DESIGNING AND DEVELOPMENT OF UNMANNED AERIAL VEHICLE

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Abstract

With the advancement in science and technology, the aviation industry is increasingly concentrating on the development of Remotely Piloted Vehicles (RPVs), Unmanned Aerial Vehicles (UAVs) and Unmanned Combat Aerial Vehicles (UCAVs). The Unmanned Aerial Vehicle (UAV) are being used for many years for a variety of different tasks like reconnaissance, bomb damage assessment (BDA), scientific research, escort EW, decoying guiding SAMs and AAMs, and target practice. These UAVs will replace the conventional aircraft in several roles and even perform novel assignments. The hostile battlefield environments and difficult access areas can be monitored without endangering human life. This paper elaborate the designing of UAV that can be used as interceptor and can perform reconnaissance/survillance missions as well.

1 Introduction

Use of the Unmanned Aerial Vehicle (UAV) has existed for many years for a variety of different tasks. In previous years, UAV missions have included reconnaissance, surveillance, bomb damage assessment (BDA), scientific research, and target practice. However, UAV's have never been widely used in direct combat. Even current high-tech UAV's such as the Darkstar are limited to non-combative missions. In an age when the physiological tolerances and physical capabilities of the crew restrain the limits of performance of a modern fighter, the use of a UAV in a combat role deserves some consideration.

2.0 Design Philosophy and Goals

The principle goal in the UAV-Ip (Unmanned Aerial Vehicle - Interceptor) design process was to create an interceptor, which could super cruise to intercept a target in a minimal time at a maximum possible range. The application of this aircraft would be defensive in nature, when conventional aircraft are immediately unavailable or unable to deploy. The UAV-Ip would be preprogrammed to carry out a certain mission

2.1 Design Requirements

A set of requirements was set for the UAV-Ip in order to accomplish mission effectively and efficiently. These requirements are:

- Payload - Four AMRAAMs weighing just under 1500 lbs.
- Dash - A 320 nm range in 20 minutes from launch.

- Range/Radius - 700nm with a 15 minute loiter/350nm radius.
- Avionics - Capability of launching all missiles given targeting information from friendly ground, sea or air based platforms. GPS/INS for accurate location of the UAV and for navigation and guidance. Yaw, pitch, roll, temperature, fuel & RPM sensors for flight control. Radio for data up & down link.
- GPS receiver for accurate location of aircraft.
- On Board Sensors - The mission sensors include video and IR cameras for day & night surveillance and reconnaissance
- Take-off/Landing - Capable of either a land or sea take-off and landing.
- Ground Control Station (GCS) – To control the UAV and display reconnaissance information.

2.2 Mission Profiles

2.2.1 Primary Mission: Intercept

The primary mission of the UAV-Ip is characterized by a high-speed dash to the target area, followed by an immediate payload release and return to base. This mission is represented below in figure 2.2.1 (a)

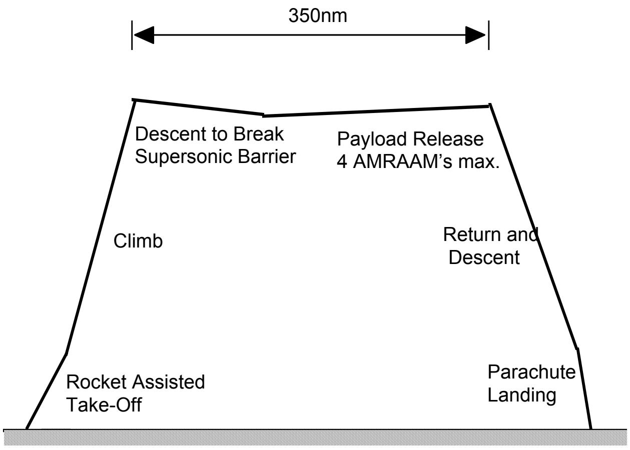


Figure 2.2.1 (a) Primary Mission Profile: Intercept

2.2.2 Secondary Mission: Combat Air Patrol / Reconnaissance

In contrast, the secondary mission of the UAV-Ip is characterized by a fuel-efficient subsonic cruise to the target area. Figure 2.2.2 (a) below shows the stages of the secondary mission

