<u>A Methodology for Solving Thermodynamics Problems[1]</u>

As you continue your education it is the general skills that you learn relating to how to attack, break down, solve, and present results from complex problems (of any type, in any subject) that *will be the most important and valuable things that you learn.*

<u>*Learning to solve problems methodically is much more important than learning the specific knowledge that is the subject of this one course*</u>. The problem solving skills and methodologies that you learn while studying this topic will continue to be of use to you in your other courses and throughout your career.

In fact, it is fair to say that it is possessing excellent problem analysis skills (and not the mere acquisition of a particular body of specialized knowledge and facts, such as the laws of thermodynamics) that "makes you an engineer."

The homework in this course is a great place to develop and practice these skills. The hope is that by the time you are finished with school analyzing problems <u>***methodically***</u> and presenting the solutions in a <u>***clearly***</u> and <u>***meaningfully***</u> will be second nature to you.

Don't "blow off" all of this "methodology stuff." It will be expected of you as a professional, so you might as well get good at it now.

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This Methodology is divided into three major parts I) the *problem statement* II) the *analysis* and III) the *discussion*. The individual steps (labeled 1-10) correspond to the detailed method presented in most texts. Each of these steps is discussed in detail below. An attempt has been made to keep this methodology as general as possible, so it can be applied to <u>any subject</u>. *Information specific to thermodynamics problems is shown in italics.*

You should view the steps in this method as being somewhat "iterative." That is, you will likely need to jump back and update steps that you did earlier as you learn more about the problem. (For example, you will often add assumptions as you work through the solution, even after you have passed the "assumptions" step.) This is to be expected and is OK! Make sure you leave yourself room to work.

<u>Note</u>: different texts, different professors, and different corporations will all have their own preferred format for how problems should be prepared and presented. It is YOUR RESPONSIBILITY to understand and work within the required format. Regardless of final presentation format you should *learn* to *always* attack problems *methodically*!

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(I) THE PROBLEM STATEMENT: communicates quickly to the reader exactly what you are doing and perhaps even why you are doing it. A mistake here can lead to hours of useless effort, so spend some time on this! The problem statement should include the following:

1) Known/Given

State briefly **in your own words** the important known or given information. This requires that you read the problem carefully and **think** about it. You should also carefully avoid including information which is NOT needed to solve the problem (i.e. eliminate "red herrings").

2) Find

State concisely in your own words what is to be determined. (i.e. how do you know when you are done?)

(II) THE ANALYSIS: consists of everything that you do to find the solution to the problem stated above. This is the part of the solution that students typically focus on, but in reality it is often the easiest of the three parts. It should contain the following parts:

3) Schematic showing Given Data

Draw a sketch of the problem or system to be considered. This should be a simplified schematic which focuses on what is important to the problem, and which eliminates unnecessary details. Label the diagram with relevant information from the problem statement. This step often "overlaps" somewhat with steps 1 and 2 above, the best way to communicate many of your "givens" and "finds" may well be to show them on your sketch.

Don't view your initial schematic as a static entity. Remember to update it frequently as the solution progresses and more information is learned. To this end, don't be afraid to make your sketches and diagrams **big** so you have enough room to add details.

Specifically for thermo problems:

- *you should at this time decide whether a closed system or control volume is appropriate for the analysis, and then carefully* ***identify the boundary and show it on your figure.***
- *Record all property values you are given or that you anticipate may be required for subsequent calculations (a tabular format is often very useful for this, leave blanks for properties that you think you will need to look up as the solution proceeds).*
- *Sketch appropriate property diagrams (P-v, T-v, T-s , etc. as appropriate), locating key state points and indicating, if possible, the processes connecting the states.*

The importance of good sketches of the system and of property diagrams cannot be overemphasized. These tools are often instrumental in enabling you to think clearly about the problem. USE THEM to help make your job easier!

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4) Assumptions

To form a record of how you model the problem, list all simplifying assumptions and idealizations made to reduce the problem to one that is manageable. Sometimes this information can also be noted on the sketches of the previous step.

Note that this step is especially "iterative" you might not realize all of the assumptions that you need to make until you are well into the analysis. This is OK, just make sure that you keep your assumptions list up to date as you work.

!! VERY IMPORTANT NOTE: Any assumption used to simplify the analysis will also limit the scope of validity of the solution! Remember to discus the limits of validity of your solution (caused by your assumptions) in the final discussion section (described below). Also be careful to consider the implications of your assumptions. By assuming too much you can accidentally "throw the baby out with the bath water" and arrive at a valid but utterly trivial solution.

