Appendix P

Gas conduction and convection modelling techniques for the ExoMars Rover

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Abstract

The operation of the ExoMars rover in the gaseous atmosphere at Mars's surface has led to several challenges in the thermal analysis. Many parameters not normally encountered in spacecraft thermal analysis - such as wind speed - have been considered. To simulate the heat transfer to the environment, the external nodes couple to a single node via a convection modelling subroutine - switching between natural and forced convection depending on the wind-speed. Due to the complex geometry inside the rover, the approach for the internal model has been to use multiple gas nodes coupled to the geometry either via conduction or convection. ESATAN-TMS tools such as; non-geometric gas nodes for visualisation, contact zones for calculating gas node coupling areas and switching flags for heat transfer method have also been used to aid analysis tasks. Modelling techniques and the choice of thermal heat transfer approach based on the geometry are discussed in this presentation.

Gas conduction and convection modelling techniques for the ExoMars Rover

30th European space thermal analysis workshop

Joshua Katzenberg
5-6th October 2016

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Gas conduction and convection modelling for the ExoMars rover

The ExoMars Rover

The ExoMars Programme comprises of two missions and is conducted with the broad cooperation of Roscosmos. TAS-I is the prime contractor for the Rover Module and Airbus Defence & Space is developing the Rover Vehicle.

- The 2016 mission consists of a Trace Gas Orbiter and an EDL Demonstrator Module
- The 2020 mission consists of a Carrier Module and a Descent Module with a Rover and a stationary Landing Platform
- The programme is a large International Cooperation with Roscosmos and some contributions from NASA

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Gas conduction and convection modelling for the ExoMars rover

Overview

- Convection theory overview
- Gas convection modelling for the ExoMars external model
- Gas modelling for the ExoMars internal model
- Automatic generation of gas conductive coupling areas
- Cruise cases

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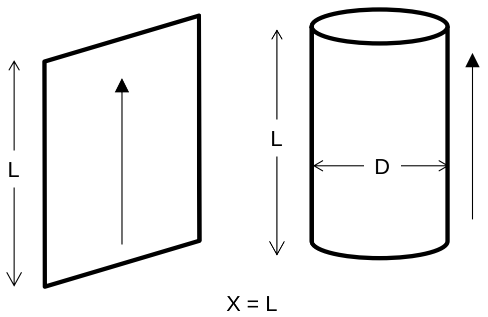
Gas conduction and convection modelling for the ExoMars rover

Convection theory overview

- The convective coupling is based on constants, correction factors and empirical formulae.
- This in turn is based on the geometry.



- L (or X) is the characteristic length
  - This can be the length of the flat plate (node) or the diameter of a cylinder
- Only flat plates and cylinders have been considered in the ExoMars model

- The constants are based on the orientation of the geometry:
  - Vertical plates/cylinders with large diameters
  - Horizontal plate facing upwards
  - Horizontal plate facing downwards

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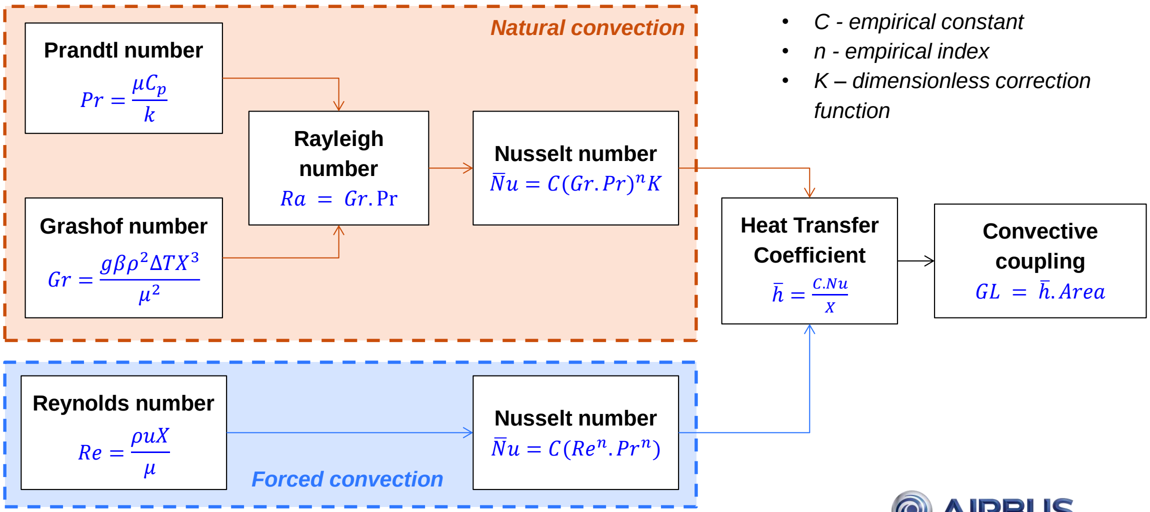
Gas conduction and convection modelling for the ExoMars rover

