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SUMMARY

An automatic go-around control system was evaluated on the Augmentor Wing Jet Short Takeoff and Landing (STOL) Research Airplane (AWJSRA) as part of a study of an automatic landing system for a powered-lift STOL airplane. The results of the evaluation indicate that the go-around control system can successfully transition the airplane to a climb configuration from any initiation point during the glide-slope track or the flare maneuver prior to touchdown.

INTRODUCTION

At one time or another, virtually every type of aircraft that is involved in operations in instrument meteorological conditions must be flown through a go-around maneuver. The go-around maneuver may be initiated either because there is insufficient visibility to permit the pilot to see the runway, or because conditions on the runway such as obstructions or wet and slippery surface conditions preclude a safe landing and stop. Whatever the reason for the go-around maneuver, the aircraft must be able to clear obstacles and to maintain sufficient airspeed or angle-of-attack margins to be able to maneuver and to counter atmospheric disturbances.

Go-around procedures for conventional takeoff and landing (CTOL) aircraft require application of power, resetting the flaps, and perhaps an associated trim adjustment to establish the airplane in a reasonable climb configuration. Subsequent configuration changes may be required, but these generally involve only discrete pilot actions such as selecting gear up or resetting the flaps.

One type of airplane that may require significant configuration changes during a go-around is the powered-lift short takeoff and landing (STOL) airplane. Such an airplane depends on engine power to establish high-lift coefficients and during a go-around can require an immediate configuration change that involves activation of multiple control devices. Several examples of powered-lift aircraft have been flown. Two STOL transport prototype aircraft which were developed for and evaluated by the Air Force are the Boeing YC-14 and the McDonnell-Douglas YC-15 aircraft (ref. 1). The Boeing YC-14 used upper surface blowing to achieve high lift. The McDonnell-Douglas YC-15 used externally blown flaps. Ames Research Center has developed and flown two different concepts for powered-lift aircraft. The Augmentor Wing Jet STOL Research Aircraft (AWJSRA) (ref. 2) used turbofan bypass air blown through a flap system to achieve high lift and drag coefficients. The Quiet Short-Haul Research Airplane (QSRA) (ref. 3) used the upper surface blowing concept in which the engine exhaust is blown over large flaps to increase lift and drag.

Ames Research Center has conducted a flight experiments program to investigate various characteristics of powered-lift STOL aircraft that operate into a microwave landing system (MLS)-equipped STOL port. Part of this program included an automatic landing system study on the AWJSRA (ref. 4). After the automatic landing system control laws were developed and evaluated, attention shifted to other aspects of autoland systems including the go-around control system which is the subject of this report.

The purpose of an automated go-around procedure is to reduce the pilot workload and to allow the pilot to concentrate on two major aspects of the approach. The first is the need to monitor and confirm adequate system performance. The second is the need to establish before the airplane reaches a decision height that the visibility and runway conditions will permit a safe landing and stop. An automated go-around procedure relieves the pilot of the demanding multiple axis control task and only requires that he push a button to arrest the sink rate and establish the airplane in a climb with a safe airspeed and angle of attack. The automatic system will either maintain the runway course if azimuth guidance is available or it will hold the runway heading during the go-around. The pilot can revert to manual control at any point in the go-around procedure or he can select subsequent autopilot modes.

This report describes the longitudinal and vertical performance of two go-around systems that were developed in conjunction with the AWJSRA autoland system studies. The report begins with a description of the airplane, the flight-test facility, and the autoland control laws that were developed. The design philosophy of the go-around control laws is explained. Flight-test results are presented and are followed by a performance comparison of the go-around control laws.

EXPERIMENTAL EQUIPMENT AND SYSTEMS

Aircraft Description

The AWJSRA shown in figures 1 and 2 is a 45,000-lb, 50-lb/ft^2 wing loading, turbofan-powered airplane designed for research in the STOL terminal flight regime. This airplane is capable of flying stabilized steep approaches (7.5°) at airspeeds of about 70 knots into STOL port runways of the type specified in reference 5. The airplane was developed as part of a cooperative program between Ames Research Center and the Canadian Department of Industry, Trade, and Commerce. The AWJSRA is a modified de Havilland of Canada DHC-5 Buffalo. The modification was made by the Boeing Airplane Company under a NASA contract. The two original turboprop engines were replaced with Rolls-Royce Spey MK 801-SF (split flow) turbofan engines. The wing modification included the installation of the autmentor flap system and leading edge slats. Wing loading was increased by reducing the span from 96 ft to 78.5 ft. To provide adequate pitch control, the spring tab on the elevator was deactivated and the elevator was hydraulically powered.

The most significant feature of the airplane is its augmentor flap that extends over approximately 70% of the exposed wing span. This is a bisurface flap that uses engine low-pressure fan bypass air to provide lift and thrust augmentation. Engine bypass air is ducted to a two-dimensional nozzle that exhausts into the entire flap span between the bisurface elements.

Bypass air is also blown over the drooped ailerons and used to control the boundary layer on the wing center section across the fuselage. Roll upset following an engine failure is substantially eliminated by crossducting approximately 65% of the fan air from each engine to the opposite wing augmentor duct. The remaining 35% of the flow is routed to the augmentor duct directly behind the engine.

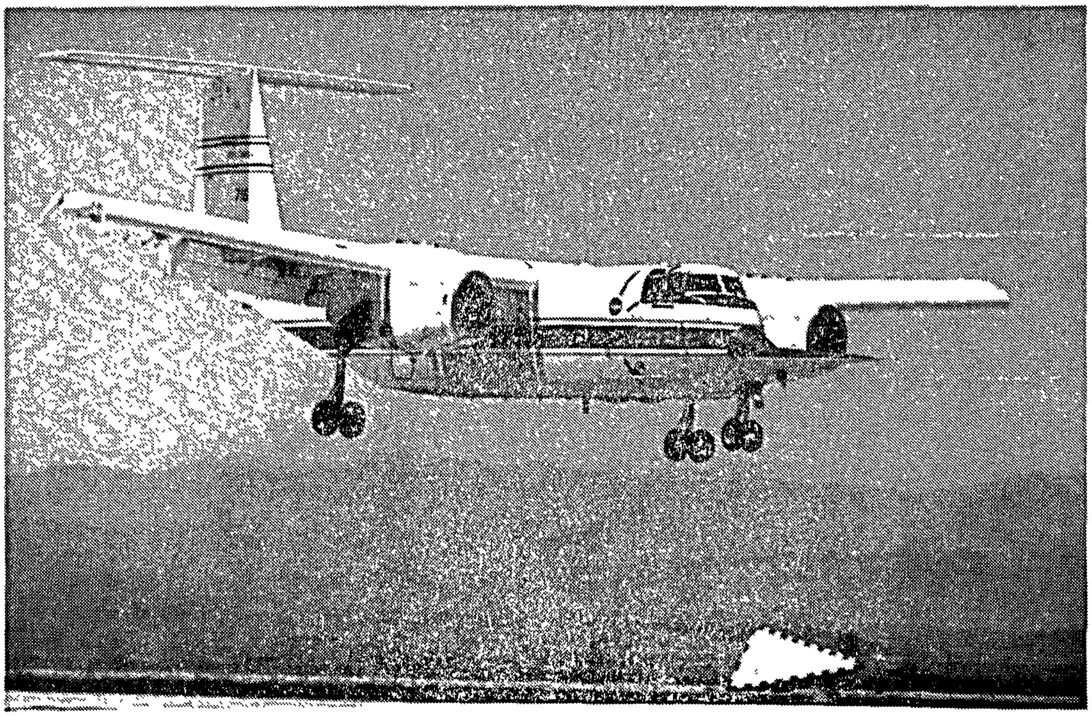

Figure 1.- Augmentor Wing Jet STOL Research Airplane (AWJSRA).

