

Steering Effect of Tilted, Free-Swiveling Nose Gears

RATIONALE

AIR4358 has been reaffirmed to comply with the SAE five-year review policy.

FOREWORD

Ground operations of aircraft equipped with free-swiveling nose gears can lead to sudden and unexpected cornering forces that may cause the aircraft to depart the runway. The development of these cornering forces can be the result of a main gear tire failure or a strut deflation, which causes the aircraft to assume a tilted or banked attitude. This phenomenon was observed in 1966 during landing-gear tests of an HL-10 manned lifting body entry vehicle. These unwanted cornering forces have also contributed to excessive differential braking requirements for some Space Shuttle orbiter landings due to crosswind and runway crown effects. Furthermore, this phenomenon may have contributed to several fighter aircraft accidents following tire failure during landing rollout.

1. SCOPE:

This Aerospace Information Report (AIR) considers the origin of cornering forces generated by tilted, free-swiveling nose gears; the effect of various landing gear parameters on the measured cornering forces; and a method of towing aircraft to measure the resulting steering forces.

2. APPLICABLE DOCUMENTS:

The following publications form a part of this specification to the extent specified herein.

2.1 SAE Publication:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

Daugherty, Robert H. and Stubbs, Sandy M.: The Generation of Tire Cornering Forces in Aircraft with a Free-Swiveling Nose Gear. SAE Technical Paper 851939, 1985.

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2.2 Other Documents:

Daugherty, Robert H. and Stubbs, Sandy M.: A Study of the Cornering Forces Generated by Aircraft Tires on a Tilted, Free-Swiveling Nose Gear. NASA TP 2481, 1985.

Stubbs, Sandy M. and Tanner, John A.: Techniques for Measuring Side Forces on a Banked Aircraft with a Free-Swiveling Nose Gear. NASA TM 87719, 1986.

3. ORIGIN OF CORNERING FORCES:

3.1 Free-Swiveling Nose Gear:

When a pneumatic tire is rolling at a tilt angle, one edge of the tire footprint will have a smaller rolling radius than the other and this forces the tire to behave like a rolling cone. This cone effect develops a torque within the tire footprint, which causes the free-swiveling tire to steer in the tilt direction. The steering angle generates a cornering force as shown in Figure 1. Because this cornering force acts along a line that is behind the steer axis of the nose gear strut, a self-aligning torque, which counters the cone effect torque, is also generated. Under steady-state tilt rolling the steer angle increases until the torque from the cone effect and self-aligning torque are balanced.

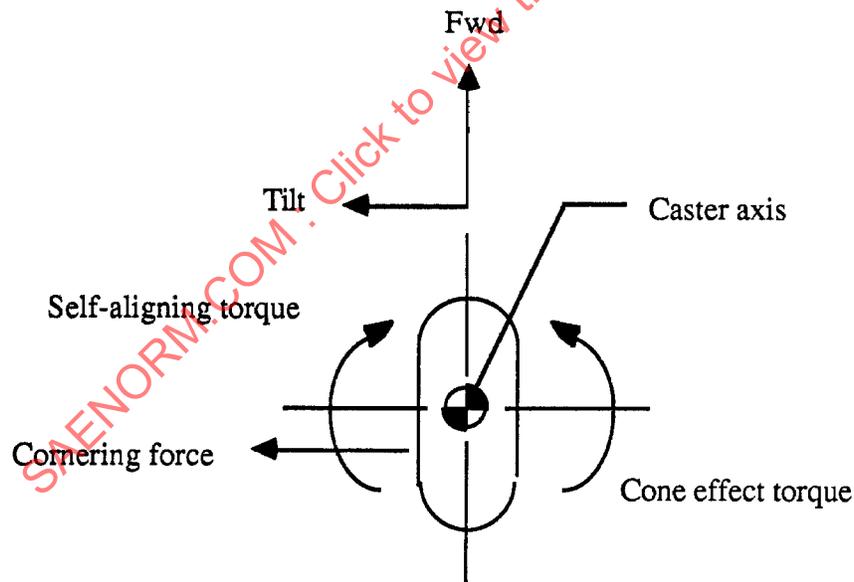


FIGURE 1 - Generation of Cornering Forces in Free-Swiveling Nose Gear Tire Footprint

3.2 Fixed Nose Gear:

A fixed nose gear tire rolling at a tilt angle also develops a cone effect torque. However, since the tire is not free to swivel, no significant cornering forces are produced and the torque from the cone effect is balanced by strut torsion.

