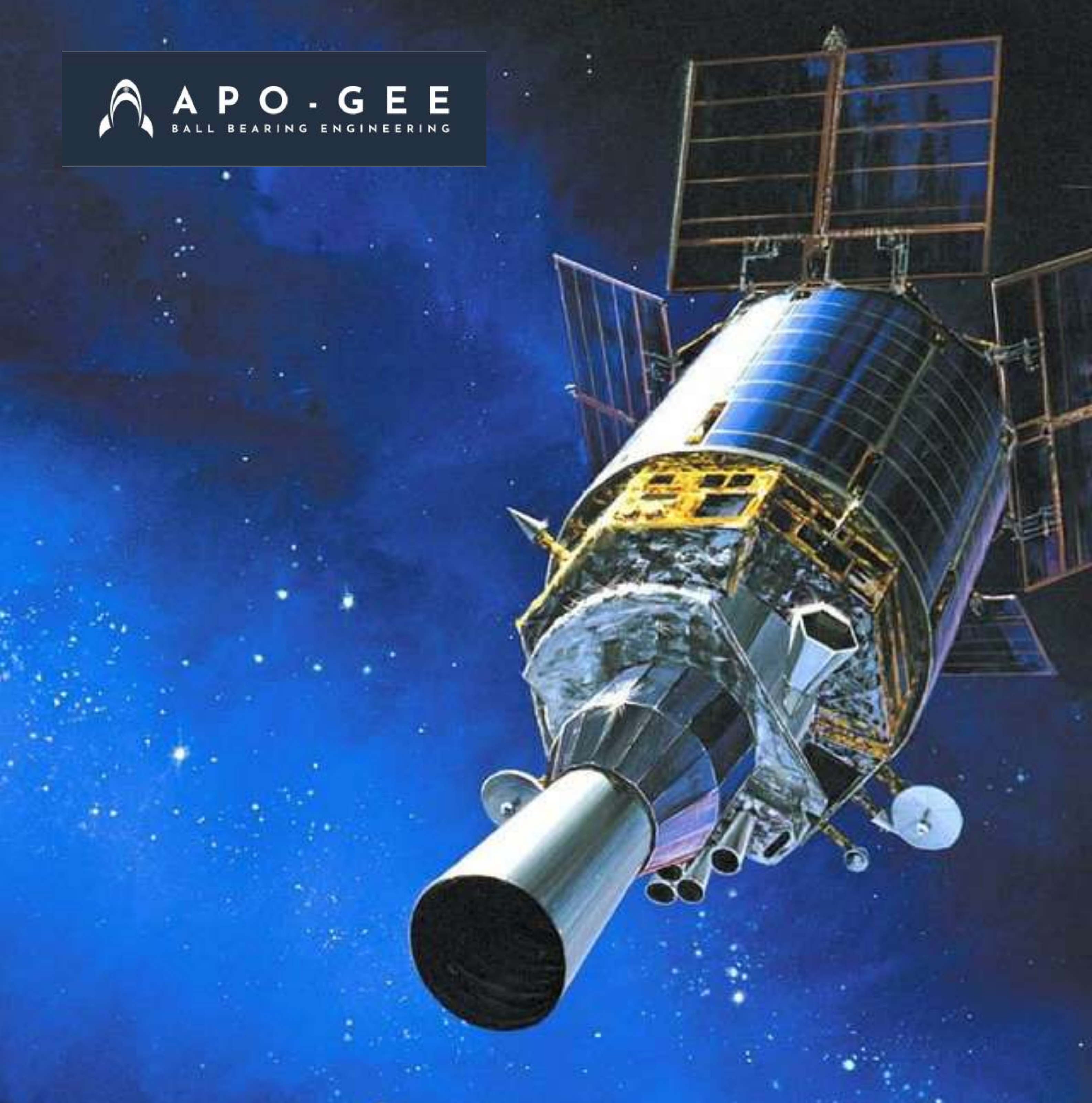

APO-GEE
BALL BEARING ENGINEERING

How (no-)gravity impacts cage instability in RWA's and gyroscope's bearings

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Cage instability in bearings

The cage instability phenomenon in gyroscopes' and RWA's ball bearings is not without consequence. It generates noise and vibrations that significantly affect the normal operation of the equipment. Over the last few decades, numerous space missions like Rosetta, GOES, Cassini, XMM-Newton, and many others encountered substantial disruptions, with some even being aborted due to ball bearing performance issues.

