13. MODEL STUDIES OF CROSSWIND LANDING-GEAR CONFIGURATIONS FOR STOL AIRCRAFT

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SUMMARY

An experimental investigation was conducted using a dynamic model to directly compare four different crosswind landing-gear mechanisms. The model was landed as a free body onto a laterally sloping runway used to simulate a crosswind side force. A radio-control system was used for steering to oppose the side force as the model rolled to a stop. The four crosswind configurations investigated were subjected to the same test conditions and a direct comparison of the configurations was made although there are several factors that limit a direct application of model test results to a full-scale aircraft. Two of the configurations appeared to be more promising than the others and one of them was clearly the best. The configuration in which the landing gears are alined by the pilot and locked in the direction of motion prior to touchdown gave the smoothest runout behavior with the vehicle maintaining its crab angle throughout the landing roll. This is not meant to imply that the other configurations could not be used successfully with full-size aircraft where the pilot has aerodynamic control, visual and motion cues, and differential braking. Nose-wheel steering was confirmed to be better than steering with nose and main gears differentially or together. Testing is continuing to obtain quantitative data to establish an experimental data base for validation of an analytical program that will be capable of predicting full-scale results.

INTRODUCTION

Future airports constructed for STOL aircraft operations will have fewer choices for runway headings and have the potential of exposing the aircraft to higher crosswinds than currently encountered. Also, since landing speeds of STOL aircraft are lower than for conventional aircraft, the problems associated with landings in crosswinds are greater. Therefore, a need exists to develop landing-gear systems which will extend the operational capability of aircraft, particularly STOL aircraft, in a crosswind environment. Several crosswind landing-gear concepts were proposed in the late 1940's and early 1950's and some flight tests were conducted, mostly on tail-wheel aircraft. Currently, crosswind landing gear are used on the B-52 and C-5A aircraft; however, these systems are limited to 20° crab angles, and no known comparisons have been made between these and earlier systems.

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The objective of the current research is to evaluate various crosswind landing-gear concepts for application on STOL aircraft, landing at crab angles up to 30°. The purpose is to establish those concepts which permit a smooth transition from flight to landing rollout with a minimum of decrabbing, yawing, lateral motions, and steering inputs during rollout.

This paper presents the results from an experimental investigation conducted to study various crosswind landing-gear concepts, utilizing a free body, radio-controlled, dynamic model. Four different crosswind gear configurations were examined and their behavioral characteristics during the landing runout under a simulated crosswind are directly compared. Three steering techniques were evaluated and the effectiveness of each is discussed together with such problems as gear alinement, shimmy, and steering torque requirements.

DESCRIPTION OF MODEL

Figure 1 is a photograph of the radio-controlled model used in the investigation, and figure 2 is a sketch which provides pertinent dimensions. The model, nominally representing a 1/10-scale prototypical STOL aircraft, was designed to minimize aerodynamic effects on vehicle motions so that the effects of a constant simulated crosswind force could be studied. It was decided at the outset of the investigation that the forces needed to overcome the crosswind force must be generated from tire steering inputs rather than from aerodynamic controls since at low speeds, near the end of the runout, aerodynamic controls would be ineffective. The basic body of the model was constructed of solid balsa wood covered with fiber glass. Lead ballast was attached to two aluminum angles shown in figure 1 to provide the desired mass, center-of-gravity location, and mass moments of inertia for the vehicle. The tricycle landing gear used on the model consisted of vertical struts, forks, and wheels equipped with pneumatic model-aircraft tires 11 cm (4.5 in.) in diameter. Mechanical stops were attached to the vertical struts to limit the swiveling action on all gears and the position of these stops was varied until an optimum yaw-angle tolerance was found. Two sets of aluminum forks were constructed to obtain a variation in the amount of trail used for the tests. The pneumatic tires were pressurized to approximately 60 kN/m^2 (9 psi).

