Project Swift

UAS Flight and Payload Challenge Concept

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ABSTRACT

Current commercial unmanned aerial systems have been designed for the average consumer. Most off the shelf systems have subpar endurance with low and high payloads. Public safety applications call for the use of moderate payloads to be in a fixed flightpoint for the maximum amount of time. Our intent to achieve the maximum amount of flight time includes optimized propeller design, a diffuser duct shroud around the propeller, adjustable propeller pitch, new battery technology and structural design improvements. The aircraft will be constructed of lightweight carbon fiber material and equipped with a fully autonomous flight package weighing no more than 55 pounds. Endurance payloads will be 10,15 and 20 pounds and we are anticipating flight times of at least 52, 44 and 36 minutes, respectively. The document herein describes how these changes will be accomplished and propose the team to supply a working prototype by May 20, 2018.

Introduction

Our mission presented in this concept is to support the public safety realm by providing a UAS that is safe, easy to use and compliant to payload change with minimized effects on performance. The methods proposed are not trivial, but have yet to make their way to the UAV/UAS sector as a whole.

The overall objective is to achieve the highest possible hover time with three different payloads 10, 15 and 20 lbs with a minimum goal of 270 points. To accomplish this goal, we plan to address and significantly optimize three major parts of the multicopter design - Aerodynamics, Aircraft Structure and Energy Management. Between these three optimization segments, we anticipate a large increase in performance for the task at hand. Details of these optimizations are described within this report.

The team consists of four engineers from the aerospace industry with a passion for UAVs and our ambitiousness is matched by none. Whether it is designing an advanced military jet engines or bringing a new, cutting edge aircraft to market, the group has a track record of consistent execution at the highest level. We are a team whose greatest strength is not that of the individual, but more so working together to execute any task. We are passionate about the future potential of the UAV industry and our expertise should be evident as you read our concept details. The individual resumes and short bios can be found in Appendix A.

We appreciate the opportunity to present you with the following concept:

The Aircraft Overview

When considering that the device is being planned to be used for public safety purposes, our intent on the aircraft design is to make it as safe as possible for the average user to operate safely. With this in mind, we are proposing fully carbon fiber multicopter layout with a protected prop that can be easily launched from a ground station and deployed to the intended position via GPS. We considered many aircraft types and although a standard single prop helicopter design provides the highest lift efficiency, it would sacrifice our intent of making the aircraft easy to fly (in the event of a manual takeover) and safe flying ops. With public health officials in mind, adding any element of risk is unacceptable.

The aircraft and ground system will be equipped with off the shelf flight controller, GPS modules, and multiple radio communication systems. Total weight including payload will be 25kg (55lbs) and with a majority of the weight dedicated to batteries and the electrical system but room remaining for payload and structure. The aircraft will be equipped with an emergency shutdown system that will cut off system operations in the event of an emergency.

Aerodynamics

The highest level of optimization to multicopters can be found in the aerodynamics. Many UAVs come equipped with a standard fixed open air propeller that has been tuned for the compromise of many different factors. In order to obtain the highest level of efficiency during a hover, the aerodynamics of the propellers and the structure must be optimized. We plan to address three different areas:

Area 1 - Propeller/Disk Loading

We plan to design a custom propeller configuration to target the highest level of lift efficiency and minimize disc loading. This can be achieved by redesigning the prop to be most efficient at the hover flight condition. See Figure 1 for desired design envelope - the optimization of disk loading is critical to driving power draw from the electrical system down. Our experience in the jet turbine design and the small aircraft propulsion design industries put us a step ahead in understanding what is necessary to optimize this metric. We will use tools such as XFOIL and XROTOR to aid in the design.