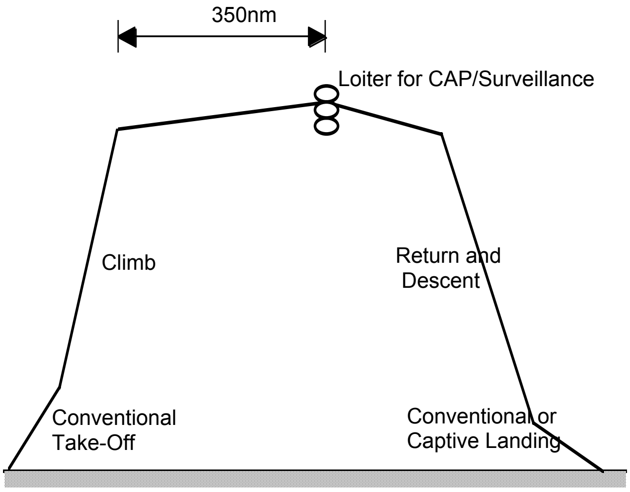


Figure 2.2.2 (a): Secondary Mission: Combat Air Patrol / reconnaissance

The mission proceeds with a conventional take off and climb to an optimum cruising altitude. The aircraft then enters a subsonic cruise stage in which fuel is conserved to a necessary degree, depending upon the mission. Upon reaching the target area, the UAV-Ip will have the capability to loiter within a specified combat radius for a maximum of 15 minutes.

At this point, there are numerous tasks that the UAV-Ip can be equipped for, including, but not limited to, the following: air combat, radar platform, surveillance, anti-ship, electronic warfare, etc. The likely role in this mission would be combat air patrol, in which the UAV-Ip would loiter in an area of suspected enemy air activity.

3.0 Weapons Package

3.1 Selection Process

The choice of the weapons package for the UAV-Ip was dependent upon two primary factors. First, in an effort to reduce the cost, weight, and size of the UAV-Ip, it was decided to attempt a design, which would not require an onboard radar system. As a consequence, only active homing weapons (missiles) were considered. Radar guided missiles such as the AIM-7 Sparrow require acquisition and tracking by the host aircraft's radar in order to home in on the target.

Second, the armament must be capable of beyond visual range interception. Because the physical structure of the UAV-Ip was designed to accommodate a high speed supercruise to the target area, it is not intended to engage in close in combat which would require excessive maneuvering (i.e. dogfighting) and remote data transfer. As a result, only extended medium range and long range missiles could be considered.

3.2 AIM-120 AMRAAM

The only publicly known air-to-air missile which fits both requirements of being active and beyond visual range is the AIM-120 Advanced Medium Range Air to Air Missile (AMRAAM). The AMRAAM does require some initial target information, which will be provided from the support crew, wherever they may be based.

3.2.1. Future Weapons Systems

In the future, other weapons systems may be considered for use in the UAV-Ip. Since there is no radar available for acquisition or tracking, any weapons considered must use an active acquisition and tracking system. Other weapons systems that might be included into an expanded mission profile are the Harpoon anti-ship missile, HARM anti-radiation missile, and laser guided smart weapons, which would track laser illumination from an exterior source.

3.3 Defensive Measures

In hopes of overcoming the UAV-Ip's inherent lack of maneuverability and making it as survivable as possible, much attention was paid to passive and active defensive capabilities.

3.3.1 Low Observability (stealth)

Low observability implies reduced radar cross section (RCS), but not so much as a total stealth aircraft. This is accomplished by eliminating vertical surfaces and any other means, which would reflect radar waves. The V-tail, interior weapons bay and over-fuselage air intake are all results of an attempt to incorporate low observability into the UAV-Ip design. Moreover Special paint will be coated on the entire surface of UAV-Ip, which will absorb the radar waves. The honeycomb design of internal wings structure is suggested for UAV-Ip that will further reduce the the chances of being observed.

4.0 Configuration

One configuration consisted of the AMRAAMs being mounted internally in two rows, two missiles across, while the other configuration had the missiles mounted in one row, four across. A design comparison between the two configurations took place, based mainly on minimizing fuselage size, weight, and drag, while maximizing storage area for fuel, avionics, and weapons. The comparison resulted in a compromise between the two configurations. This preliminary UAV-Ip design is discussed below.

