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A CASE FOR VATOL FLIGHT DEMONSTRATION,(U)
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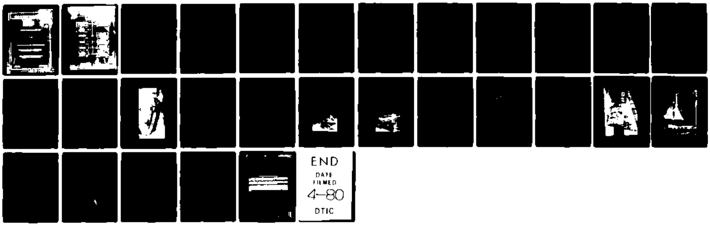

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This paper reviews the ongoing work on the Vertical Attitude Takeoff and Landing (VATOL) technology development. Studies of vertical and short takeoff and landing aircraft have shown a significant advantage in payload or performance for the vertical attitude concept. The additional payoff from the incorporation of Post-Stall Combat Maneuvering is identified.

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The VATOL post-stall control system that requires control at high angle-of-attack, provides a decisive combat advantage over a conventional fighter. The planning for post-stall aerodynamic studies at DTNSRDC and NASA Ames is presented. This includes a large powered model to be tested in the NASA 40- x 80-foot wind tunnel. Progress toward a moving base simulation of the vertical attitude landing is reviewed. Results of design studies indicating the feasibility of a VATOL research aircraft, using an existing propulsion system are outlined along with a possible configuration for an advanced VATOL fighter that incorporates a novel control system.

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VATOL FLIGHT DEMONSTRATION

by

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ABSTRACT

This paper reviews the ongoing work on the Vertical Attitude Takeoff and Landing (VATOL) technology development. Studies of vertical and short takeoff and landing aircraft have shown a significant advantage in payload or performance for the vertical attitude concept. The additional payoff from the incorporation of Post-Stall Combat Maneuvering is identified. The VATOL post-stall control system that requires control at high angle-of-attack, provides a decisive combat advantage over a conventional fighter. The planning for post-stall aerodynamic studies at DTNSRDC and NASA Ames is presented. This includes a large powered model to be tested in the NASA 40- x 80-foot wind tunnel. Progress toward a moving base simulation of the vertical attitude landing is reviewed. Results of design studies indicating the feasibility of a VATOL research aircraft, using an existing propulsion system are outlined along with a possible configuration for an advanced VATOL fighter that incorporates a novel control system.

INTRODUCTION

Vertical and short takeoff and landing (V/STOL) aircraft have existed for years. The air museums of the world have many examples of the different concepts but very few of these vehicles have actually been in use in the armed forces. However, there is now a resurgence of V/STOL interest and this, coupled with advances in propulsion and avionics technology, are providing the impetus to further development of operational V/STOL aircraft.

Navy interest in V/STOL for use at sea is accelerating as more nations introduce V/STOL capable ships to their naval fleets. The U.S. Marines adapted the AV-8A Harrier to helicopter-capable carriers; the first AV-8A was delivered to the U.S. in 1971. Three USMC combat squadrons are currently equipped with the AV-8. The Spanish Navy also flies Harriers. These aircraft, delivered in 1976, compose one squadron of the Spanish Navy and are now deployed on the DEDALO. The British are modifying the basic Harrier for fleet use. Known as the Sea Harrier, this aircraft will begin deployment on the INVINCIBLE Class through-deck cruisers in 1979 (Reference 2).

The Soviets have deployed a V/STOL air-capable ship, the KIEV, equipped with the YAK-36 Forger, the first non-Harrier vertical takeoff aircraft to become operational. Russia's second KIEV Class aircraft carrier, the MINSK, has deployed from the Black Sea and is in the Mediterranean. MINSK has been seen operating with her sister ship in what has been described as the largest collection of Soviet naval fire power ever. A third KIEV Class carrier, the KHARKOV, is undergoing sea trials in the Baltic. This V/STOL combination is a formidable opponent for it has demonstrated a capability to harass and interdict the reconnaissance and patrol capability of NATO Air Forces and to attack and, thereby, eliminate NATO surface shipping.

The U.S. Navy has plans to convert its air arm to V/STOL aircraft by the year 2000. The vertical approach will allow for an effective dispersal of air assets over a broad geographic range. This dispersal will reduce the present reliance on a few large ships. In doing this, the survivability of the dispersed elements may be enhanced. The Navy's commitment to V/STOL will have a major impact on virtually every facet of naval operations. In fulfilling the major military needs of the Navy, V/STOL must present itself as not only effective but also economical.

Today, the high thrust required during air combat maneuvering has resulted in some fighter aircraft with thrust-to-weight ratios greater than one at takeoff (Figure 1). This would seem to make vertical takeoff and landing easy to achieve, having only to direct the thrust down and lift off. However, there are many compromises to make and losses to overcome in configuring a supersonic fighter aircraft to provide adequate control and thrust margin for horizontal attitude hovering and vertical takeoff and landing. Most of these compromises disappear if the vertical attitude approach is considered. Studies indicate that vertical attitude provides, by far, the most efficient aircraft in terms of payload for a given size aircraft.

Vertical attitude takeoff and landing (VATOL) aircraft (Figure 2) have many potential advantages over horizontal attitude aircraft. The advantages include much simpler and cheaper design, development, and maintenance; lighter weight; higher performance; reduction of hot gas reingestion and other in-ground-effect problems; and improved stability in hover. On the other hand, vertical attitude takeoff and landing requires ship modifications and an unusual pilot attitude during landing. This unusual pilot attitude, coupled with the lack of conventional visual cues on landing must be reviewed.

In the past, there has always been a penalty associated with vertical flight operations. While vertical attitude minimizes this penalty, it is nonetheless still there. Now, a new German concept called Post-Stall Combat Maneuvering appea to offer highly synergistic advantages in combination with VATOL. This is very significant since the VATOL's requirement for a high angle control system, formerly regarded as its only design "penalty" relative to conventional fighters, now becomes an asset rather than a penalty. The David W. Taylor Naval Ship Research and Development Center (DTNSRDC) has undertaken a technology study to evaluate and demonstrate successful VATOL as a means of reducing the risk for vertical attitude to provide the Navy with a very cost effective overall system option.

VATOL THE BEST V/STOL

The VATOL concept is a superior approach to V/STOL. The VATOL aircraft concept consistently shows the highest payload to empty weight fraction of all the various supersonic V/STOL concepts. A study of five jet vertical takeoff and landing fighter concepts was made considering height and attitude control, ground effect, ingestion losses, control bleed effects, installation losses, component weights, and short takeoff performance (Reference 1). A fixed gross weight of 35,000 pounds (15,750 kilograms) was assumed for each of the following concepts studied:

Lift plus Lift/Cruise – L + L/C
Lift/Cruise plus Remote Burner – L/C + Burner
Lift/Cruise (bleed air for control) – L/C
Vertical Attitude Takeoff and Landing – VATOL
Tilt Wing – TW

Assuming a baseline aerodynamic design of the so-called "supercruiser," the baseline was perturbated to establish a family of V/STOL concepts. The results of the study indicate the VATOL has a greater payload to empty weight fraction than the others (Figure 3); a 25 percent greater payload weight fraction than the L + L/C, and twice the payload to weight fraction of the L/C (Harrier type) aircraft. Similar studies have been conducted by many of the major airframe manufacturers. VATOL consistently comes out as the smallest airplane or highest payload per empty weight. Since cost is always a function of operating weight, this translates into greater performance aircraft for the least cost. VATOL is the best concept for V/STOL when one considers the aircraft system. This has been confirmed by both in-house studies and industry studies. The following is a conclusion quoted from a Vought Corporation paper, "Sensitivity Studies for Several High Performance V/STOL Concepts," presented at the Society of Automotive Engineers Aerospace Meeting in 1977: "The highest performance in every category was achieved by the vertical attitude takeoff and landing (VATOL) concepts." (Reference 3).

A PENALTY IS AN ASSET

There has always been a penalty associated with vertical flight. The gross weight of an aircraft is increased to accommodate the extra systems for lift and control. It must still be accounted for, although the vertical attitude concept minimizes this increase in weight. It has been postulated that there are portions of the flight regime where the additional weight and equipment installed for vertical attitude flight would provide a significant advantage in combat over conventional aircraft.

A new German concept called Post-Stall Combat Maneuvering appears to offer highly synergistic advantages in combination with VATOL (Reference 2). It postulates that a fighter with thrust vectoring and a reaction control system capable of maintaining precise attitude control at very high angles of attack would enjoy a decisive combat advantage over a conventional fighter. Air-to-air combat simulations in Germany have shown the exchange ratio to be as high as 4 for a post-stall aircraft over an advanced conventional stall-limited aircraft. Joint American German combat simulations have provided dramatic confirmation of this hypothesis. McDonnell-Douglas and Messerschmidt-Bolkow Blohm have conducted manned air combat simulations, further demonstrating an enhancement in air combat kills for aircraft capable of post-stall flight.

Earlier studies by the Vought Corporation have shown that there is an advantage to thrust vectoring in air combat (Reference 4). The advantage of thrust vectoring in air combat was evaluated in a manned simulator – a baseline conventional fighter was flown against a vectored thrust version of the baseline. The engagements were scored by relative time in advantageous position. Figure 4 shows results in terms of time advantage ration (the conventional baseline at 1). With the forward hemisphere the vectored thrust time advantage ratio is near 5. Similar trends are noted for 10,000-feet (3,050-meters) and 3,000-feet (915-meters) range cases.

In March of 1979 actual air-to-air combat simulations were conducted in the NASA Langley Differential Maneuvering Simulator under the sponsorship of the Office of Naval Research. The simulations flown by fleet naval aviators from the Oceana Naval Air Station and the Pax River Naval Air Test Station demonstrated a significant advantage for an aircraft equipped with the post-stall capability. The study consisted of each pilot flying a total of twenty-four neutral flights. Twelve engagements were flown with an aircraft simulating the flight characteristics of a conventional high performance aircraft. Twelve engagements were flown with an aircraft simulating the flight characteristics of the conventional aircraft with additonal post-stall control forces provided by reaction control.

