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AIRCRAFT BRAKE SYSTEMS TESTING HANDBOOK

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MAY 1981

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AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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This handbook was written to provide AFFTC engineers with guidelines for the testing of aircraft brake systems. Future technological advances, characteristics of individual test programs, and cost constraints may necessitate other methods being used in some cases. A background on brake systems, test conduct, and documentation of computer software for calculation of brake energies is presented.

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LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOL	DEFINITION	UNITS
AFFTC	Air Force Flight Test Center	- -
^oC	Degrees Celsius	- -
C_B	Braking Coefficient	dimensionless
C_D	Airplane Total Drag Coefficient	dimensionless
CDC	Control Data Corporation	- -
C_L	Airplane Lift Coefficient	dimensionless
d	Distance the vertical load center of pressure is offset from the center of the tire (positive is forward)	inches
e.g.	For example	- -
^oF	Degrees Fahrenheit	- -
F_{Drag}	Drag Force acting on the tire at the ground	lbs
F_G	Friction Force or Retarding Force	lbs
F_N	Normal Force	lbs
F_t	Engine Thrust	lbs
F_{vert}	Vertical Force acting on the tire at the ground	lbs
g	Acceleration due to gravity	32.17 ft/sec^2
h	Distance between ground and wheel axle	inches
hz	Cycles per second	- -
I	Rotating Wheel Moment of Inertia	slug - ft^2
i.e.	That is	- -
K.E.	Kinetic Energy	ft - lbs
L/R	Left/Right	- -
m	Aircraft Mass	lbs mass
mA	Current	milliamps
psi	Pounds per square inch	- -
psig	Gauge Pressure (pounds per square inch gauge)	- -
q	Dynamic pressure	lbs per ft^2
r	Wheel/Tire Radius	inches

LIST OF SYMBOLS AND ABBREVIATIONS - CONTINUED

SYMBOL	DEFINITION	UNITS
rps	Revolutions per second	- -
RTO	Responsible Test Organization or Refused Takeoff	- -
T_B	Brake Torque	ft-lbs
TIS	Test Information Sheet	- -
T.M.	Telemetry	- -
V	Aircraft Inertial Speed	knots
V_e	Equivalent Airspeed	knots
w	Aircraft Gross Weight	lbs
α	Wheel Angular Acceleration (positive is spin down)	rad/sec^2
δ_a	Ambient Pressure Ratio	dimensionless
λ	Slip Ratio	dimensionless
μ	Friction Coefficient	dimensionless
μ_B	Average Brake Coefficient	dimensionless
ω	Wheel Angular Velocity	rad/sec

SUBSCRIPTS

B	Brake	- -
max	Maximum	- -

INTRODUCTION

This handbook documents the results of a study in which the objectives were to provide additional analysis methods of aircraft brake systems and to provide the computational software to compute brake energy during aircraft brake testing. It is not a manual on how to do every type of testing, nor does it cover all analysis methods possible.

Because brake testing is one of the potentially more hazardous types of testing done at the AFFTC, control of the testing is vital. A large part of this control is through a build-up sequence approaching the brake systems upper energy and temperature limits, as defined by the manufacturer or technical order. The purpose of this handbook is to provide a methodology which will allow brake testing to be safely conducted closer to these limits.

Basically, the types of data analysis can be divided into three areas; operational capability assessment, program control, and brake/antiskid systems analysis. The first consists of analyzing data which is of greatest interest to the user. It includes flight manual, maintenance, and wear data. Program control data is used to monitor the test program by developing trend information. System analysis provided an internal view into the working of the system and can best provide the information for problem solving and determining system limits.

THEORY

AIRCRAFT STOPPING PROCESS

The process of stopping an aircraft is one of energy conversion. The kinetic energy of the aircraft at the start of slowing is converted to other forms of energy. One of the prime pieces of information needed in conducting brake tests is the amount of energy absorbed by the brakes. Looking at the major forces acting upon the aircraft, as shown in Figure 1, we can see that we have the following energy sources to account for:

1. The kinetic energy of the aircraft at the beginning of the stop: $K.E. = \frac{1}{2}mV^2$ or $\frac{1}{2}w/gV^2$

where:

$K.E.$ = kinetic energy, ft.- lbs.
m = mass of aircraft, lbs. mass.
V = aircraft inertial speed, ft/sec.
w = aircraft gross weight, lbs.
g = constant for gravity, ft/sec^2.

2. The kinetic energy added to or extracted from the aircraft by the thrust of the propulsion system during the stop.

3. The kinetic energy absorbed by aerodynamic drag, including drag chute if used, during the stop.

4. The kinetic energy absorbed by wheel brakes during the stop.

These are the major energy terms. Such factors as energy absorbed in tire flexing, tread wear, and runway slope have been neglected, due to their small magnitude. Runway slope can be important if the testing is not done on a nearly level runway.

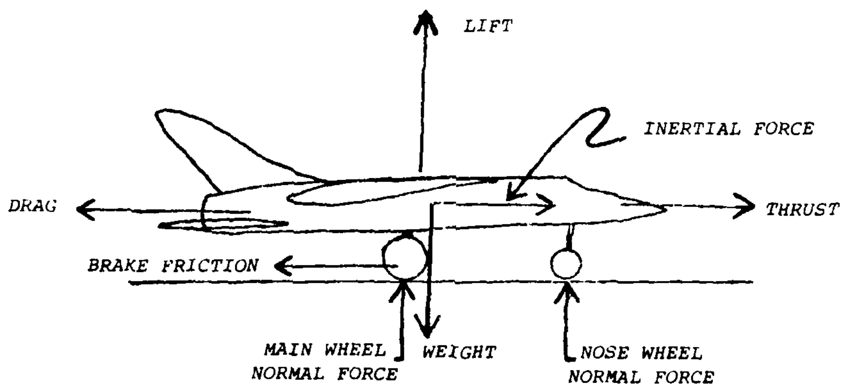


FIGURE 1 FORCES ON AIRCRAFT DURING LANDING

Figure 2 from Reference 1 illustrates the typical variation of the various forces acting on the aircraft throughout the landing roll. It is assumed that the aircraft is at essentially constant positive angle of attack from the point of nose wheel touchdown; C_L and C_D are constant and the forces of lift and drag vary as the square of the velocity. Thus, lift and drag will decrease linearly with $\bar{q}$ or V^2 from the start of stopping. If angle of attack is negative, additional down force would be added to the weight acting on the wheels. If the braking coefficient is maintained at the maximum value, this maximum value of the coefficient of friction (dry runway) is assumed to be essentially constant with speed and the braking friction force will vary as the normal force on the wheels approaches the weight of the aircraft.

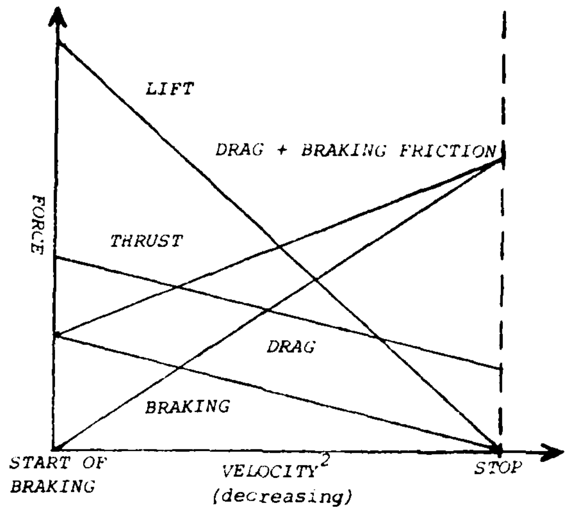


FIGURE 2 VARIATION OF FORCES DURING LANDING ROLL

In testing the aircraft brakes, accounting must be made for the energy dissipated by aircraft drag and the energy added to the brakes due to engine thrust. Wind will also add or subtract brake energy depending upon direction. A cross wind component can also create asymmetric lift and drag causing nonsymmetric braking. Therefore, brake testing should be limited to low wind conditions.

Aerodynamic braking can also be effective immediately after main wheel touchdown for some aircraft. Some delta wing aircraft may shorten total landing roll by maintaining a nose-high attitude and consequently high aerodynamic drag at high speeds immediately after touchdown. Aerodynamic braking is particularly effective during low friction runway conditions.

For most aircraft and runway conditions, the aircraft brakes furnish the most powerful means of deceleration. While details of braking systems vary for each system, there are various fundamentals which are common to all systems.

Friction is the resistance to relative motion of two surfaces in contact. When relative motion exists between the surfaces, the resistance to relative motion is termed "kinetic" or "sliding" friction; when no relative motion exists between the surfaces, the resistance to the impending relative motion is termed "static" friction. The small discontinuities of the surfaces in contact are able to mate quite closely when relative motion impends rather than exists, so static friction will generally exceed kinetic friction. The magnitude of the friction force between two surfaces will depend in great part on the types of surfaces in contact and the magnitude of the force pressing the surfaces together. A convenient method of relating the friction characteristics of surfaces in contact is a proportion of the friction force to the normal (or perpendicular) force pressing the surfaces together. The proportion defines the coefficient of friction:

$$\mu = F_G/F_N$$

where:

μ = Coefficient of Friction (mu), non-dimensional.
F_G = Friction Force or Retarding Force, lbs.
F_N = Normal Force, lbs.

The coefficient of friction of tires on a runway surface is a function of many factors. Runway surface condition, rubber composition, shearing stress, relative slip speed, tire temperature, etc., all are factors which affect the coefficient of friction. When the tire is rolling along the runway without the use of brakes, the friction force resulting is simple rolling resistance. The coefficient of rolling friction is on an approximate magnitude of 0.015 to 0.030 for a dry, hard runway surface. The application of brakes supplies a torque to the wheel which tends to retard wheel rotation. However, the initial application of brakes creates a braking torque, but the initial retarding torque is balanced by the increase in friction force which produces a driving or rolling torque. Of course, when the braking torque is equal to the rolling torque, the wheel experiences no deceleration in rotation and the equilibrium of a constant rotational speed is maintained. Thus, the application of brakes develops a retarding torque causing an increase in friction between the tire and runway surface. A common problem of braking is the application of excessive brake pressure which creates a braking torque greater than the maximum possible rolling torque. In this case, the wheel loses rotational speed and decelerates until the wheel is stationary and the result is a locked wheel with the tire surface subject to a full slip condition. The relationship of friction force, normal force, braking torque, and rolling is illustrated in Figure 3.

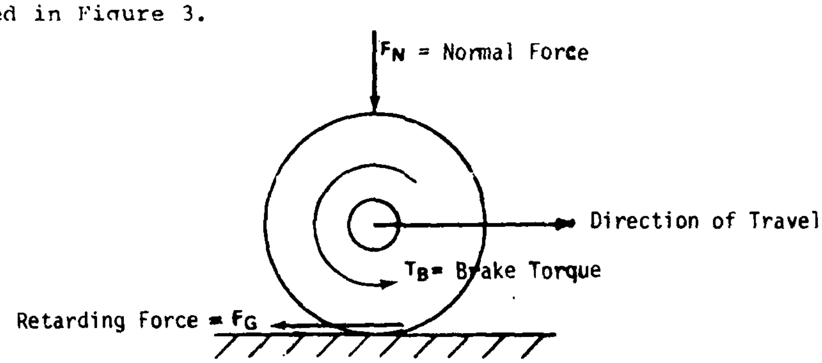
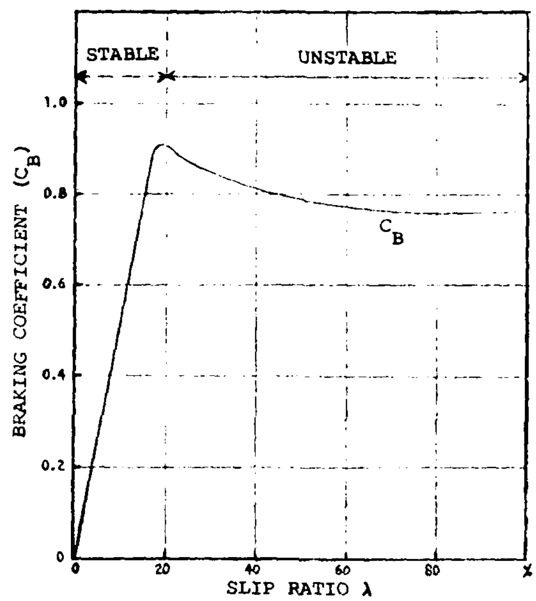


FIGURE 3 RELATIONSHIP OF FORCES ON A BRAKED WHEEL/TIRE

By taking a closer look at the tire-to-runway relationship, a better understanding of the aircraft stopping process can be gained. Whenever a horizontal, tire-to-runway force is generated, some slip always occurs between the tire and runway. This is due to the elastic nature of the tire and is true for any force and any type of runway surface. Figure 4. shows a typical slip/drag curve for a braked, tired wheel. Values vary according to runway condition, tire type, condition, and loading, but the general shape of the curve is always the same. The curve shows that as brakes are progressively applied, drag and slip increase up to a point of maximum drag, μ_{max}, after which a further increase in brake torque results in an increase in slip accompanied by a reduction in drag.



(Curve profile varies greatly, depending upon runway surface and tire condition/type.)

FIGURE 4 ADHESION/SLIP CURVE

There are thus two possible tire-to-ground conditions during the braking process. The first is a stable conditional "slip" at values up to a slip ratio, λ_{max}, in which brake torque is balanced by tire/ground drag. The second is an unstable condition of "skid" in which the forces of brake torque and tire/ground drag become unbalanced, with an excess of brake torque acting to decelerate the wheel rapidly towards a locked condition. This second condition is clearly undesirable since it results in partial loss of braking effort and can lead to loss of direction control and damage or blow tires. Typically an F-15 with locked wheel will blow a new tire in less than 300 feet.

BRAKE ENERGY

Brake energy must be computed in order to control testing. The energy which the brakes absorb is a part of the total aircraft energy. Other contributions to total aircraft energy are thrust, aerodynamic drag, and tire scrubbing.

Reference 2 develops a set of equations from which stopping distance and brake energy can be computed. These equations are valid between any two braking velocities, where the aircraft configuration and ground attitude are constant. Several other assumptions were made in developing these equations.

1. An average coefficient of friction can be used together with the vertical forces of the aircraft exerted on the runway to describe braking forces.
2. The aircraft-runway reaction loads are concentrated on the main landing gear. This, of course, is not exactly true, but the computed stopping distances and brake energies will not be affected, since the braking coefficients used to compute stopping distance and brake energy are derived using this same assumption.
3. Aerodynamic forces due to wind are assumed to be a function of ground speed and ambient air density rather than airspeed. This assumption is valid for low wind speeds, which should be a limit for brake testing.
4. Idle thrust can be reasonably well defined as a function of velocity squared.
5. Rolling friction is included with the braking coefficient of friction.

In order to compute brake energy we must first determine the average brake coefficient, μ_B, and in order to do this the lift and drag coefficients (C_L & C_D) and the thrust versus velocity function must be known.

To determine rolling friction and lift and drag coefficients a coast down test (no braking) can be conducted. The data required should be obtained at low gross weights and at high initial speeds. These conditions can easily be met during a landing. As soon as the aircraft touches down it should be configured to the desired configuration and then be allowed to decelerate to as low a speed as practical prior to braking or adding power for a go-around.

BRAKE TESTING ANALYSIS METHODS

BRAKE TESTING COMPUTER PROGRAMS

Introduction:

Four computer programs have been developed to assist the engineer in monitoring brake performance. These programs are based on the AFFTC-TIM-71-1003, May 1971, Reference 2. Other programs have been developed for computation of braking coefficients and brake energies. These data analysis programs may be used with the same effectivity as the ones presented here providing one takes into account such things as forward or reverse thrust and lift and drag for both the computation of braking coefficients and brake energies. These programs are relatively simple and easy to use and are fully operational.

The four programs are:

1. (THRUST) A program to define forward or reverse thrust as functions of velocity squared, V_e^2. This program is used to provide constants for the braking coefficient and energy programs.

2. (DRAG) A program which will extract aircraft drag coefficient data from unbraked coast down data.

