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Ames Research Center

1.0 Introduction - Ames Research Center has been conducting design and performance studies of V/STOL research aircraft. The objective of these studies is to identify a feasible V/STOL national flight facility that could be obtained at the lowest possible cost for the demonstration of V/STOL technology, inflight simulation and flight research. A discussion of the need for obtaining full scale flight test data of V/STOL airplanes is contained in reference 1.

One promising concept that is being investigated is the subject of this paper and employs an S-3A airframe with two Pegasus 11 engines. The concept is described as a research aircraft. The aircraft in its basic configuration will provide a limited research potential. The aircraft has the potential that with some modifications could perform an expanded role as a national V/STOL facility for a wide range of V/STOL technologies and flight research.

This paper presents the results of a preliminary study of the S-3/Pegasus configuration in terms of: 1) the rationale for choosing the configuration; 2) description of the configuration; 3) performance; 4) an estimated development schedule; and 5) the capability of a fully developed research aircraft.

It is recognized that this examination and the comparison of the S-3/Pegasus configuration with other configurations is not definitive. However, based on the present evidence, the S-3/Pegasus configuration appears attractive for a research aircraft and worthy of further examination.

2.0 Configuration Definition - The configuration concept is predicated on several design guidelines. The first priority is that the safety of the pilots must be provided in all flight modes. The second priority is to provide a design concept which could be achieved at a low cost. To help achieve a low cost configuration, the aircraft is not required to have an engine out capability in low-speed flight. However, it will be required that the pilots can eject while the aircraft is in a stable attitude in the event of engine failure in propulsion lift mode of flight. Again to reduce cost, the configuration will use an existing airframe, existing aircraft components and engines that do not require major modifications. The third design priority is performance which requires that the aircraft be capable of performing effectively as a research aircraft.

2.1 Choosing the Configuration - In choosing the configuration, it is apparent that a compromise between cost, performance and proof-of-concept capability must be made because a basic design goal for this study was to use an existing airframe of sufficient size to realistically perform a research mission coupled with an appropriate propulsion system that would not require major modifications. The present configuration was selected recognizing some sacrifice in V/STOL technology proof-of-concept but with an advantage in overall cost and perhaps no loss in performance.

The advantages and disadvantages of some conceptual V/STOL configurations are considered in figure 1. The S-3/Pegasus configuration is compared with configurations currently being investigated by industry, a configuration resulting from the NASA/Navy design effort of 1976 (references 2, 3, and 4) and the two place Harrier aircraft (TAV-8A). An advantage of the S-3/Pegasus configuration is its low cost primarily as the result of not requiring a major engine investment. The S-3/Pegasus also is of sufficient size and performance potential to effectively perform research missions and demonstrate V/STOL technology. This aircraft configuration suffers the disadvantages of the lack of an available thorough data base that can be used for system integration and to define the technical and operational potential of the aircraft.

The V/STOL configurations being proposed by industry are typically more ambitious undertakings with significantly greater proof-of-concept potential but with significantly increased costs. The industry concepts typically have a more thorough available data base that has already or is being developed to define their technical and performance potential.

The NASA/Navy Research and Technology Demonstrator Aircraft (RTA) has a large available data base to support the estimates of its performance and perhaps the greatest proof-of-concept potential, but with a commensurate large development cost.

The two-place Harrier (TAV-8A) has been considered for use as a research aircraft (reference 5). As a technology demonstrator this aircraft has marginal proof-of-concept potential, but it does have some research potential at a relatively modest cost.

2.2 ADVANTAGES OF S-3/PEGASUS CONFIGURATION - The S-3 airframe lends itself to an adaptation of the Pegasus engines with a high wing and pylon mounted engines (figure 2). The airframe is of sufficient size to demonstrate missionized V/STOL concepts and the existing ejection system significantly reduces the cost of aircraft development. The Pegasus 11 engines should require little modification for the configuration adaptation. Significantly, the engine is designed for large bleed rates suitable for use with a reaction control system (RCS).

The cockpit is designed for two pilots which is desirable when operating in either a demonstrator or research flight mode. A high wing with pylon mounted engines under the wing allows the Pegasus engines to be operated in the normal orientation and the fuselage mounted main gear will be modified to avoid the hot gas exhaust of the engines. The S-3A empennage has an all movable horizontal stabilizer. To reduce the force on the tail due to large downwash angles in transition to hover, the deflection angle of the horizontal stabilizer must be increased.

Both the airframe and engines are in Navy inventory which reduces the expected cost and difficulty in obtaining the units for the demonstrator aircraft modification. This study did not address the availability of either the S-3A airframe or the Pegasus engines.

