GE 124 Engineering Mechanics I (Statics)
Problem Solution Requirements
Fall 2020

Industrial practice and the profession of engineering demand that all written work be of the highest quality in terms of technical content and clarity of communication. Each submission, whether a report or other form of technical analysis, should be self-contained and effective in presenting the problem addressed and the analysis method used.

In keeping with this standard, **assignments** and **module tests** in GE 124 will include evaluation of the requirements and standards outlined in this document.

The primary objective of this document is to assist students in GE 124 by setting clear expectations about what steps are expected to be completed in problem solving, and about how those steps are expected to be executed. Another objective of this document is to assist instructors and TAs in providing consistent evaluation and feedback on problem solving skills and notation.

Always use legible handwriting throughout. Neatness, logical organization, and clarity of presentation are important. For each problem (starting with 2D Particle Equilibrium), divide your work into five parts, each with its own clearly marked heading. Place adequate space between each heading.

Given
Find
Assumptions
Analysis
Conclusions

Given

This section must provide a clear text summary of the information provided in the problem statement and diagram (if any). This does not mean copying verbatim from the problem statement. All pertinent information and data must be extracted from the problem statement and listed. And there is no need to recopy complex diagrams provided with the problem statement, although additional annotations on the diagram may be appropriate.

<u>Why it is required</u>:
Successful completion of this section illustrates that the student has understood what information has been provided to them.

<u>Good answers</u>:
The Given section is presented as a bulleted list. The bullet points will be of four general types:

(i) providing a brief description of the scenario being analyzed
(ii) directing the reader to illustrations with key information,
(iii) listing variables and their values, and
(iv) noting coordinate systems, if any are provided.

In the Given section of your solution, you provide a very brief description of the scenario being analyzed e.g. "a crate suspended from three cables as shown". This description is intended to focus the reader's attention on the important aspects of the problem.

Your Given section should also point out important dimensions and angles in any illustrations accompanying the problem e.g. "See figure/diagram for dimensions and angles" or "dimensions and angles, as shown". This point shows up in Given when valuable information appears in the original illustration. This point typically relieves you from having to restate the information that is shown in the figure. Instead, it points the reader to the given information in the figure.

A list of variables and their values from the text of the problem e.g. "m = 10 kg" should also be included. Restating this information in a clear fashion is important, as the text of the problem sometimes obscures critical information. You need to extract critical information from the provided text, and distill it into a form that is useful for problem solving.

If a coordinate system (xyz) is shown in the original illustration, you should also note it e.g. "Coordinate system, as shown". If no coordinate system is shown, you don't need this point in your Given section.

Finally, the problem statement sometimes gives limits on the values of variables. These must be clearly stated e.g. "Cables can withstand 1000 N before breaking". Students may wish to include these points in the Assumptions section, if they wish.

<u>Common errors</u>:
Students should not simply state "see figure". They should be specific about what is in the figure that they want the reader to focus on e.g. "see figure for dimensions", "see figure for angles"

Missing key information (forgetting to state a key given fact, or to note the given coordinate system)

Mis-stating key information (changing the value of a key fact, the meaning of a limitation, or the units of a variable)

Sloppiness (writing too small/sloppy for a reader, or marker, to understand)

Mixing scalars and vectors, to misrepresent what information has been given in the problem

Find

This section must contain a concise list of the information that you are looking for, including proper notation e.g. scalars versus vectors.

<u>Why it is required</u>:
Successful completion of this section of a solution illustrates that the student has understood what they have been asked to find. It helps to focus the student's efforts and it helps avoid spending time calculating things that aren't needed.

Good answers:
Bullet point answers for Find will typically state what needs to be found in terms of variable names e.g. "F_{AB}, the magnitude of the force along **AB**".

Reference may sometimes be made to qualifiers/limitations on a variable's value *e.g.* "the length of **AC**, so that the weight can be supported as shown".

Common errors:
Missing something you need to find, or something about what you need to find e.g. magnitude and direction of $\mathbf{F_R}$ (instead of just saying magnitude).

Sloppiness (writing too small/sloppy for a reader, or marker, to understand)

Mixing scalars and vectors, to misrepresent what has been asked for in the problem e.g. if a vector was asked for, then "F_{AB}" would be wrong, since it is a scalar and "$\vec{F}_{\mathbf{AB}}$" or "$\mathbf{F_{AB}}$" would be correct since they are correct vector notation.

Lack of clarity e.g. "F" (which "F" is unclear, so be precise e.g. "F_{AB}")

Assumptions

This section must list all pertinent assumptions that have been made in order to solve the problem.