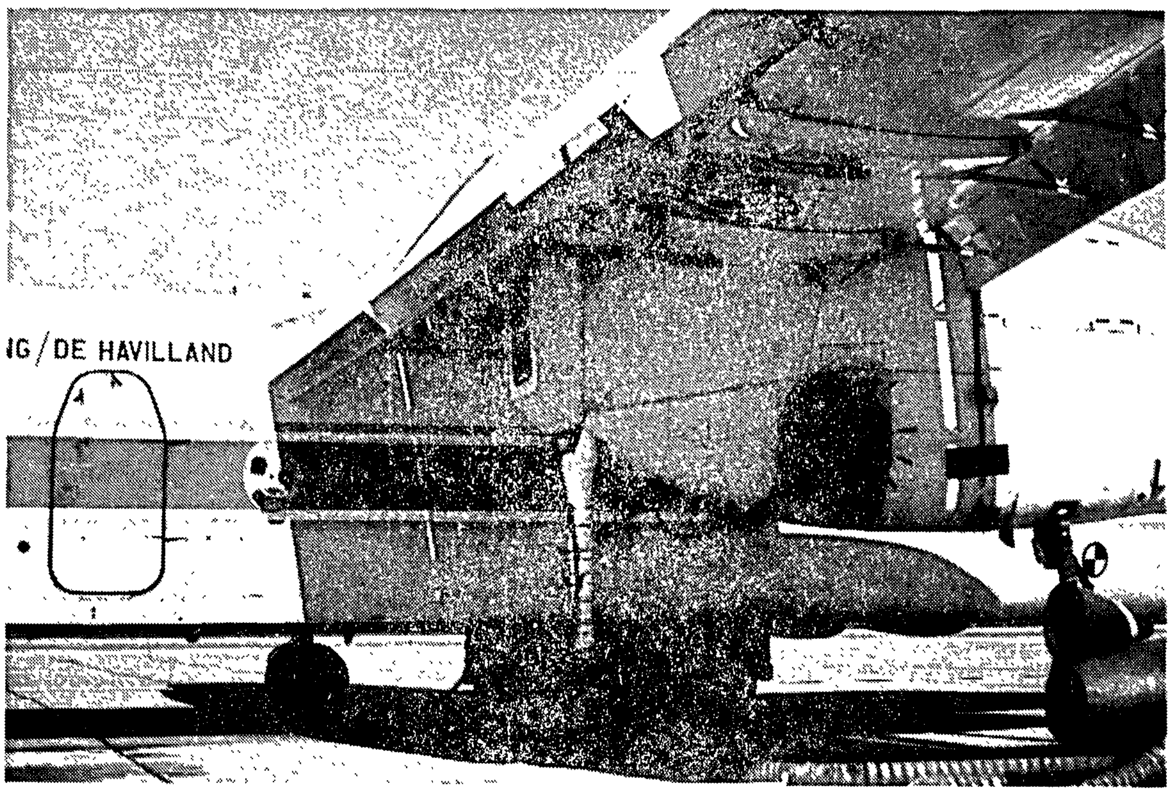

Figure 2.- Augmentor wing flap and nozzle arrangement.

The Rolls-Royce engines provide both the cold bypass fan air to the flap nozzles and the hot gas exhaust thrust to the Pegasus (Harrier-type) nozzles. These Pegasus nozzles, which direct the hot turbine gases downward, were controllable as shown in figure 3. Nozzle angles between 60° and 104°, measured relative to the aircraft waterline, were used for approaches. The minimum nozzle angle was 6°, the most-aft-vectored orientation, for takeoff.

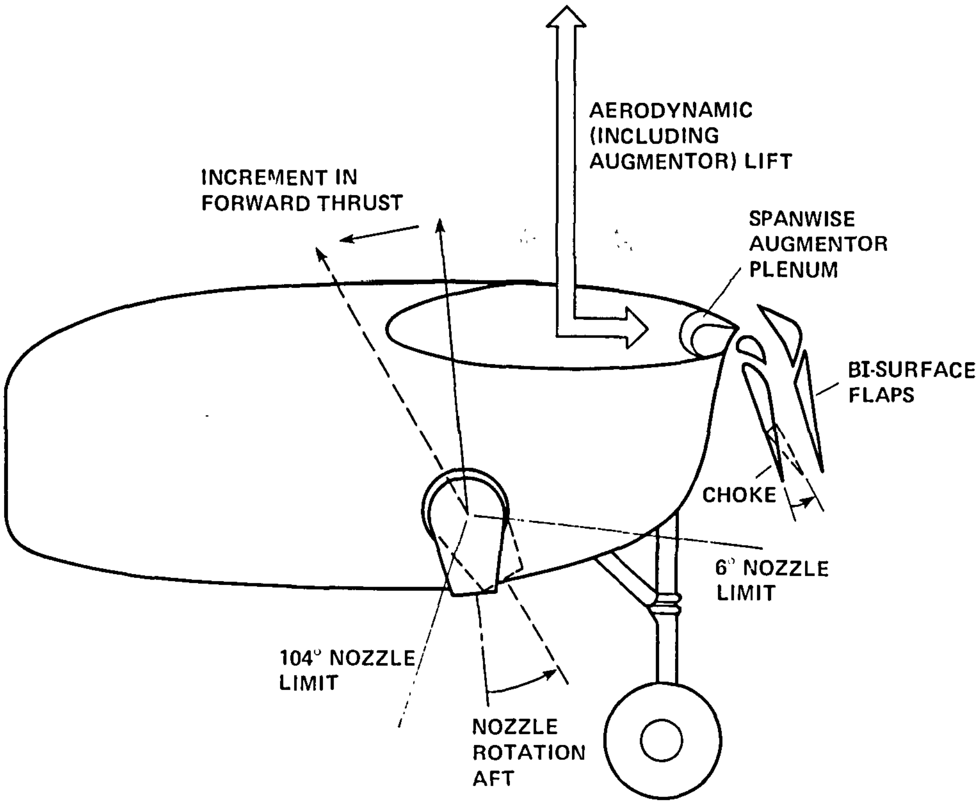

Figure 3.- Augmentor wing cross section and nozzle arrangement.

The aft portion of the lower flap surface, labeled chokes in figure 3, was hinged so flow between the flap bisurfaces could be partially blocked to decrease lift. Chokes were installed on both the inboard and the outboard flap segments. The outboard chokes were used differentially to supplement the ailerons and the spoilers for roll control. The inboard chokes could be used together to provide fast-acting direct-lift control. For further details concerning the AWJSRA, refer to reference 2.

