USAF STANDARD SKID RESISTANCE TESTING IMPLEMENTATION

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This paper presents a brief summary of the research work accomplished on runway skid resistance and hydroplaning by the USAF. The research objectives were to develop a standard evaluation system for determining the skid resistance and hydroplaning potential of Air Force runways and to develop optimum corrective techniques for improving skid resistance properties of airfield pavements. The paper describes the evaluation system developed around the Mu-Meter and the Diagonally Braked Vehicle (DBV).

Research conducted by USAF, NASA, and FAA has led to the present skid resistance evaluation program used by the Air Force. The recommended improvements, when required, have also resulted from research on methods to improve pavement friction/hydroplaning characteristics.

A brief evaluation and history of these research projects and how they have been consolidated into a standardized skid test system is included to show how the skid evaluation system has evolved and is attempting to use the latest information.

History Leading to Present Skid Evaluation Program

Higher landing speeds of jet aircraft, together with the increased number of wet weather landings permitted by improved instrument landing systems have focused attention on aircraft ground operations during inclement weather. The cost of Air Force skid/hydroplaning accidents has been substantial ($8.5 million between 1970 and 1975 attributed directly to unsafe surface conditions). A comprehensive program of research, evaluation, equipment improvement and procedural change has been developed since the early 1970s. The expectation is that the program will begin to show results in the near future.

Since the early 1960s when the problem was first apparent, there has been an effort underway to develop a technique to assess runway conditions on a near real time basis and to inform the pilot what to expect at touchdown. One of the early devices developed and used for this purpose was the James Brake Decelerometer (Inspection Decelerometer). This device consisted basically of a pendulum connected to an indicating needle; the needle recorded the deceleration due to displacement of the pendulum. The James Brake Decelerometer (JBD), mounted in a stock vehicle (sedan or station wagon), became the standard Air Force equipment to determine the Runway Condition Reading (RCR) of the pavement, a number that could vary from 01 to 26. The number provided the pilot a means of estimating how his aircraft would react when the aircraft touched down on the runway surface (1).

Unfortunately, results from the James Brake Decelerometer were often not repeatable, i.e., results were affected by a number of variables including the driver of the vehicle, the vehicle itself, and the techniques used in conducting the test. In short, the device did not have the capability of predicting the stopping distance of an aircraft nor of predicting when the aircraft was likely to encounter hydroplaning situations. It soon became apparent that this device was not the answer to the question of how to measure skid resistance properties of wet runways. A better method was sought (2, p. 44-48).

In the mid-1960s, the British began development of a device to measure the coefficient of friction of an airfield pavement. The result of this development work was the Mu-Meter, a small trailer unit designed to furnish a continuous graphical record of the pavement coefficient of friction. The Mu-Meter is described later.

In 1968, the National Aeronautics and Space Administration (NASA) developed a promising skid resistance measuring device, the Diagonally Braked Vehicle (DBV). Early exploratory tests indicated a relationship existed between wet to dry stopping distance ratio (SDR) of this vehicle to a similar ratio of an aircraft. In 1969 and 1970, the USAF participated with NASA in a project called "Combat Traction" (2). An instrumented C-141 aircraft was test landed at a number of airfields to measure the aircraft SDR. In addition, SDR measurements were made with a DBV and deceleration measurements were made with a JBD. The test results showed the JBD was unreliable; the DBV, however, did show promise as a measuring device to predict aircraft stopping distances. Project "Combat Traction" was extended to include comparison between a Boeing 727, a DC-9 and the results obtained with the M L Aviation Mu-Meter and a DBV (3 and 4). Based on the comparisons both the Mu-Meter and the DBV showed some promise of being able to predict the stopping distances of aircraft (3, 4, and 5). There is, however, a need for many more experiments. The analysis will require evaluation of the comparison between Mu-Meter and/or DBV results with each individual aircraft and for each type of surface. This would probably result in a relationship between the DBV and/or Mu and each aircraft with pavement type being one distinguishing parameter. Since the stopping characteristics will change with the pavement finish, type of aggregate, wear resistance of the aggregate, etc., the generalized relationship with pavement type as a parameter would probably not be reliable or repeatable.

More recent USAF research has focused on quantifying all the factors affecting aircraft stopping distance performance. With this information, plans were to develop a design for a skid measurement vehicle or utilize a presently available skid measurement vehicle to arrive at an input for a system for predicting the stopping distances of landing aircraft. Presently the funds are not available for continuation of the project and it appears that the research will be terminated prior to final design of skid evaluation equipment. Thus the prediction system will not be finalized at this time.

