National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas
77058

NASA

Draft

Reply to Attn of: CB

January 19, 1994

TO: Distribution (See Below)

FROM: CB/W. Thornton

SUBJECT: Status of Development of Improved Mass Measurement Device

Background: A much smaller, simpler inflight MMD was proposed in which a known and unknown mass would be accelerated and the resulting forces compared to determine the unknown masses. Accuracy goals were ± .05% for rigid and ± 0.1% for human masses. A contract was let to LMSC with the goal of demonstration of feasibility using prototype and lab hardware. Plans and funds were included for an alternative method in event of unfeasibility of the initial method.

Efforts to date: Goals and technical approaches were established with the contractor and a computer simulation done (D.S.*) to verify some parameters and to look for potential sources of error. An unsuccessful search was made for available force and acceleration transducers. This was followed by design, construction and test of the combined force transducer package. Static tests, Appendix A, showed good performance.

When taken to the NASA precision air bearing for testing, a number of problems appeared in the test arrangement and the instrument. Problems in the air bearing included heavy, mechanically unstable 'sled's', surface irregularities and consumption of air at a rate which changed masses during a single measurement trial. Instrument problems included unmatched frequency responses of the transducers which with varying force from a commercial force generator induced significant errors.

While the method 'worked', without design and construction of a true constant force generator the method was limited to accuracies on the order of a pound

*(Damon Smith, Lockheed project engineer)

and without major revamping of the air bearing facilities it could not be tested to even these accuracies.

Since a constant or known force generator was now a requirement, the simplest form of mass measurement becomes application of Newton's Law, $M=F/A$, where a known force, F, is applied and acceleration, A, is measured and Mass, M, calculated. Accelerometers of adequate characteristics are still not available and calculation from motion will be required. In the past this had not been possible but D. S. demonstrated that by using a large number of displacement increments and a fast computer, it is possible and practical to mathematically curve fit to the requisite accuracy.

A rather crude demonstration arrangement using hardware store components including support of masses by a bicycle bearing plus a photo optical displacement transducer and desk top computer has shown that it is possible to reach the requisite accuracies. Appendix B.

Results; actual and expected: At this time sufficient funds remain to construct a passive force generator that is small enough for use on Shuttle and to test this in a one-g system with rigid masses.

It was originally planned to test the system on the NASA precision air bearing floor (equivalent to single plane weightlessness) and in the KC-135. Since the NASA air bearing is unsuitable, an adequate unit is needed to demonstrate weightlessness equivalent operation, especially human mass measurement. Design and construction of such a device was not in the scope of the original contract and would require additional funding.

At the end of testing with the air bearing it now appears it will be possible to design and build a locker contained mass measurement device that can measure solid mass in weightlessness in the range of 50-220 lbs. equivalent (lbe) mass to accuracies on the order of ± .05 lbe for rigid samples and ±0.15 lbe for non-rigid masses including human bodies. After testing with the above air bearing in one-g, a contract for the construction and test of a flight prototype will be required. It will be technically easier and more practical to test the device by DTO (one-two flights) rather than to try KC-135 flights for partial tests to be followed by DTOs.

Summary: A contract was initiated for development of an improved mass measurement device for research and operational use. While workable the original scheme ran into practical difficulties and by means of an innovative computer application a simpler method has been tested and found feasible. A one-g laboratory prototype should be completed and tested with solid masses under one-g conditions within the month. Results of this contract will fall short

of the original goal, which included zero-g testing, largely due to over optimism of the writer about NASA facilities and underestimation of contractor costs, however the major goal of a practical method of mass measurement suitable for Shuttle use will have been demonstrated in one-g. Delay in completion of the contract resulted from the air bearing problems and the writer's unavoidable absence.

To demonstrate single axis weightless equivalent operation an extension of the contract will be required to acquire a suitable air bearing. Following that design and construction of a flight prototype should be straight forward.

