



# AEROSPACE INFORMATION REPORT

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## BRAKE DYNAMICS

### 1. INTRODUCTION

Designers utilizing advance state-of-the-art landing gear systems should recognize the total elastic landing gear system as a potential vibration problem. 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 efficient anti-skid braking control devices.

Brake energy per unit volume has increased markedly in the past ten years. In general, 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.

This Aerospace Information Report has been prepared by SAE Subcommittee A-5A to present a review of the landing gear system problems associated with aircraft brake dynamics. Possible solutions for these problem areas are discussed as well as facilities currently available for test along with evaluation.

While these problems are well known to a segment of the aerospace industry, a formal definition of the problem and possible solutions are not available in current literature.

### 2. PROBLEM DEFINITION

#### 2.1 Brake design, from a dynamic standpoint, centers around two problems:

- (a) Self-excitation of the natural modes of the landing gear. The source of this "negative damping" is the sensitivity of the torque developed between the rotating and nonrotating parts of the brake to the slip velocity. This problem has been accentuated by modern brake designs that universally incorporate hard, high temperature, low wear friction materials that exhibit greater variation of coefficient of friction with slip velocity than their previous counterparts.
- (b) Forced oscillations arising from irregularities in the rotating and nonrotating parts of the brake. Reduction of these forced oscillations is possible during detail design of these brake components.

#### 2.2 Of the above noted basic problems, the former causes the most concern in landing gear systems development. Landing gear vibration caused by negative damping takes place in two natural modes of the landing gear. First is the "chatter" mode or fore and aft motion of the wheel, brake, tire, axle, and bogie beam against the elastic restraint of the shock strut. The second, or "squeal" mode, consists primarily of the torque carrying linkage between the brake and the shock strut. A third natural mode of vibration can be excited during a pivoting turn. This is a torsional mode (strut torsion) which may be induced or aggravated by a combination of brake torque variation and tire slippage.

From the foregoing it can be seen that chatter can impose high loads on the strut while squeal can create problems in equalizer rods, brake attachment bolts and hydraulic lines. Acknowledgment of these, heretofore unforeseen, loads and cycles must be considered in the design of the landing gear system.

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### 3. PROBLEM SOLUTION

- 3.1 It must be recognized that some strut configurations are more sensitive to chatter than others. Thus, a friction material suitable for one strut is not necessarily satisfactory on another. One approach to providing compatibility between brake operating characteristics and strut configuration is the testing and evaluation of friction materials prior to brake production to assure that optimum "match" is achieved.
- 3.2 If it is accepted that vibration problems can be minimized through preliminary testing and evaluation of friction materials, certain basic parameters are required from the aircraft manufacturer. These parameters are used as scaling factors between either a full-scale or small-scale simulator and the aircraft strut. Usual parameters of this nature are:
- (a) Fore and aft spring rate of the landing gear ( $K_1$ ). (Specify for range of possible extensions.)
  - (b) Angular spring rate associated with squeal motion of airplane landing gear system ( $K_0$ ).
  - (c) Damping coefficient associated with the fore and aft chatter motion of the landing gear system ( $C_1$ ).
  - (d) Angular damping coefficient associated with the squeal motion of the aircraft landing system ( $C_0$ ).
  - (e) Strut mass and distribution of weight ( $M_1$ ).
  - (f) Chatter frequency of the airplane landing gear system. Axle geometry, configuration and mounting flange detail. Aircraft manufacturer to supply the vibration modes. Other parameters might be specified based on analysis of specific gear geometry.
- 3.3 Accurate data on specific problems is required from manufacturers and users of aircraft if problems occur on brakes while in service. Information on speeds at which vibrations occur, past history of the brake, frequency and amplitude of vibrations would be extremely helpful in pinpointing the problem, and, hopefully, its solution.

### 4. DATA CLASSIFICATION

- 4.1 In spite of the scatter in results of identical stops, which prevents pinpointing or predicting a specific event of any one stop, continued effort should be devoted to defining the dynamic characteristic pattern. Meaningful information can result through use of statistical analysis when a large amount of seemingly inconsistent data is at hand. Continued full effort by the brake manufacturers and cooperation with the users on vibration problems is mandatory.
- 4.2 A uniform method of classifying brake linings or entire brakes on a statistical basis is desirable. The traditional data supplied by lining manufacturers (e.g., friction coefficient and wear) has proven to be inadequate for aircraft brake design. Suggested classification of brake friction material characteristics are:
- (a) Friction Coefficient:
    1. Static-cold, hot and dynamic breakaway (termination of skid).
    2. Dynamic-initial, average, maximum and terminal versus kinetic energy between design maximum kinetic energy and taxi kinetic energy.
  - (b) Stability of Friction Coefficient versus:
    1. Kinetic energy absorption rate.
    2. Temperature and/or absorbed kinetic energy.

