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DESIGN OF SKID CONTROL & ASSOCIATED AIRCRAFT EQUIPMENT FOR TOTAL SYSTEM COMPATIBILITY

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1. PURPOSE: To recommend design practices and minimum laboratory and aircraft requirements for skid control and associated equipment, so as to provide for total aircraft system compatibility.

2. SCOPE: This document covers the general requirements for aircraft skid control systems and their components.

Methods of defining skid control system performance criteria for design and evaluation purposes are outlined and recommended.

Design and operational goals, general theory, and functions, which must be considered by the aircraft brake systems engineer to attain the most effective skid control performance, are covered in detail.

Recommended methods for measuring performance of skid control systems are included.

3. GENERAL REQUIREMENTS:

3.1 Introduction: The skid control system covered by this recommendation provides a means of detecting an incipient skid condition of the aircraft tires and thereupon functions to control the brakes to maximize braking drag, prevent tire damage and loss of aircraft control. In operation, it properly adjusts the brake pressure at all times to maintain the brake torque at the correct level to maintain the tire-runway friction force at its peak value and thus give the aircraft maximum available deceleration resulting in the shortest possible stop distance.

3.1.1 Functional Operation: The performance of the skid control equipped hydraulic brake system is dependent upon the degree of compatibility achieved between the skid control equipment, the airplane's landing gear and airframe, and the remainder of the brake control system.

In operation, the pilot commands hydraulic pressure to the brakes in proportion to his brake pedal force and/or pedal travel. If there are no incipient skids, the skid control system does not interfere with his braking. If there are incipient skids, the skid control system overrides the pilot's input and reduces the brake pressure just enough to stop the incipient skids. It does this in a manner which seeks to continuously use all of the available tire-runway friction braking force but not allow the tires to stop rotating (lockup) or even enter into deep skids.

3.1.1 Functional Operation (Continued):

The skid control system controls the brake pressure through a skid control valve in response to information obtained from a wheel speed sensor. The wheel speed information is processed by a control box which then sends a control signal to the valve, which controls the brake pressure. Upon command from the control box, the skid control valve reduces or removes brake pressure by venting fluid from the brake to the hydraulic system reservoir. When conditions improve, the skid control valve, upon command, reapplies brake pressure at a controlled rate until another incipient skid occurs.

3.1.2 Performance: The skid control system, in conjunction with the aircraft brake system, should be capable of functioning efficiently on all landing surface conditions from maximum rolling speed to the lowest speed compatible to ground handling of the aircraft, and should not permit a completely locked brake within the control speed range (assuming the brake will respond to control). It should reduce brake pressure only the smallest necessary amount, for the shortest time possible, so as to minimize stopping distance. Specific areas of concern are, (1) rapid initial adjustment to the optimum control pressure, (2) operation at partial metered pressures, and (3) rapid adjustment to changing runway conditions.

The skid control system should not induce airframe dynamic instability, gear walking, gear chatter, etc. This will be demonstrated on the aircraft throughout the forecasted aircraft ground operation spectrum.

The system should be tuned for optimum performance over a broad range of conditions particularly a wet runway surface, a dry surface, and combinations of wet and dry surfaces, considering both braking and cornering forces, throughout the control speed range. Since the total braking function involves more than the skid control system and wheel brake assemblies, the total airplane stopping performance is the responsibility of the airframe manufacturer.

3.2 Design Practices:

3.2.1 Considerations: Advanced landing gear systems contain elastic structure and can cause antiskid stability and performance problems. Current design trends emphasize reduced volume for wheels and brakes, increased shock strut flexibility arising from the use of high heat treated steels, and the use of more responsive skid control braking systems.

In general, brake linings capable of withstanding high rates of energy input, high temperatures, and exhibiting low wear rates have friction variations that can excite landing gear system natural frequencies.

The performance of the skid control system is dependent upon its mutual compatibility with the response characteristics of the aircraft brake system and associated structures; therefore, the designer must consider these and other variables as noted in Table I herein.

TABLE I - FACTORS INFLUENCING
STOPPING PERFORMANCE

SUBSYSTEM PARAMETERS

Brake Actuation System
o Pedal Linkage to Metering Valves
- Actuation mechanism mechanical advantage
- Cable length and stiffness

o Hydraulics
- Hydraulic pump capacity and recovery rate
- Accumulator pressure/volume characteristics
- fluid type
- Brake line length, size and stiffness
- Component flow restrictions
- Return line back pressure (steady state and transient)
- Metering valve flow capacity
- Metering valve pressure gain

Antiskid System
o Wheel speed detector
- Hub cap coupling mechanism
- Electrical characteristics
- Resolution
- Demodulator characteristics

o Electronics
- System type
- Detailed design (skid control circuit logic)

o Servovalve
- First stage type
- Flow gain
- Pressure gain
- Second stage lap
- Frequency response

Wheel, Brake, and Tire System
o Brake
- Pressure volume characteristics
- Lining characteristics
- Heat sink loading
- Heat transfer characteristics
- Retractor spring pressure
- Wear adjusters
- Brake mounting stiffness
- Vibration characteristics
- Torque frequency response

o Tire
- Footprint area
- Inflation pressure
- Fore and aft stiffness
- Vertical stiffness
- Lateral stiffness
- Mass
- Inertia
- Tread design and wear
- Thermal properties
- Rolling resistance
- Diameter
- Damping characteristics
- Nose wheel tire size (used as velocity reference)
- Coefficient of friction

