DRAGONFLY

A relocatable lander to explore Titan's prebiotic chemistry and habitability

SPICE Thermal Vector Input for Numerical Heating Calculations

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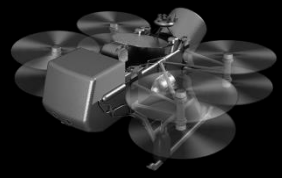
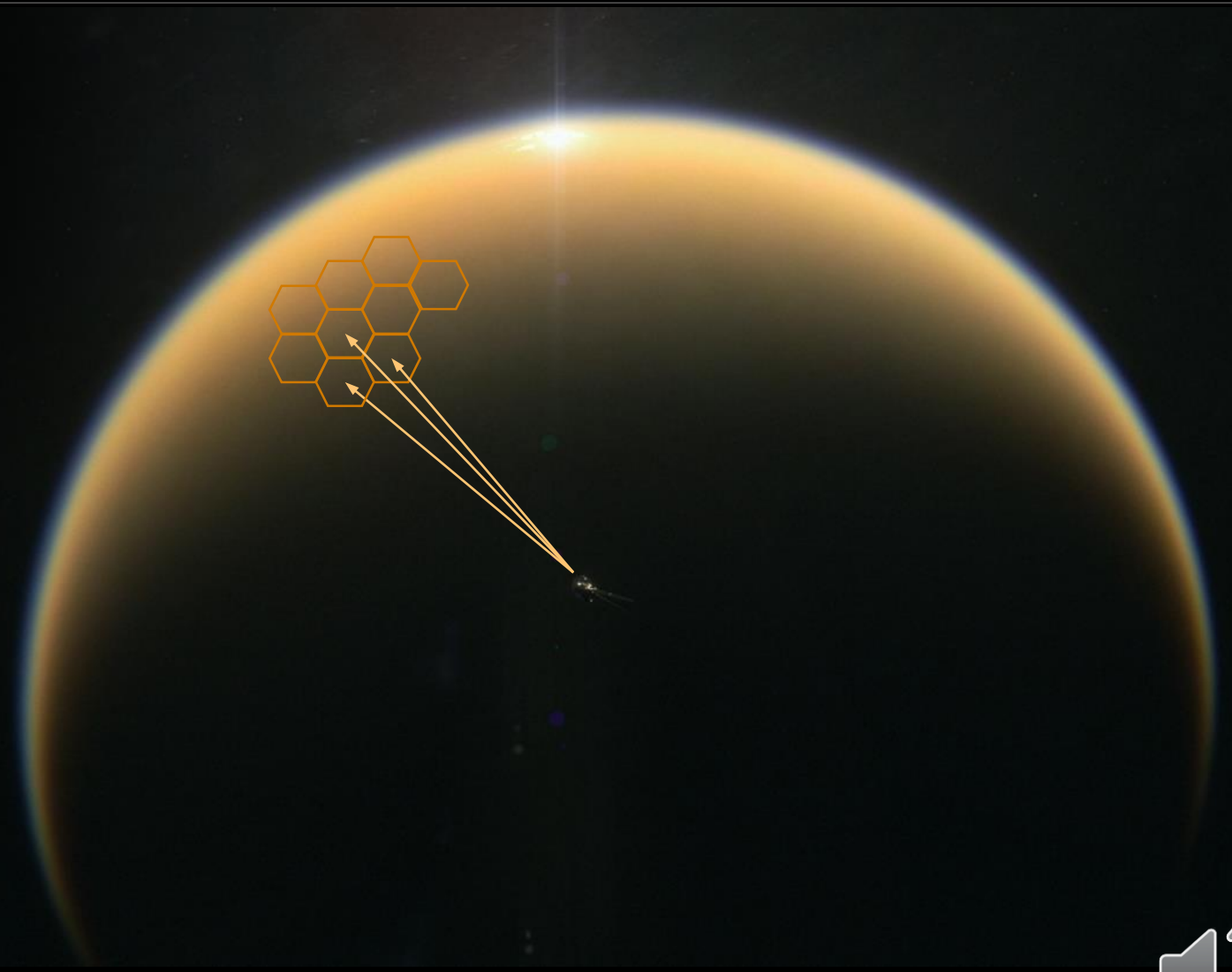
Requisite Geometry for Heating Calculations



- Heat rate calculations for spacecraft are typically performed using a commercial code, such as Thermal Desktop
  - In-house software can also be used : Numerical Method to Calculate Spacecraft Environmental Heating From Celestial Bodies With Non-uniform Surface Properties and Temperatures*
- Either way, geometry representing the S/C in relation to the planet is required to perform the heating calculations
- One way to get this information is by using SPICE …