Convection theory overview

- Convection increases the heat transfer from a surface to its environment
- Two types of convection modelled – natural and forced (laminar)
- The basic formulation of the convective coupling subroutine is shown below



- *C - empirical constant*
- *n - empirical index*
- *K – dimensionless correction function*

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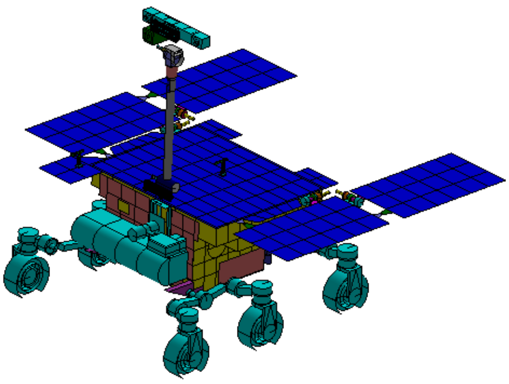
Gas conduction and convection modelling for the ExoMars rover

Gas convection modelling for the ExoMars external model

- The external model uses only convective couplings.
- Wind in the Martian environment determines if natural or forced convection is used.
  - Forced convection adds a Reynolds number term to the Nusselt number
- Each external node is coupled to a single environment boundary node.
- Each coupling assumes the full wind speed in the worst case direction – pessimistic approach for cold cases



Two convective cases:

- Wind speed = 0m/s
- Hot case – natural convection

- Wind speed = 30m/s
- Cold case – forced convection

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Gas convection modelling for the ExoMars external model

- The area of each node is generated via the GMM and used in the coupling calculation by the subroutine.

```
D1502 = 'ROVER_VEHICLE', T = 0.0,
A = 0.002348, ALP = 0.368000, EPS = 0.150000,
        FX = -0.444568, FY = 0.372371, FZ = 0.133114;
```

```
GL(10000,92000) = CONVEZ(10000,92000, 1, 7.000E-2 , 3 , 12 );
```

CONVEZ(convN, convM, Intext, Xcha,inatu,iforce)

Input description
convN - INTEGER - Node number to be coupled to gas
convM - INTEGER - Gas node number
Intext - INTEGER - Internal or external gas flag, 0 = Internal, 1 = External
Xcha - REAL - Characteristic length
inatu - INTEGER - Integer corresponding to the natural convection equation for a specific geometry, can take values of 1 to 4
iforce - INTEGER - Integer corresponding to the forced convection equation for a specific geometry, can take values of 11 to 13

Gas convection area method for the ExoMars external model

- Convection area code example:

```
GL(DMA:2500110,92000) = CONVEZ_AREA(INTNOD(DMA,2500110),
INTNOD(CURRENT,92000),3.941E-4,  1 , 1.120E-2 , 1 , 12) * CRUISE_CASE;
```

CONVEZ_AREA(convN, convM, Narea, Intext, Xcha,inatu,iforce)

