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# Review of Engineering Experience on Autonomous UAV Payload

*A sample of documentation and technical writing, highlighting design and collaboration.*

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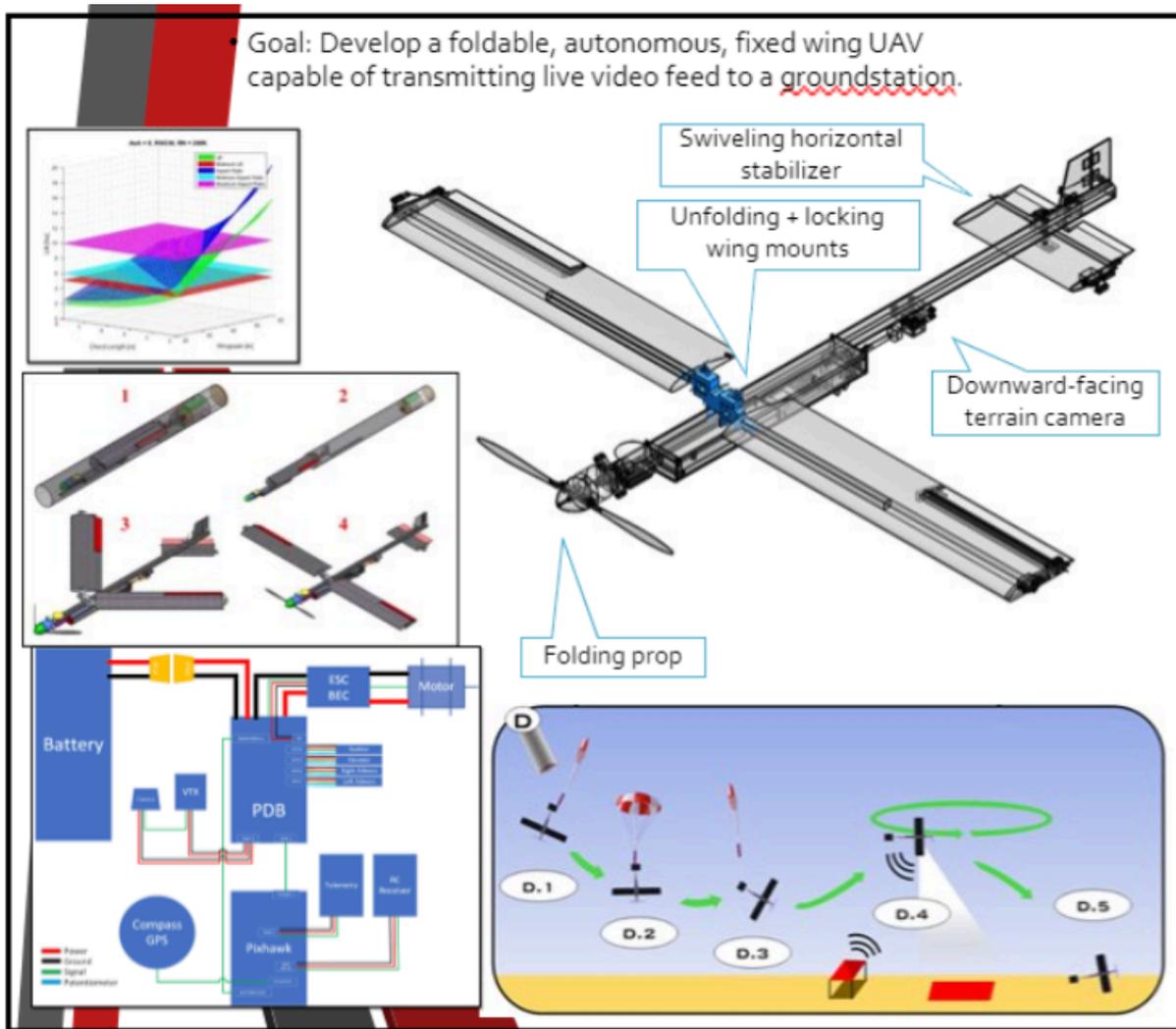
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Preface: This document is meant to sample technical writing where engineering skills and methods are addressed, but also contains reflection on these projects and their impacts on me as an engineer, student, and teammate. It is therefore written clearly and technically where design and engineering are represented, but not structured to academic, scientific, or industrial standards. See other documents for more examples of strictly styled writing.

