LUROVA – FROM RENDER ENGINE TO THERMAL MODEL

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ABSTRACT

Render Engine created surface data provides high quality polygon faces and vertex information for potential use in constructing thermal radiation analytical models. The original Apollo **LU**nar **ROV**ing **A**dventures (LUROVA) mission support thermal model, presented at TFAWS-2006, has been restored and upgraded using detailed render engine surface data. Polygon crunching and other developed surface data conversion and visualization software was used to reduce 900,000+ "faces" and 400,000+ "vertices" into a representative and manageable smaller surface model (~7800 surface nodes) to be run on the NASA Thermal Radiation Analysis System (TRASYS) computer program. The surface data conversion process is described, and a comparison of the calculated radiation environment for the enhanced thermal model to previous mission support analysis results is presented. Future plans for the LUROVA thermal model and "Edutainment" game/simulation enhancements are also discussed.

BACKGROUND – LUROVA INTRODUCED AT TFAWS-2006

The author worked for NASA on the thermal control system for the Apollo Lunar Roving Vehicle, America's "Spacecraft on Wheels", shown in Figure 1. This included thermal testing, modeling, and mission support during the Apollo 15, 16, and 17 missions. The author has helped others with their books about the Moon Rovers, participated in the "Moon Machines" movie, and is writing a book of his own titled "LUROVA – Lunar Roving Adventures". It is desired to have an interactive LUROVA thermal model simulation on a DVD to accompany the book. This model simulation will be a Science, Technology, Engineering, and Mathematics (STEM) "Edutainment" challenge for students and readers.

Figure 1. Lunar Rover on the Moon.

An overview of the LUROVA simulation is shown in Figure 2. This interactive simulation will provide users with the capability to experience Moon exploration using the previously verified Rover mission support thermal model by; planning a Moon exploration traverse and predicting expected thermal performance; unloading the folded Rover from the Lunar Module (LM) and loading communication and science equipment; performing the traverse by driving the Rover to planned experiment station stops; and be evaluated post-traverse as to how well their roving performance compared to predictions.

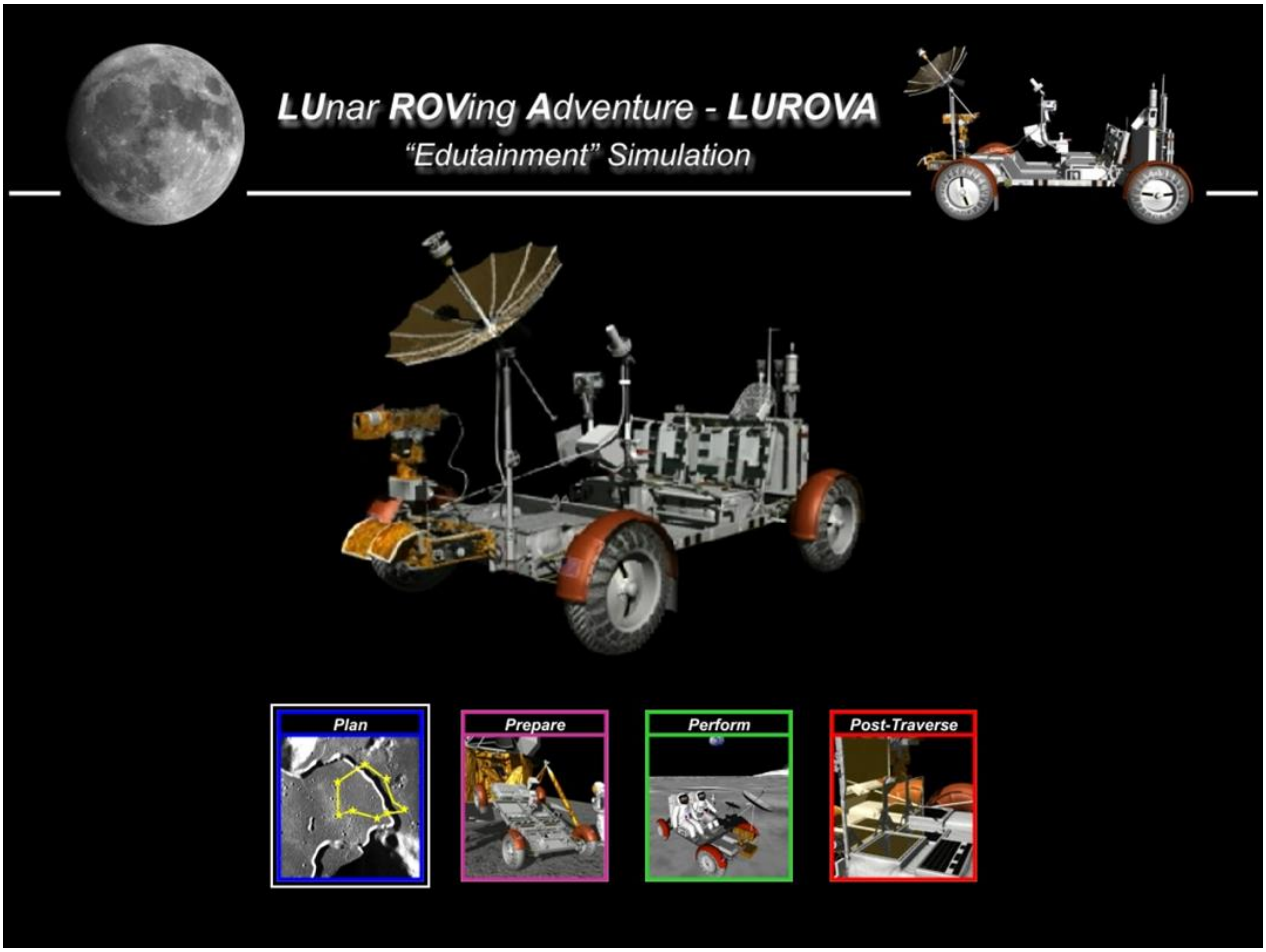

Figure 2. LUROVA "Edutainment" Simulation.

LUROVA MISSION SUPPORT THERMAL MODELS

Mission support Rover models were based on correlation with extensive Thermal Vacuum (TVAC) test data. This included mobility subsystem and full-up Rover testing, as shown in Figure 3. A 177 node thermal model was developed by separately modeling and then combining the forward, center, and aft sections of the Rover. Radiation view factors, radiation conductors, and heating rates were calculated using the Lockheed Heat Rate Program (LOHARP), a predecessor to the NASA Thermal Radiation Analysis System (TRASYS) program.

