CONCEPTUAL DESIGN OF THE
AE481 DEMON REMOTELY PILOTED VEHICLE (RPV)

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Abstract

This project report presents a conceptual design for a high speed remotely piloted vehicle (RPV). The AE481 Demon RPV is capable of performing video reconnaissance missions and electronic jamming over hostile territory. The RPV cruises at a speed of Mach 0.8 and an altitude of 300 feet above the ground throughout its mission. It incorporates a rocket assisted takeoff and a parachute-airbag landing. Missions are preprogrammed, but in-flight changes are possible. The Demon is the answer to a military need for a high speed, low altitude RPV. The design methods, onboard systems, and avionics payload are discussed in this conceptual design report along with economic viability.

Introduction

There are currently few RPVs that satisfy the drastically changing surveillance needs of the military. Specifically there are few RPV models that are capable of performing high speed, low altitude reconnaissance missions. In addition, current generation RPVs are limited by; their small, select avionics payload; their lack of launch-site mobility; and their salt water conditioning. Consequently, most current RPV models are not suited for use in all branches of the military.

This conceptual design of the AE481 Demon RPV is a response to the next generation of surveillance RPVs. Its design is a technically feasible and economically viable high speed, low altitude, multi-roled reconnaissance RPV.

The Design Project

This project was selected in January 1994 as part of Aero 481: Airplane Design, a NASA/USRA University Advanced Design Program. The goal of the class was to gain a general knowledge of airplane design in a senior level aircraft design course. The project goal of the AE481 Demon RPV aimed at producing a highly technical, market superior, conceptual design for a non-existent RPV.

Proposal Request

The military is interested in high speed remotely piloted vehicles for surveillance purposes. This RPV must provide information on enemy position, enemy surface to air missile sites (SAM sites), and bomb damage assessment (BDA). Also, further mission capabilities include electronic jamming and acting as a decoy.

The Design Process

The design process begins with establishment of the design requirements and the mission profile.

Design Requirements

The United States Military envisions an RPV that will be launched from small undetectable airstrips near the front line or from a wide range of surface vessels. It will dash at high speed into enemy territory, perform surveillance work, and return to base. Throughout the mission, it must transmit live video of the reconnaissance target area. Additional considerations require the RPV to have a minimal radar, infrared, and acoustic signature. The mission requirements for this proposed RPV are:

Payload: 300 pounds of avionics

Range: 600 nm

Altitude: 300 ft above ground level, will have terrain following capability

Speed: Cruise speed of high subsonic, M=0.8

Take-off: Carrier decks or small clearings

Propulsion: In compliance with design requirements

Mission Profile
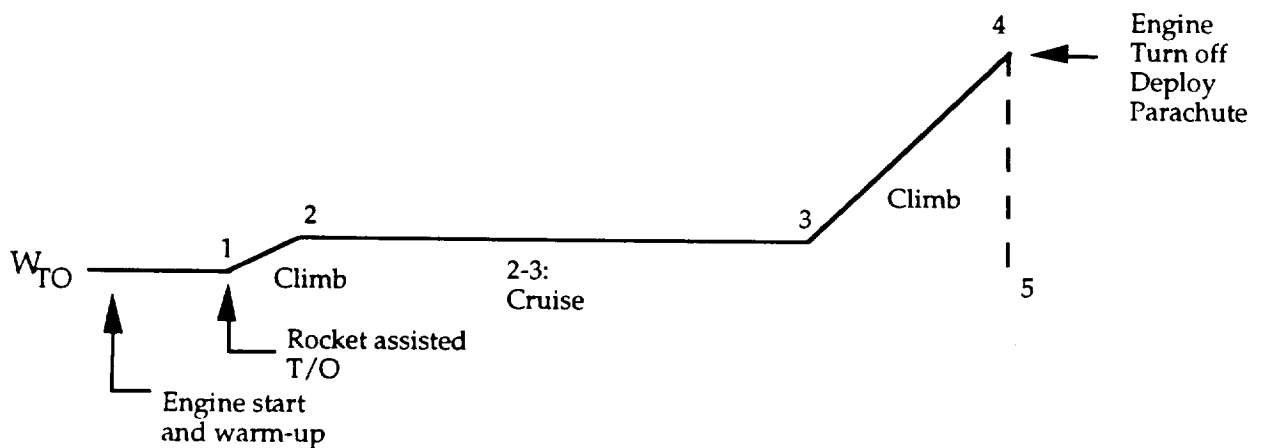
Fig. 1 Mission Profile

A rocket assisted take-off was chosen because it enables the RPV to be launched off naval vessels, ranging in size from a carrier to a patrol boat, and from small clearings. A parachute landing with deployable airbags was chosen over a conventional landing to eliminate the need for an airstrip or the need for a difficult carrier deck landing. The airbags protect the RPV avionics and structure upon touchdown.

Preliminary Estimate of Weights

The weight analysis section of this report consists of the determination of the take-off weights. These values were established by using weight and payload values of current RPVs and by establishing weight fractions for the AE481 Demon throughout its mission.

Estimated RPV Weights

The proposed RPV has the following estimated weights:

$$W_{TO} = 1368 \text{ lbs}$$
$$W_E = 731 \text{ lbs}$$
$$W_F = 354 \text{ lbs}$$
$$W_f = 337 \text{ lbs}$$

The criteria used to produce these results are as follows:

- Use of a turbo-jet engine with a cruise specific fuel consumption of 1.5 ($c = 1.5/\text{hr}$)

- A $(L/D)_{max}$ ratio of 9 and a $(L/D)_{cruise}$ of 7.794 [1]

- A final climb to 3000 feet above ground level to ensure for an effective parachute deployment

Trade Study Analysis

In an effort to provide an optimum aircraft, trade studies on payload, range, $(L/D)_{max}$ values, and velocity were produced. The purpose of these studies was to examine the possibilities for making future changes to reduce gross take-off weight. Tables 1 through 4 show a summary of the results on the trade studies performed:

Payload Weight (lbs)	WTO (lbs)	WE (lbs)
250	1142	611
400	1818	971
450	2043	1090

Table 1: Payload Trade Study

Range (nmi)	WTO (lbs)	WE (lbs)
700	1560	833
800	1805	963

Table 2: Range Trade Study

L/D max Value	WTO (lbs)	WE (lbs)
13	1103	590
17	995	532

Table 3: $(L/D)_{max}$ Trade Study

Mach Value	WTO (lbs)	WE (lbs)
0.7	1530	817

Table 4: Velocity Trade Study

Based on the Payload Trade Study, the original design specifications of 300 pounds of payload will be used. Increases in payload weight significantly raise WTO and WE and could greatly affect RPV performance. In comparison to current RPV models, 300 pounds was determined to be a more than adequate design parameter.

By looking at the results of the Range Trade Study, small changes in the range were acceptable. This was based on only small increases in WTO and WE. Since a radius of 300 nmi was requested by the Army and Navy, it was seen to be a sufficient and reasonable value to use in this design.

The results from the Velocity Trade Study indicate that reduction in cruise Mach number greatly increases WTO and WE. For this reason the RPV cruise speed requirement Mach 0.8 was retained for further design.

Sensitivity Analysis

A Sensitivity Analysis based on the mission specifications .vas performed in order to show the effect of payload changes on take-off weight, empty weight changes on take-off weight, range on take-off weight, changes in c on take-off weight, changes in velocity on take-off weight, and changes in L/D values on take-off weight. A summary of these values is as follows:

$$\frac{\partial W_{TO}}{\partial W_P} = 4.5 \frac{lb}{lb} \qquad \frac{\partial W_{TO}}{\partial W_E} = 1.9 \frac{lb}{lb}$$

$$\frac{\partial W_{TO}}{\partial W_R} = 1.7 \frac{lb}{nm} \qquad \frac{\partial W_{TO}}{\partial W_c} = 679.9 \frac{lb}{\left(\frac{1}{hr}\right)}$$

$$\frac{\partial W_{TO}}{\partial W_V} = -1.9 \frac{lb}{Kts} \qquad \frac{\partial W_{TO}}{\partial W_{\frac{L}{D}}} = -130.8 \frac{lb}{unit\left(\frac{L}{D}\right)}$$

The sensitivity analysis illustrates that changes in c and $(L/D)_{max}$ have the strongest outcome on the take-off weight. Increases in the cruise specific fuel consumption, created vast increases in the take-off weight. However, increases in the lift to drag ratio created a decrease in the take-off weight.

Wing Loading and Thrust to Weight Ratio Determination

The most important consideration in the determination of wing loading and thrust to weight ratio was the constant altitude adjustments required by the terrain following system.

