~~Major Stephen H. Birgel~~

Problem:

The achievement of orbital flight has introduced a number of problems. Many of these problems have to do with the unique environment produced by the vehicle such as acceleration, vibration, changes in atmosphere and the like. One notable difference introduced is that of weightlessness which is of particular interest to the designer of instrumentation. Gravimetric methods have been essentially the only means used for determination of mass since this procedure has been of interest to man. In essence, this method at best consists of the balancing of the forces produced by the attraction of earth for an unknown mass against the attraction of the mass of the earth against some established mass. The method is convenient and extremely accurate. For example: Relatively inexpensive scales can produce accuracies of .1 in a hundred thousand. In current space flight and particularly for future missions where increasing amounts of scientific investigation will be conducted on orbit there will be an increasing need for accurate mass determination. Gravimetric devices are, of course, useless under the conditions of orbital flight. Since our gravity is still present, it is almost exactly offset by the centrifugal forces of flight and the objects are in fact truly "weightless." The problems which are of primary interest at the moment in the space program of mass determination include the mass of the astronaut and of his liquid and solid intake and output. An accuracy on the order of .1% was felt to be adequate for current studies.

Candidate Methods:

No devices were available for non-gravimetric mass determination. Alternatives to gravimetric means would be practically limited to the inertial properties of mass. And for convenience, the methods could be considered in 2 modes of movement. These modes we will designate 1) linear (translational) ~~bracket~~ and 2) rotary. (Combinations of motion or motion along several axes could conceivably be considered, but the situation becomes very complex and will not be considered here. The potential devices could then be considered under 2 further categories which might be called acceleration and momentum. Some brief comments will be made on the various methods using this scheme. Linear acceleration devices:

1) A known acceleration is supplied to an object particularly if it could be a constant acceleration, and the reaction produced by the object could be accurately determined. This would be a perfectly acceptable method of mass determination. For example: Some form of known force could be such as a spring or a force ______________ from an electromagnetic mechanism could be applied to the object, and the resulting reaction measured directly in terms of force. This at first glance is an extremely attractive process. A modification of this could consist of a known force being applied to an object and the resulting acceleration would then become the derived measurement. These schemes, however, to be practically realizable with non-rigid objects, would require a reasonably long means of constraining