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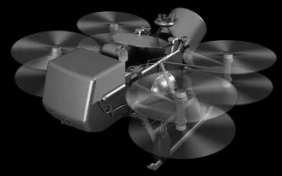
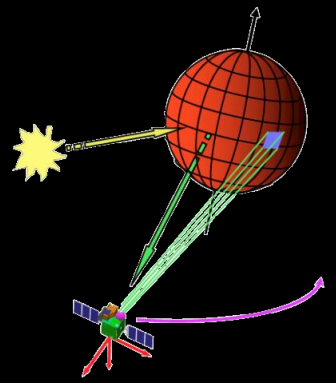
* https://nescacademy.nasa.gov/video/659670f6b7cc47b0921fb7f7e35c94961d/

SPICE Overview



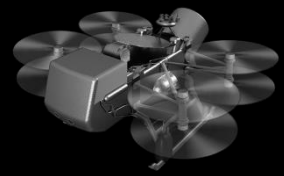
- *No, I'm not referring to Dune*
- SPICE is an information system built by the Navigation and Ancillary Information Facility (NAIF), acting under the direction of NASA's Planetary Science Division
- The acronym refers to logical components in the system (Spacecraft, Planets, Instruments, C-matrix, Events)
- SPICE can be used to extract geometric information for spacecraft and celestial bodies



- Positions and velocities of planets, satellites, comets, asteroids, and spacecraft
- Size, shape and orientation of planets, satellites, comets, and asteroids
- Orientation of a spacecraft and its various moving structures

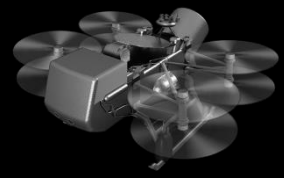
https://naif.jpl.nasa.gov/naif/geometric_parameters.png

Accessing SPICE

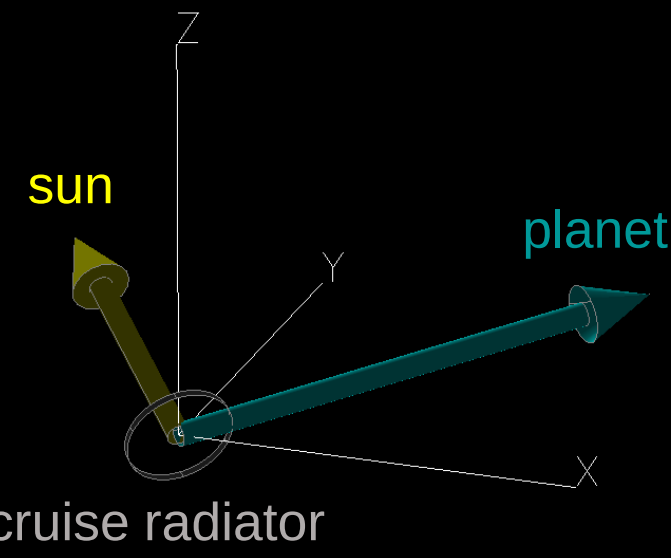


- SPICE functions can be called using C, FORTRAN, Matlab (very popular), and others
  - Third party interfaces exist for other languages, such as Python
  - I have used most of these methods, but my preference has gravitated to C (this presentation assumes a Unix operating system and the C language package installed in /naif/cspice)
- Basic steps for generating geometric information:
  - Install the SPICE libraries on your computer: https://naif.jpl.nasa.gov/naif/toolkit.html
  - Get SPICE kernels from your Mission Design and/or GNC folks (these are standard products that should already exist)
    - Kernel files typically contain location information for the relevant spacecraft and planets over the appropriate time period
    - Spacecraft orientation is generally a separate kernel file provided by GNC or other discipline, which may or may not be needed depending on the nature of your calculations
  - Examine the kernel files to ensure you have the appropriate information
    - Use the /naif/cspice/exe/brief executable to show the summary of a bsp file (shows spacecraft identifier, if it exists)
    - Alternatively, use the SPICE “spkobj” subroutine within the code
  - Use a code or script to access SPICE functions
    - Load the appropriate kernels (order could matter, last data overrides earlier)
    - Extract the geometry you need over the time period of interest
    - To compile on a Unix machine: gcc -I /naif/cspice/include -o yourcode yourcode.c /naif/cspice/lib/cspice.a -lm
  - Use this data as input to your heating calculations

