Impact Risk Assessment for Lunar Missions

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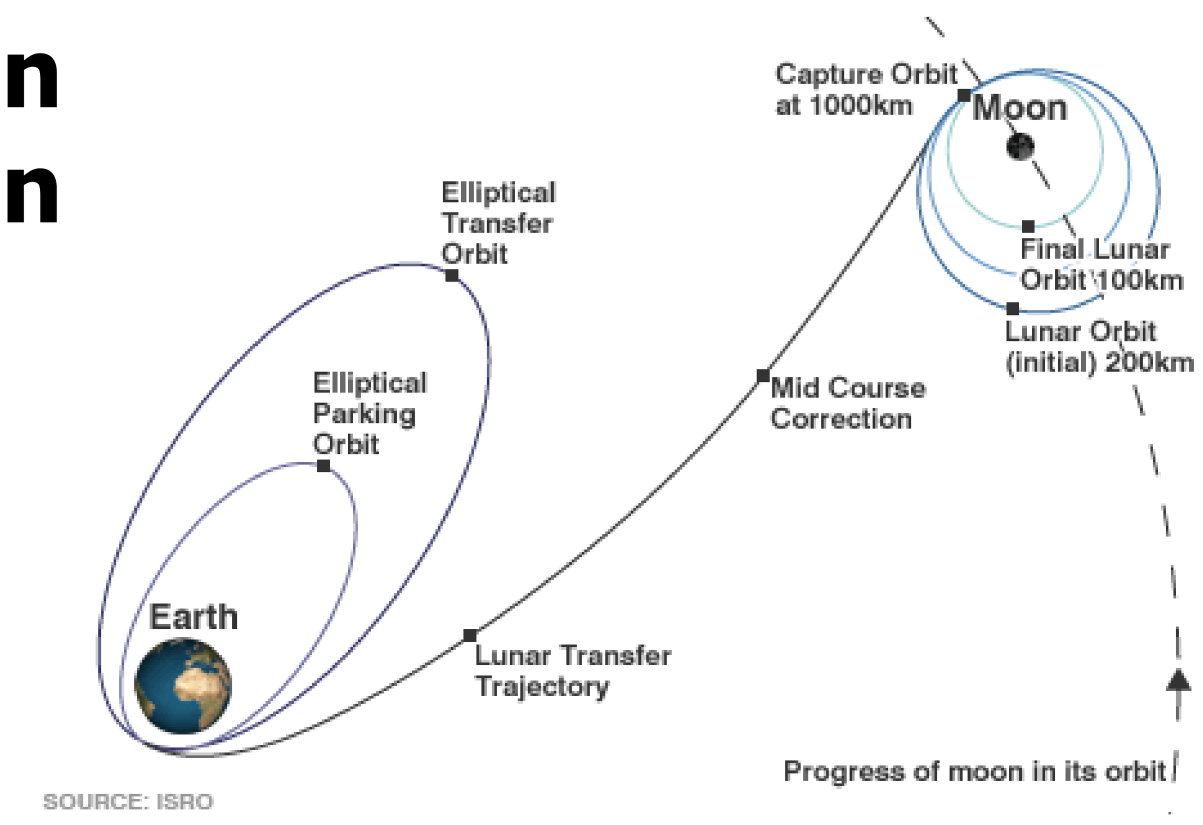
Lunar Mission Implementation

Objective:
Impact and damage analysis capability for ESABASE2/Debris

Main tasks:
Implementation of lunar orbit propagation capabilities including relevant perturbations

Implementation of lunar meteoroid environment models



Example of a complex lunar mission profile
Source: North East India News

Mission definition

- Any mission profile
- Any number of different parking, transfer and lunar trajectories
- Definition of the trajectories via
  - specification of orbit and 'mission' duration
  - external trajectory file

Environment models

- Space debris (below about 40000 km altitude):
  - MASTER-2009
- Meteoroids:
  - Grün (Earth, lunar transfer and lunar orbits)
  - MEM (Earth orbits, lunar transfer orbits)
  - LunarMEM (lunar orbits)