RELATED AIRCRAFT SYSTEM PARAMETERS

Landing Gear
o Strut
- Fore and aft stiffness
- Strut effective mass
- Fore and aft damping
- Vertical stiffness
- Metering pin design
- Torsional stiffness
- Torsional damping
- Tolerances
- Strut geometry

o Truck
- Mass
- Inertia
- Truck unbalance
- Truck pitch dynamics

TABLE I - FACTORS INFLUENCING
STOPPING PERFORMANCE (Cont'd)

Airplane
- o Aerodynamics
  - Brakes on speed
  - Aerodynamic coefficients (lift and drag)
  - Spoiler deployment rate and effectiveness
  - Engine idle spindown and reverse thrust characteristics

- o Directional Control
  - Nose gear steering system
  - Rudder(s)
  - Ailerons
  - Spoiler
  - Elevators
  - Engine(s)
  - Differential braking

- o Geometry
  - Center-of-gravity location
  - Landing gear arrangement
  - Airplane weight
  - Airplane mass moment of inertia
  - Wing stiffness

- o Operational Characteristics
  - Pilot braking technique

ENVIRONMENTAL PARAMETERS

Runway
- o Roughness (micro and macro texture)
- o Contamination (water-rubber)
- o Slope
- o Crown

Atmospheric
- o Ambient temperature
- o Pressure altitude
- o Wind velocity and direction

3.2.1 Considerations (Continued):

Poor brake control can degrade the inherent directional stability of the aircraft. Both stopping ability and directional control are dependent upon available friction or mu between the tire and runway. Referring to the tire mu-slip characteristic (a typical curve is shown in Figure 3), it is acknowledged that most modern-day skid control systems utilize some means of sensing skid level to determine available mu and thereby react to maximize the utilization of this available mu. In the sensing mode, the tire is forced into an incipient skid which allows the tire to traverse onto the back side of the mu-slip curve. Measured values indicate that the side force is reduced on the back side of curve. Therefore, it is most advantageous to specify brake control systems that dwell predominantly in the upper regions on the front side of the curve. Skid control system optimization to assure high lateral force capability can be accomplished by system "tuning". The least expensive method to accomplish this tuning is through the use of an analog or digital skid control simulator that enables assessment of the period in time the system dwells on the back side of the mu-slip curve. Although data gained through this method are valuable in determining a measure of directional control stability for the aircraft, the total ground control problem is much more complex and consideration must be given to all aircraft related influences that combine to produce satisfactory stopping performance.

3.2.2 Skid Control System Responses: A primary design objective is the attainment of minimum response time in each of the skid control components involved in the completion of a skid control cycle. Nevertheless, this objective must be compatible with the elastic characteristics of the landing gear, airframe, tire, brake, and hydraulic system. A skid control cycle consists of the following events:

(1) measure of excessive wheel deceleration or slip, (2) reduction of brake pressure at skid control system command to optimize the wheel, tire, and brake function, and (3) reapplication of brake pressure to achieve the airplane deceleration commanded by the pilot or the maximum attainable, whichever is less. In view of the fact that some skid control cycles result in oscillatory loading of the landing gear structure, it is considered good practice to perform analysis to show that the oscillatory loading resulting from skid control cycles does not cause structural damage to the landing gear or airframe. The following variables are considered pertinent to this analysis:

3.2.2 Skid Control System Responses (Continued):

(a) Skid control system frequency response characteristics.

(b) Brake assembly frequency response characteristics.

(c) Hydraulic system frequency response characteristics.

(d) Airplane gross weight and moments of inertia.

(e) The elastic and damping characteristics of the landing gear. High drag loads at low speeds may affect the structure.

(f) The airplane's aerodynamic characteristics.

(g) Tire to runway friction for various tire tread and runway conditions.

(h) The brake's pressure versus torque characteristics. Variations in brake frictional coefficients result from different energy levels.

(i) Brake system command pressure characteristics.

(j) Elastic characteristics of the tires.

3.2.3 Recommended Data Exchange: It is advantageous to provide the system analyst with the greatest quantity of information available so as to assure the least amount of system deficiencies prior to aircraft test. Therefore, the following data exchanges are recommended:

3.2.3.1 Customer Data: The following data, to the extent possible, should be provided to the skid control manufacturer:

(a) Complete brake system schematics.

(b) Diagram showing all of the hydraulic line sizes and restrictions between brake metering valves, brakes, and reservoir.

(c) Brake pressure versus fluid displacement for the brake assembly.

(d) Brake torque characteristics over the pressure and speed range.

(e) Skid control system schematics, envelope and mounting requirements, and requirements for system checkout equipment and procedures.

(f) Aircraft weight and CG location.

(g) Aircraft pitching moment of inertia.

(h) Main landing gear natural frequency and spring rate, in the drag direction and its structural damping coefficient.

(i) Mass moment of inertia of the main landing gear wheel and tire.

3.2.3.1 Customer Data (Continued):

(j) Mass moment of inertia of the rotating parts of the main landing gear brakes.

(k) Natural frequency and torsional spring rate of tire, wheel, and rotating brake parts.

(l) Natural frequency, torsional spring rate, and structural damping coefficient for the brake housing, axle, and brake non-rotating parts.

(m) Performance specification or other technical description of the main landing gear assembly, tire, wheel, and brake.

(n) A table or schematic showing the skid control valve's condition of electronic energization for various possible combinations of landing gear and pilot operated switches.

(o) Tabulation of mandatory fail-safe requirements.

(p) Maximum and minimum speeds to which skid control is expected.

(q) Skid control system efficiency requirements.

(r) Designation of special features, such as touchdown protection, locked wheel protection, or automatic prebraking features.

(s) A description of the control and warning devices to be provided for the pilot.

(t) Electrical input characteristics.

(u) Electromagnetic interferences and environmental requirements.

3.2.3.2 Vendor Data: The skid control manufacturer should provide:

(a) Electronic schematics.

