JPL Insight Mission
- Investigate the interior structure and processes of Mars
- Will be launched on a Type I trajectory to Mars in March of 2016

The main subsystems of HP3:

- Hammering mechanism , the Mole that penetrates below the Martian surface
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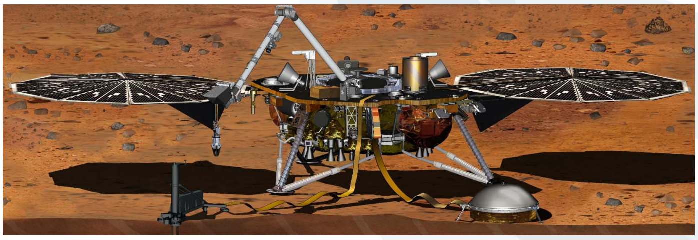

http://insight.jpl.nasa.gov/images.cfm?IM_ID=8301

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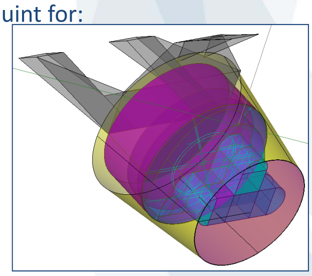
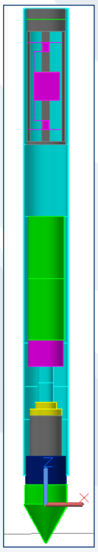
HP3 Thermal Models

Thermal Models are created using Thermal Desktop/Sinda Fluint for:

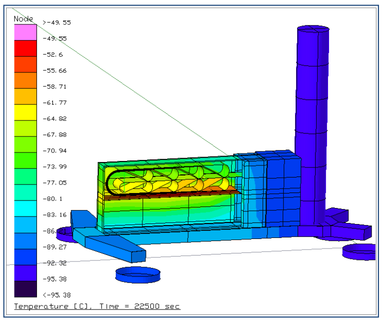
- Mole
- Support Structure
- Radiometer mounted on the lander
- Back-end electronics in the lander thermal enclosure



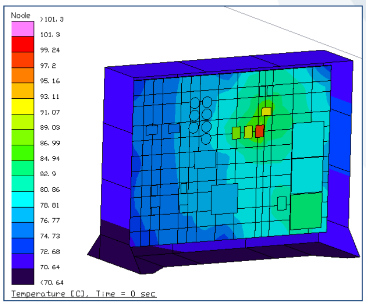
Radiometer



Mole



Support Structure



Back End Electronics

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Thermal Desktop Modelling

GENERAL FEATURES

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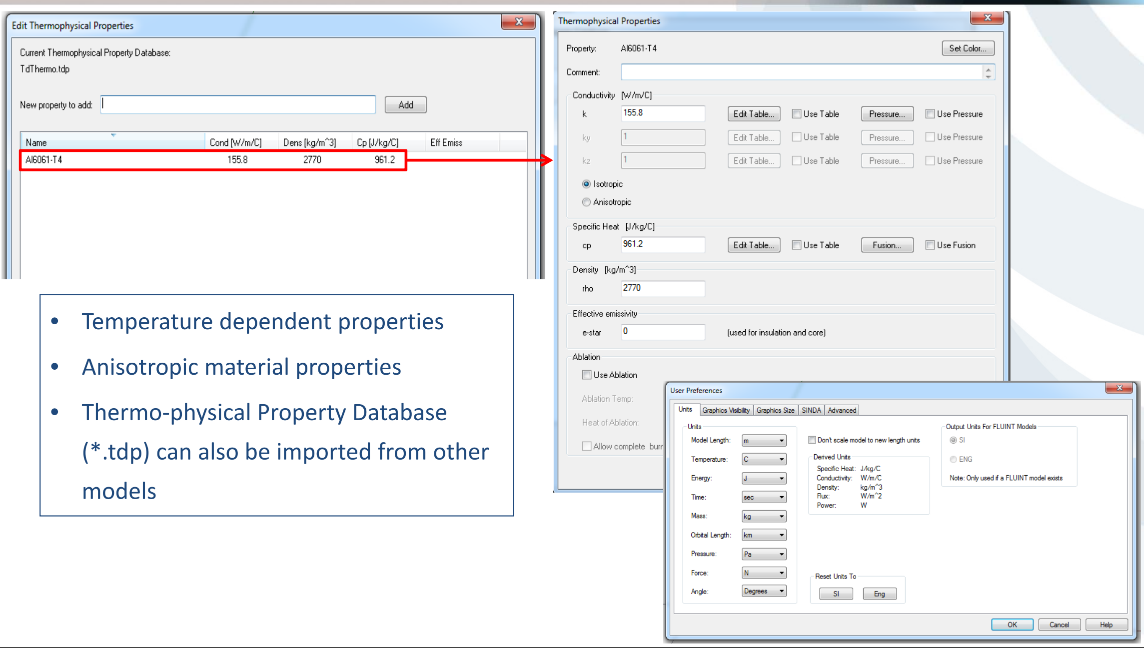
Thermophysical Property Database



- Temperature dependent properties
- Anisotropic material properties
- Thermo-physical Property Database (*.tdp) can also be imported from other models

