HPH Airframe Team (2011-2012)

Recommendations to Future Teams

Team Icarus

Cal Poly Mechanical Engineer Senior Project

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Overview
This year, we designed the geometry of the airframe, tested the strengths of various joint types, and constructed a 1/3 scale model airframe. In addition to the geometry, which is explained in detail on the CalPoly HPH dropbox account under HPH 2011-2012 Files/Truss Geometry, we would like to pass down some of the important techniques and methods we developed along the way.

Truss Geometry Recommendations

Tube Sizing
Ideally, we want our tube cross sections to maximize I_{xx} (to reduce buckling) while minimizing area (to reduce weight).The ideal way to do this would be to have a large diameter with a small wall thickness. However, we are limited by the wall thickness as the thinnest stable tube needs a thickness of about 0.030” (4-5 plies). Therefore, the truss is dimensioned so that all tubes, regardless of diameter, have a wall thickness of 0.030”.

When you manufacture the tubes to the right size, it is crucial to do a buckling test to make sure the value of IE matches the predicted value. The longitudinal modulus used in buckling calculations is assumed to be E=17 MSI, which is common for many professional-grade carbon tubes. This can be done with a ±15º wrap of UNI or some combination of 0º, 15º, or 30º. If you find that the main spars crush where the supporting members join, that area can be reinforced with a layer of 90º UNI, but it should not be necessary to apply a layer of 90º to the whole spar.

Top Face Layouts
We analyzed several different designs for the top face as shown in figure 1 on the next page.

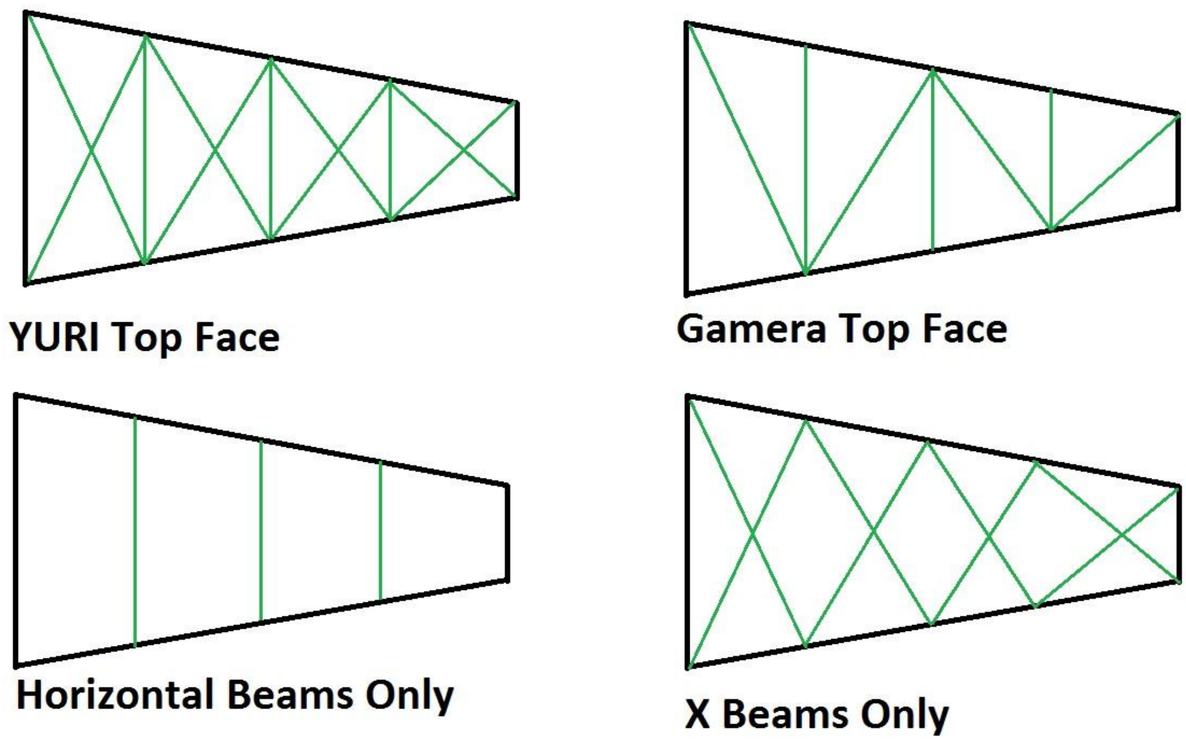

Figure 1: Top Face Design Comparison

Table 1: Analysis of the top face designs

	Pros	Cons
YURI	Extremely rigid Resists torsion	Statically Indeterminate Heavy
Gamera	Almost identical to the YURI in a statics analysis Light	Probably less torsion resistant than using X beams only Asymmetric
Horizontal beams only	Sufficient for a statics analysis Very light	Twists a lot under torsion
X beams only	Resists Torsion Statically sufficient	Slightly heavier than the Gamera

We have chosen to go with the X beams design because it is statically determinate and lighter than the YURI. Although we have not tested the Gamera, we believe our design resists twisting better than the Gamera. We believe the extra stability is enough to justify the slight increase in weight.

