You have just donwloaded a 3-page document about KEO's technical feasibility.
Writen by Marc Montagne, Aerospatiale, it is an excerpt from a paper given at the 48th International Astronautical Congress, Turin, Oct. 97.

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The technical challenge of KEO project is to guarantee the reentry, the recovery and the information delivery after a duration of about 50,000 years. The first step is a technical analysis to study the feasibility of the project with state-of-the-art technologies.

I- General analysis

The life cycle of "KEO, the Archeological Bird of the Future" project presents 5 phases with each specific problems to analyze :

- <u>storage and launch</u> : launcher interfaces
- <u>ballistic phase</u> : choice of the starting orbit and impact of radiation, micrometeorites and space debris on the KEO payload integrity structure.
- <u>atmosphere reentry</u> : definition of heat shield system
- <u>impact</u> : structure integrity, buoyancy
- <u>information delivery</u> : procedure to decode the message

The first part of feasibility study focuses on the two main points, the definition of the starting orbit and the KEO probe design structure, coupled with the mission duration analysis.

Main specifications were defined as follows:

- <u>Payload</u> : 80 Compact-Discs, 1 decoding procedure (volume equivalent to 10 CD), 1 diamond, 1 dating system, 1 glass plate (figure 1 : payload configuration - diameter about 200 mm)
- <u>Probe mass and volume</u> : target V = 600*600*800 mm, M = 80 kg
- <u>Impact velocity</u> : no more that 100 m/s
- No active systems

A first quick technical loop indicated that the more robust shape for the probe is the sphere due to its insensibility to impact and flux direction. The analysis of the wings feasibility showed that the realization with state-of-the-art deployment systems for satellite presents low problem.

A first list of materials for the probe structure, based on their aging capability, was defined and we selected metal and ceramic material to have best potential versus project goals.

II- starting orbit choice

The choice of the orbit is a compromise between different parameters :

- the duration of the mission
- the capability of the structure to sustain radiation, micrometeorite and debris impacts.
- launch possibilities

To minimize radiation problems we need to be under Van Allen belts (under 2000 km of altitude and 60° of inclination). The debris concentration is at its maximum at low altitude and in geosynchroneous orbit but there are some hollow regions between 1000 and 1500 km .(see figure 2)

To initiate study of parameters, we selected a circular orbit (1400, 52°) that would limit the radiation effect and that is often selected for satellite constellations (launch access).

The duration of the mission will depend on altitude injection, orbit eccentricity , mass and surface of the object.(see figure 3). Therefore we needed a first design of the object to estimate the total duration of ballistic flight. We supposed that the wings would come off after a decade and these effects were neglected for calculation of the total mission duration.

III- Probe preliminary design

To define a preliminary design of the probe structure we needed to study the protections against radiation, micrometeorites and debris, reentry flux and ground impact.

III-1 Radiation hardening

The total dose during 10 years at 1400 km of altitude is 80 Mrad behind 20 mm of aluminium (see figure 4). We supposed this value constant during the entire mission. Neglecting the bremsstrahlung effect and taking into account the ionization effect, the hardening capacity of material is proportional to its density. So the material with higher density leads to smaller thickness.

To minimize KEO mass and diameter, to minimize reentry heat shield thickness, we selected a shield of 3mm of tungsten. The payload behind such a shield is exposed to 8 10E9 rad. (The radiate test on the CD is in progress)

III-2 micrometeorites and debris

III-2-1 micrometeorite flux and velocity

The table figure 5 shows the number of impact and the probability of impact versus micrometeorites diameter for 50,000 years of flight and a probe diameter of 500mm. We noted a large number of impact of small particles and a very low probability of one impact with a large particle (D>1cm). The average velocity is taken to 20 km/s.

III-2-2 debris flux and velocity

If we extrapolate the classical model of flux (increase of 5% per year for new debris, increase of 2 or 4% by impact), the number of impact with large debris (>1cm) would too important to give a chance to KEO to survive. This project emphasizes the catastrophic impact of debris increase for safety in space.

