Moonshot 6000

or

how to ride a bike into orbit

Jack Miller - 2022.03.28

Agenda

1. Scenario and top level requirements
2. Cost vs. technical capabilities
3. Feasibility
4. High level block diagram of system
5. Functional block diagram of start and stop
6. Integration testing

Scenario

Reach lunar orbit

on an e-bike under human power or stored human generated energy

*not to scale

Top level requirements

1. The system of bike and rider shall achieve low altitude lunar orbit.
    a. The system of bike and rider shall achieve a tangential velocity at the lunar equator of > 1680 m/s.
2. The system of bike and rider shall accelerate to the required velocity using only human power and stored energy from human power input.
3. The system of bike and rider shall operate on the moon.
4. A suitable track or road shall be constructed as needed.
5. The system of bike and rider shall be self-contained with no external power or life support.
6. The bike shall accelerate via power transferred through at most two wheels in contact with a track or road surface.
7. To be considered orbiting the moon, the system of bike and rider shall travel at least one full rotation around the circumference of the lunar equator without exerting any force in the radial direction.

Cost vs. technical capabilities

Important cost considerations

Construction

Orbit

Means of reaching orbit

Craft design

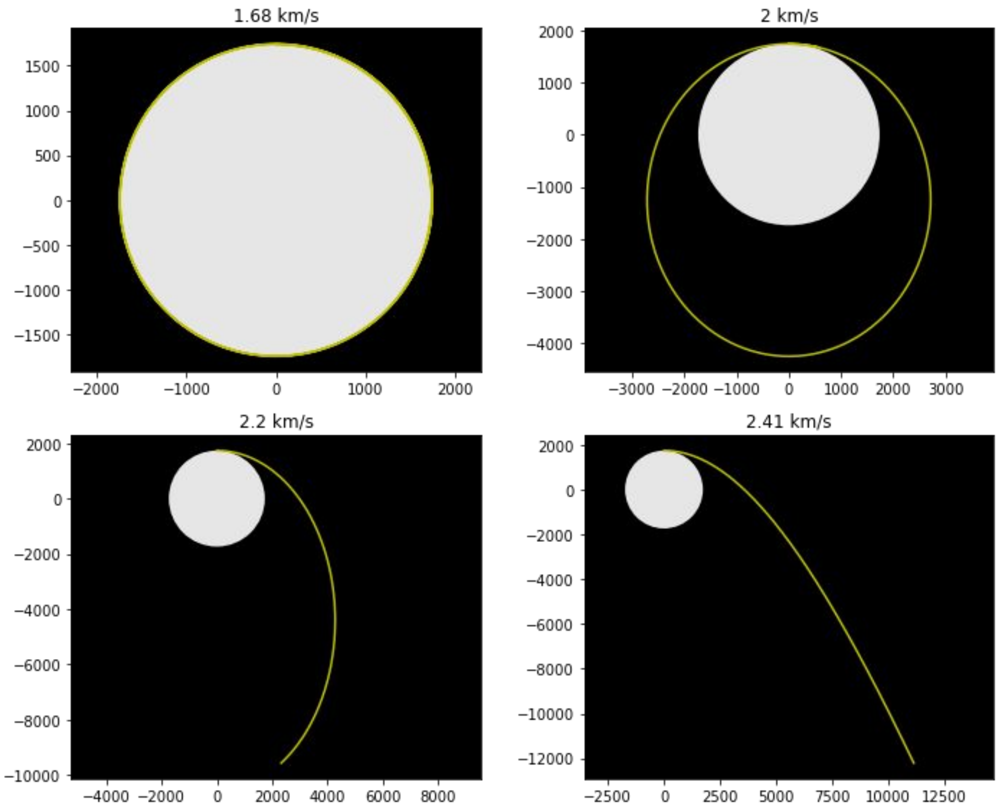
Track construction is main cost driver

The largest costs of the mission are associated with transportation of the necessary materials and manpower from Earth to the Moon

- Current estimate is 1 million USD per kg to the lunar surface
- Future costs with completely reusable rockets could be more than 1000x lower
- A track mass of 1kg/m circumnavigating the moon: 12,000,000 kg
- A track surface constructed purely of lunar regolith could reduce transportation costs by more than 10^13 USD