## Background:

Pegasus was an autonomous, folding, aerially deployed surveillance UAV built by River City Rocketry for the IREC/SA Cup (Intercollegiate Rocket Engineering Competition/Spaceport America Cup) 2018-19 competition season. It won the SDL (Space Dynamics Laboratory) Payload Challenge, being announced as “the best designed UAV payload” the announcing judge had seen. Further technical documentation of the full project can be found at:

<https://www.rivercityrocketry.com/documents>



**Fig. 1. Overview of Pegasus Design and Mission**

*Source: River City Rocketry*

Specifically, I worked on preliminary sizing and design of electrical propulsion systems, and the deployment subsystem. Also performed auxiliary duties for other subteams on RCR in wiring key-switches on the launch vehicle, and designing and implementing a dual stage blackpowder charge detonator for recovery testing.

## Part I: Preliminary Component Sizing for Electric Propulsion System

The primary defining characteristics of the payload (Pegasus UAV) were ranges and limits for mass and dimensions to fit within the launch vehicle. This informed the approximate chord for wing design, which was used along with mass to design for other aerodynamic characteristics (by other team members). Given designed coefficients of drag and lift for the wing profiles.

$$\text{Propulsive Thrust} = \text{Drag} = 0.5\rho V^2 S C_D = W C_D / C_L$$

### Eqn 1. Thrust vs Cruising Speed (V), Wing Area (S), and Drag Coefficient (Cd)

Note that estimated wing dimensions yield S,  $C_D$ , and  $C_L$ , and  $\rho$  is constant. Velocity, V, operates within a wider range, such that it ought to remain high enough for consistent laminar airflow over the wing (avoiding a stall), but above that thrust could be variable, and corresponds to different velocities.

Given estimates for those specifications, and in accordance with the requirements for propeller aircraft dynamics in level flight, I searched for Brushless DC engines that could provide the required thrust. Given motor thrust, motor current was estimated through the specifications and documentation of considered motors, and an ESC (Electronic Speed Controller) was selected to supply given current. I personally selected an ESC with a higher factor of safety (could supply 80A when we expected a maximum of about 60A drawn). This was later shaved down to save weight, as was the battery.

For specific commercial part selection, the propeller was selected first. This was driven by the design requirements discussed above, for thrust and dimensions (including a key requirement, hinged propeller blades for stowability in the launch vehicle airframe). Note in Fig. 2 below that the propellers hinge backwards, and stow roughly parallel to the UAV's longitudinal (roll) axis. This is perpendicular to their deployed position, which is obtained by centrifugal force when the motor shaft spins at high speeds. Many commercially available props are side-hinged, or in other words: hinge in plane with the propeller's rotation, such that impact force on prop blades is reduced (largely seen on quadcopters). While the longitudinally hinged propeller blades on Pegasus did not relieve impact stress, they were easily replaceable with less work than more permanently fixed alternatives.



**Fig. 2: Array of folding propellers**

*Source Banggood.com*

With a propeller selected, we then knew the relation between propeller speed and aerodynamic thrust. Constrained by this characteristic and the required thrust, a brushless DC motor was chosen that met the required rotational speed. And in turn an Electronic Speed Controller (ESC) was selected to control the motor, in accordance with the DC motor's specified current requirements for our desired thrusts/speeds. For further information on ESC and DC Motor operating principles, see Appendix B - DC Motor and ESC Generalities.



**Fig. 3: Example of an ESC and Brushless DC Motor**

Commercial options were used, so principles of motor operation were not critical to this design process. However, some high level generalities are noteworthy. For one, DC brushless motors are generally more efficient, faster, longer lasting, and more precisely controllable than brushed DC motors. These traits are largely due to the physical dynamics of the magnetic rotor and electromagnetic stators vs electromagnetic rotor and brush to contact

