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Rotor Systems Research Aircraft: Fixed-Wing Simulations Results

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Rotor Systems Research Aircraft: Fixed-Wing Simulations Results

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SUMMARY

This report covers the setup, validation, and results of the Rotor Systems Research Aircraft (RSRA) fixed-wing, moving-base simulation performed in May 1983. The emphasis of the simulation was to familiarize the pilots with the RSRA's fixed-wing configuration, which has never been flown. Additional information concerning stall speeds, minimum control speed, and various gross weights were recorded and included in the report.

INTRODUCTION

The Rotor Systems Research Aircraft (RSRA) (ref. 1), a test bed for advanced rotor systems, is capable of flying in three different modes: helicopter, fixed-wing, and compound (fig. 1). The RSRA also has a variable incidence wing that adds an additional degree of configuration variability to the fixed-wing and compound modes. Before the planned tests of the fixed-wing flight envelope, a moving-base simulation was performed. The purpose of this simulation was to familiarize the project pilots with the low-speed and high-speed handling qualities of the fixed-wing aircraft in its various flying configurations, to develop a preferred takeoff and landing technique, and to determine the fixed-wing stall speeds. The various flying configurations included in the simulation were: wing incidences from 0° to 15°, tail rotor on/off, vertical center of mass from water line 222 to water line 230, gross weights from 11,864 kg (26,100 lb) to 15,000 kg (33,000 lb), and control phasing unit (CPU) changes from 100% to 50% control authority in the pitch axis.

SIMULATION

Setup

The simulation was performed on the 6-degree-of-freedom Flight Simulator for Advanced Aircraft (FSAA) at NASA Ames Research Center (ref. 2). The mathematical model (ref. 3) used in the simulation is a modular form capable of simulating any of three RSRA modes. The equations of motion are solved interactively by summing the forces and moments of each module. The resulting aircraft motion is then transferred into the Earth inertial-frame axis to provide proper simulator motion. The mathematical model and cockpit configuration used in this simulation were previously developed and used successfully prior to this simulation project; therefore, further development was unnecessary. The cockpit was configured with the following instruments and controls:

Controls	Instruments
Collective stick	Rate-of-climb indicator
Cyclic stick	Side-slip indicator
Rudder pedals (with toe brakes)	Wing angle of attack
Flap handle	TF-34 fan speed
TF-34 engine throttles	T-58 torque
	Rotor rpm
	Turn and slip indicator
	Airspeed indicator

Validation

A static comparison of the mathematical model to actual flight data was performed to provide confidence in the results of the simulation. The static flight data were accumulated from compound flights 740-2B-14 and 740-2B-16 (ref. 4). Comparison was made of the compound mode only; fixed-wing flight data were nonexistent. Results of the static comparison are shown in figures 2-4. These plots show good agreement between flight and simulator data. The minor discrepancy shown in the lateral stick position and wing angle of attack can be attributed to known source of error. The error in lateral stick position occurs because the roll degree of freedom was eliminated from the simulation model for the static comparison. The discrepancy between simulator and flight wing-angle-of-attack data can be attributed to the error in the wing-angle-of-attack measurement, which occurred because the measurement was made in the induced flow of the wing.

Results

Takeoff- Various takeoff configurations were simulated to obtain a preferred takeoff configuration and technique for future fixed-wing flights. The pilots preferred a takeoff configuration of 5° wing incidence with flaps down. The technique used for takeoff is as follows: a full-power acceleration to takeoff speed, a small longitudinal stick displacement forward to lift the tail wheel off the ground at 60 knots, and continued to acceleration until the main wheels lift off the ground at about 120 knots. The lift-off required slight aft stick displacement. The three-point takeoff technique, where all three wheels lift off at the same time, was determined to be unacceptable because of a rapid pitch up of the aircraft at lift-off.

The directional control stability of the fixed-wing configuration during takeoff roll was also studied. It was concluded that the simulation's landing gear model could not adequately simulate the landing gear reactions, and the question of directional control stability on the ground remains unanswered. Further investigation during the high-speed taxi test will be required.

The control power of the tail rotor and vertical tail during the low-speed takeoff roll was studied. The "tail rotor on" configuration provided excellent directional control at low speeds. In the "tail rotor off" configuration, which was considered the worst-case situation, the pilots noticed that the rudder became effective at approximately 60 knots. Below 60 knots, differential brakes were used for directional control. Again, the runway interaction model makes these results questionable.