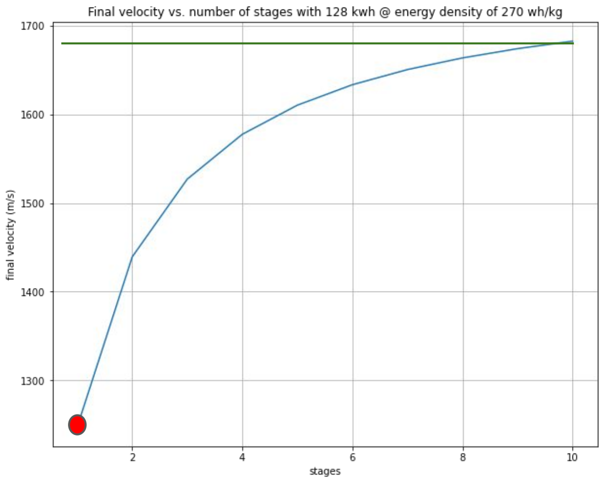
Orbital trajectory drives required speed

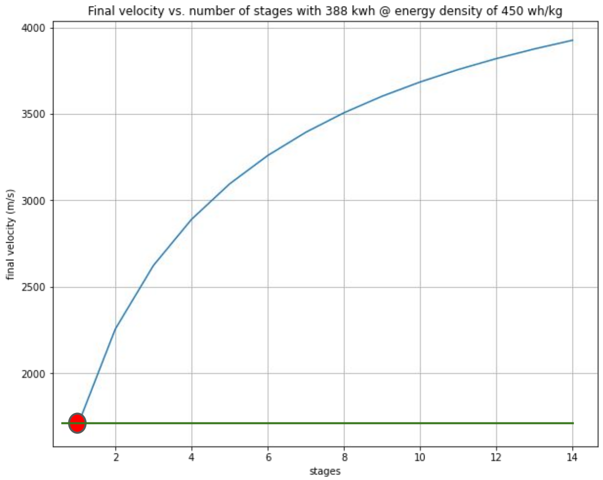
- High circular orbits require less speed, but only if already at the desired altitude
- Lack of off-surface thrust results in elliptical orbits with higher speed requirements for higher apogee
- Perigee remains at launch altitude
- Higher apogee increases cost



Staged design allows for lower cost

- Final velocity depends on
  - Total pack energy
  - Pack energy density
  - Craft mass
  - Number of stages
- 270 wh/kg (low cost commercially available) can’t achieve single stage to orbit
- 450 wh/kg (state of art aerospace) can, but with 3x initial energy requirement
- Staging introduces challenges
  - Increased failure probability
  - Increased complexity

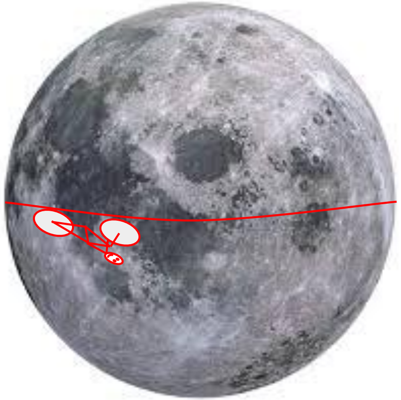




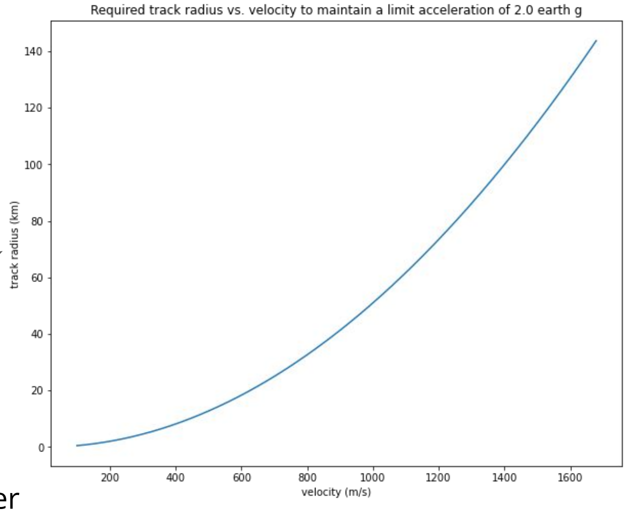
Reaching orbital speed requires a dedicated track