To go ahead and analyze this impact, two hypotheses have been made : no new debris in space beyond 2101, and beyond 2051. Figure 6 and 7 present the flux of debris and probability of impact versus these two hypotheses.

We realize that only the second hypothesis is reasonable to have a chance to built a shield that could protect the probe. So if we continue to increase the number of debris so quickly beyond 2051 the chance of KEO success is very low.

The average velocity of debris is taken to 10 km/s (for 14km/s max.)

III-2-3 shield design

A parametric study lead to select a multi-shock shield with a minimum of three bumpers (aluminium and nextel/kevlar tissues- thickness 2mm) and an internal skin (aluminium or titanium - 10mm). The total thickness of the shield is about 100 mm. This conception is based on COF MDPS experience.

It's a preliminary design that needs to be improved through a more precise study on probability of impact versus probe diameter, and material behaviour study versus multiple impacts and aging.

III-3 reentry shield

A parametric study of trajectory was made for several KEO configurations (mass and diameter). We obtained: from 70 to 150 m/s2 for the maximum deceleration, 50 to 135 m/s for ground impact velocity, and 5 to 15 mn for reentry duration. The maximum heat flux ranges from 1 to 3.5 MW/m2. These values are classical in reentry vehicle design and don't present any specific problem.

III-3-1 heat shield design

The limit temperature for the payload was fixed at 250°C.

First computations showed that the debris shield was blown out at high altitude (between 120 and 100 km).

The concept selected (see figure 8) for the heat shield is a multiple skin based on carbon/carbon material in the front (absorb the flux with ablation until the altitude of maximum of flux-thickness 10mm), tungsten material (radiate shield + reentry material- thickness 3mm), two type of insulating material (based on carbon foam with different density- total thickness of insulated materials 130mm) and finally a structure with titanium material (thickness 3mm)

III-4 Ground impact study

No specific study has been made but we selected a compact architecture and material (titanium and foam) that have been qualified to more than 100g ground impact.

III-4-1 Mass and volume

With concepts define thereunder, the total mass of KEO is 178 kg, the diameter is 770mm. That leads to a duration of ballistic flight of 57000 years and a final density of the object on the ground is 0.852. Therefore the buoyancy is acquired.

This concept seems to be robust but is far from target mass of 80 kg.

So several configurations are under study to optimize KEO's mass.

- off-centering of the gravity center (see figure 9)

This configuration leads to off-centering the center of gravity to create a rotation and a stabilization of the KEO which presents a defined side to the reentry heat flux. That allows an optimization of insulated material thickness and a decrease in mass and in diameter of the probe. We estimated a reduction of 75kg for the mass and 70mm for the diameter.

• splitting of tungsten shield

We can optimize the tungsten shield by keeping the minimum for reentry shield (1mm) and the remainder would be just around the payload. The mass reduction obtained is of about 20kg.

• increase of temperature limit of the payload

The increase of limit temperature of the payload from 250 to 350°C (that is the continuous limit temperature of the CD) permits a mass reduction of 50kg.

Therefore the potential of mass reduction is about 80 kg versus robust solution and the target of 80kg isn't impossible to realize. For diameter the limit seems to be about 700mm.
With these design and the starting orbit near 1400km of altitude a duration of 50,000 years is a most probable case.

IV- Conclusion of the technical study

The realization of the KEO probe seems to be realistic with state-of-the-art technologies, and preliminary design leads to a probe of 80 and 120 kg in mass and of about 700mm in diameter. The estimated duration of the ballistic flight is about 50,000 years.

The main problem remains debris impact because an increase of debris number beyond 2051 would be a problem for the safety of the probe. In this case the possibility to inject KEO on a higher altitude orbit (around 1800 km) could be a back-up solution. A great effort must be done during probe development to test current concepts of shield versus multiple impacts and aging.

The other aspects, reentry impact, buoyancy, seem to be feasible based on AEROSPATIALE state-of-the-art know-how on reentry vehicle.

The project is going ahead with an analysis of the development of KEO and more detailed design of the probe.