Preliminary Design Review:

Helicopter Payload Stabilization Project

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I. Explication of Problem

Problem Formulation and Solution:

A common occurrence during helicopter rescue missions are helicopter hoisting operations (HHOs). During a HHO, a stationary helicopter at a fixed elevation is positioned directly above the load, which is oftentimes a person in a stretcher. The load is connected to the helicopter through a cable, which is then used to hoist up the load so that it can be stored in the helicopter. During HHOs, downwash, which is defined as the change in direction of air by the aerodynamic action of the helicopter rotor blades, can cause the load to spin out of control[1]. This spinning has the potential to damage the helicopter, hoisting cable, and load itself, which might result in monetary damages and loss of life. Team Jury's proposed solution to this problem would be to build a stabilization device that can prevent spin when a stationary helicopter is hoisting up a load, specifically a stretcher. Below is a picture of the downwash caused by a helicopter during a HHO:

Downwash caused by helicopter during hoisting operation[2]

Problem Positioning and Justification:

The context regarding helicopter hoisting operations (HHOs) is as follows. HHOs occur in rescue scenarios where patients need to be quickly transported to hospitals in order to receive first aid. Scenarios that utilize HHOs are where patients suffer a car accident or critical work related injury, and as a result, would need to be transported to a hospital within 15 minutes in order to save their lives. HHOs can also occur when people who are trapped in remote wilderness locations need to be rescued. Examples of this include having to rescue people on a stranded ship, or having to rescue injured hikers on the side of a mountain[3]. During HHOs involving rescuing people, it is imperative that the person being hoisted does not spin due to

[1] Downwash - Wikipedia
[2] U.S. Navy photo by Photographer's Mate Airman Sarah E. Ard
[3] https://link.springer.com/chapter/10.1007%2F978-3-642-69262-8_80

downwash. Excessive spin of the load during a HHO can cause nausea, which can lead to drowning if the patient is strapped to a stretcher and cannot control their airways. Furthermore, spin of the load during a HHO can result in a severed hoisting cable, ejection of the patient from the stretcher, or collision of the patient with an external object, all of which are life threatening[4]. Spin of the load during a HHO can cause damage to the load, cable, and helicopter itself, which is why it is imperative to stop load spin during HHOs.

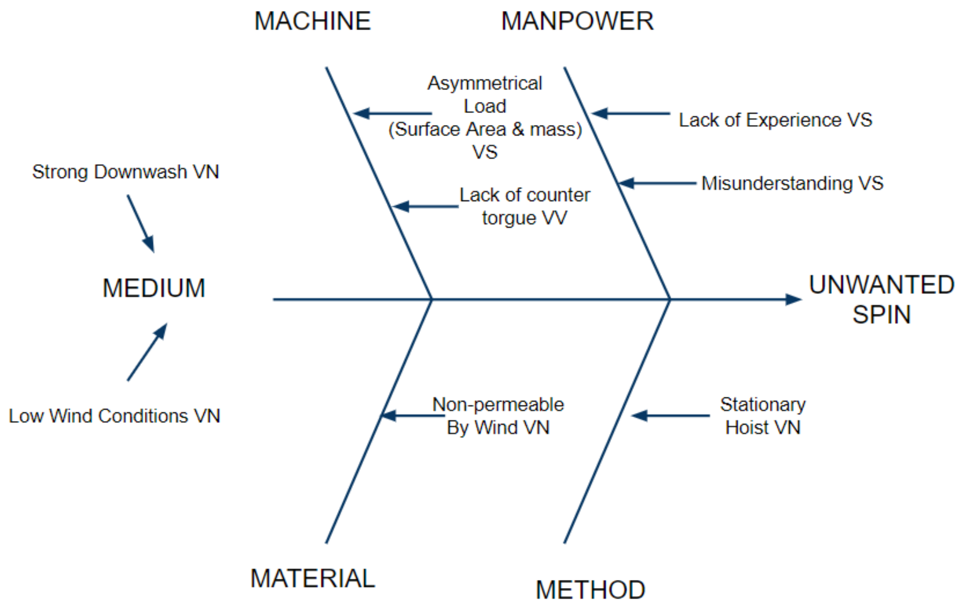
The design and computation aspects of the solution to the described problem are as follows. The solution to this problem requires the design of a device that is capable of exerting a counter torque on the load, or stretcher, in order to prevent it from spinning. These devices could include ducted fans, rotors, flywheels, gyroscopes, etc. . The design aspect of this problem would focus on deciding the type, placement, and other electrical and mechanical structures needed to make the selected counter-torque device work as specified. The computational aspects of the problem would include deriving an algorithm to control the selected actuators in order to reduce spin of the load, or stretcher. These algorithms could involve the use of PID control, or LQR control techniques. These algorithms would then be tested and refined using analytical and physics based simulations.

The solvability of the problem is described as follows. The scope of the problem is limited to designing a device with an algorithm that is capable of controlling one degree of freedom (spin), on a defined load (stretcher), attached to a stationary helicopter with variable wind conditions. By placing these limitations on the problem, the problem should be solvable within a 10-week term. If this problem turns out to be too simple, the problem can be expanded upon by adding additional factors such as having a non-stationary helicopter, or adding turbulent wind conditions. Another possibility would be to see if the device designed for anti-spin purposes can be expanded on to control multiple degrees of freedom, such as sway and vertical pitch.

Root Cause Analysis:

Below is a Fishbone Diagram detailing the root cause of the problem, that being unwanted spin of the load during helicopter hoisting operations (HHOs):

[4] Spinning Avoidance | AirMed&Rescue



The physical reasons for spin are the downwash caused by the helicopter in low wind conditions. The problem is worsened when the load is surrounded by non-permeable material, which adds to the surface area that wind can act on. On the human side, lack of experience and misunderstanding of how to properly mount the load can cause spin of the load. Therefore, the solution to this problem should be a machine that is able to deal with an asymmetrical load and exerting counter torque on the load in order to prevent spin.

Define Resources:

Parties that have experienced the problem of unwanted spin during helicopter hoisting operations (HHOs) involve helicopter pilots and rescue workers. Rescue workers include winchmen who are manually deployed in order to prevent spin on the helicopter load, as well as other staff who are responsible for placing the patient in a stretcher and mounting it to the helicopter hoisting cable. Furthermore, the most affected party in this situation is the patient itself, whose safety is predicated on the stretcher not spinning during the HHO.

Examining the literature regarding this problem shows that the most common way to solve the issue of spinning load during HHO is through non-technical solutions. The United States Department of Transportation Federal Aviation Administration released a Safety Alert for Operators, specifying techniques to reduce spin of load during HHO. Furthermore, the Air Med and Rescue magazine aimed at helicopter rescue operators go over specific techniques for preventing spin of load during HHO. The links to the following two sources are posted below:

SAFO 13010

Spinning Avoidance | AirMed&Rescue

Recently, a private company Vita Inclinata has come up with automated solutions to preventing load spin during HHOs. Vita Inclinata has developed devices that reduce swing, sway, and vertical pitch of the load during HHOs. Below is a link to the company website, which contains details regarding their various products:

Products

Define Strategies and Methods:

The problem of load spin during helicopter hoisting operations (HHOs) has been addressed in the Air and Med Rescue magazine as well as the private company Vita Inclinata Technologies. The Air and Med Rescue magazine explains to helicopter operators on things that they can personally do to reduce spin on loads during HHOs. Vita Inclinata technologies is a private company which has devised technical solutions to reduce spin and other unwanted motion during HHOs.

The Air and Med Rescue magazine covers various non-technical solutions regarding preventing spin of load during HHOs. One such technique is to manually deploy a winchman to supervise the hoisting operation and manually reduce spin. Another technique specified by the magazine is to travel in the forward direction at a speed of 10 to 15 knots[5]. Travelling at this speed would eliminate downwash, causing the load to stop spinning. The other techniques specified by the Air and Med Rescue magazine involve altering the load so that the center of mass is in line with the hoisting cable, altering the stretcher so that there is less surface area, or hoisting the load in a stretcher with vertical rather than horizontal orientation[6]. While these non-technical solutions are effective in reducing spin in HHO operations, not all of these solutions can be implemented during rescue operations due to external circumstances. In situations where the helicopter must be stationary, where no winchman is available, where the patient needs to be hoisted horizontally, and where no netted stretcher is available, it will be difficult to utilize the aforementioned non-technical solutions to prevent spin due to downwash.

The private company Vita Inclinata has come up with two relevant technical solutions that reduce unnecessary motion of the load during HHO operations. The first solution is the LSS-HR hoist rescue device. This device is autonomous, wirelessly operable, and controls 3 degrees of freedom, being spin, sway, and other oscillatory motion. The LSS-HR hoist rescue device is meant to be easily attachable to any hoisting cable, not stretcher. The LSS-HR hoist rescue device is capable of handling loads up to 750 lbs, controls at a rate of 1.5 periods per swing, and has a control range of around 1000 feet[7]. Below is a picture of the LSS-HR Hoist Rescue device, and a link to the system specification sheet of this device provided by Vita Inclinata:

[5] Spinning Avoidance | AirMed&Rescue
[6] Spinning Avoidance | AirMed&Rescue
[7] LOAD STABILITY SYSTEM

[LOAD STABILITY SYSTEM]

This product differs from our proposed solution in a number of key areas. The LSS-HR hoist rescue device is meant to be attached to a hoisting cable, while our proposed solution involves attaching a device to a stretcher. From the datasheet provided by Vita Inclinata, even while the device is autonomous, a winchman is still required to make sure the load, or patient, is properly stabilized[8]. Our solution seeks to eliminate the need for a winchman entirely. While the LSS-HR hoist rescue device is capable of loads up to 750 lbs, our proposed solution only needs to be capable of loads up to 250 lbs, which would be the approximate maximum weight of a person being hoisted in a stretcher. Furthermore, the LSSR-HR hoist rescue device is wirelessly operable, however; as seen in later parts of the PDR, our proposed solution will likely not utilize wireless communication. Most importantly, the LSS-HR device is capable of controlling three degrees of freedom, while our solution at the time being is only concentrated on controlling one degree of freedom, that being spin[9]. Similarities with our proposed solution and Vita Inclinata's proposed solution include the stability specification of being able to handle wind and down wash conditions of around 60 knots, and being lightweight, around 35 lbs[10].

