SOLUTION MANUAL

NOTE: In addition to the information in this solution manual, many CAD programs are available in the solution manual folder which are integral part of this manual.

1. INTRODUCTION TO DESIGN

Problems

1-1 *What is the difference between* ***conceptual*** *and* ***cognitive*** *design process? Which is used in each design process?*

Conceptual design process is related to or based on mental concepts. A mathematical model is a model of a concept. The idea or a concept should take some thought to figure it out if it is new, abstract, or an original notion. The conceptual design is an early stage which needs to be fleshed out by details. Conventional conceptual design would use classical concepts and knowledge of machine elements, structures, mechanisms, and alike to develop the scheme and details of the design or the product that performs a needed function or functions.

Cognitive process is the mental action or procedure of acquiring knowledge and understanding through thought, experience, and the senses. It encompasses many aspects of intellectual functions and processes such as attention, the formation of knowledge, memory and working memory, perception, mental imagery and manipulation, judgment and evaluation, reasoning and "computation", problem solving and decision making, comprehension and production of logical schema. Cognitive processes would use existing knowledge and generate new knowledge.

Cognitive design process could be an earlier step of *conceptual* design. It may involve synthesized, inventive, and additional innovative process to generate new concepts.

1-2 *Find the necessary information to consider in the design of a motorcycle.*

A motorcycle has so many subsystems components and each subsystem or component should perform a certain function.

It has a prime mover (internal combustion or electric, or … etc.). This is a main subsystem which has so many other subsystems and components. The main necessary information to consider:

- Needed minimum power to move a person or others at a maximum speed limit (to be defined) and at the maximum grade or steep hill angle.
- The power train components and reduction ratios for different performance speed and grade.
- Wheels and tires geometry, construction, joining, and specifications.
- Frame shape, geometry, and necessary joining elements.
- Steering mechanism and control.

1-3 *A trans-mixer design consideration is defined in reference [1] and Figure 1.1. Discuss the main problem considered and the method of solution used in that reference. Can the case of that reference be considered as the main design problem of this equipment? What should be the primary performance goal of the trans-mixer design?*

The main problem considered is the drum filled with concrete under some driving conditions. The method use in the analysis is the finite element method ***FE***. This design case is part of the design consideration, but it is not the main design problem. The driving power of the drum and the stress analysis of the main components are the main design problem. The primary performance goal is to get the concrete from the mixing station to the delivery site without change in properties.

1-4 *Define the expected subsystems and components in the design of the trans-mixer of Figure 1.1. Suggest the main components for a manufacturer of the trans-mixer to produce and the other components to acquire as standard or as OEM. Are there other alternatives for the trans-mixer configurations and alternatives? What are the powers driving the trans-mixer drum and the usual truck caring the drum for different sizes of the concrete loads?*

It is advisable for the students to search the net for the different trans-mixer design configurations, constructions, components, and manufacturers. For a manufacturer of the trans-mixer, the suggested main components to manufacture are the main mixing drum, its supports, the support structure, the concrete loading and unloading mechanism, the needed water tank, and the main joining means to the hauling truck. The other suggested components to acquire as standard or as OEM systems are the supporting bearings and seals, the driving prime mover, and the power transmission system to the main mixing drum. The main driving powers are either a separate internal combustion engine or a power takeoff from the hauling truck.

1-5 *What type of loading conditions you expect the trans-mixer to be subjected to on its journey from the initial unloaded state to the loading state at the mixing station and from the mixing station to the construction site?*

The trans-mixer is assumed to be the system on to the truck that the concrete is loaded in at the mixing station. When empty, the load is the dead weight of the drum on its bearings, and the load of the drum and the supporting system onto the chassis. When the drum is loaded by the concrete, the concrete weight is added to the dead weight of the drum. From the mixing station to the construction site, the road profile induces accelerations onto the drum and the concrete charge that should be considered in the dynamic analysis of the trans-mixer. The uphill and downhill grades affect the loading directions. In addition, the acceleration and braking deceleration induce forces that should be accounted for into the dynamic stress analysis of the trans-mixed.