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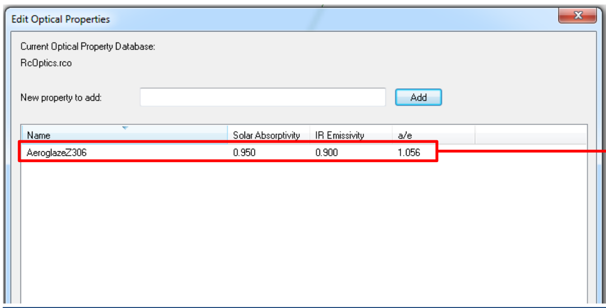
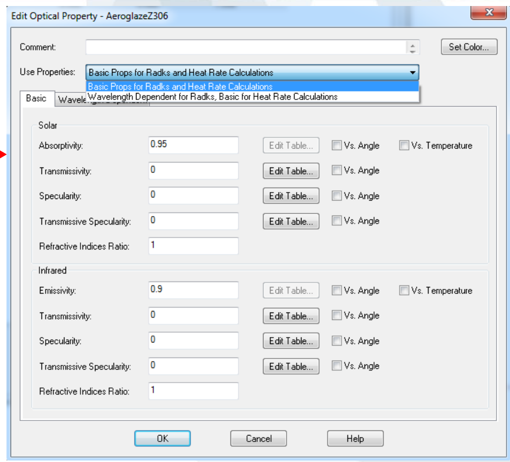
Optical Property Database





- Optical Property Database (*.tdp) can be imported from other models
- Wavelength, temperature and angle dependent properties can be defined

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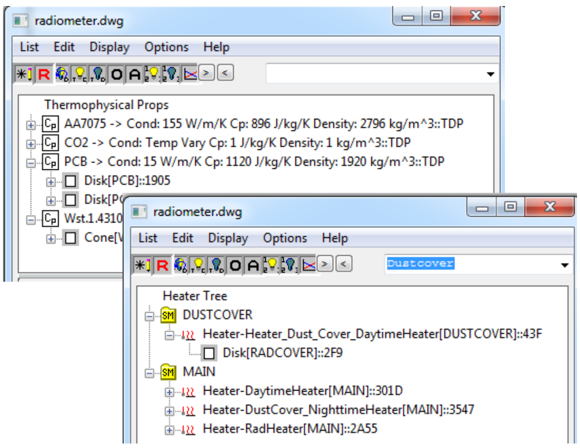
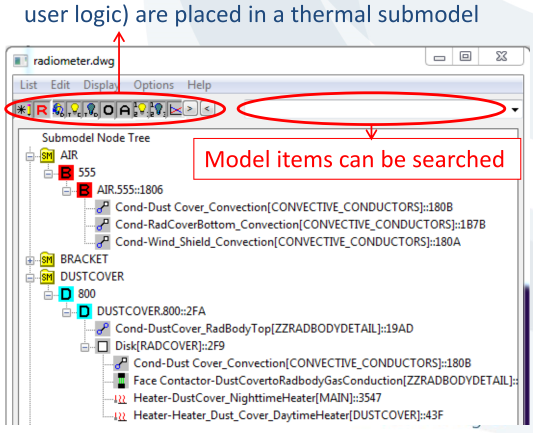
Model Browser

Several Listing Options:

- Optical Properties
- Thermo-physical Properties
- Heaters/Heat Loads
- Contactors
- Surfaces/solids etc.

- The thermal entities can be selected and edited from model browser menu
- The visibility of graphical objects can be adjusted
- The visibility of Node IDs can be turned ON/OFF
- Multiple edits can be performed
- All thermal entities (nodes, conductors, heat loads, user logic) are placed in a thermal submodel





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Thermal Desktop Modelling

GENERATION OF THERMAL MODELS

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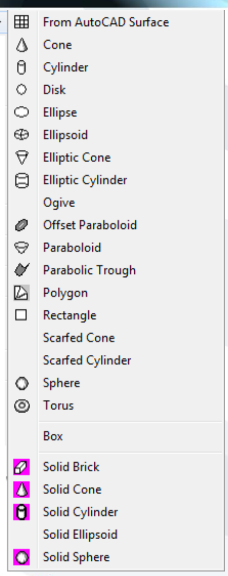
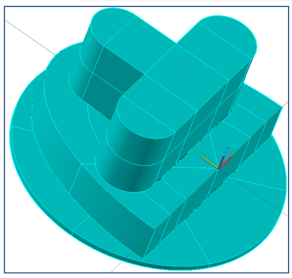
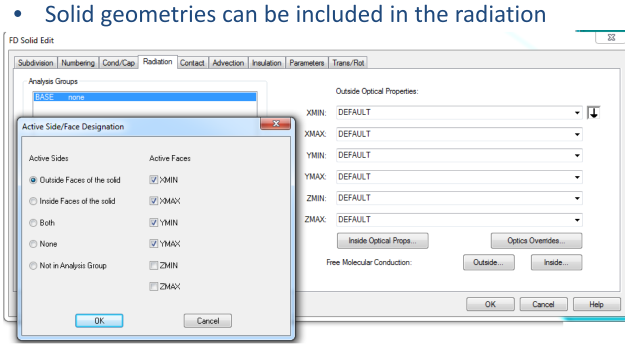
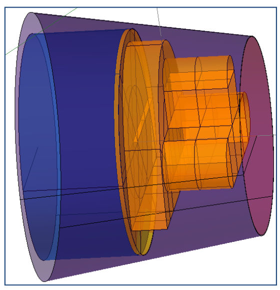
Radiometer-Finite Difference Solids

- ➢ Radiometer body temperature gradients are important
- ➢ Radiometer body radiative heat exchange
- Creating finite difference surfaces/solids using AutoCad interface
- Possibility to use AutoCad surfaces to create finite difference surfaces (drawback : irregular meshes)
- Solid geometries are useful when the through thickness gradients are important
- Solid geometries can be included in the radiation









