Flight Testing

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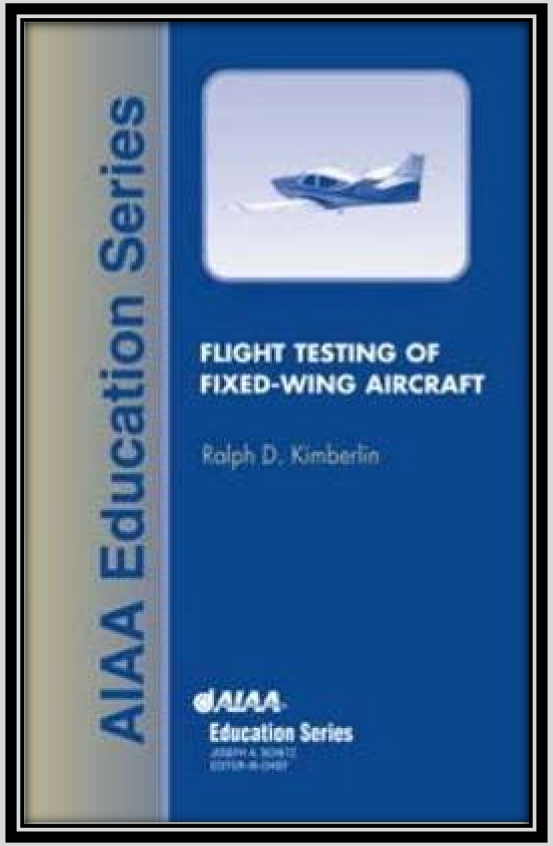
NASA’s Prandtl-D http://www.nasa.gov/centers/armstrong/news/FactSheets/FS-106-AFRC.html

Additional Reference – *Flight Testing of Fixed-Wing Aircraft,* Ralph Kimberlin



End goal for flights in spring

- Flight of your aircraft (as designed, hopefully)
- No “surprises”
- No (or minimal) “last minute fixes”
- Meets or exceeds all of your KPIs and/or mission-specific goals
- Be able to fly again

How do you get there?

- Risk mitigation
  - Assess the “riskiest” aspects of your design
  - Test those aspects more than a known, working system
- Test individual components, subsystems, and systems
  - Especially electronics
  - Bench tests are your friend
  - “Build up” to your full system
- If a specific demonstration is to be given, practice it