Steering Mechanism

Each of the three wheels of the tricycle gear had a separate radio-controlled servo to engage a steering clutch which converted the gear from free swiveling to steerable. Two additional servos were used on each gear to provide steering torque. Separate transmitter control sticks were used for each landing gear and various combinations of the sticks could be operated simultaneously by the pilot through a mechanical linkage. The radio-control system was proportional; that is, the servos displaced proportionally to control-stick displacement.

Configuration Definition

The crosswind gear configurations shown in figure 3 and described below are the configurations as they would operate on a full-scale aircraft. It was necessary during model testing of some of the configurations to modify the free-swiveling feature in order to obtain satisfactory vehicle dynamics during the early part of the landing roll.

Configuration A allows all gears to swivel freely prior to touchdown in order to achieve alinement on contact. After alinement the gears are locked to prevent further swiveling, and steering is initiated. Steering can be accomplished through the nose gear only or by steering the nose and both main gears together or differentially.

Configuration B allows all gears to swivel prior to impact, but mechanical stops are set on the main gears to prevent outward swiveling. The purpose of the stops is to permit steering by developing side forces on the upwind main gear without having to actively lock the main gears as in configuration A. On this configuration, the downwind gear alines with the direction of motion but the upwind gear is held against the stop unless the vehicle decrabs to 0°. Steering is accomplished by actuating and steering the nose gear only.

Configuration C again allows all gears to swivel freely prior to touchdown but, in this case, a crossbar linkage is used to connect the main gears so they will act in unison. The crossbar geometry is such that when the vehicle is running at 0° yaw, there is no toe-out between the main gears; but, at a 30° vehicle yaw, a 3° toe-out is generated. The purpose of the toe-out is to develop a side force with the main gear. It is theorized that the downwind main gear, which is heavily loaded, will aline itself with the direction of motion and the more lightly loaded upwind gear toes out 3° (for 30° crab angles) and produces a small side force to windward. Only nose-gear steering is used with this configuration.

Configuration D is different from the other three configurations in that all gears are alined with the direction of motion by the pilot prior to touchdown. As with configuration A, directional control during rollout can be accomplished by steering the nose gear only or by steering all gears.

APPARATUS AND PROCEDURE

The testing technique involved launching the model as a free body in a crabbed attitude onto a laterally sloping runway and evaluating the behavior of the model to various steering inputs as it freely rolled to a stop with no brakes. The runway, model, and monorail launch apparatus are shown in figure 4. The runway was 61 m (200 ft) long, 4.1 m (13.6 ft) wide, and inclined 4-1/2° to simulate a crosswind side force. This inclination produced a side force (due to the gravity vector) estimated to be equivalent to that which would occur in a 90° crosswind of one-half the aircraft landing velocity. As shown in the figure, the runway was covered with plywood to achieve a smooth surface and black lines were painted at 1.2 m (4 ft) intervals to aid in analyzing film data.

The model was launched as a free body by a monorail and carriage mechanism. Following acceleration, the carriage was arrested to allow the model to slip free and continue down the runway. Most landings were made with the model preset on the carriage at a crab angle of 30°. This crab attitude corresponded to the attitude assumed by an aircraft flying in a 90° crosswind of one-half the landing velocity. The sink speed for all tests was near zero. No attempt was made to study the impact portion of the landing since aerodynamic forces (wing lift and control-surface forces) were not available for these model tests. The model horizontal velocity was approximately 6.1 m/sec (20 ft/sec) at launch; therefore, the tests more nearly simulated the last two-thirds of the landing runout. Higher landing speeds will be investigated in future tests when brakes are installed on the model.

The only data taken thus far in the investigation have been in the form of motion pictures which are used to study vehicle behavior for the various landing-gear systems. Six cameras were mounted above the runway, each taking only a portion of the runout, and two additional cameras were used to cover the entire runout.

RESULTS AND DISCUSSION

The basic criterion used in comparing the various landing-gear configurations was that the vehicle experience a minimum lateral displacement on the runway. Another requirement was that the vehicle have a minimum, or at least slow, yaw attitude change during runout; that is, a vehicle landing at a 30° crab angle would run out at a 30° crab angle or decrab slowly.

