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SIMULATION OF PACKAGE TRANSFER CONCEPTS FOR SATURN I ORBITAL WORKSHOP

by Charles B. Nelson

George C. Marshall Space Flight Center
Huntsville, Ala.

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TABLE OF CONTENTS

	Page
SUMMARY	1
INTRODUCTION	1
SUMMARY OF SIMULATION METHODS EMPLOYED	2
PRELIMINARY SIMULATIONS	3
Rationale	3
Method	3
Results and Conclusions	5
Summary	6
PACKAGE MOMENT OF INERTIA SIMULATIONS	7
Rationale	7
Method	7
Results and Conclusions	10
PLANNED WORK	12

LIST OF ILLUSTRATIONS

Figure	Title	Page
1.	Orbital Workshop Package Transfer Route	2
2.	Test Equipment Installation in KC-135 Aircraft	4
3.	Transfer Technique	5
4.	Subject and Modified KC-135 Mock-Up	7
5.	Interchangeable Package Handles	8
6.	Subjective Rating Versus Moment of Inertia	11

LIST OF TABLES

Table	Title	Page
I.	Moments of Inertia of the Packages	9
II.	Moment-of-Inertia Limits	12

SIMULATION OF PACKAGE TRANSFER CONCEPTS FOR SATURN I ORBITAL WORKSHOP

SUMMARY

The objective of this program was to investigate the problem of manually transferring massive packages in a zero-g environment with no mechanical aids except a handrail.

INTRODUCTION

The Saturn I Orbital Workshop's (OWS) experiment packages will be stowed in the Multiple Docking Adapter (MDA) during launch. To activate the OWS, these packages must be transferred from the MDA through the Structural Transition Section (STS), the Airlock Module (AM), and a portion of the S-IVB stage LH_2 tank into the crew quarters area of the stage (Fig. 1). Initial design of the OWS provided only a single handrail (fireman's pole) to assist the astronaut in translation and in transfer of the packages. The fireman's pole extended from the S-IVB stage LH_2 tank entry hatch through the crew quarters ceiling hatch and into the crew quarters.

A preliminary task analysis revealed several critical areas requiring simulation and further study to assure successful performance of the transferral task:

a. The effectiveness of a fireman's pole as a translation aid needed verification.

b. Limitations relative to package mass and configuration had to be established.

c. Effectiveness of package handholds (design and location) required investigation.

d. A basic technique of man/package transfer had to be developed.

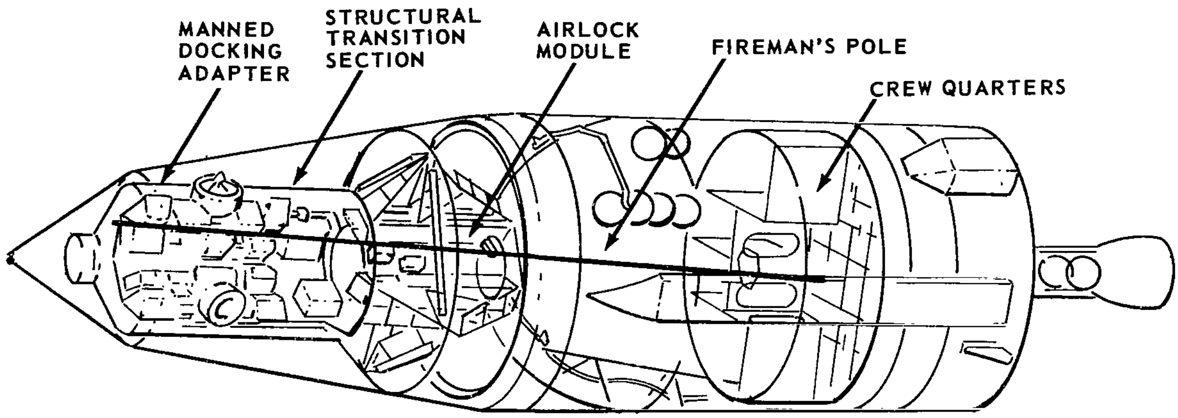


FIGURE 1. ORBITAL WORKSHOP PACKAGE TRANSFER ROUTE

SUMMARY OF SIMULATION METHODS EMPLOYED

To accomplish the tasks listed above, a preliminary simulation program utilizing a six-degree-of-freedom simulator and the KC-135 zero-g aircraft was developed. Techniques, conclusions, etc., that were established using the six-degree-of-freedom simulator were verified aboard the KC-135 aircraft.