4.1 Main Components

A three-view picture of the conceptual UAV-Ip design is shown in figure 4.1.1. The aircraft features a rear mounted, highly aft-swept true delta wing to decrease the adverse affects of transonic and supersonic flow. A fore-mounted canard coupled with a V-tail provides longitudinal control and high maneuverability at high angles of attack. A low-bypass turbofan engine combined with an over-fuselage inlet powers the aircraft. Furthermore, the weapons package consisting of four AMRAAMs is carried internally in a mid-fuselage weapons bay, with the missiles mounted in a variation of four across.

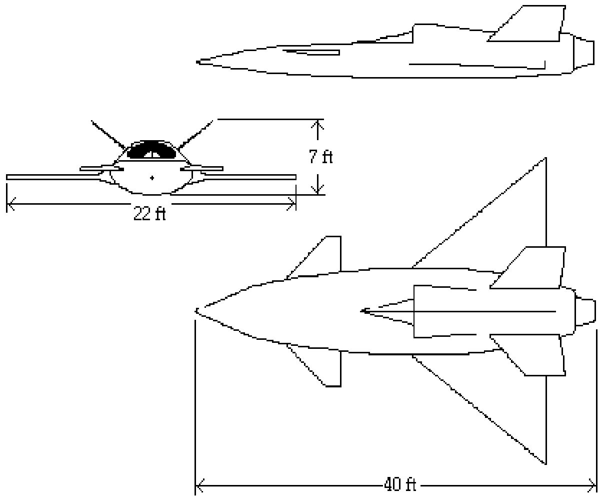


Figure 4.1.1: Three View Drawing of UAV-Ip Conceptual Design

4.1.1 Wing

The UAV-Ip aircraft has a calculated wing area of 210 sq. ft. Because the UAV-Ip's mission profile requires flight primarily in the supersonic regime, the wing was designed with a 2.3 aspect ratio, 0 taper (i.e. pointed tip), and 60° sweep, along with a 4 % thick airfoil at 40% chord line. This gives the UAV-Ip good performance at transonic and supersonic speeds, but also allows for performance in the subsonic regime. Any metal (composite) used in the wing will be limited to high temperature, high stress parts like the leading edges of the wing, the load-bearing spars, and fittings. Based on historical data for composite materials, it is expected that the UAV-Ip's wing could be up to 25% lighter than conventional wings.

4.1.2 Fuselage

The body of the UAV-Ip is approximately 40 feet long and 7 feet wide at it's mid-point. The shape of the fuselage will be optimized taking cost minimization and construction difficulty as the dominant constraints. Extensive attention was spent to ensure that all of the necessary equipment would fit inside the UAV-Ip without making it too large. The total fuselage volume is estimated at 536.0 cubic feet. The large volume amount is due to the internal storage of the AMRAAMs and fuel. Area-ruling principles were used to help design the fuselage shape while maintaining a minimum drag.

4.1.3 Stabilizers and Control Surfaces

The canard and V-tail give the UAV-Ip two longitudinal controlling surfaces. This configuration offers improved pitch control and handling over a single set of control surfaces. The V-tail's versatile combination of rudder and stabilizer capabilities was ideal implementations in the UAV-Ip design. In addition, because the V-tail avoids right angles between exterior surfaces, it reduces the aircraft's radar cross section (RCS). The inclination of the UAV-Ip's V-tail is 50° from vertical, providing longitudinal control as well as good yaw control.

4.1.4 Engine

Only one engine was utilized in an effort to minimize weight and fuel consumption. Because the UAV-Ip is unmanned, not much emphasis was placed on redundancy and/or safety factors. The engine selected is a low-bypass turbofan, which provides better fuel economy than a turbojet.

4.1.5 Weapons Bay

The weapons package of four AIM-120 AMRAAM radar-homing missiles will be carried in an internal fuselage bay at the approximate mid-point of the fuselage. The AMRAAMs will hang from pylons in the bay and will be situated in pairs slightly offset from each other to help minimize the fuselage cross section, as shown in figure 4.1.5(a). The two bay doors will be double hinged to reduce their open radar cross section, and the missiles will free-fall from the bay before their motors ignite.

