

Handling Hovercrafts: Designing a project curriculum to introduce girls to mechanical engineering

by

Sandie Yang

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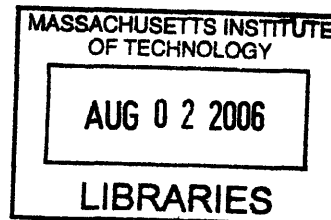
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Sandie Yang

Submitted to the Department of Mechanical Engineering
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requirements for the Degree of Bachelor of Science in
Mechanical Engineering

Abstract

The Women's Technology Program was created in MIT's Electrical Engineering and Computer Science department to expose girls to engineering topics and to encourage them to choose engineering majors in college. For the upcoming launch of a WTP in the mechanical engineering department, a new curriculum is being developed. The objective of this research was to create a capstone design project for the WTP-ME curriculum that sparks high school girls' interest in design and manufacturing. A hovercraft design contest was chosen as the basis for the project because of the range of concepts it encompasses and because the competitive nature of the project would encourage cooperation and motivation among the students. To test the project's feasibility, several hovercrafts were built using different materials and geometries. A list of materials was created and contest rules were constructed based on the results, and one hovercraft design was selected to be used as a template hovercraft for the students.

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Title: Assistant Professor of Mechanical Engineering



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Introduction to the Women's Technology Program

In 2002, a residential summer program called the Women's Technology Program (WTP) was created at MIT for high school girls. Its purpose was to encourage women to enter the fields of electrical engineering and computer science by sparking their interest with an engaging curriculum and a supportive environment.

WTP consists of four weeks of classes in electrical engineering, computer science, and mathematics. Curriculum is structured around laboratory projects that emphasize learning by doing and collaborative problem solving. Projects are designed with high school girls in mind, and all classes are taught by female graduate students.

Admission to WTP is competitive. In 2005, 408 girls applied and 40 were accepted. The program also seems to be effective: of the women who participated in WTP 2005, 37 applied to MIT in the fall. This high application rate indicates that the program may be succeeding in encouraging these girls to seriously consider careers in engineering.

Women's Technology Program – ME

WTP has been highly successful in its first four years of development. It has been so successful, in fact, that a pilot Women's Technology Program is being developed in the Mechanical Engineering department for the summer of 2006.

The goal of WTP-ME is to encourage women to become engineers by promoting the development of their self-confidence and their interest in mechanical engineering. The curriculum will be designed to introduce girls to different mechanical engineering topics, including mechanics and materials, dynamics, fluids, and design and manufacturing, along with the math they will need to grasp the material. Guest speakers, mostly faculty members from the

mechanical engineering department, will give presentations on current research at MIT. The classes will culminate in a capstone design project that encourages hands-on building and collaboration.

WTP-ME will operate on a small scale, admitting 20 students every year rather than the original WTP's 40. The goal is for WTP to eventually expand into other engineering departments at MIT.

Purpose

The purpose of this thesis is to create a capstone project for WTP-ME. Several factors must be taken into account. First, the project must be challenging but workable for 11th-grade girls, students who are academically gifted but who also come from a variety of academic backgrounds. Second, since the project will be part of an introduction to mechanical engineering, it will ideally incorporate multiple engineering concepts such as design and manufacturing, solid mechanics, and fluid dynamics. Finally, the project needs to be flexible and interesting enough to encourage creativity and collaboration among the students.

Project

The capstone project for WTP-ME is meant to be a hands-on introduction to design and manufacturing that begins during the third week of the four-week program. At this point, the students will have had brief, 90-minute lessons on broad topics such as solid materials, fluids, and thermodynamics and heat transfer. It is important that the project not require too much knowledge of these concepts, but it should give them a chance to apply what they have learned to a real design problem.

For the first WTP-ME program, a hovercraft design competition has been selected as the basis for the capstone project. A few factors were involved in making this decision. First, hovercraft design can easily incorporate concepts such as solid mechanics and fluid flow, so the students will be able to see how theoretical models relate to real-life problem solving. Hovercrafts were also chosen over more common project ideas, such as cars, because there is less of a stigma against hovercraft-building as a male-dominated activity. A contest could be an effective way to produce excitement and self-motivation among the students, and if the project is team-based, it would encourage collaboration and allow the students to take advantage of their diverse backgrounds by sharing ideas with each other.