Data obtained from the preliminary program were sufficient to verify the effectiveness of the fireman's pole as a translation aid, to determine handhold design and location, and to establish a basic man/package transfer technique. Only gross limitations of package mass and configuration could be established from these tests, however.

Analysis and correlation of data from the above simulations indicated that the most important single characteristic of a package which affects its maneuverability is the package moment of inertia about its handle. For this reason, an additional neutral buoyancy/KC-135 zero-g program was designed to obtain data on ease of handling for a wide range of package masses and moments of inertia and to determine the limiting moment beyond which control of the package cannot be maintained.

PRELIMINARY SIMULATIONS

Rationale

This phase of the study was designed as a general investigation of the problem of manual translation and package transfer for the purpose of supporting the OWS design. Objectives included developing a basic transfer technique, determining the adequacy of the fireman's pole design, investigating the necessity of tethers and mobility aids, and determining package size and weight limitations. Developmental work for this phase was conducted using a negator spring six-degree-of-freedom simulator at Marshall Space Flight Center (MSFC). Results were verified under zero-g conditions in the KC-135 aircraft during approximately 150 parabolas.

Method

Subjects. A total of three MSFC test subjects, each equivalent to an astronaut in size and physical condition, participated. One of the three took part in both the six-degree-of-freedom simulator and the KC-135 work. Additionally, four members of the Manned Spacecraft Center (MSC) flight crew participated briefly in the KC-135 tests. All subjects dressed and worked in shirtsleeves.

Apparatus. Apparatus for both the six-degree-of-freedom and the KC-135 simulations were made similar to provide consistency between the tests. As a result of stress requirements, however, the KC-135 mock-ups were considerably sturdier. The test setup included two 1.02-m (40-in.) diameter hatches separated by a distance of approximately 6.1 m (20 ft) and connected by a handrail (fireman's pole) of elliptical cross section 3.18 by 4.45 cm (1.25 in. by 1.75 in.). Entrance to one of the hatches was enclosed by a "cage" approximately 1.5 m (5 ft) in diameter and 1.2 m (4 ft) long to provide an envelope similar to that of the aft compartment of the AM (Fig. 2). Three packages were employed for each simulation:

Package #1, 0.305 m by 0.305 m by 0.61 m box on a 0.51 m by 0.76 m pallet (12 in. by 12 in. by 24 in. box on a 20 in. by 30 in. pallet).

Package #2, 0.38-m diameter by 0.66-m cylinder on a 0.51 m by 0.76 m pallet (15 in. diameter by 26 in. cylinder on a 20 in. by 30 in. pallet)

Package #3, 0.51 m by 0.76 m by 1.02 m box on a 0.76 m by 1.02 m pallet (20 in. by 30 in. by 40 in. box on a 30 in. by 40 in. pallet).