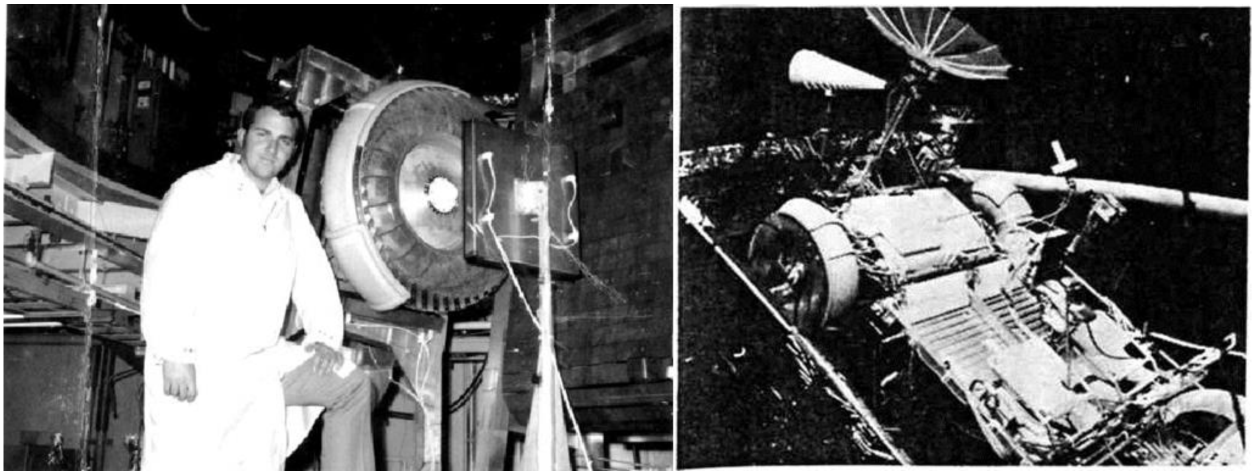

Figure 3. Lunar Rover TVAC Testing.

The 177 node thermal model was used for the first Rover mission on Apollo 15, but was found to be cumbersome to run and not responsive to mission control needs. Therefore, the author developed a condensed faster responding 19 node model for the forward chassis area containing the batteries, gyro navigation unit, drive computer and electronics, and associated fusible mass tanks (wax boxes), insulation, second surface radiators and dust covers. The mobility subsystems were not included in this smaller model due to the fact that drive motor temperatures were not observed to exceed 200 deg. F on Apollo 15, well below the operational limit of 400 deg. F. This 19 node thermal model was then used for the Apollo 16 and 17 missions.

After Apollo 16, it was necessary to specify Rover parking positions to minimize the blockage effects of the Lunar Module. View factor verification testing was performed at the U.S. Space and Rocket Center using a form factometer, as shown in Figure 4. The author received the Astronaut Silver Snoopy award for his Rover thermal modeling and mission support efforts.

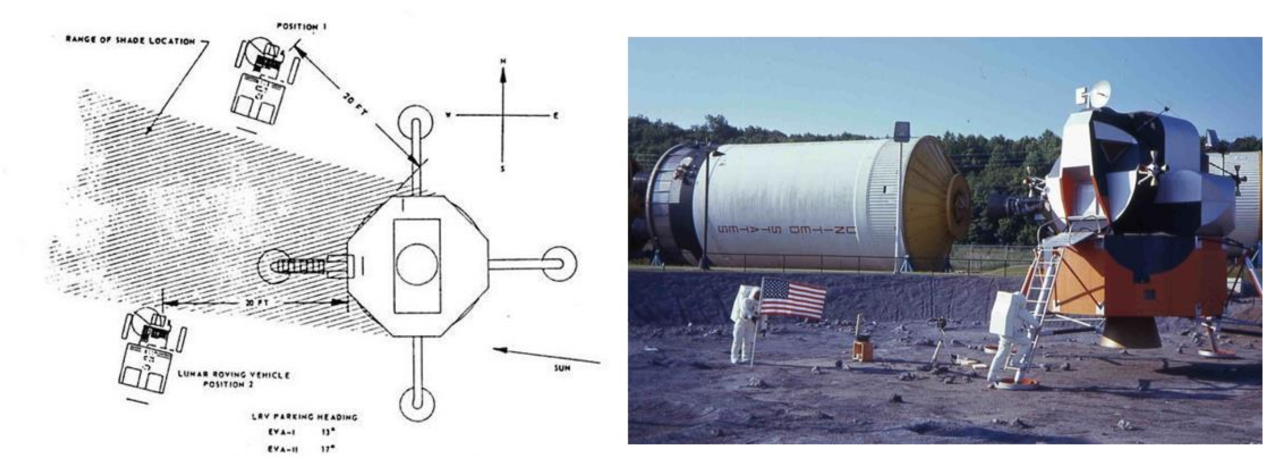

Figure 4. 19 Node Thermal Model View Factor Verification.

RENDER ENGINE PROVIDES HIGH QUALITY SURFACE DATA

The radiation and solar heating environment must be provided for the "Full" 177 node LUROVA thermal model. The original thermal model nodes and conductors listing was located, but the surface model for calculating radiation conductors and solar heat rates was not found. An associate, Don McMillan, created a Rover poster using the "Lightwave" render engine, as shown in Figure 5. These detailed rendered polygon surfaces were a candidate for use in the LUROVA thermal model, but there are more than 900,000 polygons, which is far beyond the TRASYS analysis capability. Therefore, a process was needed to reduce the number of polygons and convert that surface data for input to the TRASYS program.

