

Report No. FAA-CT-81-185

OCLC: 10734655

*CT*  
*81*  
*185*  
**COPY 1**

**THE BRAKING PERFORMANCE  
OF AN AIRCRAFT TIRE  
ON CONCRETE SURFACES**

FEDERAL AVIATION ADMINISTRATION

AUG 11 1981

TECHNICAL CENTER LIBRARY  
ATLANTIC CITY, N.J. 08405

**Satish K. Agrawal**



**PROJECT PLAN**

**JUNE 1981**

Prepared for

**U. S. DEPARTMENT OF TRANSPORTATION  
FEDERAL AVIATION ADMINISTRATION  
TECHNICAL CENTER  
Atlantic City Airport, N.J. 08405**

## TABLE OF CONTENTS

	Page
1. OBJECTIVES	1
2. BACKGROUND	1
3. EXPERIMENTAL PROGRAM	2
3.1 Test Facility and Equipment	2
3.2 Test Sections	3
3.3 Test Parameters	10
4. DATA COLLECTION	10
4.1 Test Procedure — Braking Tests	11
5. DATA REDUCTION AND ANALYSIS	11
6. COORDINATION AND AREAS OF RESPONSIBILITY	12
7. SCHEDULE	12
8. REFERENCES	12

## LIST OF ILLUSTRATIONS

Figure		Page
1	Jet-Powered Pusher Car for Providing Preselected Speeds to Test Equipment	4
2	Dynamometer and Wheel Assembly Showing Vertical and Horizontal Load Links	5
3	Hydraulic System for Applying Vertical Force on the Test Site	6
4	Dimensions of Reflex-Percussive Grooves and Conventional Saw-Cut Grooves	7
5	Dimensions of Reflex-Percussive Grooves for Optimization Study (Test Bed No. 2)	9
6	Schedule	13

## 1. OBJECTIVES.

The following objectives are established for the research and testing proposed in this project plan:

- a. Evaluation of the braking performance of an aircraft tire on reflex-percussive grooves and conventional saw-cut grooves in asphaltic concrete.
- b. Evaluation of the braking performance of an aircraft tire on a porous friction course.
- c. Evaluation of plastic-state grooving techniques for concrete.
- d. Evaluation of the braking performance of an aircraft tire on the grooves produced by promising plastic-state grooving techniques established in c., above.
- e. Determination of an optimum geometry for the reflex-percussive grooves in asphaltic concrete.
- f. Determination of a cost-effective configuration for the reflex-percussive grooves.

## 2. BACKGROUND.

The braking and cornering performance of an aircraft tire during landing operations depends upon the magnitude of the friction forces developed at the tire/runway interface. The presence of water on the runways significantly reduces the available friction at this interface and results in loss of braking and directional control of the aircraft. An extreme case of loss of control is hydroplaning.

During hydroplaning the physical contact between the tire and the runway is lost, and the tires are supported on the intervening layer of water. In general, where large water depths are present on the runways, the fluid density is the controlling factor, and dynamic hydroplaning occurs. Viscous hydroplaning occurs where a thin water film is present on the runway. In all cases, however, both dynamic and viscous hydroplaning are present to some degree.

The presence of transverse grooves results in significant improvement in the friction level available on a wet runway; dynamic hydroplaning is generally prevented, or its onset is shifted to higher operating speeds. Viscous hydroplaning can be alleviated by providing sharp microtexture in the runway surface. Sharp asperities can break through the thin viscous film and provide a direct contact between the aircraft tire and the runway surface.

Rectangular grooves are identified by pitch, width, and depth. The pitch is the distance between groove centerlines and is often referred to as groove spacing. A nonrectangular groove is identified by its geometrical shape and/or the groove installation technique and an associated dimension.

Regardless of the fact that runway grooves improve braking and cornering performance of aircraft and help alleviate hydroplaning, many runways have not been grooved. The relatively high cost of installation is mentioned as a major deterrent to the use of runway grooves.

Since 1976, the Federal Aviation Administration (FAA) Technical Center has been engaged in experimental investigations to determine a low-cost groove configuration for runway surfaces. The findings of the investigation (reference a) show that by increasing the spacing of the conventional sawcut grooves beyond the normal 1-1/4 inches recommended by FAA Advisory Circular No. 150/5320-12 (reference b), the cost of installation can be reduced. These results show that an adequate margin is available to stop an aircraft tire on wet portland cement concrete (pcc) surfaces installed with grooves at increased spacing, although total braking effectiveness is reduced. User groups have shown reluctance to universal use of grooves of larger spacing because of the reduced braking effectiveness. The investigation, however, also identified an alternative groove installation technique which is competitive to the conventional saw-cutting method. This technique is called the reflex-percussive grooving process.

