

Department of Aerospace Engineering Sciences  
Senior Projects – ASEN 4018

University of Colorado at Boulder  
Design, Build and Fly  
System Architecture White Paper

28 SEP 07

Document History

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Initial	25 SEP 07		Josh Fromm
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Approval

Title	Name	Signature	Date
Customer			
Advisor #1			
Advisor #2			
CC			

# System Architecture White Paper

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## Aerospace Senior Projects (ASEN 4018 & 4028)

### 1.0 Information

#### 1.1 Project Title

University of Colorado at Boulder Design, Build and Fly

#### 1.2 Project Customers

Brian Argrow  
Director, Research & Engineering Center for  
Unmanned Vehicles (RECUV)  
429 UCB  
Phone: 303-492-5312  
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#### 1.3 Group Members

The following are the senior DBF team members

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Oleg Usmanov <a href="mailto:Oleg.usmanov@colorado.edu">Oleg.usmanov@colorado.edu</a> 303-332-3082 Positions: Software Engineer, Webmaster, Propulsion Lead, Structures	Jonathan Todd <a href="mailto:Jonathan.todd@colorado.edu">Jonathan.todd@colorado.edu</a> 303-543-2155 Positions: Testing Engineer, Propulsion, Avionics
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Barrett Sleeper <a href="mailto:Sleepdog5@gmail.com">Sleepdog5@gmail.com</a> Positions: Chief Financial Officer, Avionics Lead, Mission/ Payload	Scott Lowery <a href="mailto:Scott.lowery@colorado.edu">Scott.lowery@colorado.edu</a> 719-640-0342 Positions: Assistant Project Manager, Aerodynamics Lead, Mission/ Payload

## 2.0 System Architecture

The CUDBF project was formed to successfully design, build, test & fly a remotely controlled aircraft to compete in the AIAA Design, Build, and Fly Competition. The rules for the 2007-2008 competition require that the aircraft be able to carry a payload of 14 0.5L water bottles. These bottles are the highest-volume payload that the team must design around. After the conclusion of the competition in April 2008, the aircraft design will be provided to RECUV to fill their high-volume payload requirements.

The team decided that two major areas of focus defined the top-level system architecture; these are payload configuration and payload bay hatch location. The payload configuration was chosen since the team must build an aircraft that meets the payload requirement. The payload bay door location directly affects the speed of payload loading, which directly relates to the competitiveness of the design. In addition, an optimal payload door location will allow greater flexibility in payload integration.

The competition-provided payload of 14 0.5L bottles was the largest in volume, and provided the basis for the payload configuration. The team looked at the options of placing the bottles in the fuselage three different ways. A side-by-side configuration provides two rows of bottles, each 7 bottles long. This configuration would provide the longest and most slender payload bay while still fitting within the footprint requirement. Placing the bottles 3-wide would create a payload bay that is wider and shorter than the 2-wide configuration. Placing the bottles in a tapered configuration (not all bottles in same row) provides a more aerodynamically shaped payload bay while staying inside the required 4' x 5' footprint.

The team decided that for the design to be successful, the payload bay must be easy to access and provide for fast payload loading. These requirements increase the competitiveness of the design as well as the efficiency of payload loading. After evaluating previous designs<sup>3</sup>, the team decided to evaluate three areas where the payload bay door could be located. The top of the aircraft would provide the largest area to access the payload bay. Locating the door in the nose or tail provides a unique way to load the payload in a similar fashion to very large transport aircraft. This option stipulates that either the nose or tail cone swing open to access the inside of the aircraft. The fuselage sides could also be door locations due to their large size. Opening the fuselage from the side is a novel idea on par with typical door locations of transport aircraft. The left or right side of the fuselage would be made into a door that opened to provide direct access to the bay.

## 3.0 Requirements

This section contains the four design driving project and system requirements for the aircraft. These requirements have been determined to have the largest effect on the system architecture of the project and are outlined below.

