SPACE MANIFOLD DYNAMICS: THE PRAGMATIC POINT OF VIEW

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Telespazio, Roma (Italy)
Being Pragmatic: Kaguya HDTV
• **SMD - Space Manifold Dynamics**
  - back to the roots
  - from ISEE-3 to SOHO
  - Where do we go from here?
• **Tisserand and SMD**
  - temporary satellite capture of comets
  - ballistic capture
• **The Accessibility of the Moon**
  - Hohmann vs SMD
  - STK modelling
• **Case studies**
  - Lunar Exploration issues
  - Lagrangian surface drifters
The terminology "Space Manifold Dynamics" (SMD) is adopted for referring to the dynamical systems approach to spaceflight dynamics, thus encompassing more specific definitions (stable/unstable manifolds, lagrange trajectories, weak stability boundary, etc.);

There is the need of establishing a strong and continuous link among the research, the industrial communities and the space agencies, even at a basic level (e.g. regular organization of workshops and schools).
CELESTIAL MECHANICS

H. Poincaré : *Les Methodes Nouvelles de la Mechanique Celeste* (pag 82, section 36, Chapter III) 1889

That which makes periodic solutions so valuable is that they are, so to speak, the only breach through which we can attempt to penetrate what was previously thought impregnable.

ASTRODYNAMICS

CELESTIAL MECHANICS

H. Poincaré: *Les Methodes Nouvelles de la Mechanique Celeste* (pag 82, section 36, Chapter III) 1889

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ASTRODYNAMICS


**Fig. 1. The flow in the equilibrium region.**

Shown are the periodic orbit, a typical asymptotic orbit (coming from the boundary of a wedge) and the two optimal crossing orbits.
CELESTIAL MECHANICS

H. Poincaré: *Les Methodes Nouvelles de la Mechanique Celeste* (pag 82, section 36, Chapter III) 1889


Simo’., Gomez, Masdemont, Jorba Llibre,., Marchal et al.

stable/unstable manifolds
halo orbits, lissajous orbits

Belbruno, Miller, Carrico, Teofilatto et al.
weak stability boundary (WSB)
ballistic capture

Lo, Ross, Marsden, Parker, Campagnola
lagrangian trajectories
interplanetary superhighways
Exploiting stability / instability

Where do we go from here?

• EL1 EL2 mission profiles well established for scientific missions

• Exploration missions?

• BepiColombo ballistic capture / outer planets satellite tour design

• Moon? Mars? (the Vision for Solar System Exploration)

• Innovation is not always welcome (safety and cost of operations)

• Communication problems (needs different thinking)

• Merging scientific and technological constraints/requirements is a key issue

• ESA ITT “Interplanetary Trajectory Design”
CELESTIAL MECHANICS

The specific interest here is the behavior of orbits near those three critical points corresponding to the collinear Lagrangian points and particularly those orbits whose Jacobi constant is just above that of the critical point.

The second purpose is to outline a scheme for designing low-energy earth-moon orbits. Numerical work on this problem has been initiated and will be described in a later paper; for the present only the general scheme is described (§4).
In the R3BP Sun-Jupiter-Comet when far from close encounters the Jacobian integral reduces to the so-called Tisserand invariant, which (in normalized units) can be expressed as:

\[ T = \frac{1}{a} + 2 \sqrt{a (1 - e^2) \cos i} \]

This quantity is related to the unperturbed relative velocity of a comet (in units of the orbital velocity of the planet) at close encounter with Jupiter

\[ U = \sqrt{3 - T} \]


JACOBIAN INTEGRAL AS A CLASSIFICATIONAL AND EVOLUTIONARY PARAMETER OF INTERPLANETARY BODIES
L. Kresák, Astronomical Institute of the Slovak Academy of Sciences, Bratislava Vol. 23 (1972), No. 1
CELESTIAL MECHANICS: temporary satellite capture of comets $T > 2.9$


ASTRODYNAMICS: lunar ballistic capture $T = 2.95$

Belbruno & Miller (1990), Parker (2006)
CELESTIAL MECHANICS: temporary satellite capture of comets $T > 2.9$

ASTRODYNAMICS: lunar ballistic capture $T = 2.95$
Belbruno & Miller (1990), Parker (2006)
In his book **DIE ERREICHBARKEIT DER HIMMELSKORPER** *(The Attainability of Celestial Bodies)*, published in 1925, Walter Hohmann gives the basis of interplanetary travelling.

Here he introduces the concept of $\Delta V$ change in velocity of a spacecraft as a measure of accessibility

$$\Delta V_1 = \mu^{\frac{1}{2}} \left[ (\frac{2}{r_1} - \frac{1}{a})^{\frac{1}{2}} - \left(\frac{1}{r_1}\right)^{\frac{1}{2}} \right]$$

$$\Delta V_2 = \mu^{\frac{1}{2}} \left[ \left(\frac{1}{r_2}\right)^{\frac{1}{2}} - \left(\frac{2}{r_2} - \frac{1}{a}\right)^{\frac{1}{2}} \right]$$

**astronautical progress was the discovery of a new use for an old object: the ellipse.**

Hohmann vs Bi-elliptic

• the Hohmann transfer represents an **optimal** strategy only if the ratio between the radius of the target and that of the departure orbits is less than 11.94.

