EME 150B
design and manufacturing project
THE *SHIGLEY* HAULER

1 introduction

This project offers scope to exercise your mechanical ingenuity in the design, analysis, fabrication, and testing of a device that must satisfy challenging functional specifications using limited resources. The device is a miniature gear–driven winch, that must be capable of hauling heavy loads up an inclined plane in compliance with the following requirements:

- it must employ a power source comprising a Mabuchi RE280 DC motor (supplied) energized by 2 AA batteries (not supplied);
- the load must be secured in a container that may slide or roll on wheels up the inclined plane, maintaining contact at all times;
- the device may be attached to the inclined plane, although it must not obstruct, damage, or otherwise alter its surface.

The slope of the inclined plane is not specified a priori — rather, your design should be capable of hauling loads up a variety of inclinations. The *speed* at which the load is transported up the slope is also a key design consideration. Among designs that succeed in lifting the load a specified distance up a given slope, those that do so in the shortest time will gain the highest score.

2 supplied materials

You will be supplied with a Mabuchi RE280 permanent–magnet DC motor, and a selection of nylon spur gears: two in each of the 50–tooth, 40–tooth, 30–tooth, 20–tooth, and 10–tooth sizes (do not use the small pinions that come in the motor box, since they are not compatible with the nylon gears). The gears come with inserts that are suitable for mounting with an inteference fit on a $\frac{5}{64}$ inch diameter shaft — or they can be used without the inserts on

$\frac{5}{32}$ inch diameter shafts. Operating at 3 V, the DC motor has the following torque–speed characteristic:

$$T = T_s \left(1 - \frac{n}{n_0}\right) ,$$

where T is the torque in $\mathrm{N \cdot m}$ and n is the speed in rpm — the *stall torque* is $T_s = 0.0127$ $\mathrm{N \cdot m}$ and the *no–load speed* is $n_0 = 9200$ rpm. Further technical specifications for the motor may be found at:

`http://www.mabuchi-motor.co.jp/cgi-bin/catalog/e_catalog.cgi?CAT_ID=re_280rasa`

(model RE–280RA–2865 @ 3V). You will also need to obtain for yourself the following items — a battery holder for 2 AA cells, a small switch, and some wire (all available from any electronics store).

Note that the 2 AA batteries are the *only* power source allowed to drive your device (the use of fresh alkaline cells is recommended for the final tests). In addition to the above items, unlimited quantities of any of the following materials may be used — paper or cardboard, wood, metal, plastic or other synthetic materials, rope or wire, and various fasteners (nails, wood screws, bolts & nuts, glue, adhesive tape) — if you are in doubt about the suitability of any items, consult the instructors. You must purchase or scrounge all the additional materials yourself, and you must supply your own batteries.

3 design process

Do not rush into building your device! A successful design will require careful pencil–and–paper consideration of issues such as power, torque, gear ratio, mechanical advantage, speed, weight, balance, stability, frictional forces, etc. You must incorporate all such analyses in your project report: we need to see evidence that your success (or lack thereof) results from engineering insight, rather than just dumb luck or brutish trial–and–error!

You should start with the *concept generation* phase, wherein each team member generates several different concepts that address the given design specifications. You may wish to consider the use of pulleys, belts, articulated mechanisms, etc. Draw sketches of each concept, and examine how well you think it will achieve the desired goals using back–of–the–envelope calculations where necessary. Finally, select the most promising concept — or create a hybrid that incorporates the best features from several different concepts.

Next, a *detailed design* of the chosen design concept should be performed, in which you are to develop complete specifications and expected performance figures for your design — include all dimensions, materials, and fabrication and assembly methods. Use the analysis and evaluation methods discussed in class wherever appropriate. Since the allowed power source for your device is rather limited, your careful conceptualization and analysis of the design *on paper*, before building and testing, will be the key to success.

Once you feel that you have a satisfactory detailed design, the device may be fabricated in the prototyping lab and/or the machine shop, on your own time (a deadline for completion will be announced in class).

