PERFORMING A FLIGHT IN THE JOVIAN STRATOSPHERE – ENGINE CONCEPT

Authors: Nedislav Veselinov, Martin Karanikolov, Vladislav Shishkin, Plamen Dankov, Dimitar Mladenov
Research objectives

**Primary objective:**
Designing of unmanned Flyers (aircrafts for other planets atmospheres) that have the ability to collect information from large areas in the atmospheres of the Solar system planets

**First steps:**
- Clarification of the physical conditions of the atmospheres of the Solar system planets
- Selection of suitable propulsion type and flight speed
- Finding the thrust in first approximation and searching for suitable flight zones
- Designing the engine inlet. Optimization of the inlet geometry using CFD analysis

**Future works:**
- Designing the diffusor, the heat chamber and the nozzle of the engine
- Designing and optimization of different types of Flyers and their components
SHORT REVIEW
<table>
<thead>
<tr>
<th>#</th>
<th>Title</th>
<th>Authors</th>
<th>Year</th>
<th>Conference/Journal/Other Details</th>
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<td>and manned exploration missions</td>
<td>Maise, G.,</td>
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<td>2</td>
<td>Nuclear propulsion and power systems for near term exploration of</td>
<td>Powell, J.,</td>
<td>2005</td>
<td>A Collection of Technical Papers - 1st Space Exploration Conference: Continuing the Voyage of</td>
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<td>the solar system</td>
<td>Maise, G.,</td>
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<td>Discovery 2, pp. 729-745</td>
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<td>Application of the MITEE nuclear ramjet for ultra long range flight</td>
<td>Maise, G.,</td>
<td>2003</td>
<td>54th International Astronautical Congress of the International Astronautical Federation (IAF),</td>
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<td>missions in the atmospheres of Jupiter and other giant planets</td>
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<td>the International Academy of Astronautics and the International Institute of Space Law</td>
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APPLICATION OF THE MITEE NUCLEAR RAMJET FOR ULTRA LONG RANGE FLYER MISSIONS IN THE ATMOSPHERES OF JUPITER AND OTHER GIANT PLANETS

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2University of Florida, Gainesville, FL 32611
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4University of Louisville, Comparative Planetary Laboratory, Louisville, KY 40292

(603) 751-2216, maier@optronics.net

Figure 6.1.3.3 Layout drawing of the Ramjet Flyer JF-6

Nuclear Propulsion and Power Systems for Near Term Exploration of the Solar System

James Powell, George Maier, and John Panagia
Plas Ultra Technologies, Shoreham, New York, 11747

Planetary Flight

Kent L. Miller*
Taipei City 10548, Taiwan, Republic of China

Fig. 2 Vehicle layout for Jupiter 3-tonne planetary flight mission.
Venus Atmospheric Maneuverable Platform (VAMP)

A Concept for a Long-Lived Airship at Venus

Kristen Griffin
NGAS Team: Ron Poldan, Daniel Sokol, Dean Dailey, Greg Lee, Steve Wanick
L’Garde Team: Nathan Barnes, Linden Bolikav, Billy Derbes, Yuki Michii, Art Palliacc

VAMP Integrates Diverse Capabilities into a Unique Planetary Exploration Vehicle

Northrop Grumman LEM-V semi-buoyant vehicle (first flight Aug 2012)

• Semi-buoyant flight
• Long-on-station time
• Reduced aerodynamic requirements

One possible structure and in-space deployment concept (study in progress)

Deployment is driven via pressure inflation of spars

Northrop Grumman Global Hawk unmanned aircraft in production and use

3. Lifetime of Months to Years

- Primary (aerostatic) mission
  - Occurs within +/- 20 day tolerance of equator
  - VAMP can be navigated to tolerate ±1°
- Lifetime in this region is limited by gradual loss of buoyant gas through envelope and/or environmental effects

Sample Altitude Trajectory in 1 Venusian Day

Day-side ComOps: variations in proximate cloud top altitude and selection of altitudes in 50-70 km range
Night-side ComOps: passive inflight at 55 km

---

400 m² platform provides more than enough real estate to house sufficient solar arrays

Choice of array size determines what fraction of day/night flight occurs at max flight speed
Helium-3 Mining Aerostats in the Atmospheres of the Outer Planets

Jeffrey E. Van Cleve, Ball Aerospace
Carl Grillmair, SIRTF Science Center, Caltech
Mark Hanna, Ball Aerospace
Rich Reinert, Ball Aerospace


Art by David Seal of JPL

The most valuable interplanetary commodities are refined He-3, deuterium, and heavy metals.
JUPITER
The atmosphere of Jupiter
GALILEO mission stats

106,000 miles per hour
(47 kilometers per second)

Speed at which Galileo entered Jupiter's atmosphere

13 years, 11 months, 3 days

Total mission duration
Extended Missions: 1997-2003

2.8 billion miles
(4.6 billion kilometers)

Total distance traveled, launch to impact

Greater than 100
scientists from 9 countries
(U.S., England, Sweden, Canada, France, & Germany)
Galileo probe data
PROPULSION
Evolution

