Super Phantom

Small, High-Speed, Unmanned Aerial Vehicle

Engineering Design Report

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May 29, 2017

Executive Summary

This report presents a design for a small, remotely-piloted aircraft that is intended to exceed a true airspeed of 500 mph in level flight. The approach to solving this problem was to design the first model of the aircraft to incorporate basic aerodynamic principles and design trends from aircraft with similar goals, before running it through a Computational Fluid Dynamics (CFD) software to evaluate its performance.

This design report documents the first design made to meet the criteria. In evaluating this design, the following criteria were considered: estimated maximum speed, estimated high and low speed handling, estimated takeoff and landing performance, and simplicity.

Problem Definition

Problem Statement

The task was to design an unmanned aerial vehicle weighing less than 100 pounds that can exceed 500 mph in level flight while having room for flight gear such as airspeed indicators, landing gear with gear brakes, etc. The Super Phantom is also currently supposed to be able to carry at least 5 pounds of payload.

Importance

There are multiple ways in which this mission is important. By building a small, high-speed UAV, it will first be proven that it is possible to build a craft to meet the criteria, which will allow for it to complete missions that other drones perform. By continuously refining and improving the experimental design, it could be put into practical use with the military as a reconnaissance drone or potentially even a light strike drone.

Design Requirements

The current design requirements for the Super Phantom is being capable of achieving a true airspeed of 500 mph in level flight, having a stall speed of less than 120 miles per hour, and being able carry enough fuel to allow for an endurance of eight minutes at military power.

Design Description

Design Specifications

The current configuration of the Super Phantom is as a swept-delta, low-wing, unmanned jet aircraft that is 6.79 feet in length and 4.34 feet in wingspan, with a tricycle gear arrangement and gear brakes. The Super Phantom is currently supposed to use a non-afterburning turbojet engine potentially with water injection, capable of an output between 50 and 120 pounds-force at military power. The Super Phantom currently uses an area ruled fuselage in order to reduce wave drag, which allows it to attain a higher top speed. Its design currently uses a swept vertical stabilizer and an all-moving, cropped-delta horizontal tail, instead of a conventional elevator. The Super Phantom uses a round nose intake eliminating the need for more complex ducting of the intake air. The Super Phantom will most likely use a first-person view (FPV) system, angle-of-attack indicator, airspeed indicator, altimeter, heading indicator, an artificial horizon, and a GPS for tracking and navigation.

Possible Uses

Currently, the Super Phantom drone would have no intended use beyond being a demonstrator, but could be used to deliver small packages in urgent situations. Although the Super Phantom is not intended to be used for any military missions currently, it could be modified and used as a reconnaissance drone for all branches of the U.S. Armed Forces, or scaled up to be used as a high-speed, light strike UCAV for the U.S. Air Force, capable of carrying small weapons such as 45 lb AGM-176 Griffin air-to-ground missiles as a ground-attack craft, or 35 lb AIM-92 Stinger air-to-air missiles; or scaled up further to carry multiple Griffins or Stingers, or even an AGM-114 Hellfire air-to-surface anti-armor guided missile, AIM-9X Sidewinder air-to-air infrared guided missiles; or a SUU-11/A gun pod, which contains a GAU-2/A Minigun or the SUU-12/A gun pod, containing a Browning AN/M3 .50 caliber heavy machine gun for strafing.

Evaluation

Design Approach

The basic design process used for the Super Phantom was to choose an airframe, apply aerodynamic principles to refine it, look for potential problems in the design, then adapt the design accordingly. This process was repeated a few times until a design was settled upon, then a 3D model of it was created so it could be uploaded into a CFD software.

Design Documentation

The preliminary design of the Super Phantom was a swept wing design with a 35-degree wing-sweep and a round nose intake, resembling the XF-85 or F-86 except with a fuselage that was wider overall, especially near the wing root (Figure 1). For the next design iteration, the wings were then swept back from 35 degrees to 45 degrees, given a shorter span and a slightly wider chord, the nose intake was deleted and it was given two smaller air inlets in the wing roots, and the craft was given an area-ruled fuselage. These changes were made in order to significantly reduce drag, especially during the transonic flight regime. The resulting aircraft bore a striking resemblance to the F-105 Thunderchief (Figure 2).

Its design then evolved into a double-delta winged aircraft in order to reduce wing loading and give it the ability produce vortex lift to allow for lift far beyond its critical angle of attack. It was also given an under-nose intake similar to the F-86D Sabre Dog, F-8 Crusader or F-16 Fighting Falcon (Figure 3). The next refinement was to give it a 45-degree, swept-delta wing and a circular nose intake due to the complexity of double-delta wings and the geometry of the old inlet (Figure 4). This new design resembled an F-100 Super Sabre mixed with an F-4 Phantom II, so the design was named the Super Phantom.