Landing- The landing configuration and technique described below were chosen by the pilots because they provided the lowest workload and a comfortable pitch attitude during landing. A landing pitch attitude less than the RSRA's ground angle of 2° was desired by the pilots to avoid tail wheel first landings. The configuration had a 5° wing incidence and the flaps were full down. Table 1 gives the other landing configurations and attitudes that were simulated. The landing technique developed in the simulation starts with an approach speed of 140 knots, flaps down, and a rate of descent of 0.305 km/min (1,000 ft/min). Once over the runway, a rotation is made to the landing attitude, decreasing power to slow down and to maintain a rate of descent. The touchdown velocity was around 125 knots, which is over 1.1 times the flaps-down stall speed (V_{sf}). The same technique is used with flaps up, except that the approach speed was 160 knots and touchdown was approximately 145 knots. Although the 5° wing incidence, full flaps configuration provided the lowest pilot workload during landing, the landing was still a very high workload condition. The simulation shows a tendency for the aircraft to climb upon the rotation to landing attitudes, and requires quite a bit of finesse to coordinate the power reduction with the rotation to maintain a rate of descent.

The landing simulation was also used to verify the response of the aircraft to a go-around situation and to landing with a crosswind. The go-around situation showed that the aircraft could be easily controlled during a sudden increase to full power. The crosswind landing showed that the aircraft responded as expected; acceptable landings were made with a 10-knot crosswind. Higher crosswind landings were not attempted. Again, conclusions drawn during the landing rollout are questionable.

Stalls- The response of the aircraft at high angles of attack in various configurations was also simulated. The power-on stall speeds and wing angles of attack for the different configurations are listed in Table 2. The aircraft showed no roll-off tendency in stall in any configuration except with 15° wing incidence and flaps full down. The stall in the simulation was distinguishable by the aircraft's inability to maintain level flight followed by a sharp rise in angle of attack and rate of descent. Lateral maneuvers were made in the stalled flight condition to confirm that the lateral controllability of the aircraft at high angles of attack was acceptable. There was no perceivable difference in stall characteristics with or without tail rotor.

Engine out- Single-engine failures in flight, single-engine-out landings, and the determination of minimum control speed (V_{mc}) were simulated in different configurations. The response of the aircraft to an engine failure in flight was a slight yaw in the direction of the failed engine, a decrease in airspeed, and a slight descent. This motion was easily controlled by the pilot. The simulation of engine-out landings provided acceptable aircraft response to the pilots. However, go-arounds from a landing attitude were marginal. The maximum rate of climb that was obtained in the simulation with wing incidence at 5° and flaps full down was 0.076 km/min (250 ft/min) at an airspeed of 125 knots. The low rate of climb coupled with an airspeed near flaps-up stall speed creates a high pilot workload.

The minimum control speed (V_{mc}) was determined in two different configurations: wing incidence 7.5°, full flaps and wing incidence 10°, full flaps. The minimum control speed is defined as the airspeed which requires 90% of the pedal deflection to overcome the asymmetrical thrust caused by an engine-out condition. The minimum control speed for 7.5° wing incidence, full flaps was 104 knots and V_{mc} for 10° wing incidence, full flaps was 106 knots.

High speed- Airspeeds up to 250 knots were flown in the simulator, where the control response of the aircraft was studied by the pilot. The only configuration change at these high speeds was moving the CPU from 100% fixed-wing pitch control to 50% fixed-wing pitch control. The pilot favored the 100% CPU position because of the increased control sensitivity. The pilot also reported no tendency for pilot-induced oscillation reported in previous simulations (ref. 5).

Weight and vertical center of mass- Small deviations from the normal flight configuration were simulated to give the pilots some experience with different weights and center of mass (CM) of the aircraft. The gross weights used were 11,834, 12,727, 13,636, and 15,000 kg (26,100, 28,000, 30,000, and 33,000 lb). The expected fixed-wing gross weight of 11,834 kg (26,100 lb) was the normal weight used in the simulation. Takeoffs and landings were simulated at each of these weights, and the response of the aircraft, as noted by the pilot, became increasingly more sluggish as the weight increased.

The CM of the aircraft was raised from its normal fixed-wing waterline position of 222 to a waterline of 230. This configuration was simulated because of a planned high vertical CM test. Again, takeoffs and landings were simulated, generating a similar response from the pilot; the new configuration was more sluggish than the nominal configuration. In all of the cases, however, the aircraft had acceptable handling qualities.

CONCLUSIONS

The RSRA fixed-wing simulation provided important information in preparation for the fixed-wing flight test. Takeoff and landing techniques were developed. The pilots became familiar with the low-speed, high-speed, and engine-out flying qualities of the aircraft. The sensitivity of the aircraft to changes to CM and gross weight was also explored.

The simulation was unable to supply useful information about directional control of the aircraft during takeoff roll but did provide information about tail rotor on/off control power. It is believed that the landing-gear mathematical model could be improved to provide directional control information and should be studied at a later time.

The simulation validation showed good comparison between flight and simulation data. A comparison of dynamic flight data with simulation data is presently being accomplished and will be discussed in a later report.