Node Positioning

In the interest of preventing buckling, one must be aware of which beams will be in compression. Since we assume that the members in tension are not at risk of failing, we should position the nodes so that

the member in compression is close to vertical, allowing for a shorter length and smaller force in that member.

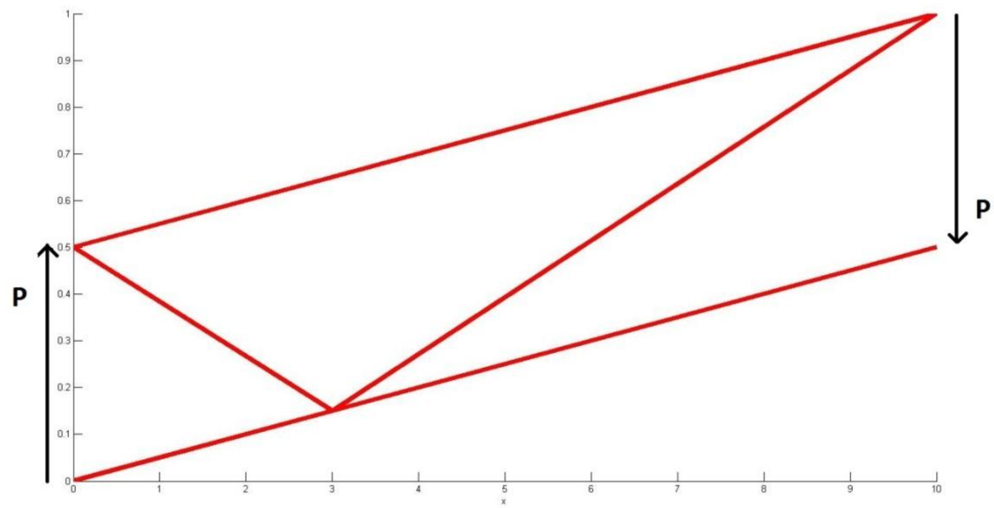

Figure 2: Bad Truss Design

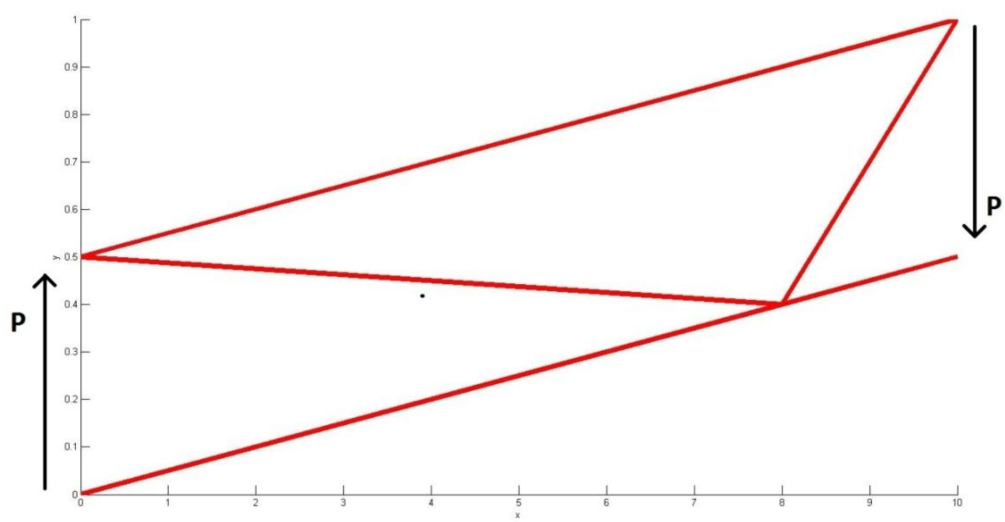

Figure 3: Good Truss Design

Figures 2 and 3 show how to alleviate buckling in a section of the arm (the left member is in tension and the right member is in compression).

