An approach to thermal modelling and analysis of Solar Array Wings for Space Rider

beyond gravity

Presented By

Adeeb Nazeeruddin

System / Thermal System Engineer

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Space Rider Mission

Space Rider (ESA mission) will be Europe's first reusable space transportation system. It is intended to be launched from Europe's Spaceport in Kourou, French Guiana, using Vega-C launcher.

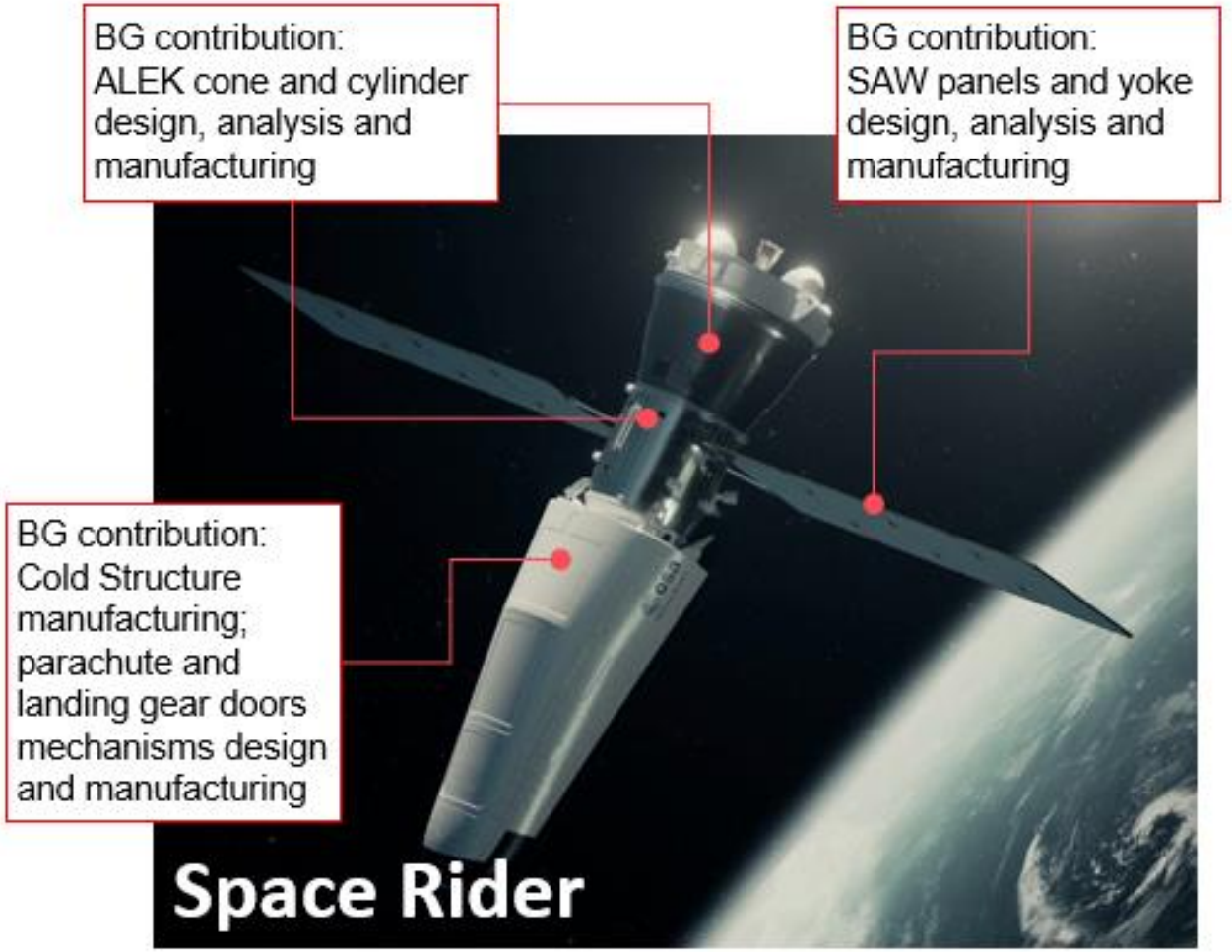
It should reach and stay in orbit as long as required to perform the payloads operations, deorbit and reenter performing a ground landing to return payloads to end users and be refurbished and reused for the next mission.

The duration of the low-orbit stay would be roughly two months, within which experiences inside its cargo bay will allow technology demonstration and benefit research in pharmaceutics, biomedicine, biology and physical science.

At the end of its mission, Space Rider will return to Earth with its payloads and land on a runway to be unloaded and refurbished for another flight.

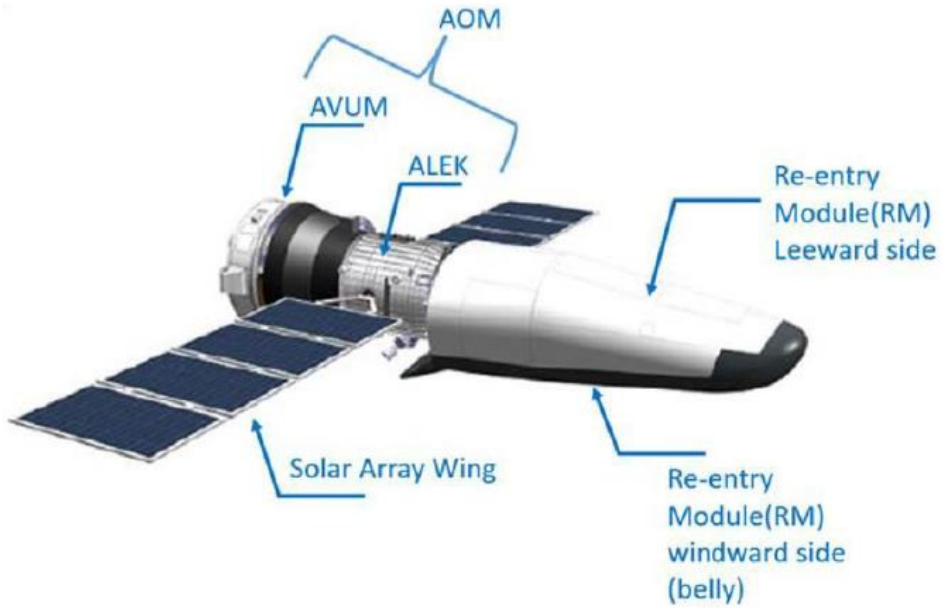
https://esamultimedia.esa.int/docs/space_transportation/Space_Rider_factsheet_HiRes_ok.pdf