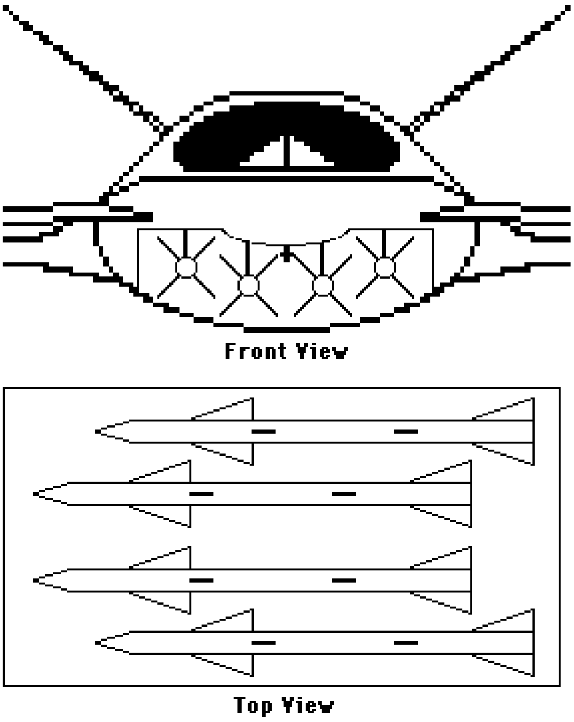


Figure 4.1.5 (a): UAV-I Weapons Bay

4.1.6 Air Intake

The UAV-Ip's air intake is an over-fuselage intake, with the opening located approximately midway back along the top surface of the fuselage. This location provides approximately 10 feet of duct length, allowing the air to slow before entering the first stage of the compressor. This duct length also provides smooth airflow that prevents an engine out due to separation. Foreign Object Damage (FOD) is minimized because the intake is on top of the fuselage, high off the ground.

4.1.7 Fuel System

The UAV-Ip's fuel system is divided into four internal fuel cells. The use of multiple cells will help ensure that the CG of the aircraft does not deviate much from specifications during flight. The four fuel cells are to be located one front and one aft of the fuselage center, and one cell in each wing root. These tanks provide a total fuel capacity of about 637 gallons, or approximately 4000 lbs

4.1.8 Landing Gear

The UAV-Ip uses a standard configuration tricycle-type landing gear. This consists of a single nose landing gear in front of the aircraft's CG and two main gear located aft of the CG. The nose gear pivots down towards the rear of the aircraft. This allows the gear to lock itself during landing in the event it does not become fully deployed. The main gear have the same type of retraction mechanism as used on the F-16. Historical data shows that this gear retraction design minimizes the required fuselage while providing a relatively simple mechanism

5.0 Weights Calculation

The weights of the individual components and systems of the UAV-Ip were calculated using the statistical formulas given in Raymer's text [p. 397]. These formulas for a fighter aircraft are based on component weight distributions of similar aircraft in history and represent the weights as functions of several fixed aircraft constants. The weights obtained are statistical approximations that would typically change up to 5% when the aircraft is actually built. These weights were summed and added to the fuel and payload in order to obtain an overall gross weight.

5.1 Iteration of Weights Calculations

The weight equations for the individual components were coded into a MATLAB script in order to ease incorporation of changes. Because some of the aircraft parameters (fuel weight, wing dimensions) were changed during the preliminary design process, the MATLAB scripts were run several times to constantly update the weight of the UAV-Ip. The results of the final iteration are shown below in table 5.2.1, and their distribution is represented in figure 5.2.1.

