AIRCRAFT TECHNICAL BOOK COMPANY

B1/B2

AVIATION MAINTENANCE TECHNICIAN CERTIFICATION SERIES

PHYSICS

2

COMPLIANT WITH
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EASA 2023-989 COMPLIANT

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VERSION	EFFECTIVE DATE	DESCRIPTION OF REVISION(S)
001	2013 12	Module creation and release.
002	2016.11	Format update and appearance update.
003	2018.07	Refined content sequencing to Appendix 1.
003.1	2020.05	Clarified formulas for Buoyant Force (Submodule 2).
003.2	2021.05	Corrected formulas for Pendular Movement and Vibration (Submodule 2).
003.3	2022.06	Clarified number of electrons in orbital shells (Submodule 1).
003.4	2023.04	Minor appearance and format updates.
004	2024.05	Regulatory update for EASA 2023-989 compliance.

Module was reorganized based upon the EASA 2023-989 subject criteria.

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SINGLE FIXED PULLEY

A single fixed pulley is really a first class lever with equal arms. In **Figure 2-18**, the arm from point "R" to point "F" is equal to the arm from point "F" to point "E" (both distances being equal to the radius of the pulley). When a first class lever has equal arms, the mechanical advantage is 1. Thus, the force of the pull on the rope must be equal to the weight of the object being lifted. The only advantage of a single fixed pulley is to change the direction of the force, or pull on the rope.

SINGLE MOVABLE PULLEY

A single pulley can be used to magnify the force exerted. In **Figure 2-19**, the pulley is movable, and both ropes extending up from the pulley are sharing in the support of the weight. This single movable pulley acts like a second class lever, with the effort arm (EF) being the diameter of the pulley and the resistance arm (FR) being the radius of the pulley. This type of pulley would have a mechanical advantage of two because the diameter of the pulley is double the radius of the pulley. In use, if someone pulled in 4 ft of the effort rope, the weight would only rise off the floor 2 ft. If the weight was 100 lb, the effort applied would only need to be 50 lb. With this type of pulley, the effort will always be one-half of the weight being lifted.

BLOCK AND TACKLE

A block and tackle is made up of multiple pulleys, some of them fixed and some movable. In **Figure 2-20**, the block and tackle is made up of four pulleys, the top two being fixed and the bottom two being movable. Viewing the figure from right to left, notice there are four ropes supporting the weight and a fifth rope where the effort is applied. The number of weight supporting ropes determines the mechanical advantage of a block and tackle, so in this case the mechanical advantage is four. If the weight was 200 lbs, it would require a 50 lb effort to lift it.

THE GEAR

Two gears with teeth on their outer edges, as shown in **Figure 2-21**, act like a first class lever when one gear drives the other. The gear with the input force is called the drive gear, and the other is called the driven gear. The effort arm is the diameter of the driven gear, and the resistance arm is the diameter of the drive gear. Notice that the two gears turn in opposite directions (the bottom one clockwise and the top one counterclockwise). The gear on top (yellow) is 9 inches in diameter and has 45 teeth, and the gear on the bottom (blue) is 12 inches in diameter and has 60 teeth.