The second technical solution devised by Vita Inclinata is the LSS-LA-litter attachment device. Similar to the LSS-HR hoist rescue device, the LSS-LA litter attachment device is autonomous, wirelessly operable, and controls three degrees of freedom, being spin, sway, and oscillatory motion. The LSS-LA litter attachment device is in the form of a netted stretcher with ducted fans placed underneath. These fans are meant to provide actuation that stabilizes the stretcher. The LSS-LA litter attachment device is capable of handling loads up to 750 lbs, controls at a rate of 1.5 periods per swing, and has a control range of around 1000 feet[11]. Below is a picture of the LSS-LA litter attachment device, alongside link to the system specification sheet provided by Vita Inclinata:

[8] LOAD STABILITY SYSTEM
[9] LOAD STABILITY SYSTEM
[10] LOAD STABILITY SYSTEM
[11] LOAD STABILITY SYSTEM

LOAD STABILITY SYSTEM

This product is similar to our proposed solution as seen later in the PDR report. Our proposed solution is structurally similar to the LSS-LA litter attachment, and seeks to provide actuation in the same way, using ducted fans. Furthermore, as seen from the product description from Vita Inclinata, the LSS-LA litter attachment device does not require a winchman, which is similar to our proposed solution as well. Our proposed solution also seeks to achieve similar stability parameters to the LSS-LA litter attachment, which is capable of stabilizing loads in winds up to 60 knots[12]. Our proposed solution differs from the LSS-LA litter attachment due to the fact that we seek to create a device that can attach to pre-existing stretchers, while the LSS-LA litter attachment product is itself a stretcher with actuators already attached to it[13]. While the LSS-LA litter attachment device is capable of loads up to 750 lbs, our proposed solution only needs to be capable of loads up to 250 lbs, which would be the approximate maximum weight of a person being hoisted in a stretcher. Furthermore, the LSS-LA litter attachment device is wirelessly operable, however; as seen in later parts of the PDR, our proposed solution will likely not utilize wireless communication. Most importantly, the LSS-LA litter attachment device is capable of controlling three degrees of freedom, while our solution at the time being is only concentrated on controlling one degree of freedom, that being spin[14].

Background / Related Work / References:

In order to understand the problem and solution, knowledge is required about the forces and torques involved on the load during helicopter hoisting operations, and knowledge for controls and stabilization is required for the design algorithm. Previous work on this issue is covered in the Define Strategies and Methods section. This work includes non-technical solutions to prevent spin on loads as stated in the Air Med and Rescue magazine, or the technical solutions proposed by Vita Inclinata. Below is a link describing the physics behind downwash related spin on loads. There is also a link to a report by NASA about how parameters on ducted fans such as diameter, duct length, number of blades, and motor choice all affect the resultant thrust and lift. Our group will reference these link, alongside other resources in order to come up with the mathematical formulation and algorithm to solve the problem:

[12] LOAD STABILITY SYSTEM
[13] LOAD STABILITY SYSTEM
[14] LOAD STABILITY SYSTEM

Helicopter Flight Physics

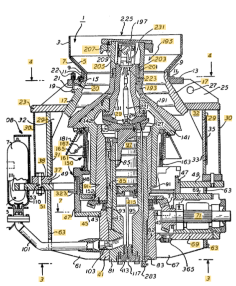
Performance Study of a Ducted Fan System

Since our solution involves spin control, or applying opposite torque to the load, other relevant research would be on anti-torque systems found on helicopter rotors. Various anti-torque systems such as tipped blades at variable pitch, or "fan in tail" systems help minimize excessive torque on helicopter rotors[15]. While these solutions regarding helicopter rotors may not be directly applicable to our design, some of the techniques described can be used on the blades of the ducted fans used as actuators for stabilization. Below are pictures demonstrating helicopter rotor stabilization systems, and links regarding sources

Helicopter Structures and Airfoils – Anti-Torque Systems

Study on Helicopter Antitorque Device Based on Cross-Flow Fan Technology

Anti-spin systems have been applied elsewhere as seen in a gyratory crusher system. The picture below shows the design for a mechanism, which through the use of uni-directional valves prevents the spin of the mantle of a crusher unless a certain force is exceeded[16]. While the context of this problem is different from helicopter rescue operations, it is interesting to see a purely mechanical approach to solving issues regarding spin. Below is a link to the patent description of said device:



US4206881A - Cone crusher anti-spin mechanism

[15] Helicopter Structures and Airfoils – Anti-Torque Systems
[16] US4206881A - Cone crusher anti-spin mechanism

The sub problem defined in the explication section has not been completely solved. The U.S government is still funding Vita Inclinata with 2 million dollars per year, showing that there is still a market for a solution to this problem[17]. Vita Inclinata's anti-spin hoist device is still in development, and the litter attachment is not modular and cannot work with existing stretchers. Our solution is unique in the sense that it can attach to existing stretchers and is relatively lightweight. Furthermore, an automated solution has not yet been standardized as helicopter operators still need to undergo manual procedures to stop spin on loads[18].

Summary of Fundamental Questions:

Below is a compilation of the answers to the fundamental questions listed in the PDR specifications.

The overall problem that this project is trying to solve is to reduce excessive load movement caused by downwash in helicopter hoisting operations (HHOs). The subset of the overall problem that our group is trying to solve is to reduce the spin of a hoisted stretcher during a HHO where the helicopter is stationary.

People should care about this problem because spinning loads during HHOs can cause damage to the helicopter, hoisting cable, and load itself, which could result in monetary loss or injury. In the context of our specific sub-problem, excessive spin can cause nausea which could result in drowning if the patient is strapped to a stretcher and cannot control their airways. Excessive spin can also cause the hoisting cable to be severed, the patient to be ejected from the stretcher, or make the stretcher collide with an external object, all of which can be life threatening for the patient. Furthermore, spinning loads can affect small helicopter's center of mass, making helicopter control difficult in low velocity launch situations.

Various non-technical solutions are used in practice to stop load spin during HHOs. These techniques are specified in the Air and Med Rescue magazine article. Furthermore, the private company Vita Inclinata has proposed two relevant technical solutions that help solve this issue.

Scope:

The overall problem is to design a device that is capable of regulating excessive load motion during helicopter hoisting operations (HHOs). The subset of this problem our group is trying to solve is to reduce the spin on a hoisted stretcher during a HHO where the helicopter is stationary at fixed elevation. Through solving this sub-problem, hopefully the technology used in this project can be expanded upon to control multiple degrees of freedom, work on other loads, or deal with situations where the helicopter is not stationary. Our group's specific approach to solving this sub problem is to build a modular device capable of attaching to existing stretchers to allow for spin stabilization during HHOs. Our group plans on testing our solution using simulation software such as Solid Works, We-bots, and analytical simulations. Using Solid Works, it is possible to conduct structural tests on our device, and perform aerodynamic flow analysis. Through modelling the problem as a controls problem, it is possible to use metrics such

[17] https://vitatech.co/news/vita-receives-us-air-force-contract/
[18] Spinning Avoidance | AirMed&Rescue

as step tracking error, sinusoid tracking error, max overshoot, peak time, and other controls parameters to quantitatively measure the performance of the device. These metrics could be attained through We-bots and analytical simulations. More details regarding simulation procedures and data are given in the Deliverables section of the PDR.

II. Requirements Review

Element Definition

The helicopter payload stabilization device is intended for use in helicopter hoisting operations (HHO). It is designed to stabilize cargo, and medical stretchers in particular. The artifact to address the problem of payload spin is a system of actuators that are mounted to a stretcher and generate force in an appropriate direction and magnitude. This of course includes a power source, a central processing unit (CPU) to run an algorithm, and all connections as well. Payload spin is a problem because it is inherently dangerous. High angular velocity causes rescuees to become nauseous and incredibly uncomfortable. If the angular velocity is fast enough it can cause them to pass out or even be ejected if not secured properly.

The technology used to combat payload spin consists of a sensor and actuators. The sensor used in the stabilization system is an inertial measurement unit (IMU). IMU's measure a body's specific force, angular rate, and sometimes the orientation of the body, using a combination of accelerometers, gyroscopes, and sometimes magnetometers. Actuation achieved using turbines to push air to generate force. These turbines are mounted a distance away from the center of rotation for the stretcher and pointed at a 90 degree angle from the center of rotation. This means that when a turbine generates a force, it induces a torque on the whole rigid body.

In order to use this device, the helicopter crew must do three things. They must mount the device properly, turn it on, and charge the battery between uses to ensure it has enough power to operate. Our device is meant to replace the training and knowledge of skilled operators that currently prevent payload spins via methods such as a crew member also being on the stretcher and leaning or putting an arm out to attempt to stabilize.

Perhaps the most difficult factor to design for is the environment. Helicopters operate outside, and in HHO's it is often an emergency situation where rain and high wind speeds are common. The distribution of weight is unknown as well. It is possible to make assumptions and educated guesses for the moment of inertia, but it will be impossible and impractical to ever calculate it in an emergency situation. Because of these factors, the payload stabilizer's effectiveness and safety rely on its robustness as well.

