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SOME MOTION CHARACTERISTICS OF TETHERED FREE-FLOATING
WORKERS

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INTRODUCTION

The purpose of this study was to describe in preliminary fashion, the freedom of movement of a free-floating and weightless operator who is tethered to a spacecraft. The intent is to determine in what manner a lifeline limits his six degrees of motion freedom and if limitations do exist to suggest schemes by which man can be tethered with minimum restrictions. The operator's motion behavior as he soars along a tether stretched between two weightless masses is also described. Orbital motions of the two bodies, tether physical characteristics and harness attachments on the operator are not considered.

SECTION I THE RESTRICTIONS IMPOSED ON A WEIGHTLESS MAN BY A TETHER ¹

Alone in a weightless environment, with no solid structure or fluid substance near him, man is practically helpless to achieve significant translations (ref. 4). To perform a task in space away from his spacecraft, man must be supplied with a means of propulsion and stability. This study assumes that an operator with a rocket powered backpack or self-maneuvering unit is capable of all six degrees of freedom of a solid body, namely rotation about and translation along each of three mutually perpendicular axes (ref. 1). A second assumption is that the man is a rigid body such that there are no additional degrees of freedom of concern in this analysis. This analysis is also restricted to geometrical considerations; no action-reaction effects on the man or tether due to motion of either were considered.

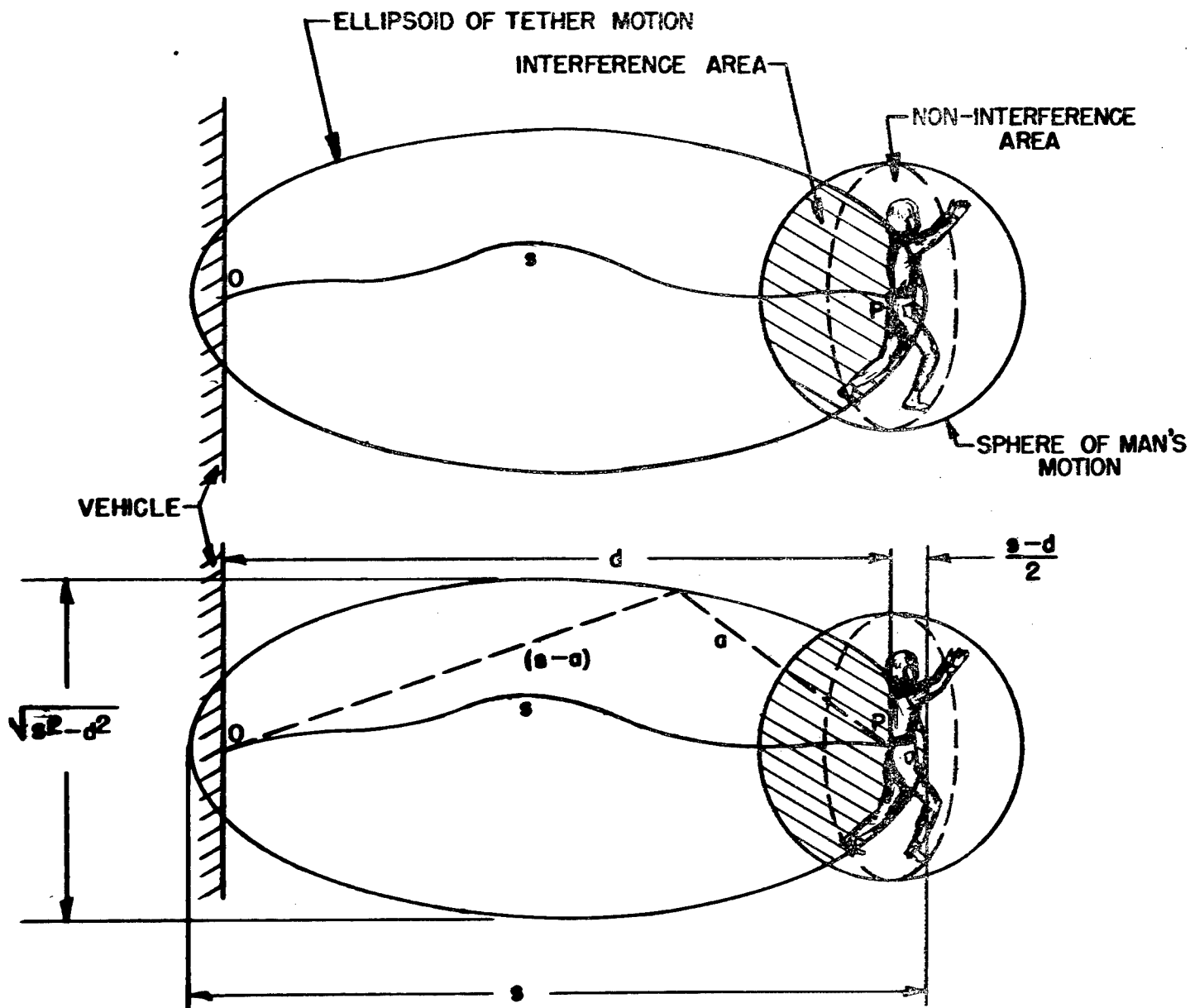
Two tethering configurations will be considered, one in which the man is physically separated from the spacecraft, and the other in which the man is in contact with the outside surface of the vehicle.