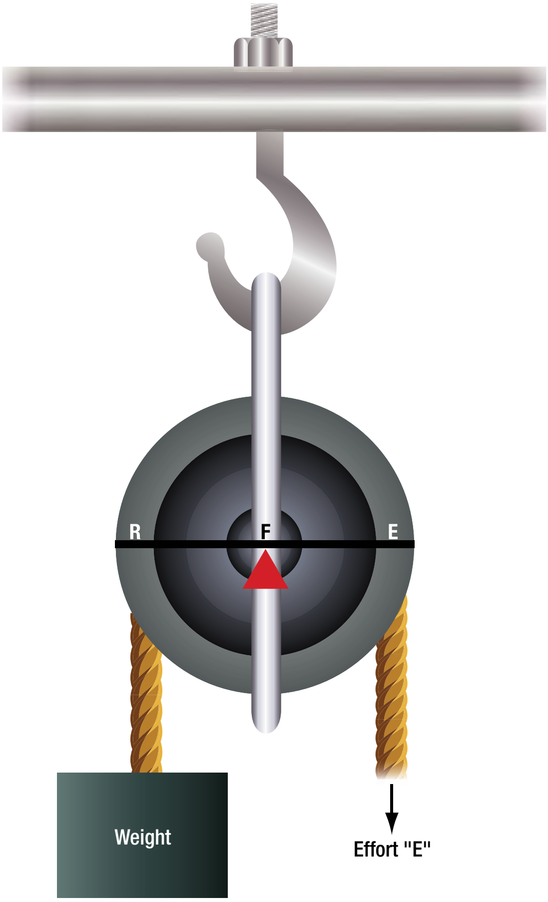

Figure 2-18. Single fixed pulley.

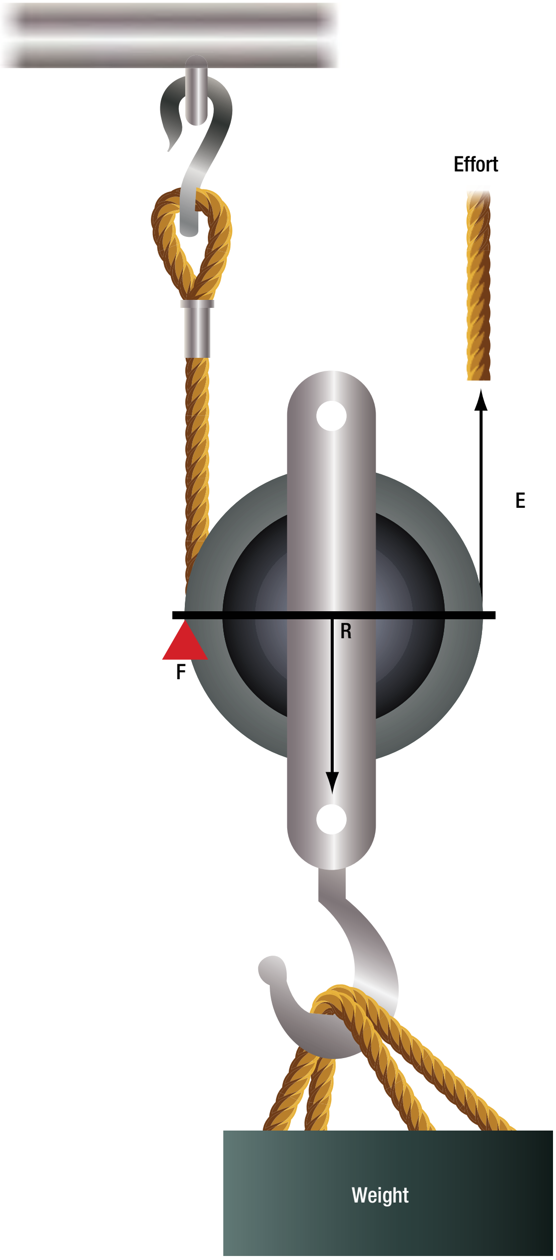

Figure 2-19. Single movable pulley.