Before the results from studies conducted with each crosswind landing-gear configuration are discussed, several remarks are in order with respect to problems inherent in relating model results to those for full-scale aircraft. One problem is that of pilot response time. Since the model is a 1/10-scale model of a typical STOL airplane, the model pilot's response should be approximately three times as fast as that of the full-scale aircraft pilot. Similarly, the steering response of the model radio-controlled equipment is less than that of a real aircraft whereas it should have been about three times as fast. Furthermore, the control problem for the model is compounded in that its pilot, not physically located in the vehicle, has no cues to motion changes other than visual; and the visual cues are hampered since the model is moving away from the pilot.

Another problem in the simulation of motions is that the model had no aerodynamic controls nor differential braking. An aircraft would have aerodynamic control to balance the crosswind forces at touchdown and during the early portion of the runout until wheel alinement had taken place and the steering system actuated. On the model there was no control until after wheel alinement and steering clutch engagement had occurred and, during the uncontrolled time interval between touchdown and steering clutch engagement, the model started a downwind drift and, at times, a change of yaw attitude. Thus, when the steering is finally attempted, it must first overcome the inertia of a downwind-drift velocity and any yaw angular velocity that has been initiated.

It was soon realized that for configurations A, B, and C (those with free-swiveling gears prior to touchdown) it was necessary to aline the gears with the direction of motion and engage the steering clutch before launch so that the initial drift and yaw changes could be minimized and steering could begin immediately. These problems with model testing place limitations on the direct application of the model test results to full-scale aircraft; however, since they apply to the four configurations investigated, a comparison of the relative merits of the various configurations appears to be justifiable.

Configuration A

In the initial tests with configuration A, the landing gears were free to swivel upon ground contact to aline themselves with the direction of motion. However, in order to obtain alinement, some amount of trail was needed on the gears which introduced a severe shimmy problem. To eliminate shimmy of the main gear it was found that long trail (1.3 times the tire radius) and a tire inflation pressure of 60 kN/m^2 (9 psi) were needed. On the lighter-loaded nose gear, a trail equal to one tire radius and an inflation pressure of 55 kN/m^2 (8 psi) were required to avoid shimmy. In both cases, lower pressures and/or shorter trail resulted in moderate to severe shimmy. However, the need for long trail to reduce the shimmy introduced severe demands upon the available steering torque. Initial tests of configuration A with the gears free to swivel prior to landing gave poor landing behavior. When landings were made with all gears prealined with the direction of motion and the steering clutch engaged prior to touchdown, very good crabbed runouts were obtained utilizing only nose-gear steering. When steering of both nose and main gears together was attempted, results were not satisfactory due to either a slight preset misalinement of the gears or misalinement of the gears due to uneven loading. The slight misalinement produced a slow continuing yaw change in the vehicle and, although the vehicle could be displaced laterally on the runway, it would continue yawing until it hit mechanical stops and then diverge off the runway. Steering the nose and main gears differentially with two controls was also unsatisfactory, even though some good runs were obtained. When differential inputs were made (steering nose gear windward and main gear leeward), yawing motions were very rapid and confusing with occasional loss of control. Differential steering was considered an unnecessary complication and could be hazardous.

Configuration B

The landing gear for configuration B was free to swivel on ground contact to aline with the direction of motion. To aid alinement, the same trail was used as on configuration A. Configuration B used mechanical stops that allowed the front of the tires to swivel outward only from a 0° stop; thus, when the vehicle landed crabbed into the wind, the nose gear and downwind main gear alined with the direction of motion whereas the upwind main gear rode against a stop which kept it alined with the longitudinal axis of the model producing a side force into the wind. Only nose-wheel steering was used on configuration B, and for these tests it was actuated only after touchdown.

No good runs were obtained with stops set at 0°. This was due to a large side force developed by the upwind tire running at a yaw angle of 30° (for 30° crab) with the direction of motion. The large side force acting behind the vehicle c.g. produced a large decrabbing torque and a violent decrab motion. The angular inertia generated by the rapid decrab rendered the model uncontrollable. It was felt that with aerodynamic control during the transition from flight to runout the violent decrab motion could possibly be reduced but not altogether eliminated.

