With Skylab, mass measurement in spaceflight became a more or less routine operation. This was not always true. Indeed this was the first example of such measurement. One of the first ~~con~~ significant and consistent changes seen in crewmen returning from spaceflight was a weight loss which sometime seemed to be a function of flight duration but with many variables. There were several theories concerning the mechanism of these losses including: (1) a shift of fluids cephlad after removal of gravitational ~~f~~ forces with dumping of this apparently excess fluid through diuresis; (2) fluid loss through sweating from increased environmental temperatures and other stresses; (3) ~~inadquate~~ inadequate fluid or food intake.

In 1965 it was obvious that daily inflight crew body and intake-output mass measurements would be required to serially document these changes and determine which mechanisms were responsible. At the Air Force's Medical Division we concluded that development of a non-gravimetric mass measuring device was of first priority to investigation of this fundamental problem, and I began such development. By 1966 a device for measuring mass of specimens over the range of 25 grams to 1 kilogram and a larger one covering the range of ½ to 100 kilograms were completed. Skylab has been the first opportunity to demonstrate their performance inflight. Since the method of mass measurement used is a fundamental departure from weighing machines, the technique will be described.

Man has been using the gravimetric balance or scales for at least 5,000 years. It is such a simple, efficient and accurate method that no alternative devices were available or needed. It is only when one attempts to develop an alternative to weighing that the method is truly appreciated. The only practical alternative to gravimetric attraction of mass is some measure of its inertial property. In 1965 the method that was chosen, a method heavily biased by size and weight requirements as well as by my previous electronic experience, was a mass dependent translational mechanical oscillator.

Slide_____ is a schematic of the method used. A sample mass is constrained to linear motion between two springs. If the mass is displaced from its rest or stable position and released, it will undergo virtually undamped natural oscillation whose frequency is a function only of the mass and spring constants. An electro-optical detector and counter times each crossing of the zero displacement point allowing accurate measurement of the period of oscillation. By calibrating the device with a series of known masses, the mass of an unknown sample can be determined from its period of oscillation.

Such a technique allows reasonable accuracies with solid masses--for example, it is not particularly difficult to obtain .01% or more. Conversely, this technique has several inherent limitations. Any motion (jitter) of the supporting mechanism or of the specimen will produce errors. Any non-rigidity of specimen (slosh) which allows secondary oscillations near the primary frequency will produce also errors. Thus, measurement of items such as liquids and of the human body require special arrangement.

Although existing vibration studies of the human body show that it behaves as a single rigid mass below one cycle per second, this proved not to be the case. The frequency of oscillation had to be lowered to less than one half cycle second, and the body folded into the most rigid configuration possible.

Motion Picture

Experiments M074/172 were also intended to explore the complete envelope of performance of this method, but since only the investigator has displayed any interest in this aspect it will not be mentioned except to say that accuracies obtained are more than adequate for any current medical investigations--a few grams for food residue and less than ±.1 lb. repeatability for body mass with absolute body mass between +.25 to +1.0 lb, probably closer to the lower figure.

Operation on Skylab has been more or less routine. There was a gap of the first few days on Skylab-2 during vehicle repairs. Virtually no uneaten food has been left to measure. Two small vomitus samples, on the order of 100 ml were produced by one crewmember on SL-3. All fecal samples were routinely measured but showed little except the marked variation in habits of individual crewmen. *

Body masses have been the most revealing. As a baseline such masses were made gravimetrically on SMEAT--the ground-based chamber simulation.

Graphs of the crewmen's body weights while on the Skylab diet are shown here. (Slides _____, _____, and ____.)

Next are shown the results from SL-2. The data has been smoothed by plotting a 3-day sliding average. Weights on beginning the diet, on launch, and on recovery are highlighted. These points are gravimetric weights. SL-2 CDR loss curve is typical of all three crewmen on this mission. There was a small but definite loss during the control period; i.e., while on the Skylab diet and in quarantine. After launch this rate of increase accelerated but remained more or less constant except for sharp drops associated with EVA's. Following recovery there was a rapid increase, accompanied by an overshoot which, although not shown here plateaued to a value some two plus pounds below launch weight. (Slide___)

The PLT's curve has the same general shape without the postflight overshoot while the SPT's curve is more variable.

There were marked differences in SL-2 curves in two of the SL-3 crewmen--CDR & PLT. (Slide____) After the first day of the stabilization period there was no loss or possibly a slight gain. Inflight there was an initial loss followed by a long stable period until just prior to the end of the mission when a rapid rate of loss (Slide____) occurred. The SPT had a slight loss during the control period, a slow loss which continued inflight after a marked decrement over the first few days. After recovery we see the typical rapid increase followed by a plateau or inflection.

There is one obvious pattern of loss here which was also seen in the control study. Conversely, there are more subtle patterns, especially the rapid shifts which must be interpreted in conjunction with a great deal of other data, some of which unfortunately doesn't exist. This additional data should include intake-output studies, physical condition of the individual crewmen, amount of exercise, lean body and fat studies, anthropometric measurements and muscle function.

For example, it is very tempting to postulate that the rapid changes seen for the first few days after orbital insertion and after recovery are fluid shifts. However, on SL-3/4 we have two crewmembers who experienced normal conditions on exposure to weightlessness; i.e., they did not have nausea, anorexia or excess environmental temperatures. There was no such rapid loss of weight seen. Conversely, the crewman who had nausea showed a "typical" rapid loss of a few pounds for the first few days. We are attempting a series of added studies on SL-4 to attempt to document any fluid shifts.

As often happens, the inflight mass measurement data from Skylab demonstrated complexities and raised questions not anticipated prior to Skylab. Most of the loss will be explained by these and corollary measurements. Equally important attention will be properly focused on the remaining unknowns such that proper investigation may be implemented.

Finally, there is the question of mass measurement itself on future missions--missions that may not have almost unlimited resources. The mass measurement devices flown on Skylab are relatively crude, obsolescent and expensive. In the intervening 7 years since their design I have developed a series of ~~sammler~~ smaller, simpler and cheaper alternatives--some of which are about to be zero-g tested which should allow mass measurements on virtually any object in almost any spacecraft.

Thank you.

* Other mass measurements have been routinely made in support of spacecraft Operations including urine pools and the amount of coolant Fluid added to the refrigerant system.