JUPITER FLYERS
MINIMUM MOVING COMPONENTS

«3M22 ZIRCON»

ENGINE: SCRAMJET
OPERATIONAL RANGE: 300 KM (186.4 MI)
SPEED: MACH 7 (8,575 KM/H; 5,328 MPH; 2.3820 KM/5)
LAUNCH PLATFORM: SHIP, SUBMARINE, AIRCRAFT AND LAND-BASED MOBILE LAUNCHERS.
Nuclear Powered Ramjet Engine (NPRE)
Thrust of NPRED

Equal initial and exit pressure

\[ p_e = p_1 \]
\[ (p_e - p_1).A_e = 0 \]

Additional resistance

\[ R = G_e v_e - G_1 v_1 + (p_e - p_1).A_e - X_\alpha \]
\[ X_\alpha = 0 \]

Initial parameters

Gas exit velocity

\[ v_e = M_e \sqrt{\gamma R_j T_e} \]

Mass flow

\[ G_1 = A_1 \rho_1 v_1 \]

Lifting force

\[ L = k \cdot R = 2.5 \cdot R \]

Thrust

\[ R = G_1 (v_e - v_1) \]

Gas exit temperature

\[ T_e = T_{hc} \frac{1 + \frac{\gamma - 1}{2} M_e^2}{1 + \frac{\gamma - 1}{2} M_{hc}^2} \]

Lifting force

Heat chamber temperatures

\[ T_{hc} = 600K, 900K, 1200K & 1500K \]

Heat chamber temperatures

\[ M_e = 3.2 \]
\[ M_{hc} = 0.5 \]
### Thrust of NPRED

#### Galeed Data

\[
G_1 = A_1 \cdot \rho_1 \cdot v_1
\]

\[
v_1 = c \cdot M_1
\]

\[
T_e = T_{hc} \frac{1 + \frac{v_e}{C}}{1 + \frac{v_e}{C}} \cdot M_{hc}^2
\]

\[
v_e = M_e \sqrt{\gamma \cdot R_t \cdot T_e}
\]

\[
R = G_1 (v_e - v_1)
\]

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**Heat chamber temperature - Thc = 600K**

| 90.4                        | 1058         | 0.000           | 2.6                           | 2774.9                      | 267.9               | 3849.1             | 2765.3    |
| 80.1                        | 1632         | 0.000           | 4.2                           | 2655.4                      | 264.9               | 3832.8             | 4943.4    |
| 70.4                        | 2587         | 0.000           | 6.9                           | 2596.0                      | 260.7               | 3825.1             | 8670.6    |
| 60.0                        | 4374         | 0.010           | 12.2                          | 2468.8                      | 257.1               | 3813.2             | 16458.1   |
| 50.2                        | 7620         | 0.018           | 22.3                          | 2377.8                      | 253.9               | 3802.7             | 3174.4    |
| 40.2                        | 13450        | 0.033           | 39.4                          | 2380.2                      | 253.0               | 3798.8             | 55849.5   |
| 30.1                        | 24150        | 0.061           | 71.3                          | 2345.8                      | 256.1               | 3811.3             | 104492.1  |

**Heat chamber temperature - Thc = 900K**

| 90.4                        | 1058         | 0.000           | 2.6                           | 2774.9                      | 357.2               | 4444.0             | 4297.3    |
| 80.1                        | 1632         | 0.000           | 4.2                           | 2655.4                      | 352.4               | 4432.0             | 7425.5    |
| 70.4                        | 2587         | 0.000           | 6.9                           | 2596.0                      | 347.6               | 4416.8             | 12755.1   |
| 60.0                        | 4374         | 0.010           | 12.2                          | 2468.8                      | 342.8               | 4403.4             | 23678.4   |
| 50.2                        | 7620         | 0.018           | 22.3                          | 2377.8                      | 338.6               | 4390.4             | 44839.7   |
| 40.2                        | 13450        | 0.033           | 39.4                          | 2380.2                      | 337.7               | 4386.5             | 78985.9   |
| 30.1                        | 24150        | 0.061           | 71.3                          | 2345.8                      | 341.5               | 4400.9             | 146531.1  |

**Heat chamber temperature - Thc = 1200K**

| 90.4                        | 1058         | 0.000           | 2.6                           | 2774.9                      | 446.5               | 4969.4             | 5648.1    |
| 80.1                        | 1632         | 0.000           | 4.2                           | 2655.4                      | 440.7               | 4955.2             | 9612.5    |
| 70.4                        | 2587         | 0.000           | 6.9                           | 2596.0                      | 434.5               | 4932.2             | 16953.1   |
| 60.0                        | 4374         | 0.010           | 12.2                          | 2468.8                      | 428.5               | 4923.2             | 30038.9   |
| 50.2                        | 7620         | 0.018           | 22.3                          | 2377.8                      | 423.2               | 4908.6             | 5683.5    |
| 40.2                        | 13450        | 0.033           | 39.4                          | 2380.2                      | 421.7               | 4904.3             | 99383.3   |
| 30.1                        | 24150        | 0.061           | 71.3                          | 2345.8                      | 426.9               | 4930.4             | 183583.8  |