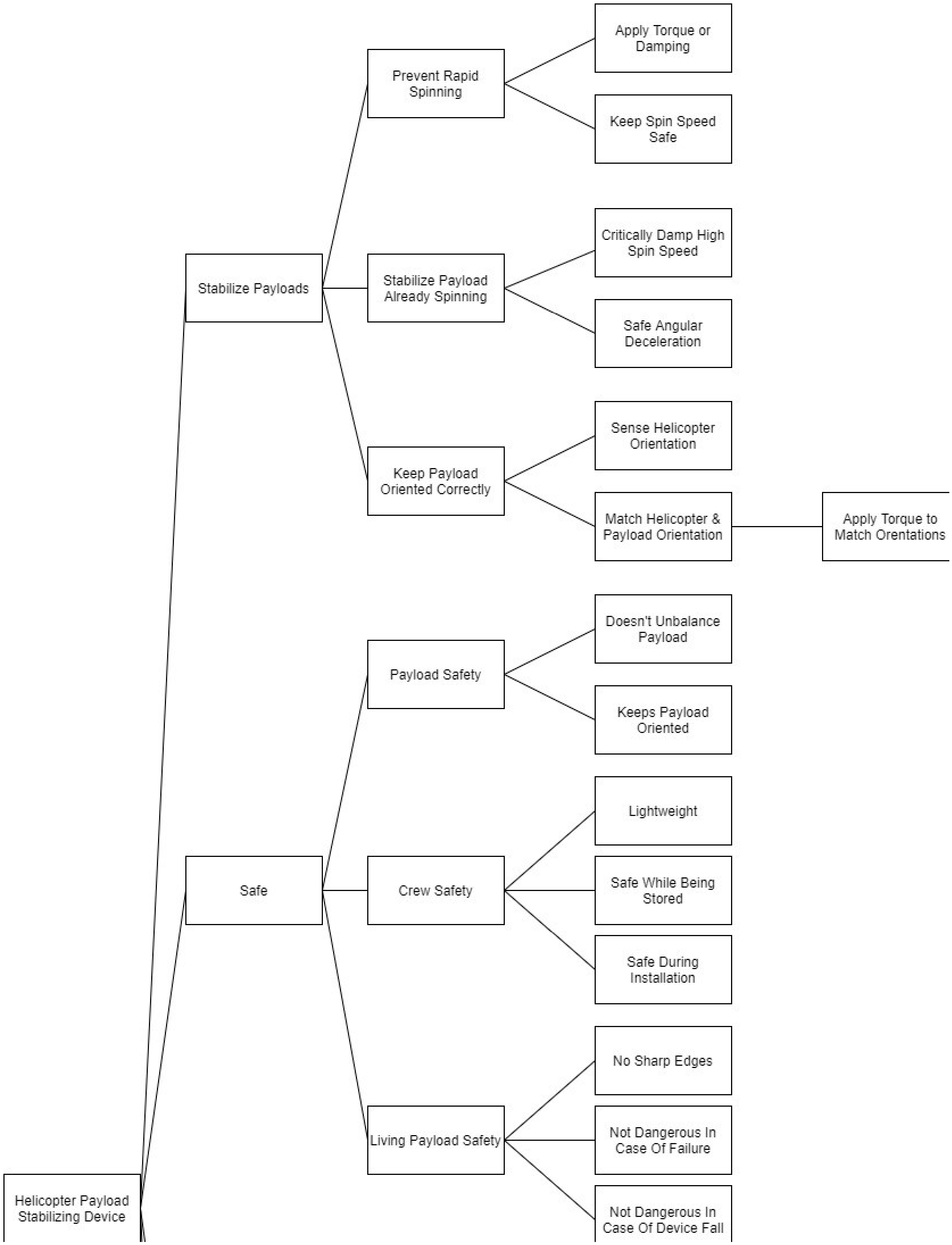
The sensor itself has three main structures. It has actuators that induce torque, it has mounting systems to make the entire payload a rigid body, and it has an electrical system to sense the current state and determine the appropriate response.

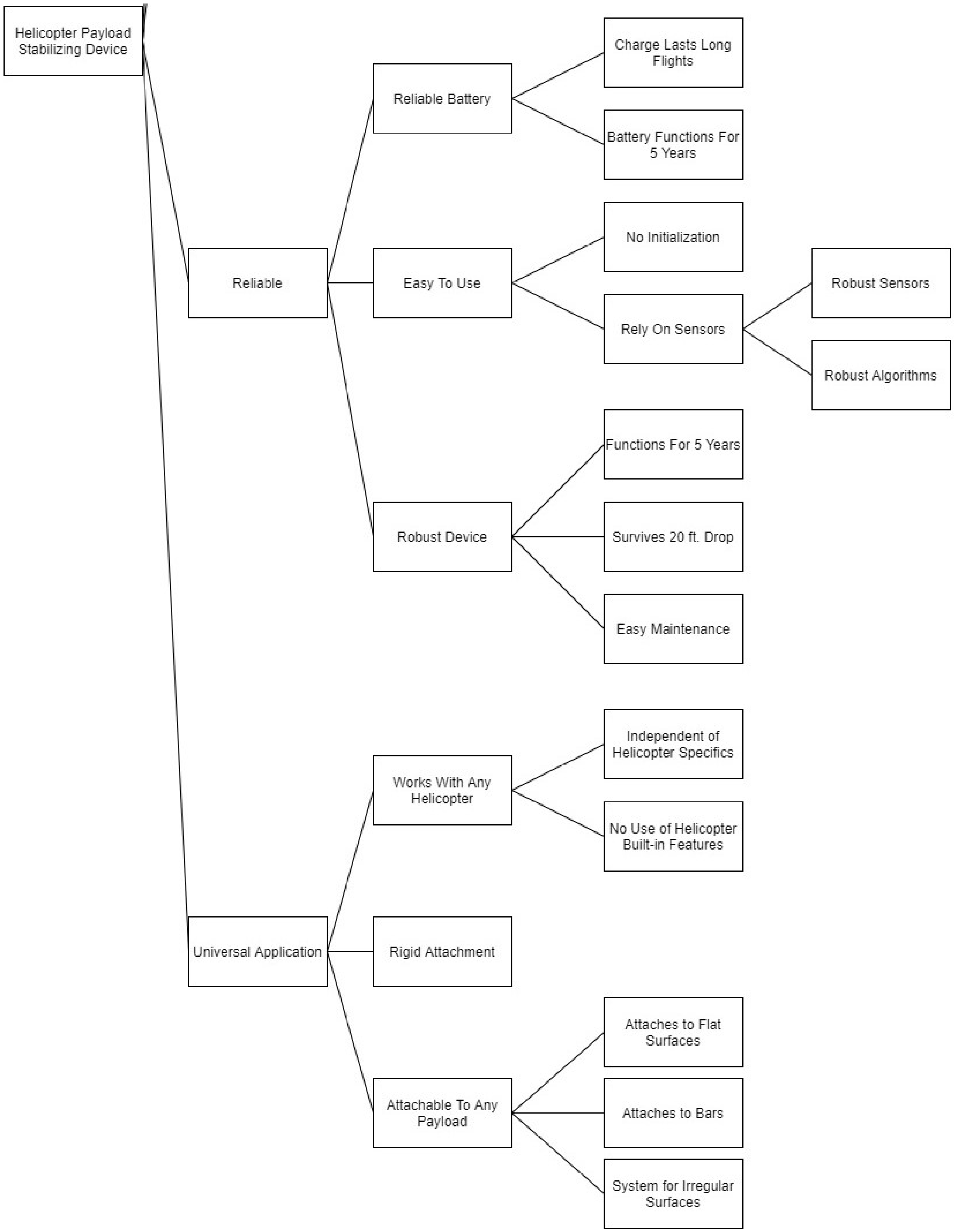
The helicopter payload stabilizer is meant to stop the rotation of payloads, and increase the safety and reliability of HHO's. The side effects of using this device to achieve those goals are twofold. The first side effect is the weight of the stabilizer. Any added weight to an aircraft is a negative, so lightweight options will be prioritized over heavier ones. The second potential side effect is if the stabilizer alters the center of mass to be more unbalanced or easier to spin.

Analysis

Objectives Tree Method

The first method of analysis used was the objectives tree. The objectives tree is a way of visualizing what we want a project to be able to do, by ranking the objectives. As the tree gets more branched out, the blocks gradually go from nebulous objectives to actionable design parameters. This way, the whole problem is though through to ensure the stabilizer does everything it needs to. There are four basic objectives for this project. It should stabilize payloads, be safe, be reliable, and have a universal application.


Helicopter Payload Stabilizing Device
Stabilize Payloads
Prevent Rapid Spinning
Apply Torque or Damping
Keep Spin Speed Safe
Stabilize Payload Already Spinning
Critically Damp High Spin Speed
Safe Angular Deceleration
Keep Payload Oriented Correctly
Sense Helicopter Orientation
Match Helicopter & Payload Orientation
Apply Torque to Match Orentations
Safe
Payload Safety
Doesn't Unbalance Payload
Keeps Payload Oriented
Crew Safety
Lightweight
Safe While Being Stored
Safe During Installation
Living Payload Safety
No Sharp Edges
Not Dangerous In Case Of Failure
Not Dangerous In Case Of Device Fall


Helicopter Payload Stabilizing Device
Reliable
Reliable Battery
Charge Lasts Long Flights
Battery Functions For 5 Years
Easy To Use
No Initialization
Rely On Sensors
Robust Sensors
Robust Algorithms
Robust Device
Functions For 5 Years
Survives 20 ft. Drop
Easy Maintenance
Universal Application
Works With Any Helicopter
Independent of Helicopter Specifics
No Use of Helicopter Built-in Features
Rigid Attachment
Attachable To Any Payload
Attaches to Flat Surfaces
Attaches to Bars
System for Irregular Surfaces

Performance Specification Method

The second method of analysis used was the performance specification method. The purpose of the performance specification method is to list performance attributes and weight them so that designs can be compared. Because the solution must fit a problem correctly and not the other way around, we considered different options besides actuators that induce torque via force generation from the side of a payload. Among alternatives considered were landing the helicopter first to remove the need for an HHO, using multiple cables to keep a payload in line, or even foregoing airlifts and using conventional ground transport. All of these alternatives are lacking in some way, and none can compete with the versatility and agility of HHO's. The next step was to determine actuators. The team considered a flywheel whose axis was tipped, passive damping, thrusters, rotors, and turbines.

