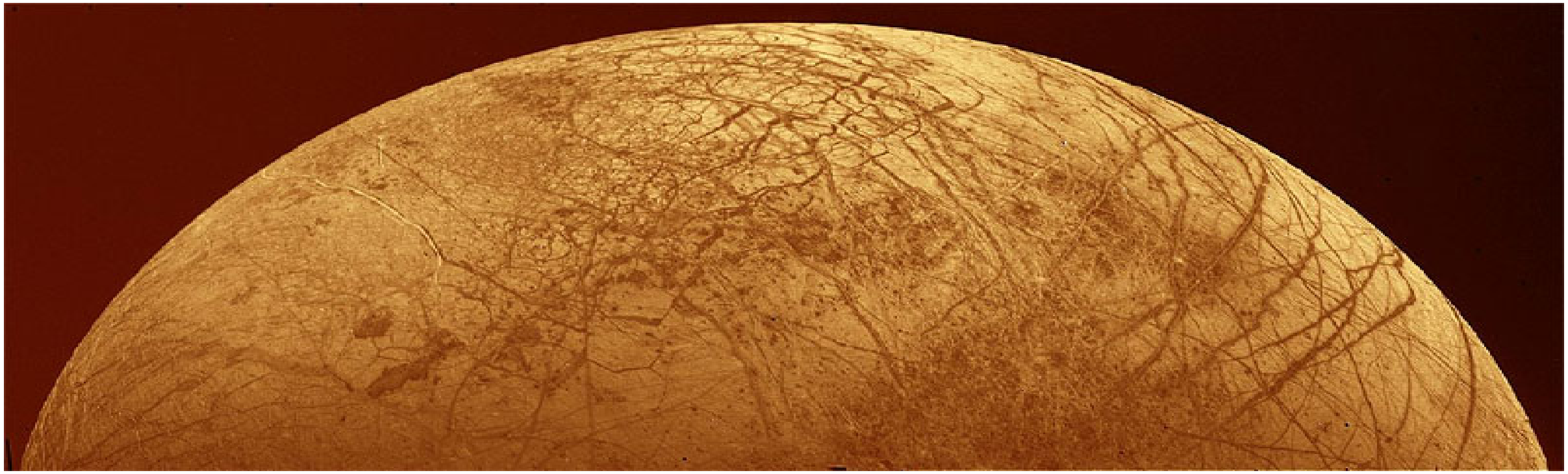

About the evidence of existence of an ocean at the Jovian moon Europa and of its rotation

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ABSTRACT

The principal possibility of direct evidence of ocean's existence at the Jovian moon Europa by means of landing probe equipped by the angular velocity sensor of high precision are under consideration. This conception is based on the theoretical solution of the problem concerning Europa's ocean and its ice shell's rotation induced by magnetic field of Jupiter.

INTRODUCTION

The investigation of Jupiter and its Galileo moons being fulfilled by *Galileo* and *Cassini* missions (fly bay of the first one on Jan. 30, 2000) gave the information of vital importance concerning magnetic field of Jovian moon Europa induced by rotating magnetic field connected with Jupiter. This information leads to conclusion of existence of liquid oceans at the Jovian moons Europa and Callisto covered completely by the ice shell. The main results of these investigations were published during last years (see [1 – 11]).

TWO QUOTATIONS

- **«The magnetic variation that induces electrical currents in Galilean satellites comes from Jupiter’s magnetosphere. Because Jupiter’s magnetic field is inclined (like Earth’s) relative to the planet’s rotation axis, the field «seen» by any satellite varies in direction and amplitude on a timescale close to the rotational period of Jupiter (about 10 hours)…**

  In the case of Europa, the magnetometer Principal Investigator Margaret Kivelson and her colleagues at UCLA and I collaborated in a study that showed that the disturbance of Jupiter’s magnetic field near Europa was that expected for induction of electrical current in a salty water ocean of 10 kilometers’ or greater thickness near the moon’s surface».

  Stevenson, D.J. An ocean in Callisto? // The Planetary report, 1999. V. XIX. No 3. pp. 7 – 11 [7]..

  (More realistic value relative to last assumptions is 100 km).

- **«If Europa`s icy surface were decoupled – mechanically – separated from its rocky mantle, <u>Jupiter`s gravity would cause the surface to spin slightly faster than the synchronous rate.</u> A subsurface ocean could easily act as such a bearing, allowing the floating ice shell to rotate nonsynchronously».**

  Pappalardo, R.R., J.W. Head, and R. Greeley, The hidden ocean of Europa. // Sci. Am., October 1999. pp. 54 – 63 [6].