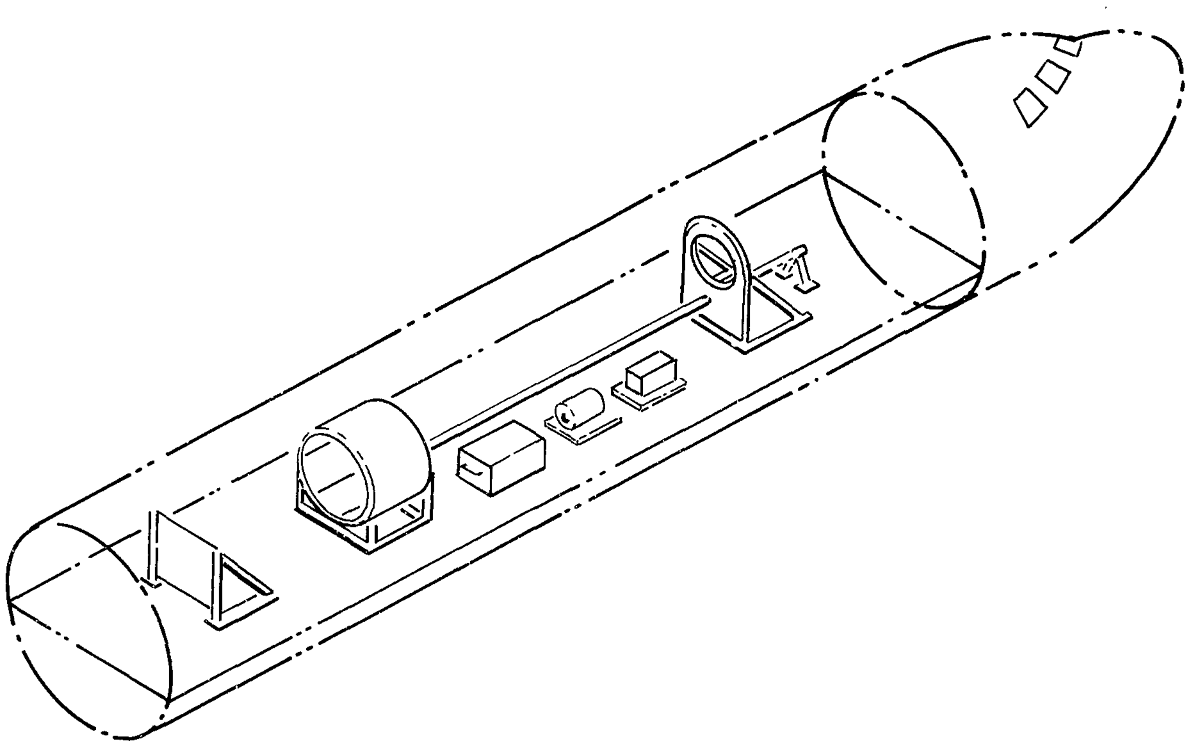


FIGURE 2. TEST EQUIPMENT INSTALLATION IN KC-135 AIRCRAFT

During the six-degree-of-freedom simulations, helium-filled balloons were attached to the packages to approximate weightlessness. For the KC-135 tests, the packages were weighted to provide the following masses:

Package #1, 27.2 kg (60 lb)

Package #2, 36.3 kg (80 lb)

Package #3, 68.0 kg (150 lb)

Tethers, tether rings, temporary storage hooks and other auxiliary equipment were similar between test setups. Still and motion picture cameras were used for data collection.

Procedure. In each simulation, the subject initially transversed the pole empty-handed to become acquainted with the equipment and to determine a basic translation technique. Afterwards, for each iteration, the subject transferred one package on a "round trip" through both hatches and along the length of the fireman's pole.

Results and Conclusions

Transfer technique. The preferred method of translation, developed in the six-degree-of-freedom simulator and verified aboard the KC-135, is illustrated in Figure 3. Major considerations of the subject's method of translation are as follows:

(1) Grasp fireman's pole in one hand

(2) Grasp package in other hand

(3) Push package in front of subject for optimum guidance and control

(4) Lock feet lightly around pole for directional stability (NOTE: This suggests that translation under suited conditions will be much more difficult than in shirtsleeves. Also, in the KC-135 the subject's legs tended to involuntarily come unlocked and float apart, which resulted in a loss of directional stability.)