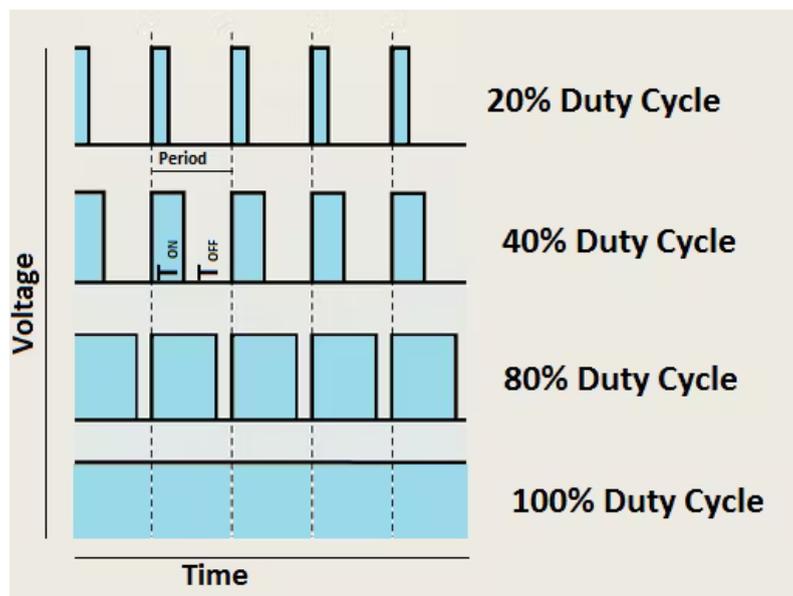
electrodes. The tradeoff is price and complexity in the control circuitry, but due to their benefits brushless motors have become a standard in industries like RC/Hobby flight.

Additionally of note: due to mission parameters (deployment from under parachute at thousands of feet, rather than taking off from the ground/at rest), the UAV was expected to have more than enough gravitational potential energy to convert into airspeed (as it separated from parachute and begins flight at 90 nose down pitch attitude (pointed at the ground). Eliminating takeoff thrust and performance as a design consideration.

## Part II: Deployment Subsystem Design

Pegasus was constrained within the launch vehicle by an ARRD (Advanced Retention & Release Device) on a bulkhead, and constrained rotationally by a T-slot delrin rail. The retention device was released via BP detonation signalled by the launch vehicle altimeters as it descended under parachute, and Pegasus slid down the rail, and out under independent recovery (parachute). Team members at the ground station would then review payload telemetry to give a final go/no-go decision. Mission deployment and autonomous navigation (as well as manual control override) could be triggered via auxiliary channels on the RC controller to trigger the deployment mechanism.

The deployment subsystem utilised a 100% duty cycle PWM signal. This functionally converts a PWM output servo header on the Pixhawk PX4 flight controller into a digital output pin for the detachment/deployment (go) signal.



**Fig. 4: PWM Duty Cycle**

*Source: Arduino Tutorials*

The connected load in the deployment system was an e-match (electrically ignited match), which was rated to ideally fire at .5A. Data provided by the manufacture gave a range to account for variations in manufacturing, for example certain percentages of tested matches would fire at different current thresholds (e.g. .35A → 75% chance of firing, .5A → 90% chance of firing). The “minimum all fire current” was also given (and was 600mA or .6A) The impedance in the e-matches was rated at 1.3Ω nominally and e-matches selected for our use were specifically tested to verify resistances between 1.2-1.4Ω.

These were connected as loads to the emitter of a Darlington transistor, used for high current gain capabilities. The digital high signal (from PWM output) was connected to the base of the Darlington transistor. The collector of the darlington transistor was connected to a Lithium Polymer battery, selected for high current output, and because the team had a surplus in varying sizes and voltages, and charging hardware.

This parachute cutaway signal needed to be carried to the ARRD retaining the payload under deployment parachute, but not act as a point of permanent attachment. As such, several temporary electrical connectors were considered. Some, including magnetic connectors, had a track record in previous teams projects of disconnecting early due to high strain during launch, flight, or initial deployment/recovery. Some friction fit connectors (such as fork, ring, and spade, terminals such as used in automotives) were too strong, too weak, or too inconsistent in testing. The determination was made to use a 2.5mm, 2 contact, audio jack, which could handle nearly 2 lbs of tension in the wire (as tested using a hanging spring scale) which is well below the over 6 lb. payload weight, which it would have seen when deployed.