Beyond Gravity Contributions

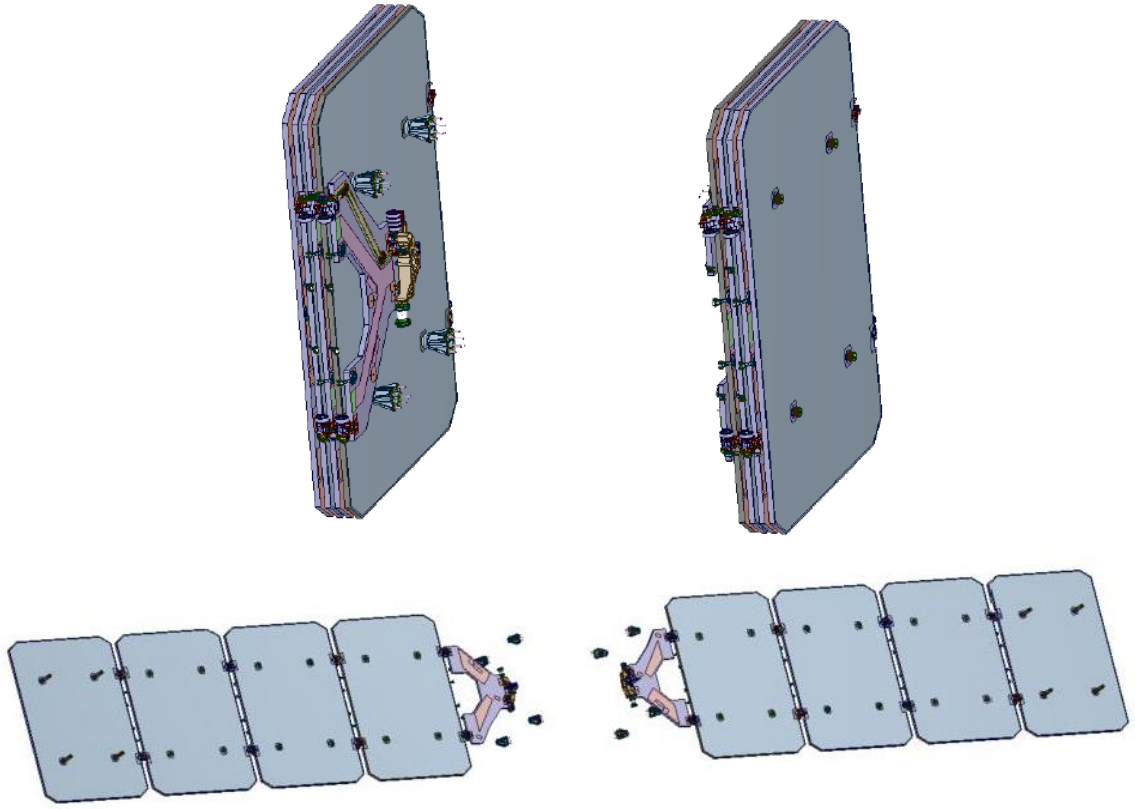


Configuration and SAW geometry

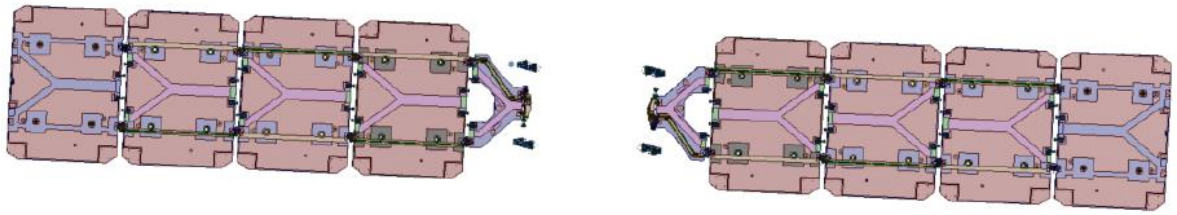
Space Rider Configuration



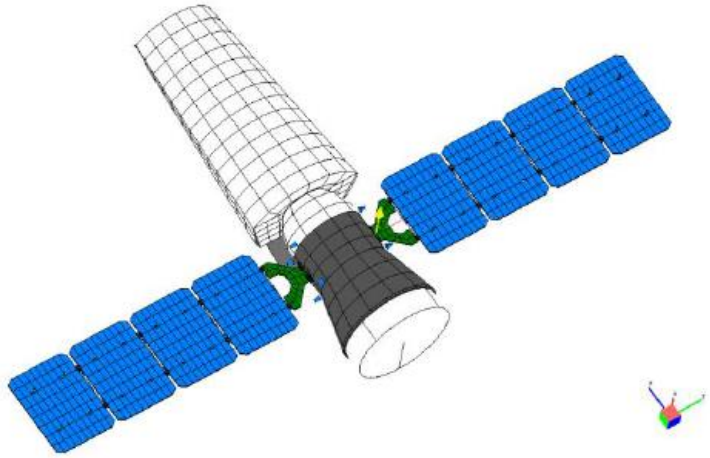
SAW stowed configuration

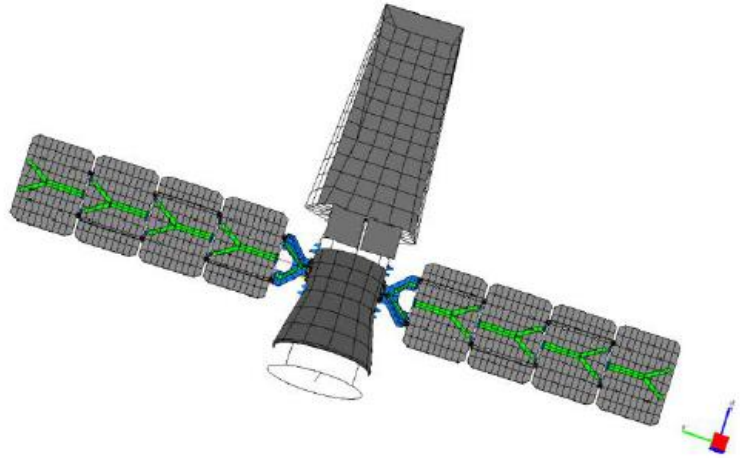


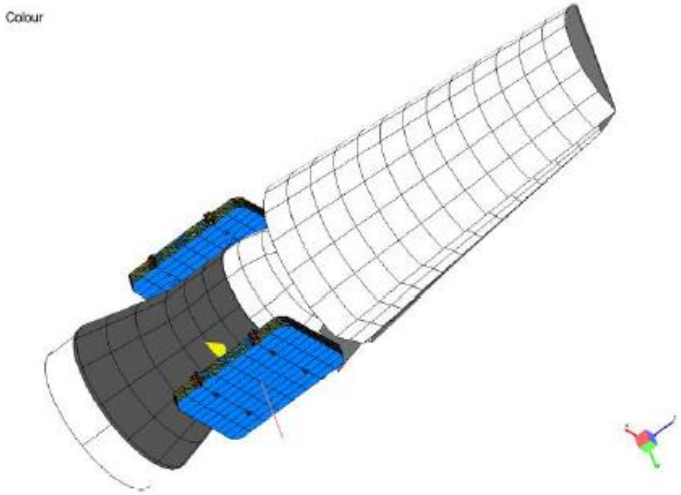
SAW deployed configuration

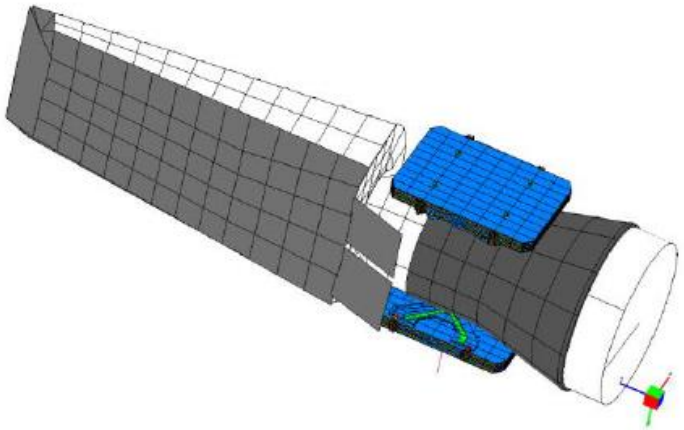


Geometrical Mathematical Model







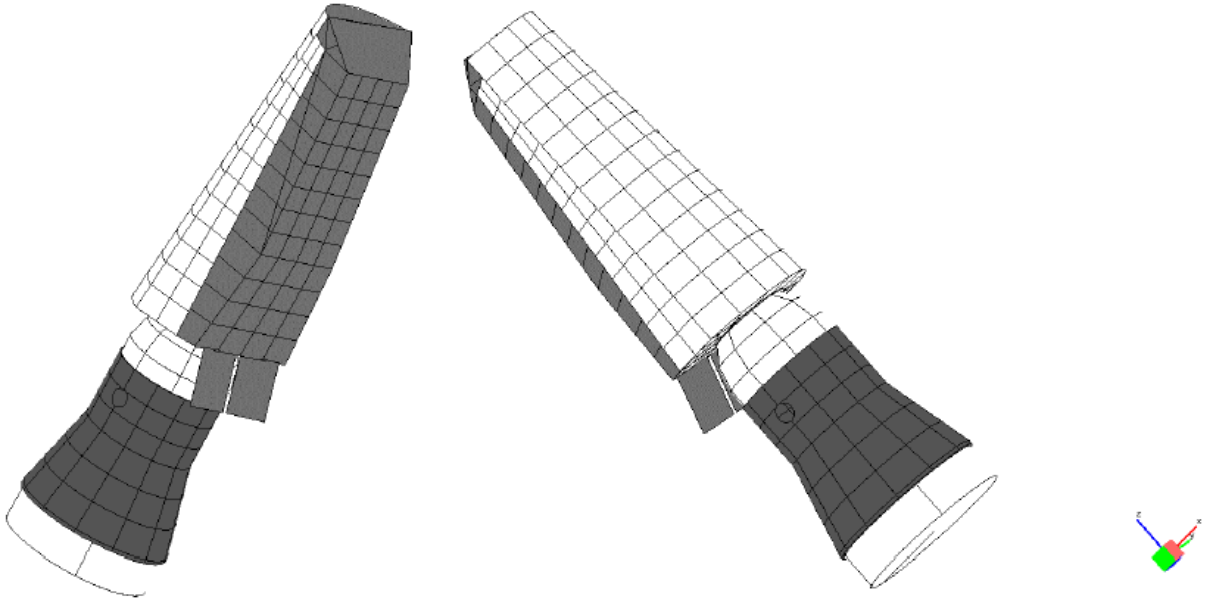


The GMM has the following variants:
- SA deployed
- SA stowed

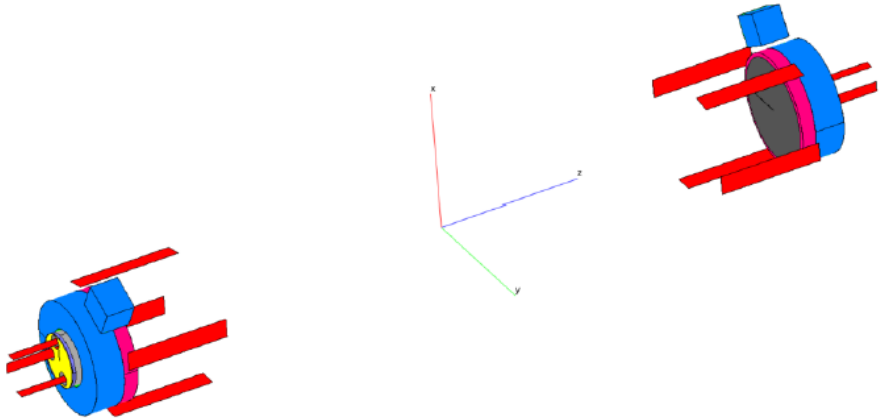
ESATAN-TMS
thermal modelling suite

ESATAN-TMS 2018 sp1

External RTMMs

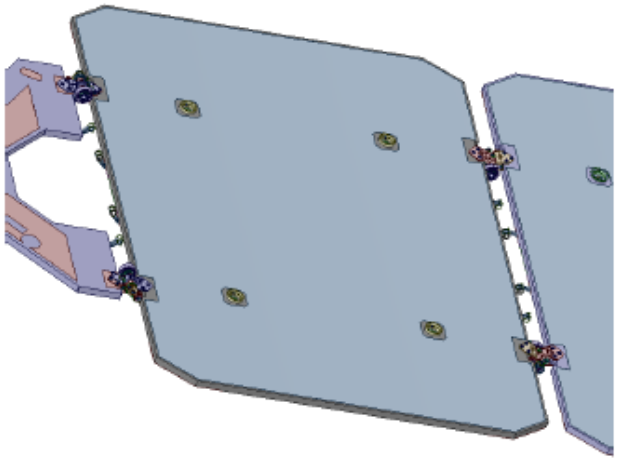


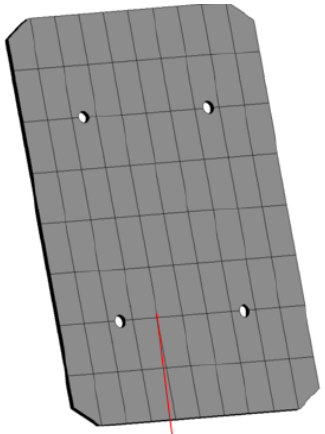
SC RTMM

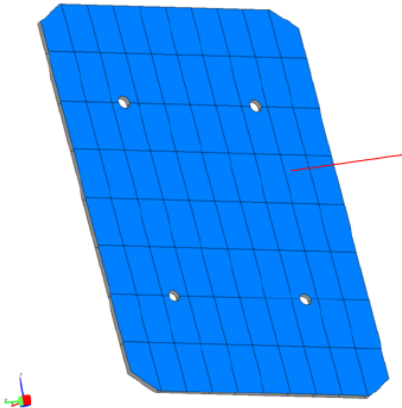


SADM RTMM

Panels modelling

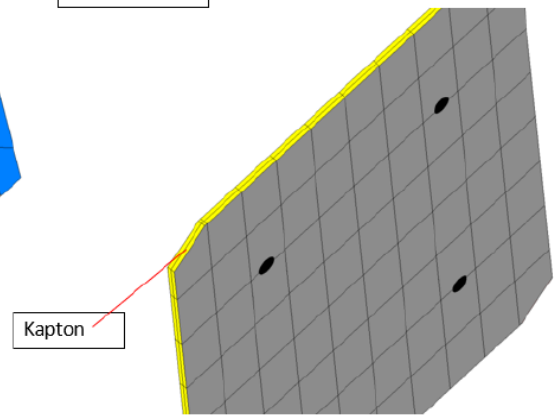






External facesheet covered in solar cells

Internal facesheet NO solar cells



Kapton

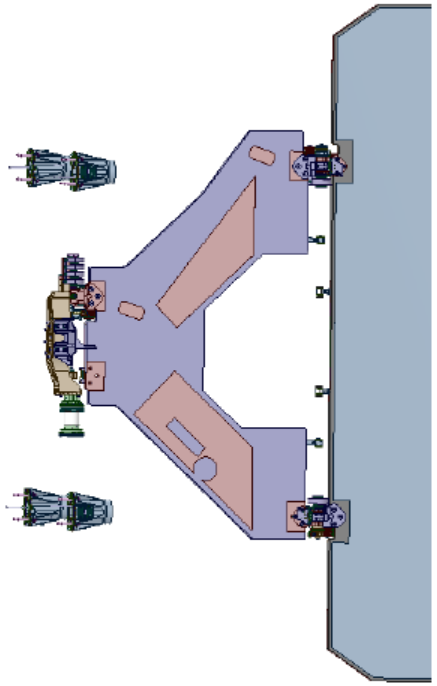
C: > Scratch > ESATAN_TMS > SpaceRider_prem > esatan > COMMON > CONDUCTORS > SAW_MY_PAN_TRANS_GL.data

```
# SAW Panel TRANSVERSE COUPLINGS MY
#
###############
# MY panel 1
    GL (11101001    ,   11102001    )   =   CF1 * k_CFRP_TRA    *   0.021586 / 0.022 ;
    GL (11101002    ,   11102002    )   =   CF1 * k_CFRP_TRA    *   0.026097 / 0.022 ;
    GL (11101003    ,   11102003    )   =   CF1 * k_CFRP_TRA    *   0.026097 / 0.022 ;
    GL (11101004    ,   11102004    )   =   CF1 * k_CFRP_TRA    *   0.026097 / 0.022 ;
    GL (11101005    ,   11102005    )   =   CF1 * k_CFRP_TRA    *   0.026097 / 0.022 ;
    GL (11101006    ,   11102006    )   =   CF1 * k_CFRP_TRA    *   0.026097 / 0.022 ;
```

C: > Scratch > ESATAN_TMS > SpaceRider_prem > esatan > COMMON > CONDUCTORS > SAW_MY_INT_GL.data

```
##########MY panel active/conductive side generated couplings
    GL(11101001,11101002) = CF1 * k_CFRP_SAW * 0.0177; # from primitive SAW_PAN1_MY:SAW_CELL_1_2_MY
    GL(11101001,11101011) = CF1 * k_CFRP_SAW * 0.00668; # from primitive SAW_PAN1_MY:SAW_CELL_1_2_MY
    GL(11101002,11101003) = CF1 * k_CFRP_SAW * 0.0190; # from primitive SAW_PAN1_MY:SAW_CELL_1_2_MY
    GL(11101002,11101012) = CF1 * k_CFRP_SAW * 0.00639; # from primitive SAW_PAN1_MY:SAW_CELL_1_2_MY
    GL(11101003,11101004) = CF1 * k_CFRP_SAW * 0.0190; # from primitive SAW_PAN1_MY:SAW_CELL_1_2_MY
    GL(11101003,11101013) = CF1 * k_CFRP_SAW * 0.00649; # from primitive SAW_PAN1_MY:SAW_CELL_1_2_MY
```

Yoke modelling

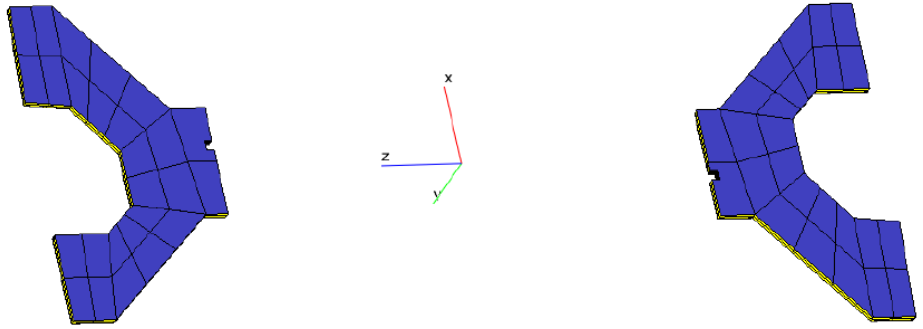


C: > Scratch > ESATAN_TMS > SpaceRider_prem > esatan > COMMON > CONDUCTORS > YOKE_INT_GL.data

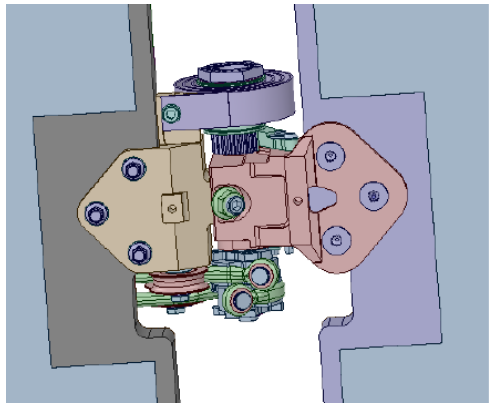
```
# Results Generated from
# ESATAN-TMS 2018 sp1, run date 14:26 Thu 19 Jan 2023
# Model name: YOKE_CDR_v2nokapton        Analysis case: yoke_case
# ESATAN-TMS 2018 sp1, run date 14:26 Thu 19 Jan 2023
# Model name: YOKE_CDR_v2nokapton        Radiative conductors
#Yoke internal PY
    GL(11212001,11212003) = CF1 * 1.0 / ((1.0 / (0.0367 * k_CFRP_SAW_Yoke)) + (1.0 / (0.0324 * k_CFRP_SAW_Yoke))); # from conductive interface Yoke_1
    GL(11212002,11212005) = CF1 * 1.0 / ((1.0 / (0.0442 * k_CFRP_SAW_Yoke)) + (1.0 / (0.0342 * k_CFRP_SAW_Yoke))); # from conductive interface Yoke_1
    GL(11212005,11212010) = CF1 * 1.0 / ((1.0 / (0.0156 * k_CFRP_SAW_Yoke)) + (1.0 / (0.0178 * k_CFRP_SAW_Yoke))); # from conductive interface Yoke_2
    GL(11212006,11212007) = CF1 * 1.0 / ((1.0 / (0.0210 * k_CFRP_SAW_Yoke)) + (1.0 / (0.0318 * k_CFRP_SAW_Yoke))); # from conductive interface Yoke_2
```

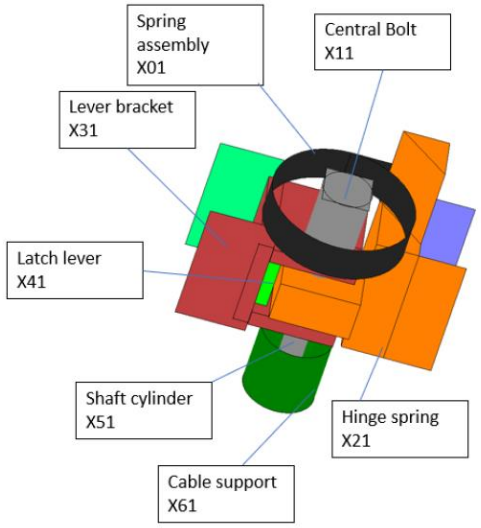
C: > Scratch > ESATAN_TMS > SpaceRider_prem > esatan > COMMON > CONDUCTORS > YOKE_TRANS_GL.data

```
# SAW YOKE TRANSVERSE COUPLINGS

#MY_Yoke transverse
    GL(11111001 ,   11112001    ) = CF1 * kY_CFRP_TRA   *   1.72E-02    /   0.022   ;
    GL(11111002 ,   11112002    ) = CF1 * kY_CFRP_TRA   *   1.38E-02    /   0.022   ;
    GL(11111003 ,   11112003    ) = CF1 * kY_CFRP_TRA   *   1.53E-02    /   0.022   ;
    GL(11111004 ,   11112004    ) = CF1 * kY_CFRP_TRA   *   1.08E-02    /   0.022   ;
    GL(11111005 ,   11112005    ) = CF1 * kY_CFRP_TRA   *   1.61E-02    /   0.022   ;
    GL(11111006 ,   11112006    ) = CF1 * kY_CFRP_TRA   *   1.16E-02    /   0.022   ;
    GL(11111007 ,   11112007    ) = CF1 * kY_CFRP_TRA   *   6.65E-03    /   0.022   ;
    GL(11111008 ,   11112008    ) = CF1 * kY_CFRP_TRA   *   6.65E-03    /   0.022   ;
```



