DEVELOPMENT OF A VTOL UAV CARRIER FOR DRAGONFLY PICTURES INC.

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ABSTRACT

As part of the Future Combat Systems program of the United States Armed Forces, Dragonfly Pictures is currently developing an Unmanned Aerial Vehicle (UAV) capable of taking off and landing vertically. This aircraft has a limited range of operation and must therefore be easily transportable by trailer to wherever it is needed. The Vertical Take Off and Landing (VTOL) UAV Carrier senior design team is responsible for designing and constructing a prototype for this part of the system. The transportation unit must meet several stringent requirements imposed by the military and by Dragonfly Pictures, which include transmissibility of vibratory forces, storage capacity, weather resistance, and compatibility with existing military hardware.

INTRODUCTION

Thanks to recent advances in computer technology, a trend which relies more on autonomous or remotely operated equipment for dangerous missions has emerged. Such devices have been used for some time now for tasks such as mine hunting and detonation. Recently, unmanned military equipment has taken to the skies as well. Though unmanned fighter aircraft are under development, reconnaissance devices are the current hot commodity in this new arena.

Dragonfly Pictures, one of several contenders for the class-3 VTOL UAV contract, is developing a helicopter with the designation DP-5X. The VTOL UAV Carrier Team is responsible for the transportability requirement of the aircraft. In order for a low altitude reconnaissance of this type to be successful, it must possess the ability to be transported anywhere, and over any terrain to where it is needed. Thus, it is infeasible to have an entire convoy of support staff and equipment following close behind. The helicopter and transportation system must exist as a quickly deployable and self-sufficient unit.

NOMENCLATURE

DP-5X – Autonomous helicopter’s designation
Dragonfly Pictures – Sponsor Company
FCS – Future Combat Systems
FEA – Finite Element Analysis
HMMWV – High Mobility Multi Wheeled Vehicle
ILD – Indentation Load Deflection
JP-8 – Turbine engine fuel
LTT – Light Tactical Trailer
UAV – Unmanned Aerial Vehicle
VTOL – Vertical Take Off and Landing
DESIGN PROCESS

The mobile carrier for the DP-5X is a rather complex system and is thus broken into its constituent pieces to facilitate design and analysis. For each component, a range of ideas is collected, recorded and weighted. After reviewing the traits of each idea, a winner is selected.

If the end product is found by Dragonfly Pictures to be satisfactory, it, or a modified version, may be mass produced and utilized. Therefore, preference is given to designs which incorporate parts that can be readily purchased rather than fabricated.

When preliminary specifications for all subsystems are defined, the UAV carrier is evaluated as a system. Each piece must interact harmoniously with the others in such a way that spatial interference, component overloading and overstressing is avoided.

TRAILER SELECTION

The trailer used for this transportation system must first and foremost be compatible with current military hardware. It must have the ability to be towed by a HMMWV and fit inside a C-130 transport aircraft along with the tow vehicle.

Additionally, the trailer must have adequate space for the loading plan as dictated by Dragonfly Pictures. This plan includes one UAV with one or two payloads, 1200 pounds of JP-8 fuel, FCS tool kit, blade storage areas, gear, food and water storage, ramps, electrical components, a lifting device and a tie down system.

The United States Armed Forces currently purchases HMMWV trailers from Silver Eagle, making this a natural starting point. The three trailers considered are the LTT-F, LTT-FE and LTT-HC. A simple flat bed trailer is desired, so the HC is ruled out automatically because of the vertical sides that it included. The FE is selected over the F because it is three feet longer and better accommodates the loading plan. The LTT-FE has a payload capacity of 2970 lbs and overall length and width, 165 inches and 86 inches respectively.

LIFTING DEVICE

Crane Selection

The substantial weight of the UAV and its payloads necessitates some form of powered lifting device. This device must be able to lift the aircraft from the trailer and place it on the ground, lift and position payloads, reposition the aircraft’s center of gravity, as well as serve as a winch when loading ramps are employed.

For this set of criteria, a crane mounted near the tongue of the trailer is the favored solution. Such a crane needs the ability to lift items very close to its base, as the payloads will be stored at the front of the trailer, as well as extending to reach the center of gravity of the 577 lb UAV.