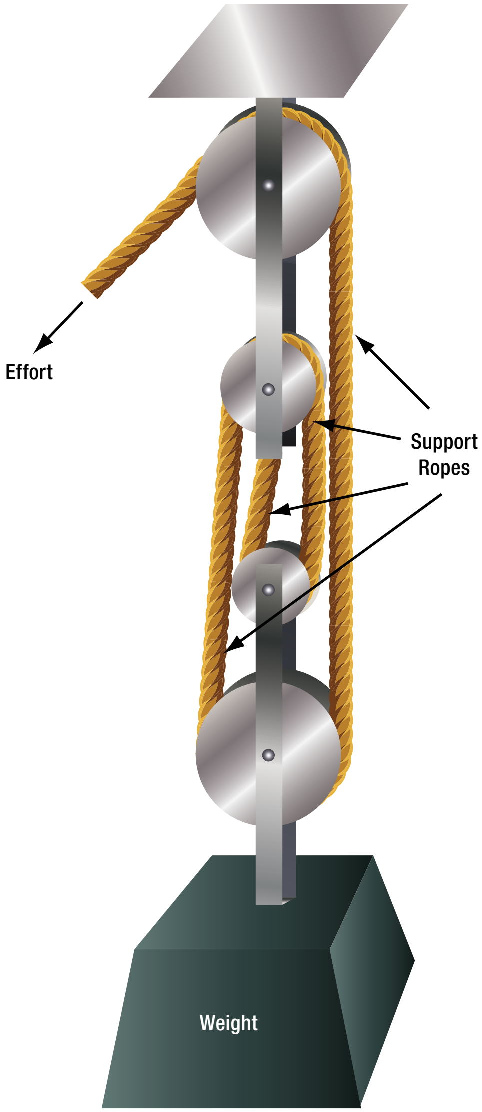

Figure 2-20. Block and tackle.

Imagine that the blue gear is driving the yellow one (blue is the drive, yellow is the driven). The mechanical advantage in terms of force would be the effort arm divided by the resistance arm, or 9 ÷ 12, which is 0.75. This would actually be called a fractional disadvantage, because there would be less force out than force in. The mechanical advantage in terms of distance (rpm in this case), would be 12 ÷ 9, or 1.33.

This analysis tells us that when a large gear drives a small one, the small one turns faster and has less available force. In order to be a force gaining machine, the small gear needs to turn the large one. When the terminology reduction gearbox is used, such as a propeller reduction gearbox, it means that there is more rpm going in than is coming out. The end result is an increase in force, and ultimately torque.

Bevel gears are used to change the plane of rotation, so that a shaft turning horizontally can make a vertical shaft rotate. The size of the gears and their number of teeth determine the mechanical advantage, and whether force is being increased or rpm is being increased. If each gear has the same number of teeth, there would be no change in force or rpm. [**Figure 2-22**]

The worm gear has an extremely high mechanical advantage. The input force goes into the spiral worm gear, which drives the spur gear. One complete revolution of the worm gear only makes the spur gear turn an amount equal to one tooth. The mechanical advantage is equal to the number of teeth on the spur gear, which in this case is 25. This is a force gaining machine, to the tune of 25 times more output force. [**Figure 2-23**]

The planetary sun gear system is typical of what would be found in a propeller reduction gearbox. The power output shaft of the engine would drive the sun gear in the middle, which rotates the planetary gears and ultimately the ring gear. In this example, the sun gear has 28 teeth, each planet gear has 22 teeth, and the ring gear has 82 teeth. To figure out how

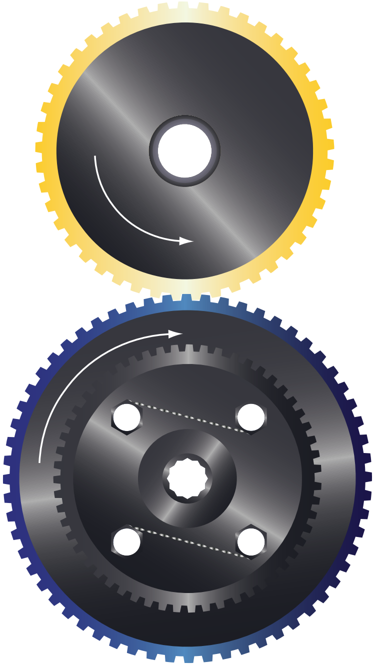

Figure 2-21. Spur gears.