• Exceeding this value the choice of a suitable **bi-elliptic** transfer is more convenient, while if \( r_2 = r_1 > 15:58 \) any bi-elliptic transfer is favourable in terms of \( \Delta V \) expenditure

• A bi-elliptic transfer is a three-impulse strategy which foresees an intermediate orbit with an apocenter distance larger than the target orbit, and this implies **long transfer times**
Earth centered H-plot

\[ \Delta V (\text{km/sec}) \]

\[ \Delta V_2 \]

\[ \Delta V_1 \]

\[ \frac{R_l}{R_i} = 15.58 \]

\[ Ve = 3.15 \]

GEO

L1

Moon

L2

GTO

L1

LTO

L2

distance from Earth (km)

0 100000 200000 300000 400000 500000

0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5

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Moon centered H-plot

![Graph showing the relationship between delta-V (km/s) and distance from the Moon (km) with various H values: H=100, H=3000, H=10000. The graph includes a note on ballistic capture.]

- Delta-V (km/s) vs. distance from the Moon (km)
- Various H values: H=100, H=3000, H=10000
- Ballistic capture indicated in the diagram.
Satellite ToolKit (STK) is a commercial software for near-Earth mission design, recently upgraded to treat interplanetary mission analysis.
SMD external
STK modelling

ballistic capture event
<table>
<thead>
<tr>
<th>Hohmann</th>
<th>SMD internal</th>
<th>SMD external</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer Time: 4 days</td>
<td>Transfer Time: 18 days</td>
<td>Transfer Time: 90 days</td>
</tr>
<tr>
<td>Total delta-V = 3.9 km/s</td>
<td>Total delta-V = 4.2 km/s</td>
<td>Total delta-V = 3.8 km/s</td>
</tr>
<tr>
<td>2 manoeuvres: TLI, LOI</td>
<td>3 manoeuvres: BOI, TLI, LOI</td>
<td>2 manoeuvres: TLI, LOI</td>
</tr>
<tr>
<td><strong>TLI=3.1; LOI=0.8</strong></td>
<td>BOI=2.9; TLI=0.7; LOI=0.0; NOI=0.6</td>
<td>TLI=3.2; LOI=0.0; NOI=0.6</td>
</tr>
<tr>
<td>Elliptic trajectory (high LOI)</td>
<td>BLT trajectory (low LOI)</td>
<td>WSB trajectory (low LOI)</td>
</tr>
<tr>
<td>LOI critical</td>
<td>Ballistic Capture (LOI non-critical)</td>
<td>Ballistic Capture (LOI non-critical)</td>
</tr>
<tr>
<td>consolidated guidance</td>
<td>innovative guidance</td>
<td>innovative guidance</td>
</tr>
<tr>
<td>Needs quick reaction time</td>
<td>Allows slow reaction time</td>
<td>Allows slow reaction time</td>
</tr>
<tr>
<td>-</td>
<td>Possible E-M cruise science</td>
<td>Possible E-M-S cruise</td>
</tr>
<tr>
<td>Apollo-like</td>
<td>Science &amp; Exploration precursor</td>
<td>Science &amp; Exploration precursor</td>
</tr>
</tbody>
</table>

=Trans Lunar Injection; BOI = Bridging Orbit Insertion; LOI = Lunar Orbit Insertion; NOI = Nominal Orbit Insertion
Moon Base Conference

International Conference
MONO BASE
a Challenge for Humanity

VENICE  WASHINGTON  MOSCOW

www.moonbase-italia.org

Con il Patrocinio della
Presidenza del Consiglio dei Ministri
Coproduzione dell’Ente Cassa di Risparmio
Ministero per i Beni e le Attività Culturali
Superintendenza BS, AS, V, D, A, E, di Venezia e Lago
Information is not knowledge, knowledge is not wisdom
The Accessibility of the Moon

ΔV km/sec

LL1    LL2
distance from the Earth km

EL2/EL2

<table>
<thead>
<tr>
<th>Description</th>
<th>ΔV</th>
<th>mission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer to the Moon</td>
<td>3.2</td>
<td>flyby</td>
</tr>
<tr>
<td>Lunar Orbit Insertion</td>
<td>4.0</td>
<td>orbiter</td>
</tr>
<tr>
<td>Landing</td>
<td>2.1</td>
<td>lander/rover</td>
</tr>
<tr>
<td>Ascent</td>
<td>2.0</td>
<td>unar operations</td>
</tr>
<tr>
<td>Transfer to Earth</td>
<td>0.8</td>
<td>sample return</td>
</tr>
<tr>
<td>Earth Orbit Insertion</td>
<td>3.2</td>
<td>round-trip</td>
</tr>
</tbody>
</table>
Moon harbor: a LL1 halo orbiting infrastructure for manned / unmanned missions support (e.g. refurbishing space relescopes, space elevator)

Low altitude lunar orbiters / landers

High altitude lunar constellations for satellite navigation

High eccentricity orbits / halo orbiters for telecommunications

Operations safety (avoiding critical events)

Flexibility of mission profile (e.g. different launch scenario)

Long transfers: cruise science (e.g. gravitational redshift, solar/magnetosphere interactions)

Manned vs unmanned missions (radiation issue, non-critical cargo delivery)
Workshop recommendation:

focus on the effect of **dissipative systems** on SMD in terms of outcomes, methods and applications (e.g. low-thrust engines, non-gravitational forces, tethered systems etc.);
surface drifters dynamics

Dispersione nel Mare Ligure

14 maggio
25 settembre
2007

Source:
OGO
GRUPPO NAZIONALE DI OCEANOGRAFIA OPERATIVA

Image NASA
Image © 2007 DigitalGlobe
Traiettorie nel Mar Mediterraneo (1986 – 2008)

 longitude East

 latitude North

 - MREA07-LASIE07 (2007)
 - Mediterranean (1986-1999)
 - Dolcevita (2001-2004)
 - Dart (2006-Now)
 - Egitto (2005-Now)
surface drifters dynamics

Source:
thank you