3. (COFS) A program which will compute average braking coefficients and brake energies between any two braking speeds wherein the aircraft configuration is constant. The program computes brake energies for the entire aircraft so that if an aircraft has two brakes, the energy per brake is half of the total braking energy.

4. (SPEED) Because not all aircraft that will be tested are equipped with inertial navigation systems with ground velocity readouts for the pilot, it is necessary to have the capability to quickly compute the indicated airspeed (pneumatic system) where the brakes must be applied to provide control of the brake energies. This program provides an equation for rapid computation of the indicated airspeed to obtain the desired target ground speed for brake application.

Each of the four programs has the same general format for operation. Each program requires control cards, followed by the program itself, followed by user supplied data. Each section is separated by an end of record card (7/8/9 in column 1 for C.D.C).

The control cards used for most operations consist of a job control card, followed by a FORTRAN compiler control card, followed by an LGO control card. Figure 5 shows a sample of these control cards.

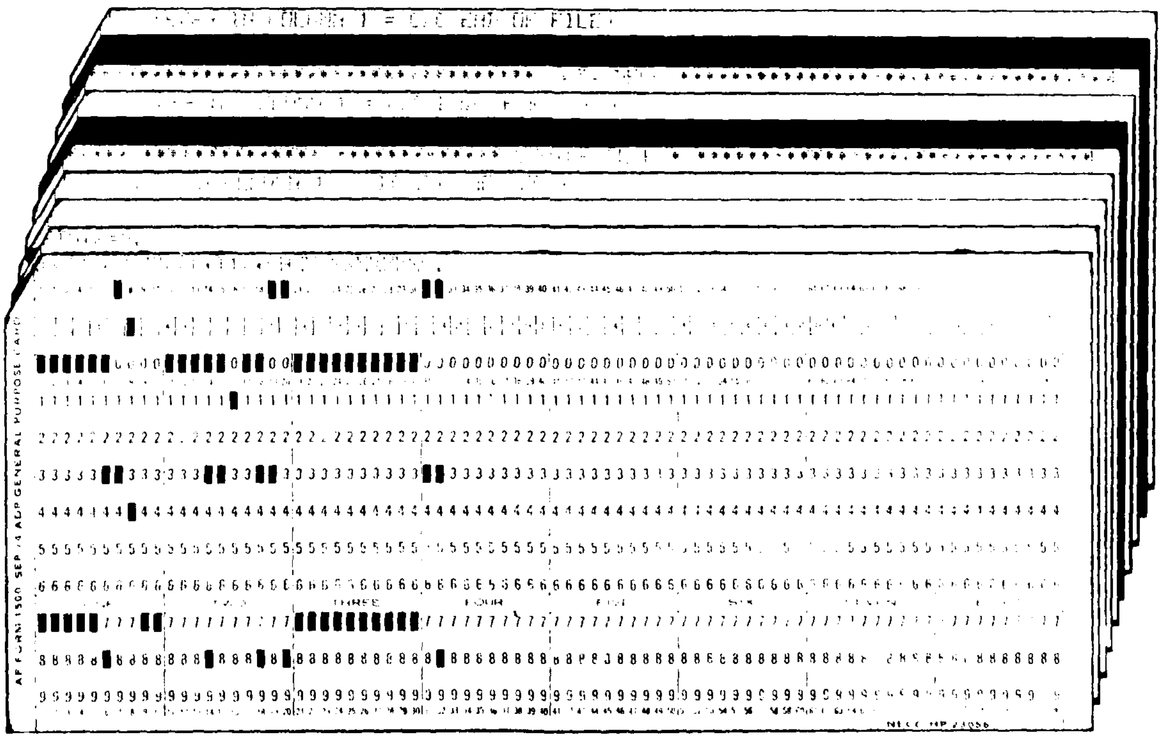


FIGURE 5 CONTROL CARDS

Program THRUST Input/Output:

The data needed for program THRUST consists of ordered pairs of F_t and V_e, where F_t is engine thrust divided by ambient pressure ratio, F_t/δ_a, and V_e is equivalent airspeed. Each ordered pair is placed on one data card in the format (F10.2, 10X, F10.2), with F_t being first and V_e second. Although the program needs only two data points to operate, the user should provide at least 8 data points to insure statistical validity. These data can be obtained from engine manufacturer's data or if the airplane is instrumented for thrust, it can be obtained from test. Figure 6 is given for further clarification of format. Sample output for program THRUST is shown in Figure 7.

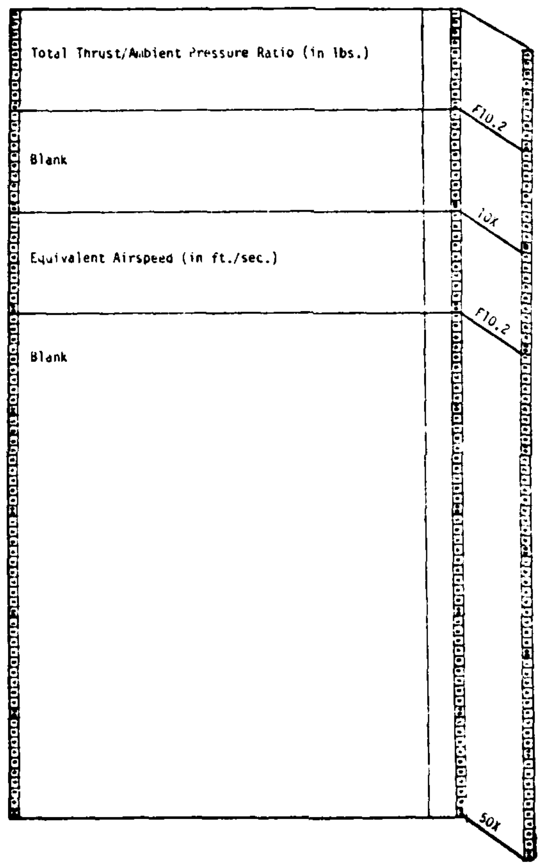


FIGURE 6 PROGRAM THRUST DATA FORMAT

```
THRUST AT ZERO SPEED =      598.00  SLOPE OF THRUST CURVE =  -.00441403
```

FIGURE 7 PROGRAM THRUST SAMPLE OUTPUT

Program DRAG Input/Output:

Program DRAG data consists of general data including aircraft constants and ambient air data, and coast down speed and distance data over two speed ranges. Each parameter value is placed on one card, along with an identifier for that parameter, and read in the format (A10, 10X, F20.2). Table 1 summarizes the data needed and the required identifiers to be used on the cards. Figure 8 is given for further clarification of format. Sample output for program DRAG is shown in Figure 9.

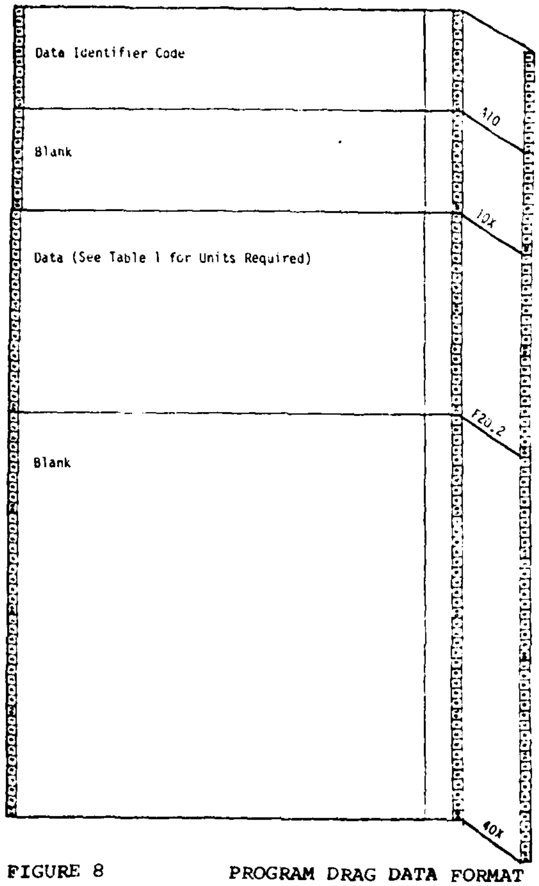


FIGURE 8 PROGRAM DRAG DATA FORMAT

WING AREA	[illegible].0000
WEIGHT	[illegible].00000
SLOPE OF T	-.01076
DENSITY RA	.[illegible]
THRUST	[illegible].00000
DRAG COEFF	.[illegible]500
LIFT COEFF	.[illegible]
INITIAL SP	[illegible].00000
FINAL SPEE	0.00000
DISTANCE	4553.00000
DISTANCE	4554.00000

DRAG COEFFICIENT = .150
ROLLING FRICTION COEFFICIENT = .7500
1. ITERATIONS WERE REQUIRED

FIGURE 9 PROGRAM DRAG SAMPLE OUTPUT

TABLE 1
Program DRAG Data

Required Data	Identifier Code
Wing Area (sq ft)	WING AREA
Aircraft Weight (lbs)	WEIGHT
Ambient Air Density Ratio	DENSITY RA
Thrust at Zero Speed (F_{t_o}/δ_a)	THRUST
Slope of Thrust Curve	SLOPE OF T
Coefficient of Lift	LIFT COEFF
Initial Speed - First Speed Range	SPI-1
Final Speed - First Speed Range	SPF-1
Distance Traveled - First Speed Range	DISTANCE 1
Initial Speed - Second Speed Range	SPI-2
Final Speed - Second Speed Range	SPF-2
Distance Traveled - Second Speed Range	DISTANCE 2

Program COFS Input/Output:

Program COFS data consists of general data including aircraft constants and ambient air data, and specific brake test data. Each parameter value is placed on one card, along with an identifier for that parameter, and read in the format (A10, 10X, F20.2). Table 2 summarizes the data needed and the required identifiers to be used on the cards. Figure 8 shows the same format required to input the data needed for Program COFS. Sample output for the program COFS is shown in Figure 10.

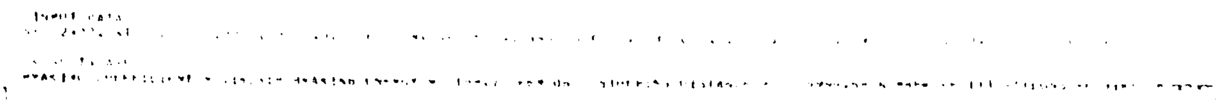


FIGURE 10 PROGRAM COFS SAMPLE OUTPUT

TABLE 2
Program COFS Data

Required Data	Identifier Code
Wing Area (sq ft)	WING AREA
Aircraft Weight (lbs)	WEIGHT
Ambient Air Density Ratio	DENSITY RA
Thrust at Zero Speed (F_{t_o}/δ_a)	THRUST
Slope of Thrust Curve	SLOPE OF T
Coefficient of Lift	LIFT COEFF
Coefficient of Drag	DRAG COEFF
Initial Speed	INITIAL SP
Final Speed	FINAL SPEE
Distance Traveled	DISTANCE

Program SPEED Input/Output:

Program SPEED data consists of general data including aircraft constants and ambient air data, and specific brake test data. Each parameter value is placed on one card, along with an identifier for that parameter, and read in the format (A10, 10X, F20.2). Table 3 summarizes the data needed and the required identifiers to be used on the cards. Figure 8 shows the same format required to input the data needed for Program SPEED. Sample output for Program SPEED is shown in Figure 11.

```
WING AREA              [illegible]
WEIGHT                 [illegible]
DENSITY RA             [illegible]
THRUST                 [illegible]
SLOPE OF T             [illegible]
LIFT COEFF             .21
DRAG COEFF             .19
BRAKING CO             .14
ENERGY                 275000.00

DESIRED BRAKE ENERGY =      .3 [illegible] 06  INITIAL SPEED =   [illegible]0.00 NUMBER OF ITERATIONS REQUIRED = 50.

STOPPING DISTANCE =   [illegible]
```

FIGURE 11 PROGRAM SPEED SAMPLE OUTPUT

TABLE 3
Program SPEED Data

Required Data	Identifier Code
Wing Area (sq ft)	WING AREA
Aircraft Weight (lbs)	WEIGHT
Ambient Air Density Ratio	DENSITY RA
Thrust at Zero Speed (F_{t_o}/δ_a)	THRUST
Slope of Thrust Curve	SLOPE OF T
Coefficient of Lift	LIFT COEFF
Coefficient of Drag	DRAG COEFF
Braking Coefficient	BRAKING CO
Desired Brake Energy (ft-lbs)	ENERGY

PROGRAM CONTROL PLOTS

Program control plots are required to give the test engineer an idea of the trends involved with the tests. Plotting the data from each individual test provides a graph of information which can be used to identify deviations from expected results and to predict critical test points. Without such trend information, some problems may not be identified and unexpected results may be more frequent than normal.

One very useful type of control plot consists of peak brake temperatures versus input brake energy (Figure 12). Since most brake tests are done in an increasing aircraft kinetic energy method, this type of plot can be used to identify when dangerous temperature levels can be expected. This type of plot is generated from dynamometer tests, normally presented in the contractor's brake qualification report, therefore flight test data can be overlayed on the dynamometer data to identify deviations.

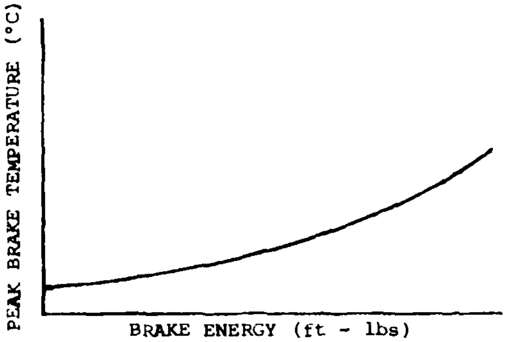


FIGURE 12 PEAK BRAKE TEMPERATURE VS BRAKE ENERGY

The only difficult portion of this analysis is determining how much of the aircraft kinetic energy actually was absorbed by the brakes. References 2-5 all present methods of computing brake energy and any consistently used method should work. The method from reference 10 was presented in the Brake Energy Section.

Another type of tracking plot is average braking coefficient vs input brake energy (Figure 13). This method computes an average value of braking coefficient for each run and plots this versus energy absorbed by the brakes. (See References 2 and 3.) Since coefficient of friction may be relatively constant for some classes of brakes (carbon, for example), this trend information would only show significant changes in braking coefficient with increasing energy absorption by the brakes. Steel brakes, for example, show a decrease in average braking coefficient with increased absorption. This is due to brake fade.

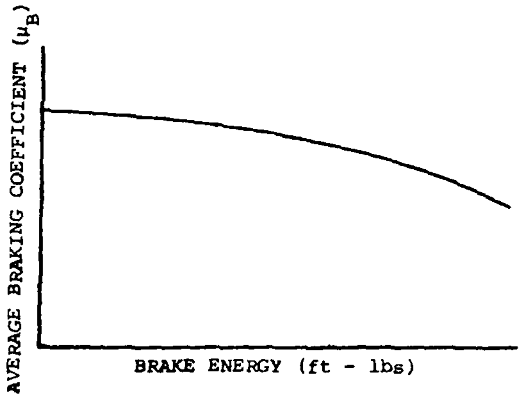


FIGURE 13 AVERAGE BRAKING COEFFICIENT VS BRAKE ENERGY

A similar type of macroscopic analysis for trend information would be plotting average slip ratio obtained during a run versus inertial velocity (Figure 14). Slip ratio is defined as the difference between aircraft velocity and wheel velocity divided by aircraft velocity.

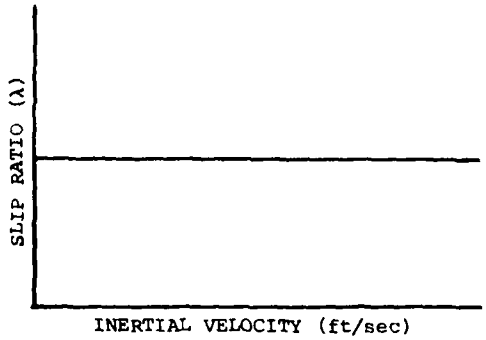


FIGURE 14 SLIP RATIO VS INERTIAL VELOCITY

As with the average braking coefficient, the slip ratios achieved should be consistent and any major deviation would be a cause for deeper investigation.