The reflex-percussive grooving process produces nonsymmetrical V-shaped grooves which provide braking performance equivalent to that provided by the conventional saw-cut grooves spaced at 2 inches or less. The installation cost of the reflex-percussive grooves can be significantly lower than that of the conventional saw-cut grooves spaced at 2 inches or less. In addition to being less expensive to install, the reflex-percussive grooves have a potential of providing braking and cornering performance exceeding that available on the conventional saw-cut grooves spaced at 1-1/4 inches. This potential can be fully utilized, however, only after the groove geometry has been optimized.

The test program described in this document will first evaluate the braking performance of an aircraft tire on reflex-percussive grooves and conventional saw-cut grooves in an asphaltic concrete surface. Later, an optimum geometry will be sought for the reflex-percussive grooves. Evaluation of porous friction courses and techniques for plastic-state grooving will also be completed. When the performance evaluation is completed, a cost-effective groove geometry and groove type will be determined.

### 3. EXPERIMENTAL PROGRAM.

#### 3.1 Test Facility and Equipment.

The test program will be conducted at the Naval Air Engineering Center, Lakehurst, New Jersey. Track No. 3 at this facility is 1-1/4 miles long and has guide rails spaced 52-1/2 inches apart running parallel to the track. Reinforced concrete strips extending beyond the guide rails to a width of 28 feet also run parallel to the track. The last 300 feet of the track will be used for installing the test bed. The asphaltic concrete test bed will be installed on top of an 8-inch-thick pcc surface existing on the track. The test bed will be 2-1/2 inches thick and 30 inches wide. An aircraft arresting system is located beyond the test track to recover the test equipment at the completion of a test run.

