NATIONAL GEOTECHNICAL CENTRIFUGE

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A new national resource that may be the world's largest centrifuge is under construction at NASA-Ames Research Center.

The new centrifuge will be able to take a 2700-kg (6000-pound) payload up to 300 G's. The 300 G's will be obtained by spinning the payload with its center of gravity at a radius of approximately 8.8 meters (29 feet) at a speed of 175 rpm. At this speed, the payload bucket will have a tangential velocity of 168 m/s (550 ft/sec), or roughly half the speed of sound. This paper describes some of the design problems encountered in such a high G-ton machine (see figures 1 and 2).

DESCRIPTION

The primary purpose of the new facility will be for the modeling of body force problems in civil engineering. Problems such as the stability of dams and embankments, the bearing capacity of soil foundations, and the dynamic behavior of foundations due to vibration of machinery can be studied using the new centrifuge. The scope of problems that can be addressed by centrifuge modeling include: static, dynamic, thermodynamic, and fluid dynamic processes coupled with body force loading. Some examples include: earthquake response of earth structures, soil-structure interaction, explosive cratering, blast-induced liquefaction, frozen soil behavior, frost heave, etc.

The Geotechnical Centrifuge will be used to verify finite element analyses and help generate new theories and analytical techniques. The new facility, because of its large payload capacity, will be able to carry larger models with greater detail than any centrifuge currently in use for geotechnical work. This will allow greater accuracy in modeling and instrumentation than is currently possible with smaller centrifuge models. This increase in modeling capability will provide for a more precise study of currently used scaling laws, and a more accurate evaluation of the effects of parameters that are difficult or impossible to accurately scale, such as grain size of the soil. The larger model dimensions will reduce inaccuracies due to model boundary effects. The initial research effort with the new facility will hopefully provide a better understanding of these effects, and also provide information for the modification of scaling laws to compensate for them.

The geometric scale of a model which represents an earth structure is inversely proportional to the G-level at which the machine is operating, and the scaling of settling or consolidation time is proportional to the square of the G-level multiplied by the time the centrifuge operates. For example, 40 years of time on a 300-meter section of an earthen dam can be simulated using a 1-meter model at 300 G's in 4 hours. (see figure 3). Other scaling laws have been developed for vibrational frequency, amplitude and duration for seismic events and explosive charge energy for cratering studies.

The new facility and initial research is being funded by grants from the National Science Foundation to NASA-Ames and The University of California, Davis. The Center for Geotechnical Modeling at The University of California, Davis, will provide management and technical expertise for the operation of the new facility. Ames is providing the design and construction management of the facility. The new centrifuge is actually a modification of an obsolete Apollo-program centrifuge. The main existing components that will be used include the motor, the power supply, and the buildings.

DESIGN

The motor that will drive the new centrifuge is a large vertical shaft dc machine built by Westinghouse and originally designed to develop 14,000-kW (18,800-hp) output power for very short durations with a limited duty cycle. The original design speed was 54 rpm. A continuous-duty rating for the motor was not established in the original design.

A recent design study by Westinghouse established a continuous-duty power rating for the motor of 6,700 kW (9,000 hp). It was also determined that 70 rpm would be an acceptable maximum speed at this power level, limited by commutation of the motor. Frequent inspection and commutator servicing would be necessary for operation at this speed and power level.

It was decided to use a speed increaser with a ratio of 1:3 to attain the required 175-rpm output speed for the new centrifuge, thus retaining a maximum motor speed only slightly higher than the original design.

The speed increaser will be an epicyclic configuration to maintain concentric input and output shafts. The large ring gear will have a pitch diameter of approximately 173 cm (68 in) and a face width of 27 cm (10-5/8 in). Lubrication for the gears and bearings is provided by spray lubrication with a dry sump gear case. The lubrication oil reservoir is an annular ring with a 225-liter (60-gallon) capacity that makes up the outer shell of the gear case. This reservoir is kept full by a combination of centrifugal pumping due to rotation of the gearing and a scavenge pump system.

A unique structural design feature of the centrifuge arm is the isolated tension straps (see figure 4). The tension straps carry the centripetal forces of the payload directly from the payload support structure (swing bucket) to the counterweight without going through the main support structure. This force [approximately 27 million newtons (6 million pounds), at full speed], which is equivalent to the thrust of 4 F-1 rocket engines used on Saturn V, is all carried through pivot pins that allow the payload bucket to swing. The tension straps are to be made from high-strength alloy steel, thus allowing the main support structure to be made from mild steel. The main support structure is a box-beam weldment that provides bending and torsional stiffness to the system and carries all of the 1G vertical loads. This structure also sees moderate tensile stress due to centripetal forces from its own mass. Using mild steel for the main support structure greatly reduces the cost of construction since material costs are less and fabrication (especially welding) is easier. The tension straps are attached to the main support structure by a single pin joint at the payload end (see figure 5). This pin joint is capable of handling an unbalanced load up to 10% of payload and carrying it back through the main structure to the spindle bearings. It is located at the payload end to minimize the displacement (due to strain) of the outer ends of the anti-spreader bar with respect to the center of the bar.

The purpose of the anti-spreader bar is to reduce the bending in the tension straps at the first support due to the lateral acceleration force acting on the clevis eyes, bucket walls, and the cantilever portion of the straps. The lateral acceleration is 33 G's on the straps along their entire length, and is supported by hockey-puck-shaped bronze bearing pads that supply support in the lateral direction, yet still allow the straps to slide when stretched by the tension forces (see figures 4 and 5).

The bucket is a swing type; this insures that the acceleration vector remains essentially normal to the floor of the bucket at all times. This is required for many geotechnical studies to keep ingredients, such as sand and loose soil, in place during the entire cycle, from at rest to full speed.

Another interesting design feature is the flexwall bucket design. This insures isolation of the bucket floor loading moment from the pivot pins; the pins are then assured of equal loading in the bucket clevis eyes (see figure 5) The walls of the swing bucket, that attach the payload-carrying surface to the clevis eyes, are made from only 1-inch-thick steel plate. Therefore, they essentially act as a large flexure.

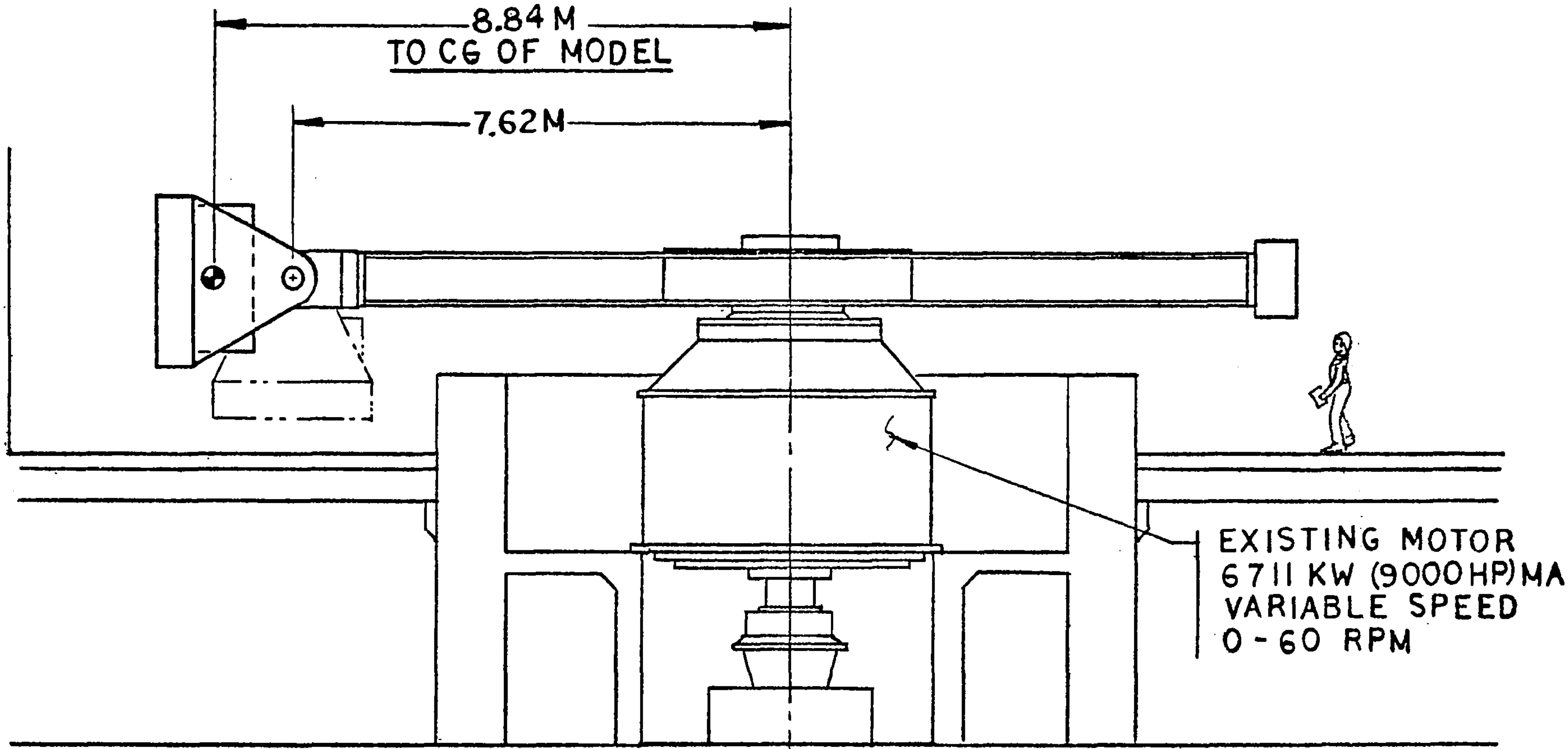
A safety barrier to be constructed within the existing centrifuge building was designed to be capable of containing the entire swing bucket with payload at full speed, should failure occur. The bucket assembly, with payload, weighs about 10,000 kg (22,000 lb.), and is traveling at a tangential speed of about 168 m/s (550 ft/sec); or in other words, the safety barrier will be able to contain the equivalent of a ten-ton truck traveling at 375 miles per hour. The safety barrier is an annulus with an outside diameter of 37 meters (122 ft). The outside wall will be the existing walls of the building which are 0.4-m (16-inch) thick steel reinforced concrete. An inside wall of steel reinforced cinder blocks will retain 6.7 meters (22 ft) of sand fill between the walls. The design assumes fracture or penetration of the inner wall with the sand providing an energy absorption role. Model studies have been performed on a ballistics range to verify the design analysis.

THE CURRENT STATUS OF THIS PROGRAM

The contractor for the centrifuge construction is March Metalfab, Inc., of Hayward, California. Philidelphia Gear Corp. was the successful bidder on a design-and-construct-type contract for the speed increaser. The electrical and controls contract and the safety barrier contract remain to be bid.

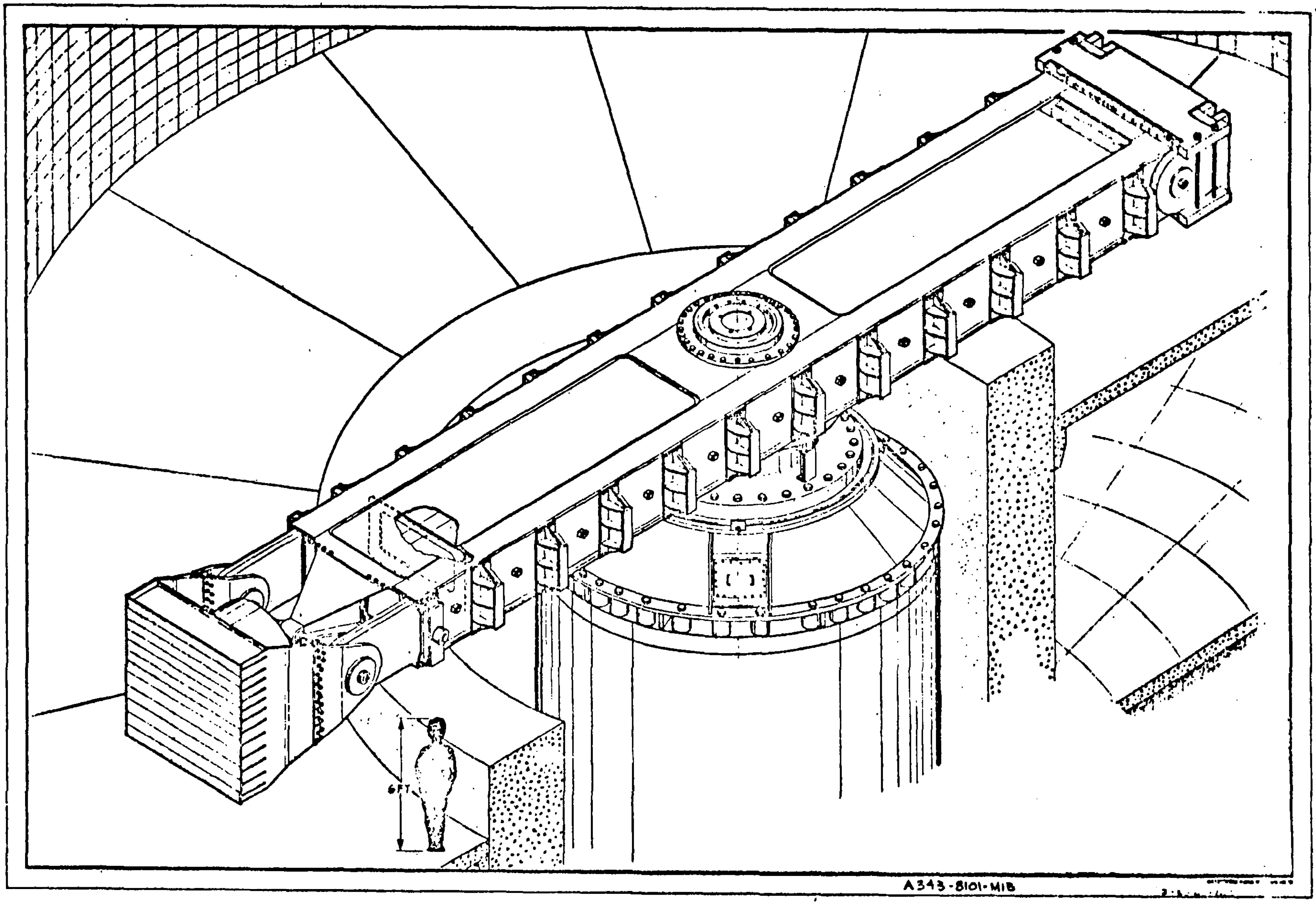
A completed gear box is to be delivered by May 1, 1982. Concurrent with this, March Metalfab will fabricate and assemble the centrifuge in their shop so that erection can begin as soon as the speed increaser is installed. The entire facility should be operational by the end of this year.

CENTRIFUGE PERFORMANCE	
SPEED	0 - 175 RPM
ACCEL.	300 G (MAX) RAD.
PAYLOAD	2727 KG (MAX) (6000 LB)