W. Thornton
William E. Thornton, M.D.
NASA Astronaut

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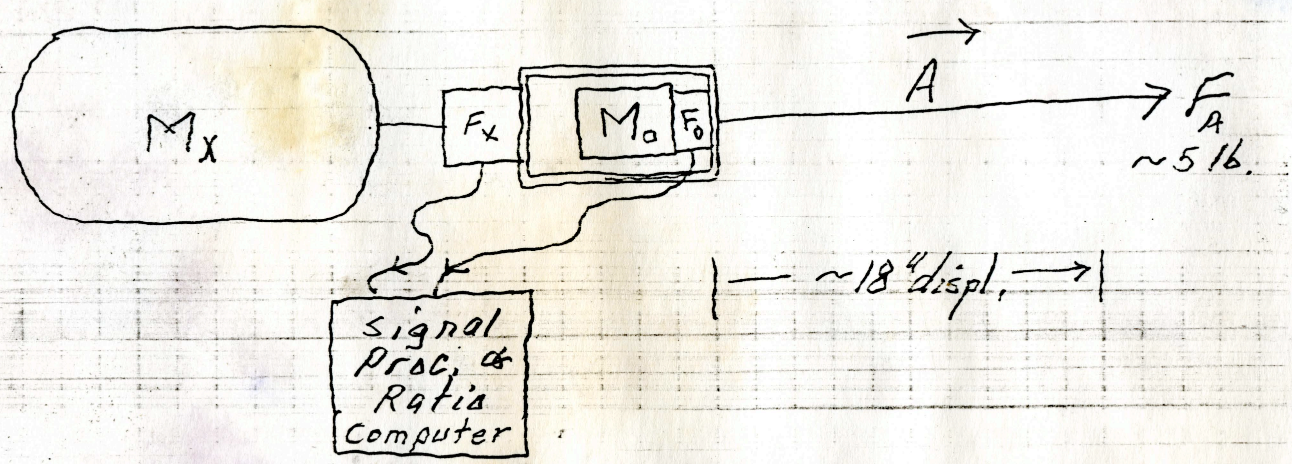
Johnson Space Center
CA/D. Leestma
CB/R. Gibson
SA/H. Schneider

Lockheed
D. Smith

Appendix A

Initial approach Fig. 1.



M_X = unknown mass
M_o = reference "
F_A = accelerating force
F_o = force on ref. mass
F_X = force " unk. "
A = acceleration of system

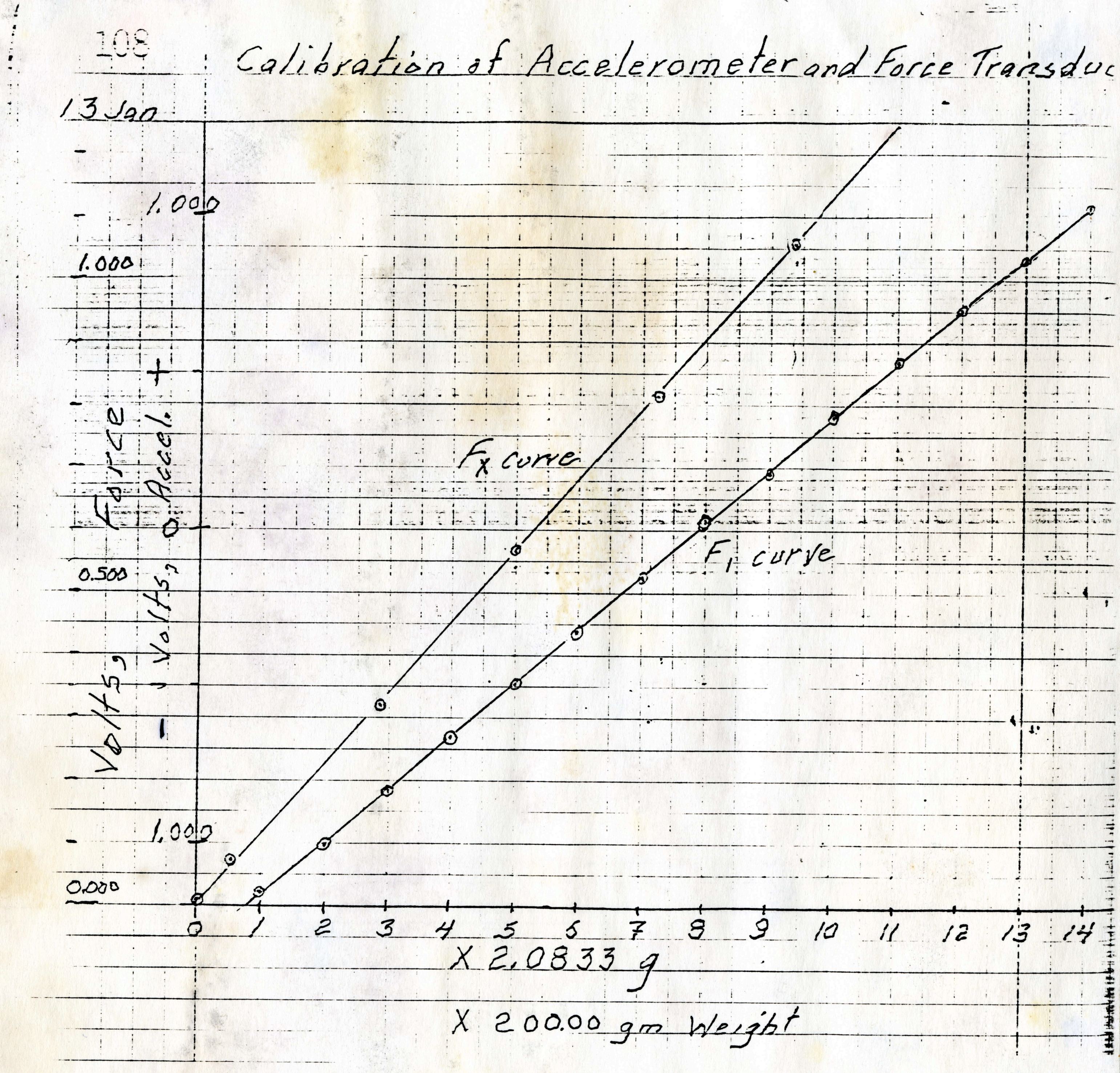
$F = MA$: $F_X/M_X = A = F_o/M_o$ and $M_X = F_X M_O/F_o$