Hovercrafts have been used to introduce students to engineering before. Southern Illinois University (SIU), for example, used kits developed by Universal Hovercraft to teach design in their Women in Engineering Summer Program.¹ Students there assembled hovercrafts from identical kits and then raced their vehicles against each other. The main difference between the WTP-ME hovercraft project and the SIU program lies in the amount of student involvement in the design of their machines. Not only will WTP-ME students have infinitely more flexibility by building their machine from raw materials, they will be able to account for their decisions using the physics and engineering concepts they have learned over the course of the program.

Considerations

There are several specific design considerations when it comes to creating a project for students. Student backgrounds, the project's fit within the curriculum, contest logistics, and design feasibility are issues that must be taken into account.

Student Background

Students are admitted into WTP and WTP-ME based on a complex selection process that emphasizes academic excellence and subjective criteria such as eagerness to learn, willingness to work with others, and creativity.

The girls will be coming from a wide range of public and private high schools from around the country, but their academic backgrounds are consistently strong. For example, the average math PSAT score of the twenty students admitted to WTP-ME this year is 74 out of 80. Most of these students have taken at least basic biology, chemistry, and physics, and some have taken one or more of these subjects at the AP level. Almost all of the admitted students are taking either precalculus or AP calculus. However, few of these girls have taken any science or math courses beyond the traditional track.

For most of the students, WTP-ME will be the first time they have ever taken something apart or put something together. One goal of this program is to teach students how to use tools such as engineering drawings and design calculations to create a final product while encouraging them to become more confident about using what they know to develop their own ideas.

Project Fit Within WTP-ME

During the first week of WTP-ME, the mechanical engineering instructors will give an overview of physics topics such as energy, forces, and simple circuits. Math class will include a review of precalculus and an introduction to word problems and problem-solving strategies. Classes the second week will introduce calculus principles, trusses, and beam-bending. The third week will be devoted to fluid-flow and heat transfer.

By the end of the first week, the students will be able to calculate forces using force-balance equations. By the end of the second, the students will have practiced making engineering drawings by taking objects apart and representing the pieces. By Friday of the third week, the girls will have the background they will need to calculate the air flow through a hovercraft using the Bernoulli equation.

Fair Contest

Twenty students can be split up in a number of ways, such as two teams of ten or four teams of five. However, based on WTP's experience in the past, girls seem to work best in pairs. No one feels left out, for example, and even very shy students can share ideas and work together comfortably. Still, the excitement of large team-based contests can be incorporated if we split the 20 students into two teams, each made up of five pairs of students.

The contest will be held in the form of a pentathlon: the two teams will compete against each other in five different categories: fastest hovercraft, highest floater, heaviest load-carrier, tightest turner, and bulkiest mover. Each pair of students is responsible for designing and building one hovercraft that represents their team in one of these categories.

Every pair of students builds their own machine, but they can consult freely with their teammates. Each team will receive a pool of materials that they can allocate any way they want. This is meant to encourage the students to group resources according to different design specifications and to promote discussion and planning among the teams.

Feasibility

Perhaps the most important thing to take into account when creating an assignment for students is the achievability of the goals that are set. How confident the students feel about completing the project will have an impact on their level of motivation and how much they accomplish during the design process.

A conservative estimate for the amount of time it would take two high school students to build their first hovercraft from explicit plans, taking into account discussion time and distractions, is nine hours, or three times the three hours it would take a college senior to assemble the hovercraft from the same drawings. The students will go through all of the hovercraft-related concepts they will need in class during the second and third weeks of the program, but any calculations and adjustments specific to their design will take up additional time. A broader estimate of the amount of time two students will need to design and fabricate their hovercraft is 30 hours, or roughly three times the amount of time it would take to make the first one.