Another area of skid resistance research is pavement surfaces. FAA and the USAF research has continued on improved surfaces for asphalt type pavements while the FAA has also continued research into developing an optimum pitch/depth pattern for runway grooving. (Because of the potential problems in grooving asphalt the USAF has not generally grooved asphalt runways.) USAF research has also dealt with testing, construction and evaluation of porous friction and surface seal type bituminous treatments. In addition to these major projects, three minor projects are being evaluated for potential improvements in equipment reliability and data analysis.

One project is the evaluation of a self-watering system for the Mu-Meter. The self-watering system will be used to evaluate the surface texture of all areas of the runway, where the present system evaluates only selected parts of the runway. This will hopefully fill the gaps left in the normal testing procedures.

The second project has replaced the original Mu-Meter hydraulic load cell with a strain gauge load cell and graphical readout in the cab of the towing vehicle. This will reduce the workload on the Mu-Meter operator and increase the reliability of the overall system.

The third project is a study of available deceleration curves from the DBV. This is to check if the types (partial, full, viscous, dynamic) of hydroplaning can be distinguished by use of the deceleration curves from the DBV. If the various types can be identified through evaluation of the curves, this will serve as additional information that can be used to develop a more comprehensive report on the condition of the pavement surface.

The present skid resistance evaluation equipment (see the equipment section), procedures, and limits have evolved as a result of the research program. The limits of acceptability resulting from these tests have been set at points where aircraft (B-727 and DC-9) actually locked wheels on landing (see Figures 1 and 2). The logical assumption made was that the SDR and/or Mu-Meter results observed during these lockups, would be an indicator that the surface being tested would be susceptible to hydroplaning (3 and 4). (Note: The limits vary between Figure 2 and Figure 6; this is a result of changing to ASTM-E-524 standard tires on the DBV).

Skid Resistance Test

In the Air Force standard skid resistance test, the skid resistance/hydroplaning characteristics of a runway surface are evaluated by two types of test equipment, the Mu-Meter and the diagonally-braked vehicle (DBV). The test program consists of field measurements of the pavement skid resistance/hydroplaning potential under dry and standardized artificially wet conditions. Other parts of the program include measurement of transverse slopes and surface texture. The slopes and texture measurements are conducted in traffic lanes on each side of the runway centerline to evaluate the surface drainage and texture characteristics.

Equipment

The principal items of field testing equipment consist of the Mu-Meter, the diagonally-braked vehicle (DBV), tank truck for water application, a device for measurement of the slope of the pavement surface and the grease texture measurement kit.

The Mu-Meter is a small trailer unit designed and manufactured by M L Aviation (Maidenhead, Berkshire, England) for the specific purpose of evaluating coefficient of friction (MU) for runway surfaces. The Mu-Meter physically evaluates the side slip force between the tires and pavement surface. Figure 7 shows the towed-out wheels and the load cell used to measure the force pulling the wheels apart. It is a continuous recording device that graphically records the coefficient of friction (MU) versus distance along the pavement. The friction measuring wheels are designed with 10 psi tires so that the test vehicle when towed at 40 mph, gives a speed equivalent to 1.2 times the theoretical hydroplaning speed (33 mph). The system has been modified to replace the standard load cell with a strain gauge load cell and an in-cab readout of the continuous graphical display.

The DBV is a specially instrumented vehicle which was developed by NASA to evaluate the stopping characteristics of runway surfaces. The DBV records the stopping distance of the vehicle in a diagonally-locked wheel mode from a speed of 60 mph (96.6KM/Hr) (2). The diagonally-braked wheels are now equipped with ASTM E-524 test tires.

A water truck is furnished by the fire department at the air base tested. The truck is fitted with a spray bar for water application, tachometer for precise speed control and integral to the truck is a constant pressure discharge system. The water is applied in two passes. The truck is carefully calibrated so that each pass places 0.1 inch (.254cm) of water on the test strip. Testing follows immediately after the second pass.

The slope measuring device consists of a rectangular section of aluminum [10 ft (3.0m) long, 5/8 inch (15.9mm) thick, and 2 1/2 inches (63.5mm) high] with machinist levels attached so as to define slopes from 0 to 2.0 percent to the nearest 0.1 percent. The slope measuring device is used to measure transverse and longitudinal gradients in the wheel path areas.