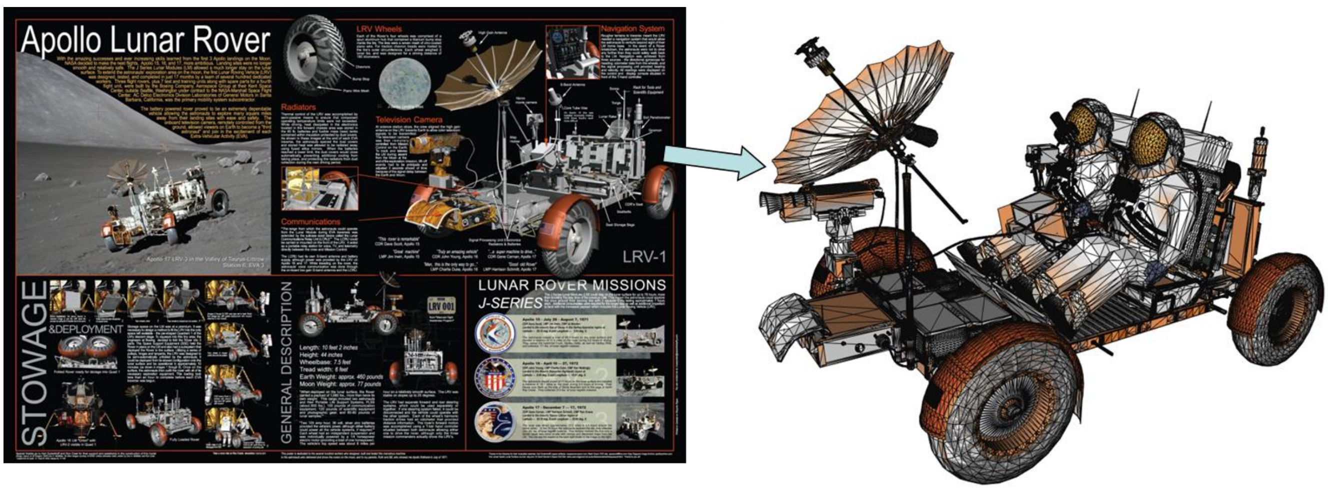

Figure 5. From Rover Poster to Rendered Polygon Model.

POLYGON REDUCTION/CONVERSION (R/C) PROCESS DEVELOPED

The needed polygon reduction and conversion process was developed using a combination of "off-the-shelf" and author developed FORTRAN software programs, as shown in Figure 6. Existing software is shown in blue and author developed software is shown in pink for the R/C process. This figure also shows how the R/C products feed into the TRASY and the NASA Systems Improved Numerical Differencing Analyzer (SINDA) programs and thermal model elements, and visualization programs that were used to verify process products. It was necessary to expand the TRASYS node handling capability from 4000 surface nodes to 8000. Another use for the R/C process products is for 3D printing of a solid model. The R/C process steps and products are further described next.

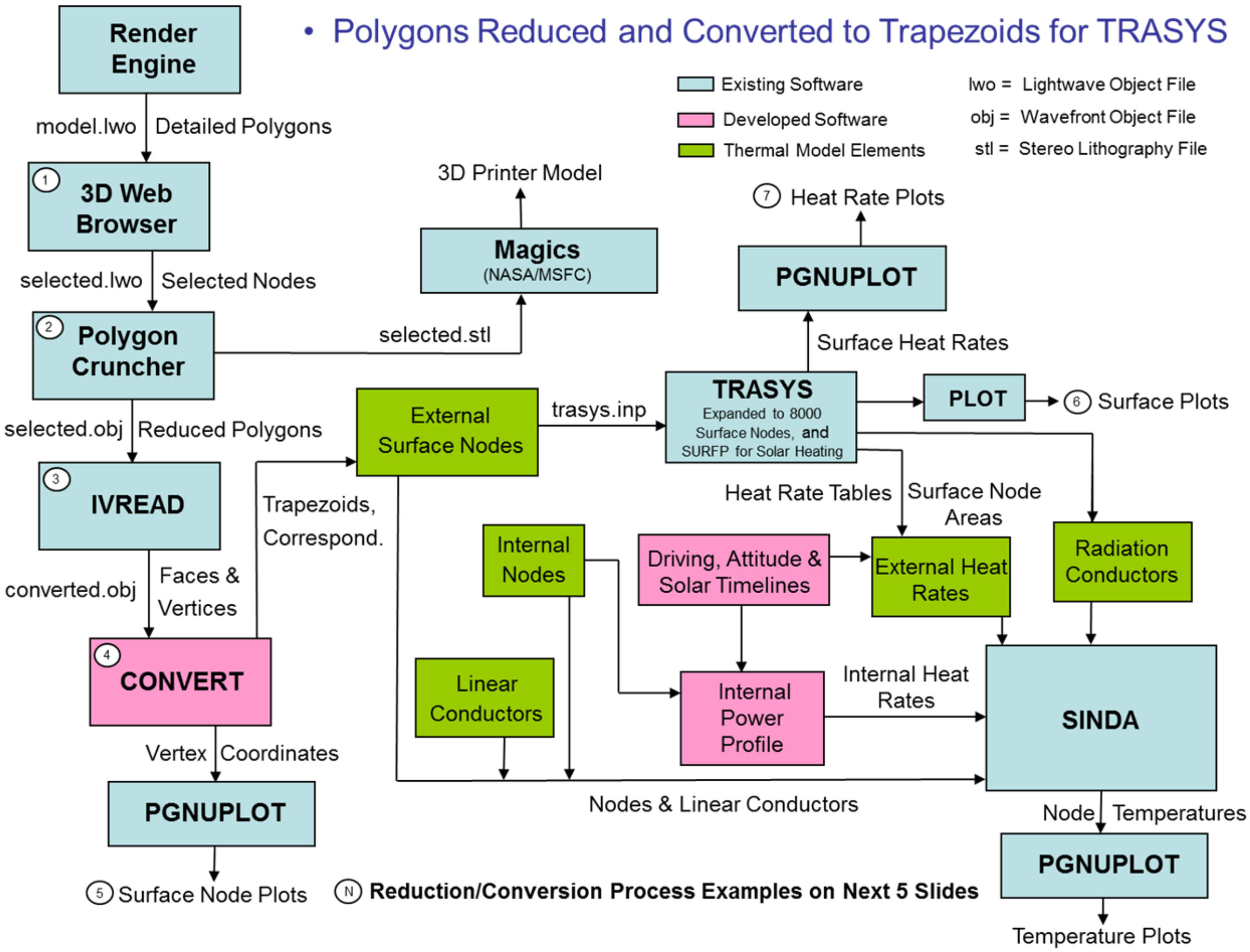

Figure 6. Polygon Reduction and Conversion Process.

POLYGON REDUCTION STEPS AND PRODUCTS

The “3D Browser” and Polygon Cruncher codes are bundled together, and were purchased. In the example shown in Figure 7, 3DBrowser was used to select forward chassis model nodes from the render engine supplied detailed quadrilateral polygons. Then Polygon Cruncher was used to reduce the quadrilateral polygons into fewer triangular polygons.

