Department of Aeronautics and Astronautics
Massachusetts Institute of Technology
Unified Engineering
16.003-004

Spring 2015

**S/L Laboratory 4**

**Aircraft Integration and Unified Engineering Flight Competition**

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| Out: Friday, April 3, 2015, 10:00AM<br>Lab Due: Monday, April 27, 2015, 11:59PM |

Overview:

In this laboratory students will get to design, build and fly a remote controlled (RC) aircraft as part of the Unified Engineering Flight Competition (UEFC). This year's competition involves the theme "multi-mission design" including the possibility of reconfiguring the RC aircraft between missions. Mission A is a speed mission, while Mission B is a maximum payload mission. The lab consists of (i) designing a competitive RC aircraft system, (ii) manufacturing and testing that system and (iii) competing in the UEFC with that system.

Learning Objectives (LO):

1. To critically analyze the requirements for a system based on written UEFC rules.
2. To design, manufacture and test an RC aircraft including its operating strategy as a team and to predict future system performance.
3. To compete in a friendly flight competition and critically post-process both successes and failures.

Deliverables:

1. A laboratory report (typically 5-6 pages in length, but could be longer or shorter) that shows the design process that was followed as well as the final design including a performance prediction ($Score_{predicted}$). This is a team deliverable. This lab will be carried out in the assigned UEFC teams. Due Monday April 27 at 11:59PM

2. A completed RC aircraft ready to compete at the UEFC. Due date is Thursday April 23 at 7PM at Johnson Athletic Center.

3. An individual reflection (about 300 words) about what you learned in this lab and how it could be improved. This is an individual deliverable. Due April 27 at 11:59PM on stellar as a PDF document.

Team Size:

This lab will be carried out in the same teams as those assigned in Labs 2 and 3 for the UEFC. A summary of the UEFC team assignments is shown below:

| | | |
|---|---|---|
| **Team 1**<br>1. Lisa Yang (lyang33)<br>2. Edward J Lopez (edlopez)<br>3. Andrew L Trattner (trattner)<br>4. Andrew E Kurtz (akurtz)<br>list of email addresses | **Team 2**<br>1. Aaron L Morris (morrisa)<br>2. Ostin D Zarse (oszarse)<br>3. James A Rivera (jarivera)<br>4. Carlos R Cruz (crcruz)<br>list of email addresses | **Team 3**<br>1. Madeline M Haas (mhaas)<br>2. Armen Samurkashian (armens)<br>3. Caroline G Hope (cghope)<br>4. Nicholas K James (nkjames)<br>list of email addresses |
| **Team 4**<br>1. Lenny Martinez (lennym)<br>2. Zhishen Wang (jujzwang)<br>3. Armando J Fadhel (afadhel)<br>4. Guillermo Bautista (gbau)<br>list of email addresses | **Team 5**<br>1. Steven Rivadeneira (stevenrr)<br>2. Samuel B Judd (samjudd)<br>3. Timothy D Nguyen (nguyen95)<br>4. Frederick O Daso (fdaso)<br>list of email addresses | **Team 6**<br>1. Olivia H Makepeace (ompeace)<br>2. David P Sherwood (dsherwoo)<br>3. David W Fellows (dfellows)<br>4. Jonas J Gonzalez (argonaut)<br>list of email addresses |
| **Team 7**<br>1. Jose A Gomez (j_g0m3z)<br>2. Kevin Castro (kcastro)<br>3. Matthew J Davis (mattjd)<br>4. Signup here<br>list of email addresses | **Team 8**<br>1. Brandt C Nelson (bnelson6)<br>2. Faith N Huynh (owly)<br>3. Victor S Zhang (victorz)<br>4. Vardaan L Gurung (vardaang)<br>list of email addresses | **Team 9**<br>1. Daniel Dalton (ddalton)<br>2. Jake P Liguori (jliguori)<br>3. Sean D Kropp (skropp)<br>4. Filip Twarowski (filipt)<br>list of email addresses |
| **Team 10**<br>1. Matthew R Ryback (mryback)<br>2. Bradley J Walcher (bwalcher)<br>3. Eric A Riehl (riehl)<br>4. Bjarni Kristinsson (bjarni)<br>list of email addresses | **Team 11**<br>1. Nicholas F Villanueva (nickvill)<br>2. Diego A Mundo (dmundo)<br>3. Veronica M Padron (vpadron)<br>4. Joseph S Figura (figura)<br>list of email addresses | **Team 12**<br>1. Zachary J Bierstedt (zjbier)<br>2. Marlyse H Reeves (mreeves)<br>3. Kelly J Mathesius (kjmath)<br>4. Jesse W Adler (jwadler)<br>list of email addresses |
| **Team 13**<br>1. Erika L Hill (erikah)<br>2. Emily C Widder (emwidder)<br>3. Tiera S Guinn (tguinn4)<br>4. Signup here<br>list of email addresses | **Team 14**<br>1. Paulo C Heredia (pheredia)<br>2. Carlos Cuevas (cuevas)<br>3. Ellie L Simonson (ellies)<br>4. Tori L Wuthrich (toriw)<br>list of email addresses | **Team 15**<br>1. Allan Ko (allanko)<br>2. Marguerite G Prescod (mprescod)<br>3. Colleen F Madlinger (cmadling)<br>4. Rachel T Harris (rh1921)<br>list of email addresses |