4 fabrication & tolerances

The core of your design will likely be a precision gearbox, using the supplied nylon gears. Great care must be exercised in fabricating this gearbox. If you plan to rely on interference fits to mount the gears on their shafts, they must be sufficiently tight to offer perfect torque transfer between shaft and gear, without any slipping. Note also that the spacing and alignment of the gear shafts is critical to proper power transmission. Although the speed–ratio of a gear train will be insensitive to slight variations in the shaft spacings, these spacings influence the pressure angle (you should aim for the nominal value $\phi = 25°$). Finally, consideration must be given to the type of bearings or bushings that the shafts will be mounted on, and whether any lubrication will be necessary. Your final prototype will be judged for design ingenuity and engineering craftsmanship, as well as nominal performance.

5 competition & final report

Each team's device will be evaluated by means of a sequence of hauling tests performed on a special test rig, at a time and location to be announced in class. The test platform is an unfinished plywood board with an adjustable angle of inclination, divided into lanes as shown in Figure 1 — note that it is designed to test several devices simultaneously. The overall length is 3 feet, and the lanes are 12 inches wide with side walls $1\frac{1}{2}$ inches high.

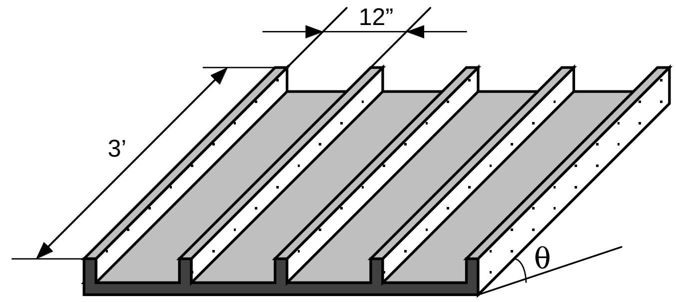

Figure 1: schematic of the test rig for the climbing tests.

The load unit to be used in the tests is the *shigley*, which is equal to the weight of Shigley’s *Mechanical Engineering Design*, 9th edition, published by McGraw–Hill (hardcover version). You must empirically determine the value of *shigley* by precision laboratory measurement techniques. Your load pallet should be capable of accommodating at least 4 *shigleys*. Please note that the winch must haul the weight of the pallet and however many *shigleys* it contains. Thus, you will want to make the pallet sturdy but light–weight (disintegration will disqaulify you from the current test).

Tests will be performed at increasing slope angles $\theta = 0°$, $10°$, $20°$, $30°$, etc. Your device will be evaluated using several criteria, including: maximum angle at which the load reached the end of the lane; speed of hauling at each slope angle; creative use of materials and principles of mechanics; sturdiness, craftsmanship, and aesthetics of construction; and design ingenuity.

After completion of the hauling tests, you will submit a project report that gives a detailed discussion of how you conceptualized and analyzed your design (including drawings where appropriate); your experience in testing it prior to the hauling tests and any resulting modifications; the outcome of the tests; and recommendations for any future improvements.

The report must include a title page with names, course, section number, and date; a one–paragraph abstract outlining the methods used and results obtained in each phase of the project; and a conclusion that summarizes all your results and lessons learned from the project. The analysis section of your report must address the following issues:

- the kinematics of your gear train, indicating its various speed reduction ratios, and the resulting linear speed of the load up the inclined plane;
- the power required to accommodate various loads, speeds, and slopes, and how it is met by the power output of the DC motor;
- the strength and rigidity of critical components of your device, and how they influence dimensions and material selection (with special attention to bending deflections of the gear shafts).