2.3 CAPABILITIES - In figure 3 the capabilities of primary interest for the S-3/Pegasus configuration are listed. The aircraft would demonstrate the proof-of-concept of multi-engine direct jet lift in V/STOL operation with an integrated airframe/propulsion/control system. Inflight evaluation of a variety of low speed control systems may be evaluated with the aircraft. Time and effort have been expended to obtain the flying characteristics and handling qualities of V/STOL aircraft using simulation techniques. It is desirable to validate the simulation results with inflight experience particularly in view of the difficulties experienced in the realistic simulation of the V/STOL environment (reference 7). The research aircraft would operate in a variety of terminal area flight modes including VTOL, STOL and CTOL and would provide the demonstration of V/STOL simulated military missions.

3.0 DESCRIPTION OF AIRCRAFT CONFIGURATION - A sketch of the S-3/Pegasus configuration is shown in figure 4. In this concept a Pegasus 11 engine is attached at each of the original two engine pylons. The Pegasus 11 engines provide vectored thrust for V/STOL and cruise flight as well as bleed air to operate the reaction control system (RCS). The original landing gear has been replaced with the main fuselage gear using hardware from other aircraft extending vertically from the fuselage to avoid the engines nozzle exhaust. Harrier outrigger gear have been attached at the position of each outboard equipment wing pylon in a manner similar to the Harrier aircraft.

In this configuration, bleed air is provided from each engine to operate the RCS. Pitch nozzles are shown extended fore and aft of the original fuselage to increase the moment arm and torque produced by the longitudinal RCS. Roll control in low speed flight is provided by RCS nozzles located near each wing tip. The initial design concept provided yaw attitude control by differential deflection of the engine nozzles on each wing. This will not require engine bleed air, will simplify the RCS system, and will result in a small loss in vertical thrust. A yaw reaction control nozzle at the tail could provide yaw control at low speed with an engine failure.

For the basic research aircraft, a mechanical/hydraulic control system with electro/hydraulic series servos would provide for the stability and control augmentation systems envisioned for the flight control system. The current Pegasus pneumatic system is expected to be used for engine nozzle rotation.

The cockpit is configured for two pilots with the aircraft flyable from either position.

For demonstration and evaluation purposes the aircraft is designed to be compatible with shipboard operation. However, in obtaining the Operating Weight Empty (OWE) of paragraph 3.3, 250 lbs. of wing fold mechanism and 36 lbs. of the vertical fin fold mechanism were removed.

3.1 ATTITUDE CONTROL POWER - Figure 5 presents the RCS attitude control power of several aircraft in terms of acceleration about the pitch and roll axes. At this time, it is assumed that the yawing acceleration for the S-3/Pegasus configuration will be provided by the differential deflection of the engine exhaust nozzles located on either side of the fuselage. Using available bleed air, the S-3/Pegasus aircraft can generate in singular demand approximately 1.3 rad/sec^2 about the roll axis or 0.7 rad/sec^2 about the pitch axis. Simultaneous acceleration command about the two axes is approximated by a straight line drawn between the two singular command characteristics.

This amount of control power appears to compare favorably with the control power of the AV-8A at maximum Vertical Takeoff Gross Weight (VTOGW) with stores loaded on the outboard pylon. The S-3/Pegasus control power is greater than that available to the DO-31 and close to the value suggested in the AGARD Report R-577; however, the suggested value is for manuevering only and does not include the requirement for trim or gusts. It is desirable to augment the RCS power to improve the research potential and simulated mission capability of the configuration. In figure 5, the attitude control characteristics of the S-3/Pegasus aircraft with the available bleed air thrust augmented by a further 1000 lbs of RCS thrust is shown. In this case, singular demand would provide 1.8 rad/sec^2 in roll and 1.0 rad/sec^2 pitch.

3.2 CRITICAL TECHNICAL ISSUES - Critical technical issues that have become apparent are listed in figure 6. With further study, other problems may be discovered. Presently there is concern over the location of the main fuselage landing gear being in proximity to the exhaust flow of the aft engine nozzles. The use of gear struts that extend vertically from the fuselage is one approach to the problem.

It is typical of V/STOL aircraft to be configuration sensitive to ground proximity operation. Static models tests are required to examine ground effect and reingestion characteristics of the S-3/Pegasus configuration as little data exists relative to 8-poster V/STOL concepts.

The horizontal empennage of the S-3A consists of a stabilizer, elevator and elevator trim tab. The stabilizer is capable of being trimmed from 1^{o} leading edge up to 9^{o} leading edge down. V/STOL aircraft in low speed flight typically experience large downwash angles in the vicinity of the horizontal tail; therefore to reduce the longitudinal trim loads, the stabilizer leading edge up deflection angle must be increased.