Program control plots enable the test engineer to monitor the pulse of the braking system. Major, unexplained changes are signs of some problem in the system and additional analysis should be done before the program continues. In this way, some of the dangers of brake testing can be limited and the test program will be under control.

BRAKE/ANTISKID SYSTEM ANALYSIS

Introduction:

The goals of this type testing are to obtain an in-depth feel for how the braking system works and to determine how efficiently the system takes advantage of the braking conditions. The requirement for system analysis data exists to provide an inside look at the working system. Using only an external view, such as stopping distance achieved, the test engineer cannot diagnose problems nor predict how the system will react under different conditions. By analyzing the system on the micro level, the test engineer can better understand the system and doesn't have to test to failure.

This type of data analysis cannot be obtained cheaply, however. First of all, highly accurate instrumentation has to be installed on the test vehicle to tell the story of the system. Secondly, the data analysis software and procedures have to be developed and checked out. Third, the reduced data has to be processed quickly enough to be used before subsequent tests. All of these take dedicated time and money. Without this support, the analysis efforts will be of limited use.

It is preferred that the data be telemetered from the aircraft so as to be available to the engineer(s) and test conductor in near real-time. This is necessary for control of the testing as well as for rapid data analysis between tests.

Antiskid Operation:

The theory of operation for an antiskid system can be learned from manufacturer's literature. Determining how well it actually works requires analysis of the system on the aircraft. To do this, special instrumentation of the antiskid system control unit has to be installed. The location of instrumentation varies with the different antiskid system control logic. The following paragraphs present an example of what could be done for one antiskid system.

One common antiskid system is the Hydro-Aire Mark III. Basically, the Mark III is a velocity-rate-controlled system. The antiskid control logic compares the instantaneous wheel velocity (computed from a digital wheel RPM counter) to the aircraft forward velocity (derived by subtracting the computed deceleration from the last known free wheeling velocity). If the difference between the two velocities exceeds a threshold value, the antiskid releases the brakes to allow the wheels to spin up. This threshold velocity is initially set at 10 feet per second but decreases with increased skid activity. (For a more detailed description of the Mark III antiskid system, see Reference 6.)

It should be noted that in previous systems tests, the manufacturer's description did not agree with how the system actually was built to operate. If the tests show the system does not operate in accordance with the manufacturer's description, before you can determine if a malfunction has occurred you must first determine if this is really how it is designed to work. These discrepancies are probably the result of poor communication between system designers and manual writers.

Analysis to determine how well this system works would center on testing the accuracy of the velocities it uses and testing how close the system operates at its self-imposed threshold value. The first will show if the inputs to the system are valid. The second will show if the system controls braking to the best of its ability.

To test the antiskid values, duplicate instrumentation would have to be installed. RPM counters could be recorded, converted to wheel velocity and checked against the antiskid value. Accurate space positioning data obtained from either external (Askania) or internal (Inertial Navigation Systems - INS) could be used to determine aircraft velocity which can be compared with the antiskid derived value.

To test the internal efficiency of the system, the velocity data could be used to compare slip velocities and slip ratios. The slip velocities could then be compared to the antiskid threshold value to determine how optimally the system is being controlled. The best braking generally occurs at slip velocities between 10% and 20% of the aircraft velocity or at slip ratios between 0.1 and 0.2. (See References 7, 8, and 9.)

Brake/Antiskid Compatibility:

Much of the AFFTC brake testing has been done to compare different brake disks. This type of testing requires an analysis of the compatibility between the brake and antiskid systems in addition to tests on the brake disks themselves. A main area of interest would be in the brake torque response to changes in antiskid applied brake pressure. Runway friction transition response will also provide some good information.

Dynamic Pressure Torque Response:

The torque response to changes in applied brake pressure provides a good indication of brake/antiskid compatibility. Looking at the pressure-torque plot for a braking run shows the response of the brake pressure applied by the antiskid system. Figure 15 is an example of such a plot.

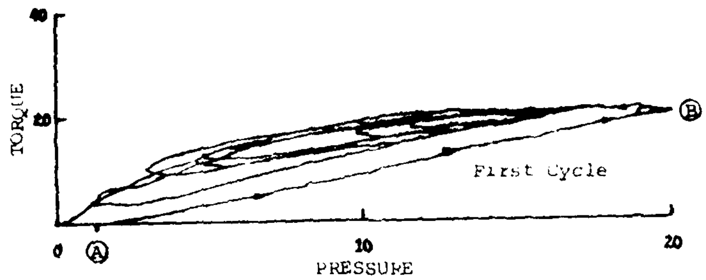


FIGURE 15 TORQUE VS PRESSURE RELATIONSHIP

The plot clearly shows the hysteretic nature of the pressure-torque relationship. Point A represents the minimum pressure required to collapse the brake stack to begin torque response. As the pressure on the brakes increases, the torque developed by the brakes also increases. This continues until the torque exceeds the available ground reaction force and the wheel enters a skid, Point B. The antiskid system detects the skid and dumps the brake pressure. As the pressure drops, however, the brake torque for a given brake pressure is higher than it was when the pressure was increasing. This is in part due to brake surface friction characteristics, brake stack construction, and hydraulic lags. In general, smaller hysteresis loops mean a better brake stack.

Ideally, the brake pressure plot should be a single line without hysteresis (Figure 16).

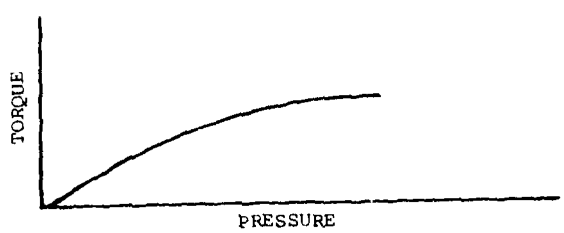


FIGURE 16 IDEAL PRESSURE VS TORQUE RELATIONSHIP

That is, for a given brake pressure input there would only be one torque possible. The antiskid system could then determine the optimum torque for braking and keep the brake pressure at that level.

In actuality, the wide range of pressure which can produce a derived torque output necessitates wide variations in applied brake pressure. Comparison of the dynamic pressure-torque response should provide a good feel for the relative effectiveness of the brake stacks.

Such tests can be easily run on a dynamometer but should also be done on aircraft to insure desired performance. It should be noted that special tests are not needed to acquire this data.

Runway Friction Transition Response:

In addition to looking at the pressure-torque response, investigation of the system response to changing runway friction could prove interesting. The system response as the landing gear goes from a dry surface to a wet surface will reflect on the effectiveness of the system. Such tests are routinely accomplished at the NASA Langley Landing Loads Facility. (See References 10, 11, and 12.)

Figures 17 and 18 are examples of two different antiskid systems. They are interesting in the fact that they show two very different response characteristics. In Figure 17 the wheel speed and brake pressure drop off as expected when the aircraft encounters the flooded area. The same occurs in Figure 18 but the wheel speed increases much more quickly, which allows the brake pressure to be reapplied more quickly and braking can once more begin.

The long time required for the brake pressure to increase in Figure 17 shows that the system responds slowly to the changing runway condition. Imagine what could happen if there were a number of badly spaced puddles on the runway; it is possible that very little braking would occur.

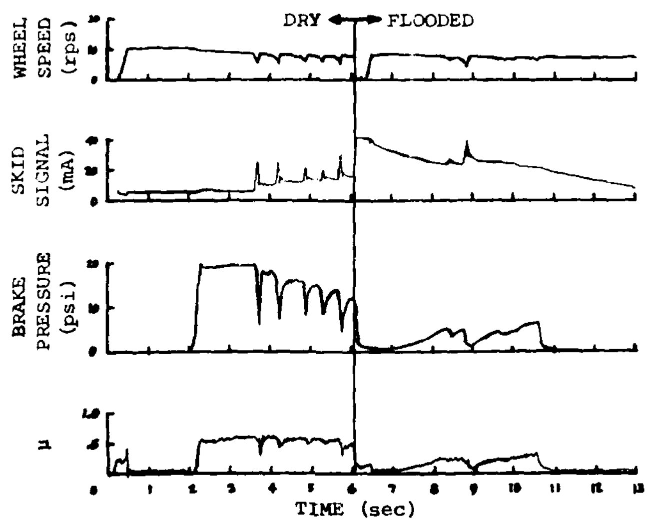


FIGURE 17 ANTISKID RESPONSE 1

The high frequency brake pressure of the signals in Figure 18 shows that the antiskid system can respond very quickly to changing conditions. The activity after the aircraft passes into the flooded area shows that the system continues to brake under the degraded conditions, although to a lesser degree than before. Figure 17 signal activity in the flooded area is much less and signifies braking to a much lesser degree.

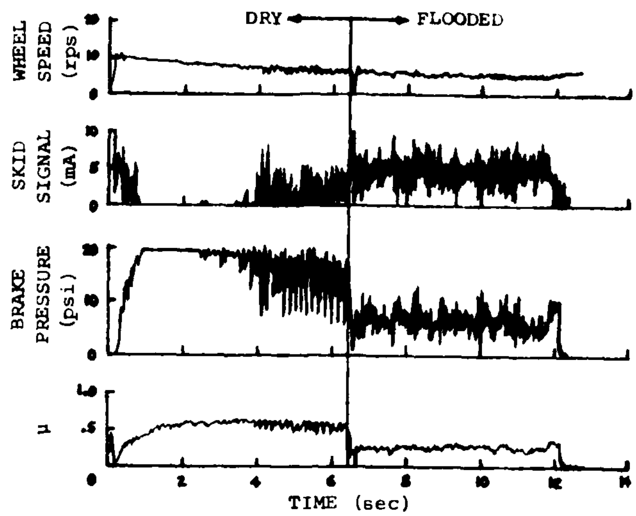


FIGURE 18 ANTISKID RESPONSE 2

The differences in response could be due to differences in the antiskid systems or in brake/antiskid compatibility. In either case, rapid response and high frequency cycling generally represent the best braking. Whether comparing different antiskid systems or different brakes on one antiskid system, the system response is very important.

Braking Efficiency:

Internal analysis of the antiskid system provides a good understanding of the system operation but the analysis of how well the system takes advantage of the available friction forces provides the best measure of braking efficiency. The difficulty in this type of analysis is measuring the parameters in the highly dynamic environment of the landing gear. Good analysis, therefore, requires very accurate instrumentation and data recording.

Efficiency calculations involve approximating the maximum available braking level and determining the percent of this level which is achieved by the braking system. The most common procedure used is the time history plot of a measured parameter (usually drag force, brake torque, or brake pressure)(Figure 19). The peaks of the time history curve represent the points of incipient skid. At these points the level of braking was reduced to prevent a locked wheel skid. Straight lines connecting the peaks represent the maximum available braking force. Therefore, the efficiency of the system is the ratio of the area under the time history curve to the area under the peak-to-peak straight lines. The ratio of these two areas results in a percentage figure which approximates how well the antiskid system controlled the braking.

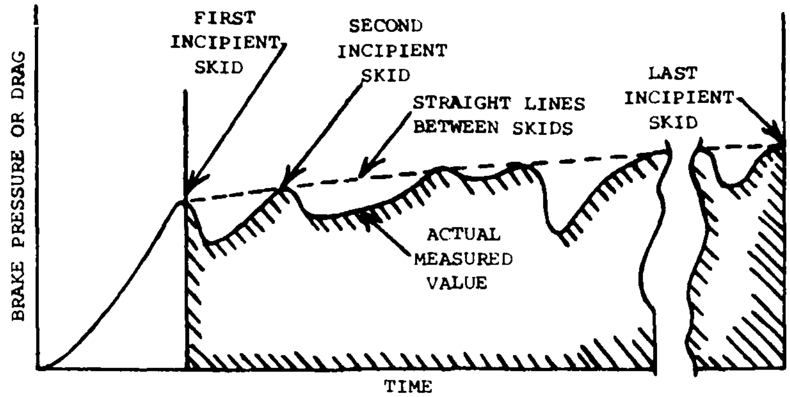


FIGURE 19 EFFICIENCY CALCULATION PLOT

The parameters normally used in efficiency calculations are drag force, brake torque, and brake pressure. The following sections explain the approximations and problems involved with each of these parameters. The purpose of these sections is to present some of the errors involved with using the efficiency calculations.

The analysis methods should not be used blindly without knowing possible sources of error. The sections occur in order of decreasing validity. Drag force efficiency involves the least possibility for error, brake torque is next, and brake pressure efficiency involves the greatest possibility for error. The order of occurence, however, is also of increasing ease of measurement. So the method of analysis will depend on how willing the program manager is to trade accuracy for effort or cost of instrumenting the aircraft.

Drag Force:

Drag force is the horizontal force generated between the tire and the ground during braking. The maximum value which this force can obtain is a function of the coefficient of friction (μ) and the vertical load (F_{vert}) on the tire, or

$$F_{Drag_{Max}} = \mu F_{vert}$$

For maximum braking, this maximum value of drag force should be achieved. Obtaining this optimum drag force, however, is very difficult since both μ and the aircraft load are changing during braking. The objective for antiskid systems is to find the maximum available force and brake at that level.

The peaks of the drag force time history plot thus represent the maximum available braking force. These peaks are clearly the points of maximum braking and using the ratio of the areas to determine braking efficiency is valid. The only source of error is in the recording of the data. If the instrumentation and data recording are accurate, this procedure will provide excellent efficiency data.

The AFFTC, however, has little experience in instrumenting for drag force. Such work has been contracted out but this adds expense. The size and orientation of the landing gear structural members make the instrumentation difficult. In the NASA Langley tests, (see References 10, 11, and 12), the strut was replaced by five dynomometer support beams. Two of the beams were used for measuring vertical forces, two were used for drag forces, and one was used for side forces. Three accelerometers on the test wheel axle provided information for inertia corrections to the force data. If this problem of data collection proves insurmountable, the next best efficiency calculation would be brake torque.

Torque:

Brake torque is the wheel spin down torque created by mechanically braking a rolling aircraft with wheel brakes. It is a resistive torque and must equal the sum of all the other torques acting on the wheel at any instant.

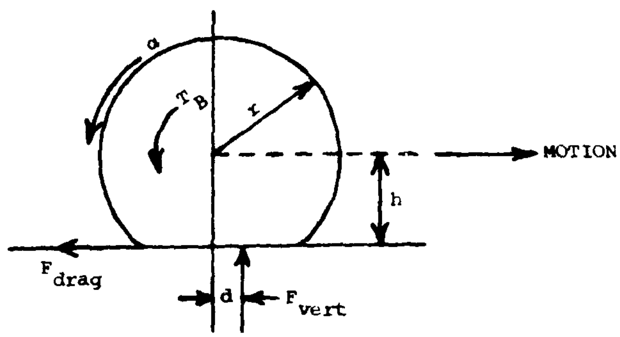


FIGURE 20 WHEEL TORQUE AND MOMENTS DIAGRAM

From Figure 20, the equation for brake torque (T) is:

$$T = F_{Drag} h - F_{vert} d + I\alpha$$

Where:

- F_{Drag} is the drag force acting on the tire at the ground
- h is the distance between the ground and the wheel axle
- F_{vert} is the vertical force acting on the tire at the ground
- d is the distance the vertical load center of pressure is offset from the center of the tire (positive is forward)
- I is the moment of inertia of the rotating wheel
- α is the angular acceleration of the wheel (positive is spin down)
- ω is the angular velocity of the wheel

This shows that brake torque cannot be completely defined by the product of drag force and its moment arm. This product may closely reflect the torque when the tire operates at a fixed slip velocity where α becomes negligible and d is rather small. However, in most cases antiskid cycling results in rapid wheel speed changes and significant shifts in the fore and aft position of the tire footprint center of pressure (d).

Therefore, it is important to understand that when brake torque is used to approximate braking efficiency, the results will not be identical to those obtained from drag force data. NASA Langley comparisons of the two efficiencies show that the differences are small. The NASA

Landing Loads Facility has a much more consistent braking surface than most runways, thus their coefficient of friction for the surface did not vary as much as it does in real braking situations. Paint, rubber deposits, and surface inconsistencies provide for a much more changing available friction force and this may cause the differences between the torque and drag force efficiencies to be greater.