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TABLE 1.- LANDING CONFIGURATION

Wing incidence, deg	Flaps position	Approach pitch altitude, deg	Landing pitch attitude, deg
0	UP	+4	9
0	DOWN	-1.5	5
5	UP	0	3.5
5	DOWN	-4.5	2
7.5	UP	-1.5	3
7.5	DOWN	-5	0
10	UP	-3.5	2
10	DOWN	-8	-1
15	UP	-7.6	0
15	DOWN	-10.6	-4

TABLE 2.- SIMULATION STALL SPEEDS

Wing incidence	Flaps position	Wing angle of attack, deg	Stall speed,[a] knot
0	UP	18	121
0	DOWN	16	99
7.5	UP	18	125
7.5	DOWN	16	100
10	UP	18	127
10	DOWN	17	101
15	UP	18	130
15	DOWN	17	107

[a]Stall speed data taken in true airspeed.

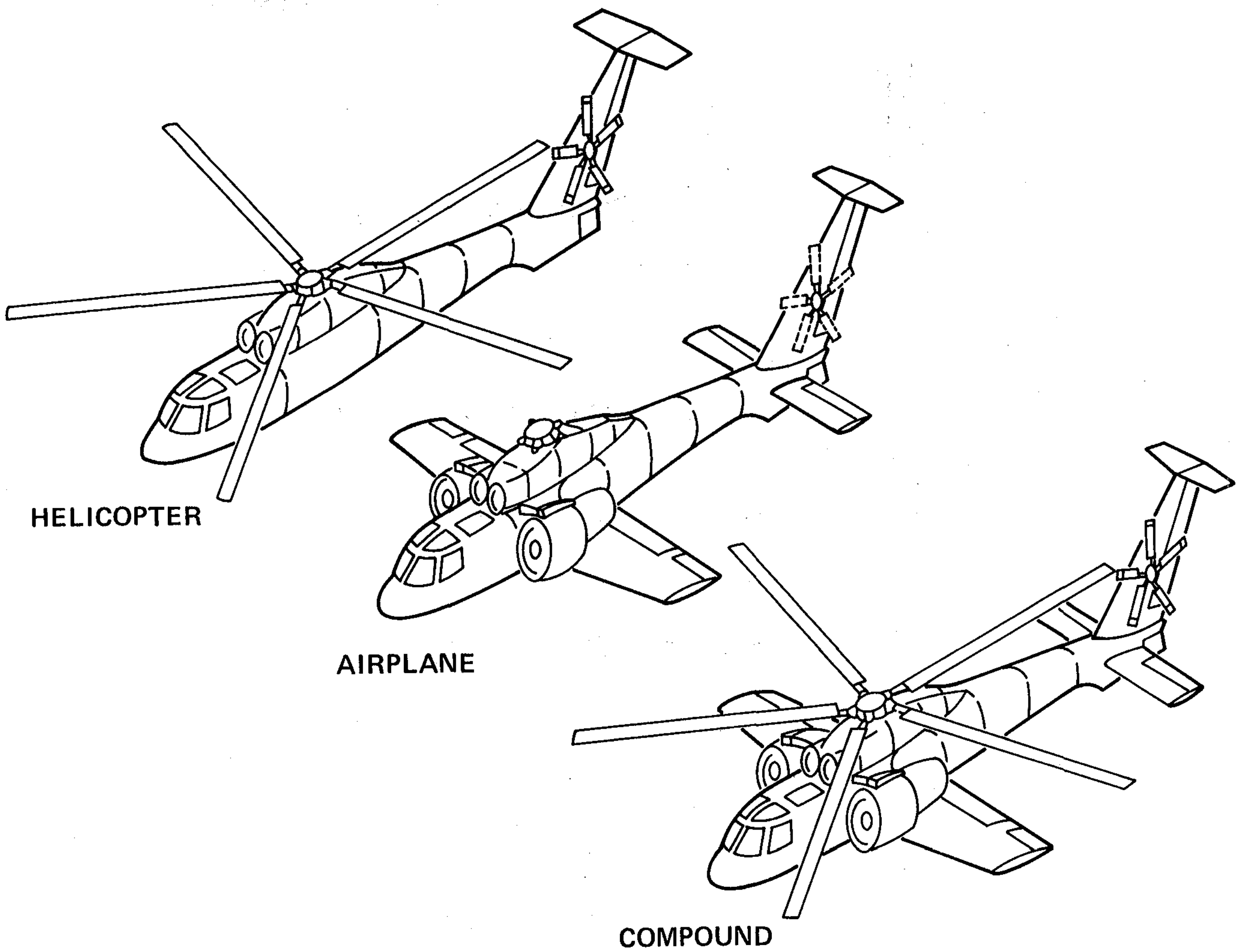
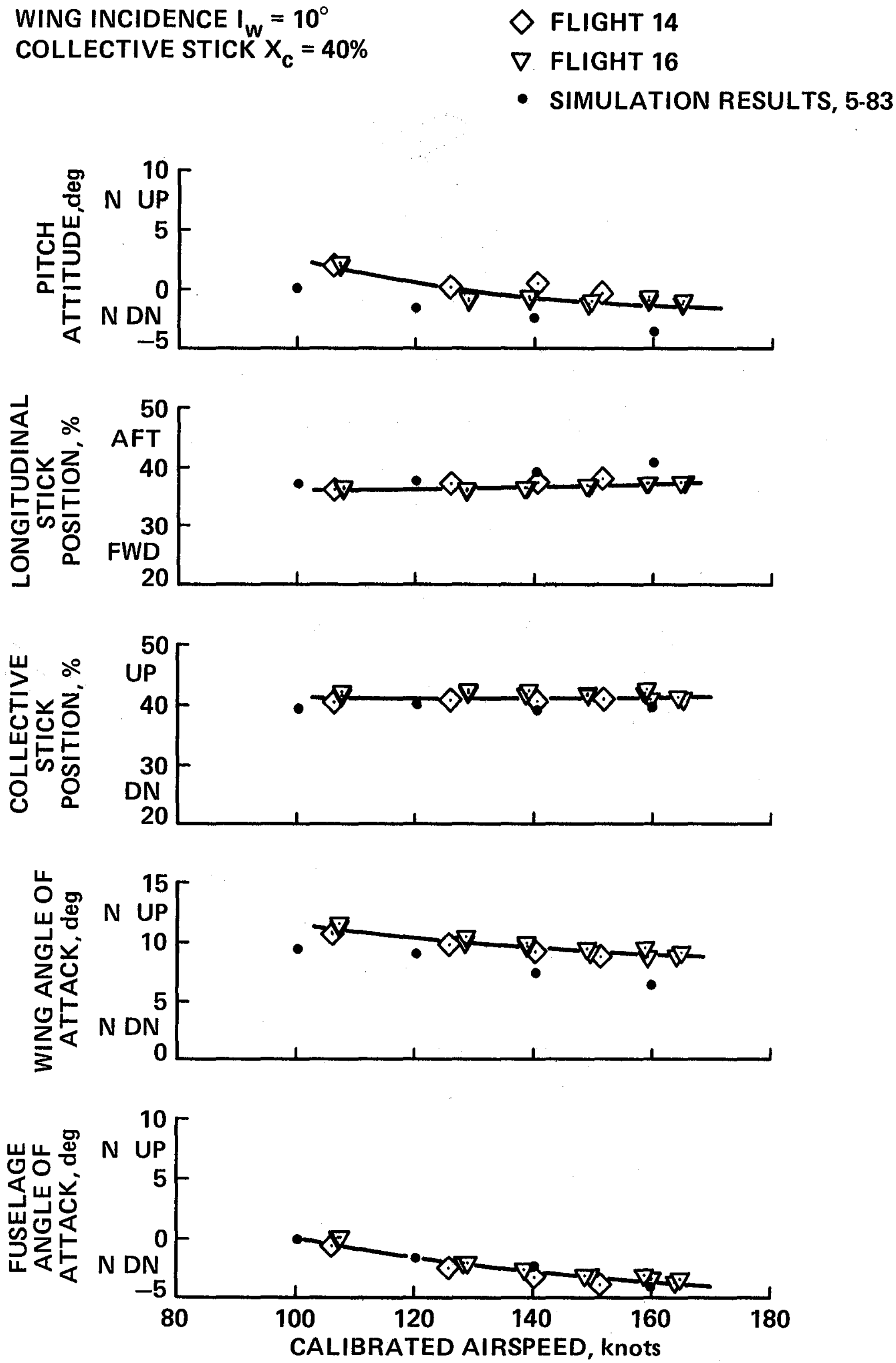
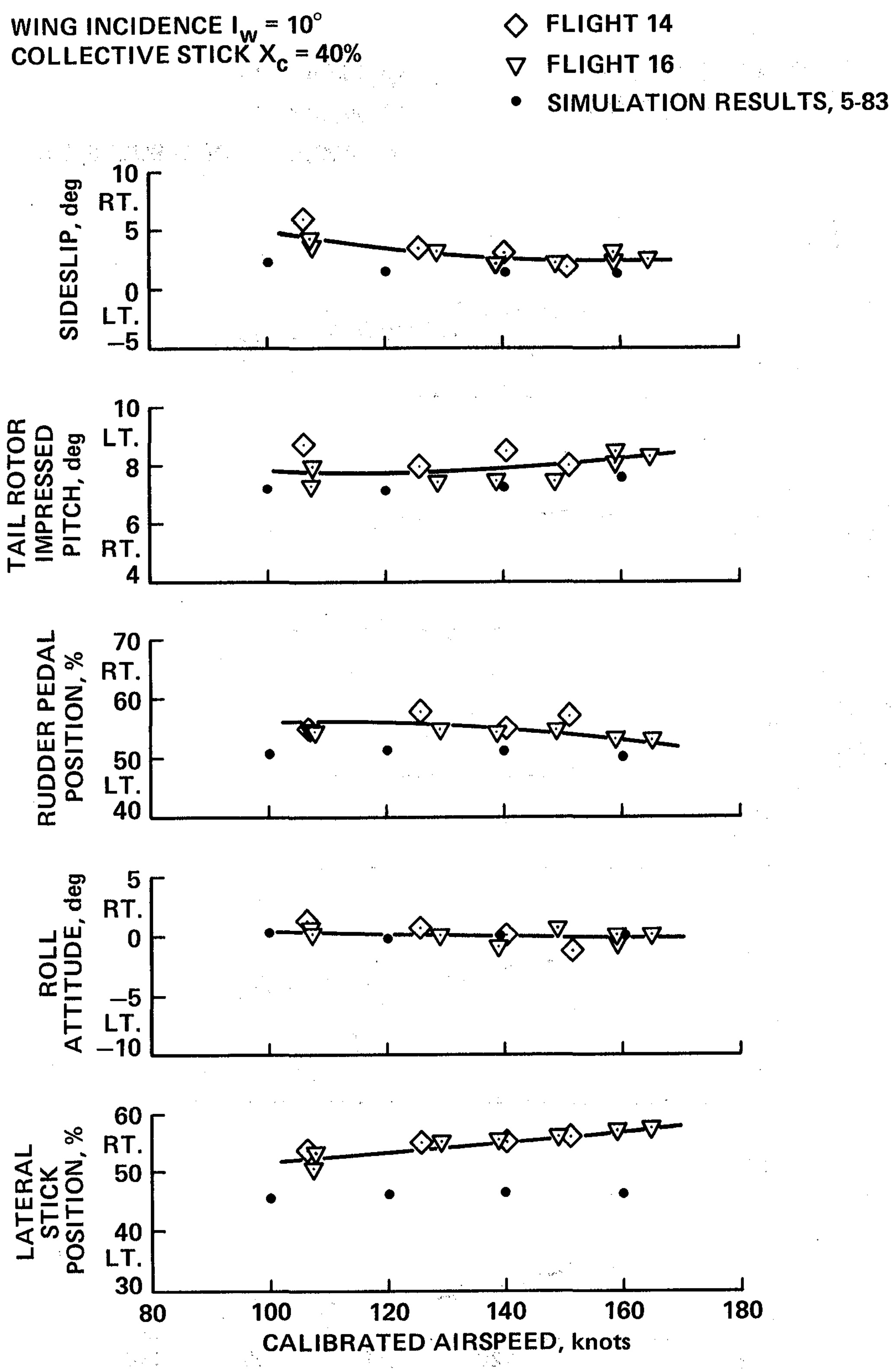