Flight-Test Facility

The go-around control system associated with the automatic landing system on the AWJSRA was evaluated during flight tests conducted at the Navy Auxiliary Landing Field (NALF), Crows Landing, California. A simulated ground level STOL port was located on the northern half of runway 35/17 as shown in figure 4. This STOL port was equipped with a narrow beam microwave landing system which had azimuth, elevation, and distance measuring equipment (DME) transmitters located as shown in figure 5. The dimensions of the STOL port and the location of the MLS transmitters

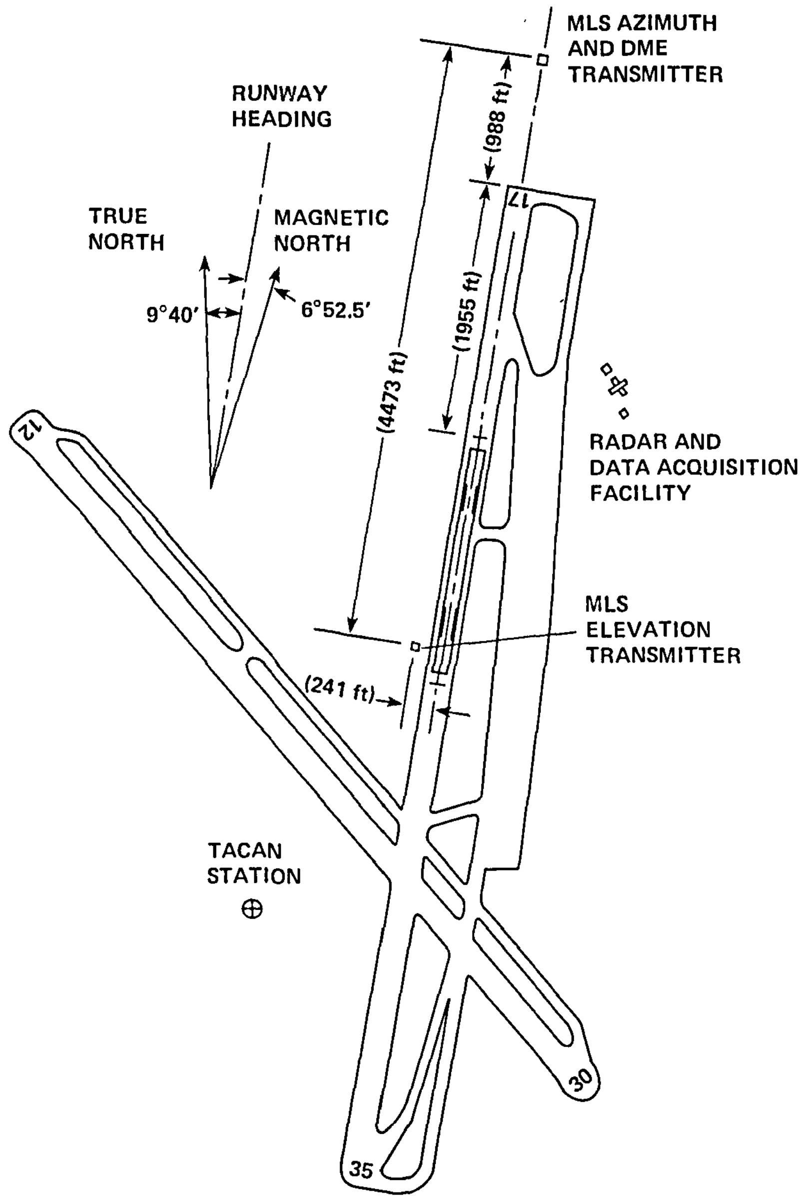

Figure 4.- STOL port location and MLS installation at Navy Auxiliary Landing Field, Crows Landing.

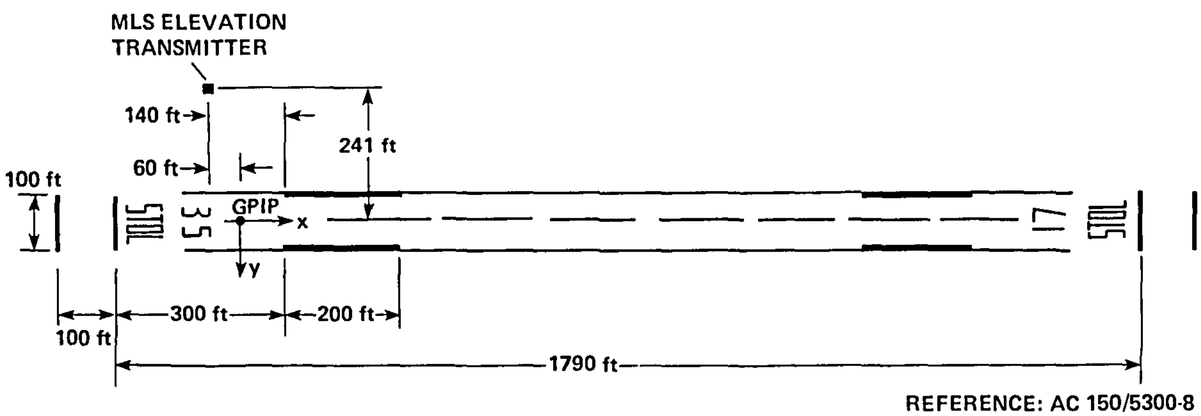

Figure 5.- STOL port layout at Navy Auxiliary Landing Field, Crows Landing.

were based on the recommendations on STOL port design contained in FAA Advisory Circular 150/5300-6 (ref. 5).

Autoland Control Laws

The go-around control laws were developed for use with two of the three autoland control laws described in reference 4. The go-around commands were designed to transition the airplane from a glide-slope track or flare mode to a climb mode.

The autoland control laws were labeled for the number of dynamically driven controls. During the glide-slope track phase of the approach, the two-control system used an elevator to regulate airspeed by pitching the airplane and used the power lever to regulate the flightpath. The nozzles were used as a trim device to maintain the engine rpm in a reasonable operating region (between a maximum temperature limit and a minimum powered-lift limit). They were therefore driven in the long term as a function of the wind condition. During the flare maneuver, the elevator rotated the airplane from the pitch attitude which existed prior to flare entry, to approximately a 6° nose-up angle at touchdown to arrest the sink rate, and to make sure that the main landing gear wheels would contact the runway before the nose wheel did. The power lever provided short term regulation of the sink rate to follow the altitude-altitude rate profile shown in figure 6.

During the glide-slope tracking mode, the four-control system commanded the elevator only for long-term speed control. The nozzles were used as a trim device to maintain a reasonable rpm operating range and also to provide short-term speed control. When the nozzles were in the near vertical position as shown in figure 3, small perturbation nozzle vectoring produced a direct fore or aft force which was

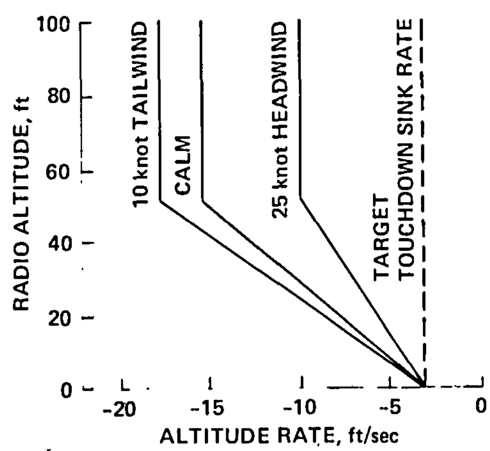

Figure 6.- Altitude vs altitude-rate references for three wind conditions.

useful in regulating speed. The pitch schedule during flare was the same for the four-control system as it was for the two-control system. A deceleration schedule commanded the nozzles to bleed off airspeed at 1.7 knots/sec, not to exceed a total increment of 10 knots. The chokes, when used in conjunction with the power lever, provided more rapid flightpath response during glide-slope tracking than could be achieved with the power lever servo alone. The fast choke response was also effective in maintaining the airplane on the flare sink rate reference shown in figure 6. A complete description of the two-control and four-control autoland control laws is contained in reference 4.

GO-AROUND TECHNIQUE

The go-around system was armed when MLS glide-slope tracking began. The pilot could initiate the automatic go-around anytime prior to the touchdown using a button located in the thumb position on the right-hand side of the control wheel.

The design goals for the automatic go-around control system were: (1) to quickly establish a positive flightpath angle (FPA); (2) to maintain a safe airspeed; and (3) to replace the airplane approach configuration with a climb configuration. Accordingly, the automatic go-around maneuver was designed with the first priority on achieving a 1° climbing FPA and the second priority on establishing a target airspeed of 80 knots. This was accomplished by augmenting the normal FPA select logic with a pitch-predict term and by commanding the autothrottle to the maximum rpm limit established in software. As the airplane proceeded to the target values of FPA and airspeed, the approach configuration was changed to a climb configuration. Specifically, the nozzles were rotated at a rate of 20°/sec from the approach setting to the fully up position used for climb and cruise flight. The chokes, if used for the approach, were commanded to the fully open position at the rate limit value of 48%/sec. Five seconds after the system entered the FPA-hold mode, the autothrottle was disconnected and the FPA-hold and speed-select modes were replaced by the speed-select (or hold)-with-elevator mode. The flaps were not automatically driven and were, therefore, not part of the automatic reconfiguration. Sometime during the go-around maneuver, typically after the transition to the speed-hold-with-elevator mode, the pilots repositioned the flaps from an approach setting near 65° to a climb setting near 20°.

The go-around control law description in the next section pertains to the transition from the approach condition to the beginning of the speed-hold-with-elevator mode.

Go-Around Control Laws

Figure 7 shows the two-control go-around system block diagram. Prior to go-around initiation, the throttle was driven by the glide-slope control law if the airplane was above 50-ft radio altitude, and by the sink-rate control law if the airplane was below 50 ft. At go-around initiation, the glide-slope track or flare-sink-rate control laws were replaced by a throttle command to maximum rpm which was computed as a function of pressure, altitude, and temperature. Before go-around initiation, the elevator was driven by an airspeed-hold or pitch-for-flare control law depending on whether the airplane was above or below 65 ft. After go-around initiation, a flightpath reference command supplemented by a pitch-predict term commanded the elevator to rotate the airplane to a 1° climb FPA. The FPA reference was smoothly

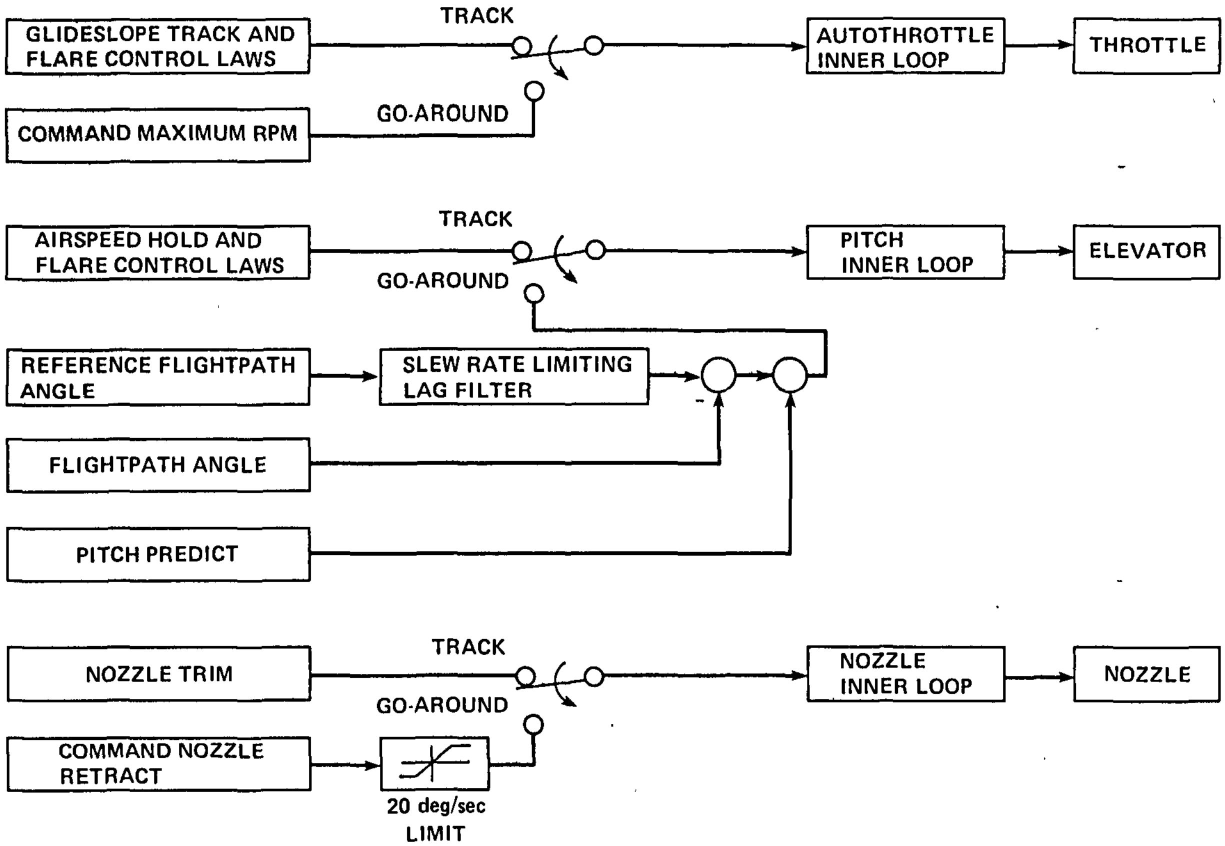

Figure 7.- Two-control go-around system.

changed from the value appropriate for glide-slope track (or flare) to the climb 1° reference through a rate-limited lag filter with a 0.7-sec time constant. The rate limit was approximately 15°/sec. The pitch-predict term expedited the nose-up rotation of the airplane to arrest the sink rate and to establish the climb FPA. This predict term was a function of aircraft gross weight and airspeed. If the calculated predict term was greater than the actual pitch attitude, the predict term was added to increase the FPA. Otherwise, the predict command term was set to zero to prevent a nose-down pitch rotation.

Prior to go-around initiation, the nozzle angle was typically between 60° and 80° measured relative to the aircraft waterline; the exact value was a function of aerodynamic FPA which in turn was a function of the glide-slope reference angle and the component of wind along the runway. At go-around initiation, the nozzle was rotated to the 6°-full-aft position which was suitable for climb and cruise flight.