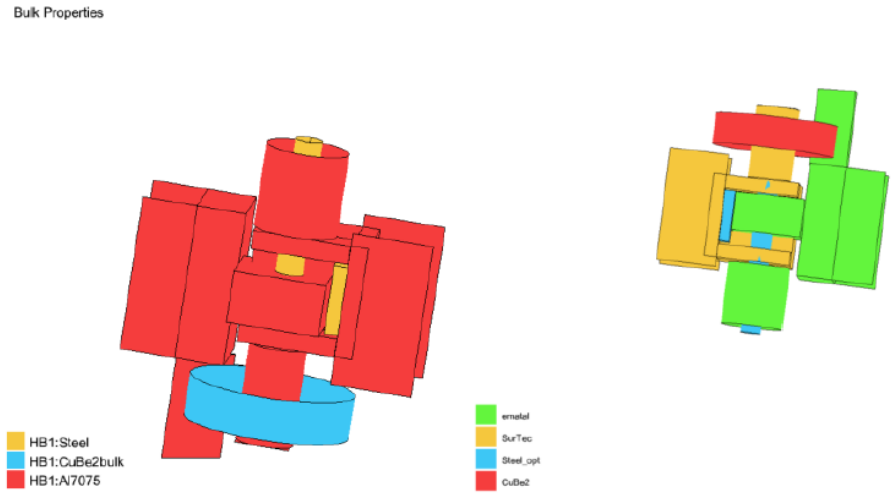
Hinges modelling

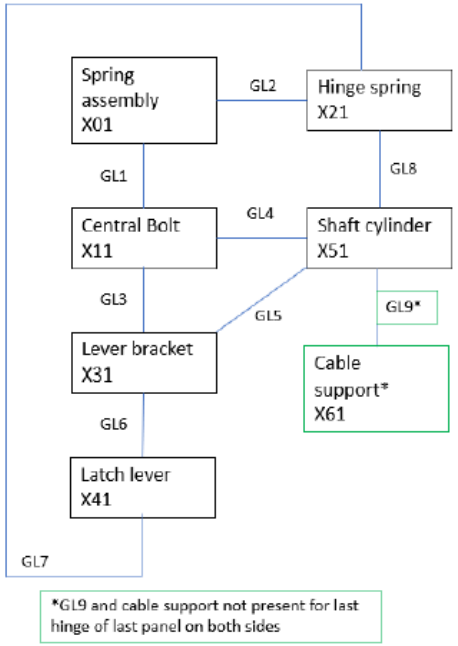




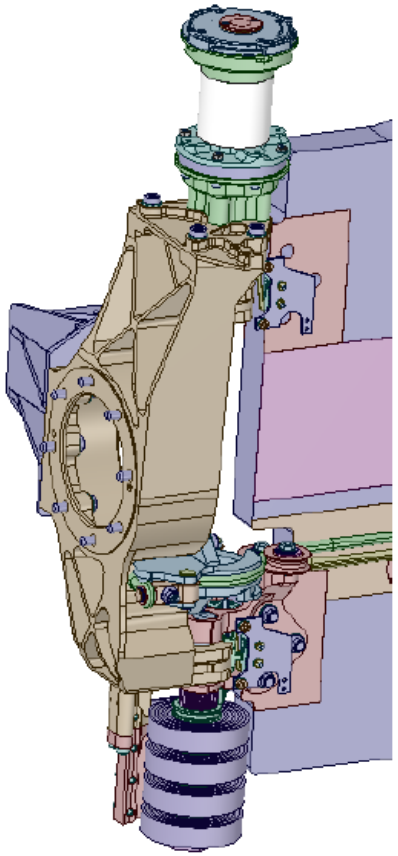

```
#############
      C11141101 = CF2 * 24.32   #   Spring assembly
      C11141111 = CF2 * 18.26   #   shaft cylinder
      C11141121 = CF2 * 178.168 #   hinge spring
      C11141131 = CF2 * 114.125 #   lever bracket
      C11141141 = CF2 * 17.5    #   latch lever
      C11141151 = CF2 * 16. #   central bolt
      C11141161 = CF2 * 85.955  #   slack compensation
```

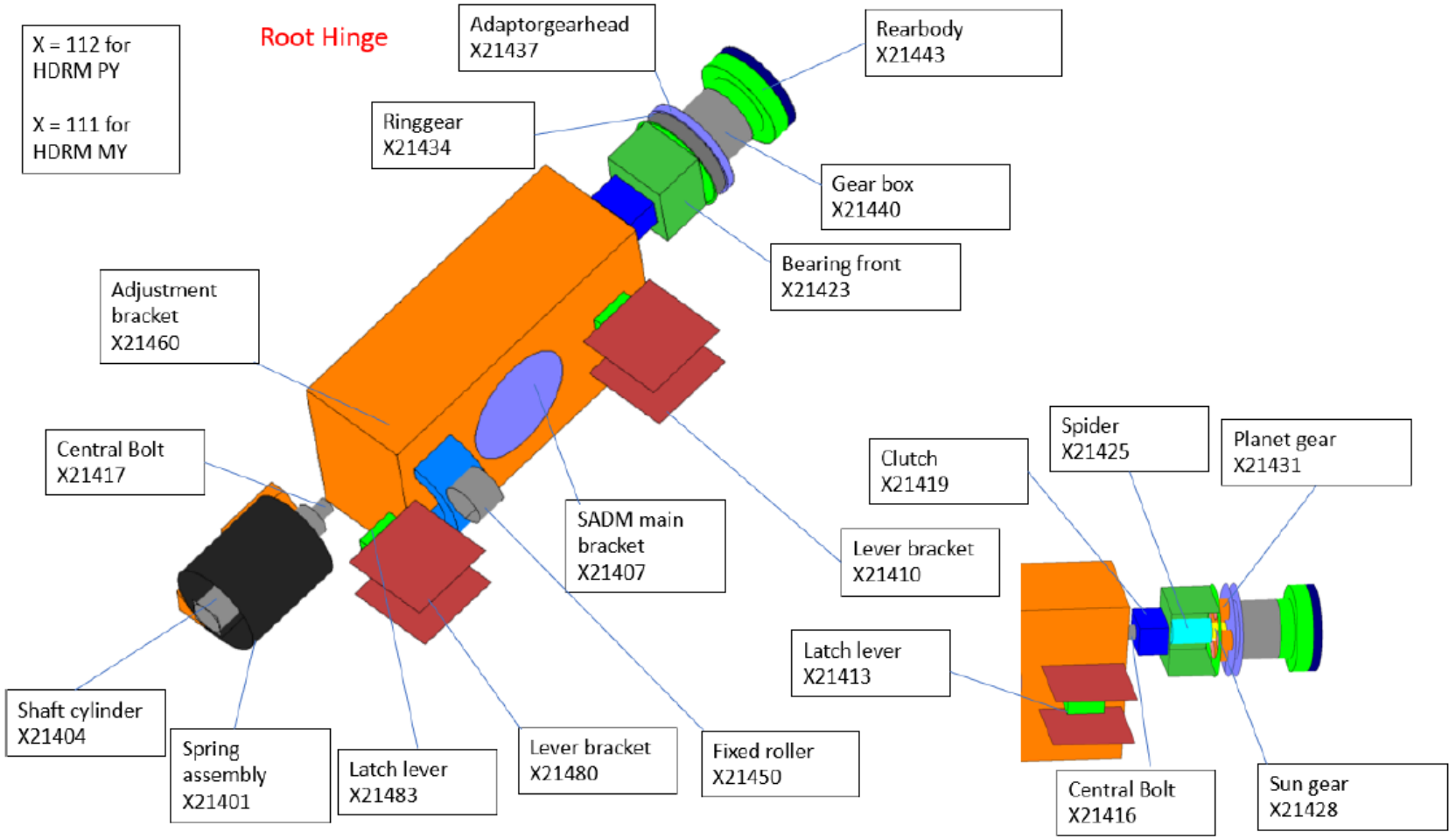
GL	W/K
GL1	4.35E-02
GL2	0.099
GL3	7.58E-02
GL4	8.58E-02
GL5	0.147
GL6	1.58E-01
GL7	1.71E-02
GL8	0.31295
GL9	0.40638



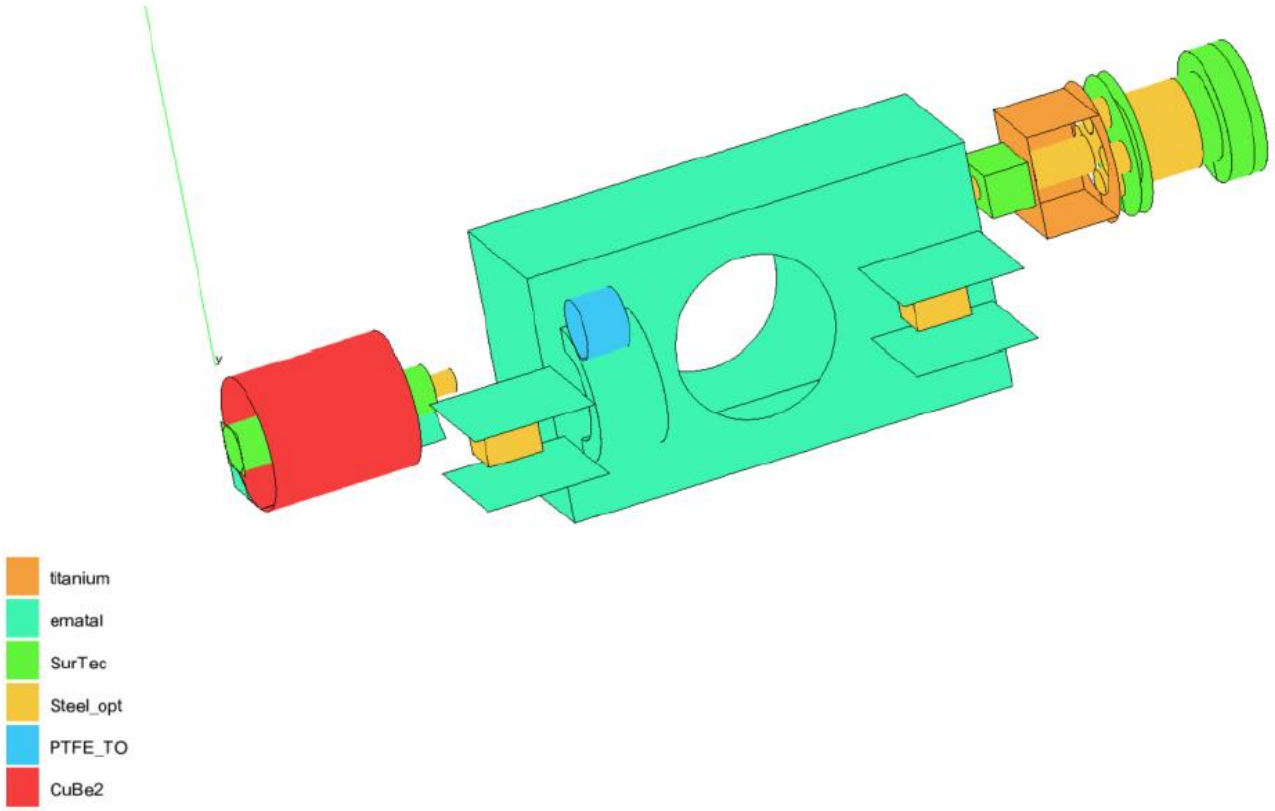


Root hinge modelling (1)



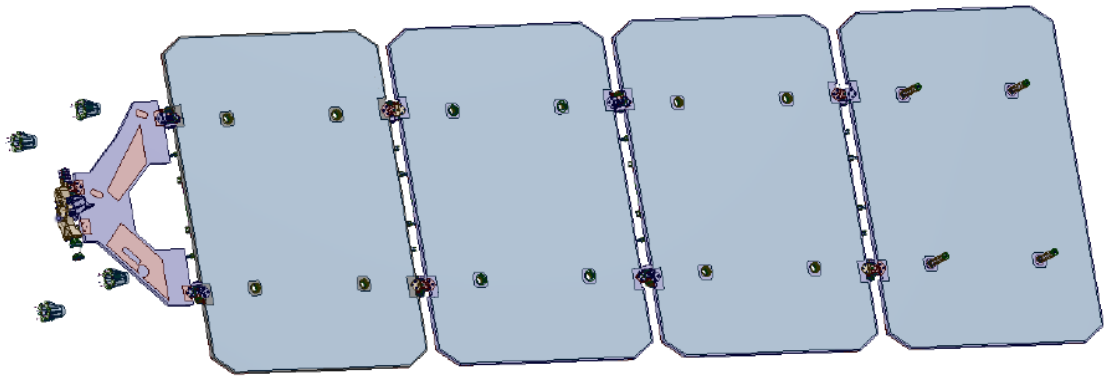


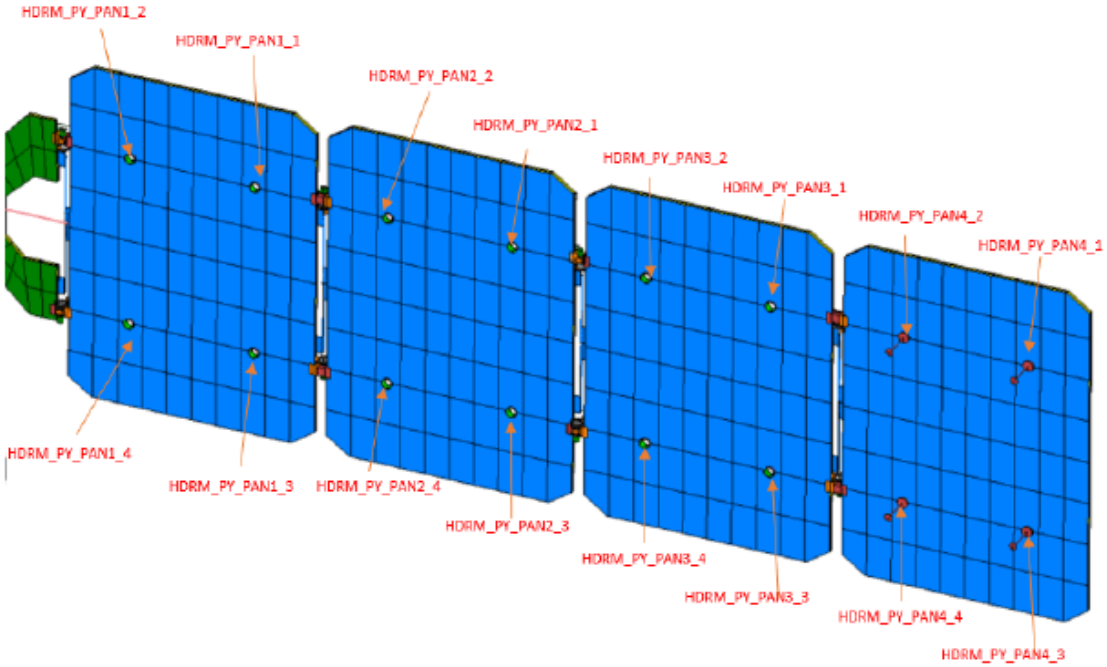
Root hinge modelling (2)

