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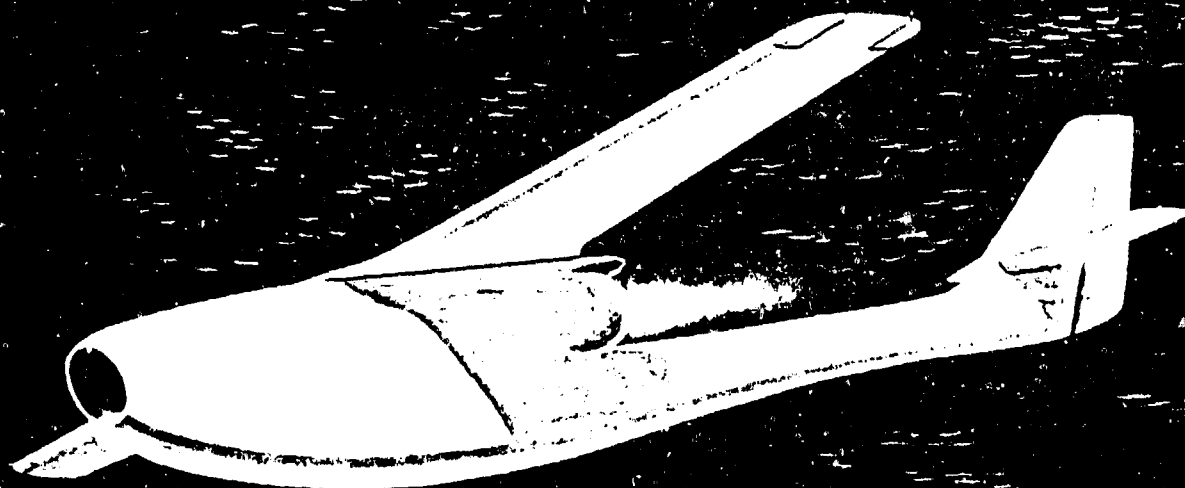
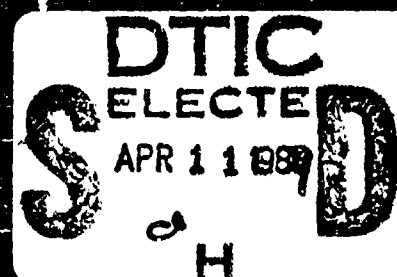
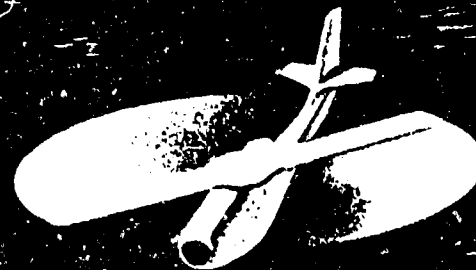
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Tipjet VTOL UAV Summary

**Volume I — 1200-Pound Tipjet VTOL
Unmanned Aerial Vehicle**

**Part 1 — Conceptual Design Study
of a 1200-Pound Vehicle**

by
Kenneth R. Reader
Jane S. Abramson
Alan W. Schwartz
James C. Biggers



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^ A new concept is developed for an unmanned aerial vehicle (UAV) configured with a tip-jet driven, two-bladed, stoppable rotor and circulation control airfoils. The conceptual design of the Tipjet Vertical Takeoff and Landing (VTOL) UAV is presented, and vehicle performance is evaluated for three mid-range UAV Navy missions: Tactical Reconnaissance, Over-the-Horizon Targeting, and Combat Support Reconnaissance. Vehicle performance predictions are presented for hover and low-speed, rotary-wing flight, for conversion between rotary-wing and fixed-wing flight, and for fixed-wing flight. Requirements for shipboard support of the vehicle are outlined. Mission specific equipment is described including size, weight, and power requirements. Standard design methods are applied to conduct a detailed mission performance analysis for the conceptual design. The analysis results indicate that the 1200-lb Tipjet VTOL UAV is a viable (Continued)					
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Part 1 of Volume I presents the conceptual design for the Tipjet VTOL UAV along with vehicle performance analysis for the designated missions. Part 2 of Volume I presents the detailed engine and vehicle performance data. This proprietary information is available upon request to qualified agencies. *CPD*



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ABBREVIATIONS AND SYMBOLS

a	Speed of sound, kn
A_w	Vehicle wetted area, ft^2
b	Wing span, ft
c.g.	Center of gravity
C_{n_0}	Wing zero-lift drag coefficient
C_L	Wing lift coefficient
CC	Circulation Control
D	Total aircraft drag, lb
e	Oswald efficiency factor
f	Equivalent parasite area, ft^2
h/c	Blade slot height-to-chord ratio
H_n	Altitude, ft
LAMPS	Light airborne multipurpose systems
L/D	Lift-to-drag ratio
M	Flight Mach number
P_R	Blade root duct pressure ratio, atm
P_{tot}	Bypass air total pressure, lb/ft^2
P_a	Atmospheric pressure, lb/ft^2
q	Dynamic pressure, lb/ft^2
R/C	Rate of climb, ft/sec
RPV	Remotely piloted vehicle
S	Wing area, ft^2
S_n	Distance, ft
SFC	Specific fuel consumption, lb fuel/lb thrust/hr

t	Time, sec
T	Thrust, lb
UAV	Unmanned aerial vehicle
V	Flight speed, ft/sec or kn
VTOL	Vertical takeoff and landing
W	Aircraft gross weight, lb
$x_{c.g.}$	Longitudinal position of vehicle c.g. from nose (fraction of vehicle length)
α_s	Wing angle of attack or rotor disc plane tilt, deg (positive nose up)
γ	Climb angle, deg
$\bar{\gamma}$	Glide angle, deg
σ	Air density ratio

Subscripts

A	Available
A/C	Aircraft
n	Identifier (1, 2, 3, etc.)
Req	Required

ABSTRACT

A new concept is developed for an unmanned aerial vehicle (UAV) configured with a tip-jet driven, two-bladed, stoppable rotor and circulation control airfoils. The conceptual design of the Tipjet Vertical Takeoff and Landing (VTOL) UAV is presented, and vehicle performance is evaluated for three mid-range UAV Navy missions: Tactical Reconnaissance, Over-the-Horizon Targeting, and Combat Support Reconnaissance. Vehicle performance predictions are presented for hover and low-speed, rotary-wing flight, for conversion between rotary-wing and fixed-wing flight, and for fixed-wing flight. Requirements for shipboard support of the vehicle are outlined. Mission specific equipment is described including size, weight, and power requirements. Standard design methods are applied to conduct a detailed mission performance analysis for the conceptual design. The analysis results indicate that the 1200-lb Tipjet VTOL UAV is a viable candidate vehicle for the specified missions. Moreover, the concept is directly applicable to much larger UAVs that will greatly enhance naval warfare capabilities.

Part 1 of Volume I presents the conceptual design for the Tipjet VTOL UAV along with vehicle performance analysis for the designated missions. Part 2 of Volume I presents the detailed engine and vehicle performance data. This proprietary information is available upon request to qualified agencies.

ADMINISTRATIVE INFORMATION

This work was conducted by the Aviation Department (Code 169) of the David Taylor Research Center (DTRC). Funding was provided by the Naval Air Development Center (NADC), Tactical Air Systems Department, RPV Project (Code 2J) under Order No. N62269188 WX/00300, Program Element 62122N, and DTRC Work Unit 1-1690-117.

INTRODUCTION

In recent years, interest has been building regarding the use of unmanned aerial vehicles (UAVs) to augment the naval warfare capabilities of small surface combatants. The UAVs are attractive to the warfare commander because of their small physical size, low risk of loss, and portability features. Additionally, systems with safe and simple means of launch, recovery, and vehicle turnaround are most

desirable. Conventional UAVs, in the 1200-lb class, cannot easily be operated from the flight decks of these ships. For example, catapult launch systems and net recovery systems become unwieldy for a 1200-lb aircraft. These small ships, however, are ideal for support of UAVs with vertical takeoff and landing (VTOL) capabilities for unassisted launch and recovery. Small, agile VTOL UAVs, with long-endurance capability would provide valuable information on enemy strength, position, and readiness.

The Department of Defense, under direction by Congress, recently consolidated the various UAV program elements among the services to reduce proliferation, enhance development and procurement, and reduce system costs. This integrated effort includes management structure, general UAV requirements, and acquisition strategy and is detailed in Ref. 1. As part of the Joint UAV Program Master Plan, the Navy is examining options for ship-based and shore-based UAVs to meet its particular mission requirements. The Tipjet VTOL UAV concept has been presented to the Joint UAV Office, and that office has encouraged pursuit of this concept.

Since the late 1960's, the David Taylor Research Center (DTRC) has conducted extensive research and development of stoppable rotor VTOL concepts, circulation control (CC) aerodynamics, and airflow management systems. The work has resulted in many significant contributions in these fields.² This specialized technical expertise provides DTRC with the background and data base to support development of certain advanced VTOL concepts. Accordingly, the Naval Air Development Center (NADC) tasked DTRC to develop the conceptual design of a tip-jet driven, stoppable rotor UAV to perform three mid-range Navy missions: (1) Tactical Reconnaissance, (2) Over-the-Horizon Targeting, and (3) Combat Support Reconnaissance. This report presents the conceptual design for the 1200-lb Tipjet VTOL UAV including vehicle performance analyses for the missions identified in the task.³

CONCEPTUAL DESIGN DESCRIPTION

The Tipjet VTOL UAV conceptual design employs a high-wing, sailplane-type configuration for efficient air loiter and a conventional turbofan engine (Fig. 1). The high aspect ratio wing "converts" to a tip-jet driven helicopter rotor for vertical takeoff and landing. Circulation control airfoils (Ref.4), based on the Coanda effect, provide the high helicopter-mode controllability necessary for reliable shipboard recoveries even in adverse weather. "Cold" bypass air is diverted from the turbofan engine to supply the tip jets and the CC blowing. The conversion between fixed-wing and rotary-wing modes is accomplished very rapidly (during several seconds) by starting or stopping the wing/rotor with appropriate directional control of the tip jets. A ballistic flight trajectory during conversion, with blowing turned off and the rotor temporarily unloaded, eliminates the need to counter high vibratory loads during this maneuver.

Figure 2 depicts the operational scenario for the Tipjet VTOL UAV. On release from the flight deck, the UAV climbs while gaining forward speed. At approximately 145 kn, the rotor is quickly unloaded and decelerated to a complete stop. From this point, the UAV operates as a high aspect-ratio, fixed-wing aircraft. After completing its mission, the UAV returns to the ship, and the conversion maneuver is reversed as the vehicle resumes a rotary-wing mode. A controlled vertical landing on the ship's deck completes the recovery phase of the scenario.

A three-view sketch of the 1200-lb Tipjet VTOL UAV is shown in Fig. 3. The engine is mounted high in the nose with an exhaust pipe extending to a point aft of the blade/wing hub. A multi-cell, antislosh fuel tank is located in the fuselage belly centered below the hub. The mission payload is housed in the tail boom and in the compartment forward of the fuel cells. The fuselage contours were chosen with emphasis on minimizing drag. The reflex cambered hub is designed to provide an

aerodynamic wing-fuselage junction in the fixed-wing straight and skewed positions. (Wing skew may be desirable for delay of Mach effects at high speeds.) An all-flying horizontal tail provides pitch control in fixed-wing flight. The vertical and horizontal tails are effective for control even in a low-speed, rotary flight mode by reacting with the flow from the turbofan exhaust.

The internal layout of the UAV wing is shown in Fig. 4. The structure is divided into flow ducts (three or four) that guide air to the tip-jet nozzles and blowing slots. These ducts, which are integrated with the blade structure, also serve as stiffeners. Air enters the blade through the center of the hub bearing, on which the wing rotates. The center (chordwise) ducts supply air to a pair of tip nozzles that eject in opposite directions (trailing-edge ejection for rotor turning and leading-edge ejection for rotor deceleration). Outer ducts serve as air plenums for the CC blade slots. The CC blowing level is controlled, collectively and cyclically, through the use of a full-span slot/valve. The slot/valve is a direct control nozzle that locally regulates the amount of airflow ejected along the blade span. Local spanwise throttling of the flow enables the blade to become a flowing plenum, thereby reducing system pressure losses and allowing design of a lighter blade structure. Airflow values for a typical hover condition are included in Fig. 4.

Pertinent geometric characteristics for the 1200-lb Tipjet VTOL UAV are presented in Table 1. The airfoil sections were selected from a family of existing airfoils that have been extensively tested over a wide range of angle of attack, Mach number, CC blowing coefficient, and Reynolds number. The comprehensive data base for these airfoils has been used for the aerodynamic analysis in this study.

CONCEPTUAL DESIGN DEVELOPMENT

Past experience with circulation control rotor systems led to the selection of a two-bladed, tip-jet configuration for the conceptual design. Initial wing/rotor design and configuration tradeoffs were performed using a desktop computer model that was set up to analyze tip-jet configurations. The analytical model has evolved over the years using model- and full-scale wind tunnel data, flight test data, and detailed comparisons with more rigorous analytical models. The following basic assumptions are used for the tradeoff study:

1. Blade taper ratio is fixed at $2/3$.
2. Tip-jet nozzle area (per blade) is 0.0255 times the square of the tip chord.
3. Duct losses from the plenum to the tipjet nozzle exit are 20 percent of the gage pressure.
4. Engine fan efficiency is 0.83.
5. No fuselage downloads are considered.
6. No maneuver margin is included.
7. Blade pitch angle is fixed at zero degrees.
8. Circulation control airfoil contours are defined at the blade root and blade tip.

An off-the-shelf engine, the Williams International F107-WR-401 turbofan, was identified as the powerplant for the 1200-lb Tipjet VTOL UAV. The F107-WR-401 is a derivative of the Navy's Tomahawk cruise missile engine and, with minimal modification, is adaptable to the UAV design. The availability of this engine enables expeditious development and fielding of the UAV.

The generalized hover performance of the two-bladed tip-jet configuration is shown in Fig. 5. Performance is characterized by the wing lift per unit of bypass

airflow versus wing loading or rotor disc loading. Tradeoffs are shown for the rotor configuration and air supply parameters. Rotor design tip speed is dependent on the other conditions and, therefore, also varies. The highest possible ratio of lift to airflow is desirable, suggesting high pressure ratio and high aspect ratio (low solidity).

Some considerations, however, constrain the design parameters. Ship compatibility requires low downwash and good handling qualities, while structural considerations limit the maximum blade aspect ratio. With these concerns in mind, a rotor disc loading of approximately 5 psf and 200 lb of lift per unit of bypass airflow were chosen. For the Williams engine with 6 lb/sec of bypass air available, this condition corresponds to a 1200-lb gross weight vehicle. This single point design (noted in Fig. 5) was analyzed in the performance of the specified missions.

After the selection of the point design, a routine conceptual design procedure was employed. The physical layout, detailed vehicle aerodynamic performance, detailed wing/rotor aerodynamic performance, and mission analyses were performed in an iterative manner. The vehicle aerodynamic performance and mission analyses were done interactively.

VEHICLE PERFORMANCE METHOD

A literature search for a standard, accepted method of determining conceptual design vehicle performance for aircraft in the 1200-lb class did not uncover any existing, recommended method. Furthermore, information on the performance (lift, drag, wetted area, flat plate area), structural weight, and tail sizing for 1200-lb class aircraft is extremely limited. (Documented wind tunnel results of a fixed-wing RPV by Pigford⁵ did prove to be useful.) Consequently, the standard method of Perkins and Hage⁶ was used to perform the mission analysis. The design and

performance predictions are based on the method of Nicolai.⁷ Vehicle drag predictions based on these two methods are in good agreement and compare favorably to the data of Pigford.⁵ This agreement inspires confidence in the drag values used for the mission analysis. The thrust required versus speed relation and the thrust available are essential to obtaining good results from the mission analysis.

GENERALIZED PERFORMANCE METHOD

The nondimensional form of the generalized thrust-required curve (from Ref. 6) is presented in Fig. 6. This generalized curve is applicable for all altitudes and any combination of aircraft characteristics. In Fig. 6, the available engine thrust is nondimensionalized by the design dependent reference thrust, $T_{(L/D)_{\max}}$, and the velocity by $V_{(L/D)_{\max}}$:

$$T_{(L/D)_{\max}} = 1.132 \frac{W}{b} \sqrt{\frac{f}{e}}$$

$$V_{(L/D)_{\max}} = \frac{14.85}{\sqrt[4]{fe}} \sqrt{\frac{W}{\sigma b}}$$

Conventional analysis methods can then be used to determine speed performance (i.e., maximum speed, best range speed, and best endurance speed).

Use of the Perkins and Hage⁶ method is based on the assumption that the drag polar of the aircraft has a parabolic shape. The parabolic feature was analytically demonstrated for the Tipjet VTOL UAV using data from the detailed aerodynamic studies. For this conceptual design, compressible speed corrections have not been applied to the mission analysis results.

The values used to calculate the reference thrusts and velocities are $e = 0.7$, $f = 1.13$, $W = 1200$ lb, and $b = 18$ ft. Figure 7 (from Ref. 6), showing the wetted

area versus the equivalent parasite area for various aircraft, indicates that the value of f is conservative. The full-scale XBQM-106 wind tunnel results of Pigford³ support the predicted drag levels used in the mission analysis. The calculated value of $T_{(L/D)_{\max}}$ is 95.9 lb; the values of $V_{(L/D)_{\max}}$ for the selected altitudes are presented in Table 2.

MISSION ANALYSIS EQUATIONS

The following equations and assumptions were used for the Tipjet VTOL UAV mission studies.

Climb

$$\text{Rate of Climb} \quad R/C = 101.29 \frac{\Delta T \times V}{W} ; \Delta T = T_A - D$$

$$\text{Time} \quad \Delta t = \frac{\Delta \text{Alt}}{R/C}$$

$$\text{Fuel Burned} \quad \Delta \text{Fuel} = \Delta t \times \text{SFC} \times T$$

$$\text{Angle} \quad \sin(\gamma) = \frac{R/C}{(101.29 \times V_{\text{kn}})}$$

$$\text{Distance Traveled} \quad S_2 - S_1 = \frac{H_2 - H_1}{\tan(\gamma)}$$

Cruise

$$\text{Velocity for Maximum Range} \quad V_{\text{max range}} = 1.95 \sqrt{\frac{W}{\sigma b \sqrt{f_e}}}$$

$$\text{Time} \quad \Delta t = \frac{\text{Distance}}{V}$$

$$\text{Fuel Burned} \quad \Delta \text{Fuel} = \Delta t \times \text{SFC} \times T_{\text{REQ}}$$

Descent

No Time

No Fuel Burned

No Distance Traveled

Terminal Dive Speed
$$V^2 = \frac{2 W \sin(\bar{\gamma})}{\rho S C_{D_0}} ; (\text{Solve for } \sin(\bar{\gamma}) = 1; \bar{\gamma} = \pi/2)$$

Loiter

Endurance Speed $T_{REQ} = q \times (D/q)$

$D/q = f$ (Solve for q with known f and T_{REQ})

$q/M^2 = \text{Constant}$ (Solve for M using q)

$V = aM$

VEHICLE DESIGN AND PERFORMANCE PREDICTIONS

POWERPLANT

The powerplant selected for the 1200-lb Tipjet VTOL UAV is the Williams International F107-WR-401 turbofan engine. The F107-WR-401 is a derivative of the F107-WR-400 engine shown in Figs. 8 and 9. The Williams engine, which is in the 600-lb thrust class, produces in excess of 6.5 lb/sec of bypass air at a pressure ratio, $(P_{tot})_{bypass}/P_{\infty}$, of 2.2. The uninstalled powerplant weighs approximately 146 lb and is commonly paired with a 5kA electric generator weighing an additional 15 lb.

Specific fuel consumption as a function of engine thrust (presented under separate cover in Volume I, Part 2) was obtained from a customer deck provided by Williams International. These data were obtained for the case of no bypass bleed, at various altitudes and flight Mach numbers, using an option in the program which simulates the full operating range of the engine fuel controller. A summary of the

minimum and maximum available thrust at sea level for standard, tropic, and hot days is also presented in Volume I, Part 2.

Because the engine provides not only thrust but also air for both tip jet operation and wing Coanda blowing, the feasibility of diverting part or all of the bypass air was discussed with the engine manufacturer. In the opinion of Williams International, provisions for the diversion of bypass air pose no difficult technical problems.

FIXED-WING AERODYNAMICS

With the basic wing/rotor configuration having been determined in the initial point design study, a fixed-wing aerodynamic analysis was conducted using the methods of Nicolai.⁷ Performance characteristics were determined for altitudes from sea level to 35,000 ft and at gross weights of 800, 1000, and 1200 lb.