**Table 1: Top-Level Project Requirements**

Requirement	Description	Parent Requirement	Verification Method
0.PRJ.1	Payload Variety	Competition	Demonstration
0.PRJ.2	Payload Restraint	Competition	Testing
0.PRJ.3	Delivery Mission	Competition	Demonstration
0.PRJ.4	Payload Mission	Competition	Demonstration

### 0.PRJ.1 Payload Variety

0.PRJ.1.1 Aircraft must accommodate all mission defined payloads in Table 2.

**Table 2: Payload Combinations**

Possible Payload Combinations <sup>2</sup>			
	Payload		Estimated Weight (lb)
	0.5 L bottles 8.5in H x 4" D	½ brick 4in x 4in x 2-2/3in	
<b>Combination 1</b>	14	0	7
<b>Combination 2</b>	0	4	7.2
<b>Combination 3</b>	10	1	6.8
<b>Combination 4</b>	7	2	7.1
<b>Combination 5</b>	3	3	6.9

0.PRJ.1.2 Required payload for flight will be randomly chosen by competition officials, but will be one of the above combinations

0.PRJ.1.3 Parent: Competition Requirement

0.PRJ.1.4 Method of verification: fly and assess all possibilities during testing

**0.PRJ.2 Payload Restraints**

0.PRJ.2.1 All payloads must be mechanically restrained

0.PRJ.2.2 Internal cargo bay must secure payload by means other than Velcro, tape or packing material<sup>2</sup>

0.PRJ.2.3 Parent: Competition Requirement

0.PRJ.2.4 Method of verification: visual inspection test, vibration test, holding the aircraft fully loaded upside down with hatch open

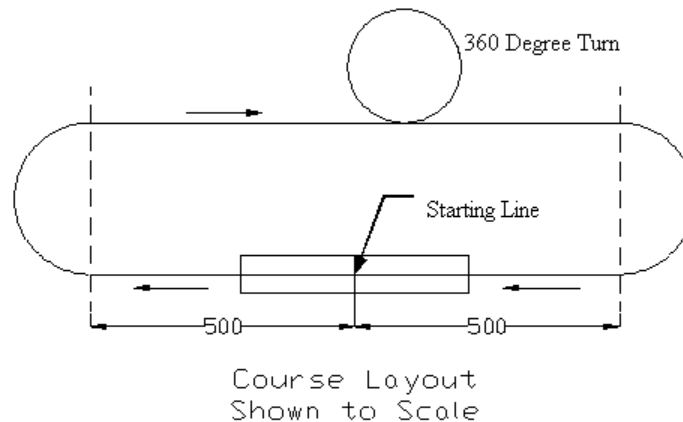
**0.PRJ.3 Delivery Flight**

0.PRJ.3.1 Aircraft must complete Delivery mission<sup>2</sup>

0.PRJ.3.2 Aircraft must take off, fly at least one lap as seen in Figure 1 and land. Aircraft must not crash. Aircraft is unloaded for this mission.

0.PRJ.3.3 Parent: Competition Requirement

0.PRJ.3.4 Method of verification: Flight Test



**Figure 1: Diagram of required flight lap<sup>2</sup>**

**0.PRJ.4 Payload Flights**

0.PRJ.4.1 Aircraft must complete Payload mission<sup>2</sup>

0.PRJ.4.2 Aircraft must be loaded with assigned payload combination, take off, fly two laps and land. Aircraft must be designed for a safe flight. Payload is randomly assigned at start of mission and the loading is timed.

0.PRJ.4.3 Parent: Competition Requirement

0.PRJ.4.4 Method of verification: scoring as defined by competition rules<sup>2</sup>

The system requirements are outlined below.

**Table 3: Top-Level System Requirements**

Requirement	Description	Parent Requirement	Verification Method
0.SYS.1	Battery Weight	Competition	Measurement
0.SYS.2	Aircraft Weight	Competition	Measurement
0.SYS.3	Takeoff Distance	Competition	Demonstration
0.SYS.4	Vehicle Endurance	Competition	Demonstration

**0.SYS.1 Battery Weight**

- 0.SYS.1.1 Maximum battery weight is 4lbs
- 0.SYS.1.2 A battery pack must weigh less than 4lbs; however, separate packs, of other sizes (total < 4 lbs) for each mission are allowed
- 0.SYS.1.3 Parent: Competition Requirement
- 0.SYS.1.4 Method of verification: measure weight of battery packs