Brake Pressure:

Brake pressure is the pressure of the hydraulic fluid which compresses the brake stack. It is often used for efficiency determination since it is very easy to measure. The peak values of brake pressure on the time history plot represent the points at which the antiskid detected a skid and then reduced the pressure.

However, even more so than with brake torque efficiency, there is a question of how well the brake pressure peaks actually represent the points of true peak drag forces. Since the level of pressure is produced by the antiskid and not by the extent of braking, the brake pressure peaks could be somewhat offset. For instance, the peaks could be lower because the antiskid reacted to some threshold other than peak braking, or the peaks could be higher due to some lag which causes the brake pressure to continue to increase while the wheel is actually entering a skid.

As with brake torque efficiency, NASA Langley results show that pressure efficiencies do correspond with drag force efficiencies but differences in the level of test control could change results. Brake pressure efficiencies can be used but the possible errors should be understood.

TEST PLANNING

ADVANCE PLANNING

When the Flight Test Center is assigned as the Responsible Test Organization (RTO) for brake system testing, a certain amount of advance planning is required. An estimate of the number of flights (ground tests also) and hours required to evaluate the system will be made. The number of tests and hours will depend upon the test objectives and other factors which must be agreed upon between the RTO and test sponsor.

OBJECTIVES

General objectives for braking tests and antiskid compatibility tests are as follows:

A. Determine brake compatibility with respect to:
   (1) Antiskid system (wet and dry runway)
   (2) Aircraft structure/landing gear structure
   (3) Engine run-up capability (wet and dry brake)
   (4) Wheel and tire temperature (relationship with energy absorbed)
   (5) Aircraft directional control (differential braking)
   (6) Mixed brakes, i.e., brakes from one vendor on one side of aircraft and brakes from another vendor on the other side of the aircraft.

B. Gather brake stack wear data

C. Gather maximum brake stack temperature data vs brake energies

D. Perform reliability and maintainability evaluation

E. Obtain comparative braking distance data

INSTRUMENTATION

The following instrumentation is recommended for all brake and anti-skid compatibility tests:

PARAMETER	TYPICAL RANGE/UNITS	FREQUENCY RESPONSE	PRIORITY SEE NOTE	COMMENTS
Brake Pedal Force	0-200 lbs	5hz	B	L/R
Rudder Pedal Force or Position	0-200 lbs	20-100hz	B	Both L/R
Nose Gear Angle	+70°	5hz	C	-
Nose Gear Strut Pressure (used to determine weight on nose gear)	0-2000 psig	20-100hz	C	-
Skid Control Value Input and Output Pressure	0-3000 psig	20-100hz	B	L/R
Skid Control Value Signal	0-12 voltsDC	50-100hz	A,B	L/R
Main Gear Wheel Speed	RPM Equiv of 0-180 kts	50-100hz	A,B	L/R
Main Gear Strut Pressure	0-3000 psig	50-100hz	C	All Gear
Nose Gear Steering Mode	Discrete	-	C	-
Brake Stack Temperature	0-2000°C	1hz	A,B	All Brakes
Aircraft Ground Speed - Inertial	0-180 kts	1hz	A,B	From INS
Airspeed	0-200 kts	1hz	A,B	-
Fuel Quantity	Dependent on A/C Type	1hz	C	Fuel Quantity Indicators
Brake Torque or Force	Dependent on A/C Type	20-50hz	C	L/R
Altitude	0-5000 ft	1hz	C	-

Aircraft Velocity, Deceleration, Distance Traveled	B	Askania coverage
Photographs (still, motion picture, onboard/on ground	B	
Wind Velocity and Direction	B	Portable Weather Equipment
Ambient Temperature	B	
Correlation Signal Between Onboard and Askania Data	B	

Notes: 1. Priority Code: A - Safety of Flight Required (cockpit display or T.M.)
B - Required for Engineering Analysis
C - Desirable for Engineering Analysis

2. Safety of flight required parameters must all be operational or testing cannot be accomplished.
3. Engineering required parameters must be operational or a thorough technical evaluation cannot be completed. At least one side of the aircraft (left or right gear) should have all parameters operational.

For control of tests, readouts of brake temperature, velocity, and fuel quantity must be available to the test conductor.

TEST CONDITIONS

Various types of testing are necessary to evaluate aircraft brakes and antiskid systems. Basically the tests are of two types; taxi, and various stopping tests on wet or dry runways.

Control of brake temperatures and energies must be exercised in all tests. Tracking test results is vital for following the progress of individual tests and for identifying trends. These are methods of providing this data to the analysis section. Because temperatures are critical to conducting safe tests, a plot of peak brake temperature versus brake energy is probably the most useful for test control. Further, it is possible to compare temperature/energy data directly to dynamometer tests. Significant deviations from anticipated temperature trends must be resolved before proceeding to critical test conditions.

While it is possible to use total aircraft energy as the abscissa of temperature control plots, it must be recognized that total aircraft and brake energy are not the same. Other contributors to total aircraft energy are thrust, aerodynamic drag, and tire scrubbing. These are accounted for in the computer programs in Appendix A.

Other control plots can be obtained from average braking coefficients and slip ratios. Both of these types of plots should provide insight into brake and antiskid performance. It should be recognized that each brake and antiskid system may have specific characteristics which would dictate the tracking of other important or meaningful parameters.

DETAILED PLANNING

Test Information Sheet (TIS):

After the preliminary test planning has been identified, documented, and provided to the project engineer, the systems analyst (test engineer responsible for the analysis of test data on the brake system) should begin detailed test planning. AFFTC regulations 80-12 and 80-13 should be consulted. The Systems Engineering Handbook has a section on TIS preparation. An example TIS is included in Appendix B. A discussion of the TIS topics follows in paragraphs which are numbered as they are addressed in the TIS.

1.0 References: The first reference to be listed is the Air Force management document that is used to generate the aircraft or system contract. This document will detail the operational requirements that were intended to be satisfied. The next reference document will be the contractor's system specification document. In this document, the contractor tries to quantify the operational requirements contracted for by the Air Force. The third reference document should be the detailed braking system specification document published by the braking system manufacturer. There may be separate references for the brakes and the antiskid system. The fourth reference document should be the aircraft flight manual showing how the system operates. A fifth document is the dynamometer test report. All of the maintenance documents used at the AFFTC to maintain the system should also be referenced.

2.0 Test Item Description: The description should not be of a braking system in general, but rather what makes up this particular braking system. Identify all the aircraft components that are considered to be a part of the braking system and that will be included in the testing. Describe the antiskid system and the control modes.

3.0 Test Objective: The test objective will be what was agreed upon by the RTO and customer, i.e., determine brake system compatibility with other aircraft systems.

4.0 Success Criteria: What determines if the system is adequate, meets specifications, or is operationally suitable? If any development changes are made to the system after the testing has been completed and if those changes could affect the system performance, then significant re-testing may be required. Operational suitability testing will continue to the end of the test program.

5.0 Data Requirements: What data is required from the tests and how is data to be presented: i.e., program control plots.

Ground test data should be obtained and compared with the specifications called out in the maintenance technical publications.

6.0 Test Procedures: This section will contain the overall test plans for the brake/anti-skid system. Specific test techniques are described in this section.

7.0 Support Requirements: This section should detail all of the services furnished by organizations other than the engineer's own division or branch. Included should be a list of instrumentation parameters, range support, weather support, data support, photo support, fire department, weight and balance, etc.

DATA COLLECTION

Collection of the brake system data is the responsibility of the test engineer assigned to evaluate the brake system. The test engineer must plan in great detail how the test points are to be obtained. After he has planned how to obtain the points for each mission, he should make up cards for this part of the testing. He should discuss the test cards with the project personnel to make sure that all test points are practical. A test support summary should be written for each test flight detailing flight speed and duration, photo or safety chase requirements, range support requirements, and instrumentation support requirements.

Instrumentation support requirements should produce a prioritized list of parameters which must be operating for data analysis and safety on each mission. The planning should also identify any special instrumentation pre- and post-flight requirements.

TEST CONDUCT

GENERAL

All critical tests should be conducted on Edwards AFB Runway 04 if the lake bed is usable. If the lake bed is not usable, and if the aircraft is equipped with an arresting hook, the tests may be performed on Runway 22. If Runway 22 is used, provisions must be made to assure that the arresting system is operational. A determination if the runway is to be used should take into consideration lake bed condition, aircraft arresting hook capability, and barrier arresting system capability. Testing should be terminated whenever winds exceed previously determined test limits, including gusts in any direction.

After each test, cooling fans will be used to lower the wheel/tire/brake temperature for the next test (probably down to about 100°F). Consideration should be given to prepositioning the cooling fans so that the aircraft can be taxied into position without using personnel to place the fans. Fan placement near the hot tire/wheel is a hazardous task and should be done with extreme caution. Airborne cooling of brakes can be accomplished if telemetered brake temperature is available to the test conductor.

After each test, (when the temperature has lowered to a point which is safe) tire wear will be measured, tires examined for flat spots, chunking and separation, and the brake visually inspected for wheel and tire damage. If found acceptable, the aircraft will taxi slowly to the end of Runway 04 for the next test.

(Note: For safety, any time a hot wheel/tire has to be approached, it should be from the front or rear direction (not the side) due to the possibility of bursting because of over pressurization. This includes cooling fan placement.)

COMMAND CONTROL

Overall control of the test operations will be exercised by the project engineer or his designated representative as the test conductor. The water trucks and all the fire fighting equipment will be under direct control of the fire chief on duty or his designated representative, who will respond for normal test operations to the direction of the test conductor. If a tire is blown or any other mishap occurs, control of clearing the runway and/or recovering the aircraft will revert to the on-site or on-scene commander in accordance with normal crash recovery plans and procedures.

Specifically, the runway will be closed to normal takeoff and landing traffic during testing. The tower will clear vehicles and personnel onto and off the runway through the test conductor. After the aircraft has stopped, and prior to the next test, vehicles and personnel will be cleared onto and off the runway by the test conductor. The test conductor will notify the tower when the runway is clear for the next test. The test conductor will maintain communication with the tower at all times in order to clear the runway in case any other aircraft must make an emergency landing.

The only vehicles allowed on the runway during testing will be the water truck, the fire chief's, and the test conductor's. Figure 21 shows locations for the various vehicles and the runway wetted area.

TYPES OF TESTS

Various types of testing are necessary to thoroughly evaluate the aircraft brakes and antiskid system. The following subparagraphs detail the common tests required and the order in which they should be performed:

Fit and Function Check:

If the brakes have not been used on the aircraft previously, checks should be made for hydraulic line clearance, etc. With the aircraft on jacks, each gear should be slowly retracted to note clearances between brake and the strut, gear door, and equipment in the wheel well (door must be disconnected from actuator to check wheel well clearances).

Taxi Tests:

A number of low speed taxi tests will be done on the runway to ensure integrity of the modifications, and to ensure proper functioning of the instrumentation and brake system. Brake temperatures must be monitored during these tests to ensure that no limits are exceeded. Brakes must be allowed to cool before starting additional tests. Taxi tests should be done at low weights at 50-60 knots with light braking building up to heavy braking. Tire taxi limits as to distance/weight must not be exceeded.

Brake Tests:

Since these tests may be used for a variety of test objectives, the procedures defined here are general in nature, but will follow what is normally required. The methodology is always to use a buildup of energy levels and to monitor temperatures and wear/condition of tires/brakes. Generally, at least five stops will be required at gradually increased brake energies for each test objective, i.e., dry runway antiskid on, dry runway antiskid off, wet runway antiskid on, etc.

Operational Check:

Four or five stops will be made in the normal gross weight range on a dry runway. Braking should be moderate, such that antiskid activity is kept at a minimum. Braking should be terminated at the flight manual recommended speed. A buildup approach will be used such that the highest brake energy will be on the last test. Maximum energy permitted would not exceed the normal brake energy zone for the aircraft.

Antiskid Compatibility:

Four to five braking stops will be required to verify compatibility between the brake and antiskid system. Normally this will consist of three wet runway braking stops and two dry runway stops.

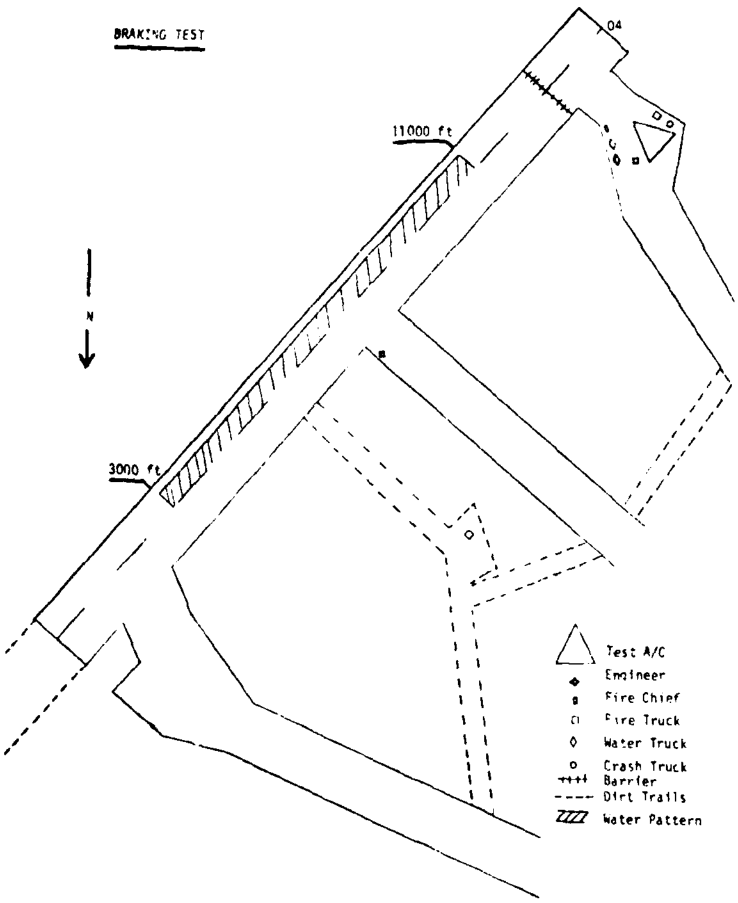


FIGURE 21 BRAKE TEST RUNWAY/VEHICLE PLACEMENT

The order of these tests should be as follows:

Type of Stop	Runway Condition	Acft. Gross Wt. Range
Landing	Wet	Maximum Landing
Landing	Wet	Minimum Fuel Reserve
Landing	Dry	Minimum Fuel Reserve
RTO	Wet	Maximum Takeoff
RTO	Dry	Maximum Takeoff

The braking speeds should be controlled such that all aircraft energies will be essentially the same for each test point and this energy level should not exceed the midpoint between the normal and overload brake energy zones. All of the braking stops during this test should be heavy braking, i.e., full brake pedal deflection, down to the Flight Manual recommended brake release speed.

Maximum Brake Capability:

Four to five rejected takeoffs on a dry runway should be performed to verify the brakes' capability in aiding the aircraft to stop, or abort a takeoff, at maximum gross weight. The initial brake energy should be slightly higher than the antiskid compatibility test energy and each successive stop should be incrementally higher until the maximum planned energy or temperature is attained.

Wet Brake:

The brakes should be sprayed for one minute with water from a fire hose so that static and dynamic torque can be evaluated. Cycling the brake pedals will aid in assuring all brake disks are exposed to water. To evaluate static torque, soak the brakes in an engine runup area with chocked tires. After the soak, remove the chocks, hold the brakes and slowly increase engine power until normal takeoff runup power is achieved or until the aircraft moves. For dynamic torque use the same soaking and chocking procedure. After the soak, remove the chocks and perform a taxi stop with one brake from approximately 20 knots. Repeat the soaking and stop for the other brake.