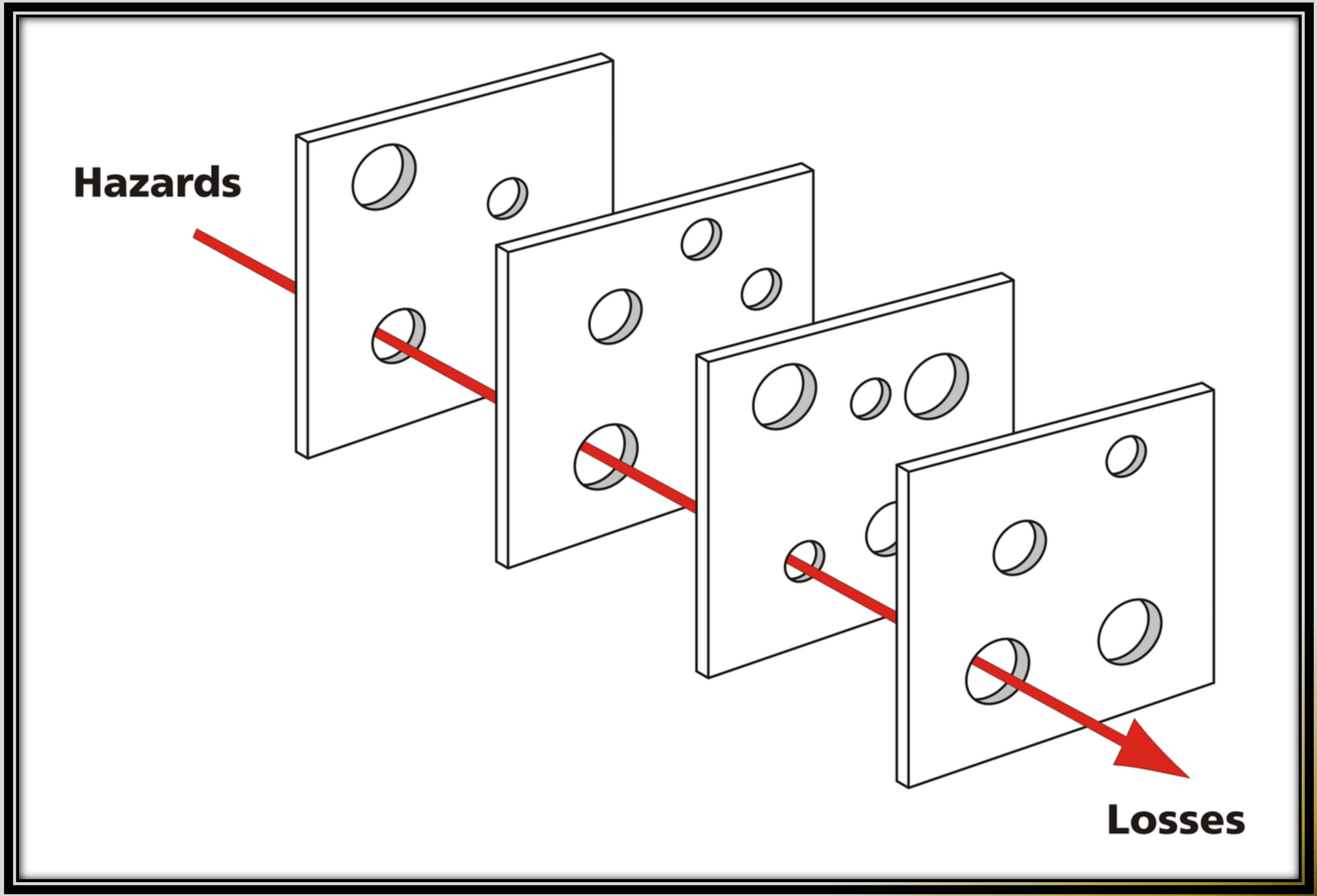
Main considerations

- Safety
- Operating Limitations
- Regulations
- Documentation
- Procedures
- Data Acquisition
- Instrumentation
- Data Reduction

Safety

- Maintain safety for EVERYONE involved
  - Pilot
  - Ground crew
  - Spectators
  - Bystanders
- Set up safety procedures *and follow them*
- No one person is in charge of safety during testing: everyone must be aware of what is happening
- “Swiss cheese” model
  - Several seemingly small events lead to major loss