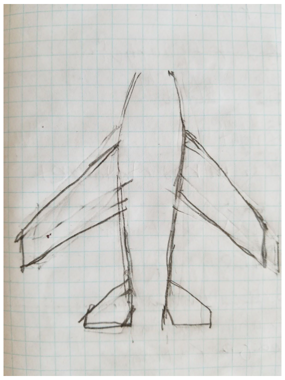

Figure 1

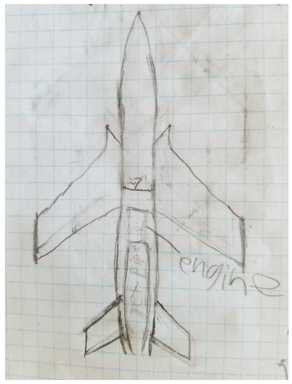

Figure 2

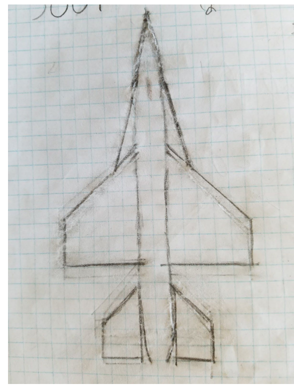

Figure 3

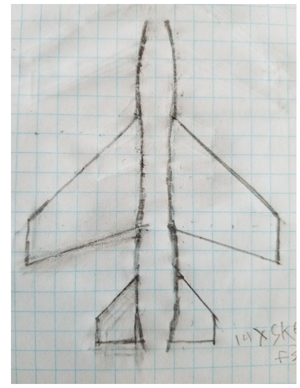

Figure 4

Current Design

The Super Phantom is currently designed to be single-engine, swept-delta, low-wing, non-afterburning jet aircraft, with an area ruled fuselage, retractable gear with gear brakes, and an all-moving tailplane (Figure 5). The Super Phantom will be made out of carbon fiber with fuel tanks in the fuselage and wings.

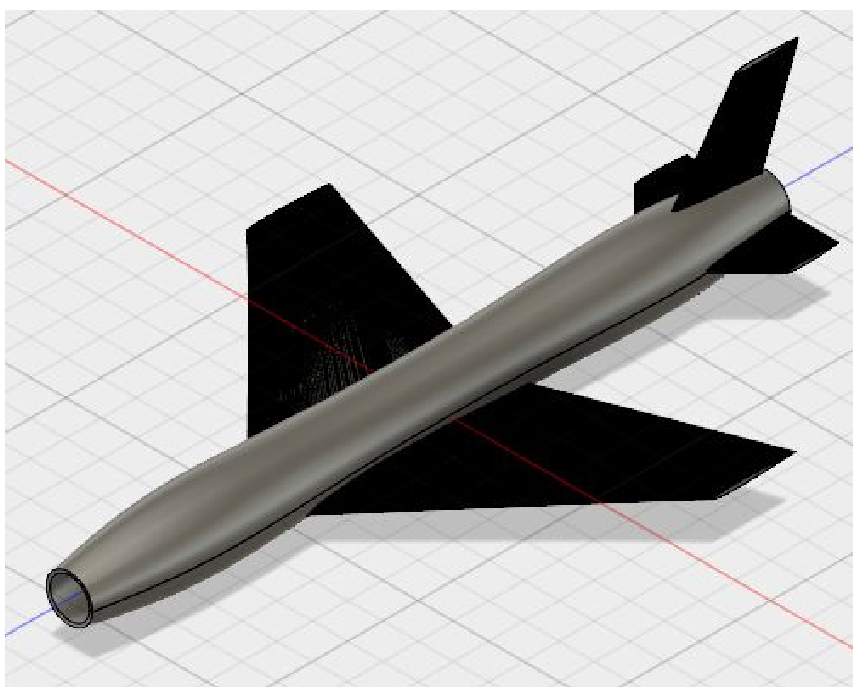

Figure 5

Mathematical Analysis

History

During the early 20th century, prior to World War I, aircraft design was wind-tunnel based. Wind tunnels were used for calculating the lift coefficients for different airfoils in order to help decide what airfoil would be used on an aircraft. As time went on, wind-tunnel testing techniques evolved and led to more advanced aircraft designs. Aircraft design continued to improve as time went on, but one of the most significant leaps in aircraft design was during World War II, when the company, North American Aviation, used a purely mathematical approach to design one of the best fighters of the war, the P-51 Mustang[1]. The P-51 utilized carefully designed laminar flow wings in order to reduce drag and increase its maximum speed. This is the reason to why the P-51A was faster than another fighter from the war, the P-40 Warhawk, even though the P-51 was heavier at normal weight and the A model of the Mustang used the same engine as the Warhawk. Aircraft design techniques continued to evolve. In the late 1950s and 1960s, two-dimensional Computational Fluid Dynamics (CFD) softwares were beginning to be used in aircraft design in order to create more advanced aircraft. As time passed, aircraft design and CFD evolved even further. CFD softwares became capable of operating in three dimensions, enabling even more advanced designs to be designed and flown without as extensive wind tunnel testing. Today, there are highly versatile 3D CFD softwares capable of processing supersonic flows that are open-source and free to use. This availability of powerful CFD tools creates a vast number of opportunities in aircraft design, because now anybody can learn how to use CFD softwares without huge sums of money.