**0.SYS.2 Aircraft Weight**

- 0.SYS.2.1 Aircraft must weigh less than 55lbs
- 0.SYS.2.2 AMA regulations require gross takeoff weight with payload to be less than 55lbs
- 0.SYS.2.3 Parent: AMA Insurance Regulations<sup>3</sup>
- 0.SYS.2.4 Method of verification: measure weight of final product

**0.SYS.3 Takeoff Distance**

- 0.SYS.3.1 Aircraft must take off in 75ft
- 0.SYS.3.2 Once moving, the aircraft must be completely off the ground before it reaches 75ft downrange
- 0.SYS.3.3 Parent: competition requirement
- 0.SYS.3.4 Method of verification: set distance markers along runway during testing

**0.SYS.4 Vehicle Endurance**

- 0.SYS.4.1 System must keep airplane aloft for at least 5 minutes
- 0.SYS.4.2 To complete the delivery mission the aircraft must fly for at least 5 minutes. During this mission the aircraft must complete as many laps as possible requiring optimal performance and efficiency.
- 0.SYS.4.3 Parent: Competition Requirement
- 0.SYS.4.4 Verifiable through component testing and demonstration

**3.1 Payload Configuration (see Figure 2)**

3.1.1 Two Bottles Wide

3.1.1.1 Pros

- This configuration has the smallest profile (when viewed from the front) and therefore does not require a wide fuselage
- The mass of the bottles is near the center axis and therefore the payload weight does not produce a large roll moment
- The narrow fuselage permits this configuration to be used in most possible aircraft configurations

3.1.1.2 Cons

- Since the bottles are two across, they must be seven long, which requires the longest fuselage possible
- If front/back loading is chosen, the sliding platform/tray/box will be long and will thus take more time to insert into the fuselage

### 3.1.2 Three Bottles Wide

#### 3.1.2.1 Pros

- The shorter grid of bottles allows the payload bay length to be reduced by up to 57 percent
- This configuration is more square and therefore produces more symmetrical moments

#### 3.1.2.2 Cons

- The 50 percent wider fuselage increases drag by a factor of 1.5<sup>1</sup>
- Works best in only one configuration: flying wing

### 3.1.3 Tapered Bottles

#### 3.1.3.1 Pros

- Since there are many different tapered shapes, the fuselage can be custom-shaped to satisfy other requirements

#### 3.1.3.2 Cons

- The staggered bottles may increase loading complexity
- This configuration will also increase the complexity of the CG and stability analysis

## 3.2 Access Location

### 3.2.1 Top

#### 3.2.1.1 Pros

- Lowering payloads from the top benefits from a gravity assist in speed and convenience
- Regardless of the aircraft configuration, the motor will not cause interference with a top load
- Since there will not be a tray structure to slide, loading time is likely to be decreased and points of mechanical failure reduced

#### 3.2.1.1 Cons

- There is the possibility of interference from the wings with a biplane configuration
- There will be a structural penalty to pay in terms of mass and complexity due to the large hatch

### 3.2.2 Sides/Bottom

These areas were not considered due to the increased complexity that previous CUDBF teams have faced when using these areas.

### 3.2.2 Nose/Tail

#### 3.2.2.1 Pros

- This design permits a smaller hatch that will not be as subject to the above concerns
- Regardless of the aircraft configuration, there will never be any interference from the wings

#### 3.2.2.2 Cons

- A tray must be moved in and out of the airplane, increasing loading time
- This configuration introduces the problem of interference from either the motor or the tail

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<sup>1</sup>The basic equation for the force of drag is  $D=0.5*\text{density}*\text{area}*\text{drag coefficient}*\text{velocity}^2$

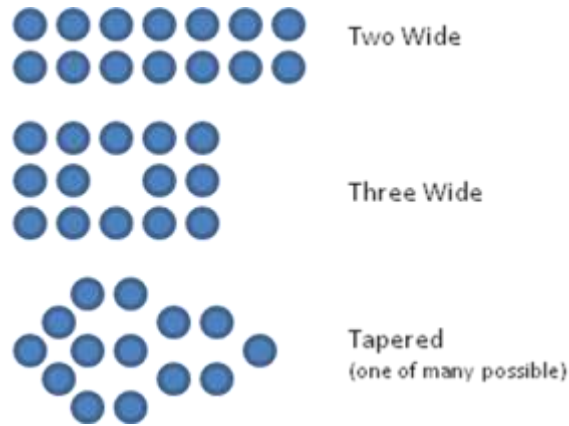


Figure 2: Payload Configuration

After careful consideration of the above options and their associated benefits and drawbacks, the team has selected the two-wide configuration and the top access location. This will result in a long, narrow fuselage, with a large hatch for quick access.

## 4.0 Feasibility

### 4.1 Mass Budget

Table 4 is a rough, over estimated mass budget for the competition aircraft with the heaviest payload. With a 10% margin, the aircraft is estimated to weigh 16.1 lbs, which falls within the weight limit of the current propulsion system used on previous year’s aircraft (See figure 3 below). Propulsion and aerodynamic feasibility studies will demonstrate that this weight can be moved by the propulsion system and lifted by the aerodynamic system.

Table 4: Preliminary Mass Budget  
 Feasibility - Basic Mass Budget

Component	Weight (lbs)
<b>Propulsion</b>	
Motor	0.40
Propulsion Battery Pack	3.00
Electronic Speed Control	0.13
<b>Structures</b>	
Wing	1.50
Empennage	0.30
Fuselage	1.50
Landing Gear	0.30
<b>Payload</b>	
Heavy payload	7.20
<b>Avionics</b>	
Receiver	0.05
Receiver Battery Pack	0.13
Servos	0.13
Sub-total	14.63
Margin	10%
<b>Total + Margin</b>	<b>16.0875</b>

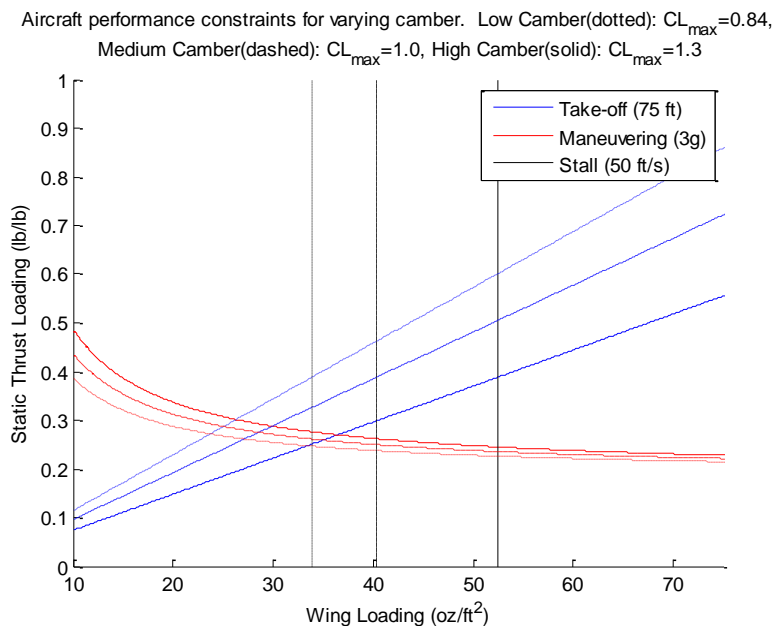
The mass budget above was determined using components from the 2006-2007 aircraft, with increased weights for motor and battery weight to compensate for the increased payload weight<sup>1</sup> of 1 lb. These weights are difficult to estimate from year to year due to widely varying competition rules, but a confidence interval for the average payload-to-empty weight of DBF planes over the past few years provides an estimate of the maximum weight of the aircraft<sup>4</sup>. Data for empty-to-payload (empty / payload) weights for 36 teams was analyzed with the results in Table 5.

