Response to Geoffrey Bodenhausen

Comments are in black, responses are in blue

It would be interesting to know if more than 5 rotors were tested, and if the performance documented in Fig. 3 refers to their average performance or to unique cases.

We tested all 8 rotors, however rotors E, F and G did not spin stably. Figure 3 refers to unique cases, but the results are reproducible to within ~100 Hz for each rotor at each pressure value. Collecting statistics is useful for our development of these rotors and stators, but the results can vary based on which printed stator is used and the exact conditions of the experimental setup. The figure shown represents a unique test series performed using the same stator and experimental conditions for all rotors, as described in the experimental details.

The description of the curves of Fig. 3 as “pressure increases at higher pressures less effectively increased at spinning rate than at lower pressure” should be replaced by a sober reference to the figure itself.

We agree that this sentence does not benefit the discussion and have removed it.

While the discussion of the moments of inertia for empty spherical and cylindrical rotors is interesting, it is only at the very end that the authors admit that the sample and caps will affect these considerations.

To address this concern, as other reviewers have also noted interest in this issue, we have added as supplementary material an interactive Mathematica document which allows the reader to independently adjust the densities for the sample, caps, and rotor in order to see the effect on the moments of inertia as a function of normalized inner radius. We have added additional discussion on this topic to this document. The model we use is a simple approximation of how we pack sample into the rotors, but should give a sense for the effects of sample and cap density on the moments of inertia of the overall packed rotor.

The sentence “adjusted until the rotor’s spinning axis was inclined to the magic angle, taken as the maximal number of rotor echoes in the time domain data” leaves me dumbfounded. Surely it is the decay of the envelope of the rotational echoes that could be taken as a measure for the adjustment of the magic angle.

In a practice, when setting the magic angle, the researcher usually looks to see if more echoes are visible beyond the noise level out to a certain time in the time domain data as the angle is adjusted. Perhaps we chose a bit too practical of a description. We have modified this sentence to read: “The stator's pitch angle was adjusted until the rotor's spinning axis was inclined to the magic angle, as observed by measuring the decay of rotor echoes out to 10 ms in the time domain data.”

The claim that “the fact that rotor H established a stable spinning axis about its own axis of symmetry” is interesting, but this hardly “shows that the grooves do not direct the rotor to spin about this axis, but rather the geometry of the rotor itself is responsible”. There is no evidence that the machining of the groves agrees with the geometry.

We have measured the rotors that were machined, and found them to be within the tolerance levels of our design specifications. If a rotor with no grooves spins stably about its own axis, it shows that the grooves are not required in order to spin stably. The reason it spins stably about its own axis must be due to another factor, and that is the spherical-ring geometry of the rotor itself.

I have learned in a first-year physics course (at ETH!) that objects end up tumbling around the axis with the largest moment of inertia. I believe that this has been known since the XIXth, perhaps even since the XVIIIth century. It is unfortunate that the designers of “early spacecraft such as Explorer 1” were not aware of this phenomenon.

This is a very important issue, and there is a lot of confusion surrounding this topic (including for us as we have worked on writing and developing this manuscript!), as classical rotational dynamics is an issue which seems simple on first glance, but is actually quite complex and has received significant attention and development over the past century. Euler’s equations have been known since the 18th century, but they do not say anything about objects ultimately ending up spinning about the axis with the greatest moment of inertia. They predict that a rigid, axially-symmetric object will spin stably about its axis of symmetry regardless of whether the moment of inertia along that axis is the greatest or smallest moment. What happened with the Explorer 1 was that the satellite was intended to spin about its lowest inertia axis, which should have been fine if the object was rigid. However, due to avenues for dissipating rotational energy internally being present (antennas on the craft) the satellite began a precession which eventually turned into an end over end spin. The result of Explorer 1 spurred the further development of rigid-body rotational dynamics to account for this phenomenon. If avenues to dissipate rotational energy are present, the “stable” configuration initially predicted by Euler’s equations is no longer stable. In MAS, a cylindrical rotor exchanges energy with the surrounding gas and can enter into a precession if it is not actively kept from doing so. This is partly why oversized bearings in the stator result in unstable spinning.