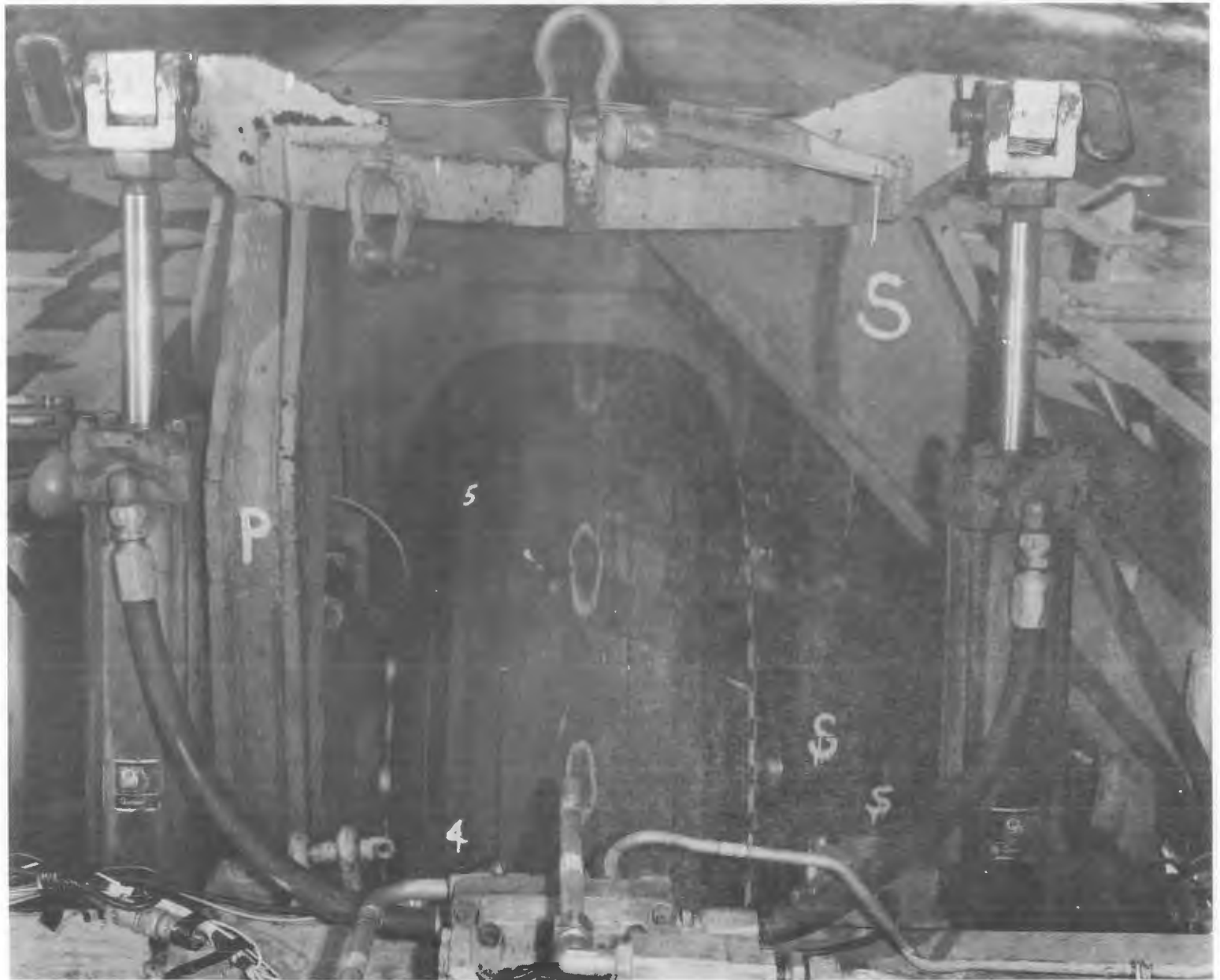


FIGURE 3. HYDRAULIC SYSTEM FOR APPLYING VERTICAL FORCE ON THE TEST SITE

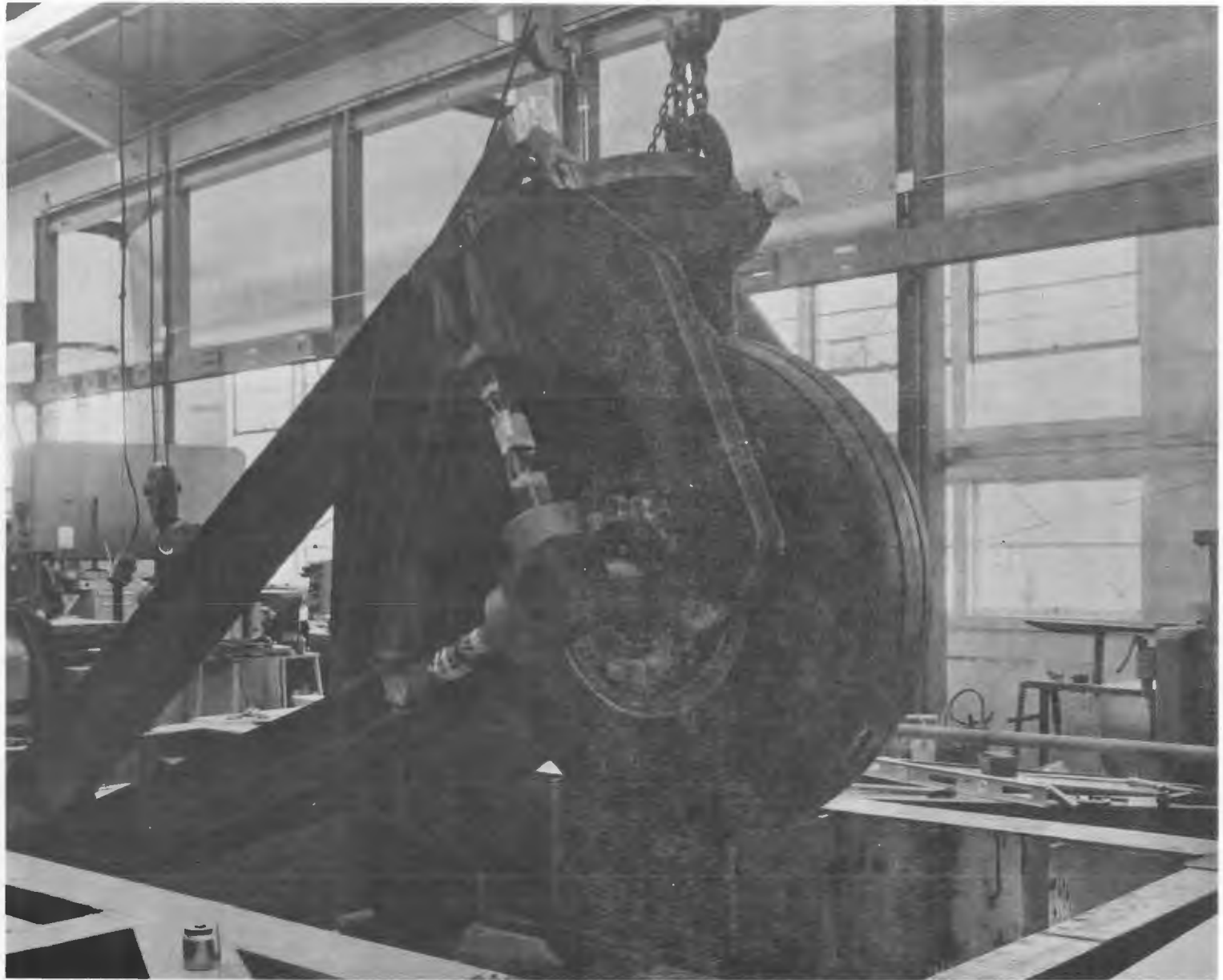


FIGURE 2. DYNAMOMETER AND WHEEL ASSEMBLY SHOWING VERTICAL AND HORIZONTAL LOAD LINKS



4

FIGURE 1. JET-POWERED PUSHER CAR FOR PROVIDING PRESELECTED SPEEDS TO TEST EQUIPMENT

The major components of the test equipment are: the four-wheeled jet car, the dead-load carriage which supports the dynamometer and wheel assembly, and the measuring system. The jet car is powered with J48-P-8 aircraft engines (24,000 pounds total thrust) and is used to propel the dynamometer and wheel assembly and the carriage from the launch end at a preselected speed. The jet car (figure 1) is disengaged when the test speed is attained, and the dynamometer assembly and the carriage are allowed to coast at this speed into the test bed.

The dynamometer and wheel assembly was jointly developed by the FAA and the Navy and has the capability of simulating a jet transport tire-wheel assembly under touchdown and rollout conditions. Test