Figure 1.- Simulations of RSRA helicopter, airplane, and compound modes.



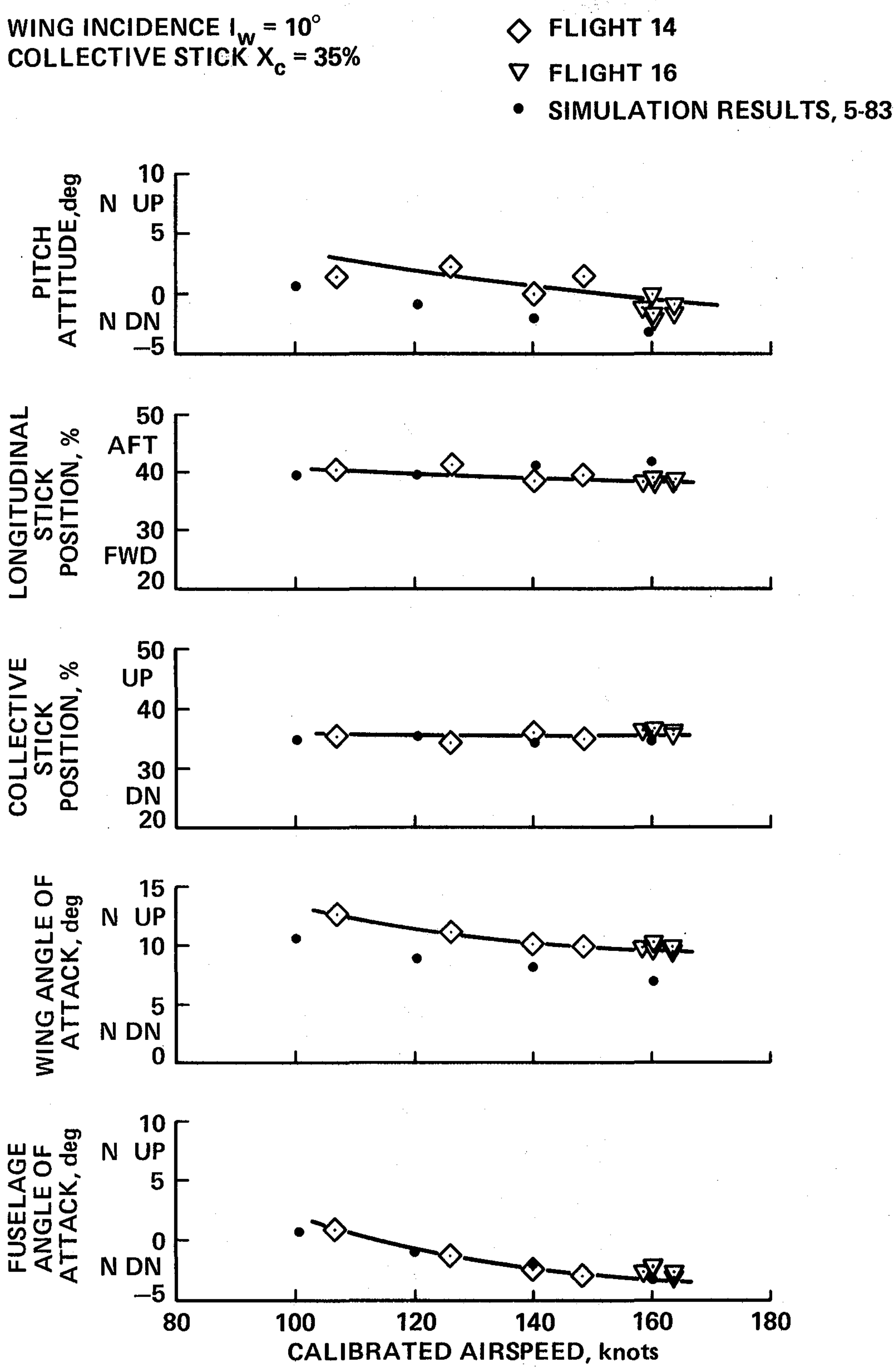
(a) Longitudinal comparisons.