Two main options

- Circumnavigation at equator
  - Potential other uses for a track around lunar equator
  - High effort to construct due to transportation of materials
  - Reducing rolling resistance with increasing speed, but eventually need artificial normal force to allow for continued acceleration/stability
- Velodrome
  - Localized construction
  - Consistent normal force can be maintained for wheel contact
  - Large structure



This, but 3500x bigger

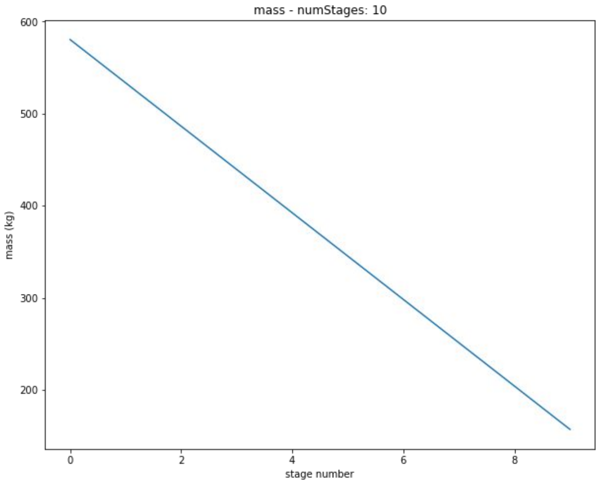


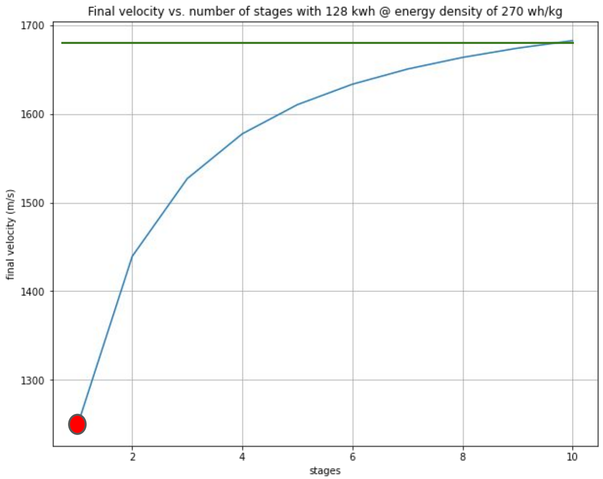
Feasibility

Feasibility: Energy requirements and mission design

Given a suitable track surface a craft with the following basic parameters could achieve lunar orbit

- Starting battery energy: 128 kwh
- Energy density of battery packs: 270 wh/kg
- 10 stages