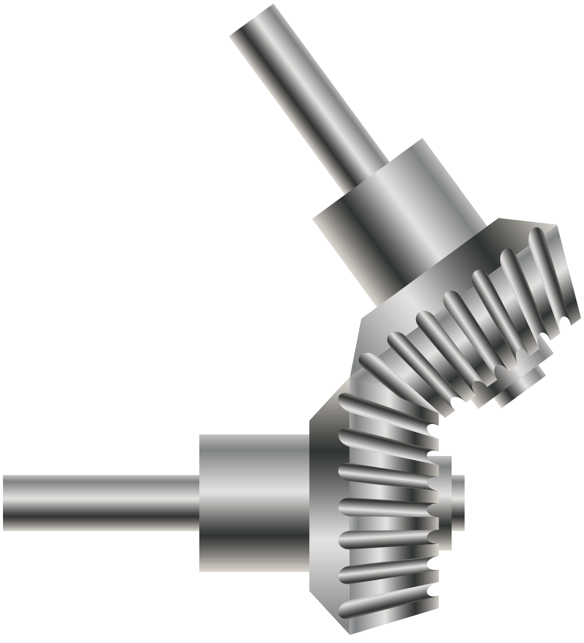

Figure 2-22. Bevel gears.

much gear reduction is taking place, the number of teeth on the ring gear is divided by the number of teeth on the sun gear. In this case, the gear reduction is 2.93, meaning the engine has an rpm 2.93 times greater than the propeller. [**Figure 2-24**]

GEAR RATIO

The velocity ratio and the gear ratio of a geared drive are essentially the same thing. A gear ratio is calculated by comparing the number of teeth on a drive gear to the number of teeth on the driven gear. The result is a ratio that brings into focus the amount of mechanical advantage produced by the assembly.

A speed ratio or velocity ratio can also be calculated. Instead of comparing the number of teeth on the gears, the rotational speed of each gear is considered. When two gears are used in an aircraft component, the rotational speed of each gear is represented as a speed ratio. As the number of teeth in a gear decreases, the rotational speed of that gear increases, and vice-versa. Therefore, the speed ratio of two gears is the inverse (or opposite) of the gear ratio. If two gears have a gear ratio of 2:9, then their speed ratio is 9:2.

Example:
A pinion gear with 10 teeth is driving a spur gear with 40 teeth. The spur gear is rotating at 160 rpm. Determine the speed of the pinion gear.

$$\frac{\text{Teeth in Pinion Gear}}{\text{Teeth in Spur Gear}} = \frac{\text{Speed of Spur Gear}}{\text{Speed of Pinion Gear}}$$

$$\frac{\text{10 Teeth}}{\text{40 Teeth}} = \frac{\text{160 rpm}}{\text{Sp (speed of pinion gear)}}$$

To solve for SP, multiply 40 × 160, then divide by 10. The speed of the pinion gear is 640 rpm.

Example:
If the cruising speed of an airplane is 200 knots and its max speed is 250 knots, what is the ratio of cruising speed to max speed?

First, express the cruising speed as the numerator of a fraction whose denominator is the maximum speed.

$$\text{Ratio} = \frac{200}{250}$$

Next, reduce the resulting fraction to its lowest terms.

$$\text{Ratio} = \frac{200}{250} = \frac{4}{5}$$

The ratio of cruising speed to maximum speed is 4:5.

Another common use of ratios is to convert any given ratio to an equivalent ratio with a denominator of 1. Example: Express the ratio 9:5 as a ratio with a denominator of 1.

$$R = \frac{9}{5} = \frac{?}{1} \text{ Since } 9 \div 5 = 1.8\text{, then } \frac{9}{5} = \frac{1.8}{1}$$

Therefore, 9:5 is the same ratio as 1.8:1. In other words, 9 to 5 is the same ratio as 1.8 to 1.

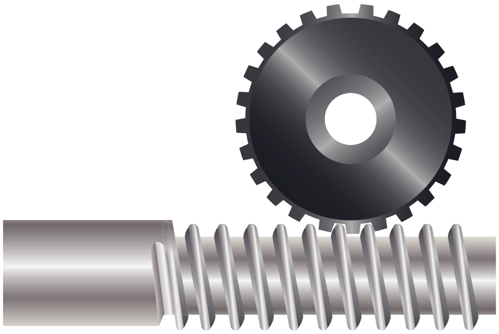

Figure 2-23. Worm gear.