**Heat chamber temperature - Thc = 1500K**

| 90.4                        | 1058         | 0.000           | 2.6                           | 2774.9                      | 546.3               | 5649.4             | 5648.8    |
| 80.1                        | 1632         | 0.000           | 4.2                           | 2655.4                      | 540.5               | 5635.2             | 9612.6    |
| 70.4                        | 2587         | 0.000           | 6.9                           | 2596.0                      | 534.3               | 5612.2             | 16953.1   |
| 60.0                        | 4374         | 0.010           | 12.2                          | 2468.8                      | 528.3               | 5592.2             | 30038.9   |
| 50.2                        | 7620         | 0.018           | 22.3                          | 2377.8                      | 523.2               | 5578.6             | 5683.5    |
| 40.2                        | 13450        | 0.033           | 39.4                          | 2380.2                      | 521.7               | 5574.3             | 99383.3   |
| 30.1                        | 24150        | 0.061           | 71.3                          | 2345.8                      | 526.9               | 5602.4             | 183583.8  |

**Nama Ilia Data**

 Heat chamber temperature - Thc = 1200K

 Heat chamber temperature - Thc = 1500K
Thrust of NPRE

**Thrust (Atmosphere pressure)**

- \( T_{h.c.} = 1500^\circ K \)
- \( T_{h.c.} = 1200^\circ K \)
- \( T_{h.c.} = 900^\circ K \)
- \( T_{h.c.} = 600^\circ K \)

**Thrust (Altitude above JSL)**

- \( T_{h.c.} = 1500^\circ K \)
- \( T_{h.c.} = 1200^\circ K \)
- \( T_{h.c.} = 900^\circ K \)
- \( T_{h.c.} = 600^\circ K \)

**Kuchemann’s relationship**

\[
k_{max} = \left( \frac{L}{D} \right)_{max} = \frac{4(M + 3)}{M}
\]

**Lift-to-Drag ratio**

\[ k = 2.5 \]
STEADY FLIGHT ZONES ON JUPITER
Steady flight

All Forces Balance in Steady Flight

Lift

Drag

Thrust

Weight
Steady flight zones for two Flyers mass of 1000 kg and 2000 kg

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<th>$T_{h.c.}$ [K]</th>
<th>Altitude of steady flight with flyer mass of 1000 kg, given in [km]</th>
<th>Altitude of steady flight with flyer mass of 2000 kg, given in [km]</th>
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<td>68</td>
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<tr>
<td>1200</td>
<td>77</td>
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<td>900</td>
<td>69</td>
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<td>600</td>
<td>58</td>
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Mass of the Flyer (Altitude above JSL)

- $T_{h.c.} = 1500^\circ K$
- $T_{h.c.} = 1200^\circ K$
- $T_{h.c.} = 900^\circ K$
- $T_{h.c.} = 600^\circ K$
CFD SIMULATIONS OF THE INLET
Flight conditions

\( h_{\text{steady flight}} = 60 \text{ km} \)

\[ \rho_{u.f.} = 4374 \text{ Pa}; \quad \rho_{u.f.} = 0.00991 \text{ kg/m}^3; \quad T_{u.f.} = 122.6^\circ K; \]

\[ \gamma = 1.534; \quad M_j = 2.309 \times 10^{-3} \text{ kg/mol}; \quad R_j = 3600.8 \frac{J}{\text{kg.K}} \]
2-D mesh of 36,000 finite elements
CFD Analysis
CFD Analysis
CFD Analysis
### CFD Analysis

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<th>Позиция</th>
<th>Число на Max</th>
<th>Статично налягане [Pa]</th>
<th>Плътност [kg/s]</th>
<th>Температура [K]</th>
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TEST FACILITIES
Aerospace simulator “Photonics”
Aerospace simulator “Photonics”
References

4. Frank E. Rom, Analysis of a Nuclear-Powered Ramjet Missile, Research memorandum, Lewis Flight Propulsion Laboratory, Cleveland, Ohio, (1954); (https://digital.library.unt.edu/ark:/67531/metadc60302/m2/1/high_res_d/19930088171.pdf)
5. Antonella Ingenito, Stefano Gulli, Claudio Bruno; Preliminary Sizing of Hypersonic Airbreathing Airliner; Transactions of the Japan Society for Aeronautical and Space Sciences, Aerospace Technology Japan, Volume 8, (2010); DOI: 10.2322/tastj8.Pa_19
6. Johnson, T.V., Yeates, C.M., & Young, R.; Space Science Reviews volume on Galileo Mission overview; Space Science Reviews (ISSN 0038-6308), vol. 60, no. 1-4, May 1992, p. 3-21; DOI: 10.1007/BF00216848
7. Galileo mission overview; https://solarsystem.nasa.gov/missions/galileo/overview/
12. NASA PDS: The Planetary Atmospheres Node, Galileo Probe Data Set Archive (2003); https://pds-atmospheres.nmsu.edu/PDS/data/gp_0001/
14. M. Bondaryuk, S. Il'yashenko, Ramjet Engines (Gosudarstvennoy Izdatel'stvo Oboronnnoy Promyshlennosti), Moscow, 1958
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