The reaction control system (RCS) will require the integration of the bleed air from two engines as well as the integration of some type of augmentation. Attitude control power with acceptable control time constants must be provided without unduly affecting the performance of the propulsion units.

3.2.1 ENGINE OUT CONSIDERATIONS - With a complete single engine failure during propulsive lift flight, it is assumed that the aircraft will descend. However, the pilots must be provided a stable platform from which to eject if at a safe attitude or the ability to descend at a level attitude. With sudden thrust loss of a single engine, the remaining engine's thrust will produce upsetting moments about the lateral-directional axes. This condition is being analyzed and there appears to be several means of resolving the problem.

One means of resolving the engine-out-in-hover problem is to augment the RCS controls with power from sources other than the basic Pegasus engines. One alternative source is a turbo-shafted auxiliary power unit driving a compressor which would provide high energy air for the RCS augmentation. It is also desirable to provide RCS augmentation to increase the operational maneuvering capability of the aircraft.

3.3 AIRCRAFT WEIGHT - Figure 7 presents the preliminary estimates of the Operating Weight Empty (OWE) with two pilots. The OWE was obtained by removing the two TF-34 engines and the S-3A operational equipment including catapult and arrested landing gear, wing and fin fold mechanism, and provisions for the two additional non-piloting occupants. To this stripped down airframe are added two Pegasus 11 engines with estimated nacelle weight and strengthened pylons, an RCS for attitude control and a weight increment for revised landing gear with outriggers. The estimated OWE with two pilots is 28,434 lbs.

The maximum VTOGW shown in figure 7 was obtained by doubling the advertised VTOGW of the AV-8B (reference 6). With a payload of 1000 lbs., the available fuel weight is such that even with a typical growth in the OWE, the aircraft should have sufficient fuel to effectively demonstrate simulated military missions.

The maximum Short Take Off Gross Weight (STOGW) (figure 7), was obtained from a performance prediction using of the Aircraft Synthesis (ACSYNT) Computing Program. The prediction model consisted of S-3A aerodynamics and approximated characteristics of two Pegasus 11 engines. The takeoff was accomplished in 400 ft. with zero wind-over-the-deck (WOD). The nozzles were positioned horizontal to the ground during the initial acceleration and prior to lift off the nozzles were rotated 60° below the horizontal and the aircraft was rotated 10° nose up. The maximum STOGW based on a 400 ft. take-off run is 46,500 lbs. With same OWE and payload as the VTO case, the available fuel weight is 17,066 lbs., which exceeds the internal fuel capacity of the unmodified S-3A. The unmodified S-3A is capable of carrying only 13,142 lbs. of fuel internally.

4.0 PERFORMANCE

4.1 Time on Station (TOS) vs Radius of Action - Estimated performance in terms of TOS and Radius of Action is presented in figure 8. Performance is indicated for the S-3/Pegasus aircraft with a 1000 lb. payload in the VTO mode at maximum TOGW, the STO mode at maximum TOGW for a 400 ft. takeoff distance with zero wind and the STO mode with internal fuel only. For comparison the estimated VTO and STO performance of an AV-8A with no payload is indicated. In VTO mode the S-3/Pegasus aircraft has a combined performance of approximately 1 hour TOS and 340 n.m. radius of action whereas the AV-8A with 1 hour TOS has mission radii of approximately 210 n. m. and 430 n. m. in VTO and STO mode respectively. With 3 hours TOS the S-3/Pegasus aircraft in STO mode with internal fuel and maximum fuel has mission radii of approximately 310 and 580 n.m. respectively.

4.2 LANDING AND TAKEOFF PERFORMANCE - Landing and takeoff distances for varying weights of the S-3/Pegasus aircraft are presented in figure 9. Takeoff data for a near optimal takeoff procedure (aircraft rotation and thrust vector schedule) is presented with both engines operating and with failure of one engine at liftoff. With a TOGW of 46,500 lbs. and with both engines operating, the aircraft can takeoff in 400 ft. with zero wind. With one engine inoperative (OEI) at lift off, the takeoff distance must be increased to approximately 470 ft. to provide a positive rate-of-climb after lift-off.

The landing performance is given for OEI during the approach and landing rollout. The aircraft at 34,000 lb. gross weight can complete the landing roll out in approximately 400 ft. For this landing performance calculation, the approach angle was -4°, the thrust vector angle was 125° at 90% thrust and the rollout braking coefficient was 0.35g. No propulsion induced effects on aerodynamics or lateral-directional trim requirements were assumed for these performance analyses.