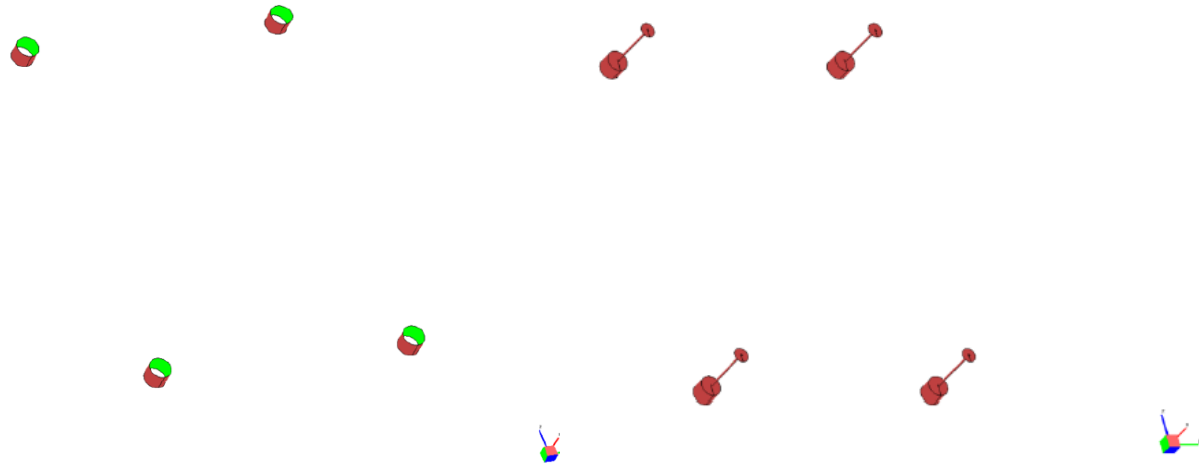



```
# Root HINGES COUPLINGS PY
###
########
    GL(11221401 ,   11221407    ) = CF1 * 0.72  ;   #spring assembly to main bracket
    GL(11221401 ,   11221404    ) = CF1 * 0.05  ;   #spring assembly to shaft cylinder  #decouple assumption
    GL(11221404 ,   11221480    ) = CF1 * 7.58E-02  ;   #connection shaft cylinder to lever bracket 2
    GL(11221417 ,   11221404    ) = CF1 * 8.58E-02  ;   #connection centralbolt2 to shaft cylinder
    GL(11221417 ,   11221480    ) = CF1 * 0.294 ;   #connection centralbolt2 to lever bracket2
    GL(11221417 ,   11221407    ) = CF1 * 3.13E-01  ;   #connection centralbolt to main bracket ###
    GL(11221483 ,   11221407    ) = CF1 * 1.71E-02  ;   #connection latchlever2 to main bracket ###
    GL(11221480 ,   11221483    ) = CF1 * 0.176346  ;   #connection leverbracket2 to latchtlever2 ###
    GL(11221407 ,   11221460    ) = CF1 * 0.463 ;   #main bracket to adjustment bracket     ###
    GL(11221413 ,   11221407    ) = CF1 * 1.71E-02  ;   #connection latchlever to main bracket  ###
    GL(11221413 ,   11221410    ) = CF1 * 0.176346  ;   #connection latchtlever to leverbracket1 ##
    GL(11221416 ,   11221407    ) = CF1 * 3.13E-01  ;   #connection centralbolt 1 to main bracket ##
    GL(11221416 ,   11221410    ) = CF1 * 0.294 ;   #connection centralbolt 1 to leverbracket1  ###
    GL(11221416 ,   11221419    ) = CF1 * 0.0762    ;   #connection centralbolt to clutch   ##
    GL(11221425 ,   11221419    ) = CF1 * 2.24E-01  ;   #connection spider to clutch        ##
    GL(11221423 ,   11221407    ) = CF1 * 0.22605   ;   #connection bearingfront to main bracket    ##
    GL(11221423 ,   11221425    ) = CF1 * 2.50E-02  ;   #connection bearingfront to spider      ##
    GL(11221423 ,   11221434    ) = CF1 * 4.09E-01  ;   #connection bearingfront to ringgear    ##
    GL(11221425 ,   11221431    ) = CF1 * 3.60E-01  ;   #connection spider to planet gear       ##
    GL(11221428 ,   11221431    ) = CF1 * 8.68E-02  ;   #connection sun gear to planet gear     ##
    GL(11221428 ,   11221440    ) = CF1 * 3.84E-01  ;   #connection sun gear to gear box        ##
    GL(11221434 ,   11221431    ) = CF1 * 2.60E-01  ;   #connection ringgear to planet gear     ##
    GL(11221434 ,   11221437    ) = CF1 * 5.50E-01  ;   #connection ringgear to adaptorgearhead      ##
    GL(11221440 ,   11221437    ) = CF1 * 1.59E-01  ;   #connection gearbox to adaptorgearhead      ##
    GL(11221440 ,   11221443    ) = CF1 * 5.85E-01  ;   #connection gearbox to rearbody         ##
    GL(11221450 ,   11221480    ) = CF1 * 1.14E-01  ;   #connection fixed roller to lever bracket 2     #
    GL(11221450 ,   11251701    ) = CF1 * 9.67E-02  ;   #connection fixed roller to cable   #
    GL(11251701 ,   11221460    ) = CF1 * 2.30E-01  ;   #connection cable to adjustment bracket #
    GL(11221480 ,   11211001    ) = CF1 * 0.985 ;   #connection hinge to yoke upper 1   #
    GL(11221480 ,   11212001    ) = CF1 * 1.656 ;       #connection hinge to yoke lower 1   #
    GL(11221410 ,   11211002    ) = CF1 * 0.985 ;   #connection hinge to yoke upper 2       #
    GL(11221410 ,   11212002    ) = CF1 * 1.656 ;   #connection hinge to yoke lower 2       #
```

HDRM modelling







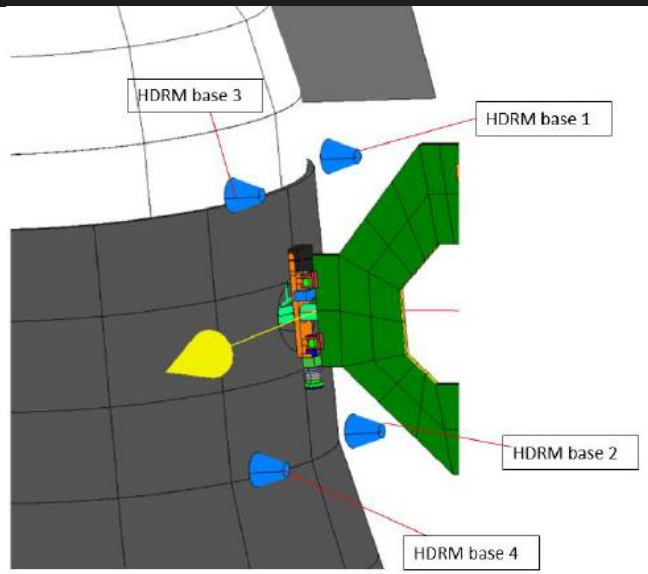
Scratch > ESATAN_TMS > SpaceRider_prem > esatan > COMMON > CONDUCTORS > HDRM_PY_GL.data

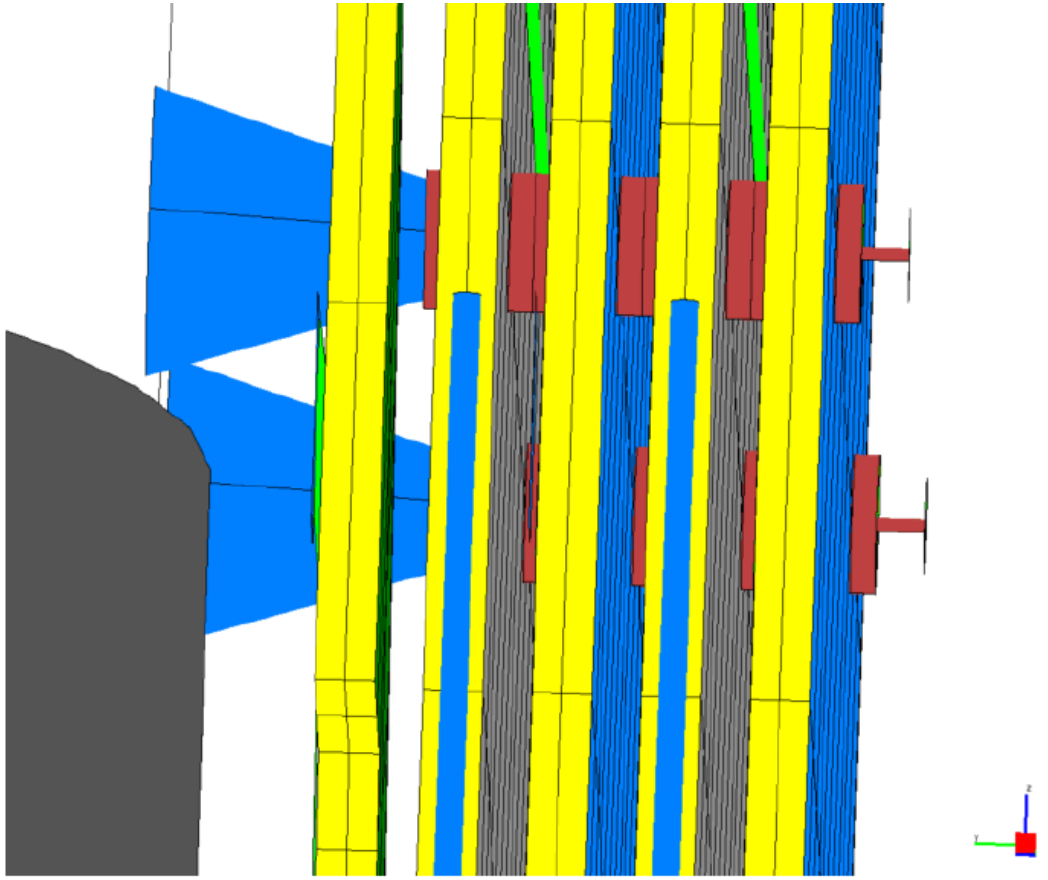
```
# HDRM MY COUPLINGS
###
##
#MY_Panel  1 to HDRM 1a
    GL(11231301,11201013) = CF1 * (1.0/5.28)/4.0; #assumption from ref project
    GL(11231301,11201023) = CF1 * (1.0/5.28)/4.0; #assumption from ref project
#########
    GL(11231301,11202013) = CF1 * (1.0/5.28)/4.0; #assumption from ref project
    GL(11231301,11202023) = CF1 * (1.0/5.28)/4.0; #assumption from ref project
####################################
#MY_Panel  2 to HDRM 1b
    GL(11231801,11203013) = CF1 * (1.0/5.28)/4.0; #assumption from ref project
    GL(11231801,11203023) = CF1 * (1.0/5.28)/4.0; #assumption from ref project
#########
    GL(11231801,11204013) = CF1 * (1.0/5.28)/4.0; #assumption from ref project
    GL(11231801,11204023) = CF1 * (1.0/5.28)/4.0; #assumption from ref project
```

Base HDRM Modelling

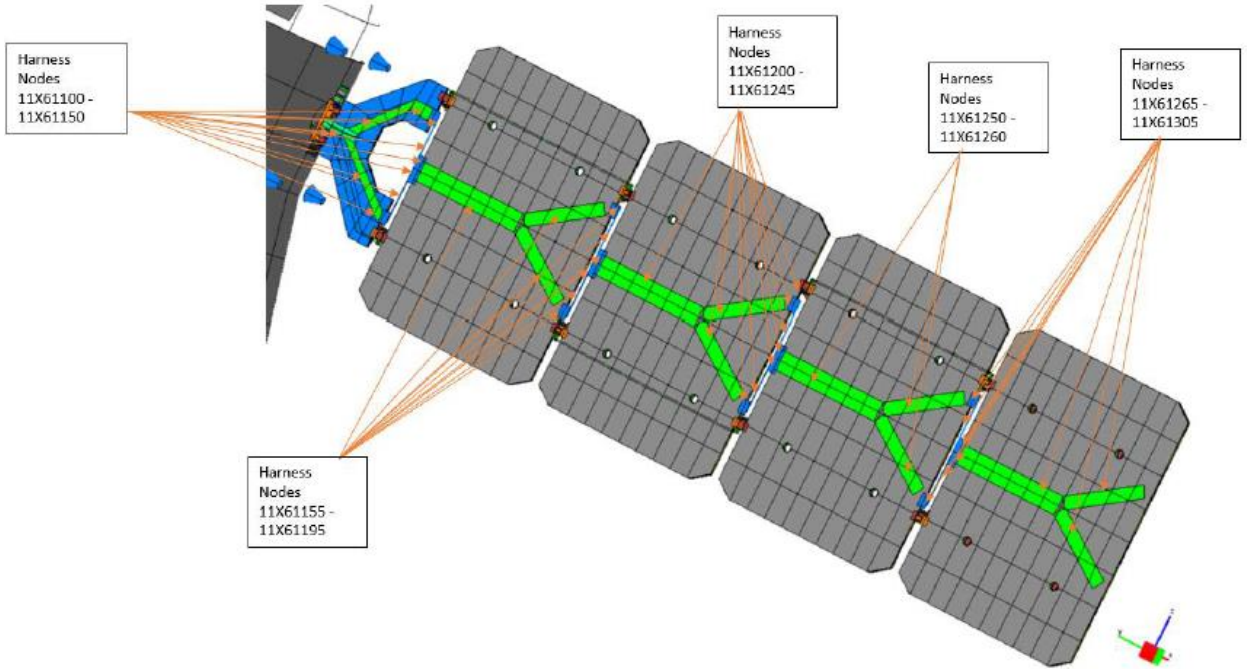
Scratch > ESATAN_TMS > SpaceRider_stow > esatan > COMMON > CONDUCTORS > HDRM_STOWED_GL.data

```
# HDRM STOWED
###
##
#
#PY Panel
    GL(11232301,11233201) = CF1 * 1.0/10.63; #assumption from ref project
    GL(11233201,11231801) = CF1 * 1.0/10.63; #assumption from ref project
    GL(11231801,11231201) = CF1 * 1.0/10.63; #assumption from ref project
    GL(11231201,11232801) = CF1 * 1.0/10.63; #assumption from ref project
####
    GL(11232201,11233301) = CF1 * 1.0/10.63; #assumption from ref project
    GL(11233301,11231701) = CF1 * 1.0/10.63; #assumption from ref project
    GL(11231701,11231301) = CF1 * 1.0/10.63; #assumption from ref project
    GL(11231301,11232601) = CF1 * 1.0/10.63; #assumption from ref project
#
    GL(11232101,11233001) = CF1 * 1.0/10.63; #assumption from ref project
    GL(11233001,11231601) = CF1 * 1.0/10.63; #assumption from ref project
    GL(11231601,11231001) = CF1 * 1.0/10.63; #assumption from ref project
    GL(11231001,11232701) = CF1 * 1.0/10.63; #assumption from ref project
#
```