The initial conditions for these engagements were neutral, that is, a head-to-head pass with an initial separation of 15,000 feet (4,575 meters) at an altitude of 25,000 feet (7,625 meters) and Mach number of 0.7. In addition to the above neutral flights, 12 disadvantageous engagements were also conducted. Eight of these engagements gave the conventional aircraft an advantage and four flights gave the reaction control aircraft the advantage. These flights were conducted at altitudes from 15,000 to 30,000 feet (4,575 to 9,150 meters) and initial Mach numbers of 0.6. These simulations were initiated with the advantage aircraft in trail formation with a 5,000-foot (1,525-meter) separation.

The scoring criteria presented in a preliminary summary is time on advantage (TOA). Time on advantage is defined as having the opposition in your forward hemisphere while you are in his aft hemisphere.

The post-stall fighter experienced a 4-to-1 time advantage ratio over a conventional stall-limited aircraft in neutral engagements. When at a disadvantege, it has a TOA ratio of 1.66 -to-1 and when at an advantage the post-stall airplane TOA ratio jumped to 28-to-1. This is very significant since the VATOL's requirement for thrust vectoring and reaction control were formerly regarded as its only design "penalty" relative to conventional fighters. This has now become an asset rather than a penalty. On a VATOL, two separate control systems may not be needed as on the V/STOL. The facts that VATOL aerodynamic requirements are congruent with those for good post-stall maneuvering and that the VATOL approach makes all installed thrust available for combat maneuvering are further evidence of synergism.

POST-STALL AERODYNAMICS

This is an area of emerging importance for highly maneuvering aircraft as well as for VATOL aircraft and, while little systematic research has been done, much has been learned in exploring and improving the characteristics of aircraft developed in recent years. Maximum lift can be increased and stall delayed by the use of leading edge extensions and canards to control vortex lift. Lateral and directional characteristics can be improved by proper shaping of the fuselage forebody and by proper sizing and positioning of vertical tails with respect to the flow field. The general flow phenomena are beginning to be understood, but good characteristics can only be obtained as the end result of an extensive wind tunnel program, guided by concurrent aircraft design studies.

In an attempt to gain maximum benefits from the post-stall combat and realize a smooth vertical attitude transition, high angle of attack aerodynamic programs have been initiated at both DTNSRDC and NASA Ames Research Center.

The DTNSRDC program will look at many different variations of proven and "far-out" aerodynamic components to determine the effects on post-stall aerodynamics. The goal is to identify those components suitable for an aircraft that exhibit minimum trim requirements in the high angle of attack regime (30 to 75 degrees). Figure 5 is one example of the configurations under study. Initial experiments began in August 1979.

A joint Navy and NASA project was initiated at NASA Ames in 1977 to study the aerodynamics of advanced high performance fighter attack aircraft. During Phase I of this program two VATOL aircraft were designed and analytically evaluated (References 6 and 7) by Vought and Northrop. These aircraft are depicted in Figures 6 and 7. An extensive high speed experimental program is ongoing at NASA utilizing the Northrop design (see Reference 5 for details).

NASA Ames has also undertaken to generate low speed aerodynamics for both configurations. The experiments will be conducted in the 40 x 80-foot wind tunnel using one-third scale powered models. The models will be capable of going to an angle of attack of 110 degrees (Figure 8). Each of the two configurations will be equipped for a systematic configuration evaluation. The models will be equipped with various leading edge and trailing edge devices and canard or lex planforms. The top or side inlets will be installed and 12-inch fans will simulate the engines. The experiments are scheduled to take place in the April May 1980 timeframe.

OPERATING CONCEPT

The operating concept envisioned for fleet operations is shown in Figure 2. After a constant altitude transition from wingborne horizontal flight to jetborne vertical attitude, the aircraft would then approach the landing platform which has been raised to the vertical position (Figure 9). A harpoon like hook on the nose wheel would engage a grid or wire on the landing platform to secure the aircraft (Figure 10). Takeoff could be either a reverse of the landing sequence or, at higher gross weights, a short horizontal takeoff using a ski-jump ramp. Although Figure 2 shows a stern mounting on a small waterplane area, twin-hull (SWATH) ship, there is nothing to restrict the VATOL to this position or ship type. Both stern and side mounting of the platforms on conventional monohulls is acceptable. On land bases, the aircraft could land conventionally or, in restricted space, a landing platform might be mounted on a truck so that it can be moved and dispersed easily.

MANNED SIMULATIONS

Demonstrating an acceptable level of flight control during transition and landing and quantifying pilot performance during this task are being accomplished using a full-scale, moving base simulation at NASA Ames. In this way the total representation of the landing can be duplicated and analyzed. One of the primary problems facing the VATOL concept is the combined physiological and psychological problem of "the pilot laying on his back." One reason for the manned simulation is to dispose of these problems by developing techniques and demonstrating that the VATOL concept is operationally functional.

Another purpose of the manned simulation is to investigate flying qualities and control. The flying qualities requirements for vertical takeoff and landing (VTOL) aircraft have been derived largely from experience with horizontal attitude types. The moments of inertia and the pilot are oriented differently in a VATOL and there may be significant difference in the control power requirements; particularly for roll and yaw. Also ship motions should be included as they may make a sizable difference in the requirements. The NASA Ames six degree of freedom manned simulator will be used for piloted simulations of VATOL in hover and transition to landing (Figure 11). The aerodynamic characteristics for the aircraft described in Reference 6 will be used initially. Aerodynamic and propulsion computer models along with the control laws are being established under contract with Vought Corporation. Ship motions will eventually be included in the simulation. The first phase to be conducted in the spring of 1980 will be moving based with a fixed cockpit. The second phase, in the fall of 1980, will include provisions for pilot tilting and incorporate some advanced displays.

RESEARCH AIRCRAFT

It has been recommended that the best approach to assuring proper development of the VATOL technique is to build a research aircraft (Reference 8.)

The vertical attitude takeoff and landing (VATOL) concept is not a new approach to V/STOL. This concept was explored in the late 1950's with turboprop and turbojet demonstrators having been flight tested (Convair/Navy XFY-1, Lockheed/Navy XFV-1, and Ryan/USAF X-13). These tests showed that, in a demonstration flight test environment, the pilots could adapt to this somewhat unorthodox mode of operation. The X-13 jet VATOL has already demonstrated numerous vertical attitude takeoff's and landings (Figure 12) and transitions to and from conventional flight; including a demonstration from the parking lot in front of the Pentagon. This testing, however, has not resolved the questions of feasibility of VATOL for day-to-day operations in a fleet operating environment. Fleet operations are often performed in adverse weather with a minimum of ground handling personnel and a demand for rapid launch and recovery of many aircraft.

Although these earlier flight programs were completed (over 20 years ago) without serious incident, they were not followed up because of the weight and performance penalties due to the then available technology. Modern engine, structures and avionics technology has largely eliminated these penalties. There remains, however, concern about the operational feasibility of the concept in the hands of service pilots operating in field conditions in all kinds of weather.

A flight research program is needed to explore the operational problems, to develop and demonstrate solutions and operating techniques, and to determine the operational feasibility and limitations of the VATOL concept. Because the areas of concern relate only to the low speed region of performance, it should not be necessary that the research aircraft demonstrate the full supersonic fighter envelope. It should be possible to build such a research aircraft using available engines.

Conceptual designs of suitable research aircraft have been identified in Reference 8 and are presented in Figures 13 and 14. A research aircraft to study the VATOL operations would not need an afterburning engine and considerable development cost and time can be saved by using an available engine. The aircraft in Figure 13 is based on a Pratt and Whitney YF-401 engine and in Figure 14 on a General Electric TF-34 engine.

In hovering and transition flight, a VTOL aircraft must derive its control from the engine either from bleed air reaction control and/or by thrust vectoring. Bleed air is very expensive in terms of thrust penalty resulting either in significant oversizing the engine to provide the bleed air or limited overheating the engine during the brief intervals when bleed air is being used. In Reference 9, a small scale remotely piloted VATOL vehicle was flown in hovering using only jet vane thrust vectoring for control about all three axes. A direct scale up of the concept to fighter size aircraft showed that vanes in the exhaust of a conventional round nozzle could not provide enough moment for roll control. A modification of the concept was adopted.

The new control system ducts the fan air to two two-dimensional nozzles, one on either side of the core nozzle. These two-dimensional nozzles are deflected differentially for roll control and together for pitch control.

With the YF-401 engine operating dry (afterburner removed), the fan air could be taken off at the beginning of the burner section and ducted to two-dimensional nozzles. These nozzles would provide pitch and roll control with a maximum deflection of +31 degrees.

The TF-34 powered research aircraft would duct fan air to the two-dimensional nozzles and uses only a 10-degree deflection for pitch and roll control, since 80 percent of the thrust is from the fan.

The YF-401 powered research aircraft would be close to an actual fighter. A conceptual fighter is shown in Figure 15. This airplane would require an engine development program. The fan flow would be taken off downstream of the fan section, through two duct burners, to the two-dimensional nozzles. These nozzles would have to be convergent-divergent nozzles as well as provide thrust deflection. This is shown in a cutaway drawing in Figure 16. The engine characteristics are based on a Pratt and Whitney STF 527-529 class with a BPR of 1.0. With the engine bypass ratio of about 1.0, each nozzle would provide about 1/4 of the thrust and only about ±20 degrees deflection is needed for control. The remainder of the deflection would be available for high lift (along with the all-moving canard) in STO operation. Yaw control would be provided by lateral deflection of the core nozzle.

The conceptual designs were sized by standard methods to ensure that performance, weights, stability, and control were realistic. They are not the result of detailed design and should be considered only as a conceptual arrangement intended to illustrate potential VATOL concepts.

CONCLUDING REMARKS

A VATOL flight demonstration is aimed at developing the technology to introduce a superior fighter aircraft with VTOL capability into the fleet. Numerous studies have shown that, of the various approaches to VTOL capability, the vertical attitude requires the least change from a good fighter configuration and has the least weight penalty. Coupled with the post-stall capability and common control in all flight modes, the VATOL penalty is reduced further and the air combat capability is enhanced significantly.