**Table 5: Statistical Data of Historical DBF Aircraft**

Mean	1.159
Standard Deviation	0.367
Confidence	$\pm 1.279$
alpha	0.05
Lower Limit	1.04
Upper limit	1.279

Table 5 demonstrates that the empty weight fraction is between 1.04 and 1.279; this range is within a 95% confidence interval (found from  $100\% * (1 - \alpha)$ ). Multiplying the upper and lower limits by the 7.2 pound payload weight translates to a fully loaded aircraft weight between 14.69 and 16.49 lbs. This range matches closely with the estimate of the components from last year's aircraft in Table 5.

## 4.2 Aerodynamic Feasibility



**Figure 3: Performance Constraint Chart**

The figure above is a performance constraint plot for the aircraft. Using equations from Shevell and Roskam Part I, several critical performance criteria can be analyzed simultaneously by solving them in terms of wing loading and thrust loading. Wing loading is defined as the weight of the aircraft divided by the wing area and thrust loading is the thrust of the engines per pound of aircraft weight. Static thrust was used in this case simply because a procedure (discussed later) has been developed for testing static thrust, as opposed to dynamic thrust.

The equations were solved using several  $C_{Lmax}$  values which are representative of a range of camber common to RC planes<sup>5</sup>. Ideally, an airplane is designed to have the highest wing loading and lowest

thrust loading possible. A high wing loading is beneficial because it means a smaller wing area (less drag and weight) and greater resistance against wind gusts. A low thrust loading is desirable because it implies a lower overall weight of the aircraft. In order to satisfy all of the constraints, a design point must be located above and to the left of all of the lines. This defines a ‘design envelope,’ an area in the upper left of the chart which contains all of the appropriate wing and thrust loading values. Since it is likely that the design will call for the high camber value, the optimal design point is a wing loading of about 44 oz/ft and a thrust loading of about 0.38. A ten percent margin was added as a safety factor. These numbers translate to a wing area of about 5.08 square feet and a required maximum thrust of about 6 lbs. The dimension requirement already discussed fits nicely with the required area, and the next section will show that the required thrust can be met.

### 4.3 Thrust

The propulsion system is required to provide thrust necessary to take off in 75 ft followed by 5 minutes of powered flight. Battery types are limited to NiMH or NiCd packs by competition rules and cannot exceed 4 pounds. The information in Table 5 shows that the airplane weight is approximately 15.48 pounds, using the mean weight fraction.

To be sure the airplane can have sufficient thrust to take off it was decided to determine if a thrust-to-weight ratio of 0.4 is possible for both empty and full weights. SLK Electronics ElectriCalc software was used to estimate the aircraft’s flight characteristics. An off-the-shelf system consisting of a Neumotor brushless motor model 1515/2.5D-1700, 24 GP 3300 mAh NiMh battery cells, 5.3:1 gear ratio gearbox, Master Airscrew 15x8 propeller, and Phoenix 60 A brushless speed controller. The plot in Figure 4 was generated by ElectriCalc and represents the thrust profile at a 39.6 A maximum current draw, which is below the 40 A limit.