Figure 8 shows the four-control, go-around system block diagram. The initial go-around procedure for the four-control system was similar to that of the two-control system except for the additional requirement that the four-control system chokes be open at go-around. During glide-slope tracking or flare, the chokes operated about a nominal dwell position of 30% of closure to provide the capability to make both upward and downward path corrections. As explained in reference 4, the chokes rapidly responded to the same path sink-rate correction commands that were sent to the autothrottle servo. As soon as the engine rpm responded to the autothrottle command, the chokes were no longer needed and were returned to the 30% dwell position. Opening the chokes at a rate limit of 48%/sec contributed a 0.1-g normal acceleration

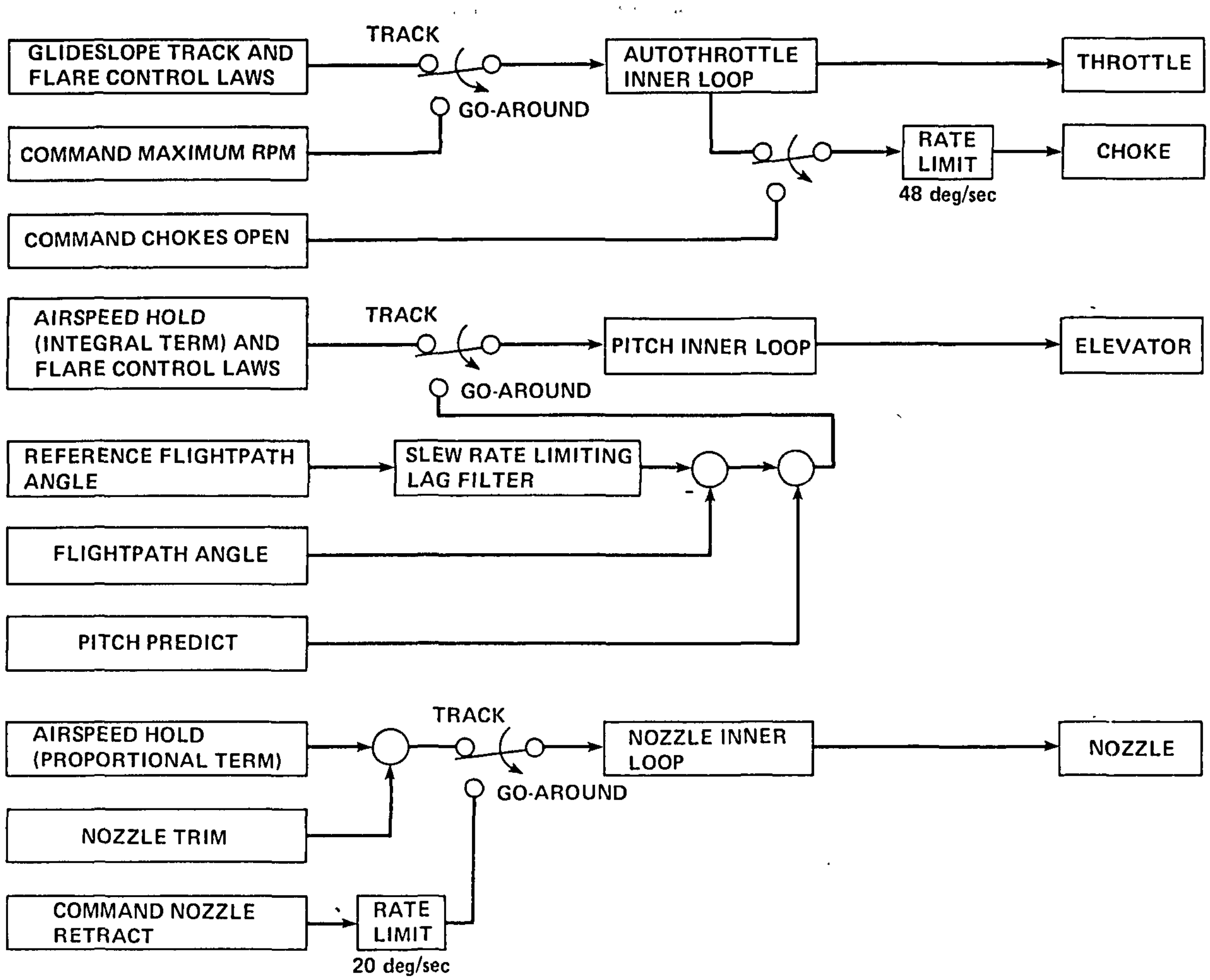

Figure 8.- Four-control go-around system.

increment to help arrest the sink rate. Because the chokes were deployed to the 30% closure dwell position during the glide-slope track, they caused a lift loss on the wing that required an additional 2 knots to be added to the approach reference airspeed for adequate safety margins.

Other differences between the two-control and the four-control systems were associated with the method used for speed control during glide-slope track rather than operation after go-around initiation. There were minor differences in the two-control and four-control reference flightpath slew-rate-lag filter and the predict magnitude. The time constant for the four-control slew-rate filter was 0.6 sec, and the rate limit was 17°/sec. The predict pitch command term was set at 2° for the four-control system. The exact values used for the filter time constant, the rate limit, and the predict pitch command were adjusted experimentally in flight to provide the most rapid FPA change after go-around initiation.

Five seconds after go-around initiation, after the automatic configuration change provided by the control laws shown in figures 7 and 8 was complete, the system automatically reverted to airspeed-hold-with-elevator if the speed at that time was greater than 80 knots. If the speed at that time was less than 80 knots, the system automatically commanded an airspeed-select-with-elevator to 80 knots and then reverted to airspeed-hold when 80 knots was reached. At any time the pilot could either manually take control, or he could select new autopilot modes to continue the climb.

FLIGHT TEST RESULTS

Automatic go-around maneuvers were evaluated with the AWJSRA for the two-control system and the four-control system. The initial go-around system evaluations were initiated before the flare maneuver began. Some subsequent evaluations were initiated late in the flare maneuver just before touchdown.

Figure 9 shows the time history of a two-control-system go-around maneuver which was initiated at a ratio altitude of 385 ft. The airplane was on an automatic

