Comments on Body Mass Changes During Long-Duration Spaceflight

William Thornton

ABSTRACT: The paper "Body Mass Changes During Long-Duration Spaceflight" allows a comparison of devices, their application, results obtained and their interpretation from the two programs of such studies to date. There were significant differences in all aspects of the two programs which are briefly commented on here.

KEYWORDS: Skylab, Linear Acceleration Mass Measurement Device.

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The authors of the article "Body Mass Changes during Long Duration Spaceflight"[5] are to be commended for the first comprehensive report of body mass measurement on the International Space Station (ISS). This paper allowed comparison of mass measurement on the ISS with mass measurement that was first performed on Skylab 44 yr ago.[4] Data and the results from these studies are the basis for this commentary.

The author designed, developed, and tested Specimen and Body Mass Measuring Devices (MSMMD and MBMMD) for the U.S. Air Force Manned Orbiting Laboratory (MOL) Project in 1965-1967 at Brooks AFB, TX. MOL was cancelled and the devices and designer went to the NASA Apollo Applications Project (which became Skylab) in 1967. Two MSMMDs and an MBMMD were flown on Skylab. The Soviets also developed a mass measurement device (RBMMD), which was first flown on Salyut 5 and 6.[1] This design has continued to fly onboard the ISS. In 1993-1994 the author began development and testing of a Linear Acceleration Mass Measurement Device (LAMMD). On his leaving NASA his design was made the responsibility of Lockheed Martin, who produced an altered version as the Space Linear Acceleration Mass Measurement Device (SLAMMD).[2] This device is currently on ISS. Both the MOL/Skylab MBMMD and the Russian RBMMD use a passive Spring Mass Oscillator (SMO), but in very different configurations. The MBMMD was designed to allow operation both on the Earth (1 g) and in weightlessness (0 g) by placing its axis of oscillation normal to the g vector. Axis of oscillation of the RBMMD is on a vertical axis aligned with Earth's g vector, making determination of accuracy, calibration, and measurement of the effects of nonrigid masses (human body) practically impossible in 1 g.

Other significant differences are the maximum resolution of period measurement, amplitude of oscillation, mechanical resistance (friction), and attachment of the body to the SMO. Resolution of the measurement period of an SMO determines its maximum possible accuracy. It is 10^{-5} s in the MBMMD, two orders of magnitude greater than in the RBMMD, which is 10^{-3} s. In practice, rigidity of the body mass and its method of restraint determine the limits of accuracy. Mechanical resistance affects both amplitude and period of oscillation in an SMO. Coaxial tubes and eight mechanical bearings appear to be used for axial constraint in the RBMMD. Resistance as a source of error was practically eliminated in the MBMMD by the use of eight flexure pivots. Validation of performance is the greatest difference in the design and use of these instruments. In the MBMMD, repeated pre- and in-flight calibrations were made with masses traceable to the National Bureau of Standards. In the RBMMD, calibration consists of measuring the period of oscillation without a sample and using a mass assigned to the subject platform to calculate the spring's constant. This constant was then used with the subjects' period of oscillation to calculate the subject mass. This in effect compares the instrument to itself. Designers of the RBMMD addressed the subject of accuracy by calculation rather than by validated measurement. Calculated effects of the maximum error produced by an oscillation

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period time resolution of 10^{-3} s were added to the theoretical effects of mechanical resistance to produce the quoted values of accuracy. Source, nature, or determination of the value of this resistance was not given.

There are several fundamental differences in the Skylab and the ISS data bases. In Skylab we had 9 subjects vs. 25 subjects in the ISS. Mission durations were 28, 59, and 84 d in space in Skylab vs. 93 to 199 d on the ISS. In Skylab we performed daily preflight, in-flight, and postflight mass measurements vs. only one measurement 74 d preflight, 6 measurements every 2 wk in flight, and 2 measurements postflight on the ISS. The total measurements on Skylab were 232 preflight, 501 in flight, and 156 postflight vs. 25 preflight, 152 in flight, and 50 postflight on the ISS. Most importantly, nutrition data was tightly controlled and premeasured on Skylab vs. ad lib and data dependent on subject recall on the ISS. There is no way to quantitatively compare the accuracy of the instruments without a comparison of RBMMD to an accepted standard. Comparison of results of the two devices on ISS confirms that one or both must have a significant error.

Looking at the individual mass measurement data curves from Skylab, an unexpected change found in weightlessness during Skylab was a rapid loss of 3–4% equivalent of total body mass from the legs followed by an obligatory loss of mass, typically over the first 3 to 5 d of spaceflight.[3] This produced a biphasic pattern with a rapid loss of body mass on the initial 3 to 5 d exposure to weightlessness and a rapid recovery of this loss on return to 1 g after landing. Between these two periods of rapid change the mean slopes of the curves were directly related to measured caloric intake. Semi-quantitative estimates of the RBMMD curves from ISS show a loss (in all but one subject measured) during this time of 4 to 5 kg. Given the many possible sources of error, including unknown accuracy and precision of the RBMMD, the unstated protocols for baseline and in-flight measurements, and the separation of months between baseline and in-flight data, these results are not surprising. The single postflight measurement at unstated times without measurement protocols and the rapid gains of mass possible during this time, a kilogram or more in tens of minutes, produced large variations in these data.

The hypothesis that most, if not all, the losses seen here were caloric since diuresis does not accompany the loss seems untenable in the face of accepted theory and practice. Water is the major component of body mass and determined by the balance between intake and output, both of which have several control systems. Thirst control receives a number of inputs but a baroreceptor mediated cardio-renal diuresis is not observed on entry to weightlessness. Rather reduced fluid intake and several days of obligatory water loss, including urine, can account for the volume reduction to a new set point over the first days of flight

Advances in currently used instruments, accuracy and application of body mass measurement will be required for successful exploratory missions.

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