Wing Loading Calculation

Due to the uniqueness of the AE481 Demon RPV, wing loading determination methods suggested by Raymer and other texts did not produce sufficient results. Therefore, a hybrid method involving finding the surface area of the wing and using the weight of the RPV was used to determine the wing loading. A rough estimate of the wing surface area was determined by using the steady level flight cruise equation (EQN 1). In this equation, the coefficient of lift and the surface area were the two unknowns. Since a coefficient of lift was not known for this type of vehicle and cruise condition, a small coefficient of lift, 0.05, was assumed. This value assured a large wing surface area, adequate handling, and good control properties during all aspects of the mission.

$$L = W = \frac{1}{2}\rho V^2 C_l S \qquad \text{EQN 1}$$

From this equation the wing loading was calculated to be:

$$W/S = 38.5 \text{ lbf/ft}^2$$

Thrust to Weight Ratio Calculation

The RPV will be flying at 300 feet for the majority of its mission; Therefore, the RPV must be responsive to changes in the terrain. This terrain avoidance of the RPV drives the thrust to weight ratio because of the need to frequently increase altitude. The RPV has to be able to react quickly when encountering extreme conditions, such as steep cliffs. An angle of climb of 10 degrees was chosen for avoiding obstacles in the forward path of the Demon.

All equations were solved for a 5000 foot, 40° C operating condition. It was also assumed that during a climb, the coefficient of drag increased from 0.015 to 0.035 due to deflections in the control surfaces. Using these considerations and Equation 2 the thrust to weight ratio was calculated.

$$\frac{W}{S} = \frac{[(\frac{T}{W}) - G] \pm \sqrt{[(\frac{T}{W}) - G]^2 - (\frac{4C_{DO}}{\pi Ae})}}{\frac{2}{q\pi Ae}} \qquad \text{EQN 2}$$

Where G is the climb gradient and e is the Oswald Efficiency (calculated to be 0.3869167). The minimum thrust to weight ratio required was calculated to be:

$$T/W = 0.46$$

Propulsion

The RPV incorporates the use of two propulsion systems due to the fact that it is going to be launched from a skid instead of performing a conventional take-off. The first system is a rocket booster, which is only required for the initial launch and climb sequence of the RPV. The second is the turbojet, which will take over at cruise altitude to continue and complete the mission. The rocket booster will be jettisoned once the RPV reaches cruise altitude. Therefore, a new rocket booster will be required for each launch.

Rocket Booster

The launch of the Demon will require the assistance of a rocket booster to give it enough power to get to required altitude and speed without the use of a conventional takeoff. In order to determine the size of the rocket booster required for the launch of the Demon, the take-off thrust had to be calculated. Using basic equations of motion, take-off thrust and acceleration were determined. A summary of the results is as follows:

$$\text{Take-Off Acceleration} = 138 \text{ ft/sec}^2$$
$$\text{Take-Off Thrust} = 5876 \text{ lbf}$$

The following assumptions were made when determining these values:

- Initial take-off altitude of 5000 feet above sea level and an air temperature of 40°C (this insures that the RPV will be able to perform in rigorous conditions)

- Rocket engine burn-out at the cruise altitude of 300 feet. At this point the RPV velocity will be Mach 0.5.

- The RPV will reach the cruise altitude and Mach 0.5 in five seconds.

Based on the maximum thrust rating required at the take-off conditions an appropriate rocket booster was chosen. The Morton Thiokol TE-M-707, currently in production, was favored due to cost constraints and because it fulfills the thrust requirements. This rocket produces a thrust of approximately 6000 lbs, which can accelerate the Demon to M = 0.5 in five seconds. Characteristics of the TE-M-707 can be found in the Table 5.

	Values
Outside Diameter	13.5 in
Length	29 in
Weight	150 lbs
Total Impulse	36,000 lb-sec

Table 5: TE-M-707 Rocket Booster Characteristics

Turbojet Engine for Cruise Conditions

The rocket engine is jettisoned after completing its role and upon main engine takeover. A turbojet engine was selected based on the RPV's ability to

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climb quickly and efficiently to avoid obstacles during the cruise segment of the mission. The engine sustains the RPV at a speed of Mach 0.8 while following the terrain in flat or mountainous regions. A thrust of 620 pounds was determined to meet these specifications. Currently, the J402-CA-702 turbojet, built by Teledyne Ryan CAE, is able to fulfill this thrust requirement cost effectively.

This engine is required to be capable of landing in sea water due to Naval applications. If the engine takes in salt water, it can easily be reconditioned by submersion in a container of WD-40.[2] Characteristics of the J402-CA-702 at SLS conditions can be found in Table 6.

|	Values
Thrust at Cruise	960 lbf
Width	12.5 in
Length	33.3 in
Airflow	13.7 lb/sec
Dry Weight	138 lbs
SFC	1.42 lb/hr/lb thrust

Table 6: J402-CA-702 Turbojet Design Characteristics

Fuselage Design

The fuselage design was based on the avionics, engine intake location, engine size, and fuel needed. These factors directly correspond to the mission performed, the stealthiness, and the weight of the RPV. These elements combined to create a fuselage body which stands 28.5 inches tall with a curved semi-circular upper surface. Then tapers down to a flat underbelly which is 30 inches wide. The overall length is 20 feet. The RPV fuselage structure is presented in Figure 2. The fuselage skin, wings, and tail configuration are made of aluminum and weigh approximately 329 pounds.

The avionics were placed within the fuselage along the centerline for both balance and easy access through removable fuselage panels. Cameras and terrain following equipment were placed in the underbelly, with the additional units being placed between the nose and the center of gravity. By placing the heavy units in the nose section, the weight of the engine (138 dry pounds) was offset. Overall there are 280 pounds of avionics in the Demon.

The engine intakes are located on the sides of the fuselage and over the wings. Placing the inlets over the wings helps conceal them from ground-based radar. This allows for surveillance equipment to be placed in the underbelly without interference. This also allows the parachute to deploy

TOP VIEW

SUPPORT RING

SIDE VIEW

FIREWALL

SUPPORT RING

AVIONICS SUPPORT PLATE
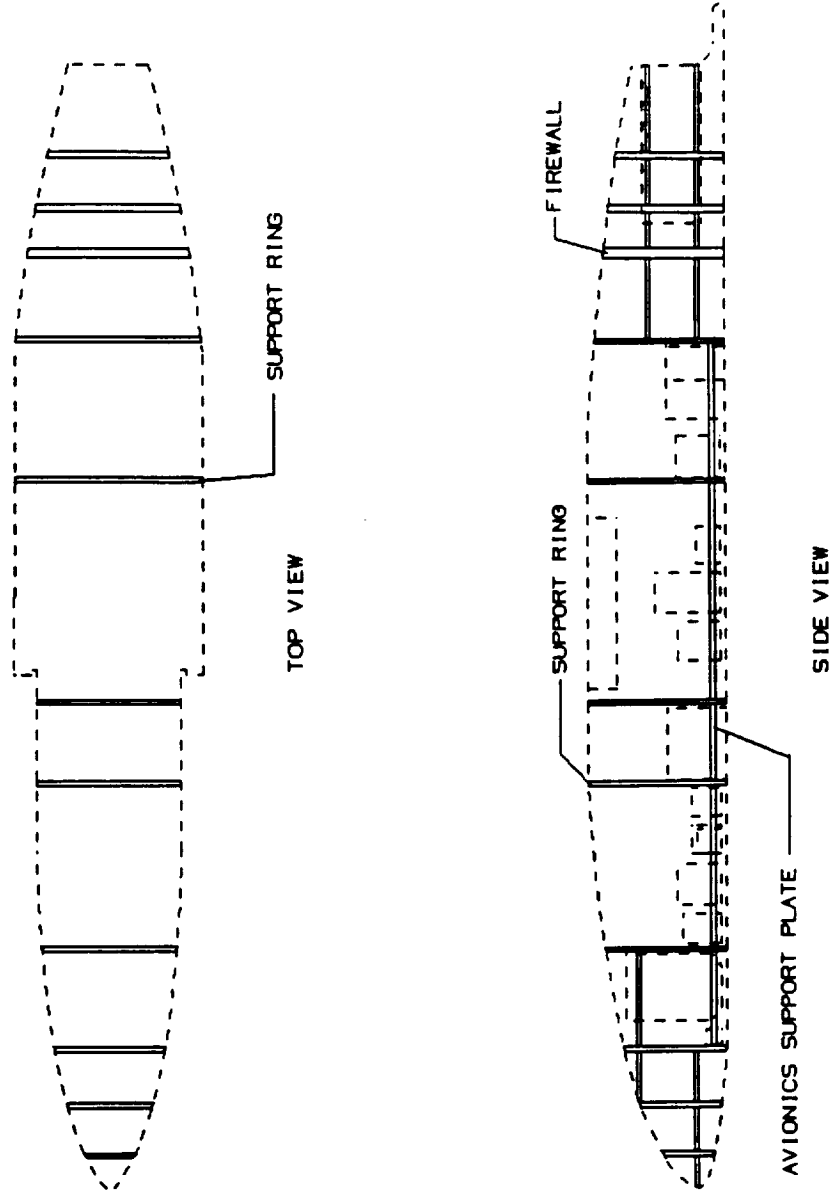
NOTE: STRINGERS NOT SHOWN

AE481 DEMON RPV DESIGN TEAM	7-5-94	
SUPPORT STRUCTURE		

Figure 2: Fuselage Structure Design

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from the top of the RPV. The inlet area of the nozzles combined is 0.32 ft^2 based on the mass flow rate of the engine.