Lift coefficient requirements for vehicle weights of 800 and 1200 lb are shown in Fig. 10 for speeds from 60 to 380 kn. The capability to produce the wide range of lift coefficients shown in Fig. 10 is due to the use of circulation control blowing on the Tipjet VTOL UAV wing/rotor.

Drag for all vehicle components, except wing zero-lift drag (C_{D_0}), was calculated using the methods of Nicolai.⁷ The wing C_{D_0} was determined from wind tunnel data for the proposed airfoil sections. The drag calculation includes a prediction of C_D for the following components: the fuselage and fuselage base drag, wing/body interference, horizontal and vertical tails, wing C_{D_0} and induced drag. Total C_D for the configuration is $0.0402 + 0.036 (C_L)^2$, which yields drag values comparable to wind tunnel data for the similarly configured XBQM-106 shown in Fig. 11. Since this study represents a conceptual design effort, no drag reduction was assumed for aerodynamic tailoring of the vehicle. This detailed calculation of

drag was compared with that obtained using the Generalized Performance Method of Perkins and Hage.⁶ As can be seen from Fig. 12, the two methods show very good agreement for drag (thrust required) versus speed.

The predicted drag and the F107-WR-401 engine characteristics were used to compute the vehicle speed, range, and endurance parameters for lg flight at various altitudes and weights. Figure 13 shows typical results. (Additional data are presented in Volume I, Part 2.) The influence of minimum available engine thrust is also shown in Fig. 13. As weight (required C_L) is decreased, induced drag is reduced to the point that the total drag is less than the minimum engine thrust, and unaccelerated level flight is no longer possible. This is seen in Fig. 13b where, at $M_\infty = 0.2$, there is no data point representing a solution for either the range or endurance parameters. Flight at Mach 0.2 would represent either accelerated or climbing flight. Summary plots of the range parameter as a function of altitude for unaccelerated lg flight are presented in Fig. 14. Note that a significantly longer range is generally available at 35,000 ft than at 20,000 ft.

WEIGHT AND BALANCE

The target gross weight for the Tipjet VTOL UAV is 1200 lb, which includes up to 200 lb of payload. Most weight estimates were obtained using the empirical formulations developed by Nicolai.⁷ The resulting component weights in Table 3 assume the use of all metal structures with an ultimate load factor of 4.5. Some of the vehicle structure, however, will be of composite material for which no weight reduction is taken into account. Of the components listed in Table 3, only the engine and the electric generator weights were supplied by the manufacturer. Weight estimates for the components and secondary structures listed in Table 4 have not been determined. This undetermined weight, in combination with the 386 lb

ified in Table 3, is considered to be within the 600-lb allotment for structural weight assumed in the performance analysis.

The position of the longitudinal center of gravity ($x_{c.g.}$) was determined using the structural weights in Table 3 and the supplied payload weights. Figure 15 shows the $x_{c.g.}$ location for all three mission equipment packages at vehicle weights representing full, half, and no remaining fuel load. The line at $x_{c.g.} = 0.31$ in Fig. 15 represents the wing center of lift. For the configuration presented, the location of the aircraft c.g. is insensitive to the fuel load.

PAYLOAD AND CONFIGURATION

The configuration shown in Fig. 16 is carrying the maximum prescribed mission payload with room to accommodate the required 30 percent growth. The internal layout of the vehicle provides space for the propulsion engine and completely separate outlets for the "cold" bypass air and the hot exhaust gases. Bypass air is exhausted into a plenum chamber within the fuselage. When either the tip jets or the Coanda slots are in use, the bypass air will flow from the plenum, up through the wing/rotor bearing, and out the wing. When only part or none of the bypass air is required, the remainder will leave the fuselage through an area surrounding the hot gas exhaust pipe. The bypass exhaust exit area is variable and will be controlled by a valve to automatically maintain a specified pressure in the plenum chamber.

The single fuel tank (Fig. 16) is centered about the wing 50-percent chord, the center of lift for blown airfoils. Tank size is based on storing 400 lb of JP-10 fuel with a specific gravity of 0.935. (JP-10 is considered to be a high density fuel.) For further information regarding JP-10 fuel, see Ref. 8.

WING/ROTOR AERODYNAMIC ANALYSIS

Aerodynamic performance capabilities and design sensitivities for the 1200-lb Tipjet VTOL UAV were evaluated in both rotary-wing and fixed-wing flight regimes. This analysis was carried out with the in-house computer codes CRUISE4 (rotary-wing) and CRUISE5 (fixed-wing). Both performance programs use a blade-element strip theory approach and have the capability of employing circulation control aerodynamics for airfoil performance. The codes have been used extensively at DTRC on previous programs and have been correlated with model test data.

Particular performance characteristics are of interest in each of the various flight conditions. The following is a summary of the flight regimes evaluated with the corresponding performance characteristics of interest:

<u>Flight Regime</u>	<u>Performance Characteristic</u>
Hover	Maximum lift capability
Transition	Control power
Rotary-Wing, Pre-Conversion (145 kn)	1g trim and maximum load factor
Conversion (no blowing, ballistic trajectory)	Trim and loads control
Fixed-Wing, Post-Conversion (145 kn)	Trim sensitivities at 1g and 2.6g's
Fixed-Wing, Cruise (35,000-ft altitude)	Trim and airspeed sensitivities
Fixed-Wing, Dash (M=0.67)	Trim sensitivities

HOVER

In hover, lift is controlled by modulating the blade supply pressure ratio (engine throttling) and blade slot height setting. Engine bypass air provides the circulation control for blade lift and the jet thrust for tip drive. Figure 17a

shows the predicted lift performance map for sea level standard conditions. Maximum rotor lift is constrained by the available bypass air supply rate. The resulting relationship between lift capability and blade root pressure ratio (P_R) is shown in Fig. 17b. As noted in the figure, the design gross weight of 1200 lb can be met with a pressure ratio of 1.9, which is within the supply range of the engine. Blade slot-height to chord ratios of about 0.0006 to 0.0007 are required to provide the necessary blowing levels.

TRANSITION

The aircraft will be started (rotor turning and loaded) while secured to the deck or launching fixture. Upon release, the lifting rotor and the engine thrust will propel the vehicle quickly through the transition speed regime. Control margins during this maneuver are predicted to be more than sufficient.

Vertical landing requires deceleration of the aircraft through the transition speed range. This maneuver is complicated by the excessive residual engine thrust acting to accelerate the aircraft. In order to balance horizontal forces and provide a net decelerating force, the aircraft must be flown at a substantial nose-up attitude. Figure 18a shows the relevant forces acting on the aircraft in hover or in low-speed flight (where drag is negligible). Figure 18b shows the pitch angle required for hover (zero net horizontal force) as a function of aircraft gross weight and engine thrust.

Vehicle attitude must be maintained within a range where the rotor is controllable with cyclic variation of the slot-height setting. The cyclic slot-height control becomes saturated (100 percent) when the slot is commanded closed at some rotor azimuth. Beyond this point, control sensitivity is reduced. Figure 19a shows the relationship between the cyclic control level and rotor pitch at various

aircraft speeds. Nose-up attitude demands increased cyclic control as airflow up through the rotor disc reduces the mean slot-height required for lift. Conditions of 100-percent cyclic level are plotted in Fig. 19b yielding the controllable aircraft pitch envelope.

Comparison of Figs. 18b and 19b reveals that deceleration of the aircraft in level flight depends on the degree to which the engine can be throttled and the gross weight at the time of the maneuver. It is expected that tailoring of the spanwise slot distribution or the incorporation of lower surface blowing slots on the blades will increase the control range. Another alternative is a climbing transition with a settling hover to the deck. These options, however, were not pursued within the scope of this study.

ROTARY-WING, PRE-CONVERSION

Prior to conversion, at 145 kn, the analysis predicts that the rotor can easily generate 1g lift and control moments (Fig. 20a). A 2g pullup maneuver is desirable before the initiation of the ballistic conversion. Figure 20b shows the trimmed maximum predicted lift capability is approximately 2g's at zero-deg attitude and a root pressure ratio of 2.0.

CONVERSION

The Tipjet VTOL UAV concept does not employ higher harmonic control (HHC) of the circulation control blowing to attenuate vibratory loads in conversion. Rather, the aircraft is flown through conversion on a ballistic trajectory with the rotor unloaded (no blowing). Figure 21a shows that the predicted steady forces and moments are minimal at a pitch angle of -3 deg (nose-down), which is chosen as the attitude at which to initiate conversion. As seen in Fig. 21b, the lift and moments

remain small throughout a conversion at -3 deg. If it is necessary, aircraft pitch could be scheduled through conversion to minimize loads.

FIXED-WING, POST-CONVERSION

Results of the analysis that was conducted for fixed-wing flight at 145 kn are shown in Fig. 22. The aircraft lift-to-drag ratio, L/D , (including body flat plate area of 0.675 sq ft) is shown as a function of aircraft pitch angle for conditions of 1g and 2.6g lift. At 1200 lb of lift (Fig. 22a) L/D is relatively insensitive to angle-of-attack. At higher lift (Fig. 22b) it is preferable to operate the wing at a higher angle of attack. The L/D was observed to be independent of the blade slot blowing level; consequently, CC control may be chosen for optimum engine performance (maximum engine thrust). Note that although the 2.6g lift condition represents the highest valid CC blowing level for the available airfoil data base, this does not indicate a known physical limit of lift capability.

FIXED-WING, CRUISE

Parametric tradeoffs were performed for fixed-wing flight at 35,000-ft altitude with a gross weight of 1130 lb. Figure 23 shows the variations of aircraft L/D to changes in airspeed, pitch angle, and blade slot-height. Optimum operating conditions are predicted at $\alpha_s = 0$ deg, $h/c = 0.0015$, and $V_\infty = 257$ kn.

FIXED-WING, DASH

Analytical results for the low altitude, dash overfly segment of the missions are shown in Fig. 24. The L/D is relatively insensitive to pitch angle and blowing level at these high dash speeds ($M = 0.67$). Also, the high speed results in high wing profile drag, which has substantially reduced L/D compared to other fixed-wing

regimes. A small envelope of pitch attitude exists within which the aircraft will trim.

SHIPBOARD SUPPORT

AIRCRAFT-SHIP INTERFACE

For a VTOL UAV, the simplest interface approach is to use an adaptation of the Recovery Assist, Securing and Traversing (RAST) system. Powered traversing is necessary with the 1200-lb Tipjet VTOL UAV because it is too heavy to be safely moved by hand in adverse weather. As envisioned, a carriage for the UAV would rest on the deck with a probe extending into the RAST shuttle. In addition to serving as a handling dolly for moving the vehicle independent of the RAST, the carriage would also contain the charging system for the vehicle batteries, preflight automatic testing and diagnostic equipment, and other support equipment.

The Tipjet VTOL UAV lands and takes off in a nose-high attitude because of the residual engine thrust at low speeds. A platform, shaped to fit the vehicle, would rest on top of the carriage and serve in place of a landing gear. The platform will tilt to accommodate the nose-high attitude during VTOL maneuvers, and hold-downs will engage to secure the vehicle once it settles onto the platform; see Fig. 25.

UAV STORAGE REQUIREMENTS

The preferable means of storing the UAV is in existing hangers, onboard ships with compatible hanger facilities (e.g., LAMPS I or LAMPS III). In this case, the UAV would be moved from the flight deck to the hangar using the existing RAST system where available. Once in the hangar, the vehicle could be lifted by crane and stored on a rack attached to the hangar wall. In some cases, this rack could be

designed to support the vehicle at the proper height for easy maintenance. The wing/rotor would be removable when necessary, and could be stored separately.

Onboard ships that are not equipped with compatible hangars, the UAVs must be stored in water-tight containers adjacent to the flight deck. This arrangement is less desirable for maintenance and servicing, since these functions would have to be performed on the flight deck. This could be a serious limitation when operating in adverse weather.

Additional ship assets must be allocated for UAV support, including shop space for maintenance of payloads and storage space for fuel, expendable stores, and spare parts. Furthermore, the UAV crew complement must be berthed and fed. A more thorough analysis of the total ship requirements to accommodate these new assets is recommended.

CREW REQUIREMENTS

It is assumed that the maintenance and management of the ship systems associated with the UAV (radar, shipboard telemetry systems, fuel handling, and recovery systems) can be handled by the regular ship's crew. A supplementary UAV crew will furnish services uniquely associated with this vehicle. When based on ships equipped for LAMPS helicopters, the UAV crew will merely augment the LAMPS crew as follows:

1 Officer Flight management, safety

5 Enlisted Maintenance, handling

If this vehicle is based where there are no other aviation assets, the complement will be nearly as large as a LAMPS crew including:

2 Officers System management, flight management, safety

10 Enlisted All maintenance functions, vehicle handling

MISSION DESCRIPTIONS

The three specified missions for the 1200-lb Tipjet VTOL UAV are Tactical Reconnaissance (ship-based), Over-the-Horizon Targeting (ship-based), and Combat Support Reconnaissance (ground-based). As defined in the DoD Joint UAV Program Master Plan, these are mid-range missions. Complete operational scenarios are described in Ref. 3.

In the following sections, mission profiles are presented along with mission descriptions and specific equipment required. For the Tactical Reconnaissance and Combat Support Reconnaissance Missions, the equipment packages are identical. The mission equipment for the Over-the-Horizon Targeting Mission is lighter weight, allowing additional fuel to be carried, if needed. For the design calculations presented, the mission equipment weight is assumed to be 30 percent higher than the total weight for each package to allow for vehicle and equipment growth. The volume and power requirements of mission equipment were supplied by NADC and are listed in Table 5. Sensor cooling is assumed to be included in the specified weights, volumes, and power.

TACTICAL RECONNAISSANCE

The Tactical Reconnaissance mission profile is illustrated in Fig. 26. This ship-based mission is intended to provide information on shore targets for amphibious operations or bombardment. Low altitude, maximum velocity transit to and over the target area is necessary to limit exposure of the UAV to enemy weapons. The mission is composed of the following legs:

- A. Launch from ship, 300 nmi (maximum) from target area.
- B. Climb to best cruise range altitude.
- C. Transit 250 to 260 nmi toward target area.

- D. Descend to 500- to 1000-ft altitude.
- E. Transit 50 nmi to overfly target area at maximum speed.
- F. Climb to best range altitude.
- G. Transit 300 nmi at best range speed to recovery ship.
- H. Conduct recovery.

The following equipment, with weight, volume, and power requirements, is needed for this mission:

Mission Equipment	Weight, lb	Volume, ft	Power, A (28Vdc)
Data Link	12.5	0.22	6.1
Control and Navigation	62.1	1.23	6.2
Sensors	28.7	0.52	8.9
Recorder	<u>25.0</u>	<u>0.95</u>	<u>1.5</u>
Basic Payload	128.3	2.92	22.7
30-Percent Growth	166.8		

OVER-THE-HORIZON TARGETING

This ship-based mission is designed to localize and classify surface targets, maintain real time surveillance during attack, and provide damage assessment following the engagement. Air-launched or surface-launched missiles, such as the Harpoon and the Tomahawk, are envisioned for attacking the target(s). The Over-the-Horizon Targeting Mission, illustrated in Fig. 27, is composed of the following legs:

- A. Launch from ship.
- B. Climb to best cruise range altitude.

- C. Transit devious path to target area at a 130 nmi Radius of Action (ROA) from host ship.
- D. Descend to 1000- to 2000-ft altitude.
- E. Fly within 15 nmi radius area (50 nmi path) to classify six or more contacts.
- F. Climb to best loiter altitude and loiter until commanded to perform Battle Damage Assessment (BDA) (20 to 30 min).
- G. Descend to 1000- to 2000-ft altitude.
- H. Fly within 15 nmi radius area (50 nmi path) to perform BDA.
- I. Climb to best loiter altitude and loiter (20 to 30 min).
- J. Descend to 1000- to 2000-ft altitude.
- K. Fly within 15 nmi radius area to perform BDA on three or more contacts.
- L. Climb to best cruise range altitude.
- M. Return to ship.
- N. Conduct recovery (10 to 15 min).

The following equipment, with weight, volume, and power requirements, is needed for this mission:

Mission Equipment	Weight, lb	Volume, ft	Power, A (28Vdc)
Data Link	12.5	0.22	6.10
Control and Navigation	46.1	0.74	4.00
Sensor	4.1	0.04	0.25
Sensor Electronics	<u>11.0</u>	<u>0.23</u>	<u>5.40</u>
Basic Payload	73.7	1.23	15.75
30-Percent Growth	95.8		

COMBAT SUPPORT RECONNAISSANCE

The Combat Support Reconnaissance Mission is intended to provide information on potential target areas to a ground-based commander. The mission profile is shown in Fig. 28. The mission is composed of the following legs:

- A. Surface launch from land-based area.
- B. Climb to best cruise range altitude.
- C. Transit 150 nmi to first target area.
- D. Descend to 5000- to 6000-ft altitude.
- E. Fly 1 nmi at maximum speed (300-ft bridge).
- F. Climb to best cruise range altitude.
- G. Fly 75 nmi to next target area.
- H. Descend to 3000- to 4000-ft altitude.
- I. Fly 3 nmi at maximum speed (fuel storage area).
- J. Climb to best cruise range altitude.
- K. Fly 75 nmi to next target area.
- L. Descend to 1000- to 2000-ft altitude.
- M. Fly 10 nmi at maximum speed (vehicle staging area).
- N. Climb to best cruise range altitude.
- O. Loiter for maximum allowable time.
- P. Transit 150 nmi to recovery area.
- Q. Conduct recovery (10 to 15 min).

The following equipment, with weight, volume, and power requirements, is needed for this mission:

Mission Equipment	Weight, lb	Volume, ft	Power, A (28Vdc)
Data Link	12.5	0.22	6.1
Control and Navigation	62.1	1.23	6.2
Sensor	28.7	0.52	8.9
Recorder	<u>25.0</u>	<u>0.95</u>	<u>1.5</u>
Basic Payload	128.3	2.92	22.7
30-Percent Growth	166.8		

RESULTS AND DISCUSSION

The mission analysis procedures were developed simultaneously with the conceptual layout, design, and detailed performance predictions for the Tipjet VTOL UAV. An initial engineering estimate of the gross weight, payload, and fuel for the vehicle was used to perform the mission analysis. Generally, the mission began with an assumed gross weight of 1200 lb, a payload of 200 lb, and a fuel weight of 400 lb. (A variation in fuel weight was required for the Over-the-Horizon Targeting Mission.) Note that no fuel reserve was specified for any of the three missions. The aircraft layout, design, performance prediction, and mission analysis were all reconciled prior to accepting the three missions as successfully completed. Calculations for each segment of the missions were based on the conditions at the end of the previous leg.

During the study, emphasis was on successful completion of the design missions. Optimization of the mission performance was not attempted. However, a limited examination was conducted to determine the effect of the assumed flight profile on the resultant segment duration and fuel burned. Figure 29 shows the sensitivity of

time and fuel used to climb to an arbitrary altitude and to cruise so that the combined horizontal distance covered is 75 nmi; see Flight Profile insert, Fig. 29. For this profile, the best altitude for cruise is 15,000 ft, considering both total time and total fuel used.

Tables 6, 7, and 8 summarize the mission study results. The equations and assumptions presented in the Vehicle Performance Method section were used to calculate time, fuel used, and distance covered for each mission segment. The segment final weight is determined by subtracting the weight of fuel expended during the segment. For each mission leg, either the length of time or the distance covered is the critical parameter in determining the amount of fuel used. The appropriate representation of fuel usage for each segment is presented in the tables. These parameters enable both the designer and the warfare commander to assess where best to use available fuel during the mission. For the mission analysis, the difference between the assumed payload (200 lb) and the specified payloads represents a margin of 17 to 36 percent.

TACTICAL RECONNAISSANCE MISSION

Key specifications for the Tactical Reconnaissance Mission are: (1) Information shall be available no later than two hours after launch. (2) The mission range shall not be less than 600 nmi. (3) The mission shall be performed at the maximum surface launch weight with necessary payload. The 1200-lb Tipjet VTOL UAV meets or exceeds these mission specifications.

As shown in Table 6, hover and recovery are costly in terms of fuel consumed per hour and, therefore, must be closely managed. Another critical flight condition for fuel consumption is the high-speed dash at low altitude. Aircraft recovery was

conducted with 15 percent remaining fuel and with no fuel reserve, which allowed for recovery times of 2 and 10 min, respectively. (No requirement was specified for reserve fuel.) The assumed payload weight of 200 lb exceeds the specified payload weight of 128 lb (167 lb with 30 percent growth). Thus, a 33- to 72-lb margin can be applied to additional mission fuel and/or other component weights.

OVER-THE-HORIZON TARGETING MISSION

Key specifications for the Over-the-Horizon Targeting Mission are: (1) Vehicle endurance shall not be less than two hours. (2) The mission shall be performed at the maximum surface launch weight with necessary payload. The 1200-lb Tipjet VTOL UAV meets or exceeds these mission specifications.

For the Over-the-Horizon Targeting Mission, the payload was adjusted to 121 lb and the fuel weight to 479 lb. Hover, recovery, and loiter are the critical legs of the mission where fuel usage must be closely managed. These results, including both 10- and 15-minute recoveries, are presented in Table 7. The specified base payload is 74 lb (96 lb with 30 percent growth). The assumed payload of 121 lb allows an additional 47 lb (25 lb) that can be used throughout the mission.

During the analysis of this mission, an extraneous climb-loiter-descent series (segments I, Ia, J, K in Table 7) was identified in the mission profile that does not correspond to any specification of the operational scenario. Communication with NADC verified that the series of segments was inadvertently included in the mission profile. Because the inclusion of these additional legs did not prevent the successful completion of the mission, the mission results have not been modified. It is recommended, however, that segments I through K be removed from the mission specifications.

COMBAT SUPPORT RECONNAISSANCE MISSION

Key specifications for the Combat Support Reconnaissance Mission are:

(1) Information shall be available no later than two hours after launch. (2) The mission shall be performed at the maximum surface launch weight with necessary payload. The 1200-lb Tipjet VTOL UAV meets or exceeds these mission specifications.

Table 8 shows hover and recovery again consuming considerable fuel per hour and, therefore, fuel must be closely managed. The specified recovery maneuver time is 10 to 15 min. Although the results presented in Table 8 are for only a 10-min recovery, with the assumed payload, sufficient fuel is available for a 15-min recovery. The specified payload is 128 lb (167 lb with 30 percent growth). The assumed payload of 200 lb allows an additional 72 lb (33 lb) that can be used throughout the mission.

SUMMARY AND RECOMMENDATIONS

A conceptual design study was conducted for a 1200-lb Tipjet VTOL UAV. The vehicle component layout was established, and the static weight and balance was satisfied. A compatible, off-the-shelf powerplant (Williams International F107-WR-401 turbofan engine) was identified. Engine performance characteristics were determined and used directly in the mission analysis.

The Tipjet VTOL UAV is shown to be a viable candidate to fulfill the missions designated for a dry, at-sea, recoverable unmanned vehicle. All three design missions, Tactical Reconnaissance, Over-the-Horizon Targeting, and Combat Support Reconnaissance, were accomplished using standard conceptual design performance methods. (Note that the Over-the-Horizon Targeting mission profile includes extraneous segments and should be revised.) Hover, climb, and low-altitude, high-speed flight, due to their high rate of fuel consumption, are considered critical

mission segments. Fuel management, therefore, will be an important consideration in design development and operation of the Tipjet VTOL UAV. Estimated payloads, used in the mission analysis exceed both the baseline weight specifications and the designated 30-percent growth allowance.

The Williams F107-WR-401 engine, which was selected for its size, pressure ratio, and bypass flow capability, has limitations on minimum thrust that inhibit optimum fixed-wing flight efficiency. Engine performance, however, is adequate to satisfy the design mission specifications. In low-speed, rotary flight, residual engine thrust requires that the vehicle assume a nose-up attitude in order to decelerate (in steady, level flight) and hover. Depending on the specifics of the final configuration, special design or operational considerations may be required to control the vehicle in this flight regime. (Tentative solutions for these requirements are suggested in the section titled Transition.)

Various auxiliary equipment and ship assets are necessary to support the Tipjet VTOL UAV. The vehicle is compatible with current and future LAMPS-capable ships, and operations can be adapted to allow basing on smaller ships. With its VTOL capabilities, this concept has substantial advantages over concepts employing other launch and recovery methods.

In addition to successfully addressing the targeting and reconnaissance missions in this conceptual design study, the 1200-lb Tipjet VTOL UAV embodies the flight demonstration of a concept that is applicable to a much larger vehicle. Early in the next century, 12,000-lb ship-based UAVs capable of 12-hour, on-station loiter with 2,000-lb sensor payloads will be necessary to counter the threat of stealthy, supersonic, sea-skimming missiles. The Tipjet VTOL UAV, with excellent high-altitude loiter characteristics and VTOL shipboard capabilities, has the unique potential to fulfill this requirement. Furthermore, the concept will pioneer an

array of mission applications for which heavier payloads and/or greater speed, range, altitude, and endurance are required. Development of the Tipjet VTOL UAV should be pursued vigorously both for the direct application as a 1200-lb UAV and, even more importantly, for the breakthrough capability of operating large, long-endurance UAVs from combatant ships.

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Fig. 1. 1200-lb Tipjet VTOL UAV.

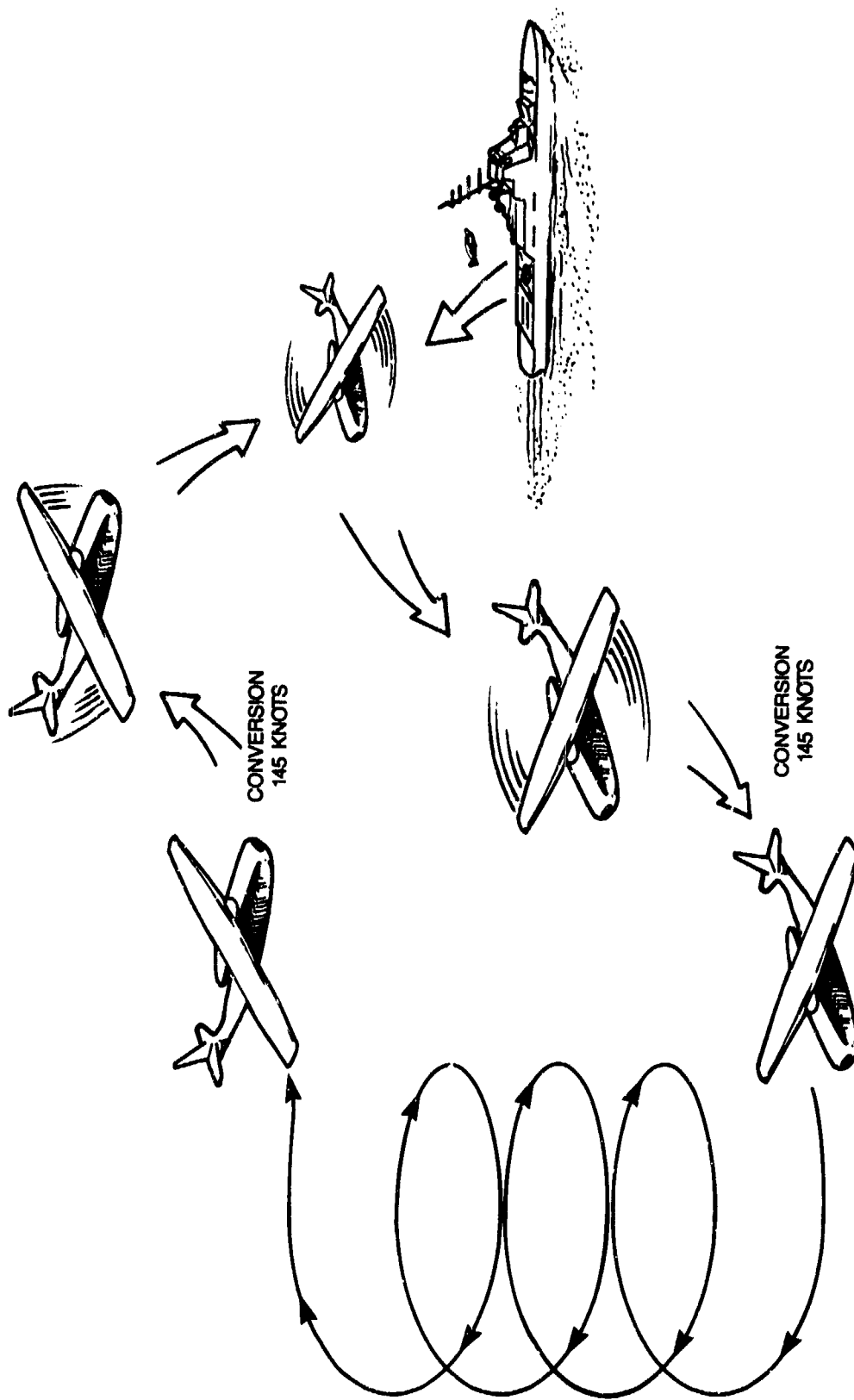
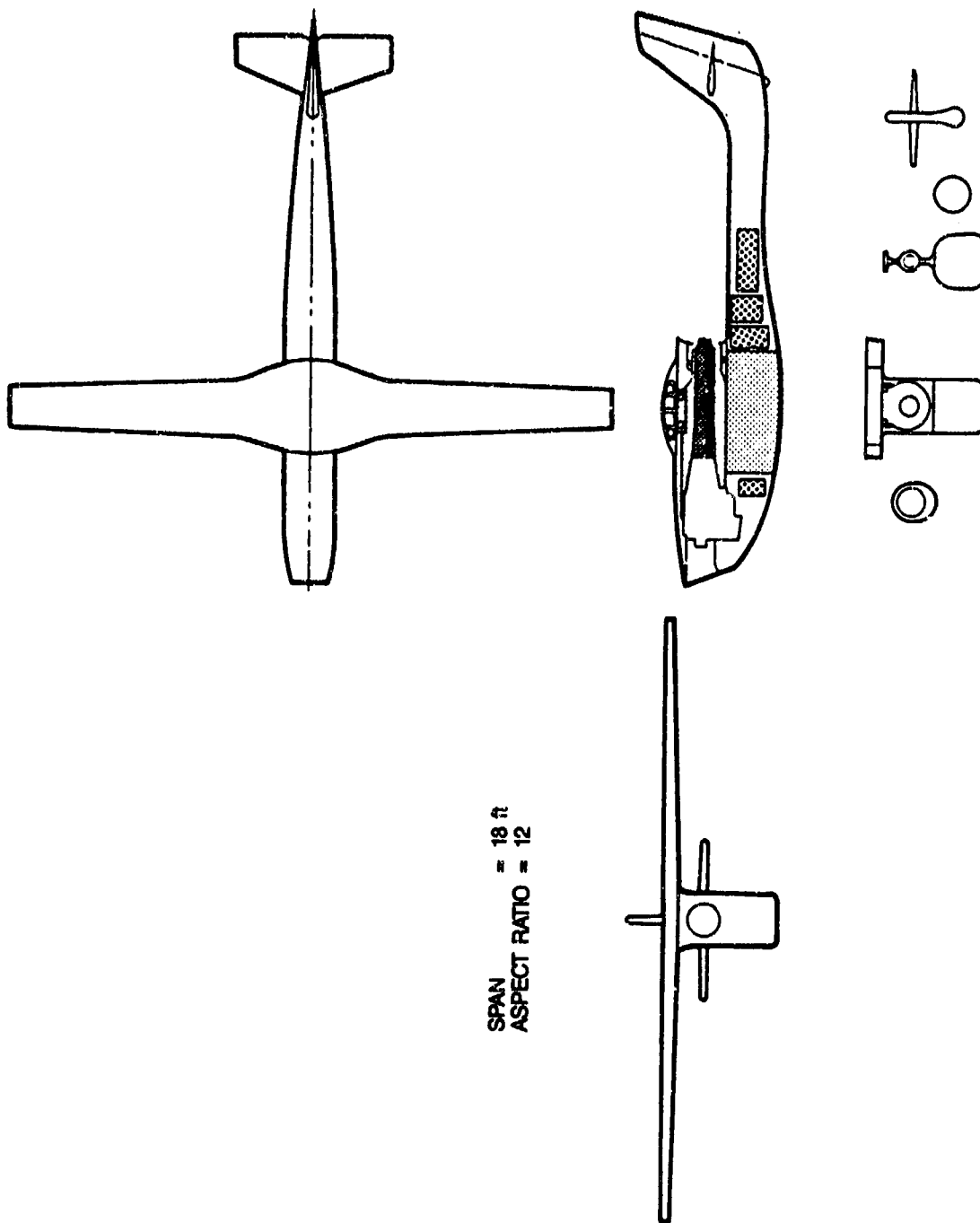


Fig. 2. Operational scenario.



SPAN = 18 ft
ASPECT RATIO = 12

Fig. 3. Three-view of 1200-lb Tipjet VTOL UAV.

HOVER TYPICAL AIRFLOW CONDITION

LIFT = 1200 lb
 $P_R = 1.9$
 $A_{jet} = 0.0345 \text{ ft}^2$
 $V_{jet} = 1103 \text{ ft/sec}$
 $\dot{m}_{jet} = 2.72 \text{ lb/sec}$
 $\dot{m}_{act} = 0.48 \text{ lb/sec}$

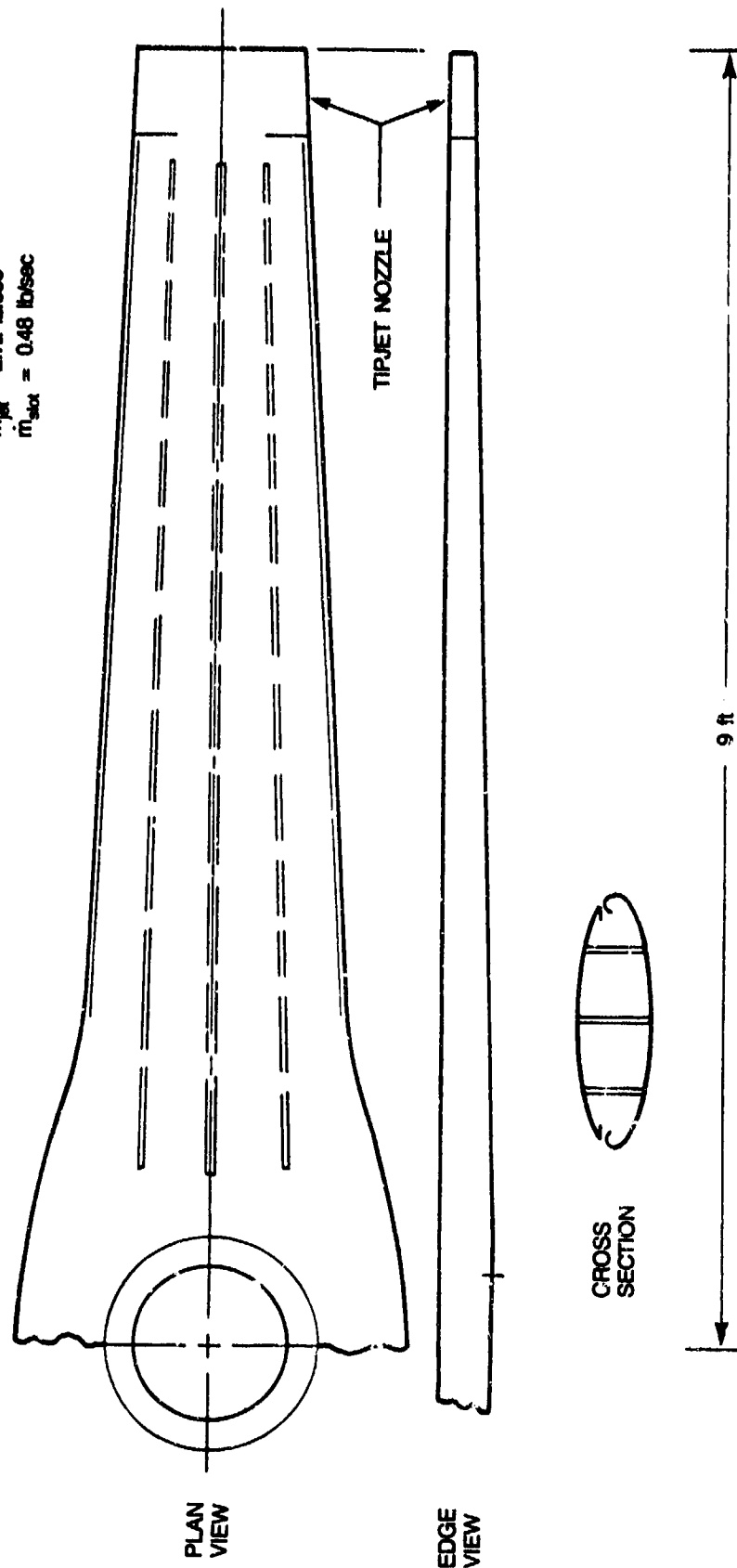


Fig. 4. Wing geometry.

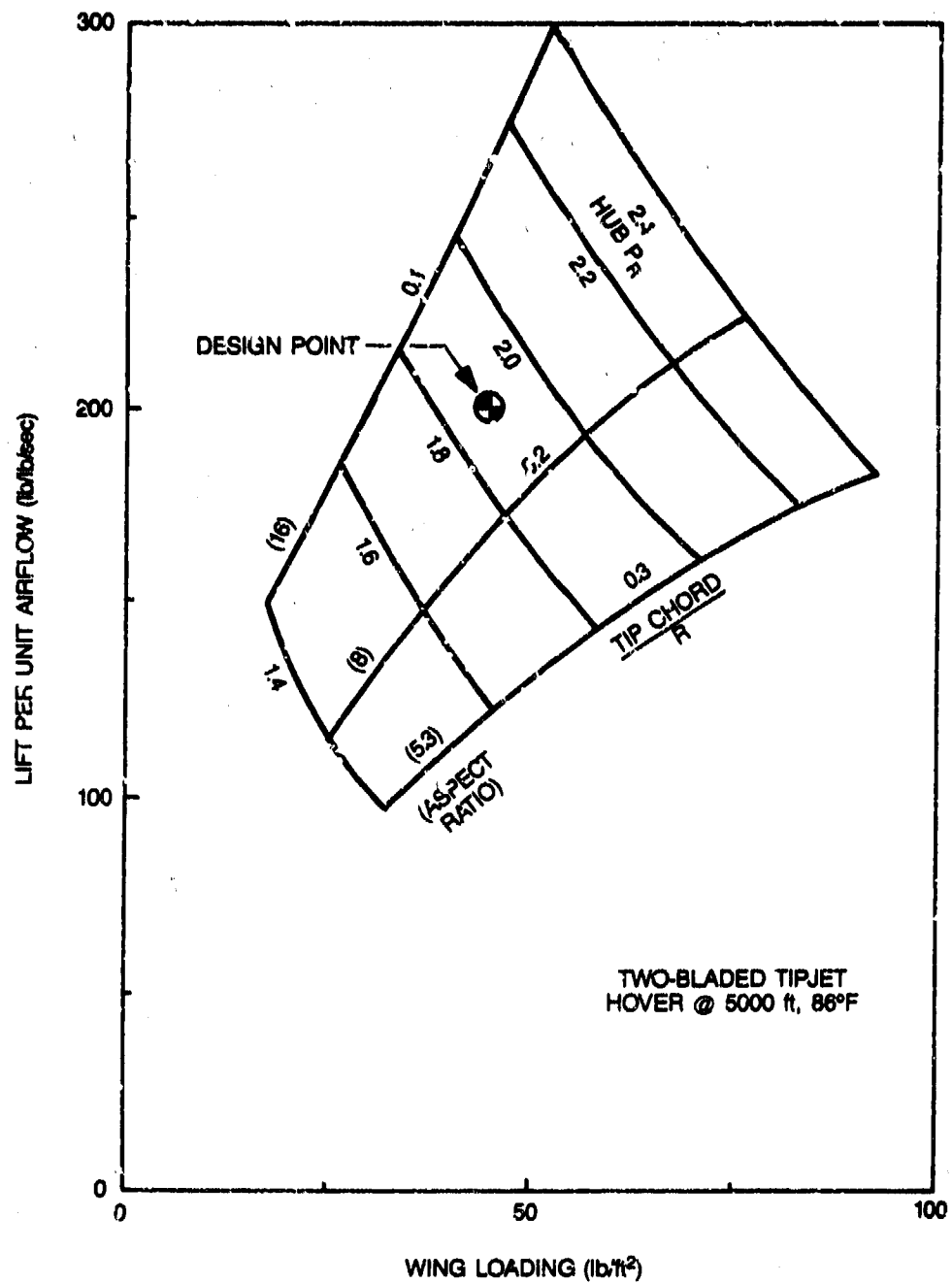


Fig. 5a.

Fig. 5. Tipjet wing/rotor hover performance.