The hovercraft project will be introduced at the end of the third week of WTP-ME, which means that the students will have one week, including more than 22 hours of class time, to plan, design, and build their machines. Instructors will be free during class the entire final week to help students with planning and design. Also, during the first three weeks of the program, the girls will work on short homework assignments during the hours outside of class. By the fourth week, homework will no longer be assigned, so the girls will be free to work on their hovercraft projects outside of class. Three tutors will be on call at any time to help them with any questions they have about the project.

In addition to time constraints, it is important to consider the robustness of homemade hovercrafts. Machines that hover inconsistently or that require too much precision to make will be frustrating for the students to build. At the same time, the project must be flexible. The hovercrafts the students design must be different enough from each other that the contest categories are meaningful.

Building Hovercrafts

To test the robustness and flexibility of this project, several hovercrafts were built using different materials and various configurations. Successful hovering seemed to depend more on the weight and flow rate of the fans than on any of the other materials. The most common problems that prevented a hovercraft from working were too much weight, a skirt that did not contain enough air, and clinging in the skirt that prevented air from circulating underneath the hovercraft.

One hovercraft geometry that consistently hovers and requires only three hours to build was adapted from a model by Jackson.² Its double-layered hull allows air to pass freely underneath the fan by preventing the skirt from clinging to itself. It can be made from cheap materials, such as foam, tape, and trash bags, and its deck is stable and broad enough to serve as a platform. For example, additional fans, batteries, and even a servo motor can be added for propulsion and directional control. A picture of a basic, working hovercraft is shown in Fig.(1). The fan used to lift the hovercraft in the photograph is a DC Brushless WFB1212 H.

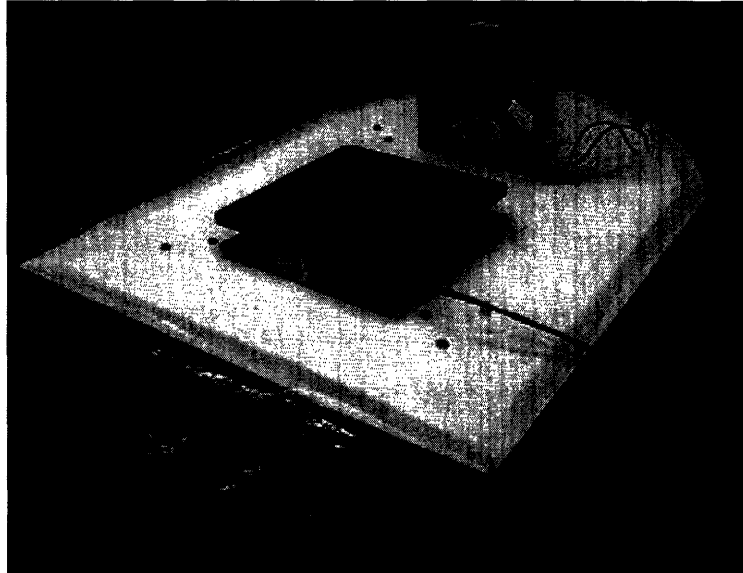


Figure 1. Working model hovercraft. The upright fan can be used to propel the hovercraft and moved around to redistribute the hovercraft's weight.

Engineering drawings for this basic hovercraft are included in the project kit that the students will receive. However, while this hovercraft will hover, the template is by no means an ideal design. There is a lot of room for adjustment in the geometry of the hovercraft, which should allow the students to make their own hovercrafts faster, higher, stronger, nimbler, or bulkier.

The basic hovercraft can be altered in many ways to change its performance. For example, decreasing the hull width and increasing the number of propulsion fans are two ways to increase a hovercraft's speed. Also, decreasing the weight of the hovercraft and increasing the skirt width should allow the hull to float higher above the ground. The shape and size of the hovercraft hull can be altered considerably without affecting the vehicle's ability to hover. However, because the hovercraft design is so robust, a change in the hovercraft's geometry that is too small may not result in a noticeable change in behavior.