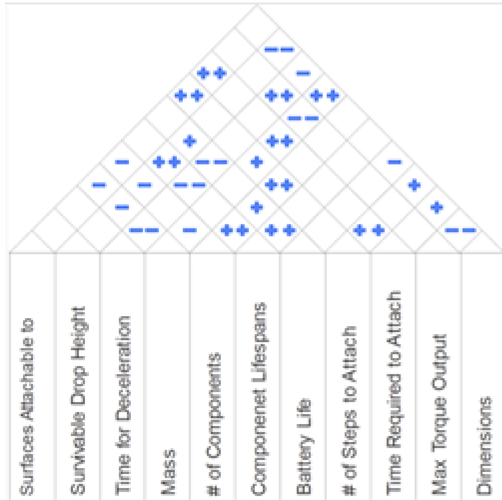
It was determined that the angular payload should not be allowed angular velocity greater than 15 rpm, and a maximum angular acceleration of 30 rpm^2. All assembly and parts must have a factor of safety of 2.5 or higher to keep in line with industry standards, and the device must be effective on a payload of 300 lbs. or more.

Quality Function Deployment Method

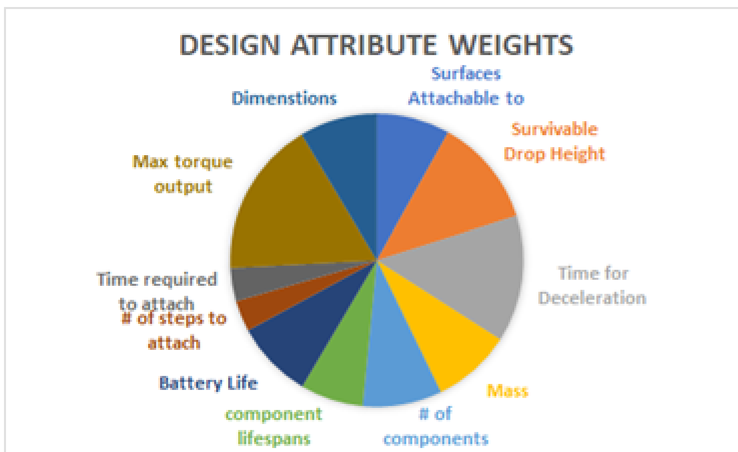
The last method of analysis used was the quality function deployment method, also known as the house of quality. This method uses a complex weighting system to determine what design attributes are the most important to design for.

	Weight (1-10)	% Weight	Surfaces Attachable to	Survivable Drop Height	Time for Deceleration	Mass	# of components	Component Lifespans	Battery Life	# of Steps to attach	Time Required to Attach	Max torque output	Dimenstions
			↑	↑	↓	↓	↓	↑	↑	↓	↓	↑	↓
Stabilize Payload	8	0.296296296											
Safe	9	0.333333333											
Reliable	6	0.222222222											
Easy to Use	4	0.148148148											
		Imputed importance	4	5	6	4	4	3	4	2	2	8	3.9
		Units	#	m	s	kg	#	hr	hr	#	s	Nm	m^3
		Design % Weight	8	12	14	9	9	7	9	3	4	17	8.6

The "roof" on the house of quality is used to visually understand how changing an aspect can affect others.



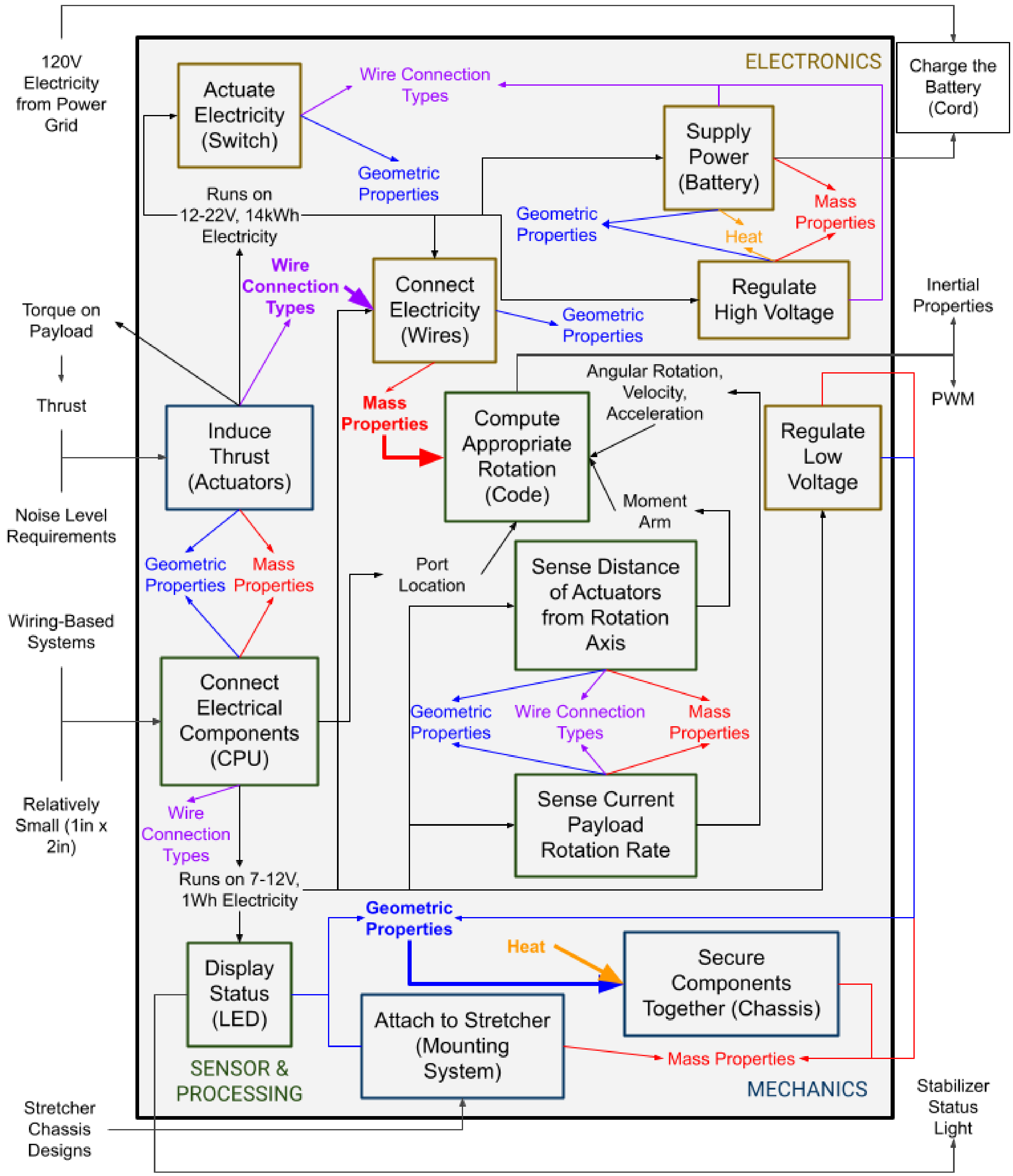
The end result of performing a quality function deployment method analysis is a series of design weights that tell the designers what the most important attributes to design for are.



As is evident in the above figure, maximum torque output is the most important parameter, and the time for deceleration is second most important.

III. System Design & Block Diagram

The following figure shows the block diagram for the stabilizer system. This diagram is meant to show the design decisions that must go into each subsystem and subproblem such that the completion of these specifications ensure overall project success. The solutions to these design decisions affect the design parameters of the blocks that each subproblem points to. Some properties do not have arrows pointing to the subproblem specified; in these cases, 'teleport' to the bolded property with the bolded arrow. For example, the geometric properties specified by the "Actuate Electricity (Switch)" show that design decisions about the switch design dictate how components are secured together in the chassis.



There are three types of components given by different colors in the diagram above: electronics (given in gold), sensor and processing (given in green), and mechanics (given in dark blue). Additionally, information each component produces or is dependent on is described below. Three pieces of information (the geometric properties, the wire connections, and the mass properties) have colors associated with them. These components and information in the diagram are discussed in detail below.

Components: Electronics

Supply Power (Battery)

The rechargeable battery supplies 12-20V electricity to each actuator as well as the CPU. The electricity is sent to these devices through wires and regulated through a voltage regulator. The geometric properties of the power supply will be taken into account such that the chassis can hold the battery and prevent movement throughout actuation. Currently, we will need as many battery packs as there are actuators, (the number of actuators needed is discussed in Part V). The mass of each battery will also be taken into account when calculating the required thrust. Heat will be produced by the battery and accurate ventilation will be designed to prevent overheating of other elements.

Depending on the type of battery, the charging cord will be designed such that it can plug into the electricity grid of a standard American 120V. The charging cord must be able to recharge the battery. Mass and geometric properties of the charger do not need to be considered since it is outside of our stabilization system.

Connect Electricity (Wires)

The wires distribute electricity from the battery throughout the module. The chassis must be designed such that the wires are able to reach the devices they need to supply power and the mass of each wire must be accounted for. Except for the LED, chassis, and the mounting system, all components use wires to route electricity back and forth; thus, the wire selection is dependent on the connection mechanisms of each device. Additionally, the wires are dependent on the voltage and power of the electricity that is run through them.

Actuate Electricity (Switch)

The switch will receive an on/off orientation. When on, it will distribute electricity to the voltage regulator. We assume that the mass of the switch is negligible, but include its geometric properties in the design of the chassis. Only one switch is needed, and this switch is located on the module with the CPU.

Regulate Voltage (High and Low)

The voltage regulator receives electricity from the wires from the battery and adjusts the voltage to the correct amount so as not to overheat the electrical components. The sensors and CPU will operate at 7-12 V while the actuators, switch, battery will operate at around 12-20 V. One type of voltage regulator is needed and is located with the CPU to adequately distribute the adjusted power. The chassis must be designed to ensure that the voltage regulators are held secure and their mass properties are taken into account when calculating the appropriate thrust.

Components: Sensors and Processing

Connect Electrical Components (CPU)

The CPU's purpose is to receive and distribute information such as the moment arm, angular kinematics, and pulse-width modulation inputs (PWM's) to the appropriate devices. Only one CPU is required for this system. The CPU will house the code that computes the appropriate rotation. The types of wires used must be able to connect to the CPU. The CPU determines the electricity we will use throughout the system, which is 7-12V. The chassis must be designed to ensure the safety of the CPU, and its mass properties will be taken into account in the rotation calculation. The current plan is to use an Arduino, thus, the appropriate port locations must be taken into account from the Arduino guide.[19]

Display Status (LED)

The LED displays light from the CPU to give visual feedback that the system is online. It receives electricity from the voltage regulator. Though we assume the mass of the LED is negligible, we must design the chassis in a way such that the light can be seen from outside the module. The LED must also be compatible with 7-12V electricity run from the CPU.

Compute Appropriate Rotation (Code)

The code's purpose is to calculate the inertial properties and the appropriate amount of thrust for the actuators in PWM based on the mass properties of each component and the angular kinematics gathered from the sensors and distributed by the CPU. The code is the only component without a mass, inertial, or geometric property under consideration in this module. The code will be uploaded into the CPU before the CPU is installed. The code must be compatible with the CPU's programming language.[20]

The code will calculate the moment of inertia of the payload and stabilizer system. First, the moment of inertia for the actuators is calculated based on the mass properties and moment arm:

$$I = MR^2$$

We assume that the mass of the actuators is a point mass given its relative size compared to the stretcher. We assume that the stretcher and person are a single thin rod rotating around its central axis. In this case, the formula is given below:

$$I = 1/12 \bullet ML^2$$

Combining these two formulas gives us the moment of inertia for the whole system. We send these values to the code to determine the appropriate PWM's for the actuators.

Sense Distance of Actuators from Rotation Axis

These sensors must determine the location of the actuators from the axis of rotation so that the appropriate thrust is calculated. The sensors receive electricity from the voltage

[19] Arduino Uno Rev3 | Arduino Official Store
[20] Arduino - Introduction

regulator. The sensors calculate the moment arm based on the placement of the actuator on the stretcher, which combined with the thrust produces a torque on the stretcher. These sensors are located with the actuators used. The mass of the sensors must be taken into account and their geometric properties must be considered in the design of the chassis. The wires connecting the sensors must have adequate connections and the sensors must be able to run 7-12V electricity.

Sense Current Payload Rotation Rate

These sensors determine the current rotation rate of the payload and determine the payload's current angular rotation, velocity, and acceleration. This information is sent to the code via the CPU. The current payload rotation rate is also based on the torque previously applied by the actuators in a negative feedback loop. The sensor locations correspond to the location of the actuators. The mass of the sensors must be taken into account and their geometric properties must be considered in the design of the chassis. The wires connecting the sensors must have adequate connections and the sensors must be able to run 7-12V electricity.

Tentatively, the sensors we are using will be linear accelerometers on opposite ends that determine the angular acceleration through mathematical manipulation.

Components: Mechanics

Secure Components Together (Chassis)

The chassis's purpose is to secure all devices. It must ensure that adequate ventilation is met for devices that produce heat. It must consider the geometric properties of all components except the code. The chassis will be designed into multiple parts, one part for each actuator. Its mass must be considered when calculating the appropriate thrust.

Induce Acceleration (Actuators)

The actuators receive electricity from the power supply via the wires and PWM inputs to produce the appropriate thrust determined by the code in the CPU. The thrust creates a torque on the payload. The electricity we will use is 12-22V, 14kWh based on the 70mm fan we are considering. The maximum rotation rate of the actuators is targeted to be around 45000RPM to achieve the proper thrust. This determines the power requirements of the battery, wires, voltage regulator, and the switch.

The design of the actuators must produce the required amount of torque. As shown in Part V, the torque that is to be generated is at around 12Nm. Given that the radius is about 1.1m, our actuators must provide 11N of thrust. Given the fans that we are considering,[21] this estimate seems to be realizable.

Depending on the type of actuator, it will also produce sound that must not exceed the noise level requirements given by the National Institute for Occupational Safety and Health. It is

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[21] Amazon.com: Powerfun EDF 90mm 12 Blades Ducted Fan with RC Brushless Motor 1450KV Balance Tested for EDF 6S RC Jet Airplane: Toys & Games

recommended that the sound generation be below 85 dB[22], but we do not anticipate the actuators we use to exceed 60 dB. More on actuators is discussed in Part V, including the type and quantity of each actuator. The chassis must be designed to ensure the proper operation of the actuator, and its mass properties will be taken into account in the rotation calculation.

Attach to Stretcher (Mounting System)

The attachments to the stretcher secure the actuators and CPU to the stretcher such that a force created by the actuators will not cause actuators to fall off. The attachments are designed based on the stretcher chassis designs we will clamp the device to. Ideally, the modules would be able to attach to any stretcher regardless of design. The number of attachment mechanisms correspond to the number of modules needed.These attachments must be designed to fit the chassis and its mass properties will be taken into account in the rotation calculation.

Information

Heat

Some heat is generated through the CPU and the sensors, but most heat in our system is generated through the batteries. The chassis must be adequately designed such that the heat is appropriately ventilated away from the device to be sure to not melt any critical components.

Geometric Properties

These properties are required of all physical components so that the chassis can be designed to fit them.

Mass Properties

These properties are required of all non-negligible physical components so that the appropriate and values can be calculated for the thrust. The heavier the actuators, the more thrust the actuators must be able to provide.We assume that the weight of the payload is about 95kg and the mass of the system is expected to be around 35-40lbs (18kg). Maximum load is 250 lbs (113kg). The code uses the mass to calculate the inertial properties of the system.

Wire Connection Types

The wires will have different connection types depending on the device it is connecting to. The wires will be designed depending on these device connections.

Electricity (12-22V, 14kWh; 7-12V, 1Wh; 120V from Power Grid)

The only source of energy used in our design is from our battery. The battery will output electricity for each component through wires. Electricity will be used exclusively to power our system, from the actuators and sensors to the central processing unit (CPU) itself. The electricity will undergo conversion to the appropriate voltage to be sure to power each device appropriately

[22] Noise Infographic - Levels by Decibels | NIOSH | CDC

and not blow anything up. The electricity will be distributed through wires from the power supply, which is charged with electricity through a charging port and wire from the electrical grid before use in a helicopter.

Angular Rotation, Velocity, Acceleration

Different angular kinematics are output depending on the type of sensor. The code must be adjusted to convert and manipulate these values into usable quantities.

Moment Arm

This value is calculated from the actuator placement on the stretcher to produce the correct amount of torque by adjusting the force. For now, we hardcode the value of 3.5ft (1.1m) into the moment arm. These values are fed to the code via the PCB and are used along with the mass of the actuators to calculate the appropriate torque on the payload.

Port Location

The code must be compatible with the CPU's ports such that the right signals are sent to the right places using the right commands. The code must be adjusted if a change in CPU or CPU orientation occurs.

Thrust

Thrust is generated from electricity in the actuators that propels the stretcher. Ideally, the thrust will come from two actuators equally at a certain distance apart such that a torque is created on the stretcher with a net force of zero, preventing additional sway from the stretcher. To produce the torque, the thrust works with the lever arm of the system.

$$\tau = r \times F$$

The thrust works in concert with the inertial properties of the payload-stabilizer system to produce a torque. The torque on the payload is sensed by the sensors to determine the next torque needed.

IV. Development of Design Candidates

In this section, we analyze the design requirements outlined previously in the report and began developing potential design candidates for the payload stabilization system. These development processes include creative methods such as brainstorm and synectics sessions, as well as rational methods like the morphological chart and the weighted objectives chart. Through these design development methods, we gain clarity on the possible design features that satisfy our requirements and rationalize which features result in the best design candidates.

Creative Methods

The first of our creative methods is a brainstorm session, where we contemplated all possible design solutions to our problem statement and documented the results. For each solution proposed by a team member, we consider the viability and how the solution can be improved or modified before moving on to the next topic of discussion. Finally, we grouped ideas together based on similarity and interchangeability. Listed below are the design groupings and their corresponding solutions.

- Device Type
  - Modular vs Combined Basket system
  - Anti Spin
  - Anti Sway
  - Mounted Rotor
- Actuation
  - Rotors/Turbines
  - Tilted Flywheel
  - Spin actuations on track around stretcher
  - Rotate turbines
- Passive Damping
  - Dampen twist of cable
  - Use existing Anti-twisting cable[23]
  - Gravitational damping
- Feature Location
  - Between basket and helicopter
  - Under basket/stretcher
  - Next to basket/stretcher

As part of our brainstorming, we also adapted some ideas to follow the synectics creative method. In this method, we started with the problem statement as given, which in short is the instability of the payload during helicopter takeoff. We likened the situation to a gyroscope or spinning top, where in both cases the problem is conceptualized as conservation of angular momentum. From this analogy, we came up with the spinning flywheel solution, which resists change in angular momentum by exerting forces opposite to external forces.

Through our discussions, we found that the issues that required the most discussion were the method of actuation and damping as well as the style of the overall system (modular or combined). We also considered that although our solution primarily focuses on anti-spin during helicopter takeoff, we should also design for anti-sway in order to design a complete solution.

[23] Rotation-resistant and low-torque ropes

Morphological Chart

The first of our rational methods is the morphological chart, in which we create design blocks that present many alternates for a given feature of the solution. By comparing many possible design decisions, we can explore different combinations of design features and determine which best satisfy the design requirements. Below is our morphological chart, with most viable options listed in bold.

Design Block	Option 1	Option 2	Option 3	Option 4
Actuation	Flywheel	**Turbine**	**Rotor**	Twisting Cable (powered)
Number of Actuators	1	**2**	3	**4+**
Power	**Electric**	Gas	Hybrid	
Device Location	**Edge of payload**	**Under Payload**	Center of mass	Hoist cable replacement
Shape	Basket/Bed	**Box attached to payload**	Cable	
Sensors	IMU	Compass		
Modular vs. Combined	**Modular**	Combined		

For actuation, we found that having a turbine or rotor to enact forces in various directions would be the most simple and reliable way to stabilize the payload system. Rotating flywheels require large power input and complex actuation, and focusing actuation on the cable would only solve anti-spin stabilization and ignore the possibility of anti-sway. In terms of the number of actuations, two actuators is the minimum number needed to counteract spin, and four is the minimum to counteract sway; similarly, an even number of actuators is preferred to maintain symmetry. Finally, we determined that a modular approach is advantageous because it minimizes weight, allows for versatility with existing stretcher models, and separates our design from existing products such as that from Vita Inclanata. More detail on the above design choices and others is presented in the **Design Candidate Selection** section.