The grease smear texture kit consists of disposable 30 cc syringes, masking tape, ruler and hard rubber squeegee. Texture measurements are taken in each test section.

Testing Procedure

The field test procedure used for the evaluation of skid resistance/hydroplaning characteristics of the runway surface is described in an Air Force Weapons Laboratory Technical Report (7). An outline of the current test procedures follows:

1. Generally five test areas of 10 feet (3.0m) by 2000 feet (609.6m) are selected as a representative sampling of the entire runway surface (Figure 3). Test sections are selected to examine the pavement traction in (1) the aircraft touchdown areas, (2) the runway interior along traffic lanes where maximum aircraft braking is normally accomplished, and (3) the pavement edge which is representative of non-traffic areas.

2. Transverse slope measurements are conducted at 500 or 1000 foot (152.4m or 304.8m) intervals in the wheel path areas on each side of the runway centerline.

3. Surface texture measurements are obtained in each test section.

4. The water truck is calibrated to discharge 0.1 inch (.254cm) of water.

5. The skid resistance test for the dry pavement condition is conducted using the DBV and Mu-Meter.

6. Skid resistance tests under a standardized artificially wet condition are conducted as follows:

a. Water is applied to the test area in two passes. Each pass places 0.1 inch (.254cm) of water.

b. DBV and Mu-Meter tests are conducted immediately following the second pass of the water truck. The test is continued for up to thirty minutes after wetting, depending on the recovery rate. Tests are conducted in both directions.

c. All water truck, Mu-Meter and DBV operations are recorded versus time to the nearest second. The sequence of operations is controlled by radio.

Test Results

The pavement skid resistance results are reported in terms of coefficient of friction (Mu), as measured by the Mu-Meter, and the wet-to-dry stopping distance ratio (SDR), as measured by the DBV. Research conducted during Combat Traction II has been used to define breakpoints in the values of Mu and SDR which define potential hydroplaning problem (see Figures 1 and 2); these breakpoints are shown on the charts in Table 1. While current technology does not permit exact prediction of aircraft stopping distances, the charts provide a good rule of thumb for interpretation of data. The results are tabulated, analyzed and published in runway skid resistance survey reports for each Air Force base evaluated.

Friction Variation

Figure 4 shows the friction versus distance trace as recorded by the modified Mu-Meter during the first runs after wetting for several different surfaces. It shows the continuous variation of friction within the 2000 foot (609.6m) test sections. Comparisons can be made with dry conditions which are recorded in the data sections of the reports. Sharp dips or rises indicate a change in surface characteristics or the location of local ponding areas. In an evaluation, comparisons may be made between various sections of the runway and the probable hydroplaning areas pinpointed. Typically each runway will have touchdown areas with the highest probability of hydroplaning and edge sections (nontrafficked areas) with the lowest probability. Figure 4 presents several friction traces. The bold trace shows one minor ponding area approximately 440m (1400 ft) into the test section. The reports present only the first trace recorded after the surface is wetted, but as time allows drainage, the traces are closely checked for trends to identify any ponding due to lack of adequate cross-slope or excessive rutting. The transverse slope measurements are used to help point out potential problem ponding areas that are not tested by a wet test procedures. The wet test procedures also show visually when and where there are ponding problems on the runway.

Friction Recovery With Time

Figures 5 and 6 show the effects of time after wetting on changes in surface friction for several typical pavement types. The figures demonstrate the natural drainage characteristics of the runway surface and times required for the friction in the test sections to return to an acceptable condition (assuming recovery in the 30 minute time period). If the section does not recover to an acceptable level during the time period, the runway or section is a prime candidate for runway improvements. These curves were derived by plotting the average coefficient of friction over the 2000 feet (609.6m) test section or SDR versus time after wetting. These recovery curves are typical of several types of pavements and of several areas of the runway. These curves are affected primarily by pavement surface texture and pavement surface drainage. Rates are also affected by weather conditions, such as wind, free air temperature and pavement temperature. All variables are weighted by engineering judgement when final analysis of a particular curve is presented.

Data Reduction Program

The AFWL developed a computer analysis package to process all data gathered in the standard test. Data is recorded on standard forms designed for keypunching directly from the original data. Output from the analysis program includes data summary charts for each test section, plotted curves showing Mu vs time and SDR vs time for each test section. The printout also includes weather data recorded during the testing of each runway (8).