(b) Failure modes and effects analysis.

(c) Reports showing compliance with specified requirements. Detail design analysis by components and as a system.

(d) Skid control system component characteristics as required by the procuring activity for overall brake system analysis.

(e) Recommended system maintenance and checkout procedures.

(f) Recommended ground support equipment.

3.2.3.2 Vendor Data (Continued):

(g) Complete working drawings except proprietary data.

(h) Unit acceptance test procedures including substantiation of testing requirements.

(i) Qualification test procedure and test results.

3.3 Design Goals: The skid control system should be capable of providing brake drag efficiencies on the order of 90% when required, prevent locked wheel skids, and provide optimized cornering capability under normal operating conditions, e.g., dry, wet, slush, and ice.

During the design phase, consideration should be given to the energy transfer through the tire into the brake. While it is important to operate the tire at a slip that maximizes the drag force, it is also important, in order to minimize tire heating, to limit this slip. In other words, it is important to maximize the power transmission to the brake and minimize the power dissipated in the tire.

Figure 1 illustrates the relationship between tire and brake energy absorption or power versus the tire slip.

From Figure 1, it is obvious that the same tire drag force can be developed whether the control is operating on the left side or the right side of the tire drag force curve. However, the relative energy dissipation in the tire and brake is considerably different for each case.

The relative effect on the brake is minimal, but the impact on the tire can be significant. This has a major impact on tire wear and life. Also, if chronic, it may lead to unexpected blowouts due to continually overheating in the area of the tire tread.

Therefore, any demonstration of skid control performance should contain a means to evaluate the position of the control with relation to the leading edge of the tire drag force curve.

3.3.1 Braking Vs. Cornering Interaction: The early work performed by NASA and published in report NASA TN D-4602 covered tire braking in conjunction with cornering forces and measured at various yaw angles, velocities and runway conditions. Figure 2 is a record taken from this report and illustrates the relationships of the forward drag forces to the side or lateral forces. It is quite apparent that the lateral force capacity decays rapidly as the slip is increased. This again reiterates the need to maintain skid control on the forward portion of the tire drag force curve.

For performance evaluation, the control simulation should incorporate characteristics similar to Figure 3.