The VATOL concept involves an unusual operating mode resulting in a transition from wing-borne to jetborne flight that may present a unique operation for the pilot. The previous VATOL test beds have demonstrated, on numerous research flights, that it can be done. The VATOL manned simulation and research aircraft are needed to explore, develop, and demonstrate the full operational feasibility of the VATOL concept for routine fleet use.

Vertical attitude may well prove to be, by far, the most efficient and cost effective solution to the problem of equipping the Navy's air arm with a V/STOL capable fighter. A course of technology development which will make this option fully available and viable is being pursued.

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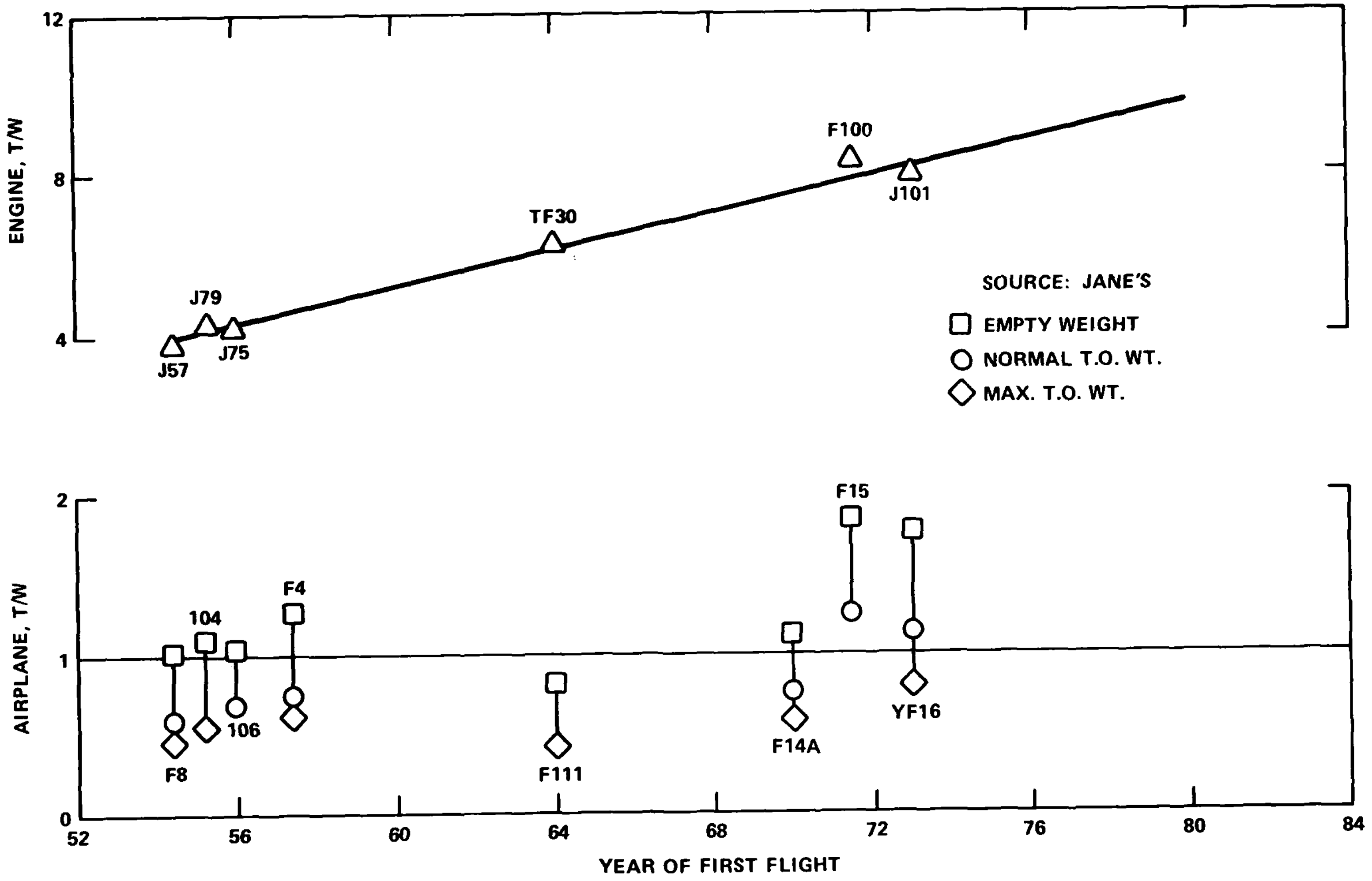


Figure 1 – Thrust to Weight Trends of Fighter Aircraft

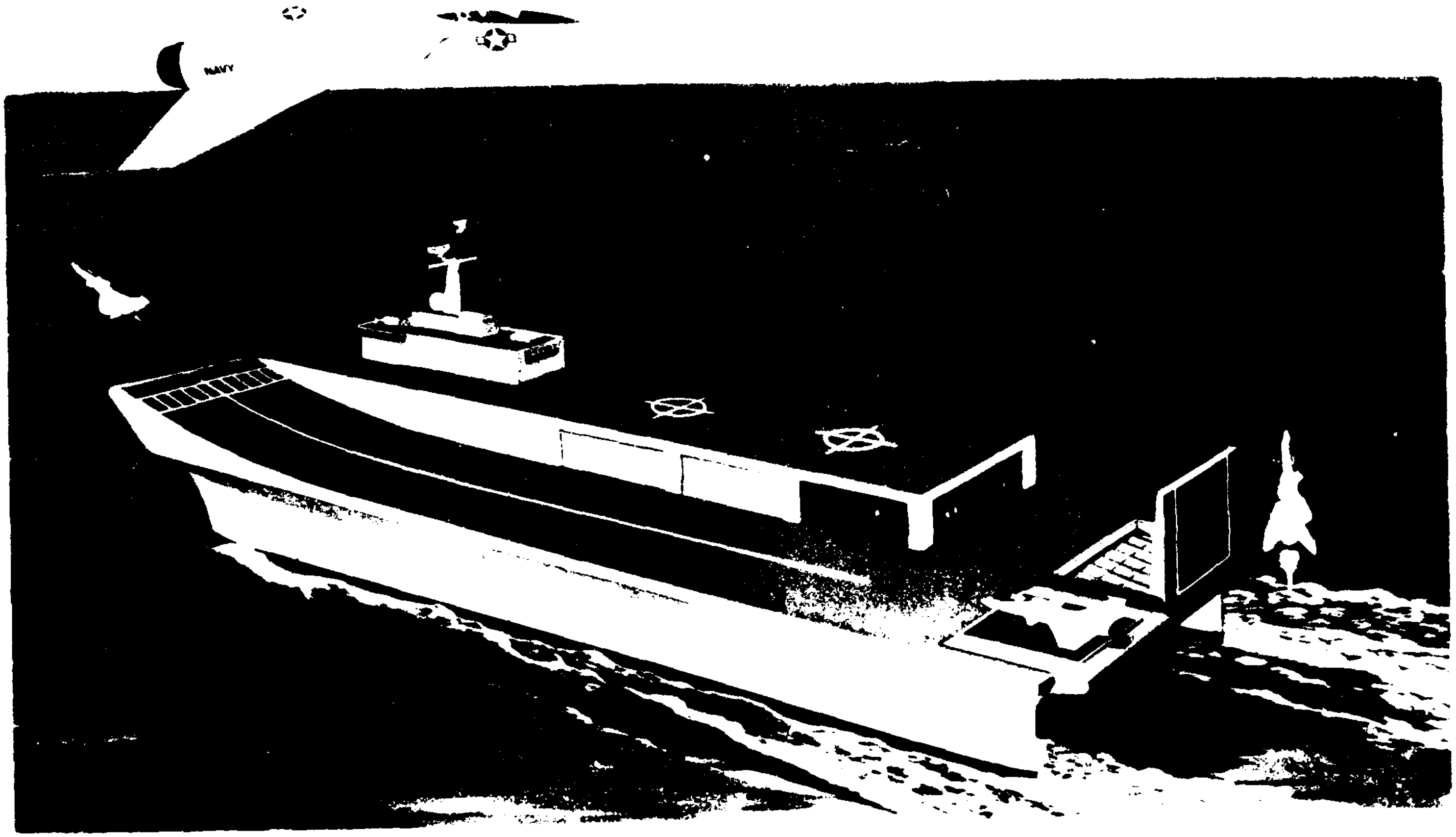


Figure 2 VATOL Aircraft on SWATH Ship

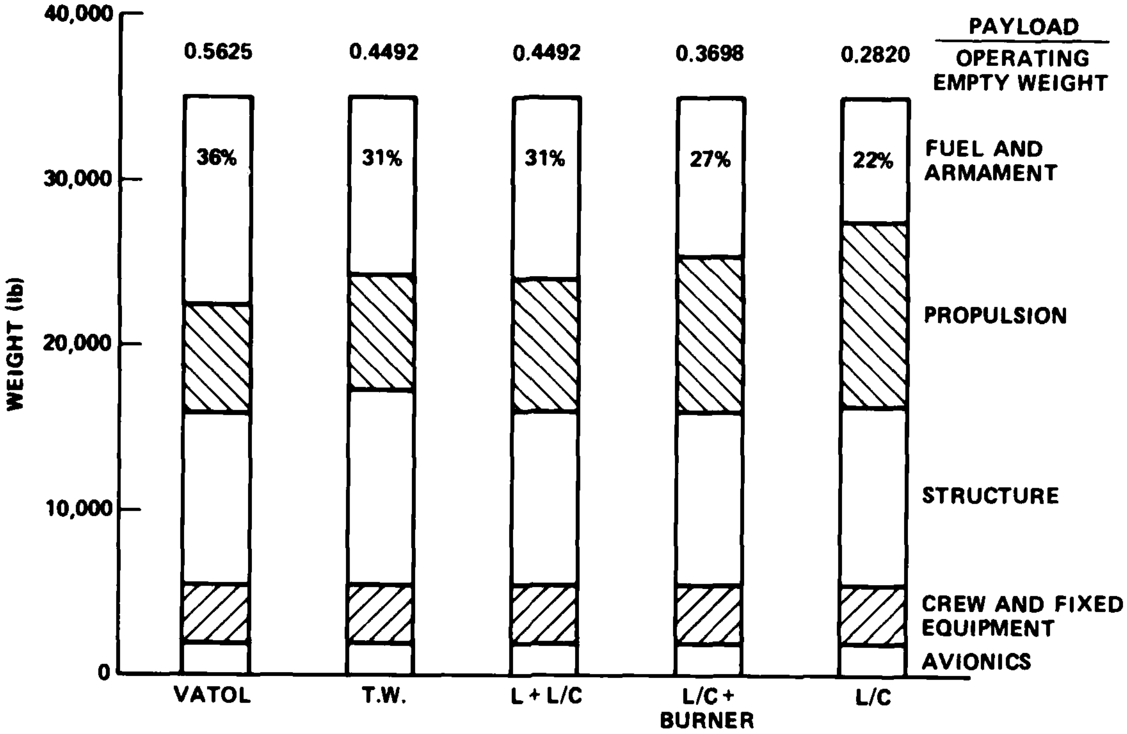


Figure 3 – Weight Breakdown of VTOL Configurations (Figure from Reference 1)