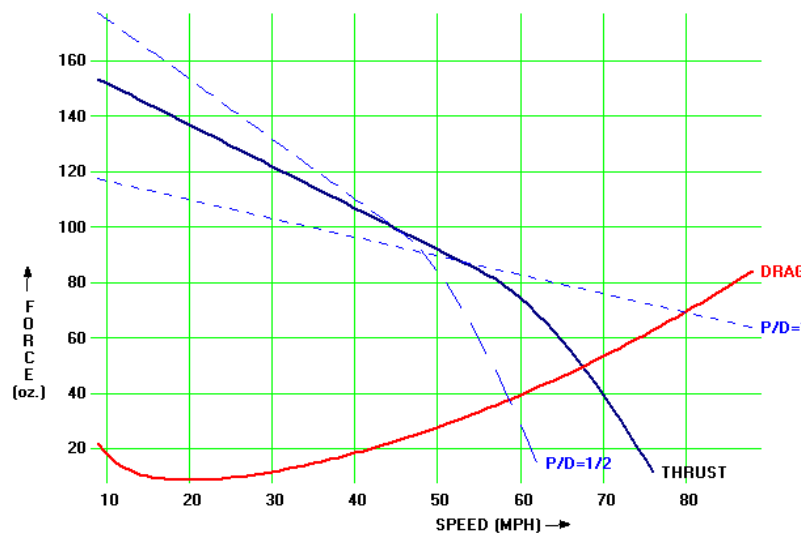


Figure 4: Thrust and Drag for Varying Airspeed

The plot above represents thrust (blue solid line) and drag (red line) as a function of aircraft speed. The two other blue dashed lines represent thrust profile as a function of the speed, if the current propeller would have been replaced with the propeller with the Pitch to Diameter ratios (P/D) of 1/2 and 1. ElectriCalc assumes same maximum current when it does those calculations. These two additional profiles help select the correct size propeller depending on if the speed or static thrust is of the most importance. It was noted that even though the 15 x 8 propeller has the pitch to diameter ratio of almost 1/2, the actual thrust profile (solid blue) deviates from the predicted profile for that ratio (long dashed blue). This could not be explained at this time, but is likely due to the fact that ElectriCalc generates a dashed profile based on the 100% propeller efficiency, but it could also be a bug in the software. This will be resolved with the manufacturer of the software.

From the plot above it can be concluded that with this motor/gearbox/cell/prop/speed controller configuration the aircraft will be able to produce more than 9 lbs (144 oz) which corresponds to thrust to weight ratio greater than one assuming the plane flies empty weight and a thrust to weight ratio of 0.6 fully loaded. This ratio is greater than the 0.4 ratio required to meet all performance constraints.

The cruise speed can also be determined from the plot above (intersection of drag and thrust curves) to be 67 mph which is higher than the required stall speed in the performance constraint chart above. The flight time was also estimated using the same software and is 8.8 minutes, which is adequate to meet the 5 minute maximum flight time. The chosen motor and gearbox weights 12 oz and the battery pack weight 54 oz, which is less than 64 oz battery limit weight. The retail cost of the motor is \$270, the speed controller is about \$150, and multiple battery packs would cost around \$200. The team also has a discount worked out in the previous years with component suppliers that will reduce the cost of the propulsion components further. Thus, the off-the-shelf propulsion requirement can also be met when the thrust requirements are met.

#### 4.4 Cost & Time Feasibility

An important consideration for the design is the cost required to produce and test the design, as well as compete in the DBF competition. Previous years' have shown that a budget of \$10,000 was required in order to complete the project<sup>1</sup> and attend competition. The department provides \$4000, but the team plans to apply for Undergraduate Research Opportunity Fund (UROP) and Engineering Excellence Fund (EEF) funding in order to provide vertical integration across all classes within the Department of Aerospace Engineering Sciences. The team anticipates full funding from each organization, as shown in Table 5, which would bring the total budget to \$11,000. This is greater than the minimum cost of the project, signifying that money will not provide a bottleneck to the successful completion of the project. The team's customer, Dr. Brian Argrow, has verbally committed to funding of the project from RECUV. This funding would provide auxiliary funding for the project, but is not required to complete the project.

**Table 5: Project Funding Sources**

<b>Funding Source</b>	<b>Amount</b>
Department of Aerospace Engineering Sciences	\$4000
UROP	\$3000
EEF	\$4000
RECUV	Variable
<b>Total</b>	<b>\$11000+</b>

The base project of designing and testing an aircraft to meet requirements can be constructed with the Senior Project budget of \$4000, as shown in Table 6 below.

**Table 6: Basic Project Materials Budget**

<b>Product</b>	<b>Total Cost</b>
Epoxy	\$280.52
Wood	\$208.68
CA	\$35.94
Servos	\$126.94
Horns & Linkages	\$22.88
Nuts & Bolts	\$6.45
Layup Supplies	\$234.95
Propulsion	\$900.00
Composite Materials	\$100.00
Mold Supplies	\$100.00
Payload Material	\$100.00
Telemetry System	\$700.00
Printing	\$200.00
<b>Total Cost Estimate</b>	<b>\$3,016.36</b>
<b>Total Cost Estimate + 25% Margin</b>	<b>\$3,770.45</b>

The parts in Table 6 consist of all the parts required to build an aircraft assuming that no parts are available at no cost to the team. The table shows that the aircraft can be designed, built, and tested for under \$3000. A 25% margin on this cost brings the project cost to about \$3800, still under the \$4000 given budget.