Safety

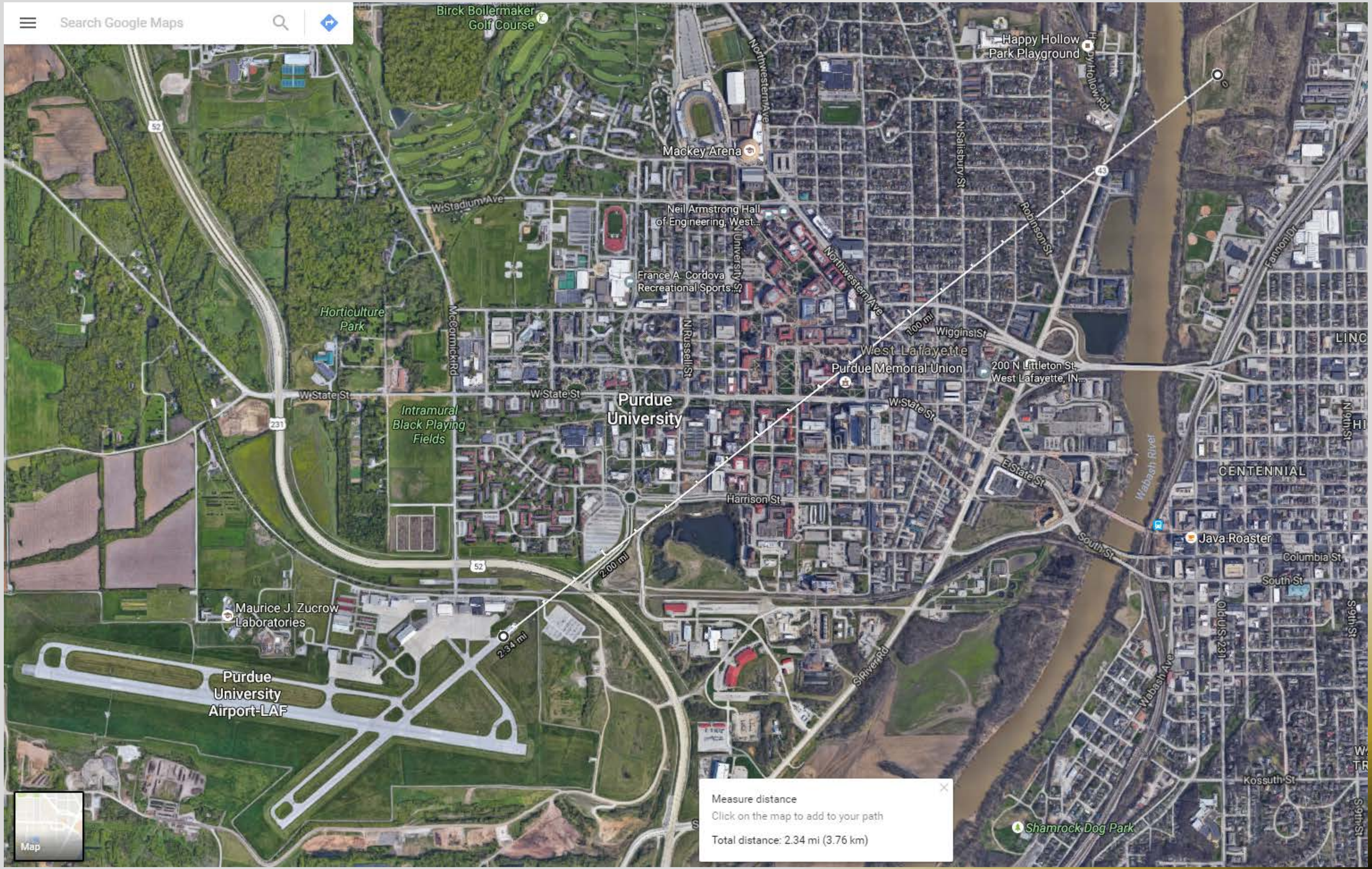


https://en.wikipedia.org/wiki/Swiss_cheese_model

Safety

- Maintain situational awareness
  - Other people may be flying with you
  - An extra set of eyes is always helpful
- AMA Safety Code
- Flight Test Safety's Best Practices
- Absolutely must maintain sufficient clearance from manned aircraft
  - For UAS: FAA-mandated maximum of 400 ft AGL
  - Example: at the local AMA field, 400' AGL puts only 300 feet in between our aircraft and aircraft on glideslope for RW 23 at KLAF
    - If the manned aircraft is 1° below glideslope, that clearance is down to about 100 feet

Safety


Search Google Maps
Birck Boilermaker Golf Course
Happy Hollow Park Playground
Mackey Arena
Neil Armstrong Hall of Engineering, West...
France A. Cordova Recreational Sports...
Horticulture Park
West Lafayette
Purdue Memorial Union
200 N Littleton St, West Lafayette, IN...
Purdue University
Intramural Black Playing Fields
CENTENNIAL
Java Roaster
Maurice J. Zucrow Laboratories
Purdue University Airport-LAF
Shamrock Dog Park
Wabash River
W Stadium Ave
W State St
Harrison St
Wiggins St
E State St
South St
Columbia St
Kossuth St
2.00 mi
1.00 mi
2.34 mi
Measure distance
Click on the map to add to your path
Total distance: 2.34 mi (3.76 km)
Map

Operating Limitations

- Intrinsically related to the safety of the operation
- Often driven by weather or other physical factors
  - Cloud ceiling
  - Temperature limits
    - Can be an aircraft or a pilot limitation
  - Wind speed/direction
  - Visibility
  - Battery voltage
  - Did you bring a tool kit?
- Develop a GO/NO-GO decision tree for testing based on your operating limitations

Regulations

- Federal
  - FAR Part 107
- State or local legislation
- Community-Based Organization
  - Academy of Model Aeronautics
    - Provides insurance and other services
- Local club
  - Often have their own safety rules for specific sites
- Land owner