The turbojet engine is located within the rear of the fuselage. Figure 3 details the complete internal layout of the Demon.

The fuel required for the mission is stored within rubber storage bags. These bags are located within the fuselage around the avionics and sub-systems to accommodate 7.35 cubic feet of fuel. Fuel is not carried in the wings due to their small volume and their chance of damage during landing. The fuel bag locations are shown in Figure 4.

Avionics

The payload was the main driver of the fuselage design. The avionics selected for the RPV include an auto-pilot system to make it autonomous, electronic jamming equipment, and several video reconnaissance systems. The layout of the avionics is presented in Figure 3.

The RPV avionics package consists of the following systems [3]:

1. Type AD 1990 Radar Altimeter
2. Stabilized Thermal Imaging System (STIS)
3. Versatile Drone Autopilot
4. Mission Control Computer
5. Flight Computer
6. Global Positioning System
7. RT-1379A/ASW Transmitter/Receiver/Processor
8. Wide-Band Video Downlink
9. F-979Le Electro-Optical Reconnaissance System
10. Super SVCR-V301 High Resolution Airborne Video Recorder (2)
11. Hercules ECM Jammer
12. Auxiliary Power Unit

General descriptions of each item in the avionics package is as follows:

1. Type AD 1990 Radar Altimeter

This altimeter remains covert in operation, rendering it virtually undetectable by the enemy. This is achieved by spreading the transmitted signal over a very wide bandwidth through the application of pseudo-random phase modulation and adaptive power tailoring. This also provides the RPV with high resistance to jamming.

240.00

30.00

TOP VIEW

1. TYPE AD 1990 RADAR ALTIMETER
2. STABILIZED THERMAL IMAGING SYSTEM
3. VERSATILE DRONE AUTOPILOT
4. MISSION CONTROL COMPUTER
5. FLIGHT CONTROL COMPUTER
6. GLOBAL POSITIONING SYSTEM
7. RT-1379A/ASW TRANSMITTER/RECEIVER
8. WIDE-BAND VIDEO DOWNLINK
9. AUXILLARY POWER UNIT
10. F-979LE MODULAR ELECTRO-OPTICAL
    RECONNAISSANCE SYSTEM
11. SUPER SVCR-V301 HIGH RESOLUTION
    AIRBORNE VIDEO RECORDER (2)
12. HERCULES ECM JAMMER
13. FORWARD AIRBAG
14. AFT AIRBAG
15. PARACHUTE RECOVERY SYSTEM

HOR. TAIL
SPAR

WING SPAR

28.50

SIDE VIEW

NOTE: ALL DIMENSIONS IN INCHES
      INTAKES OMITTED FROM SIDE VIEW
      FOR CLARITY

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INTERNAL LAYOUT		

Figure 3: Internal Layout

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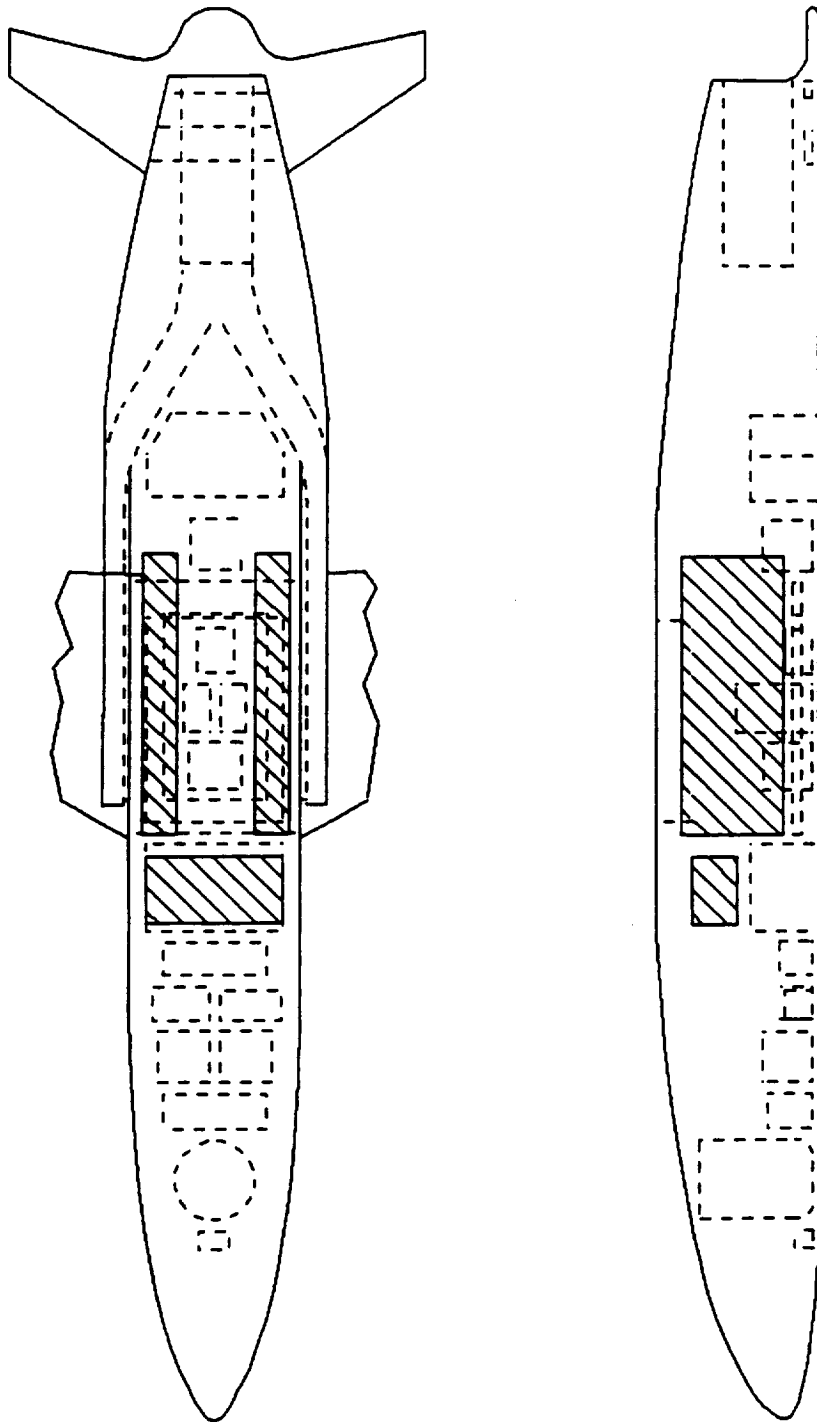
Figure 4: Fuel Location

FUEL VOLUME

Weight = 11.57 lbs
Dimensions: 4.29 x 6.06 x 12.52 in.

2. Stabilized Thermal Imaging System (STIS):

Provides for day and night surveillance requirements. Features the mini-FLIR, which is a serial scanning IR sensor incorporating DC restored electronics to give crisp bloom-free displays. STIS incorporates a three field-of-view telescope, with up to 12 power magnification.

Weight = 75 lbs
Dimensions: 14.02 in. (diameter) x 20 in. (height)

3. Versatile Drone Auto pilot

This system contains various sensors, which include a vertical gyro, altitude transducer, airspeed transducer or Mach computer and a yaw rate gyro. This system is adaptable to a wide range of vehicles and missions. The VDA is capable of g levels within +/- 0.25g up to airframe limits and within 3 seconds of command.

Weight = 28.66 lbs
Dimensions: 6.5 x 8 x 18 in.

4. Mission Control Computer

Contains the computer generated terrain map and the MIL-STD-1553B Bus Controller. Controls aspects of the mission, including surveillance equipment and ECM jammer.

Weight = 15 lbs
Dimensions: 9 x 9 x 12 in.

5. Flight Control Computer

Controls flight functions of the RPV, including actuators, pyrotechnics (to jettison rocket and recovery system panels), and the engine. Incorporates a launch discrete that guards against activation of engine and pyrotechnics in the event of a failed launch.

Weight = 15 lbs
Dimensions: 9 x 9 x 12 in.

6. Global Positioning System

This system receives data from satellite once every 0.1 seconds. It is used in conjunction with the radar altimeter and computer generated map to allow for autonomous flight.

Weight = 10 lbs
Dimensions: 6 x 6 x 10 in.

7. RT-1379A/ASW Transmitter/Receiver/Processor

The RT-1379A/ASW interfaces with the mission computer on the MIL-STD-1553B bus. Allows two-way transfer of target information, aircraft vectoring data, and general data reporting of aircraft status. Any data available on the aircraft bus can generally be transmitted.

Weight = 25 lbs
Dimensions: 5.35 x 5 x 10.65 in.

8. Wide-Band Video Downlink

Allows for the downlinking of video obtained from the reconnaissance system and the STIS to the ground. This will be achieved through a data link with a trailing RPV or a high-flying aircraft which will relay the information to the controllers, who will be out of line-of-sight from the RPV.

Weight = 25 lbs
Dimensions: 18 x 6 x 6 in.

9. F-979Le Modular Electro-Optical Reconnaissance System

This system is an electro-optical sensor for low to medium altitude reconnaissance. It has been designed to be a cost-effective alternative to TV systems with over ten times the performance. The F979Le has interchangeable lenses, small size, light weight, and low power consumption. The full resolution of the sensor can be captured on a super VHS airborne recorder and disseminated in real-time by relatively simple data links.

Weight = 24.0 lbs
Dimensions: 8.25 x 8.75 x 9.4 in.

10. Super SVCR-V301 High Resolution Airborne Video Recorder (2)

This system is a high resolution, lightweight, compact recorder. It incorporates a Super VHS format, rewind and playback, over two hours of recording, high speed forward and reverse search, as well as many other useful characteristics. This Super VHS format provides a significantly higher picture clarity with 400 lines of horizontal resolution in both color and black and white recording. It is designed to record video camera, infra-red sensor, and multi-function displays. Two of these systems are located in the A481 Demon. One records information from the Modular Electro-Optical Reconnaissance System and the other records information from the STIS.

Weight = 15.807 lbs
Dimensions: 4.5 x 8.35 x 13.6 in.

11. Hercules ECM Jammer

Especially designed for RPVs and unmanned air vehicles. Its low cost makes it ideal for expendable aircraft. The mini-jammers, using Hercules voltage tuned megatrons, cover a large part of the likely threat frequencies.

Weight = 12.125 lbs
Dimensions: 8 x 6.5 x 5 in.

12. Auxiliary Power Unit

Weight = 17 lbs
Dimensions: 8 x 8 x 12 in.

Automated Control System

The RPV is designed to maintain autonomous control by use of a Global Positioning System (GPS), a computer stored terrain map, and a radar altimeter. The GPS system provides RPV latitudinal and longitudinal positioning along with ground speed. The RPV determines its above ground altitude from the radar altimeter. Finally, the terrain map provides the RPV with knowledge of ground elevations and features. Through these three systems, the RPV is designed to perform a pre-programmed reconnaissance mission. [3]. Figure 5, an Avionics Block Diagram, further details the operations of the avionics and automated control system.
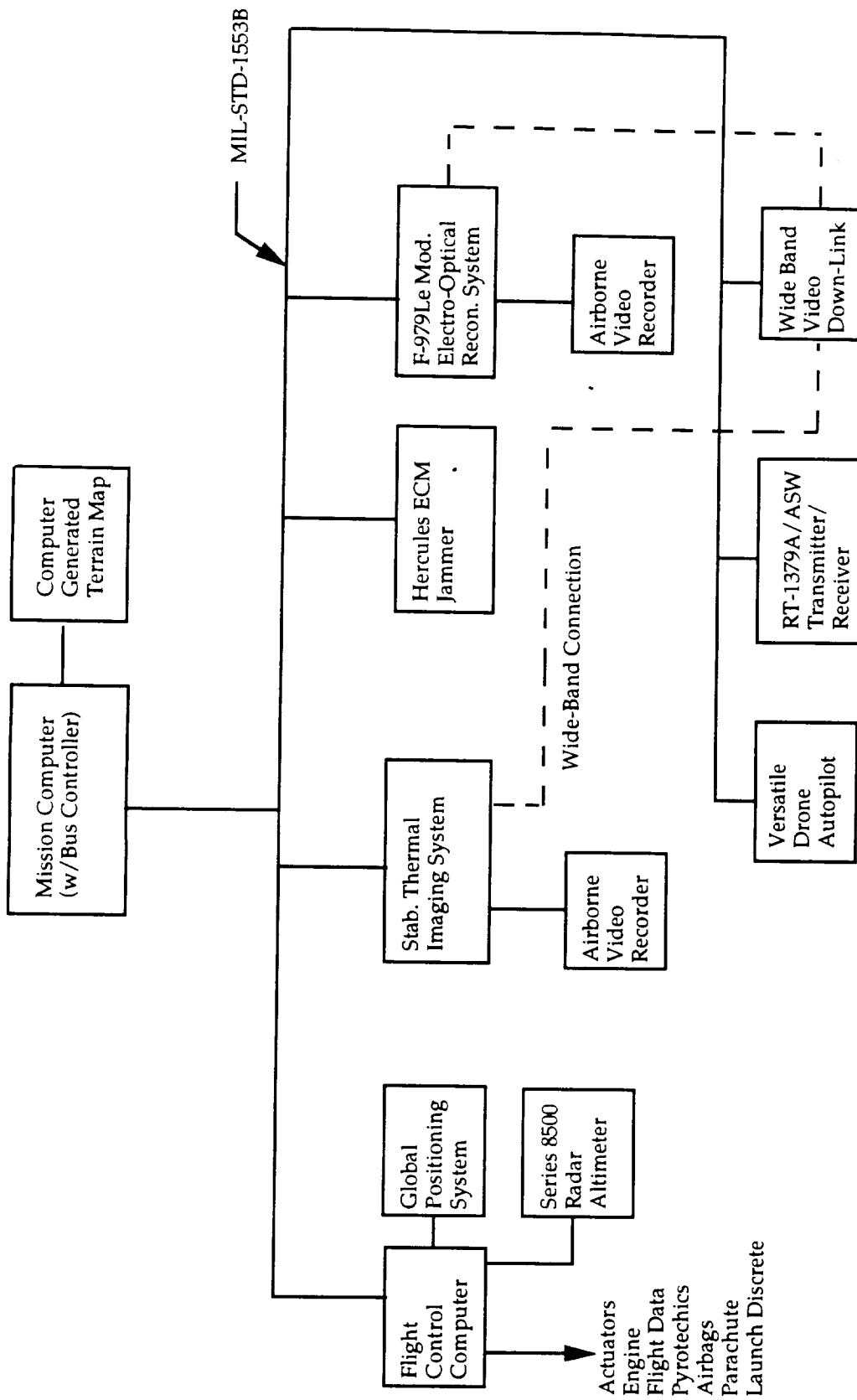
MIL-STD-1553B

Computer Generated Terrain Map

Mission Computer (w/Bus Controller)

F-979Le Mod. Electro-Optical Recon. System

Airborne Video Recorder

Wide Band Video Down-Link

Hercules ECM Jammer

RT-1379A/ASW Transmitter/ Receiver

Wide-Band Connection

Stab. Thermal Imaging System

Airborne Video Recorder

Versatile Drone Autopilot

Global Positioning System

Series 8500 Radar Altimeter

Flight Control Computer

Actuators
Engine
Flight Data
Pyrotechics
Airbags
Parachute
Launch Discrete

Figure 5: Avionics Block Diagram

Launch Systems

The RPV uses a rocket assisted launch from a specially designed skid instead of a conventional takeoff. The skid launch method gives the RPV launch site mobility. It is this mobility that makes the Demon suitable for a wide range of military missions. The skid can be mounted to a truck trailer for ground transportation or to a smaller push trailer for deck launches.

The skid base is fitted with tires, as shown in Figure 6, to allow for easier transportation and mobility. The angle of launch is able to be adjusted by two hydraulic lifts located under the rails that the RPV rests on. The skid is also specially fitted with a crane for mounting and dismounting of the RPV from the rails. This is an important detail for retrieval of the RPV when it lands on the ground. When the RPV is being transported, the hydraulic lifts lower the rails on to two additional rails on the skid base. This allows for greater stability during transportation.

