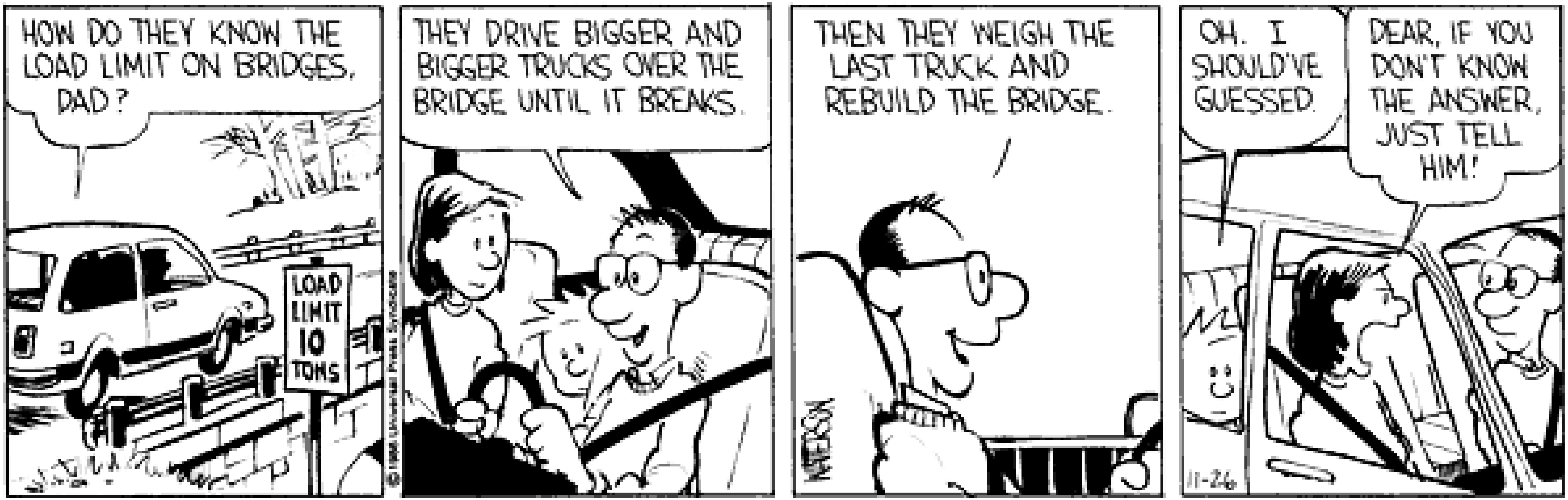
Planning for experiments



When designing a system, you're continually testing the system, whether implicitly or explicitly

- Here's an idea!
- Can this work?
- What does it take to make this work?
- How do I make this work best?
- Does this meet the expected performance?
- Can the client/customer/user operate the system as intended?

Exploration

Specification

"Optimization"

Verification

Validation

Early prototyping should encourage creativity

- Playful experimentation and 'trial-and-error' are useful in the early stages of design.
  - They can help generate ideas by stimulating creativity
  - Documentation and direct planning should be kept lightweight so as not to stifle creativity
- As your design progresses, however, it is important to *keep increasing levels of detail behind design decisions*
  - Sharing information
  - Avoiding duplication of effort
  - "Enlightened" trial-and-error is better than 10,000 monkeys

Parametric prototypes and testing

- Early prototypes are useful for answering basic questions:
  - Could this work?
  - How does it work?
  - *What do I need to know to make it work*?
- As your design becomes better defined, prototyping and testing becomes more focused:
  - How does changing X affect Y?
  - What parameters work best?

You need to build deliberate, directed prototypes to answer these questions

Later prototypes are often directed at proving performance

- Does the integrated system work as expected?
- Does the system meet requirements?
- Does the user use the system as expected?

