Comment on egusphere-2022-59
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Referee comment on "In situ calibration of the Swarm-Echo magnetometers" by Robert M. Broadfoot et al., EGUsphere, https://doi.org/10.5194/egusphere-2022-59-RC2, 2022

General Comments
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This is an important paper describing the methods used to calibrate the processed CASSIOPE fluxgate magnetometer (MGF) data products that are currently available to the public.

The results are impressive. However, the style is uneven and at times there are errors, omissions or inconsistencies that must be remedied in order to make the descriptions of the methods sufficiently accurate for publication.

Specific Comments
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Section 1:

Line 49: Tests were run to evaluate mutual interference of the two sensors. Was any interference identified? If so, how is this information used to aid the calibration process?

Section 3:
Although Olsen et al. (2003) is referenced for the notation used in this paper, there are many departures from this notation in this section, and it is unclear how the notation in this section relates to the results presented in Section 7.

Line 67: it would be more accurate and consistent with Olsen et al (2003) to say that the raw sensor data, \( E \), is in engineering units that are approximately equivalent to nT.

Line 71, As used in Equation (1), \( b \) is a pseudo-vector (in a non-orthogonal system), and in engineering units. specifying 1,2,3 is appropriate for the non-orthogonal system, but I note that this is inconsistent with Table 1... do the results offX, offY, offZ in Table 1 correspond to \( b_1, b_2, b_3 \) (in which case, they might be labeled as engineering units, not nT), or are they actually nT (ie they are the offsets to be subtracted in the orthogonal, calibrated system)?

Line 74: It would be appropriate to describe the dimensions of \( S \) as \( eu/nT \), consistent with the results in your Table 1 in section 7. Subscripts 1,2,3 would be more appropriate, as \( S \) is in the non-orthogonal system...

Lines 78-79, If Equation (4) is correct, then the angles \( u_1, u_2 \) and \( u_3 \) are not the same as the angles of the same names in Olsen et al. (2003). Please describe how \( u_1, u_2 \) and \( u_3 \) defined, and their relation to the angles \( Oxy, Oxz, \) and \( Oyz \) reported in Table 1. Are they the angles between each pair of the slightly non-orthogonal sensors 1, 2, 3? While a figure would be helpful, it would be sufficient to define the terms clearly in the text, indicating, for example, that \( P \) represents the projections of sensors 1, 2, and 3 onto the orthogonal magnetometer reference frame, that sensors 1 and 2 are presumed to be in the X-Y plane, etc... Consider using a different notation (e.g. \( o_{12}, o_{13}, o_{23} \)) that clarifies that these angles are not same as \( u_1,u_2,u_3 \) in Olsen et al. (2003).

Lines 79-80. The definitions of the Euler angles (order 1-2-3) appears to differ from Olsen (2003), can you provide a reference? A more detailed description would be helpful to evaluate the physical significance of each parameter, when evaluating the results presented in Section 7.

Section 4:

There is discussion of the "original" attitude system based on STK, but it is not clear what is the relevance of this system to this study. Was it relevant to previously released versions of the data? If so, please specify.

What were the methods used to verify and obtain the revised attitude solutions that "included improved alignment between different star camera modes, corrections for chromatic aberration and thermal effects in the star cameras, and corrections to frame, location, and epoch transforms"?
Is the uASC accuracy of <2arcseconds achieved only the beginning of the mission, or is this the lifetime accuracy specification? How was this verified?

Line 135: At this point, it is enough to know that "improved methods of attitude interpolation are applied to achieve robust attitude transformations", and leave the detail about SQUAD/SLERP to section 5, where you provide the reference...

The relationship between section 4 and section 5 is confusing. In some ways, section 4 appears to be intended as an introduction to section 5... It would be helpful to mention which topics will discussed further in section 5, and which topics are beyond the scope of this paper.

Section 5:

I feel like I should be able to understand exactly what this section is talking about, but I'm finding it extremely difficult to follow.

Lines 138-139: This sentence is unclear. I think it's a typo. Is it intended to say: "In-situ calibration of the MGF instruments requires rotating the reference magnetic field from its native North, East, Center (NEC) frame into the local CRF frame of the spacecraft by convolution against the spacecraft attitude solution."?