Mathematics of Flight

In aircraft design, there are some basic equations that are very important and very useful when doing design work. The coefficient of lift equation is one of the basic equations used in aeronautical engineering $C_L = \frac{2L}{\rho U^2 S}$ where L is the lift of the aircraft, which equals its weight in level flight; ρ is the air density; U is the flow velocity; and S is the wing area. The equation can be simplified into $C_L = \frac{L}{qS}$ because the quantity $0.5\rho U^2$ is the dynamic pressure, q.

[1] "Lofting." Wikipedia, Wikimedia Foundation, 19 May 2017, en.wikipedia.org/wiki/Lofting. Accessed 29 May 2017.

A second very useful equation is the thin airfoil theory, which allows you to estimate the coefficient of lift in incompressible flows for an airfoil an airfoil of zero thickness and infinite span, but can be applied to most symmetrical airfoils. The thin airfoil theory is written as $C_L = 2\pi\alpha$ where C_L is the section lift coefficient and α is the angle of attack in radians, measured relative to the chord line.

Additionally, there is set of equations that can be used to solve for the velocity vectors in any fluid flow, known as the Navier-Stokes equations. The Navier-Stokes equations are dependent on time and based on conservation of mass, conservation of momentum, and conservation of energy. CFD softwares commonly use either the Navier-Stokes equations or an abbreviated form of them.

During my project, I was able to meet with Rob Chapman, an engineer from Northrop Grumman, to discuss my project and receive advice on aircraft design and design process. He told me that in aircraft design, the first thing you do is determine an estimate for the weight, so you can then choose the engine. Next he said to determine your wingspan and wing area. Then he said that you can use your approximations to refine themselves as you smooth out the design and work out the details. These recommendations were tremendously helpful, especially in the early stages of my design process.

CFD Wind Tunnel Simulations

CFD softwares are commonly used tools that solve for the Navier-Stokes equations or one of their abbreviated forms, to allow you to simulate fluid flows. CFD softwares will give you large amounts of information about the fluid in many different areas called cells, including the velocity vectors, pressure, and density for each cell. When operating most CFD softwares, you have to set the starting flow velocity, and kinematic viscosity, which are used to determine the Reynolds number $Re = \frac{uL}{v}$ where u is the fluid velocity, v is the kinematic viscosity, and L is the characteristic linear dimension. In order to generate the mesh, you need to set the size of the simulation area, the number and shape of cells, and the grading of cells. You will also need to set the boundary conditions.

When the CFD software to be used for simulating flow around the Super Phantom was being decided, the decision was between two softwares, CFD Motion, made by Autodesk; and OpenFOAM, an open-source, free CFD software. After reading about both softwares, OpenFOAM was selected because of its ability to handle compressible and supersonic flows.

Using OpenFOAM involves first loading a case, which involves defining the case dimensions, setting the boundary conditions, setting the kinematic viscosity, defining the grading scheme, the timestep, the start and stop times and generating the mesh. OpenFOAM contains a variety of tutorials to help familiarize users with its mechanics and interface. A common tutorial is the lid-driven cavity case, which is a cavity one cell thick with the top surface of the cavity moving across it. Once the case is loaded and run, the results can be viewed in a viewing software called ParaView. In ParaView, you can select the simulation you want to view, then apply different filters to view your results. ParaView can display contours, velocity vectors, and flow lines; and apply coloring schemes to view pressure, density, and other properties of the simulation. ParaView can also view the different timesteps, or play through the timesteps to form an animation of the conditions in the case.

Next Steps

The next steps in the design of the Super Phantom involve adjusting the size of the tailplane to offer adequate control and giving it a blended wing body. The data from the OpenFOAM testing will also be implemented in the design to improve its estimated characteristics and handling. The area ruling will also be refined based on the tests, which should help reduce drag.

I am currently continuing to work through tutorials in OpenFOAM so that I better understand it for when I upload my CAD drawing of the Super Phantom into it. After becoming more proficient in OpenFOAM, the next step in the project is to evaluate the design of the Super Phantom in OpenFOAM and obtain the critical angle of attack, critical mach number, the shockwaves formed during the transonic regime, and drag at different speeds. In order to do this, I need to learn more about how to generate meshes; how to load my design into OpenFOAM; and how to set the boundary conditions, the flow velocity inside the simulation, the Reynolds number, and the mesh grading.

Lessons Learned

From working on this project, I learned how beneficial it is to develop a project plan. However, next time I would make one much sooner, and not underestimate the time it takes to do certain things. I also learned to seek outside help when working on a project. Something that I would do differently next time would be to start documenting the project earlier on, so that it is not left for the end.

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