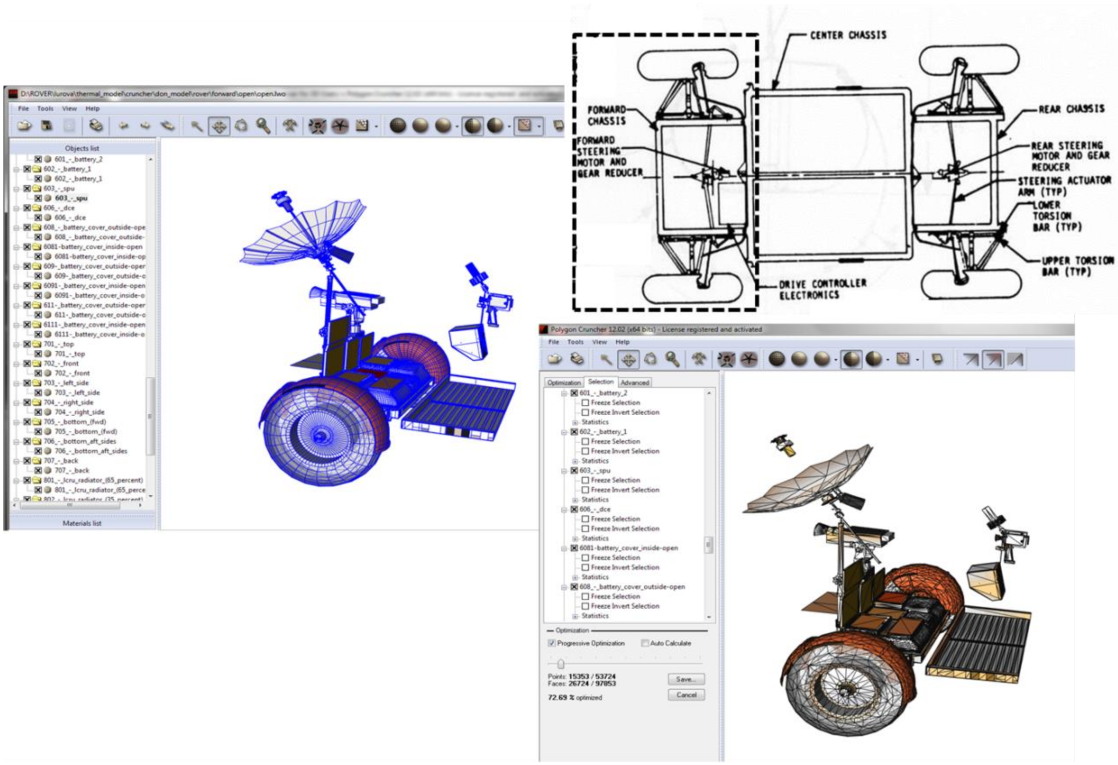

Figure 7. (1) 3D Browser and (2) Polygon Cruncher Products.

TRIANGULAR POLYGONS CONVERTED TO TRASYS TRAPEZOIDS

The reduced triangular polygon conversion process and products are shown in Figure 8. The IVREAD program was downloaded from the Internet. IVREAD reads a 3D graphics file and converts to other formats. In this case, the Lightwave “.lwo” file is read in and converted to a Wavefront“.obj” ASCII readable file format containing polygon “faces” and vertices”.

The CONVERT program was developed by the author to provide trapezoids to TRASYS for calculating radiation conductors, and related correspondence data to combine surface node trapezoids for calculating surface heat rates and areas. As shown in Figure 9, CONVERT takes polygon “faces” and “vertices” and converts them to trapezoids for TRASYS. CONVERT also allows mirroring for symmetrical left and right and forward and aft mobility subsystems, and for surface node vertex coordinate rotations for variable solar orientations.