Component/System	Weight (lbs)
Payload	1340
Wing	1110
Canards	232

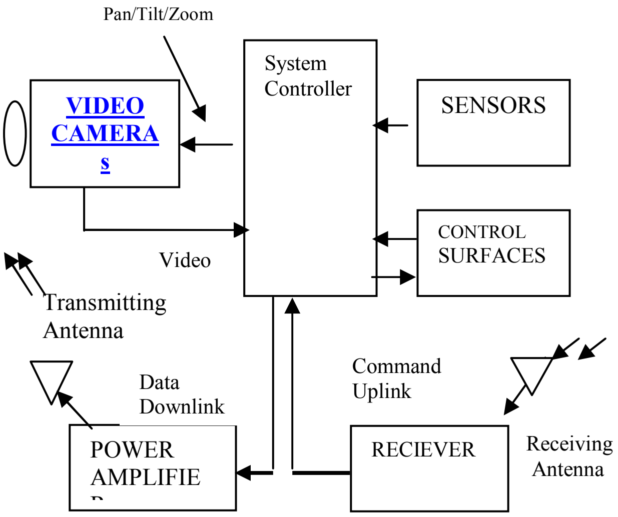
Tails	7865
Fuselage	1060
Fuel System	280
Avionics	1580
Fuel	4000
Landing Gear	689
Propulsion	2469
Flight Controls	794
Miscellaneous	235
Total	14654 lbs

Figure 5.2.1: Weight Distribution Among Components and Systems

6.0 Avionics

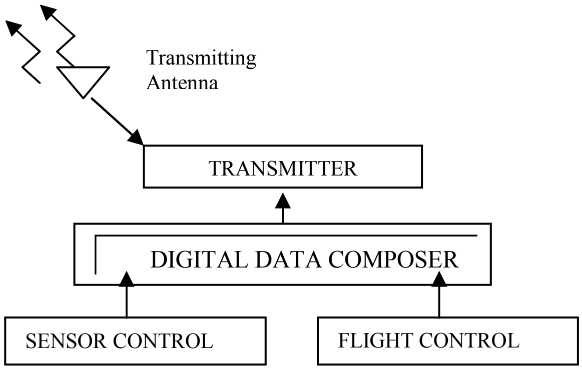
The UAV-Ip has video and IR cameras for day and night surveillance & reconnaissance. System controller controls the tilt, zoom and pan of the cameras after getting commands through data up link. The system controller takes the input from the sensors and arranges data down link. The system controller, in manual or auto mode, controls the flight of the UAV-Ip. It also has control system and navigation & guidance system for automatic guidance and control.

The envisaged block diagram of the UAV-Ip is shown in fig.6.1

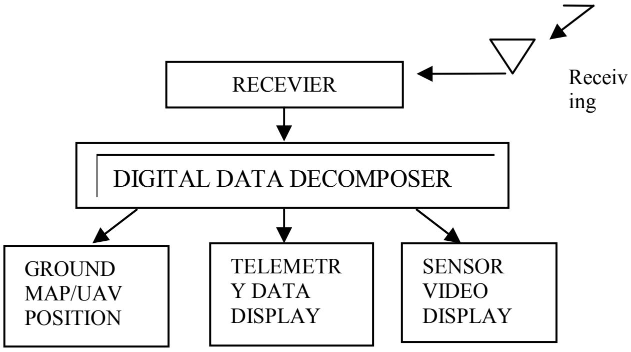


6.1 Ground Control Station

A Ground Control Station (GCS) is required to control the UAV-Ip and on board cameras. A real time **data up link** is used to command and control flight of the UAV-Ip and on board camera sensors. The data of flight and sensor controls is composed and transmitted using an UHF radio. The major components of GCS up link are as given in fig 6.1.1(GC Uplink)



L-Band receiver is used for real time **data down link** to relay video and telemetry information. This digital data is then decomposed to display "ground map, ground contours and "UAV position", "telemetry data", and "sensor's video". The GCS downlink scheme is as in fig-6.1.2.(GC Downlink)



State of art PCs can be used to establish the GCS. The information of the UAV-Ip sensors is displayed for the remote controller to be able to either fly the UAV-Ip in manual mode or take appropriate decisions in auto pilot mode. The UAV-Ip position is displayed on the ground map to know where about of the UAV-Ip. The video from the cameras is displayed for the remote controller and it can be further relayed to concerned agencies for real-time monitoring, decisions and operations.

7.0 Stability and Control

A major goal for the UAV-Ips to perform at high speeds giving the capabilities of a pure interceptor. Therefore, the UAV-Ip is neutrally stable aircraft that will utilize a fly-by-wire control system for controlled flight.