Harness and cables modelling

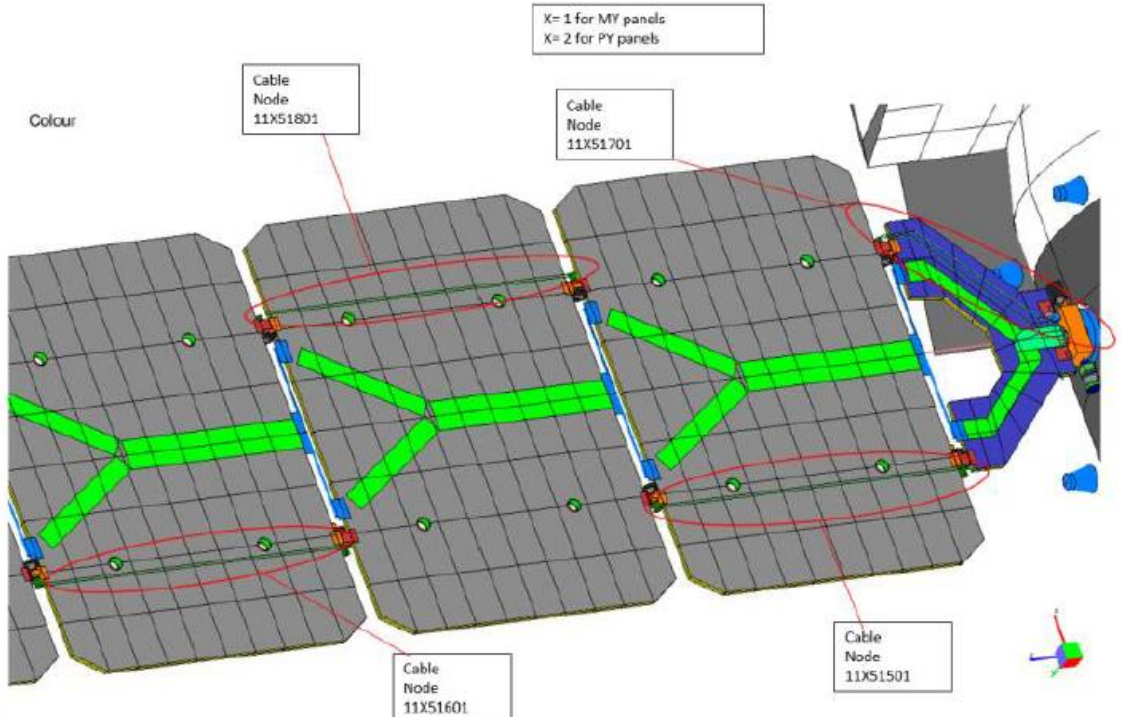


C: > Scratch > ESATAN_TMS > SpaceRider_stow > esatan > COMMON > CONDUCTORS > Harness_GL_MY.data

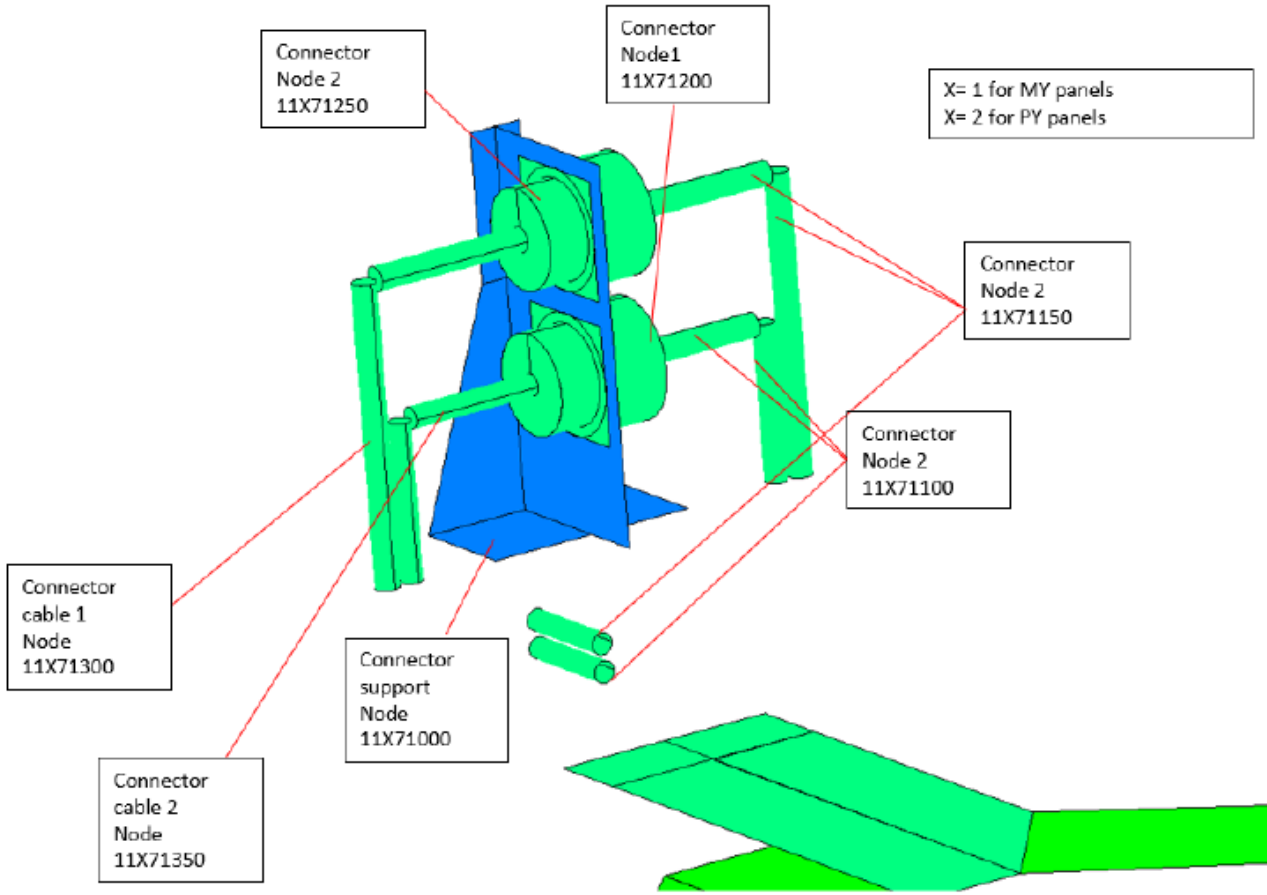
```
# harness COUPLINGS
###
#MY
# harness COUPLINGS

    GL(11161105 ,   11161110    ) =  CF1 * 401.0 *  0.068   *   0.00125 /   ((0.439 + 0.139)/2.0)   ;#
    GL(11161100 ,   11161115    ) =  CF1 * 401.0 *  0.09    *   0.00125 /   0.0415  ;#
    GL(11161115 ,   11161120    ) =  CF1 * 401.0 *  0.08    *   0.00125 /   ((0.328 + 0.105)/2.0)   ;#
    GL(11161110 ,   11161150    ) =  CF1 * 401.0 *  0.08    *   0.00125 /   ((0.05 + 0.0855)/2.0)   ;#
    GL(11161120 ,   11161125    ) =  CF1 * 401.0 *  0.08    *   0.00125 /   ((0.05 + 0.105)/2.0)    ;#
    ########################################################################
    GL(11161150 ,   11161145    ) =  CF1 * 401.0 *  0.085   *   0.00125 /   0.2185  ;
    GL(11161145 ,   11161140    ) =  CF1 * 401.0 *  0.085   *   0.00125 /   0.2185  ;
    GL(11161125 ,   11161130    ) =  CF1 * 401.0 *  0.085   *   0.00125 /   0.2185  ;
    GL(11161130 ,   11161135    ) =  CF1 * 401.0 *  0.085   *   0.00125 /   0.2185  ;
```

Scratch > ESATAN_TMS > SpaceRider_stow > esatan > COMMON > CONDUCTORS > Harness_GL_MY.data

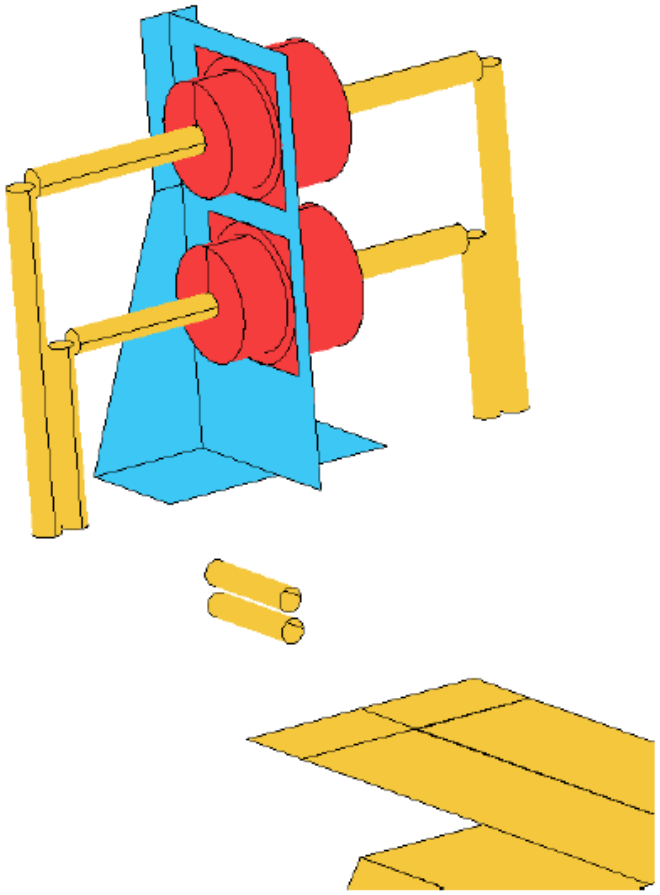
```
#########                   harness contact zone
# Results Generated from
# ESATAN-TMS 2018 sp1, run date 13:45 Mon 6 Feb 2023
# Model name: SpaceRider_prem        Analysis case: harness_contact_couplings
# ESATAN-TMS 2018 sp1, run date 13:45 Mon 6 Feb 2023
# Model name: SpaceRider_prem        Generated conductors
    GL(11102028,11161160) =  CF1 * 0.000256275 * 200.000; # from contact zone harness_contact
    GL(11102029,11161160) =  CF1 * 0.00716805 * 200.000; # from contact zone harness_contact
    GL(11102030,11161160) =  CF1 * 0.00618885 * 200.000; # from contact zone harness_contact
    #
    GL(11102030,11161195) =  CF1 * 0.00196222 * 200.000; # from contact zone harness_contact
    #
    GL(11102031,11161155) =  CF1 * 0.00726834 * 200.000; # from contact zone harness_contact
```



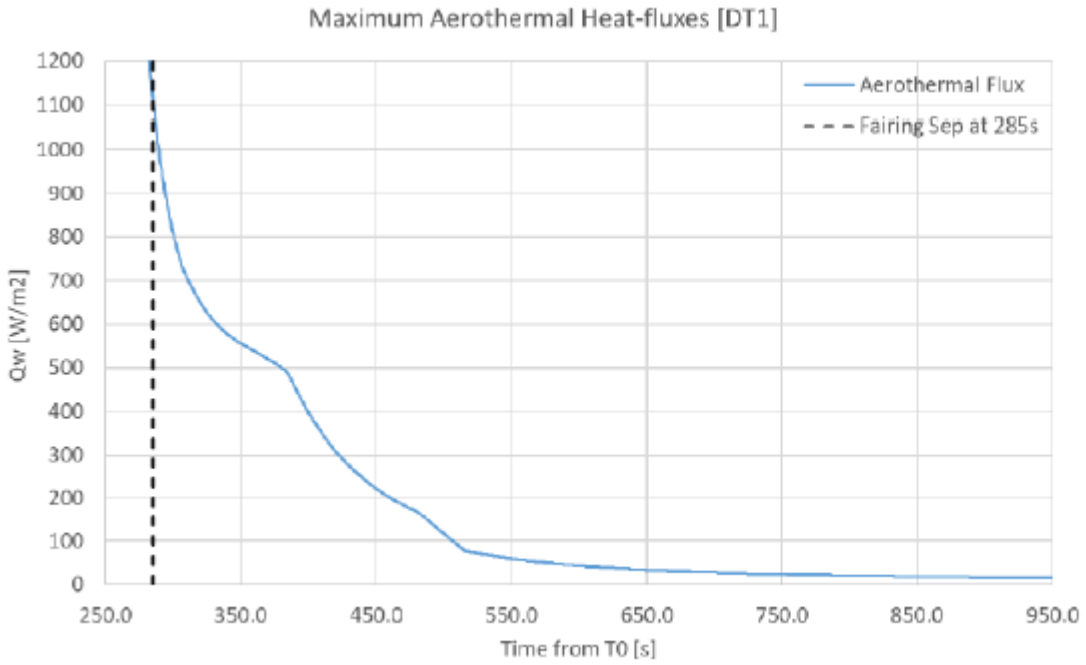
Connector modelling



Thermo Optical Properties

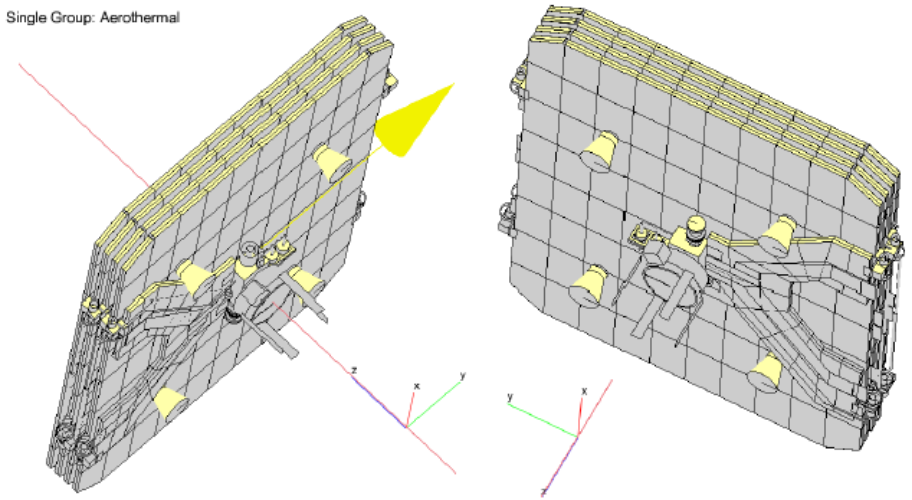


Loads definition: Aerothermal flux modelling



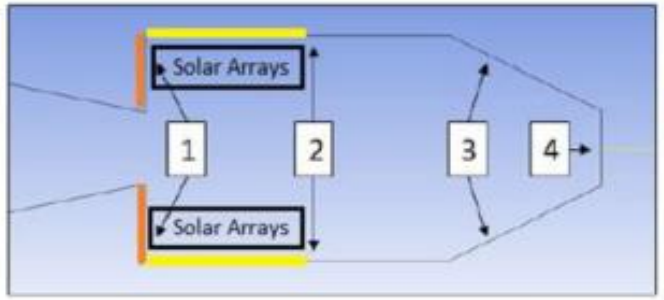

```
AEROTH_ARR(2, 13) =
  0.0,   0.0,
308.9,   0.0,
309.0,1135.0,
336.0, 702.0,
374.0, 559.0,
407.0, 499.0,
448.0, 300.0,
503.0, 173.0,
540.0,  81.0,
974.0,  10.0,
1500.0,  5.0,
1501.1,  0.0,
4000.1,  0.0;
```

Aerothermal flux applied to the +Z exposed surfaces of panels, yoke, HDRM and hinges