speeds of up to 150 knots can be attained on the test track. The dynamometer is similar in design to the one developed by the National Aeronautics and Space Administration (NASA) for the Langley Test Facility (reference c). Figure 2 shows the dynamometer and wheel assembly and the details of the instrumentation for measuring vertical and horizontal loads at the axle. The assembly is pivoted about an axis contained in the dead-load carriage. (The carriage weighs 60,000 pounds.) Figure 3 shows the hydraulic system for applying vertical load on the test tire.

The dynamometer is instrumented to measure the vertical load on the tire, the horizontal force developed at the tire/pavement interface, the angular velocity of the test tire, the vertical motion of the dynamometer assembly relative to the dead-load carriage, and the change in test speed along the test bed. The water depth on the test bed will be measured by the use of a NASA water level depth gauge.

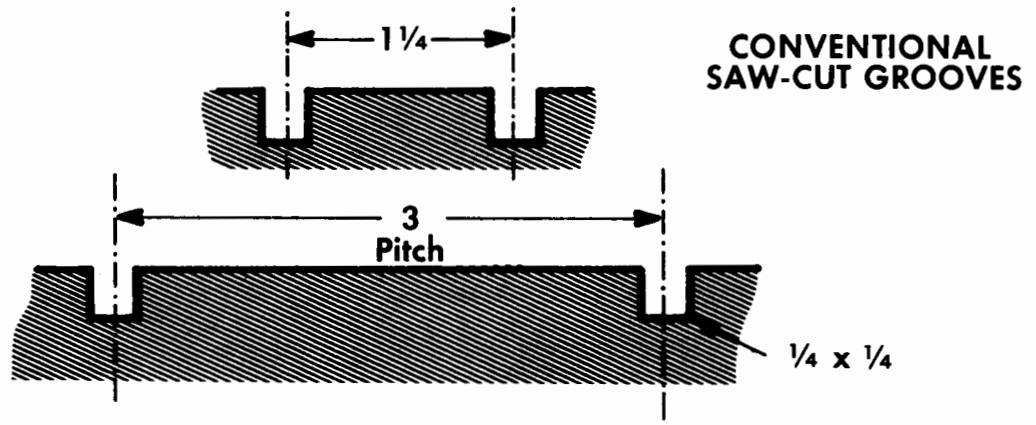
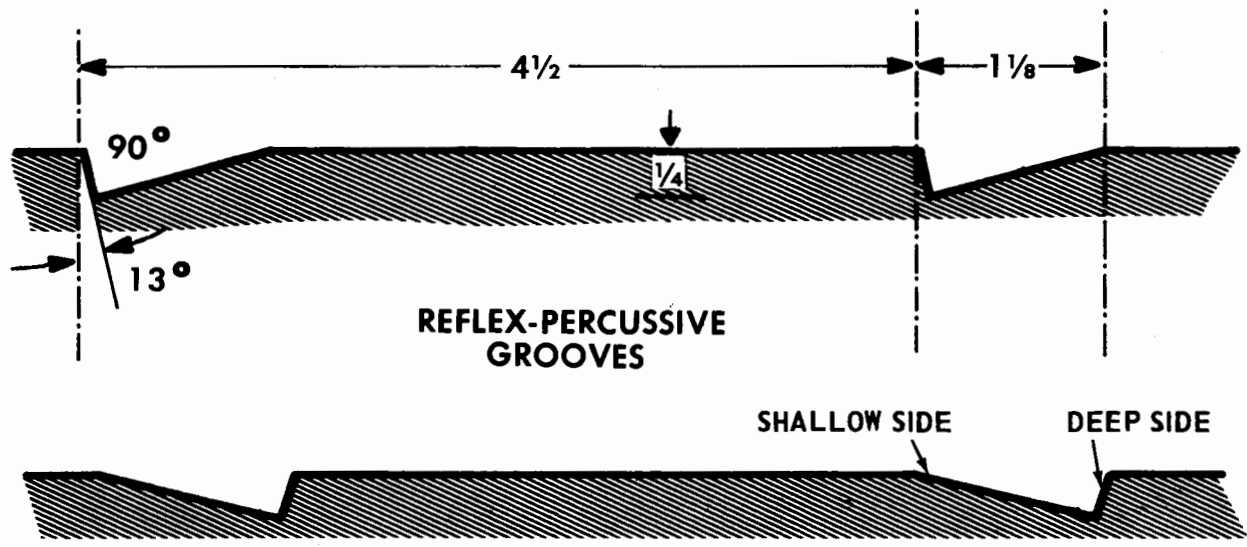
### 3.2 Test Sections.