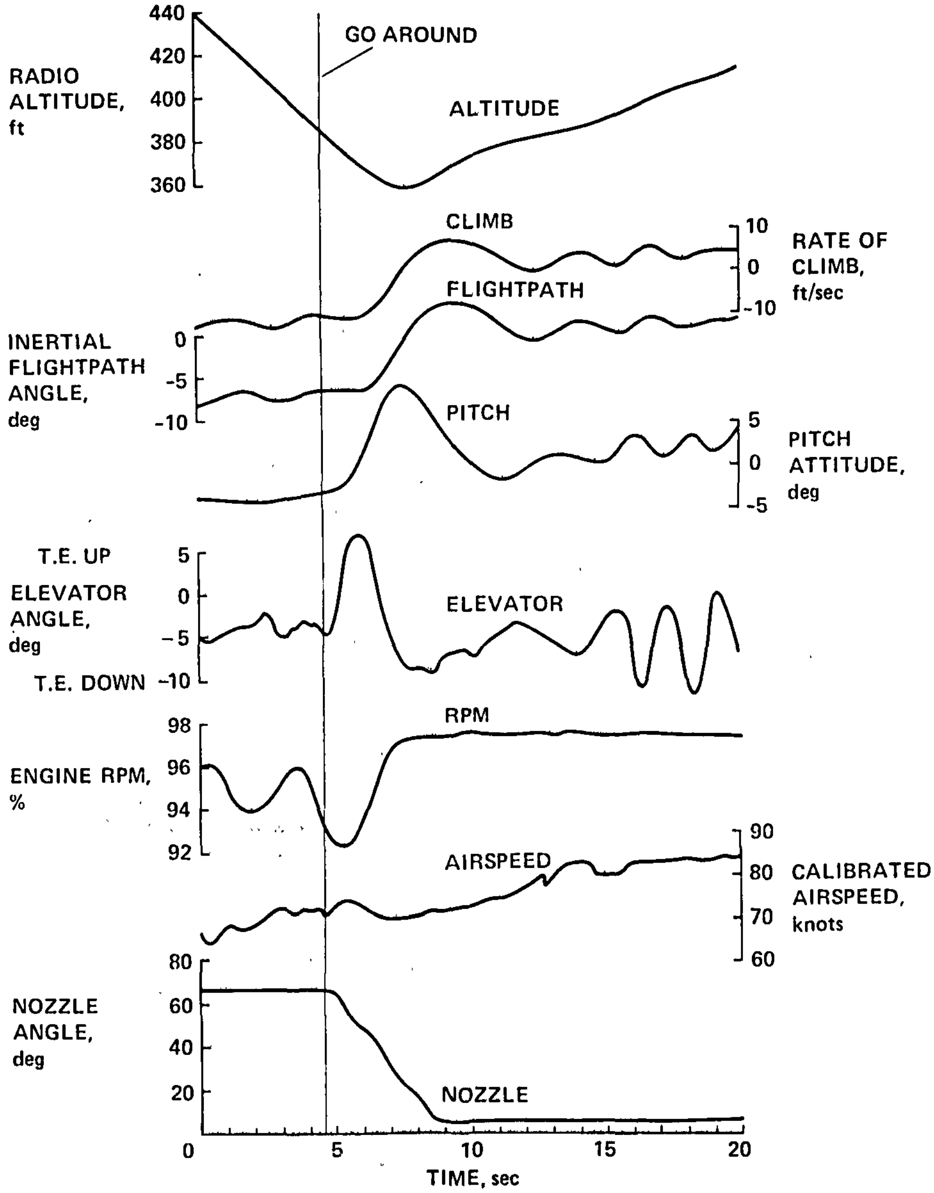

Figure 9.- Two-control-system go-around from 385 ft.

approach along a 7.5°-MLS glide slope. The surface wind was reported to be between 10 and 15 knots. Prior to initiation of the go-around maneuver, the airplane was tracking the glide slope with an FPA of approximately -7°. The sink rate at go-around was 11 ft/sec.

Figure 9 shows that by pitching the airplane nose-up and adding power to increase rpm to the maximum software limit, the FPA became positive within 3 sec after the go-around maneuver was initiated. The altitude loss from go-around initiation to a positive FPA was 25 ft. The subsequent FPA response to the +1° command was oscillatory and lightly damped. A pronounced oscillation in elevator angle and pitch-attitude angle began at 15 sec in the time history in figure 9. This oscillation, which began when (1) the autothrottle was disconnected 5 sec after FPA hold was initiated and (2) the FPA-hold mode was replaced by the airspeed-hold-with-elevator mode, was the result of a nonoptimized airspeed-hold-with-elevator mode. The airspeed at the initiation of the go-around mode was 72 knots. By the time the FPA-hold mode was replaced by the airspeed-hold-with-elevator mode, the airspeed had increased to 80 knots.

The go-around maneuver configuration change for the two-control system involved an automatic rotation of the nozzles from 67° to 6° over a 4-sec time period.

Figure 10 shows the performance of the four-control system for a go-around maneuver initiated at a radio altitude of 280 ft. The wind was calm. The airplane was tracking a -7.5° MLS glide slope when the go-around maneuver was initiated. Sink rate when go-around was initiated, was 17.5 ft/sec.

By pitching the airplane nose-up, adding power to increase rpm to the maximum software limit, and opening the chokes, the FPA was positive 3.5 sec after initiation of the go-around maneuver. The altitude loss from go-around initiation to a positive FPA was 33 ft. The FPA response to the +1° command was well-damped although the error from the command was not eliminated until just before the autothrottle was disconnected and the subsequent transition was made to the airspeed-hold-with-elevator mode. Airspeed at initiation of the go-around maneuver was 71 knots. Except for transients, probably caused by light turbulence, the airspeed increased steadily to 81 knots which was the value when the altitude-hold-with-elevator mode was initiated.

The configuration change associated with the transition from the approach mode to the go-around mode consisted of raising the nozzles from 80° to 6° in 4 sec and opening the chokes in 0.5 sec.

Figure 11 is the time history of the two-control go-around system when the go-around was initiated during the flare at a radio altitude of 8 ft. At this point, the flare maneuver had already reduced the sink rate from a nominal approach value near 15 ft/sec to a pretouchdown value of 5 ft/sec. The go-around system produced a positive FPA within 2.5 sec by using airplane nose-up pitch and an autothrottle to establish rpm on the maximum software limit. The altitude loss following go-around initiation was recorded as 8 ft. Although not evident in figure 11, the main landing gear just contacted the ground before the airplane climbed away. At initiation of the go-around maneuver, the airspeed was 59 knots. Airspeed sagged to 57 knots before increasing in an unsteady manner to 70 knots, at which point the autothrottle was disconnected and the FPA-hold mode was replaced by the airspeed-hold-with-elevator mode.

Figure 12 shows the time history of a go-around maneuver conducted with the four-control system which was initiated at a radio altitude of 10 ft. This figure

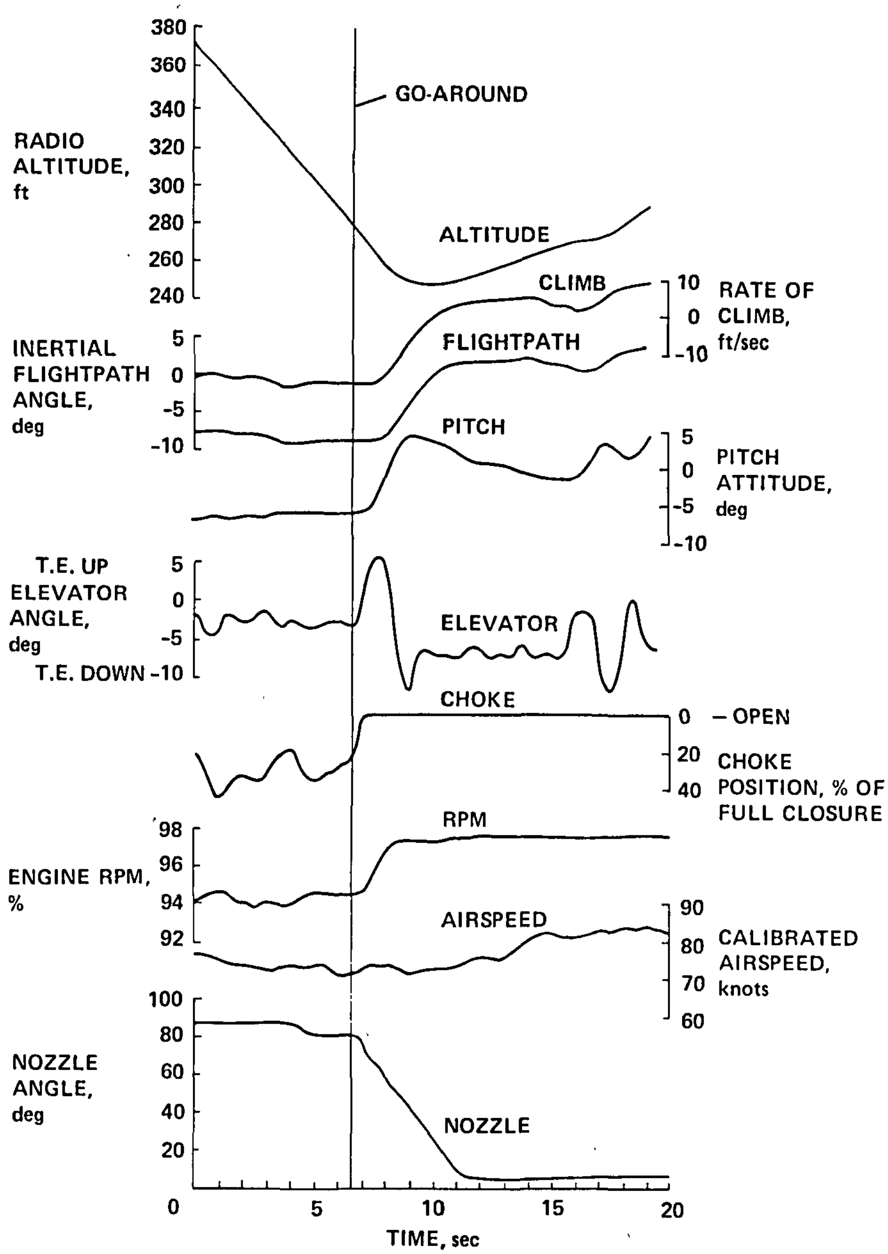

Figure 10.- Four-control-system go-around from 280 ft.