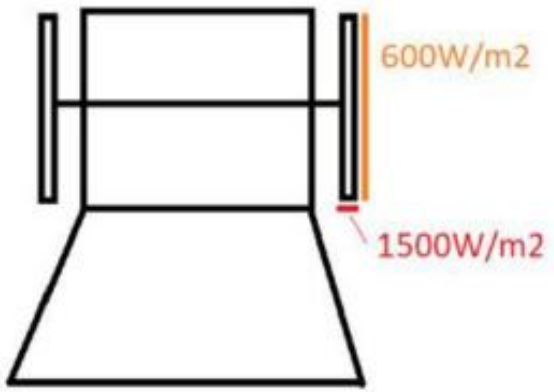

```
QR11106005 = 0.00135410 * INTRP1(TIMEM, AEROTH_ARR, 1)
QR11106006 = 0.00135410 * INTRP1(TIMEM, AEROTH_ARR, 1)
QR11106007 = 0.00135410 * INTRP1(TIMEM, AEROTH_ARR, 1)
QR11106008 = 0.00135410 * INTRP1(TIMEM, AEROTH_ARR, 1)
QR11106009 = 0.00135410 * INTRP1(TIMEM, AEROTH_ARR, 1)
QR11106010 = 0.00154098 * INTRP1(TIMEM, AEROTH_ARR, 1)
QR11107001 = 0.00154098 * INTRP1(TIMEM, AEROTH_ARR, 1)
QR11107002 = 0.00135410 * INTRP1(TIMEM, AEROTH_ARR, 1)
QR11107003 = 0.00135410 * INTRP1(TIMEM, AEROTH_ARR, 1)
QR11107004 = 0.00135410 * INTRP1(TIMEM, AEROTH_ARR, 1)
```

Loads definition: Plume modelling



Surface	Radiative Heat Flux [kW/m2]	
1	1.5	Solar Arrays Bottom Surface
2	0.6	Solar Arrays Lateral Surface
3	0.6	
4	0.6	

Radiative Fluxes during Z9 Flight Phase



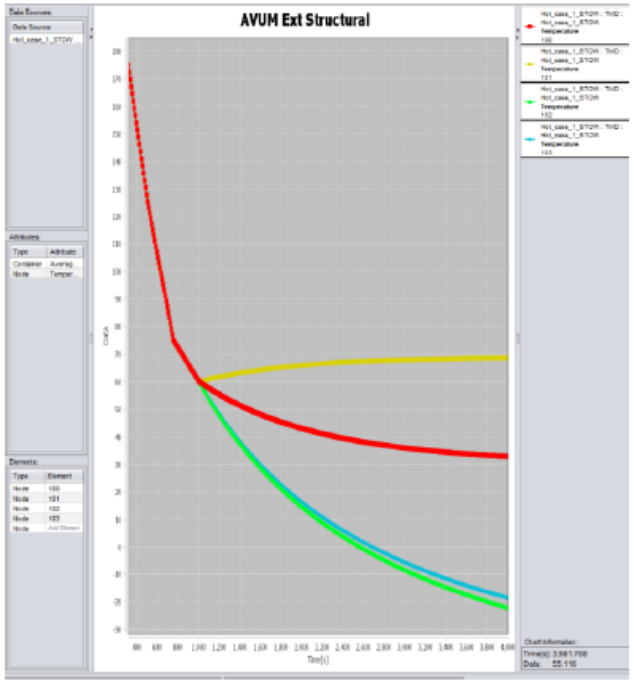

```
#
    $REAL
      # User-defined  'z9plume'
      z9plume(2, 6) =
       0.0, 0.0,
       309.0, 0.0,
       309.1, 1.0,
       553.9, 1.0,
       554.0, 0.0,
       4000.0,  0.0;
#
```

```
      QR11107066 = INTRP1(TIMEM, z9plume, 0) * PLcoeff1 * 0.026
      QR11107067 = INTRP1(TIMEM, z9plume, 0) * PLcoeff1 * 0.026
      QR11107068 = INTRP1(TIMEM, z9plume, 0) * PLcoeff1 * 0.025
      QR11107069 = INTRP1(TIMEM, z9plume, 0) * PLcoeff1 * 0.026
      QR11107070 = INTRP1(TIMEM, z9plume, 0) * PLcoeff1 * 0.026
##############
      QR11107071 = INTRP1(TIMEM, z9plume, 0) * (PLcoeff1 * 0.022 + Plcoefflat * 0.0015)
      QR11107072 = INTRP1(TIMEM, z9plume, 0) * (PLcoeff1 * 0.026 + Plcoefflat * 0.0014)
      QR11107073 = INTRP1(TIMEM, z9plume, 0) * (PLcoeff1 * 0.026 + Plcoefflat * 0.0014)
      QR11107074 = INTRP1(TIMEM, z9plume, 0) * (PLcoeff1 * 0.026 + Plcoefflat * 0.0014)
      QR11107075 = INTRP1(TIMEM, z9plume, 0) * (PLcoeff1 * 0.026 + Plcoefflat * 0.0014)
      QR11107076 = INTRP1(TIMEM, z9plume, 0) * (PLcoeff1 * 0.026 + Plcoefflat * 0.0014)
      QR11107077 = INTRP1(TIMEM, z9plume, 0) * (PLcoeff1 * 0.026 + Plcoefflat * 0.0014)
      QR11107078 = INTRP1(TIMEM, z9plume, 0) * (PLcoeff1 * 0.026 + Plcoefflat * 0.0014)
      QR11107079 = INTRP1(TIMEM, z9plume, 0) * (PLcoeff1 * 0.026 + Plcoefflat * 0.0014)
      QR11107080 = INTRP1(TIMEM, z9plume, 0) * (PLcoeff1 * 0.022 + Plcoefflat * 0.0015)
##############
      QR11108071 = INTRP1(TIMEM, z9plume, 0) * (Plcoefflat * 0.0015)
      QR11108072 = INTRP1(TIMEM, z9plume, 0) * (Plcoefflat * 0.0014)
      QR11108073 = INTRP1(TIMEM, z9plume, 0) * (Plcoefflat * 0.0014)
      QR11108074 = INTRP1(TIMEM, z9plume, 0) * (Plcoefflat * 0.0014)
      QR11108075 = INTRP1(TIMEM, z9plume, 0) * (Plcoefflat * 0.0014)
      QR11108076 = INTRP1(TIMEM, z9plume, 0) * (Plcoefflat * 0.0014)
      QR11108077 = INTRP1(TIMEM, z9plume, 0) * (Plcoefflat * 0.0014)
      QR11108078 = INTRP1(TIMEM, z9plume, 0) * (Plcoefflat * 0.0014)
      QR11108079 = INTRP1(TIMEM, z9plume, 0) * (Plcoefflat * 0.0014)
      QR11108080 = INTRP1(TIMEM, z9plume, 0) * (Plcoefflat * 0.0015)
```

Environmental loads and boundary conditions

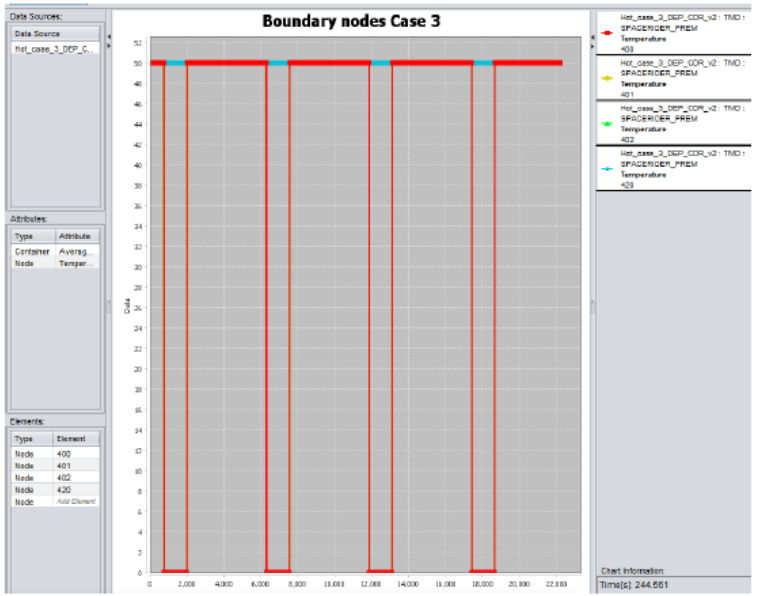
Environmental loads: solar flux, Planetary flux and Albedo, were automatically generated through ESATAN

```
C AVUM External Structure Diffusive to Boundary
C
      IF(TIMEM .LE. 1000.0) THEN
          CALL STATST ('N100','B')
          CALL STATST ('N101','B')
          CALL STATST ('N102','B')
          CALL STATST ('N103','B')
          T100 = INTRP1(TIMEM, AVUM_T_B, 1)
          T101 = INTRP1(TIMEM, AVUM_T_B, 1)
          T102 = INTRP1(TIMEM, AVUM_T_B, 1)
          T103 = INTRP1(TIMEM, AVUM_T_B, 1)
      ELSE
          CALL STATST ('N100','D')
          CALL STATST ('N101','D')
          CALL STATST ('N102','D')
          CALL STATST ('N103','D')
      ENDIF
#
```



Stowed case AVUM external structure boundary nodes

```
##################################################
##################################################
      IF (QS400 .LE. 0.001) THEN

      CALL STATST('N400','B')
          T400 = 0.0   #ALEK External Structure
      CALL STATST('N401','B')
          T401 = 0.0   #ALEK External Structure
      CALL STATST('N402','B')
          T402 = 0.0   #ALEK External Structure
#      CALL STATST('N425','B')
#          T425 = 10.0   #stator PY

      ELSE

      CALL STATST('N400','B')
          T400 = 50.0   #ALEK External Structure
      CALL STATST('N401','B')
          T401 = 50.0   #ALEK External Structure
      CALL STATST('N402','B')
          T402 = 50.0   #ALEK External Structure
#      CALL STATST('N425','B')
#          T425 = 40.0   #stator PY

      END IF
##################################################
```




```
# Internal boundary temperature node for connecting SADE/SADM equipment
      B420 = 'ALEK Internal Structure', T = 50.0, A = 1.0D10, ALP = 1.0, EPS = 1.0;
#
```

boundary condition setup for deployed case 3

Power drain modelling

Power drain was applied as a negative heat power QR (for deployed) or QI (for stowed) function of temperature.

SpaceRider_powerdrain_MY_BOL.data

C: > Scratch > ESATAN_TMS > SpaceRider_prem > esatan > COMMON > VARIABLES > SpaceRider_powerdrain_MY_BOL.data

```
1   #
2       QR11101001  =     -1.0  *     INTRP1(T11101001  , PWDBOL,1) *     ((    QS11101001  +     QA11101001  )     /     alphaBOL)
3       QR11101002  =     -1.0  *     INTRP1(T11101002  , PWDBOL,1) *     ((    QS11101002  +     QA11101002  )     /     alphaBOL)
4       QR11101003  =     -1.0  *     INTRP1(T11101003  , PWDBOL,1) *     ((    QS11101003  +     QA11101003  )     /     alphaBOL)
5       QR11101004  =     -1.0  *     INTRP1(T11101004  , PWDBOL,1) *     ((    QS11101004  +     QA11101004  )     /     alphaBOL)
6       QR11101005  =     -1.0  *     INTRP1(T11101005  , PWDBOL,1) *     ((    QS11101005  +     QA11101005  )     /     alphaBOL)
```

This power is applied for all the solar cells nodes only of all panels for the deployed configuration and the outermost panels of the stowed configuration.

For the stowed case, the power drain is applied only on the outermost panel solar cells, as the others have no or negligeable view with the sun.

Powerdrain_BOL.dat

C: > Scratch > ESATAN_TMS > SpaceRider_prem > esatan > COMMON > ARRAYS > Powerdrain_BOL.dat

```
1   #
2       $REAL
3         # User-defined  'PWDBOL'
4         PWDBOL(2, 6) =
5          -110.0,  0.349,
6          -80.0, 0.337,
7          28.0,  0.287,
8          60.0,  0.27,
9          80.0,  0.258,
10         110.0, 0.24;
11  #
```

It is an applied QR on the solar cells defined as follow:

QR solar cell node = -1 * solar cell efficiency in function of solar cell node temperature [INTRP (Tsolar cell node, PWDBOL;1] * ((Solar power absorbed + Albedo absorbed) / alpha of the solar cell node [parameter alphaBOL = 0.9]).

Harness dissipation

The harness dissipation was applied as a QI (for deployed) constant value spread evenly on the back panel nodes in agreement with LDO. The amplitude of the harness dissipation varies depending on the panel and depending on the case.

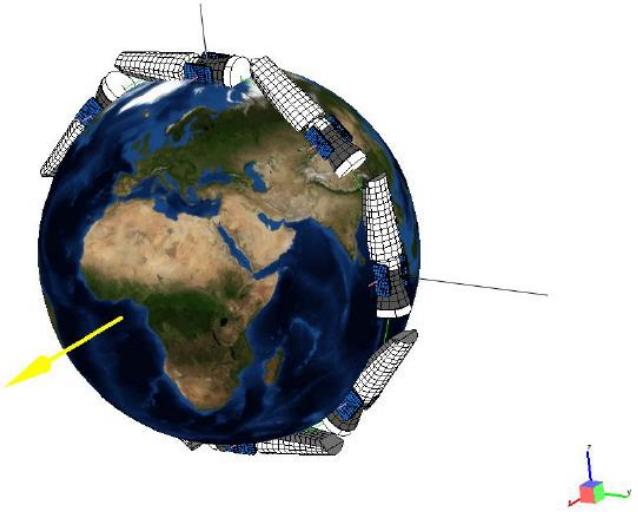
```
#
      HarDis_3_pan1 = 3.81;  #LDO inputs
      HarDis_3_pan2 = 5.05;  #LDO inputs
      HarDis_3_pan3 = 6.28;  #LDO inputs
      HarDis_3_pan4 = 7.52;  #LDO inputs
#
#
      HarDis_4_pan1 = 2.82;  #LDO inputs
      HarDis_4_pan2 = 3.74;  #LDO inputs
      HarDis_4_pan3 = 4.66;  #LDO inputs
      HarDis_4_pan4 = 5.58;  #LDO inputs
#
#
      HarDis_5_pan1 = 3.25;  #LDO inputs
      HarDis_5_pan2 = 4.30;  #LDO inputs
      HarDis_5_pan3 = 5.36;  #LDO inputs
      HarDis_5_pan4 = 6.41;  #LDO inputs
#
```

C: > Scratch > ESATAN_TMS > SpaceRider_prem > esatan > COMMON > VARIABLES > SpaceRider_harDiss_5_PY.data