Meteoroid Models for Lunar Orbits

Meteoroid fluxes on lunar orbits can be computed with two available environment models

Grün model implemented as internal function in ESABASE2/Debris

MEM and LunarMEM models are available as external executables

The omni-directional Grün model

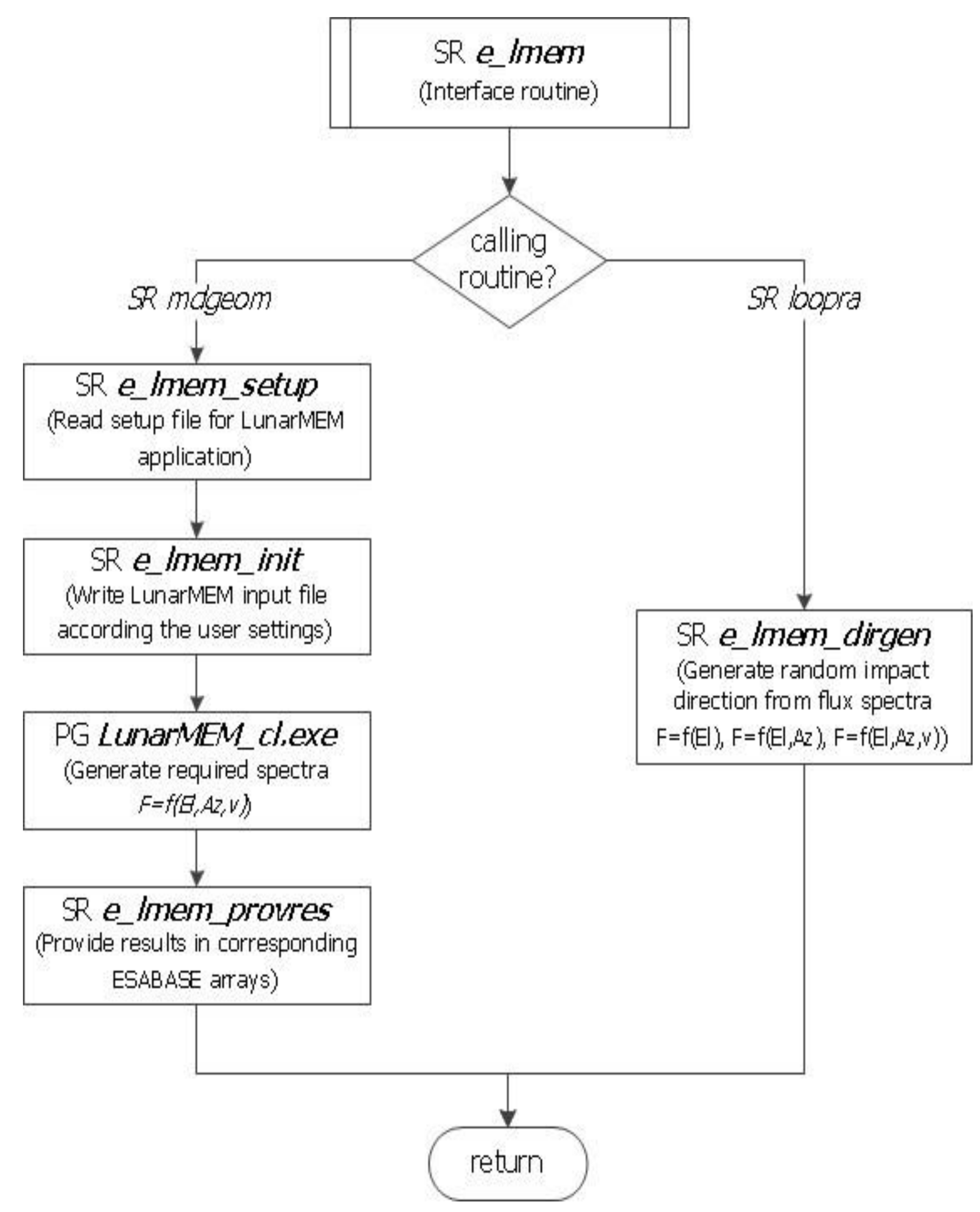
- Interplanetary flux model of sporadic meteoroid environment
- Represents the total meteoroid flux at 1 AU distance from the Sun in the ecliptic plane in absence of the Earth
- Used as is, but adaptation of the focussing and shielding factors