## Part III: Auxiliary Team Duties & Experience:

### Introductory Summer Project

Joining, travelling, and competing with a team also meant taking on tasks as needed. The very first project I was asked to do upon joining the team was design and implementation of a Level 1 High Powered Rocket to attempt NAR (National Association of Rocketry) licensing. This project was selected for new team members as an introduction/overview of rocket design and assembly, and the challenges and considerations therein. A Commercial Off-the-Shelf (COTS) Solid Rocket Motor was selected first, because the main constraint of L1 certification flight eligibility is motor class. The selected motor was the Cesaroni Technology I243(-I13A).

The rocket was designed using 3 inch outer diameter blue-tube for the airframe airframe, a COTS fiberglass nosecone was selected due to high strength and density (acting as ballast to shift the center of mass upward/forward. Fin geometry was simulated iteratively and the shape was selected due to having strong stability characteristics, without having narrow corners or protrusions that may be subject to damage on setup or recovery, potentially endangering NAR certification. The simulated projected apogee was 3165 ft. See Appendix B for detailed information on the motor and rocket performance. The actual altitude was about

200-300ft under, likely due to unaccounted for weight in recovery hardware, adhesives, and/or fasteners. Altitude was also likely influenced by weathercocking into the wind, apparently a result of overstability (1.89 cal at Mach 0.3)

## Dual Deployment Detonator

Nearly all rockets launched by the team (whether for L1 or L2 certification, or team competition launch vehicles) used two stage recovery, first a charge to release the drogue parachute, slowing down the airframe to reduce opening forces for the following main recovery deployment, and then the larger main parachute. However, testing of these blackpowder charges was done using the same electrical controller as launch.

To improve this flow, and save time during crunch time and launch day, I was asked to design a dual stage blackpowder charge detonator. This consisted of a weatherproofed box, into which through holes were cut for a master power safety switch, two Nominally Open, momentary pushbuttons for arming each charge, two LEDs displaying continuity/that each was ready to fire, and another two NO momentary pushbuttons for detonating each charge.

Inside, a battery pack was contained, a protoboard facilitated soldering junctions between components, and two output ports had 4 20 foot leads of 18 AWG wire. This was successfully used to test the recovery charges for the following summer's incoming new members performing L1 projects.

Additional Auxilliary duties were to help out wherever possible, whether as an electrical engineering student or just as a teammate, including helping other subteams solder (for example soldering the keyswitches to the competition launch vehicle, or headers to microcontrollers), and helping layup carbon fiber with the mechanical engineers for the payload.

## Appendix A: DC Motor and ESC Generalities

Brushless DC motors are driven by pulsing signals through stator coils that surround the central rotor in sequential phase delays, generating an electromagnetic force that torques the magnet fixed to the central rotor (and therefore torques the rotor shaft). Note that this is done without physical contact, which is the advantage over conventional or “brushed” DC motors that make electrical contacts via flexible conductive “brushes” but generate friction, wear and heat that hurts lifespan and efficiency. Typically there will be a number of stator coils in multiples of 3. This functionality and construction is similar to many power generation turbines, but it takes in 3 phase supply, rather than outputting it. This is in contrast, however, to a brushed motor which mechanically shifts its contacts, and only requires 2 input wires.

The 3 phase input, analogous to our 3 phase power grid, is generated from the supply battery and through power transistors by an ESC, or Electronic Speed Controller. The ESC takes in a PWM signal from whatever main controller is master, and the output coil energization varies correspondingly. A wider PWM pulse (higher duty cycle) results in faster pulsing stators, and a faster turning rotor. This pulsing is also dependent on the current position/rotation of the motor, which is sometimes measured by sensors onboard, but usually determined by the ESC measuring the induced back-emf on un-energized coils, determining

## Appendix B : Supplemental Data for L1 Individual Project

The following figure is a thrust curve for the CTI I243-13A Pro29-6GXL motor. Further test parameters and results are shown in the second figure.