7.1 Stability

Three parameters were considered for the initial stability analyses: the static margin (SM), the roll stability derivative (Clβ), and the yaw stability derivative (Cnβ). Each parameter has typical values depending on the type of aircraft. The location and size of the canard, wing, and V-tail were then iterated until the desired values for each parameter were obtained. The analysis was divided into two categories: longitudinal (pitch) and lateral stability.

The longitudinal stability of the aircraft was determined by calculating the SM. For a stable aircraft the SM is positive, and for an unstable aircraft the SM is negative. The main contribution to the SM is the dihedral angle of the V-tail. Thus, the dihedral angle of the V-tail (40° from the vertical) was dictated by the SM.

Lateral stability was established by considering the values for the roll (Clβ) and yaw (Cnβ) moment coefficients. Beginning with roll, (Clβ) must be negative to assure a stable aircraft in the roll direction. Typical values of Clβ for a fighter are -0.3 to -0.1. The initial sizes for the canard, wing, and V-tail provide sufficient roll stability. However, to obtain yaw stability, the vertical-projected area for the V-tail was increased. This also affecting the V-tail dihedral angle and total size. Some iterations were required to size the surfaces.

Each of the three parameters varied with Mach number. Figures 7.1.1-7.1.3 below show how SM, Clβ, and Cnβ vary with Mach number.

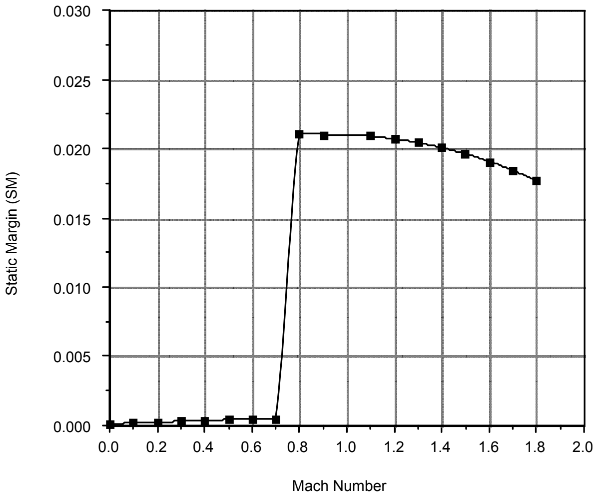


Figure 7.1.1: Static Margin vs. Mach Number

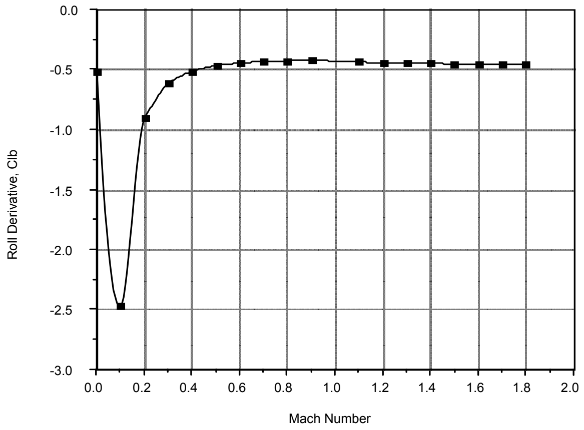


Figure 7.1.2: Roll Derivative vs. Mach Number

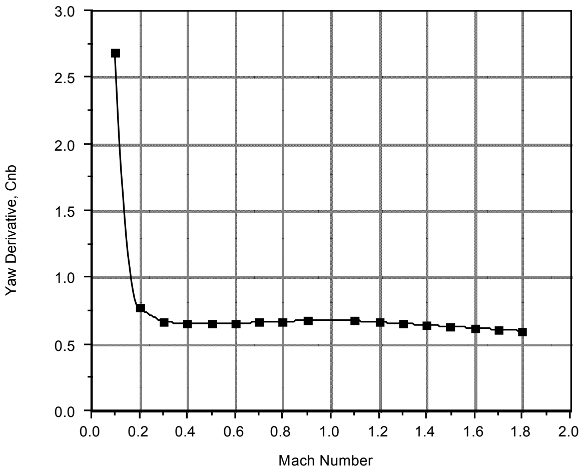


Figure 7.1.3: Yaw Derivative vs. Mach Number

7.2 Control Surfaces

The UAV-I conceptual design does not lend itself to detailed control surface analysis. However, the performed preliminary control calculations for the UAV-I used primarily historical data. The UAV-I utilizes conventional aerodynamic control surfaces to provide fighter-like control and handling.