NASA's LunarMEM model

- Derivative of NASA's Meteoroid Engineering Model MEM
- Applicable to lunar orbits up to an altitude of 66.000 km

LunarMEM implementation

- 1. branch:
  - External executable is launched for each orbital point
  - LunarMEM results are read and processed
- 2. branch:
  - Reproduction of the impact velocity, azimuth and elevation distribution of LunarMEM with a ray-tracing method for each geometrical element



Flow chart of the LunarMEM implementation

Validation ESABASE2/Debris vs. Bumper

Thorough validation of all implemented capabilities and features

Automated unit and integration testing including continuous integration

Nearly 100 system test cases

Comparison with NASA's Bumper software by means of the so called IADC test cases

IADC test cases

- Geometry:
  - cube with an edge length of 1 m
  - sphere with a cross-section of 1 m²
- Orbits:
  - ISS orbit
  - high eccentric lunar transfer orbit
  - low lunar orbit
  - polar lunar orbit
- Flux and damage assessment:
  - Grün, MEM and LunarMEM models
  - two lower particle size thresholds
  - single wall and double wall shielding
  - agreed damage laws; example:

$$d_{p,lim} = \left[\frac{t_t}{K_f \cdot K_1 \cdot \rho_p^{\beta} \cdot \nu^{\gamma} \cdot (\cos\alpha)^{\xi} \cdot \rho_t^{\kappa}}\right]^{\frac{1}{\lambda}}$$

K_f	K_1	λ	β	γ	ξ	κ
1.8, 2.2	0.5665	1.056	0.5	0.6667	0.6667	-0.5

Single wall equation parameters

Symbol	Unit	Description
$d_{p,lim}$	[cm]	Critical diameter for penetration
t_t	[cm]	Thickness of target
K	[-]	Characteristic factor
ρ_t, ρ_p	[g/cm³]	Density of target, particle
v	[km/s]	Impact velocity
a	[-]	Impact angle

Shielding and impact parameters

Results (example)

- Meaning of the "Test cases" column:
  - d > 0.1 mm (diameter dependant impact flux)
  - d > 1.0 cm (diameter dependant impact flux)
  - p > 1.0 mm (number of diameter dep. craters)
  - single (number of single wall penetrations)

	Test cases	BUMPER	ESABASE2	diff [%]
MEM ISS Orbit	d > 0.1 mm	1.929E+01	1.93E+01	-0.16
	d > 1.0 cm	1.289E-06	1.26E-06	-2.09
	p > 1.0 mm	1.378E-01	1.34E-01	-2.47
	single	8.807E-01	8.53E-01	-3.18
MEM LLO orbit	d > 0.1 mm	9.555E+00	9.71E+00	1.59
	d > 1.0 cm	6.387E-07	6.36E-07	-0.42
	p > 1.0 mm	6.892E-02	7.29E-02	5.73
	single	4.388E-01	4.60E-01	4.88
MEM highly elliptical orbit	d > 0.1 mm	1.408E+01	1.438E+01	2.13
	d > 1.0 cm	9.413E-07	9.423E-07	0.11
	p > 1.0 mm	1.045E-01	1.046E-01	0.10
	single	6.651E-01	6.618E-01	-0.50

- Excellent correspondence
- Similar results for the other test cases
- Additional comparison: impacts on the 6 sides of an orbiting central-body oriented cube: