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# Some considerations on the vibrational environment of the DSC-DCMIX1 experiment onboard ISS

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ABSTRACT

The present work attempts to characterize the accelerometric environment of the DSC-DCMIX1 thermodiffusion experiment carried out in the International Space Station, from November 7th 2011 until January 16th 2012. Quasi-steady and vibrational/transient data coming from MAMS and SAMS2 sensors have been downloaded from the database of the PIMS NASA website. To be as exhaustive as possible, simultaneous digital signals coming from different SAMS2 sensors located in the Destiny and Columbus modules have also been considered. In order to detect orbital adjustments, dockings, undockings, as well as, quiescent periods, when the experiment runs were active, we have used the quasi-steady eight hours averaged ($X_A$, $Y_A$ and $Z_A$) acceleration functions as well as the eight hours RMS ones. To determine the spectral contents of the different signals the Thomson multitaper and Welch methods have been used. On the other hand, to suppress the high levels of noise always existing in the raw SAMS2 signals, denoising techniques have been preferred for comparative reboostings considerations. Finally, the RMS values for specific 1/3 octave frequency bands showed that the International Space Station vibratory limit requirements have not been totally accomplished during both quiescent periods and strong disturbances, specially in the low frequency range.

## 1. Introduction

The accurate determination of the diffusion and thermodiffusion coefficients in ternary liquid systems is a relevant question not only because of its relation with the flow behaviour of the mixture but also because of its implications with the validity of the non-equilibrium thermodynamic matching models of the mixture itself [1,2]. Due to the very small magnitude of these coefficients, thermal and solutal convective mechanisms in terrestrial laboratories can mask their determination. So, to avoid this masking, experiments as the DCMIX (Diffusion Coefficients in ternary MIXtures) ones are conducted in space platforms, where the gravity is reduced. But, because the own nature of the physical processes implied, molecular diffusion and thermodiffusion experiments take a long time. On Earth laboratories this is not a problem, but in space platforms as the International Space Station, thereafter ISS, the duration of the experiment implies a previous and careful global planning in order to make long enough compatible quiescent intervals with the ISS mandatory daily activities. However, compatibility is sometimes difficult because the ISS is a very active environment. Boostings for orbital adjustments or to avoid collisions with orbital debris, dockings/berthings to bring astronauts/equipment to the ISS, undockings to return the crew to the Earth, flight attitude changes to reorient the ISS to the Sun for power supply reasons, extra vehicular activities for maintenance purposes, crew activities and so on [3–6].

Due to the importance of the impact of the external environment in any generic liquid experiment, when a large disturbance occurs, (such as during Orbital Adjustments like the Zvezda's ones in DCMIX1), the experiments are systematically stopped by the User Support Operations Centres (USOCs) personnel. In order to prevent possible errors and inaccuracies, the different runs are thus carried out during quiescent periods. Studies about the impact of large disturbances on the flow field [7,8] but specifically in DCMIX experiments, are being carried out actually by the authors. So, the aim of the present work concerns the first step of these studies, the accurate characterization of the accelerometric quasi-steady and vibratory/transient ISS environ-

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ment, focusing on the period when the DSC-DCMIX1 experiment was carried out [9–12]. This period covers since November 7th 2011 until January 16th 2012. That is to say, the period comprising the installation of the SODI-DSC hardware in the Microgravity Science Glovebox, MSG, in the Destiny module, until the day in which the experiment hardware was finally removed and stowed. The quasi-steady range will give us useful information about the quasi-constant levels attained by large disturbances happened during the experiment while that, the vibratory/transient range will inform us about the spectral characteristics of the mechanical vibrations acting simultaneously. This second range will also check if the environment of the experiment operates accomplishing the ISS vibratory limit requirements or not [13]. Mention here that despite the literature proposes other possible classifications of microaccelerations depending on the inner/outer character of the source or depending on the way of control these microaccelerations [14], the present work uses the common signal frequency classification (quasi-steady and vibratory) because the results presented here are focused on the analysis of the signal itself, regardless the cause that generates it.

The present work constitutes, thus, a first step to a more wide and complete accelerometric characterization of the rest of the DCMIX experiments.

## 2. Digital signal processing details

All acceleration data were downloaded from PIMS NASA website [15]. The quasi-steady range is composed by oscillations whose frequencies are lower than 0.01 Hz. Acceleration data in this range, came from the MAMS OSSBTMF accelerometer located in the middeck Lockers 3 and 4 of EXPRESS Rack 1 (ER1), in overhead bay 2 (O2) of the Destiny module (LAB1O2). The vibratory/transient range covers oscillations between 0.01 and 400 Hz. These data came from the MAMS OSS raw sensor also located in the LAB1O2, ER1, Lockers 3,4 and from the SAMS2 121f08 sensor, at that time near Deck 1 (D1), EXPRESS Rack 3 of the Columbus module (COL1A1, ER3, Seat Track near D1). Also, SAMS 121f02 and 121f03 sensors were at that time located in the Destiny module. SAMS2 121f02 was mounted in the Microgravity Science Glovebox (LAB1S2, MSG, Upper Left Seat Track) while that SAMS2 121f03 was mounted on the lower Z panel assembly of the EXPRESS Rack 2, in overhead bay 1 (LAB1O1, ER2, Lower Z Panel). Therefore, 121f03 measured directly what the ISS structure was experiencing in terms of vibration while 121f02 measured in contact with the Glovebox. The sample rate of MAMS OSSBTMF and OSS raw are 0.0625 Hz and 10 Hz respectively. The cutoff frequencies are 0.01 and 1 Hz respectively. The 121f02, 121f03 and 121f08 sensors gather data at 1000, 500 and 1000 Hz with cutoff frequencies of 400, 200 and 400 Hz, respectively. Unfortunately, simultaneous data from the Japanese segment of the ISS is not available for comparisons during the different episodes analyzed.

In order to eliminate possible instrument bias we have systematically demeaned all the raw signals before attempting any mathematical manipulation. The results presented here are always related to the common ISS Absolute Coordinate System, SSA. Referred to this system the velocity vector is oriented in the same direction as the $X$-axis and the $Z$-axis is oriented toward the local vertical (nadir).

Concerning the Power Spectral Density, PSD, mention that the periodogram is not a consistent estimator of its true value. To produce a consistent estimate of it, two different strategies have been used here. The first one is the so-called Welch technique, the second is the Thomson's multitaper method. In summary the Welch technique reduces the variance of the periodogram dividing the time series into segments usually overlapped. Multiplying then each segment by a window function and averaging the set of uncorrelated periodograms obtained a final estimation of the true PSD is made. The Welch method uses, then, the segmenting to decorrelate the different modified periodograms. On the contrary, the Thomson's multitaper method does not consider segments, the method uses the entire signal and a family of mutually orthogonal windows with optimal time-frequency concentration properties (Slepian sequences) to generate each uncorrelated periodogram [16]. Here, thus, the orthogonality of the Slepian sequences decorrelates the different modified periodograms. To estimate the PSD of the MAMS signals, the Thomson's method has systematically been used, but, for large SAMS2 signals, the Welch method with Hanning windows has been considered more versatile and operative. Mention also that, for convenience, the ordinate scale of the different graphic representations of PSD uses a linear scale for the PSD magnitude in the case Thomson's method ($g^2/Hz$). In the Welch method the scale is logarithmic (dB/Hz) -although, obviously, both scales are equivalent-.

On the other hand, due to the existence of an important amount of masking noise in all SAMS2 signals, a systematic cleaning process has been carried out before any further comparison. To do so the literature

**Table 1**
Accelerometric episodes all along the DSC-DCMIX1 experiment.**QP** – Quiescent Period chosen as representative of the different runs; **DCK** – Docking; **ZOA** – Zvezda's Orbital Adjustment (**reboosting**); **UDCK** – Undocking; **SGP** – Short Generic Perturbation (unknown origin).

| | Day | Analyzed Interval(UTC) | Analyzed sensor | | Episode type | Origin |
|---|---|---|---|---|---|---|
| | | | MAMS | SAMS2 | | |
| 1 | 09-11-2011 | 05:07–23:00 | OSS raw | 121f02<br>121f03 | QP | – |
| 2 | 14-11-2011 | – | – | – | SGP | ? |
| 3 | 16-11-2011 | – | – | – | DCK | Soyuz TMA-22 MKC Astraeus (Port: Mini-Research Module 2 -Poisk-) |
| 4 | 18-11-2011 | 04:06 – 04:11 | OSS raw | 121f02 | ZOA | Thruster ignition (Zvezda Service Module) |
| 5 | 21-11-2011 | – | – | – | UDCK | Soyuz TMA-02 Eridanus (Port: Mini-Research Module 1 -Rassvet-) |
| 6 | 22-11-2011 | – | – | – | SGP | ? |
| 7 | 26-11-201 | – | – | – | SGP | ? |
| 8 | 30-11-2011 | 23:19–23:24 | OSS raw | 121f02 | ZOA | Thruster ignition (Zvezda Service Module) |
| 9 | 02-12-2011 | 11:30–23:31 | OSS raw | 121f02<br>121f03 | QP | – |
| 10 | 09-12-2011 | 19:50–19:51 | OSS raw OSSBTMF | 121f02<br>121f03<br>121f08 | ZOA | Thruster ignition (Zvezda Service Module) |
| 11 | 23-12-2011 | – | – | – | DCK | Soyuz TMA-03 M Antares (Port: Mini-Research Module 1 -Rassvet-) |
| 12 | 24-12-2011 | 13:03–23:50 | OSS raw | 121f02<br>121f03 | QP | – |
| 13 | 09-01-2012 | 13:41–23:46 | OSS raw | 121f02<br>121f03 | QP | – |
| 14 | 13-01-2012 | 16:18–16:23 | OSS raw | 121f02 | ZOA | Thruster ignition (Zvezda Service Module) |