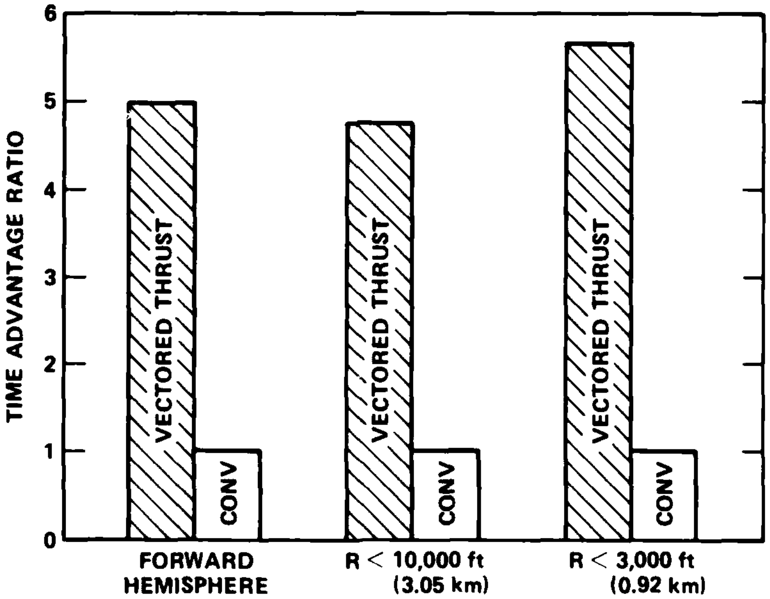


Figure 4 – Time Advantage Ratio for Vectored Thrust Fighters (Figure from Reference 4)

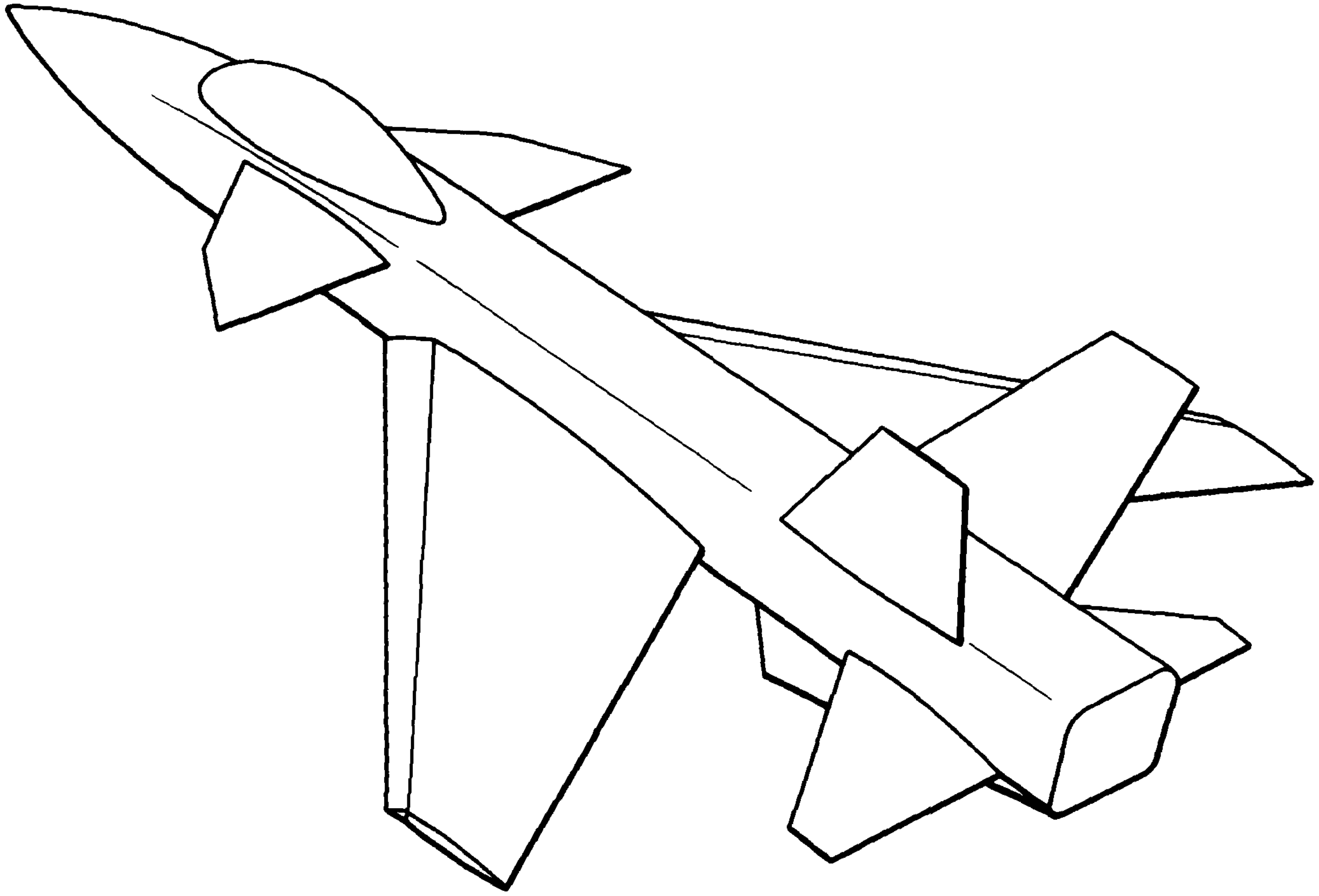


Figure 5 – DTNSRDC Post-Stall Aerodynamics Wind Tunnel Model

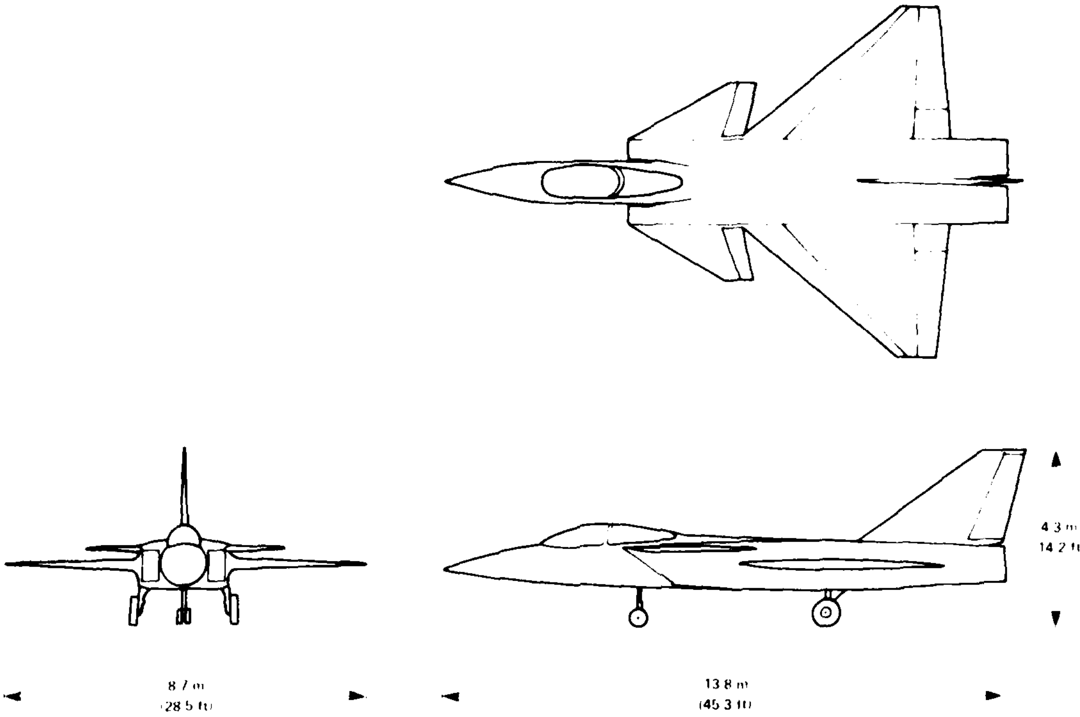


Figure 6a - Three View

Figure 6b – Artist Rendering of the Vought VATOL Concept in a STOVL Configuration

Figure 6 – Vought VATOL Concept
(Figure from Reference 5)