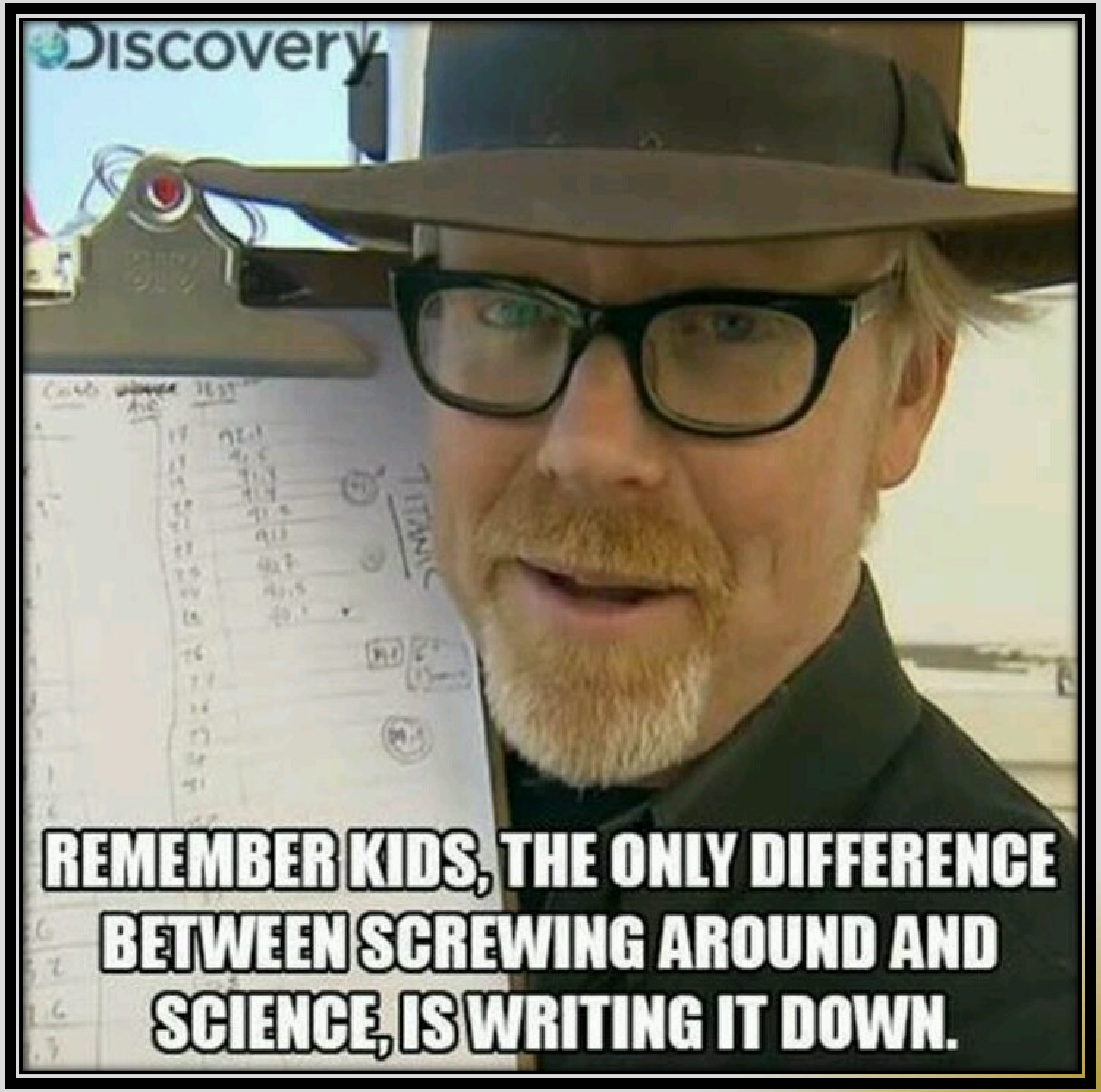
Documentation

- Prepare everything beforehand
  - If you need to manually record data, have documents created to record data before you need to record it and take it with you (electronic or hard copy)
  - Should be able to plug acquired data into analysis code immediately upon completion of the flight
- Record everything
  - Aircraft configuration (Weight, CG, installed equipment, …)
  - Field conditions (Temperature, wind, vis, ceiling, …)
  - Pilot feedback
    - Flying qualities
    - Cooper-Harper rating scale
    - See Kimberlin, Chapter 32

Documentation

- Videos/pictures
  - Proof of flight
    - Always celebratory background noise on first flight
  - Depending on quality and position, can be used to do a rough flight path angle calculation on takeoff
  - Takeoff roll distance
  - Post-crash
    - Might be able to pinpoint a structural failure
    - Might notice something wrong with the aircraft before it took off that didn't get caught before takeoff