Man Separated from the Vehicle

The first configuration is defined in two dimensional terms in Figure 1 in which point O is the point of attachment of the tether to the spacecraft, P is the other end of the tether, s is the actual length of the tether, d is the distance between O and P. If d is less than s, there is slack in the tether, and the locus of all points representing the maximum distance from O and P where the tether may be found is an ellipse. The length of the major axis of the ellipse is s, the minor axis is $s^2 - d^2$, with the foci at O and P. In three dimensional terms, the ellipse becomes an ellipsoid of revolution.

If a rigid body is attached to the tether at P, see Figure 2, with coordinate axes as shown, so long as there is sufficient slack and assuming relatively small rotations (on the order of 90° or less), then the body has unrestricted capability of movement in all six degrees of freedom (Fig. 2). However, from the practical standpoint, if several revolutions about the X or Z axes were made, it is probable that entanglement would result. If the body could position the tether prior to rotation to a point, P', on the axis of rotation, as shown in Figure 3, then unrestricted rotation would be

¹ This section is based upon the report titled, "The Restriction Imposed on a Weightless Man by a Tether", U. D. Memo No. 146, University of Dayton Research Institute, Dayton, Ohio, Mar 1961.



LEGEND:

s = LENGTH OF TETHER LINE

P = POSITION OF MAN

FIGURE 1 Definition of Terms

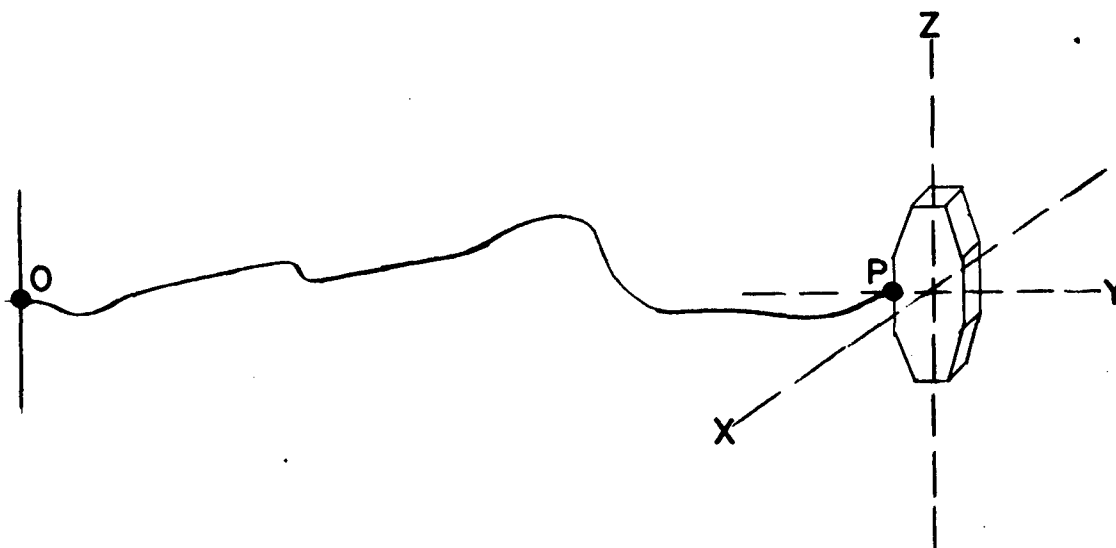


FIGURE 2 Rigid Body Attached to Tether

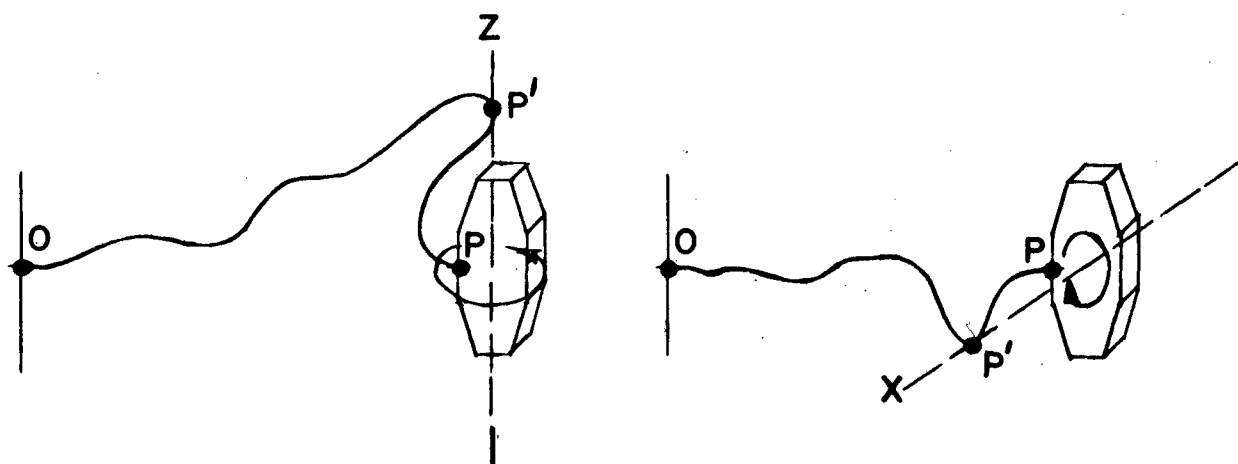


FIGURE 3 Ideal Tether Positions for Unrestricted Rotations

available without fear of entanglement. When the tether is moved to an ideal location prior to rotation, the geometry of the ellipsoid of all possible tether positions is changed to a more favorable form as shown in Figure 4.

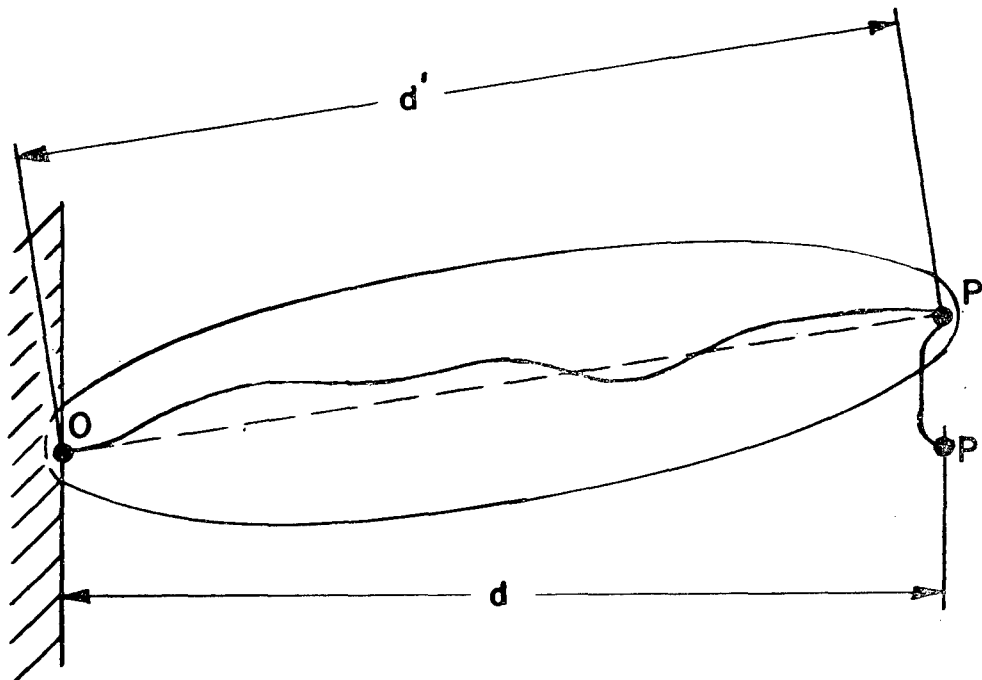


FIGURE 4 Altered Geometry of the Ellipse

Since the free length of the tether has been decreased, the new ellipsoid, with foci at O and P', will be shorter and narrower with consequent reduction of the entanglement problem, but only during the time the tether is held at P'.

A body tied to a spacecraft by a slack tether can move in any direction, limited only by the amount of slack, and can rotate about any axis without limitations providing the tether is moved to a point on the intended axis of rotation. The ellipsoid of all possible tether positions does extend beyond the point of attachment P and would, with a nominal amount of slack encircle the body. It is possible that the tether, placed into motion by some slight outside force, could wrap around the body even if the body were at rest. This suggests the concept of separating the point of attachment and the body.

If the tether were attached to the surface of a sphere, and the body were inside the sphere and free to move within it, the body would enjoy unrestricted rotations, and translations would be limited only by the size of the sphere and the amount of slack, and the hazards of entanglement would be minimized. However, anticipating objections as to the practicality of this scheme, a variation of the idea would use a belt-shaped platform and a rigid pole. If the stable platform could be built in the form of a ring, the man could wear this ring like a belt (see Fig. 5). To be stable about the Z axis the man would be fastened, by means

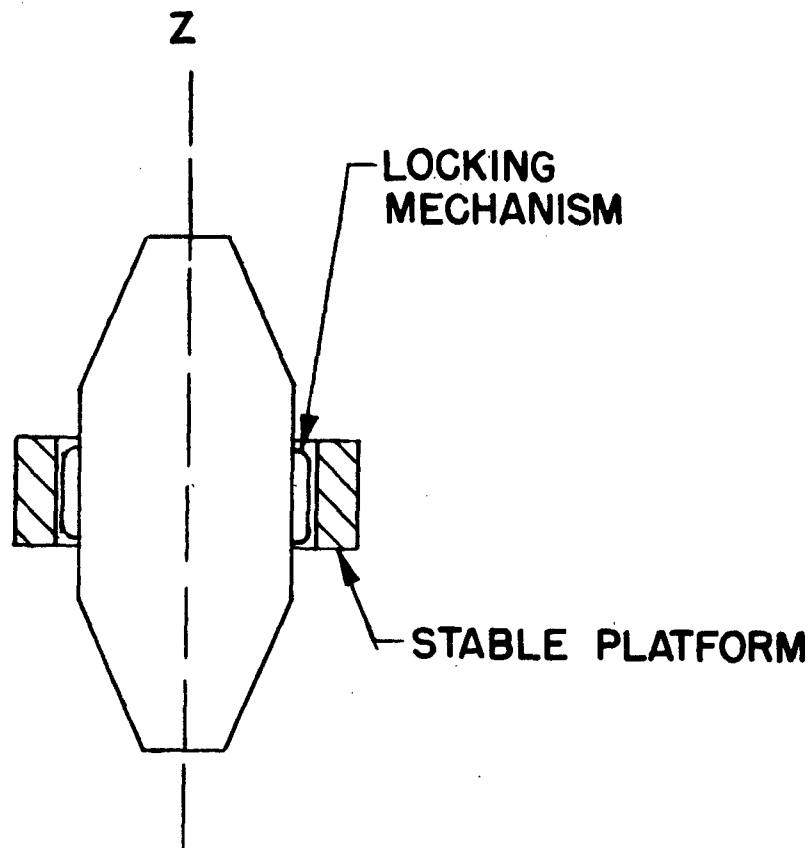


FIGURE 5 Concept of Ring-Shaped Stable Platform

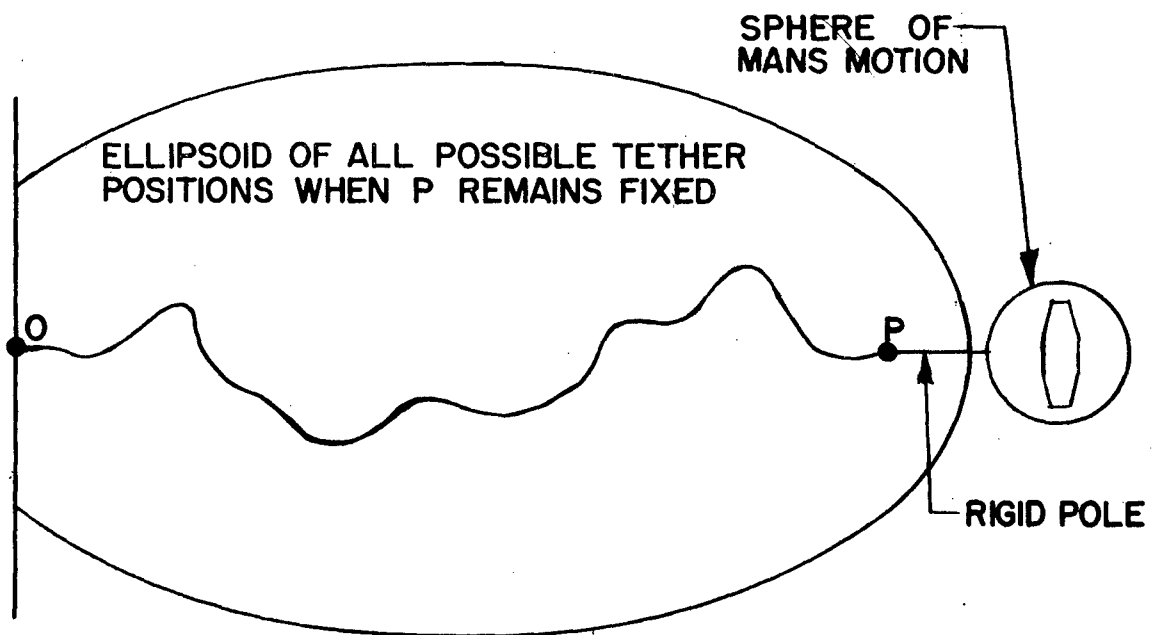


FIGURE 6 Flexible Tether With Rigid Pole

of a locking mechanism, to the platform. To rotate about the Z axis, the attachment would be unlocked, the rotation affected, and the lock resecured. To achieve rotations about axes other than Z, the stable platform itself must be rotated by some control system. If the platform were stabilized by gyros, the system could be controlled by the application of torques to effect gyro precessions. The platform could be connected to the tether by means of a rigid pole, the objective being to keep the tether sufficiently far from the body to avoid entanglement. As shown in Figure 6, if the point of attachment of the tether, P, is removed from the body by a rigid pole of sufficient length, the ellipsoid of all possible tether positions no longer encircles the body and entanglement is impossible. If the volume of space in which the body might be found during rotational movements is defined as the sphere of influence of the body, and if a separation of the ellipsoid and the sphere can be maintained without overlapping of the two volumes, then complete freedom from entanglement is insured. For an appreciation of the dimensions being discussed, Figure 6 was drawn to scale such that $d = 50$ ft, $s = 60$ ft, the sphere of influence is 8 ft in diameter, and the length of the rigid pole from P to the center of the body is 10 ft.

To achieve this objective of continuous separation of the ellipsoid and the sphere, the design shown in Figure 7 is suggested. The pole is attached to the platform so that it extends radially outward from the cylindrically-shaped platform and is free to move around the cylinder on a track device. For rotation about the Z axis the man would move inside the platform as previously discussed. For rotation about the X axis, with the pole position as shown in Figure 7, no difficulty should be encountered. For rotation about the Y axis, the pole could be moved around the cylinder on the track to a position along the Y axis, then rotation could be accomplished without difficulty. The movement of the pole on the track could be accomplished by the man, prior to his rotating the platform, but this necessitates that the man be aware of the pole position every time before he moves the platform controls. The scheme could be made automatic by providing a servomechanism to move the pole and by interlocking the position of the pole and the controls that rotate the platform. If the man desired to rotate the platform and operated the control system to achieve this, and if the pole were in the proper position, the platform would rotate. If the pole were not in the proper position, the interlock would not allow the rotation to start, but the servomechanism would move the pole to the proper position which action would close the interlock circuit thereby allowing the platform to rotate. In this manner, the man can forget about the tether and as long as a suitable relationship between the amount of slack and the length of the pole is maintained, no entanglement should occur and therefore no restrictions on motion are imposed.

All or part of the flexible tether might be developed from a small-diameter, thin plastic tube which would become semi-rigid if inflated with a gas under pressure. The "rigid pole" might be such a device with the application and release of the rigidizing gas under the control of the tethered man.

