<u>Some Comments regarding Engineering "Trade" Studies and AME40463:</u>

As discussed in this and in previous courses "design" is a complex process and it involves many people and activities. There is no single "recipe" for design and the process can be very different depending upon whether you are designing a simple "product" (e.g. a manual can opener) or a complex, highly technical system (e.g. an automobile).

In AME40463 you are conducting the <u>conceptual design</u> of a moderately complex artifact. By the end of the course you want to be in the position to describe an "idea" - or concept - for a device that would achieve desired behaviors or performance. You will attempt to demonstrate the suitability of your concept using <u>engineering analysis</u> to predict behaviors, <u>virtual prototyping</u> (CAD) to illustrate form and <u>proof-of-concept prototype</u>/s to demonstrate selected capabilities. At the end of the course, you will be asked to make a recommendation as to whether your concept would be suitable for further engineering development (i.e. simply stated, you propose an idea and spend about 10 weeks exploring the feasibility of your idea.) You are NOT tasked with developing the final detailed design.

In order to achieve this outcome, you will be required to make many "design decisions" and hopefully each of these decisions is aided by your intuition, experience and engineering skills. Could you propose a concept and fabricate a proof-of-concept prototype using only intuition and experience - probably! Would that be the most appropriate approach for your capstone design course as a Mechanical Engineering - probably not! You will find that during the course you will perform a large number of "engineering studies" of the types described in the list below. Some may take just a few minutes (e.g. look up in a text book how to calculate the stress in a circular rod loaded in torsion). Others may take a few days (e.g. select the gears, belts, bearings and shafts necessary to transmit the torque from a motor shaft to the drive axle of a vehicle.) In this course, these "studies" will be informally documented in your notebooks and the results of some will reflect themselves in the proposed concept by the decisions that result from the studies.

One of these studies - we've refer to it as an <u>engineering trade study</u> - is a special study conducted as part of this course. Our definition of a trade study is provided below and it is important to understand what it is in the context of the other kinds of studies you might perform. But maybe it is important to first indicate what it **isn't**:

- The five trade studies your group performs **aren't** the only studies you will conduct this semester. They are simply the only ones you will document in detail.
- The five trade studies your group performs will **not** allow you to design the entire product.
- You should **not** try to decompose your idea into five subsystems and attempt to develop a trade study for each subsystem.
- They should **not** be too complex and you should make every effort to select topics for your study for which you understand the "engineering science" behind the study.
- Using trade studies to differentiate between competing concepts can be difficult and should be **avoided** for this project. Assume you have a "concept" for some element of your entire concept and use the trade study to assist in providing detailed information for that element.

So in order to satisfy this assignment for the course, it is suggested:

- Identify some feature or element of your concept which you need to design - in contrast to simply "select" from a vendor or catalog. (e.g. a bracket in contrast to a motor)
- Identify a few key features or aspects of that "element of your concept" for which you will need to make "decisions" in order to build it, (e.g. critical physical dimensions or material) and identify those as design variables.
- Use a small (2-3) number of design variables or the study can become unmanageable.
- Identify a few key behavioral or performance characteristics of the "element of your concept" that are important, (e.g. stress levels, pressure, temperature, weight, etc.) and identify those as state variables.
- Identify a few key behavioral or performance characteristics of the "element of your concept" that you have identified as design requirements and set limits on those states, (e.g. maximum stress levels, maximum deformations, etc.) and identify those as constraints.
- Develop or apply an engineering analysis or numerical technique you learned in one of your technical courses to compute the state variables as functions of the design variables. (e.g. predict the deflection and stress in a bracket under various loading conditions.)
- Compute the values for the state variables for ranges of the design variables that you think might be appropriate for this particular "element of your concept."
- Analyze the results, try to identify key trends or important design variables.
- Document the results and indicate how this study did - or didn't - influence your design or your design decision process.