Figure 2.- RSRA trim level flight; collective stick = 40%.



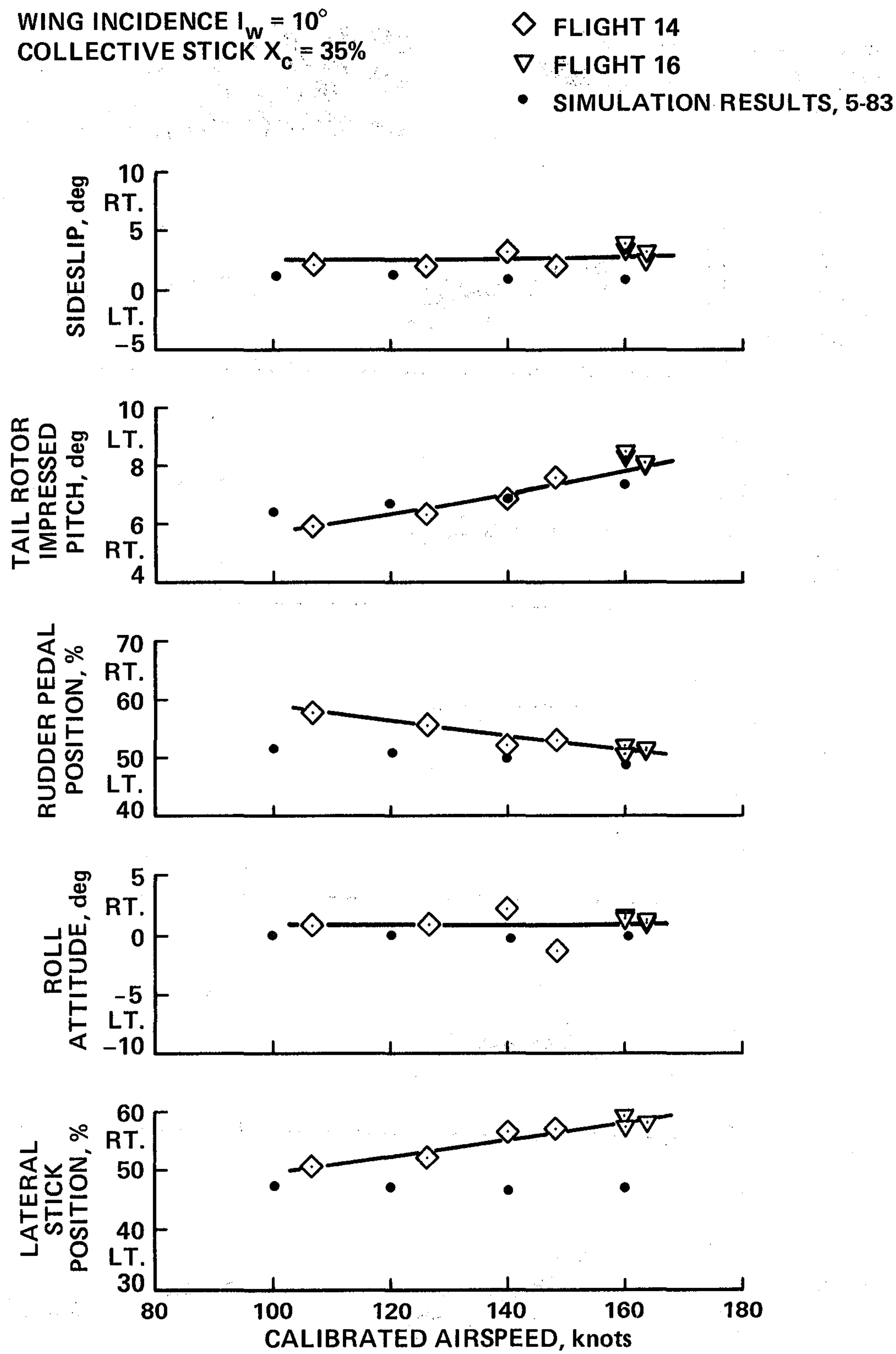
(b) Lateral comparisons.