One basic assumption in the analysis is that the slack in the tether is controlled to be a reasonable amount by some mechanical means. A spring-loaded reel would insure no slack but the tension in the tether would pull the man back to the spacecraft. An automatic device could be built to sense the straightline distance to the man and to maintain the length of the line accordingly. A simpler approach could be to have a man inside the spacecraft monitor the actions of the tethered man and manually vary the line length as required.

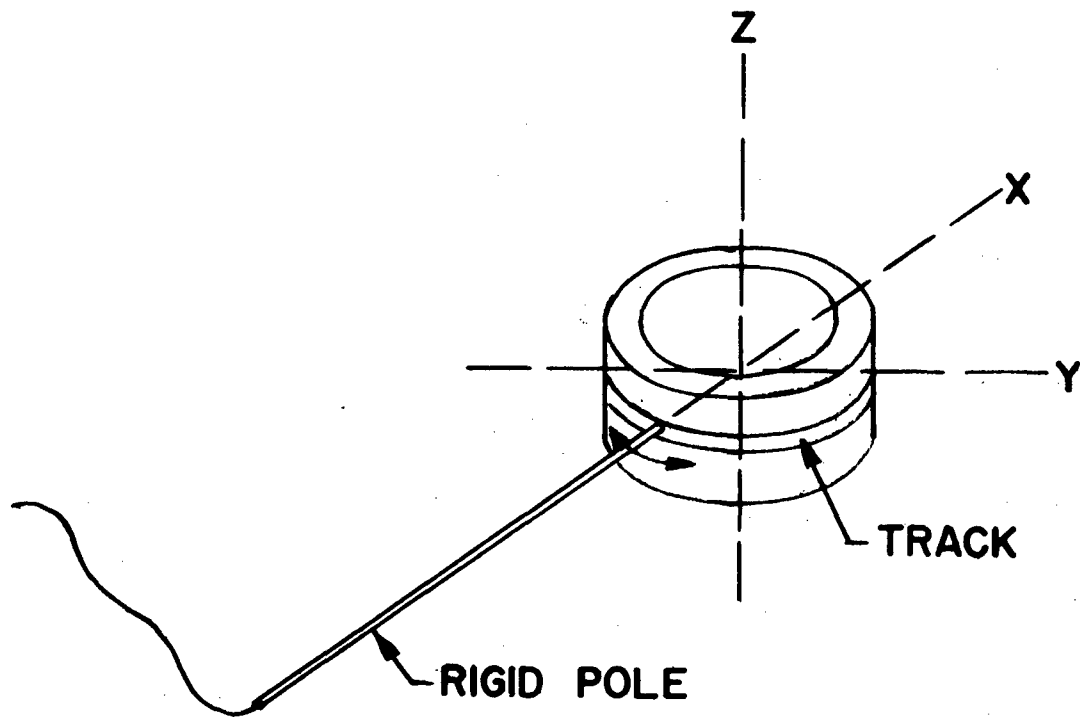


FIGURE 7 Attachment of Rigid Pole to Stable Platform

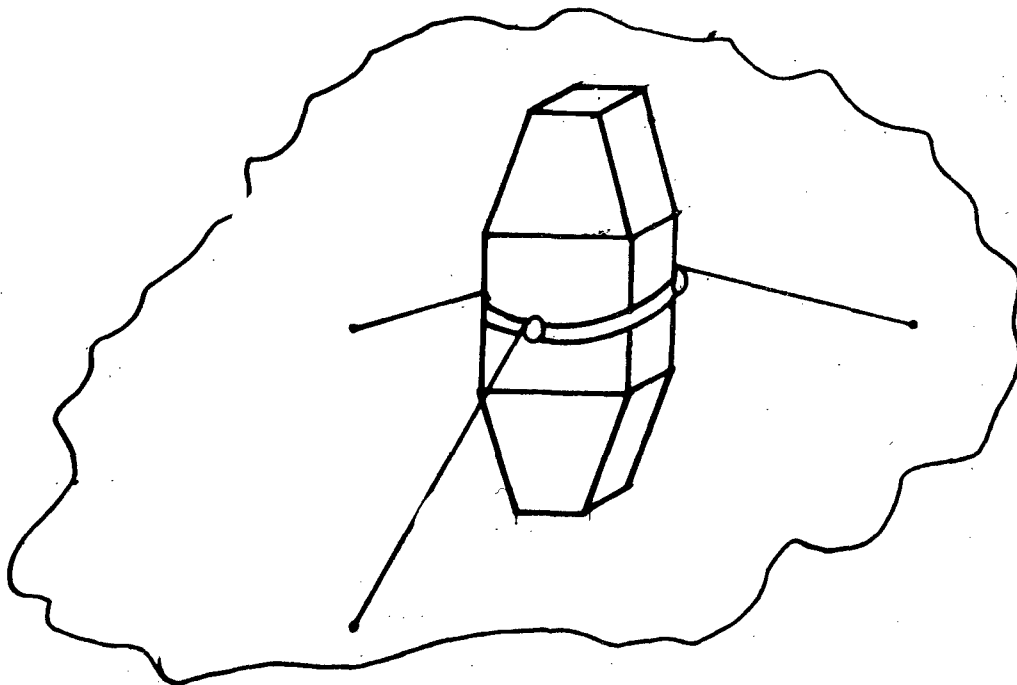


FIGURE 8 Tie Down Tether Technique

Man on Outside Surface of Vehicle

For a task involving limited amounts of movement in the immediate vicinity of one portion of the outside surface of the spacecraft, a springloaded tiedown technique could be employed. As sketched in Figure 8, the man would wear a "belt within a belt", in which he could twist. To the belt, at perhaps three places, would be attached lines which would also be secured to the surface of the spacecraft. Tension in the lines would be maintained by a spring-loaded reel device at the belt end of each line. If the line tensions were equal, the only force on the man would be toward the spacecraft which he could oppose by standing or kneeling on the surface. Motion away from the surface would be limited by the standing height of the man. Motion in a direction parallel to the surface would be limited somewhat since any displacement away from the zero point would cause unequal tension in the lines and this net force would have to be overcome by the man through friction with the surface and the torque overcome by spreading the feet. Rotational movements about any axis other than that perpendicular to the surface would be limited to a few degrees, again because unequal tensions would result and would be difficult to overcome. Within the limitations discussed, the tiedown scheme may constitute a very simple and effective means of tethering a man in a gravity-free environment.