Several runs were made with the stops moved from 0° to 28° and resulted in a reduction of the upwind tire yaw angle with respect to the direction of motion from 30° to 2° when the model was crabbed 30°. Good 30° crab landings were made with the stops relocated but if, for example, landings were made at smaller crab angles the vehicle would have to yaw to the 30° angle in order to develop side forces on the main gear to allow steering with the nose gear.

Configuration C

As with configurations A and B, the landing gear of configuration C was free to swivel prior to contact and, like configuration B, only nose-wheel steering was available. The trail used to achieve alinement was the same as that for configurations A and B. Since the main gear was tied together by a crossbar linkage, it would be expected that the downwind gear, which was more heavily loaded, would aline itself with the direction of motion and the more lightly loaded upwind gear would toe out (3° for 30° crab angles) and produce a small side force to windward to facilitate steering.

No good runs were made when the steering clutch was engaged after contact. When the gear was alined with the direction of motion and the steering clutch engaged prior to contact, good runs were obtained at a 30° crab angle. However, it was necessary in those tests to set mechanical stops on the main gear at 30°; otherwise, during runout the tail would continue to swing downwind. To verify the existence of this problem, several landings were made at 0° yaw but in the presence of the constant side force (sloped runway). Undesirable tail swing was observed for all landings until the main gear hit the 30° stops. Throughout this crabbing maneuver, it was found that the nose gear must be steered or the model would be uncontrollable. Good runs were obtained by first steering into the wind to initiate tail swing, then rapidly steering into the swing until the main gear hit the 30° stops and, from that point, making small corrections with nose steering. In other words, there was no directional control unless the main gear was against a 30° stop and the model was crabbed 30° with a side force strong enough to hold it against the stop.

Configuration D

For a landing with configuration D, it is assumed that a mechanism was provided that allowed the pilot to aline all three landing gears with the direction of motion and lock them in position prior to touchdown. Since the self-alining feature was not needed, no trail was used on this configuration. With no trail on the landing gears, the torques required to steer the model were considerably reduced and steering was quite responsive. Thus, in effect, configuration D is essentially the same as configuration A when the gear of A is alined and locked in the direction of motion, but configuration D lacks the severe steering torque demands that occur on the long-trail configuration A. Good runs were obtained immediately with configuration D when steering was done by the nose gear. The model touched down in a 30° crab and a smooth uneventful runout followed.

An interesting observation with this configuration was that, even though the model was crabbed 30° and the gear was lined up with the direction of motion, the model weather vaned or crabbed even farther because of the uneven loading of the main gears. With no steering inputs, the vehicle on touchdown moved leeward slightly, then weather vaned slightly, and starts a slow windward drift. Small leeward steering inputs are needed for control and control is relatively easy.

Runs were made with a 5° preset error in the gear alinement with the direction of motion to simulate pilot error. The vehicle was controllable but not without some initial weaving down the runway. When 10° errors in alinement were tried, the vehicle was still controllable, but initial lateral motions were bordering on excessive and some tire squeal was noted. With aerodynamic controls, however, it was felt that landings with even larger alinement errors could be satisfactorily made.

As was observed with configuration A, steering all gears together was unsatisfactory since slight misalinement of the gears would cause a slow ground loop. Steering both nose gear and main gears differentially was tried and a fair run was obtained; however, differential steering increased the sensitivity of an already adequately sensitive steering system and added an unnecessary complication.

CONCLUSIONS

The four crosswind gear configurations investigated were subjected to the same test conditions; thus, comparison of the relative merits of the various configurations can be made even though there are several factors, such as time scaling, only visual cues from a remote position, steering response, and no aerodynamic control, that limit a direct application of these model test results to a full-scale aircraft.