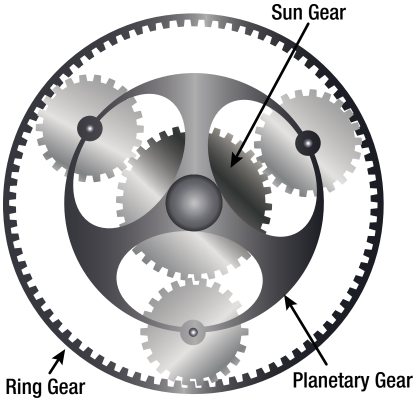

Figure 2-24. Planetary sun gear.

INCLINED PLANE

The inclined plane is a simple machine that facilitates the raising or lowering of heavy objects by application of a small force over a relatively long distance. Some familiar examples of the inclined plane are mountain highways and a loading ramp on the back of a truck. When weighing a small airplane, like a Cessna 172, an inclined plane (ramp) can be used to get the airplane on the scales by pushing it, rather than jacking it. A ramp can be seen in **Figure 2-25**, where a Cessna 172 right main gear is sitting on an electronic scale. The airplane was pushed up the ramps to get it on the scales.

With an inclined plane, the length of the incline is the effort arm and the vertical height of the incline is the resistance arm. If the length of the incline is five times greater than the height, there will be a force advantage, or mechanical advantage, of five. The Cessna 172 in **Figure 2-25** weighed 1 600 lb on the day of the weighing. The ramp it is sitting on is 6 inches tall (resistance arm) and the length of the ramp is 24 inches (effort arm).

To calculate the force needed to push the airplane up the ramps, use the same formula introduced earlier when levers were discussed, as follows:

$$\text{Effort (E)} \times \text{Effort Arm (L)} = \text{Resistance (R)} \times \text{Resistance Arm (l)}$$
$$E \times 24 \text{ in} = 1\,600 \text{ lb} \times 6 \text{ in}$$
$$E = 600 \text{ lb} \times 6 \text{ in} \div 24 \text{ in}$$
$$E = 400 \text{ lb}$$

Bolts, screws, and wedges are also examples of devices that operate on the principle of the inclined plane. A bolt, for example, has a spiral thread that runs around its circumference. As the thread winds around the bolt's circumference, it moves a vertical distance equal to the space between the threads. The circumference of the bolt is the effort arm and the distance between the threads is the resistance arm. [**Figure 2-26**]

Based on this analysis, it can be seen that a fine threaded bolt (more threads per inch) has a greater mechanical advantage than a coarse threaded bolt.

THE WEDGE

A chisel is a good example of a wedge. A chisel might be 8 inches long and only ½ inch wide, with a sharp tip and tapered sides. The 8 inch length is the effort arm and the ½ inch width is the resistance arm. This chisel would provide a force advantage (mechanical advantage) of 16.

EFFICIENCY

Mechanical efficiency is always a goal of the aircraft designer. Efficiency refers to how well a machine uses input energy. Losses due to heat, friction, deflection and wear cause a machine to be inefficient. A machine that minimizes these losses in said to be efficient. Efficiency is measured in percentage. No machine can be 100% efficient. A way to calculate efficiency is with the following equation:

