ME 72 Engineering Design Laboratory
Fall, 2005

Instructor:
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Machining and Design Experts:
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Teaching Assistants:
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TA Office hours and shop hours for will be announced.

Objective:

The goal of the ME 72 contest is for student teams to design a small Stirling engine, which will be powered from waste heat from a low-temperature source. This small engine (power production on the order of 1 W) can be used to power a device of the student's choosing (such as a fan, a light bulb,…). As described below, there are restrictions on size, source of heat, and materials that can be used in the engine. By midterms, students will be asked to submit a proposal that outlines the device design as well as specifications for power, speed, size and cost. A "Power On" (a contest modeled on a cook-off) will be held at the end of the quarter (December 1, 2005). The winner will be determined based on a range of factors including creative use of output power, quality of design and manufacturing, engine power and speed, as well as a determination of how well student devices meet design specification.

A Stirling engine is an externally-heated engine that can run on virtually any fuel or heat source. For the contest, the input heat to the engines will be from waste heat from a large cooking griddle in Chandler Dining Hall. During the contest, however, the griddle will only be used for powering the engines and not for cooking pancakes.

Teams:

Students will work in groups of two; if there are an odd number of students, one group will have 3 members. At the beginning of the quarter, students will be divided into two groups (I and II). Students in group I will rank order their preferences for working with students in group II; group II students will rank group I students. To the extent possible, compatible students will be paired. All pairing will be done by the instructor.

For the final contest, teams will submit one device. Ideally this device will be the second or third iteration of the team's design.

Engine restrictions:

Waste heat recovery or energy scavenging is of growing interest because of increasing cost of fuel and energy production. There are other technologies being developed to use waste heat, such as thermoelectric devices, turbocharging engines, absorption cycles, etc. For this class, we will only allow waste-heat-powered Stirling engines. You cannot provide additional heating, fuel, batteries or power source. As you will find, there are a variety of ways to configure your Stirling engine, and any configuration is acceptable.

The only heat input to the engine will be from the griddle surface. This surface will be maintained at a temperature between 50 to 150^{o}C (120 ^{o}F to 300^{o}F). The maximum temperature is set by limits on the materials (standard silicone cylinder seals).

Each engine can occupy at most an area of 15.25 cm by 15.25 cm (6 inch square) on the surface of the griddle. The engine plus powered device must fit within the 6-in square footprint; the system can be any height.

Only air can be used as the working fluid.

The engine can only be cooled by convection to the room (no use of water or other coolants). No external cooling devices. Remember that the 2nd law of thermodynamics states that all heat engines require cooling.

We have a heated plate in the ME shop that can be used for testing prior to the contest.

We will provide a plot of power as a function of surface temperature for the heated griddle surface that will be used in the contest.

Analysis:

As with any thermodynamic system, it is possible to model and predict the performance of the system. Part of the class will involve modeling the engine to predict output power and engine speed. The modeling done by your team should be used to improve the engine design. Homework 2 and 3 should get you started on the modeling for your engine; these assignments will be done individually.

Materials:

Power pistons (graphite) and mating cylinders (quartz) have been purchased from AirPot (http://www.airpot.com/beta/html/exhibit21.html) for approximately $20 per set. The inner bore is 0.945 in and outer diameter 1.088 in. The piston-cylinder should be *handled with care*. A drawing of the piston and cylinder will be provided. The manufacturer also has included specifications for the mounting of the cylinder. Since the quartz cylinder and graphite piston have a small coefficient of thermal expansion, the cylinder can be cracked if adjoining pieces expand significantly during heating. Also note that the manufacturer cautions against removing the piston from the cylinder; this piston-cylinder has very low friction and is self-lubricated. Hence, any dirt in the cylinder will affect the piston performance.

Students may only use the AirPot piston-cylinders. There is a limit of two piston-cylinders per team.

Some materials for the engine will be readily available in the shop; other materials will need to be ordered. All materials that are needed for the engines must be approved by either John or Rodney. If supplies are needed from a local store, please consult with them prior to purchasing the materials.

John and Rodney can *veto* material requests. Exotic requests will not be supported.

You must keep track of all materials used by the team and their cost. In the final analysis, each team will need to report the total spent by the team for all materials, and the amount spent on the prototype used for the Power-On.

John and Rodney are available to help. If their *machining* services are need to cut large materials, etc., you must include the cost of their services in your overall cost analysis. This cost is $45 per hour. Note, you do not have to pay the cost out of your pocket; the charge will be part of the cost of your overall materials.

As a reference, the engine built by American Stirling Company retails for $359, and the smaller engine built by Kontax Stirling Engines retails for $141.

Notebooks:

Each student will be expected to keep a design notebook (the notebook must be bound) to record on a regular basis your thoughts and design ideas (both in words and sketches), a list of materials used, list of upcoming tasks, modifications to your design and design alternatives, etc.

Date the entries in your notebook.

We also expect to see some of your analysis, although we recognize that much of the analytical work will be done on the computer and be reported through the homework and midterm.

We will collect the notebooks to review at the end of every week. The contents of the notebook will be treat confidentially (we won't share your secrets).

Late homework:

Late homework is strongly discouraged. If you get behind in this class, you'll never catch up. If homework is turned in late, you will lose 10% of the points for each day late.