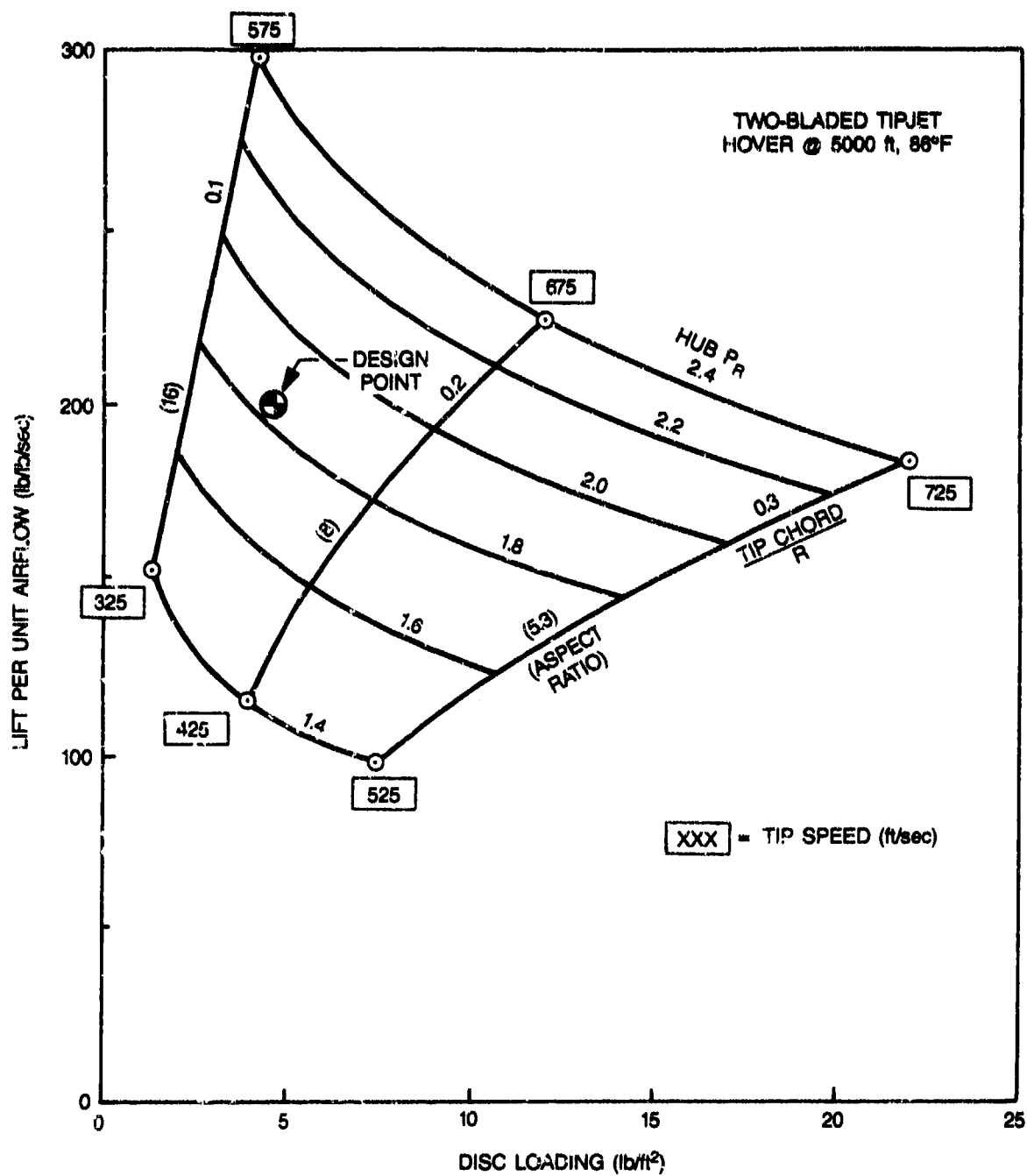


Fig. 5b.

Fig. 5. (Continued)

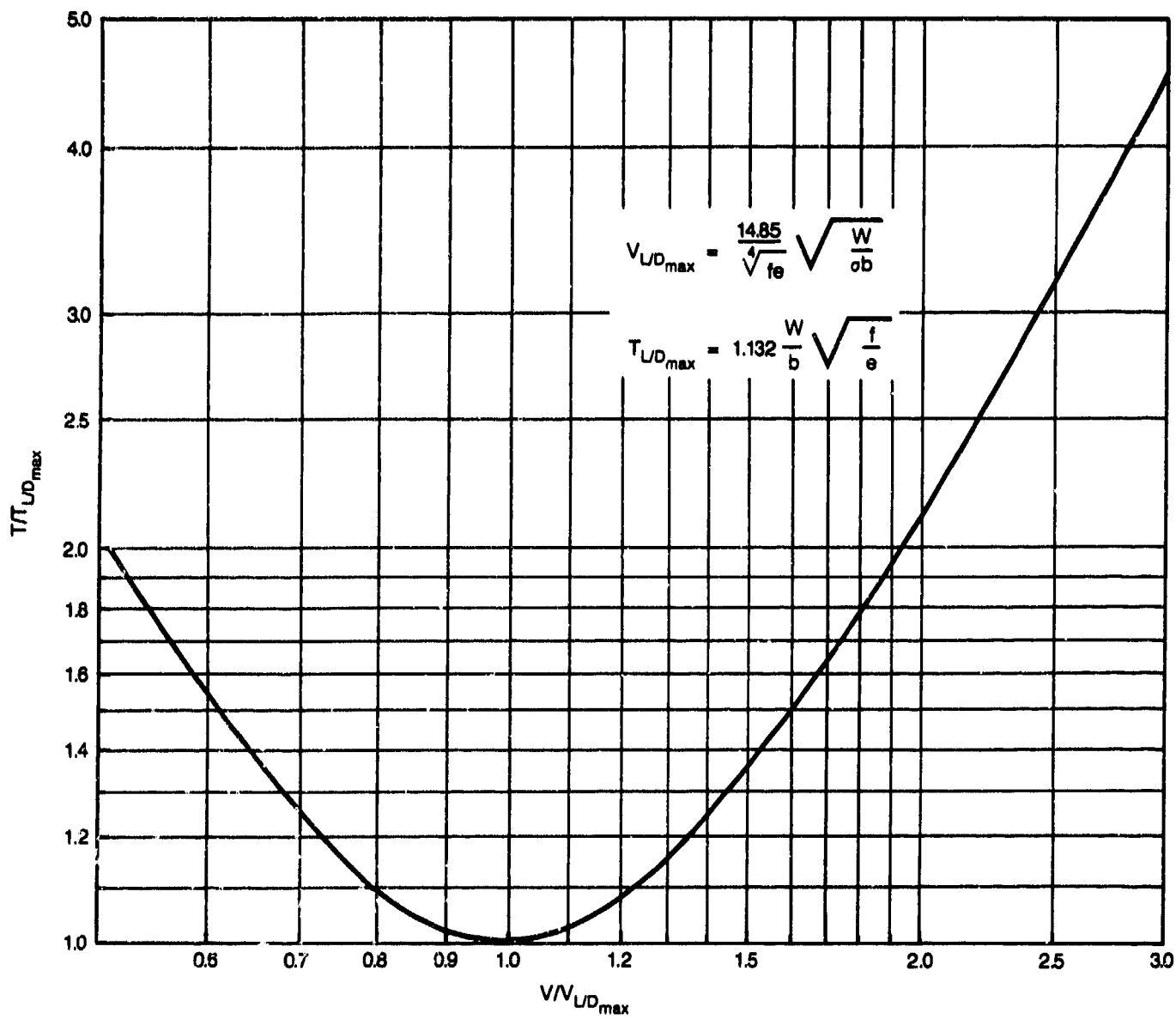


Fig. 6. Generalized thrust-required curve.
(From Perkins and Hage⁶)

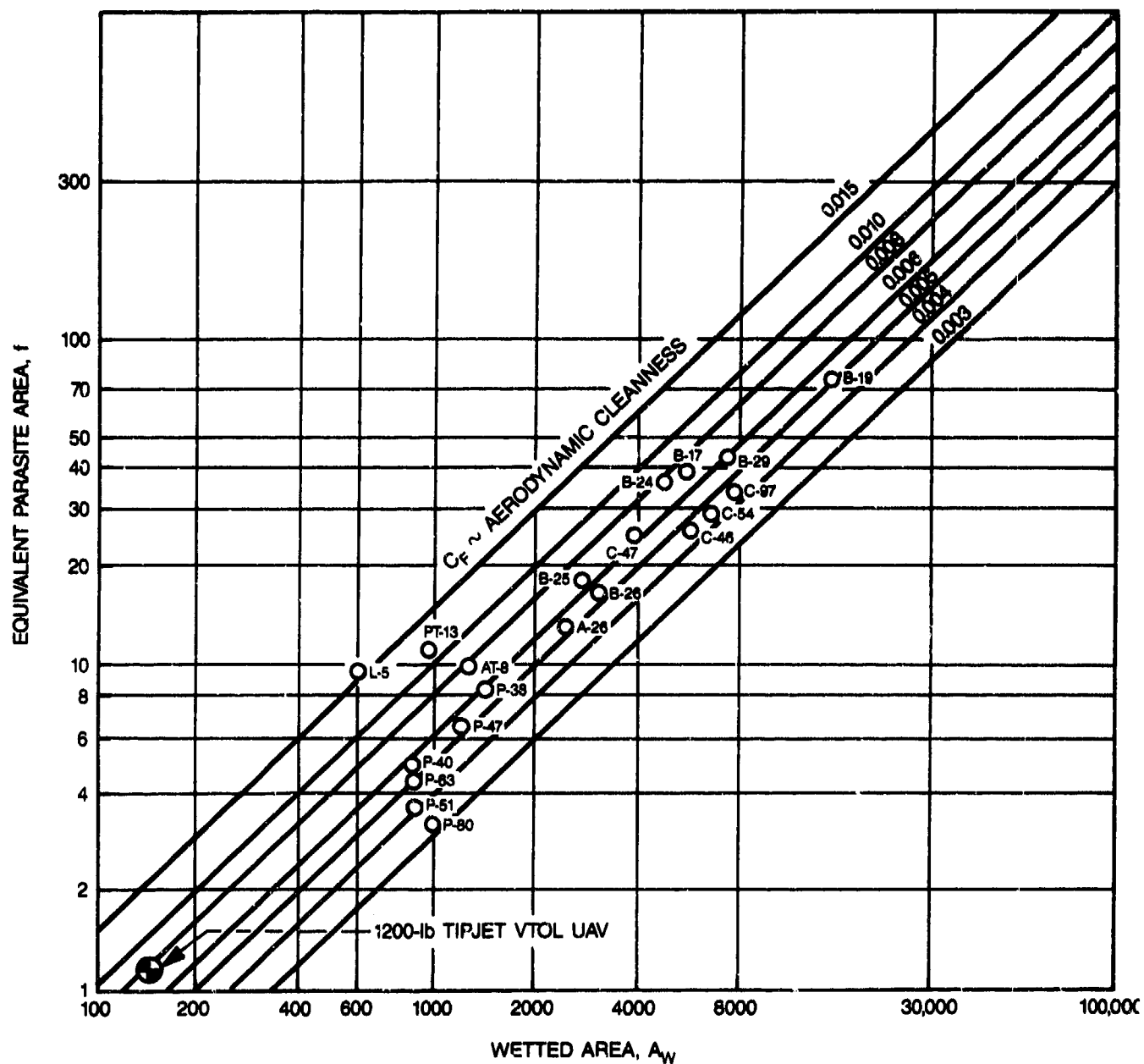


Fig. 7. Wetted area chart.
(From Perkins and Hage⁶)



Fig. 8. Cutaway of Williams F107-WR-400 engine.

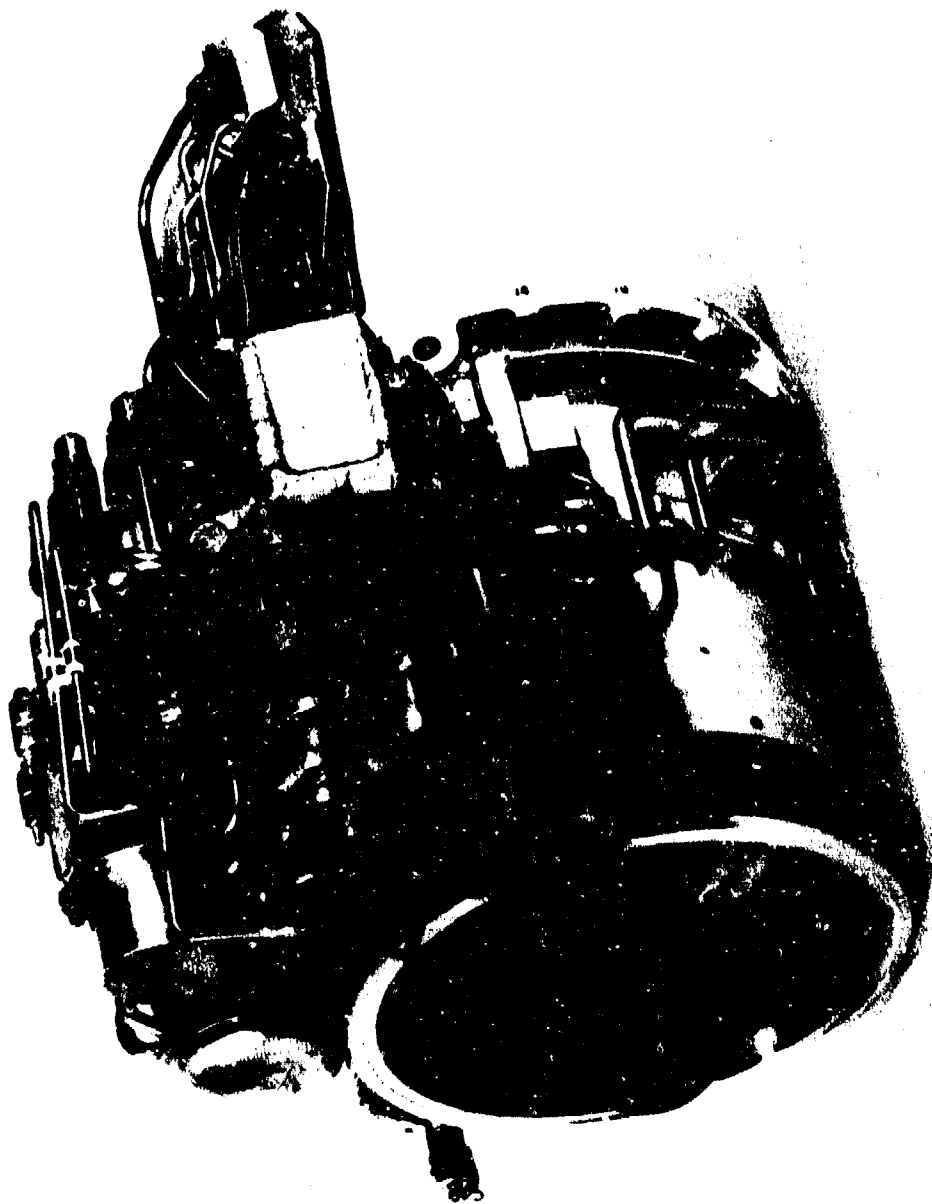


Fig. 9. Exterior of Williams F107-WR-400 engine.

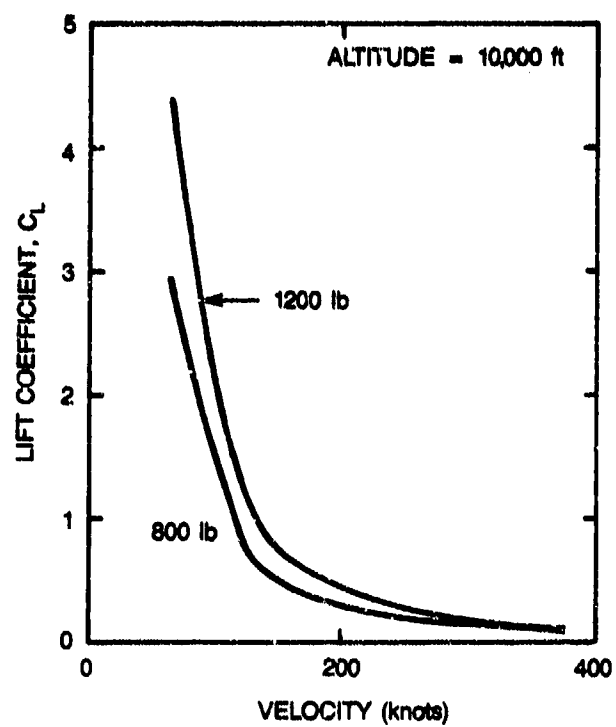


Fig. 10. Tipjet VTOL UAV required lift coefficient.

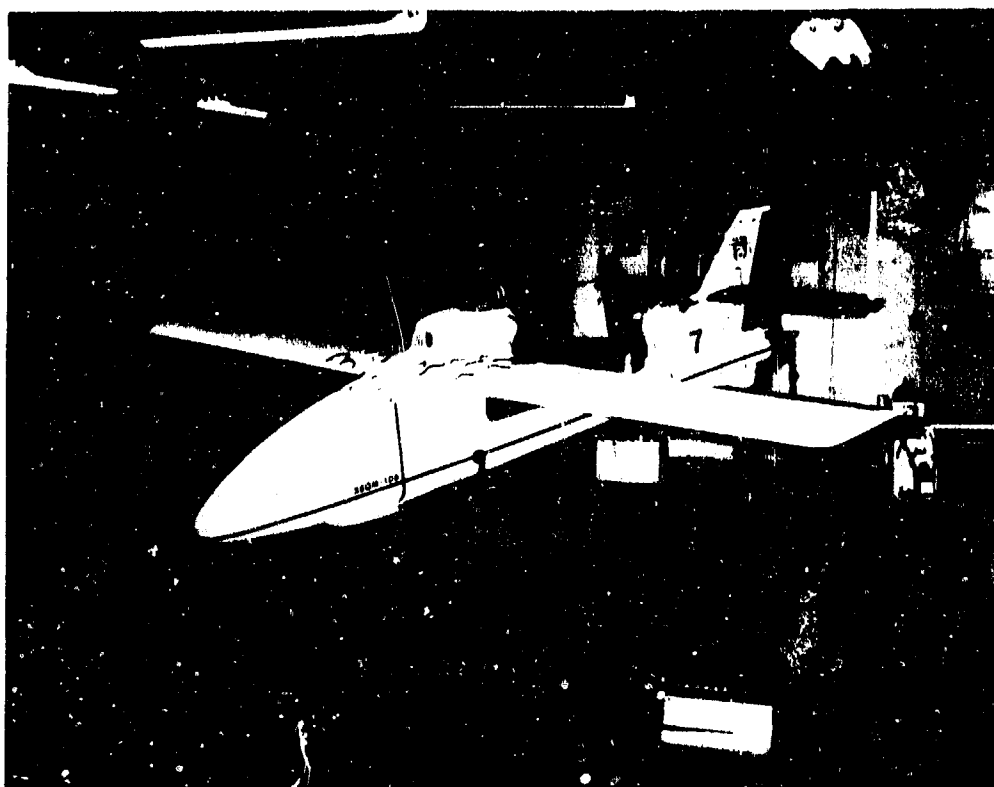


Fig. 11. XBQM-106 mini-RPV powered model.