Dates:

3/30 Introduction of Lab 4 during class

4/23 UEFC Main Event from 7-10PM in Johnson

4/27 Final Deliverables due for Lab 4

## Background

Increasingly aircraft are asked to carry out several missions rather than be optimized for only a single mission. An extreme example is the Transition vehicle shown in Figure 1. It can fly in the air at subsonic speeds and also operate on roads as a passenger car. Compared to a specialized vehicle that can only fly (e.g. the Cessna C172 shown next to the Transition on Fig. 1) or only drive the Transition represents a compromise and requires reconfiguration between missions. On the upside such a single vehicle can carry out multiple missions. Another example is commercial aircraft (e.g. Boeing, Airbus) that have to carry a wide range of passengers and cargo over different distances. One of the key questions in the market today is whether it is better to offer more different specialized vehicles, or a single platform that can cover a wide range of missions.


**Fig. 1**: Terrafugia Transition Flying Car (right) next to a Cessna C172 (left)

The rules for this year's UEFC are summarized in Appendix A. This also serves as this year's official rulebook. The rules may be slightly amended as questions come up during execution of lab 4. Any changes will be announced on stellar and over email. The following sections contain detailed instructions for Lab 4.

Detailed Instructions:

1. **Requirements Analysis, Conceptual and Detailed Design**

    a. Analyze the UEFC rules in Appendix A and write down the key requirements that you think your system needs to satisfy
    b. Brainstorm design concepts for your vehicle as a team. Specifically rank your ideas in terms of how competitive you think they are. Things to consider are:
        i. Size and physical configuration of the aircraft
        ii. Shape and number of airfoils / wings
        iii. Placement and attachment of payload (hardboiled eggs)
        iv. Weights and balance and pitch / roll / yaw stability
        v. Predicted flight performance
        vi. Whether to design a single aircraft that can carry out both missions A and B, or a reconfigurable aircraft whose configuration can be adjusted between the two missions. The latter approach may yield better performance but at the cost of additional complexity.
    c. Pick the top two concepts
    d. Using the scoring formula from Appendix A and any of the governing equations and physical principles and insights you have learned in Unified Engineering to date try to quantify the expected system performance of your top two ideas and down-select to one single design concept.
    e. Refine the details of your selected design and document your final design using both equations and a dimensional sketch. Include this information in your final lab report for Lab 4.
    f. Explicitly include your predicted score $Score_{predicted}$ and how you arrived at this prediction. Discuss which part of the prediction you are most uncertain about and why.

2. **Build and Test your R/C Aircraft for the UEFC**
    a. Fabricate and assemble your UEFC aircraft. Be careful to only use materials and parts from the approved list (see Appendix B)
    b. If you choose to design and manufacture a 3D-printed part, please follow the instructions in Appendix C. You may also choose to use another 3D printer outside the department at no penalty, but should describe the details in your report.
    c. Make sure you follow lab etiquette in the Gelb Lab
    d. Test your aircraft during the times indicated in Appendix D. Feel free to ask for help from the TA team (email: nshoug@mit.edu) and get additional flight experience ahead of time

## 3. Compete at UEFC

a. Show up at *6:45PM* at the latest at Johnson on *Thursday April 23* for the UEFC. All your team members need to be present[1]. You are allowed and encouraged to invite guests. The guests will sit on the bleachers on the right side of Johnson Athletic Center.