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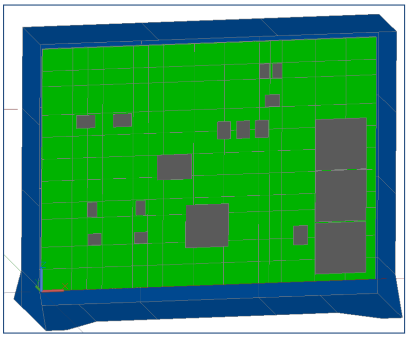
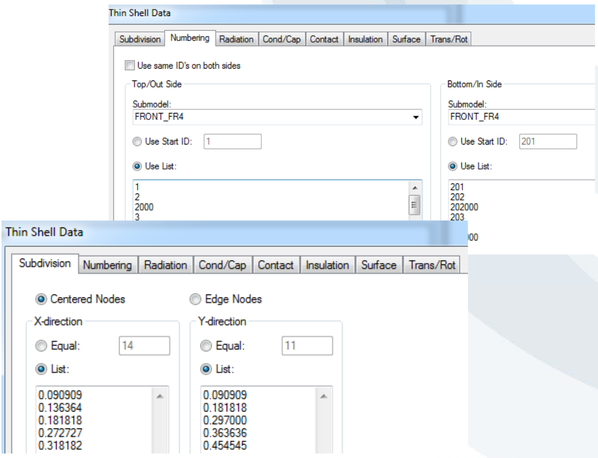
BEE-Thin Shell Data

- BEE PCB nodal break-down is adjusted to fit component dimensions
- It is important to have control on the node sizes
- It is important to have control on the node numbering, especially for the late stage modelling changes



- Possibility to create user defined sub-divisions
- Possibility to define node IDs manually
- Assigning different node IDs for different sides of the surface



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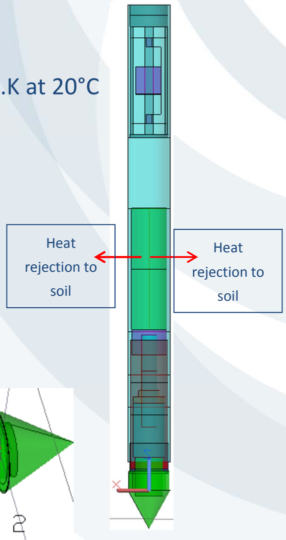
Mole-Mars CO_2 Gas Conduction

- Mars Atmosphere: 95.5% CO_2
- Surface Pressure : around 8 Torr
- Thermal conductivity of CO_2 varies from 0.010W/m.K at -60°C to ~0.016W/m.K at 20°C
- Gas conduction is dominant, clearances are small <0.3mm
- Pure gas conduction, no convection
- The Mole consists of many concentric cylinders

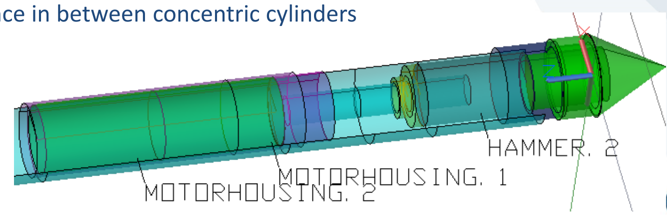
  Modelling of CO_2 conduction is important :
  - To estimate the required heater power for the motor
  - To estimate the maximum allowable operation time



- The gas conduction is modelled in radial direction: k(T)*(A/l)