A force F_a equally accelerates the system which may include a human body as M_X. Since M_O is constant and known, with ideal force transducers the unknown mass is simply determined from a ratio of known and unknown forces.

Characteristics of the transducers are shown Fig 2 however with a varying force their frequency characteristics had to be perfectly matched, an expensive and complex task.

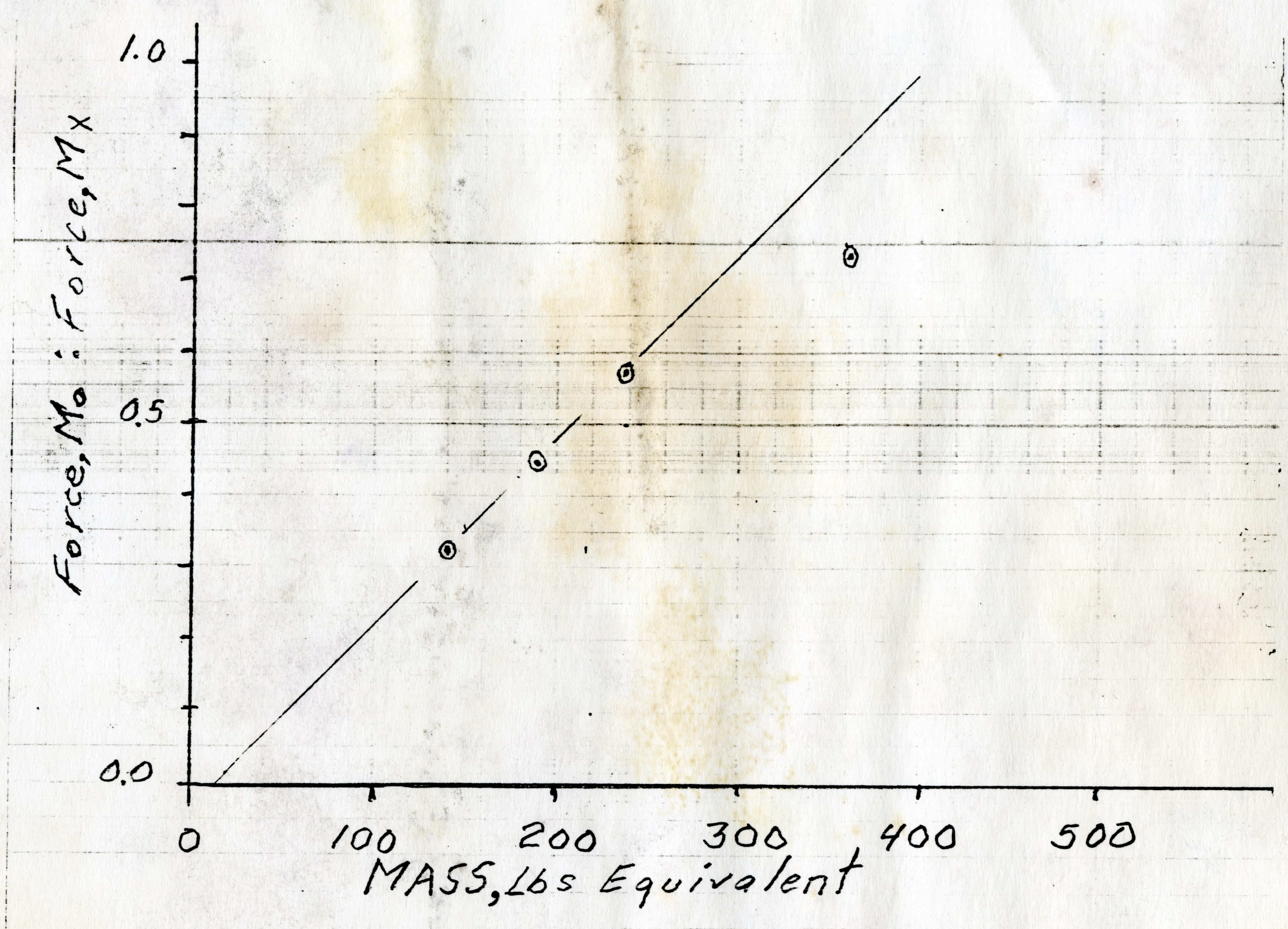
Appendix A

Fig. 2.



Appendix A

Fig. 2A



The above curve is best of method 1 results using solid masses and JSC 'precision' air bearing. Although method 'worked', scale is too small to show errors. Various test facility problems and instrument limits made these and especially human mass results unacceptable.

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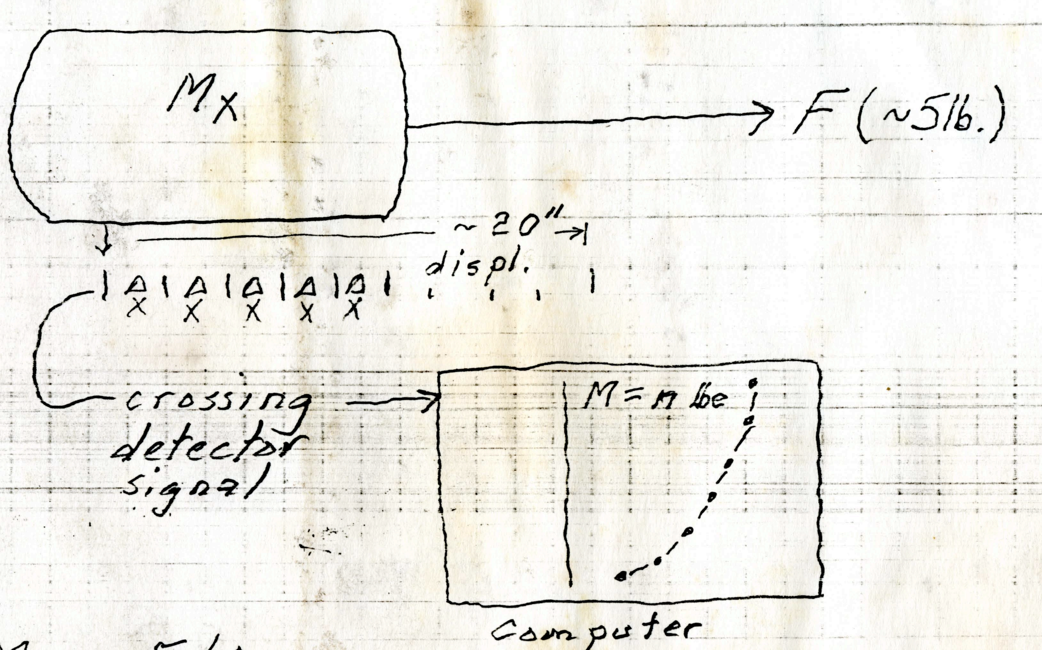
Appendix B

Second approach - Fig. 3.



$M_x = F/A$

T = Time

M_x = unknown mass

F = Known force

A is calculated, then M_x is calculated by a computer program.

In practice a known force accelerates the unknown mass past a series of known distance increments, ΔX. By timing these successive passages a computer program analytically fits a curve of the form $X = V_o T + \frac{1}{2}AT^2$, and calculates A and then Mx.

Results from a demonstration system using accurate weights and a precision displacement (ΔX) detector are shown in Fig. 4. While the errors are too small to be seen on the gravimetric vs. measured weight curve, an amplified error correction curve is shown and its slope variation plus S.D. are already within the error goal of $\pm$ .05 lb.

Appendix B

Fig. 4.