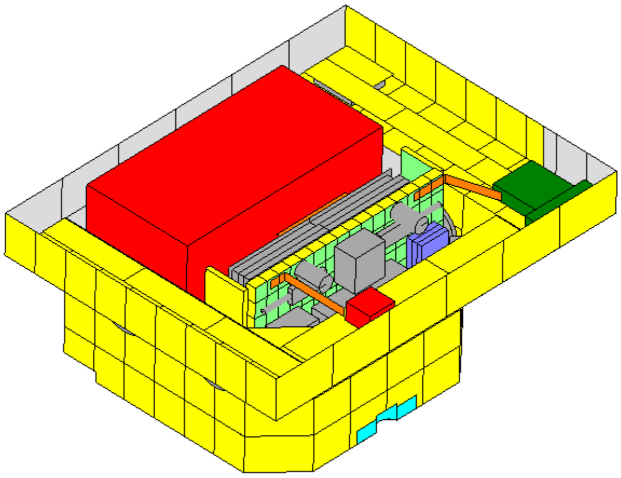
Input description
convN - INTEGER - Node number to be coupled to gas (internal node number, obtained using INTNOD function)
convM - INTEGER - Gas node number(internal node number, obtained using INTNOD function)
Narea – REAL – Node area
Intext - INTEGER - Internal or external gas flag, 0 = Internal, 1 = External
Xcha - REAL - Characteristic length
inatu - INTEGER - Integer corresponding to the natural convection equation for a specific geometry, can take values of 1 to 4
iforce - INTEGER - Integer corresponding to the forced convection equation for a specific geometry, can take values of 11 to 13

- Cannot parse submodel name as string into the subroutine if the GL is calculated at a lower level in the model tree.
- INTNOD returns the internal node number from submodel name.
- Internal model calculated via same method when area considered.

Gas conduction and convection modelling for the ExoMars rover

Gas modelling for the ExoMars internal model

- The internal model can use conduction or convection
- It has been broken down into multiple gas nodes
  - This allows gradients to be observed



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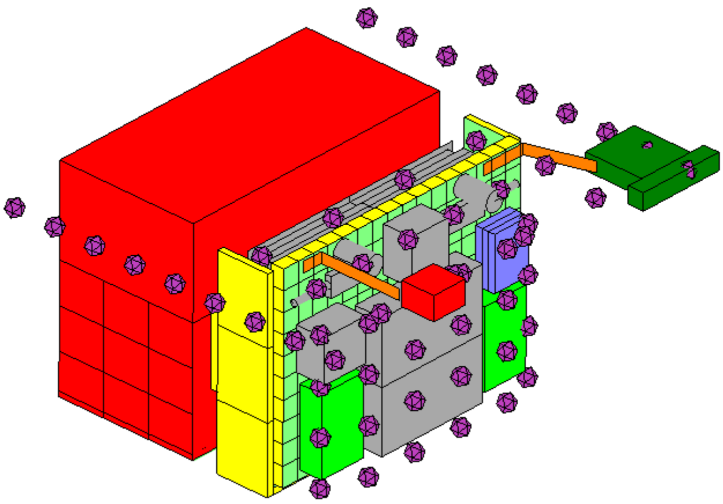
Gas conduction and convection modelling for the ExoMars rover

Non-geometric nodes for the ExoMars internal model

- To act as a visual aid, non-geometric nodes have been added to the GMM
- Helps determine couplings for the TMM



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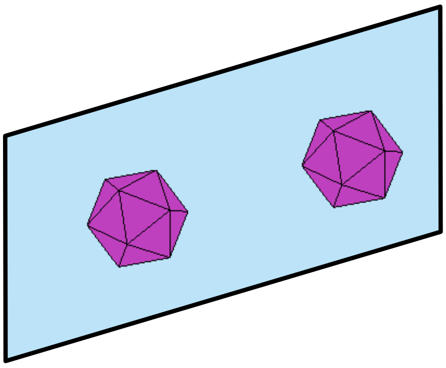
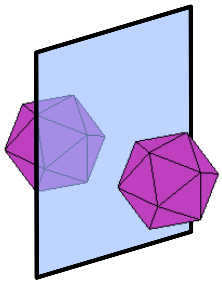
Gas convection method for the ExoMars internal model

- Only natural convection is considered in the internal model
- Convection will only occur in gaps greater than ~30mm
- Manual checks on gap sizes - Conduction used if gap less than ~30mm

- Certain nodes will be double-sided or cover multiple gas nodes
- The convection subroutine is updated here to scale the coupling based on area (CONVEZ_AREA method)



