SPACE: Three Decades of Spacecraft Power Analysis with Fortran

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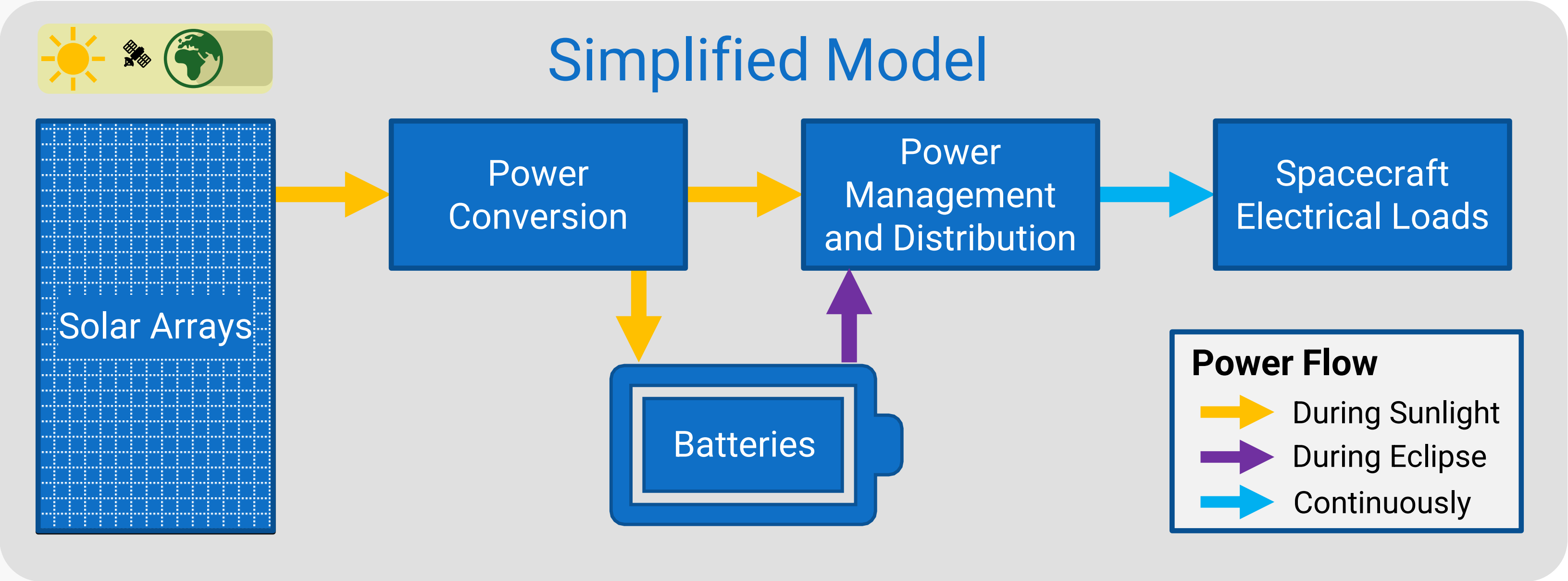
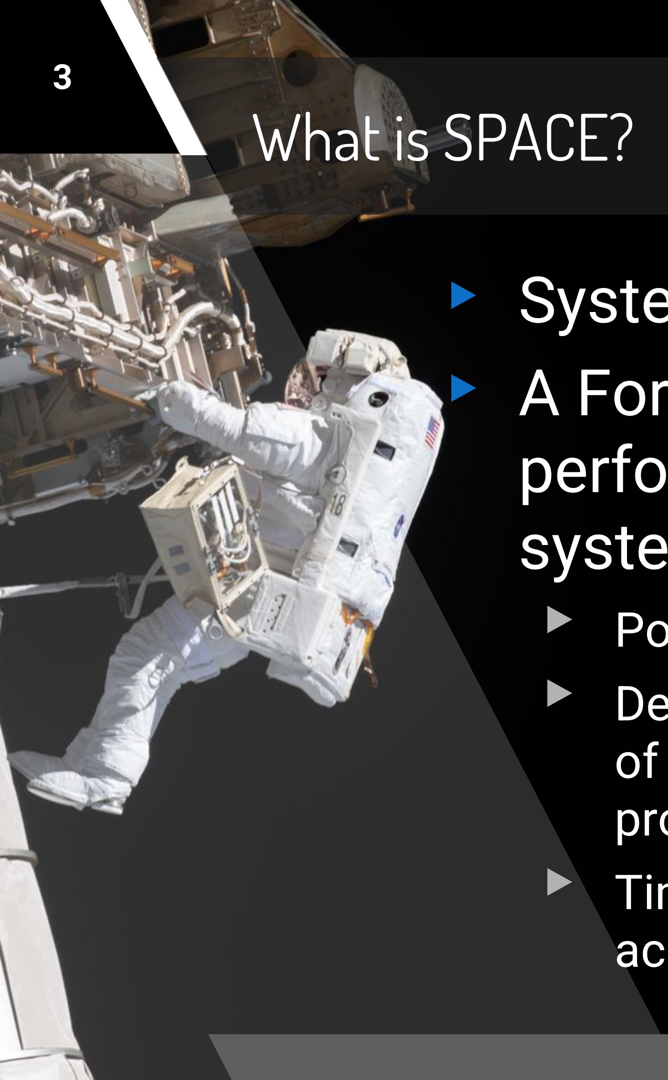
International Fortran Conference, 23 September 2021