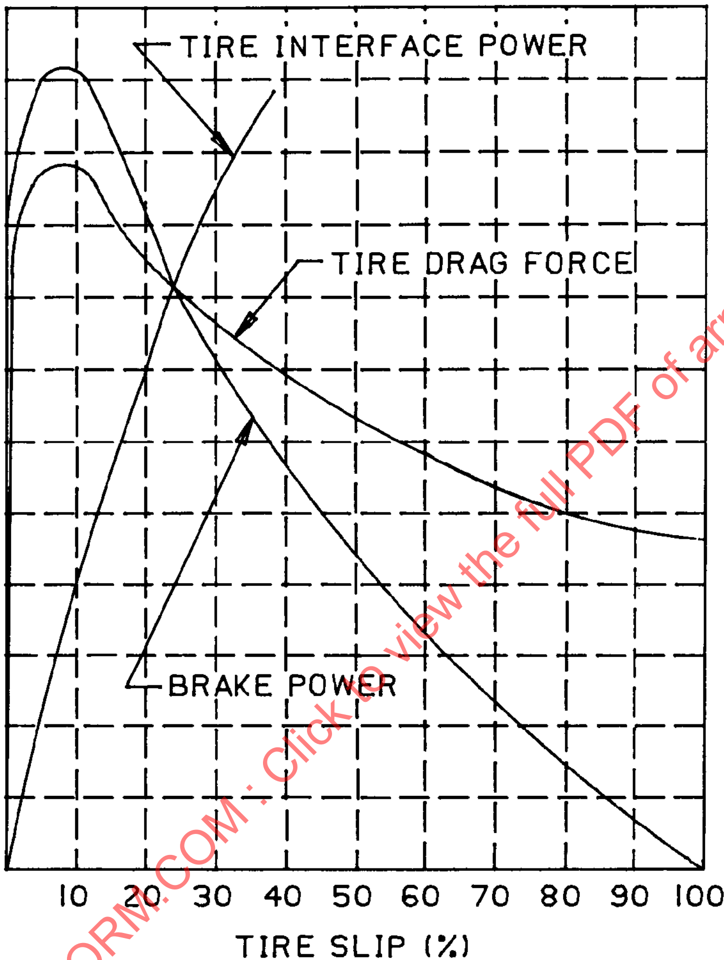


FIGURE 1. POWER VS SLIP

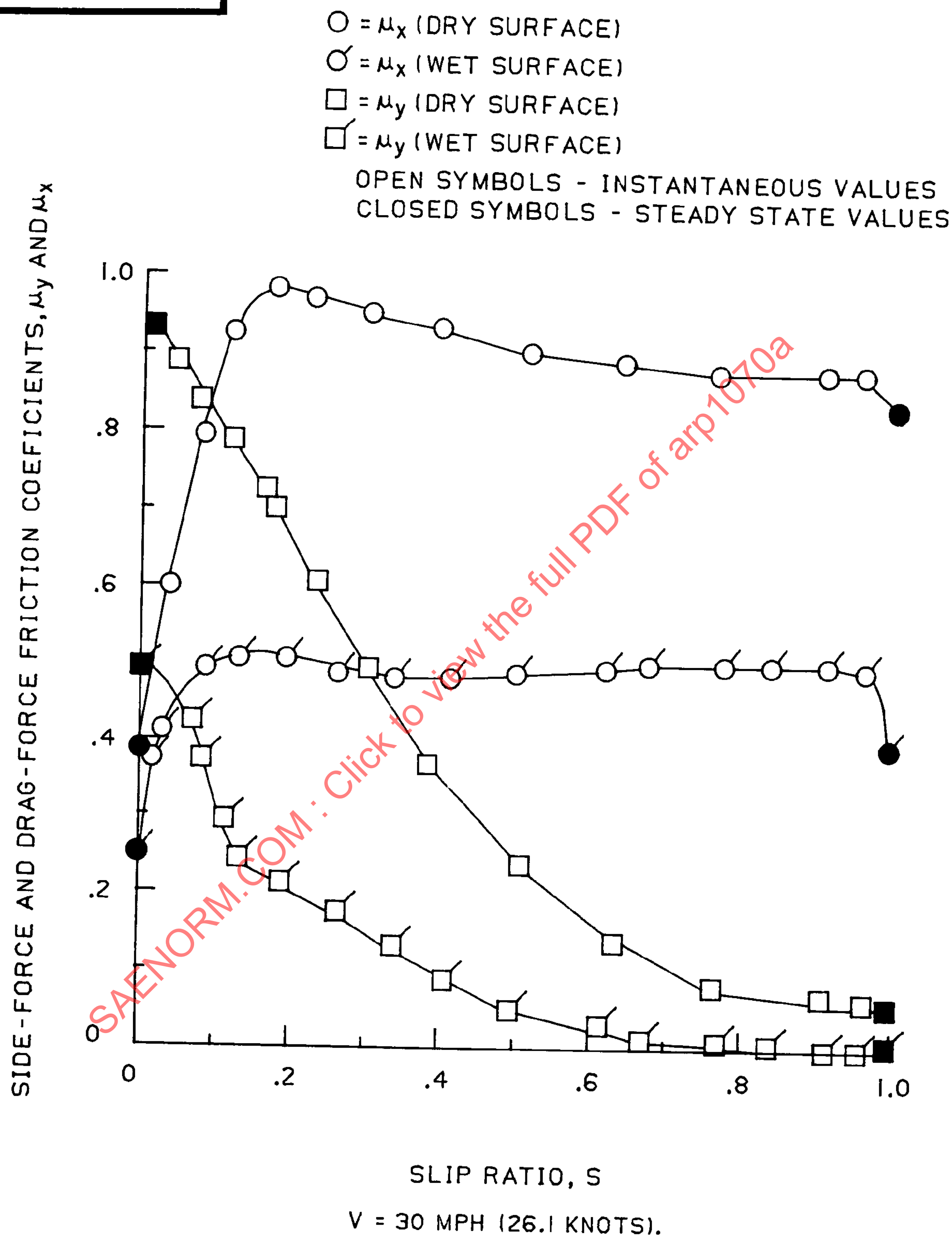


FIGURE 2. - NASA TN D-4602 TEST DATA

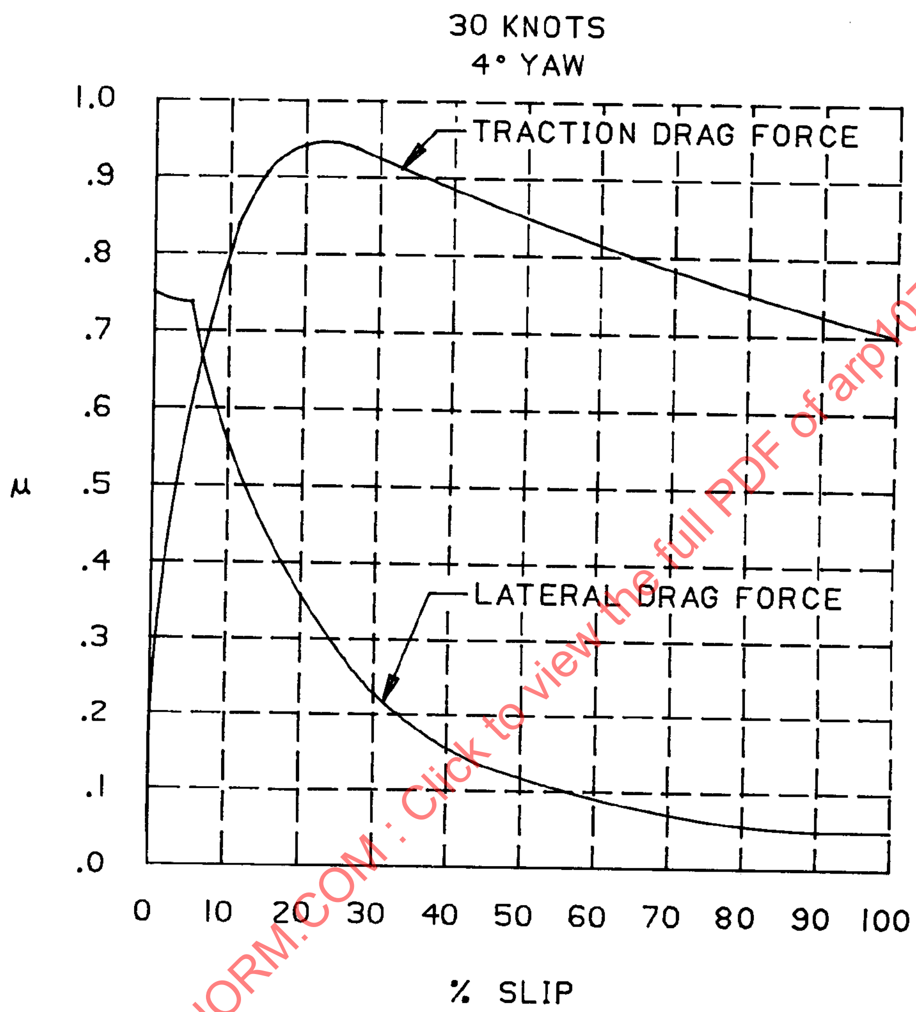


FIGURE 3. - COMPUTED DRAG FORCE DATA

3.3.2 Brake Application Response: The skid control system should not reduce the brake control system's ability to respond to the pilot's commands. However, if the addition of a skid control system to the aircraft should cause a significant change in the brake control system's ability to respond to rapid changes in pilot command, an analysis to show that this change does not adversely affect landing gear dynamic loads or introduce any undesirable airplane pitching characteristics should be performed.