The 300-foot test bed at the end of the track will be divided into seven 40-foot sections following a 20-foot section. The 20-foot section is intended for ensuring proper approach of the test wheel into the test sections. The dimensional tolerance of the test surface will be kept within  $\pm 1/8$  inch from horizontal level in each test section.

#### 3.2.1 Test Bed No. 1.

The following sequence of grooves and surface treatment is proposed for the first test bed. It is expected that a second and possibly a third test bed may be required for fulfilling the objectives of this research.

<u>Section No.</u> and <u>Surface Type</u>	<u>Grooves and/or Surface Treatment</u>
0 asphalt	20 feet, nongrooved.
1 asphalt	40 feet, reflex-percussive grooves, tire encountering deep side first, major groove dimensions: 4-1/2 inches and 1-1/8 inches, groove angle 13° (figure 4).
2 asphalt	Same as 1, except tire encountering shallow side first.



NOTE: ALL DIMENSIONS IN INCHES  
81-185-4

FIGURE 4. DIMENSIONS OF REFLEX-PERCUSSIVE GROOVES AND CONVENTIONAL SAW-CUT GROOVES

3 asphalt	40 feet, saw-cut grooves with 1-1/4-inch pitch.
4 asphalt	40 feet, saw-cut grooves with 2-inch pitch.
5 asphalt	40 feet, CMI Corp. Roto-Mill method for installing grooves.
6 asphalt	40 feet, porous friction course.
7 asphalt	40 feet, other promising grooves or surface treatment.

### 3.2.2 Test Bed No. 2.

The second test bed will contain a 40-foot section of pcc having a groove-like surface treatment formed by wire combing. The wire-combed grooves will be approximately 1/8-inch square and spaced at 1/2-inch center to center. The other six surfaces will be used for the optimization of the reflex-percussive grooves. Three alternative patterns (figure 5) are proposed; these three patterns have approximately equal flow area per unit length. The entire test bed will have the following grooves and/or surface treatment:

<u>Section No. and Surface Type</u>	<u>Grooves and/or Surface Treatment</u>
0 pcc	20 feet, nongrooved.
1 pcc	40 feet, wire-combed (1/8 inch x 1/8 inch x 1/2 inch).
2 asphalt	40 feet, reflex-percussive grooves, tire encountering deep side first, groove angle 13°, distance between grooves 3-1/2 inches (figure 5 pattern a).
3 asphalt	Same as 2, except tire encountering shallow side first.
4 asphalt	40 feet, reflex-percussive grooves, tire encountering deep side first, groove angle 20°, distance between grooves 2-3.4 inches (figure 5 pattern b).
5 asphalt	Same as 4, except tire encountering shallow side first.
6 asphalt	40 feet, reflex-percussive grooves, tire encountering deep side first, groove angle 16°, distance between grooves 3-1/4 inches (figure 5 pattern c).
7 asphalt	Same as 6, except tire encountering shallow side first.