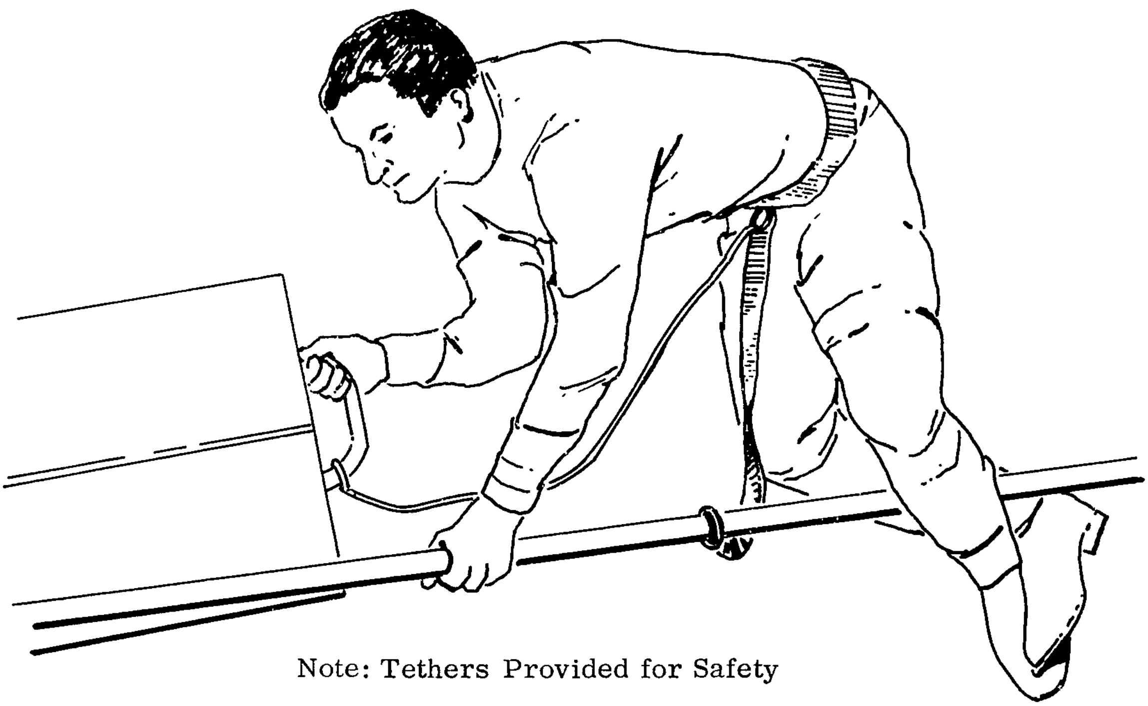

Note: Tethers Provided for Safety

FIGURE 3. TRANSFER TECHNIQUE

Handrail design. The cross section of the fireman's pole was a 3.18 by 4.45 cm (1.25 in. by 1.75 in.) ellipse. This proved to be a definite advantage in preventing rotation around the pole and is the recommended configuration.

Tethers. Tethers for connecting man to package, man to handrail, or package to handrail are not required except as a safety measure.

Package handhold design and location. Handholds should be located on the package in such a manner that, as the package is "pushed" in front of the subject, the force exerted against the handle passes directly through the package's center of mass. Generally, this would mean locating the handle at the center of the package side directly in front of the subject. A contoured pistol grip handle configuration is recommended for adequate control of the package in both pitch, roll, and yaw.

Package mass limitations. Subjects were able to safely and accurately transfer the 27.2 kg (60 lbm) and the 36.3 kg (80 lbm) packages. The 68.0 kg (150 lbm) box, however, was too massive to be handled safely by one man within a desirable time. Subjects suggested that approximately 41 to 45 kg (90 to 100 lbm) appears to be a reasonable maximum for one man to manually transfer, provided the package center of mass is not more than 0.36 to 0.41 m (14 to 16 in.) from the handhold.

Package size limitations. So that visibility should not be obstructed, the side of the package directly in front of the subject's face should be limited to no more than 0.51 to 0.64 m (20 in. by 25 in.). Package length may vary, but the resultant moment of inertia should remain within those limits established by the second phase of this study. (Approximately 2.8 N-m-sec^2 or 250 in-lbf-sec^2 max.)

Summary

Most of the objectives of this phase of the study were accomplished. As stated previously, however, it was discovered that package maneuverability is not a function of either package mass or package size but is a combination of both parameters. Thus the hypothesis was formed that the greater the moment of inertia of the package the more difficult its translation and/or maneuverability. Additional testing was suggested to test this hypothesis and to establish a maximum allowable moment about the handle.

PACKAGE MOMENT OF INERTIA SIMULATIONS

Rationale

The purpose of this portion of the simulation program was to explore and refine results of the preliminary tests by investigating package maneuverability in terms of the package moment of inertia about its handle. Data were obtained using both a neutral buoyancy simulator and the KC-135 during 77 parabolas.

Method

Subjects. A total of five MSFC test subjects participated in these tests, three in the neutral buoyancy simulator and two in the KC-135. Each subject was equivalent to an astronaut in size and physical condition, and the neutral buoyancy subjects were qualified Scuba divers. One of the KC-135 subjects had participated in the earlier KC-135 tests. Neutral buoyancy subjects operated in Scuba equipment and KC-135 subjects in shirt sleeves.

Apparatus. Test equipment setup for each simulation mode basically consisted of a fireman's pole and a package "receptacle" arranged in such a manner that the package had to be transferred along the pole and maneuvered into the receptacle. Clearance between the inside of the receptacle and the exterior of the packages was approximately 2. 5 to 5. 1 cm (1 to 2 in.). KC-135 mock-ups used in the earlier phase of the study were modified to include an extension to the handrail and the receptacle mounted on the simulated airlock. This required the subject to turn the package through a full 180 degrees just prior to insertion into the receiver (Fig. 4).