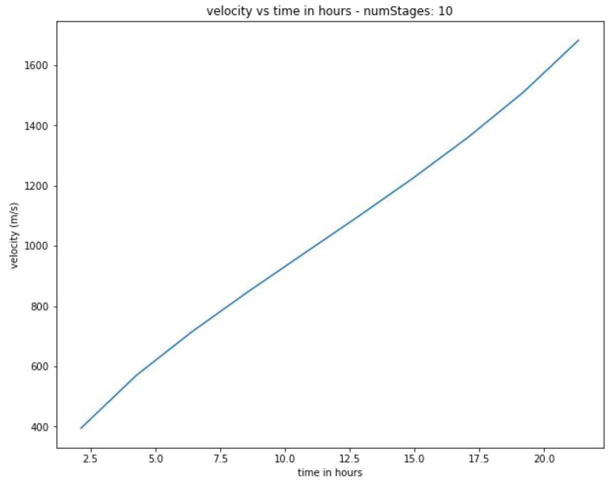


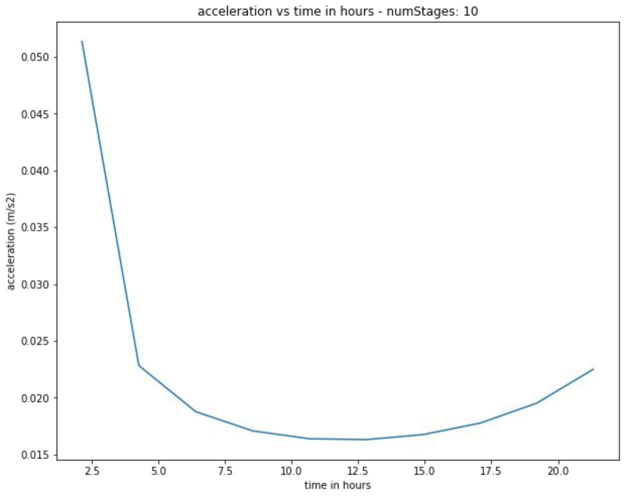


Feasibility: Power and duration

Although the mission requires high velocity, it does not require high acceleration.

- Low rolling resistance
- Modest power 6 kw
- Time to orbit of ~21 hours





Feasibility: Rider contribution

To maintain the spirit of the concept, the rider contribute to powering the mission

Charging the batteries pre-launch

- Given a 250 w output, the rider can charge the batteries in 224 hours (about 2 months at 8 hours per day)

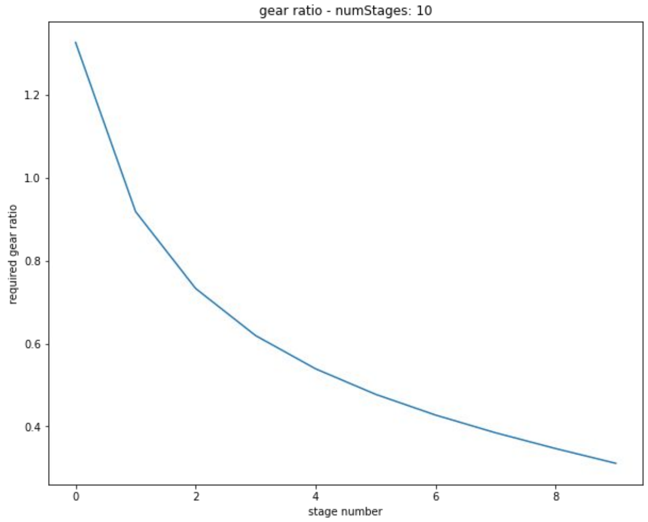
Providing auxiliary power during the mission

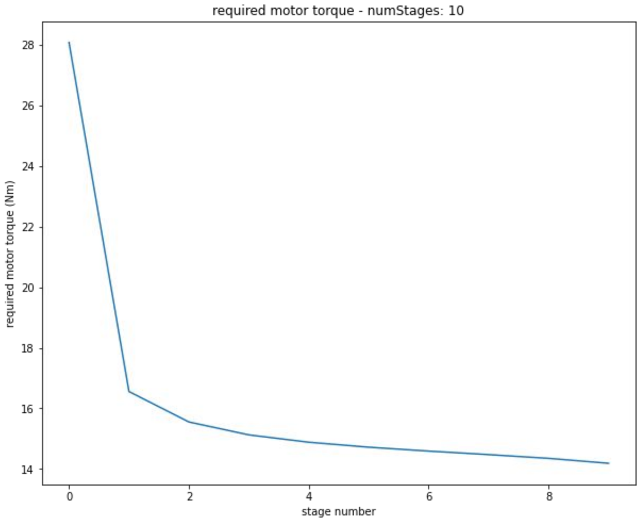
- Survival a strong motivating factor
    - 250-350 w output from rider to power life support system and magnetic bearing control system

Feasibility: Powertrain

One 3 kw motor per wheel with a typical speed of 4000 rpm coupled to 2.5 m diameter wheels would require the following gearing

15 Nm peak torque would be sufficient





Feasibility: Braking

The primary issue with decelerating after reaching orbit is that the wheels of the craft will no longer be in contact with a track

Many options exist including

- Carrying a small forward facing thruster to reduce vehicle speed until ground contact,
- After ground contact is reestablished, the drive motor can be used as a generator connected to a radiantly cooled resistor
  - no batteries will remain to be charged via regenerative braking

Feasibility: Wheel design

A velocity of 1680 m/s is high compared to a standard bicycle ridden on earth.