The crane selected is manufactured by Ferrari Articulating Cranes and distributed in the US by Venturo Cranes. The crane features powered rotation, boom elevation, and boom extension and has a capacity rating of 6,000 ft*lbs. This supplies us with a lift of 700 lbs at a fully extended boom length of 9'-3” and a minimum reach of 3’, which satisfies all lifting and reach requirements.

STORAGE COMPARTMENTS

Fuel Containers

In order to complete its mission, each UAV must be transported with 1200 lbs of JP-8 fuel. This requirement consumes a great deal of the available space on the trailer. To leave sufficient space for the aircraft, the fuel is stored in compartments along the sides of the trailer. Because of their location, the fuel containers must be able to take on irregular shapes and have some tolerance to small arms fire.

Customizable semi-rigid fuel containers from Fuel Safe are used for this application. The containers can be manufactured to any desired size and shape, are ballistic tolerant, will deform under load to dissipate...
vibration associated with travel over rough terrain and contain foam baffles to prevent fuel from sloshing.

There are a total of four, fourteen inch wide fuel containers dimensioned to fit into the trapezoidal area defined by the fuel enclosure shown in Figure 4.

**Blade/Tool Boxes**

Along each side of the trailer, atop the fuel enclosure will be a water tight storage box. These boxes will be used to store spare rotor blades for the UAV, the FCS tool kit, fluids, spare parts, miscellaneous maintenance equipment, and soldier gear.

**Fuel Enclosure**

The space in which the fuel containers are enclosed is defined by a truss structure of square steel tubing. Several beams are welded to the bottom of the trailer to help support the truss, as the trailer did not provide adequate mounting points to support such a structure. To further protect the flexible fuel containers from road debris and small arms fire, the sides of the truss have been skinned with 16 gage sheet metal.

The fuel enclosure truss and the additional beams on the bottom of the trailer were analyzed to ensure sufficient strength under maximum loading conditions. Of the beams, the highest loaded member incurred a bending stress of 1309 psi and a shear stress of 676 psi. A Mohr’s Circle analysis yields a maximum principle stress of 1330 psi, which is well below the yield strength of 36,000 psi [1]. According to an ANSYS analysis, under maximum loading conditions the maximum stress in the fuel enclosure is 11,000 psi with a deflection of 0.1”.

**Payload Box**

Located at the front of the trailer are two boxes, specially designed to house the interchangeable payloads used by the UAV. The boxes are specially shaped to allow clearance for the rotation of the crane. A hinged door on the top provides easy access to the payload for removal by crane and a measure of weather resistance. Each box can accommodate a payload of 1900 cubic inches in volume with 6 vertical inches for foam padding at the bottom for shock absorption.

**Vibration Analysis**

As a piece of military rolling stock, the UAV carrier must be able to endure frequent use over rough terrain. Additionally, its contents must be adequately shielded from the induced shock and vibrations. The entire unit must be capable of traversing rough terrain at sixty five miles per hour while imparting an acceleration of no more than 3 g’s to the UAV and 2.5 g’s to the payload. According to the manufacturer, the trailer can meet the 3 g requirement without any modification. The payload, however, requires additional protection in order to meet the more stringent requirement.

“Rough terrain” is conservatively modeled as repeating sinusoidal bumps of ten inch amplitude and forty eight inch wavelength. The trailer is modeled as the three degree of freedom oscillating system in Figure 5 that accounts for spring and damper rates of the trailer tires, suspension and additional payload protection. This model is then broken into a system of three second order differential equations [2].

$$
\begin{align*}
    m_1 x_1 + c_2 x_1 + k_2 x_1 - c_1 x_2 - k_1 x_2 - m_2 g &= 0 \\
    m_2 x_2 + (c_1 + c_2) x_2 + (k_1 + k_2) x_2 - c_1 x_1 - k_1 x_1 - c_2 x_3 - k_2 x_3 - m_2 g &= 0 \\
    m_3 x_3 + (c_1 + c_2) x_3 + (k_1 + k_2) x_3 - c_1 x_1 - k_1 x_1 - c_2 x_2 - k_2 x_2 - c_3 x_4 - k_3 x_4 - m_3 g &= 0
\end{align*}
$$

Both the models of the simulated terrain and that of the trailer are input into MATLAB and simulated using SIMULINK. Spring and damper constants for the payload protection are varied until the system meets the criteria of 2.5 g’s or less.