3. Velocity.
4. Unit pressure.
5. Working life.

(c) Wear - Variation With:

1. Temperature and/or kinetic energy absorption.
2. Velocity and/or rate of kinetic energy absorption.
3. Working life.
4. Unit pressure.

(d) Peak to Mean Torque Amplitude: (Also a function of brake rotational velocity).

1. 10 to 50 cps (Chatter) - Definition.
2. 50 to 500 cps (Squeal) - Definition.

4.2.1 The above would classify either a lining and its opposing surface alone or an entire brake.

4.2.2 Further classification to account for geometry, brake control system and mechanical factors of a complete brake system would include:

- (a) Torque "rise time" response to a step input pressure signal at the inlet.
- (b) Torque "decay time" response to a step input for a decreased pressure.
- (c) Transient "overshoot or undershoot" of torque versus step input pressure signal.

## 5. BRAKE DYNAMIC CHARACTERISTIC EVALUATION TECHNIQUES

5.1 Following is a discussion of equipment and/or facilities that can be used for brake dynamics evaluation.

### 5.1.1 Shaft Dynamometer:

5.1.1.1 The advantage of this type of machine is that comparative evaluation of brake geometry and performance can be achieved at relatively low cost and time. Brake design characteristics that can be obtained under controlled conditions are:

- (a) Wear.
- (b) Temperature of brake elements.
- (c) Static and dynamic friction coefficient.
- (d) Variation of friction coefficient within a given brake application or with life.

5.1.1.2 Several disadvantages of this equipment are:

- (a) The flywheel kinetic energy is transmitted directly to the brake, thus removing the tire effects on brake energy absorption.
- (b) The influence of tire or strut elasticity on brake dynamic characteristics is not measured.

5.1.2 Conventional Brake Test Dynamometer:

5.1.2.1 The most general brake testing consists of landing a complete wheel, brake and tire unit against an inertial wheel. The unit tested is mounted on a fixture that can simulate the aircraft axle and brake mounting flange. This equipment enables measurement of dynamic brake characteristics from the tire-dynamometer interface to the brake mounting interface. It is also possible to vary wheel vertical loading by (a) varying tire pressure (at fixed radius) or (b) adjustment of actuating pressure on dynamometer applicator arm for fixed load (varying rolling radius). Possible extension of present practice, to obtain additional information of brake dynamics is to duplicate as much of the aircraft hydraulic system as possible.

5.1.2.2 Disadvantages and/or limitations of this equipment are:

- (a) Limits test to single wheel-brake installation mounted on cantilever axle.
- (b) Cannot duplicate complicated trucks.
- (c) Lacks fore and aft freedom for chatter assessment.

5.1.2.3 Adaptations of fixtures are available to provide flexible mounting of the wheel-brake combination. No significant testing has been reported to date to determine the value of these supplementary fixtures.

5.1.3 Landing Gear Simulation:

5.1.3.1 Recognition of the elastic nature and complex interaction of each element of the landing gear system has resulted in the desire to test as much of the actual system as possible. Under certain conditions it is possible to duplicate or simulate the full scale landing gear from the trunnion attachment interface to the tire flywheel interface. Several aircraft systems have been investigated in this manner, and in some cases the simulation has been extended to include the wing beam.

5.1.3.2 Some of the limitations of this type test equipment are:

- (a) Physical size of system. Present test dynamometers do not have the necessary width to accommodate truck type gears. It is possible to accommodate single and some dual wheel gear.
- (b) For conceptual convenience, the equipment should be positioned above the dynamometer. Some facilities do not have this capability.
- (c) The aircraft must be in an advance state of construction to utilize actual gear components. The alternate method, simulation, requires detail knowledge of actual strut parameters. In view of this, it is suggested that this type of testing would be warranted only for specific problems. Cost and size will be a limiting consideration of broadened applicability.

5.1.4 Analog Computer Simulation Alternative to Test:

Computer analysis is valuable in the assessment of the effects of assignable variables on brake dynamic characteristics. This tool must rely upon an accurate assessment of both strut and brake design parameters.

5.1.5 NASA Track:

5.1.5.1 Use of the NASA track at Langley Field offers the advantage of testing the entire landing gear, running over varying runway surfaces and introducing water and slush effects.

5.1.5.2 Known limitations are:

- (a) Availability restricted to NASA schedule.
- (b) Vertical load 20,000 pounds maximum.