The best crosswind gear system based on subjective results from this investigation was clearly configuration D with nose-gear steering. Configuration A gave good landings when the gears were alined with the direction of motion and the steering clutch engaged prior to touchdown; however, torque demands were high because of long trail requirements. Configuration C with a free-swiveling main gear had a tail-swing problem that was considered undesirable. No good runs were obtained with configuration B with stops at 0°. These conclusions are not meant to imply that an aircraft could not be successfully landed with configurations B and C as well as A and D; for with aerodynamic control, pilot cues, and differential braking, results from all configurations would be expected to improve.

Testing is continuing to obtain quantitative data on the four configurations to establish an experimental data base with which to validate an analytical program that will predict full-scale results.

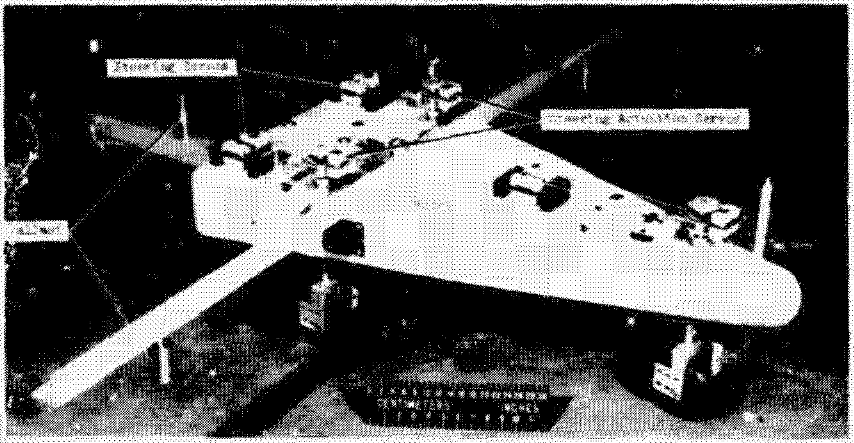


Figure 1.- Photograph of crosswind model with configuration D landing gear installed.

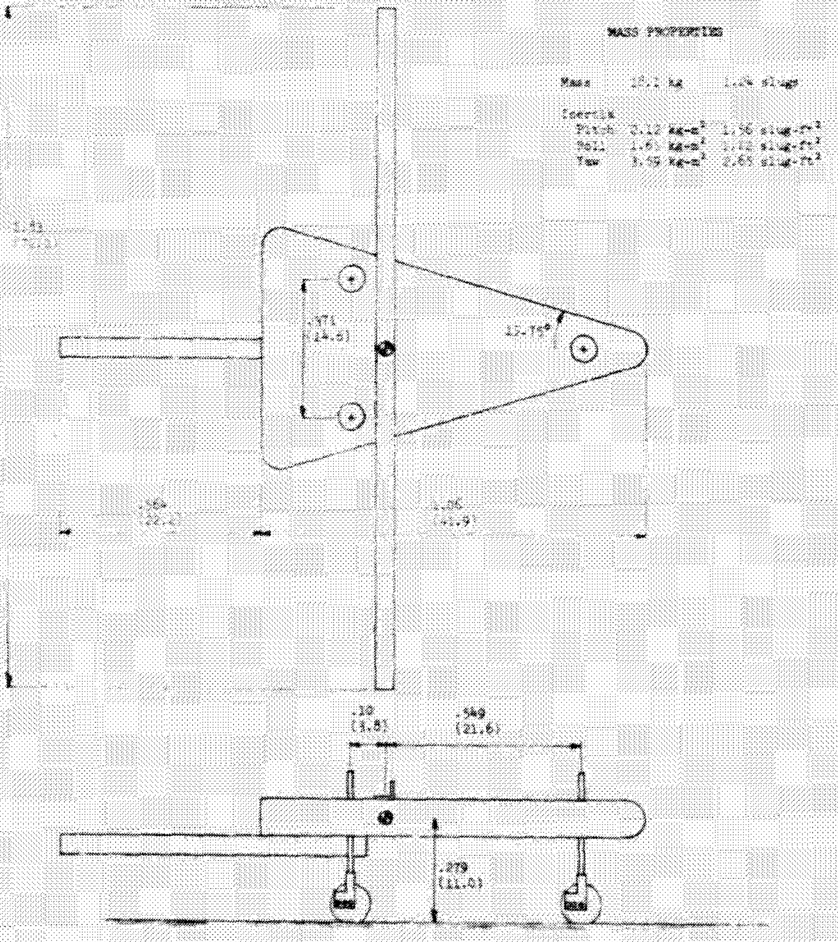
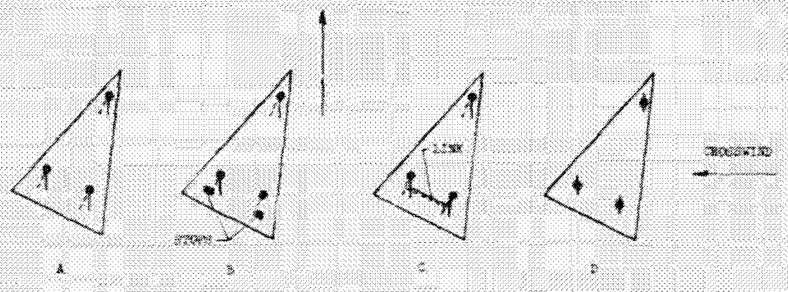