b. Register at the registration desk. During registration the following things will happen:
   i. The presence of your team will be recorded
   ii. A team photograph with your RC aircraft will be taken
   iii. The aircraft (both in configuration A and B) will be weighed and key dimensions will be recorded on a log sheet. To speed up the process we recommend you download the log sheet and pre-fill it. In that case the process is merely verification of the data you already entered.
   iv. It will be determined whether or not your aircraft meets the constraints of the competition rules (see Appendix A). Assuming a green light you proceed to the next step.

c. Announce yourself to one of the judges and let them know whether you want a staff member to fly for you or whether you will fly yourself. You will be given a sequence number and will carry out your two missions. Each mission sequence can be attempted up to twice and the best score from each attempt will be used. Scores can be mixed between the two attempts[2].
   i. Mission A: Speed Mission (5 laps)
   ii. Reconfiguration Period (300 seconds), including loading payload
   iii. Mission B: Payload Mission (5 laps)

d. After completing all your mission attempts make sure that your score sheet has been properly filled in and recorded with the judges.

e. Clean up all your materials in Johnson and the Gelb Lab.

f. The official scores and winner will be announced during lecture S/L-11 on May 1, 2015

## 4. Lab Report

a. Complete and submit your final lab report for Lab 4 to stellar. Make sure you compare your actual score obtained at the UEFC with your apriori predicted score and explain any differences.

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[1] Please contact Prof. de Weck (dweck@mit.edu) and cc the head TA (nshoug@mit.edu) for S/L if there are attendance issues in your team for the UEFC.

[2] For example if the fastest time for Mission A is recorded during the first attempt and the heaviest payload during the second attempt then the best score for each mission will count towards the combined final score.

## Appendix A

## UEFC Rulebook 2015

Version 1.0

The overarching learning goal of the Unified Engineering Flight Competition (UEFC) is for students to experience the lifecycle of an aerospace engineering system in a safe and fun environment. The UEFC is a yearly tradition in Unified Engineering [1]. Students get to work in teams to conceive, design, implement and operate (CDIO) a simple remote controlled (RC) airplane and to enter this vehicle into a flight competition. The rules are different every year to provide variety and prevent students from simply copying prior year designs. The UEFC encourages students to use the theory and see the interconnections amongst the Unified Engineering disciplines: materials and structures, fluid dynamics, thermodynamics and propulsion and signals and systems.

### 2015 Competition Rules

The 2015 competition is inspired by the idea of *multi-mission aircraft design*. As we saw during our visit at Boeing in January 2015 today's commercial aircraft have to satisfy a wide variety of requirements from different customers. For example, some customers need aircraft that can fly for large transcontinental distances and carry fewer customers while others require large capacity for shorter hop flights, yet for other customers speed is of the essence. In all these cases the aircraft manufacturer has to decide whether it is better to design a single airplane that can carry out all these missions, but represents a "compromise" design or whether to offer several specialized and highly optimized designs for each mission. Yet, another idea is to design an aircraft that can be reconfigured between missions. Indeed, reconfigurability [2] is an increasingly important design principle in many industries.

For the 2015 UEFC students will design an aircraft that can fly two missions, one after the other. The first mission (A) is a timed speed mission with no payload, while the second mission (B) is a maximum payload mission under maximum takeoff distance and maximum wingspan constraints.

The high-level rules are as follows:

- **Multi-Mission Aircraft Design**
  - **Mission A:** Maximum Speed – Minimum Time for flying 5 laps[3]
  - **Mission B:** Maximum Payload - Carried over 5 laps
- The Aircraft can be reconfigured between Mission A and B
  - Maximum Reconfiguration Time: 300 seconds
  - Reconfiguration Time includes the time to load the payload

[3] Assume that a single lap at Johnson will be about 150 meters in length.