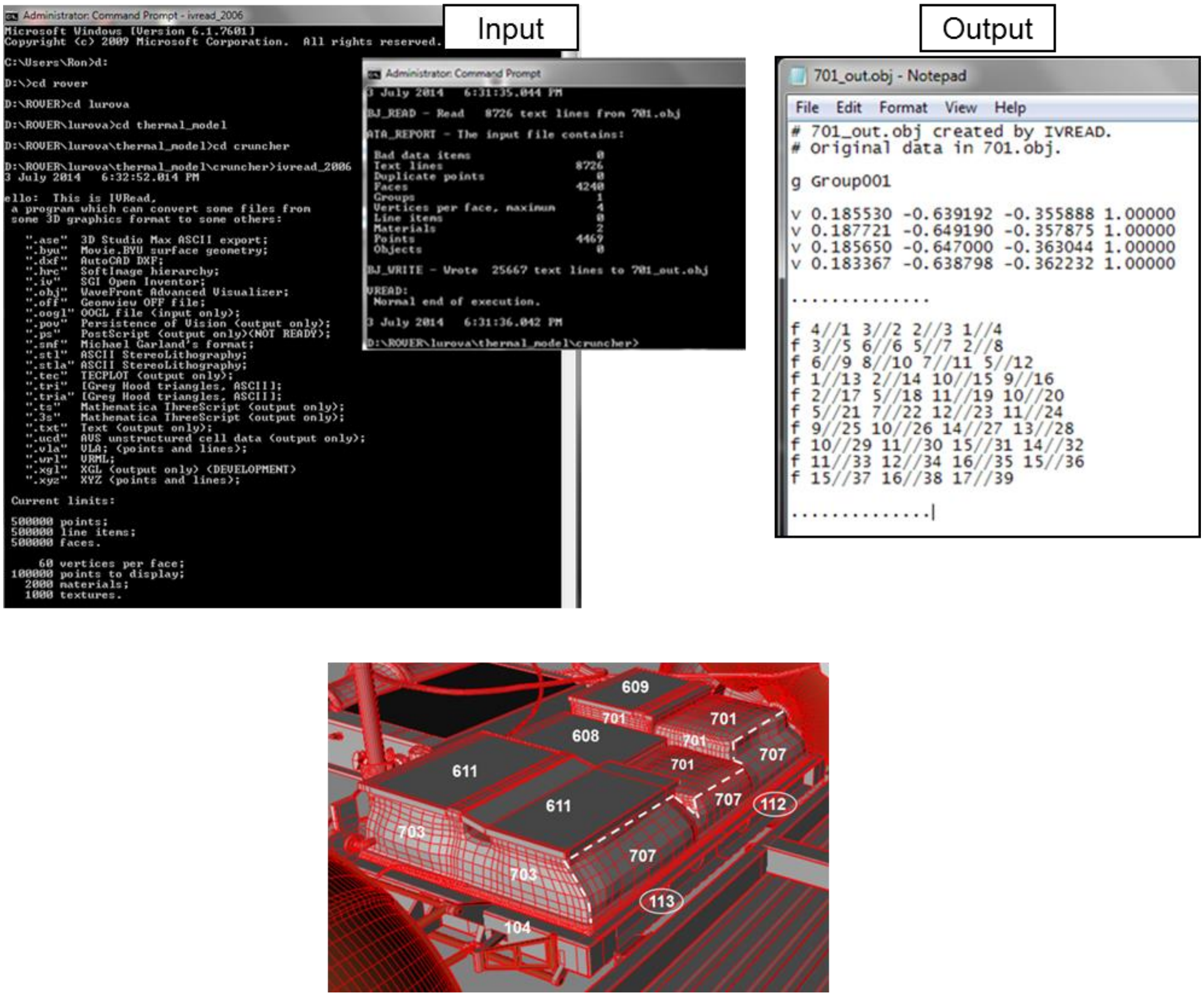

Figure 8. (3) IVREAD Provides Triangular Polygon "Faces" and Vertices".

```
HEADER OPTIONS DATA
TITLE LUROVA
      MODEL = LUROVA
      RSO
HEADER SURFACE DATA
S       SURFN        = 601001
        TYPE         = TRAP
        ACTIVE       = TOP
        PROP         = 0.90, 0.90
        P1 =  -0.46338487 , -3.09466863 , -0.89315426
        P2 =  -1.28817642 , -2.37285924 , -0.89315426
        P3 =  -1.28817642 , -3.09466863 , -0.89315426
        P4 =  -0.46338487 , -3.09466863 , -0.89315426
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        NNY = 1
S       SURFN        = 601002
        TYPE         = TRAP
        ACTIVE       = TOP
        PROP         = 0.90, 0.90
        P1 =  -0.46338487 , -2.37285924 , -0.89315426
        P2 =  -1.28817642 , -2.37285924 , -0.89315426
        P3 =  -0.46338487 , -3.09466863 , -0.89315426
        P4 =  -0.46338487 , -2.37285924 , -0.89315426
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        NNY = 1
S       SURFN        = 602001
        TYPE         = TRAP
        ACTIVE       = TOP
        PROP         = 0.90, 0.90
        P1 =   0.75579894 , -2.38128114 , -0.94096255
        P2 =   1.61763108 , -3.08834314 , -0.94096255
        P3 =   1.61763108 , -2.38128114 , -0.94096255
        P4 =   0.75579894 , -2.38128114 , -0.94096255
        NNAX = 1
        NNY = 1
```

```
HEADER CORRESPONDENCE DATA
FIG     LUROVA
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        601001,601002
        602 =
        602001,602002
        603 =
        603001,603002
        606 =
        606001,606002,606003,606004
        608 =
        608001,608002,608003,608004,608005,608006,608007,
        608008,608009,608010
        609 =
        609001,609002,609003,609004,609005,609006,609007,
        609008,609009,609010,609011,609012,609013,609014,
        609015,609016,609017,609018,609019,609020,609021,
        609022,609023,609024,609025,609026,609027,609028,
        609029,609030,609031,609032,609033,609034,609035,
        609036,609037,609038,609039,609040,609041,609042
        610 =
        610001,610002,610003,610004,610005,610006,610007,
        610008,610009,610010,610011,610012,610013,610014,
        610015,610016,610017,610018,610019,610020,610021,
        610022,610023,610024,610025,610026,610027,610028,
        610029,610030,610031,610032,610033,610034,610035
```

Figure 9. (4) CONVERT Provides Surface Node Trapezoids and Correspondence Data for TRASYS.

VISUAL VERIFICATION OF REDUCTION AND CONVERSION PROCESS

It was important to verify that polygon reduction and conversion products are as expected. As shown in Figure 10, PGNUPLOT, the PC version of GNUPLOT, was used to verify polygon faces and vertices. The processed Rover forward chassis model (7805 polygons) is shown on the left, and R/C processed data for Rover and Lunar Module (LM) polygons are shown on the right.

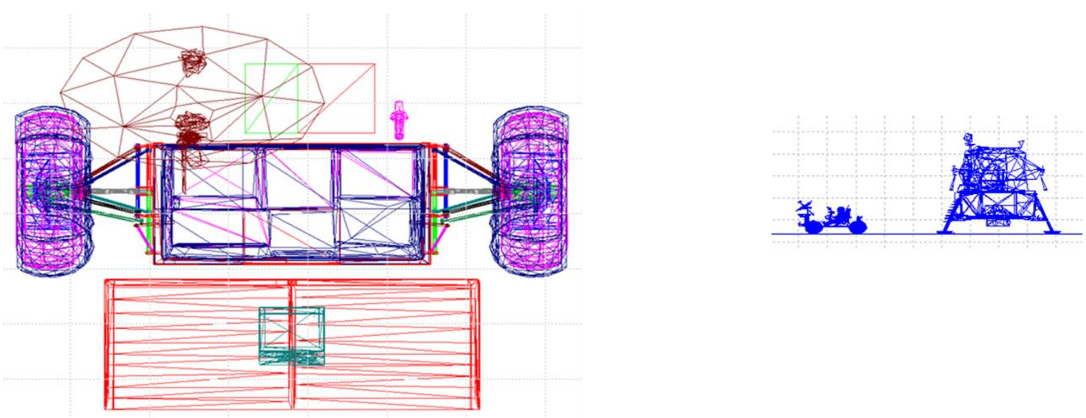

Figure 10. (5) PGNUPLOT Verification of Polygon Faces and Vertices.

As shown in Figure 11, using the PLOT capability in TRASYS yielded verification of the R/C processed trapezoids. TRASYS also provides the heat rate arrays and interpolation "Call" statements for the SINDA thermal model.

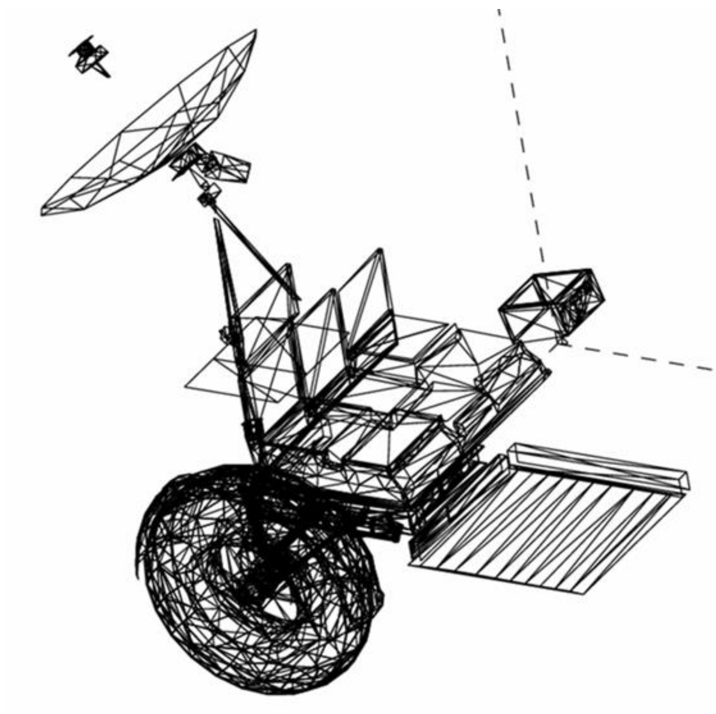

Figure 11. (6) PLOT Verification of Processed Trapezoids for TRASYS.