Based on the recovery graphs, slopes, visual observation, grease texture measurements, weather, Mu-Meter traces, and experience, the engineer can develop an evaluation that will provide operators with the expected response of his runway(s) during wet weather operations.

Test Limitations

Research conducted to date allows identification of runways (or parts thereof) where skid potential is at a potentially dangerous level. In these cases, the situation can be pointed out to aircrews and remedial action can be taken by the civil engineer at the base. These recommendations for tower advisories to aircrews or improvements should help prevent potential skid/hydroplaning accidents. This nonquantitative identification of potential problem areas is the best we can do for operators, since at the present time we cannot

Table 1.

MU-METER AIRCRAFT PAVEMENT RATING (7, AFWL-TR-73-165)

MU	EXPECTED AIRCRAFT BRAKING RESPONSE	RESPONSE
Greater Than 0.50	Good	No Hydroplaning Problems Are Expected.
0.42 - 0.50	Fair	Transitional.
0.25 - 0.41	Marginal	Potential For Hydroplaning For Some A/C Exists Under Certain Wet Conditions.
Less Than 0.25	Unacceptable	Very High Probability For Most Aircraft to Hydroplane

STOPPING DISTANCE RATIO/AIRFIELD PAVEMENT RATING (7, AFWL-TR-73-165)

SDR	HYDROPLANING POTENTIAL
1.0 - 2.5	No Hydroplaning Anticipated.
2.5 - 3.2	Potential Not Well Defined.
3.2 - 4.4	Potential For Hydroplaning.
Greater Than 4.4	Very High Hydroplaning Potential.

Note: Technical Report No. AFWL-TR-73-165 (Source of Ratings) Adjusted To Reflect Use of 15 Inch Tires on the Diagonally Braked Vehicle.

with any statistical reliability predict the amount of runway that it will take for a given aircraft to stop under a specific set of circumstances. We will provide information based on breakpoints shown in Table 1 about the relative probability of incurring a hydroplaning situation or other skid phenomena. The USAF standard skid resistance test and subsequent report will (1) determine/report if and where there is a potential hydroplaning problem on the runway, (2) determine how serious the problem is, if one exists, (3) permit base civil engineers to program improvements and (4) give the aircrews better knowledge of what to expect when operating on the runway.

At this time, the USAF considers that the use of both the Mu-Meter and the DBV provides information that would otherwise be unavailable if only one type of equipment was used in the evaluations. An example of this is where excess bituminous material is on the surface. The Mu-Meter will not necessarily point out the problem but the DBV dry stops will generally create enough heat to melt the asphalt and a skid over the melted asphalt will result. This type of condition may present a hazard to aircraft during both dry and wet weather conditions.

Program Operation

The standard USAF skid resistance evaluation program was started in FY74. Since that time improvements have been integrated into the procedures. The program will be continued for the foreseeable future because of the lack of any more reliable system. The Air Force Civil Engineering Center at Tyndall AFB FL is program coordinator for the USAF. To date, most Air Force bases have been evaluated and as base runway surfaces are changed, tests will be conducted to detect any changes caused by new construction. Through a slow process of education, the base level engineers are beginning to become aware of the problems created by lack of attention to specifications or lack of compliance with specifications by contractors. Through this education process, the Air Force will be able eventually to have runway surfaces with such surface characteristics that the only skid/hydroplaning accidents will be a result of either extreme carelessness, mechanical malfunctions, or extremely adverse weather conditions.

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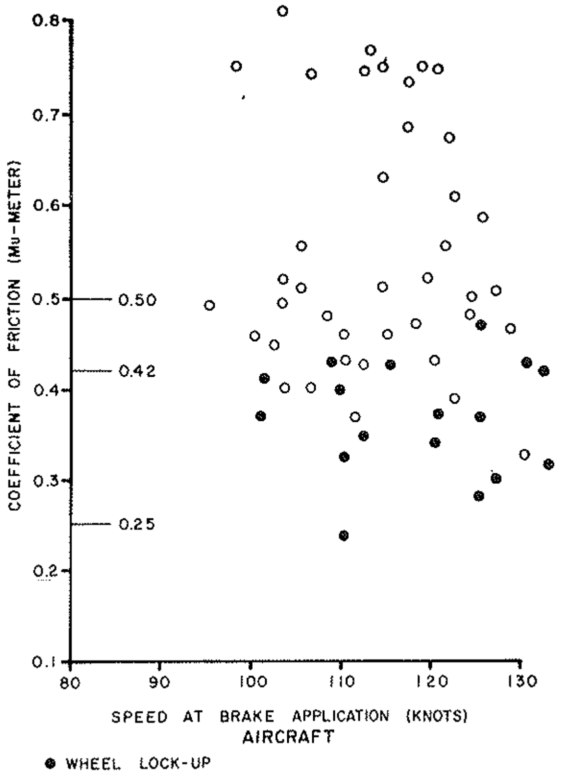