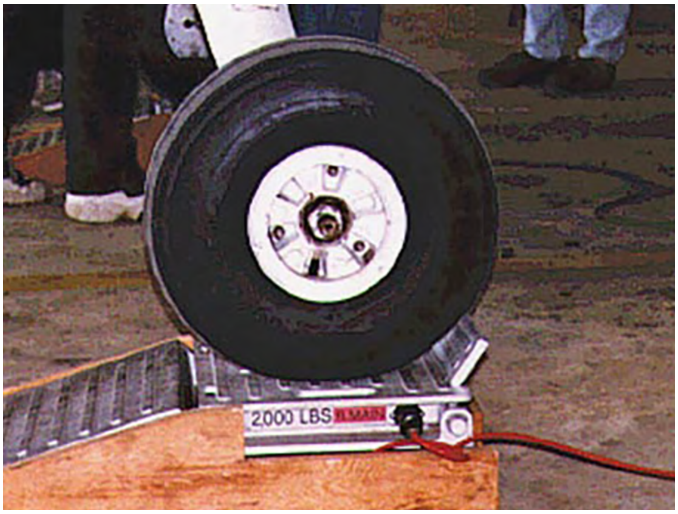

Figure 2-25. Ramp in use with a Cessna 172.

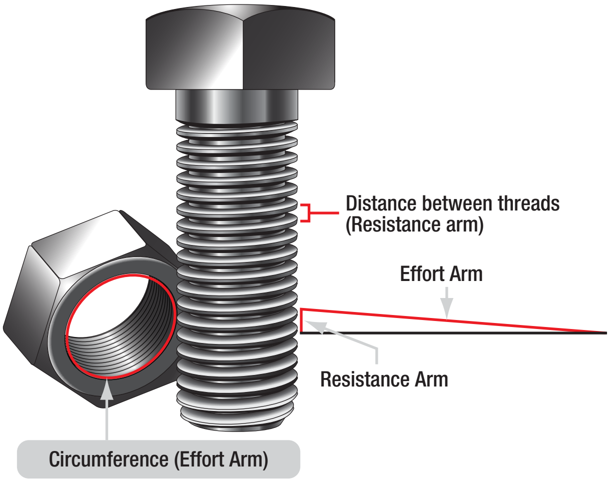

Figure 2-26. A bolt and nut as an inclined plane.

$$\text{Efficiency} = \text{Mechanical Advantage} \div \text{Speed Ratio} \times 100$$

Another way to look at efficiency is as follows:

$$\text{Efficiency} = \text{Measured Performance} \div \text{Ideal Performance}$$

In the next section of this sub-module, force, work and one of the major factors that causes machines to not be efficient, friction, are examined.

2.2.3 DYNAMICS

SECTION A

MASS AND WEIGHT

Mass is a measure of the quantity of matter in an object. In other words, how many molecules are in the object, or how many atoms, or to be more specific, how many protons, neutrons, and electrons. The mass of an object does not change regardless of where you take it in the universe, and it does not change with a change of state. The only way to change the mass of an object is to add or take away atoms. Mathematically, mass can be stated as follows:

$$\text{Mass} = \text{Weight} \div \text{Acceleration due to gravity}$$

The acceleration due to gravity here on earth is 32.2 feet per second per second (32.2 fps/s). An object weighing 32.2 pounds (lbs) here on earth is said to have a mass of 1 slug. A slug is a quantity of mass that will accelerate at a rate of 1 ft/s^2 when a force of 1 pound is applied. In other words, under standard atmospheric conditions (gravity equal to 32.2) a mass of one slug is equal to 32.2 lb.

Weight is a measure of the pull of gravity acting on the mass of an object. The more mass an object has, the more it will weigh under the earth's force of gravity. Because it is not possible for the mass of an object to go away, the only way for an object to be weightless is for gravity to go away.

We view astronauts on the space shuttle and it appears that they are weightless. Even though the shuttle is quite a few miles above the surface of the earth, the force of gravity has not gone away, and the astronauts are not weightless. The astronauts and the space shuttle are in a state of free fall, so relative to the shuttle the astronauts appear to be weightless. Mathematically, weight can be stated as follows:

$$\text{Weight} = \text{Mass} \times \text{Gravity}$$

FORCE

Before the concept of work, power, or torque can be discussed, we must understand what force means. Force is the intensity of an impetus, or the intensity of an input. For example, if we apply a force to an object, the tendency will be for the object to move.

Another way to look at it is that for work, power, or torque to exist, there has to be a force that initiates the process.