  A: cylindrical area

  l : Clearance in between concentric cylinders



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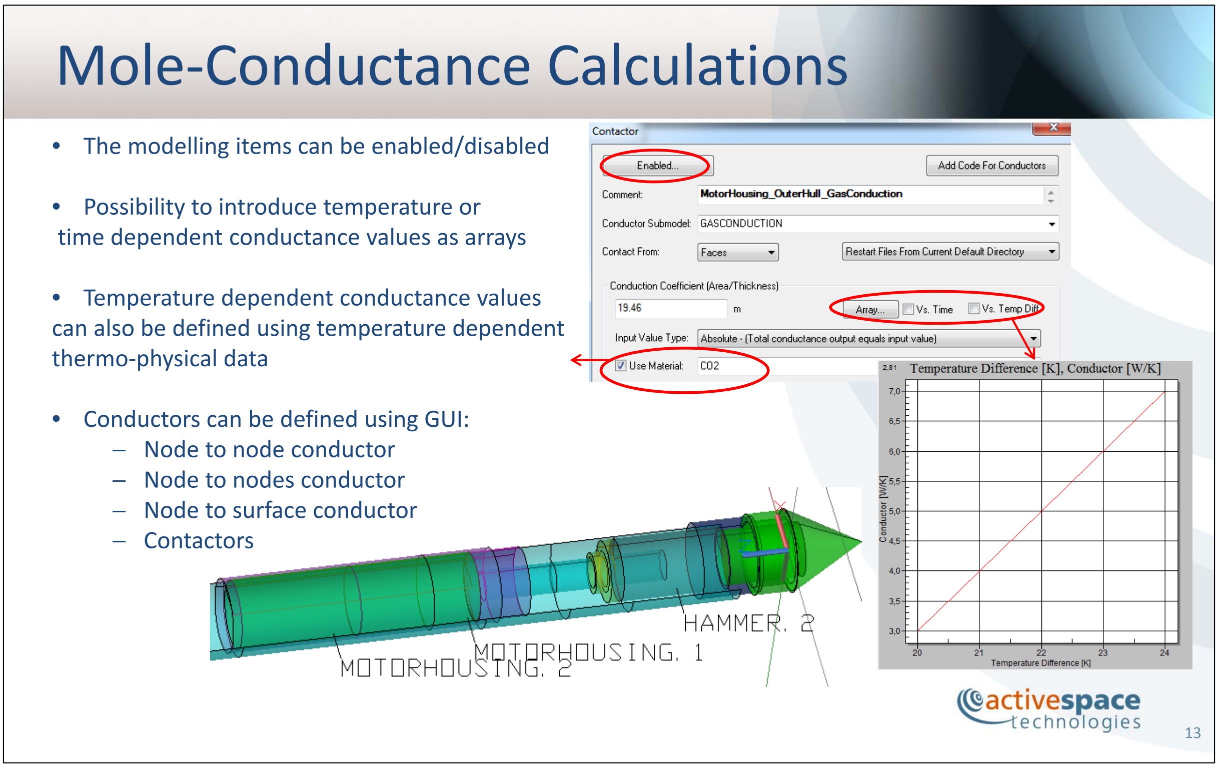
Mole-Conductance Calculations
• The modelling items can be enabled/disabled
• Possibility to introduce temperature or time dependent conductance values as arrays
• Temperature dependent conductance values can also be defined using temperature dependent thermo-physical data
• Conductors can be defined using GUI:
– Node to node conductor
– Node to nodes conductor
– Node to surface conductor
– Contactors
Contactor
Enabled...
Add Code For Conductors
Comment: MotorHousing_OuterHull_GasConduction
Conductor Submodel: GASCONDUCTION
Contact From: Faces
Restart Files From Current Default Directory
Conduction Coefficient (Area/Thickness)
19.46
m
Array...
Vs. Time
Vs. Temp Diff
Input Value Type: Absolute - (Total conductance output equals input value)
Use Material: CO2
Temperature Difference [K], Conductor [W/K]
Conductor [W/K]
Temperature Difference [K]
HAMMER. 2
MOTORHOUSING. 1
MOTORHOUSING. 2
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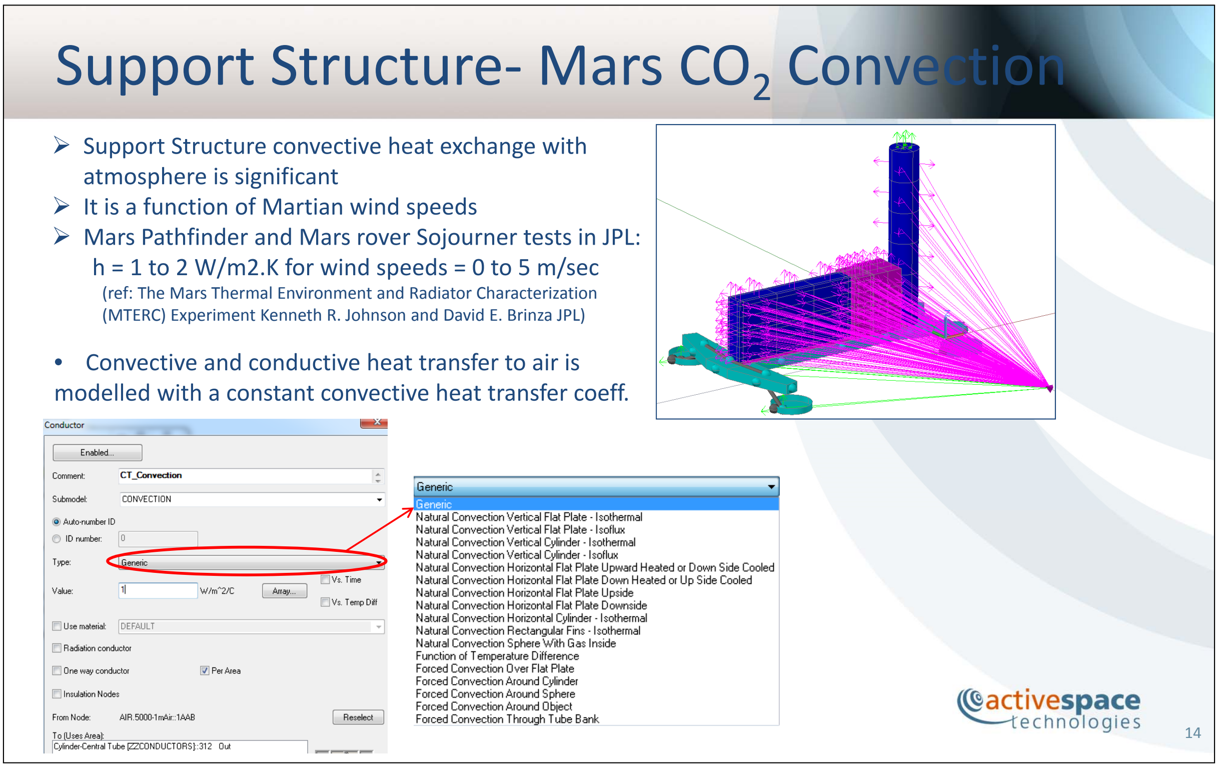
Support Structure- Mars CO_2 Convection
➢ Support Structure convective heat exchange with atmosphere is significant
➢ It is a function of Martian wind speeds
➢ Mars Pathfinder and Mars rover Sojourner tests in JPL:
h = 1 to 2 W/m2.K for wind speeds = 0 to 5 m/sec
(ref: The Mars Thermal Environment and Radiator Characterization (MTERC) Experiment Kenneth R. Johnson and David E. Brinza JPL)
• Convective and conductive heat transfer to air is modelled with a constant convective heat transfer coeff.
Conductor
Enabled...
Comment: CT_Convection
Submodel: CONVECTION
Auto-number ID
ID number:
Type: Generic
Value: 1 W/m^2/C
Array...
Vs. Time
Vs. Temp Diff
Use material: DEFAULT
Radiation conductor
One way conductor
Per Area
Insulation Nodes
From Node: AIR.5000-1mAir::1AAB
Reselect
Generic
Natural Convection Vertical Flat Plate - Isothermal
Natural Convection Vertical Flat Plate - Isoflux
Natural Convection Vertical Cylinder - Isothermal
Natural Convection Vertical Cylinder - Isoflux
Natural Convection Horizontal Flat Plate Upward Heated or Down Side Cooled
Natural Convection Horizontal Flat Plate Down Heated or Up Side Cooled
Natural Convection Horizontal Flat Plate Upside
Natural Convection Horizontal Flat Plate Downside
Natural Convection Horizontal Cylinder - Isothermal
Natural Convection Rectangular Fins - Isothermal
Natural Convection Sphere With Gas Inside
Function of Temperature Difference
Forced Convection Over Flat Plate
Forced Convection Around Cylinder
Forced Convection Around Sphere
Forced Convection Around Object
Forced Convection Through Tube Bank
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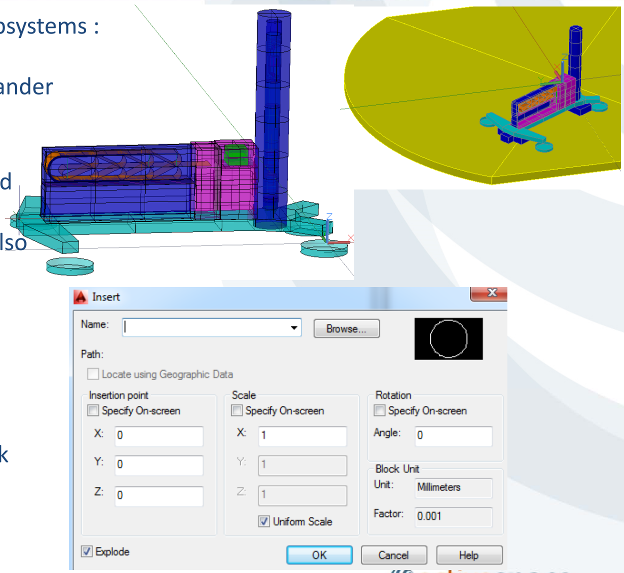
HP3-Integrating Thermal Models