Documentation



Procedures

- Step-by-step of each segment of testing, from beginning to end
  - One action per step, e.g.
    1. Ensure prop arc clear
    2. Insert safety plug
    3. Verify correct ESC tone output (verify # battery cells)

    INSTEAD OF

    1. Power up propulsion system
  - Checklist format is nice
- If you have one person create procedures, have another verify and offer corrections/improvements
- Likewise, have a second person verify all checklist items during test execution

Procedures

- Pre-flight procedures ensure you will be ready to fly at the field
  - There will be snow on the ground (in Indiana anyway…) at some point
- Procedures for flight are broken down by maneuver
  - Traditionally called "cards" as the pilot would have them on a kneeboard in the aircraft
  - For UAS flight testing:
    - All or most data acquired on-board
    - Have a teammate tell the pilot what maneuvers are to be flown and with what parameters
      - Airspeed tolerances, altitude tolerances, power settings, etc.
      - Live data on the ground makes this easy
    - Once autopilot control gains are known, may be able to automate some tests
  - Pilot input is valuable to assessing the performance

Procedures

- Should be designed to answer a question
  - What is the power-on stall speed in a clean configuration (Vs_1)?
  - What is the best glide speed?
  - What is the dynamic response to a rudder doublet?
- Answer one question at a time
  - Reduce as many “variables” from an equation as possible

Procedures

- Your flight test program should itself follow a procedure
  - Test individual electrical components
    - Even servos and BECs
    - Make sure everything works as it should before integrating it into the aircraft
  - Propulsion system
    - Should be able to calculate J, Ct, Cp from RPM and airspeed
    - Monitoring RPM during flight would be a good goal
  - Wind tunnel test of whole airframe (if possible)
  - Verify flight envelope to mitigate risk on future tests
    - Stall, controllability
  - Verify/calculate aircraft aerodynamic data (L/D, CD_0, etc.)
  - Verify/calculate aircraft stability derivatives

Data Acquisition

- Stand-alone or control-integrated systems
- Live data relay or stored on-board
- The “Extreme” of live data use is On-Screen Display (OSD)
  - Can be used as a HUD for FPV flight
  - Or overlaid on to gimbal camera for GPS/ground track/speed info
- Instrumentation for each flight should be pre-defined
  - Some flights you may want to add or remove components
  - Ensure instruments are all calibrated correctly

Data Acquisition

PixHawk

- Arduino-based with data acquisition and flight control
- Replaces standard RC receiver
- Can interface with almost any other i2c or serial devices
- Takes some time to get set up properly
- PC interface with 3DR (or other brand) radios

EagleTree eLogger

- Stand-alone data acquisition
- Mostly proprietary sensors
- Can do live telemetry w/ proprietary radio
- Can add A/D breakout
- Fairly easy setup

Instrumentation

- Where the data comes from
- With PixHawk, can find documentation of many different devices being interfaced
  - Airspeed and altitude via pitot-static probe
  - GPS location/ground speed via GPS antenna
  - Temperature
  - Position feedback of control surfaces or air data probes
  - Accelerometer/gyro data (useful for control)
- One note: GPS groundspeed does NOT equal airspeed
  - Common mistake in past projects

Instrumentation

- Full-size aircraft use air data booms with pitot-static ports, along with angle of attack and sideslip sensors

Instrumentation

- Can do the same for RC, but may have to DIY
- This example used a Hall effect rotation sensor to deduce the AoA sensor's orientation
- You can get creative, but there is a lot of historical precedence on flight testing instrumentation and what is useful

Data Reduction

- What does the data mean?
  - Take all data collected during the flight and make the jumble of numbers into a logical report complete with plots, written sections, and conclusions.
    - Yes, this is more documentation
  - Easy example: you want to know L/D during steady level flight
    - L = W. You weighed your plane in flight condition before flying, right?
    - D = T. You know what thrust you are producing from your propulsion system based on airspeed and the propeller's RPM (or from doing wind tunnel tests on your propulsion system before you started flying)
  - Should be able to calculate lots of instantaneous values similarly
- Should be set up before you get data from your first flight test
  - Plug in new data set from flight test → Get answers

Results

- Flight test results in final presentations make your stakeholders happy
- Shows that a realistic version of your design was built and flown with at least some level of success
- Comparison of expected/theoretical values to what you actually achieved is paramount
  - What values were you close on?
  - What values did you miss by a mile?
    - Most importantly: WHY?

Questions?