Line 143-145: The wording of this sentence is very confusing, and I'm pretty sure I don't understand it correctly.... "The coordinate system that defines this spacecraft (SC) coordinate system..." I'm used to thinking of SC coordinates to mean a system fixed to the spacecraft, and the reference to Figure 2, in particular, appears to re-enforce that assumption: It is the same figure that is used to illustrate the CASSIOPE spacecraft frame (CRF?) in the CASSIOPE DATA HANDBOOK online... Meanwhile, this sentence appears to describe a coordinate system defined by the spacecraft orbit: ie. one in which "+X points towards ram [and perpendicular to nadir], +Z points nadir, +Y completes the right-handed system". This is what the CASSIOPE DATA HANDBOOK calls the Orbital Reference Frame... is this what you are calling the SC coordinate system, in this paper? If so, then it does make sense to say that SC and CRF are co-aligned when YPR are all zero, as implied by this sentence....

Line 149: What is the relevance of this 'secondary-source attitude solution' if you are are using the raw star camera data to get superior revised attitude solutions? Do you have access to the raw quaternions representing the attitude of the star camera frame? Wouldn't the raw output of the star cameras be quaternions representing the star camera frame in the ECI J2000 coordinate system? How does J2000 get transformed to SC? The transformation would require the ephemeris as an input. Is this done on board, or is it re-calculated on the ground?
Line 156: "the attitude solutions are then rotated into CRF": rotated nto CRF from what system? Does this mean, for example, that you apply an X-to-CRF rotation appropriate to each attitude knowledge source (X could be "star tracker A", "star tracker B", etc.) to obtain a CRF to SC attitude solution?

Line 158: SLERP is definitely to be recommended over per-element interpolation! I would be concerned about splining with SQUAD unless you are sure that the precision of each solution is much smaller than the change in attitude from one solution to the next.

Lines 158-161. Confusing sentence. Maybe SC serves as a refers to a specific coordinate system in the first instance, and as an abbreviation for 'spacecraft' in the second?

In flight, one can only calibrate against the attitude determination system's idea of what CRF is, which will always contain a bias with respect to the mechanical CRF that was used to measure alignments on the ground. As you have noted, this bias will vary depending on the attitude source (star camera A, star camera B, etc.) and the solution will have varying levels of noise, depending on the source... Have you used the vector-vector calibration to evaluate the relative bias of each source, and then incorporated these bias corrections into the Swarm-Echo attitude CDF product? (That is what I assumed you meant back in section 4, when you mentioned 'improved alignment between different star camera modes'...)

Line 160: What is a Body-to-ITRF transformation? How is it derived? If Body = SC, then I would agree that a SC-to-ITRF is what is required at this point. It would be well-defined, given the ephemeris data expressed in ITRF as an input. A reference, or more details would be helpful. The documentation of the Attitude Quaternion File in the CASSIOPE PROCESSED DATA HANDBOOK seems to use the term "ITRF<-Body" to refer to the final attitude quaternion itself, rather than something used rotate the interpolated quaternions at this stage.

In any case, have you verified the accuracy of the ephemeris?

Lines 176-179: Reading this, it seems that SC and CRF are actually supposed to be the the same thing... So, either I misunderstand this paragraph, or I misunderstood everything leading up to it...

Line 180: What is SP3 format?
The data selection methods described are all reasonable. The weighting method described in lines 220-228 seems appropriate, and is well referenced...

Section 7:

Table 1 and Figure 4: see my comments in section 3, regarding consistency of notation...

Line 256: what is meant by 'regularization'?

Fig 4: Do you have an explanation for the greater variability observed on the outboard sensor, as opposed to the inboard sensor?

What mechanism is assumed to be the cause of the reaction wheel tone in the MGF data? Is it electromagnetic, or mechanical? If mechanical, it might explain why the deviations in the parameters is similar for both the inboard and outboard and outboards sensors, and that the outboard deviations appear to be slightly larger in some cases (the boom may amplify the vibrations at larger distances... ) if it is assumed to be electromagnetic, I would expect the outboard deviations to be smaller...

I note that for the outboard sensor, there is a significant correlation between variations in off_x and the e3 parameter... Perhaps only one of them is physically changing... What degree of angular error would correspond with an offset error of 15 nT?

Lines 249-250: sounds plausible... Can you show an example of the reaction wheel noise? Is it a monochromatic high frequency (whether electromagnetic or mechanical) that is aliased down into the MGF frequency range, or is it more broadband? What is the amplitude?

Section 8:

I very much look forward to seeing these further developments!
For mitigating the reaction wheel tone: I would need to see examples, but I could imagine that more specific methods could be applied to identify and remove the 1 sps samples that are impacted by the reaction wheels... but indeed this might still require longer bins to make up for the lost data.

Technical Corrections
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Line 59-60: typo, should be 'et al.'
Line 47: typo, should be 'stimuli'
Line 193: typo, should be 'more important than'
Line 250: typo, should be 'steps will need to be taken'