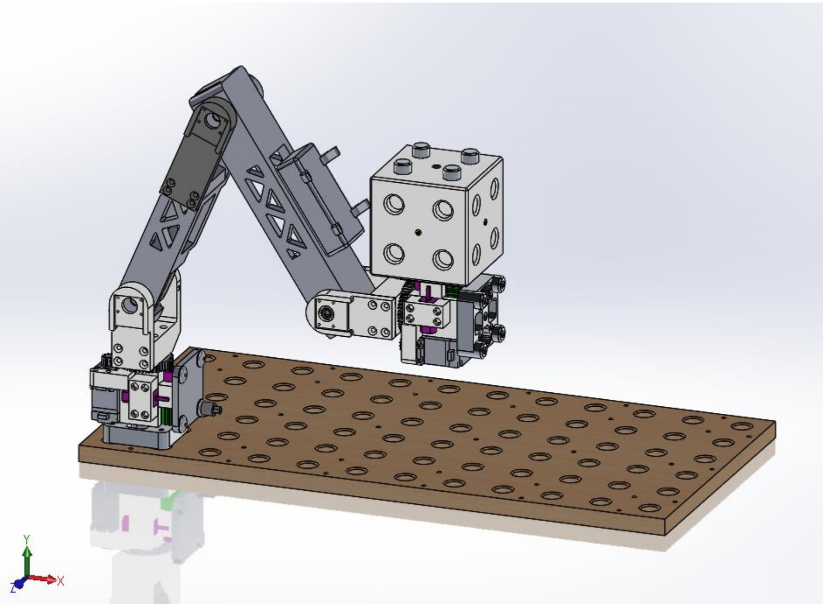
Verification and *validation* refer to <u>proving performance</u>.

Justifying your decisions

- Ultimately, your design work is directed at making the best decisions
- Your client or customer (or professor!) wants to know that you made the best decisions

You need to provide evidence to justify your decisions.

Why make this more complex?



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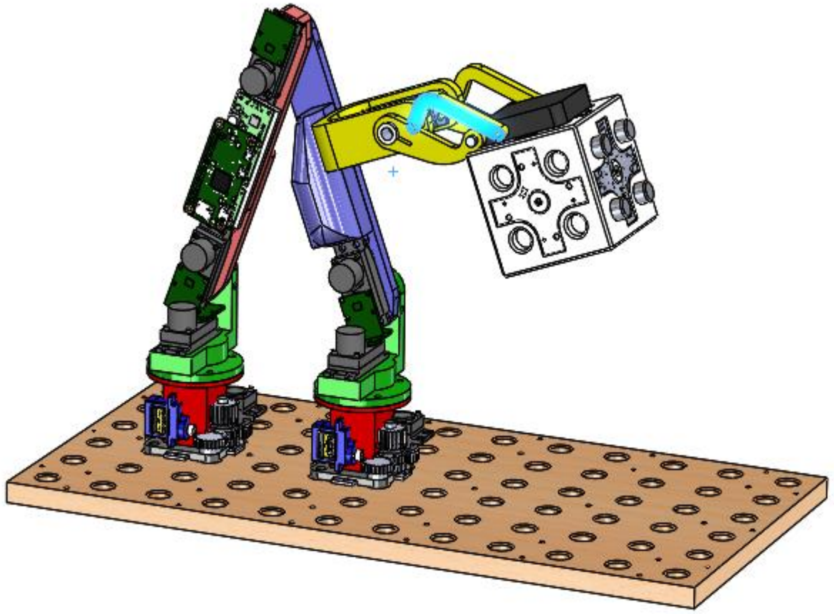
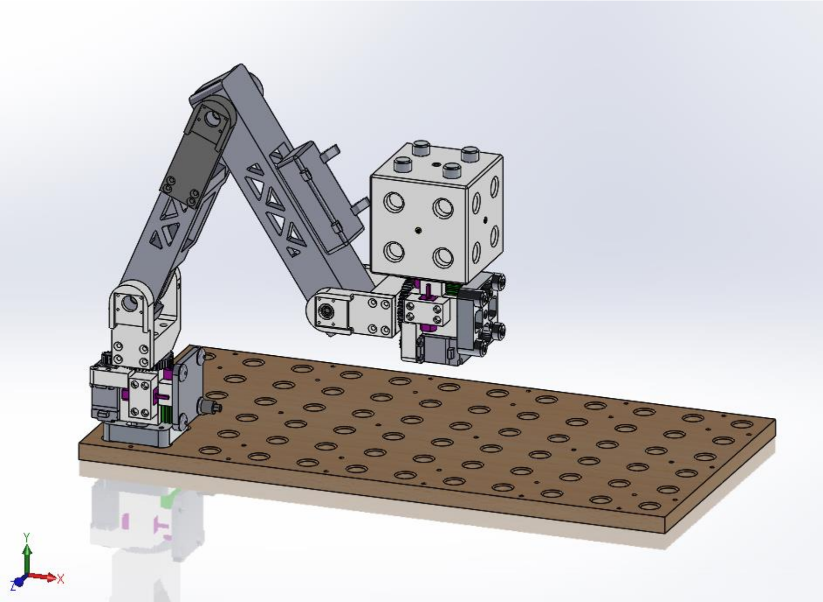