The asymptotic solution of the magnetic field problem in the electric conductive shell in unsteady magnetic field

$$\mathbf{H} = I(t)\mathbf{H}^0 + J(t)\mathbf{H}_0\,;\ I(t)\mathbf{H}^0(\infty) = H_\infty\,;\quad j = 1,\,2\,;$$

$$\int_{G_i} (\mathbf{H}_0, \mathbf{H}_0)\,dQ\,(\dot{I} + \dot{J}) + \sqrt{\frac{\nu_M}{\pi}} \sum_{j=1}^{2} \oint_{S_j} (\mathbf{H}_0, \mathbf{H}_0)\,dS \int_{-\infty}^{t} \frac{\dot{J}(\tau)\,d\tau}{\sqrt{t-\tau}} = 0.$$

$$\mathrm{Re}_M = \frac{\omega l^2}{\nu_M} >> 1;\quad \nu_M = \mu_0 \mu \sigma,$$

In the case of Europa **l** ~ 100 000 m, σ ~ 50 (Ohm) $^{-1}$ m $^{-1}$,

ω = 1.62.10 $^{-4}$s^{-1}; Re$_M$ ~ 100.

If Re$_M$=.∞

$$\nu_M = 0;\quad J(t) = -I(t);\quad \mathbf{H} = I(t)(\mathbf{H}^0 - \mathbf{H}_0);$$

$$I(t)\mathbf{H}(\infty) = H_\infty;\ (\mathbf{H}, \mathbf{v})\Big|_{S_j} = 0;\ j = 1,\,2.$$

Mathematical model of Europa's magnetosphere [12]

- **Coordinate system** *Oxyz*:

  Ox is directed along the tangent to Europa`s orbit in the moon's movement direction,
  Oy - opposite to the Jovian centric radius – vector,

  Oz - perpendicular to the moon orbit's plate.
- **Mathematical model**

$$\boldsymbol{\Phi} = F_{\Phi}\, \mathfrak{J}; \quad \boldsymbol{\Psi} = F_{\Psi}\, \mathfrak{J}; \quad \mathbf{H}_R = F_{\mathbf{R}}\, \mathfrak{J},$$

$$\mathbf{H}_{\theta} = F_{\theta}\, \mathfrak{J}; \quad \mathfrak{J} = \mathbf{i}_x \mathfrak{J}_{\mathbf{x}} + \mathbf{i}_{\mathbf{y}} \mathfrak{J}_y + \mathbf{i}_{\mathbf{z}} \mathfrak{J}_z,$$

$$F_{\Phi}(R,\theta) = -\left(R + \frac{R_E^3}{2R^2}\right)\sin\theta; \quad F_{\Psi}(R,\theta) = \frac{R}{2}\left(R - \frac{R_E^3}{R^2}\right)\cos^2\theta;$$

$$F_R(R,\theta) = -\left(1 - \frac{R_E^3}{R^3}\right)\sin\theta; \quad F_{\theta}(R,\theta) = -\left(1 + \frac{R_E^3}{2R^3}\right)\cos\theta.$$

Mathematical model of Europa's magnetosphere [11, 12]

Main disturbance **[11]**

$$\Im_{\mathrm{x}} = \mathrm{H}^0\left[\left(1+\wp\cos\chi\right)^3 - 1\right] \approx 3\wp\cos\chi = 0.5\cos\chi;$$

$$\Im_{\mathrm{y}} = \mathrm{H}^0\left[\left(1+\wp\sin\chi\right)^3 - 1\right] \approx 3\wp\sin\chi = 0.5\sin\chi;$$

$$\Im_{\mathrm{z}} = \mathrm{H}^0\left\{\left[1+\delta\cos(\chi+\gamma)\right]^3 - 1\right\} \approx 3\delta\cos(\chi+\gamma) =$$

$$= 0.42\ \cos(\chi+\gamma); \mathrm{H}^0 = \mathrm{H}_0\left(\mathrm{R}_{\mathrm{J}} / \mathrm{r}_{\mathrm{E}}\right)^3; \chi = \omega t; \gamma = \mathrm{const}.$$

$\wp = 0.167$, $\delta = 0.14$, $r_E = 1560$ km, $r_E <= R <= 4000$ km.