Weighted Objectives Chart

The weighted objectives chart is the second of the rational design methods for this project. This chart is derived from the weighted objective tree, where we assign a weight to each objective at a given layer. This weight is scaled similar to a rank, and is normalized to a factor such that the combined weights at a given layer add up to one. Below is an example of the calculations involved in the top layer of the objective tree.

Objective	**Weight (scaled)**	Weight (fraction)	Weight (normalized/sum of 1)
Safety	3	3/10	0.3
Universal Application	1	1/10	0.1
Reliability	2	2/10	0.2
Payload Stabilization	4	4/10	0.4

Under each node, its children are similarly weighted and normalized to a sum of one. The total weight of a given node is the multiplication of its weight and that of its parent nodes. We repeat this process for each node in the tree until the third and bottom layer, when we can compare the final weight of each objective and determine which design criteria are the most important to consider. The weight and normalization is based on the total number of sibling nodes. Below is the final weighted objectives chart, with local and total weights shown for each node.

Layer 1	Layer 2	Layer 3
Payload Stabilization (**0.4**)	Prevent Spinning (0.4x0.5)=**0.2**	Apply Torque/Damping (0.2x0.5)=**0.1**
		Safe Spin Speed (0.2x0.5)=**0.1**
	Stabilize Payload already spinning (0.4x0.333)=**0.13**	Damp high spin speed (0.13x0.5)=**0.065**
		Safe deceleration (0.13x0.5)=**0.065**
	Keep Payload Oriented Correctly (0.4x0.167)=**0.07**	Sense Helicopter Orientation (0.07x0.33)=**0.023**
		Match Orientations (0.07x0.66)=**0.046**

Safety (**0.3**)	Payload Safety (0.3x0.167)=**0.05**	Doesn't unbalance payload (0.05x0.66)=**0.033**
		Maintain orientation (0.05x0.33)=**0.017**
	Crew Safety (0.3x0.333)=**0.1**	Portable (0.1x0.33)=**0.033**
		Safe in Storage (0.1x0.17)=**0.017**
		Safe in Installation (0.1x0.5)=**0.05**
	Living Payload Safety (0.3x0.5)=**0.15**	Safe in use (0.15x0.5)=**0.075**
		Safe in structural failure (0.15x0.33)=**0.05**
		Safe when device fails (0.15x0.17)=**0.025**
Reliability (**0.2**)	Reliable Battery (0.2x0.5)=**0.1**	Lasts long flights (0.01x0.66)=**0.066**
		5 Year reliability (0.01x0.33)=**0.033**
	Easy to Use (0.2x0.333)=**0.07**	No Initialization (0.07x0.33)=**0.023**
		Reliable Sensors (0.07x0.66)=**0.046**
	Robust Device (0.2x0.167)=**0.03**	5 Year functionality (0.03x0.167)=**0.005**
		Survives 20 ft. drop (0.03x0.5)=**0.015**
		Minimal Maintenance (0.03x0.33)=**0.01**
Universal Application (**0.1**)	Works with Any Helicopter (0.1x0.5)=**0.07**	Independent of Helicopter specifics (0.07x0.5)=**0.035**
		No use of Helicopter features (0.07x0.5)=**0.035**

	Rigid Attachment (0.1x0.167)=**0.0167**	N/A (**.0167**)
	Attachable to any payload (0.1x0.333)=**0.033**	Attach to flat surface (0.033x0.33)=**0.01**
		Attach to Bars (0.033x0.5)=**0.0165**
		System for irregular surfaces (0.033x0.17)=**0.006**

As we can see from the weighted objectives chart, objectives that have a higher parent such as payload stabilization and safety tend to have higher final weights. In addition, throughout the final layer we see that objectives related to the hoisting/rescue operation and the safety of the patient involved are of higher priority than those relating to long-term reliability or general compatibility. As such, in our design process our priority is to create a product that solves the problem statement by safely stabilizing, and compatibility and convenience is an important but secondary objective.

V. Design Candidate Selection

Actuator Requirements:

Fortune rigid II litter[24]

ABC15 Arizona[25]

[24] Fortune Srl
[25] Chopper rescue turns scary as stretcher spins

Rotational inertia of litter about cable axis:

$$I = \frac{1}{12} m_{load}(h^2 + w^2) \approx 39\ kg\ m^2\ \ ;\ \ m_{load} = m_{litter} + m_{human} = 95kg$$

Estimated angular acceleration of litter in video (assuming constant torque):

$$\alpha = \frac{w_f - w_i}{\Delta t} \approx \frac{2\pi(1.2 - 0.72)\ rad/s}{10\ s}$$

$$\alpha \approx 0.3\, {}^{rad}/_{s^2}$$

Estimated external torque on litter:

$$\tau_{ext} = I\alpha \approx 12\ Nm$$

Actuator torque, if placed near end of litter

$$\tau_{act} = r_{litter} \times F_{act}$$

$$\tau_{act} = (1.1m) \cdot F_{act}$$

Thus, in the case of the spinning litter shown in the video, $F_{act} > 11N$ to counter the external torque.

Actuator Choice

Flywheel

Flywheels can induce a large force, and provide quick stabilization. However, they must be heavy, have poor aerodynamics when mounted below litter, and are not very safe. Additionally, the actuation hardware will require 2 motors per wheel (one to rotate wheel, one to tilt wheel).

Ducted fan

11N can be achieved with relatively small fans. According to product specs on a ducted fan by the company Powerfun, a 70mm ducted fan can produce a maximum of 22N of thrust[26]. Ducted fans simply provide a thrust vector in the direction they are pointing, so they will not require any additional hardware. Additionally, ducted fans are very safe due to the enclosed housing of the fan blades.

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[26]https://www.amazon.com/Ducted-Blades-Brushless-Airplane-Balance/dp/B07CTM8XSD/ref=sr_1_2?dchild=1&keywords=Ducted+Fan+with+Motor&qid=1616020749&sr=8-2

Rotors

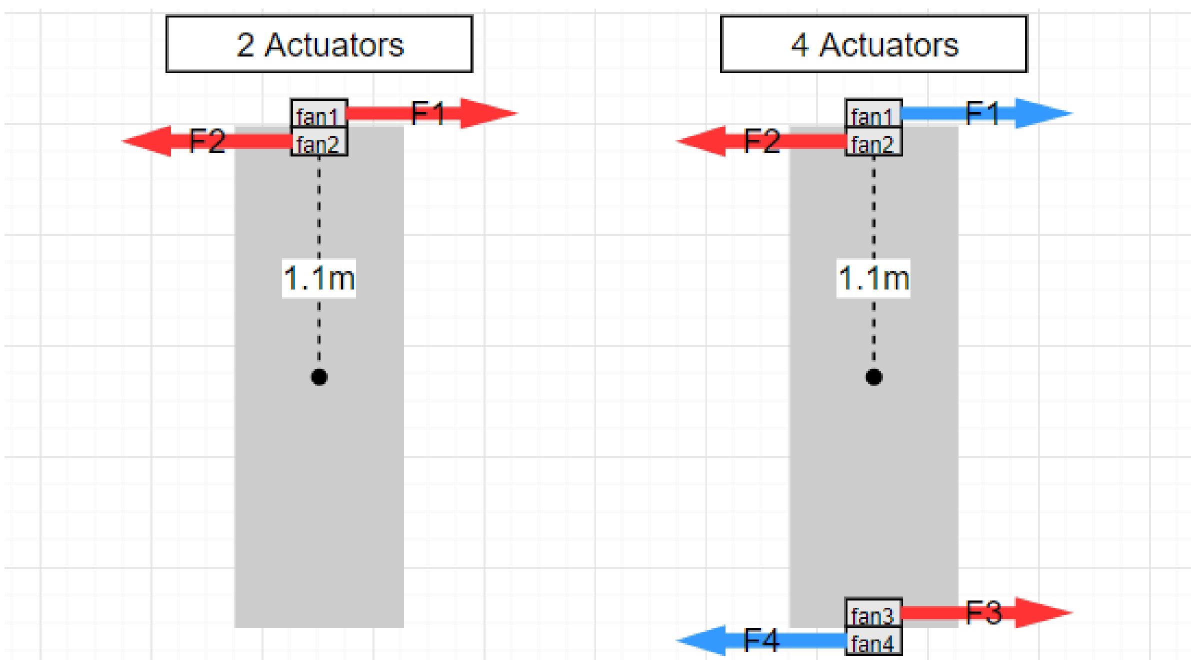
Rotors can provide the same benefits as ducted fans, but the blades are open and exposed. While this makes them lighter, it is a major safety concern to the occupant of the stretcher.

Twisting Cable

While this could be a viable option if the cable stayed at a somewhat fixed length, it will most likely not work well to solve our problem. The stretcher must still be hoisted into the helicopter, requiring the cable to be spooled up as it is lifted. Logistically delivering torque through a spooled cable could be difficult.

Number of Actuators

Stretcher - Top View



2 Actuators

Since fans provide thrust in the direction they are pointing, we need at least 2 fans to counteract any external torque. One fan is dedicated to clockwise rotation, while the other is dedicated to counterclockwise rotation. In this case, each fan would need to produce at least 11N of thrust to counteract the external torque seen in the video. Using 70mm ducted fans, this design could produce a maximum of 24 N m of torque. However, this design could require a counterweight on the opposite end to keep the stretcher balanced.