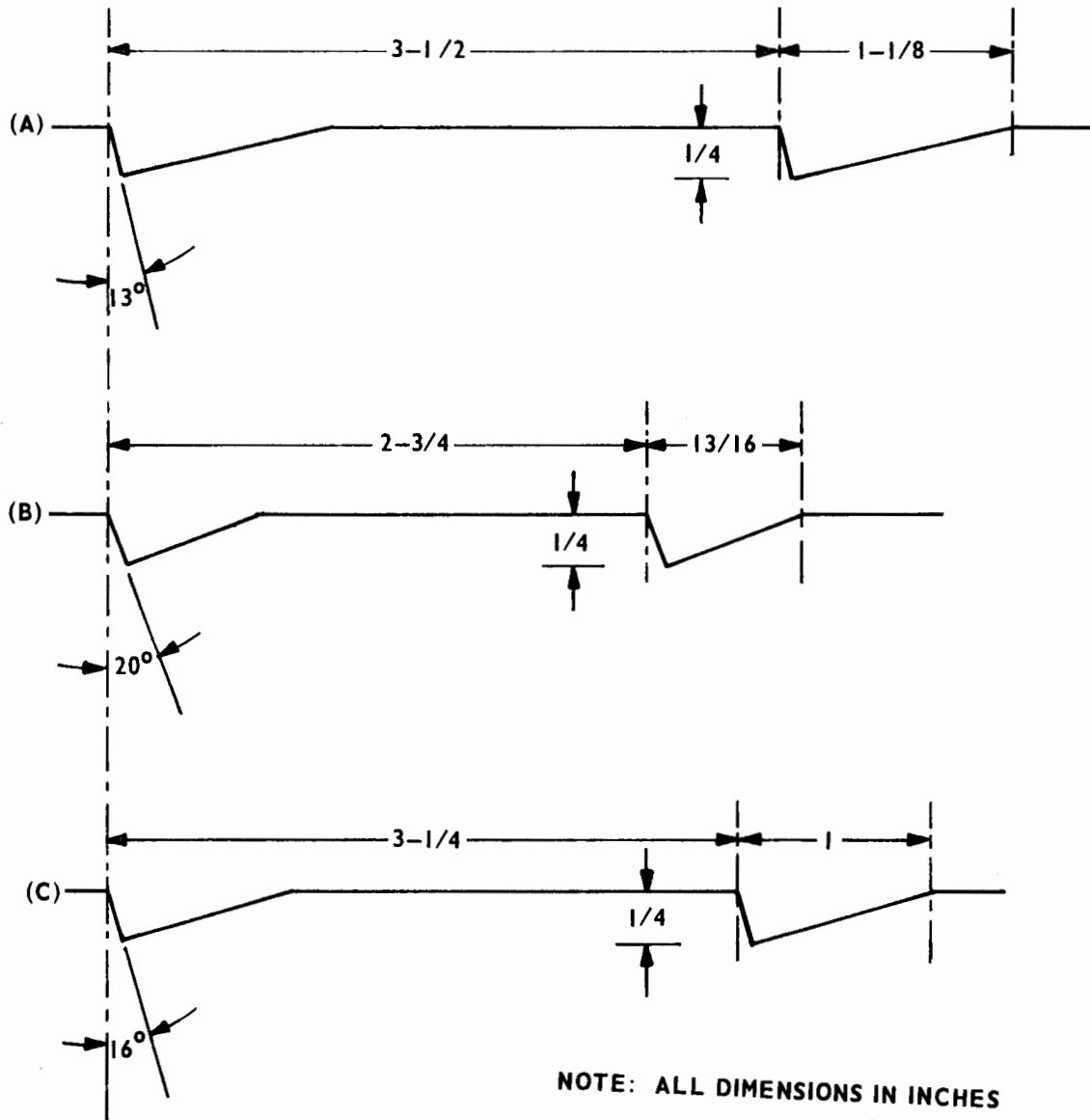


FIGURE 5. DIMENSIONS OF REFLEX-PERCUSSIVE GROOVES FOR OPTIMIZATION STUDY (TEST BED NO. 2)

### 3.2.3 Other Test Beds.

A third test bed, if needed, will primarily contain other promising surface treatments. The hot-rolled grooving technique is one example.