SECTION II THE MOTIONS OF A WEIGHTLESS MAN ALONG A TETHER

Motion along a lifeline strung within a large spacecraft or between stabilized vehicles could offer the worker guided trajectories. This motion behavior was briefly studied in the weightless aircraft facility at Aeronautical Systems Division (ref. 2).

A nylon parachute cord was tightly stretched 40 feet between tiedowns in the KC-135 cabin. Three subjects soared along the tether grasping a 3-inch ring handhold (Fig. 9) and later trials included a short 30-inch tether tied from various body points to the ring.

Using hand and foot launches, the subjects easily maintained position control by using the free hand or hands as braking agents by grasping the life line*. Body attitude was erratic and somewhat uncontrolled and single-impulse foot launches resulted in higher velocities but poorer attitude control as the workers torso tended to rotate ahead of the moving handhold.

Figure 10 shows a single soar (L to R) as the subject completed one revolution around the tether. Attitude control was more stable as the number of body to ring attachment points increased, as the short tether was shortened and as two or more body attachment points were symmetrically separated from the body center of mass.

Deceleration could probably be handled with a hand-grasped friction clutch built within the ring mechanism and a hands-free motion capability might best be achieved by attaching a short one-foot tether from the operators shoulder to the ring. The single short shoulder tether will not limit attitude oscillations but will keep the operator in reaching distance of the long line and still allow almost unlimited torso-to-line alignment for various tasks.

* The author has thrown a ball above the subject to judge the Coriolis effects on soaring subjects in a rotating aircraft; forward moving masses tend to move toward the ceiling (ref. 3). The comparative mass (ball) is used to identify motions of the subject from motions of the aircraft around the subject.