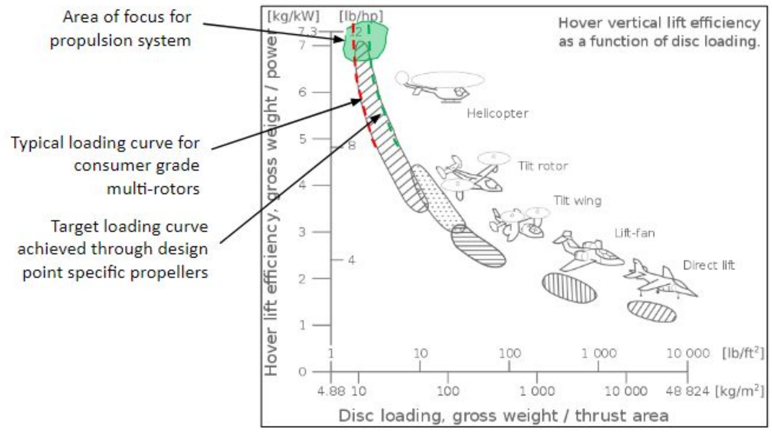

Figure 1. Ideal Lift Efficiency For Sustained Hover (Source: Wikipedia - Modified)

Preliminary calculations suggest we are capable of achieving the desired disc loading to meet the objective of the mission. Figure 2 is our first pass on achieving optimal disc loading for the three given design points with the same propeller. Figure 3 shows more details on the vehicle specification with minimum flight times calculated at a gross weight of 55lbs with only the propeller optimized.

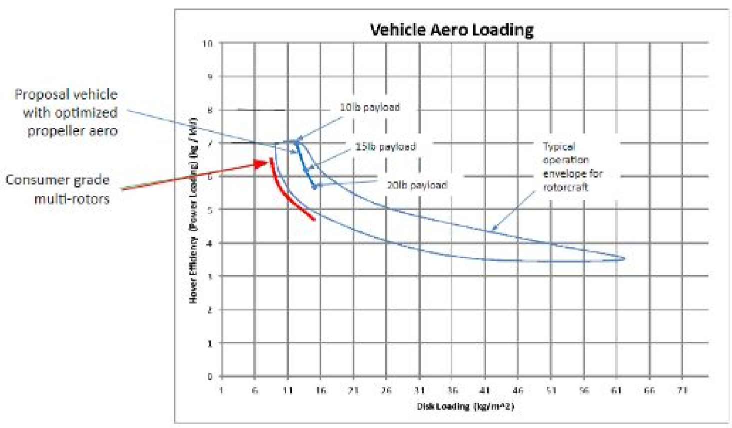

Figure 2. Vehicle Aero Loading w/Optimized Propeller

Proposed Vehicle Specification				
Parameter	Units	20lb payload	15lb payload	10lb payload
Disk loading	kg/m^2	15.0	13.6	12.7
Power loading	kg/kW	5.7	6.2	7.0
Weight	kg	24.9	22.6	20.4
Payload	kg	9.1	6.8	4.5
Energy density	W h / kg	180	-	-
Flight time	min	28	34	42
Propulsion Power consumption	W	4376	3658	2916
Battery weight	kg	11.4	-	-
Frame weight	kg	4.4	-	-
Voltage	V	14.8	-	-
Propulsion system amp draw	A	295.0	247.0	197.0
Motors	qty	4	-	-
Motor power	W	1094	914	729
Motor amp draw	A	74	62	49
Thrust per motor	N	61	55	50
Prop diameter	m	0.73	-	-
Prop diameter	in	28.6	-	-
Points / min	pts/min	6	3	1
Points	pnts	169	101	42

Figure 3. Optimized Propeller Challenge Performance

Area 2 - Addition of Diffuser

We will also be adding an integral diffuser around the propeller. The diffuser will act as a way to protect bystanders but will also aide in aero performance significantly. Figure 4 shows how the diffuser duct will minimize lift induced drag from the prop tips and also add additional lift from the diffuser design. To verify assumptions and design intent we plan to use CFD tools such as FLUENT to design and optimize this configuration along with the propeller. The net benefit of the design due to increased performance yet offset by a weight gain is difficult to quantify. Conservatively we are bookkeeping an additional 10% increase in flight time.