The unit for force in the English system of measurement is pounds, and in the metric system it is newtons. One pound of force is equal to 4.448 newtons. When we calculate the thrust of a turbine engine, we use the formula "Force = Mass × Acceleration," and the thrust of the engine is expressed in pounds. The GE90-115 turbofan engine (powerplant for the Boeing 777-300) has 115 000 pounds of thrust.

INERTIA

Inertia is the resistance of an object to a change in its state of motion, including changes to its speed or direction. Inertia tends to keep an object moving in a straight line and a constant velocity. Similarly, inertia is the property, which needs to be overcome before a stationary object may begin to move from its present position. Thus, an object will continue moving at its current velocity until some force causes its speed or direction to change. [**Figure 2-27**]

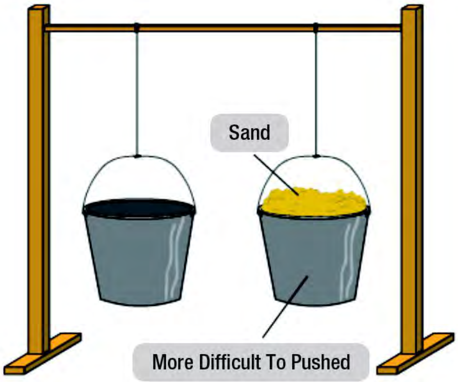

Figure 2-27. An object of greater mass has more inertia than a lesser object.

WORK

The study of machines, both simple and complex, is in one sense a study of the energy of mechanical work. This is true because all machines transfer input energy, or the work done on the machine, to output energy, or the work done by the machine.

Work in the mechanical sense of the term, is done when a resistance is overcome by a force acting through a measurable distance. Two factors are involved: (1) force and (2) movement through a distance. As an example, suppose a small aircraft is stuck in the snow. Two men push against it for a period of time, but the aircraft does not move. According to the technical definition, no work was done in pushing against the aircraft. By definition, work is accomplished only when an object is displaced some distance against a resistive force.

To calculate work, the following formula is used:

$$\text{Work} = \text{Force (F)} \times \text{Distance (d)}$$

In the imperial system, the force will be identified in pounds and the distance either in feet or inches, so the units will be foot-pounds or inch-pounds. Notice these are the same units that were used for potential and kinetic energy.

In the SI/Metric System, the force is identified in newtons (N) and the distance in meters, with the resultant units being joules. One pound of force is equal to 4.448 N and one meter is equal to 3.28 feet. One joule is equal to 1.36 ft-lb.

Example:
How much work is accomplished by jacking a 150 000-lb Airbus A-320 airplane a vertical height of 3 ft? [**Figure 2-28**]

$$\begin{aligned} \text{Work} &= \text{Force (F)} \times \text{Distance (d)} \\ &= 150\,000 \text{ lb} \times 4 \text{ ft} \\ &= 600\,000 \text{ ft-lb} \end{aligned}$$

Figure 2-28. Airbus A-320 being jacked.

Example:
How much work is accomplished when a tow tractor is hooked up to a tow bar and a Boeing 737-800 airplane weighing 130 000 lbs is pushed 80 ft into the hangar? The force on the tow bar is 5 000 lb.

In this last example, notice the force does not equal the weight of the airplane. This is because the airplane is being moved horizontally and not lifted vertically. In virtually all cases, it takes less work to move something horizontally than it does to lift it vertically. Most people can push their car a short distance if it runs out of gas, but they cannot get under their car and lift it off the ground.

POWER

The concept of power involves the previously discussed topic of work, which was a force being applied over a measured distance, but adds one more consideration: time. In other words, how long does it take to accomplish the work. If someone asked the average person if he or she could lift one million pounds 5 feet off the ground, the answer most assuredly would be no. This person would probably assume that he or she is to lift it all at once. What if he or she is given 365 days to lift it, and could lift small amounts of weight at a time? The work involved would be the same, regardless of how long it took to lift the weight, but the power required is different. If the weight is to be lifted in a shorter period of time, it will take more power.