APPENDIX A: FLOW DEFINITIONS

The set of flow definitions that follow is part of the functional basis described in Section 4. A flow from this list is selected to fill the object position of the verb-object functional description. Flows in the functional basis are more abstract representations of the actual problem's flows. The given definitions make the transformation from actual flow to basis flow more methodical and repeatable. An example of the flow usage follows each definition.

1. Material

(a) **Human**. All or part of a person who crosses the device boundary. Example: Most coffee makers require the flow of a *human hand* to actuate (or start) the electricity and thus heat the water.

(b) **Solid**. Any object with mass having a definite, firm shape. Example: The flow of sand paper into a hand sander is transformed into a *solid* entering the sander.

(c) **Liquid**. A readily flowing fluid, specifically having its molecules moving freely with respect to each other, but because of cohesive forces, not expanding indefinitely. Example: The flow of water through a coffee maker is a *liquid*.

(d) **Gas**. Any collection of molecules which are characterized by random motion and the absence of bonds between the molecules. Example: An oscillating fan moves air by rotating blades. The air is transformed as *gas* flow.

2. Energy

(a) **Human**. Work performed by a person on the device. Example: An automobile requires the flow of *human energy* to steer and accelerate the vehicle.

i. **Force**. Human effort that is input to the system without regard for the required motion. Example: *Human force* is needed to actuate the trigger of a toy gun.

ii. **Motion**. Activity requiring movement of all or part of the body through a prescribed path. Example: The trackpad on a laptop computer receives the flow of *human motion* to control the cursor.

(b) **Acoustic**. Work performed in the production and transmission of sound. Example: The motor of a power drill generates a flow of *acoustic energy* in addition to the torque.

i. **Pressure**. The pressure field of the sound waves. Example: A condenser microphone has a diaphragm which vibrates in response to *acoustic pressure*. This vibration changes the capacitance of the diaphragm, thus superimposing an alternating voltage on the direct voltage applied to the circuit.

ii. **Particle velocity**. The speed at which sound waves travel through a conducting medium. Example: So-

nar devices rely on the flow of *acoustic particle velocity* to determine the range of an object.

(c) **Biological**. Work produced by or connected with plants or animals. Example: In poultry houses, the *biological energy* produced by thousands of chickens (in the form of heat) is an important flow in determining cooling requirements for the house.

i. **Pressure**. Energy flow utilized is the pressure field exerted by a compressed biological fluid. Example: The high concentration of sugars and salts inside a cell causes the entry, via osmosis, of water into the vacuole, which in turn expands the vacuole and generates a hydrostatic *biological pressure*, called turgor, that presses the cell membrane against the cell wall. Turgor is the cause of rigidity in living plant tissue.

ii. **Volumetric flow**. Energy flow utilized is the kinetic energy of molecules in a biological fluid flow. Example: Increased metabolic activity of tissues such as muscles or the intestine automatically induces increased *volumetric flow* of blood through the dilated vessels.

(d) **Chemical**. Work resulting from the reactions by which substances are produced from or converted into other substances. Example: A battery converts the flow of *chemical energy* into electrical energy.

i. **Affinity**. The force with which atoms are held together in chemical bonds. Affinity is proportional to the chemical potential of a compound's constituent species. Example: An internal combustion engine transforms the *chemical affinity* of the gas into a mechanical force.

ii. **Reaction rate**. The speed or velocity at which chemical reactants produce products. Reaction rate is proportional to the mole rate of the constituent species Example: Special coatings on automobile panels stop the *chemical reaction rate* of the metal with the environment.

(e) **Electrical**. Work resulting from the flow of electrons from a negative to a positive source. Example: A power belt sander imports a flow of *electricity* from a wall outlet and transforms it into a rotation.

i. **Electromotive force**. Potential difference across the positive and negative sources. Example: Household electrical receptacles provide a flow of *electromotive force* of 110 V.

ii. **Current**. The flow or rate of flow of electric charge in a conductor or medium between two points having a difference in potential. Example: Circuit breakers trip when the *current* exceeds a specified limit.

(f) **Electromagnetic**. Energy that is propagated through free space or through a material medium in the form of electromagnetic waves (Britannica Online, 1997). It has both wave and particle-like properties. Example: Solarpanels convert the flow *electromagnetic energy* into electricity.

i **Optical**. Work associated with the nature and properties of light and vision. Also, a special case of solar energy (see **solar**). Example: A car visor refines the flow of *optical energy* that its passengers receive.

(a) **Intensity**. The amount of optical energy per unit area. Example: Tinted windows reduce the *optical intensity* of the light entering.