"It can't turn corners."

Why make this more complex?



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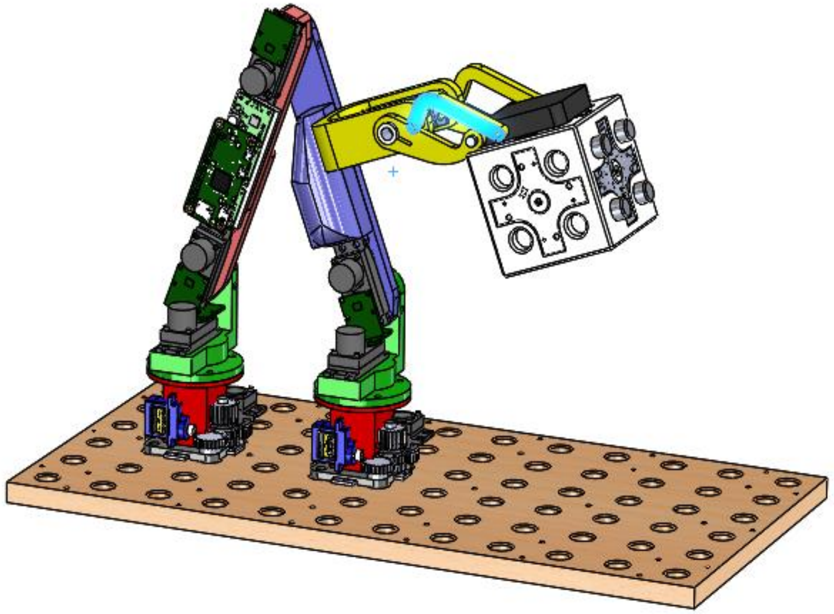
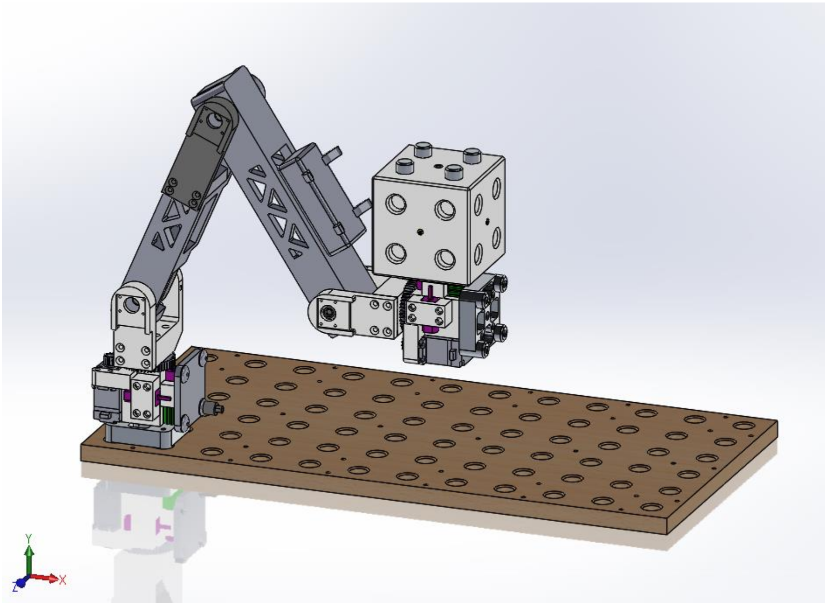
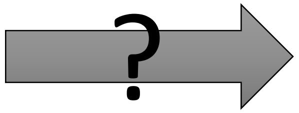
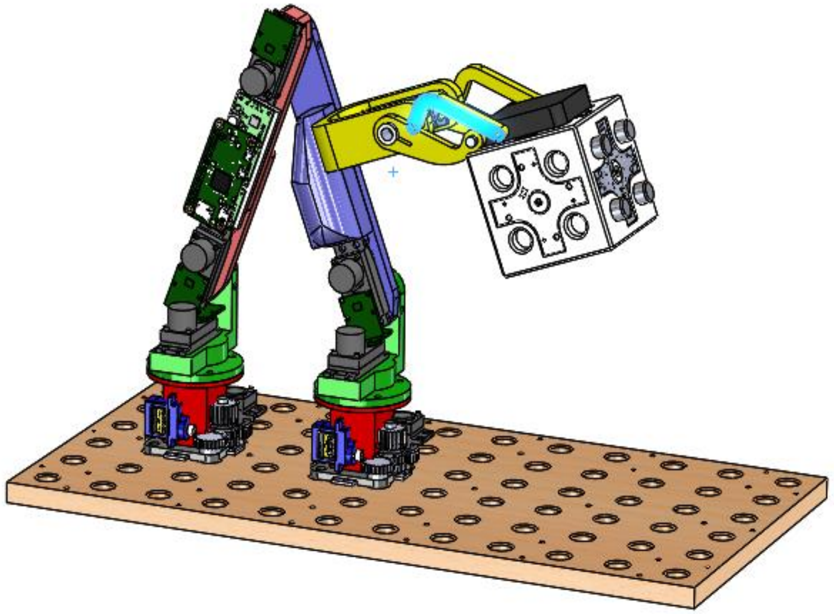


“It can’t turn corners.” (Actually, it can.)
“It requires two separate end effectors.

Why make this more complex?

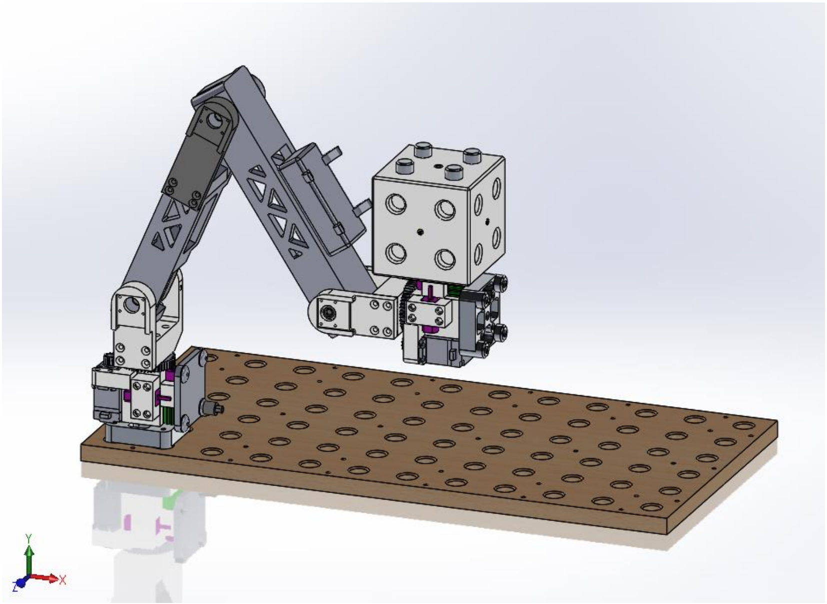






"It can't turn corners." (Actually, it can.)
"It requires two separate end effectors. (It *has* two, but does it *need* two?)

Why make this more complex?



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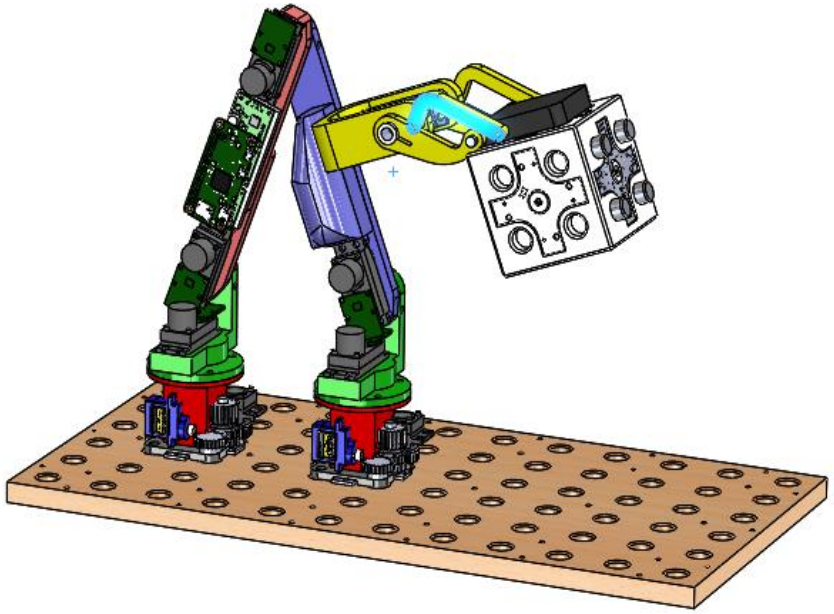


It is important to define *metrics* to help direct decisions

Experiment and analysis

- A good engineer knows *how* to use both experiments and analysis to answer questions
- A better engineer knows *when* to use each

Analysis

- Easy to change parameters to see how they affect the system
- Easy/fast to do many iterations
- Models are <u>always</u> simplifications of the system