- The Support Structure is housing the other subsystems : Mole, TLM, Tethers etc.
- The Support Structure itself mounted on the lander before deployment

- Entire thermal desktop models can be inserted to merge thermal models
- A subset of thermal desktop submodels can also be inserted (defined subset should be exported first)
- Thermo-optical and thermo-physical data bases should be imported separately

- Once the defined models are inserted as a `block` then it is exploded to convert the block into individual entities
- Sub-model names should be checked
- Boundaries should be checked



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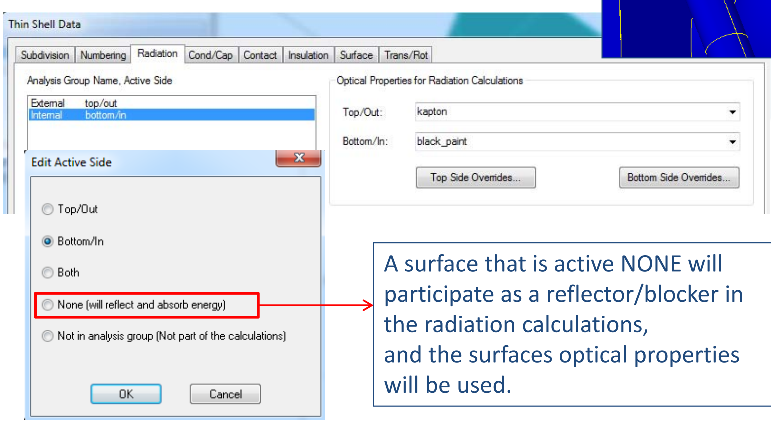
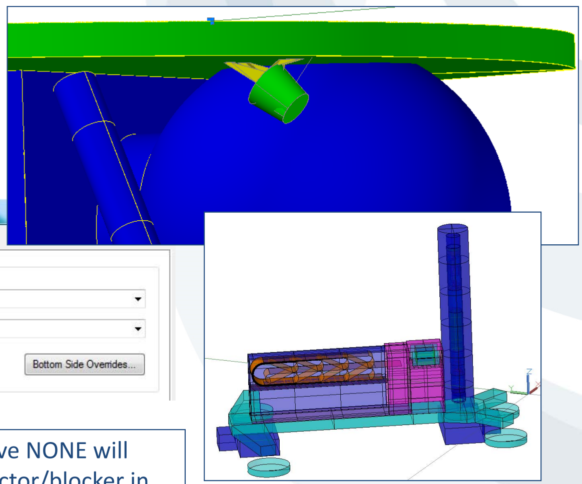
Radiation Analysis Groups

- Radiation analysis groups can be created for radiation and external heating calculations
- The radiation groups can be included/excluded from the analysis
- The active sides can be displayed by colors for the selected radiation group



A surface that is active NONE will participate as a reflector/blocker in the radiation calculations, and the surfaces optical properties will be used.



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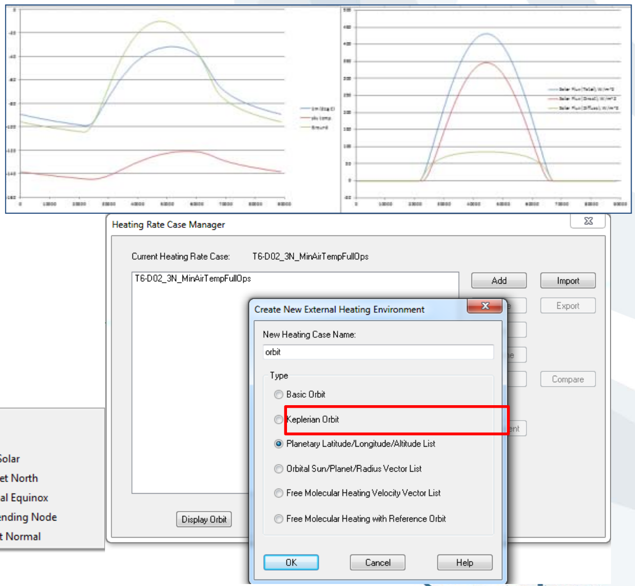
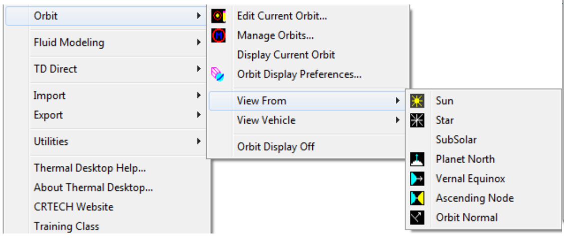
HP3- External Heating Modelling