Additional disturbance **[12]**

$$h = \mathrm{H}^0\left[\frac{1}{\left(1-\Delta\right)^3} - 1\right] \approx 3\mathrm{H}^0\Delta = 0.007\mathrm{H}^0,\ \ \Delta = 0.0023.$$

Mathematical model of Europa's ocean covered by thin ice shell

The main equation

$$J_F\dot{\Omega}_F + \beta\Omega_F + \gamma\int_0^t \frac{\dot{\Omega}_F(\tau)d\tau}{\sqrt{t-\tau}} = L^0.$$

The analytical solution in the case L^0 = const:

$$\Omega_F(t) = \Omega^0\left\{1 - \frac{\beta}{q_2 - q_1}\left[\frac{e^{q_1^2 t}}{q_1}\vartheta\left(-q_1\sqrt{t}\right) - \frac{e^{q_2^2 t}}{q_2}\vartheta\left(-q_2\sqrt{t}\right)\right]\right\} \Rightarrow \Omega^0\left(1 - \frac{\beta\gamma}{q_1^2 q_2^2\sqrt{\pi t}}\right);$$

$$q_1 = -\frac{1}{2}\left(\gamma - \sqrt{\gamma^2 - 4\beta}\right); \quad q_2 = -\frac{1}{2}\left(\gamma + \sqrt{\gamma^2 - 4\beta}\right).$$

$$\vartheta\left(-q_j\sqrt{t}\right) = 1 - \frac{2}{\sqrt{\pi}}\int_0^{-q_j\sqrt{t}} e^{-u^2}du. \qquad \Omega_S(\infty) = \Omega_F(\infty) = \Omega^0 = \frac{L^0}{\beta}$$

EXPERIMENTAL INVESTIGATION

Mathematical model

$$J_F \dot{\Omega}_F + \gamma \int_0^t \frac{\dot{\Omega}_F(\tau)\,d\tau}{\sqrt{t-\tau}} = 0;$$

$$\gamma = \gamma^* \sqrt{|\Omega_F|}; \quad M(t) = -J_F \dot{\Omega}_F .$$

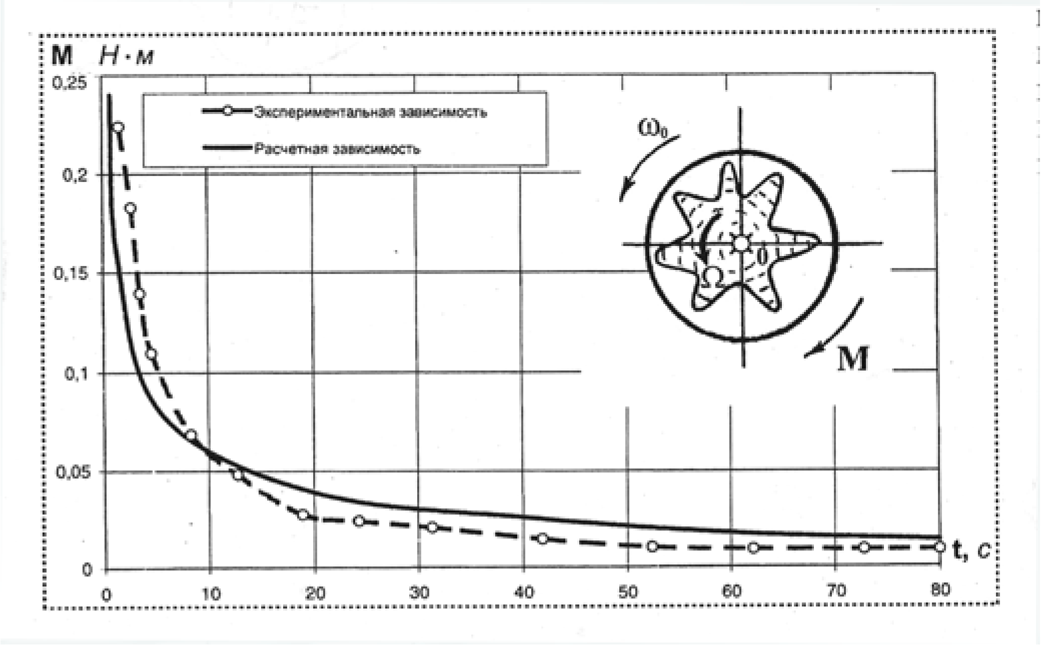
Experiments' series

№ 1. **m = 33 kg, ω_0 = 3.025 s^{-1}, J_F = 0.972 kg m^2,**
γ^* = 0.0265 N m s^2/(rad)$^{3/2}$.