Why it is required:
A thorough list of assumptions should be viewed as part of the answer to the problem. The numerical values you calculate are only useful if the assumptions used to obtain them are clear. In engineering practice, clarity about the conditions under which a numerical value was calculated is **very** important to ensure the value is not used under conditions where it is not valid.

Common Assumptions:
Here are some common assumptions and an explanation of why they are required.

a. "Given information is exact" (or precise)
This assumption should be stated for any problem where numerical values are given. GE 124 requires that students express final answers to three significant figures. This was chosen as a reasonable value for most engineering applications. However, a more thorough treatment would demand that careful attention be paid to the precision of the given data when doing any calculation. Very often, the given information in GE 124 appears to have only one significant figure e.g. L = 1 m. Since it is not reasonable to restrict final answers to one significant figure, this assumption is used to remove the issue of stating a final answer to greater precision than the given information. While not incorrect, stating that the given information is correct (or accurate) is **not** useful. This assumption is implicit and does not need to be stated. And it is not a replacement for saying that the given information is exact (or precise) because precision is different than accuracy.

b. *"*Static equilibrium*"*

This means there is no net acceleration and no motion. Therefore, the equilibrium equations for statics apply ($\sum \vec{F} = 0, \sum \vec{M} = 0$). This assumption must be stated any time the equilibrium equations are used in a situation with no motion. However, keep in mind that questions early in GE 124 are not always concerned with static equilibrium. For example, if you are asked to add two or more vectors together to get a resultant, "static equilibrium" would be an <u>incorrect</u> assumption. Also, there are situations in Statics when there is no net acceleration but there is motion (constant velocity). In those cases, you should say "Equilibrium" as an assumption instead of static equilibrium.

c. *"*Rigid system*"*

In GE 124, most structural and machine members are assumed to be rigid. This means that the members do not deform when loaded and any dimensions given in the problem statement apply to the member at all times. Do NOT say that particles are rigid, or that ropes/springs are rigid. By definition, they are not.

d. *"*Ropes/cords/strings/chains/cables are taut*"*

Ropes, cords, strings, chains, and cables are not rigid members. However, they are generally assumed to be straight or taut, which makes geometry much easier for us.

e. *"*Ropes/cords/strings/chains/cables are inelastic*"*

They are assumed to not stretch, which means their lengths do not change.

f. *"*Linear springs*"*

This means that the spring force varies linearly with the spring displacement. It also means that the spring stiffness, k, is constant. This assumption must be stated any time F$= ks$ is used. It will apply to all springs in GE 124 unless otherwise noted.

g. *"*Frictionless pins/pulleys*"*

This means that there are no moment reactions generated at pinned joints or pulleys. Therefore, when a free-body diagram is drawn for any member connected by a 2D pin, the reactions consist only of forces, not moments.

h. *"*Weight of members is negligible*"*

This means that the loads applied to the structure or machine are large compared to the weights of the members themselves. This assumption applies to ropes/cords/cables, as well as pulleys (unless otherwise stated), or any time a mass of a member is not stated.

i. *"*<xxx> is a Particle*"*

This assumption is required whenever the equilibrium equations for a particle are being applied to a physical object. This may be a pin connection between two or more members, a pulley, a knot joining two or more cords etc. Since the object is being represented by a particle, the equilibrium equations consist only of a sum of forces, not a sum of moments.

Since most objects can be considered either as a particle or as a body with dimensions, it is important to state this assumption if you are, in fact, treating something as a particle.

j. *"*g = 9.81 m/s^2 (or 32.2 ft/s^2)*"*
This assumption for the acceleration due to gravity is required any time a force (weight) is being determined from a mass (or vice versa) using W=mg. Other values could be specified, since the exact value depends on latitude and elevation, but these are the values that we will use as a default in GE 124.

k. *"*Frictionless surface <and specify the surface>*"*
This means that there will be no frictional forces involved with the surface i.e. the surface will only produce normal forces.

l. *"*<a rope, spring or member> is horizontal/vertical*"*
Here you are clearly stating that you assume a specific rope/spring/member is either horizontal or vertical in its orientation. We will try and make this clear in diagrams for problems, but if it isn't stated and you believe something is oriented horizontally (or vertically), state this assumption.

Analysis

This section should contain all relevant free-body diagrams (if appropriate), auxiliary sketches, governing equations, and calculations required to arrive at the answer(s). Follow a logical order in the analysis which the reader can easily follow. Put some explanation of the steps you are following between the equations. Leave enough space between steps that the analysis can be easily followed.

Free-Body Diagrams

Free-body diagrams (FBDs) are **essential** components of **any** question where the equilibrium equations are being applied to either a particle or a rigid body (2D or 3D). They serve to isolate and clarify **all** of the information required to write the equilibrium equations. If there is any information that you need to complete the equilibrium equations that is **not** on the free-body diagram, this means your free-body diagram is **incomplete**.