### 3.3 Test Parameters.

The following is a summary of the test parameters to be investigated in this test program:

#### Tire Parameters:

Vertical Load : 35,000 pounds  
Inflation Pressure : 140 pounds per square inch (psi)  
Tread Design : Worn and fully treaded (six grooves)  
Tire Size/Type : 49x17, 26-ply, type VII

#### Pavement Parameters:

Type of Surface : Asphaltic concrete and pcc  
Type of Grooves : Reflex-percussive and conventional saw-cut  
Other Treatments : CMI Roto-Mill texture, porous friction course, wire-combed (plastic state grooves)

#### Spacings of:

Saw Cut Grooves : 1-1/4 inches and 2 inches  
Reflex-Percussive Grooves : Distance between grooves, 4-1/2 inches, 3-1/2 inches, 3-1/4 inches, and 2-3/4 inches.  
Groove angles, 13°, 16°, and 20°.

#### Environmental Parameters:

Water Depths : Less than 0.01 inches wet.  
0.10 inches ±0.02 inches puddled.  
0.25 in. ±0.05 inches flooded.

#### Operational Parameters:

Wheel Operation : Rolling to locked  
Brake Pressure : Variable  
Speeds : 40 knots to 150 knots

## 4. DATA COLLECTION.

A major portion of the program will be devoted to conducting braking tests. These tests are intended for determining the braking effectiveness of an aircraft tire on wet, grooved asphaltic concrete surfaces (or on surfaces with other treatments). Additional tests may be conducted for determining the extent of tire damage or amount of rubber deposit on these surfaces; these tests are commonly referred to as the drop tests. The test facility at Lakehurst is capable of conducting the drop tests by simulating the first few seconds of a typical landing. The drop tests will be conducted on dry pcc surfaces.

The test equipment will be calibrated prior to the start of testing to measure the following quantities:

- a. Horizontal force at the tire/runway interface,
- b. Translational speed of the test tire, and
- c. Vertical load on the tire.

Development of appropriate techniques for the calibration of the above quantities is currently underway at the FAA Technical Center.

#### 4.1 Test Procedure — Braking Tests.

To obtain maximum available friction level for each set of operating conditions, multiple tests will be conducted at a constant speed while the brake pressure is being gradually increased in successive tests until wheel lock occurs. Since each test bed contains several test sections, multiple data points will be collected in each test. A braking test consists of the following steps:

- a. The test tire is selected and checked for inflation pressure.
- b. The desired water depth is obtained on the test sections.
- c. The jet engines are started at the launch end and set to provide pre-selected test speed in the test section.
- d. The jet car is released to propel the test equipment.
- e. The jet car is braked and separated from the test equipment to allow the dead load and dynamometer to enter the test sections at the preselected speed. (Vertical load and brake pressure are applied on the tire before the dynamometer enters the first test section.)
- f. The brakes are released, the wheel unloaded, and the test equipment arrested at the recovery end.
- g. The test equipment is returned to the launch end for the next test.
- h. The test is repeated with increased brake pressure.

The data will be collected on oscillographs. Typical data collected in a test will include horizontal force at the tire/pavement interface, vertical load on the tire, coefficient of friction developed at the interface, wheel revolution, and change in tire translational speed. Additional data will be recorded and computed manually; these will include water depth, tire translational speed, brake pressure, and ambient temperature.

#### 5. DATA REDUCTION AND ANALYSIS.

The data from oscillographs and computations will be tabulated to show the relationship between the translational speed of the tire and the maximum available friction level at each water condition (wet, puddled, and flooded). The data will be

plotted using a least-square-fit equation to show the changes in the friction level as speed increases. With the experience gained in previous testing (reference a) and using generally accepted physical concepts, an attempt will be made to identify a cost-effective groove geometry that provides braking effectiveness (to an aircraft tire) at least as high as that provided by the currently recommended groove configurations.

#### 6. COORDINATION AND AREAS OF RESPONSIBILITY.

The work described in this project plan has been undertaken in response to a request for research, development, and engineering effort (no. 9550-1-AAS-502-76-4) from the Office of Airport Standards in the Federal Aviation Administration. Mr. Herman D'Aulerio from the Airport Development Division, ARD-500, of the Systems Research and Development Service, will provide program direction. The testing will be conducted at the Naval Air Engineering Center, Lakehurst, New Jersey.

#### 7. SCHEDULE.

The schedule for this project is shown in figure 6.