A resilient, high density packing foam that possesses these desired properties is used to pad the
inside of the payload box. Foam is typically specified by Indentation Load Deflection, which is defined as the force required to deflect a piece of foam 25% of its thickness when a load is applied to a 50 in\(^2\) plate [3]. The foam selected is available from Foam by Mail and has an ILD of 35 pounds. With this foam, acceleration peaks at about 2 g’s during the initial shock and quickly damps out to a steady 0.5 g oscillation as shown in Figure 6.

**Rotor Blade Protection and Packing**

Though fairly durable by nature, the rotor blades must be provide a secure means of stowage. To keep them from bouncing around during transportation, the spare blades will be sandwiched between sheets of foam in their respective storage boxes. Several sheets of inch thick foam having an ILD of 70 lbs will be employed for this purpose.

**TIE DOWN SYSTEM**

A ratchet strap is used due to its ease of operation as well as its durability. The tie-down used is a woven 1” flat strap. Available in any custom length and having test strength of 4000 lbs, the straps are more than sufficient for this application.

**ANCHORS**

A heavy duty recessed anchor ring made by Erickson Mfg. LTD. is the best choice for an attachment point. It has a maximum load capacity of 5000 lbs per hook and is one of the least expensive anchor points available. It also satisfies safety concerns by being recessed, leaving less of a possibility of becoming a trip hazard or getting in the way of other applications.

**RAMPS**

When the UAV is unloaded from the back of the trailer, the crane will be used as a winch, and a set of three ramps are employed to span the distance to the ground. Aluminum center-folding ramps manufactured by Better Built have been specified for this purpose. Each ramp has a 1500 lb load capacity, and together, the three ramps can accommodate the 40” wheelbase of the UAV.

**WEATHERPROOFING**

The UAV is not tolerant to water and environmental exposure in its transport state. A canvas cover encloses the exposed front, top, sides, and rear of the trailer. Aqualon fabric has been selected for its resistance to mildew, abrasions, water penetration, most petroleum products, ultraviolet rays, and a wide range of acid and alkaline liquids. Aqualon boasts an excellent dimensional stability and strength-to-weight ratio. The color tan is used to match desert environment camouflage. Brass zippers allow easy access from the rear, while bungee tie downs prompt quick, complete cover extraction for deployment.

Support bows made of 1010 cold drawn steel support the cover. The bows have and outer diameter of 2” and an inner diameter of 1.870”. Their shape has been optimized to ensure dimensional stability under severe transport conditions and snow cover. Using a 30 lb/ft\(^2\) loading, the bows are analyzed as beams in bending. Maximum bending moment is found, outer diameter specified, and inner diameter extracted from the stress equation. A safety factor of 3 is used in all calculations. The bows are removable and normally held in the upright position by a set of female receptacles made of the same 1010 cold drawn steel. To ensure a proper sliding fit, the inner dimension is set at 2.008”, and the outer at 2.250” inches.

**LOADING/UNLOADING**

Loading and unloading of the UAV is highly dependant on the terrain of the launch location. If conditions are favorable and the ground is relatively flat, the ramps can be used. The front of the aircraft will be connected to the crane via a hook on its nose. One crew member will roll the aircraft down the ramps while the other operates the crane controls. If the ground is too rough to allow rolling, or if the landing gear of the UAV is for some reason inoperative, it can be picked up by the rotor head, lifted over the side tool boxes and placed on the ground. From this position, either the UAV or the entire trailer can then be moved out of the way to allow for sufficient space to either launch or perform maintenance. Putting the aircraft back on its trailer is exactly the reverse of unloading, i.e., either by winching or lifting with the crane.