- At least 50% of the dry mass of the aircraft needs to be the same between mission A and B (not counting the R/C controller itself)
- Building a compromise design without reconfiguration is allowed

- The Payload consists of hard-boiled eggs (for mission B)
  - The aircraft can only carry an integer number of eggs on the aircraft
  - Assume the average mass of an egg is: 57 grams (~ 2 ounces). A number of hard-boiled eggs will be available at the competition and teams can then select the eggs they wish to carry
  - Credit is only given for eggs that are still un-cracked at the end of mission B (check that eggs are undamaged at the start of mission B)
- Extra points will be given if using at least one 3D printed part (see Appendix C)
- Each team will be allowed two attempts per mission and the best score from each attempt of mission A and mission B, respectively, will be counted in the final score

Scoring Formula

- The winning team will maximize the following total score

$$Score = \frac{M_{payload} + 50D}{T_{5laps} + M_{A+B}}$$

where

- $M_{payload}$ [grams] – total payload mass (in the form of hardboiled eggs) carried over a distance of 5 laps in mission B
- $T_{5laps}$ [sec] - time in seconds to fly 5 complete laps in mission A[4]
- $M_{A+B}$ [grams] – total mass of aircraft components carried on both missions A and B. If a component is carried on both missions it is only counted once.
- $D$ =1 if an original[5] 3D-printed part is used, 0 otherwise

Constraints and Detailed Rules

Each team needs to satisfy all constraints and safety procedures as outlined below:

- Maximum takeoff distance $s_g$ : 20 meters
- Maximum Wingspan $b$: 2 meters[6]
- Maximum empty mass for mission A and B together $M_{A+B}$: 1,000 grams. This mass is obtained by simply adding the mass of all the components that are required to fly missions A and B. If a component is used on both missions A and B

[4] For purposes of design you can assume that the total distance for one lap is approximately 150 meters.
[5] By original we mean a part that was designed from scratch by the team and fabricated using an additive manufacturing technique as described in Appendix C.
[6] Note: The wingspan of the Plane Vanilla Aircraft is 1.52 meters.

it is only counted once towards this mass constraint. The empty mass does not include the payload.

- The aircraft will be weighed by the judges in both its mission A and mission B configuration at registration and cannot be modified thereafter, except for the reconfiguration between missions A and B.
- By reconfiguring we mean adding, removing or changing the position of any component on the aircraft. Normal movement of the flight control surfaces is not considered to be reconfiguration.
- The aircraft must land if the **low battery** alarm goes off, or the propeller stops spinning due to insufficient battery charge, whichever comes first. Make sure you fly with fully charged batteries from the start.
- The full competition sequence (mission A, reconfiguration, mission B) can be attempted up to twice, the best result from each these two attempts is used for final scoring. Scores from the two attempts (e.g. time from mission A in the first attempt and payload from mission B in the second attempt) can be mixed.
- The teams can fly their own planes or ask one of the judges/TAs to fly their plane for them. There is no penalty for having someone else fly the plane.
- Only materials on **the official parts list** can be utilized (see Appendix B)

o Mission A specific rules:
  - Time will be kept with manual stopwatches by the judges, the recorded time will be the average time recorded for completing 5 laps of the interior track (one lap will be approximately 150 meters in length).
  - Teams that cut inside the orange cones when flying laps will be disqualified for that particular attempt. All cones must be passed on the outside.

o Mission B specific rules:
  - Teams can select the individual hard-boiled eggs they want to carry for mission B. These eggs will naturally vary in shape, color and weight and will be provided by the judges
  - A team's mission B score will only include eggs that are <u>un-cracked</u> at the end of that mission.
  - Teams are responsible for proper payload accommodation on their aircraft for mission B. The time to load and secure the payload is included in the maximum reconfiguration time of 300 seconds.

<u>References</u>

[1] Young P.W., de Weck O.L. and Charles Coleman, "Design and Implementation of and Aeronautical Design-Build-Fly Course", <u>2003 ASEE Annual Conference & Exposition</u>, Nashville, Tennessee, June 22-25, 2003. (9 pages)

[2] Siddiqi A., de Weck O. L., "Modeling Methods and Conceptual Design Principles for Reconfigurable Systems", *Journal of Mechanical Design*, <u>130</u>, 101102, October 2008