FIGURE 9 Soaring Along Tether with Ring Handhold

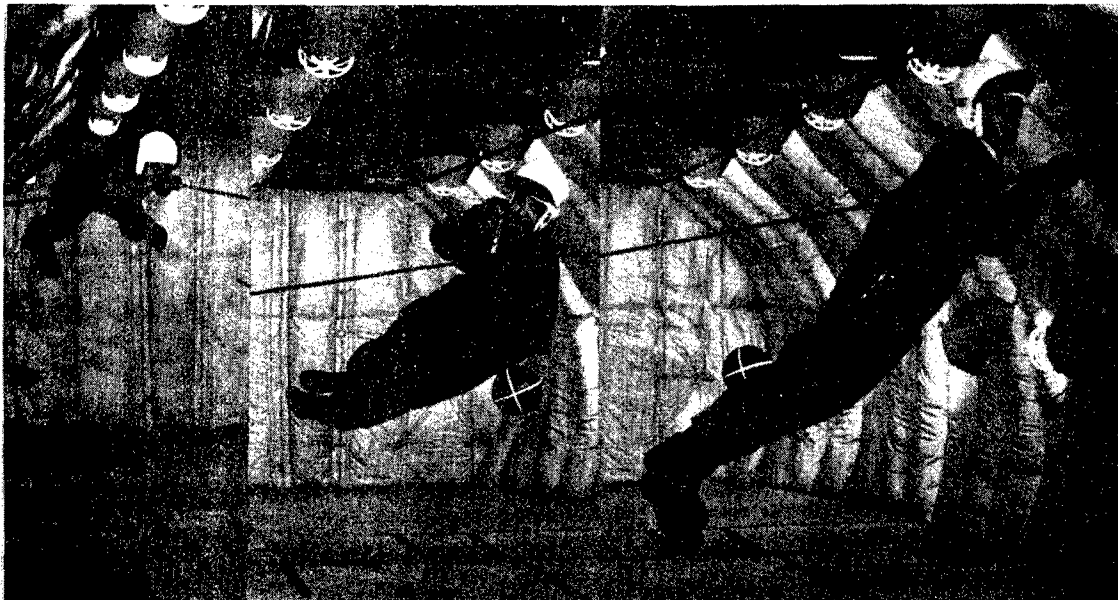


FIGURE 10 Erratic Attitude Response During Soar

SECTION III SUMMARY AND SUGGESTED AREAS OF FUTURE RESEARCH

The worker separated from the vehicle by a slack tether can move in any direction, limited only by the amount of tether slack and can rotate about any axis without limitation provided the tether is attached to the intended axis of rotation. A continuous separation of the ellipsoidal motion of the slack line and the spherical rotation of the worker can be achieved by using a semirigid extension from the workers attachment point.

The worker attached to the vehicle can wear a rotating belt tied to vehicle with spring-loaded lines. With equal tension in all of the lines, the only force on the man will be toward the spacecraft, which he will oppose by standing or kneeling on the surface. Motion parallel to the surface is limited since any displacement away from the zero point causes unequal tension in the lines and this net force has to be overcome by the man through friction with the surface and the torque overcome by the spreading of the feet. The worker can vary his alignment to the surface by using various lines with desired body attachment points.

The worker can soar along stretched lines and confine his motion to predetermined trajectories. Position control is easily maintained; however, attitude behavior can be erratic. Potential problems with this motion may include the motion of the lifeline anchor points (a taut line may move two free-floating and attached masses toward each other) and line whiplash. However, this activity within a large vehicle should be relatively free of hazards provided adequate deceleration control is maintained by the operator.

The effort in this report suggested future areas of research as the work progressed. (1) The desired physical properties of the between-vehicle tether appears worthy of study. Reinkensmeyer* is investigating the material needs in terms of elasticity and strength-mass ratio requirements that will minimize line flexion causing the operator to rebound after flexion. (2) Capt. R. F. Vachino* suggested the drafting of orbital projections of free-tethering motion and the motion of an operator affixed to the spin axis of a rotating space station. Mueller* is plotting the orbital behavior of the tethered operator and Kulwicki* is studying the problems of tethered performance along a moving surface. (3) The question of the stability and tumble properties of the flexible-weightless man is being determined by Whitsett* and such analyses may determine the optimum number and points of tether attachment to the body.

A later consolidation of all of these studies may determine design and training requirements for the tethered orbital operator and his equipment.

* Air Force personnel at ASD, Wright-Patterson Air Force Base, Ohio

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3. Mueller, D. D., The Coriolis Effect in Zero-Gravity Aircraft, MRL Memorandum P-9, 6570th Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio.
4. Simons, J. C. and M. S. Gardner, Weightless Man: A Survey of Sensations and Performance While Free-Floating, AMRL TDR 62-114, 6570th Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio (in editing).