Mixed Brake:

If the particular aircraft program has two or more qualified wheel and brake vendors, it is necessary to conduct a mixed brake test. This test will be a repeat of the test conditions and procedures identified for the antiskid compatibility tests in the paragraph describing those tests. It should be noted that both vendors' brakes must have completed all testing identified in this section prior to the mixed brake test. During this test, every combination of using one vendor's brake on one side of the aircraft with a different vendor's brake on the other side should be evaluated.

RUNWAY WETTING PROCEDURE

It is important to observe the procedure and locale for wetting the runway. Standard wetting procedures are as follows:

A. Enter active runway.

B. Wet a 50 foot wide test section to one side of the centerline starting at the 11,000 foot runway remaining marker and proceed toward the approach end of Runway 04 at approximately 10 mph.

C. Stop wetting at the 3000 foot runway remaining marker. Exit the runway.

D. Notify the pilot and test conductor when wetting is complete.

The wetting pass should be made with a 1.1 percent foam/water mixture. The second pass should use water only. With these two passes the first wet runway test can be performed. After each aircraft pass, the runway should be re-wet alternating between the foam/water mixture and water only. It is mandatory that the aircraft make its test run immediately after the water trucks exit the active runway to assure that water consistency, or runway slipperiness, is maintained between test points. See Figure 21 for the test section locale.

CHECKLISTS

AIRCREW CHECKLIST

Call Sign ____________________
Test Frequency ________________

1. Taxi to end of test runway.
2. *Notify test conductor when ready for first wetting pass.
3. *Notify test conductor when ready for second wetting pass.
4. Turn data recorder on. Time ____________
5. Fuel quantity. lbs. fuel ____________
6. Notify test conductor when ready to start run.
7. Antiskid as called for. (down/off)
8. Push event switch for time correlation. (Give countdown for Askania.)
9. Start test run.
10. Accelerate to test velocity.
11. Note fuel quantity and speed.
12. Throttle to idle.
13. Apply maximum (or as specified) braking upon entering test section.
14. Hold brake pressure on until speed is below 20 knots or aircraft exits wetted test section, where applicable.
15. Below 20 knots release brakes and turn antiskid off.
16. Call data off, push event and turn recorder off.
17. Monitor brake temperature.
18. Notify test conductor of entry speed and weight.
19. Test conductor will notify crew whether or not brake energy limit has been exceeded.
20. Aircraft will be taxied to point where cooling fans are to be applied.
21. When brakes cool to 100°F, crew chief will inspect tires and brakes.
22. Tread wear measurement will be made.
23. Test conductor will notify when to taxi for next test point.

*Wet Runway Only

TEST CONDUCTOR CHECKLIST

Call Sign______________

Test Frequency__________

1. Check that all vehicles and aircraft are in the staging area.
2. Make sure all communications and telemetry is up and operating.
3. Obtain meteorological data from base weather.
4. Obtain initial tire, wheel, and outside brake temperatures from on-site engineer.
5. Re-brief test conditions and check that all support personnel are ready.
6. Notify pilot when clear to proceed with run.
7. Notify pilot if data shows signs of a "wheel lock".
8. Note time at brake application.
9. Check actual brake energy.
10. Monitor brake temperatures for clearances to on site personnel.
11. After brake temperature is less than 210°F, clear engineer and crew chief to visually inspect brakes and tires.
12. If satisfactory for next test point, clear aircraft to staging area.

ENGINEER/CREW CHIEF CHECKLIST

1. Take tire/wheel and brake temperatures with hand held pyrometer.
2. Notify test conductor of findings and test status.
3. Prior to run, drive to center runway.
4. During run, monitor wheels with field glasses and notify pilot if a wheel lock is spotted.
5. Keep all personnel clear from the aircraft and take temperatures at clearance from test conductor.

FIRE CHIEF CHECKLIST

Call Sign______________

Test Frequency__________

1. Prior to first test run, wet the runway test section with a 1.1 percent foam/water mixture.
   a. Enter runway from center taxiway when cleared onto runway by test conductor.
   b. Wet a 50 foot wide test section to one side of the centerline, starting halfway between the 5000 foot and 4000 foot runway remaining markers and proceed toward the approach end of Runway 04 at approximately 10 mph.
   c. Stop wetting halfway between the 12000 foot and 13000 foot runway remaining markers.
   d. Notify test conductor when wetting complete.
   e. Exit runway at taxiway at approach end of Runway 04.
   f. Notify test conductor when clear of runway.
   g. Proceed to refilling point and refill trucks. When full, return to position on center taxiway and stand by.
2. Re-wet runway using above procedures when directed by test conductor.
3. Each subsequent wetting pass will be alternated between a 1.1 percent foam/water mixture and water only.

SAFETY

HAZARDS INVOLVED

The tests will consist of braking tests on wet and dry runways. The tests are necessary to evaluate wet and dry brake system performance, including the antiskid system. The hazards involved are possible brake failure, blown tires, loss of directional control, and brake fires.

TEST PROCEDURES AND PRECAUTIONS

1. A thorough briefing of the pilot, engineers, and test conductor will be held prior to each day's testing.
2. In addition to normal duty crews, at least one fire truck and an ambulance will be positioned near where the aircraft is expected to stop.
3. If possible, all runs will be made toward the lake bed.
4. There will be a 4500 foot section of dry runway at the exit end of the wetted test section to provide a good braking surface in the event the aircraft cannot stop in the wetted section.
5. Although the drag chute will not normally be used during the stopping tests, one will be aboard the aircraft, if so equipped, to be used as needed.
6. Brake pressure will be released prior to coming to a complete stop (about 20 knots) to prevent brake seizure. This energy, not expended, needs to be accounted for.
7. Brake temperatures will be monitored on board the aircraft (preferably in rear cockpit/copilot position). It is highly desirable to T.M. this data so as to be available to the test conductor.
8. The maximum temperature of the wheels and tires due to heat transfer from the brakes is estimated to occur approximately 20 to 30 minutes after stopping. Therefore, the time between coming to a stop and taxi to cool the wheels/tires with fans will not exceed 10 minutes.
9. If the stopping kinetic energy exceeds the maximum allowable limit, or if tires are flat spotted, the aircraft will be taxied directly to the hot gun line and parked. The area immediately adjacent to the aircraft will be evacuated and a fire truck will stand by until the brakes/tires have cooled.
10. Tire tread measurements will be taken only when the tires are cool between tests.
11. The brakes will be inspected for wear and any evidence of brake component failure before each test period. The brakes will be serviced/changed in accordance with the applicable Technical Order.
12. To obtain good data, testing will be terminated whenever winds exceed eight knots including gusts in any direction. This limit is well below any wind limit for safety purposes.
13. Aircraft wheels/tires are protected from explosive failure, due to extreme pressure buildup caused by high temperatures, with fuse plugs which melt at certain specified temperatures. Plugs at a specified melting temperature will be required for the tires/wheels/brakes to be tested. It has been found that batches of plugs vary in melting temperature from that given by the manufacturer. To ensure safety of the tests, the melting temperature of the batch to be used (ensure that a sufficient supply from one batch is on hand) must be determined by selecting in a random manner at least 5 plugs and by using a high temperature oven to determine their melting temperature. If the melting temperature is found to be higher than the maximum allowed, a new batch must be ordered and the test repeated.

A sample Operating Hazard Analysis (AFFTC Form 28A) and a sample Test Project Safety Review (AFFTC Form 28) are shown in

Appendix C. Additional information on control plots and brake energy is found in the Brake Analysis Section.

The most important element in conducting these tests is control, which can only occur from program tracking of brake energy and temperatures.

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APPENDIX A

BRAKE TESTING COMPUTER PROGRAMS

PROGRAMMERS GUIDE

To aid the test engineer in brake test planning and data reduction, four short computer programs have been written in FORTRAN IV extended. Each program consists of a control program and one or more subroutines. Some of the subroutines are used by two or more of the programs. The four programs are THRUST, DRAG, COFS, and SPEED.

Program THRUST:

Program THRUST consists of a control program called THRUST, and a single subroutine called LINFIT. THRUST reads the ordered pairs of F_t and V_e, establishes a new set of ordered pairs of F_t and V_e^2, calls subroutine LINFIT, and writes the result.

Subroutine LINFIT comes from Reference 13, performs a linear least squares fit on an array of up to 50 pairs of data points. It requires an X-array of up to 50 values, a Y-array of up to 50 values, and the number of points to be analyzed. The subroutine then transfers the slope and Y-intercept. A complete program listing follows.

```
      PROGRAM THRUST(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION FT(50)
      DIMENSION VE(50)
C
C     THIS PROGRAM DETERMINS THE ZERO SPEED THRUST AND THE SLOPE OF
C     THE THRUST CURVE.  IT USES A LINEAR LEAST SQUARES FIT .
C             INPUT REQUIRED
C        FT==TOTAL THRUST DIVIDED BY AMBIENT PRESSURE RATIO
C        VE==EQUIVALENT AIRSPEED
C
      J=0
      DO 2 I=1,50
      READ(5,1)FT(I),VE(I)
    1 FORMAT(F10.2,10X,F10.2)
      IF(EOF(5).NE.0)GO TO 3
      J=J+1
      VE(I)=VE(I)*VE(I)
    2 CONTINUE
    3 CALL LINFIT(VE,FT,J,FTO,RK)
      WRITE(6,4)FTO,RK
    4 FORMAT(25H1 THRUST AT ZERO SPEED = ,F10.2,26H  SLOPE OF THRUST CUR
     1VE = ,F10.8)
      STOP
      END
```

```
      SUBROUTINE LINFIT(X,Y,NPTS,A,B)
C
C-------THIS SUBROUTINE FINDS THE LEAST SQUARES STRAIGHT LINE FIT FOR
C-----UP TO 50 PAIRS OF DATA POINTS.
C-----(ASSUMING EQUATION  Y=A+BX)
C                     REQUIRED INPUT
C               X==ARRAY OF X VALUES (1 DIMENSIONAL, 50 SPACES)
C               Y==ARRAY OF Y VALUES (1 DIMENSIONAL, 50 VALUES)
C               NPTS==NUMBER OF DATA POINTS
C                     OUTPUT TRANSFERED
C               A==Y INTERCEPT
C               B==SLOPE
C               REFERENCE:
C       BEVINGTON,PHILIP R.,DATA REDUCTION AND ERROR ANALYSIS FOR THE
C       PHYSICAL SCIENCES,MCGRAW-HILL BOOK COMPANY,NEW YORK, 1969.
C
      DIMENSION X(50)
      DIMENSION Y(50)
      SUMX=0.0
      SUMY=0.0
      SUMXX=0.0
      SUMXY=0.0
      DO 1 INDX=1,NPTS
      SUMX=SUMX+X(INDX)
      SUMY=SUMY+Y(INDX)
      SUMXX=SUMXX+(X(INDX)*X(INDX))
      SUMXY=SUMXY+(X(INDX)*Y(INDX))
    1 CONTINUE
      SQSMX=SUMX*SUMX
      DELTA=NPTS*SUMXX-SQSMX
      A=(1.0/DELTA)*(SUMXX*SUMY-SUMX*SUMXY)
      B=(1.0/DELTA)*(NPTS*SUMXY-SUMX*SUMY)
      RETURN
      END
```

Program DRAG:

Program DRAG has been written to compute the drag coefficient and the rolling friction coefficient from coast down data. The program consists of the main program called DRAG, and two subroutines called DIST and FINDC.

Program DRAG reads the data and performs the top level of a two level iteration process, by iterating the drag coefficient to obtain an acceptable rolling friction coefficient. The result is the simultaneous solution of two equations in two unknowns.

Subroutine FINDC performs the second level iteration required by program DRAG. It iterates the coefficient of friction (either rolling or braking) to obtain an acceptable stopping distance.

Subroutine DIST calculates the stopping distance given a rolling friction or braking friction coefficient and a drag coefficient. Subroutine DIST directly solves the equation for stopping distance.

A complete program listing follows.

```
      PROGRAM DRAG(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      COMMON /FILES/ S,WT,SIGMA,FTO,RK,CD,CL,VGI,VGF,DS
      DIMENSION DRG(3)
C
C      THIS PROGRAM COMPUTES THE DRAG COEFFICIENT (CD) AND THE ROLLING
C      FRICTION COEFFICIENT GIVEN COAST DOWN DATA OVER TWO SPEED RANGES.
C      IT USES AN ITTERATIVE PROCESS.
C        REQUIRED DATA
C             GENERAL
C                  WING AREA
C                  AIRCRAFT WEIGHT
C                  AMBIENT DENSITY RATIO
C                  THRUST AT ZERO SPEED
C                  SLOPE OF THRUST CURVE
C                  COEFFICIENT OF LIFT
C             FIRST SPEED RANGE
C                  INITIAL SPEED
C                  FINAL SPEED
C                  DISTANCE TRAVELED
C             SECOND SPEED RANGE
C                  INITIAL SPEED
C                  FINAL SPEED
C                  DISTANCE TRAVELED
C
10    READ (5,20) DATA,VARE
20    FORMAT (A10,10X,F20.2)
      WRITE(6,21)DATA,VARE
   21 FORMAT(10X,A10,10X,F20.5)
      IF (DATA.EQ.10HWING AREA ) S=VARE
      IF (DATA.EQ.10HWEIGHT    ) WT=VARE
      IF (DATA.EQ.10HDENSITY RA) SIGMA=VARE
      IF (DATA.EQ.10HTHRUST    ) FTO=VARE
      IF (DATA.EQ.10HSLOPE OF T) RK=VARE
      IF (DATA.EQ.10HLIFT COEFF) CL=VARE
      IF (DATA.EQ.10HSPI-1     ) VGII=VARE
      IF (DATA.EQ.10HSPI-2     ) VGIF=VARE
      IF (DATA.EQ.10HSPF-1     ) VGFI=VARE
      IF (DATA.EQ.10HSPF-2     ) VGFF=VARE
      IF (DATA.EQ.10HDISTANCE 1) XA=VARE
      IF (DATA.EQ.10HDISTANCE 2) XB=VARE
      IF (EOF(5).EQ.0.0) GO TO 10
      DRG(1)=0.150
      DRG(2)=0.140
      DRG(3)=0.130
      DELTA=0.010
      Z=0.0
      Y=1.0
      DIFF=1.0
30    VGI=VGII
      VGF=VGFI
      DS=XA
      CD=DRG(1)
      CALL FINDC (COEFF,SA)
      VGI=VGIF
      Z=Z+1.0
      VGF=VGFF
      IF (Z.GT.50) GO TO 50
      DS=XB
      CD=DRG(1)
      CALL FINDC (COEF,SB)
      DIF=ABS(COEF-COEFF)
      IF (DIF.LE..00005) GO TO 50
      IF (DIFF.LT.DIF) GO TO 40
      DIFF=DIF
      DRG(3)=DRG(2)
      DRG(2)=DRG(1)
      DRG(1)=DRG(1)+DELTA
      COEFF=COEF
      GO TO 30
40    Y=Y+0.5
      DELTA=((1./2.**Y)*(DRG(2)-DRG(1)))
      DIFF=DIF
      DRG(3)=DRG(2)
      DRG(2)=DRG(1)
      DRG(1)=DRG(1)+DELTA
      COEFF=COEF
      GO TO 30
50    AVGE=(COEF+COEFF)/2.0
      WRITE (6,60) CD,AVGE
60    FORMAT (20H1DRAG COEFFICIENT = ,F7.3,/32H ROLLING FRICTION COEFFIC
     1IENT = ,F7.4)
      WRITE (6,70) Z
70    FORMAT (1X,F3.0,27H  ITTERATIONS WERE REQUIRED)
      STOP
      END
```

```
      SUBROUTINE DIST (COEFF,SS)
      COMMON /FILES/ S,WT,SIGMA,FTO,RK,CD,CL,VGI,VGF,DS
C
C     -------THIS SUBROUTINE CALCULATES THE STOPPING DISTANCE GIVEN A
C     -----BRAKING COEFFICIENT AND OTHER DATA (TRANSFERED IN THE COMMON
C     -----STATEMENT).
C            REQUIRED INPUT
C               COEFF==BRAKING COEFFICIENT
C            OUTPUT TRANSFERED
C               SS==STOPPING DISTANCE
C
      SS=0.
      IF (COEFF.GT.1.0) RETURN
      B=(SIGMA*S/841.4)*(COEFF*CL-CD)+RK
      A=FTO-COEFF*WT
      C=ALOG((1.0+(B/A)*VGI*VGI)/(1.0+(B/A)*VGF*VGF))
      SS=((-1.C*WT)/(64.348*B))*C
      IF (SS.LT.0.0) SS=0.1
      RETURN
      END
```

```
      SUBROUTINE FINDC (COEF,Z)
      COMMON /FILES/ S,WT,SIGMA,FTO,RK,CD,CL,VGI,VGF,DS
C
C       THIS SUBROUTINE CALCULATES THE BRAKING COEFFICIENT FROM THE
C     DATA RECIEVED IN THE COMMON STATEMENT.  IT USES AN ITTERATIVE
C     PROCESS.
C          DATA TRANSFERED
C               COEF == COEFFICIENT OF FRICTION
C               Z == NUMBER OF ITTERATIONS
C
      Z=0.0
      Y=1.0
      COEFF=0.25
      COEF=0.25
      COFF=0.25
      DELTA=-0.04
      CALL DIST (COEFF,SA)
      DSA=ABS(DS-SA)
      IF (DSA.LT.1.0) GO TO 20
10    COEF=COEFF+DELTA
      CALL DIST (COEF,SB)
      Z=Z+1.
      DSB=ABS(DS-SB)
      IF (DSB.LT.1.0) GO TO 20
      DDS=DSA-DSB
      IF (DDS.LT.0.0) DELTA=-1.0*DELTA
      TEST=(DS-SA)*(DS-SB)
      IF (TEST.LT.0.0) GO TO 30
      SA=SB
      DSA=DSB
      COFF=COEFF
      COEFF=COEF
      GO TO 10
20    RETURN
30    Y=Y+0.5
      DELTA=((1.0/2.0**Y)*(COFF-COEFF))
      SA=SB
      DSA=DSB
      COFF=COEFF
      COEFF=COEF
      GO TO 10
      END
```

Program COFS

Program COFS calculates the braking coefficient and braking energy from brake test data and ambient air data. It uses subroutines FINDC and DIST to perform the required iteration. (See the discussion of program DRAG for more on FINDC and DIST.) Program COFS reads the data, calls the necessary subroutines and writes the results.