R/C PROCESS HEAT RATES VERIFICATION

The SURFP subroutine in TRASYS was used to calculate solar heating rates for the Rover forward chassis thermal model. The Rover surface model was positioned with respect to the rising and setting Sun as shown in Figure 12, i.e. with the Sun rising over the left side and setting over the right side at a time of 354 hours (14.75 days).

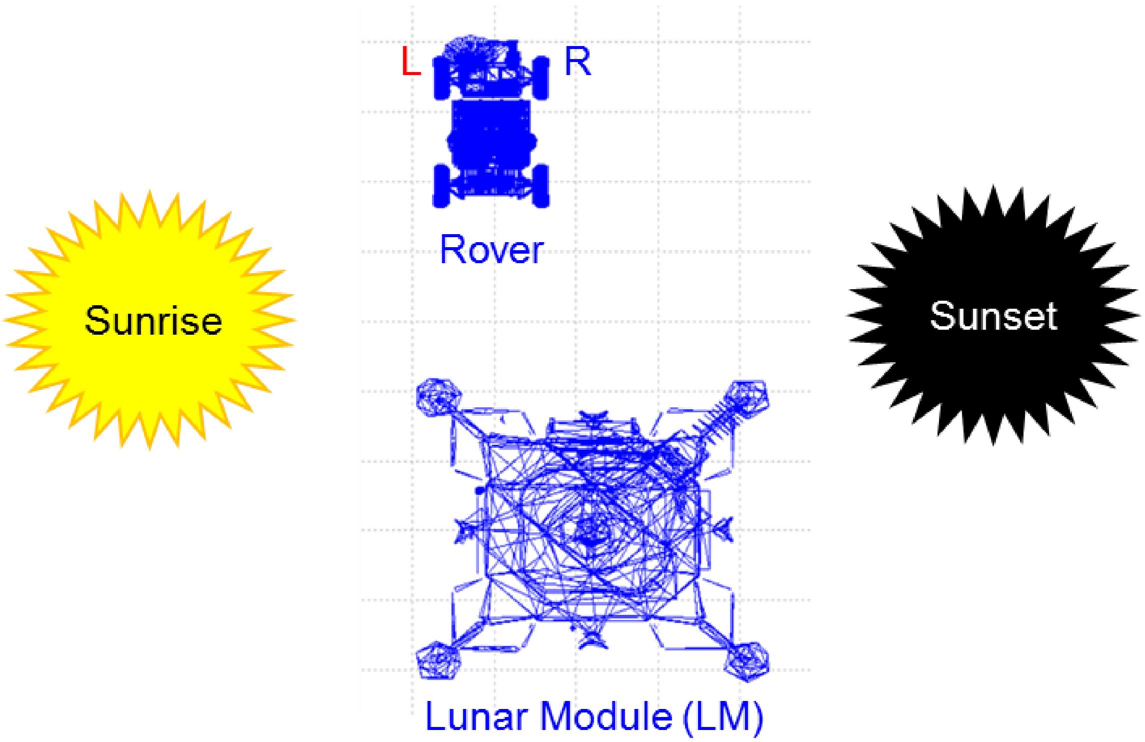

Figure 12. SURFP Solar Heating Configuration.

Figures 13 and 14 show heat rate results for the left and right side nodes of the forward chassis thermal model, respectively. Solar heat rates for the left side nodes begin to decrease before the solar heat rates for the right side nodes begin to decrease. This verifies movement of the Sun from left to right over the Rover model. The maximum solar heat rate of 386 BTU/hr/ft^2 corresponds to the expected maximum value of solar heating for flat plates on the Moon, like the exposed radiators with a solar absorptance of 0.90 for assumed dust coverage.

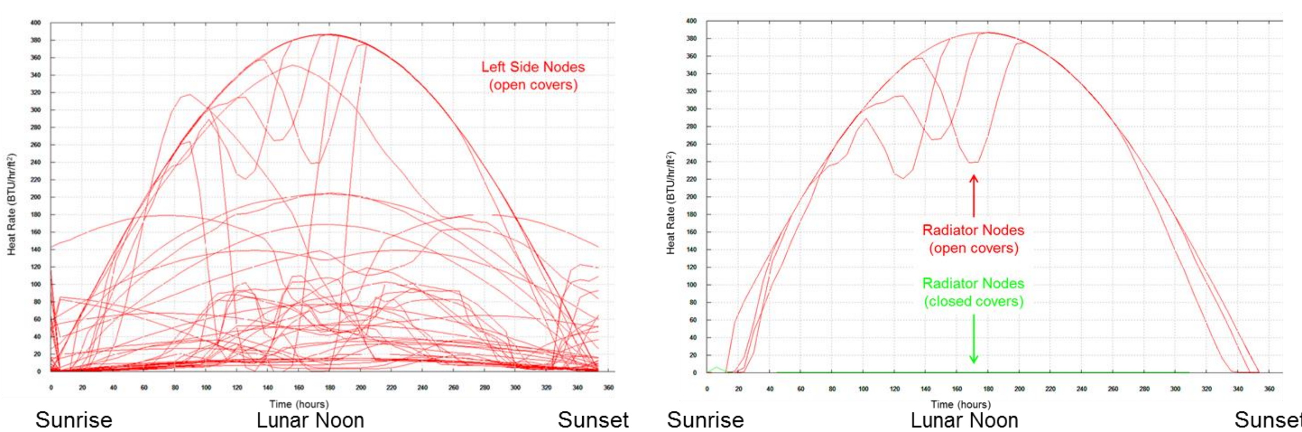

Figure 13. (7) TRASYS Left Side Nodes Solar Heating.

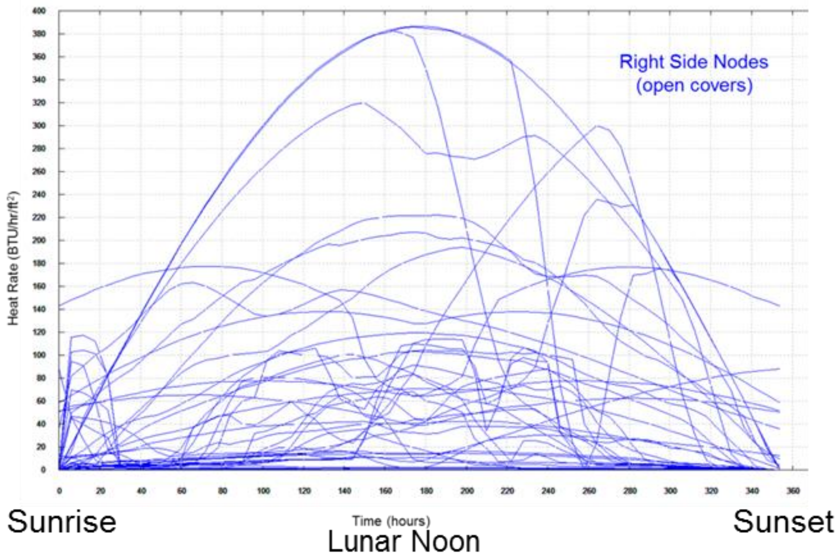

Figure 14. (7) TRASYS Right Side Nodes Solar Heating.