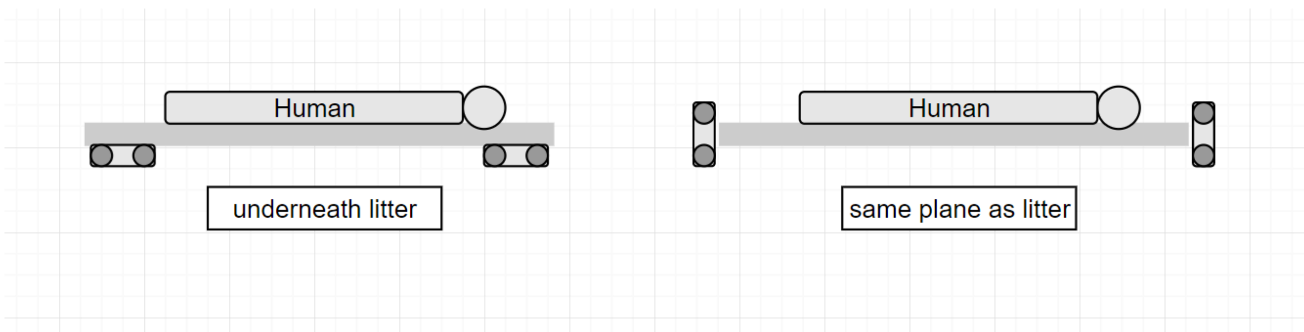
4 Actuators

The benefit to this design is it can achieve the same torque as the previous design, but with half the force output per fan. using the same 70mm fans, this design could achieve 48 N m of torque. Additionally, this design could also solve the future problem of swing, as opposite fans thrusting in the same direction would create a net force on the whole stretcher. The downside of this design is the added complexity and power consumption of the additional actuators.

Actuator Placement:

To provide maximum torque, the actuators should be mounted near the ends of the litter. Below are our possible design choices

Stretcher - Side View



Underneath Litter

Increases height of stretcher, but length is unchanged. May be difficult to attach while the stretcher is on the ground.

Coplanar with Litter

Increases the length of the stretcher, which could make it harder to fit in the helicopter. Easier to attach while the stretcher is on the ground.

Sensors

In order to counteract an external torque, we must be able to detect one. This will be done using our sensors. The best choice for our design will be IMUs. We are mostly concerned with angular acceleration, so a single IMU placed at the center of the litter could give us a measure of the litter's rotation about the cable axis. However, placing the sensor at the center of the litter means the sensor will not be physically attached to the actuators. The other choice is to place the sensors in the same module as the actuators. This design can only measure angular velocity if we are using two modules (one on each end), since the litter rotates about the cable axis.

Main CPU Location

Located in One Actuator Module

Since both actuators should be controlled by the same CPU, the simplest option is to put the main CPU in only one of the actuator modules. This leaves the remaining module with only the ability to send and receive information.

Located in All Actuator Models

All actuator models will have a cpu with the ability to control the entire system. Upon connection, an arbitrary CPU will take command. This will allow modules to be identical, but requires more overall hardware.

Located in a Separate Third Module

Housing the CPU in a third dedicated module is another option that leaves the actuator modules identical. However, the third module adds complexity to the design.

Communication

Cable

Connecting the modules via a cable is simple and effective. It removes the need for extra communication hardware, and has high throughput. However, running a cable between actuator modules could be problematic.

Wireless

Wireless communication between modules is desirable, but may not be worth it. Apart from the additional hardware, wireless communication could interfere with instruments/devices in the actual helicopter.

Final Design

Our goal is to specifically solve the problem of helicopter litter spin, as seen in the video. The only existing solution similar to ours is the LSS-LA – Litter Attachment by Vita Inclinata, which ships as a single unit (actuators + litter).

LSS-LA by Vita Inclinata[27]

While this device solves the same problem, it is very heavy duty, bulky, and replaces any existing litter. The LSS-LA is very powerful, and is almost overkill for the type of forces seen in the video. Our solution, while less powerful, should be less bulky, more convenient, and work with existing litters. Operators should be able to keep their existing (expensive) litters, and attach/detach our device easily. Thus, both plan A and plan B feature modular designs, and use the safest actuation method available.

Plan A

Option	**Our Choice**	**Reason**
Actuators	Ducted Fan	High thrust/weight ratio, safe, simple
Number of Actuators	4	Balanced weight, high torque output, can solve future problems (swing)
Actuator placement	Same plane as litter	Top rail of most litters is easiest to mount to
Sensor placement	One IMU in each actuator module	Sensors are contained in actuator module, one on each end provides good estimate of angular acceleration
Main CPU placement	Only in one actuator module	Simplest option
Communication	Wired	Simple, easier to get approved because it cannot interfere with helicopter instruments

[27] LSS-LA – Litter Attachment – Vita Inclinata Technologies

Plan B (differences highlighted)

Option	Our Choice	Reason
Actuators	Ducted Fan	High thrust/weight ratio, safe, simple
Number of Actuators	4	Balanced weight, high torque output, can solve future problems (swing)
Actuator placement	Under the litter	If top mounting rail is unsuccessful, we will attempt to mount underneath
Sensor placement	One IMU in each actuator module	Sensors are contained in actuator module, one on each end provides good estimate of angular acceleration
Main CPU placement	CPU in separate module	Actuator modules are identical/interchangeable (best option if module interchangeability becomes priority)
Communication	Wired	Simple, easier to get approved because it cannot interfere with helicopter instruments

Summary

In both designs, we will use two modules, each containing two ducted fans and an IMU. The modules will each have their own power source, and are only connected to each other via a communication cable. Our primary plan is to mount the devices to the upper rail of the litter, but will attempt to attach them below the litter if the upper rail is not feasible. Additionally, we will design one of the modules to contain the main CPU, but could move the CPU to a separate third module if actuator interchangeability becomes a priority.

VI. Broader Impact

This class develops engineering skills that go beyond the two quarters we spend designing this product. The following section addresses the broader impact this class will have on our future endeavors as engineers, whether in academia, the startup world, or industry.

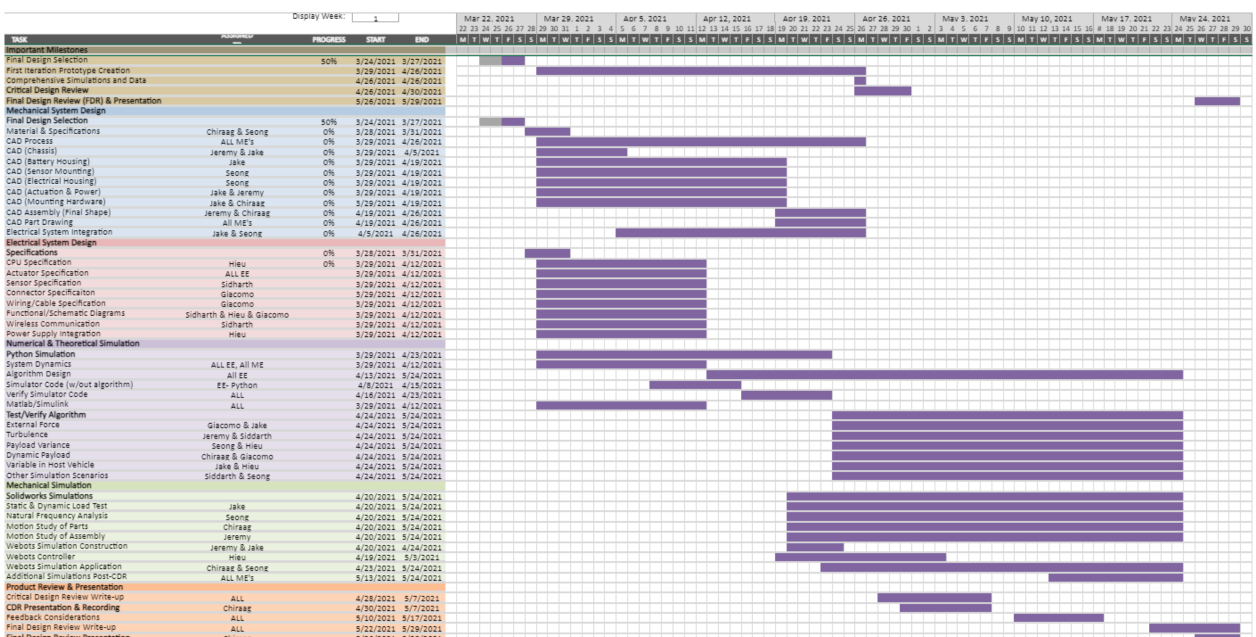
This engineering effort will allow us to incorporate and design different fields of engineering together in a product design fashion. For us specifically, this involves learning to incorporate and design mechanical hardware, electrical hardware, and control software such that they are compatible with each other. We also learn how to design each system based on the other more important systems with external requirements imposed on them. This effort teaches us to incorporate different parts of our robot together, specifically, the control system, sensors, actuators, power supply, and end effectors. This effort will allow us to be familiar with different simulation tools, both numerical and analytical, such as Solidworks, Webots, and Python.

In terms of social effects, this effort will allow us to increase our design capabilities by combining both our technical and numerical knowledge with creativity and commercial awareness skills. This effort also pushes us to foster teamwork skills such as research skills, conflict resolution, communication, leadership, time and resource management, and presentation and oral skills. As Dr. Mehta says, half our engineering work is being able to communicate effectively our knowledge and research.

For helicopter stabilization, using our system to solve this specific sub-problem opens up opportunities to solve the big picture problem. The methods used in this section to stabilize spin dynamics in one dimension of freedom provides a path to stabilization in the other 5 dimensions, allowing us to have a completely stable stretcher no matter the dynamics. The methods we use here can be applied not only to helicopters but other extreme situations, such as evacuation in subaquatic regions and outer space. Stability of the patient in these circumstances prevents the emergency from escalating into a more dire situation with bigger consequences. Finally, stability of the patient as soon as possible allows medical professionals the opportunity to execute definitive care actions earlier as opposed to the long patient transition time from the emergency scene to hospital.

VII. GANTT Chart

The following is the image of the GANTT chart that the team will use to complete the project in the next 10 weeks.