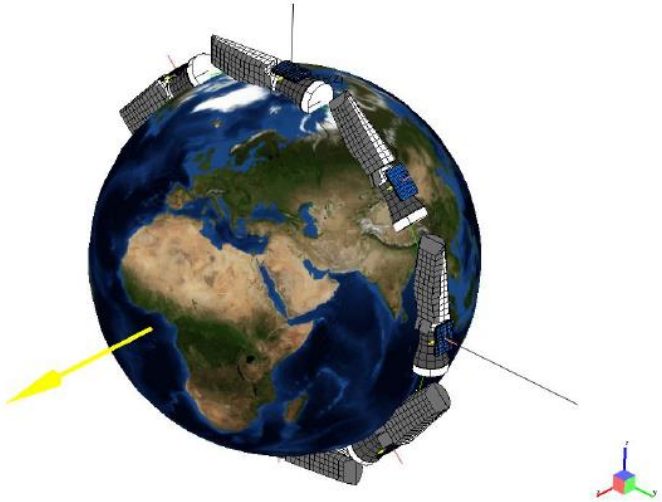
```
1   #
2
3       QI11202001 = HarDis_5_pan1 /80.0
4       QI11202002 = HarDis_5_pan1 /80.0
5       QI11202003 = HarDis_5_pan1 /80.0
6       QI11202004 = HarDis_5_pan1 /80.0
7       QI11202005 = HarDis_5_pan1 /80.0
8       QI11202006 = HarDis_5_pan1 /80.0
9       QI11202007 = HarDis_5_pan1 /80.0
10      QI11202008 = HarDis_5_pan1 /80.0
11      QI11202009 = HarDis_5_pan1 /80.0
12      QI11202010 = HarDis_5_pan1 /80.0
13      QI11202011 = HarDis_5_pan1 /80.0
14      QI11202012 = HarDis_5_pan1 /80.0
15      QI11202013 = HarDis_5_pan1 /80.0
16      QI11202014 = HarDis_5_pan1 /80.0
17      QI11202015 = HarDis_5_pan1 /80.0
18      QI11202016 = HarDis_5_pan1 /80.0
19      QI11202017 = HarDis_5_pan1 /80.0
20      QI11202018 = HarDis_5_pan1 /80.0
21      QI11202019 = HarDis_5_pan1 /80.0
```

Analysis cases

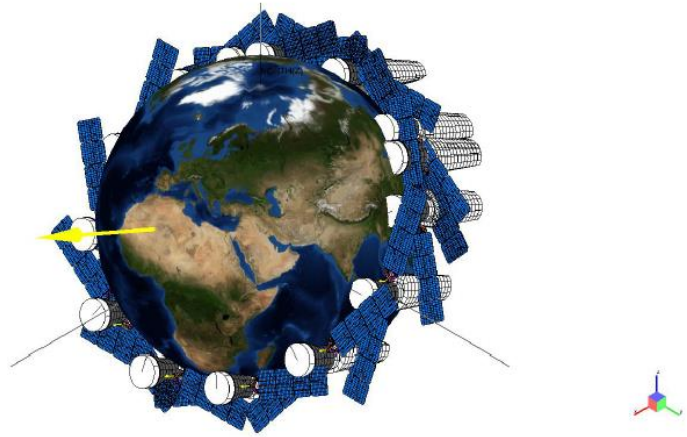
Case 1 orbit



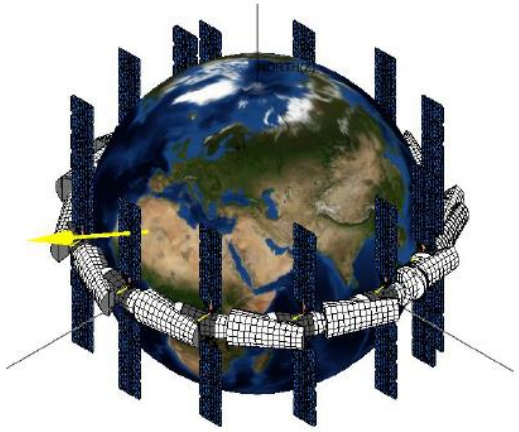
Case 2 orbit



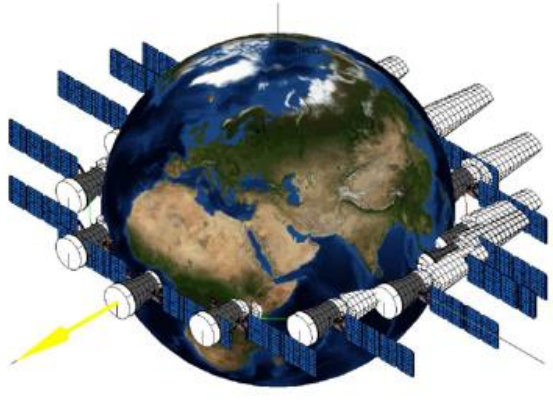
Case 3 orbit



Case 4 orbit



Case 5 orbit



Margin philosophy

from ECSS-E-HB-21-03A15

Sensitivity parameter variation	Parameter definition
CF1	Thermal Couplings (+/-20%)
CF2	Thermal Capacitance (+/-20%)
CF3	emissivity +/-0.03 (+/-0.02 for emi <0.2)
CF4	absorptivity +/-0.1 (+/-0.03 for abs <0.2)
CF5	max delta shape factors +/-10%
Uncertainty $= \sqrt{\sum (T_i - T_{ref})^2}$ With : T_{ref} temperature for reference case. T_i : temperature for case i	Total Uncertainty from Sensitivities UCS
3°C	Systematic error SE
UCS+3°C	Total calculation uncertainty

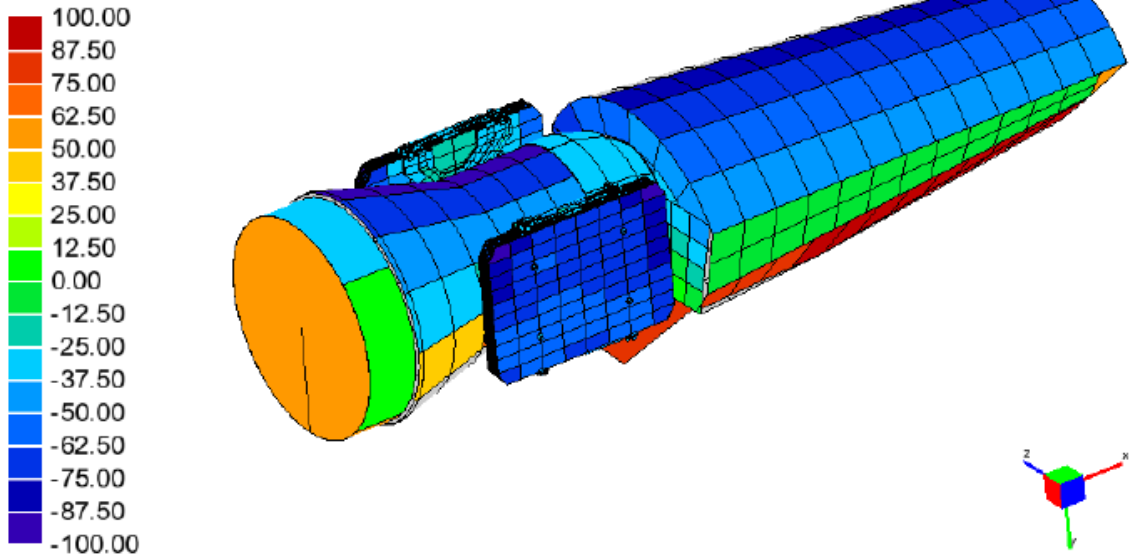
acceptance and qualification margins have been assumed and considered to establish the allowable temperatures, as follow:
- 5K acceptance margin
- 5K qualification margin

Results (1/3)

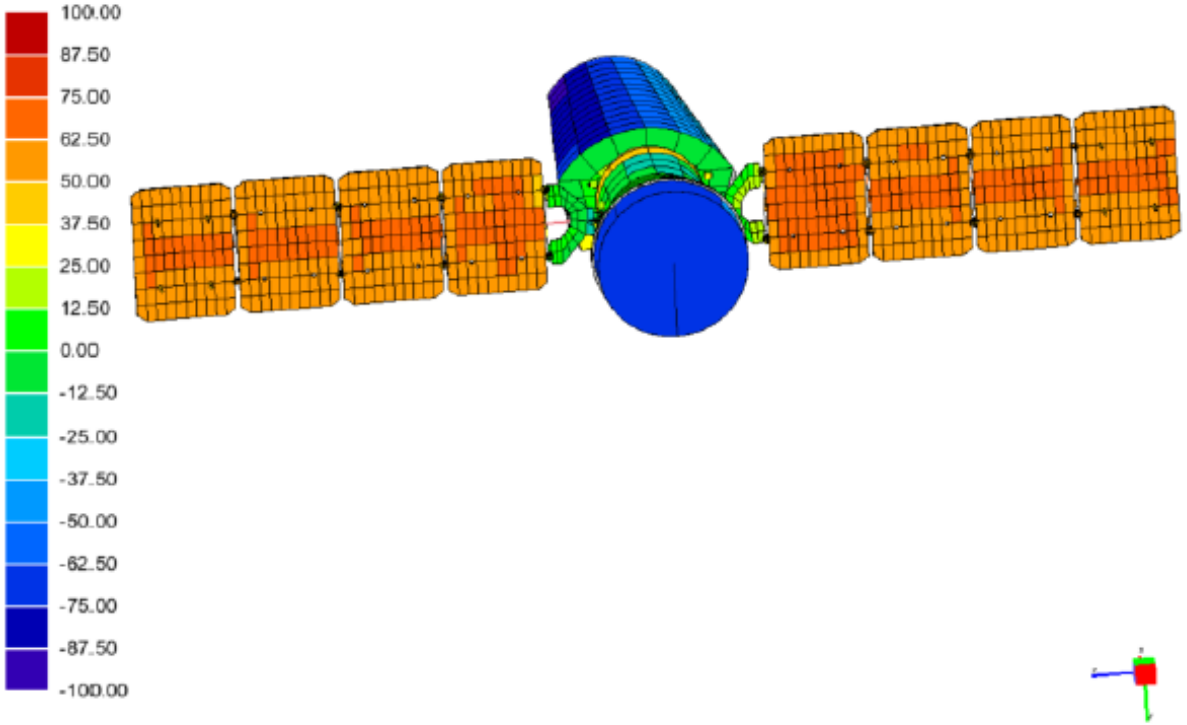
STOWED	Min temp °C	Max temp °C
Solar Cells	-170	140
HDRM	-55	+100
Connectors	-75	+210
Hinges	-130	+130
Root Hinge (+ECD)	-55	+100
Solar Panels (structure)	-125	+160
Harness	-210	+210
Yoke	-125	+160
Synchro Cables	-200	+200

DEPLOYED	Min temp °C	Max temp °C
Solar Cells	-170	140
HDRM	N/A	N/A
Connectors	-75	+210
Hinges	-85	+125
Root Hinge	-90	+130
Solar Panels (structure)	-125	+160
Harness	-210	+210
Yoke	-125	+160
Synchro Cables	-200	+200

Results (2/3)



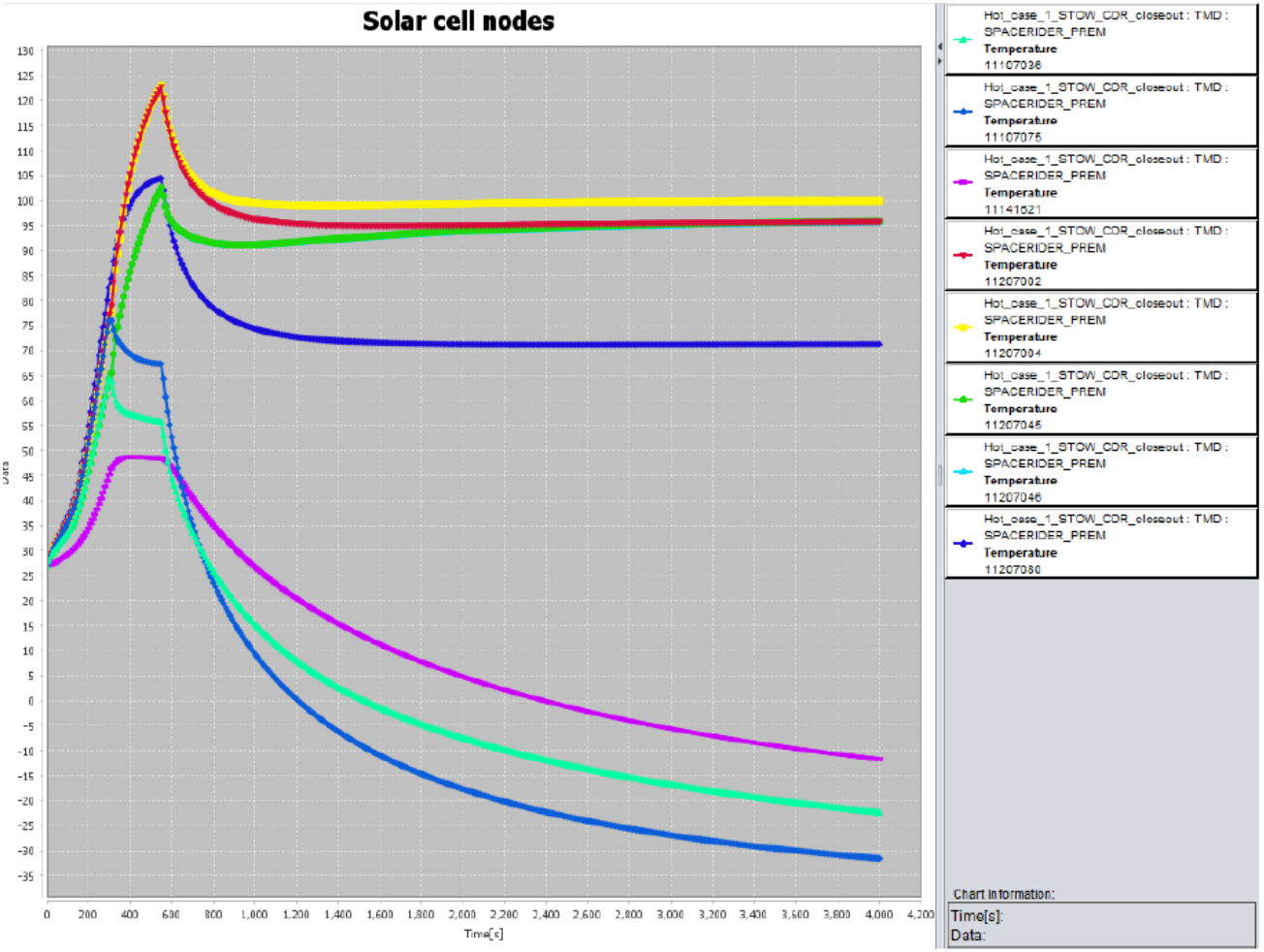
Case 2 temperature map (time =4000s coldest map)