Procrastination will not be permitted in this class!

Record of hour spent:

We also ask that you keep a record of the number of hours spent on this class. It is useful to the instructor to see how you have spent your time. At the end of this handout, you will find a table that should be placed at the beginning of your design notebook, and updated regularly.

ME 72 is a 15-unit course. Hence, you should expect to spend 150 hours over the next 10 weeks.

Design reviews:

Each team will participate in preliminary and advanced design reviews, scheduled for 3rd week (beginning October 10th) and 7th week (beginning November 7th). We will not have class during the design review weeks.

During these reviews, each team will have approximately 20 minutes to meet with the instructor and assistants. The meetings are an opportunity to provide guidance and advice to the student teams. By the advanced design review, the team should have most of a prototype fabricated.

Machine shop:

All of the device manufacturing will take place in the ME machine shop, which will be open from 8 am to 5 pm Monday through Friday. The shop will not be open to ME 72 students during ME 72 class times.

To fabricate the devices, students will be able to use the mills, lathes and other tools that were used in ME 71. The CNC machine is not available for use. No welding; light brazing is okay.

Other ME shop policies are in place regarding machine use, conduct and safety, sign up lists, etc.

Collaboration Policy:

All students will work in teams of two. However, students will be expected to submit homework that has been done on an individual basis. The midterm proposal will be collaborative, as well as the final design prototype and the final poster presentation. Each student will also participate in the design reviews, which will be used to assess the contributions of individuals to the team effort.

You should treat the design project similar to an ordinary homework set. It is permissible to collaborate with our classmates, and seek the advice of the instructor, TAs, John, Rodney; however, the final product must be your own work.

If you are concerned about acceptable limits to collaboration, discuss the situation with the instructor.

Honor Code:

The Honor Code will be strictly enforced in the class. Hence, students must adhere to the collaboration policy that will be listed with each homework assignment, and as described above.

Remember, as part of the Honor Code a student is responsible for reporting violations observed by the student.

Midterm:

By midterms (Oct 26/27), each team will be expected to submit a proposal for their device. In the proposal, the teams will be asked to specify the following: engine speed, engine power, cost, and functionality. The teams will submit drawings, and a materials list. The details of the proposal will be distributed by October 5. The students should also list any references or other sources that have been used in designing their device.

Also by October 26/27, each team will have fabricated pieces that function or fit together. Each student in the team will have fabricated one of the two pieces. Students are responsible for showing the pieces to either John or Rodney.

ME 72 website:

As the course progresses, the instructor may need to modify or to add additional constraint to this handout. These changes will be announced in class and posted on the ME 72 website. It is the student's responsibility to look for these announcements.

"Power On" and final presentation:

We have scheduled the afternoon of Thursday, December 1 (probably a 2 pm start) for the contest and final device demonstration in Chandler Dining Hall. Besides demonstrating devices, we also ask each student team to develop a poster that shows drawings and ideas, and specifies the anticipated engine performance parameters from the midterm proposal (speed, power, cost and functionality). Although only one device from each team will be used during the contest, all devices can be displayed at this time. Details of the power-on will be forthcoming.

All members of the Caltech community are invited to attend.

Final grade:

The final grade for the course will be a composite of the first three homework assignments (15%); the midterm (25%); participation in class and design reviews, and lab notebooks (10%); final contest, demonstration of device, final poster (50%).

Schedule:

September 27 – first class; team partner selection; first shop assignment (HW 1)
September 29/30 – teams finalized; HW 2 out.
October 4 – Shop assignment (HW 1) due
October 6/7 – HW 2 due; HW 3 out
October 10 (week) – preliminary design review
October 18 – HW 3 due
October 26 – Midterm proposal due; demonstration of 2 functioning pieces
November 7 (week) – advanced design review
November 24/25 Thanksgiving; no class; devices are impounded
December 1 – POWER-ON

References:

Hirata, K., Schmidt Theory for Stirling Engines, 1997. Available on the web at http://www.bekkoame.ne.jp/~khirata/academic/schmidt/schmidt.htm

Martini, W.R., *Stirling Engine Design Manual*, University Press of the Pacific, 2004 (available from Professor Hunt).

Organ, A.J., *Thermodynamics and Gas Dynamics of the Stirling Cycle Machine*, Cambridge University Press, 1992 (on reserve in Caltech library).

Van Arsdell, Brent H., *Around the World by Stirling Engine. Environmentally Friendly Stirling Engines, Their Applications Worldwide and into Space,* 2003 (available from Professor Hunt).

Senft J.R., Theoretical Limits on the Performance of Stirling Engines, *Int. J. Energy Research*, **22**, pp. 991-1000, 1998 (handout in class).

Senft, J.R., Optimum Stirling Engine Geometry, Int. J. Energy Research, **26**, pp. 1087-1101, 2002 (handout in class).

Senft, J.R., An Introduction to Low Temperature Differential Stirling Engines, Moriya Press, 1996. Available at amazon.com for $13.95. Several copies are available; see instructor or John.

Plus lots more available on the web, and in the library.

ME 72
Fall 2005

Hours spent including class time, background reading, design, fabrication, testing, redesign, etc.

	Mon	Tues	Wed	Thurs	Fri	Sat	Sun	Total
Week 1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

Please place this time record (or an equivalent) in the front of your design notebook.