Some essential elements of FBDs are as follows:

The only object that should be shown is the object that you are isolating i.e. your free-body. This will either be a particle or a rigid body. For example, if a crate of known mass is suspended from three ropes and you are solving for the tension in the three ropes, you must draw a free-body diagram of the knot (assumed to be a particle) where the three ropes and the rope connected to the crate, join together. You do **not** draw the ropes and you do **not** draw the crate. Instead, you show the force vectors acting along those ropes.

A coordinate system **must be shown** on/near every FBD. The equilibrium equations involve forces and forces have both magnitude and direction. In order to specify directions properly, the coordinate system must be shown.

Sufficient dimensions must be shown so that the point of application of forces on rigid bodies is fully defined. This is required so that moments can be taken properly.

All forces acting on the particle/rigid body must be shown. The direction of all forces must be specified. If the magnitude is known, a numerical value must be given. If the magnitude is unknown, it must be represented by a variable. Alternatively, the force can be shown by its separate xyz components.

Common errors:

No FBD is shown, when it should be shown

Sloppiness (writing too small/sloppy for a reader, or marker, to understand)

No coordinate system (xyz) for the free-body diagram

Missing or incorrect forces and/or moments

Equations of Equilibrium

For any 2D or 3D static equilibrium problem, you must state your equations of equilibrium

e.g. 2D - $\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma M_A = 0$

3D - $\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma F_z = 0$, $\Sigma M_x = 0$, $\Sigma M_y = 0$, or $\Sigma M_z = 0$

Some additional tips for the Analysis section:

- pay attention to the proper position for subscripts and superscripts,
- place arrows over vector quantities and a circumflex (^) over unit vectors,
- all numerical quantities must have proper units attached, and
- include all equations that you use and show every step of your work.

This will help prevent you from making simple computational mistakes.

Conclusions

This section must provide a **sentence** that answers the original question. Final numerical answers must be as you calculated them. Final numerical answers must have units. Express all final answers to three significant figures. This means that you should record any intermediate results to at least five significant figures in order to maintain precision in your calculations.

Why it is required:

Clear conclusions are the bottom-line "take away" from your problem solving efforts. They directly address what it is that you were asked to "Find". Conclusions need to be clear and precise so that readers do not misinterpret your findings.

Good answers:

A sentence or two that summarize your conclusions. Included should be quantitative answers to three significant figures with correct units. There should be no ambiguity about notation and terms.

Common errors:

No sentence is written. This prevents the reader from understanding the context of your answer(s).

Units are incorrect. You need to use correct units to convey your conclusions correctly.

Notation is incorrect. For example, you might be describing a vector but you notate it as a scalar.

More/less than three significant figures. Our standard is three significant figures for conclusions, as these are generally valid and provide a good amount of precision on your answers.

Numerical answers are incorrect. We don't actually penalize you for this, if everything else is well done (sentence, units, significant figures, notation) as long as your answers are "reasonable". If the answers are obviously incorrect, then you will lose marks as this is something that you should have recognized and realized. This is an issue of professional credibility.

Vectors

Vectors can be represented in 5 different ways in this course:

i) a right directed arrow over the variable e.g.

$$\vec{A} \quad \overrightarrow{ABC}$$

ii) a right directed half arrow over the variable e.g.

$$\vec{a} \ \overrightharpoon{AB}$$

iii) a bolded variable name e.g. **A** or **ABC**, for <u>typed</u> solutions

iv) a circumflex (^) over unit vectors e.g.

$$\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$$

v) state as "vector A", "vector B" etc.

For handwritten solutions, please use the arrows (half or full) and the circumflexes, but not the bolding.

There are 4 main types of vectors that we'll use in GE 124: unit vectors, position vectors, force vectors, and moment vectors.

Unit vectors come in two forms; **i**, **j**, **k** or $\mathbf{u}_{AB}$. The **i**, **j**, **k** vectors are the unit vectors along the x, y, z axes. The $\mathbf{u}_{AB}$ vector is a unit vector along AB. It is very important to have the subscript because it tells us what **u** is a unit vector for e.g. along AB. Also, the directionality is important i.e. $\mathbf{u}_{AB}$ isn't $\mathbf{u}_{BA}$ (they have opposite orientations).

Position vectors should be of the form **AB** or $\mathbf{r}_{AB}$ or $\mathbf{r}_{A}$ i.e. a vector named by two points or an "r" with a subscript of two points or "r" with one subscript of the end point which assumes that the position vector starts at the origin i.e. $\mathbf{r}_{A}$ is from the origin to point A. Note that the order of the two points indicates directionality of the vector.