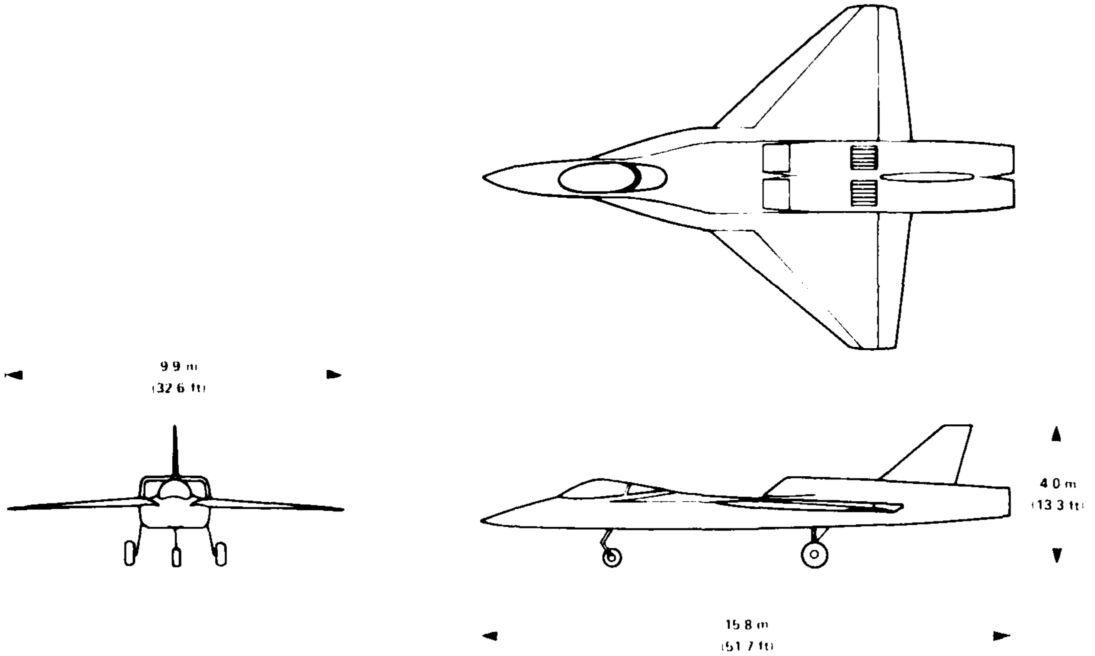


Figure 7a   Three View

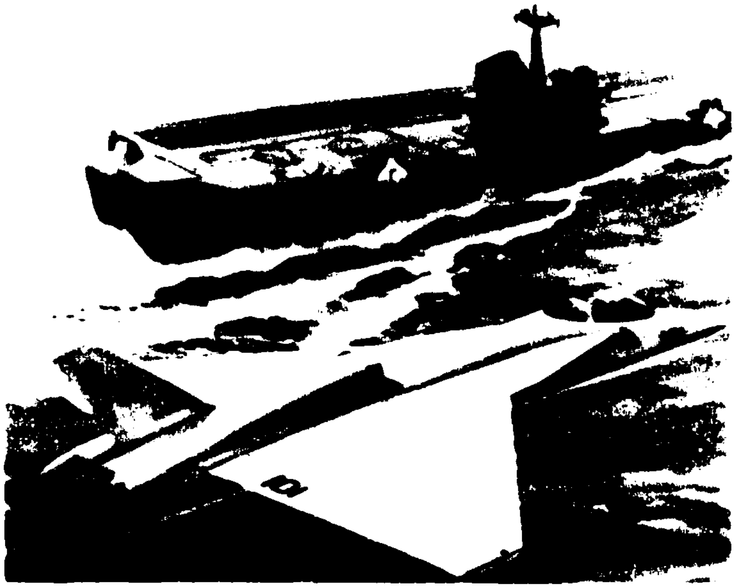


Figure 7b - Artist Rendering of the Northrop VATOL Concept

Figure 7 – Northrop VATOL Concept
(Figure from Reference 5)

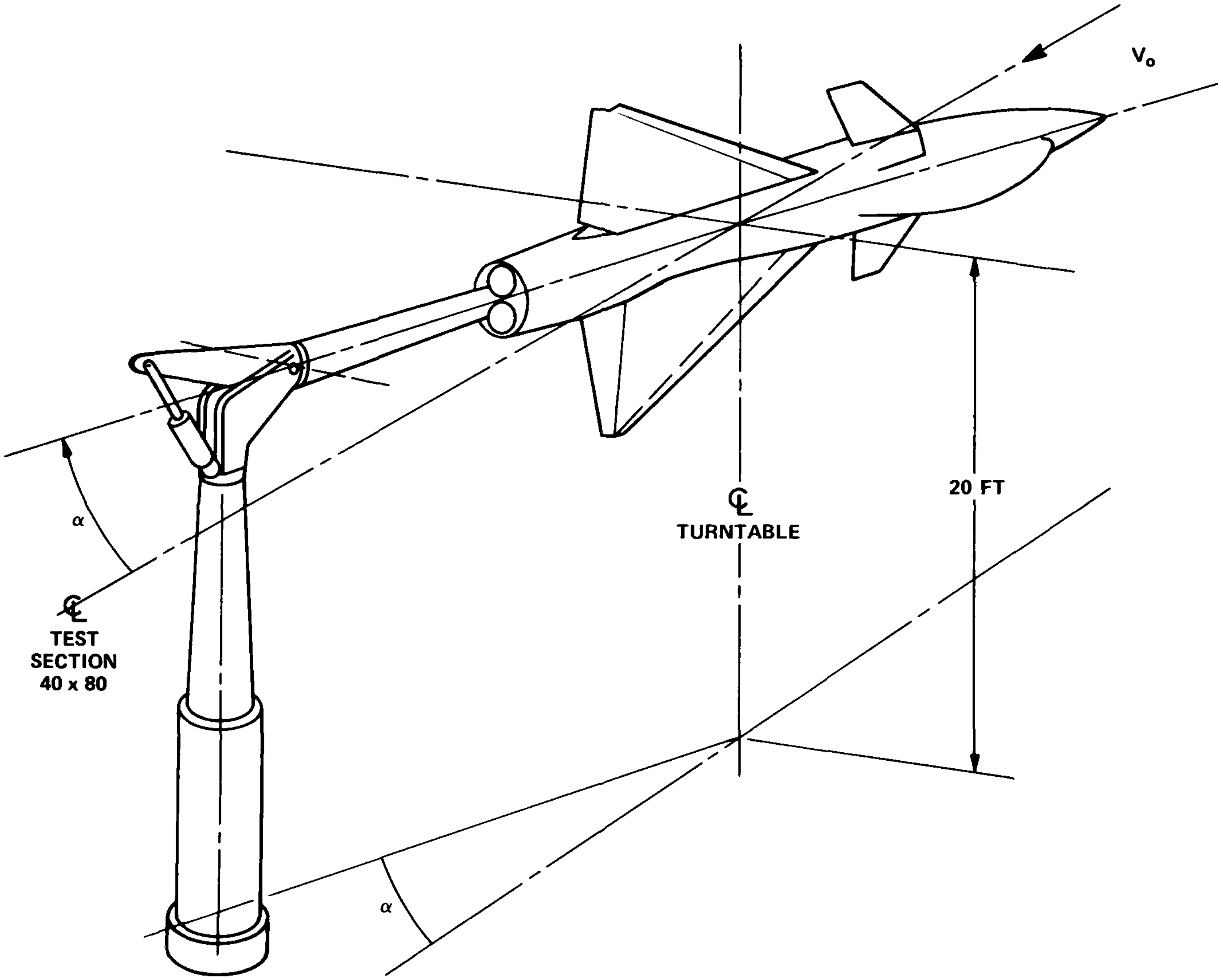


Figure 8 – Installation Sketch of VATOL 0.38 Scale Model in NASA Ames 40- x 80-Foot Wind Tunnel