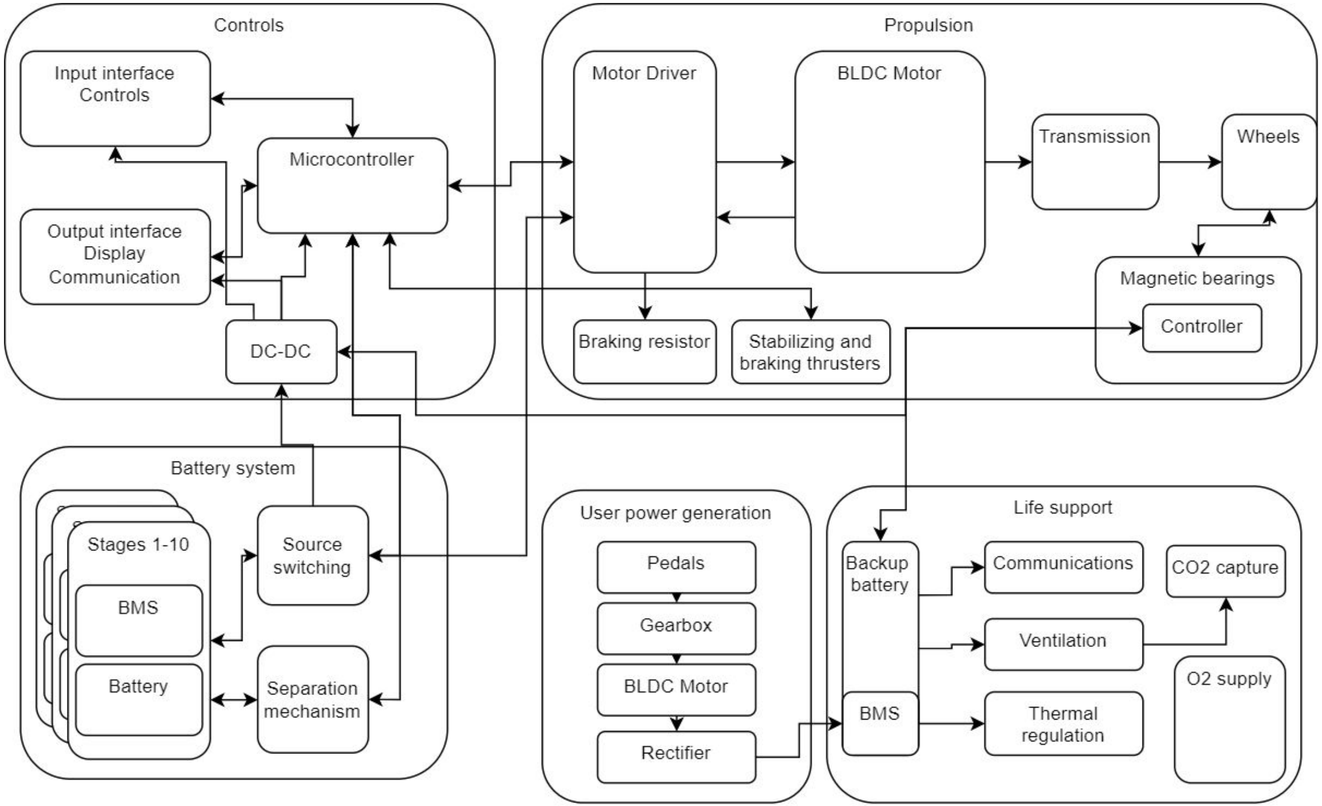
- about 151x as fast as the average winning speed for the Tour de France.