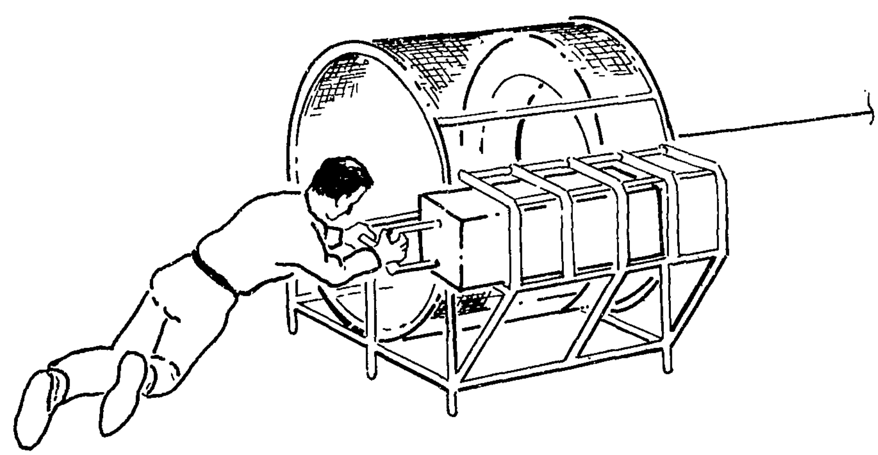


FIGURE 4. SUBJECT AND MODIFIED KC-135 MOCK-UP

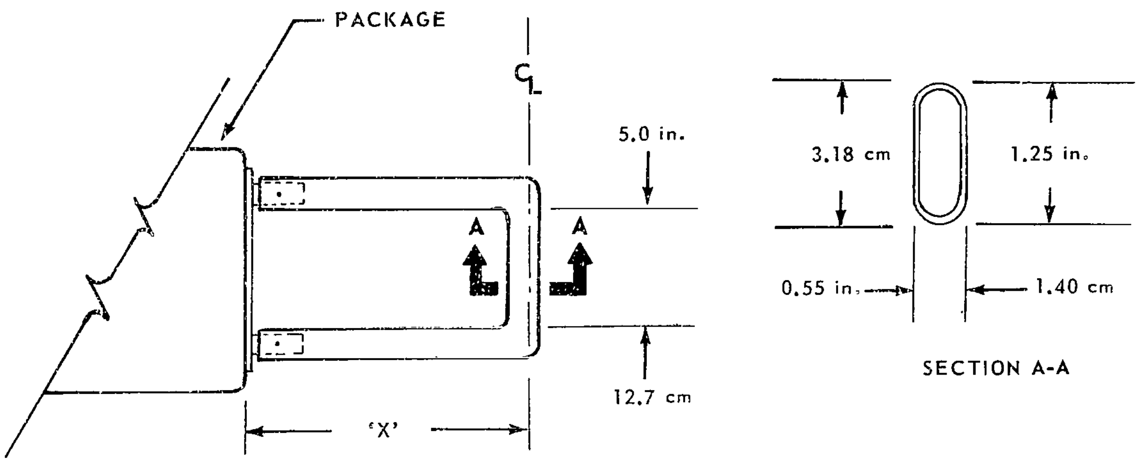
Neutral buoyancy packages used were of the following configurations:

Package #1, 0.25 m by 0.25 m by 0.51 m, 31.7 kg, moment of inertia about handle = 4.63 N-m-sec^2 (10 in. by 10 in. by 20 in., 70 lbm, moment of inertia about handle = 41 in.-lbf-sec^2)

Package #2, 0.25 m by 0.25 m by 0.76 m, 49.8 kg, moment of inertia about handle = 15.5 N-m-sec^2 (10 in. by 10 in. by 30 in., 110 lbm, moment of inertia about handle = 137 in.-lbf-sec^2)

Package #3, 0.25 m by 0.25 m by 1.02 m, 63.5 kg, moment of inertia about handle = 34.5 N-m-sec^2 (10 in. by 10 in. by 40 in., 140 lbm, moment of inertia about handle = 306 in.-lbf-sec^2)

Each neutral buoyancy package was modified to receive each of five interchangeable handles of different "grip area to mounting surface" lengths (Fig. 5). This enabled the packages to be rapidly modified to vary the moment of inertia while maintaining the same mass. Table I summarizes the combinations which could be achieved.