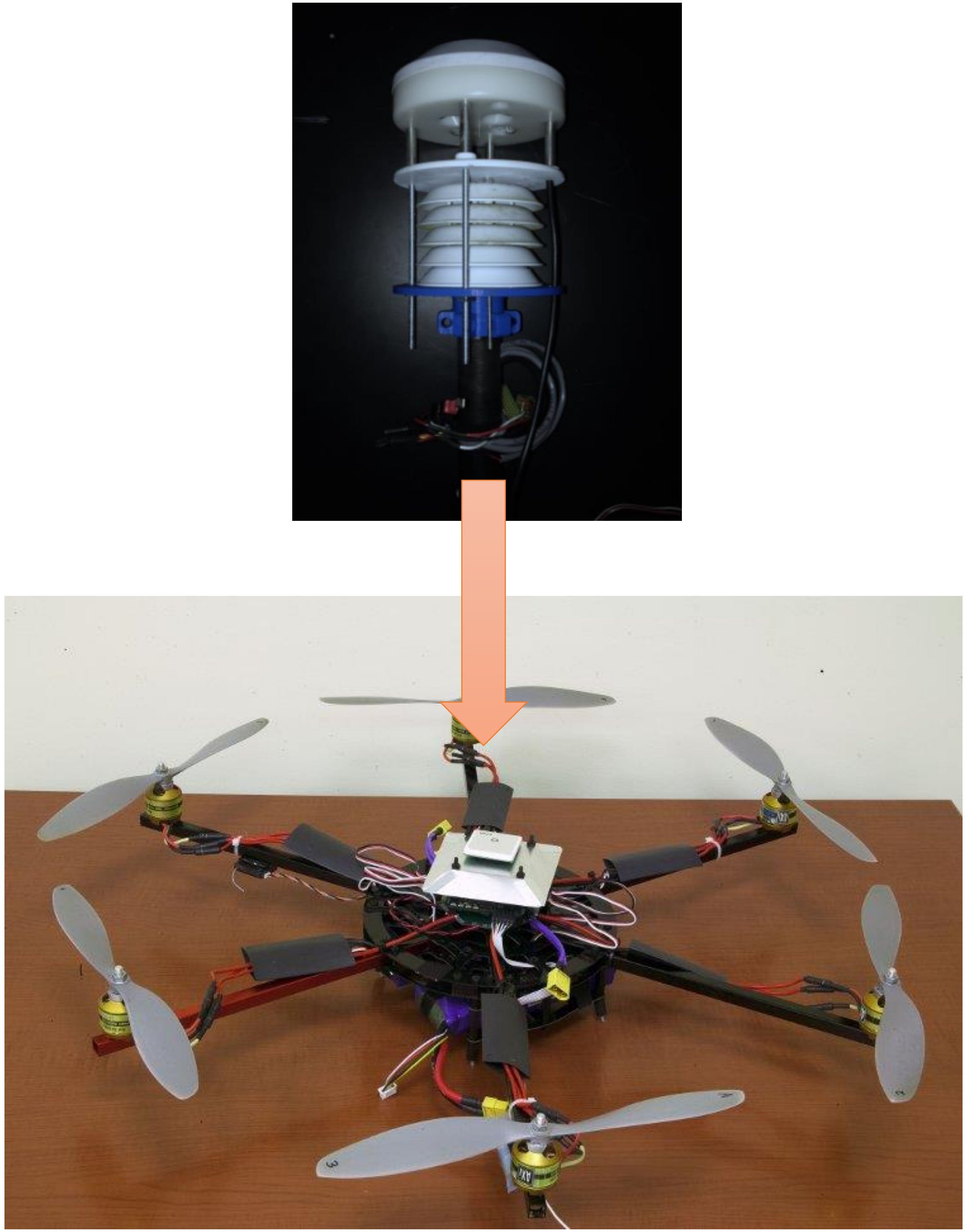
Experimentation

- Done in the real-world, so the physics is always `true`
- Particularly helpful for identifying interactions
- Typically, more time consuming