- Several thermal analysis cases depending on the environmental parameters and the mission
- Multiple orbit definitions can be created
- Orbits can be imported from other Thermal Desktop models
- Orbits can be viewed from preset points
- Planetary Latitude/Longitude/Altitude List option is available for planet surface external heating modelling





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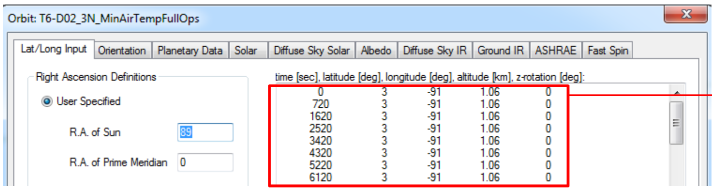
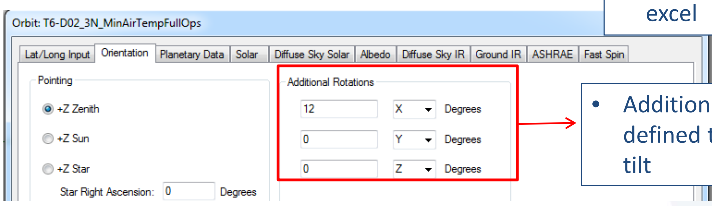
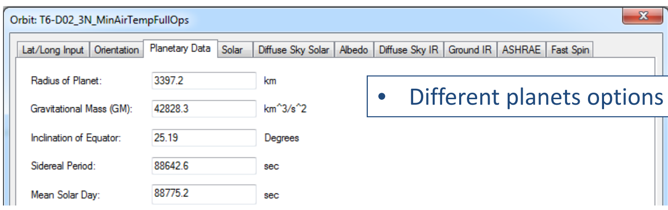
Planetary Heating Environment



- Vehicle positions as a function of time, input as latitude, longitude and altitude. For stationary vehicles: same values at each time step)
- Inputs can be cut/pasted from excel



