Laboratory 2 – Units, Dimensions & Significant Figures
Assigned Week of September 26, 2011
Due Week of October 3, 2011

I — Introduction:

We often become annoyed when we have to make tedious conversions between various units. At times, it seems so unbearable that a logical question comes to mind: why do we bother with units anyway? Can't everything be just measured in "elephants", for example? And why do textbook problems keep giving you quantities first in pounds and then in kilograms (or worse, in both!)? An interesting and instructive Canadian case study comes to mind, where passengers of Air Canada's flight 143 learned the importance of units the hard way.

On July 23, 1983, twelve kilometres above the Manitoba countryside, the unthinkable happened: a brand new Air Canada Boeing 767-200, flying from Montreal to Edmonton, ran out of fuel. The 120 tonne, $40-million aircraft became a glider, dropping at over 600 metres per minute with no hope of reaching the closest city airport, which was in Winnipeg. Amazingly, the powerless aircraft made a successful emergency landing at an abandoned airbase in Gimli. The incident became so famous, that the aircraft was given a nickname – the "Gimli Glider". In fact, in Western Canadian slang, "to pull a Gimli Glider" is to make a spectacular foul-up. So what really happened? How could a modern jetliner, equipped with the latest technology and piloted by skilled people, run out of gas at 26 000 feet? There was no fuel leak or engine malfunction. The hard truth is that the ground crew simply did not put enough fuel into the aircraft before it departed. Let's see how this happened.

A Boeing 767 is normally fueled using a device known as the Fuel Quantity Information System Processor (FQIS), which operates all of the internal pumps and reports to the pilots on the status of the fuel load. However, Flight 143's FQIS was not working properly, and instead, the fuel load was measured with an aircraft dipstick. The maintenance worker, who found that the fuel gauge did not work on ground inspection, incorrectly assured the pilot that the aircraft was certified to fly without the functioning gauge if the crew checked the fuel tank levels regularly. Crew members measured the 2 fuel tank levels at 62 cm and 64 cm. This corresponded to 3 758 L and 3 924 L for a total of 7 682 L according to the aircraft's manual (notice that at the time the Canadian government was painfully introducing the metric system nationwide). The ground crew knew that the flight required 22 300 kg of fuel. The problem they faced was: with 7 682 L of fuel on the aircraft, how many more litres were needed to make the total 22 300 kg of fuel? One crew member informed the other that the "conversion factor" (being the fuel density) was 1.77. So it was calculated that the aircraft needed an additional 4 917 L of fuel for the flight. The crucial fault was that no one ever questioned *what were the units of the conversion factor*. Thus, the ground crew's calculations were:

$$7\,682 \text{ L} \cdot 1.77 = 13\,597 \text{ kg of fuel on board}$$

$$22\,300 \text{ kg needed} - 13\,597 \text{ kg on board} = 8\,703 \text{ kg to be added}$$

$$8\,703 \text{ kg} / 1.77 = \textit{4 916 L of fuel to be added}$$

The metric changeover in Canada should have been accompanied by further education on the airline's part. The "conversion factor" of 1.77 was actually the fuel's density in *pounds* per litre, not kilograms. The fuel's density in kilograms per litre was actually 0.803. The ground crew should have computed the following:

7 682 L · 0.803 kg/L = 6 169 kg of fuel on board

22 300 kg needed − 6 169 kg on board = 16 131 kg to be added

16 131 kg / 0.803 kg/L = *20 163 L of fuel to be added*

The bottom line is that by not accounting for the units in the density of the fuel, the ground crew added 4 916 L of fuel to an aircraft that needed 20 163 L of fuel and nearly killed more than 60 people! Still think units aren't really important?

It is absolutely essential to understand the concepts of dimensions, dimensional measurements, significant figures and unit systems before the fundamental tools—mathematics and physics—can be applied to an engineering situation. The fundamental meaning of a dimension was introduced in class. In addition, dimensional measurements and significant figures were discussed. Finally it was pointed out that there is more than one primary unit system used to quantify engineering measurements based on mathematical equations. While the Système Internationalle (SI) is preferred, the gravitational system (otherwise known as FPS) and the hybrid American system are still very much employed in the engineering world. Therefore you will have to be familiar with all three systems in your professional lifetime. These are all brought together in this laboratory exercise.

IntelliCAD: You are going to need to do some software sketching in this laboratory exercise and you will need some experience in this regard. Therefore, before proceeding to the primary focus (dimensions, units and significant figures), you are asked to become familiar with the sketching capabilities of a computer aided drafting (CAD) system called IntelliCAD, which is similar to AutoCAD.

In this laboratory exercise, you are asked to produce some sketches in support of the calculations for your report. IntelliCAD sketching is not just used in this laboratory; it will be used as a general sketching tool in support of laboratory exercises to come later, and it will also be used for producing engineering drawings near the end of this course.