Hovercraft Theory

Hovercrafts, also called air-cushion vehicles, are characterized by their movement, in which “a significant portion of the weight is supported by forces arising from air pressures developed around the craft, as a result of which they hover in close proximity to the Earth’s surface”.³

A hovercraft will float when the air pressure beneath it, contained within its skirt, is great enough to support its weight. Using Bernoulli’s equation, it is possible to calculate the volumetric flow rate of a hovercraft fan necessary for the vehicle to hover, based on its dimensions and its mass.

A diagram of a simple hovercraft is shown in Fig.(2).

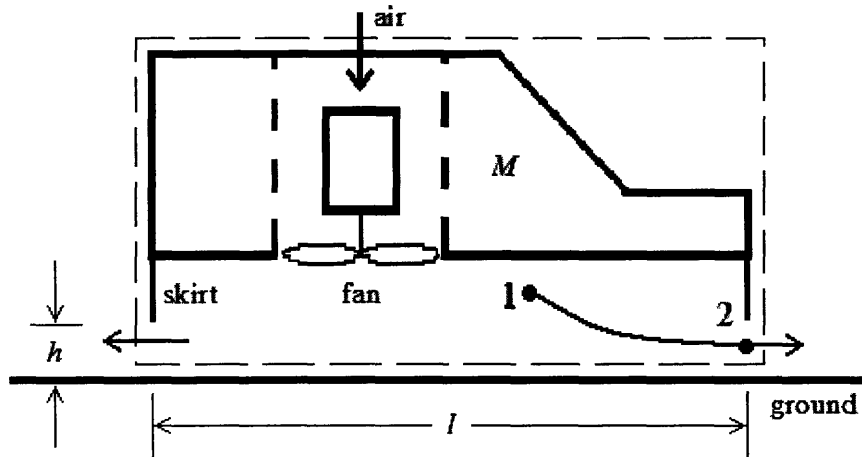


Figure 2. Labeled schematic of a floating hovercraft. Adapted from Cravalho’s “Thermal-Fluids Engineering”.⁴

The vertical forces acting on a hovercraft of mass M include gravitational force Mg , force due to air pressure P_{int} acting on surface area A_{bottom} beneath the hovercraft, and force due to air at

atmospheric pressure pushing down on the top surface A_{top} of the hovercraft. Viscous forces are assumed to be negligible. The force equation becomes

$$\sum F_y = -Mg + P_{int} A_{bottom} - P_{atm} A_{top} . \quad (1)$$

Since the system is in steady-state when the vehicle is hovering, the sum of the vertical forces is zero, and Eq. (1) can be rearranged to determine the necessary internal pressure P_{int} :

$$P_{int} = P_{atm} + \frac{Mg}{A_{bottom}} , \quad (2)$$

assuming that the area of the top of the hovercraft is equivalent to the area of the bottom of the hovercraft.

To find volumetric flow rate of the air beneath the hovercraft, it is necessary to first find the flow velocity of air between the skirt edge and the ground. Since the air flow through the hovercraft can be modeled as inviscid and incompressible, the Bernoulli equation can be used for the streamline between points 1 and 2 in Fig.(1) to determine flow velocity.

Assuming that the difference in height between points 1 and 2 is small and the area beneath the hovercraft is large enough that the velocity of the air at point 1 is approximately zero, the Bernoulli equation becomes

$$\frac{P_1}{\rho} = \frac{P_{atm}}{\rho} + \frac{v_2^2}{2} . \quad (3)$$

Rearranging Eq.(3) and substituting for $P_{int} - P_{atm}$ using Eq.(2), velocity at point 2 can be determined:

$$v_2 = \sqrt{\frac{2 Mg}{\rho A}} . \quad (4)$$

Total volumetric flow rate equals the velocity of the air flow through the gap between the hovercraft skirt and the ground multiplied by the total area of the gap. To support a hovercraft of length l and width w at a gap height of h , volumetric flow rate \dot{V} must become

$$\dot{V} = v_2 \cdot 2(l+w)h = 2(l+w)h \sqrt{\frac{2 Mg}{\rho A}}. \quad (5)$$

Eq.(5) can be used to determine the volumetric flow rate necessary to lift the hovercraft in Fig.(1). The perimeter of the sample hovercraft is roughly 1.3m, the mass of the hovercraft, including the second fan, is 0.325kg, and the total surface area of the hovercraft top is 0.116m². To lift the hovercraft by 1mm, the volumetric flow rate of the fan must then be

$$\dot{V} = (1.3m)(0.001m) \sqrt{\frac{2 \cdot 0.325kg(9.8m/s^2)}{1.2kg/m^3 \cdot 0.116m^2}} = 0.0088 m^3/s, \quad (6)$$

or 18.7 cubic feet per minute, well under the DC Brushless WFB1212 H maximum flow rate of 94.9 CFM.