- Additional rotations can be defined to account for lander tilt



- Different planets options can be selected

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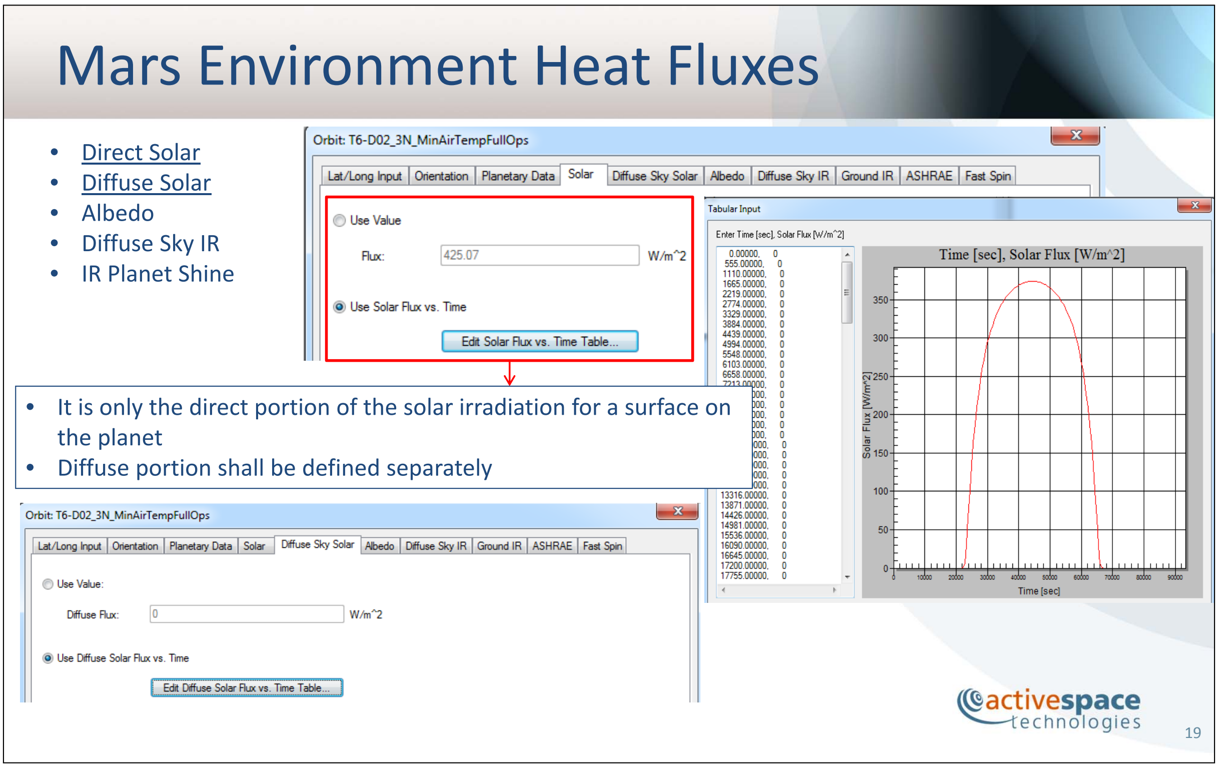
Mars Environment Heat Fluxes
Direct Solar
Diffuse Solar
Albedo
Diffuse Sky IR
IR Planet Shine
Orbit: T6-D02_3N_MinAirTempFullOps
Lat/Long Input | Orientation | Planetary Data | Solar | Diffuse Sky Solar | Albedo | Diffuse Sky IR | Ground IR | ASHRAE | Fast Spin
Use Value
Flux: 425.07 W/m^2
Use Solar Flux vs. Time
Edit Solar Flux vs. Time Table...
Tabular Input
Enter Time [sec], Solar Flux [W/m^2]
Time [sec], Solar Flux [W/m^2]
Solar Flux [W/m^2]
Time [sec]
It is only the direct portion of the solar irradiation for a surface on the planet
Diffuse portion shall be defined separately
Orbit: T6-D02_3N_MinAirTempFullOps
Lat/Long Input | Orientation | Planetary Data | Solar | Diffuse Sky Solar | Albedo | Diffuse Sky IR | Ground IR | ASHRAE | Fast Spin
Use Value:
Diffuse Flux: 0 W/m^2
Use Diffuse Solar Flux vs. Time
Edit Diffuse Solar Flux vs. Time Table...
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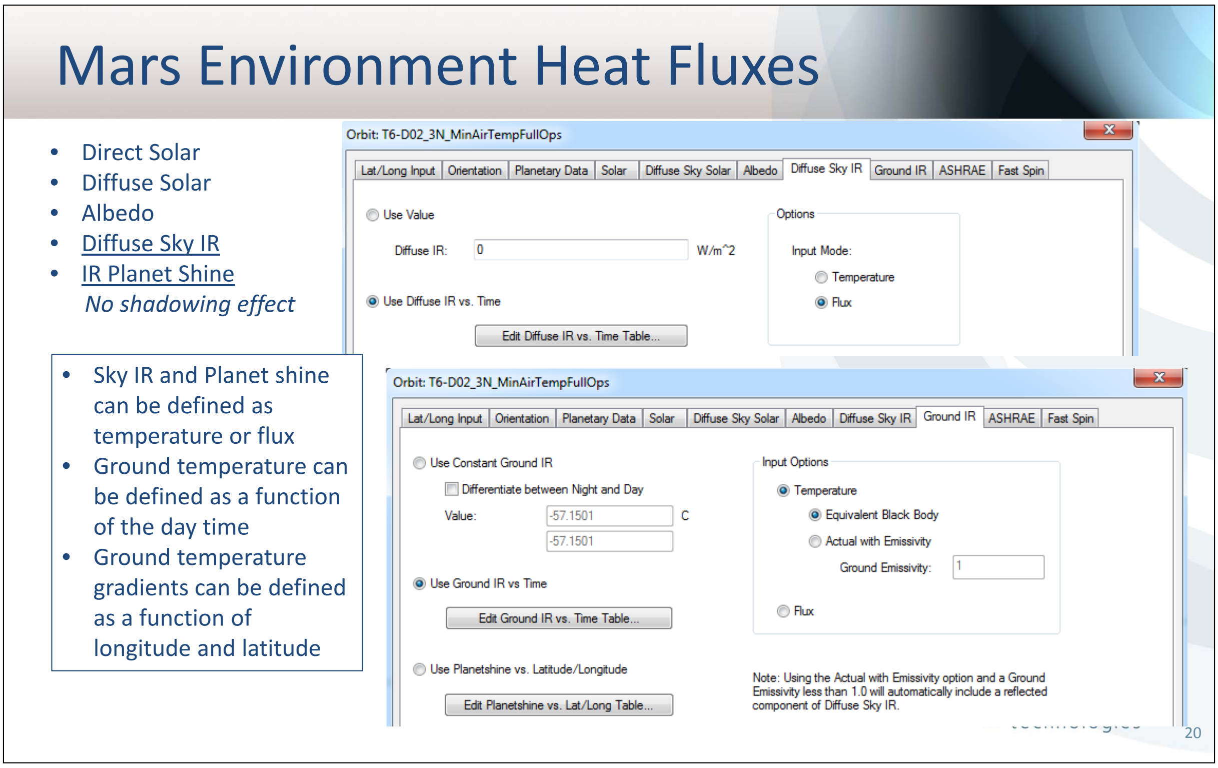
Mars Environment Heat Fluxes
Direct Solar
Diffuse Solar
Albedo
Diffuse Sky IR
IR Planet Shine
No shadowing effect
Sky IR and Planet shine can be defined as temperature or flux
Ground temperature can be defined as a function of the day time
Ground temperature gradients can be defined as a function of longitude and latitude
Orbit: T6-D02_3N_MinAirTempFullOps
Lat/Long Input | Orientation | Planetary Data | Solar | Diffuse Sky Solar | Albedo | Diffuse Sky IR | Ground IR | ASHRAE | Fast Spin
Use Value
Diffuse IR: 0 W/m^2
Use Diffuse IR vs. Time
Edit Diffuse IR vs. Time Table...
Options
Input Mode:
Temperature
Flux
Orbit: T6-D02_3N_MinAirTempFullOps
Lat/Long Input | Orientation | Planetary Data | Solar | Diffuse Sky Solar | Albedo | Diffuse Sky IR | Ground IR | ASHRAE | Fast Spin
Use Constant Ground IR
Differentiate between Night and Day
Value: -57.1501 C
-57.1501
Use Ground IR vs Time
Edit Ground IR vs. Time Table...
Use Planetshine vs. Latitude/Longitude
Edit Planetshine vs. Lat/Long Table...
Input Options
Temperature
Equivalent Black Body
Actual with Emissivity
Ground Emissivity: 1
Flux
Note: Using the Actual with Emissivity option and a Ground Emissivity less than 1.0 will automatically include a reflected component of Diffuse Sky IR.
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Thermal Desktop Modelling

POST PROCESSING

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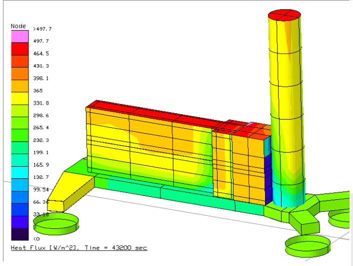
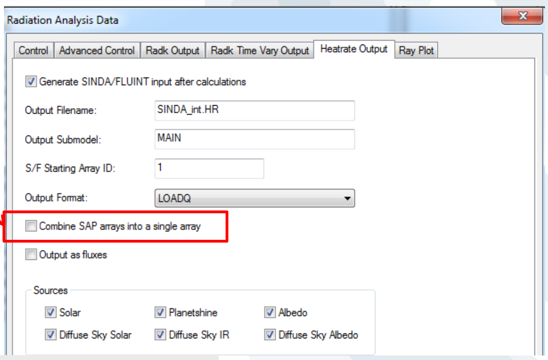
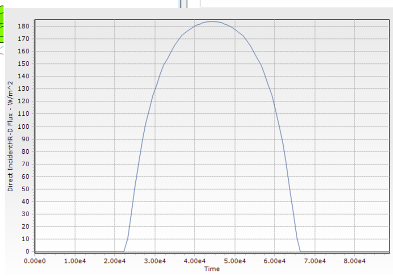
SS-Post Processing of Heat Fluxes