4. EFFECT OF LANDING GEAR PARAMETERS ON FREE-SWIVELING STEERING FORCES:

4.1 Tilt Angle:

The cornering force friction coefficient developed by a free-swiveling nose gear tire generally increases linearly with tilt angle. The magnitude of the tilt steering effect for a particular nose gear configuration will be a function of the characteristics of that gear as shown in Figure 2.

4.2 Trail:

The cornering force friction coefficient developed by a free-swiveling nose gear tire will decrease with increasing trail as shown in Figure 3.

4.3 Rake Angle:

Forward rake angle has the effect of reducing the cornering force friction coefficient due to the tilt angle as shown in Figure 4. No data are presently available to define the effect of rearward rake angle.

4.4 Tire Load:

Increasing the tire loading reduces the cornering force friction coefficient due to tilt angle as shown in Figure 5.

4.5 Corotating Twin-Tires:

A nose gear strut equipped with corotating twin-tires can produce significantly higher cornering force friction coefficients due to tilt than a strut equipped with noncorotating twin-tires as shown in Figure 6.

4.6 Nose Gear Steering:

The cornering force friction coefficients generated by tilt angle are essentially eliminated if the nose gear steering system is engaged.

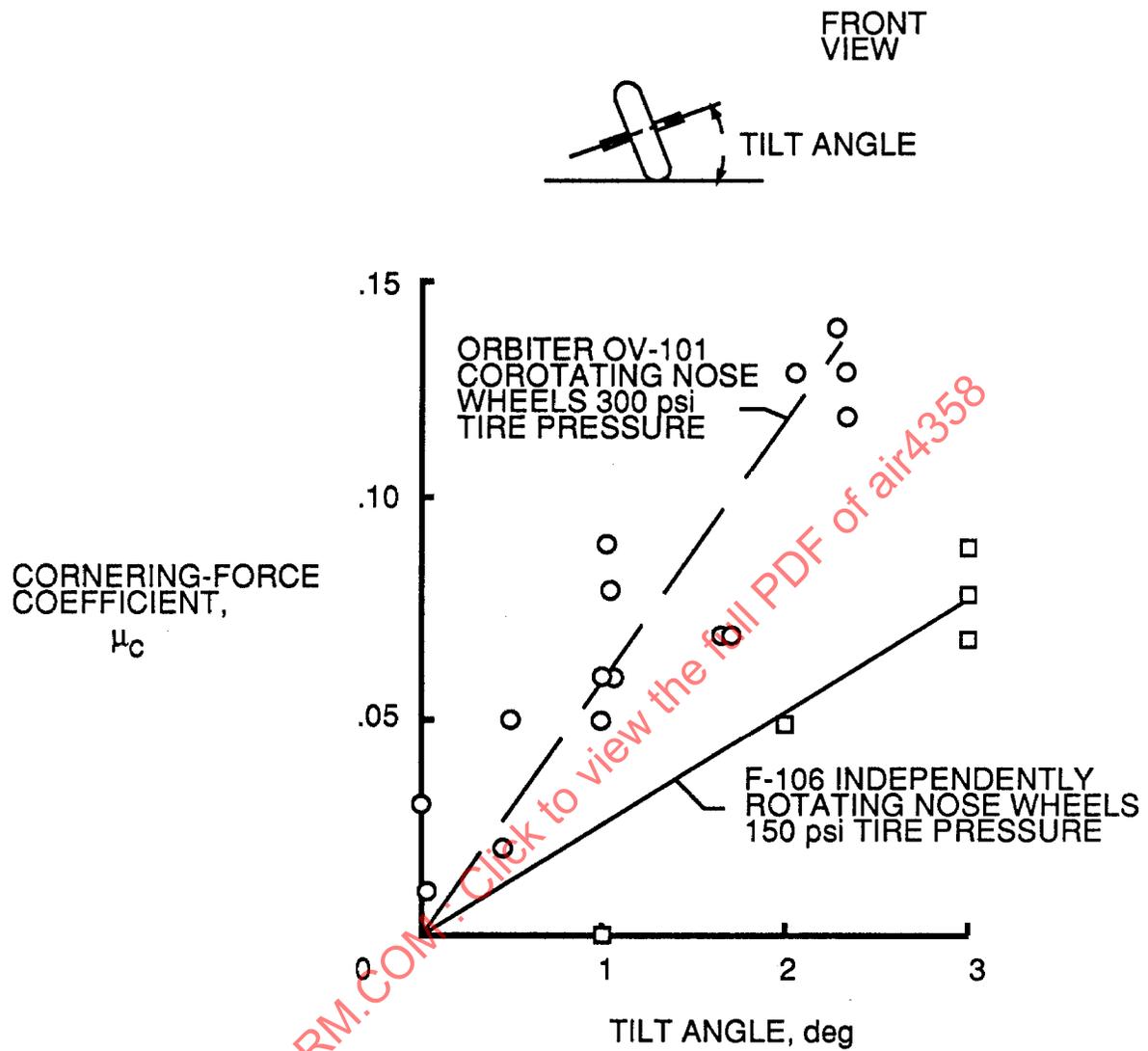


FIGURE 2 - Cornering-Force Coefficients for Both Shuttle Orbiter OV-101 and F-106 for Bank Angles Up to 3°

