Veterinary Prosthetics
Consider a canine front double amputee (i.e., hind legs intact, but fore legs gone – humerus removed from the scapula). The owners of the dog would like it to achieve mobility and independence. In previous HW’s, a rough Engineering Design Specification and Morphological Matrix for this problem have been developed. You may refer to these, or you may modify them as you think fit, to best inform the following assignment.

1. Concept Synthesis. From a previously-constructed (or reconstructed) morphological matrix of lowest level subfunctions and working principles, synthesize three unique overall concepts. For each concept, submit:
   a. Sketch. Simple, surely, but not ‘rough’ (i.e., it still has to be uniquely communicative, neat, professional, understandable, and legible, and come with enough notes and call-outs that a fresh observer can readily interpret it). Best to make a rough sketch, and then revise it in a clean copy. Both hand and CAD are OK.
   b. Assure (and explain) that constraints are met.
   c. Explain how Customer Requirements are satisfied.
   d. Note how EC levels can be measured and evaluated.
   e. Demonstrate (describe, illustrate) the load path in weight-bearing, from the ground to the dog’s skeleton.

Note: This should not be an overly time-consuming assignment. If way too much time is going into it, consider whether the level of detail is too high. Each concept (sketch and description) should fit on one page.

Functional Decomposition for this problem focused on obstacle capability as a from-determiner. Other necessary functions that must be included in an overall concept are:
- Attachment to dog (vertically load scapula and resist slip in the other 5 degrees of freedom)
- Motion in ground plane (forward/reverse, turn, terrain-following)

Cost and owner care will be used as guides. Bodily function (elimination) will be covered by standing stability in ground plane mobility. House damage will be checked in the embodiment process. Self-feeding can be accomplished by auxiliary devices (elevated bowls), though ability to self-feed without these will be considered desirable.
- **Scapula Load** – Statics evaluation of design-standard 20 kg dog (need representative biometrics; embodiment should address dynamic loading and a range of dog breeds)
- **Scapula Pressure** – Initially, load divided by area (more in-depth evaluation of pressure profile during embodiment)
- **Forebody compliance** – Effective spring rate (force divided by deflection) at scapula from kinematic analysis with known stiffness of installed spring (embodiment should consider member compliance)
- **Forebody damping** – Damping rate (force divided by deflection velocity) at scapula from kinematic analysis with known damping coefficient of installed damper
- **Axial resistance** (i.e., how hard it is for the dog to push) – rolling resistance coefficient of wheel (tire) on terrain (dirt/grass or floor/carpet) plus resolved torque of motor/regenerator and bearings
- **Stability index** – Tough to evaluate, but crucial to course stability (ability of dog to run in a straight line). A reasonable proxy for concept evaluation would be yawing moment per degree of yaw about the dog’s forebody, as the dog/device assembly is pushed forward. More is better. Will depend upon wheel (tire) characteristics and mechanical trail (caster). And ground characteristics, but a test case can be chosen.
- **Step height** – For wedges, 90% of wedge tip height (factor of safety); for rolling elements, height of wheel axis less 20% of wheel radius (to start wheel rotating)
- **Cost** – Rough Bill of Materials with manufacturing labor hours estimate (neglect assembly labor and overhead for now).
Concept 1 emphasizes capability.

Customer Requirement and Constraint satisfaction:

- Vertical traction – surface friction (a powered traction device – single or multiple wheels or tracks – dog can be trained to lean into obstacle to provide surface normal force)
- Vertical path – rolling contact works well with surface traction
- Vertical power – onboard (do not have a Working Principle that will motivate rolling contact on a 90° angle of approach using lift or thrust at the dog’s hindquarters), with regeneration (in consideration of keeping owner from having to recharge energy storage)
- On/off – bumper (dog can be trained to push device into obstacle to initiate lift – relaxing push will deactivate device)
- Transfer – rolling (choose single wheels (or lateral pair) in consideration of higher speed ground plane motion)
- Attachment – medium density foam pads to contact scapula, rib cage tray to locate pads (molded to dog’s biometrics), rib cage tray extends back towards waist to stabilize the tray in pitch (compliant hind tip to avoid injury), straps over neck and waist to fix tray in place on dog.
- Motion in ground plane – lateral pair of wheels for roll stability; with suspension travel, spring, and damping; dependent suspension (both wheels move together) for simplicity in driveline and regeneration; wheels non-reversing (makes standing easier – dog must spin around one stopped wheel to reverse direction)
- Bodily function – reverse thrust from hindquarters locks wheels
Concept 2 emphasizes cost. [Sort of - another way to make a new concept to work is to force-choose one working principle, and then work the rest to suit.]

- Vertical traction – lever rotation (‘ski’, with tip set above obstacle height, projects forward)
- Vertical path – sliding contact with edge
- Vertical power – Dog’s hindquarters (energy storage/delivery by electrical or hydraulic means is a nice cost to be without)
- On/off – Dog controls motion with forward or reverse traction from its hind feet
- Transfer – rolling contact with top (Google ‘ski plane’ and look at hybrid ski/wheel undercarriages)
- Attachment – Scapula pads necessary because of obstacle impact force, brace (simple beam) to hind part of rib cage to reduce pitch deflection between device and dog on impact, diagonal strut to fix ski in pitch, straps to cinch it all up
- Motion in ground plane – lateral pair of wheels for roll stability; suspension only through wheel (tire) compliance.
- Bodily function – trailing brakes arrests reverse wheel motion upon dog backing up, allowing standing stability
Concept 3 emphasizes robustness.

- **Vertical traction** – lever rotation (rolling contact with top of obstacle – climbing wheel mounted high enough that its axle is above effective top edge of obstacle)
- **Vertical path** – rolling contact with face (and edge)
- **Vertical power** – Dog’s hindquarters
- **On/off** – Dog controls motion with forward or reverse traction from its hind feet
- **Transfer** – ground wheel mounted below climbing wheel (axle high enough that it climbs when it hits the obstacle edge)
- **Attachment** – medium density foam pads to contact scapula, rib cage tray to locate pads (split at fore end and cinched to adjust to dog’s biometrics), rib cage tray extends back towards waist to stabilize the tray in pitch (also split on centerline - compliant hind tip to avoid injury), straps over neck and waist to fix tray in place on dog.
- **Motion in ground plane** – lateral pair of ground wheels for roll stability; suspension independent trailing arms pivoted near climbing wheels with spring and damp
- **Bodily function** – On reversing leg thrust, climbing and ground wheel axles slide together to lock wheels
Morphological Matrix Redevelopment

- Could a working principle for vertical motion power be generated that uses the dog’s hindquarters moving sideways, or in reverse? Can the dog’s powerful neck and jaw muscles be employed?
- Could a working principle for vertical motion path be based on levering, like pole vaulting from the base of an obstacle? The moment arm between the dog’s center of gravity and the base of the obstacle might generate a working principle for vertical powering.
- Could castering wheels (grocery cart) be used as a working principle to enhance ground plane maneuverability? Without losing control?

It may take a few iterations of refining the morphological matrix to generate the highest quality range of overall concepts. The design process is logically sequential, but is usually not followed in a unidirectional chronological sequence.