## **Appendix B** – Approved Materials List

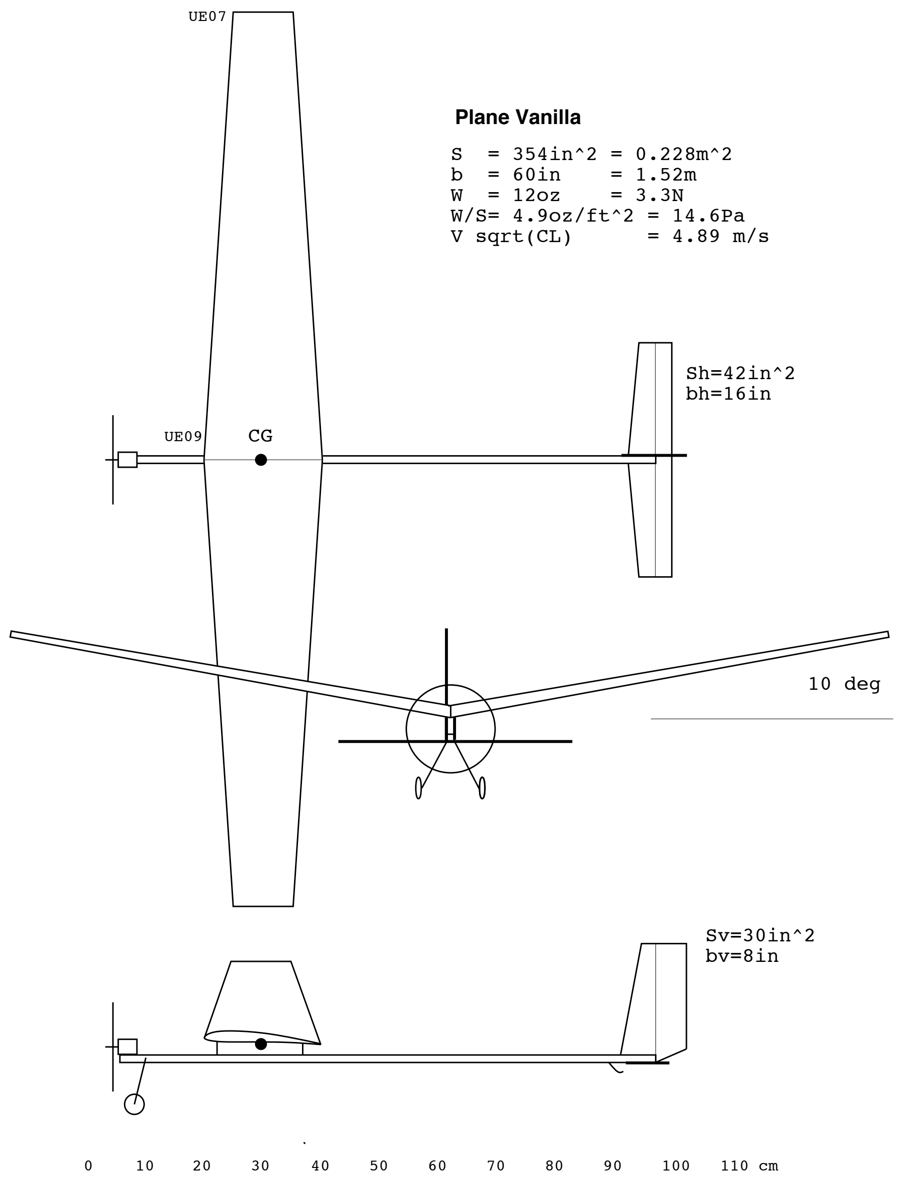
- Blue foam
- Balsa wood (rods, sheets etc..)
- Plastic foil, aluminum foil
- Epoxy and other kinds of wood glue
- Clear tape, duct tape, electrical tape
- Servos, control rods and R/C control horns
- LiPo battery from Lab 2 (1,200 mAh at 7.4 Volts) – (maximum one such battery)
- Electrical jumper wires, selector switches and start/stop buttons
- Electric motor (maximum 2)
- Plastic motor mounts (maximum 2)
- Propellers (maximum 2) available in Gelb Lab
- Fiber glass and epoxy
- Proto-board, solder and generic R, L, C components (but no specialized ICs or other microcontrollers other than the ones used in Unified so far during Fall and Spring)
- Landing gear and tail hook (from Lab 2)
- Rubber bands (of any kind)
- Black O-rings
- Plastic or metal screws and other types of fasteners
- Zip-ties (also known as tie-wraps) of any kind
- 4 or 6 channel R/C Tx/Rx handheld unit as used in Lab 2
- Paint and/or decorative stickers
- 3D printed parts (see Appendix C)
- *Any other components require faculty/TA approval*

<u>Starting Kit and Ideas</u>

To facilitate a good start, the UEFC teams built an initial functional RC aircraft as a starting point as part of Lab 2 (see Figure A1). As part of Lab 2 teams got to test the baseline performance of this aircraft. It is possible for teams to simply rebuild Plane Vanilla and compete with that baseline aircraft. This aircraft will obviously not be able to reconfigure between missions A and B.