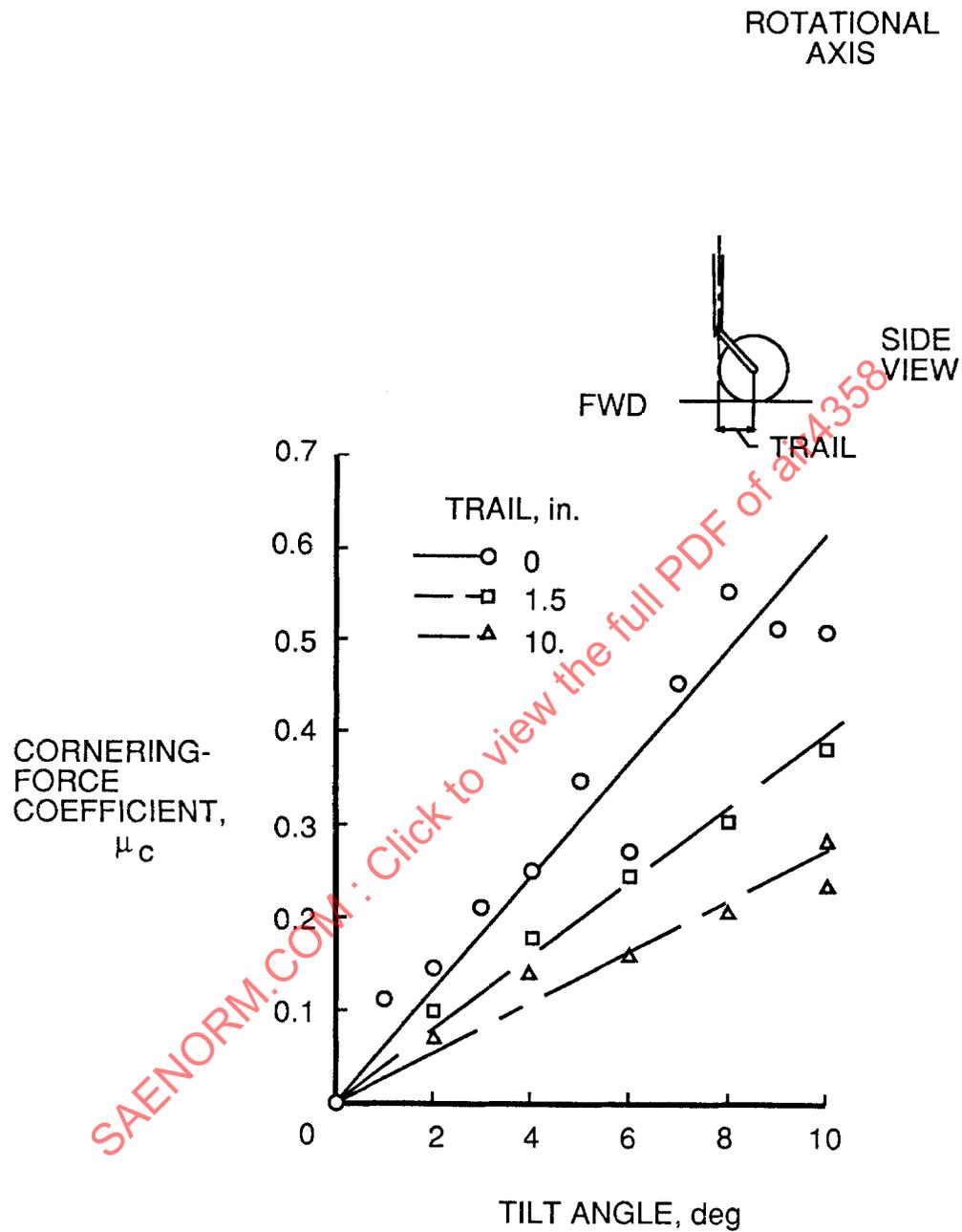


FIGURE 3 - Variation of Cornering-Force Coefficient as a Function of Tilt Angle for Various Nose Gear Trails