### Guide to Conventions and Abbreviations In Motor Name (

**CTI** = Cesaroni Technologies Inc. a leading commercial HPR solid engine manufacturer.

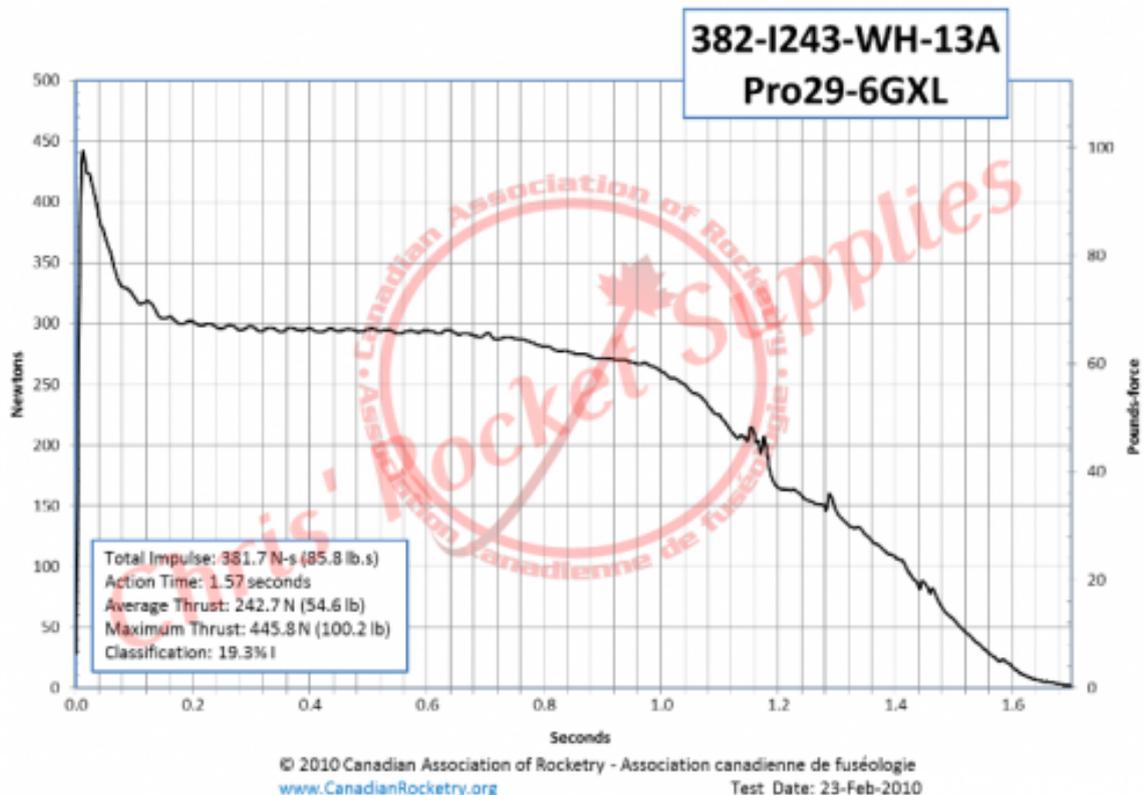
**Pro29** is a series of motors which is 29mm in outer diameter

**6GXL** denotes the motor is comprised of 6 grains, each grain being an individually cast section of solid propellant, stacked vertically into one engine.

**I** is the class of rocket motor, classified (and regulated) based on overall impulse. For class I, this means an impulse in the range of 320.01–640 Newton-seconds.

**243** in the name denotes average thrust in Newtons (242.7 N).

**-13A** denotes the timing delay from engine burnout to recovery charge detonation of 13s



**Fig. C.1 - Solid Motor Thrust Curve (Newtons vs. Seconds)**

*(Source: Chris' Rocket Supplies).*

<b>Brandname</b>	Pro29 382I243-13A	<b>Manufacturer</b>	Cesaroni Technology
<b>Man. Designation</b>	382I243-13A	<b>CAR Designation</b>	382-I243-13A
<b>Test Date</b>	4/17/2010		
<b>Single-Use/Reload/Hybrid</b>	Reloadable	<b>Motor Dimensions mm</b>	29.00 x 365.00 mm (1.14 x 14.37 in)
<b>Loaded Weight</b>	398.6 g	<b>Total Impulse</b>	381.7 Ns (85.8 lb-s)
<b>Propellant Weight</b>	212.1 g	<b>Maximum Thrust</b>	445.8 N (100.2 lb)
<b>Burnout Weight</b>	172.1 g	<b>Avg Thrust</b>	242.7 N (54.6 lb)
<b>Delays Tested</b>	"13,10,8,6,4"	<b>ISP</b>	183.50 s
<b>Samples per second</b>	1000	<b>Burntime</b>	1.57 s
<b>Notes</b>	White™		

The following view is the high level simulation data for the overall airframe as designed, and then the overall rocket schematic.