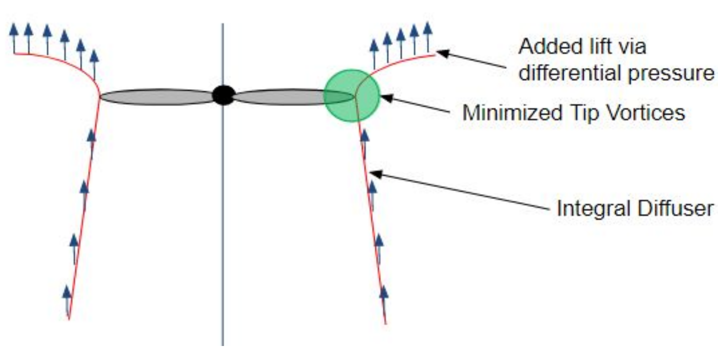

Figure 4: Diffuser Diagram

Area 3 - Autonomous Adjustable Propeller Pitch

Fixed pitch propellers are ubiquitous on commercially available VTOL UAVs. This means no matter which payload the user has attached, the aircraft performance is going to change, significantly. If the consumer wants better performance with a heavier payload, they are forced to change propellers, or worse, upgrade their entire vehicle. Figure 2 presented a fixed propeller concept that shows this effect as a large drop in hover performance between payloads. Being able to adjust the propeller pitch for a given payload will help improve overall aerodynamic performance. The "constant speed propeller" is common in civil aircraft and allows the engine to operate within its most efficient RPM range at all flight conditions. Our intent of making this available is similar to find the compromise between motor efficiency and lift efficiency. See Figure 5 for an illustration of the improvement.

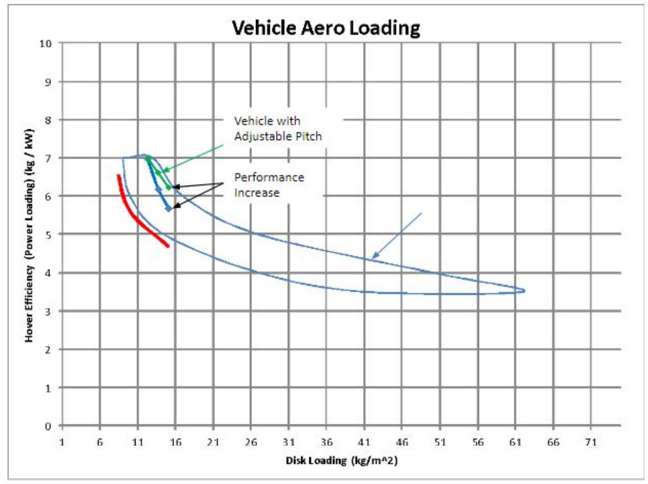

Figure 5. Adjustable Prop Pitch Performance Illustration

Our design objective is to make an autonomous adjustable prop pitch system that allows the aircraft to "seek" its optimal aero efficiency during the mission profile. The concept we have developed is similar to a standard helicopters swashplate, with only one degree of freedom. The propeller pitch will be controlled via daisy chained servos and controlled by the modified flight controller software. For purposes of our test within the timeline available, we propose having 4 settings available (takeoff, hover10, hover15, and hover20) to prove the value of the adjustable prop on VTOL aircraft. Future development on this system could include new flight software that allows the prop to always spin at the same speed and control all aspects of the aircraft. We anticipate this concept yielding an increase of at least 5% efficiency at the off-design points.

Energy Management

Outside of fossil fuels. the energy source of choice in UAVs is Lithium-Ion Polymer (LiPo) batteries. Lipo batteries offer a high energy density (120-220Wh/kg) and very high dissipation rates. Most multicopter enthusiasts prefer the highest discharge rates possible to give the most responsive and fastest aircraft possible.