Engineering Design Studies:

1. **Research study** - developing new knowledge or locating and evaluating existing knowledge that can be used in concept selection, feasibility or trade studies. Research studies provide information and typically don't require "decisions." They are used to help inform decisions made in other studies. (e.g. look up in a text book how you calculate the stress in a circular rod loaded in torsion)

2. **Concept selection study** - used early in the design process to select between competing "ideas" for an entire product or subsystem or even a part. Different concepts typically differ in rather substantial ways so most often the comparison between concepts at the early stages of the design process is difficult to perform. Since the competing concepts themselves are usually only defined in general terms (e.g. horizontal axis wind turbine vs. vertical axis wind turbine) it is often impossible to compare them using quantitative indicators (states, behavioral variables or merit) since there are an infinite number of specific implementations of each concept. There would be a complex, multi-dimensional design space associated with each concept and drawing comparisons between different designs spaces is difficult to do at this point in the design process. Intuition, experience and the consideration of qualitative technical and non-technical factors often are used in concept selection studies. (e.g. vertical axis wind turbines aren't as sensitive to changes in wind directions)

3. **Feasibility study** - use analysis (i.e. formulate and solve equations), numerical simulation or experiments (or some combination of all three) to determine if a specific

instantiation of a concept will satisfy design requirements. Once a “concept” is selected, and specific values assigned to all the design variables, you can evaluate the behavior or characteristics. (e.g. you have selected the geometry, cross-sectional areas, materials, support locations and applied loads for a “truss-like” framework for a lightweight vehicle and you want to determine if that particular design satisfies all the stress and deformation requirements.)

4. **Component selection study** - use analysis, numerical simulation or experiment to assist in the selection of existing component/s for a specific instantiation of an idea or concept to determine if it will satisfy design requirements. May be composed of a series of “feasibility studies.” Many engineering products/systems are assembled from existing components that are selected from vendors/catalogues, (e.g. select the gears, belts, bearings and shafts necessary to transmit the torque from a motor shaft to the drive axel of a vehicle.)

5. **Trade study** - use analysis, numerical simulation or experiment to identify key design variables, parameters and constraints and to determine the behavior of a design concept over a range of choices of selected design variables. In many cases the number of design variable that are used in the “trade study” must be limited as the complexity of the design space grows exponentially with the number of design variables. Often the behavior of a selected number of states is studied as you vary a selected design variable through a specific range of values. (e.g. predict the torsional deformation and maximum stress (states) in a thin walled shaft used to transmit torque in a machine as a function of the shaft diameter, material and wall thickness (design variables) for a range of applied loads (design parameters).) Trade studies don’t necessarily give you the “design” but provide information in the form of trends and sensitivity that would assist in making a decision. (e.g. once you have performed the ‘drive-shaft” trade study you can identify key design variables and use the information to help select the most appropriate shaft geometry and material from those available from various vendors.)

6. **Design optimization study** - systematic, and sometimes automated, trade study in which design variables are selected in order to satisfy constraints but to also improve the merit of the design or locate a single design with maximum or minimum merit. To find an “optimum” you need a quantifiable measure of merit. These studies are becoming much more common in engineering design as more complex and highly automated design tools (finite element analysis (FEA) and computational fluid dynamics (CFD)) are developed and employed in engineering practice.

One final note - in practice you often find that you perform “studies” that are actually combinations of those listed above, but understanding the different ways you go about gathering information to help inform the design process is important and that is why these distinctions are made at this time.

Some - hopefully familiar - Design Terminology:

1. **Design variable:** A specific, quantifiable, descriptor of some feature of a design over which the designer has "control." Specific values of a complete set of design variables define a specific instantiation of the design. There are various types of design variables:
    - Continuous - the DV can assume any number over a range
    - Discrete - the DV can assume a finite number of values in a range
    - Batch - the DV is represented by a choice of finite number of options

   If you can't specify it and control it (within some reasonable tolerance), it's probably not a design variable and most likely it's a state.

2. **Design parameter:** A specific, quantifiable, number that is used to describe a feature of the design or the environment in which the design functions. Parameters are those quantities used to model the design and its environment and over which the designer does not have or does not wish to exercise control at this point in the design process. Design parameters can remain fixed or vary during a design study.

3. **Behavior or state variable:** A quantity that is the result of analysis, numerical simulation or experiment and is used to describe a characteristic, behavior or "state" of a specific instantiation of a design. You influence these by controlling design variables.

4. **Constraint:** A limit (stated as either an equality or an inequality) that is imposed on either a design variable or a state/behavior variable. Constraints are most often used to assure the satisfaction of a design requirement. Some constraints are "hard" and some are "soft" and this usually is determined by the consequences of violating the constraint.

5. **Merit:** A state or combination of states and design variables that is used to establish preference between different instantiations of a design concept. Each instantiation of a design concept will have a single value of "merit" for the merit to be useful.