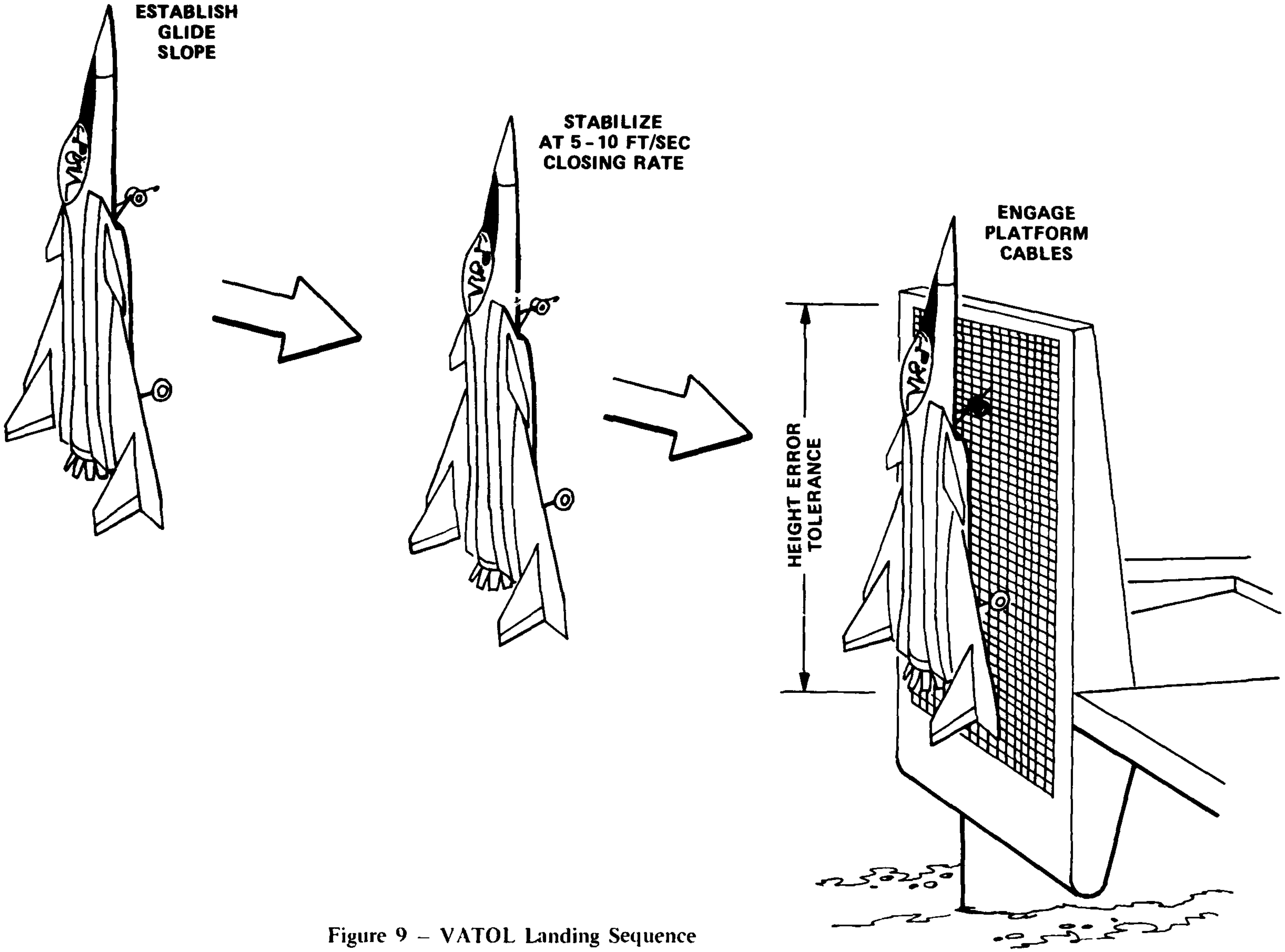


Figure 9 – VATOL Landing Sequence

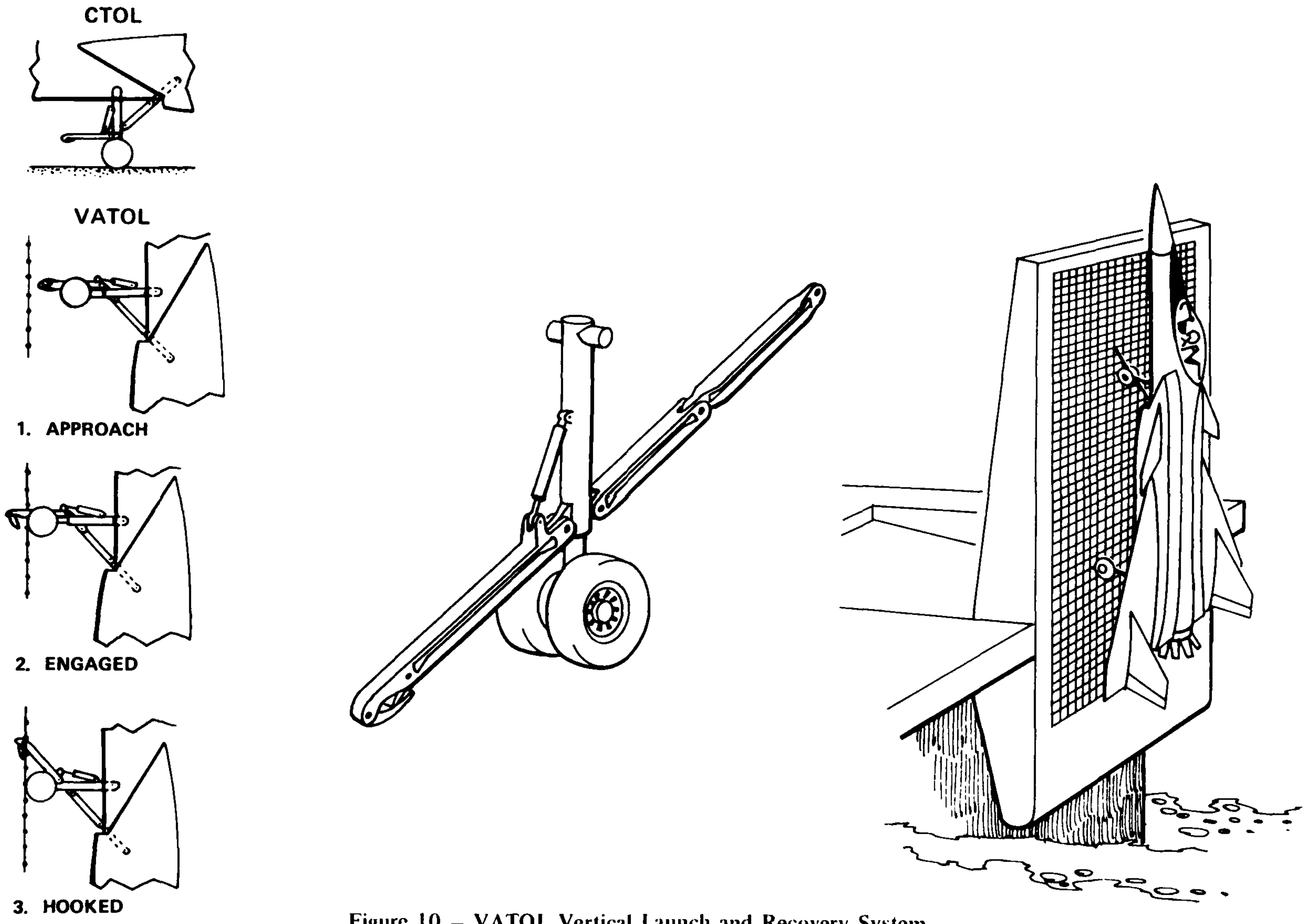


Figure 10 – VATOL Vertical Launch and Recovery System

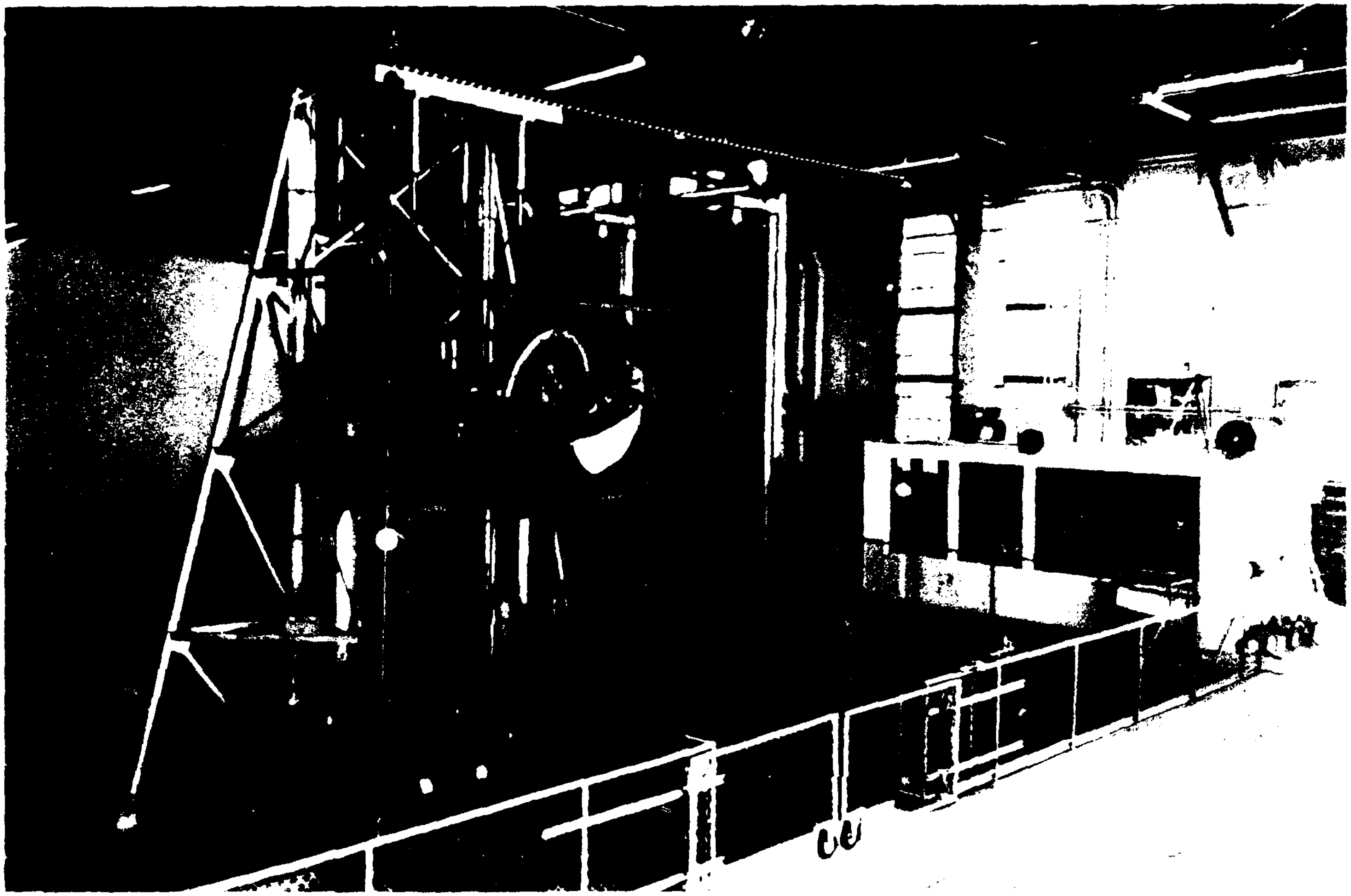


Figure 11   NASA Six Degree of Freedom Simulator.