- All heat fluxes can be stored separately and post-processed when the radiation and heating calculations are completed







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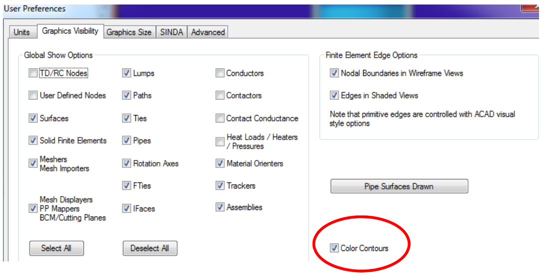
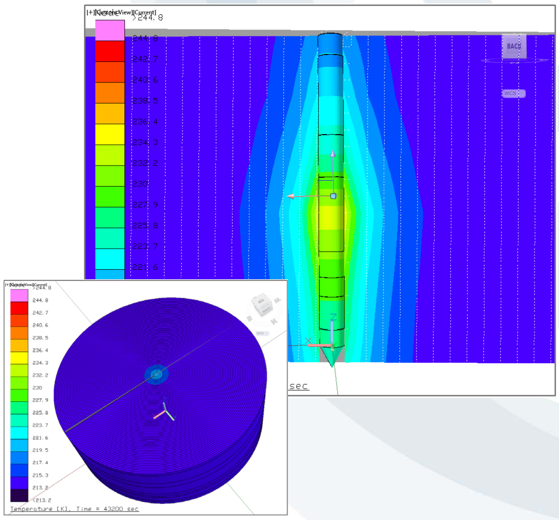
Soil- Post Processing Cutting Plane

- Visualization of results within a solid object
- Mapping the temperature results
- Domain Tag sets can be created to select the solids to be included in the cutting plane

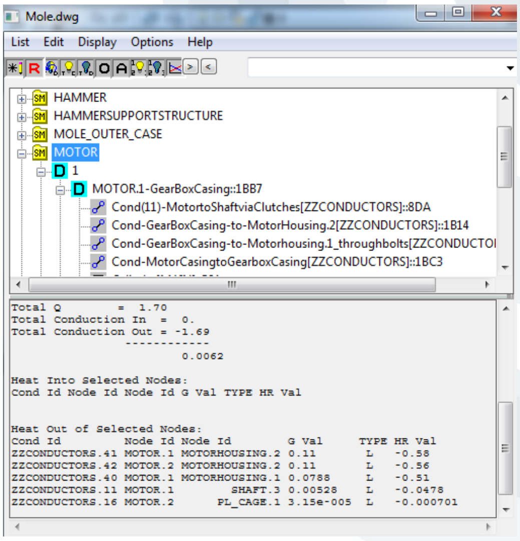




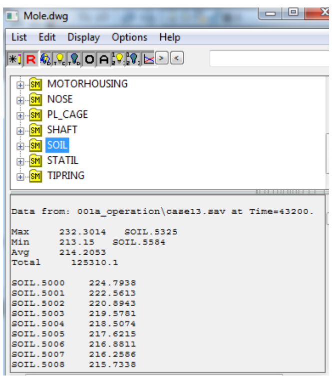
Post Processing – Model Browser

Heat Map:

- The heat flow in between nodes can be listed from Model Browser, selecting the individual nodes or submodels
- The radiative and conductive heat flows are listed separately
- No visual thermal map generation, each node or submodel is displayed separately



Temperature List:



Thermal Desktop Modelling

DATA EXCHANGE

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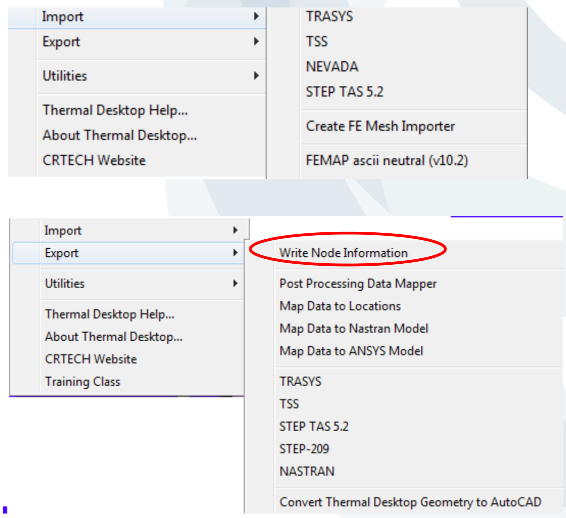
Importing/Exporting Models

- Geometric models can be imported from other radiation analysis codes
- Only the surface types supported by Thermal Desktop are imported
- The capacitance and conductance values can be assigned once the geometries are imported into Thermal Desktop
- Node locations , current post-processed values, surface areas can be exported into a text file



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Thank you for the attention!

For further information, please visit our website

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References

- Thermal Desktop user manual
- Kenneth R. Johnson and David E. Brinza JPL 001CES-178 “The Mars Thermal Environment and Radiator Characterization (MTERC) Experiment“
- Pradeep Bhandari, Paul Karlmann, Kevin Anderson and Keith Novak Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109 “CO2 Insulation for Thermal Control of the Mars Science Laboratory“

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