Prior to launch, the RPV's computer is connected by an umbilical to the command center computers. Flight data and mission information is transferred through the umbilical to the RPV. Until launch the RPV rests, without the use of bolts or fasteners, on two rails (located equidistant to the port and starboard sides of the centerline) until it is launched.

Recovery Systems

The recovery system of the Demon consists of two airbags and a parachute. These units allow the Demon to land safely without the use of a runway. The parachute produces enough drag to slow the rate of descent and the airbags absorb the impact during touchdown. The main purpose of the airbags is to protect the avionics and the fuselage.
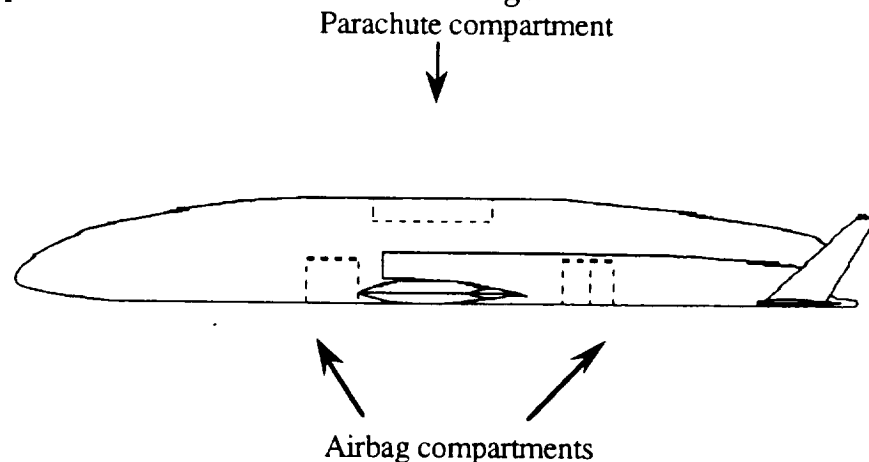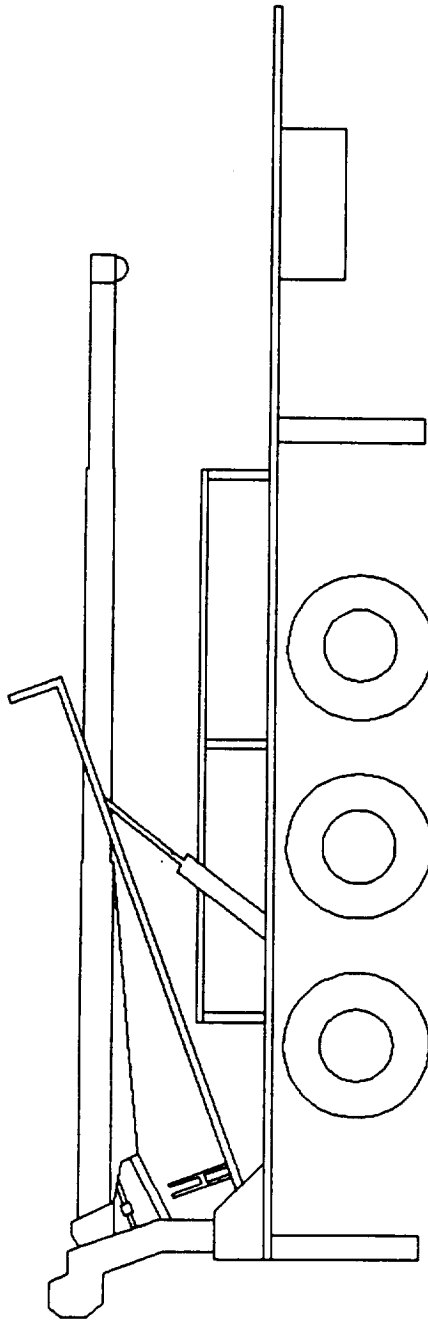
Parachute compartment

Airbag compartments

Figure 7: Recovery Systems Locations

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SKID DESIGN

Figure 6: Skid Design

The recovery system also allows for the possibility of a Mid-Air Recovery. A Mid-Air Recovery System (MARS) involves the use of a helicopter fitted with a trailing cable and a hook to snag the parachute of the descending RPV. The helicopter can then return the RPV to base. [4] A MARS can be used in an effort to decrease the takeoff weight since the airbag units would not be needed.

Parachute

The main component of the landing system is the parachute. The parachute is placed near the aircraft center of gravity so that the RPV will land in a safe, horizontal position. The size of the parachute will be determined by the size and weight of the RPV, and by the rate of descent which provides minimal damage during impact. The parachute will be constructed of lightweight ripstop nylon, with suspension lines fabricated of Dupont Kevlar.[5] The parachute is expected to be reusable.

Once the RPV completes its final climb to at least 3000 feet above ground level, the engine will shut down to allow for a safe parachute deployment. This altitude is determined by the onboard radar altimeter.

Airbag Systems

The landing and recovery system also consists of front and rear airbags to protect the avionics, the engine, and the fuselage structure. The airbags will deploy and inflate between 500-1000 feet above ground level to allow for complete expansion. The deployment will be controlled automatically by the radar altimeter, because the RPV may not always be in line-of-sight for manual deployment via radio signal.

Aerodynamics

The Aerodynamics section of this report consists of the wing planform design, vertical and horizontal tail sizing, airfoil selection, subsonic lift curve slope and zero lift angle, and the parasite drag.

Wing Planform Design

The wing planform design was determined based on lift equations and the weight of the Demon. The surface area, wing span, mean aerodynamic center, and mean aerodynamic chord were all determined at steady level flight conditions.

The density of air value was calculated at an altitude of 5000 feet and a temperature of 40 degrees Celsius to provide a worst case scenario. The other values used in the design calculations were a coefficient of lift equal to 0.05 and a cruise velocity of Mach 0.8. The resulting wing surface was calculated by using Equation 3.

$$L = W = \frac{1}{2}\rho V^2 S C_L \qquad \text{EQN 3}$$

The RPV's wing surface area was calculated as:

$$SA = 35.53 \text{ feet}^2$$

The assumptions that were made in order to complete the wing geometry calculations were:

$$
\begin{aligned}
AR &= 4 \\
\lambda LE &= 30^\circ \\
\lambda &= 0.3
\end{aligned}
$$

Where AR represents the aspect ratio and λ signifies the taper ratio.

From these assumptions the wing span (b), mean aerodynamic chord ($\bar{c}$), and location of the aerodynamic center (X_{ac}) were determined to be the following values:

$$
\begin{aligned}
b &= 11.921 \text{ feet} \\
\bar{c} &= 3.268 \text{ feet} \\
X_{ac} &= 2.2925 \text{ feet}
\end{aligned}
$$

Figure 8 illustrates the layout of the wing planform.

Vertical and Horizontal Tail Sizing

The empennage for the RPV is a partial H-tail configuration. The H-tail allows for stealth characteristics, stability, and reduced vertical height of the RPV (for ease of transportation). The surface area of the vertical (vt) and horizontal tails (ht) was calculated using the tail volume coefficients. [1] It was assumed that the coefficients for the RPV are best represented by those of a jet fighter. Equations 4 and 5 were used to determine these coefficients.

$$c_{vt} = \frac{L_{vt} S_{vt}}{b_w S_w} \qquad \text{EQN 4}$$
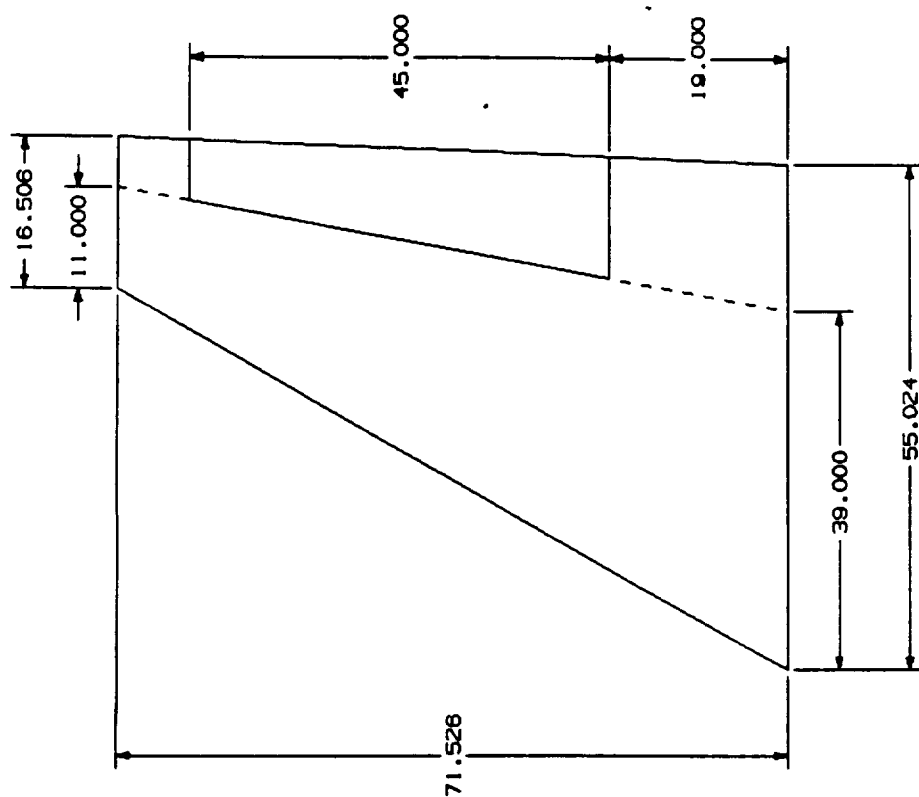
Figure 8: Wing Planform