shows the flare entry events as well as the history of the go-around maneuver. The sink rate was just under 5 ft/sec when the go-around was initiated. A positive FPA was established in 2.1 sec after go-around initiation. The altitude loss from go-around initiate to a positive FPA was 6 ft. The airspeed decreased from 66 knots to 61 knots during the first 4 sec following initiation of the go-around maneuver and then increased to 70 knots when the FPA-hold mode was replaced by the airspeed-hold-with-elevator mode.

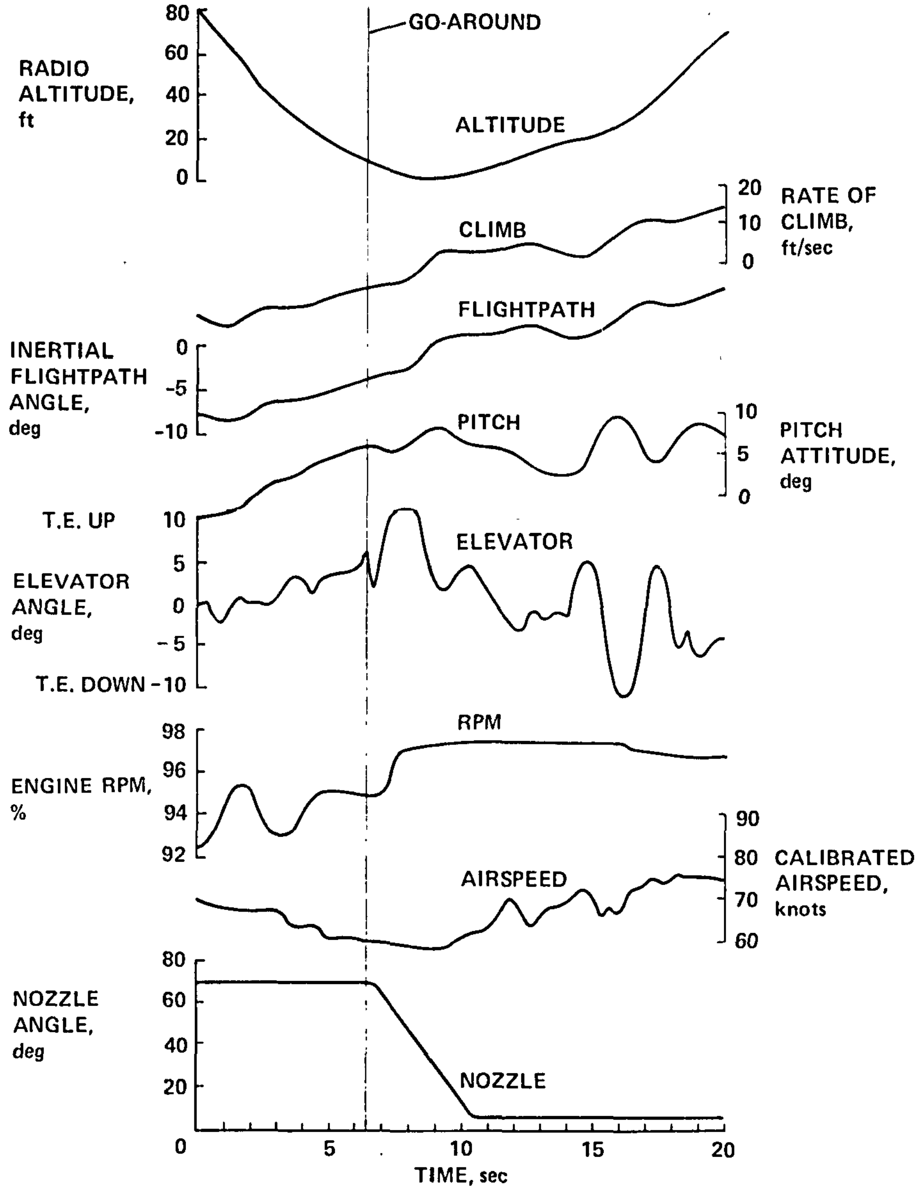

Figure 11.- Two-control-system go-around from 7 ft.

Performance Comparison

The performance of the two-control and four-control-system go-around control laws was generally similar except for a minor difference in the tuning of the FPA select law. A comparison of figures 9 and 10 shows that when the go-around maneuver was initiated while the airplane was tracking the glide slope, the time to a positive FPA was shorter and the altitude loss was less for the two-control system than for the four-control system. This performance difference is attributable to the differences in the sink rates prior to go-around since the control action was essentially the same for both systems. The two-control system was more oscillatory than was the four-control system. The airspeed increased monotonically from the go-around initiate value to the target value near 80 knots by the time the FPA-hold mode was replaced by the airspeed-hold-with-elevator mode.