1-6 *Select a machine tool and define its main subsystems and components. Identify the expected loading types and variations.*

It is advisable for the students to search the school workshop or the net for a machine tool, or the instructor specifies a machine tool. The main subsystems would include the motor or the prime mover, and the power transmission to the part intended to be manufactured. The power is also transmitted through components to the tool acting onto the part to be machined. The cutting or forming forces between the part and the tool affect the power transmission system and the tool supporting structure. The specifics depend on the type of the machine tool. A lathe, a milling machine, a drill, or a press would be such a machine tool type.

1-7 *Few mechanisms are usually used in dump trucks. Select one of these mechanisms and define its main subsystems and components. What are the expected loading variations and extremes?*

It is advisable for the students to search the net for different dump truck mechanisms. Alternatively, the instructor can specify one or more systems to consider. The usual dump truck is operated by a hydraulic cylinder lifting the dump container on top of the truck chassis. The main components are then the dump container, its support bearings to the sub-chassis, and the sub-chassis structure. The hydraulic cylinder that lifts the dump container, the hydraulic pump, hydraulic fluid tank and the fluid power controls are the other subsystem. The loading extremes are dependent on the hydraulic cylinder location and the lifting mechanism geometry. Many alternatives are available, and few can be comparatively evaluated.

1-8 *Define the expected basic mechanical functions in the systems and subsystems of the trans-mixer of Figure 1.1.*

The basic mechanical functions that are of concern in the trans-mixer are mainly the supporting, the power transmission, the enclosing, and the sealing functions. The drum is supporting the concrete mix. The drum bearings are supporting the drum to the sub-chassis. The sub-chassis is supported onto the truck chassis. The power is transmitted from the prime mover to rotate the drum while hauling the concrete and discharging it at the construction site. The drum is enclosing the concrete and the sub-chassis is enclosing the trans-mixer system. Sealing is essential in the power transmission system and in the water tank function to clean the drum after concrete dumping. The controlling functions are usually on-off type.

1-9 *Identify the basic mechanical functions in each of the subsystems in a motorcycle.*

The basic mechanical functions that are of concern in a motorcycle are mainly the supporting, the power transmission, the enclosing, the sealing, and the controlling functions. A motorcycle has so many subsystems components and each subsystem or component should perform a certain function. The main subsystems are:

- It has a prime mover (internal combustion or electric, or … etc.). This is a main subsystem which has so many other subsystems and components. All basic mechanical functions are present in this subsystem.
- The motorcycle frame is mainly supporting the rider or riders, the prime mover, the gas tank, the battery, … etc. It is also enclosing all these components.
- The wheels and tires including brakes are supporting, power transmitting, and controlling the motion including directional steering.
- The battery and electric facility subsystem are power transmitting, and controlling functions.

1-10 *Select a machine tool in the workshop or lab and study the subsystems defining the basic mechanical functions in each subsystem and its connections.*

It is advisable for the students to search the school workshop or the net for a machine tool, or the instructor specifies a machine tool. Again, the main subsystems would include the motor or the prime mover, and the power transmission to the part intended to be manufactured. The power is also transmitted through components to the tool acting onto the part to be machined. The cutting or forming forces between the part and the tool affect the power transmission system and the tool supporting structure. The specifics depend on the type of the machine tool. A lathe, a milling machine, a drill, or a press would be such a machine tool type.

The basic mechanical functions that are of concern in a machine tool are mainly the supporting, the power transmission, the enclosing, the sealing, and the controlling functions. Each of the previous subsystems has most of these basic mechanical functions.

1-11 *Which are the major performance objectives in the design of motorcycles, trans-mixers, machine tools, and dump trucks? Can you suggest a categorized hierarchy from the necessary to the required objectives if more than one is there?*

The major performance objectives differ from a system to the other. The major performance objective of a motorcycle is to transport rider from a place to another place in a reasonable time. The major performance objective of a trans-mixer is to transport concrete mix from the mixing station to the construction site without degradation of the concrete mix. The major performance objective of a machine tool is to accurately produce a certain step in the manufacturing of a product. The major performance objective of a dump truck is to transport mainly loose objects from a place to another place where it would be dumped.

1-12 *What are the safety and reliability measures anticipated in each of the designs of motorcycles, trans-mixers, machine tools, and dump trucks?*

The safety and reliability measures anticipated in each of these designs are to perform the major performance functions without failure for the duration of the intended life, minimum degradation of the performance below a least bound, and the guarantee of a minimum acceptable accuracy in the delivered objective.