Single node to multiple gas nodes

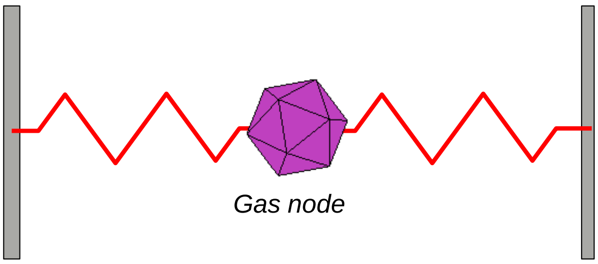


Double-sided node to multiple gas nodes

Gas conduction and convection modelling for the ExoMars rover

Gas conduction for the ExoMars internal model - Large gaps

- For gas conduction couplings with large gaps i.e. to gas nodes:



- Acts as a traditional conductive through coupling (kA/x)
- Conductivity of the carbon dioxide is interpolated between the gas and geometry node temperatures
- Area for the coupling is determined as the area facing the gas node

```
GL(21150,41004) = CNDFNC(1, CO2_K1, 1) * 0.002475 / 3.829E-2 *CRUISE_CASE;
```

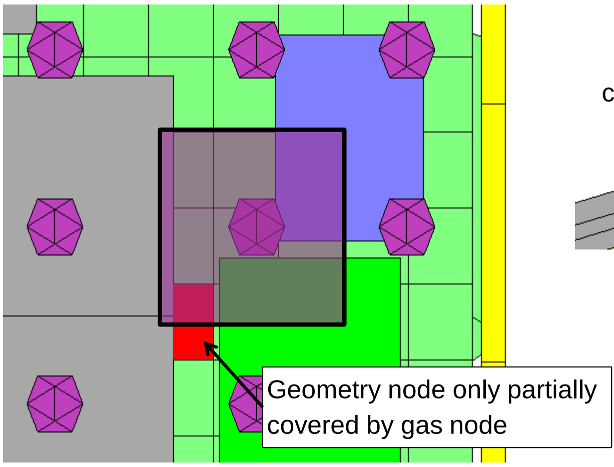
```
GL(58002,21678) = INTRP1(T21678, CO2_K1, 1) * A58002 / 8.187E-2 *CRUISE_CASE ;
```

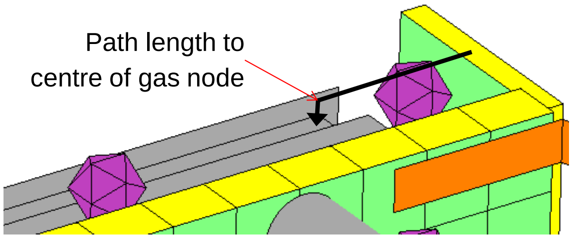
- CNDFNC: Average temperature of gas and structure (Tn1+Tn2)/2 – small gaps
- INTRP1: Just gas node temperature – larger volume gas nodes where effect of structure node is, relatively, reduced.

Gas conduction and convection modelling for the ExoMars rover

Gas conduction for the ExoMars internal model - Large gaps

- The area and path length for gas conduction couplings can become difficult to determine as the internal geometry becomes more complex. It is particularly prominent for:
  - Edges of panels and units
  - Where a gas node only partially encompasses a geometry node





- Scaling factors and meticulous manual path length calculations are required via referencing 3D CAD models or CAD drawings.

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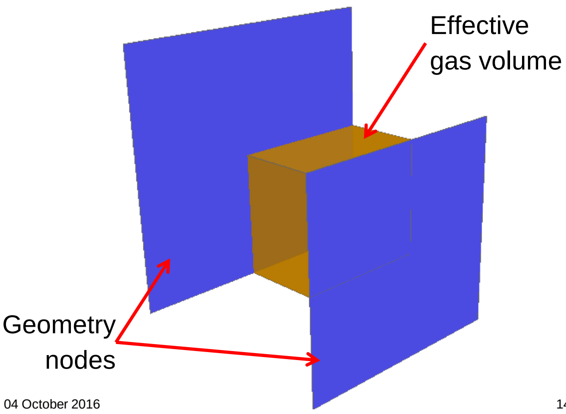
Gas conduction and convection modelling for the ExoMars rover

Gas conduction for the ExoMars internal model - Small gaps

- There are several sites in the internal model where the gap size is small and no gas node is present
- As the conductive coupling through the gas must still be considered, a different approach is used for surface-surface couplings for small gap sizes
- The coupling needs to reflect each node's area facing its opposite node and the gas between the nodes:



- As the model becomes more detailed, this task becomes more complex and time consuming
- A way to automate this process was used

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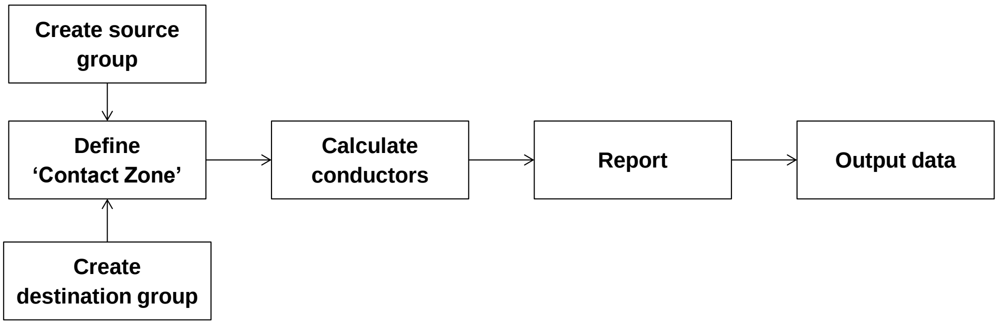
Gas conduction for the ExoMars internal model - ESATAN auto-coupling generator

- A contact zone between two groups of faces/surfaces can be defined in ESATAN-TMS:
  - For coupling units → panels over small gaps.
- This works by firing rays from a source to a sink
- For each source node, the area that directly faces a sink node will be calculated and can be output as a text file.



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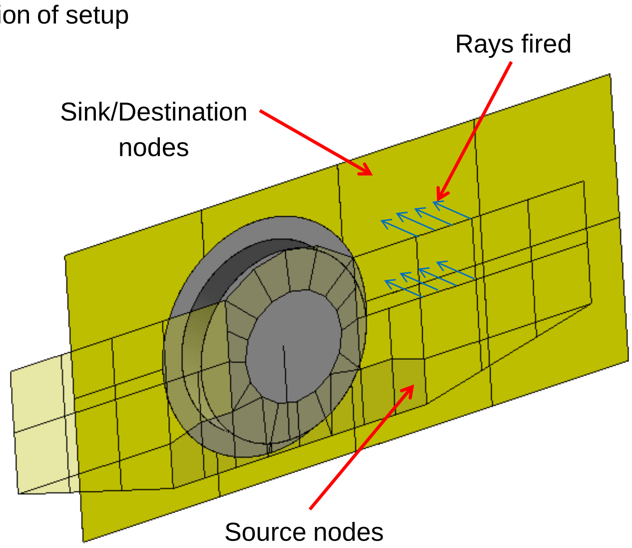
Gas conduction and convection modelling for the ExoMars rover

Gas conduction for the ExoMars internal model - ESATAN auto-coupling generator

- Visualisation of setup



- Rays are fired normal to surface unlike when generating GRs.

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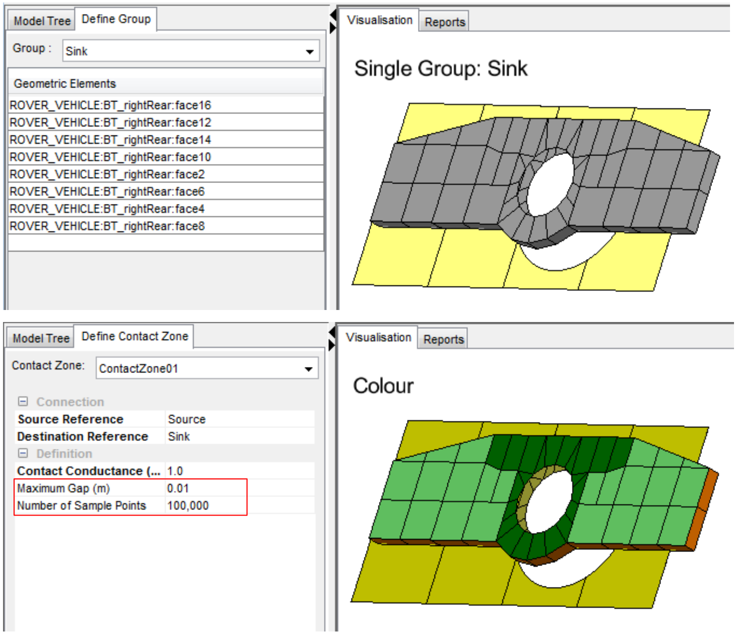
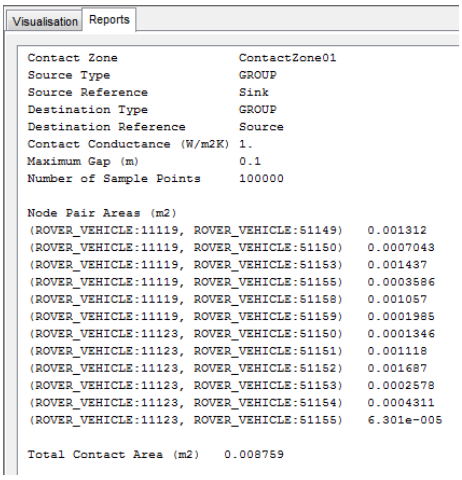
Gas conduction for the ExoMars internal model - ESATAN auto-coupling generator