A 2.5 m wheel (larger = lower rolling resistance) would rotate at over 12000 rpm

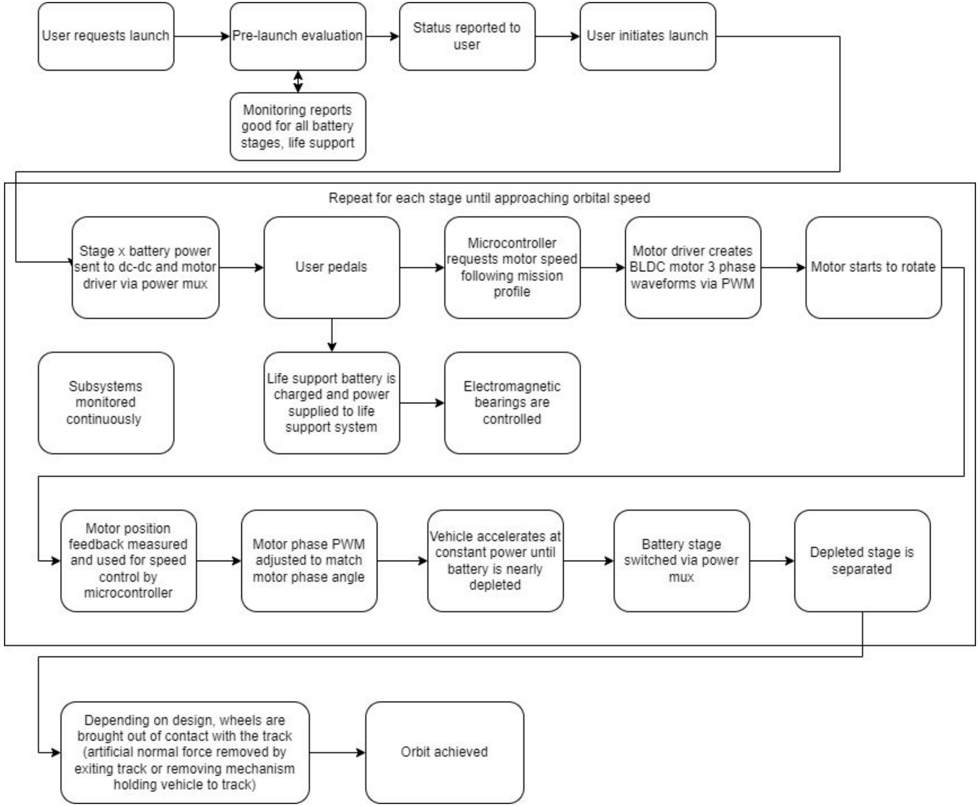
- Resulting acceleration at the wheel circumference ~230000 earth g's
- High, but feasible as it is 4x less than that of a commercially available ultracentrifuge rotor