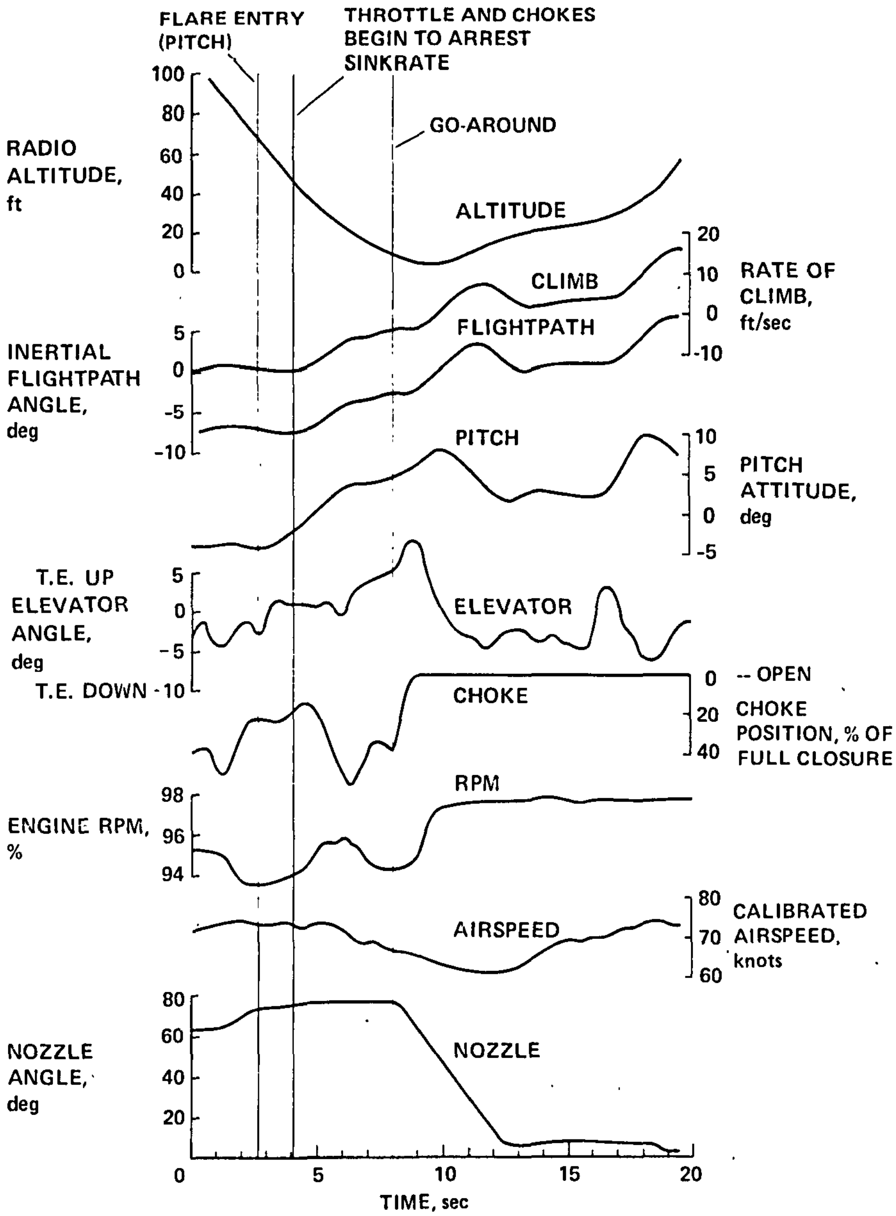

Figure 12.- Four-control-system go-around from 10 ft.

Because the flare maneuver had already partially arrested the sink rate when the go-around was initiated during the flare maneuver, the time to positive FPA and the altitude loss were reduced as compared with go-around initiated during glide-slope track. There was no significant difference in the FPA response or airspeed response between the two-control and four-control systems. Since the flare maneuver caused an airspeed reduction as the airplane neared touchdown, the airspeed at go-around initiate was lower than for a go-around maneuver initiated from glide-slope track. Figures 11 and 12 show that the airspeed sagged 2 to 5 knots below the airspeed at go-around initiate before beginning to increase toward the target value of 80 knots. These figures also show that the airspeed was increasing through 70 knots when the FPA-hold mode was replaced by the airspeed-select-with-elevator mode. The glide-slope track to go-around mode nozzle rotation occurred at the same rate for all of the approaches recorded.

DISCUSSION

The go-around control system that was developed in conjunction with the AWJSRA autoland system has been demonstrated to effectively transition the airplane from an approach mode to a climb mode. Insufficient data were accumulated to establish statistical performance characteristics in all wind conditions. However, the time histories contained in this report indicate that satisfactory performance can be achieved if the go-around is initiated anytime prior to 2 sec before autoland touchdown.

Issues that were beyond the scope of this preliminary evaluation include:

1. How much time is needed by the pilot to make the go-around decision and then to activate the go-around button?

2. Is there a minimum decision height or can the go-around maneuver be initiated anytime in the approach, the flare maneuver, or during the landing rollout?

3. What are the performance requirements for go-around with all engines operating and with an engine out?

4. What are the effects of significant atmospheric disturbances such as wind shears and strong turbulence?

5. What display elements are most effective for helping the pilot monitor approach, flare, and stopping progress?

Reference 6 suggests that the pilot of a powered-lift STOL airplane should be able to execute a go-around anytime up to the point where the airplane is configured to stop by deployment of spoilers or initiation of thrust reversal or braking. Some go-around maneuvers were conducted with the AWJSRA which were initiated after the airplane had touched down. These go-around maneuvers were accomplished by the pilot using the procedures for a normal touch and go landing. After touchdown the pilot disconnected the autoland system, carefully lowered the aircraft nose, called for the copilot to raise the flaps to a 20° takeoff setting, added power, and accelerated the airplane to a safe takeoff speed. While all of these pilot actions were taking place, the airplane was rolling down the runway and using a significant portion of the available STOL port length. The ground-roll distance associated with the manually flown go-around maneuver initiated after touchdown was no less than that which was required to stop the airplane using moderate braking as described in reference 7.

Go-around maneuvers have been conducted with another powered-lift STOL airplane, the quiet short-haul research aircraft (QSRA), as part of an evaluation of that airplane for landing on an aircraft carrier (ref. 8). On the QSRA, go-around maneuvers after touchdown are simply a matter of advancing power and raising the flaps. Both of these actions can be conducted with the hand that is on the power lever. Loss of an engine on the four-engine QSRA does not affect performance as seriously as an engine loss on the two-engine AWJSRA. The supposition that the go-around maneuver is feasible up to the point where the airplane is configured to stop appears to apply to the QSRA. However, no work as yet has been done with an automatic landing system on that airplane.

The performance requirements for climb gradient have not been defined for the AWJSRA, but a considerable body of information on takeoff and climb performance has been developed for the QSRA (ref. 9).

Although the primary emphasis in this report is on the go-around control law mechanization and performance, another aspect of system design that surfaced during the flight evaluation was the location of the go-around button. The evaluation was conducted using the research digital flight control system described in reference 10. A feature of that system which was considered objectionable was the location of the go-around button under the pilot's right thumb position on the control wheel. This is not a good location for the go-around switch, because the pilot is forced to remove his hand from the overhead power lever in order to initiate the go-around maneuver. Since the pilot preferred to guard against an autothrottle servo runaway by keeping his hand on the power levers, a better location for the go-around button is on the power lever handle.

CONCLUSIONS

An autoland research program has been conducted with the AWJSRA flying into an MLS-equipped STOL port. The objective of one phase of the autoland research program was to develop and to evaluate control laws for an automatic go-around system that could be activated by the pilot by pushing a single button located on the control wheel. The automatic go-around system study followed the development of the autoland glide-slope track and flare laws reported in reference 4. Only a few go-around maneuvers were conducted and these were insufficient in number to warrant a statistical analysis of the system performance. However, the main features of the go-around system were demonstrated.

The AWJSRA flight tests indicated that go-around can be successfully initiated at any altitude during the approach prior to 2 sec before touchdown. Before flare entry, when the rate of descent was near 15 ft/sec in calm wind conditions, the maximum increment of altitude lost was 33 ft and the time to a positive flightpath angle was less than 3.5 sec after the go-around maneuver was initiated. If the go-around was initiated after the flare maneuver began, when the automatic landing system had already decreased the sink rate, the altitude loss after the go-around initiation was, for the approaches shown, as low as 6 ft before a positive flightpath angle was established. Successful go-around maneuvers were demonstrated from initiation altitudes under 10 ft. There was no appreciable loss of airspeed during the go-around maneuver initiated from glide-slope track. There was some decrease in airspeed during a go-around maneuver initiated after the flare maneuver was under way, but, in each case evaluated, the airspeed was building to an acceptable reference value at the conclusion of the go-around maneuver.

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16. Abstract

An automatic go-around control system was evaluated on the Augmentor Wing Jet Short Takeoff and Landing (STOL) Research Airplane (AWJSRA) as part of a study of an automatic landing system for a powered-lift STOL airplane. The results of the evaluation indicate that the go-around control system can successfully transition the airplane to a climb configuration from any initiation point during the glide-slope track or the flare maneuver prior to touchdown.

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