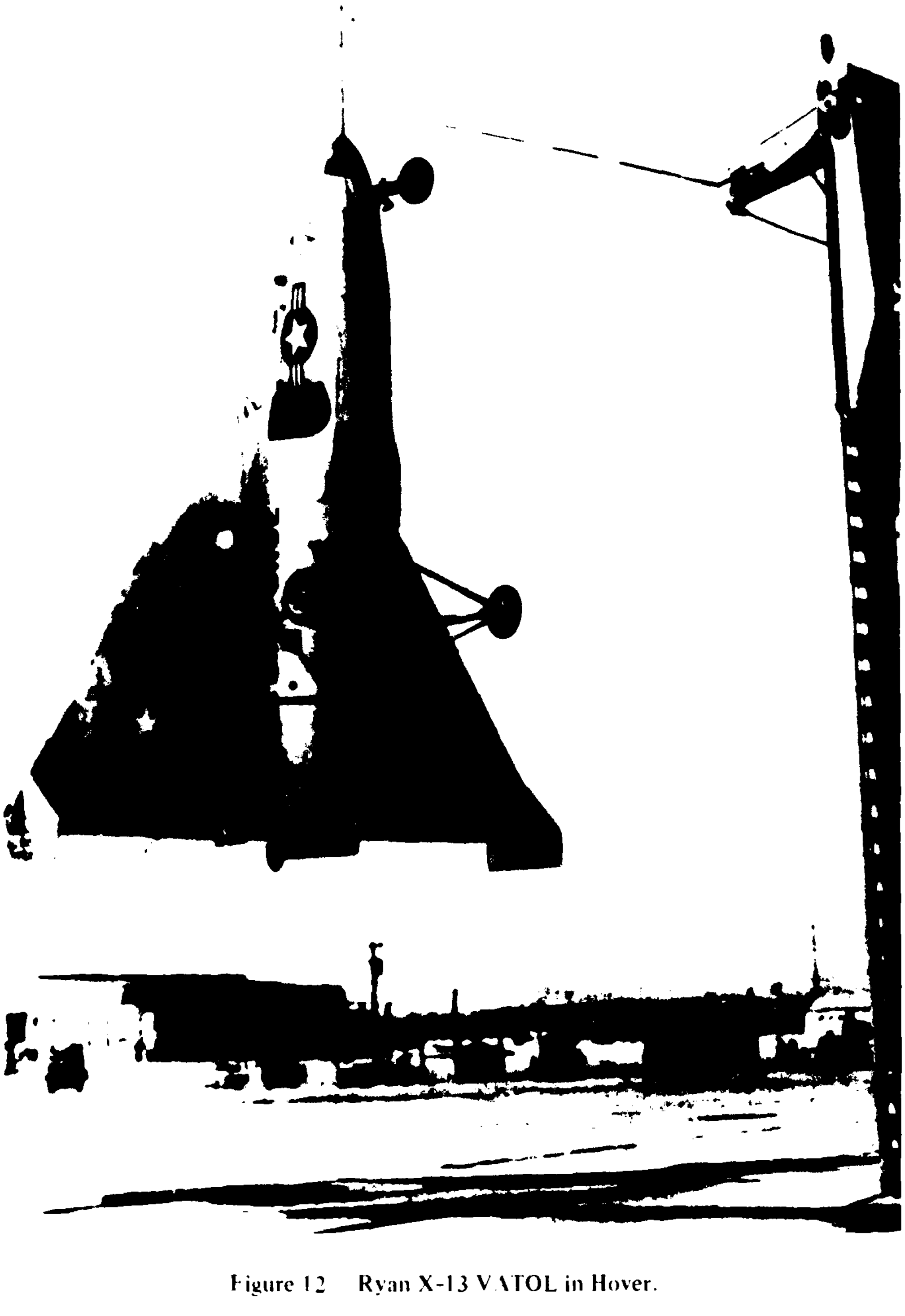


Figure 12 Ryan X-13 VATOL in Hover.

BASIC DIMENSIONS

	WING	CANARDS (EXPOSED) (EACH)	VERTICAL TAILS (EACH)
AREA, ft^2	333	18.4	32
SPAN, ft	25	4	6.4
ROOT CHORD, ft	24.2	7.6	8
TIP CHORD, ft	2.5	1.6	2
ASPECT RATIO	1.88		
THICKNESS RATIO	0.06	0.06	0.06
L.E. SWEEP ANGLE, deg	60	60	50

WEIGHTS (lb)

STRUCTURE	3482
PROPULSION	3695
FIXED EQUIPMENT	1562
EMPTY WEIGHT	8739
CREW	400
RESEARCH EQUIPMENT	200
FUEL	3411
VTO GROSS WEIGHT	12,750

ENGINE

P&W YF 401–DRY
T = 16,100 lb S.L. STD.
T = 14,500 lb S.L. 90 F

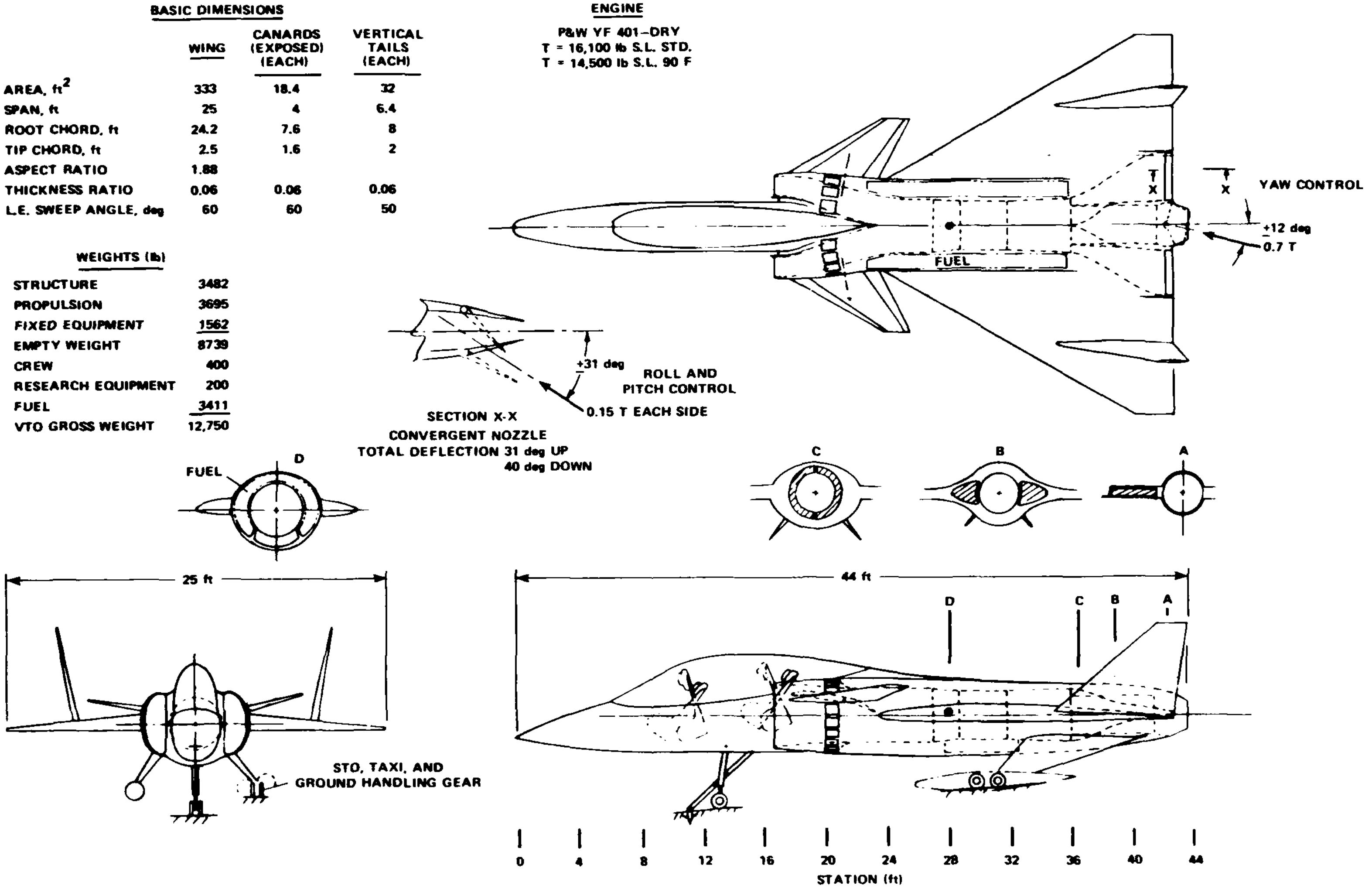
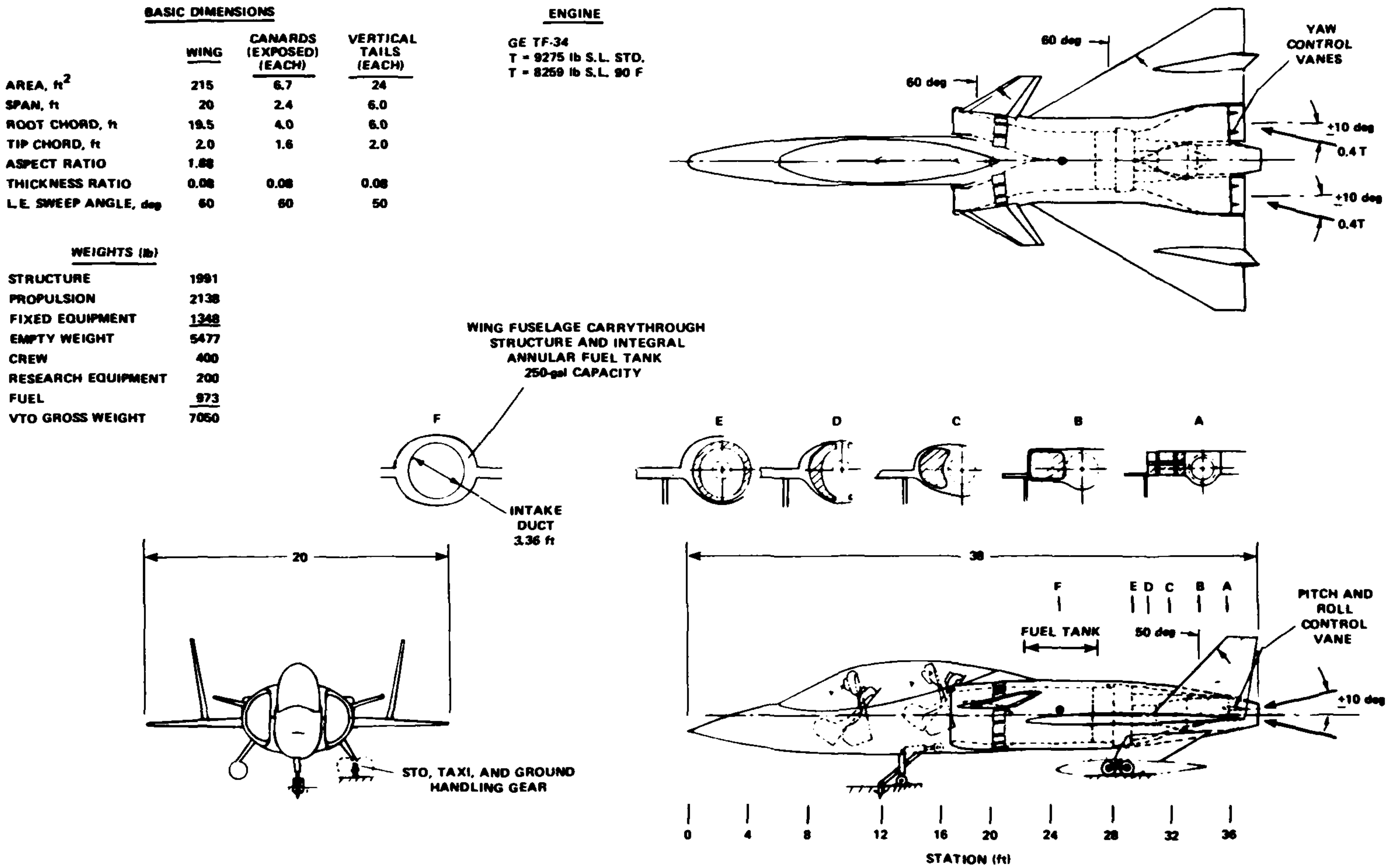