However, the proposed solution for this project is to use a Lithium-Ion battery pack. This battery type has a higher energy density (>250Wh/kg) than LiPo batteries and is becoming commonplace in electric automobiles (ie. Tesla). Lithium Ion batteries are notorious for having much lower discharge rates which make them suboptimal for UAV use. For the mission at hand that is more focused on stationary positioning, there could be a substantial benefit to changing technologies. To address the discharge rate limitation, the systems design engineers will work closely with the aero engineer during motor selection and system sizing to ensure safe operation. We will also closely evaluate discharge rates in different flight/wind conditions to protect from overdrawing the battery (Note: performance calculations were done using 180Wh/kg, assuming the conservative LiPo battery if design cannot be achieved with Li-Ion). We don't anticipate seeing a proportionate increase in flight time and until comparison testing can be completed, we are bookkeeping an additional 10% flight time but could be up to 40%.

Aircraft Structure

Each engineer dedicated to this project has extensive composite structure design experience and we will evaluate every component for optimal loading and use. We will use the lowest possible resin weight pre-impregnated carbon fiber material with ideal ply orientation to create a custom structure that meets and exceeds all flight and handling loading requirements. For the prototype, we will use our utilize our local and on-site resources to manufacture custom foam tooling and process the parts in the same fashion as typical aerospace components.

This will help reduce structure weight by a small amount (10%) but also affords engineering full control over the component layout which helps significantly when it comes to using Lithium-Ion batteries as opposed to LiPo. As an example, the arms and center frame could be integral while using the root of the individual arms as a way to mount auxiliary equipment while optimizing the center shape for the battery pack and payload. We are anticipating at least a 10% structure weight which will add 2-4% of flight time to the mission.

Project Management

The tight project deadlines is going to require very precise project management from any group. To go from the concept paper to a high-level safe aircraft in less than 16 weeks is going to be difficult. We believe we have the expertise that it will take to achieve such an accomplishment. Shortly after acceptance the project manager will host a kickoff meeting to align resources. A project schedule will be developed on a standard gantt chart with inputs from the individual engineers while ensuring there is ample slack time and contingency as necessary. The project schedule will be updated regularly and available to the competition regulators as necessary. This process is the team's standard means of working in industry.

The budget will be managed very strictly with contingency to ensure successful completion without overspend. A preliminary budget between each functional system has been established (Figure 6), and will begin to be detailed at a lower level during the first weeks of the project. In addition, we have accounted for outside test equipment and contract services as necessary. We feel that the $20,000 budget for this project is well within the means of being successful.

The technology development of the aircraft will follow the V-model (See Figure 7). Which is typical in lean order to delivery engineering environments. The essence of the V-model is to ensure the requirements set at the highest level flow down into the system requirements and then the component requirements. After design is complete, prototype parts will be built. From here the components will be tested against their individual requirements prior to being tests as a system. Then the systems will be tested and validated prior to final validation testing in the aircraft. Through many different systems, we have learned this is the means to produce the highest quality product the first time. The V-Model image shown below shows the general flow of the project to successful flight.

High Level Budget Item	Amount Allocated	Details
Structural Supplies	$1,800.00	400 Sqft Pre Preg + Consumables
Composite Fab/Bond	$1,000.00	(If needed)
Foam Tooling	$1,500.00	High Temp Foam + Machining
Batteries	$3,400.00	$400 for component test, $3000 for 2x final build
Electrical Supplies	$1,000.00	ESCs, Power Distribution/Control Thermal Management
Motors/Wiring	$2,000.00	High level motors+Wiring
OnBoard Systems	$800.00	Controller, GPS, Receiver
Ground Station	$1,500.00	Includes Coms/Transmitters
Contract Services	$1,000.00	Programming Support (if needed)
Emergency Equipment	$500.00	Shutoff switch/Coms
Test Equipment	$1,400.00	Daq Card, Software, sensors (current monitoring, accels)
Current Contingency	$4,100.00	To be revised once drill down budget completed