$$C_{ht} = \frac{L_{ht}S_{ht}}{\overline{C}_w S_w}$$
EQN 5

The values assumed are:

$$C_{vt} = 0.07$$
$$C_{ht} = 0.4$$

The moment arms were initially approximated based on the length and the location of the center of gravity of the fuselage. However, due to stability considerations, the length of the moment arm was adjusted until the RPV met static stability conditions. Then the tail surface areas were calculated.

The final surface areas are:

$$S_{vt} = 4.24 \text{ feet}^2$$
$$S_{ht} = 9.29 \text{ feet}^2$$

The assumptions that were made in order to complete the vertical tail geometry calculations are:

$$AR = 3.5$$
$$\lambda_{LE} = 40°$$
$$\lambda = 0.3$$

From these assumptions the span, mean aerodynamic chord, and location of the aerodynamic center were determined to be the following values:

$$b = 3.85 \text{ feet}$$
$$\overline{c} = 1.21 \text{ feet}$$
$$X_{ac} = 1.05 \text{ feet}$$

The assumptions that were made in order to complete the horizontal tail geometry calculations are:

$$AR = 4$$
$$\lambda_{LE} = 35°$$
$$\lambda = 0.3$$

From these assumptions the span, mean aerodynamic chord, and location of the aerodynamic center were determined to be the following values:

$$b \quad = \quad 6.09 \text{ feet}$$
$$\bar{c} \quad = \quad 1.67 \text{ feet}$$
$$X_{ac} \quad = \quad 1.41 \text{ feet}$$

The planform views of the vertical and horizontal planform can be seen in Figures 9 and 10 respectively.

Airfoil Selections

The airfoil selections for the wing, horizontal tail, and vertical tail were based on the aerodynamic requirements of the RPV. The wing airfoil will be a NACA 0006. This airfoil was selected because the Demon does not require a high cruise lift coefficient. The airfoil for the vertical and horizontal tails is also the NACA 0006. This decision was based on the need for symmetry and minimal thickness. Transonic flight requires this airfoil designs because of the need to prevent shock formation. Other advantages to using the NACA 0006 are reductions in manufacturing costs, tool needs, and machining. A side view of the airfoil can be seen in Figure 11.
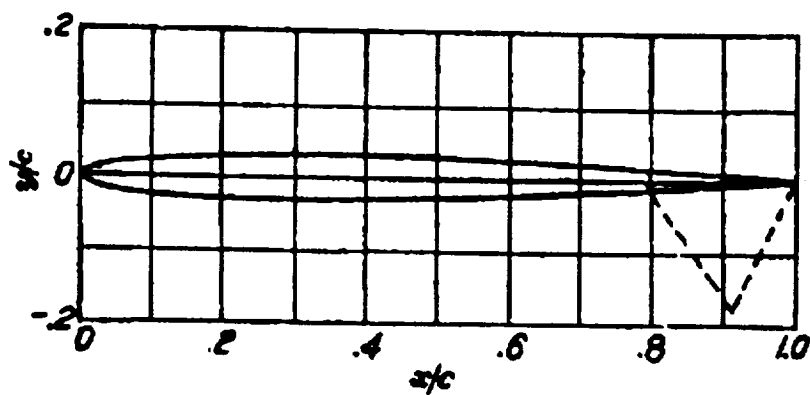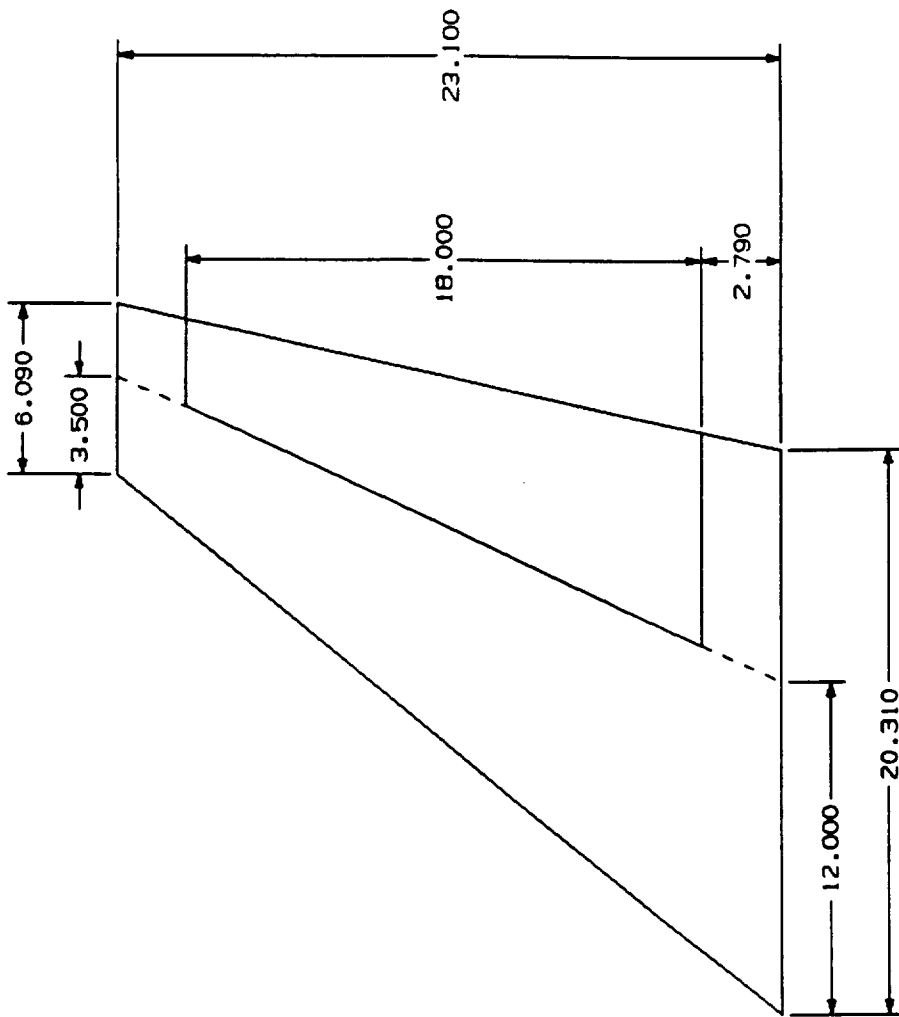

Figure 11: NACA 0006 Symmetric Airfoil [1]

Subsonic Lift Curve Slope and Zero Lift Angle

The Demon is a small, high speed, low altitude vehicle which does not require the use of high lift devices. A semi-empirical formula from was used to calculate lift curve slope for the wing and tail and is as follows [1]:

Figure 9: Vertical Tail Planform

AE481 RPV DESIGN TEAM	4/21/94
VERTICAL TAIL PLANFORM	
AR=3.5	40 DEG. SWEEPBACK

NOTE: ALL DIMENSIONS IN INCHES

24
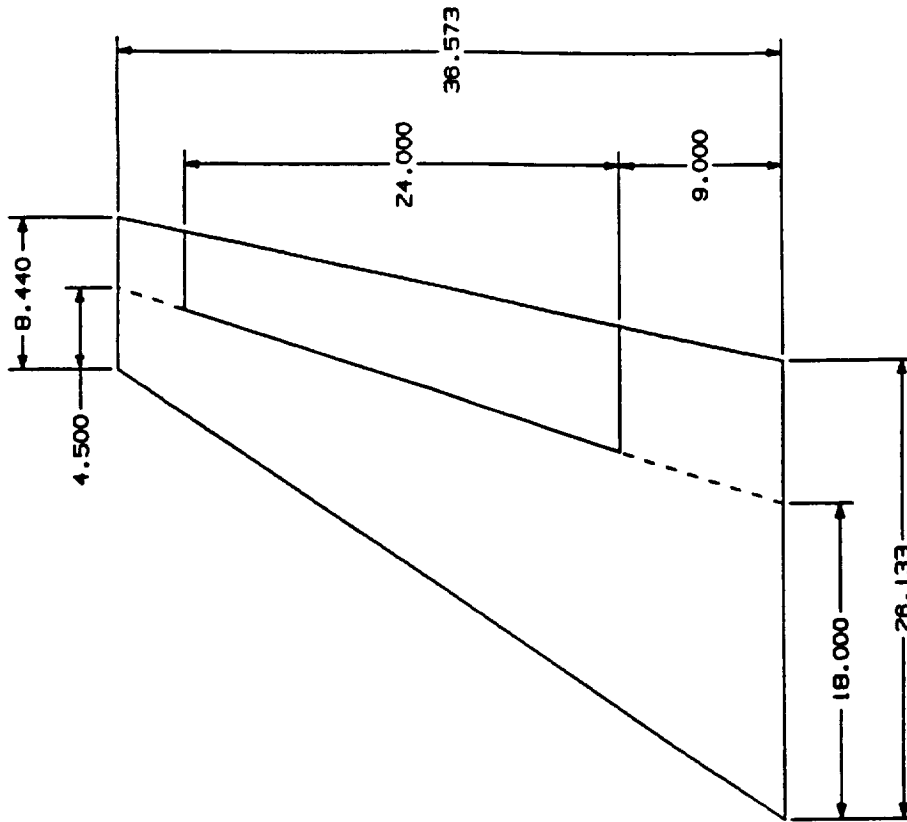
AE481 RPV DESIGN TEAM	4/21/94
HORIZONTAL TAIL PLANFORM	
AR=4	35 DEG. SWEEPBACK

NOTE: ALL DIMENSIONS IN INCHES

Figure 10: Horizontal Tail Planform

25

$$C_{L_\alpha} = \frac{2\pi A}{2 + \sqrt{4 + \dfrac{A^2\beta^2}{\eta^2}\left(1 + \dfrac{\tan^2 \Lambda_{max\,t}}{\beta^2}\right)}}\left(\frac{S_{exposed}}{S_{ref}}\right)(F) \qquad \text{EQN 6}$$

where

$$\beta^2 = 1 - M^2 \qquad\qquad\qquad\qquad\qquad \text{EQN 7}$$

$$F = 1.07\left(1 + \frac{d}{b}\right)^2 \qquad\qquad\qquad \text{EQN 8}$$

A summary of these calculations is as follows:

Wing
$$C_{L_\alpha} = 4.33 \text{ /radians}$$

Horizontal Tail
$$C_{L_\alpha} = 4.66 \text{ radians}$$
$$\alpha_{LO} = 0° \text{ (because of symmetry)}$$

Where α_{LO} represents the zero lift slope.

Vertical Tail
$$C_{L_\alpha} = 4.16 \text{ radians}$$
$$\alpha_{LO} = 0° \text{ (because of symmetry)}$$

Parasite Drag Coefficient

The parasite drag coefficient was determined based on the component build-up method [1] shown in EQN 9.

$$C_{D_O} = \frac{\sum\limits_{c=1}^{n} C_{fc} FF_c Q_c S_{wet_c}}{S_{ref}} + C_{D_{misc}} \qquad \text{EQN 9}$$

From this method the parasite drag coefficient was calculated as:

$$C_{D_O} = 0.00788$$

26

Stability and Control

The Neutral Point was found using the following equation [1]:

$$\overline{X_{np}} = \frac{C_{La}\,\overline{X_{acw}} - C_{ma_{fus}} + \eta_h \dfrac{S_h}{S_w} C_{La_h} \dfrac{\partial \alpha_h}{\partial \alpha}\,\overline{X_{ach}}}{C_{La} + \eta_h \dfrac{S_h}{S_w} C_{La_h} \dfrac{\partial \alpha_h}{\partial \alpha}} \qquad \text{EQN 10}$$

The results are as follows:

$$
\begin{aligned}
X_{np} &= \quad 10.7 \text{ ft (measured from the nose)}\\
X_{cg} &= \quad 10.5 \text{ ft (measured from the nose)}
\end{aligned}
$$

The power off static margin was 6.1% of the mean aerodynamic chord. This shows that the RPV is statically stable because the location of the neutral point is further aft than the location of the center of gravity.

The following stability and control moment derivatives were also determined:

- Yaw moment derivative was calculated to be 0.235.
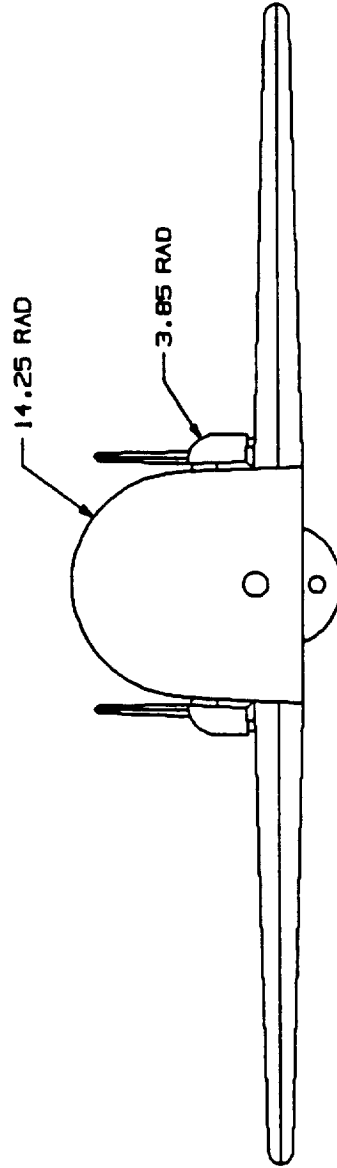- Pitching moment derivative calculated to be - 0.09955

Configuration

The front, side, and top views of the RPV are shown in Figures 12, 13, and 14 respectively.

Stealth Considerations

RPV survivability was a major consideration during the conceptual design. The detectability of the RPV was reduced by reducing the Radar Cross Section (RCS) and the Infrared (IR) signature using:

- Radar absorbing materials in select locations
- H-tail design with the extended fuselage behind the nozzle exit
- Engine nozzle angled slightly upward
- The use of gap-fillers between the fuselage panels [6]

The RCS represents the amount of returned electromagnetic energy. The RCS is also dependent on the "looking-angle" of the threat radar. Major fuselage contributors to the RCS include flat surfaces, intersecting surfaces

14.25 RAD

3.85 RAD

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FRONT VIEW

NOTE: ALL DIMENSIONS IN INCHES

Figure 12: Front View of RPV

28

6.09

23.10

110.00

28.50
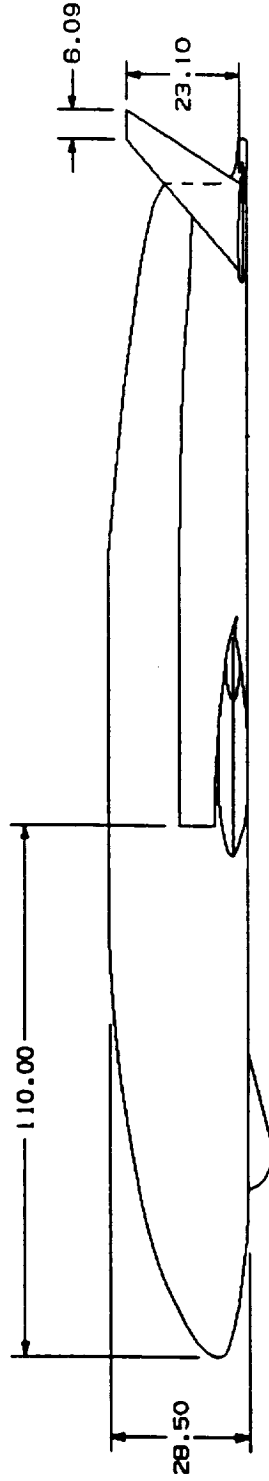
NOTE: ALL DIMENSIONS IN INCHES

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SIDE VIEW

Figure 13: Side View of RPV

29

36.57

16.00

8.44

18.50

240.00

138.78

71.53

15.00

NOTE: ALL DIMENSIONS IN INCHES

Figure 14: Top View of RPV

which form right angles, and electromagnetic currents that build up on the skin when illuminated by a radar. These currents will flow across the skin until they hit a discontinuity such as the gap in between fuselage panels.