(b) **Velocity**. The speed of light in its conducting medium. Example: NASA developed and tested a trajectory control sensor (TCS) for the space shuttle to calculate the distance between the payload bay and a satellite. It relied on the constancy of the *optical velocity* flow to calculate distance from time of flight measurements of a reflected laser.

ii **Solar**. Work produced by or coming from the sun. Example: Solar panels collect the flow of *solar energy* and transform it into electricity.

(a) **Intensity**. The amount of solar energy per unit area. Example: A cloudy day reduces the *solar intensity* available to solar panels for conversion to electricity.

(b) **Velocity**. The speed of light in free space. Example: Unlike most energy flows, *solar velocity* is a well known constant.

(g) **Hydraulic**. Work that results from the movement and force of a liquid, including hydrostatic forces. Example: Hydroelectric dams generate electricity by harnessing the *hydraulic energy* in the water that passes through the turbines.

i. **Pressure**. Energy flow utilized is the pressure field exerted by a compressed liquid. Example: A hydraulic jack uses the flow *hydraulic pressure* to lift heavy objects.

ii. **Volumetric flow**. Energy flow utilized is the movement of fluid molecules. Example: A water meter measures the *volumetric flow* of water without a significant pressure drop in the line.

(h) **Magnetic**. Work resulting from materials that have the property of attracting other like materials, whether that quality is naturally occurring or electrically induced. Example: The *magnetic energy* of a magnetic lock is the flow that keeps it secured to the iron based structure.

i. **Magnetomotive force**. The driving force which sets up the magnetic flux inside of a core. Magnetomotive force is directly proportional to the current in the coil surrounding the core. Example: In a magnetic door lock, a change in *magnetomotive force* (brought about by a change in electrical current) allows the lock to disengage and the door to open.

ii. **Magnetic flux rate**. Flux is the magnetic displacement variable in a core induced by the flow of current

through a coil. The magnetic flow variable is the time rate of change of the flux. The voltage across a magnetic coil is directly proportional to the time rate of change of magnetic flux. Example: A magnetic relay is a transducer that senses the *time rate of change of magnetic flux* when the relay arm moves.

(i) **Mechanical**. Energy associated with the moving parts of a machine or the strain energy associated with a loading state of an object. Example: An elevator converts electrical or hydraulic energy into *mechanical energy*.

i. **Rotational energy**. Energy that results from a rotation or a virtual rotation. Example: Customers are primarily concerned with the flow of *rotational energy* from a power screwdriver.

(a) **Torque**. Pertaining to the moment that produces or tends to produce rotation. Example: In a power screwdriver, electricity is converted into *rotational energy*. The more specific flow is *torque*, based on the primary customer need to insert screws easily, not quickly.

(b) **Angular velocity**. Pertaining to the orientation or the magnitude of the time rate of change of angular position about a specified axis. Example: A centrifuge is used to separate out liquids of different densities from a mixture. The primary flow it produces is that of *angular velocity*, since the rate of rotation about an axis is the main concern.

ii. **Translational energy**. Energy flow generated or required by a translation or a virtual translation. Example: A child's toy, such as a projectile launcher, transmits *translational energy* to the projectile to propel it away.

(a) **Force**. The action that produces or attempts to produce a translation. Example: In a tensile testing machine, the primary flow of interest is that of a *force* which produces a stress in the test specimen.

(b) **Linear velocity**. Motion that can be described by three component directions. Example: An elevator car uses the flow of *linear velocity* to move between floors.

iii. **Vibrational energy**. Oscillating translational or rotational energy that is characterized by an amplitude and frequency. In the rotational case, motion does not complete a 360° cycle (if > 360°, then use **rotational energy** category). Example: In many block sanders, the sanding surface receives a flow of *vibration* to remove the wood surface. *Vibration* is produced by an off-center mass on the motor shaft.

(a) **Amplitude**. Energy flow is characterized by the magnitude of the generalized force or displacement. Example: In fatigue testing, the *vibrational amplitude* of the tensile stress is more important than the speed of each loading cycle.

(b) **Frequency**. Energy flow is characterized by the number of oscillatory cycles per unit time. Example. Exposure to certain *vibrational frequencies* can induce sickness in humans.

(j) **Pneumatic**. Work resulting from a compressed gas flow or pressure source. Example: A B-B gun relies on the flow of *pneumatic energy* (from compressed air) to propel the projectile (B-B).

i. **Pressure**. Energy utilized is the pressure field exerted by a compressed gas. Example: Certain cylinders rely on the flow of *pneumatic pressure* to move a piston or support a force.

ii. **Mass flow**. Energy utilized is the kinetic energy of molecules in a gas flow. Example: The *mass flow* of air is the flow that transmits the thermal energy of a hair dryer to damp hair.