Specifically for Thermo Problems:

Typically at this point in the analysis you should state how you intend to determine the physical properties that will be used in your solution. (e.g. "assume ideal gas" or "use steam tables for all properties")

Examples For Thermo:

Assume: Steady State Steady Flow

Implication: this solution will not give any information about the transient behavior of the system.

Example of "throwing the baby out…"

FIND: Heat transfer from compressor housing

Assume: Adiabatic (Adiabatic means heat transfer = 0 … Doh!)

5) Physical principles and model

Decide what physical laws (*e.g. first law, second law, conservation of mass, etc.*) will be used to solve the problem, and what general form of these is best suited to the particular problem (*e.g. system or control volume form*).

6) Mathematical model and equations

Write down the most general form of the equation first then use your assumptions step by step to simplify it to the form you will actually solve. Note the effect of each assumption on the equations as you simplify them. Starting with the general form of the equations will prevent you from accidentally leaving anything out. Terms you don't need will be eliminated by assumptions or filled in with given information.

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You should work with variables in your equations for as long as possible before substituting numerical values (this will make your solution more generally applicable and hence more valuable). **When you have the equations in final form, check that you have enough equations to solve for the number of unknowns that you are dealing with.** If not, go back and see what other physical relations or extra information you can apply to eliminate unknowns. (*e. g. can you fix any system states and then find other properties in the thermo tables? Does the process followed by the system give you any additional equations like* $P_1V_1=P_2V_2$?)

7) Substitute Numerical values and Calculate
Only when you are sure that you have enough information (equations, relations) to solve for the number of unknowns should you substitute numerical values into your equations and perform your final calculations. I call this the "calculator step." Be certain to indicate where values used in your calculations come from (e.g. the properties of nitrogen were taken from table 3.54 on page 544 of …). Be careful with numerical calculations.

Again, it should be emphasized that the "calculator step" is probably the least important step that you do in solving a problem! If you do everything else correctly and clearly, a well trained monkey (i.e. your boss who only has a business degree) could plug in the numbers and make the calculation. This does not mean you should be sloppy or negligent with this step … just don't focus solely on it.

8) Units Check
Make sure that consistent units are employed on every term in the equation. The final answer should be clearly marked (boxed) and ***must*** have appropriate units and a reasonable number of significant figures.

9) REVIEW (Sanity check)
Finally, consider whether the magnitudes of the numerical values are reasonable and the algebraic signs associated with the numerical values are correct. Make sure no physical laws are violated (e.g. no negative masses, nothing moving faster than the speed of light etc.) and that common sense seems to be satisfied (e.g. I don't think that anyone would design a car engine that produces negative horsepower ?!? I should check this again…) You will be amazed how many points (and how much embarrassment) this simple step can save you … IF YOU ACTUALLY TAKE THE TIME TO DO IT!

III) THE DISCUSSION
(10) This is where you make your solution worth something to someone else (e.g. your boss).

In your career you as an engineer will be expected to analyze technical situations (problems) and produce meaningful input about the solution to these problems. That input starts with the numerical solution to the problem, but a simple numerical answer is useless without a meaningful framework to consider it in.

At the minimum your discussion should specify the limits of validity of your calculation (remember to check back to your assumptions) and an estimate for the accuracy of the solution (e.g. "we used empirical correlations that are only accurate to within 10%, hence our answer cannot be expected to be more accurate than this…"). You should note potential sources of error (e.g. "we had to estimate the properties of water at –150 °C since no value is given in the steam table…") and possibly weak assumptions (e.g. "the above analysis is founded on the assumption of a frictionless piston, but as we all know this is an impossibility, hence the work calculated should be viewed as an upper bound of what a real system would produce…). Beyond this minimum you might want to indicate how your solution could be improved (e.g. "by replacing ideal gas behavior with measured property behavior greater accuracy is possible…"). Or include statements about the broader significance of your solution (" by switching to this new cycle with higher efficiency the US could save 100,000 barrels of oil a year…").

In "real life" it is this understanding of your solution and its ramifications that you are being paid for … **the number that you produced, in and of itself, is useless**. Therefore the discussion is a critically important part of any solution. To reflect this the discussion section will be heavily weighted in the grading of the homework.

[1]Sources for this Methodology:
Stephen R. Turns, Thermal Fluid Sciences An Integrated Approach, Cambridge University Press, 2005.
M.J. Moran and H.N. Shapiro, *Fundamentals of Engineering Thermodynamics*, 4th Edition, John Wiley & Sons, Inc., 2000, p. 24.
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