Joint Fabrication

Three major types of joints

- Basic Joint: Connects the smaller supporting members to the main spars (Figure 4).
- Non-Permanent Joint: Allows airframe to be disassembled for transport and/or storage.
- Permanent Joint: Used to connect main spars end-to-end, necessary because the spars used for this model were COTS and too short for each arm.

Basic Joint

Ends of supporting members are ground with a sanding drum to fit against the main spars. The contact area of the main spar is sanded to remove any smooth finish and help the adhesives bond. After testing, CA glue alone was deemed strong enough for 1/3 scale construction. Afterwards, gel epoxy with chopped carbon tow was added to reinforce the joints as CA glue is quite brittle. Currently, this method is recommended for full scale investigation.

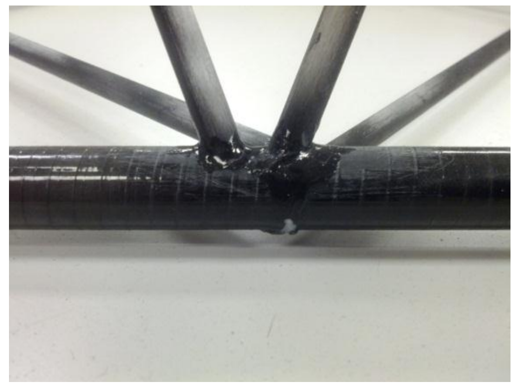

Figure 4: Basic Joint: A typical node with four supporting members connected to the main spar. Only CA glue has been used at this point.

Issues with Basic Joints:

The long cure time of the epoxy originally used (105/206 West Systems) and uneven area of the joint made it difficult to keep the epoxy in place while curing and also remove any air bubbles.

Possible Solutions/Recommendations

Thicker epoxies seem to be easier to apply and keep in place. Gel or even putty epoxies appear promising. Adding chopped carbon tow to gel epoxy or buying a premade mix may also be viable. The epoxy used on this scale model is Proset 175/275 gel epoxy with about 1 cup of chopped fibers cut in 1/8” strips. The chopped fiber appears to help create large fillets without adding much weight.

Non-Permanent Joints

The purpose of these joints is to allow the model to be partially disassembled for ease of transport. For the full scale, they will be necessary if the aircraft is to fit inside a standard trailer. There are three types of non-permanent joints on the model:

Figure 5: Flange Joint: Two solid pieces of aluminum provide stiffness but take up a lot of space and weight. Not recommended for full scale.

- **Flange Joint** (Figure 5):
    - A single piece of aluminum was milled down to fit inside the tubes, leaving one end at the original

diameter to create a large contact area. The flanges are bolted together with three bolts each and bonded to the spars with epoxy.

- Pros:
  - Very strong and stiff
- Cons:
  - Very heavy (adding 3 flange joints increased the weight of the arm by about 50%).
  - Extensive milling time.
  - Bulky – forces undesirable separation in supporting members.

- **Threaded Rod Joint** (Figure 6):
  - Two threaded inserts are bonded via epoxy to the inside of the main spars. An aluminum COTS right-hand rod is threaded into one side, then partially threaded back out and into the other side by clamping and turning the exposed threads with pliers.
  - Pros:
    - Good in tension
    - Easy to keep straight
  - Cons:
    - Heavy –could possibly use threaded composite in lieu of aluminum.
    - Creates separation between main spars – recommended for tension spar only

Figure 6: Threaded Rod Joint: A solid right-hand threaded rod with aluminum inserts bonded to the main spars.

- Pin Joint (Figure 7):
  - Two hollow aluminum inserts are bonded to the inside of each side to reinforce the carbon tube- chiefly to prevent matrix cracking. A second, smaller aluminum tube is placed inside and held in place with cotter pins.
  - Pros:
    - Doesn’t require separation between main spars
    - Good in compression
  - Cons: Difficult to reduce clearances between tubes and inserts. Any play is magnified by the long spars and very noticeable.

Figure 7: Pin Joint: Hollow aluminum insert held in place with cotter pins. Ideally, if the spar is loaded in compression, the pins are not under any shear.

Issues with Non-permanent Joints:

- Often difficult to ensure bonds between the main spars and inserts are perfectly concentric.
- Depending on the exact design, precision machining may be required to ensure minimized tolerances.

Possible Solutions/Recommendations

Threaded rod joint is recommended for tension spar and pin joint is recommended for the two compression spars. Aluminum was used for all inserts in each joint; however, composite inserts may also be a viable option. Composite inserts are commercially made and can be purchased from a company such as Shur-Lok.

Permanent Joint

The main beams were purchased in 60" lengths, which is too short for a 1/3 scale arm. Thus, some main beams were permanently bonded end-to-end as shown in Figure 8.