1-13 *Is it possible to guess or find out the cost and economy of the motorcycles, trans-mixers, machine tools, and dump trucks? What is the usual price range for each excluding off-range values of special products if any?*

It is usually not possible to guess any unless with some previous experience. It is possible, however, to find the cost and economy of each of these products. It is advisable for the students to search the net or other means for that. It is also advisable to get the cost per unit weight of each of these products.

1-14 *Would you prefer design by repeated analysis or by synthesized means to aid in defining geometry and selection of materials? Identify your reasons for your selection.*

It is advisable for the students to think, debate, and experiment with each design process of these.

1-15 *Select a very old technology of a design that is not used nowadays and a very advanced technology of a design that you expect to be used in the future suggesting each product life cycle with past and future time.*

It is advisable for the students to think, select, evaluate, and experiment with each design.

1-16 *Study one of the following products namely: motorcycles, trans-mixers, machine tools, and dump trucks (or any other similar product). What is the global market size last year or year before? What are the market shares of the top producers? Is it possible to guess the sales margin from the profit of the top producer's annual budget? What is the amount of research and development (R&D) spending by the producer in its budget? Is it possible to identify the (R&D) teams in the producer's employee structure?*

This is an investigative project that each student should do if the economic part of the design is highlighted.

1-17 *What do you suggest to make sure that no confusion or errors in the applications of mass, weight and force in the US or SI systems of units? Did you experience a problem or problems in applications?*

One ought to change all the variables or quantities to the adopted US units of [lb, in, s] or to the adopted SI units of [N, m, s] or [m, kg, s] before proceeding into any further calculations. For mass, weight, and force, see section 1.11.1 particularly the part about *Weight*. If the student did not experience a problem or problems in applications, he should explain the reason.

1-18 *Define the relations to the adopted ones (US [lb, in, s] and SI [m, kg, s]) among the following units:*

- *Ton (long), ton (short), ounce* [oz] to [lb].
- *Mile, yard, foot, to* [in].
- *Gallon, quart, pint to* [in^3].
- *Yard^3, ft^3 to* [in^3].
- *Hour, minute to second* [s].
- *Degree, minute, second to radian* [rad].
- *Liter to meter^3* [m^3].
- *Bar of pressure to pascal* [Pa] and [psi].

To change all the variables or quantities to the adopted US units of [lb, in, s] or to the adopted SI units of [N, m, s] or [m, kg, s] before proceeding into any further calculations, one gets the following.

- Ton (long) = 2240 [lb], 1 ton (short) = 2000 [lb], 1 ounce [oz] = 0.0625 [lb].
- Mile = 63360 [in], 1 yard = 36 [in], 1 foot = 12 [in].
- Gallon = 231 [in^3], 1 quart = 57.75 [in^3], 1 pint = 28.875 [in^3].
- Yard^3 = 46656 [ft^3], 1 Yard^3 = 46656 [in^3], 1 ft^3 = 1728 [in^3].
- Hour = 60 [min], 1 hour = 3600 second [s].
- Degree = 0.0174533 [rad], 1 degree = 60 minutes, 1 minute = 0.000290888 [rad], 1 second = 4.84814e-6 radian [rad].
- Liter = 0.001 [m^3].
- Bar of pressure = 10^5 pascal [Pa] = 0.1 [MPa] and bar of pressure = 14.5038 [psi].

1-19 *What is the factor of the following related to the basic unit: tera, deci, centi, pico, and femto?*

1 tera = 10^{12} = 1000 [G], 1 deci = 0.1, 1 centi = 0.01 = 10^{-2}, 1 pico = 10^{-12}, and 1 femto = 10^{-15}.

1-20 *A vehicle is traveling at 70 miles per hour. What is the vehicle speed in [in/s], [m/s] and [km/s]?*

Speed = 70 [mi/hr] = 70 (63360 [in]/[mi]) (1/3600 [hr]/[s]) = 1232 [in/s].
Speed = 70 [mi/hr] = 70 (1609.34 [m]/[mi]) (1/3600 [hr]/[s]) = 31.2927 [m/s].
Speed = 70 [mi/hr] = 70 (1.60934 [km]/[mi]) (1/3600 [hr]/[s]) = 0.0312927[km/s].