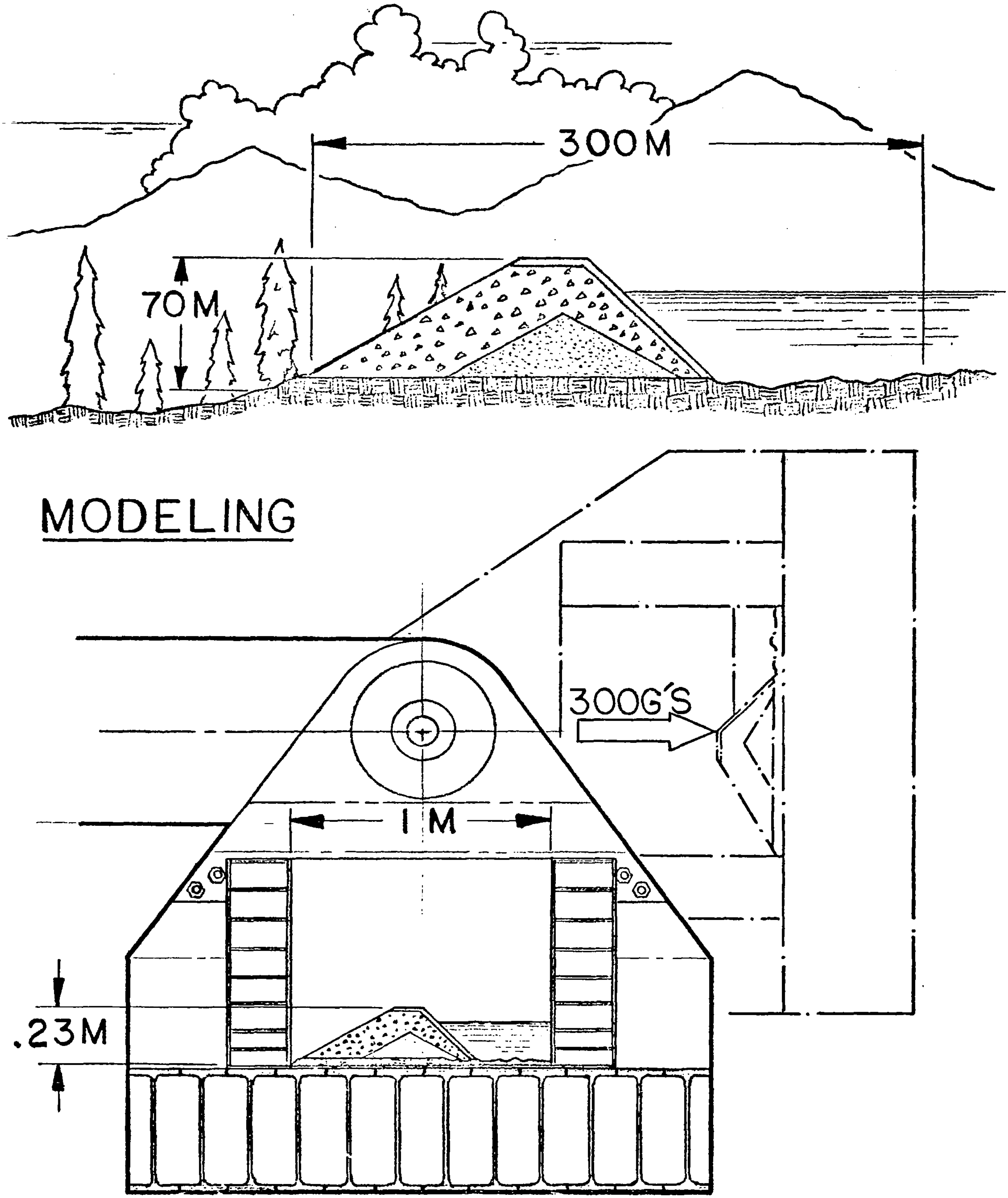
CENTRIFUGE CONFIGURATION

Figure 1



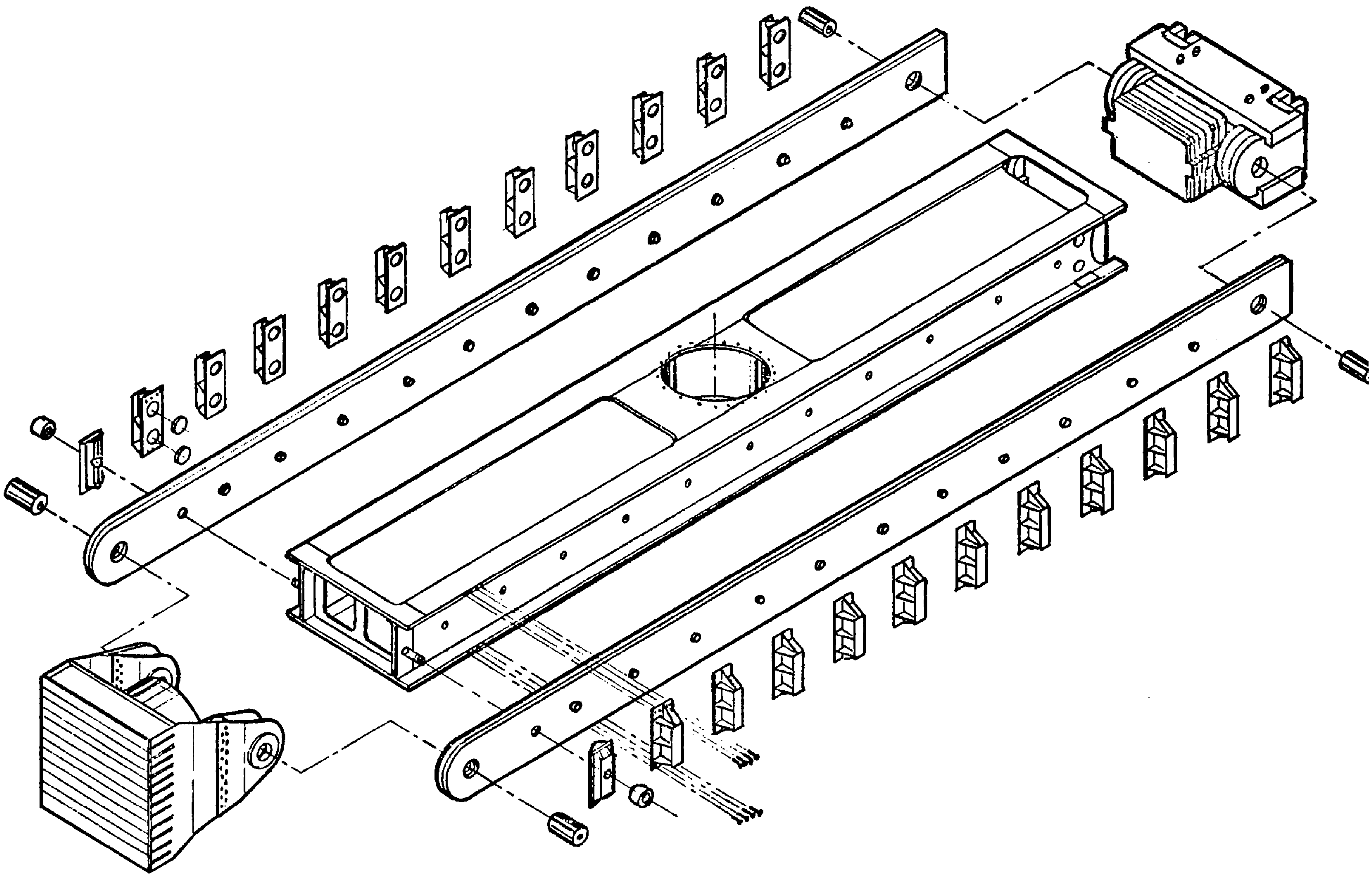
CENTRIFUGE PICTORIAL

Figure 2



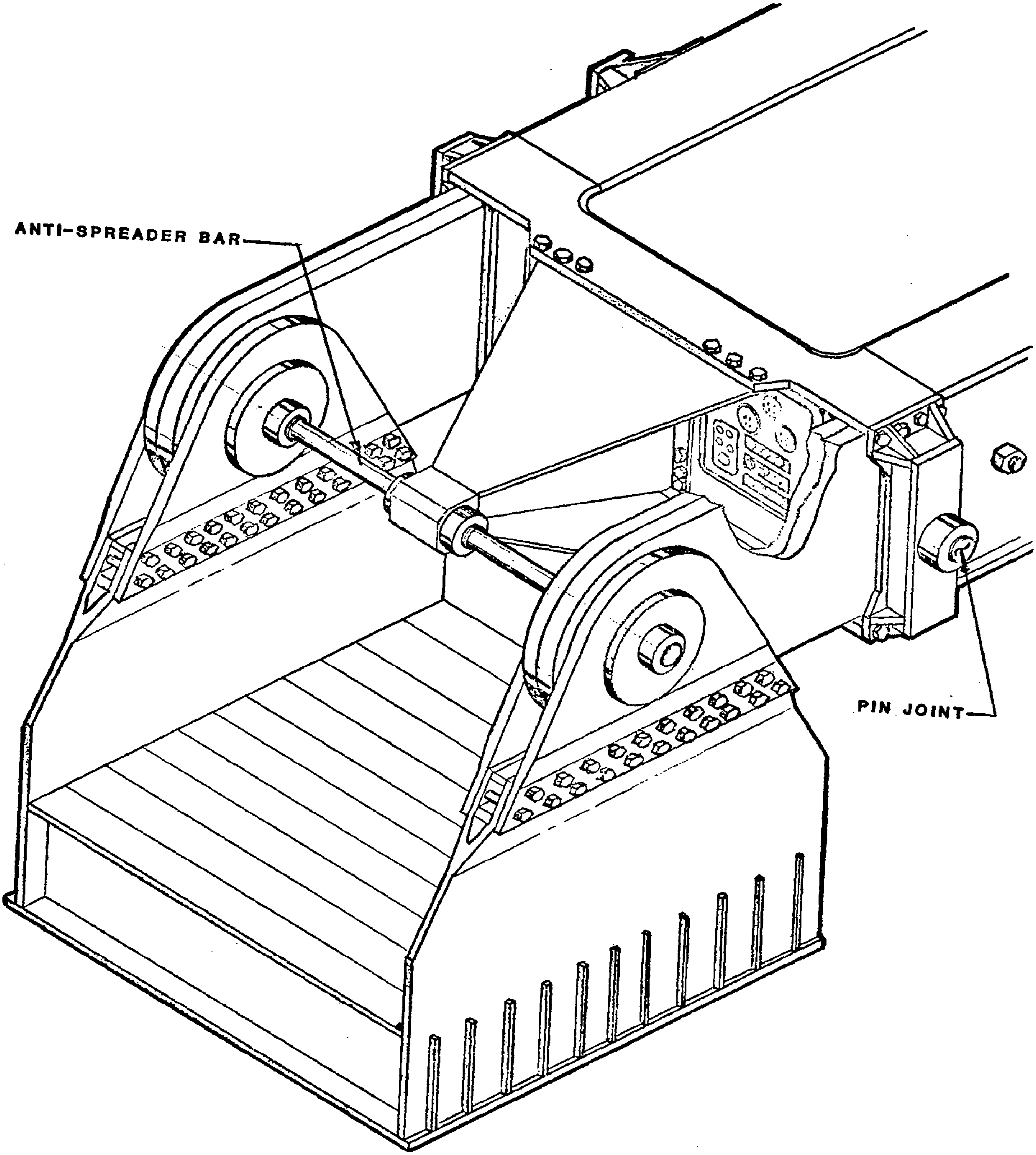
MODEL SCALING LAWS

Figure 3



CENTRIFUGE EXPLODED VIEW

Figure 4



CENTRIFUGE SWING BUCKET

Figure 5

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Mr. Kunz has been working for NASA-Ames Research Center as a research engineer in the Research Equipment Engineering Branch since June 1978. During this time, he has been primarily involved in the design of research equipment such as wind tunnels and aircraft and space flight hardware, as well as finite-element analysis of the same equipment using MSC/NASTRAN. He graduated from Oregon State University in 1978 with a B.S. degree in Mechanical Engineering. Mr. Kunz is currently doing graduate work at Stanford University.

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