Figure 2.- Crosswind model dimensions for configuration D. Dimensions are given first in meters and parenthetically in inches.



PRIOR TO TOUCHDOWN	ALL GEARS FREE TO SWIVEL	NOSE GEAR FREE TO SWIVEL MAIN GEAR SWIVEL-DIRECTION LIMITED	NOSE GEAR FREE TO SWIVEL MAIN GEAR SWIVEL TOGETHER WITH TOE-OUT	ALL GEARS SET TO CRAB ANGLE
DURING ROLLOUT	NOSE OR ALL GEARS STEERABLE	NOSE GEAR STEERING ONLY	NOSE GEAR STEERING ONLY	NOSE OR ALL GEARS STEERABLE

Figure 3.- Crosswind gear configurations.

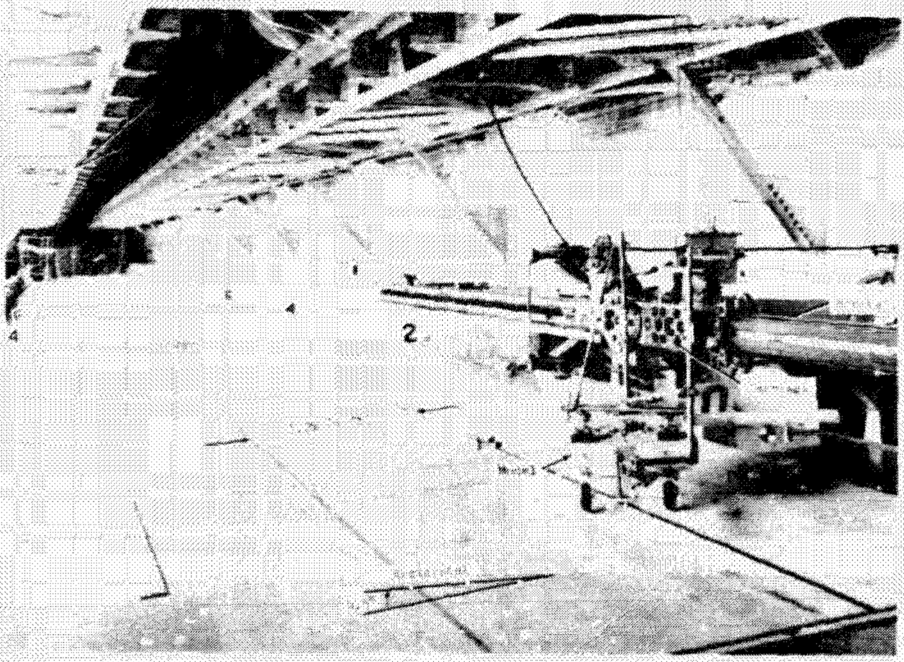


Figure 4.- Photograph of test setup showing model, monorail, carriage, and slanted runway.