After the braking coefficient has been determined by FINDC, then program COFS calls subroutine ENERG. ENERG determines the braking energy.

A complete program listing follows.

```
      PROGRAM COFS(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      COMMON / FILES / S,WT,SIGMA,FTO,RK,CD,CL,VGI,VGF,DS,ENER
C
C-------THIS PROGRAM CALCULATES THE BRAKING COEFFICIENT FROM THE DATA
C-----READ BELOW.
C           REQUIRED DATA
C                 WING AREA
C                 AIRCRAFT WEIGHT
C                 AMBIENT DENSITY RATIO
C                 THRUST AT ZERO SPEED
C                 SLOPE OF THRUST CURVE
C                 DRAG COEFFICIENT
C                 LIFT COEFFICIENT
C                 INITIAL SPEED
C                 FINAL SPEED
C                 DISTANCE TRAVELED
C
      ENER=0.0
      DO 2 IDUM=1,10
C
C-------DATA CARDS ARE READ
C
      READ(5,1) DATA,VARI
    1 FORMAT(A10,10X,F20.2)
      IF(DATA.EQ.10HWING AREA )S=VARI
      IF(DATA.EQ.10HWEIGHT    )WT=VARI
      IF(DATA.EQ.10HDENSITY RA)SIGMA=VARI
      IF(DATA.EQ.10HTHRUST    )FTO=VARI
      IF(DATA.EQ.10HSLOPE OF T)RK=VARI
      IF(DATA.EQ.10HDRAG COEFF)CD=VARI
      IF(DATA.EQ.10HLIFT COEFF)CL=VARI
      IF(DATA.EQ.10HINITIAL SP)VGI=VARI
      IF(DATA.EQ.10HFINAL SPEE) VGF=VARI
      IF(DATA.EQ.10HDISTANCE  )DS=VARI
    2 CONTINUE
      WRITE(6,3)
    3 FORMAT("1 INPUT DATA")
      WRITE(6,4)S,WT,SIGMA,FTO,RK,CD,CL,VGI,VGF,DS
    4 FORMAT(4H S= ,F6.0,5H WT= ,F10.2,8H SIGMA= ,F5.4,5H FTO=,F6.1,4H
     1K= ,F10.F,5H CD= ,F4.3,5H CL= ,F4.3,6H VG1= ,F6.1,6H VG2= ,F6.1,11H DISTAN
     2H DISTANCE= ,F7.1)
C
C         SUBROUTINES ARE CALLED
C
      CALL FINDC(COEF,Z)
      CALL ENERG(COEF,EG)
      CALL DIST(COEF,SB)
      E=EG/1000000.
      WRITE(6,9) COEF,E,SB,Z
    9 FORMAT("0 RESULTS ARE",/," BRAKING COEFFICIENT = ",F7.6," BRAKING
     3ENERGY - ",F5.1," LEX 06   STOPPING DISTANCE = ",F10.2," NUMBER OF
     4F ITTERATIONS REQUIRED = ",F3.0)
      STOP
      END
```

```
      SUBROUTINE ENERG(COEFF,E)
      COMMON / FILES / S,WT,SIGMA,FTO,RK,CD,CL,VGI,VGF,DS
C
C--------THIS SUBROUTINE CALCULATES THE TOTAL BRAKING ENERGY GIVEN A
C-----BRAKING COEFFICIENT AND OTHER DATA (TRANSFERED IN THE COMMON
C-----STATEMENT).
C             REQUIRED INPUT
C                COEFF==BRAKING COEFFICIENT
C             OUTPUT TRANSFERED
C                E==BRAKING ENERGY
C
      B=(SIGMA*S/841.4)*(COEFF*CL-CD)+RK
      A=FTO-COEFF*WT
      G=ALOG((1.0+(B/A)*VGI*VGI)/(1.0+(B/A)*VGF*VGF))
      C=(SIGMA*S/841.4)*CL
      D=(WT+(G/(B/A)))*C
      E=((COEFF*WT)/(64.348*B))*(G*((VGI*VGI)-(VGF*VGF))-D)
      RETURN
      END
```

```
      SUBROUTINE FINDC(COEF,Z)
      COMMON / FILES / S,WT,SIGMA,FTO,RK,CD,CL,VGI,VGF,DS
C
C       THIS SUBROUTINE CALCULATES THE BRAKING COEFFICIENT FROM THE
C     DATA RECIEVED IN THE COMMON STATEMENT.  IT USES AN ITTERATIVE
C     PROCESS.
C          DATA TRANSFERED
C               COEF == COEFFICIENT OF FRICTION
C               Z == NUMBER OF ITTERATIONS
C
      Z=C.0
      Y=1.0
      COEFF=0.25
      COEF=0.25
      COFF=0.29
      DELTA=-0.C4
      CALL DIST(COEFF,SA)
      DSA=ABS(DS-SA)
      IF(DSA.LT.1.0)GO TO 5
    7 COEF=COEFF+DELTA
      CALL DIST(COEF,SB)
      Z=Z+1.
      DSB=ABS(DS-SB)
      IF(DSB.LT.1.0)GO TO 5
      DDS=DSA-DSB
      IF(DDS.LT.0.0)DELTA=-1.0*DELTA
      TEST=(DS-SA)*(DS-SB)
      IF(TEST.LT.0.0)GO TO 11
      SA=SB
      DSA=DSB
      COFF=COEFF
      COEFF=COEF
      GC TO 7
   11 Y=Y+0.5
      DELTA=((1.0/2.0**Y)*(COFF-COEFF))
      SA=SB
      DSA=DSB
      COFF=COEFF
      COEFF=COEF
      GC TO 7
    5 RETURN
      END
```

```
      SUBROUTINE DIST(COEFF,SS)
      COMMON / FILES / S,WT,SIGMA,FTO,RK,CD,CL,VGI,VGF,DS
C
C-------THIS SUBROUTINE CALCULATES THE STOPPING DISTANCE GIVEN A
C-----BRAKING COEFFICIENT AND OTHER DATA (TRANSFERED IN THE COMMON
C-----STATEMENT).
C             RECUIRED INPUT
C                COEFF==BRAKING COEFFICIENT
C             OUTPUT TRANSFERED
C                SS==STOPPING DISTANCE
C
      SS=C.
      IF(COEFF.CT.1.0) RETURN
      B=(SIGMA*S/841.4)*(COEFF*CL-CD)+RK
      A=FTO-COEFF*WT
      C=ALOG((1.0+(B/A)*VGI*VGI)/(1.0+(B/A)*VGF*VGF))
      SS=((-1.C*WT)/(64.348*B))*C
      IF(SS.LT.C.0)SS=0.1
      RETURN
      END
```

Program SPEED:

Program SPEED is designed to aid the engineer in determining an initial speed for a braking test to yield a desired braking energy.

Program SPEED consists of a control program called SPEED, and three subroutines called VEL, DIST, and ENERG. Program SPEED reads the data, calls the needed subroutines, and writes some of the results.

Subroutine VEL calculates the initial speed needed to yield the desired braking energy by using an iterative process. (For more information on subroutine ENERG, see the discussion of program COFS.)

A complete program listing follows.

```
      PROGRAM SPEED(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      COMMON / FILES / S,WT,SIGMA,FTO,RK,CD,CL,VGI,VGF,DS,ENER
C
C-------THIS PROGRAM READS THE DATA AND CALLS THE SUBROUTINES FOR
C-----FOR CALCULATING THE INITIAL SPEED  NEEDED FOR A DESIRED BRAKE
C-----ENERGY.
C               REQUIRED DATA
C                    WING AREA
C                    AIRCRAFT WEIGHT
C                    AMBIENT DENSITY RATIO
C                    THRUST AT ZERO SPEED
C                    SLOPE OF THRUST CURVE
C                    DRAG COEFFICIENT
C                    LIFT COEFFICIENT
C                    BRAKING FRICTION COEFFICIENT
C                    DESIRED BRAKING ENERGY
C
      DO 2 IDUP=1,9
      READ(5,1) DATA, VARE
    1 FORMAT(A10,10X,F20.2)
      WRITE(6,5)DATA,VARE
    5 FORMAT(1X,A10,2X,F20.2)
      IF(DATA.EQ.10HWING AREA )S=VARE
      IF(DATA.EQ.10HWEIGHT    )WT=VARE
      IF(DATA.EQ.10HDENSITY RA)SIGMA=VARE
      IF(DATA.EQ.10HTHRUST    )FTO=VARE
      IF(DATA.EQ.10HSLOPE OF T)RK=VARE
      IF(DATA.EQ.10HDRAG COEFF)CD=VARE
      IF(DATA.EQ.10HLIFT COEFF)CL=VARE
      IF(DATA.EQ.10HBRAKING CO)COEF=VARE
      IF(DATA.EQ.10HENERGY    )ENER=VARE
    2 CONTINUE
      WRITE(6,3)
    3 FORMAT(1H1)
      CALL VEL(COEF)
      CALL DIST(COEF,SS)
      WRITE(6,4)SS
    4 FORMAT(/21H STOPPING DISTANCE = ,F10.2)
      STOP
      END
```

```
      SUBROUTINE DIST(COEFF,SS)
      COMMON / FILES / S,WT,SIGMA,FTO,RK,CD,CL,VGI,VGF,DS
C
C-------THIS SUBROUTINE CALCULATES THE STOPPING DISTANCE GIVEN A
C-----BRAKING COEFFICIENT AND OTHER DATA (TRANSFERED IN THE COMMON
C-----STATEMENT).
C             REQUIRED INPUT
C                 COEFF==BRAKING COEFFICIENT
C             OUTPUT TRANSFERED
C                 SS==STOPPING DISTANCE
C
      SS=0.
      IF(COEFF.GT.1.0) RETURN
      B=(SIGMA*S/841.4)*(COEFF*CL-CD)+RK
      A=FTO-COEFF*WT
      C=ALOG((1.0+(B/A)*VGI*VGI)/(1.0+(B/A)*VGF*VGF))
      SS=((-1.0*WT)/(64.348*B))*C
      IF(SS.LT.0.0)SS=0.1
      RETURN
      END
```

```
      SUBROUTINE VEL(COEF)
      COMMON / FILES / S,WT,SIGMA,FTO,KK,CD,CL,VGI,VGF,DS,ENER
C
C-------THIS SUBROUTINE CALCULATES AN INITIAL SPEED FOR A DESIRED
C-----BRAKING ENERGY.  IT USES AN ITTERATIVE PROCESS.
C             REQUIRED INPUT
C                  COEF==BRAKING COEFFICIENT OF FRICTION
C             ALL OUTPUT TRANSFERED IN THE COMMON STATEMENT
C
      VGI=200.
      VGF=0.0
      IF(ENER.EQ.0.0)RETURN
      Z=0.0
      Y=1.0
      VGO=VGI-30.
      VGII=VGI
      DELTA=30.
      CALL ENERG(COEF,EGI)
      DEA=ABS(ENER-EGI)
      IF(DEA.LT.1000.)GO TO 2
    1 VGI=VGII+DELTA
      Z=Z+1.0
      IF(Z.EQ.50)GO TO 2
      CALL ENERG(COEF,EGII)
      DEB=ABS(ENER-EGII)
      IF(DEB.LT.1000.)GO TO 2
      DDE=DEA-DEB
      IF(DDE.LT.0.0)DELTA=-1.0*DELTA
      TEST=(ENER-EGI)*(ENER-EGII)
      IF(TEST.LT.0.0)GO TO 4
      EGI=EGII
      DEA=DEB
      VGO=VGII
      VGII=VGI
      GO TO 1
    2 ENEG=EGII/1000000.
      WRITE(6,3)ENEG,VGI,Z
    3 FORMAT(25HO DESIRED BRAKE ENERGY = ,F6.1," 6X 10    INITIAL SPEED
     1 = ",F4.2," NUMBER OF ITTERATIONS REQUIRED = ",F3.0)
      RETURN
    4 Y=Y+0.5
      DELTA = ((1.0/2.0**Y)*(VGO-VGI))
      EGI=EGII
      DEA=DEB
      VGO=VGII
      VGII=VGI
      GO TO 1
      END
```

```
      SUBROUTINE ENERG(COEFF,E)
      COMMON / FILES / S,WT,SIGMA,FTO,KK,CD,CL,VGI,VGF,DS
C
C--------THIS SUBROUTINE CALCULATES THE TOTAL BRAKING ENERGY GIVEN A
C-----BRAKING COEFFICIENT AND OTHER DATA (TRANSFERED IN THE COMMON
C-----STATEMENT).
C             REQUIRED INPUT
C                COEFF==BRAKING COEFFICIENT
C             OUTPUT TRANSFERED
C                E==BRAKING ENERGY
C



      B=(SIGMA*S/841.4)*(COEFF*CL-CD)+KK
      A=FTO-COEFF*WT
      C=ALOG((1.0+(B/A)*VGI*VGI)/(1.0+(B/A)*VGF*VGF))
      G=(SIGMA*S/841.4)*CL
      D=(WT+(G/(B/A)))*C
      E=((COEFF*WT)/(64.345*B))*(G*((VGI*VGI)-(VGF*VGF))-D)
      RETURN
      END
```

APPENDIX B

SAMPLE TEST INFORMATION SHEET (TIS)

AFFTC TEST INFORMATION SHEET (TIS) (TEST PROGRAM)	DATE	PAGE 1 OF 6 PAGES
TITLE OF TEST: F-15 GOODYEAR GENERATION 5 CARBON BRAKE EVAL	VEHICLE TYPE: F-15	TIS NUMBER: 13
	EFFECTIVITY: TBD	REVISION: E

TIS TYPE	LOCATION OF TEST	TESTING ACTIVITY	HAZARDOUS/UNUSUAL TEST
☐ PLAN ☒ PROCEDURAL	Edwards AFB CA	AFFTC	

1.0 BACKGROUND The Air Force has a critical spares shortage for F-15A/B brakes (Generation 4) due to the unavailability of the carbon fiber to the vendor. The new Generation 5 brake has no materials availability problems. In addition, the Generation 5 brakes have lower manufacturing costs and improved durability as shown through dynamometer verification tests. ASD/AEAA and ASD/YFA (TEST) have requested an immediate compatibility test to qualify the Generation 5 brakes on F-15A/B aircraft.