Spacecraft Electrical Power Systems



Goal: Ensure spacecraft electrical loads can be powered while maintaining adequate charge in the batteries

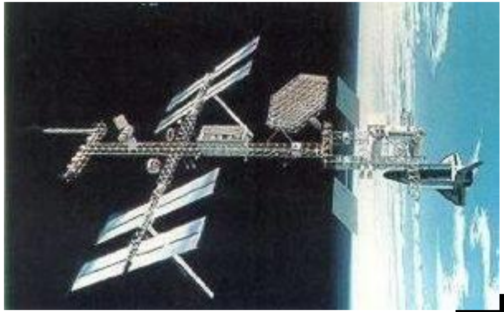
What is SPACE?



- System Power Analysis for Capability Evaluation
- A Fortran computer model used to predict the performance of a space-based electrical power system (EPS)
  - Power system performance is a complicated problem
  - Depends on positions of the spacecraft and sun, orientation of solar arrays, age and condition of components, thermal properties, electrical load demand, and much more
  - Time-phased simulation written in Fortran is much more accurate than simplified spreadsheet models

SPACE History

- **1988:** SPACE code designed for independent verification and validation of EPS calculations by the space station prime contractor



- **1993:** SPACE code becomes the primary EPS performance tool used to support station redesign activities
  - Portions of the SPACE code are used by mission operators for real-time operations

- **2003:** SPACE code earns NASA Software of the Year Award runner-up

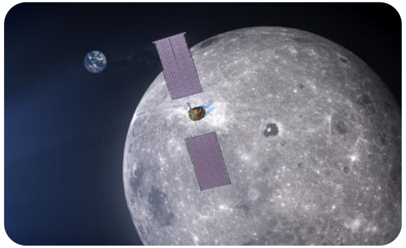
Current SPACE Versions

SPACE-ISS (International Space Station)

Performs EPS assessments prior to spacewalks and flights of crew and cargo for the ISS

SPACE-TNG (The Next Generation)

Models the EPS of the Orion spacecraft and Power and Propulsion Element (PPE) for NASA's Lunar Gateway



Each vehicle is in a different stage of development, posing unique challenges and requirements for EPS modeling

SPACE is flexible enough to support spaceflight programs from early design through sustaining operations

Example Analyses

ISS

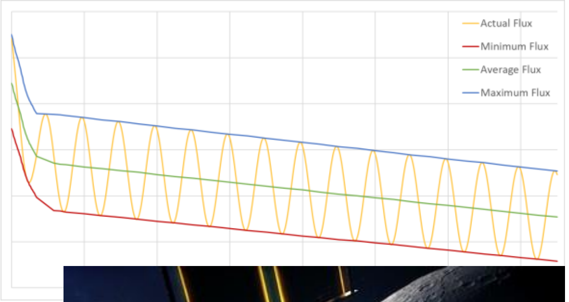
Evaluating the ability of the EPS to support operations

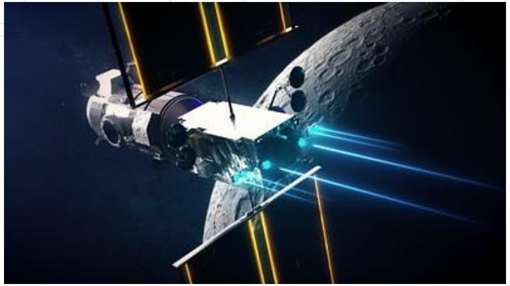
Orion

Trade study comparing different spacecraft attitudes during the low-Earth orbit phase of the mission