As the overlaps in the timeline show, every person was delegated to specific tasks so that the team would optimally work on a part of the project at any given time. The first 4 to 5 weeks will be devoted to the Mechanical System Design and Electrical System Design main tasks, with the mechanical and electrical engineers completing their respective prototype models, specifications, and codes. The three main tasks of Numerical/Theoretical Simulation, Mechanical Simulation, and Product Review & Presentation will be largely worked on by all team members with sub task leaders. Although every task is assigned to a certain member, all parts of the project will be continuously communicated and discussed. This GANTT chart schedule allows us to satisfy the two major milestones, the Critical Design Review in Week 5 ~ 7, and the Final Design Review in Week 10, on schedule.

Link to the full detailed GANTT chart is provided.[28]

[28] https://1drv.ms/x/s!AtTCPtS9I4IDahvKsKKCLeNEf_g?e=30bqjd

GANTT Chart Task Specifications

TASK	ASSIGNED TO	PROGRESS	START	END
Important Milestones				
Final Design Selection		50%	3/24/2021	3/27/2021
First Iteration Prototype Creation			3/29/2021	4/26/2021
Comprehensive Simulations and Data			4/26/2021	4/26/2021
Critical Design Review			4/26/2021	4/30/2021
Final Design Review (FDR) & Presentation			5/26/2021	5/29/2021
Mechanical System Design				
Final Design Selection		50%	3/24/2021	3/27/2021
Material & Specifications	Chiraag & Seong	0%	3/28/2021	3/31/2021
CAD Process	ALL ME's	0%	3/29/2021	4/26/2021
CAD (Chassis)	Jeremy & Jake	0%	3/29/2021	4/5/2021
CAD (Battery Housing)	Jake	0%	3/29/2021	4/19/2021
CAD (Sensor Mounting)	Seong	0%	3/29/2021	4/19/2021
CAD (Electrical Housing)	Seong	0%	3/29/2021	4/19/2021
CAD (Actuation & Power)	Jake & Jeremy	0%	3/29/2021	4/19/2021
CAD (Mounting Hardware)	Jake & Chiraag	0%	3/29/2021	4/19/2021
CAD Assembly (Final Shape)	Jeremy & Chiraag	0%	4/19/2021	4/26/2021
CAD Part Drawing	All ME's	0%	4/19/2021	4/26/2021
Electrical System Integration	Jake & Seong	0%	4/5/2021	4/26/2021
Electrical System Design				
Specifications		0%	3/28/2021	3/31/2021
CPU Specification	Hieu	0%	3/29/2021	4/12/2021
Actuator Specification	ALL EE		3/29/2021	4/12/2021
Sensor Specification	Sidharth		3/29/2021	4/12/2021
Connector Specification	Giacomo		3/29/2021	4/12/2021

Wiring/Cable Specification	Giacomo	3/29/2021	4/12/2021
Functional/Schematic Diagrams	ALL EE	3/29/2021	4/12/2021
Power Supply Integration	Hieu	3/29/2021	4/12/2021
Numerical & Theoretical Simulation			
Python Simulation		3/29/2021	4/23/2021
System Dynamics	ALL EE, All ME	3/29/2021	4/12/2021
Algorithm Design	All EE	4/13/2021	5/24/2021
Simulator Code (w/out algorithm)	EE- Python	4/8/2021	4/15/2021
Verify Simulator Code	ALL	4/16/2021	4/23/2021
Dynamic & Control Analysis: Matlab/Simulink	ALL	3/29/2021	4/12/2021
Test/Verify Algorithm		4/24/2021	5/24/2021
External Force	Giacomo & Jake	4/24/2021	5/24/2021
Turbulence	Jeremy & Siddarth	4/24/2021	5/24/2021
Payload Variance	Seong & Hieu	4/24/2021	5/24/2021
Dynamic Payload	Chiraag & Giacomo	4/24/2021	5/24/2021
Variable in Host Vehicle	Jake & Hieu	4/24/2021	5/24/2021
Other Simulation Scenarios	Siddarth & Seong	4/24/2021	5/24/2021
Mechanical Simulation			
Solidworks Simulations		4/20/2021	5/24/2021
Static & Dynamic Load Test	Jake	4/20/2021	5/24/2021
Natural Frequency Analysis	Seong	4/20/2021	5/24/2021
Motion Study of Parts	Chiraag	4/20/2021	5/24/2021
Motion Study of Assembly	Jeremy	4/20/2021	5/24/2021
Webots Simulation Construction	Jeremy & Jake	4/20/2021	4/24/2021
Webots Controller	Hieu	4/19/2021	5/3/2021
Webots Simulation Application	Chiraag & Seong	4/23/2021	5/24/2021
Additional Simulations Post-CDR	ALL ME's	5/13/2021	5/24/2021

Product Review & Presentation			
Critical Design Review Write-up	ALL	4/28/2021	5/7/2021
CDR Presentation & Recording	Chiraag	4/30/2021	5/7/2021
Feedback Considerations	ALL	5/10/2021	5/17/2021
Final Design Review Write-up	ALL	5/22/2021	5/29/2021
Final Design Review Presentation	Chiraag	5/26/2021	5/29/2021

VIII. Deliverables

Hardware

The mechanical design of hardware consists of chassis, and mounting devices. The chassis acts as a connector that links all the parts together, so we will use light weight, sturdy and cost-effective material. Mounting devices will also use the same material. The dimension of overall design will be large enough to fit in a 70 ducted fan, and not too excessive so it matches that of the stretcher where we might mount. We will base our tolerances off of the non-manufactured components (the stretcher, sensors, wires, and actuators) as well as our materials.

Simulation

Analytical Simulation

Although Matlab/Simulink is well-known for solving dynamic and control problems, we will use Python because of the convenience of object structures and the speed of simulation. The packages that we will use are os, numpy, panda, matplotlib, math, slycot, and control . We might have to use additional packages if we feel necessary during the design process.

We will mainly use Python IDE to implement the dynamic system, controller, environment model, and sensor models. The general aims of simulations in Python include validating mathematical formulation of the sensor dynamics and the system dynamics, verifying the models through collecting data and comparing with physics models, testing the models in different environments (constant wind, varying wind, etc.), and evaluating the capabilities of the controller in different scenarios.

Dynamic and Control Analysis

For Dynamic and Control Analysis, we will use Matlab to estimate the transfer function of the dynamic system and apply that transfer function into Simulink, built-in tool of Matlab, to do time domain analysis and frequency analysis. We will focus on analyzing the maximal overshoot, sensitivity to parameter variations, the robustness again disturbance and the stabilization of the system. The goal is to calculate the appropriate gains for the controller that can solve spinning problems on its own.

Physics Simulation

Heat Transfer Analysis

Heat Transfer Analysis is a tool that can be found in Solidworks' Thermal Analysis. We will make use of this tool in testing ventilation capacity of the design chassis.

Motion Analysis

The moment of inertia is the most important factor when dealing with spinning problems, so we will utilize the Solidworks' Motion Analysis to calculate the moment of inertia values for the individual parts as well as the assembly of all parts.

Finite Element Analysis (FEA) and Tolerance Stacking Analysis

The modeling process in Solidworks includes designing each individual part and assembling all of the parts. Hence, we will use Finite Element Analysis (FEA) and Tolerance Stacking Analysis to test structural integrity of all parts under maximal stresses and make cross-comparison of tolerances between all parts to ensure that everything goes together in the manufacturing process.

Webots Simulator

Webots is a tool where users can import an existing CAD model, customize physics plugin and controller, so we can apply the same setup we use in analytical simulations onto the physics model designed in Solidworks. With that, we can observe the behavior of our prototype design in the simulated physics world, test the interaction of the actuators and sensors through the controller, and validate the control algorithms.

User Guidelines

Here is the collection of the user guidelines that will be helpful for the simulation.

- Webots: https://cyberbotics.com/doc/reference/
- Python Packages:

- Numpy: https://numpy.org/doc/stable/reference/routines.html
- Pandas: https://pandas.pydata.org/docs/user_guide/index.html
- Math: https://docs.python.org/3/library/math.html
- Os: https://docs.python.org/3/library/os.html
- Matplotlib: https://matplotlib.org/stable/tutorials/index.html
- Slycot and control: https://python-control.readthedocs.io/en/0.8.3/intro.html

- Matlab/Simulink:
  - https://www.mathworks.com/help/control/ug/dynamic-system-models.html
  - https://www.mathworks.com/discovery/pid-control.html

Algorithm

Due to the nature of the problem, we want to build a controller that can maintain the orientation of the payload at a setpoint and reject the wind disturbance. PID controller is the best candidate to solve the problem. Our job is to calculate appropriate proportional gain k, integral gain ki and derivative gain kd[29].

For the purpose of operational analysis via scenarios, we will model different kinds of disturbances which mimic the real life environment. In addition, we will set a random starting orientation of the payload each time we run a simulation because of the uncertainty of how the user will set up the payload.

Data and Analysis

To be able to finalize our prototype model, we must run many simulations before manufacturing. We will do statistical analysis between analytical and physics simulations to understand the capabilities and the limitations of each simulator. We will compute quantitative results to answer whether the results match up between simulators, which scenario causes the significant deviation in errors, which simulator should be used for a specific scenario. With this information, we will be able to transfer from designing a prototype to designing a product without much struggling.

Summary

Throughout the project, we will focus on modeling a design that is ready for manufacturing, implementing a control algorithm that can solve spinning problems by commanding the system to produce thrust through ducted fans, understanding the limit of the design and anticipating the posible limit that can not be found in software simulation. Given this framework, we expect our design to be an anti-spin device which is capable of deploying thrust from high performance electric ducted fans by using a PID controller that can track a reference

[29]https://web.archive.org/web/20150421081758/http://saba.kntu.ac.ir/eecd/pcl/download/PIDtutorial.pdf

setpoint and reject disturbance. Through software simulations, we will validate our design expected features including autonomous helicopter payload stabilization, and one DOF control. The design hardware will be an assembly of chassis, mounting devices, battery housing, sensor housing, electrical wires, and actuators. This setup will give us enough room so that we can expand our solution to three DOF to solve spinning problems along with swinging and swaying problems after the verification of the expected features. The methods learned will also help us apply the process we used to other engineering projects in our future careers.