2.0 TEST OBJECTIVES: To verify compatibility between the F-15 anti-skid system and Goodyear Generation 5 carbon brakes. Demonstrate that the stopping distance of the Generation 5 brake is compatible with the F-15A/B flight manual. Verify that the hot and cold static torque is sufficient for engine runup. Verify compatibility of mixed sets of Goodyear Fourth and Fifth Generation brakes with the F-15 anti-skid system, normal braking system and emergency braking system.

3.0 GENERAL INFORMATION: AFFTC and Goodyear engineers will be in attendance for preflight and postflight inspections of the brakes. Wear data will be taken after each flight. Should any hydraulic or structural problem become apparent during inspection, a fix will be made or the brakes will be removed and the project ended. All standard preflight/postflight procedures will be followed. During tests, all necessary fire equipment will be present along with an engineer in a radio vehicle. The Test Conductor or the project pilot will have the authority to suspend further testing at any time. The brakes will have thermocouples so that stack temperatures can be monitored during each test.

BRAKE TEST MEASURANDS

SEQUENCE NUMBER	PARAMETER NAME	SAMPLE RATE (SPS)
SM13*	Brake Stack Temp, Left	10
SM14*	Brake Stack Temp, Right	10
MA07*	Wheel Speed, Left	60
MA08*	Wheel Speed, Right	60
SM11*	Brake Pressure, Left	60
SM12*	Brake Pressure, Right	60
SM17*	Anti-Skid Control Valve Signal	60

ACTION	OFFICE OR POSITION/PHONE	SIGNATURE	DATE
PREPARE			
REVIEW			
REVIEW			
REVIEW			
APPROVE			

AFFTC [illegible] 261b REPLACES AFFTC FORM 0-128, JUN 73 WHICH WILL BE USED.

TITLE OF TEST	DATE	PAGE 2 OF 6 PAGES
F-15 GOODYEAR GENERATION 5 CARBON BRAKE EVAL	VEHICLE TYPE F-15	TIS NUMBER 13
	EFFECTIVITY TBD	REVISION E

TIS TYPE	LOCATION OF TEST	TESTING ACTIVITY	HAZARDOUS/UNUSUAL TEST
☐ PLAN X PROCEDURAL	Edwards AFB CA	AFFTC	

SM15	Pilot Metered Pressure, Left	10
SM16	Pilot Metered Pressure, Right	10
CF04	Brake* Pedal Pressure, Left	10
CF05	Brake Pedal Pressure, Right	10
AA04	Nx	10
AA05	Ny	10
AA01	Airspeed	10
EN05	INS E-W Velocity	10
EN06	INS N-S Velocity	10
EN40	INS Groundspeed	10
EN07	INS Heading	10
PF09	Internal Fuel Quantity	10

*These are no-go parameters which must be operational and telemetered to the real time control room.

Winds will be below 10 knots for the tests in paragraphs 4.2 and 4.5.

4.0 BRAKE SUBSYSTEM TESTS:

4.1 OBJECTIVE: To conduct an operational checkout of the Generation 5 brake through a buildup technique to energy levels that will be required during anti-skid compatibility testing.

4.1.1 Test Conditions: These tests will be conducted on a dry surface. A table will be given to the pilot providing different initiation speeds at different gross weights for desired energy levels. Aircraft will be configured for these tests with flaps down and speed brake out.

OPERATIONAL CHECKOUT TEST CONDITIONS

Test Point	Anti-Skid	Gross Weight (pounds)	Stop Initiation Speed (knots)	Runway Condition	Total Aircraft Energy (ft-lbs X 10^{-6})	Brake Pedal Force
1	NORM	35,000	60	DRY	5.6	MEDIUM
2	OFF	35,000	60	DRY	5.6	AS REQUIRED
3	EMER	35,000	60	DRY	5.6	AS REQUIRED
4	NORM	35,000	96	DRY	14.4	LIGHT
5	NORM	35,000	108	DRY	18.0	LIGHT-MEDIUM
6	NORM	35,000	116	DRY	21.0	MEDIUM-HEAVY
7	NORM	35,000	124	DRY	24.0	HEAVY

AFFTC TEST INFORMATION SHEET (TIS) (TEST PROGRAM)	DATE	PAGE 3 OF 6 PAGES
TITLE OF TEST: F-15 GOODYEAR GENERATION 5 CARBON BRAKE EVAL	VEHICLE TYPE: F-15	TIS NUMBER: 13
	EFFECTIVITY: TBD	REVISION: F

TIS TYPE	LOCATION OF TEST	TESTING ACTIVITY	HAZARDOUS/UNUSUAL TEST
☐ PLAN X PROCEDURAL	Edwards AFB CA	AFFTC	

4.1.2 Test Procedures: These brake tests will be accomplished prior to the testing of para 4.2. During taxi out to the main runway the pilot will perform brake applications as required. Brake parameters will be monitored by the Test Conductor in the telemetry room. The Test Conductor will be in radio contact with the pilot. The pilot will initiate braking based on INS ground speed. At the conclusion of each test point, the brake stacks will be cooled to a temperature of 100 degrees C or less before the next test point. This will be accomplished either with cooling fans or by using a stop-and-go technique with the gear down during the go around. If the stop and go technique is used, the pilot will aerobrake to the initial speed.

4.1.3 Support Requirements: A P-2 fire truck with a two-man crew is required. Crash recovery support will be required for the cooling fans.

4.1.4 Data: Telemetry data, inspection data, and pilot comments will be used for evaluation of the brake.

4.2 OBJECTIVE: To verify compatibility between the F-15 anti-skid system and Goodyear Generation 5 disc brake and to demonstrate that the stopping distance of the Generation 5 brake agrees with the flight manual.

4.2.1 Test Conditions: Tests will be conducted on both dry and wet surfaces. Aircraft configuration for these tests will be flaps down, speed brake out and three ballast tanks.

TAXI/ANTI SKID TEST CONDITIONS

Test Point	Gross Weight (pounds)	Stop Initiation Speed (knots)	Runway Condition	Total Aircraft Energy (ft-lbs X 10^{-6})
1	35,000	130	Dry	26.2
5	53,000	107	Dry	27.1
6	53,000	130	Dry	39.4
2	35,000	136	Wet	28.6
3	44,000	117	Wet	26.7
4	53,300	103	Wet	25.1

Note: Brakes Dynamometer qualified to 24.6 X 10^6 foot-pounds each. Higher weights achieved using ballast tanks filled with water

4.2.2 Test Procedures: During taxi out, brake temeratures will be monitored in the telemetry room by the Test Conductor. The brakes will be cooled to 100 degrees C before each test point. The pilot and the Test Conductor will insure that the anti-skid is in normal position. Heavy braking will be used for each test point to obtain adequate anti-skid cycling. The Test Conductor will monitor the telemetry and be in radio contact with the test pilot to prevent hot or locked brakes. The pilot will initiate braking based on INS ground speed. A fire truck will be in

AFFTC FORM JUN 73 261a REPLACES AFFTC FORM 0-128, JUN 73, WHICH WILL BE USED

AFFTC TEST INFORMATION SHEET (TIS) (TEST PROGRAM)		DATE	PAGE 4 OF 6 PAGES
TITLE OF TEST F-15 GOODYEAR GENERATION 5 CARBON BRAKE EVAL		VEHICLE TYPE F-15 EFFECTIVITY TBD	TIS NUMBER 13 REVISION E
TIS TYPE ☐ PLAN ☒ PROCEDURAL	LOCATION OF TEST Edwards AFB CA	TESTING ACTIVITY AFFTC	HAZARDOUS/UNUSUAL TEST

attendance throughout the period of testing. Cooling fans will be used to cool the brakes. The brakes and tires will be inspected after each test point. At the completion of these tests, the brakes will be removed from the aircraft for a tear-down inspection.

4.2.3 Support Requirements: Same as 4.1.3. Demineralized water will be required to fill the external ballast tanks.

4.2.4 Data: The data specified in 4.1.4 is required. A brake inspection will be performed and wear data taken at the conclusion of this testing. Dual-station phototheodolite data is required during each run.

4.3 OBJECTIVE: Verify that the hot and cold static torque is sufficient for engine runup.

4.3.1 Test Conditions: The tests will be conducted on a dry surface with both engines operating. Engines will be advanced to produce thrust equivalent to that predicted for 80% RPM at Sea Level with a -40 degree F ambient temperature. Brake temperatures between ambient and 1000 degree F will be used with at least one test at 1000 degree F. Tests will also be conducted with one engine at first stage after-burner.

4.3.2 Test Procedures: These points will usually be points of opportunity during the braking tests. For each point, the pilot will advance the throttles to obtain computed RPM/FTIT based on temperature and pressure altitude while holding the aircraft with the brakes. If the brakes hold, the pilot will slowly release pedal pressure until the aircraft just begins to move and then increase the pedal force. If the brakes do not hold, the pilot will reduce the throttle settings to IDLE, apply pressure to the brakes (to get maximum brake pressure) and advance throttles until the aircraft just begins to move. The pilot will record RPM and FTIT at this point.

4.3.3 Support Requirements: Same as 4.1.3.

4.3.4 Data: Telemetry data, pilot comments, and pilot recorded FTIT and engine RPM are required.

4.4. OBJECTIVE: To conduct an operational checkout of a mixed set of Goodyear Generation 4 and Generation 5 carbon brakes through a buildup technique to energy levels that will be required during anti-skid compatibility testing.

4.4.1 Test Conditions: These tests will be conducted on a dry surface. A table will be given to the pilot providing different initiation speeds at different gross weights for desired energy levels. The Generation 5 brake can be mounted on either side of the aircraft. The same test conditions as in section 4.1.1 will be used.

4.4.2 Test Procedures: Same as 4.1.2 except these are prerequisites for 4.5.

AFFTC FORM JUN 73 2610 REPLACES AFFTC FORM 0-120, JUN 73 WHICH WILL BE USED

AFFTC TEST INFORMATION SHEET (TIS) (TEST PROGRAM)	DATE	PAGE 5 OF 6 PAGES
TITLE OF TEST: F-15 GOODYEAR GENERATION 5 CARBON BRAKE EVAL	VEHICLE TYPE: F-15	TIS NUMBER: 13
	EFFECTIVITY: TBD	REVISION: E

TIS TYPE	LOCATION OF TEST	TESTING ACTIVITY	HAZARDOUS/UNUSUAL TEST
[ ] PLAN [X] PROCEDURAL	Edwards AFB CA	AFFTC	

4.4.3 Support Requirements: Same as 4.1.3.

4.4.4 Data: Same as 4.1.4.

4.5 OBJECTIVE: To verify compatibility between the F-15 anti-skid system and a mixed set of Generation 4 and 5 brakes and to demonstrate that the stopping distance of the mixed set of brakes agrees with the flight manual.

4.5.1 Test Conditions: Same as 4.2.1.

4.5.2 Test Procedures: Same as 4.2.2.

4.5.3 Support Requirements: Same as 4.2.3.

4.5.4 Data: Same as 4.2.4.

4.6 OBJECTIVE: To verify that the hot and cold static torque of a mixed set of Goodyear Generation 4 and 5 carbon brakes is sufficient for engine runup.

4.6.1 Test Conditions: Same as 4.3.1.

4.6.2 Test Procedures: These points will usually be points of opportunity during the braking tests. For each point, the pilot will advance the throttles to obtain computed RPM/FTIT based on temperature and pressure altitude while holding the aircraft with the brakes. If the brakes hold, the pilot will slowly and evenly release pedal pressure until either brake begins to slip and then increase pedal force. If either brake does not hold, the pilot will reduce the throttle settings to IDLE, apply pressure to the brakes to get maximum brake pressure and advance throttles until the aircraft just begins to move. The pilot will record RPM and FTIT at this point.

4.6.3 Support Requirements: Same as 4.1.3.

4.6.4 Data: Same as 4.3.4.

AFFTC TEST INFORMATION SHEET (TIS) (TEST PROGRAM)	DATE	PAGE 6 OF 6 PAGES
TITLE OF TEST F-15 GOODYEAR GENERATION 5 CARBON BRAKE EVAL	VEHICLE TYPE F-15 EFFECTIVITY TBD	TIS NUMBER 13 REVISION E

TIS TYPE	LOCATION OF TEST	TESTING ACTIVITY	HAZARDOUS/UNUSUAL TEST
[ ] PLAN [X] PROCEDURAL	Edwards AFB CA	AFFTC	

APPENDIX - AIRCRAFT CHECKLIST

1. Prior to the tests turn records on and record full brake pedal deflection, cycle of anti-skid switch, and full rudder pedal deflection in the normal and maneuver modes

2. Notify the Test Conductor that the records are complete.

3. Before rolling:

   a. Check anti-skid in NORM (if required)

   b Check flap position (down)

   c. Record fuel quantity

   d. Call "recorder on" and turn recorder on.

4 While rolling:

   a. Check wheel speed indicator

   b When target speed is attained, retard throttle to IDLE and apply brakes.

   c. Note speed when brakes are applied.

5 After stop - record fuel quantity.

   a. Call "recorder off" and turn recorder off.

6. Cool brakes.

7 When cleared by the Test Conductor, taxi back to runway 04 using the brakes sparingly.

8. Repeat procedures from step 3.

AFFTC FORM JUN 73 261a REPLACES AFFTC FORM 0-128, JUN 73, WHICH WILL BE USED

APPENDIX C

SAMPLE TEST PROJECT SAFETY REVIEW (AFFTC FORM 28)

AND

SAMPLE OPERATING HAZARD ANALYSIS (AFFTC FORM 28A)

TEST PROJECT SAFETY REVIEW

I. SAFETY REVIEW REQUEST

PROJECT TEST TITLE & JON: F-15C AFDT&E Phase I, 328AZW		PERFORMING AGENCY: 6510 TESTW/TEVJ	
PROJECT MANAGER (Typed Name & Grade)	SIGNATURE	PHONE NUMBER	DATE
UNIT SSO (Typed Name & Grade)	SIGNATURE	PHONE NUMBER	DATE

II. SAFETY REVIEW BOARD ACTION

TEST STARTING DATE	TEST COMPLETION DATE	RISK LEVEL	CONTROL NUMBER
16 July 1979	30 June 1980	Medium Risk	79-48

- [ ] TEST PLAN REVIEWED. NO OPERATING HAZARD ANALYSIS REQUIRED.
- [ ] TEST PLAN REVIEWED. OPERATING HAZARD ANALYSIS APPROVED.
- [ ] TEST PLAN REVIEWED. FURTHER HAZARD ANALYSIS REQUIRED
- [ ] PRESTO HAZARDOUS TEST REPORT REQUIRED

III. SAFETY REVIEW BOARD MEMBERS

NAME, GRADE & TITLE	SIGNATURE	NAME, GRADE & TITLE	SIGNATURE
Chairman		MSUG Rep	
Performance Engr			
Systems Engr			
Systems Engr		Operations Rep	
Engr Rep			

IV. BRIEF DESCRIPTION AND JUSTIFICATION OF TEST
(Use additional sheet of plain bond paper if needed)

These tests are a combination of ground and flight tests to evaluate the F-15C (PEP 2000) aircraft. Ground tests will include: Mass Properties and Fuel Gaging, Engine Trim and Static Thrust Calibration, Flight Control System Characteristics, Taxi Tests, Braking Tests, Barrier Engagements, Ground Fuel Transfer and Pressurization, Fuel System Failure Modes, Water Entrapment, Maintainability, and Human Factors. Flight tests include: Takeoff Performance and Flying Qualities, Climb Performance, Longitudinal Stability and Control, Maneuvering Flight, Lateral Control, Static Lateral-Aerial Refueling, Gear Retraction and Extension, and Landing and Stopping Performance. These tests will be conducted to evaluate the impact of the PEP 2000 modifications on established Performance and Flying Qualities, Systems Qualities, and Aircrew/Maintenance Procedures. The Electronic Warfare, Radar, Weapons and Environmental Systems will not be evaluated. The test configurations will be limited to stores currently certified on F-15B aircraft; however external tanks will be filled with water for some ground tests. This test program was requested by the F-15 System Program Office ASD/YF

REFERENCES

1. Air Force Technical Order 1F-15A-1, Flight Manual, USAF Series F-15 A/B Aircraft, Revision D, Change 1, 1 May 79. (Continued on Atch Sheet)

V. FINAL COORDINATION AND APPROVAL

COORDINATING OFFICIAL: TYPED NAME, GRADE AND TITLE	SIGNATURE	DATE	CONCUR YES	CONCUR NO	COMMENTS ADDED YES	COMMENTS ADDED NO
Director, F-15 JTF						
Dep Director/Test Forces						
6510 TEST WING COMMANDER						
AFFTC DIRECTOR OF SAFETY						
AFFTC ... COMMANDER						

TEST APPROVED DISAPPROVED APPROVED SUBJECT TO MY REMARKS IN SECTION VI

TYPED NAME AND GRADE OF AFFTC COMMANDER	SIGNATURE OF AFFTC COMMANDER	DATE

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VI. **REMARKS**

1. The SRB was held at 1300 hours in the Directorate of Safety Conference Room on 17 July 1979. In addition to the board members listed in Section III, the following personnel were present:

2. Test Description: The Production Eagle Package (PEP) 2000 modification has increased the internal fuel capacity; increased the takeoff gross weight capability to 68,000 lbs and added provision for conformal tanks. The main landing gear assemblies have been modified to accomodate the increased takeoff weight. These changes include increased strut pressure new wheels and brakes, increased tire pressure and a new anti-skid, wheel speed sensor. Numerous minor changes to the routing of hydraulic and electrical lines as well as flight control linkages were made to accomodate the increased internal fuel. The test aircraft also has been modified to increase the rudder hinge moment. The intent of the design for these changes was to maintain, as much as possible, the same handling qualities as the F-15A/B.