Radar Absorbing Material (RAM) [1]

In an effort to reduce the RCS , the leading and trailing edges of the wing, tail, and horizontal stabilizers will be covered in carbon epoxy. In addition, the interior surfaces of the intakes and the intake inlet will also be covered. These materials are heated by the radar electromagnetic waves, thus absorbing some of the energy. These materials reduce, not eliminate, the radar return due to perpendicular bounce.

H-tail Design with Extended Fuselage [1]

The extended fuselage is a one foot extension on the underbelly of the fuselage aft of the nozzle exit. This extension allowed for the H-tail to be moved back far enough to mask the hot exhaust. The purpose of the H-tail and the extended fuselage is to mask the exhaust from side and ground angles. In addition, the H-tail and the extended fuselage allow for the hot exhaust to mix with the ambient air before the flow is exposed to IR sensors.

Engine Nozzle Angled Slightly Upward [1]

Directing the engine nozzle upward relative to the free stream allows for the exhaust to be mixed with the ambient air. This reduces the IR signature of the Demon at the expense of some loss in thrust. It was assumed based on the desire for minimal thrust loss and minimal disturbances to longitudinal stability that an upward angle of 2 degrees would facilitate mixing of the exhaust with the turbulent flow coming off the fuselage. Calculations show there will be a 0.061% decrease in thrust by angling the engine. This was determined by knowing the amount of thrust needed and the upward angle of the engine. Since the engine being used for the Demon has excess thrust, this method was determined to be viable for increasing RPV survivability.

Gap Fillers [6]

One of the largest contributors to the RCS is the electromagnetic currents that build up on the skin when illuminated by a radar. These currents will flow across the skin until they reach a discontinuity, such as the gap between fuselage panels. The discontinuous electrical surfaces do not

dissipate radar signals well and reflect a stronger signal than continuous surfaces. By using a newly designed device called a "gap-filler", a continuous electrical surface is established between adjacent panels. This reduces the reflected signal thus reducing the RCS.

In its basic form, the design consists of a continuous strip of friction-fit clips that bridge the small space between panels. The snap-in gap filler clip consists of two parts: a vertical retaining piece with edges that friction-fit into the gap, and a horizontal cap that covers the gap and attaches to the vertical portion. The modular clip design is shown below in Figure 5. Each T-shaped cap of the clip is tailored to be composed of the same material as the fuselage skin. Additional benefits include drag reduction, reduced fuel consumption, and are less corrosive and easier to install than current caulk gap fillers.
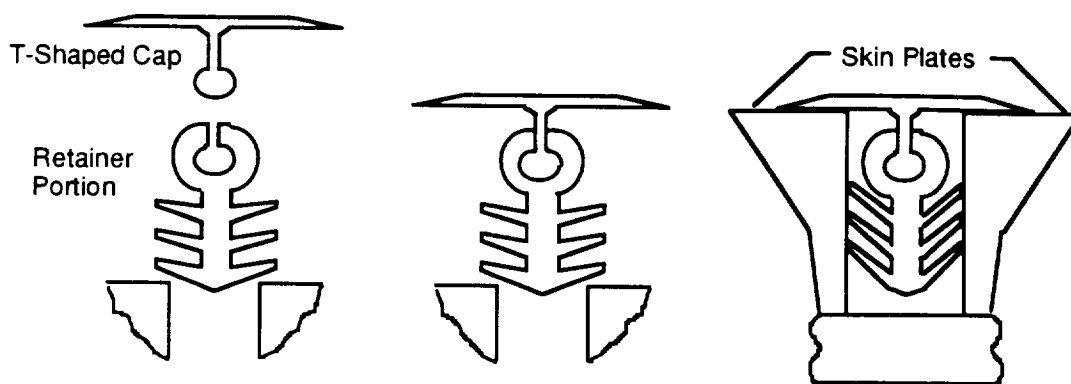
Figure 15: Modular Clip Design

Economic Analysis

The economic considerations examined for the RPV design were cost, profitability, and size of the aircraft program. The economic analysis will determine production and manufacturing costs, as well as the man-hours put into the research, development, and production program. The economic study is based on the life cycle cost analysis program created by Raymer. [1]

Research, Development, and Test

The cost analysis estimation for the research and development of this aircraft is based on empty weight, maximum speed, and the number of test aircraft. The research and development segment is based on the use of 10 developmental aircraft. This portion of the program is the most expensive due to the amount of time required to test the aircraft and certify the various standards required by the customer. The results of the cost analysis are contained in Table 7.

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	Cost
Development Support Cost	10 million
Flight Test Cost	30 million

Table 7: Development and Test Costs

Production and Manufacturing

The estimated production and manufacturing costs are based on the amount of aircraft produced, man-hours, and the labor rate of pay during various manufacturing procedures. The number of aircraft to be produced will depend on the military demand for such a vehicle. A study of various numbers of aircraft produced was done to indicate the cost differences. The information obtained by this study is presented in Figure 16, which indicates that the larger the number of aircraft produced the cheaper the manufacturing and selling cost per airplane. Based on this study, the number of RPVs produced was determined to be 400.
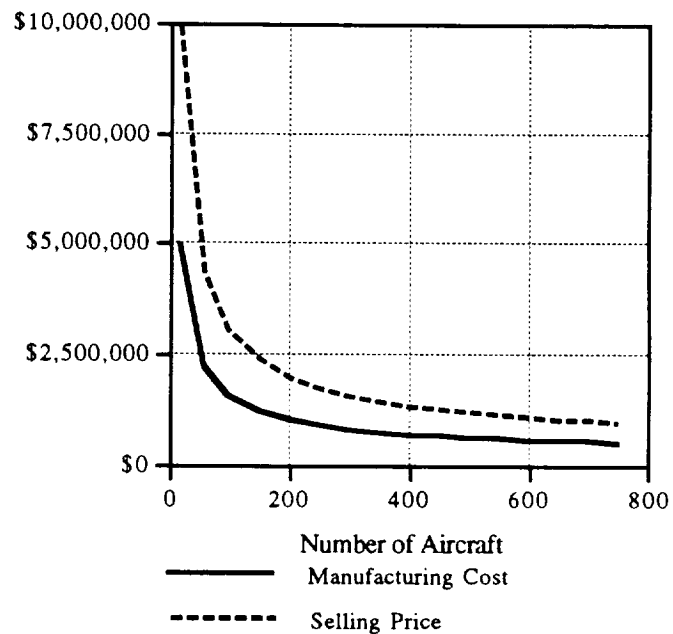
Figure 16: Manufacturing Costs and Selling Price

The man-hours required to produce the aircraft are dependent upon the empty weight, velocity, and quantity of the aircraft. The areas included in the required man-hours consists of engineering, tooling, manufacturing, and

33

quality control. The time demanded of these areas is presented in Table 8, based on the production of 400 aircraft.

	Hours
Engineering	588,900
Tooling	381,800
Manufacturing	1.6 million
Quality Control	211,400

Table 8: Man-hours for Program

The estimated cost for the engines, materials, and fuel was determined through research and calculations. The approximate cost of the turbojet engine was given by a representative of Teledyne Ryan CAE [1], where the approximate costs of materials and fuel was obtained through calculations. These values are located in Table 9.

	Cost
Cost per Engine	80,000
Fuel Cost per year per aircraft	13,300
Materials Cost	28 million

Table 9: System Costs

Direct Operating Cost

The estimated costs for operating the Demon are based on maintenance, engine, depreciation, and fuel costs. Maintenance costs include the material and labor costs for the engine and airframe upkeep. The direct operating cost of the aircraft is very sensitive to any fluctuations in the price of fuel. Therefore, as the price of fuel increases the direct operating cost will increase significantly. The values for all of these parameters are presented in Table 10.

	Cost
Maintenance per year per aircraft	60,120
Depreciation per year	51,670
Direct Operating Cost	95,730

Table 10: Direct Operating Cost

Economic Analysis Conclusion

The unit cost of the Demon is 1.3 million dollars per aircraft based on the production of 400 aircraft. Since the Demon is a unique RPV, based on its mission requirements, it cannot be compared to other RPV's. The predicted demand by the military for the Demon should make it a profitable design.

Concluding Remarks

The AE481 Demon is a practical and economically feasible design for a high-speed, surveillance remotely piloted vehicle. The final design meets all of the mission requirements. The RPV has the necessary electronics for its mission and has the required survivability built into it using new technology and materials. Each component of the design utilizes current technology, which further improves the Demon's practicality. A cost analysis shows that the RPV is also economically feasible. Considering the practicality and economic feasibility, the Demon RPV design meets and exceeds the requirements of the United States Military.

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