As part of Lab 4 teams will modify the baseline aircraft or design and manufacture an entirely new aircraft for the competition. Lab 3 focused on testing different airfoils and wings in the 1x1 ft tunnel. Teams are free to change airfoils and redesign their wings and even test those again.

Figure A1 – Plane Vanilla Baseline Configuration




For all design decisions we encourage you to use the theory and design rules you learned in Unified Engineering so far. You also have to balance competing objectives and constraints such as flight performance, resilience, complexity and expected workload. Nominally a team of 4 students is expected to collectively spend about ~48 person-hours on this assignment.

## **Appendix C** – Instructions for 3D Printing

Teams who decide to design one or more 3D printed part(s) should do so using a standard CAD package such as *Solidworks*. Then bring your part(s) design file(s) to Todd Billings and make an appointment to manufacture your part(s) on the department's 3D printer. Take into account the following parameters:

Make and Model: Fortus 250mc by Stratasys (Fig. A2)
Maximum Dimensions: 10 in x 10 in x 12 in tall
Material type: ABS Plus[7]
Quality settings: 3 layer thicknesses, .007, .010, .013 in
File Format: .STL (on a USB thumb drive please)[8]

To expedite the builds both in the printer and of the RC model plane parts, we will seek to fit as many parts as possible on the 10 in x 10 in footprint. We may print parts from several teams in the same batch.

Depending on the parts, whether there is support material or not, there may be an additional amount of time, 3-4 hours, needed to sit in a bath of churning 2.3% Sodium Hydroxide solution at 161.6 deg F to dissolve the support material.

Figure A2: Fortus 250mc

Please contact Todd Billings with detailed questions.

Todd Billings
Email trb@mit.edu
Technical Instructor
MIT Aero/Astro Dept.
MIT 33-009A
617-253-7726

[7] For material properties see http://teststandard.com/data_sheets/ABS_Data_sheet.pdf
[8] http://www.stratasys.com/customer-support/cad-to-stl

## **Appendix D**– Flight Reservation Times at Johnson (JAC 2$^{nd}$ Floor)

MIT Department of Athletics, P.E., and Recreation
W35-297
120 Vassar Street
Cambridge MA 02139
617.253.4916

CONFIRMATION

| **Sponsor** | **Reservation:** | 233534 |
|---|---|---|
| Olivier de Weck | Event Name: | Unified Engineering Flight Competition |
| Aeronautics & Astronautics, Dept. of | Status: | Confirmed |
| | Phone: | 3-0255 |
| | Event Type: | Academic Class |
| | Cost Center: | 1454109 |
| | G/L: | 420376 |

| **Bookings / Details** | **Quantity** | **Price** | **Amount** |
|---|---|---|---|
| DAPER Comments | | | |
| *Safety Plan on File* | | | |

**Tuesday, April 21, 2015**

**10:00 AM - 2:00 PM Unified Engineering Flight Competition Practice (Confirmed) Johnson JAC TRACKINFIELD**
**6:00 PM - 8:00 PM Unified Engineering Flight Competition Practice (Confirmed) Johnson JAC TRACKINFIELD**

**Wednesday, April 22, 2015**

**7:30 AM - 11:00 AM Unified Engineering Flight Competition Practice (Confirmed) Johnson JAC TRACKINFIELD**

**Thursday, April 23, 2015**

**7:00 PM - 10:00 PM Unified Engineering Flight Competition (Info Only) Johnson JAC INDOOR TRACK**
**7:00 PM - 10:00 PM Unified Engineering Flight Competition (Confirmed) Johnson JAC TRACKINFIELD**

| Misc Charges (Athletics): | Quantity | Price | Amount |
|---|---|---|---|
| Chair | 6 | $1.75 | $10.50 |
| PA System | 1 | $65.00 | $65.00 |
| Tables | 3 | $6.00 | $18.00 |

Remarks (Athletics):
3 tables left at entrance of Johnson Indoor Track with 6 chairs
Portable scoreboard with extension cord left for group to use

| | |
|---|---|
| Subtotal | $93.50 |
| Grand Total | $93.50 |

3/26/2015 10:55 AM SHL    Page 1 of 1

The final time slot April 23, 2015 from 7-10PM is the actual UEFC.