- Defining source and sink groups
- Defining contact zone
  - Gap distance and sample points critical

Gas conduction for the ExoMars internal model - ESATAN auto-coupling generator

- After ‘calculating conductors’, a report can be produced from the contact zone:
- This output can be saved as a text file




```
Contact Zone                       ContactZone01
Source Type                        GROUP
Source Reference                   Sink
Destination Type                   GROUP
Destination Reference              Source
Contact Conductance (W/m2K)        1.
Maximum Gap (m)                    0.1
Number of Sample Points            100000

Node Pair Areas (m2)
(ROVER_VEHICLE:11119, ROVER_VEHICLE:51149)   0.001312
(ROVER_VEHICLE:11119, ROVER_VEHICLE:51150)   0.0007043
(ROVER_VEHICLE:11119, ROVER_VEHICLE:51153)   0.001437
(ROVER_VEHICLE:11119, ROVER_VEHICLE:51155)   0.0003586
(ROVER_VEHICLE:11119, ROVER_VEHICLE:51158)   0.001057
(ROVER_VEHICLE:11119, ROVER_VEHICLE:51159)   0.0001985
(ROVER_VEHICLE:11123, ROVER_VEHICLE:51150)   0.0001346
(ROVER_VEHICLE:11123, ROVER_VEHICLE:51151)   0.001118
(ROVER_VEHICLE:11123, ROVER_VEHICLE:51152)   0.001687
(ROVER_VEHICLE:11123, ROVER_VEHICLE:51153)   0.0002578
(ROVER_VEHICLE:11123, ROVER_VEHICLE:51154)   0.0004311
(ROVER_VEHICLE:11123, ROVER_VEHICLE:51155)   6.301e-005

Total Contact Area (m2)   0.008759
```

- Comparing to hand-calculations and depending on the number of nodes/geometry, approximately 100,000 rays are required.
- A test between 10,000 and 100,000 rays, the area output generated:
  - At 10k rays = +16%
  - At 100k rays = -0.2%
- Works with cuts.
- Some areas may appear with magnitudes 10^{-6}. These can be safely excluded.

Cruise cases

- During cruise, no gas will be present
- To save from having to duplicate coupling include files, a 'CRUISE' flag was added.
- When the cruise case is run, this flag is set to zero, negating all gas couplings.

```
GL(21150,41004) = CNDFNC(1, CO2_K1, 1) * 0.002475 / 3.829E-2 * CRUISE_CASE;
```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Gas conduction and convection modelling for the ExoMars rover

Thank you

Any questions?

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Convection theory notations

Prandtl number

- μ – Viscosity of fluid (kg/ms)
- C_p - Specific heat (J/kg.K)
- k – Conductivity (W/m.K)

- g – Gravitational acceleration (m/s^2)
- β – Coefficient of volumetric thermal expansion ≈ 1/T_f for gases (K^{-1})
- ρ – Density (kg/m^3)
- T – Temperature (K)
- X – Characteristic length (m)

Grashof number

- C – Empirical constant
- n – Empirical index
- K – Dimensionless correction function

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