FIGURE 1

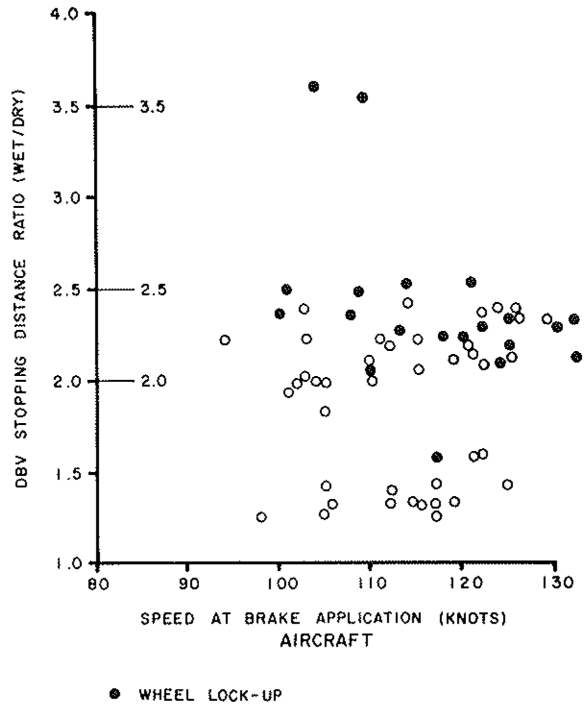
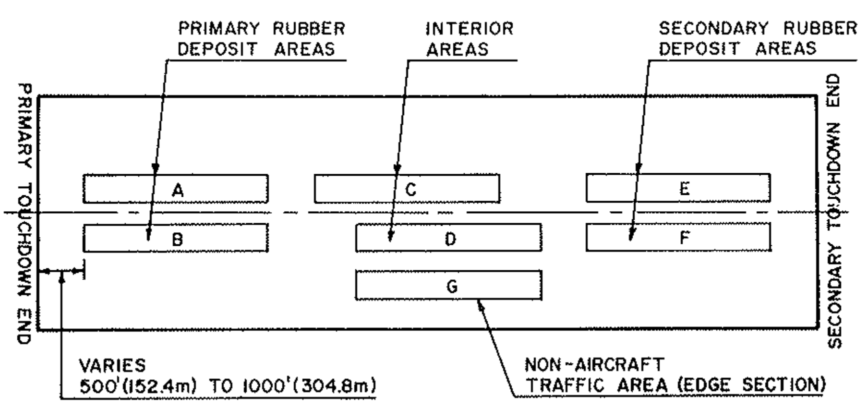