5.0 DEVELOPMENT SCHEDULE - An estimated development schedule for two S-3/Pegasus V/STOL aircraft is presented in figure 10. Neglecting the procurement process time, (conducted in year 0), the first aircraft could complete its initial airworthiness flight tests at the conclusion of the third year. Procurement would be conducted in two phases. Phase I would consist of a preliminary design effort to determine the general configuration and design options and performance and cost estimates as well as the initial wind tunnel tests and simulation investigations. Prior to conducting Phase II, the results of Phase I would be critiqued and an option to continue would be exercised. Phase II will be initiated with a detailed engineering design effort. This is the final design activity prior to fabrication of the modified aircraft and would be followed by delivery of three Pegasus engines and an S-3A airframe required for the modification of aircraft No. 1. Two of the Pegasus engines would be used in the modification of the aircraft and the third engine will be used in the control system tests and as a spare. Airworthiness flight tests would commence in the latter part of year three of engineering activity.

6.0 S-3/PEGASUS BASIC AIRCRAFT MODIFIED TO FULL RESEARCH CAPABILITY

Subsequent to the fabrication of the basic aircraft, it is suggested that a second modification could be conducted to produce a national contemporary V/STOL research facility. This second modification would provide for the addition of 1) integrated computer and software, 2) large authority servos for flight and propulsion control, 3) programmable control systems and heads-up display, 4) a research guidance and navigation system and 5) a low speed airspeed system. With these modifications it is expected that the research aircraft would have the following characteristics.

6.1 V/STOL Research Aircraft Capability - Given the second modification of the S-3/Pegasus configuration, the aircraft is predicted to have the research capability indicated in figure 11. Classicially it has been desirable to correlate ground based simulation and flight data. This increases the accuracy and credibility of the simulation results. The research aircraft offers this potential over a wide range of variables. The tradeoff in control system and display complexity can be evaluated in a realistic environment. Terminal area guidance and navigation systems using flight hardware with the attendant sensor errors and maintenance problems can be evaluated. The research aircraft would have large attitude control power margins with good response characteristics so that specific handling qualities problems can be resolved and the handling qualities of specific aircraft can be simulated in flight. With the flexibility offered by the computer and software onboard the research aircraft, the integration of several control systems with airframe and propulsion systems can be obtained. The completion of each of the items shown in figure 11 is important for the orderly advance of V/STOL technology.

7.0 CONCLUSIONS

A preliminary examination of an S-3/Pegasus V/STOL configuration has been conducted and compared with other aircraft which appear competitive with the S-3/Pegasus configuration in terms of performance and potential for simulated military mission capabillity. As a result of this preliminary examination the following conclusions were drawn:

1. The S-3/Pegasus aircraft appears to compete favorably with other contemporary configurations in terms of low cost, performance, data base requirements and aircraft size.

2. Estimates of the propulsion system performance and the empty weight of a S-3/Pegasus configuration indicate that the payload/fuel weight fraction should allow realistic capability to perform effective V/STOL flight research and to demonstrate simulated military missions.

3. Several technical issues have been identified which will require further study and tests prior to fabrication and operation of the S-3/Pegasus aircraft. Specifically, the available bleed air from two Pegasus 11 engines offers marginal attitude control power and may require augmentation.

4. The estimated performance of the S-3/Pegasus in terms of time on station and radius of action indicate that the aircraft could be used to demonstrate realistic simulated military missions.

5. An optimistic estimate of a schedule for the fabrication of two S-3/Pegasus aircraft indicate that airworthiness flight tests of the first vehicle could be completed at the conclusion of the third year. This schedule is predicated on the timely delivery of GFE items and disregarding the time required for procurement activities.

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CONFIGURATION	ADVANTAGES	DISADVANTAGES
S-3/PEGASUS	• AIRCRAFT SIZE (OWE ~ 28,000 lb) • USE OF EXISTING COMPONENTS • COST LESS THAN $30M	• LACK OF DATA BASE • RCS AUGMENTATION REQUIRED
TAV-8A	• EXISTING TECHNOLOGY • LOW COST	• LACK OF PROOF-OF-CONCEPT • RESEARCH AND DEMONSTRATION POTENTIAL
INDUSTRY CONCEPTS	• PROOF-OF-ADVANCED CONCEPT • DATA BASE • USE OF EXISTING COMPONENTS	• ENGINE MODS. REQUIRED • COST OVER $50M
NASA/NAVY RTA (1976)	• PROOF-OF-ADVANCED CONCEPT • HIGH RESEARCH POTENTIAL • DATA BASE	• NEW FAN AND POWER TRANSFER SYSTEM • COST OVER $100M

Figure 1.- S-3/Pegasus and alternate concepts.