1-21 *The trunk space of a vehicle is 50 foot^3. What is the volume in* [in^3]*, liter and* [m^3]*?*

50 foot^3 = 50 [ft^3] (12 [in]/[ft])^3 = 86400 [in^3].
50 foot^3 = 50 [ft^3] (12 [in]/[ft](25.4 [mm]/in)^3 (1/10^6 [liter]/[mm^3]) = 1415.84233 [liter].
50 foot^3 = 50 [ft^3] (12 [in]/[ft](25.4 [mm]/in)(1/1000[m]/[mm])^3 = 1.41584233 [m^3].

1-22 *The drive power H in a power station is 15000 [kW], and the rotational speed N_{rpm} is 3000 [rpm]. It is required to evaluate the torque **T** in both SI and customary US units. What is the equivalent power H in horsepower [hp] and in pound-inch-second units?*

From equations (1.6), (1.12), and (1.13), the torque ***T*** is given by the following relations.

$$\boldsymbol{T}_{N.m} = \frac{60 H_{kW}(1000)}{2\pi\ N_{rpm}} = \frac{60(15000)(1000)}{2\pi(3000)} = 47746.48\ \text{[N.m]}$$ (1-22 (a))

$$\boldsymbol{T}_{lb\ in} = \frac{63025 H_{hp}}{N_{rpm}} = \frac{63025(1/0.7457\text{[hp]/[kW]})(15000)}{(3000)} = 422589.5\ \text{[lb.in]}$$

From equations (1.12) and (1.13), and Table 1.3, one can get the following.

$$H_{hp} = 0.7457\ H_{kW} = 0.7457\ (15000) = 11185.\ \ \text{[hp}$$ (1-22 (b))

$$H_{lb.in/s} = \boldsymbol{T}_{lb\ in}\cdot\boldsymbol{\omega} = \frac{2\pi\ N_{rpm}\boldsymbol{T}_{lb.in}}{60} = \frac{2\pi\ (3000)(422589.5)}{60} = 132760406.87\ \text{[lb.in/s]}$$ (1-22 (c))

1-23 *The power H of a fan is 0.075 [kW], and the rotational speed N_{rpm} is 1000 [rpm]. Evaluate the torque T in both SI and customary US units. What is the power H in horsepower [hp] and in pound-inch-second units?*

From equations (1.12) and (1.13), and Table 1.3, one can get the following.

$$H_{hp} = 0.7457\ H_{kW} = 0.7457\ (0.075) = 0.05592\ \ \text{[hp}$$ (1-23 (a))

$$H_{lb.in/s} = \frac{2\pi(63025)H_{hp}}{60} = 6600(1/0.7457\text{[hp]/[kW]})(0.075) = 663.80\ \text{[lb.in/s]}$$ (1-23 (b))

1-24 *A cylinder with an internal piston has a diameter of 6 [in]. The internal pressure can have a maximum value of 3000 [psi]. What is the maximum force the piston rod can deliver in US and SI units?*

From Tables 1.2 and 1.3, one can get the basic parameters as follows. The piston diameter d_P = 6 [in] or 152.4 [mm] or 0. 1524 [m]. The pressure p = 3000 [psi] or 3000 (6894.8 [Pa] / [psi]) = 20,684,400 [Pa]. The piston force $\boldsymbol{F}_P$ is simply the pressure times the piston area. This gives the following.

$$\boldsymbol{F}_P = p\ A_P = p\left(\frac{\pi}{4}d_P^2\right) = 20\ 684\ 400\left(\frac{\pi}{4}0.1524^2\right) = 377\ 314\ \text{[N]}$$

$$\boldsymbol{F}_P = p\ A_P = p\left(\frac{\pi}{4}d_P^2\right) = 3000\left(\frac{\pi}{4}6^2\right) = 84\ 823\ \text{[lb]}$$

1-25 *A manual air pump cylinder has an internal diameter of 1.5 [in]. If the maximum force that can be exerted on the piston rod is 60 [lb], what is the maximum pressure that can be delivered by the pump. If the pump is to be used to pressurize a tire to 35 [psi], what should be the maximum necessary force exerted manually to do the job?*

From Tables 1.2 and 1.3, one can get the basic parameters as follows. The piston diameter d_P = 1.5 [in] or 38.1 [mm] or 0.0381 [m]. The maximum piston force $\boldsymbol{F}_P$ = 60 [lb] or 60 (4.4482 [N] / [lb]) = 266.89 [N]. The maximum pressure p_{max} is simply the force divided by the piston area. This gives the following.