**ELECTRONICS**

In order to be able to maintain the UAV in a mission ready capacity or carry out tests of the UAV and its payloads, a means to charge the UAV batteries must be present. Additionally, power must be available for both the crane and the ground control station. The simplest source of power is the HMMWV itself. It has a 24V battery and alternator which can supply up to 200A of current. The ground control station and crane can utilize power directly from the HMMWV. The UAV on the other hand, would require a battery charger since that device has the ability to “smart” charge the battery and prevent degradation or accidents which could occur if the battery is overcharged or allowed to reach high temperatures.
The main design issue here would be to find the minimum wire sizes that can accommodate the systems power requirements. Based on the crane and battery charger specifications, and a conservative estimate of the ground control station’s power consumption, it’s estimated that the HMMWV would supply 2400W of power, 100A at 24V, if all the attached devices were being powered simultaneously. Since the voltage available at the HMMWV would be 28V when the engine is running, we can conservatively tolerate a 4V maximum drop between the HMMWV and carrier system. Incidentally, a 4V drop corresponds to a 400W power loss in the wires. By determining the corresponding maximum resistance the wires connecting the system to the UAV can have, the smallest AWG (American Wire Gauge) number can be found.

An AWG number indicates both wire size and resistance per foot or 1000 feet. First, using Ohm’s Law: V= IR and solving for resistance, the total maximum resistance for each length of wire needed can be found for the 4V maximum drop. By dividing by the length of wire and multiplying by 1000, the resistance per 1000 feet is found. This allows quick indexing into the table of resistance per 1000 feet as a function of AWG [4].

<table>
<thead>
<tr>
<th>Length (ft)</th>
<th>Max Voltage Drop (V)</th>
<th>Current (A)</th>
<th>Resistance per 1000ft (Ω/1000ft)</th>
<th>Minimum AWG</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4</td>
<td>100</td>
<td>1.6</td>
<td>11</td>
</tr>
<tr>
<td>B</td>
<td>6</td>
<td>60</td>
<td>2.962962963</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>10</td>
<td>17.77777778</td>
<td>22</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>30</td>
<td>17.77777778</td>
<td>22</td>
</tr>
<tr>
<td>E</td>
<td>6</td>
<td>30</td>
<td>8.888888889</td>
<td>19</td>
</tr>
</tbody>
</table>

The table provides a summary of the minimum wire sizes required for each portion of the electrical plan. A corresponds to the wire linking the HMMWV to the crane. B corresponds to the trailer’s connection to the crane. C, D, and E correspond respectively to the trailer to ground station, battery charger, and battery charger to UAV battery. These calculations assume that the crane, battery charger, and computer station can tolerate an additional variation of 1.6V from 24V.

CONSTRUCTION

The budget did not allow construction on the selected Silver Eagle trailer. An economical alternative trailer with similar dimensions was obtained and modified to match the physical deck dimensions of the specified Silver Eagle trailer. This required removing the side walls and adding length and width to the existing deck. All manufacturing and assembly has been performed on campus with the exception of the payload, blade, and storage boxes. The crane will not be on this prototype due to budget constraints and may change in a later iteration of the design process and therefore the proposed mounting base will not be provided. Alternatively a 3000lb electric winch will be provided to aid the loading and unloading up the DP-5X. The fenders on the Silver Eagle trailer have a different size, shape and location than those on the economical trailer. This required modification to the existing fenders to maintain the fuel storage shape and volume. Maintaining the specified shape and volume of the fuel bladders will allow Dragonfly Pictures Inc. to purchase and install the fuel bladders at a later date as the budget has precluded their purchase at this time. The Silver Eagle trailer utilizes surge brakes to aid in bringing the system to a halt behind a HMMWV, however the economical trailer uses air over hydraulic drum brakes. This prototype will primarily be used in demonstrations and will be towed by the president of Dragonfly Pictures Inc.’s GMC Suburban which is equipped with an electric brake controller. The trailer has been modified with an electric hydraulic actuator that will couple the existing electronic brake controller with the existing drum brakes on the economical trailer allowing it to be registered in the state of Pennsylvania.

CONCLUSION

Developing the deployment system for the DP-5X military aircraft has proved to be a challenging experience. The team has taken on the task of designing and building this system that will transport the aircraft and all necessary equipment to sustain a 72 hour mission. There are many requirements that needed to fit in a compact package. The project began with a semi-open-ended budget, and ended with very stringent budget constraints that forced the design to be modified to fit on an economical base trailer without changing the sizes or shapes of our original model. The transport system will be employed by Dragonfly Pictures’ engineers for testing and demonstration purposes and has already been used in marketing proposals by the company.
ACKNOWLEDGMENTS

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REFERENCES