The time required to complete the project within the scope of Senior Projects is a major consideration when determining if the project can be completed. The time allotted for the design stage is approximately 3 months, and the building and testing time is also about 3 months. The DBF project has, in years' past, been run on a time table similar to the Senior Projects course; as an extracurricular activity, this time table was usually successful. With more resources and more commitment to the project, the team is confident that the given time table will be sufficient to complete all phases of the project.

## 5.0 Testing and Verification

Testing and verification of the design will be conducted using a bottom up approach. Each subsystem team will identify and conduct testing of the critical performance components of the design, before integration into the larger system. These tests will verify that the subsystems meet the specified design-to-requirements. This approach will allow design problems to be identified and addressed with minimal impact to the overall design. Below is a brief list of top level system tests that will be conducted.

### **Propulsion**

Static and dynamic testing of the propulsion system to ensure design-to thrust is delivered . This testing will be performed on RECUV engine test stand and a mobile test platform. Thrust data will be collected and analyzed using Labview software. In addition, testing will be conducted on the competition required 40 amp fuse to analyze the fuse opening time and sensitivities.

### **Structures**

Static testing of the aircraft structure to ensure design-to load carrying capacity will be conducted. The wing will be tested using RECUV span loading “wiffle tree” apparatus. Further testing will be conducted as required using RECUV and ITLL testing resources.

**Payloads**

Payload testing will be conducted ensure that all payload loading and retention competition requirements are met. Additional testing of the payload restraint system will be conducted as required to ensure that payloads will remain secured during all design flight phases. Payload loading testing will be used to determine the most efficient method of loading the aircraft.

**Avionics**

Static and dynamic testing of aircraft telemetry system to validate data will be conducted. The telemetry system GPS data will be tested against other GPS devices to verify system accuracy and precision meets design-to specifications. Airspeed data will be validated using a mobile test platform.

**Aerodynamics**

Aerodynamic aspects of the design will be tested by incorporation into flying mockup test aircraft or existing RECUV aircraft. Additional testing will be conducted as required to verify meeting design-to specifications.

**Integrated system testing**

The completed design will be flight tested to verify that the required take off distance, cruise altitude, and flight duration performance parameters are achieved. Additional performance data parameters, including airspeed, thrust, power management, and turn performance, will be collected and compared to predicted performance models.

**6.0 Risks**

**Table 6: Risk Analysis**

Risk	Description	Mitigation
0.RSK.1	Choosing Wrong aircraft configuration	In-depth trade studies, iteration
0.RSK.2	Insufficient Thrust	Accommodate for additional cells in fuselage
0.RSK.3	Unstable Aircraft	Design: Stability Analysis, Testing: Active Stability Correction

**6.1 Choosing Wrong Aircraft Configuration**

The DBF plane must be designed to not only function as a payload carrying aircraft, but to also be competitive at competition. The risks must be properly balanced in the deciding factors such as to build an aircraft with a competitive edge and also meet the class requirements. If proper attention is not given to the aircraft configuration, the team will **not** suffer in terms of class requirements, but **will** suffer in competitiveness at completion. As of now, this is the greatest design risk.

**6.2 Insufficient Thrust**

Properly designing and implementing the propulsion system is extremely important to the competition requirements. Battery weight must be as small as possible, but the aircraft must still take off within 75 feet. Under designing the propulsion power packs can be extremely debilitating to the team at competition. It should be noted that designing the propulsion to meet completion requirements will sufficiently meet the specified class requirement defined in the Project Definition Document. If a pack is under powered, the team will need to add more cells to the pack. This introduces problems with pack charging (max # of cells), CG location, and weight. This also is an entire day or two set back if this were to occur on a test day. It should also be noted that the testing phase occurs during the winter / spring and “good” testing days can be rare.