II — Problem Statement:

Part 1: The efficiency η of a pump is defined as the (dimensionless) ratio of the power developed by the flow to the power required to drive the pump:

$$\eta = \frac{Q\Delta p}{input\ \ power}$$

where Q (with dimensions of volume/time) is the volume flow rate and Δp is the pressure increase produced by the pump. In turn, Q can be calculated as the product of the cross-sectional area (A) for flow and the average flow velocity (v_n) perpendicular to that area:

$$Q = v_v A$$

You are given three different pumps to analyse for efficiency:

1. 267 kW of power is supplied to *Pump 1*. This allows it to raise the pressure of a flow, traveling at an average velocity of 11 811 in/min through a 1.00 m by 1.00 m rectangular cross-sectional area, from 759 mm of Hg (millimetres of mercury) to 911 mm of Hg.

2. *Pump 2* develops a pressure increase of 35 lbf/in^2 when its flow rate is 39.2 L/s. Its input power is 16 HP (horsepower).

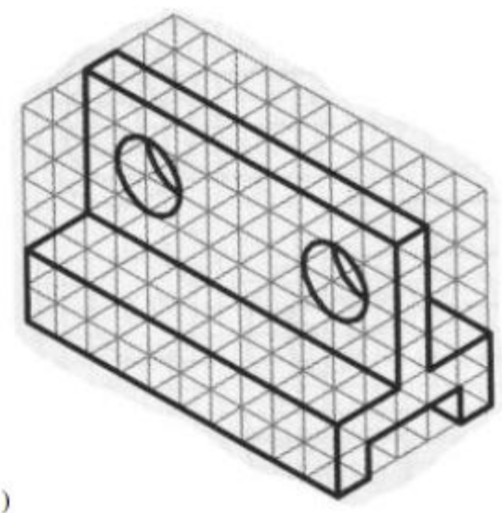
3. A flow is pumped at a rate of 57 061 US gal/hr (United States gallons per hour) through *Pump 3*, which is supplied with 29 037 Btu/hr, and which raises the pressure from 15 psi to 2 atm (two atmospheres).

Unfortunately, each pump's performance characteristics are presented in all three unit systems – SI, FPS and with US units – which makes comparisons difficult. You are asked to rank these pumps in terms of efficiency according to their η values expressed in %.

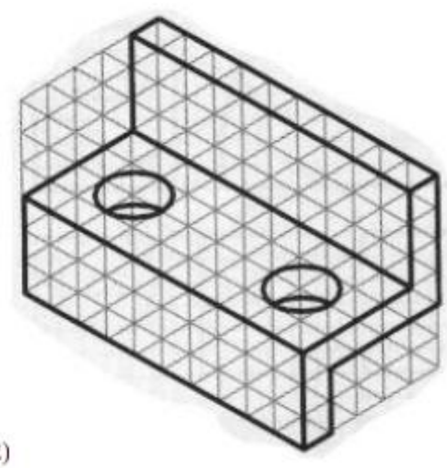
Note: A table of conversion factors is given at the end of this document. A number of software tools to convert units can also be found (many freely available) on the Internet. However, good engineering practice is, if you use a software tool be sure that you know how to use it properly and that you can trust its output.

Part 2: In order to become familiar with basic IntelliCAD operation, read Chapter 15 in your textbook.

Part 3: Imagine that a particular mechanical device contains three different steel alloy brackets 1, 2 and 3 as part of its assembly design. Their isometric views are presented below. In order to protect these components from corrosion and other effects of the surrounding environment, they are to be covered with an expensive coating. To determine the amount and cost of the coating, the total surface area must be calculated first. The surface areas can be readily calculated from sketches done in IntelliCAD by dimensioning each bracket's three primary views: top, front and side. You are to produce the working (detail) drawings and calculate their surface areas.



1)



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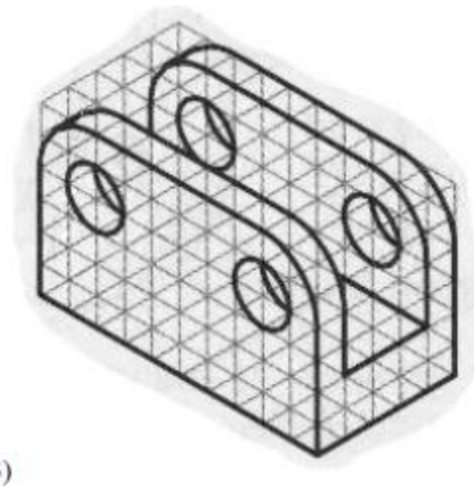

3)

III — Steps and Calculations:

1. For Part 1, calculate the efficiencies (η), as percentages, for each of the given pumps, keeping good track of the units and their conversions, and significant figures. Use the efficiencies to rank the pumps from most efficient to least efficient.