Primary pitch control will come from the canard. Flaperons will serve for roll control as well as high lift surfaces for takeoff and landing. Rudders, in a twin vertical tail configuration, will provide the necessary yaw inputs.

7.2.1 Canard

The UAV-I utilizes an all-moving canard based on construction simplicity and drag considerations for hinged surfaces. To prevent flutter at higher speeds, the connecting/control tube for the canard should be located at approximately 50% of its mean aerodynamic center. Full forward rotation could be designed to aid in braking after landing, with canard serving as a speed brake.

7.2.2 Flaperons

The UAV-I utilizes flaperons to incorporate the necessary aileron and flap surface areas. For the flaperon sizing, the UAV-I utilized a combination of aileron and flap size historical data.

7.2.2.1 Flaperon Sizing

After determining a necessary aileron area of 56 sq. ft and a plain flap area of 35 sq. ft, the UAV-I requires a flaperon area to be 56 sq. ft. The use of the flaperons allows a control surface area 40 percent smaller than the combined areas of standard ailerons and flaps. The 11 ft span of the flaperon increases the flapped area, $S_{flapped}$, as seen in Figure 7.4. The increase flapped area enables the creation of greater DC_{Lmax}. Flaperons increase Clmax from 1.15 to 1.39 for landing and from 1.15 to 1.68 for takeoff, for the same area as compared to standard flap configuration.

7.2.2.2 Flaperon Deflection

Flaperons deflect both upward and downward serving for roll control and as high-lift devices for takeoff and landing. In the takeoff or landing settings the flaperons deflect some 10° and 40°, respectively.

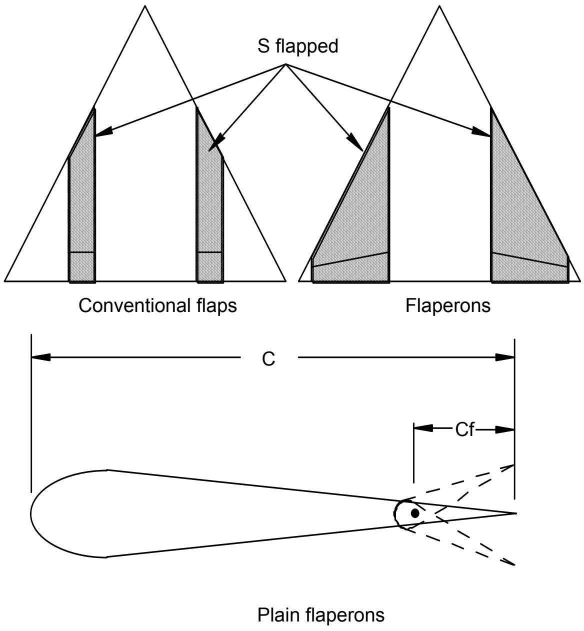


Figure 7.2.2.2.1: Flapped Reference Area and Flaperon Deflection

7.2.2.3 Flaperon Drag

The increase in drag as a result of flaperon deflection, d, was estimated using empirically derived equations. When deployed 10°, flaperons increase parasite drag by 10 drag counts, while when deployed 40° the flaperons increase drag by nearly 70 counts.

7.2.2.4 Change in Zero Lift Angle

For stability estimated, the change in zero lift angle as a result of flaperon deflection needed to be calculated. The UAV-I requires a change of roughly 1.7° to 2.5° for takeoff and landing settings, respectively. No further calculations were performed to predict drag, increase lift, or roll performance from the flaperons.

7.2.3 Rudders

For preliminary rudder sizing, the UAV-I utilized the rudder chord as 40% of the mean rudder chord, and the rudder span is 50% of the V-tail span. The resulting rudder surface area is roughly 8.5 ft^2 per rudder. Further detailed analysis, beyond the scope of this project, would involve flutter considerations at high speeds, as well as sufficient yaw control in an engine-out situation.

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