3.3.3 Hydraulic System Design Goals:

3.3.3.1 Brake Metering Valves: Valve ports and internal fluid passages should be sized to permit adequate flow to and from the skid control valve. Consideration should include the desired initial brake response from the fully released position against residual reservoir pressure to brake applied position in addition to subsequent cyclic reapplication of pressure by the skid control valve. Additional consideration should be given to the metering valve's compatibility relative to the demands placed upon it by the skid control valve in the application and release of brake pressure associated with skid control.

3.3.3.2 Hydraulic Lines: Hydraulic piping and fittings should be designed to minimize restriction of flow with the objective of optimizing skid control response time.

Size: Hydraulic lines for supply and return should be selected to provide minimum pressure drops compatible with flow requirements of the brake metering valves, skid control valves, and brake assemblies under installed environmental conditions.

Type: Hydraulic tubing, rather than hoses, should be installed downstream of the brake metering valves where possible to minimize the accumulator effect during pressure changes.

Parking Requirements: System parking requirements should recognize internal leakage of the skid control valve. Shutoff valves may be used to block quiescent flow to system return.

System Bleeding: Provisions should be incorporated to minimize entrapped air within the system. Reverse bleeding of the system should be limited to those installations which provide adequate internal or external means to prevent entry of contaminants into hydraulic components. Some skid control valves, for example, can be rendered inoperative if contaminants reach valve spools and orifices. Self-contained inlet filters in these control valves are not effective during reverse bleeding. System designers should consider location of bleeder valves, integral bleeding devices, and number of personnel plus equipment necessary for proper system bleeding.

3.3.3.3 Internal Leakage of the Skid Control Valve: Internal leakage of the skid control valve should be minimized in installations where it is necessary to reduce the bleed-off of any accumulator pressure which is available for parking or as a stored emergency supply. However, consideration should be given to any reduction in valve performance that may result from reduced internal leakage.

3.3.3.4 Contamination Control: Filtration of fluid to the skid control valves should be provided. The filter should retain all particles which can adversely affect valve operation, and its capacity should be consistent with established overhaul periods. Filtration size should be larger (never smaller) than the aircraft hydraulic system filters.

3.3.3.5 System Flow: Initial consideration should be given to provisions for decreasing brake release time. Subsequent analysis should show that components of the skid control and hydraulic brake system, when functioning together, are capable of achieving the required skid control cycle. This analysis should take into consideration possible limited hydraulic capacity which may adversely affect the braking system when combined with the flow rates that occur during skid control cycling. Extremes of operating temperatures which will be encountered during the operation of the airplane should also be considered in this analysis.

3.3.4 Brake Design Goals:

3.3.4.1 Response: Minimum brake response time is desirable. The procuring activity should determine and provide brake response time data to the skid control system manufacturer such as step response and frequence response between brake pressure and torque.

3.3.4.2 Pressure: Maximum aircraft hydraulic system pressure should be specified for maximum metered brake operating pressure whenever practicable.

The following are reasons for the use of maximum hydraulic system pressure:

(a) Conditions for best possible antiskid braking performance are enhanced by keeping the operating pressures as high as possible.

(b) Metering valves that regulate maximum brake pressure below system pressure may experience high momentary pressure drops which will tend to introduce cross-talk between two or more skid control valves that are supplied from the same metering valve. This problem does not occur where only one skid control valve is supplied from the metering valve.

(c) For paired wheel skid control systems, directional control problems due to production tolerances on the maximum pressure setting will be eliminated.

3.3.4.2 Pressure (Continued):

A reason that may exist for not using maximum hydraulic system pressure is the situation where it is desired to use accumulator pressure in the hydraulic system for emergency braking. In this case, a lower brake operating pressure is required to allow a maximum number of brake applications. Another reason might be for dual brake pressure control systems, where loss of one system is compensated by an increase in maximum output pressure from the other system.

3.3.4.3 Fluid Displacement: Hydraulic fluid volume change should be a minimum from residual pressure to maximum operating pressure for both new and fully worn brake conditions (compatibility with the antiskid system should be confirmed). A relatively high brake structural spring rate and self-adjusters should be considered to accomplish the above.

3.3.4.4 Fluid Passages: Ports and internal fluid passages should be designed to assure minimum air entrapment and minimum flow restrictions and to assure lowest practicable resistance to fluid flow.

3.3.4.5 Mechanisms: Brake release mechanism, self-adjusters if employed, brake rotor wheel drive key interface, brake stator torque tube spline interface, and hydraulic seals should be designed to minimize friction and its effects on the hysteresis associated with application and release of the brakes.

3.3.4.6 Seals: The brake's hydraulic seals should be adequately protected against entry of foreign material and selected for life within the expected environment.

3.3.4.7 Port Location: The brake pressure ports should be located after having given due consideration to the configuration of the supply piping.

3.3.4.8 Reaction Torque: For airplanes with multi-wheel bogies, the brake's torque should react in such a manner that brake applications do not result in variations of the vertical wheel loads.

3.3.4.9 Return Springs: Return springs should be strong enough to overcome maximum squeeze brake piston seal friction and reservoir pressure plus additional force for satisfactory brake-off response.