$$p_{max} = \frac{\boldsymbol{F}_P}{A_P} = \frac{4\boldsymbol{F}_P}{\pi d_P^2} = \frac{4(266.89)}{\pi(0.0381^2)} = 234\ 095\ \text{[Pa]}$$ (1-25 (a))

$$p_{max} = \frac{\boldsymbol{F}_P}{A_P} = \frac{4\boldsymbol{F}_P}{\pi d_P^2} = \frac{4(60)}{\pi(1.5^2)} = 33.953\ \text{[psi]}$$

The pressure p = 35 [psi] or 35 (6894.8 [Pa] / [psi]) =241318 [Pa]. The maximum force $\boldsymbol{F}_P$ is given by:

$$\boldsymbol{F}_P = p\ A_P = p\left(\frac{\pi}{4}d_P^2\right) = 241318\left(\frac{\pi}{4}0.0381^2\right) = 275.12\ [\text{N}] \qquad (1\text{-}25\ (b))$$
$$\boldsymbol{F}_P = p\ A_P = p\left(\frac{\pi}{4}d_P^2\right) = 35\left(\frac{\pi}{4}1.5^2\right) = 61.850\ [\text{lb}]$$

1-26 *Solve problem 25 using the SI units.*

The solution is given in problem 1-25.

1-27 *Use the determinant expansion of the cross product in equation (1.23) to verify the equivalent position matrix multiplication of equation (1.22) of the text.*

$$\boldsymbol{r}_1 \times \boldsymbol{F}_1 = \begin{vmatrix} \boldsymbol{i} & \boldsymbol{j} & \boldsymbol{k} \\ r_{1x} & r_{1y} & r_{1z} \\ F_{1x} & F_{1y} & F_{1z} \end{vmatrix} = \left(r_{1y}F_{1z} - r_{1z}F_{1y}\right)\boldsymbol{i} + \left(r_{1z}F_{1x} - r_{1x}F_{1z}\right)\boldsymbol{j} + \left(r_{1x}F_{1y} - r_{1y}F_{1x}\right)\boldsymbol{k} = \begin{bmatrix} r_{1y}F_{1z} - r_{1z}F_{1y} \\ r_{1z}F_{1x} - r_{1x}F_{1z} \\ r_{1x}F_{1y} - r_{1y}F_{1x} \end{bmatrix}$$

This is exactly the same as equation (1.22).

1-28 *A body is subjected to the three force vectors of $[3\ \ 0\ \ 0]$, $[0\ \ 4\ \ 0]$, and $[0\ \ 0\ \ 5]$ in [lb]. Find the force matrix and the resultant of the combined force vectors on the body in US and SI units. What is the magnitude of the resultant force in US and SI units? Find the direction cosines of the resultant.*

With (4.4482 [N] / [lb]), the three force vectors of $[3\ \ 0\ \ 0]'$, $[0\ \ 4\ \ 0]'$, and $[0\ \ 0\ \ 5]'$ in [lb] are three force vectors of $[13.345\ \ 0\ \ 0]'$, $[0\ \ 17.793\ \ 0]'$, and $[0\ \ 0\ \ 22.241]'$ in [N].. According to equation (1.19), the force matrix is as follows.

$$\left[\boldsymbol{F}\right] = \begin{bmatrix} F_{1x} & F_{1y} & F_{1z} \\ F_{2x} & F_{2y} & F_{2z} \\ F_{3x} & F_{3y} & F_{3z} \end{bmatrix} = \begin{bmatrix} 3 & 0 & 0 \\ 0 & 4 & 0 \\ 0 & 0 & 5 \end{bmatrix}[\text{lb}] = \begin{bmatrix} 13.345 & 0 & 0 \\ 0 & 17.793 & 0 \\ 0 & 0 & 22.241 \end{bmatrix}[\text{N}] \qquad (1\text{-}28\ (a))$$

According to equation (1.20), the resultant $\boldsymbol{R}_F$ of the combined force vectors is as follows.

