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Impact of Ramp Launch Technology on a Navy Support Aircraft

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Abstract

LIGHT aircraft carrier designs are being considered in order to increase the number of air-capable ships and disperse air power more widely at sea. The deletion of catapult launch devices is a major contributor to reducing the weight, complexity, and cost of these ships, but this requires aircraft with short takeoff run capability. The ramp launch technique developed by the British and used by the Sea Harrier, which is a very high thrust-to-weight ratio design, is shown to be applicable to reducing the deck run of conventional Navy aircraft. A short takeoff using a free deck run and a ramp is achieved by lifting off at a speed less than stall speed and accelerating to a 1-*g* flight speed during a ramp induced semiballistic flight trajectory. This paper shows the impact of the ramp launch technique on low thrust-to-weight ratio aircraft and describes a design study to modify the Navy S-3A ASW aircraft to operate from a light aircraft carrier with an 800-ft deck run and a 4-deg circular arc launch ramp.

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Configuration Development

Currently, S-3A ASW aircraft are operating from the large aircraft carriers of the U.S. Navy. Normal takeoff gross weight is about 46,000 lb, the high wing has 598 ft^2 of area, and power is provided by two G.E. TF34 axial flow fan engines rated at 9275 lb of thrust. Catapult assist is required for a carrier takeoff. Normal takeoff ground run on a flat surface, without catapult assist, is 2200 ft, using a conventional minimum allowable takeoff speed of 1.2 V_S, where V_S is stall speed.

The basic mechanics of a ramp launch to reduce takeoff distance are as follows[1]:

1) The ramp imparts an upward velocity to the aircraft at takeoff for a gain in height.

2) Takeoff speed is less than stall speed and the aircraft is rotated after liftoff to a high angle of attack to gain as much wing lift as possible while the aircraft continues to accelerate.

3) As speed increases, angle of attack can be reduced to sustain 1-*g* flight.

In adapting the S-3A aircraft to takeoff in 800 ft the major design variables are engine thrust and wing lift. When the short takeoff run is followed with a ramp launch, two other design variables become of prime importance: thrust vectoring and pitch attitude control throughout the ramp induced semiballistic flight trajectory. Consequently, the design variables investigated to create a short takeoff-arrested landing (STO-AL) configuration of the S-3A fall in one of these four categories: thrust, lift, thrust vectoring, and pitch control.[2]

The design value of these variables that eventually evolved, as limited by practical considerations and preliminary cost analysis, is shown in Table 1. It was found to be more cost effective to combine airframe changes with thrust changes rather than to arrive at a brute force solution to the STO-AL problem by merely increasing aircraft propulsive force. Also, auxiliary engines and jet-assisted takeoff units were found to have drawbacks. They restrict the aircraft's operational capability because of location, such as in the bomb bay or on an external pylon intended for missiles or external fuel tanks, and impose additional maintenance and supply problems.

Powered lift systems have been studied but they are complex and, in general, are not necessary until more wing lift is required than can be realized with a conventional mechanical lift system.

Before evaluating design options, a set of performance requirements were developed for the S-3 STO-AL configuration. The requirements, as shown in Table 2, are based on mission performance required, takeoff performance required, and flight safety.

Each option was optimized by a separate analysis and the most cost effective were combined, as shown in Fig. 1. To meet the STO-AL requirements in Table 2 requires a 59% increase in thrust for the basic S-3A with takeoff from a flat deck. Adding leading-edge slats, a 4-deg ramp, and a pitch damper reduces the required thrust increase to 15%. Then the two thrust vectoring features, nose landing gear extension and nacelle tilt, reduce the required thrust increase to a final value of 9%. Further reduction in thrust is possible but is more costly than the modification to the TF34 engine to meet the final thrust requirement.

For the final general arrangement of the S-3 STO-AL configuration, thrust of the basic TF34 was increased by 12%, adding water injection for takeoff. Lift was increased 20% by

Table 1 Propulsion and design options

Thrust increase in basic TF34 engine	5-26%
Auxiliary jet engines	2500-6000 lb of thrust
Jet-assisted takeoff units	2000-4000 lb of thrust
Leading-edge slats	$\Delta C_{L\max} = +0.44$
Double slotted flaps	$\Delta C_{L\max} = +0.40$
Increased wing area	12%
Vectored engine thrust	3.5-70 deg
Pitch damper	As required