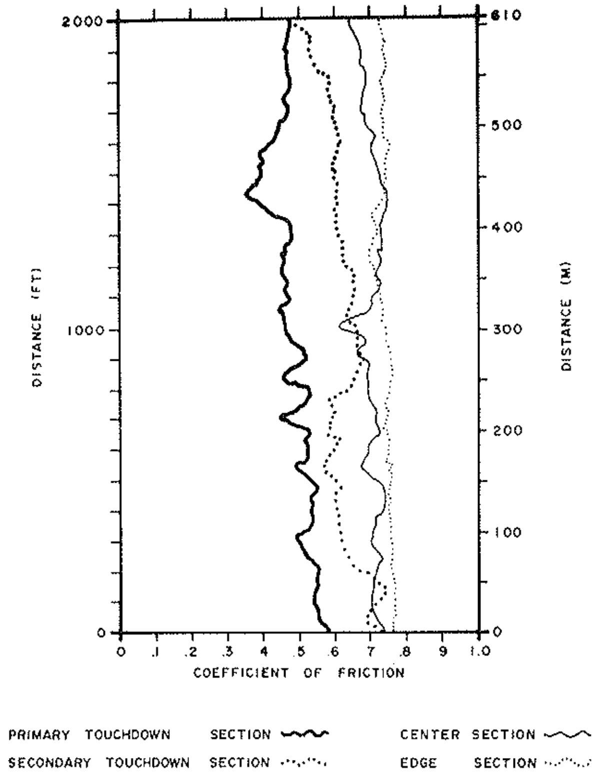
FIGURE 2



NOTE: TYPICAL TEST SECTION DIMENSIONS
10' (3.0m) WIDE BY 2000' (609.6m) LONG

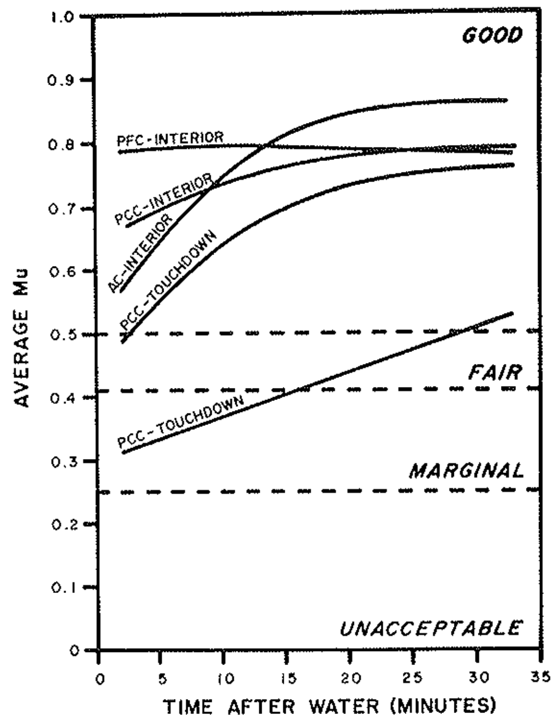
LAYOUT OF TEST SECTIONS

FIGURE 3



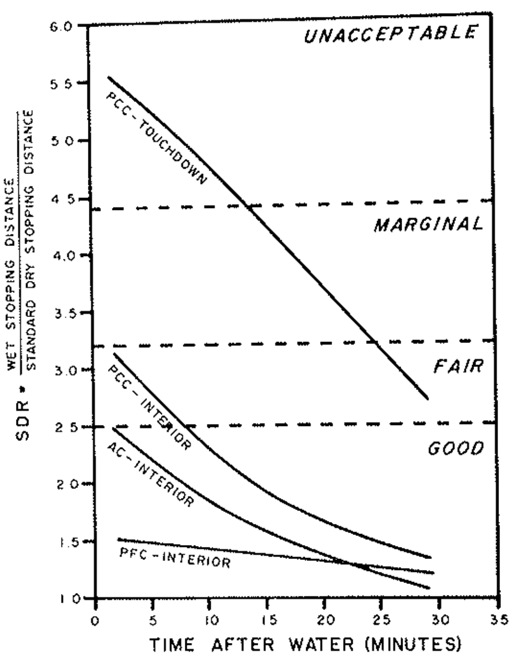
TYPICAL Mu-METER TRACES
AT NELLIS AFB

FIGURE 4



RECOVERY RATES

FIGURE 5



RECOVERY RATES

FIGURE 6

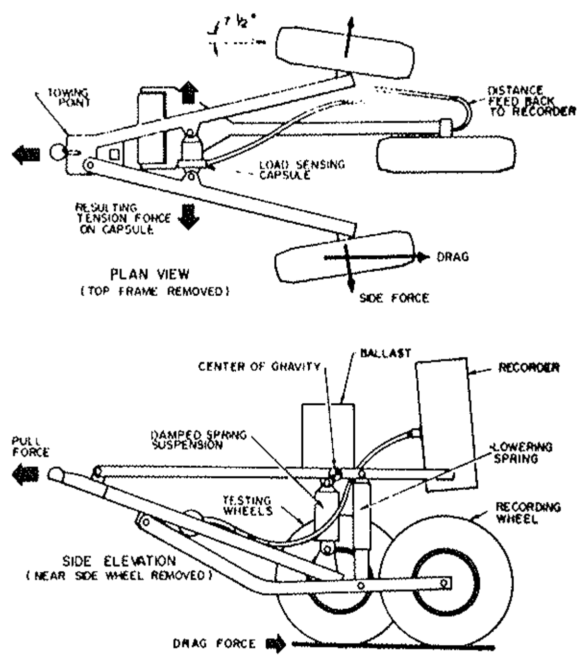


FIGURE 7. DIAGRAMMATIC LAYOUT OF MU-METER.