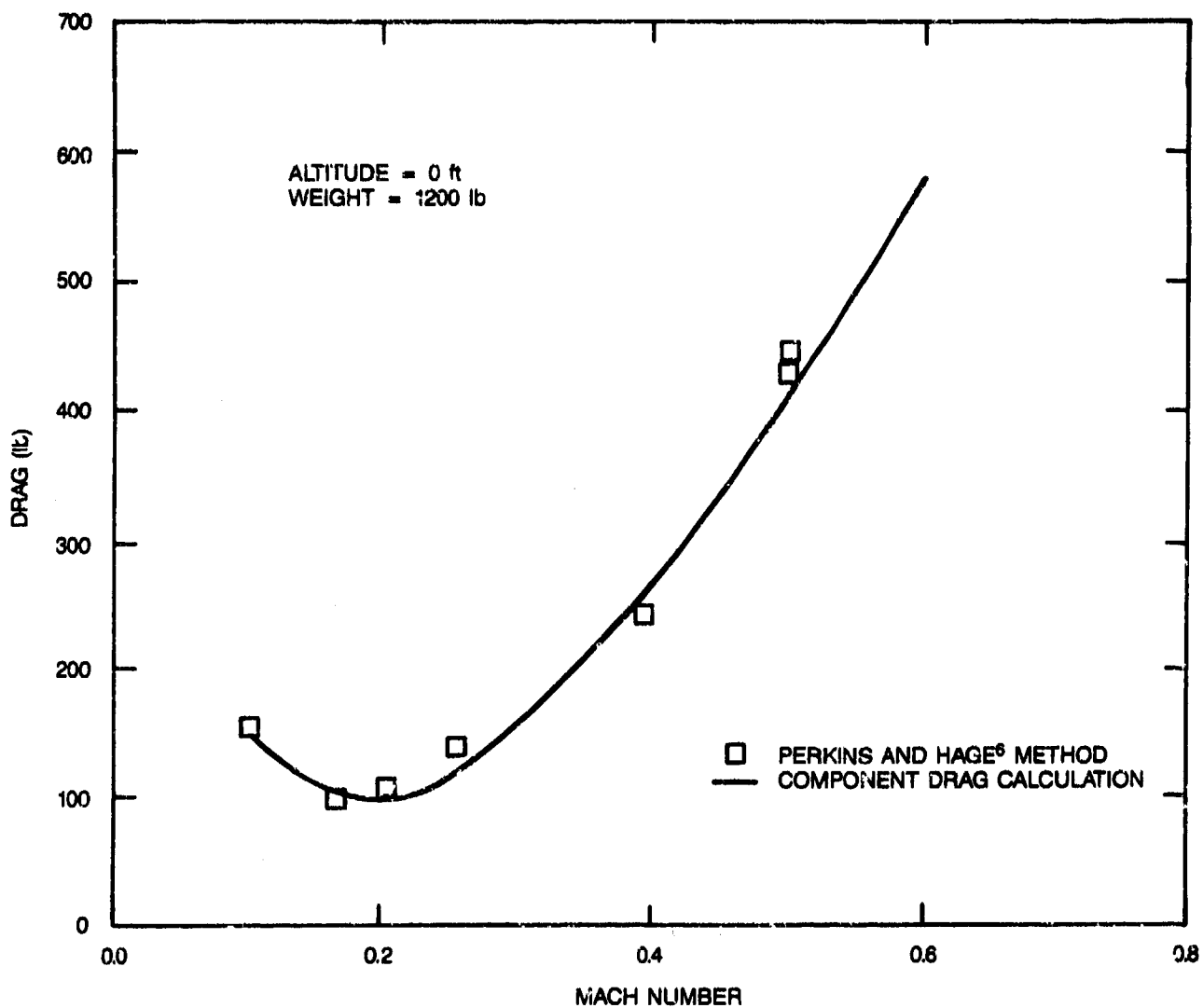


Fig. 12. Tipjet VTOL UAV drag calculation comparison.

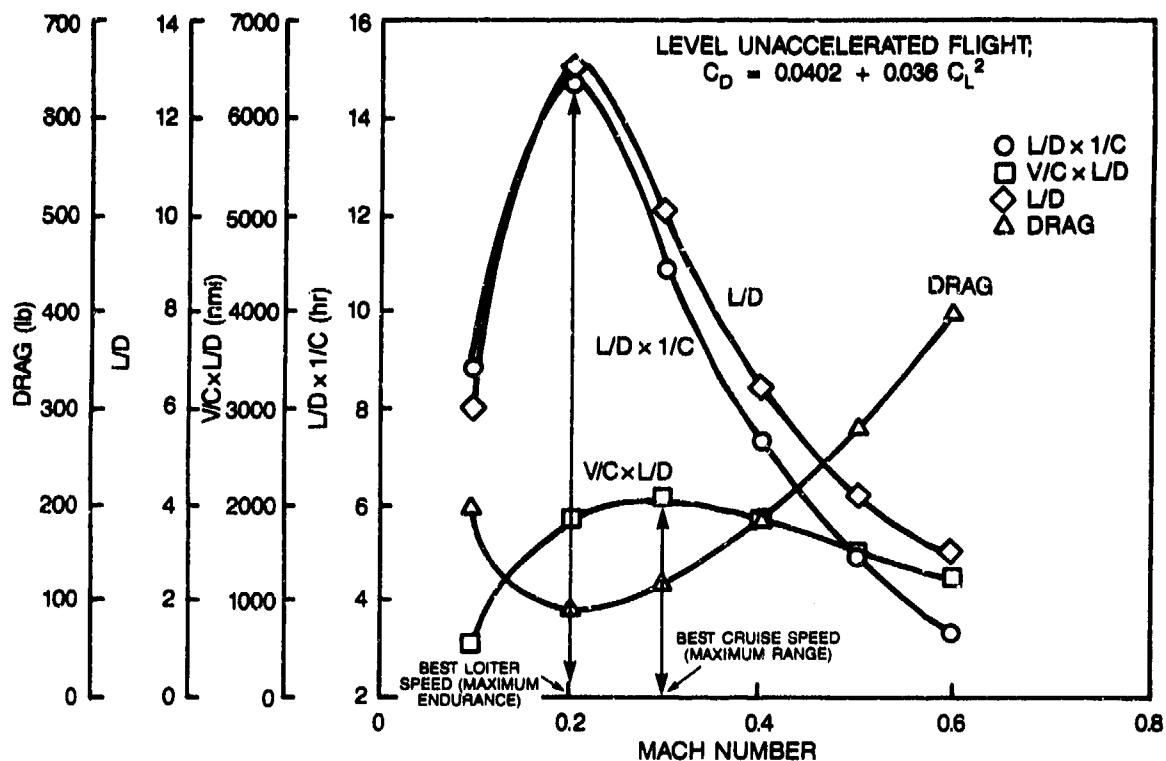


Fig. 13a. Altitude = 10,000 ft, gross weight = 1200 lb.

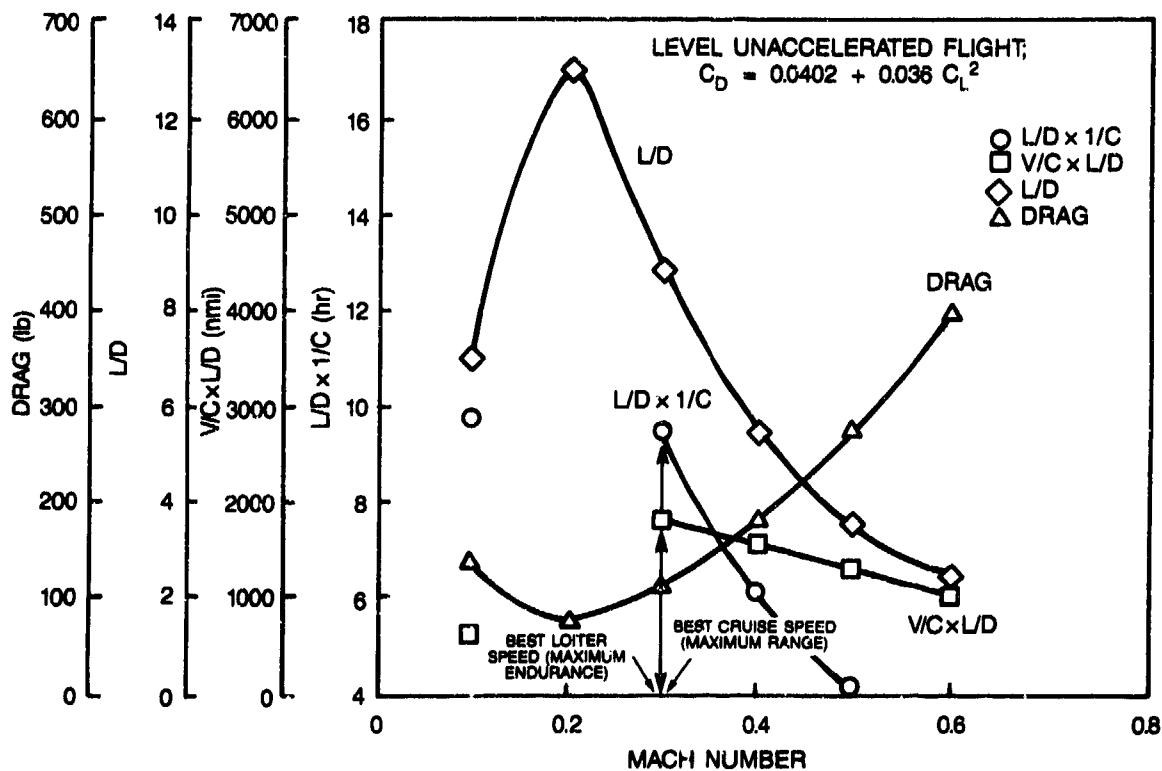


Fig. 13b. Altitude = 10,000 ft, gross weight = 1000 lb.

Fig. 13. Speed, range, and endurance parameters.

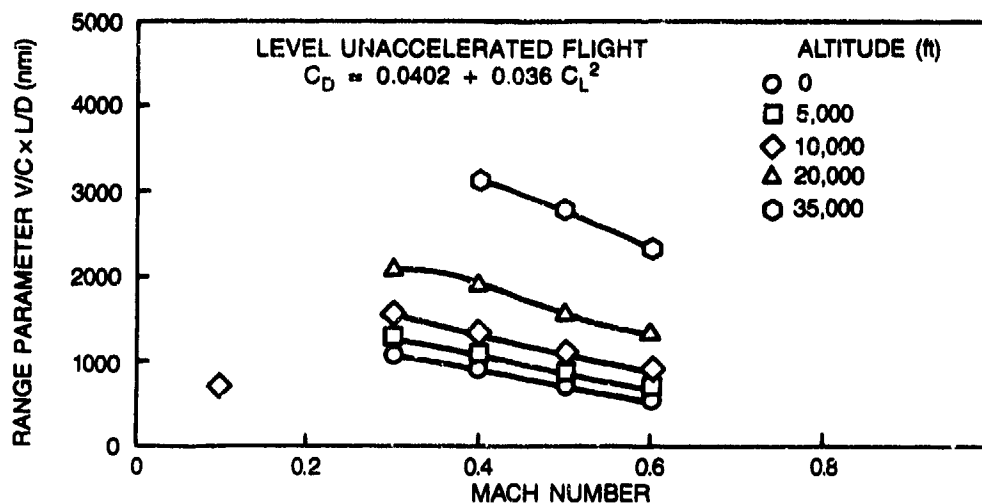


Fig. 14a. Weight = 800 lb.

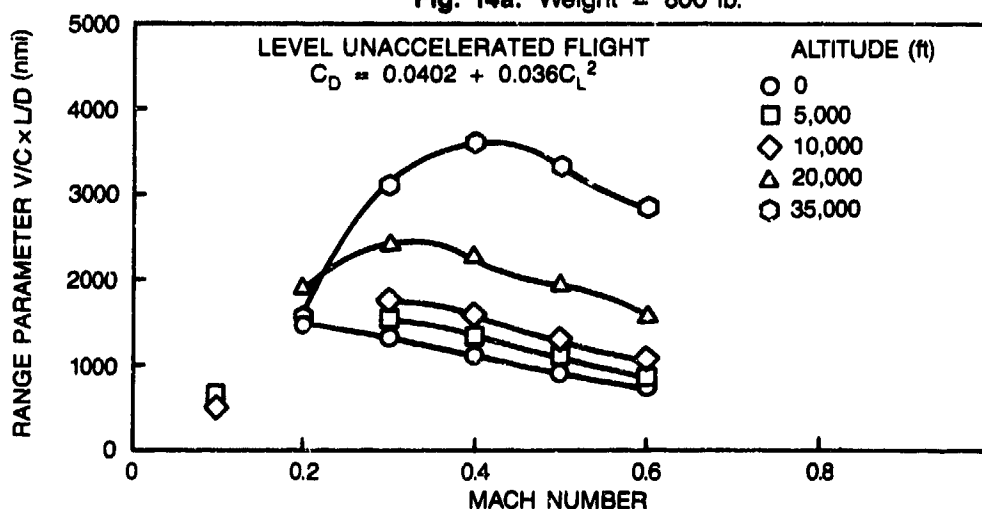


Fig. 14b. Weight = 1000 lb.

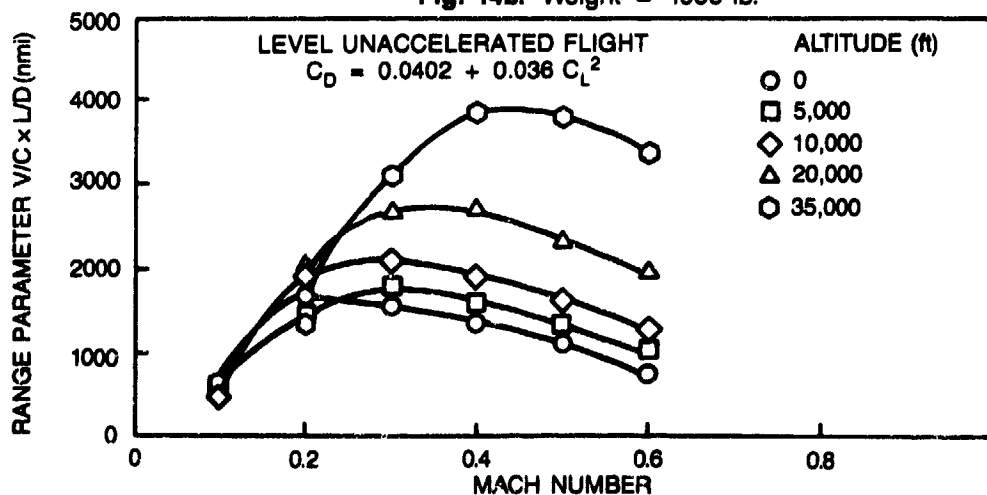


Fig. 14c. Weight = 1200 lb.

Fig. 14. Range parameter at various altitudes.

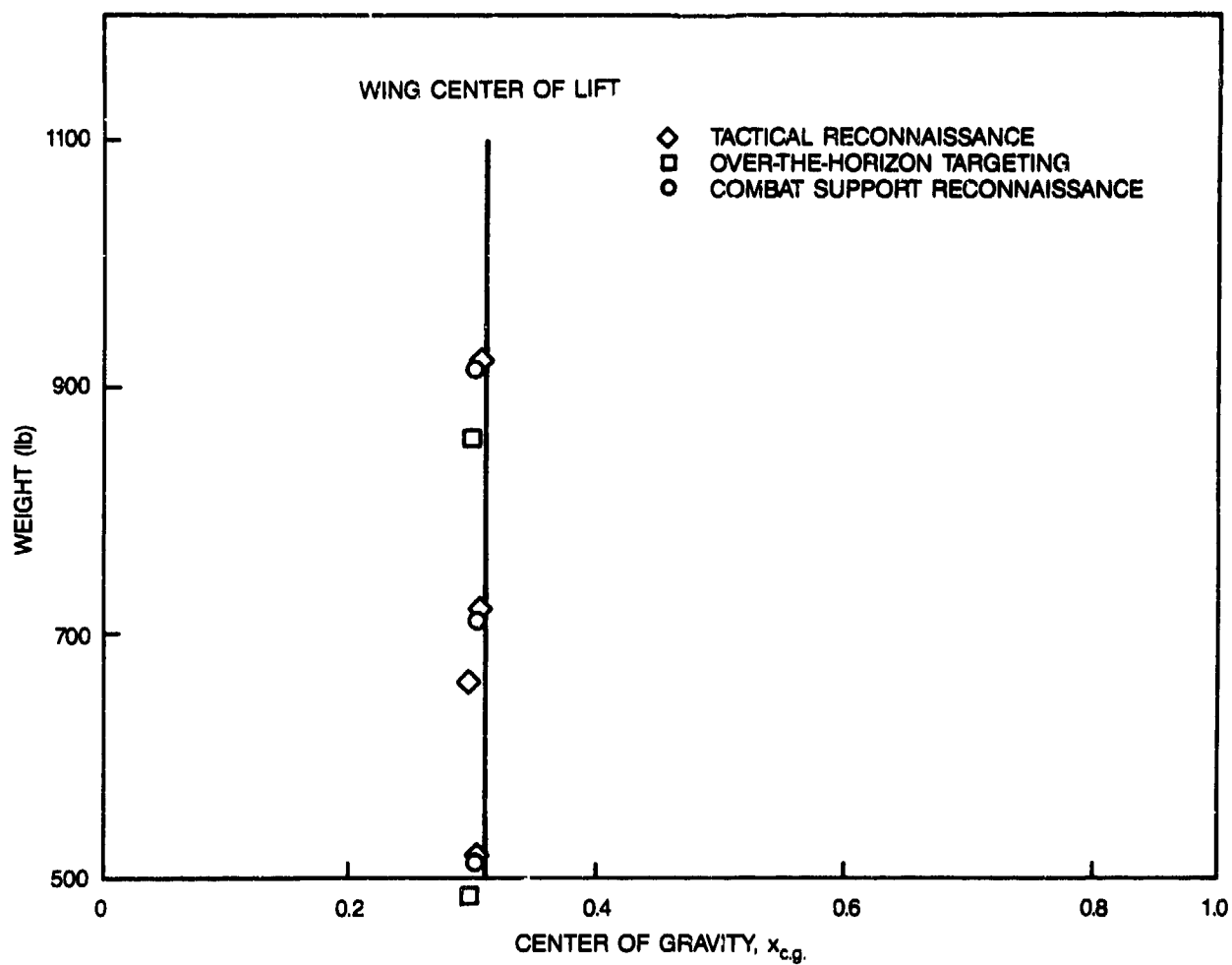


Fig. 15. Center-of-gravity location.

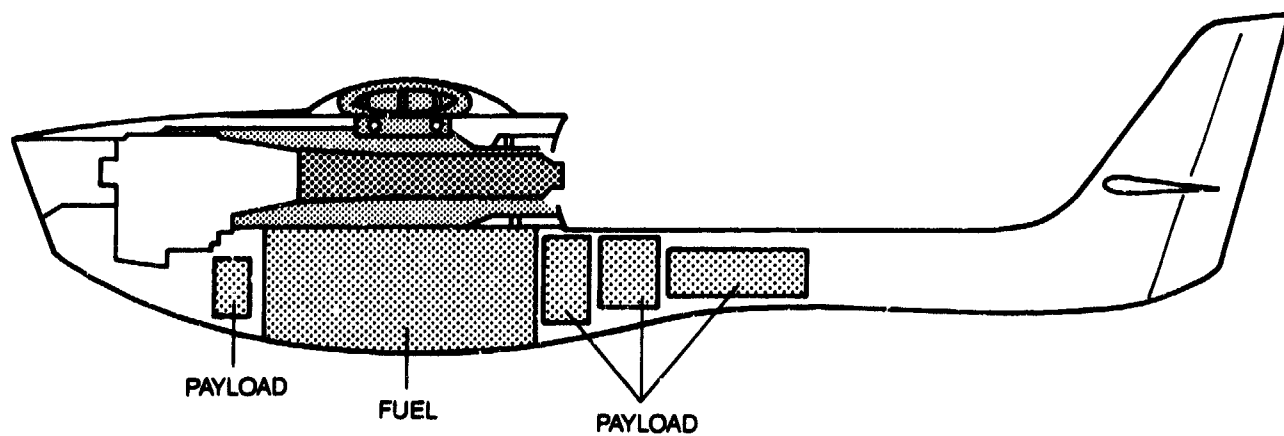


Fig. 16. Payload configuration.