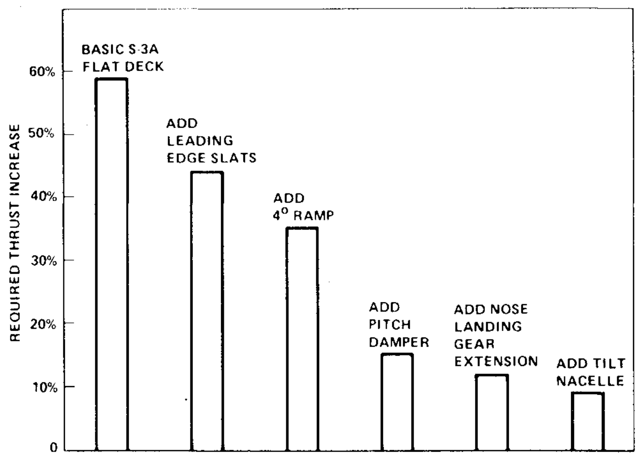

Fig. 1 Effect of design variables on thrust required.

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Table 2 STO-AL performance requirements

Takeoff	
Deck run including 100-ft ramp[3]	800 ft
Ramp angle	4 deg
Wind over deck (WOD)	10 knots
Maximum sustained lift coefficient	0.8 $C_{L\max}$
Maximum overshoot lift coefficient	0.9 $C_{L\max}$
Maximum height loss below the carrier deck	10 ft
Rate of climb with one engine out at 10-ft sink point	100 ft/min
Ambient condition	Sea level, 89.8°F
Shall be controllable at launch speed with one engine out	
Aircraft configuration	
ASW mission	
Full internal fuel	

eliminating leading-edge flaps and stall strips, and substituting full-span leading-edge slats. A degree of thrust vectoring was achieved by changing the thrust angle by a fixed tilt of the nacelles from 3.5 deg up to 6 deg down and extending the nose landing gear for takeoff to increase the thrust vector another 3.5 deg. A pitch damper was added to limit the aircraft attitude after liftoff to the angle of attack for 0.9 $C_{L\max}$ and stabilize trimmed flight at an attitude corresponding to 0.8 $C_{L\max}$. This provides safety from stall and maintains a high-wing lift while the airplane is accelerating to a speed for sustained flight.

S-3 STO-AL Minimum Control Airspeed

The STO-AL configuration of the S-3A operating in accordance with the performance requirements in Table 2, previously discussed, has a liftoff speed of 81 Knots, Equivalent Airspeed, which is approximately 11% below stall speed. Minimum control airspeed (V_{mca}) is defined by military specifications for the basic S-3A and is greater than the liftoff speed (V_{lo}) of the S-3 STO-AL. Consequently, this condition required a separate investigation to determine the actual capability of the systems to control the aircraft in a safe manner in the event of an engine failure at V_{lo}.

Data derived from flight tests of the S-3A showed that at zero sideslip, straight flight, full rudder provides about 60% of the maximum directional control capability. By using 11 deg of sideslip, directional control capability is increased an additional 37% and results in a yawing moment coefficient of 0.07. Using this coefficient as a limit and plotting the aircraft's engine-out yawing moment coefficient vs speed, a control-limited V_{mca} equal to 77.5 Knots Equivalent Airspeed is established as compared to V_{lo} equal to 81 Knots, Equivalent Airspeed for the S-3 STO-AL. Thus it provides a margin of safety with an engine failure at V_{lo}. At the design ASW weight of 47,028 lb, the required bank angle exceeds the 5-deg military specifications requirement, but only by 0.2 deg.

Summary

The impact of ramp launch technology applied to a Navy support aircraft is modest as far as modifications to the aircraft are concerned to meet the performance requirements specified. Takeoff, at a liftoff speed that is less than stall speed, requires that special attention be paid to the dynamics of the aircraft in pitch and to the minimum control airspeed with a failed engine.

For a required deck run of 800 ft using a 4-deg ramp with a 10-knots WOD (wind over deck), modifications to the S-3A are well within the state-of-the-art.

Acknowledgment

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References

[1]Fozard, J.W., "Ski-Jump—A Great Leap for Tactical Airpower," British Aerospace, presented at First Aeronautical Conference, Williamsburg, Va., March 1979.

[2]Englebry, C.R., "Design Feasibility Study of an S-3A Short Takeoff-Arrested Landing (STO-AL) Aircraft," Lockheed Rept. LR 29189, Sept. 1979.

[3]"Light ALL-TOL Carrier, All Takeoff and Landing Modes," Jan. 1980.