Figure 2.- Concluded.



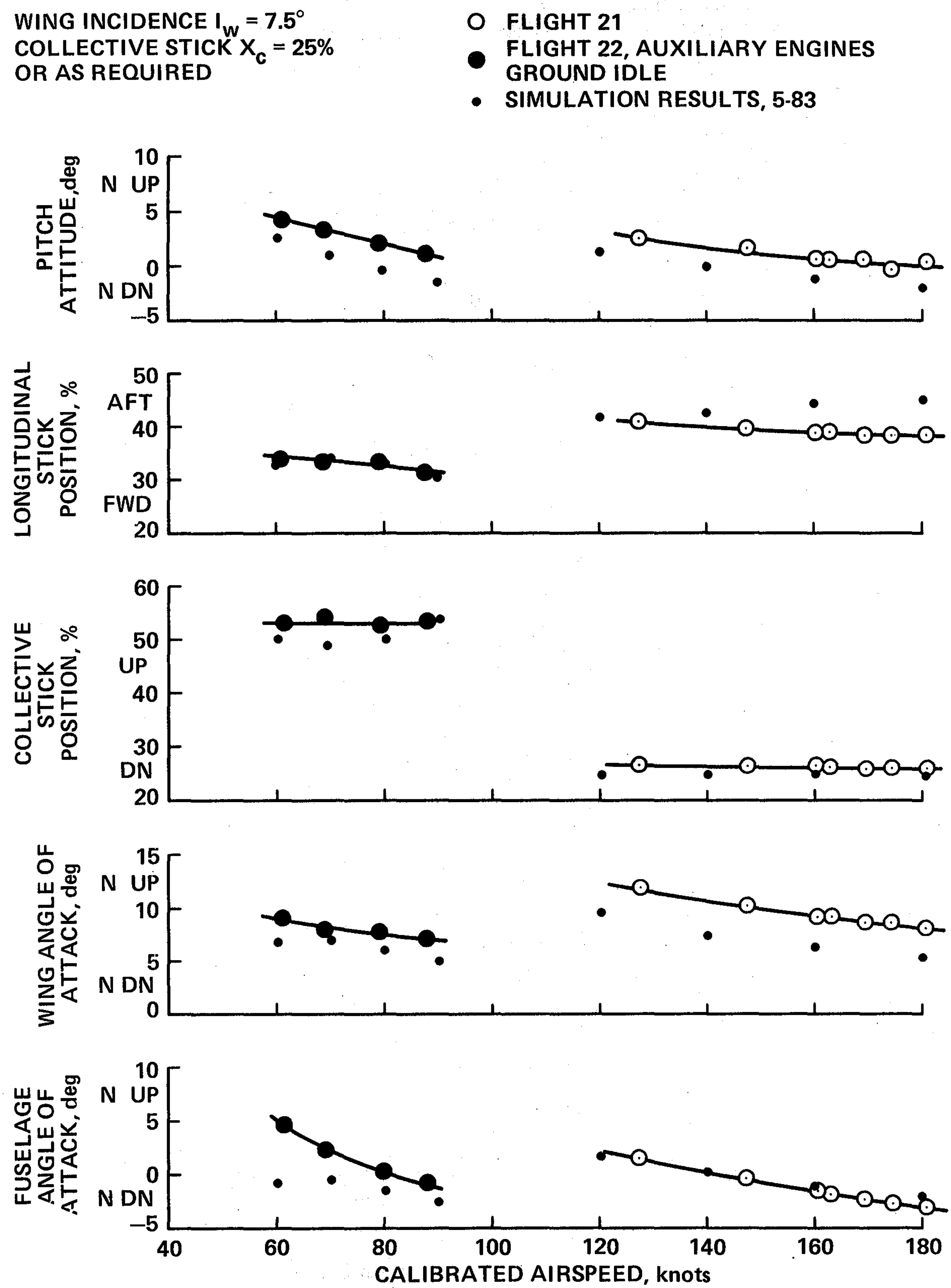
(a) Longitudinal comparisons.