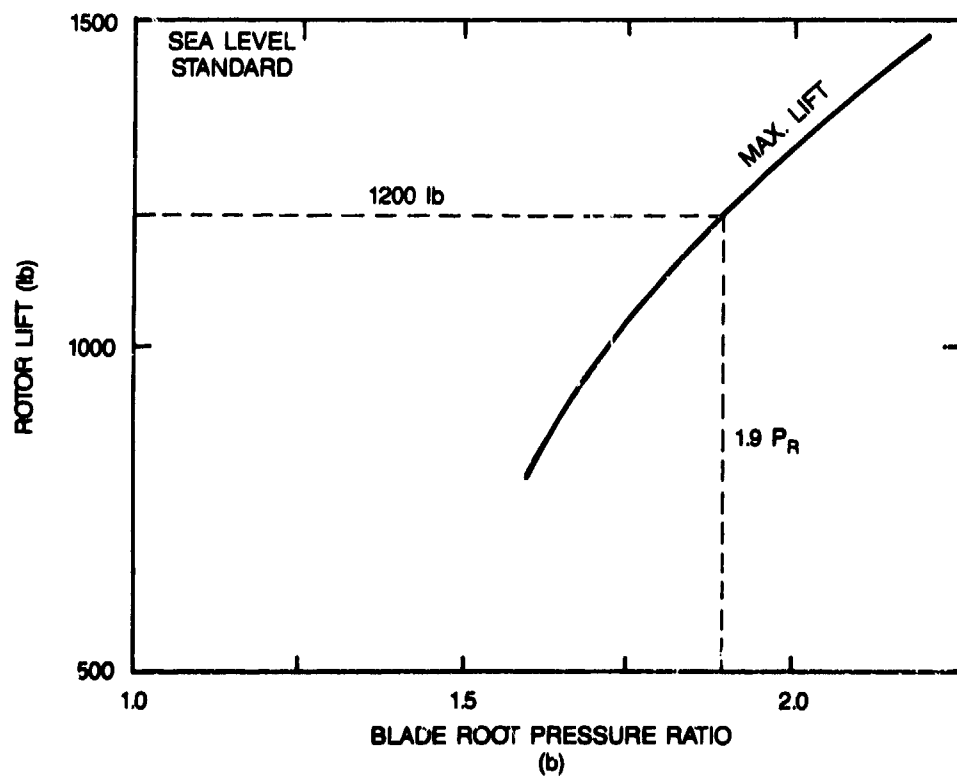
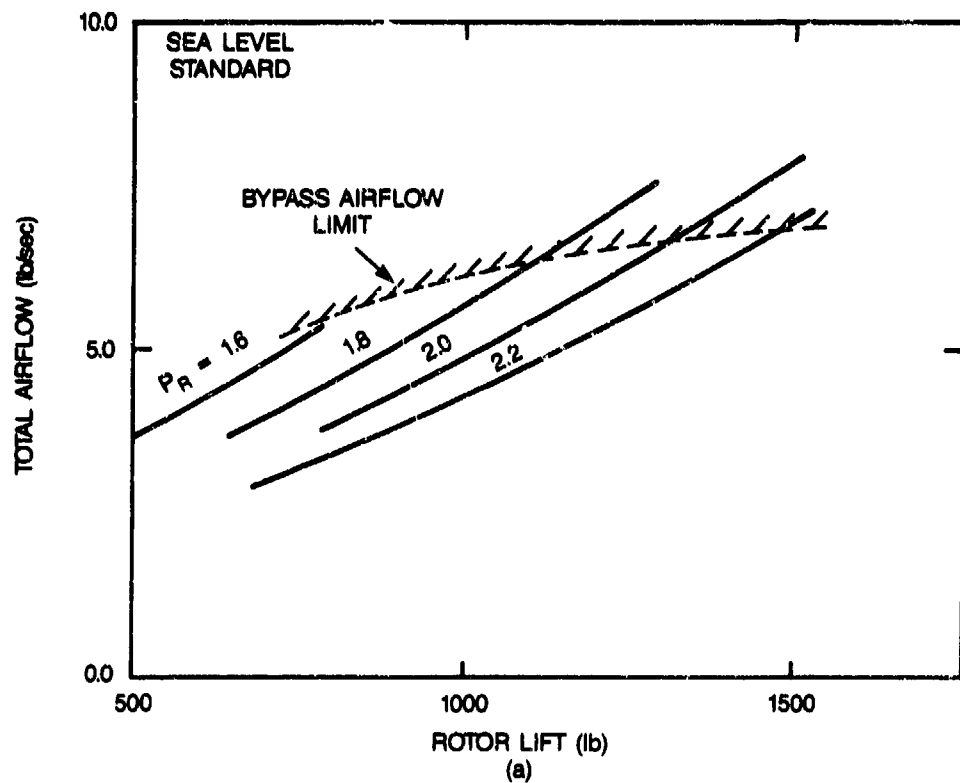


Fig. 17. Hover lift capability.

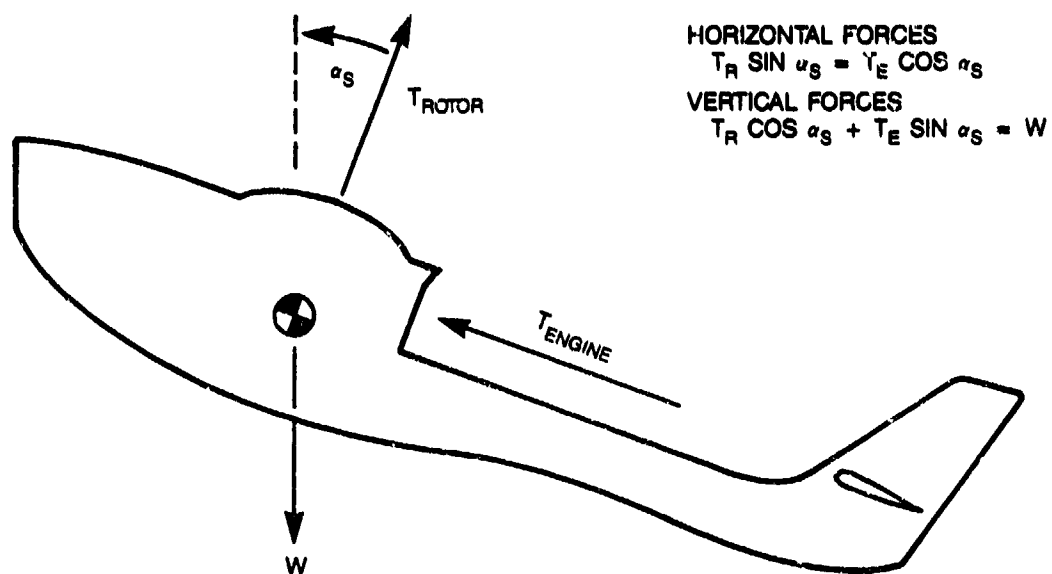


Fig. 18a. Relevant forces.

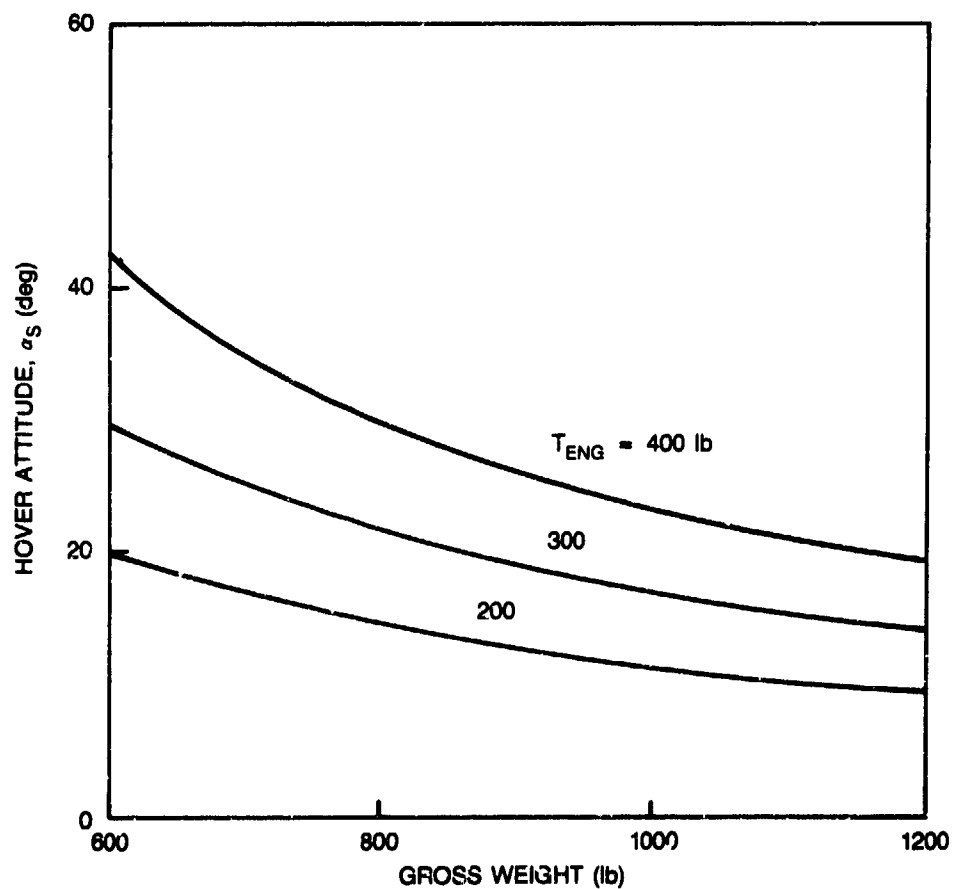


Fig. 18b. Vehicle attitude trim map.

Fig. 18. Tipjet VTOL UAV low speed force balance.

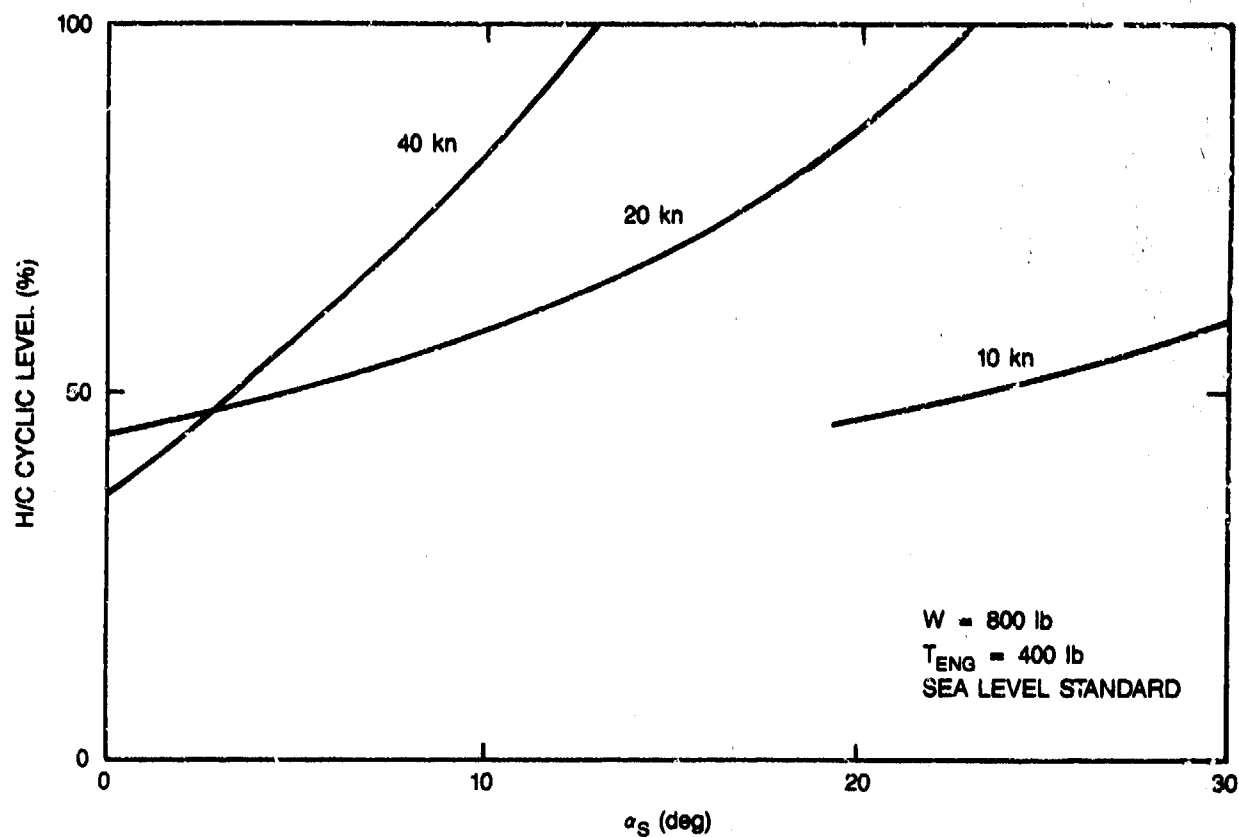


Fig. 19a. Control settings.

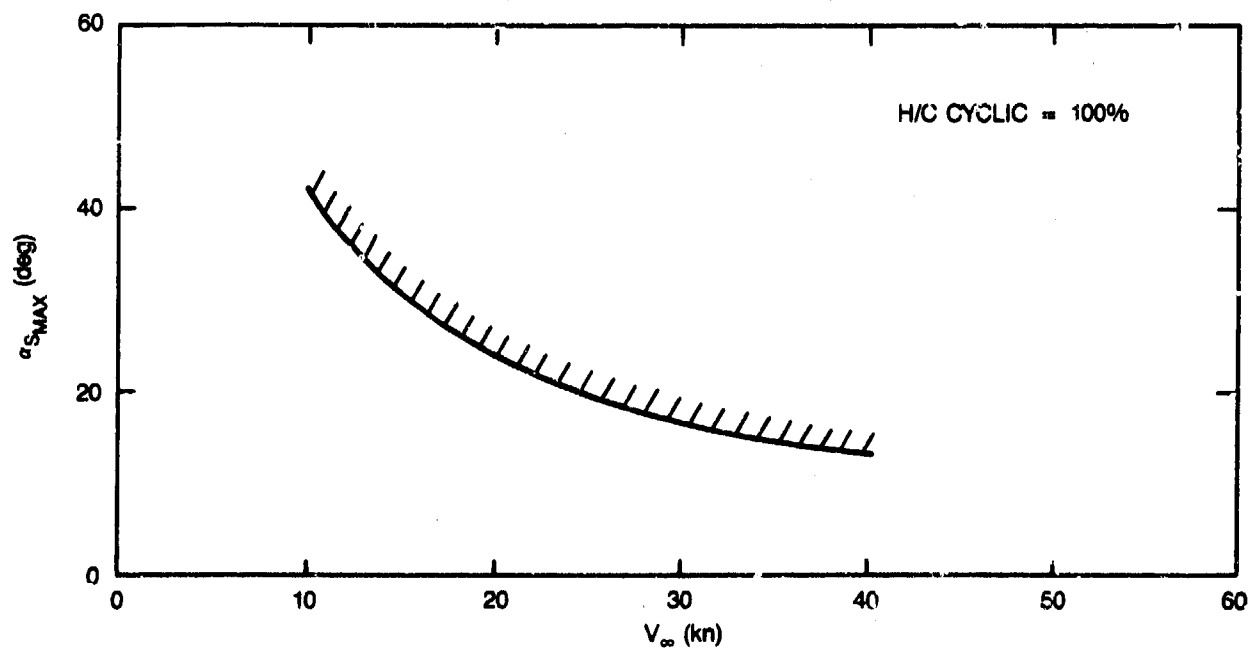


Fig. 19b. Vehicle attitude control limits.

Fig. 19. Control through transition flight regime.

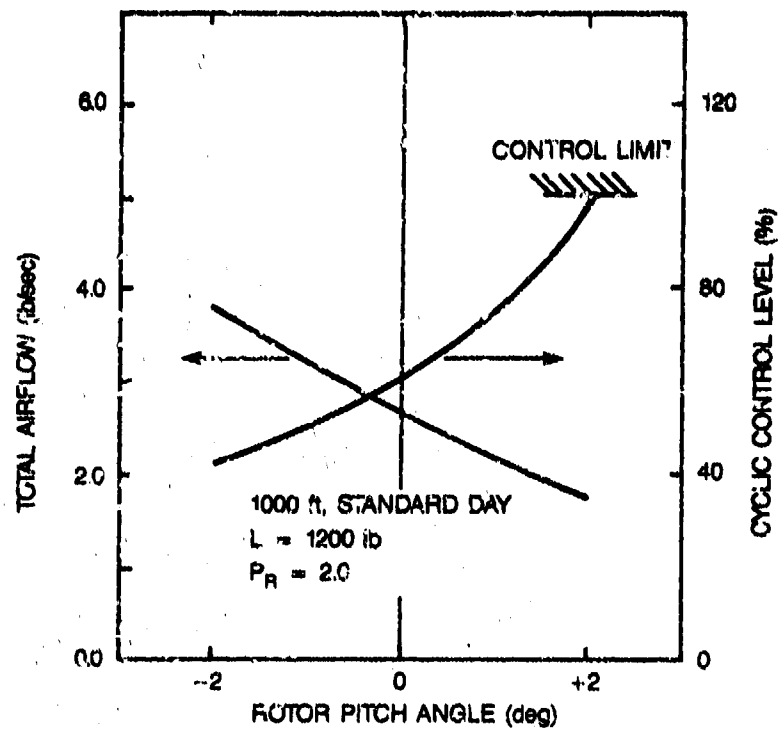


Fig. 20a. 1g trim.

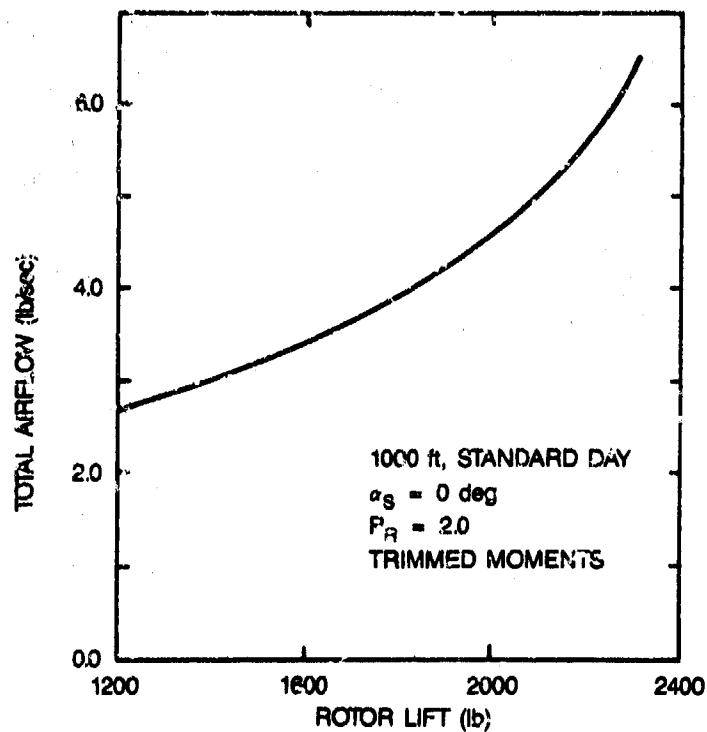


Fig. 20b. Maximum lift.

Fig. 20. Rotary-wing lift capability (145 kn).

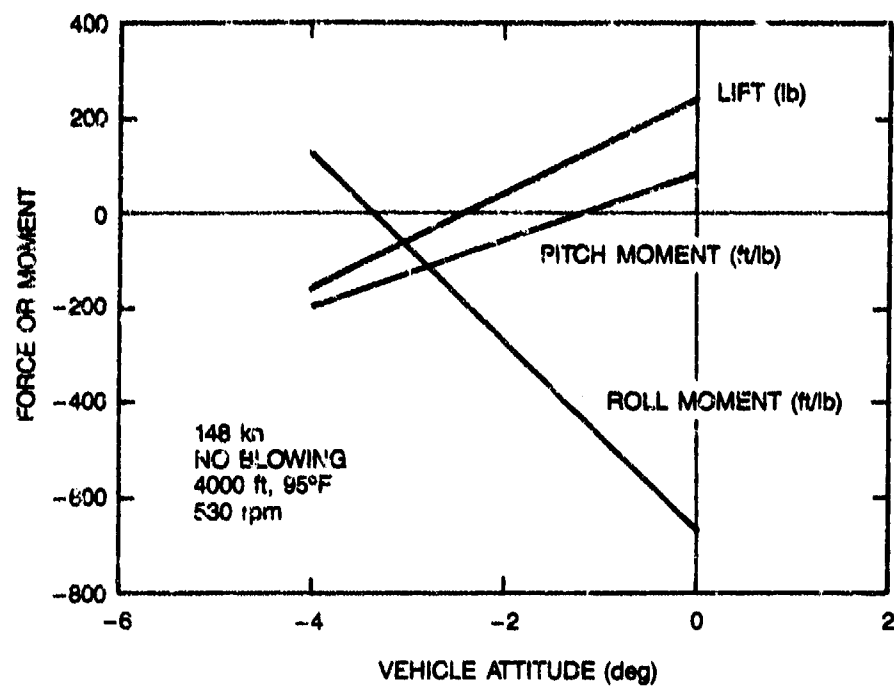


Fig. 21a. $\mu = 0.5$.

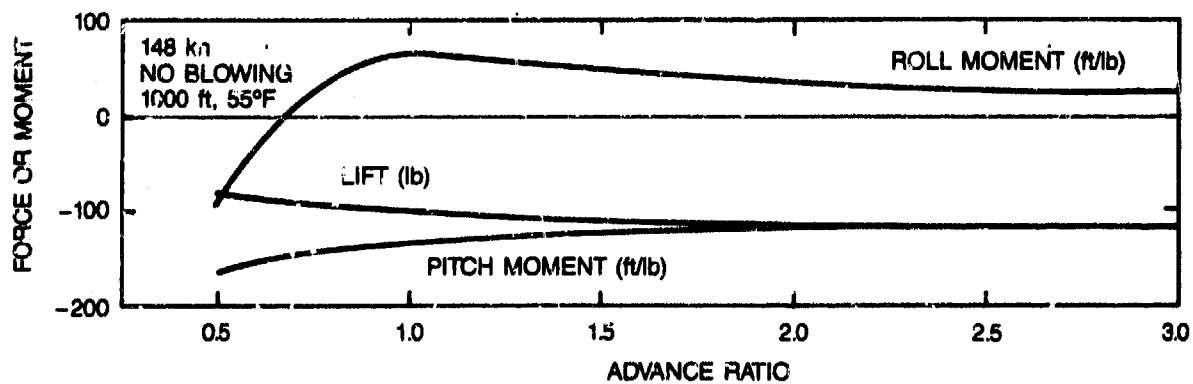


Fig. 21b. $\sigma_s = -3$ deg.