Project Curriculum: Hovercraft Contest Kit

The project kit includes everything a team of ten students will receive to build their hovercrafts. It consists of three components: contest details, materials, and engineering drawings. The contest description and rules are listed in Appendix A. A comprehensive list of materials is located in Appendix B, and the engineering drawings of the hovercraft designed and built as a template for this project are located in Appendix C.

WTP-ME should obtain materials for two of these kits, one for each of the two teams. In addition, WTP-ME should have on hand extra materials, especially fans, charged batteries, and

sheets of foam core. Students should be given the option to trade in damaged materials for fresh pieces at any time. This way, they will be encouraged to make daring design decisions instead of worrying, for example, about cutting the last piece of foam.

Conclusions

The purpose of this research was to design a capstone project for WTP-ME. A hovercraft contest was designed based on considerations such as student backgrounds, fit within the general WTP-ME curriculum, and hovercraft design feasibility. After building several hovercrafts with different materials in various geometries, a particularly robust hovercraft design was selected for use as a template for the students.

The geometry of the design can be modified considerably to change the performance of the hovercraft, and components such as extra fans and servo motors can be added to increase speed and directional control. One concern, however, is that even large changes in the geometry of the hovercraft may not result in a noticeable change in the hovercraft's performance. Further research should be done to determine just how sensitive to change this particular hovercraft design is. In the case that the design is not responsive enough to change, the contest may need to be modified, for example, to include only two out of the five design categories.

Acknowledgments

Special thanks to Dr. Barbara Hughey and Christina Chestnut for the shaping of this project and to Professor Carol Livermore-Clifford for her guidance.

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- ² K. Jackson. Build Your Own Model Hovercraft. 2003. 14 April 2006 <<http://members.aol.com/modelhov2/index.html>>
- ³ "air-cushion machine." Encyclopædia Britannica. 2006. Encyclopædia Britannica Premium Service. 8 May 2006 <<http://www.britannica.com/eb/article?tocId=9110743>>
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Appendix A

Contest Details

The purpose of this contest is for you to have fun and to use your creativity while you build a real, working hovercraft! A hovercraft is any vehicle that floats above the ground by using air pressure to support its own weight. Because it doesn't actually touch the ground at full speed, this type of vehicle is extremely versatile and can be used to travel over water or ice as well as solid ground. In fact, a hovercraft traveling over a river can move as fast going against the current as it would going with it!

The Rules

1. There will be two teams with ten students on each team.
2. Each team will be divided into five pairs. Each pair of students is responsible for building a hovercraft that represents their team in one of the following five categories: Fastest Hovercraft, Highest Floater, Heaviest Load-Carrier, Tightest Turner, and Bulkiest Mover. Each hovercraft will be competing against the hovercraft representing the other team in the same category. No two hovercrafts on the same team can compete in the same category.
3. On contest day, both teams must identify which hovercrafts will be competing in which category. Once the competition begins, these designations cannot be changed.
4. Hovercrafts can only be built using the provided materials. A list of the materials allocated to each team is included in this project kit.

5. In the case a hovercraft fails to hover, the hovercraft will be given up to three tries in competition. Between tries, team members can have up to thirty seconds to make any adjustments on their machine, but no materials not already on the machine can be used at this time.
6. When a hovercraft wins in one category, a tally point goes to the team that it represents. At the end of the fifth contest, the team with the most tally points wins!