S-3 AIRFRAME

- IN NAVY INVENTORY
- CARRIER COMPATIBLE
- REPRESENTATIVE OF "LARGE" SIZE FOR V/STOL
- RECENT TECHNOLOGY
- ZERO-ZERO EJECTION SEATS
- 2 OR MORE CREWMEN
- HIGH-SPEED CRUISE
- HIGH WING
- PYLON-MOUNTED ENGINES
- ALL MOVEABLE HORIZONTAL TAIL
- FUSELAGE-MOUNTED LANDING GEAR

PEGASUS F402-RR-404 ENGINES

- IN NAVY INVENTORY
- OPERATIONAL ON HARRIER SERIES AIRCRAFT
- DEVELOPED THRUST VECTORING SYSTEM
- DESIGNED FOR HIGH BLEED RATES
- DEVELOPED ASSOCIATED LOW-SPEED CONTROL SYSTEM

Figure 2.- Benefits of S-3/Pegasus configuration.

- PROOF-OF-CONCEPT OF MULTI-ENGINE, DIRECT JET LIFT V/STOL CONFIGURATION
- EVALUATION OF ADVANCED INTEGRATED LOW-SPEED CONTROL SYSTEM
- INFLIGHT VALIDATION OF PILOTED MOVING-BASE GROUND SIMULATIONS
- V/STOL, STOVL, STOL, AND CTOL OPERATIONAL RESEARCH
- REPRESENTATIVE V/STOL SEA-BASED SUPPORT MISSIONS (i.e., ASW, AEW)
- V/STOL NATIONAL FLIGHT RESEARCH FACILITY

Figure 3.- Capabilities of S-3/Pegasus research aircraft.

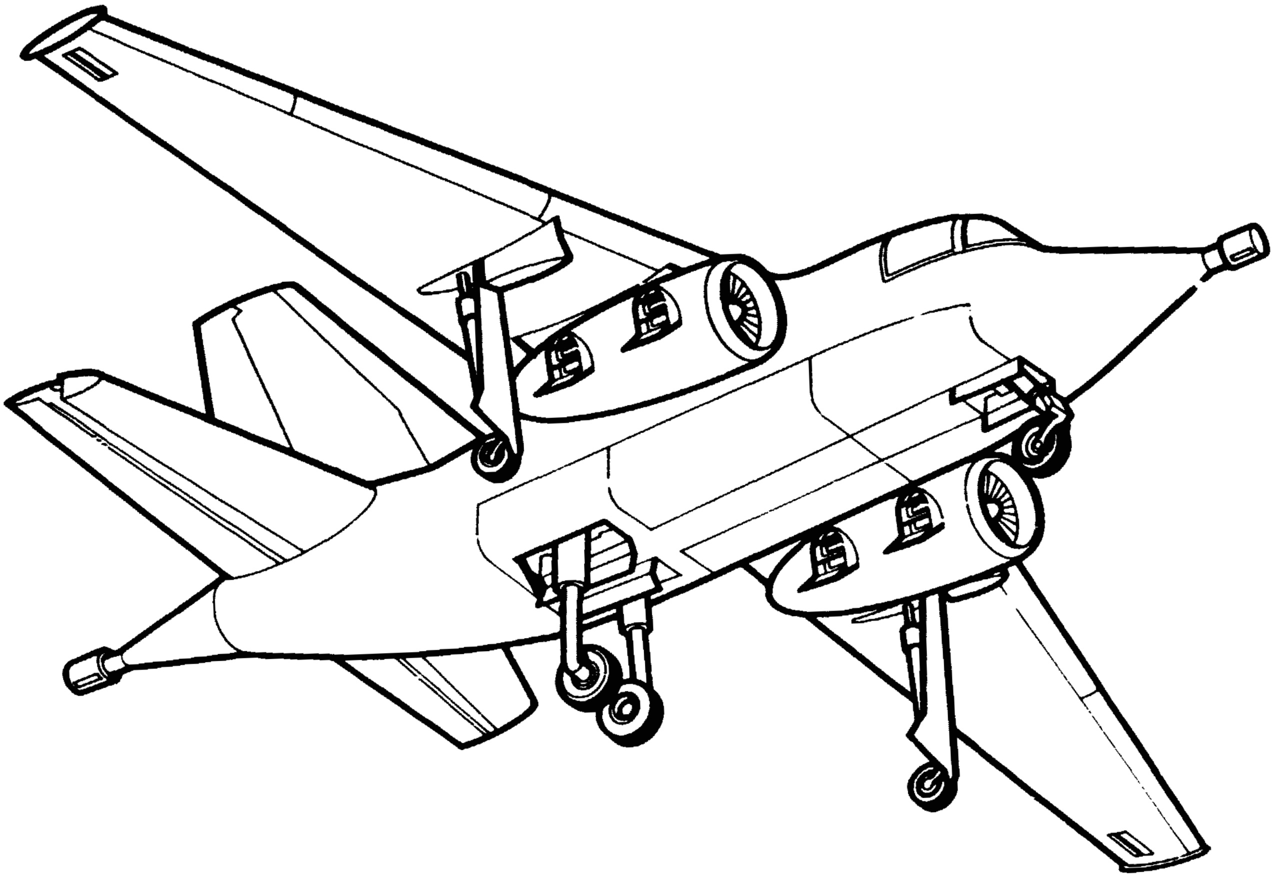

Figure 4.- Sketch of S-3/Pegasus concept.