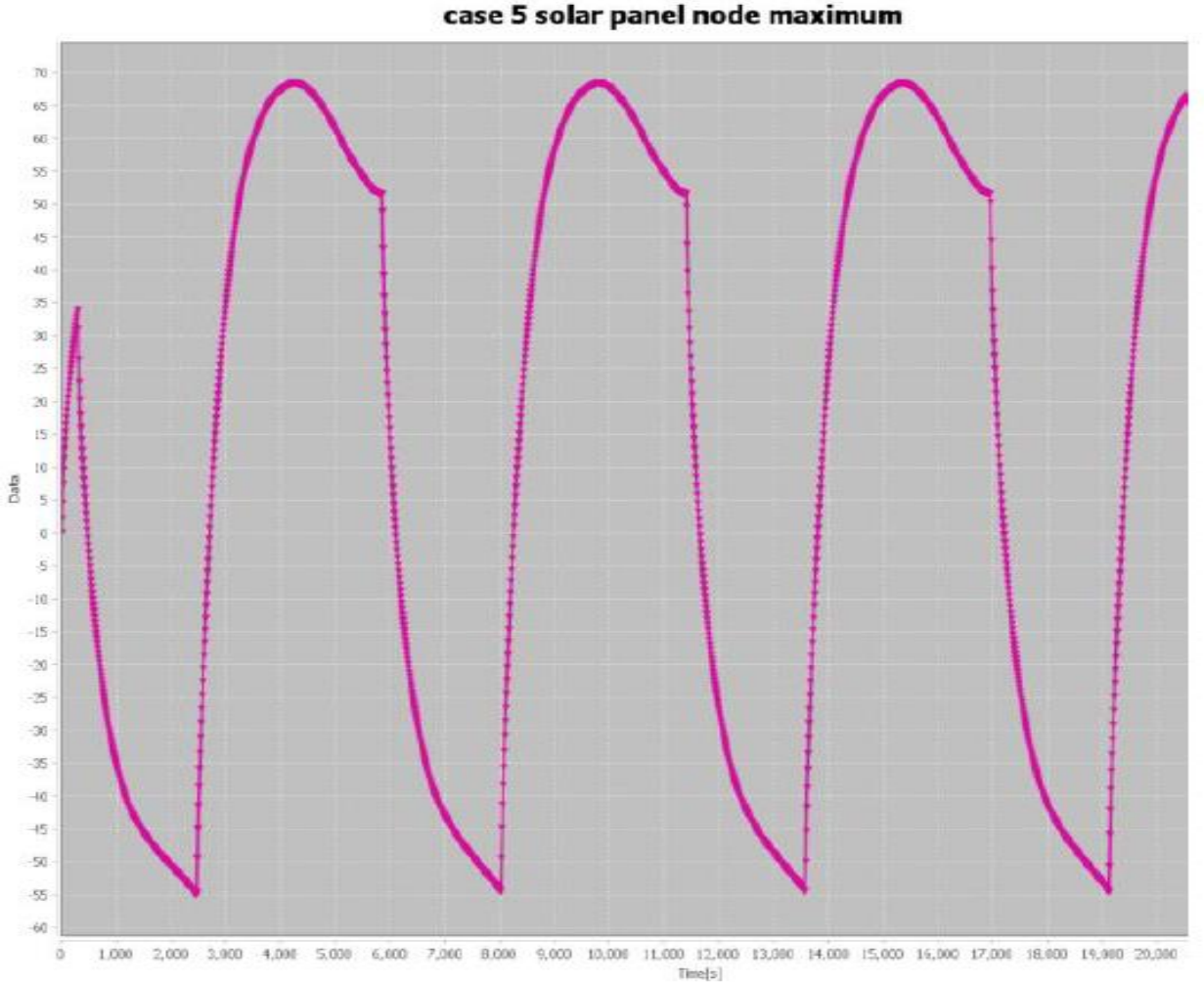


Case 5 temperature map at 1530s

Results (3/3)

Case 1 temperature of solar cells nodes





Conclusion and way forward

- Model and analyses allowed to assess the ranges of temperatures for all components
- Thermal maps provided to the mechanical team for thermo-elastic distortion analyses
- Thermal modelling correct validation only through thermal testing
- Any other ways of modelling and improvements?

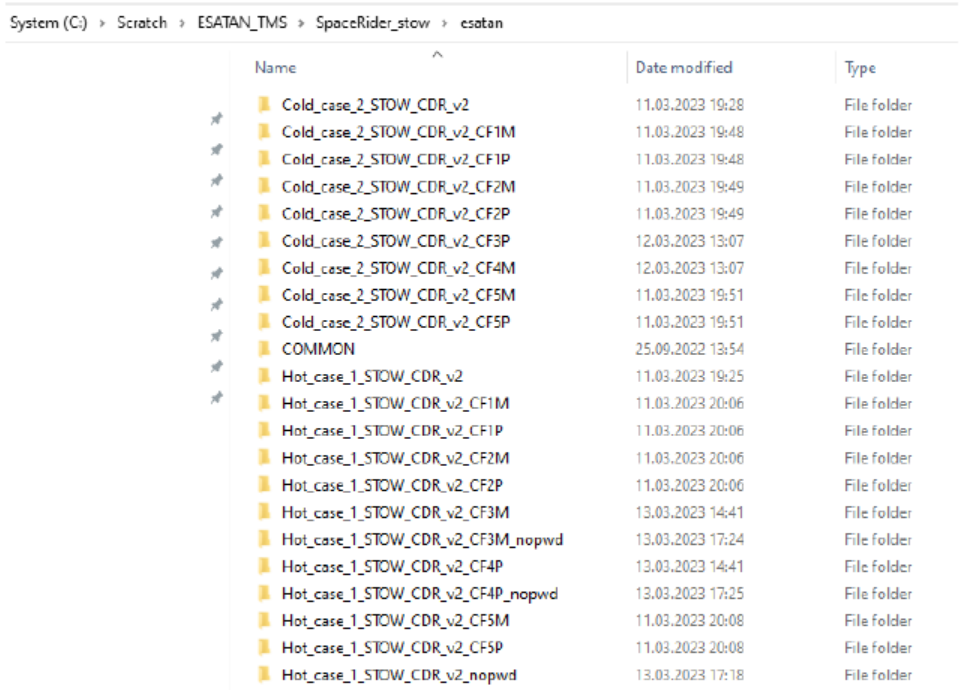
beyond gravity

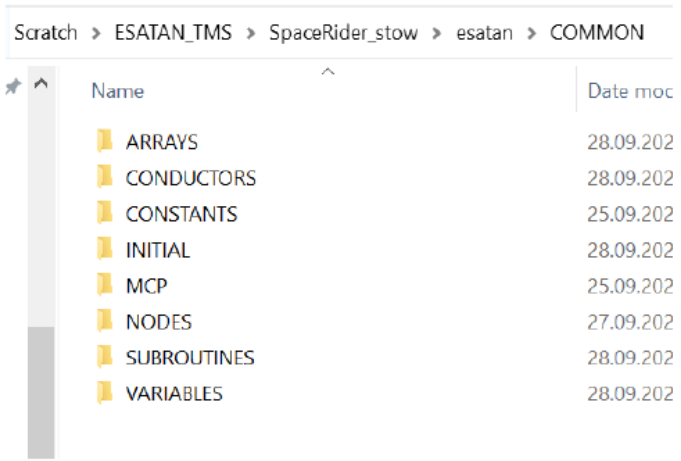
Thank you for your attention!

For further information or questions, please contact me on:

adeeb.nazeeruddin@beyondgravity.com

EXTRA slide Model organisation





The Thermal model consists of:

- A Geometrical Mathematical Model (GMM) (.erg.file)

- (.dat) files containing the arrays, the couplings, the capacitances (MCP), the nodes declaration, the constants and subroutines used, all gathered in a folder named “COMMON”

EXTRA slide TMM files

Scratch › ESATAN_TMS › SpaceRider_prem › esatan › COMMON › CONSTANTS

Name	Date modified
GMM_LOCALS_IF.dat	10.03.2023 14:5
GMM_LOCALS_IF_CF1M.dat	10.03.2023 16:4
GMM_LOCALS_IF_CF1P.dat	10.03.2023 16:4
GMM_LOCALS_IF_CF2M.dat	10.03.2023 16:4
GMM_LOCALS_IF_CF2P.dat	10.03.2023 16:4
GMM_LOCALS_IF_CF4M.dat	13.03.2023 14:5
GMM_LOCALS_IF_CF4P.dat	13.03.2023 14:5
GMM_LOCALS_IF_CF5M.dat	10.03.2023 18:0
GMM_LOCALS_IF_CF5P.dat	10.03.2023 18:0
K5TG_RTMM.locals	20.02.2023 13:4
K5TG_RTMM_const.dat	20.02.2023 13:4

Scratch › ESATAN_TMS › SpaceRider_prem › esatan › COMMON › VARIABLES

Name	Date modified
K5TG_Motor_and_AuxDissipation.dat	24.02.2023 18:58
K5TG_DissipationON.dat	24.02.2023 18:49
K5TG_variable.dat	24.02.2023 18:36
SpaceRider_harDiss_5_PY.data	02.02.2023 17:38
SpaceRider_harDiss_5_MY.data	02.02.2023 17:38
SpaceRider_harDiss_4_PY.data	02.02.2023 17:25
SpaceRider_harDiss_4_MY.data	02.02.2023 17:25
SpaceRider_harDiss_3_PY.data	02.02.2023 17:24
SpaceRider_harDiss_3_MY.data	02.02.2023 17:23
K5TG_DissipationOFF.dat	23.01.2023 17:15
SpaceRider_powerdrain_PY_EOL.data	16.01.2023 13:44
SpaceRider_powerdrain_PY_BOL.data	16.01.2023 13:43
SpaceRider_powerdrain_MY_EOL.data	16.01.2023 13:39
SpaceRider_powerdrain_MY_BOL.data	16.01.2023 13:36

Scratch › ESATAN_TMS › SpaceRider_prem › esatan › COMMON › NODES

Name	Date modifie
newSADM_nodes_PZ.dat	18.02.2023 19
newSADM_nodes_MZ.dat	18.02.2023 19
GMM_SAT_nodes_case_4_CDR.dat	18.02.2023 19
GMM_SAT_nodes_case_3_CDR.dat	22.02.2023 14

Scratch › ESATAN_TMS › SpaceRider_prem › esatan › COMMON › ARRAYS

Name	Date modified
fluxes_arrays_case4_CF4M.dat	11.03.2023 15:39
fluxes_arrays_case4_CF3P.dat	11.03.2023 10:47
fluxes_arrays_case5_CF3M.dat	10.03.2023 22:56
fluxes_arrays_case5_CF4P.dat	10.03.2023 22:55
fluxes_arrays_case5.dat	10.03.2023 16:10
fluxes_arrays_case3.dat	10.03.2023 15:07
fluxes_arrays_case4.dat	10.03.2023 14:59
Dissipation_5_5A.dat	18.02.2023 18:41
Dissipation_4_3A.dat	16.12.2022 16:44
Powerdrain_BOL.dat	24.09.2022 19:16
Powerdrain_EOL.dat	24.09.2022 17:22

Scratch › ESATAN_TMS › SpaceRider_prem › esatan › COMMON › MCP

Name	Date modified
SADM_MZ.dat	23.01.2023 16:43
SADM_PZ.dat	23.01.2023 16:46
Hinges.dat	07.03.2023 11:44
Yokes.dat	07.03.2023 11:46
SAW_panels_MY_pan1.dat	07.03.2023 11:47
SAW_panels_MY_pan2.dat	07.03.2023 11:48
SAW_panels_MY_pan3.dat	07.03.2023 11:48
SAW_panels_MY_pan4.dat	07.03.2023 11:49
SAW_panels_PY_pan1.dat	07.03.2023 11:50
SAW_panels_PY_pan2.dat	07.03.2023 11:52
SAW_panels_PY_pan3.dat	07.03.2023 11:53
SAW_panels_PY_pan4.dat	07.03.2023 11:53
HDRM.dat	07.03.2023 11:54
RootHinge.dat	07.03.2023 11:55
Connectors.dat	07.03.2023 11:56

Scratch › ESATAN_TMS › SpaceRider_prem › esatan › COMMON › CONDUCTORS

Name
YOKE_TRANS_GL.data
YOKE_INT_GL.data
SAW_PY_PAN_TRANS_GL.data
SAW_PY_INT_GL.data
SAW_MY_PAN_TRANS_GL.data
SAW_MY_INT_GL.data
ROOTHINGES_GL_FIX.data
K5TGFlight_RTMM_PZ.dat
K5TGFlight_RTMM_MZ.dat
HINGES_internal_GL.data
HINGES_GL_PY.data
HINGES_GL_MY.data
HDRM_PY_GL.data
HDRM_MY_GL.data
Harness_GL_PY.data
Harness_GL_MY.data
GR_BOL_Case5_CF4P.dat
GR_BOL_Case5_CF3M.dat
GR_BOL_Case5.dat
GR_BOL_Case4_CF4M.dat
GR_BOL_Case4_CF3P.dat
GR_BOL_Case4.dat
GR_BOL_Case3.dat
Connectors_GL.data
Cables_GL.data

Scratch › ESATAN_TMS › SpaceRider_prem › esatan › COMMON › SUBROUTINES

Name	Date modified
fluxes_sub_case3.dat	10.03.2023 15:09
fluxes_sub_case4.dat	10.03.2023 15:03
fluxes_sub_case4_CF3P.dat	11.03.2023 10:40
fluxes_sub_case4_CF4M.dat	11.03.2023 15:30
fluxes_sub_case5.dat	10.03.2023 16:13
fluxes_sub_case5_CF3M.dat	10.03.2023 22:59
fluxes_sub_case5_CF4P.dat	10.03.2023 22:59

Extra slide: Skeleton file

SpaceRider_stow_Hot_case_1_STOW_CDR_v2.d

C: > Scratch > ESATAN_TMS > SpaceRider_stow > esatan > Hot_case_1_STOW_CDR_v2 > SpaceRider_stow_Hot_case_1_STOW_CDR_v2.d

```
$MODEL SpaceRider_prem, GLOBALFILE = Global_file.data

###hot case 1
  $LOCALS

  $INCLUDE "../COMMON/CONSTANTS/GMM_LOCALS_IF_stow.dat"
##

  $INCLUDE "../COMMON/CONSTANTS/K5TG_RTMM.locals"
#
  $NODES
  $INCLUDE "../COMMON/NODES/GMM_SAT_nodes_case_1.dat"
  $INCLUDE "../COMMON/NODES/newSADM_nodes_MZ.dat"
  $INCLUDE "../COMMON/NODES/newSADM_nodes_PZ.dat"
#########################
  $CONDUCTORS
  $INCLUDE "../COMMON/CONDUCTORS/HDRM_MY_GL.data"
  $INCLUDE "../COMMON/CONDUCTORS/HDRM_PY_GL.data"
  $INCLUDE "../COMMON/CONDUCTORS/HINGES_GL_MY.data"
  $INCLUDE "../COMMON/CONDUCTORS/HINGES_GL_PY.data"
#  $INCLUDE "../COMMON/CONDUCTORS/SADM_SC_GL.data"
  $INCLUDE "../COMMON/CONDUCTORS/SAW_MY_INT_GL.data"
  $INCLUDE "../COMMON/CONDUCTORS/SAW_MY_PAN_TRANS_GL.data"
  $INCLUDE "../COMMON/CONDUCTORS/SAW_PY_INT_GL.data"
  $INCLUDE "../COMMON/CONDUCTORS/SAW_PY_PAN_TRANS_GL.data"
  $INCLUDE "../COMMON/CONDUCTORS/YOKE_INT_GL.data"
  $INCLUDE "../COMMON/CONDUCTORS/YOKE_TRANS_GL.data"
  $INCLUDE "../COMMON/CONDUCTORS/Connectors_GL.data"
```

EXTRA slide Model Verification

There is no automatic way to verify the GMM and TMM.
However, the following steps have made it possible to detect and eliminate errors:

- visualization of all surface and nodes properties in the GMM
- use of automatically generated data everywhere possible
- use of declared constants for computation of couplings and capacities
- analysis of results (temperature distribution, heat flux balance)