PPE

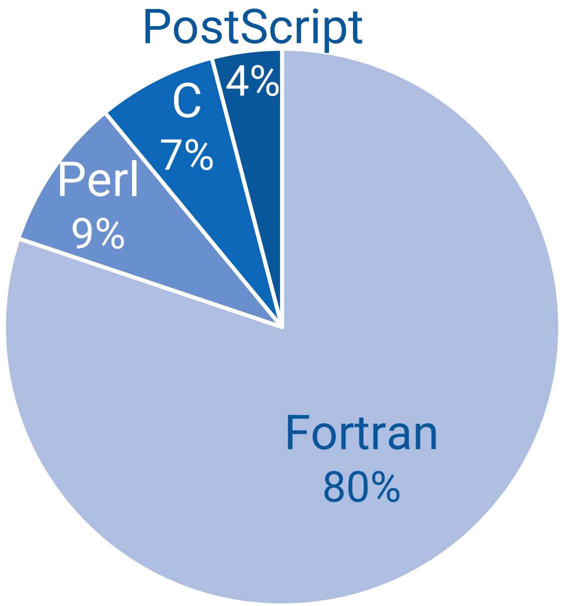
Predict the solar array and power system performance over the mission life





SPACE Statistics

- Over 400 Fortran subroutines
- Over 100,000 source lines of code
- Over 500 data files
- Over 80 total code contributors
- Including over 30 students
- More than 26 papers published



SPACE Development Environment

Operating Systems

Current:

CentOS 7.8

Future:

Red Hat Enterprise Linux 8

Languages

Fortran (Absoft 18.0)

Perl (5.16.3)

C (gcc 4.8.5)

Data Management

NASA GSFC Common Data Format (CDF) (3.7.1):

Fortran API

Perl API

Visualizations

Plotting:

GV PostScript Viewer (3.7.4)

Vehicle Animations:

GLUT/OpenGL 1.4

ffmpeg

Version Control

git (2.32.0)

GitLab Community (14.2.1)

Editors

Visual Studio Code

Kwrite

Kate

Gedit

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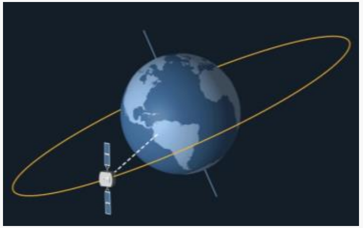
SPACE Architecture

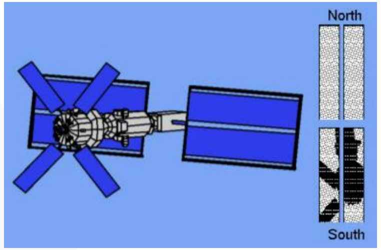
Orbit conditions
Trajectory information
Analysis time

Orbital Mechanics



Spacecraft geometry
Spacecraft orientation
Solar cell wiring

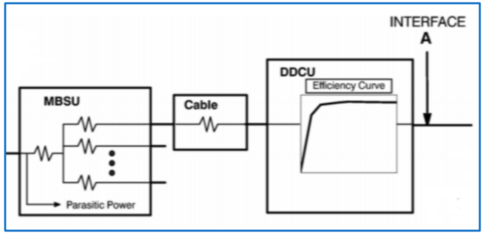
Solar Array Shadowing



Array power generation

Component data
Battery state
Electrical loads
PMAD configuration

Power Management & Distribution (PMAD)



Models internal power consumption and inefficiencies between "upstream" power sources and "downstream" loads

Outputs

EPS capability
Component states
Array temperatures
Plots and visuals

SPACE performs iterative calculations on the EPS model to reach energy balance

SPACE Operation

Analysis parameters specified via namelist inputs

Arguments provided to Perl script launcher via command line

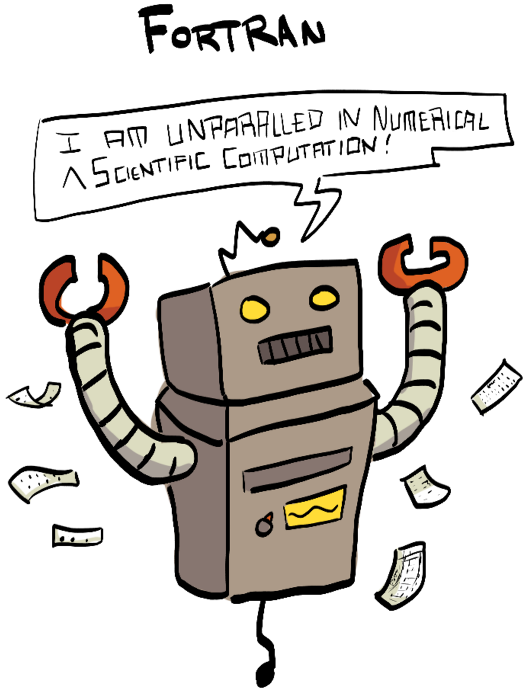
Information displayed to screen while SPACE is running