Design

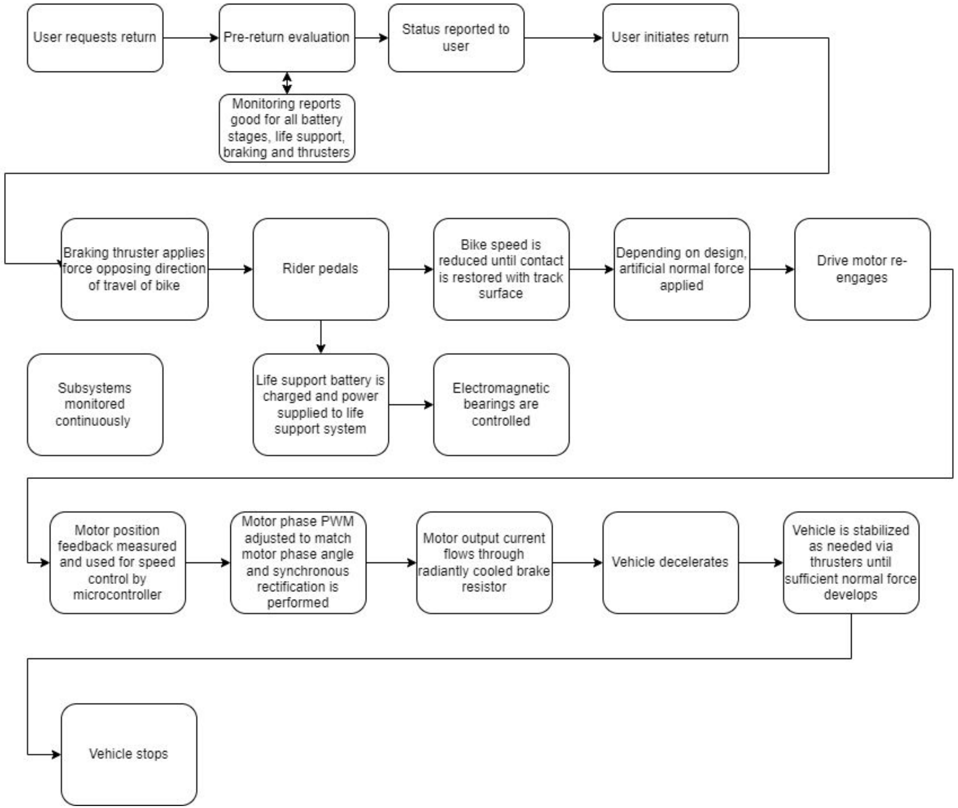
High level block diagram of the system



Functional block diagram for launch

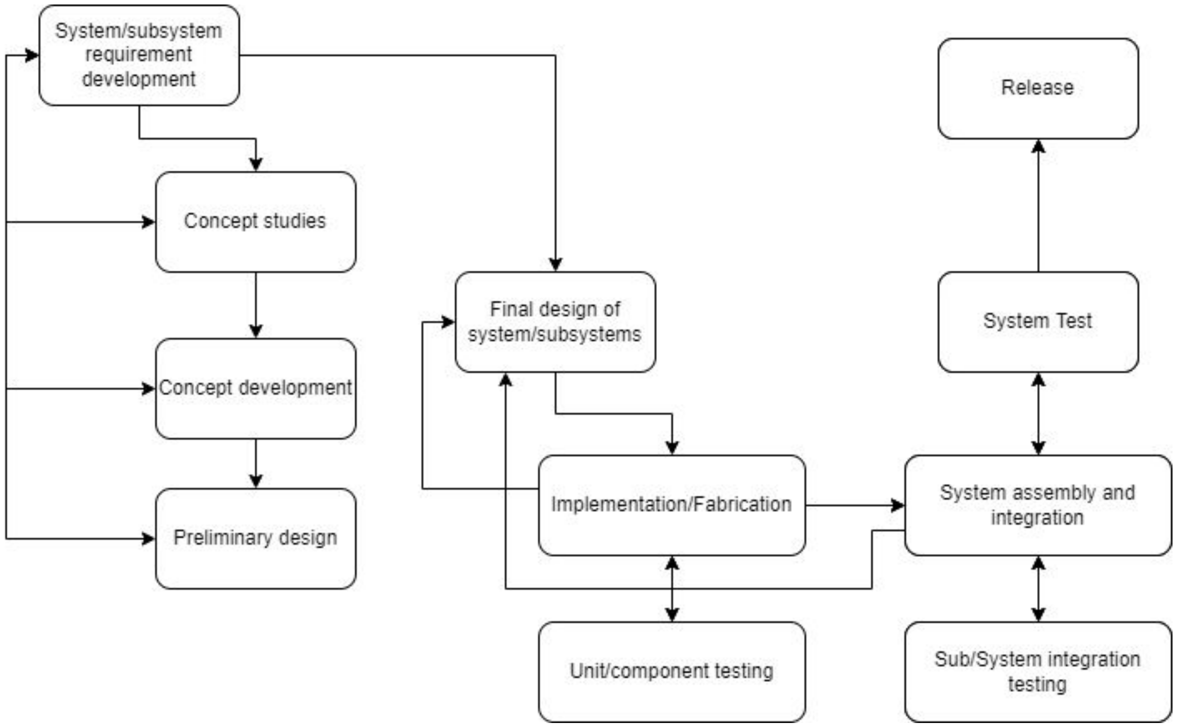


Functional block diagram for return



Test

Development process



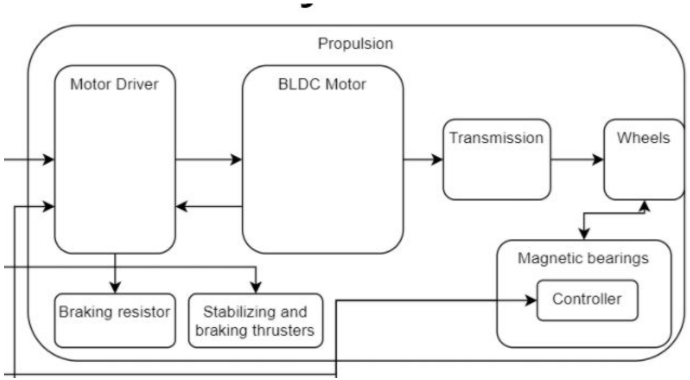
Early and often: model based development and integration testing

The purpose of integration is to test the interactions between components and subsystems.

- Integration testing should be performed early via simplified models with expected interfaces
  - Owners of a subsystem or component can provide a mock of the expected output
  - Assumptions about expected interface behavior can be checked early
  - Prevent detailed development of components with totally wrong expectations
  - Models enable detailed understanding of behavior
  - Models are easier to change than hardware (usually)