#### 8. REFERENCES.

a. Agrawal, Satish K. and Hector Daiutolo, The Braking Performance of an Aircraft Tire on Grooved Portland Cement Concrete Surfaces, Interim Report FAA-RD-80-78, Department of Transportation, Federal Aviation Administration Technical Center, Atlantic City Airport, New Jersey, January 1981.

b. Joyner, Upshur T., Walter B. Horne, and T. J. W. Leland, Investigation on the Ground Performance of Aircraft Relating to Wet Runway Braking and Slush Drag, Report 429, Advisory Group for Aeronautical Research and Development, Paris, France, January 1963.

c. Method of Design, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces, Advisory Circular No. 150/5320-12, Department of Transportation, Federal Aviation Administration, Washington, D. C., June 1975.

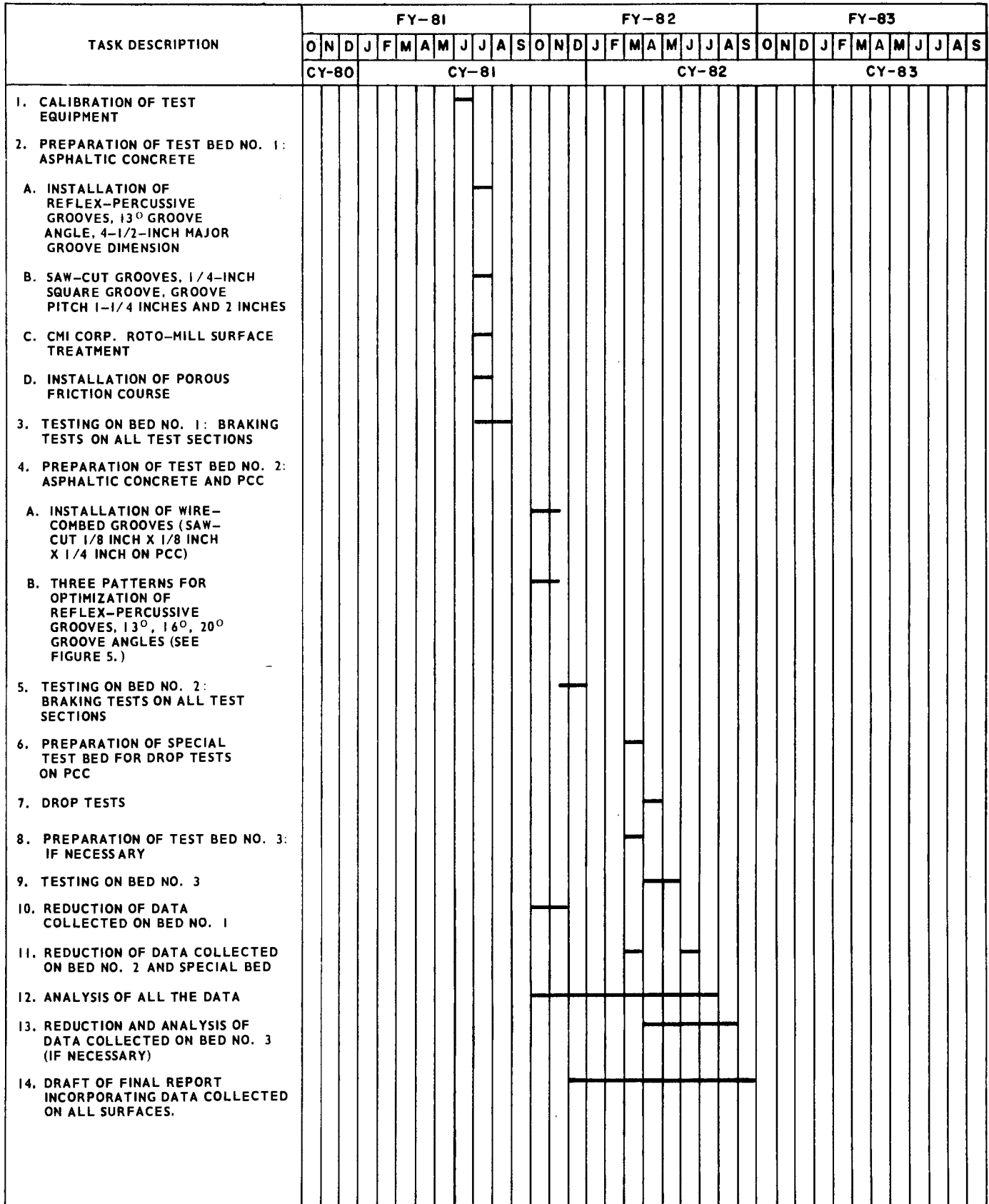


FIGURE 6. SCHEDULE

81-135-6