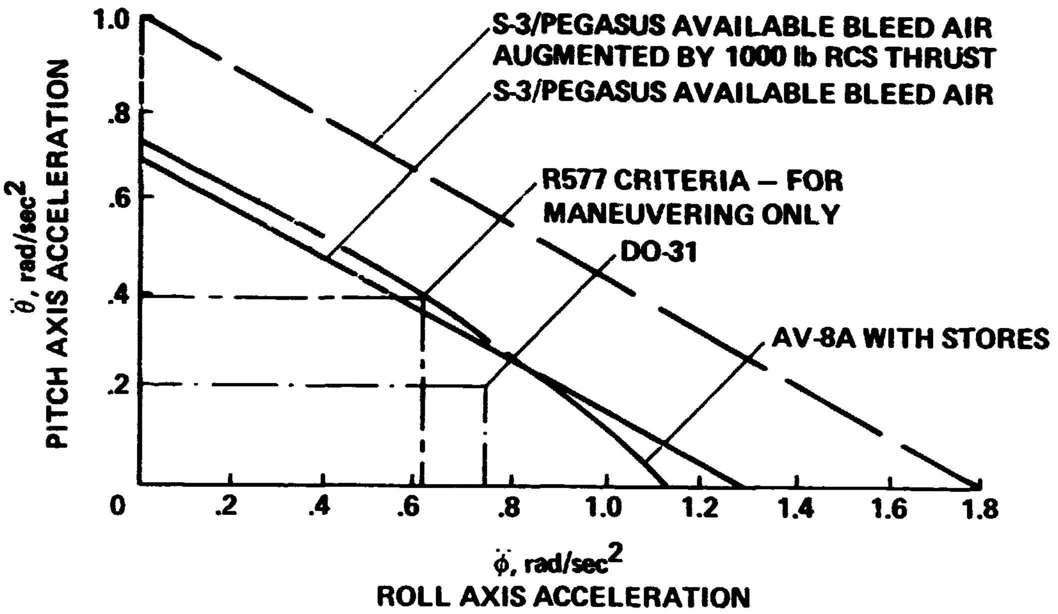

Figure 5.- Attitude control power characteristics.

- LANDING GEAR LOCATION AND SELECTION
- ROLL COMPENSATION AND ATTITUDE CONTROL DURING ENGINE THRUST LOSS
- REACTION CONTROL SYSTEM AUGMENTATION
- GROUND EFFECT AND INGESTION
- HORIZONTAL STABILIZER DEFLECTION REQUIREMENTS

Figure 6.- Critical technical issues.

STRUCTURE		15290
WING, TAIL, BODY GROUPS	11075	
ALIGHTING GEAR	1740	
SURFACE CONTROLS	1515	
NACELLES	860	
STRENGTHENED PYLONS	100	
PROPULSION		8495
ENGINES	8094	
FUEL SYSTEM	401	
ELECTRICAL		2008
POWER	811	
ELECTRONICS	1023	
INSTRUMENTS	174	
FURNISHINGS AND AIR CONDITIONING		1464
CREW EQUIPMENT	407	
AIR CONDITIONING	702	
APU	275	
HYDRAULIC AND PNEUMATIC GROUP		389
REACTION CONTROL SYSTEM		428
OWE		28074
2 PILOTS		360
OWE WITH PILOTS		28434

Figure 7.- S-3/Pegasus V/STOL aircraft weights.

	VTOL	STOL
OWE WITH PILOTS	28434	28434
PAYLOAD	1000	1000
FUEL	8266	17066 (MAX INTERNAL FUEL 13142)
MAX TAKEOFF GROSS WEIGHT	37700	46500

Figure 7.- Concluded.