LENGTH 'X' (CENTIMETERS)	LENGTH 'X' (INCHES)
A = 7.62	A = 3
B = 15.24	B = 6
C = 25.40	C = 10
D = 40.64	D = 16
E = 60.96	E = 24

FIGURE 5. INTERCHANGEABLE PACKAGE HANDLES

TABLE I(A). MOMENTS OF INERTIA OF THE PACKAGES

Package Size (meters)	Handle Length / Package Mass	Package's Moment of Inertia (N-m-sec^2)				
		0.076 m	0.152 m	0.254 m	0.406 m	0.610 m
0.25 × 0.25 × 0.51	31.7 kg	0.396	0.576	0.870	1.44	2.42
0.25 × 0.25 × 0.76	49.8 kg	1.47	1.83	2.43	3.51	5.31
0.25 × 0.25 × 1.02	63.5 kg	3.01	3.57	4.52	6.15	8.75

Moment of inertia = $I_0^* + \frac{MK^2}{g}$, where I_0^* is determined empirically on an air bearing table and K is the radius of gyration. (I_0 = moment about center of mass.)

TABLE I(B). MOMENTS OF INERTIA OF THE PACKAGES

Package Size (inches)	Handle Length / Package Mass	Package's Moment of Inertia (in.-lbf-sec^2)				
		3 in.	6 in.	10 in.	16 in.	24 in.
10 × 10 × 20	70 lb	35	51	77	127	214
10 × 10 × 30	110 lb	130	162	215	311	470
10 × 10 × 40	140 lb	266	318	400	545	775

Moment of inertia = $I_0^* + \frac{MK^2}{12g}$, where I_0^* is determined empirically on an air bearing table and K is the radius of gyration.

Procedure. In each simulator the subjects were allowed two practice runs to familiarize themselves with the equipment and the transfer technique. Afterwards each iteration required the subject to translate approximately 3 m (10 ft) of the fireman's pole, and insert the package into the receptacle. On the KC-135 this included maneuvering through the simulated airlock and guiding the package through the 180 degree turn.

Data. Data recorded included movies, time required to complete each task, and subjective evaluation of each iteration. The subjective evaluation was based on a five point rating scale:

1. . . Excellent
2. . . Good
3. . . Fair - some reservations
4. . . Poor - many reservations
5. . . Unacceptable

Results and Conclusions

This phase of the testing program verified that a combination of the package parameters size and mass (moment of inertia) is a very significant factor affecting package maneuverability. Average subjective ratings for the various moments investigated are plotted in Figure 6. This plot assumes a reasonable package configuration for adequate vision and a reasonable amount of time within which to complete a transfer operation. (With unlimited time restraints and with a package of small dimensions, the upper limit on package mass would be considerably higher.) The moment-of inertia limits presented in Table II were derived from the data plotted in Figure 6. These limits suggest that a package with a moment of inertia less than 0.735 N-m-sec^2 (65 in.-lbf-sec^2) can be easily maneuvered and precisely positioned under zero-g conditions. If the requirement exists to transfer a package through a large open area where few positioning constraints exist, approximately 2.8 to 3.4 N-m-sec^2 (250 to 300 in.-lbf-sec^2) can be tolerated. A value of 3.4 to 4.0 N-m-sec^2 (300 to 350 in.-lbf-sec^2) appears to be an upper limit for one man to transfer within a reasonable time frame.