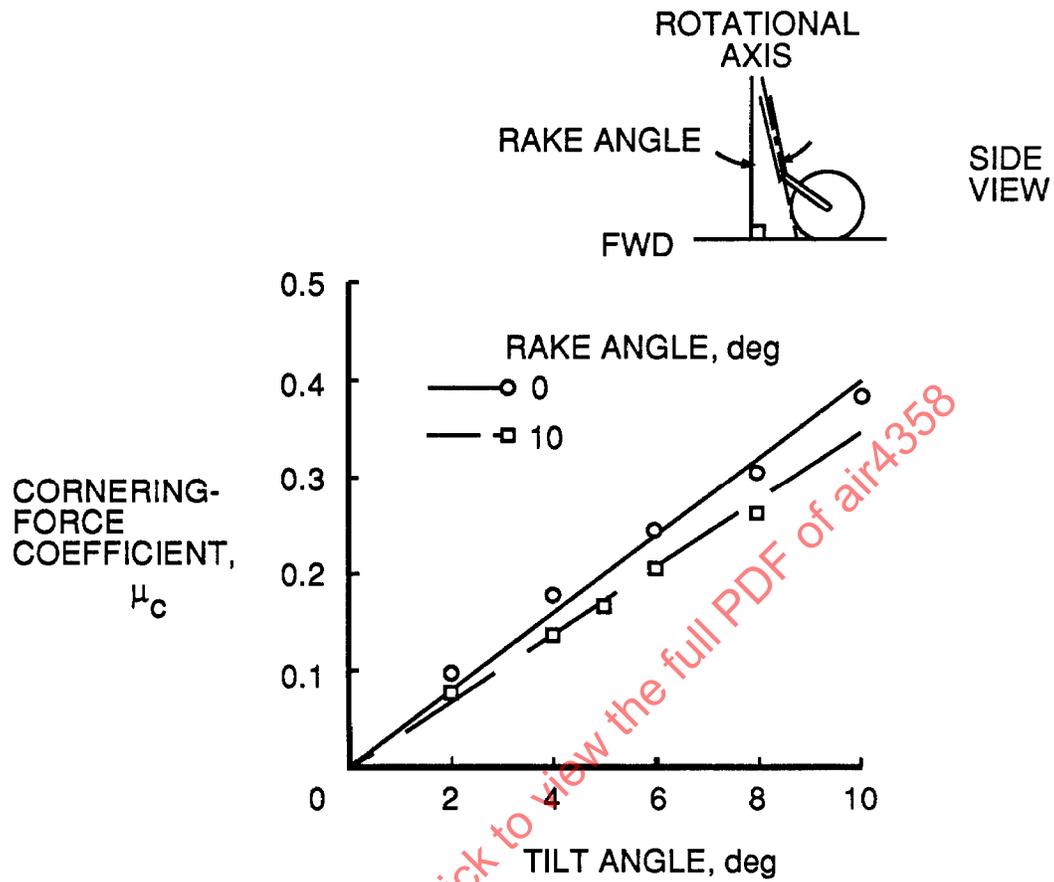


FIGURE 4 - Variation of Cornering-Force Coefficient as a Function of Tilt Angle for Various Rake Angles (Trail = 1.5 in)