Also, when the dust covers are closed over the radiators, solar heat rates are greatly decreased, as shown by the low values for the “green” plotted data in Figure 13. It was also verified that processed radiation conductors exhibited reasonable view factor relationships between model surface nodes.

Therefore, the R/C polygon reduction and conversion process has been verified.

PROCESSED MODEL TEMPERATURE COMPARISON

The next step is to compile the LUROVA SINDA forward chassis model (Figure 15) to compare with the 19 node model that was used for the NASA Night Rover Centennial Challenge. Power providers were challenged (with a prize) to extend non-nuclear energy storage capability to support future extended Moon missions. As shown in Figure 16, extended survival and operation on the Moon are highly influenced by solar heating and Moon surface temperature profiles.

```
HEADER NODE DATA, LUROVA
C    FORWARD CHASSIS STRUCTURE NODES
          101, 100.0, 0.2514      $FORWARD RAIL, RIGHT HALF
          102, 100.0, 0.2514      $FORWARD RAIL, LEFT HALF
          103, 100.0, 1.1711      $RIGHT SIDE RAIL
          104, 100.0, 1.1711      $LEFT SIDE RAIL
          105, 100.0, 0.1924      $BATTERY SUPPORT CHANNEL - RIGHT HALF
          106, 100.0, 0.1924      $BATTERY SUPPORT CHANNEL - LEFT HALF
          107, 100.0, 0.0825      $RIGHT SUPPORT CHANNEL
          108, 100.0, 0.0825      $LEFT SUPPORT CHANNEL
          109, 100.0, 0.0565      $STEERING SUPPORT CHANNEL
          110, 100.0, 0.0989      $LOWER SKIN PANEL
          111, 100.0, 0.0989      $UPPER SKIN PANEL
          112, 100.0, 0.0896      $AFT CHANNEL, RIGHT HALF
          113, 100.0, 0.0896      $AFT CHANNEL, LEFT HALF
C    CENTER CHASSIS STRUCTURE NODES
          121, 100.0, 1.0048      $FORWARD RAIL, RIGHT HALF
          122, 100.0, 1.0048      $FORWARD RAIL, LEFT HALF
          123, 100.0, 0.5880      $RIGHT SIDE RAIL, FORWARD HALF
          124, 100.0, 0.3687      $CENTER RAIL, FORWARD HALF
          125, 100.0, 0.5880      $LEFT SIDE RAIL, FORWARD HALF
          126, 100.0, 0.2414      $FLOOR PANEL, RIGHT FORWARD QUARTER
          127, 100.0, 0.2414      $FLOOR PANEL, LEFT FORWARD QUARTER
          128, 100.0, 0.6278      $RIGHT SIDE RAIL, AFT HALF
          129, 100.0, 0.3687      $CENTER RAIL, AFT HALF
          130, 100.0, 0.6278      $LEFT SIDE RAIL, AFT HALF
          131, 100.0, 0.2414      $FLOOR PANEL, RIGHT AFT QUARTER
          132, 100.0, 0.2414      $FLOOR PANEL, LEFT AFT QUARTER
          133, 100.0, 0.7085      $AFT RAIL, RIGHT HALF
          134, 100.0, 0.7085      $AFT RAIL, LEFT HALF
C    AFT CHASSIS STRUCTURE NODES
         141, 100.0, 0.0896      $FORWARD CHANNEL, RIGHT HALF