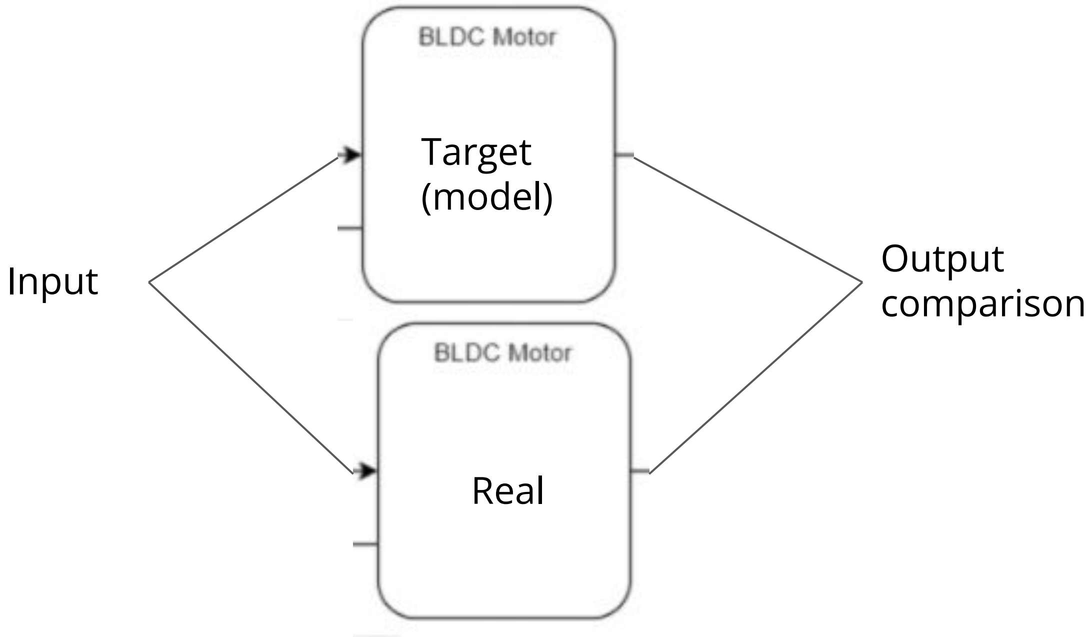
As design maturity increases, so should model complexity

- Develop components based on simplified models of neighboring components
- Combine detailed models of components after design phase into subsystem model
- Test interaction of detailed models
- Fix assumptions about neighboring component behavior, update design as needed
- Repeat until subsystem model meets requirements testable in a model based env.



Validate and verify component

- Validate and verify real component against model (since model meets requirements)
- Combine real components into subsystem or full system, depending on coverage of requirements via model based testing



Full system integration

- Combine real subsystems into final product
- Test expected interactions between real subsystems as needed based on coverage of model based testing