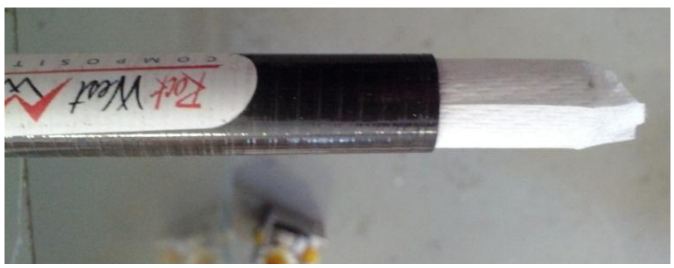

Figure 8: Partially complete permanent joint. A hollow aluminum insert is bonded via epoxy to the inside of the main spars. The insert is wrapped in paper towel to ensure a snug fit and to help hold the epoxy in place around the entire circumference while it cures.

Notes on Permanent Joints

Depending on the lengths of tubes used for the full scale, permanent joints may not be necessary. If this airframe is ever flown or put under flight loading, the permanent joints represent a possible primary failure location. These joints were not extensively tested and until verified should be considered for model construction only.

Discarded Non-Permanent Joint Design

The first non-permanent joint design was similar to the current threaded rod design, but used both right and left-hand threads (Figure 9). A hole drilled through the middle allowed the joint to tighten both sides simultaneously by inserting a lever into the center hole to turn the rod. This design was deemed inadequate prior to construction of the model and never implemented.

Figure 9: Dual-threaded non-permanent joint design. Due to structural weakness in the center section around the hole, this design was not implemented in model construction.

Notes on Discarded Design

The dual-threaded design may still be viable for the full scale. At the 1/3 scale, drilling the center hole removed most of the material, creating a very weak point susceptible to bending. This was the primary reason for rejecting it. A larger full scale model might not be as weak and merits further research.

Construction Procedure

The following section is written as a step-by-step instruction manual for 1/3 scale construction. Most of the steps are also applicable to full-scale construction.

1. Inspect tubes for manufacturing defects.
    a. Cracks
    b. Bumps/dimples
    c. Flaking
    d. Bending
    e. Dry spots (lack of resin)
2. Join tubes together to create full length main tubes.
    a. Use permanent/non-permanent connections where specified
    b. Sand the inside of each tube to the depth of the joint to be installed. Inspect after sanding, no glossy regions.
    c. Sand the outside of each joint where in contact with resin.
    d. Clean joining surfaces with acetone.
    e. Apply epoxy resin to joint and insert into tubes.
    f. Rest tubes in a channel (i.e. 80/20, long v-block, angle iron) and secure in place for the duration of resin cure time. (See Appendix C Figure 1)
    g. Once cured, inspect tube for joint straightness. If applicable, check non-permanent joints for ease of removal/installation.
3. Install main tubes in fixture
    a. Cut each tube to length.
    b. Grind/sand tube ends to match desired angle.
    c. Support main tubes along the span if sagging occurs.
4. Prepare node locations of top and bottom tubes
    a. Mark each node location starting at arm tip and measure towards the center of the airframe.
    b. Thoroughly sand each node location where supporting members contact the main tubes. Remark node locations if necessary after sanding.
5. Fit supporting members in place
    a. Cut supporting members to length, leave ~0.250” extra for grinding into place.
    b. Grind supporting tubes to length using a sanding drum with the same diameter as the main tubes. Match the angle of intersection between the supporting

members and the main tube. Check for joint flushness, no gaps should be present.

Note:
When grinding supporting members, a slightly dull sanding drum has a tendency to fray the end of the tube. This fraying creates loose fibers which appear to provide additional bond area. Do not grind away frayed fibers before gluing into place.

c. Clean the ends of the supporting members and the bonding location on the main tubes with a rag or paper towel wetted with acetone.
d. Place the ends of the supporting members carefully in place, being sure to account for other tubes that meet in the same location. Using cyanoacrylate glue, carefully bond each supporting member between the main tubes. If necessary, spray Insta-Set catalyst onto joint.
   Note:
   It may be easier to assemble the 'X' sections of the arm first i.e. join the top two main tubes together before connecting the 3rd tube. Also, consider building the tip triangle early in the build phase; it helps keep all three tubes together while placing the supporting members.