Fig. 21. Hub loads during ballistic conversion.

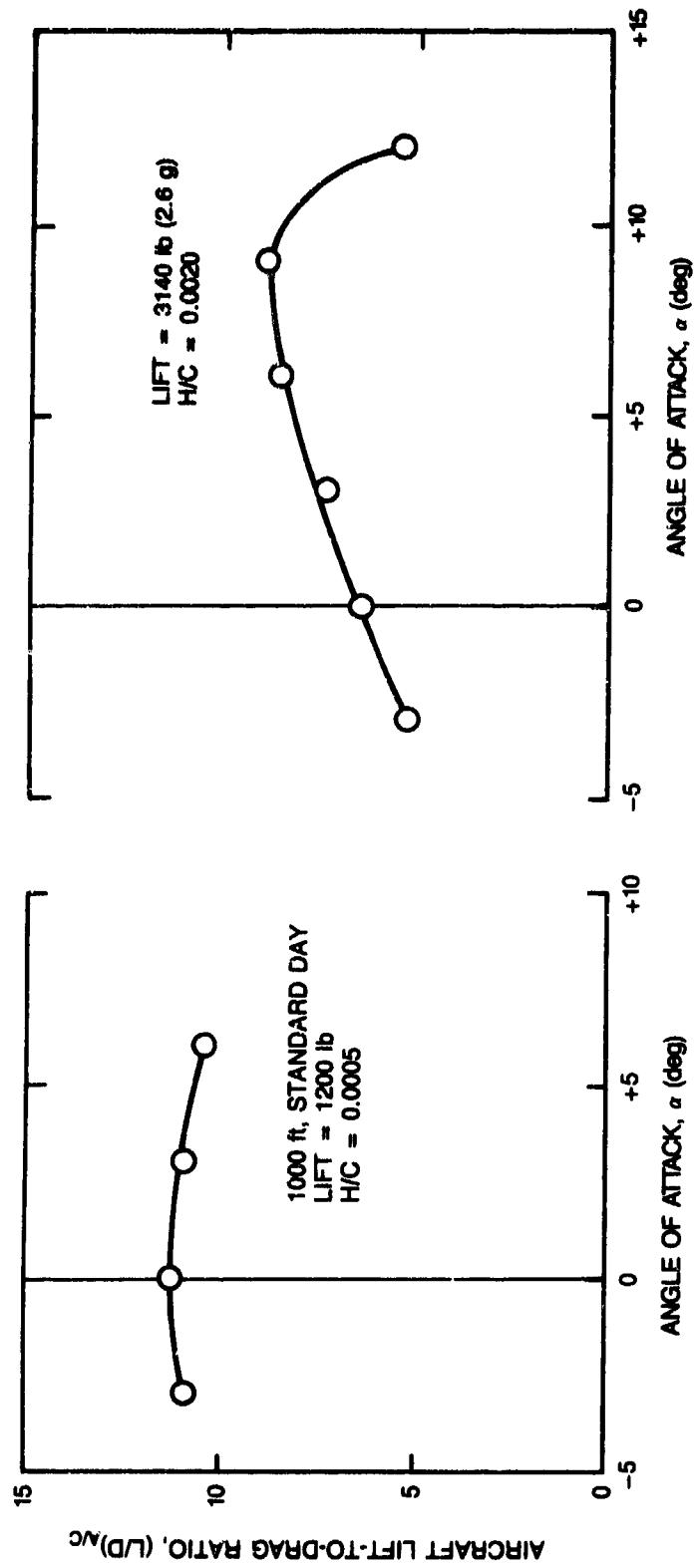


Fig. 22. Fixed-wing performance, attitude sensitivity (145 kn).

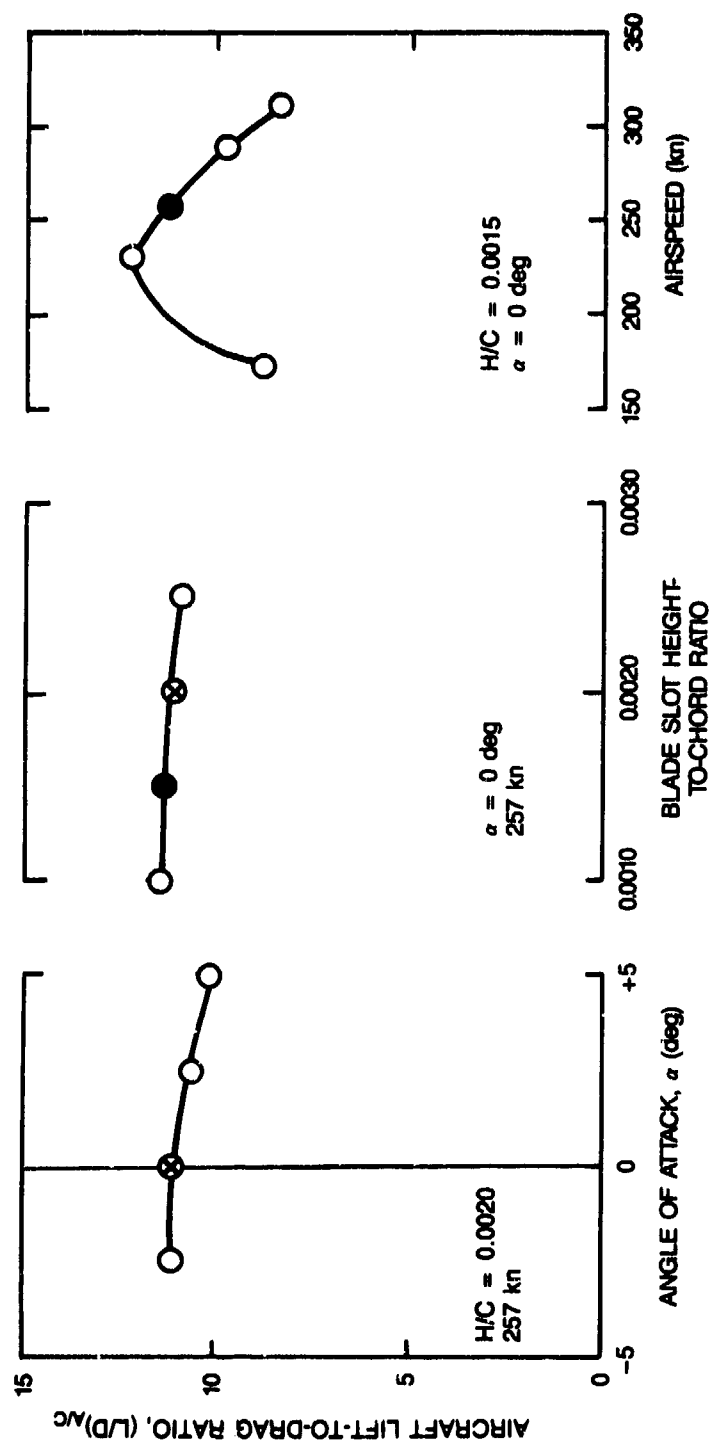


Fig. 23. Fixed-wing cruise performance at 35,000 ft and gross weight of 1130 lb.

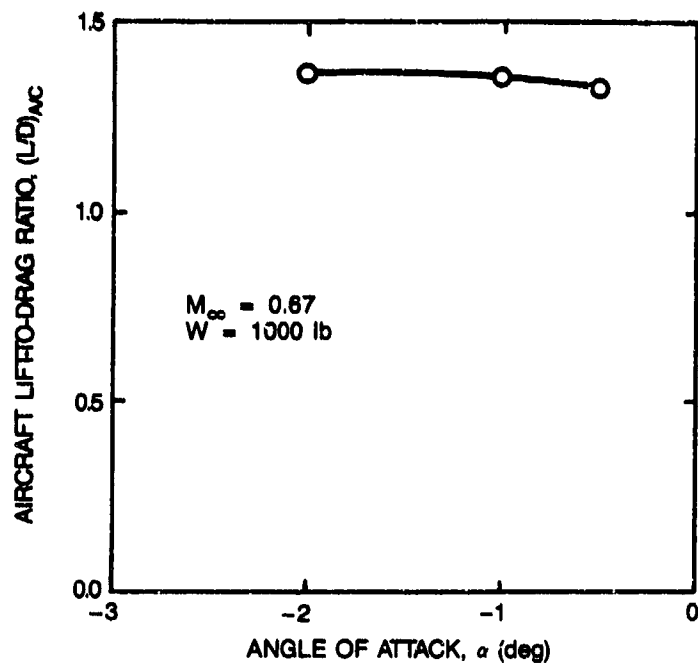


Fig. 24. Fixed-wing dash performance.

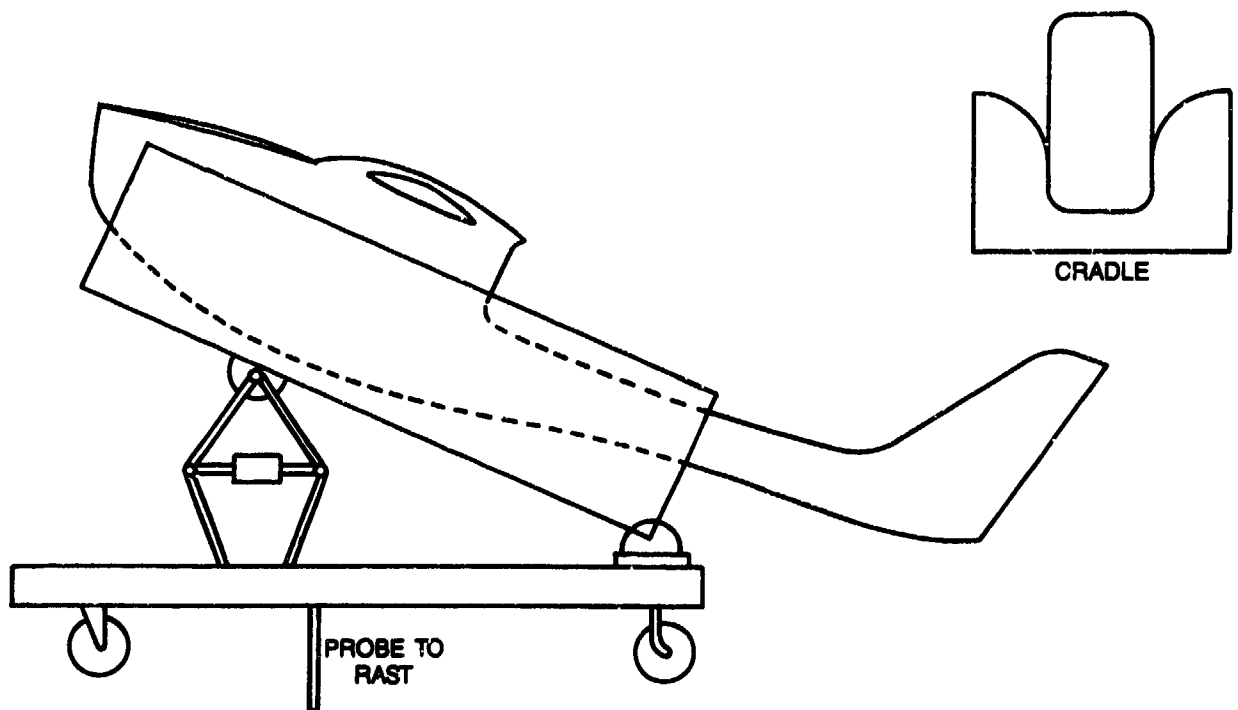


Fig. 25. Tipjet VTOL UAV recovery/traverse system.

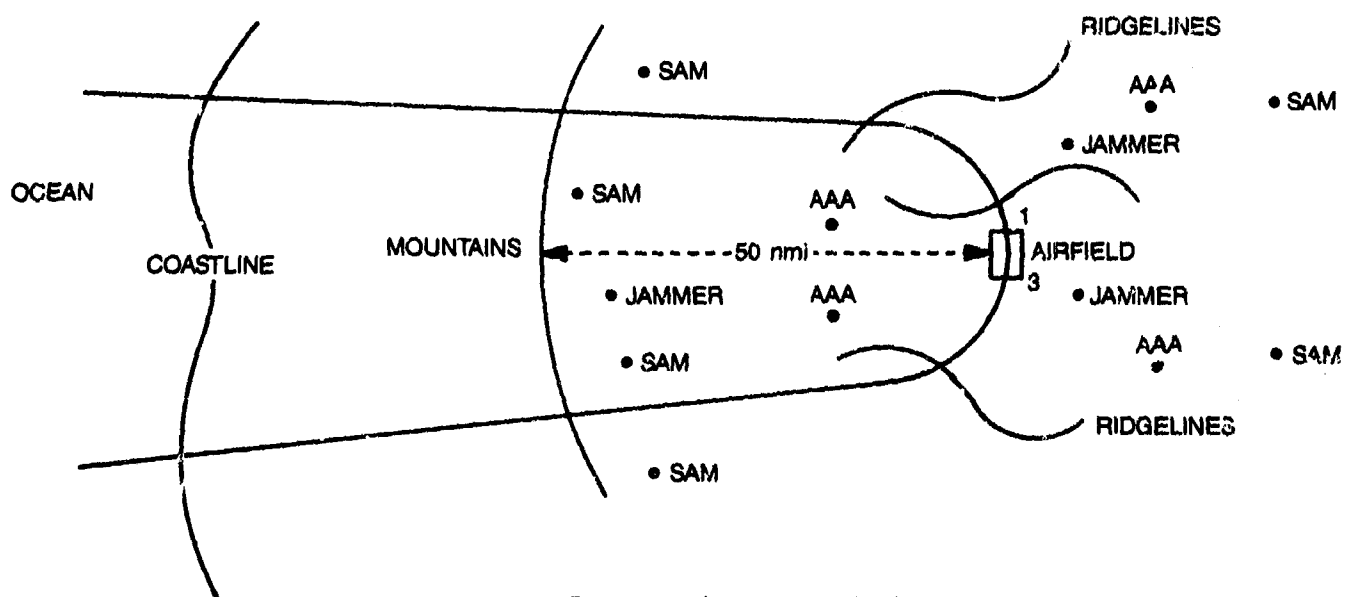
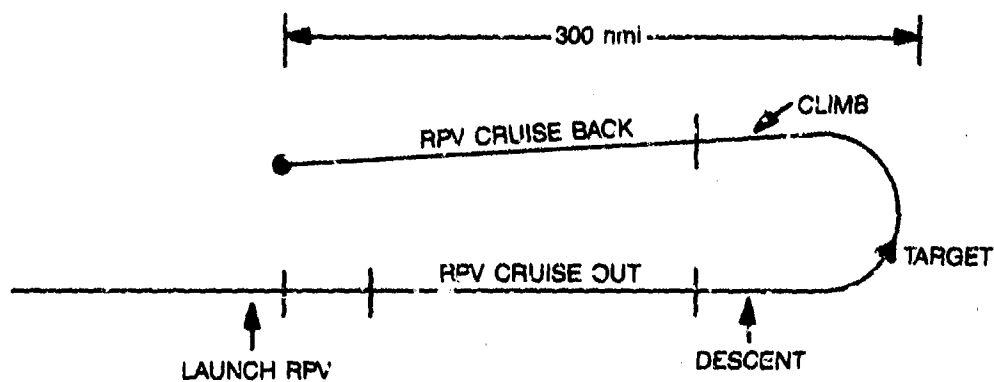
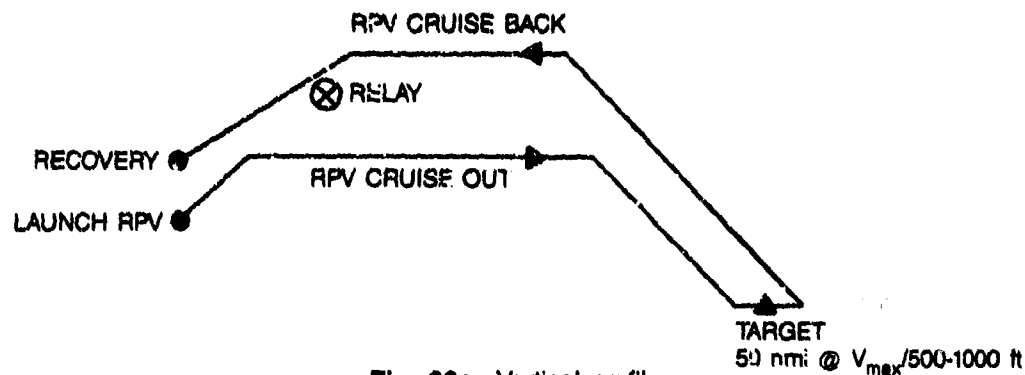


Fig. 26. Tactical reconnaissance mission profile.

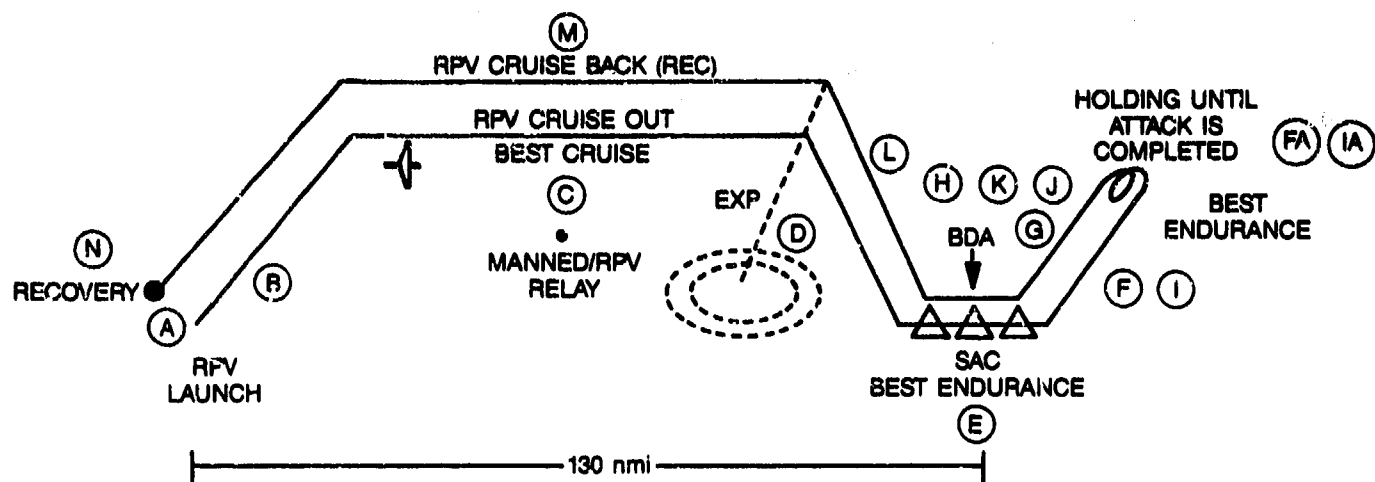


Fig. 27a. Vertical profile.

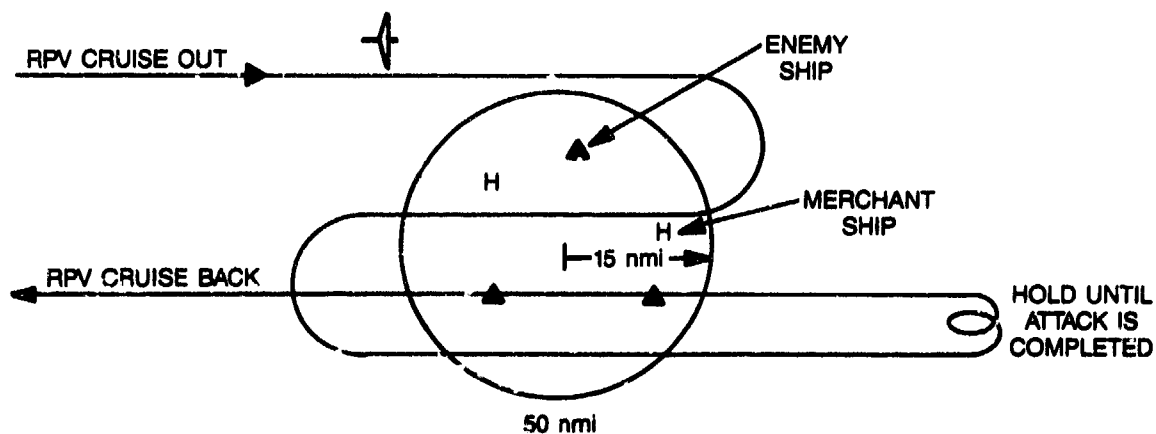


Fig. 27b. Horizontal profile.