$$\boldsymbol{R}_F = \begin{bmatrix} \sum_{i=1}^{3} F_{ix} \\ \sum_{i=1}^{3} F_{iy} \\ \sum_{i=1}^{3} F_{iz} \end{bmatrix} = \begin{bmatrix} 3 \\ 4 \\ 5 \end{bmatrix}[\text{lb}] = \begin{bmatrix} 13.345 \\ 17.793 \\ 22.241 \end{bmatrix}[\text{N}] \qquad (1\text{-}28\ (b))$$

The magnitude of the resultant $\|\boldsymbol{R}_F\|$ of the combined force vectors is then

$$\left\|\boldsymbol{R}_F\right\| = \sqrt{R_{Fx}^2 + R_{Fy}^2 + R_{Fz}^2} = \sqrt{3^2 + 4^2 + 5^2} = 7.0711\ [\text{lb}] \qquad (1\text{-}28\ (c))$$
$$\left\|\boldsymbol{R}_F\right\| = \sqrt{R_{Fx}^2 + R_{Fy}^2 + R_{Fz}^2} = \sqrt{\quad{}^2 + \quad 93^2 + 22.24\ {}^2} = 31.454\ [\text{N}]$$

The direction cosines of the resultant should be the same for the US and the SI systems. They are then given by:

$$\begin{aligned} \alpha &= \frac{R_{Fx}}{\|\boldsymbol{R}_F\|} = \frac{3}{7.0711} = 0.42426 \\ \beta &= \frac{R_{Fy}}{\|\boldsymbol{R}_F\|} = \frac{4}{7.0711} = 0.56568 \\ \gamma &= \frac{R_{Fz}}{\|\boldsymbol{R}_F\|} = \frac{5}{7.0711} = 0.70710 \end{aligned} \qquad (1\text{-}28\text{ (d)})$$

1-29 *The maximum applied force on the door handle of Figure 1.8 is 20* [N] *and the applied force position vector is* $[0.05, 0.05, 0.12]^T$ *in* [m]. *What is the maximum moment at the base of the handle?*

Applying equation (1.22), one gets

$$\boldsymbol{M}_0 = \boldsymbol{r}_1 \times \boldsymbol{F}_1 = \begin{bmatrix} 0 & -r_{1z} & r_{1y} \\ r_{1z} & 0 & -r_{1x} \\ -r_{1y} & r_{1x} & 0 \end{bmatrix} \begin{bmatrix} F_{1x} \\ F_{1y} \\ F_{1z} \end{bmatrix} = \begin{bmatrix} 0 & -0.12 & 0.05 \\ 0.12 & 0 & -0.05 \\ -0.05 & 0.05 & 0 \end{bmatrix} \begin{bmatrix} 0 \\ -20 \\ 0 \end{bmatrix} = \begin{bmatrix} 2.4 \\ 0 \\ -1 \end{bmatrix} \text{ [N.m]}$$

See MATLAB code ***Cross_product_Prob_1_29_30.m***.

1-30 *Solve problem 29 using the US system of units.*

According to Table 1.2, the force is 20 (0.22481 [lb]/[N]) = 4.4962 [lb] and as there is (39.37 [in]/[m]), the position vector is (1.9685, 1.9685, 4.7244) in [in], equation (1.22), gives the following.

$$\boldsymbol{M}_0 = \boldsymbol{r}_1 \times \boldsymbol{F}_1 = \begin{bmatrix} 0 & -r_{1z} & r_{1y} \\ r_{1z} & 0 & -r_{1x} \\ -r_{1y} & r_{1x} & 0 \end{bmatrix} \begin{bmatrix} F_{1x} \\ F_{1y} \\ F_{1z} \end{bmatrix} = \begin{bmatrix} 0 & -4.7244 & 1.9685 \\ 4.7244 & 0 & -1.9685 \\ -1.9685 & 1.9685 & 0 \end{bmatrix} \begin{bmatrix} 0 \\ -4.4962 \\ 0 \end{bmatrix} = \begin{bmatrix} 21.242 \\ 0 \\ -8.8508 \end{bmatrix} \text{ [lb.in]}$$

See MATLAB code ***Cross_product_Prob_1_29_30.m***.

2. DESIGN CONSIDERATIONS

NOTE: In addition to the information in this chapter, many CAD programs are available in the folder of the solution manual, which are integral part of this chapter.