Figure 13 – VATOL Research Aircraft Conceptual Arrangement Pratt and Whitney 401 Engine



BASIC DIMENSIONS

	WING	CANARDS (EXPOSED) (EACH)	VERTICAL TAILS (EACH)
AREA, ft^2	215	6.7	24
SPAN, ft	20	2.4	6.0
ROOT CHORD, ft	19.5	4.0	6.0
TIP CHORD, ft	2.0	1.6	2.0
ASPECT RATIO	1.88		
THICKNESS RATIO	0.08	0.08	0.08
L.E. SWEEP ANGLE, deg	60	60	50

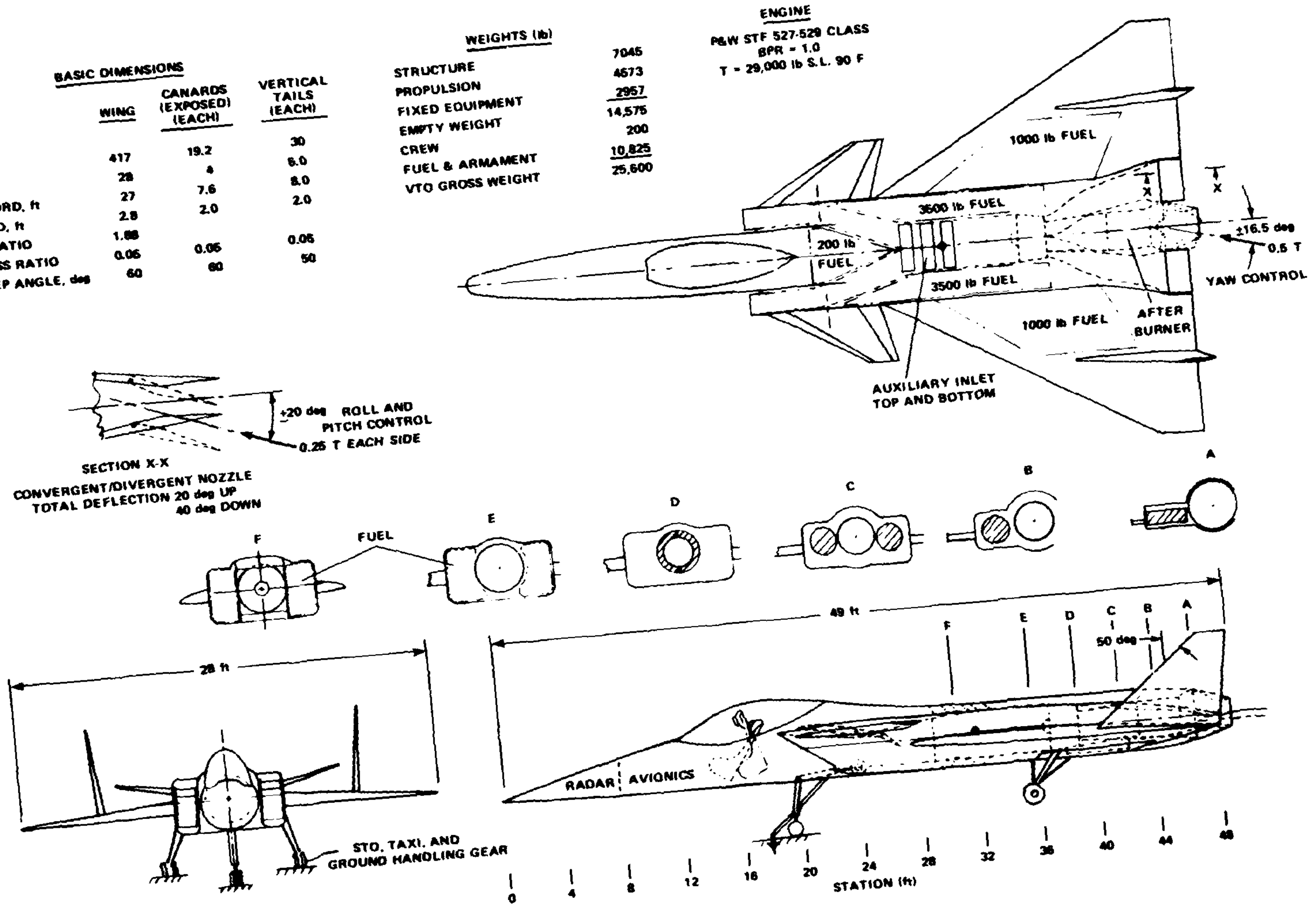
ENGINE

GE TF-34
T = 9275 lb S.L. STD.
T = 8259 lb S.L. 90 F

WEIGHTS (lb)

STRUCTURE	1991
PROPULSION	2138
FIXED EQUIPMENT	1348
EMPTY WEIGHT	5477
CREW	400
RESEARCH EQUIPMENT	200
FUEL	973
VTO GROSS WEIGHT	7050

Figure 14 – VATOL Research Aircraft Conceptual Arrangement General Electric TF-34



BASIC DIMENSIONS

	WING	CANARDS (EXPOSED) (EACH)	VERTICAL TAILS (EACH)
AREA, ft^2	417	19.2	30
SPAN, ft	28	4	6.0
ROOT CHORD, ft	27	7.6	8.0
TIP CHORD, ft	2.8	2.0	2.0
ASPECT RATIO	1.88		
THICKNESS RATIO	0.06	0.05	0.05
L.E. SWEEP ANGLE, deg	60	60	50

WEIGHTS (lb)

STRUCTURE	7045
PROPULSION	4673
FIXED EQUIPMENT	2957
EMPTY WEIGHT	14,575
CREW	200
FUEL & ARMAMENT	10,825
VTO GROSS WEIGHT	25,600

Figure 15 – VATOL Fighter – New Engine.

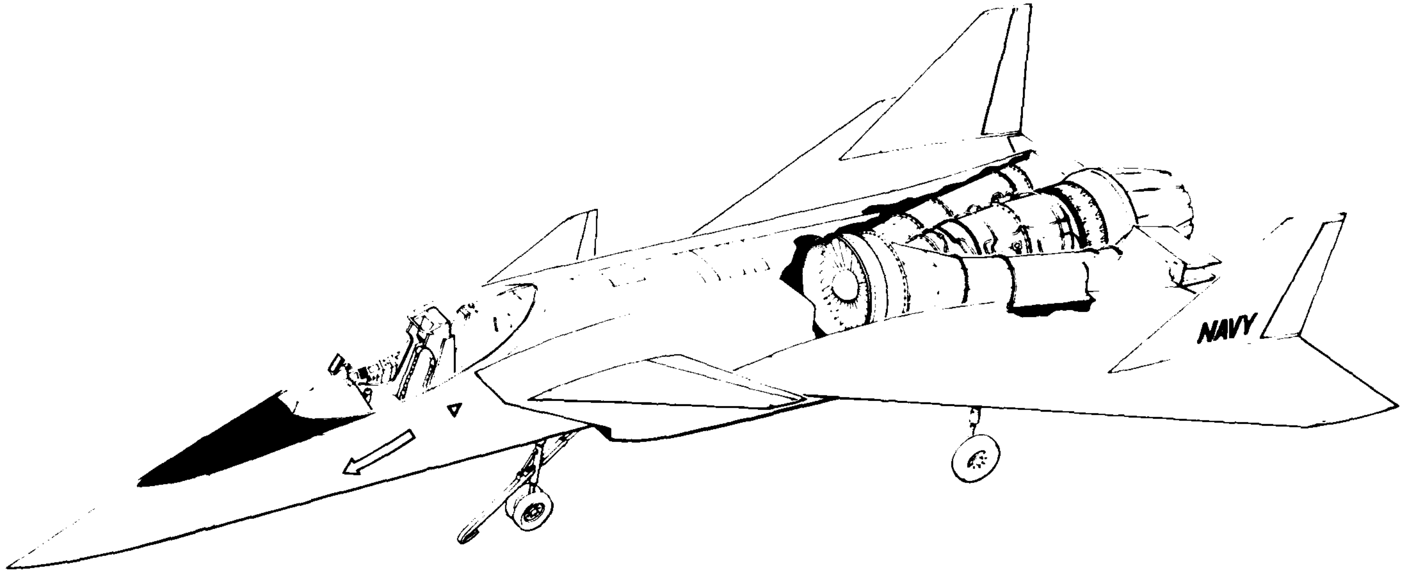


Figure 16 – VATOL Fighter Cutaway of Engine Installation

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