Fig. 27. Over-the-horizon targeting mission profile.

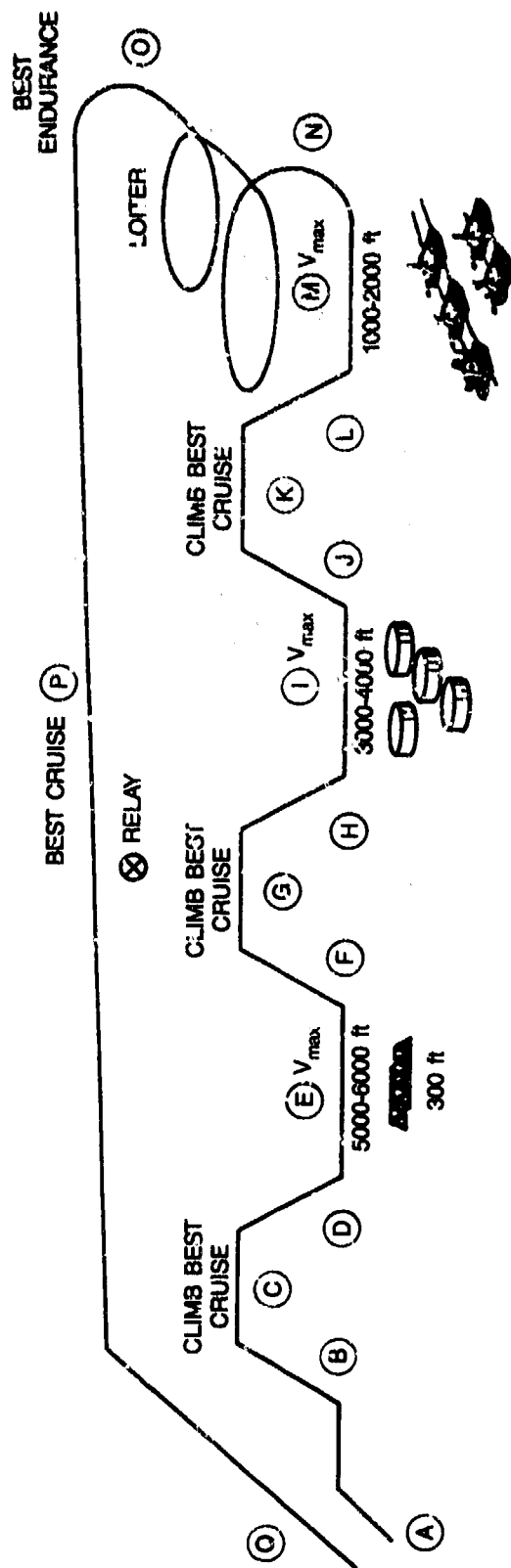


Fig. 28a. Vertical profile.

Fig. 28. Combat support reconnaissance mission profile.

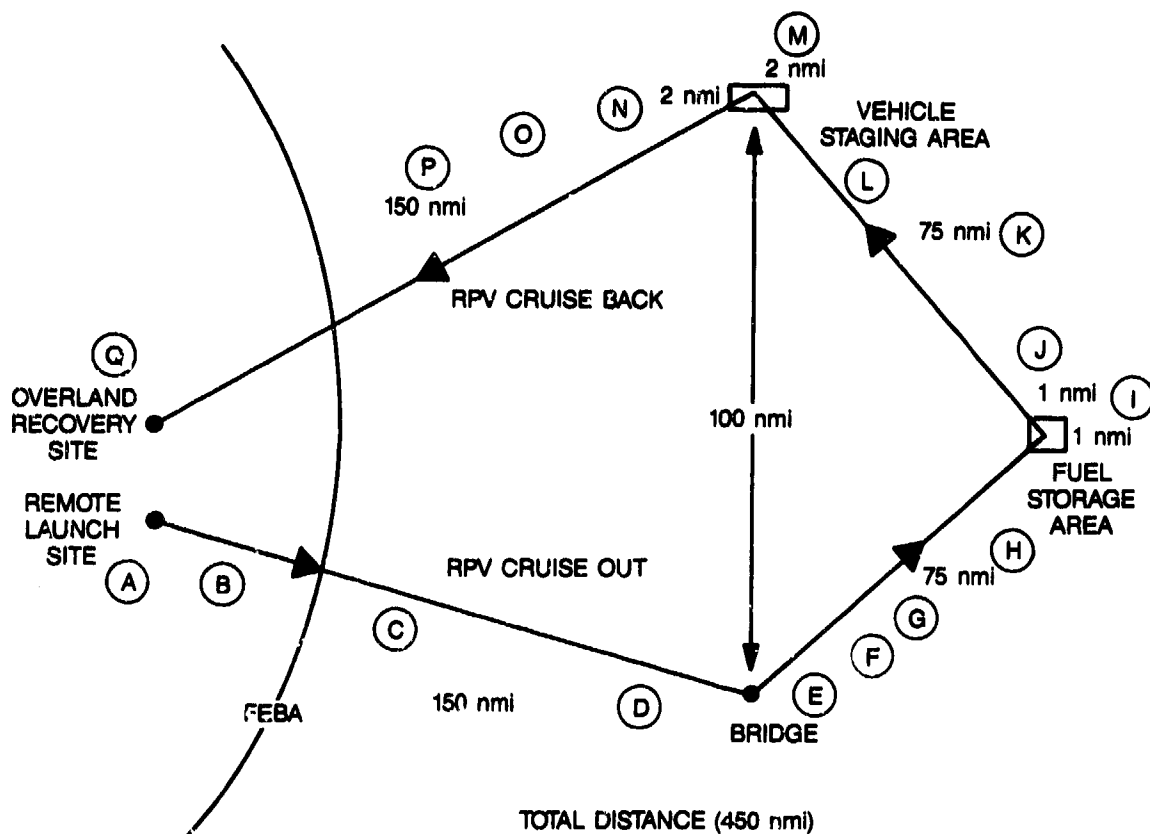


Fig. 28b. Horizontal profile.

Fig. 28. (Continued).

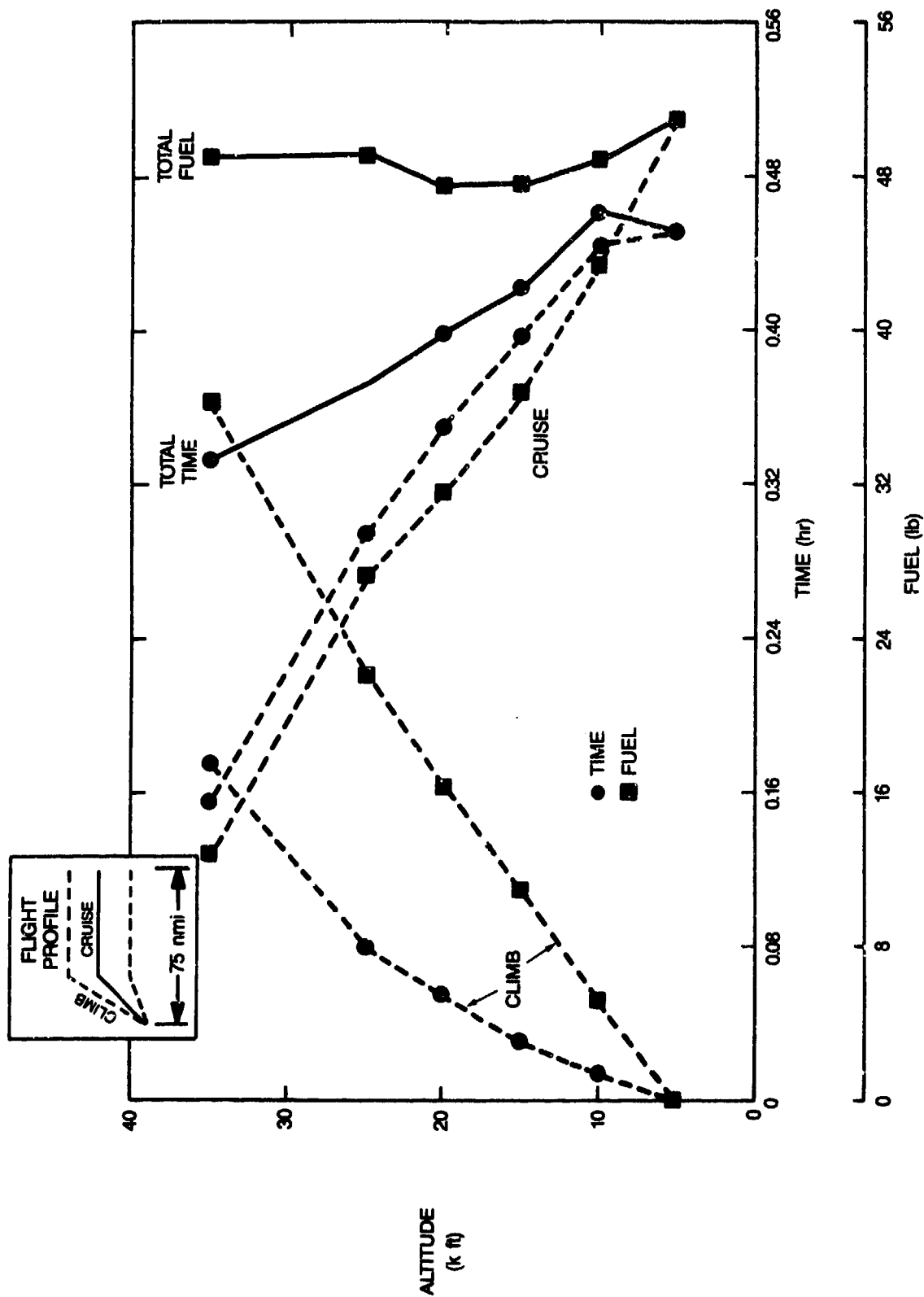


Fig. 29. Mission performance sensitivities.

Table 1. Tipjet VTOL UAV characteristics.

Gross Weight, lb	1200
Williams Engine	F107-WR-401
VTOL Configuration	
Number of Blades	2
Rotor Diameter, ft	18
Disc Loading, lb/ft ²	4.7
Tip Speed, ft/sec	500
Rotor Speed, rpm	530
Disc Area, ft ²	254.5
Solidity	0.1053
Airplane Configuration	
Wing Area, ft ²	26.8
Wing Loading, lb/ft ²	44.8
Wing Span, ft	18
Mean Chord, ft	1.49
Aspect Ratio	12
Blade Geometry	
Radius, ft	9
Chord Taper (center to tip)	2/3
Twist, deg	0
Tip Planform	Square

Table 1. (Continued)

Airfoils

First Blown Section

Airfoil	CC20/05/050/968
Chord, ft	1.79
Thickness	0.20c
Camber	0.05
Slot Location	0.032c/0.968c
First Blown Station	0.25R

Last Blown Section

Airfoil	CC17/015/030/968
Chord, ft	1.19
Thickness	0.17c
Camber	0.015
Slot Location	0.032c/0.968c
Last Slot Station	0.907R

Nozzle

Tip Nozzle Area, ft ²	0.07222
	(10.4 in ²)
Hub Fairing	Reflex Cambered
Thickness (centerline)	0.13c

Table 1. (Continued)

Horizontal Tail		
Area, ft ²		3.453
Span, ft		4.630
Tip Chord, ft		0.953
Root Chord, ft		1.565
Vertical Tail		
Area, ft ²		4.2
Span, ft		2.4
Tip Chord, ft		1.2
Base Chord, ft		2.3
Fuselage		
Length, ft		16.1
Width, ft		1.5
Height, ft		3.5

Table 2. Velocity for maximum lift-to-drag ratio.

Altitude (k ft)	Air Density Ratio, σ	$V_{L/D_{max}}$	
		(mph)	(kn)
0	1.0000	128.2	111.4
5	0.8617	138.1	120.0
10	0.7386	149.2	129.6
15	0.6295	162.0	140.8
20	0.5332	175.6	152.6
25	0.4486	192.0	166.8
35	0.3106	230.0	199.9

Table 3. Component weight estimate.

Component	Weight (lb)
Wing (including bearings)	100
Fuselage	72
Vertical Tail	6
Horizontal Tail	5
Engine	146
Electric Generator	15
Fuel Tanks, Supports, Dump, and Drain	31
Inlet Duct and Supports	<u>11</u>
Estimated Structural Weight	386*
Fuel	400
Payload	<u>132</u>
Estimated Gross Weight	918*
* Does not include weight of items in Table 4.	

Table 4. Components with undetermined weights.

Tail Pipe for Engine Core Air
Bypass Air Valving
Plerum Wall Structure
"Landing Gear"
Tip-Jet Control Mechanism
Slot Adjustment Mechanism
Flight Control Computer
Control Actuators

Table 5. Avionics payload size and weight.

Table 5a. Combat support reconnaissance and tactical reconnaissance missions.

Unit Group	Size, LxWxH (in)	Volume (ft ³)	Weight (lb)	Power (Vdc;A)
Data Link	6.5x3.2x4.2	0.05	2.4	28;0.35
				15;0.10
	6.5x4.5x4.5	0.07	4.0	5;0.05
	6.9x10.0x1.0	0.04	1.0	-
	4.2x3.0x2.6	0.02	1.4	28;0.60
	6.5x4.0x2.1	0.03	2.7	28;5.00
	5.4x1.0x2.2	<u>0.01</u>	<u>1.0</u>	<u>-</u>
		0.22	12.5	28;6.10
Flight Control/Navigation	5.0x7.25x9.0	0.19	8.6	28; -
	14.0x1.5x7.6	0.46	30.0	28;2.90
	-	-	2.5	28;0.10
	5.0x5.0x3.0	0.04	3.0	28;0.20
	5.5x4.0x3.4	0.04	3.0	28;3.00
	6.5x7.5x3.0	0.08	5.0	-
	3.18x4.18x2.0	0.02	1.0	-
	-	<u>0.40</u>	<u>9.0</u>	<u>-</u>
		1.23	62.1	28;6.20

Table 5a. (continued)

Unit Group	Size, LxWxH (in)	Volume (ft ³)	Weight (lb)	Power (Vdc;A)
Sensor	11.2x8.35x9.72	0.52	28.7	28;8.90
Sensor Electronics/Recorder	9.5x6.25x13.0	0.45	23.0	28;1.10
	5.0x5.0x5.0	0.30	1.0	-
	-	<u>0.20</u>	<u>1.0</u>	<u>28;0.40</u>
		0.95	25.0	28;1.50

Table 5b. Over-the-horizon targeting mission.

Unit Group	Size, LxWxH (in)	Volume (ft ³)	Weight (lb)	Power (Vdc;A)
Data Link				
	6.5x3.2x4.2	0.05	2.4	28;0.35
	-	-	-	15;0.10
	6.5x4.5x4.5	0.07	4.0	5;0.05
	6.9x10.0x1.0	0.04	1.0	-
	4.2x3.0x2.6	0.02	1.4	28;0.60
	6.5x4.0x2.1	0.03	2.7	28;5.00
	5.4x1.0x2.2	<u>0.01</u>	<u>1.0</u>	<u>-</u>
		0.22	12.5	28;6.10
Flight Control/Navigation				
	5.0x7.25x9	0.19	8.6	28; -
	14.0x7.5x7.6	0.46	30.0	28;2.90
	-	-	2.5	28;0.10
	5.0x5.0x3.0	0.04	3.0	28;0.20
	3.18x4.18x2.0	0.02	1.0	-
	-	<u>0.03</u>	<u>1.0</u>	<u>-</u>
		0.74	46.1	28;3.20

Table 5b. (Continued)

Unit Group	Size, LxWxH (in)	Volume (ft ³)	Weight (lb)	Power (Vdc;A)
Sensor	5.0x2.75 D	0.02	2.30	12;0.25
	5.0x2.75 D	<u>0.02</u>	<u>1.75</u>	<u>-</u>
		0.04	4.05	12;0.25
Sensor Electronics	1.5x6.0x8.0	0.21	10.0	28;5.00
		<u>0.02</u>	<u>1.0</u>	<u>28;0.40</u>
		0.23	11.0	28;5.40

Table 6. Tactical reconnaissance mission summary.

Ref.	Mission Segment	Altitude (k ft)	Duration (hr)	Distance (nmi)	Fuel Used (lb)	Fuel Rate [lb/hr] (lb/nmi)	Segment Final Weight (lb)
-	Launch	0	0.0000	0.0	0.0	-	1200.0
A	Hover	0	0.0333	0.0	15.2	[456.4]	1184.8
B	Climb	0-35	0.2006	39.1	44.6	1.141	1140.2
C	Cruise	35	0.8219	210.9	69.2	0.329	1071.0
D	Descent	35-1	0.000	0.0	0.0	-	1071.0
E	Dash	1	0.1238	50.0	74.1	1.482	996.9
F	Climb	1-35	0.1689	41.9	37.5	0.895	959.4
G	Cruise	35	1.0854	257.9	83.0	0.322	876.4
H	Recovery						
	w/reserve	0	0.0360	0.0	16.4	[456.4]	860.0
	w/o reserve	0	0.1679	0.0	76.4	[456.4]	800.0

Table 7. Over-the-horizon targeting mission summary.

Ref.	Mission Segment	Altitude (k ft)	Duration (hr)	Distance (nmi)	Fuel Used (lb)	Fuel Rate [lb/hr] (lb/nmi)	Segment Final Weight (lb)
-	Launch	0	0.0000	0 0	0.0	-	1200.0
A	Hover	0	0.0333	0.0	15.2	[456.5]	1184.8
B	Climb	0-35	0.2006	39.1	44.6	1.141	1140.2
C	Cruise	35	0.3542	90.9	29.8	0.328	1110.4
D	Descent	35-1	0.0000	0.0	0.0	-	1110.4
E	Classify Contacts	1	0.3234	50.0	32.2	0.644	1078.1
F	Climb	1-35	0.1833	36.4	40.7	1.118	1037.4
Fa	Loiter	35	0.5000	0.0	33.6	[67.6]	1003.8
G	Descent	35-1	0.0000	0.0	0.0	-	1003.8
H	Assess Damage	1	0.3234	50.0	32.3	0.646	971.5
I	Climb	1-35	0.1691	33.5	37.6	1.122	933.9
Ia	Loiter	35	0.5000	0.0	33.6	[67.2]	900.3
J	Descent	35-1	0.0000	0.0	0.0	-	900.3
K	Assess Damage	1	0.3234	50.0	32.3	0.646	868.0
L	Climb	1-35	0.1461	28.6	32.4	1.133	835.6
M	Cruise	35	0.3952	101.4	33.3	0.328	802.3
N	Recovery						
	10 min	0	0.1667	0.0	76.1	[456.6]	726.2
	15 min	0	0.2500	0.0	114.1	[456.6]	688.2

Table 8. Combat support reconnaissance mission summary.

Ref.	Mission Segment	Altitude (k ft)	Duration (hr)	Distance (nmi)	Fuel Used (lb)	Fuel Rate [lb/hr] (lb/nmi)	Segment Final Weight (lb)
-	Launch	0	0.0000	0.0	0.0	-	1200.0
A	Hover	0	0.0333	0.0	15.2	[456.5]	1184.8
B	Climb	0-35	0.2006	39.1	44.6	1.141	1140.2
C	Cruise	35	0.4320	110.9	36.4	0.328	1103.8
D	Descent	35-5	0.0000	0.0	0.0	-	1103.8
E	Dash	5	0.0024	1.0	1.3	1.300	1102.5
F	Climb	5-15	0.0310	5.0	11.0	2.200	1091.5
G	Cruise	15	0.3970	70.0	36.9	0.527	1054.6
H	Descent	15-3	0.0000	0.0	0.0	-	1054.6
I	Dash	3	0.0073	3.0	4.0	1.333	1050.6
J	Climb	3-15	0.0310	5.0	10.8	2.160	1039.8
K	Cruise	15	0.4064	70.0	38.1	0.544	1001.7
L	Descent	15-1	0.0000	0.0	0.0	-	1001.7
M	Dash	1	0.0518	20.0	14.4	0.720	987.3
N	Climb	1-35	0.1669	33.0	37.1	1.124	950.2
O	Loiter	35	0.7595	0.0	36.0	[47.0]	914.2
P	Cruise	35	0.5089	117.0	38.9	0.332	875.3
Q	Recovery	0	0.1655	0.0	75.3	0.322	800.0