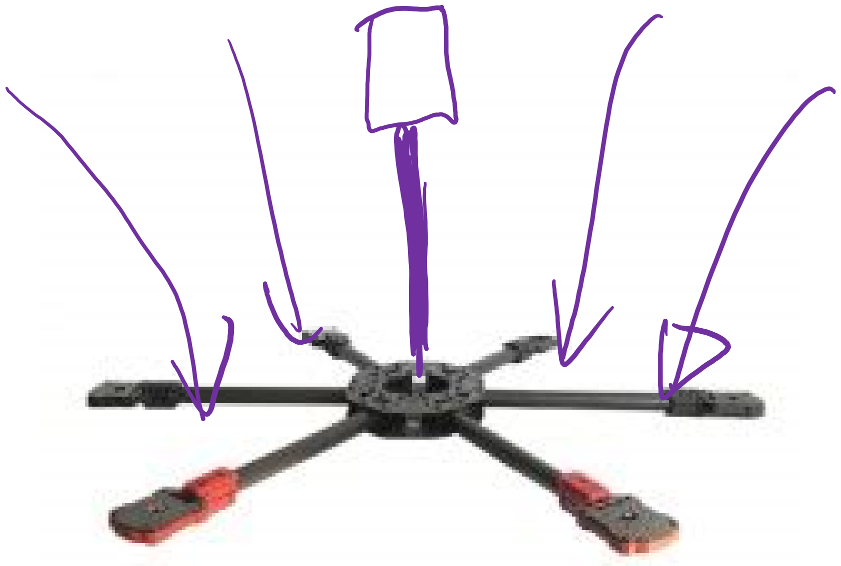
The Art of Prototyping

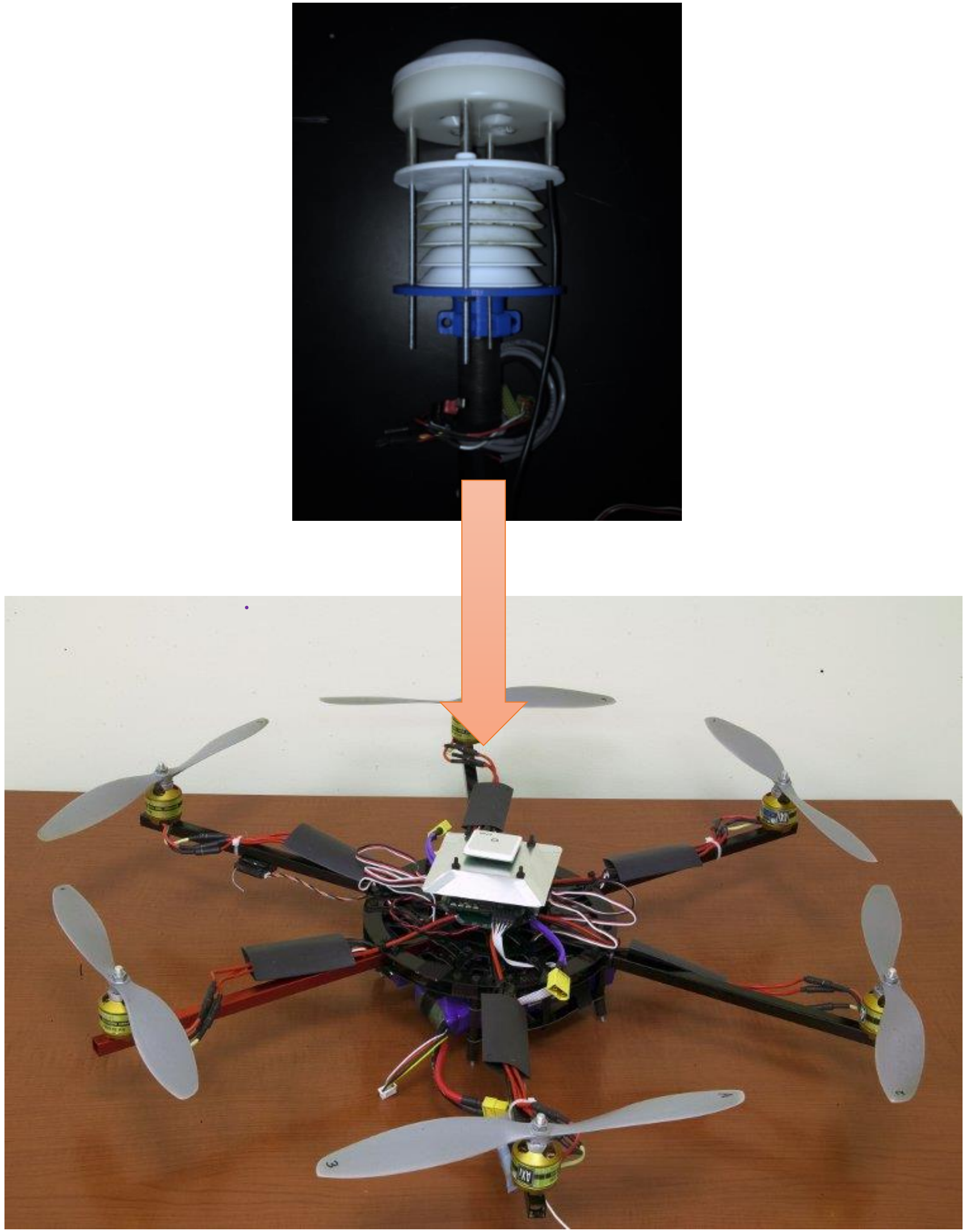
“Let me show you my plan for sending you home. Please excuse the crudity of this model – I didn't have time to build it to scale or to paint it.”