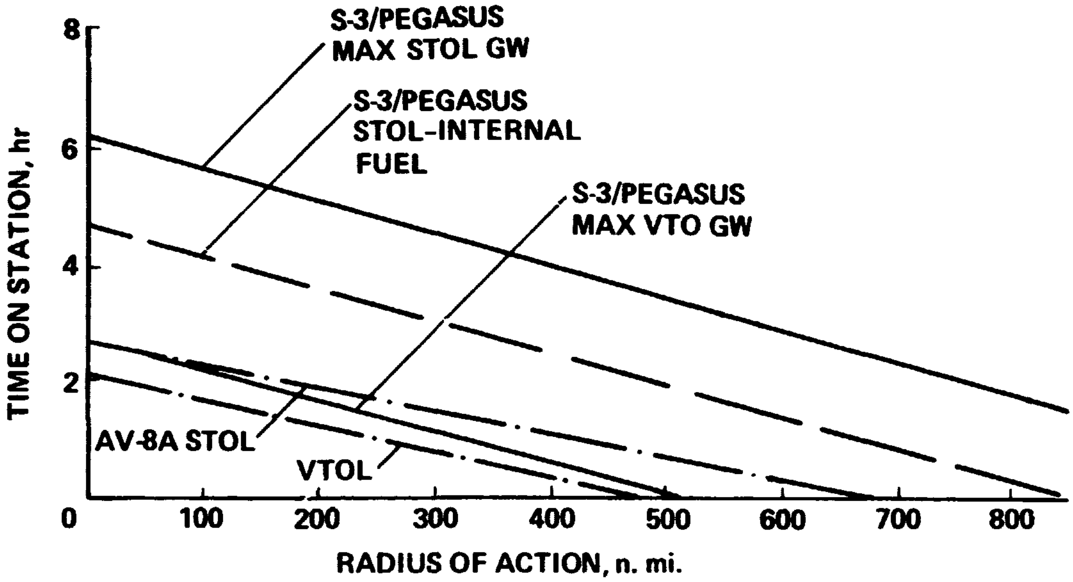

Figure 8.- S-3/Pegasus V/STOL aircraft estimated performance.

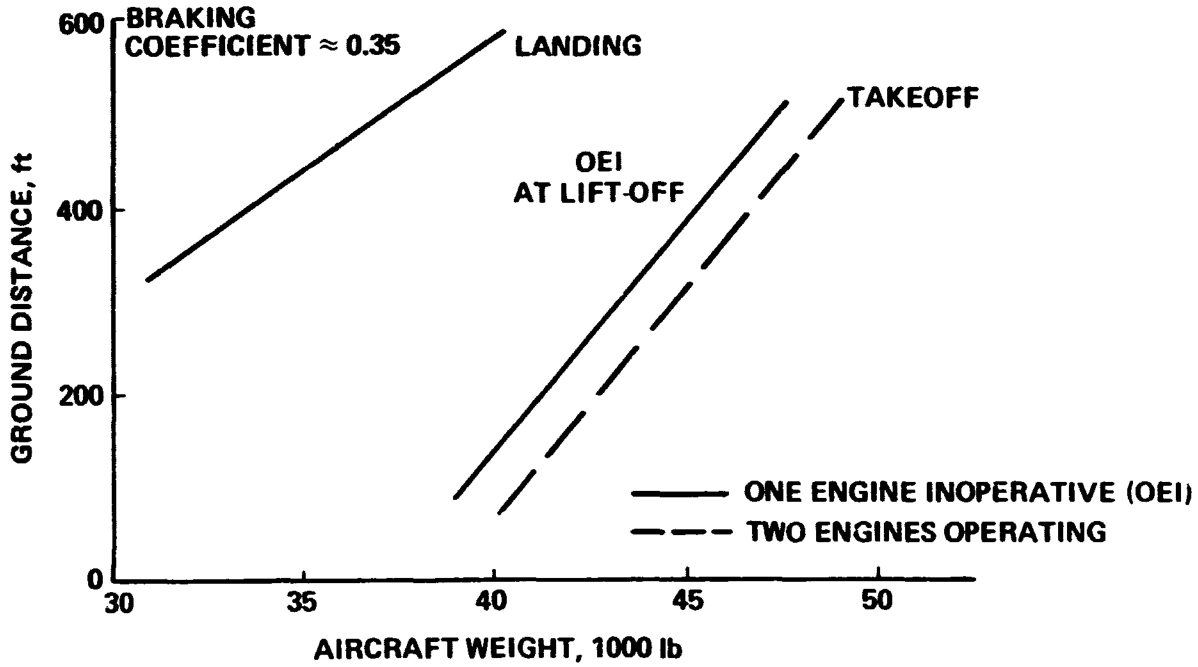

Figure 9.- S-3/Pegasus performance — landing and takeoff distance.