№ 2. **m = 42 kg, ω_0 = 3.266 s^{-1}, J_F = 1.648 kg m^2,**
γ^* = 0.0220 N m s^2/(rad)$^{3/2}$.

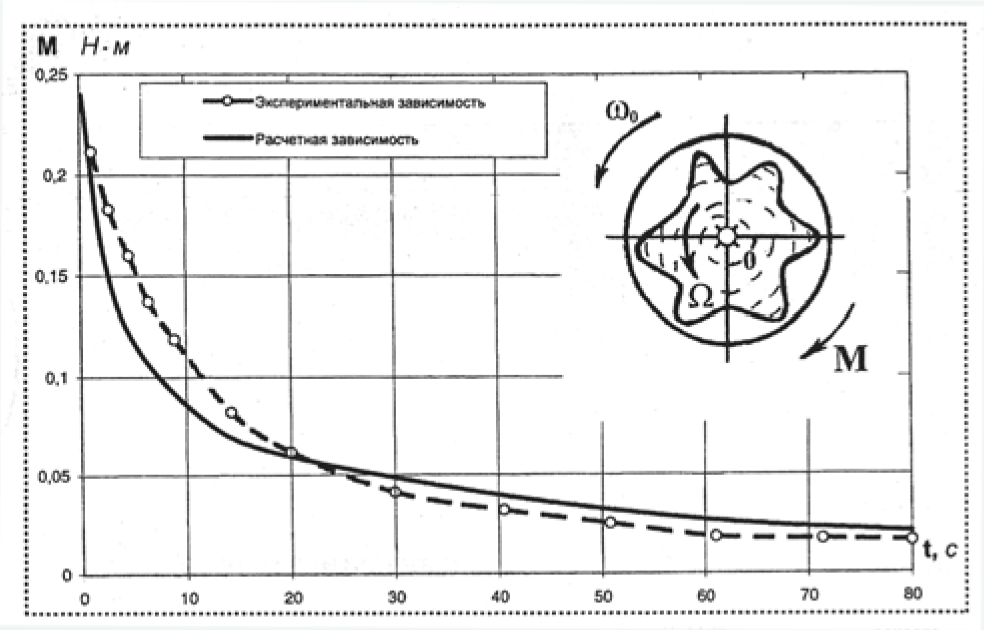
Experiment number 1

- Continuous line – numerical mathematical simulation
- Dotted line and signs – experiment, ○ - the point of the bag fastening



Experiment number 2

- Continuous line – numerical mathematical simulation
- Dotted line and signs - experiment, ○ - the point of the bag fastening



CONCLUSION

- *The initial state of the ocean-ice shell system (the synchronous rotation) is unstable. The system has a tendency to transform in the steady state one, the partial co rotation namely.*
- *This means the relative rotation of the ocean together with its ice shell with very slow constant angular velocity* Ω^0 *in the direction of Jovian magnetic field's rotation.*
- *The asymptotic state of the system is stable relatively to the angular velocity: the breaking moment will be greater then the twisting one while increasing of the angular velocity, and the system will come back to the non disturbed state.*

Evidence of ocean's existence [12]

- Steady state rotation velocity of the ocean and ice shell while L^0 = const:

$$\Omega_S(\infty) = \Omega_F(\infty) = \Omega^0 = \frac{L^0}{\beta}$$

- Synchronous angular velocity $\Omega^0 = 1.27.\ 10^{-5} s^{-1}$
- Co rotation angular velocity $\Omega^0 = 1.62.\ 10^{-4} s^{-1}$

- **The general flight experiment by usage of landing probe:**

The effect of ice shell rotation may be used as a direct evidence of liquid ocean at Europa by means of landing probe equipped with angular velocity gyroscopic or star sensor. The angular velocity Ω^0, measured by this sensor is greater then synchronous orbital one and smaller then co rotation angular velocity**:**

$$10^{-5} s^{-1} < \Omega^0 < 2.\ 10^{-4}\ s^{-1}$$

Such accuracy is of course very high but, as the Russian speak in such case, «*The play is worth of candles!*».

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