them to translation without appreciable friction or with friction being very carefully known. With non-rigid objects a starting transient would be induced and sufficient time and distance would then be required to allow this transient to damp out. Only at this time would force or acceleration measurements be valid. This might have some advantage with liquids; however, the track for this device would be quite long. There is little question that springs or some other arrangement could be used to apply fairly constant force, but then one has the problem of accurate determination of acceleration over the distance. Accuracies on the order of 1% would probably not be very difficult to obtain. A variation of this linear-fixed acceleration is the use of a what has been called a "linear spring mass pendulum" in which the unknown mass is subjected to forces ~~that~~ of the form $F = KX$ by a linear spring. If the mass is displaced and released, the system will go into a natural oscillation whose period is a function of the mass frequency of oscillation. This method will be ~~discussed in great detail in the following~~ at length. The analogous cases of these two situations in circular coordination would in one case be a centrifuge in which an object would be rotated and the amount of centrifugal force would be determined. This requires rather precise knowledge of the rotational speed - omega - (~~how do you write it in Greek? I have enough trouble with English~~) and more importantly of knowledge of the center of mass of the object. Some of the problems of the knowledge of the center of mass may be circumvented by a two-length centrifuge at which the device is excessively rotated with two different radii of rotation. In spite of its apparent attractiveness the complexity of this method in practice makes it most unattractive except in the case of liquids in which it may become the method of choice since the liquid can be made to form a "rim" of equal thickness about the centrifuge, and with a given liquid this in turn would allow a simple calibration method. An alternative to the linear spring mass methods would be a rotational pendulum with a torque provided by a torsion bar or a spring arrangement. All of the problems associated with the centrifuge are present here plus new ones introduced by non-rigid objects which at some frequencies will have certain of their portions moving out of phase with the desired oscillation. Finally, in the linear case, one could consider systems involving the conservation of momentum in which an object of known mass and velocity struck a second object, an unknown mass was locked to this object and the two then proceeded to move at a new velocity which could be determined. This method has a number of obvious difficulties, particularly with non-rigid objects which would obviously be shocked into some form of oscillation which would then be dissipated with a resulting loss of energy and momentum. It does introduce further errors into the system. A number of individuals and organizations have done varying amounts of work on this problem which will be indicated very briefly here. There may well be others of which I am unaware. Lockheed Missiles and Space Company are one of the earliest groups to approach this problem and in a Technical Report, LMSC-A745458·17 May 65, they discussed various methods of mass determination of man including torsional pendulum, centrifuge, impulse momentum, conservation of momentum, linear acceleration, and inertia being imbalanced and frequently of a spring mass system. In addition they described experiments in which laboratory verification of linear acceleration and of the spring mass system were explored with a wheel craft and negated spring arrangement they were able to obtain accuracies of ± 2 pounds. In their spring mass pendulum experiment they suspended the subject on a platform from a ceiling 19 feet above and attached springs to each end of the resulting pendulum. The period of the pendulum was then measured. They were able to obtain accuracies of ± one-half pound using this arrangement. They continued their work both in-house and under NASA contract and in their report, NASA CR-66174, they described two versions of a spring mass pendulum which consist of low-friction mechanical bearing arrangements to constrain oscillation along a steel track with the restoring force being supplied by a long coil of springs pretensioned. The period of oscillation was timed by means of conventional electronic devices. The device used in initial amplitude for oscillation of approximately 1-1/2 feet with spring constance of approximately 3 pounds/inch which resulted in an accelerated force of approximately 27 pounds. In addition, the system was fairly heavily damped with a relatively few cycles of oscillation. A restraint harness was used to aid in coupling of the man to the system. This arrangement produced a relative accuracy of ± 1 pound for human subjects and an accuracy of rigid objects of ± 1 pound over the range of 41 to 250 pounds. The absolute accuracy of the device, i.e., comparison of the mass of man to fixed mass is on the order of 7 pounds. Douglas Aircraft has also performed theoretical and experimental work in the problem of mass determination[3,4]. In this paper Mr. Butler examines 4 methods of mass determination, the first of which is an accelerational method in which the unknown mass is accelerated by a spring of known force, oscillating spring mass system, a centrifuge and double radii centrifuge method, and

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[3]Butler, F.H., "Methods of Determining Mass or Weight in a Zero G Environment," Douglas Paper Nr. 3362, Douglas Missiles and Space Division, Santa Monica, California, 1965

[4]White, W. J., et al, "Biomedical Potential of a Centrifuge in an Orbiting Laboratory," Douglas Aircraft Company, July 1965, AB Nr. 472550

a momentum method in which a mass moving at a known velocity strikes and remains with the unknown mass from which the velocity is determined. He reached the conclusion that the momentum method would be the method of choice since it "utilizes the principal of momentum conservation, which bypasses energy losses." In addition, Douglas proposed to use the short radius centrifuge of the mass measuring device[4] and examined the theoretical performance of single radii and double radii centrifuges as well as _______________ analysis indicated maximum errors of ± 1%. Experimental results were not reported. In addition Douglas did an analysis of and constructed an oscillating spring mass system using a wheeled carriage arrangement working on a relatively large displacement. Again, the experimental results remained unreported and work has not been continued. NASA Ames Laboratory has investigated and constructed a spring mass pendulum for determination of very small masses and this reportedly has an accuracy of approximately 1%. Work currently continues on this device. Mr. Blank of Biomedical Engineering Section of the School of Aerospace

Medicine proposed a 2 radii oscillatory pendulum method and analyzed this in detail, but this was not pursued experimentally. The use of gamma ray densitometry as a mass measurement determination has been proposed several times as has centrifugal methods for urine measurement. NASA Langley Laboratories have worked with the Lockheed device and achieved considerably higher relative accuracies for it than were first claimed and in addition have made analysis of the performance of a spring mass pendulum under various dynamic situations in spacecraft.

Biological Measurement of Man in Space: Final Report, Volume 2, M61-64-1-II· 3 Dec 1964, Lockheed Missiles and Space Company, pages 539, 540, and 541. M-61-64-2-3 Dec 64.