Figure 3.- RSRA trim level flight; collective stick = 35%.



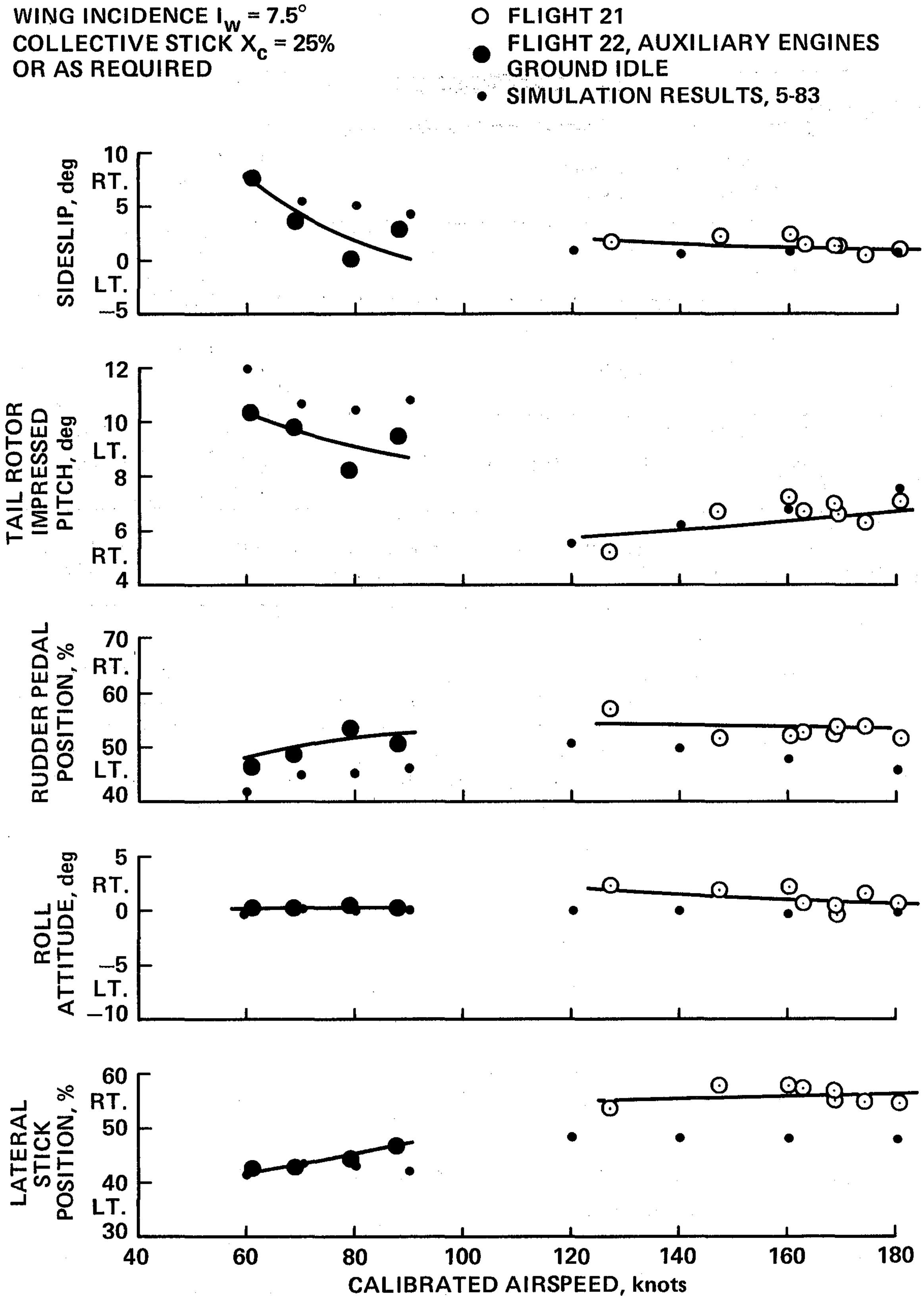
(b) Lateral comparisons.

Figure 3.- Concluded.



(a) Longitudinal comparisons.

Figure 4.- RSRA trim level flight; collective stick = 25%.



(b) Lateral comparisons.

Figure 4.– Concluded.

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15. Supplementary Notes

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16. Abstract

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