3.3.5 Electrical Design Goals:

3.3.5.1 Electrical Power: The following items should be considered in regard to electrical power for the skid control system:

a) Normal and emergency power characteristics should be evaluated for any detrimental effect on system performance.

b) A means to engage or disengage electrical power should be made available to the pilot.

c) Voltage transient protection should be incorporated in all electrical and electronic assemblies.

d) Power interruption characteristics should be evaluated and criteria established for skid control performance.

e) Power redundancy or isolation should be utilized to minimize total system failures.

3.3.5.2 Electromagnetic Interference (EMI): Consideration should be given to EMI design requirements sufficiently early in a skid control system design program to preclude operational problems on the aircraft.

EMI tests should be performed on the skid control system installed in a simulated aircraft network.

3.3.5.3 Wiring: Wire routing should be controlled to prevent interaction between the skid control system and other equipment.

It is generally considered good design practice to not use wire smaller than No. 22 gage.

Shielded wire should be considered for sensitive circuits such as the wheel speed sensing circuit. It is recommended that the shield be continuous and grounded at both the sensor and the control box connector.

3.3.5.4 Connectors: Connectors should be environment resisting type. In high vibration areas, such as the landing gear, the connectors shuld be the threaded type with lock wire. The larger pin sizes should be used wherever possible and the maximum spacing maintained between the pins.

3.4 Design Implementation: Preference should be given to established and proven design concepts and features.

New design features should be adequately evaluated and supported by theory, analysis, and planned test and evaluation.

State-of-art devices and features should be of a mature design.

3.5 Evaluation Methods:

3.5.1 Techniques: It is strongly recommended that a multi-discipline approach be employed in the evaluation of each feature and functional aspect of the design as well as to the evaluation of the adaptation and integration of the design into the total system.

3.5.2 Methods: This should include design analysis and planned test.

Evaluation of Product: Acceptance test data, and review of field service history will give much insight on maintainability and reliability.

Worst case analysis of critical design features is mandatory.

Planned demonstrations tests should be performed at ambient and environmental extremes.

Computer simulation tests and analysis should be employed when practical.

4. PERFORMANCE EVALUATION:

4.1 Laboratory Tests: The following type tests are suggested as an indication of anticipated performance prior to first flight.

4.1.1 Dynamometer Test: Dynamometer testing is a valuable tool for evaluating operating behavior and compatibility between the various active elements of the total braking system. Dynamometer tests should not be considered a substitute for aircraft or computer tests in determining and optimizing overall braking efficiency and effectiveness. Dynamometer testing, while not mandatory during the development cycle of a skid control system, can offer information on potential problem areas, such as brake vibration and torque variations.

As a minimum, the skid control system components should be mounted in a manner similar to the proposed aircraft installation on a suitable stub axle or landing gear carriage. For all tests performed, the following quantities should be recorded with respect to time:

(a) Hydraulic pressure at the skid control valve inlet port.

(b) Hydraulic pressure at the brake inlet port.

(c) Hydraulic pressure in the brake.

(d) Dynamometer peripheral speed.

(e) Aircraft wheel speed.

(f) Skid control valve signal.

(g) Brake torque as measured at the axle.

4.1.1 Dynamometer Test (Continued):

(h) Drag force (ground reaction force) if available.

(i) Wheel load.

4.1.1.1 Procedure: The aircraft wheel radial load should be applied by a loading mechanism which holds the ram pressure constant during braking.

Consideration should be given to adjusting tire inflation pressure for appropriate deflection for each load condition.

Both lift and weight transfer effects (due to deceleration) should be taken into account. However, weight transfer may be computed on the assumption that the aircraft nose wheel suspension is infinitely stiff.

4.1.1.2 Efficiency Determination: Dynamometer braking efficiency can be determined by utilizing data obtained from representative dynamometer runs. The drag force, brake torque, or brake pressure curves should be integrated from "brakes on" to ten miles per hour at a minimum of four representative sections to get the actual area under the curves. The peaks (not transients) of the curves may be connected and integrated to get the optimum area. The efficiency of braking is defined as the ratio of the actual area to the optimum area (see ARP 862).

A digital computer program may be developed to perform the numerical integration. Four sets of data of at least 2.0 seconds should be taken at different aircraft speed for each curve. Each set of data with 20 sample points (100 milli-second time interval) may be used as the input of the computer program. Four sections of area may be computed for actual drag, torque or pressure curves, and optimum drag, torque or pressure respectively. The integration may then be accomplished with the aid of a digital computer routine. The efficiency may be calculated by taking the ratio of the average of actual area to the optimum area.

4.1.1.3 Computer Simulation Test: In conjunction with, or in lieu of, the dynamometer tests described above; computer simulation testing should be conducted to ascertain the degree of flexibility that exists within the control loop of the skid control system. The minimum variations that should be explored are: gear damping, reduced pressure input, truck pitch, and variations in runway mu.