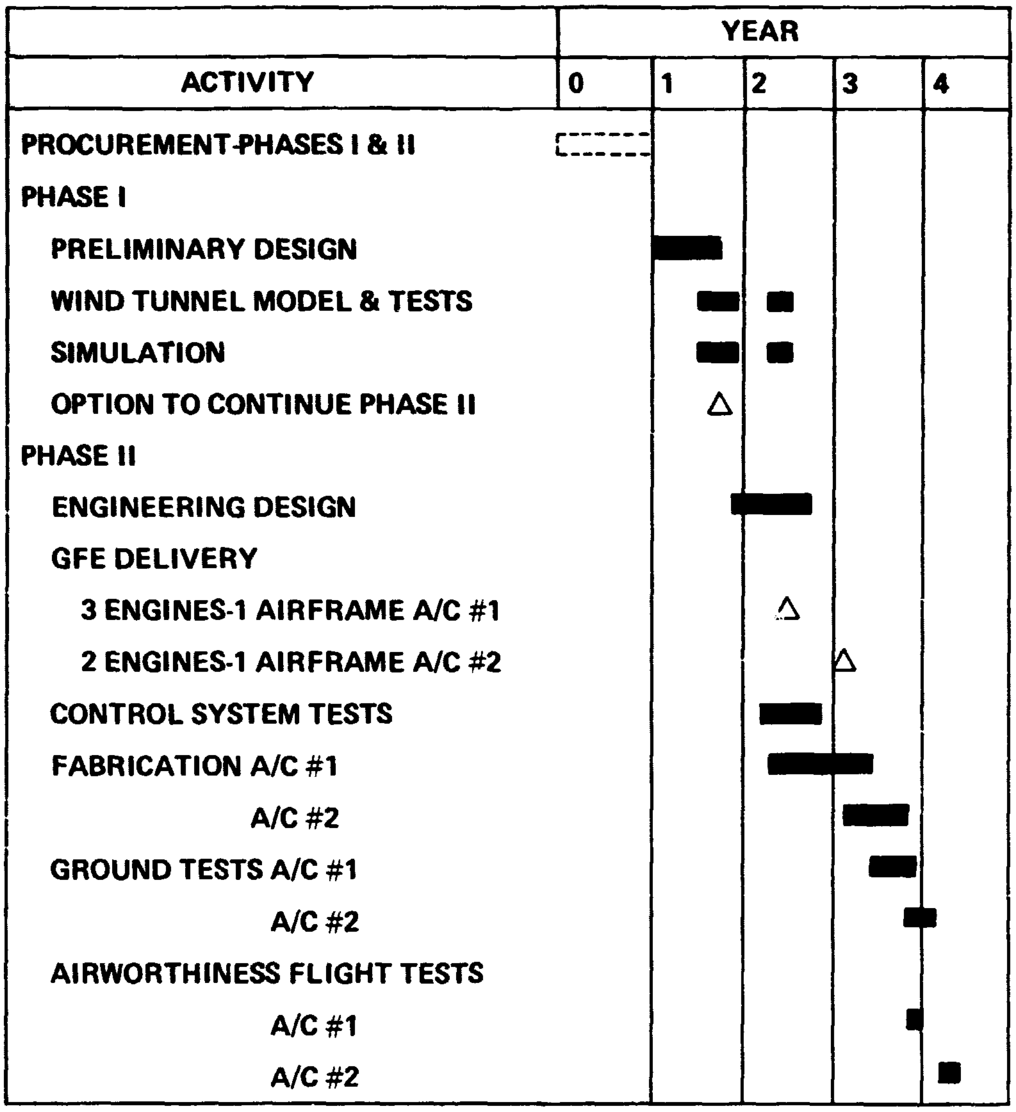

Figure 10.- S-3/Pegasus V/STOL aircraft development schedule.

- GROUND-BASED SIMULATION VALIDATION
- CONTROL/DISPLAY COMPLEXITY TRADEOFF
- TERMINAL AREA GUIDANCE AND NAVIGATION
- HANDLING QUALITIES EVALUATION
- SOLUTION TO SPECIFIC HANDLING QUALITIES PROBLEMS
- AIRFRAME/PROPULSION/CONTROL SYSTEMS INTEGRATION
- IN-FLIGHT SIMULATION OF SPECIFIC AIRCRAFT CHARACTERISTICS
- SIMULATED MISSION FLEXIBILITY
- ADVANCED TECHNOLOGY VALIDATION

Figure 11.- S-3/Pegasus V/STOL research aircraft capability.

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15. Supplementary Notes

16. Abstract

The results of a preliminary study of a candidate V/STOL research aircraft concept is presented. The design concept uses an S-3A airframe and two Pegasus 11 engines. The objective of the study is to identify a feasible V/STOL national flight facility that would be obtained at the lowest possible cost for the demonstration of V/STOL technology, inflight simulation, and flight research. This study is presented in terms of: (1) the rationale for choosing the configuration; (2) the description of the configuration; (3) performance; (4) an estimated development schedule; and (5) the capability of a fully developed research aircraft.

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