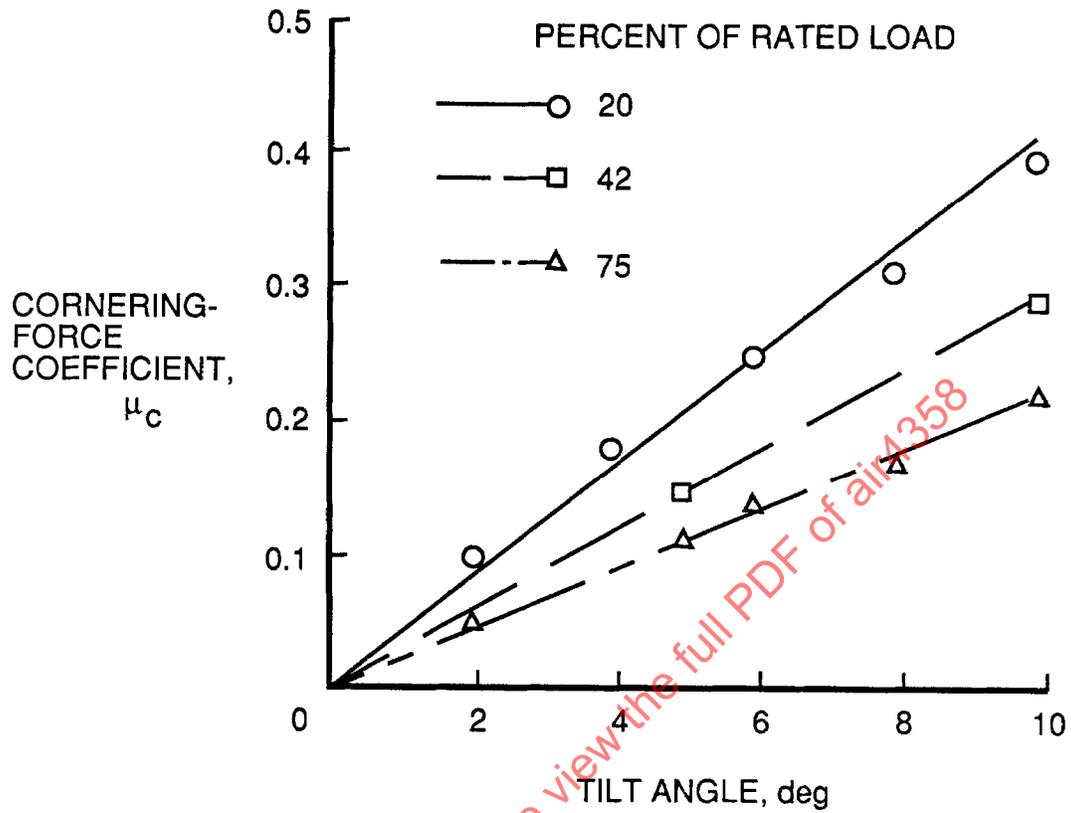


FIGURE 5 - Variation of Cornering Force Coefficient as a Function of Tilt Angle for Different Vertical Loads (Trail = 1.5 in)