What the categories mean:

- **Fastest Hovercraft:** the first hovercraft to travel a distance of thirty feet
- **Highest Floater:** after 10 seconds of floating time, the hovercraft whose lowest point – excluding the skirt – is highest off the ground
- **Heaviest Load-Carrier:** the hovercraft that holds the most pennies while hovering
- **Tightest Turner:** the hovercraft with the smallest turning radius
- **Bulkiest Mover:** the hovercraft with the largest surface area that still hovers

Appendix B

Materials

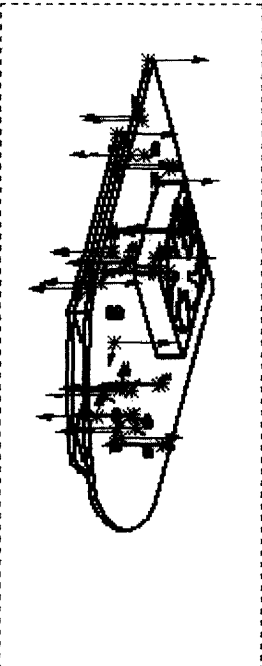
Materials provided for each team are listed in Table 1.

Table 1. Comprehensive list of hovercraft materials.

Hovercraft	Material	Quantity	Size
Hull	¼-inch thick foam core	10	20" x 30" sheets
	1-inch thick styrofoam	1	10" x 20" block
Skirt	High-density clear trash bags or can liners	1	carton
	Reynolds Oven Bags, large size	3	boxes
Adhesives and Fasteners	Electrical tape	5	rolls
	Clear tape	5	rolls
	Duct tape	1	roll
	Velcro	2	yards
	Thumb tacks	1	box
Fans and Motors	DC Brushless WFB1212 H	3	
	NMB 3610KL-04W-B50	3	
	NMB 4715KL-04W-B59	3	
	Comair Rotron Brushless DC CR0412HB-C50	6	
	DC Servo Motor	4	
Batteries	12V drill batteries	5	
	9V alkaline batteries	10	
Tools	Olfa model retractable knives	10	
	Scissors	5	
	Rulers	10	
	Felt tip markers	10	
	Soldering iron, solder, electrical wire	1	
	Cardboard (as a cutting surface)	10	20" x 30" sheets

Appendix C
 Drawings of Template Hovercraft

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	top	hull top	1
2	bottom	hull bottom	1
3	connector	frame spacer	5
4	WFB1212H	DC Brushless fan	1
6	bolt	C ap Screw, 10-32, 2", Hex Socket	10