Output files and plots generated upon analysis completion

```
[tng][stipler:~]$space -e -std ecaps-CaseA -o example

System Power Analysis for Capability Evaluation.........

Analysis Name: ABC 123 Case A: LEO, Cat, Beta=0 (ECA  ECAPS/MPCV 3.7.2id
Input File: ecaps-CaseA                              Sep 14, 2021  6:28PM
************************************************************************

##### Setting up Model Parameters..........
?(CHKINP) - Warning # 1117: ECAPS must use ATYPE=conorbit; resetting ATYPE & continuing
      Beta Angle =   0.00 degrees
      ** Array Pointing "unknown" defined in NAMELIST input

##### Created CDF file: example.cdf

##### Analysis begins:     0 hrs  00 min   0.0 sec into orbit   1

##### Start Orbit Number:   1 on  9/23/2021 ....................
      Beginning of SHADE:    0 hrs  00 min   0.0 sec
#####    Performing Shadowing Calculations........
      Beginning of SUN:      0 hrs  46 min  29.0 sec
         No PMAD Capability:  PV Only Option
##### Creating plot files for orbit #  1..........
##### Done! Closing CDF file.

|==============================================================================================================|
| Summary of Orbit:   1  Date:  9/23/2021  Assembly Sequence: ABC-123-ecaps     Version: ECAPS/MPCV 3.7.2id    |
|==============================================================================================================|
| ECAPS - PVONLY Mode            | Wing 1 | Wing 2 | Wing 3 |  Wing  |  Wing  |  Wing  |  Wing  |  Wing  |
| Solar Array Performance:       |        |        |        |        |        |        |        |        |
|--------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Average Power (kW)             |   3.84 |   3.84 |   3.84 |   0.00 |   0.00 |   0.00 |   0.00 |   0.00 |
| Available Energy (kW-Hr)       |   4.38 |   4.38 |   4.38 |   0.00 |   0.00 |   0.00 |   0.00 |   0.00 |
| Avg Temperature in Sun (C)     |  58.27 |  58.27 |  58.27 |   0.00 |   0.00 |   0.00 |   0.00 |   0.00 |
| Max Temperature (C)            |  94.84 |  94.84 |  94.84 |   0.00 |   0.00 |   0.00 |   0.00 |   0.00 |
| Min Temperature (C)            | -57.99 | -57.99 | -57.99 |   0.00 |   0.00 |   0.00 |   0.00 |   0.00 |
| Pointing Efficiency (%)        |  99.99 |  99.99 |  99.99 |   0.00 |   0.00 |   0.00 |   0.00 |   0.00 |
|==============================================================================================================|
```

Why Fortran?

- Easy to use
- Excellent execution speed
- Active ISO standards board
- Availability of compilers
- Cost benefits



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Code Modernization Efforts

Adopt Modern Fortran Programming Techniques

- Use of Fortran modules and object-oriented programming techniques
- Newer Fortran constructs, array operators/syntax
- Free-form source format
- Replacing common variables with modules

Enhance Code Portability

- Utilize standard Fortran intrinsic functions and modules where available
- Test across multiple compilers and operating systems

Future Development Plans

Unit Testing

Evaluating pFUnit:

- Developed at NASA Goddard Space Flight Center
- Wide range of built-in test functions

New Compilers

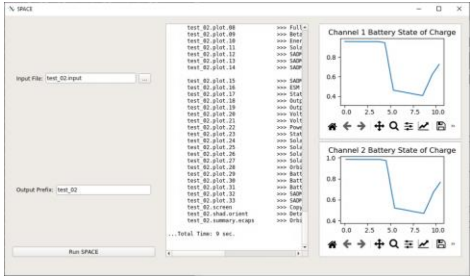
Testing SPACE with:

- GFortran
- Intel Classic Fortran compiler

SPACE GUI

Creating graphical user interface:

- PyQt and Python
- Rewrite Fortran to take command-line arguments directly



Increase code robustness and reduce regression errors

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Conclusion

- SPACE has employed Fortran for decades of impactful spacecraft EPS analysis

- Leveraging modern Fortran standards will launch SPACE into the future of spaceflight

Acknowledgements

Adam Sajdak
Amy Bartlett
Andy O'Connor
Ann Delleur
Barb McKissock
Barb Olsafsky
Ben Curatolo
Beth Hietanen
Bill Stone
Bob Green
Bob Klimek
Bobby Millinghausen
Brandon Klefman
Brendan Cheng
Brian Munguia
Bruce Canright
Bruce Manners
Carlos Rodriguez
Caroline Austin
Charlie Finlay
Clint Ensworth
Colleen Withrow
Connor Beierle
Courtney Gras
Cynthia Munoz
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Rochelle May (Sears)
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Sarah Tipler
Shuonan Dong
Spencer Furin
Stephen MacNeil
Stephen Ryan
Steven Korn
Stuart Wodzro
Terrian Nowden
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Thuy Truong
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Any questions?