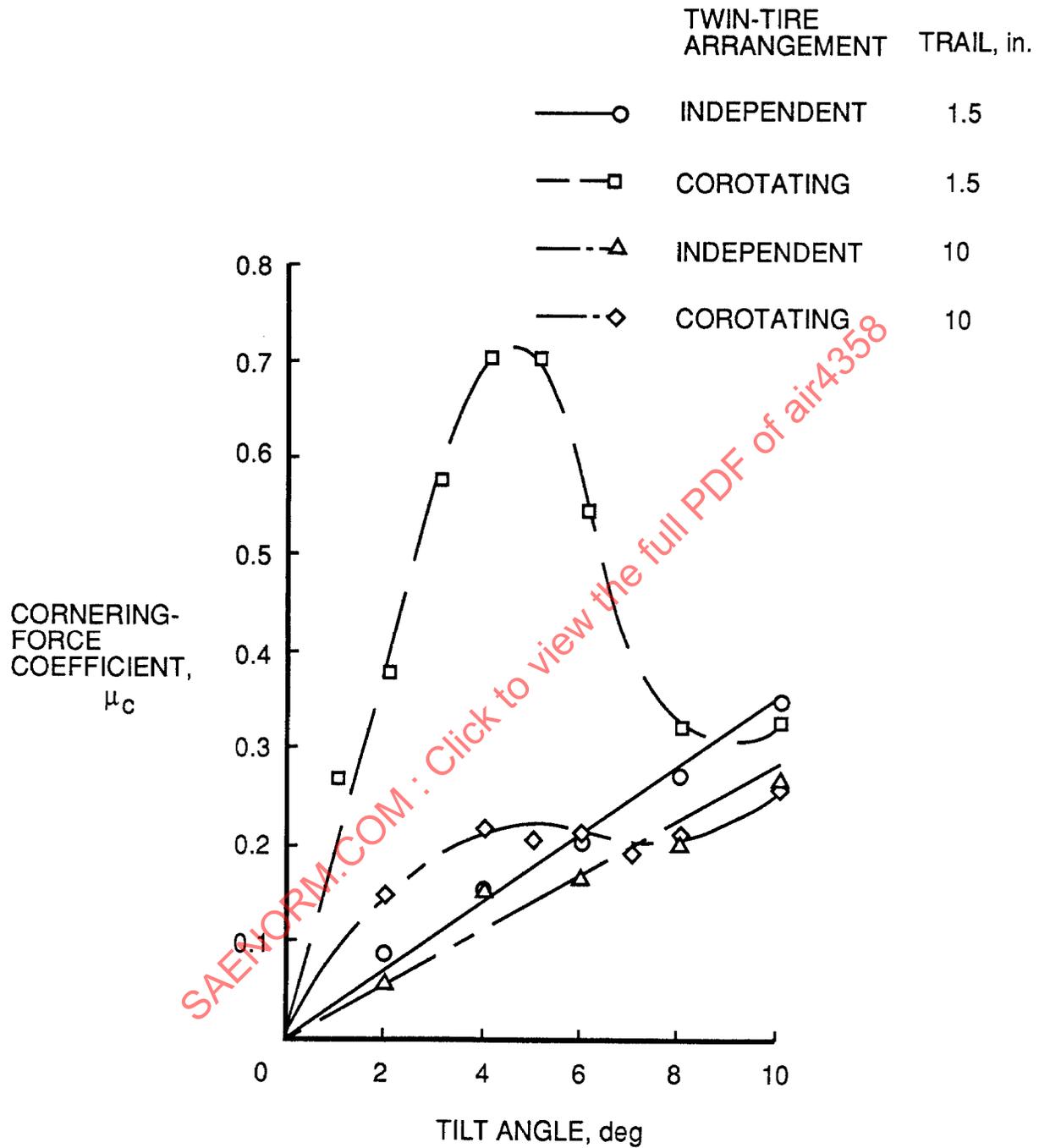


FIGURE 6 - Variation of Cornering-Force Coefficient as a Function of Tilt Angle for Various Twin-Tire Arrangements and Trails

5. DESIGN CONSIDERATIONS:

The possibility of departing the runway after main gear tire failure or loss of strut pressure should be considered in the design of the nose gear strut. To minimize the possibility of a runway departure, the following design practices are suggested:

- a. Make the track of the main gear as wide as possible to reduce the tilt angle following tire failure or strut deflation.
- b. Incorporate a trail in the nose gear strut design where practical or employ a rake angle concept.
- c. Avoid corotating nose gear designs if possible.

6. TESTING TECHNIQUES:

6.1 Aircraft Landing Gear Geometry:

The geometry of the landing gear including the gear loads should be noted for any aircraft undergoing tests to define the effect of tilt steering. Figures 7 and 8 show the landing gear geometries of an F-106 fighter aircraft and the space shuttle orbiter Enterprise, which were employed in a NASA test program.

6.2 Towing Techniques:

A typical setup for towing an aircraft to establish the tilt steering effect is shown in Figure 9. The tow tug is connected by cables to a mooring lug on the aircraft nose gear and to the idler tug. The idler tug is unpowered so that the two tugs move at the same speed. The braking tug is optional and can be used to stop the tow test in case of an emergency. The tow tug and the idler tug operators steer their vehicles along parallel expansion joints in the test surface.

6.3 Instrumentation and Test Procedure:

A load cell and recording device are required to determine the cornering forces developed by the free-swiveling nose gear when the aircraft is tilted. The desired tilt angle is achieved by differential pressures in the main gear struts, and the aircraft should be tilted away from the idler tug to keep the load cell and cable connecting the aircraft to the idler tug in tension (left wing down in Figure 9). Individual tow tests should cover a distance of approximately 200 ft so that transient loads associated with initial startup can dissipate and not interfere with the cornering force measurements.

7. KEY WORDS:

Steering effect