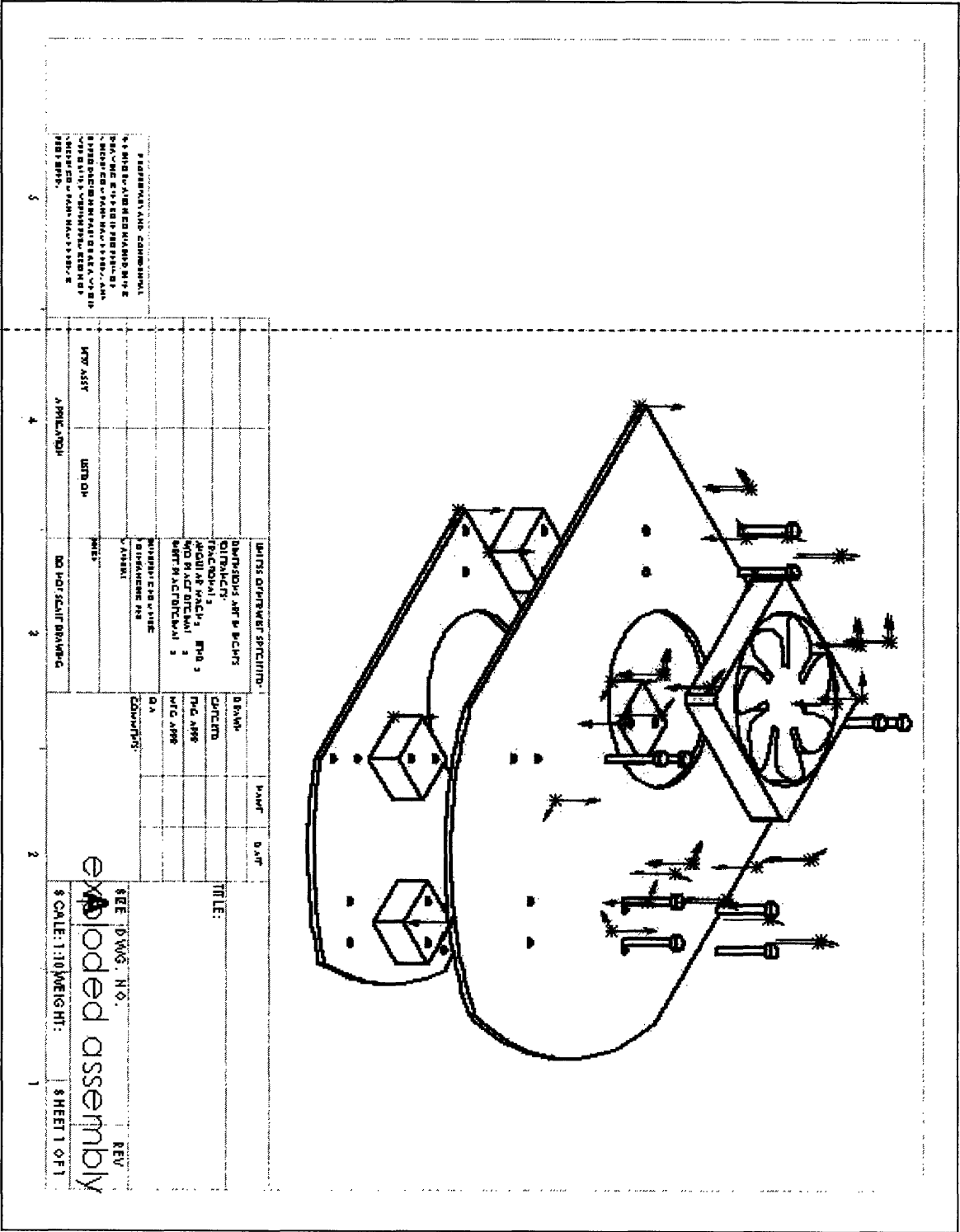


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PARTS LIST
 PART NO. PART NAME QTY. UNIT
 1 HULL TOP 1 PC
 2 HULL BOTTOM 1 PC
 3 FRAME SPACER 5 PC
 4 DC BRUSHLESS FAN 1 PC
 6 BOLT 10-32, 2", HEX 10 PC

SEE DWG. NO. 10-32-2-HEX
 HOVERCRAFT Assembly
 SCALE: 1:5 WEIGHT: SHEET 1 OF 1

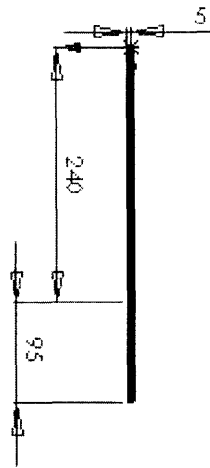
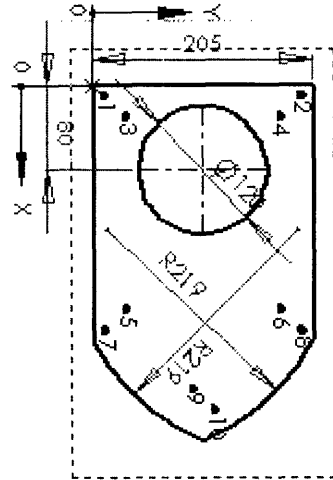


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2	10	195	
3	30	30	
4	30	175	
5	210	30	
6	210	175	
7	230	10	
8	230	195	
9	285	92.50	
10	305	112.50	

1. HOLE AND DIMENSIONS
 2. HOLE POSITION
 3. HOLE SIZE
 4. HOLE LOCATION
 5. HOLE DEPTH

5

PROPERTY
 APPROVED
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4

UNLESS OTHERWISE SPECIFIED:
 1. MATERIALS AND FINISHES
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3

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