(k) **Radioactive**. Work resulting from or produced by particles or rays, such as alpha, beta and gamma rays, by the spontaneous disintegration of atomic nuclei. Example: Nuclear reactors produce a flow of *radioactive energy* which heats water into steam and then drives electricity generating turbines.

i. **Intensity**. The amount of radioactive particles per unit area. Example: Concrete is an effective radioactive shielding material, reducing the *radioactive intensity* in proportion to its thickness.

ii. **Decay rate**. The rate of emission of radioactive particles from a substance. Example: The *decay rate* of carbon provides a method to date pre-historic objects.

(l) **Thermal**. A form of energy that is transferred between bodies as a result of their temperature difference. Example: A coffee maker converts the flow of electricity into the flow of *thermal energy* which it transmits to the water. *Note: A pseudo bond graph approach is used here. The true effort and flow variables are temperature and the time rate of change of entropy. However, a more practical pseudo-flow of heat rate is chosen here.*

i. **Temperature**. The degree of heat of a body. Example: A coffee maker brings the *temperature* of the water to boiling in order to siphon the water from the holding tank to the filter basket.

ii. **Heat rate**. (Note: this is a pseudo-flow) The time rate of change of heat energy of a body. Example: Fins on a motor casing increase the flow *heat rate* from the motor by conduction (through the fin), convection (to the air) and radiation (to the environment).

3. Signal

(a) **Status**. A condition of some system, as in information about the state of the system. Example: Automobiles often measure the engine water temperature and send a *status signal* to the driver via a temperature gage.

i. **Auditory**. A condition of some system as displayed

by a sound. Example: Pilots receive an *auditory signal*, often the words "pull up," when their aircraft reaches a dangerously low altitude.

ii. **Olfactory**. A condition of some system as related by the sense of smell or particulate count. Example: Carbon monoxide detectors receive an *olfactory signal* from the environment and monitor it for high levels of CO.

iii. **Tactile**. A condition of some system as perceived by touch or direct contact. Example: A pager delivers a *tactile signal* to its user through vibration.

iv. **Taste**. A condition of some dissolved substance as perceived by the sense of taste. Example: In an electric wok, the *taste signal* from the human chef is used to determine when to turn off the wok.

v. **Visual**. A condition of some system as displayed by some image. Example: A power screwdriver provides a *visual signal* of its direction through the display of arrows on the switch.

(b) **Control**. A command sent to an instrument or apparatus to regulate a mechanism. Example: An airplane pilot sends a *control signal* to the elevators through movement of the yoke. The yoke movement is transformed into an electrical signal, sent through wiring to the elevator, and then transformed back into a physical elevator deflection.

APPENDIX B: FUNCTION DEFINITIONS

The function classes are introduced in Section 4. Definitions for each class and basic function are presented below. Examples are given for the basic functions. Used with the flow definitions of Appendix A, the function definitions complete the functional basis, improving repeatability of function structure development and providing a standard level of detail at which the decomposition process stops.

1. **Branch**. To cause a material or energy to no longer be joined or mixed.

(a) **Separate**. To isolate a material or energy into distinct components. The separated components are distinct from the flow before separation, as well as each other. Example: A glass prism *separates* light into different wavelength components to produce a rainbow.

i. **Remove**. To take away a part of a *material* from its prefixed place. Example: A sander *removes* small pieces of the wood surface to smooth the wood.

(b) **Refine**. To reduce a material or energy such that only the desired elements remain. Example: In a coffee maker, the filter *refines* the coffee grounds and allows the new liquid (coffee) to pass through.

(c) **Distribute**. To cause a material or energy to break up. The individual bits are similar to each other and the undistributed flow. Example: An atomizer *distributes* (or sprays) hair-styling liquids over the head to hold the hair in the desired style.

2. **Channel**. To cause a material or energy to move from one location to another location.

(a) **Import**. To bring in an energy or material from outside the system boundary. Example: A physical opening at the top of a blender pitcher *imports* a solid (food) into the system. Also, a handle on the blender pitcher *imports* a human hand. The blender system *imports* electricity via an electric plug.

(b) **Export**. To send an energy or material outside the system boundary. Example: Pouring blended food out of a standard blender pitcher *exports* liquid from the system. The opening at the top of the blender is a solution to the *export* sub-function.