6 performance index

Here are further details for those who wish to optimize their design to the specific manner in which it will be tested. The loads and ramp angles for the various runs are listed in the table below. A time limit $t_{\max} = 40$ seconds is imposed for each run. If t_{jk} is the time needed to haul a load of j *shigleys* up the ramp inclinded at angle θ_k, your overall performance will be measured by the composite index

$$\text{SCORE} = \sum_{j=1}^{\#\,\textit{shigleys}} j \times \left[\sum_{k=1}^{n} \theta_k \cdot \max(0, t_{\max} - t_{jk}) \right] .$$

Note that this is heavily weighted toward performance at the heaviest loads and steepest angles, and that speed is also an important factor.

run #1	angle = 20°	load = 1 shigley
run #2	angle = 30°	load = 1 shigley
run #3	angle = 30°	load = 2 shigley
run #4	angle = 40°	load = 3 shigley
run #5	angle = 40°	load = 4 shigley
run #6	angle = 60°	load = 4 shigley
run #7	angle = 60°	load = 5 shigley

At most two gentle *sideways* taps to the pallet are allowed to dislodge it from collisions with side walls of the test ramp (in an emergency, you can begin again at the start line, but no additional time is allowed). For load j and angle θ_k, we take t_{jk} to be the *smaller* of the values achieved in two independent runs. A 2 min. pit–stop time is allowed between runs for adjustment, repairs, etc. At least 2 team members must be present at all times (although everyone is welcome to stay and cheer or jeer the other teams).

7 project grade

The total grade for this project will be broken down as follows — 50% for the device performance, as measured by the SCORE value; 15% for physical design & fabrication aspects (design ingenuity, workmanship and aesthetics, use of materials, principles of mechanics, etc.); and 35% for the final report (including all appropriate analysis) on your device.

8 poetry

Silly me! I forgot to mention a most important requirement for this project! Your team must also compose a *poem*, extolling the virtues of your design! This poem may be in ode, sonnet, lyric, epic, limerick, or alliterative form — or rhyming in iambic pentameter. If you suffer doubts about the performance of your device, you will be permitted to chant your poem in unison during the hauling tests, urging it along with a charge of psychic energy.[1] The following excerpts give an idea of the level of literary proficiency that we expect:

Tyger! Tyger! burning bright
In the forests of the night,
What immortal hand or eye
Could frame thy fearful symmetry?
When the stars threw down their spears,
And water'd heaven with their tears,
Did he smile his work to see?
Did he who made the Lamb make thee?

William Blake

Superior beings, when of late they saw
A mortal man unfold all nature's law,
Admired such wisdom in an earthly shape,
And showed a NEWTON as we show an ape.

[1]Since psychic energy is exempt from the First Law of Thermodynamics, this is *not* a violation of the restriction to 2 AA batteries as the only power source for your device.

Could he, whose rules the rapid comet bind,
Describe or fix one movement of his mind?
Who saw its fires here rise, and there descend,
Explain his own beginning, or his end?
Alas, what wonder! Man's superior part
Unchecked may rise, and climb from art to art:
But when his own great work has but begun,
What reason weaves, by passion is undone.

Alexander Pope

Come, my friends,
'Tis not too late to seek a newer world.
Push off, and sitting well in order smite
The sounding furrows; for my purpose holds
To sail beyond the sunset, and the baths
Of all the western stars, until I die.
Tho' much is taken, much abides; and tho'
We are not now that strength which in old days
Moved earth and heaven; that which we are, we are;
One equal temper of heroic hearts,
Made weak by time and fate, but strong in will
To strive, to seek, to find, and not to yield.

Alfred Tennyson

Since brass, nor stone, nor earth, nor boundless sea,
But sad mortality o'ersways their power,
How with this rage shall beauty hold a plea,
Whose action is no stronger than a flower?
Oh, how shall summer's honey breath hold out
Against the wreckful siege of battering days,
When rocks impregnable are not so stout,
Nor gates of steel so strong, but time decays?
Oh fearful meditation! where, alack!
Shall Time's best jewel from Time's chest lie hid?
Or what strong hand can hold his swift foot back?
Or who his spoil of beauty can forbid?
Oh none, unless this miracle have might,
That in black ink my love may still shine bright.

Wm. Shakespeare