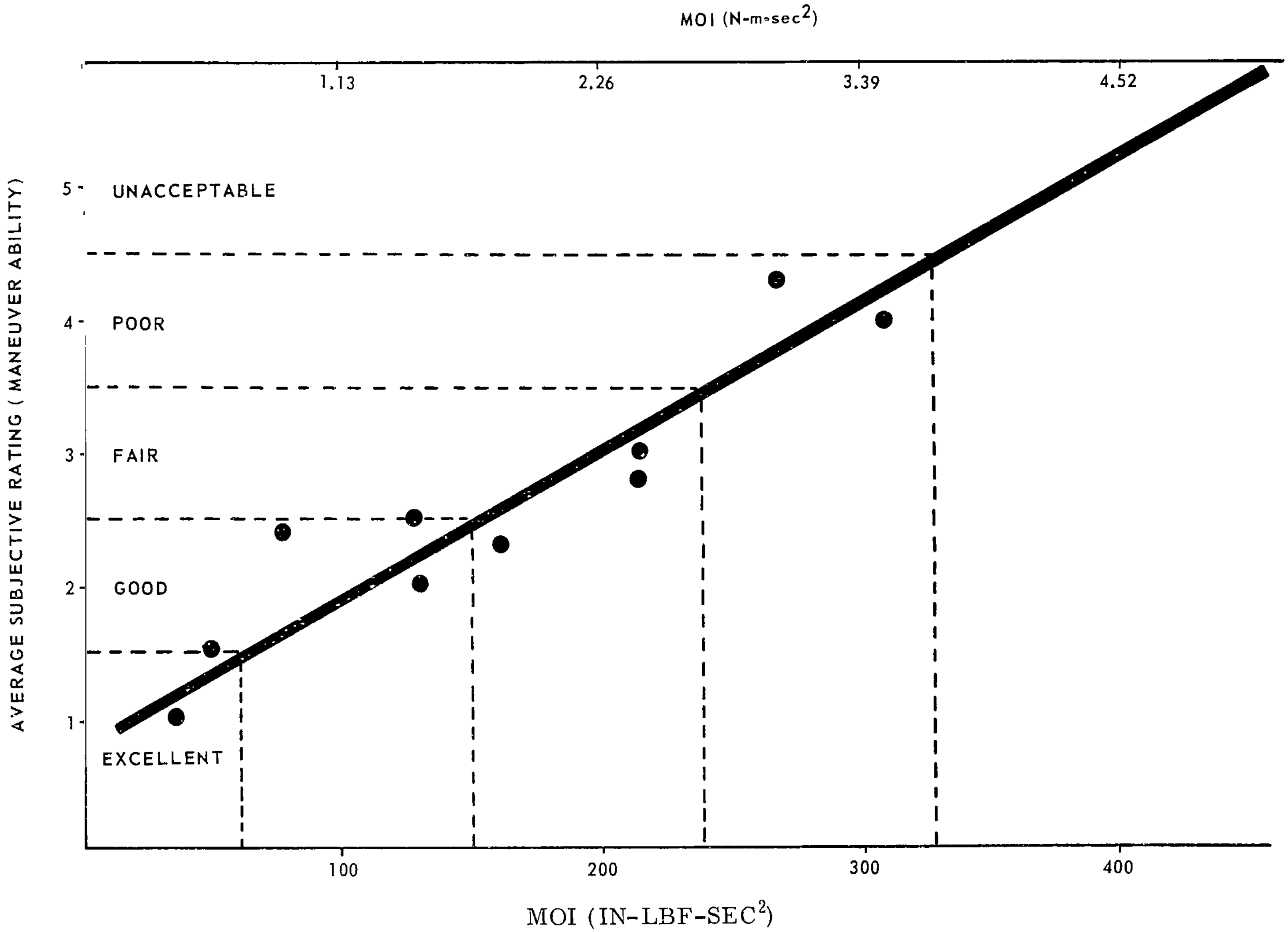


FIGURE 6. SUBJECTIVE RATING VERSUS MOMENT OF INERTIA

TABLE II. MOMENT-OF-INERTIA LIMITS

Maneuverability	Moments of Inertia ($in.-lbf-sec^2$)	Moments of Inertia ($N-m-sec^2$)
Excellent	0 - 65	0 - 0.735
Good	66 - 150	0.745 - 1.70
Fair	151 - 240	1.71 - 2.71
Poor	241 - 330	2.72 - 3.73
Unacceptable	331 →	3.74 →

PLANNED WORK

Experiments conducted to date have provided significant data on man's ability to transfer massive packages in a zero-g environment. However, many additional tests, as well as experience gained from actual extra-vehicular activity/intra-vehicular activity, are required before a reasonable degree of confidence can be attached to results obtained. Planned experimental work at MSFC includes the following:

a. An investigation to determine maneuverability of a very heavy (approximately 136 to 227 kg, or 300 to 500 lbm) package with its handle at the center of mass.

b. More work to validate the recommended pistol grip handle configuration.

c. A study to determine the upper limits of moments of inertia about each of the pitch, roll, and yaw axes.

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