Force vectors should be of the form $\mathbf{F}_{AB}$ or $\mathbf{F}_{1}$ or **F** or $\mathbf{T}_{AB}$ i.e. **F** indicates a force vector and they often have a subscript denoting the line along which they act (e.g. AB) or which force is which (e.g. $\mathbf{F}_{1}$). If there is only one force with no reference points, it may be called **F**. The force in ropes may be noted by **T**, for tension, but it will usually have a subscript denoting the specific rope. Note that **F** for **T** should be capitalized.

Moment vectors should be of the form $\mathbf{M}_O$ or **M** or $\mathbf{M}_{AB}$ or $\mathbf{M}_x$ i.e. a moment vector about a specific point such as O, a generic moment vector, or a moment vector about an axis e.g. AB, or a moment about a major axis e.g. the x axis. Note that couple moments can be represented the same ways, though they are often shown as **M** or $\mathbf{M}_1$ i.e. a general or specific couple moment.

When expressing any vector in Cartesian form, we use the format $\mathbf{F} = \{F_x\,\mathbf{i} + F_y\,\mathbf{j} + F_z\,\mathbf{k}\}$ N, in the case where the force is measured in Newtons. The equivalent for a position vector would be $\mathbf{AB} = \{AB_x\,\mathbf{i} + AB_y\,\mathbf{j} + AB_z\,\mathbf{k}\}$ m (when distance is measured in metres), while a moment or couple moment vector would be $\mathbf{M}_O = \{M_x\,\mathbf{i} + M_y\,\mathbf{j} + M_z\,\mathbf{k}\}$ Nm (if measured in Nm).

Coordinates of Points

When listing the coordinates of a point, use the following format: A (x, y, z) m (if measured in metres). Just make sure units are included at the end of the coordinates of the point.

Scalars

No special notation, except to say that magnitudes of vectors are **always positive**.

Units

When representing moments, one can use Nm or N•m (for SI) or lbft or lb•ft (for US Customary).

M vs m

M is a moment, m is a mass.

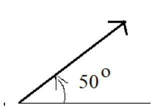
Indicating Angles

There are three acceptable ways to indicate angles in GE 124.

i) A specified number of degrees from a specified fixed axis, CCW or CW e.g. 50° CCW from + x-axis

ii) A specified number of degrees following an appropriate angle icon e.g. ∡ 50°

iii) An appropriate angle icon with the angle and an arrow inside it e.g.



Speed versus Velocity (and Distance versus Displacement)

If a speed has a magnitude but no direction, it's a speed value. If it also has an indication of direction, it is taken to be a velocity vector. Similarly for distance and displacement, if only a magnitude is given it is considered to be a distance measurement. If direction is also provided, then it is a displacement vector.

Positive Direction for Axis Perpendicular to Paper

For determining the positive z axis in 2D problems. It is determined according to the right hand rule.

Directions of Moments about a Point

CCW is positive and is considered to be “out of the page” i.e. the direction of the thumb with right hand.

CW is negative and is considered to be “into the page” i.e. the direction of the thumb with right hand.

Directions of Moments about a 3D Axis

CCW is positive, looking down the axis towards the origin i.e. the thumb of the right hand will be pointing along the positive direction of the axis.

CW is negative, looking down the axis towards the origin i.e. the thumb of the right hand will be pointing along the negative direction of the axis.

Equations of Equilibrium for 2D and 3D Calculations

The sum of the forces in the x-direction is equal to zero: $\Sigma F_x = 0$

The sum of the forces in the y-direction is equal to zero: $\Sigma F_y = 0$

The sum of the forces in the z-direction is equal to zero: $\Sigma F_z = 0$

The sum of the moments around a point is equal to zero e.g. $\Sigma M_A = 0$

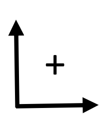
The sum of the moments around the x-axis is equal to zero: $\Sigma M_x = 0$

The sum of the moments around the y-axis is equal to zero: $\Sigma M_y = 0$

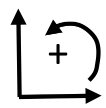
The sum of the moments around the z-axis is equal to zero: $\Sigma M_z = 0$

How to Show Coordinate Axes

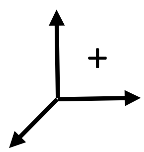
For positive x and y axes, no moments e.g. 2D particle equilibrium



For positive x and y axes, and moments e.g. 2D rigid body equilibrium



For positive x, y, and z axes, no moments e.g. 3D particle equilibrium



For positive x, y, and z axes, and moments e.g. 3D rigid body equilibrium