This technique permits testing the skid control sub-systems and units under planned simulation of system environment. Each of the interface signals and parameters to the test item is computer synthesized and simulated thereby permitting precise, repeatable evaluation of system performance without the expense, logistics, and delays intrinsic to flight testing. A typial model of an analog brake simulation is exhibited in Figure 4. The following is a description of the symbols used:

4.1.1.3 Computer Simulation Test (Continued):

D - Drag Due to Brake Torque

D_A - Aerodynamic Drag

F_G - Braking Drag Acting on Aircraft Mass

F_M - Vertical Load on Main Gears

F_N - Vertical Load on Nose Gear

L - Aerodynamic Lift

P_B - Brake Pressure

T_B - Brake Torque

$\dot{X}$ - Aircraft Velocity

$\dot{X}_G$ - Gear Fore-Aft Velocity

$\dot{X}_S$ - Tire-Runway Slip Velocity

$\dot{\Theta}_W$ - Wheel Velocity

$\dot{Z}$ - Aircraft Vertical Velocity at CG

Z - Aircraft Vertical Displacement at CG

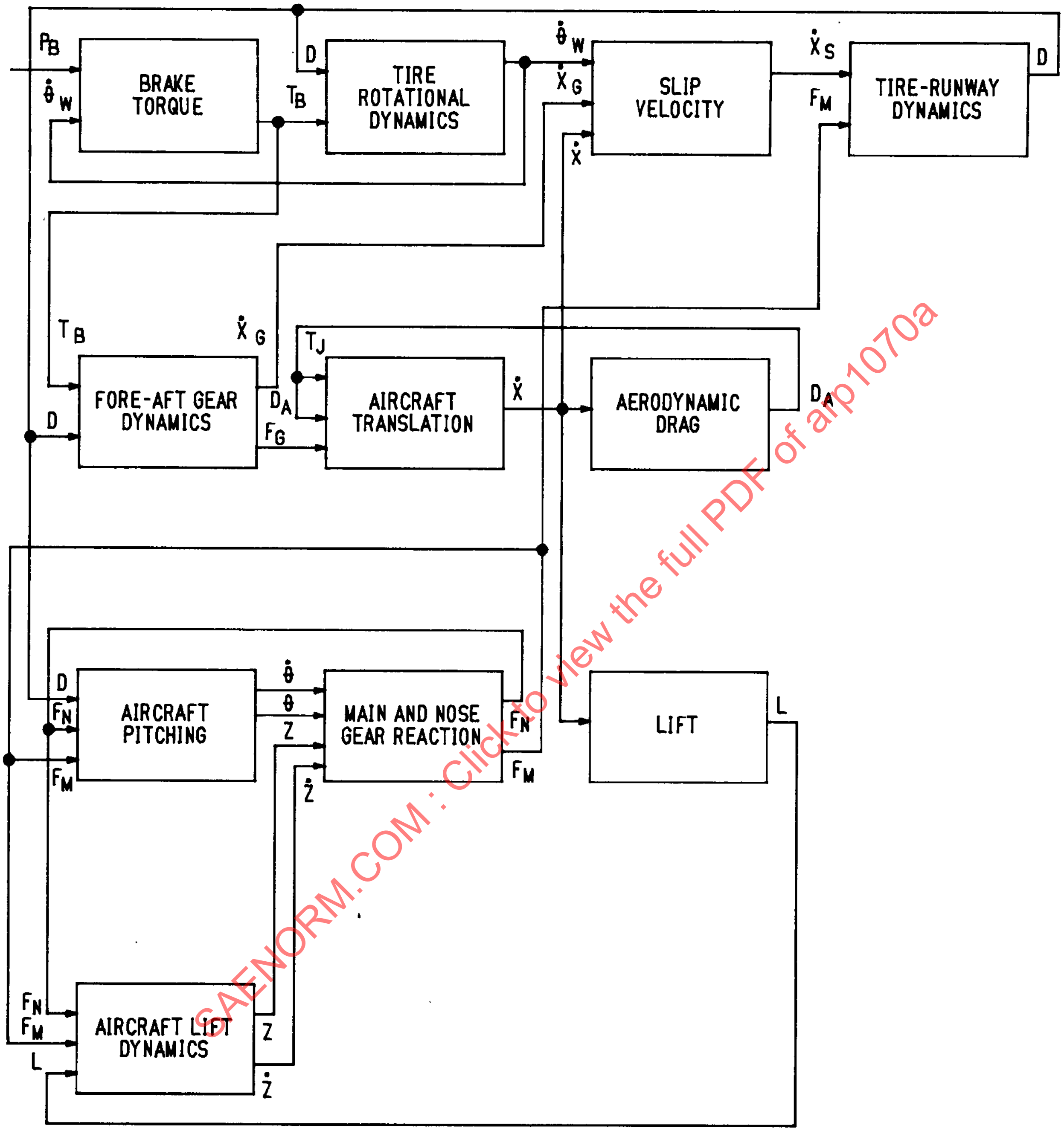
$\dot{\Theta}$ - Pitch Rotation Velocity

Θ - Pitch Rotation

T_J - Idle Thrust

4.2 Aircraft Tests:

4.2.1 Test Description: Aircraft testing is the final proof of system adequacy as far as system stability, performance, and efficiency are concerned. Therefore, certain minimum aircraft testing is required to demonstrate design goals and system requirements. A suggested general aircraft flight test schedule is presented in Table II. More or less, testing may be required depending on the aircraft's intended usage. If the skid control system contains entirely new or unproven circuits, consideration should be given to providing a prototype control box with a number of externally variable parameters (gains, time constants, etc.) available for expeditious tuning of the system to the airframe. Also, very early in the aircraft test program, relatively high (80% and up to expected max.) kinetic energies should be investigated, as this is an area where landing gear component/skid control system instability phenomenon is most likely to occur.



COMPUTER SIMULATION MODEL

FIGURE 4.

4.2.2 System Efficiencies: During test Number 3, conduct sufficient tests over a variety of wet and dry surfaces to permit development of an Efficiency versus Coefficient of Friction Curve. Efficiency of the total system can be determined by a variety of methods, similar to determining of efficiency during a dynamometer test. Brake torque, brake pressure, stopping distance, or drag force can be utilized to determine the efficiency of the total system. Total system performance is important because it includes the hydraulic system interface, the landing gear responses, the brake characteristics, and antiskid system characteristics. It is the prime responsibility of the airframe manufacturer to control a total system efficiency and not a single supplier effort. It is conceivable that total system efficiency can be determined on a computer simulation if the component or subsystem inputs are available. However, the flight test approach is preferred.