The common denominator among these mission setbacks is the cage instability problem in bearings. This problem resembles the chaos theory's butterfly effect—it's a complex and chaotic issue that has been hard to predict and widely misunderstood. This unpredictability has plagued space missions for years, causing uncertainty and costly setbacks.

Can we rely on qualification?

A natural question arises: can a successful qualification of the gyroscope or RWA guarantee cage stability once the spacecraft or satellite is launched into space?

Fig. 1 – Space probe qualification challenge

The answer is definitively negative, and for two essential reasons.

The first reason lies in the intrinsically chaotic nature of the cage instability phenomenon. This means that slight modifications in operational conditions (speed, friction, etc.) or slight changes in the cage's geometry can trigger cage instability. Many parameters indeed contribute to triggering this phenomenon. No matter how extensive the qualification, it's nearly impossible to precisely predict the actual evolution of operational conditions or wear, for example. The nature of the phenomenon also means that studying and testing extreme or limit cases cannot guarantee proper future functioning.

The second reason is directly linked to the first. It's related to the fact that experimental tests and qualification of bearings generally consider the presence of gravitational force. But what is the impact of gravity on the bearing cage's stability? Experimental tests cannot disregard gravity for an obvious reason, and numerical simulations account for it for realism, aiming to replicate the experience. But what about the ABSENCE of gravity? Experimental tests won't be of any help since gravity cannot be removed by any means.

The weight of the cage negligible, really?

However, the weight of the cage is negligible, around some millinewtons. How then could such a weak force play a significant role on a spacecraft's scale? Cage instabilities merely translate the establishment of a coherent mechanism that tends to amplify exponentially. In other words, regardless of the intensity of the efforts identified once instability sets in, it always starts from an extremely calm situation. Thus, even an infinitesimal force, like the cage's weight, can undoubtedly influence the cage's movement. This is particularly true at low speeds or in transient regimes, where the cage's kinetic energy cannot produce inertia forces much greater than those generated by gravity. Consequently, the mechanisms involved in the birth of instability cannot operate; they are constrained by the cage's weight, which tends to maintain it in a stable state.

Fig. 2 – Laundry behavior in washing machine analogy

This reality changes as the bearing's rotational frequency increases. We can draw here the analogy of the washing machine. The cage undergoes its own weight just as laundry in a washing machine undergoes its own. When the machine starts its cycle, the drum rotates very slowly around its axis (similar to a bearing ring). The clothes are slightly jostled but remain confined to the lower part of the drum: the weight of the damp laundry is enough to keep the mass within the machine's drum. However, as soon as the cycle reaches its spin speed, between 1000 and 2000 revolutions per minute, the laundry gets pressed against the walls of the drum. At these speeds, the centrifugal forces are much greater, and the weight fades in comparison, as if it ceases to exist. It's precisely this transition that the cage of the bearing experiences when its rotational frequency increases. In the same manner, with the increase in the cage's kinetic energy, gravitational force gradually fades in the face of inertia effects, eventually becoming negligible. It's only at this moment that the unstable nature can be observed, if it exists. The tragic corollary is that terrestrial experimental tests cannot anticipate a potential tendency toward instability at low and moderate speeds! In practice, the targeted speed ranges fall within the standard operation of the RWA or gyro incorporating the bearings. In such cases, predicting a FAILURE ON EARTH appears impossible! With the possible disastrous consequences that can be imagined.

Mitigating risk is definitely possible

Based on the deep understanding of the mechanisms driving cage instability, APO-GEE has engineered a new cage design, the Butterfly cage, that is intrinsically stable and has been experimentally validated (patent pending). APO-GEE also knows perfectly how to assess the instability risk associated with any cage, beyond terrestrial qualification, while also considering the effect of non-gravity.

For additional information and concrete demonstration based on real applications cases, contact us via www.apo-gee.tech.

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APO-GEE ENGINEERING SRL has fully solved the CAGE INSTABILITY PROBLEM, to which no fully satisfactory response has been possible for more than 50 years (patent pending). See www.apo-gee.tech.