Problems

2-1 *What is the **inertial** coordinate system? What is the difference between inertial and **Cartesian**, polar, cylindrical, and spherical coordinate systems? Which is the mostly used in each design process and why? Did you know that there is a **Homogeneous** coordinate system that is very useful in **projection**?*

The *inertial* coordinate system is the global coordinate system fixed in the absolute stationary universal coordinate system. It may be also moving at a constant velocity so that no inertia effects would be present. *Cartesian* coordinates are the system of coordinates that is used in an inertial reference frame. The three space coordinates are usually Cartesian coordinates (x, y, z), and the time coordinate is the time as measured at rest in the coordinate system. The *polar* coordinate system in a two-dimensional coordinate system in which each point on a plane is determined by a distance from a reference point and an angle from a reference direction. *Cylindrical* coordinates are a generalized *2D polar* coordinate to *3D* by superposing a height (h) axis. The ISO standard 31-11 recommends (ρ, φ, z), where ρ is the radial coordinate, φ the azimuth, and z the height. However, the radius is also often denoted r or s, the azimuth by θ or t, and the third coordinate by h or (if the cylindrical axis is considered horizontal) x, or any context-specific letter. *Spherical* coordinate system is a system for *3D* space where a point is definite by three numbers: the radial distance from a fixed origin, its polar angle from a fixed *zenith* direction, and the *azimuthal* angle of its orthogonal projection on a reference plane that passes through the origin and is orthogonal to the zenith, measured from a fixed reference direction on that plane. ISO convention frequently encountered in physics: (r, θ, φ) defines the radial distance, polar angle, and azimuthal angle.
For ***Homogeneous*** coordinate system, see section 4.1.2.

2-2 *A door is pivoted to the left by two hinges into the wall. The door handle is to the right edge of the door similar to Figure 2.3. To open the door, one needs to unlock the door using the handle and then pull the door open. What mathematical model can be adopted? Is the origin better being at the handle base or one of the door hinges? Draw a free body diagram (**FBD**) of the door and handle. When do you consider friction at the hinges or handle lock?*

Figure 2.3 is the ***FBD*** of the handle. No need to include the door in the ***FBD*** since no motion is needed to be modeled for the door. The origin is then better be at the handle base. The ***FBD*** of the door and handle will be modeled by moving the coordinate origin in the negative z direction by an amount equals to the door width minus the door handle z distance r_{1z} and moving the z coordinate axis in the negative y direction by the door reaction $\boldsymbol{R}_1$ distance r_{W1y}, see Figure P 2-2. The friction is considered at the handle or door hinges if it is significant with respect to the applied forces and moments.

2-3 *A very heavy steel door has a handle similar to that in Figure 2.3. The door is homogeneous and weighs 500* [lb]. *To open the door, the handle is first pushed down by a vertical force to its maximum of 5* [lb] *to unlock and simultaneously pulled horizontally by a necessary force of 9* [lb] *to move the door. It is required to model the door and its handle to find the reaction at the lock support and door hinges. If the door is 4 feet wide, find the forces and moments acting on the door at its inception of movement. The door has two vertical hinges. Suggest the locations of the hinges and handle? Assume any missing data. Do vertical locations of the hinges affect the calculations?*