Figure 6 - Preliminary Budget

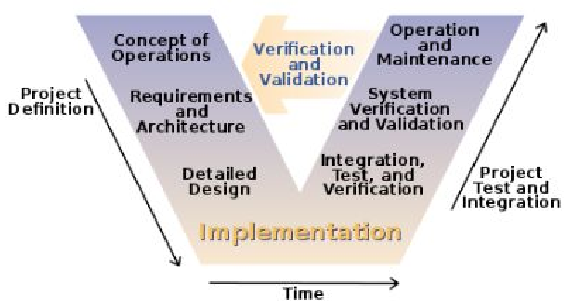

Figure 7 - V-Model (Source: Wikipedia)

Summary

Between the aerodynamic improvements over the current state of the art, the energy management improvements and design the structure around the aircraft, we are convinced we will meet all expectations of the task and will be competing for the top spot in the payload endurance competition. With all items considered from the most conservative standpoint we anticipate flight times of 52, 44 and 36 minutes for the given payloads. This flight time far exceeds the minimum requirements for the contest and we strongly believe we will exceed the numbers presented in Figure 8.

	Payload Flight Times (minutes)			
Opportunity	10 lbs	15 lbs	20 lbs	
Propeller Aero Baseline	42	34	28	
Diffuser Duct	4	3	3	Added Flight Time
Adjustable Prop Pitch	0	2	1	
Energy Management	4	3	3	
Aircraft Structure	1	1	1	
Total Flight Time	52	44	36	
		Total Points	397	

Figure 8. Expected Flight Times and Points

Our team is very happy and excited to submit this concept. We have worked diligently to put together a package that is realistic and feasible. Thank you for your time and your consideration.

Appendix A
The Team

Raphael Diaz - *Aerodynamic Engineer.* Raphael (Raph) will be responsible for aerodynamic design of the propeller/diffuser concept. He currently serves as propulsion engineer for small aircraft development company and his normal job duties are design of propulsion systems including engine, exhaust, thermal management and propeller to ensure highest levels of performance while minimizing NVH for the passengers/aircraft systems. His previous role has been aerodynamic/design engineering multiple jet/land based turbine. Raph has built many custom UAV systems including RC long endurance flying wings and a waterproof quadcopter for filming his weekend passion of kitesurfing.
LinkedIn: https://www.linkedin.com/in/raphael-diaz-33868157/

Darren Freitas - *Systems/Structural Engineer*. Darren will be responsible for the propulsion system integration, including the battery system. Darren is currently a Mechanical Systems Engineer. In this role he has had a numerous responsibilities ranging from design of a total fuel system package including thermal management to design of numerous structural/system components. Darren has also built numerous RC UAVs which range from custom 3D printed structures to an in progress custom RC Osprey design.
LinkedIn: https://www.linkedin.com/in/darren-freitas-b3791a20/

Clayton Patton - *Systems/Test Engineer.* Clayton will be working through the details of the prop pitch adjustment system while also being responsible for most of the performance testing. Clayton is also a Mechanical Systems engineer with most of his experience revolving around solving some of the most difficult mechanical challenges. Clayton has worked extensively with data acquisition systems (LabView) to administer numerous tests ranging from flight testing to land based high speed dynamic testing.
LinkedIn: https://www.linkedin.com/in/clayton-patton-08999165/

Ryan Boysen - *Project/Compliance Manager.* Ryan will be primarily responsible for managing the project timeline and overall system compliance to the mission/guidelines. This role is in Ryan's wheelhouse as he currently serves as a Lead Engineer for a jet turbine project and has previously served as an Engineering Manager and once as team captain on his FSAE car in college. Ryan has a breadth of knowledge in project management as well as an equally strong engineering background. Ryan's UAV experience is focused more on the filmography realm but has also built and flown racing quads.
LinkedIn: https://www.linkedin.com/in/ryan-boysen-9903a31b/