         142, 100.0, 0.0896      $FORWARD CHANNEL, LEFT
         143, 100.0, 0.8371      $RIGHT SIDE RAIL
         144, 100.0, 0.0993      $RIGHT SUPPORT CHANNEL
         145, 100.0, 0.0993      $LEFT SUPPORT CHANNEL
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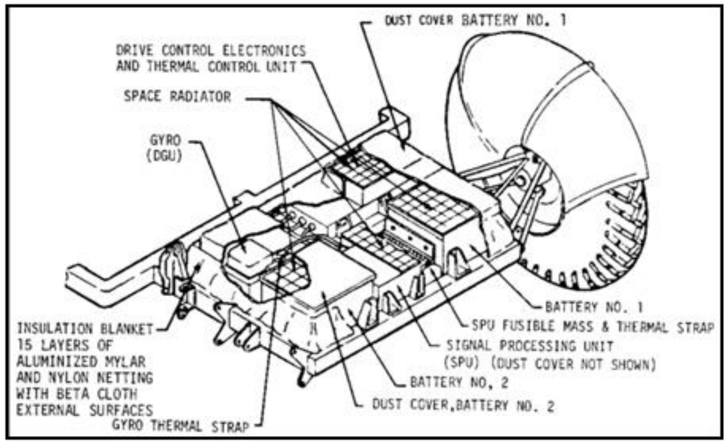

Figure 15. LUROVA SINDA Thermal Model.

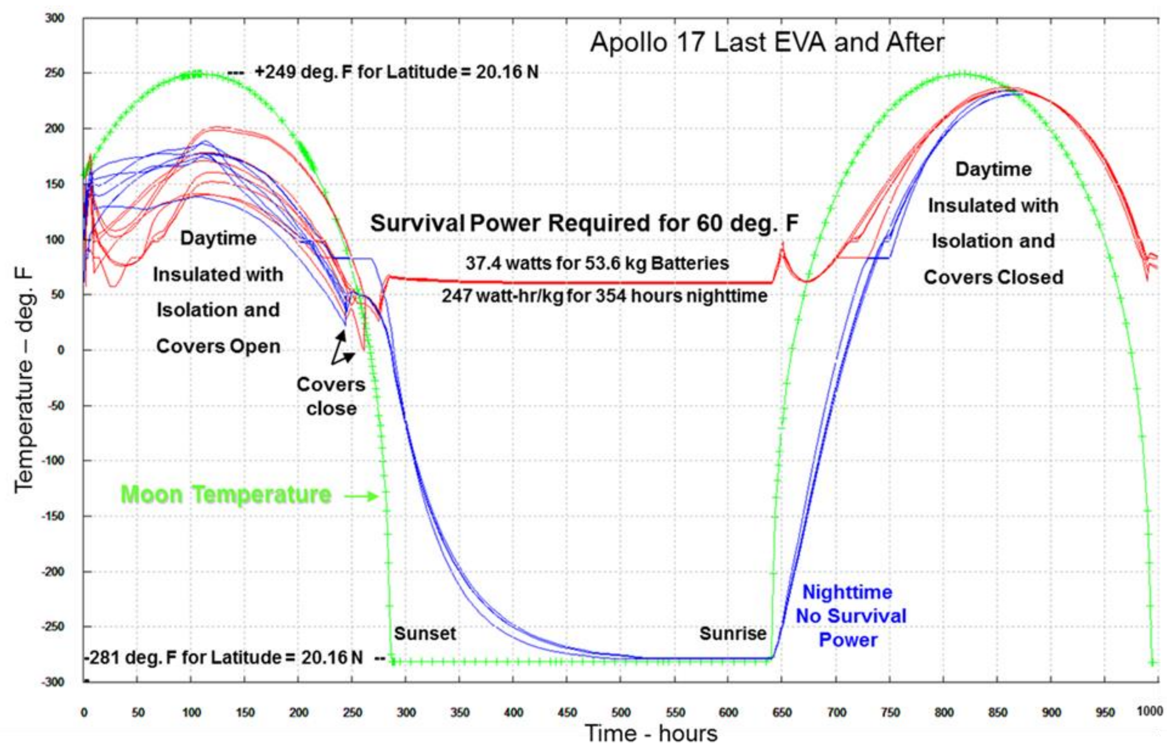

Figure 16. (8) 19 Node Forward Chassis Thermal Model Used for Night Rover Challenge.

CONCLUSION AND FUTURE PLANS FOR LUROVA

It has been demonstrated that the developed render engine polygon reduction and conversion process to provide surface data for thermal radiation models was successful. This process will next be used to add the Rover center and aft sections to the LUROVA thermal model.

Development of the complete interactive SINDA model for the LUROVA book and accompanying DVD will continue. The full interactive model will include versions for the astronaut (user) to sit on and drive the Rover and to park it at station stops or back at the LM with the dust covers closed or open, and the LM providing for radiation blockage.

Work has already begun on a thermal model of the docked Apollo LM and Command and Service Module (CSM), as shown in Figure 17. This model will allow analysis of Rover temperatures during the Passive Thermal Control (PTC) of the LM/CSM assembly with a 3 revolutions per hour rotation during transportation to the Moon. The 338,417 polygons in this model will be reduced and converted using the described process.

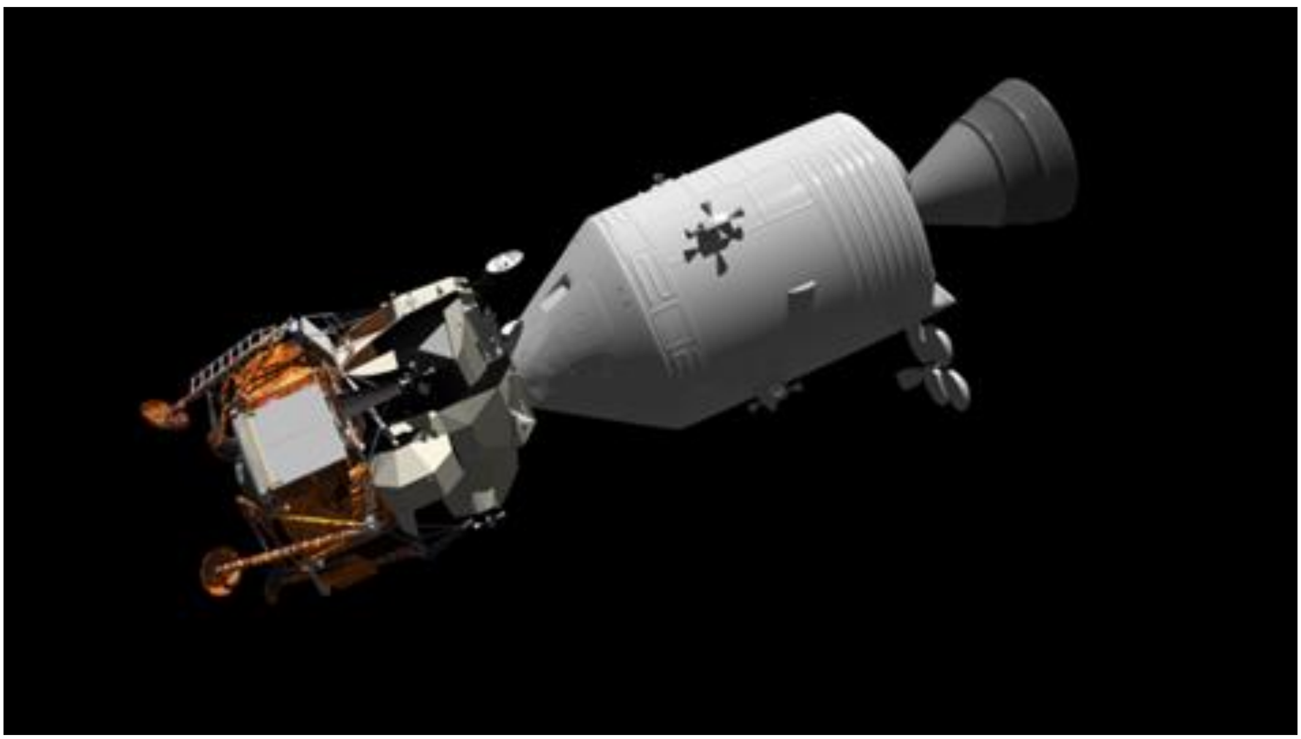

Figure 17. LM/CSM Passive Thermal Control "Barbeque" During Transit to the Moon.

The NASA Marshall Space Flight Center (MSFC) is sponsoring delivery of an "Additive Manufacturing" 3D printer to the International Space Station (ISS), as shown in Figure 18. Using R/C processed data, this group used another 3D printer to create a solid model of the Rover forward chassis with dust covers raised over the radiators, and will expand that model to include the center and aft sections and mobility subsystems, when available. Then these complete Rover 3D models can be produced for student lectures and competition awards.

Figure 18. Additive Manufacturing for the ISS and Creating Rover 3D Model.

The author will continue STEM student lectures and support the Human Exploration Rover Challenge (formerly the Moonbuggy Races). These activities allow the author to share his Rover adventures with the next generation of engineers and explorers.

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CONTACT

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