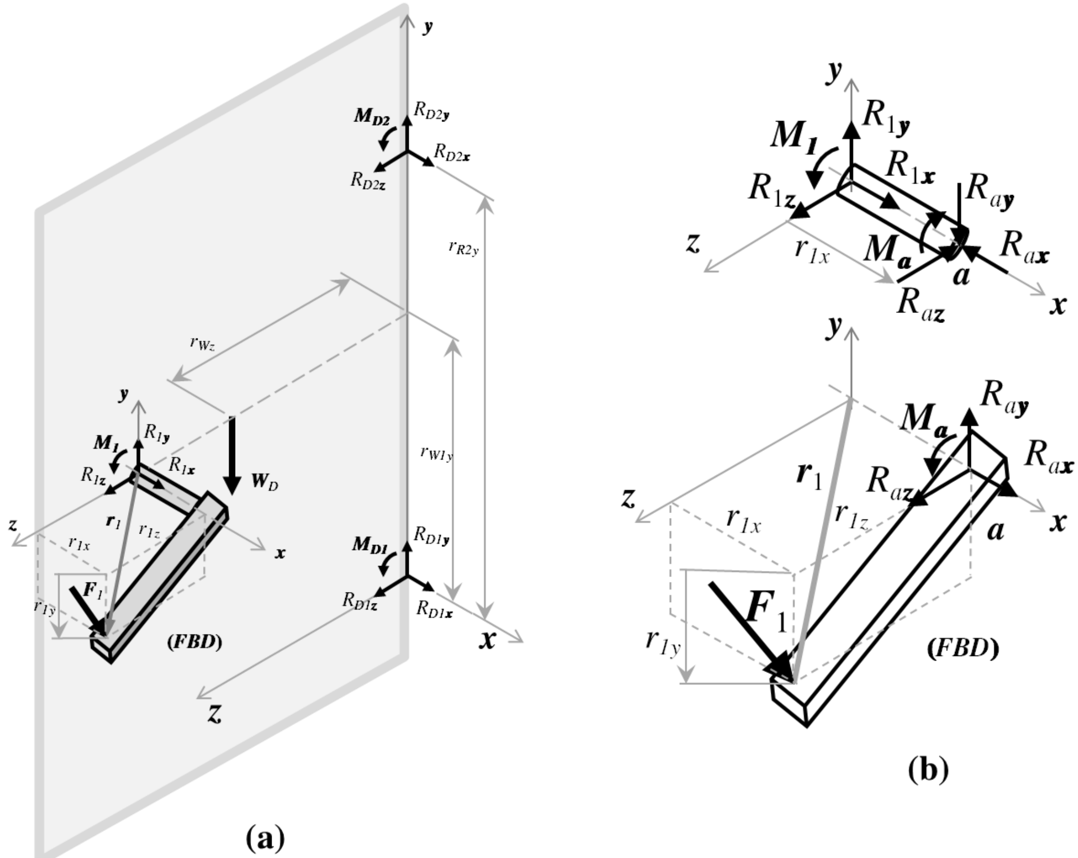

Figure P 2-2, 2-3, and 2-4.

Data: $\boldsymbol{F}_1 = [9\ \ -5\ \ 0]^T$ [lb], $\boldsymbol{r}_1 = [3\ -2\ 4]^T$ [in] (with respect to handle local coordinates), $\boldsymbol{W}_D = [0\ -500\ \ 0]^T$ [lb] and assume $\boldsymbol{r}_W = [0\ \ 40\ \ 44]^T$ [in] (with respect to door local coordinates at its $\boldsymbol{R}_{D1}$).

Either solve the handle as example 2.1 and then solve the door problem or solve the door-handle system applying the handle force and the door weight to get the door reactions. The second alternative is simpler and is seen in Figure P 2-2, 2-3, and 2-4.

The ***FBD*** of the door and handle is modeled by moving the coordinate origin in the negative z direction by an amount equals to the door width (4 [ft] = 48 [in] minus the door handle z distance r_{1z} (4 [in])) and moving the z coordinate axis in the negative y direction by the door reaction $\boldsymbol{R}_1$ distance r_{W1y}, see Figure P 2-2, 2-3 and 2-4.

The parameters are then $\boldsymbol{F}_1 = [9\ \ -5\ \ 0]^T$ [lb], $\boldsymbol{r}_1 = [3\ -2\ 48]^T$ (with respect to door local coordinates), $\boldsymbol{W}_D = [0\ -500\ \ 0]^T$ [lb] and assume $\boldsymbol{r}_W = [0\ \ 40\ \ 44]^T$ (with respect to door local coordinates at its $\boldsymbol{R}_{D1}$).

Substituting for the numerical values of the force $\boldsymbol{F}_1$ and its position vector $\boldsymbol{r}_1 = [3\ -2\ 48]^T$ [in] (with respect to door coordinates), $\boldsymbol{F}_2 = \boldsymbol{W}_D = [0\ -500\ \ 0]^T$ [lb], assume $\boldsymbol{r}_2 = \boldsymbol{r}_W = [0\ \ 40\ \ 44]^T$ [in] (with respect to door local coordinates at its $\boldsymbol{R}_{D1}$), assume $\boldsymbol{r}_{D2} = [0\ \ 80\ \ 0]$ [in], one gets the following from the MATLAB program ***Force_Analysis_3D_Short_Prob_2_2_3.m*** (for the local door coordinates).