5. SKID CONTROL SYSTEM CONFIGURATION:

5.1 Configuration Considerations: The selection of a skid control system configuration is conditioned by considerations usually including the following:

(a) Number and arrangement of braked wheels.

(b) Degree of emphasis on stopping/cornering performance.

(c) Available space.

(d) Airplane electrical wiring configuration.

(e) Wheel brake friction variation.

(f) System cost.

(g) Reliability and maintainability.

(h) Weight

5.2 Wheel Speed Sensors, Number, Arrangement, and Location: A wheel speed sensor should be provided at each braked wheel or group of braked wheels which are restrained to rotate together to assure detection of incipient skids. The wheel speed sensor installation should assure accurate sensing of wheel angular motion. Constant velocity coupling between the wheel and wheel speed sensor should be provided to remove any velocity effect resulting from offset between the center lines of rotation.

5.3 Skid Control Valves, Number Arrangement, and Location:

TABLE II - SUGGESTED AIRCRAFT ANTISKID TEST SCHEDULE

TEST NO	TEST	G.W. LBS.	C.G.	TAS KTS	GEAR	FLAPS AND SPOILER	EPR	DESCRIPTION OF TEST	REQUIRED DATA	PRESENTATION OF DATA	TECHNICAL NOTES SPECIAL INSTRUCTIONS
1	Skid Control Operation	---	---	Static	Dn	---	---	Conduct skid control functional checkout with airplane on jacks.	1. Skid control valve voltage signal. 2. Whl speed voltage signal. 3. Skid control valve outlet pressures (LH and RH). 4. Skid control valve inlet pressures (LH and RH). 5. Return pressure from anti-skid valve. 6. Brake torque 7. Gross weight & C.G.	1. Data to be used for verification of correct skid control operation.	1. The system will be checked out per installation and functional test procedure. 2. This test will be primarily a checkout for flight test instrumentation.

TABLE II - SUGGESTED AIRCRAFT ANTISKID TEST SCHEDULE (CONT'D)

TEST NO	TEST	G.W. LBS.	C.G.	TAS KTS	GEAR	FLAPS AND SPOILER	EPR	DESCRIPTION OF TEST	REQUIRED DATA	PRESENTATION OF DATA	TECHNICAL NOTES SPECIAL INSTRUCTIONS
2	Skid Control and Brake System Operation.	Min. Wt.	Fwd.	Noted	Dn	Landing Config.	As Req'd	1. Perform slow speed (40 KTS max) taxi check with skid control on and off for pilot reaction to brake response. 2. Cal. KE & brake H.P. read brake pressure. 3. Apply max. brake effort with skid control "ON" at 60 knots, continue test until application becomes undesirable. 4. Same as No. 2. 5. Conduct high speed taxi runs with skid control "ON" (Max. Vs. TAS). 6. Same as No. 2.	Requirements one through five, the same as Test No. 1.	1. Time histories of the following: a) Brake pressures b) Skid control valve inlet pressures c) Brake control valve inlet d) Brake temperature e) Axle temperature f) C.G. longitudinal accel. g) System hydraulic pressure. h) Brake torque.	1. Various electrical signals to be used for correlation and troubleshooting.

TABLE II - SUGGESTED AIRCRAFT ANTISKID TEST SCHEDULE (CONT'D)

TEST NO	TEST	G.W. LBS.	C.G.	TAS KTS	GEAR	FLAPS AND SPOILER	EPR	DESCRIPTION OF TEST	REQUIRED DATA	PRESENTATION OF DATA	TECHNICAL NOTES SPECIAL INSTRUCTIONS
3	Skid Control Development Tests	1&2 min. wt. #3 avg. wt.	Fwd.	Max V_S	Dn	Landing Config.	As Req'd	1. Conduct sufficient braking test to optimize the skid control system for dry and wet runway surface. 2. Conduct several tests with reduced pilot metered pressure. 3. Conduct dry runway test with anti-skid "ON".	Same as Test No. 2.	Same as Test No. 2.	Same as Test No. 2.
4	Locked Wheel Control	Opt.	Opt.	$1.3V_S$	Dn	Landing Config.	Idle	Conduct landing with skid control on and brake pedals depressed.	1. Same as Test No. 2. 2. Touchdown indication.	1. Time histories of the following: a) Brake pedal position b) Brake pressure c) Wheel speed d) Skid control valve voltage	1. Conduct normal landing with maximum effort on brake pedal.

TABLE II - SUGGESTED AIRCRAFT ANTISKID TEST SCHEDULE (CONT'D)

TEST NO	TEST	G.W. LBS.	C.G.	TAS KTS	GEAR	FLAPS AND SPOILER	EPR	DESCRIPTION OF TEST	REQUIRED DATA	PRESENTATION OF DATA	TECHNICAL NOTES SPECIAL INSTRUCTIONS
5	Brake System Operation During Gear Retraction	Opt.	Opt.	Opt.	Dn to up	Opt.	Opt.	Retract gear and evaluate wheel anti-rotation system.	1. Brake system return pressure. 2. Wheel speed 3. Main gear position.	1. Gear position vs. wheel speed and brake pressure.	1. Retract gear as soon as it is safe after lift-off.
6	Brake Accum. Capacity During Normal Landing (if equipped)	Opt.	Fwd.	$1.3V_S$	Dn	50° Landing Config.	Mct lev.	Conduct one landing on a wet runway from a normal approach. a) Select norm. brake system. b) Aux. & main pump off. c) Skid control O.K.	Same as Test No. 2.	Same as Test No. 2.	Same as Test No. 2.