(c) **Transfer**. To shift, or convey, a flow from one place to another.

i. **Transport**. To move a *material* from one place to another. Example: A coffee maker *transports* liquid (water) from its reservoir through its heating chamber and then to the filter basket.

ii. **Transmit**. To move an *energy* from one place to another. Example: In a hand held power sander, the housing of the sander *transmits* human force to the object being sanded.

(d) **Guide**. To direct the course of an energy or material along a specific path. Example: A domestic HVAC system *guides* gas (air) around the house to the correct locations via a set of ducts.

i. **Translate**. To fix the movement of a *material* (by a device) into one linear direction. Example: In an assembly line, a conveyor belt *translates* partially completed products from one assembly station to another by .

ii. **Rotate**. To fix the movement of a *material* (by a device) around one axis. Example: A computer disk drive *rotates* the magnetic disks around an axis so that data can be read by the head.

iii. **Allow degree of freedom (DOF)**. To control the movement of a *material* (by a force external to the device) into one or more directions. Example: To provide easy trunk access and close appropriately, trunk lids need to move along a specific degree of freedom. A four bar linkage *allows* a rotational *DOF* for the trunk lid.

3. **Connect**. To bring two or more energies or materials together.

(a) **Couple**. To join or bring together energies or materials such that the members are still distinguishable from each other. Example: A standard pencil *couples* an eraser and a writing shaft. The coupling is performed using a metal sleeve that is crimped to the eraser and the shaft.

(b) **Mix**. To combine two materials into a single, uniform homogeneous mass. Example: A shaker *mixes* a paint base and its dyes to form a homogeneous liquid.

4. **Control Magnitude**. To alter or govern the size or amplitude of material or energy.
   (a) **Actuate**. To commence the flow of energy or material in response to an imported control signal. Example: A circuit switch *actuates* the flow of electrical energy and turns on a light bulb.
   (b) **Regulate**. To adjust the flow of energy or material in response to a control signal, such as a characteristic of a flow. Example: Turning the valves *regulates* the flow rate of the liquid flowing from a faucet.
   (c) **Change**. To adjust the flow of energy or material in a predetermined and fixed manner. Example: In a hand held drill, a variable resistor *changes* the electrical energy flow to the motor thus changing the speed the drill turns.
      i. **Form**. To mold or shape a material. Example: In the auto industry, large presses *form* sheet metal into contoured surfaces that become fenders, hoods and trunks.
      ii. **Condition**. To render an energy appropriate for the desired use. Example: To prevent damage to electrical equipment, a surge protector *conditions* electrical energy by excluding spikes and noise (usually through capacitors) from the energy path.
5. **Convert**. To change from one form of energy or material to another. For completeness, any type of flow conversion is valid. In practice, conversions such as *convert electricity to torque* will be more common than *convert solid to optical energy*. Example: An electrical motor *converts* electricity to rotational energy.
6. **Provide**. To accumulate or provide material or energy.
   (a) **Store**. To accumulate material or energy. Example: A DC electrical battery *stores* the energy in a flashlight.
   (b) **Supply**. To provide material or energy from storage. Example: In a flashlight, the battery *supplies* energy to the bulb.
   (c) **Extract**. To draw, or forcibly pull out, a material or energy. Example: Metal wire is *extracted* from the manufacturing process of extrusion.
7. **Signal**. To provide information.
   (a) **Sense**. To perceive, or become aware, of a signal. Example: An audio cassette machine *senses* if the end of the tape has been reached.
   (b) **Indicate**. To make something known to the user. Example: A small window in the water container of a coffee maker *indicates* the level of water in the machine.
   (c) **Display**. To show a visual effect. Example: The face and needle of an air pressure gage *display* the status of the pressure vessel.
   (d) **Measure**. To determine the magnitude of a material or energy flow. Example: An analog thermostat *measures* temperature through a bimetallic strip.
8. **Support**. To firmly fix a material into a defined location, or secure an energy into a specific course.
   (a) **Stop**. To cease, or prevent, the transfer of a material or energy. Example: A reflective coating on a window *stops* the transmission of UV radiation through a window.
   (b) **Stabilize**. To prevent a material or energy from changing course or location. Example: On a typical canister vacuum, the center of gravity is placed at a low elevation to *stabilize* the vacuum when it is pulled by the hose.
   (c) **Secure**. To firmly fix a material or energy path. Example: On a bicycling glove, a velcro strap *secures* the human hand in the correct place.
   (d) **Position**. To place a material or energy into a specific location or orientation. Example: The coin slot on a soda machine *positions* the coin to begin the coin evaluation and transportation procedure.