**6.3 Unstable Aircraft**

This is yet another very debilitating risk that the team faces. If the aircraft is unstable, consequences can range anywhere from redesigning and building parts of the aircraft, to entire wings, to losing the entire aircraft in a crash. Note that occasionally motors, battery packs, speed controllers and other expensive components are sometimes lost in a crash. Proper stability analysis will help to greatly reduce this risk. If through testing it is found that the aircraft is still slightly unstable, active correction can be added in the form of a gyro. The only consequence will be ~25 grams for the unit.

## 7.0 Team Qualifications

**Table 7: Team Qualifications**

Technical Area	Team Member Responsible	Level of Expertise
Electronics / Propulsion Lead	Oleg Usmanov	High Experience: 2 years as DBF propulsion
Aerodynamic Design Lead	Scott Lowery	Medium Experience:
Structural Analysis Lead	Andrew Bell	Medium-High Experience:
Construction	Michelle Tamayo	Medium Experience:
Aerodynamics, Avionics	Spencer Riggs	Medium-High Experience: 3 years in DBF, RECUV
Avionics Lead	Barrett Sleeper	Medium-High Experience:
Testing Engineer	Jonathan Todd	Medium-High Experience:
Mission Design Lead	Joshua Fromm	Medium-High Experience: 3 years in DBF, RECUV

## 8.0 Response to PDD feedback from PAB

**Table 8: Response to PDD Feedback**

PAB Comment	Response
No literature review	The team has begun a scoring analysis as well as a review of previous designs in order to determine factors contributing to the success of other schools at competition.
Specify what a lap is.	The lap diagram from the competition rules has been added to the PDD.
Consider vibration testing	The team is unsure how a full system vibration test might be conducted at CU. The team will consult Trudy Schwartz in order to determine the need.
Con-ops too short	This section will be edited in order to lengthen the section per PAB comments.
Altitude excursion limits should be added.	This requirement is a nominal safe operation altitude, to ensure safety of people on the ground. The upper and lower limits will be defined after consulting the pilot and airfield safety personnel.
General Editing	This will be fixed with all other changes suggested.

## 9.0 Resources and References

### 9.1 Facilities

Table 9: Facilities

Facility	Comment
RECUV Fabrication Lab	This facility is for general construction and non-specialized testing. Spencer Riggs and Joshua Fromm serve as managers of this lab, and have agreed to provide this space.
Boulder Model Airfield	The airfield is for all flight testing as well as ground testing that requires a large space. Access to this field is controlled, but the team already has access to the field.
Composites Lab	This lab is used for heavy-duty composite fabrication that requires ventilation and space for layups to be fabricated and processed.

### 9.2 References

1. Annabel, Seth, Tavin Green, Jake Nelson, Luis P. Zevallos, and David Thomas. University of Colorado Design Build and Fly Competition. U. of Colo. 2007.
2. Page, Gregory. "2007-2008 Contest Rules." AIAA DBF Official Page. 15 Aug. 2007. American Institute of Aeronautics & Astronautics. 26 Sept. 2007 <[http://www.gregorypage.net/aiaadb/2008\\_rules\\_fp.htm](http://www.gregorypage.net/aiaadb/2008_rules_fp.htm)>.
3. "The Hangar." Terrabreak. 28 Sept. 2007 <<http://www.terrabreak.org>>.
4. AMA National Model Aircraft Safety Code. Academy of Model Aeronautics. 2007. 28 Sept. 2007 <<http://www.modelaircraft.org/PDF-files/105.pdf>>.

## 10.0 Acknowledgements

### 10.1 Customer contacts

The team would like to thank Dr. Brian Argrow for his sponsorship of the project.

### 10.2 Faculty members

The team also would like to thank all members of the Project Advisory Board (PAB) for their input and advice. The team would especially like to thank Dr. Donna Gerren, Dr. Ryan Starkey, and Dr. Jean Koster for their advisement and feedback on all project aspects thus far.

### 10.3 Graduate Students

The CUDBF team would like to thank Jason Roadman for his advice, input, and experience that he has provided to help the team.

### 10.4 Undergraduate Students

The project has a large undergraduate component, and the seniors would like to thank the following undergraduate students for their input: Daniel Colwell, Thomas Wormer, Annie Frederick, Chelsea Goodman,

## **10.5 Others**

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## **A. Appendices**