Example: *Dragonfly* Venus Flyby

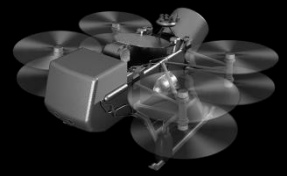


- Problem statement: Determine the approximate temperature increase of the *Dragonfly* spacecraft during a Venus flyby
  - S/C orientation is just spin-stabilized anti-sun, so getting orientation information from SPICE is not required (only location)
  - The *Dragonfly* cruise stage utilizes a fluid loop, which ties most components, including its MMRTG, thermally to the external radiator, making a simple model sufficient for estimating the impact of Venus flyby heating (except for external, lightweight S/C components that are not on the fluid loop, for which a more detailed model is required)
- Solution: Use a simple Thermal Desktop model to solve for the transient temperature response
  - Start with a steady-state no-Venus condition, with the balance of MMRTG heat that makes it into the fluid loop, with S/C spinning anti-sun
  - Apply transient heat loads by setting up a vector input for the “orbit” heating with spin in Thermal Desktop
  - Vector input format is in the S/C body frame, and includes the ratio of the S/C location divided by the planet radius
  - Note the S/C orientation is anti-sun, which prevents any direct solar input to the cruise stage radiator



Vector orbit input:
t, V_{sun}, V_{planet}, r_{ratio}

Example: C Code for SPICE Extraction



```
#include <stdio.h>
#include "SpiceUsr.h"
#include <math.h>
int main () {
  const double CONST_AU = 149597870.61368887; // in km
  const double VENUS_RADIUS = 6051.8; // in km
  double rratio; // ratio of the S/C-planet center distance divided by the planet radius
  SpiceDouble tbeg;
  SpiceDouble tend;
  SpiceChar scid [41] = "-6200005"; // identifier for Dragonfly
  SpiceDouble ven[3]; // Venus vector from point of view of the S/C
  SpiceDouble lt;
  SpiceDouble sun[3]; // Sun vector from point of view of the S/C

  furnsh_c("inputFromMissionDesign.bsp"); // Load all input files from Mission Design, bsp, tls, tpc
  . . .
  str2et_c("15 Apr 2027 00:00:00.000", &tbeg); // Convert time strings to elapsed time
  str2et_c("15 Apr 2027 05:00:00.000", &tend); //  from the J2000 epoch

  printf("t\tsunx\tsuny\tsunz\tplanx\tplany\tplanz\trratio\n");
  SpiceDouble tcur = tbeg;
  while(tcur<tend) {
     spkpos_c("299", tcur, "j2000", "none", scid, ven, &lt); // Venus barycenter is id 299
     spkpos_c("sun",   tcur, "j2000", "none", scid, sun,  &lt);
     sun[0]=sun[0]/CONST_AU; sun[1]=sun[1]/CONST_AU; sun[2]=sun[2]/CONST_AU; // Sun vector is in AU
     rratio = pow(pow(ven[0],2)+pow(ven[1],2)+pow(ven[2],2),0.5)/VENUS_RADIUS;
     printf("%11.1f\t%11.6f\t%11.6f\t%11.6f\t%11.3f\t%11.3f\t%11.3f\t%11.6f\n", tcur-tbeg,sun[0],sun[1],sun[2],ven[0],ven[1],ven[2],rratio);
     tcur=tcur+60.0; // output every minute
  }
  kclear_c ();
  return(0);
}
```

Include files

Parameters

Needed by Thermal Desktop

Get S/C identifier from Mission Design (or examine their files), or use cspice_spkobj to return the identifier

This is where you load the input files, can load separately or specify a metakernel file
Locations of S/C and planets, moons, etc. can be input

Calculations use an elapsed time from an epoch

Get the planet vector in the S/C frame (barycenter by “99” suffix)

Get the sun vector in the S/C frame, convert from km to AU (needed by Thermal Desktop)