This test series will address the impact of these changes of the aircraft operation with the following evaluations:

a. Ground Tests

(1) Aircraft mass properties and fuel gaging characteristics will be investigated by use of the weight and balance facility. Fuelin operations will b performed in the weight and balance hangar while the fuel gaging system is powered to determine cg variations and fuel system characteristics.

(2) Standard engine trim and static thrust calibration will be performed.

(3) Evaluation of the breakout force and hysteresis of the flight control system by performing control sweeps.

(4) Taxi tests at light and heavy weights (58,780 lbs) to evaluate handling qualities, gear loads, and minimum radius turns.

(5) Braking tests will evaluate brake and antiskid performance at gross weights up to 59,400 lbs and up to 80% of brake energy capacity. The tests will be performed on both wet and dry runway surfaces.

(6) Landing gear loads and structural margins will be evaluated during barrier engagements with the BAK-12ER and BAK-13 barriers at gross weights up to 60,000 lbs with both on and off-center engagements and speeds up to 140 knots.

(7) The fuel system will be evaluated during normal ground refuel and defueling operations. Proper fuel system operation will be verified by the use of several normal servicing and trouble shooting T.O. procedures

(8) Maintainability and human factors evaluation will be conducted qualitatively throughout the test program.

b. Flight Tests

(1) Takeoff performance and handling qualities both normal and single engine.

(2) Military check climbs.

(3) Longitudinal trim and inlet structural verification will be

(Continued on Attached Sheet)

VI. REMARKS

accomplished with level accelerations.
ITEM IV. CONTINUED

REFERENCES CONTINUED

2. Air Force Technical Order 1F-15C-1, Flight Manual USAF Series F-15C/D Aircraft, 1 Feb 79

3. AFFTC TR 76-48, F/TF-15A Flying Qualities Air Force Development Test and Evaluation AFDT&E), Vol I and II, Final Report (SECRET), July 1977

4 AFFTC TR 75-36, Fuel Subsystem Evaluation, Final Report, October 1975

5. AFFTC TR 77-7, F-15 Performance Air Force Development Test and Evaluation (AFDT&E). Final Report (CONFIDENTIAL) July 1977

6. AFFTC Form 28 Control No. 78-70, F-16 FSD Arresting Hook System, 2185AO, 7 Aug 1978.

7. AFFTC Form 28 Control No. 79-11, F-15 Dunlop Carbon Brakes 2098AO, 25 Jan 1979.

ITEM VI. REMARKS CONTINUED

(4) Pushover, pullup and windup turn maneuvers will be accomplished to evaluate maneuvering flight characteristics.

(5) Roll performance with 360 degree and 90 degree rolls.

(6) Lateral-directional stability will be evaluated using steady heading sideslips.

(7) Short period and Dutch Roll characteristics will be evaluated.

(8) Handling qualities during tracking (HQDT) using standard profiles will be evaluated.

(9) Fuel system operations will be evaluated during all phases of flight as well as aerial refueling.

(10) Landing gear extension and retraction in flight will be evaluated to verify the existing flight envelope.

(11) Cross wind landings at light gross weights with heavy servicing of the landing gear up to 30 kts of cross wind.

3. General Procedures.

a. Direct communications between flight crew and test conductor will be maintained during all tests and the test conductor will provide point-to-point clearance on test points. Build up will be used on all tests.

b. The mass properties evaluation, engine trim, flight control and taxi handling qualities tests will be performed prior to first flight.

c. Engine calibrations will be accomplished prior to performance evaluations.

d. After approximately eight weeks of testing, additional instrumentation will be added to monitor structural loads on the landing gear and tail hook. These modifications are required prior to the quantitative taxi tests and barrier engagements.

e. Braking tests will be performed as soon as practical during the test phase. Contractor and AFPE tests have already tested the brake system to 50% energy levels and verified system operation.

f. Aerial refueling will be used throughout the flight test program. Fuel system failure modes tests will be completed prior to aerial

(CONTINUED ON ATTACHED SHEET)

VI. **REMARKS**

refueling with external tanks. Mass properties tests will identify critical cg fuel loadings and these conditions will be monitored during refuelingoperations.

g. All flight tests are within T.O. limits. All test conditions are CAS on and control ratios AUTO except for some of the dynamic stability test points and some of the HQDT tests.

h. Landing tests will be performed on the main runway except that the cross wind landings may be performed as touch-and-gos on the lakebed.

4. Specific Procedures:

a. Engine trim, flight control evaluations and fuel system evaluations will be in accordance with established maintenance procedures.

b. Operations in the Weight and Balance facility will follow established procedures.

c. Firefighting equipment will be on standby for all fuel system ground tests.

d. Taxi tests on both wet and dry surfaces will be performed on cleared ramp areas which will allow adequate room to stop straight ahead without obstructions.

e Firetrucks and crash rescue will be on standby for barrier and brake tests.

f Barrier tests will be performed on the barrier test facility at South Base in accordance with AFFTCR 80-11. Barrier tests will be discontinued when approaching 75% tail hook ultimate load or 80% lateral limit load on the landing gear.

g. High energy brake tests and single-engine takeoffs will be performed on runway 04 to allow overrun into the lakebed.

h. Single-engine takeoffs will utilize a two engine acceleration to an intermediate speed followed by a single-engine takeoff with the "bad" engine in idle. This is to maintain takeoff rolls at or below 10,000 feet.

i. Prior to single-engine takeoff tests, single-engine climb performance at 1000 feet AGL and single-engine handling qualities at 5000 feet AGL will be evaluated.

j. 1000 foot minimum separation between tracker and target will be maintained during HQDT.

h. Safety chase is not required When chase is used, standard chase procedures will be followed.

5. The SRB reviewed the attached OHA and the board considered these tests to be Low Risk except for the brake tests and the barrier tests.

The Brake Tests were considered Medium Risk due to the uncertainty of heat dissipation characteristics of the new brake and wheel assembly.

The Barrier Tests were considered Medium Risk. Although the probability of loss of control is considered low, little can be done to minimize the potential effect.

OPERATING HAZARD ANALYSIS (OHA)

TEST SERIES	PREPARED BY (Name and Title)	SIGNATURE	REVIEWED BY (Name and Title)	SIGNATURE
F-15C AFDT&E				

HAZARD	CAUSE	EFFECT	HAZARD CATEGORY	CORRECTIVE ACTION/MINIMIZING PROCEDURES	REMARKS
MASS PROPERTIES AND FUEL GAUGING					
Fire	Fueling in operations in Weight and Balance Hangar with electrical power connected to aircraft.	Loss of A/C and government property, personnel/injury and/or death	I	1. Use established Wt and Balance facility fueling and defueling procedures. 2. All personnel will be briefed prior to the test on emergency procedures. 3. Only required personnel will be allowed in hangar during test. 4. All test operations and personnel will be under control of the test director located in the Wt and Balance Hangar.	

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OPERATING HAZARD ANALYSIS (OHA)

TEST SERIES: F-15C AFDT&E

PREPARED BY | SIGNATURE | REVIEWED BY (Name and Title) | SIGNATURE

HAZARD	CAUSE	EFFECT	HAZARD CATEGORY	CORRECTIVE ACTION/MINIMIZING PROCEDURES	REMARKS
TAXI TESTS					
Structural failure of landing gear	Increased wt & stresses on landing gear	Major A/C damage, personnel injury or death	I	1. Use buildup to determine loads and stresses on gear. 2. Real time TM monitor of gear stresses 3. External tanks will be filled with water to achieve desired weight. 4. Discontinue tests when reach 60% of limit load on most critical landing gear components. 5. Test conductor will provide point-to-point clearance	
Tip Over	Exceeding tip-over speed at test turn radius	Major A/C damage, personnel injury/death	I	1. Lateral accelerations necessary to tip over will be determined and monitored in real time during the conduct of the test. Predicted lateral acceleration will be used to provide point-to-point clearance for each test point. 2. Buildup in speed and turn radius will be used.	
Blown Tire	Extensive taxi operations; improper servicing of tires.	Personnel injury/death	I	1. Tire surface temperatures will be checked before and after prolonged taxi. 2. Tire temperatures will be allowed to cool for at least 15 minutes if the temperature exceeds 200°F. No personnel will approach the tires during cooling period. 3. If tire temp exceeds 250°F, tests will be discontinued for a tire change. 4. Tire pressures will be checked prior to taxi tests and will be in accordance with T.O. 5. Tire will be serviced to pressure for highest planned gross weight. 6. Tire bead temperatures will be below 200°F before pressure measurement.	

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OPERATING HAZARD ANALYSIS (OHA) — PAGE 7 OF 10 PAGES

TEST SERIES: F-15C AFOT&E

HAZARD	CAUSE	EFFECT	HAZARD CATEGORY	[illegible]	REMARKS
				7. Tires will be allowed to cool to a uniform surface temperature prior to each test run.	
BRAKING TESTS					
Loss of Directional Control	Anti-skid/brake malfunction, blown tire	A/C damage, personnel injury/death	I	1. Buildup procedure for point-to-point test conditions. 2. Test conductor has real time monitor of anti skid signal as well as direct communication with the pilot. 3. 10 knot wind limit used during tests. 4. Brake and tire temperatures will be checked before and after test runs. The same procedures as the taxi tests relative to tire temperatures will be used. 5. Runway wetting pattern leaves dry areas on both sides to regain directional control. 6. Runway 04 will allow use of lakebed for overrun.	Brakes have been successfully tested to 100% energy on Dynamometer. These tests are to 80% KE.
Overtemp of wheel/brake assembly	Heavy braking	Brake fire, blown tire, personnel injury/death	I	1. Test conditions are sequenced to provide a logical buildup with point-to-point clearance from real time data monitor. 2. Brakes and tires will be cooled below 100°C prior to each run. 3. Pilot will use INS ground speed to establish test conditions. 4. Fire truck and cooling fans will be available for immediate use. 5. Personnel will not approach wheels until tires are cooled below critical levels. 6. Fuse plugs are in wheels. 7. If test data indicates approaching 2300°F, the tests will not be conducted to higher energy levels.	

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OPERATING HAZARD ANALYSIS

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HAZARD	CAUSE	EFFECT	HAZARD CATEGORY	CORRECTIVE ACTION/MINIMIZING PROCEDURES	REMARKS
BARRIER ENGAGEMENTS					
Barrier system component failure	Hook damage, exceeding system loads.	A/C damage, personnel injury	II	1. New tapes and cables will be installed for this test. T.O. replacement procedures will be used. 2. System thoroughly inspected before and after each run. 3. Strip chart data will be analyzed after each run to assure proper system operation and no limits exceeded 4. Point-to-point clearance will be based on predicted loads 5. Emergency equipment and personnel will be on standby at the test site	
Loss of Directional Control	Equipment failure, unanticipated off-center engagement, blown tire	A/C damage, crew injury or death	I	1. Tests performed in buildup of speed & weight 2. 10 knot wind limit for barrier tests 3. Test conductor has real time monitor of anti skid signals and brake temperatures as well as direct contact with the pilot. 4. Brake and tire temperatures will be checked before and after each run. Tire condition will be checked before & after each run. The same tire temperature procedures as used for taxi tests will apply.	
Aircraft rotation/airborne at barrier engagement	Exceeding test conditions, flight control system anomaly	A/C system damage, loss of A/C, personnel injury/death	I	1. Flight controls are instrumented to aid in detecting anomalies. 2. Test conditions are at or below rotation speed for each gross weight. 3. INS data used to establish test condition. 4 Flaps down and nose down trim will be used.	

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OPERATING HAZARD ANALYSIS

TEST SERIES: F-15 AFDTSF

HAZARD	[illegible]	[illegible]	HAZARD CATEGORY	[illegible] MINIMIZING PROCEDURES	REMARKS
Aircraft damage during rollback	Setting or fail, overstress of main landing gear	Tail cone or slab damage, gear failure	II	1. Pilot braking procedures, in accordance with the T.O. will be briefed prior to the test.	Not a problem in previous tests.
Hook failure	Exceeding hook limitations	A/C structural damage	II	1. Hook loads will be instrumented and maintained in real time. 2. Buildup approach will be used in building up hook loads. Point-to-point clearance will be made by the test conductor. 3. Tests will be discontinued at 75% limit load of the hook assembly	Basic aircraft and hook structure are unchanged from F-15A/B
Cable engage main landing gear and/or centerline tank.	Unanticipated vibrations of cable	A/C system damage, personnel injury/death	I	1. Cable tendencies will be evaluated during buildup tests. 2. External tanks will be filled with water. 3. Pilot, support, and rescue personnel will be thoroughly briefed on actions to be taken and specific conditions to watch for during the tests.	

AFFTC FORM 28A PREVIOUS EDITIONS ARE OBSOLETE

OPERATING HAZARD ANALYSIS

TEST SERIES: F-15 AFCT&E [illegible]

HAZARD	CAUSE	EFFECT	HAZARD CATEGORY	CORRECTIVE ACTION / PROCEDURE	REMARKS
FLIGHT TESTS					
Engine failure during single-engine takeoff	Unknown engine fault	Possible loss of A/C and crew	I	1. All single-engine takeoffs will be on Runway 04 to allow [illegible] into the [illegible] 2. The second engine will be set at idle and available [illegible] 3. Single engine climb potential and performance will be [illegible] prior to single-engine takeoffs [illegible] read [illegible] total [illegible] limit for single [illegible] takeoff [illegible]	
Mid air collision with tanker during aerial refueling	Unanticipated cg shift during refueling with external tanks	Possible loss of A/C and crew	I	[illegible] cg variations at various fuel loads will be evaluated during mass properties ground tests [illegible] fuel loading conditions will be identified during [illegible] and monitored in real time during refuel tests 3. Fuel system failure mode tests will be completed prior [illegible] aerial refueling with external tanks. 4. [illegible] pilot will be fully qualified and current in aerial refueling	
Gear overspeed	Exceeding test conditions	A/C damage, loss of gear doors, dropped object, personnel injury, property damage	II	1. Buildup in speed to approach test condition from safe side 2. High power test points to be flown in a climb to reduce acceleration. 3. Tests over sparsely populated area.	

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