The Art of Prototyping

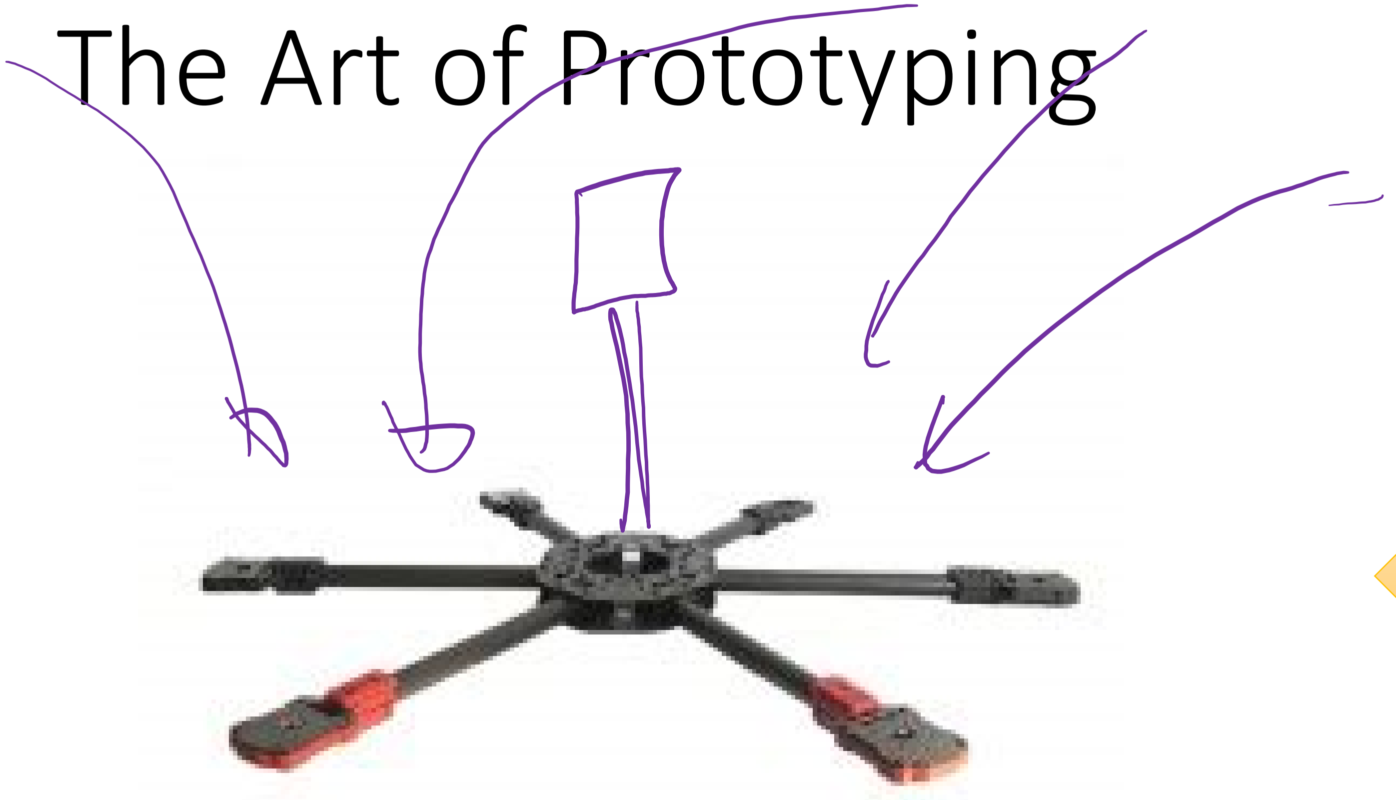


The Art of Prototyping





The Art of Prototyping



Define metrics

- **Wind speed anomaly:**

- Flight time:

- Stability:

Define metrics

- **Wind speed anomaly:** Difference between true and measured wind speeds
- Flight time: How long the hexarotor can remain aloft with one battery charge.
- Stability: Increased moment due to change in CoG; wind speed at onset of “wobble”

Determine how to calculate metrics

- **Wind speed anomaly:** Measure the difference between measured and true wind.
- Flight time: Measure the weight of the base copter, calculate the weight of a pipe, and calculate the extra power needed to the motors.
- Stability: Calculate the increased moment due to higher center-of-gravity; Measure the maximum side wind before “wobble” sets in.

Build a prototype/test system for testing

- Socket and PVC pipe to quickly change height
- Laboratory experiment
  - Control “wind speed” with a fan (better would be a wind tunnel)
  - Measure “true” wind speed and reading from the anemometer
  - Measure wobble with a gyroscope

We recommend a 13” offset

- With a **13-inch offset**, the effect of the rotor downwash is less than 2%, which is within the accuracy range of the anemometer
- The system remains stable in sidewinds up to 30 m/s, which is far greater than the expected operating conditions
- A tube made of Schedule 40 PVC pipe is expected to reduce flight time by less than 1%, which is negligible; other, lighter materials could be used, but they must be tested for rigidity in flight

Your turn

<u>3d-printed autonomous ground vehicle</u>

For simplicity, we wanted to test performance with four, fixed wheels and skid steering. We needed to know how well it performed.

Your turn

<u>3d-printed autonomous ground vehicle</u>

For simplicity, we wanted to test performance with four, fixed wheels and skid steering. We needed to know how well it performed.

- How fast
- How steep
- How tall of a curb it can climb
- How ‘tire’ material affects turning (on different surfaces)