Output the time, V_{sun}, V_{planet}, r_{ratio}

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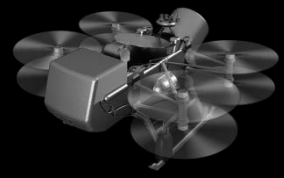
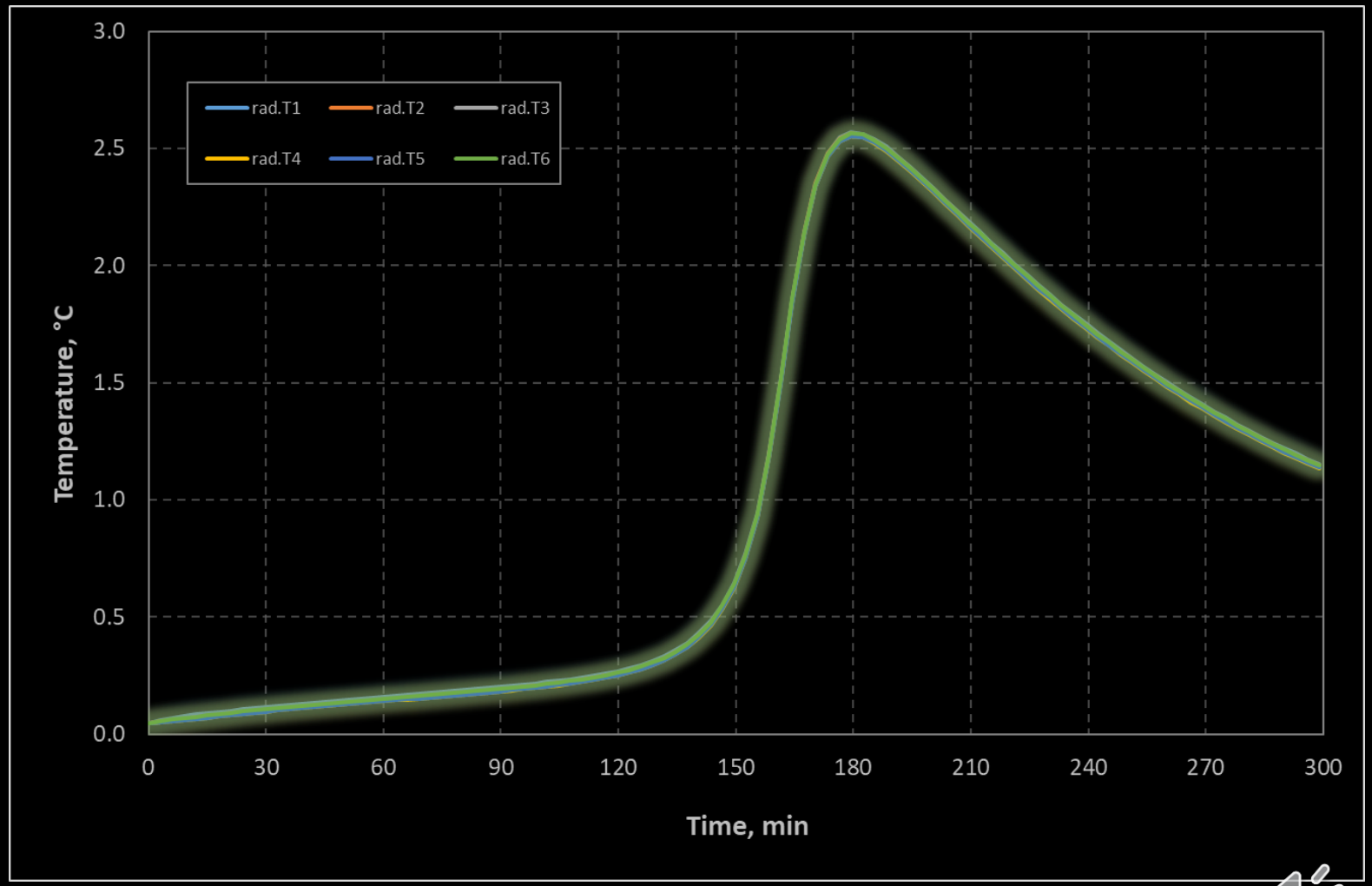
Example: *Dragonfly* Venus Flyby Results



- Using the vector output from the code on the previous slide, temperatures are obtained from a simple Thermal Desktop model of the cruise radiator with an approximate system thermal capacitance
- Steady-state, anti-sun, pre-Venus radiator temperatures are around 0 °C, due to the heat load from the MMRTG
- Peak temperature for the *Dragonfly* radiator due to this Venus flyby is less than 3 °C
  - This is due to the relatively short heating pulse from Venus and high thermal capacitance of the system, thanks to the pumped fluid loop tying all the spacecraft components together



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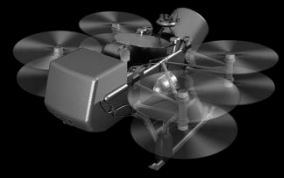
Conclusions



- Using SPICE to extract the basic information needed for a thermal heating calculation is fairly simple
  - As evidenced by the brevity of this presentation, and the example C code
- The SPICE tool is free to use, and if you use gcc, so is the compiler
- Code complexity goes up slightly if you need to account for S/C orientation
  - Need to load an extra kernel file, call one more subroutine, and use the C-matrix
- SPICE kernel files likely already exist for your mission, or can be easily generated
- Output from SPICE can be used for a variety of purposes
  - Drive Thermal Desktop, or in-house software, for heating calculations
  - Process S/C->planet distances to determine where flybys occur, and their nature
  - Determine if a solar array is eclipsed by any solar system body
    - I did this for Europa mission, including Jupiter, Earth, Venus, Jovian moons, etc., predicting full and partial eclipses

The sky is the limit!