2. Part 2 simply allows you to become comfortable with essential IntelliCAD functions and commands that you will need to produce the sketches in Part 3.

3. For guidance in sketching the working drawings for each of the brackets given in Part 3, you can refer to Chapter 12 of your textbook. Since the units are not given explicitly, your dimensions should be in 'arbitrary units' and your calculated surface area would be in (arbitrary units)^2. Include only the most essential dimensions and follow the dimensioning rules outlined in your textbook. Make sure to show all hidden lines and centre lines. The 'area' command in IntelliCAD may be of some assistance. The drawings must have an appropriate title block. You can find a template for this on WebCT.

IV — Report Requirements:

• Using the guidelines presented in Laboratory 1, produce a formal laboratory report that summarizes your findings.

• Reproduce (using IntelliCAD) and print Figure 15.25 at the end of Section 15.2.3 of the textbook.

• In the "Results and Discussion" section of your report, among other things, you should:

- state the results obtained for efficiency of the pumps calculated in Part 1;
- rank the pumps from most to least efficient;
- state the surface areas of the brackets in Part 3;
- briefly evaluate the validity and accuracy of the results;

- try to avoid leaving any important data in the Appendix(ces) unmentioned and unsupported in the body of the discussion.

• In the appendix(ces) you must include:

- all your calculations and conversion factors used in Parts 1 and 3;
- a copy of Figure 15.25 produced in Part 2;
- working drawings with proper title blocks of the brackets in Part 3.

• Don't forget that the written text of the report must be no longer than 1 page. Additional materials are to be included as appendix pages - sketches, figures and tables, etc. Note that the figures and tables must be properly labelled, titled and supported with text as described above.

V — Submission and Timing:

Your report is to be submitted to the Teaching Assistant within the first 30 minutes of your next laboratory period (week of October 3 to 6, 2011). **LATE SUBMISSIONS WILL NOT BE ACCEPTED.**

Important Note: Friday October 7, 2011 is University Day (there are no undergraduate classes). For those with labs normally held on Friday's, this laboratory is due no later than 16:30 on Thursday October 6, 2011 in the ECOR 1010 slot of the orange cabinet located outside of 3135ME.

VI — Marking:

Laboratory submissions will be marked on a 10-point scale: 9-10 (excellent); 7-8 (good); 5-6 (marginal); less than 5 (fail). **Be sure that you are familiar with the University's policy on plagiarism and academic integrity. Your instructors are obligated to report all suspected violations to the Associate Dean's office for investigation.**

Length

1 ft = 0.3048 m
1 m = 3.2808 ft
1 in = 2.54 cm
1 cm = 0.3937 in

1 mi. = 5280 ft
1 km = 0.6214 mi.

Mass

1 lbm = 0.453592 kg
1 kg = 2.20462 lbm
1 slug = 14.594 kg

1 slug = 32.174 lbm
1 ton = 2000 lbm
1 tonne = 1000 kg

Pressure

1 psi = 6.894757 kPa
1 Pa = 145.04×10^{-6} psi

1 bar = 100 kPa
1 atm = 101.325 kPa
1 atm = 14.696 psi
1 in. Hg = 0.4912 psi
1 mm Hg = 0.1333 kPa
1 in. Hg = 3.387 kPa

Energy

1 Btu = 1.055056 kJ
1 kJ = 0.947817 Btu
1 lbf.ft = 1.35582 J
1 J = 0.73756 lbf.ft
1 cal = 4.1840 J
1 IT cal = 4.1868 J
1 Btu = 778.169 lbf.ft

Volume

1 ft^3 = 0.028317 m^3
1 m^3 = 35.315 ft^3
1 in^3 = 16.387 cm^3
1 cm^3 = 0.061024 in^3

1 US gal = 0.0037854 m^3 = 231 in^3
1 Imp gal = 1.2009 US gal
1 lt. = 0.001 m^3
1 lt. = 0.0353 ft^3

Density

1 lbm/ft^3 = 16.018 kg/m^3
1 kg/m^3 = 0.062428 lbm/ft^3

Specific Volume

1 ft^3/lbm = 0.062428 m^3/kg
1 m^3/kg = 16.018 ft^3/lbm

Force

1 lbf = 4.448222 N
1 N = 0.224809 lbf
1 dyne = 1×10^{-5} N

Specific Energy

1 Btu/lbm = 2.326 kJ/kg
1 kJ/kg = 0.42992 Btu/lbm
1 Btu/lbmol = 2.326 kg/kmol
1 kJ/kmol = 0.42992 Btu/lbmol

Energy Transfer Rate

1 Btu/s = 1.055056 kW
1 kW = 0.947817 Btu/s
1 HP = 550 lbf.ft/s
1 HP = 2545 Btu/hr
1 HP = 0.7457 kW