6. Epoxy supporting members in place.
   a. Chop carbon tow into very small lengths (approximately 1/8") to be mixed with epoxy resin slurry. 1 cup unpacked carbon tow mixes with approximately 6 ounces (by weight) of Pro-Set 175/275 epoxy resin. Too much carbon tow makes it difficult to apply, too little doesn't add much strength to the joint. Exact amounts should be experimented with for optimal joint performance.
   b. Thoroughly mix chopped carbon tow and epoxy resin together ensuring complete mixing of resin and hardener.
   c. Pack a large syringe (100cc) with the mixture. The syringe helps apply the mixture directly to the joint location.
   d. Apply resin mixture to all supporting member joints. The goal is to fill any gaps and to create fillets where tubes meet each other. Fillets should be at most double the diameter of the supporting members to ensure strong light weight connections while reducing stress concentrations.
   e. Once cured, sand the epoxied joints to prevent carbon splinters when handling.
7. Construct the center section.
   Note:
   The center section should be constructed upside down. This puts the square section of the center on the bottom while each arm attaches at an upward angle.

a. Mark out the square dimension of the center section on a flat board. This will help when lining up the center tube and the angled tubes that connect to each arm.
b. Place the center tube in the middle of the center section, elevated to the location where all four arms meet at one point as seen in Appendix C Figure 3 of the full report.
c. Cut and grind the four lengths of tube that bond to the center section that each arm will connect to.
d. Sand the center tube and prepare with acetone
e. Using CA glue, bond the four angled tubes to the center tube.
f. Orient the arms of the HPH to the angle specified by the design. Match the top two ends of each arm to the corners of the square as seen in Appendix C Figure 4
g. While making sure the arms are square and the correct finished length, grind the main tubes to match the radius of the center section and the angled tubes. When done correctly, all four arms should fit flush against the center tube and the angled tubes while the arm tips are the correct vertical height.
h. Prepare and bond all four arms into place using CA glue.
i. Cut and bond in any additional tubes to finish the center section.
j. Finish bonding the center sections with carbon tow and resin mixture similar to step 6.

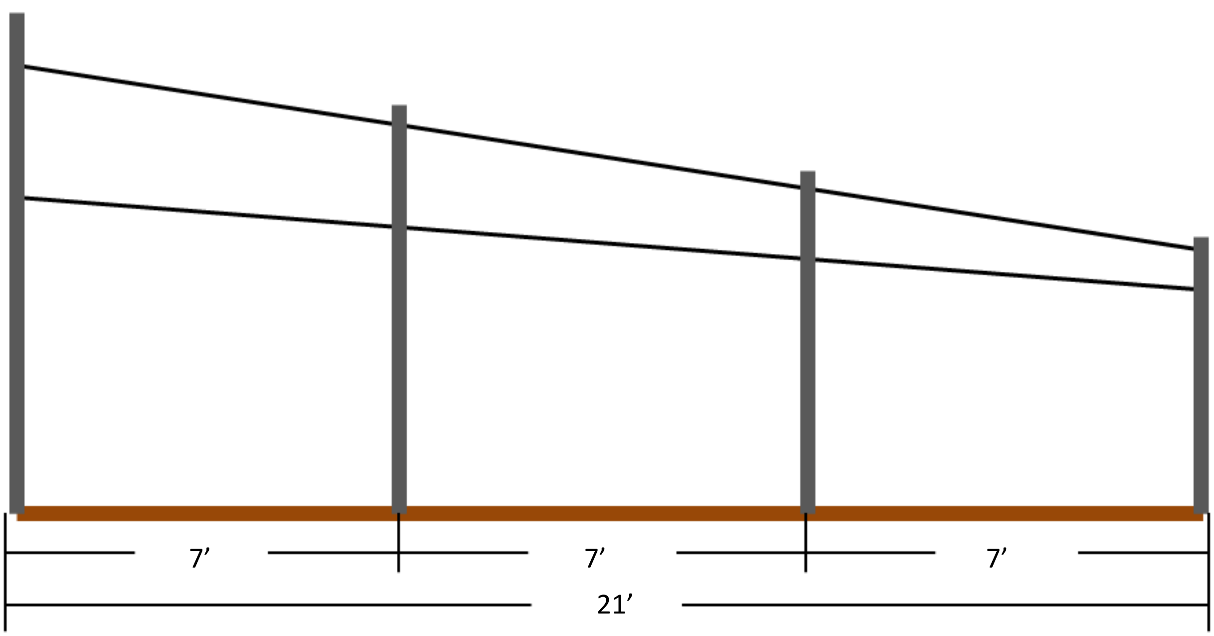

Figure 10: The full scale fixture may require addition supports along each arm to minimize bending. While the two end supports could be used similar to the 1/3rd scale fixture, the additional supports prevent sagging during construction.

Human Power Output Graph

We believe, with this graph, usefulness will be found by teams, in the future.

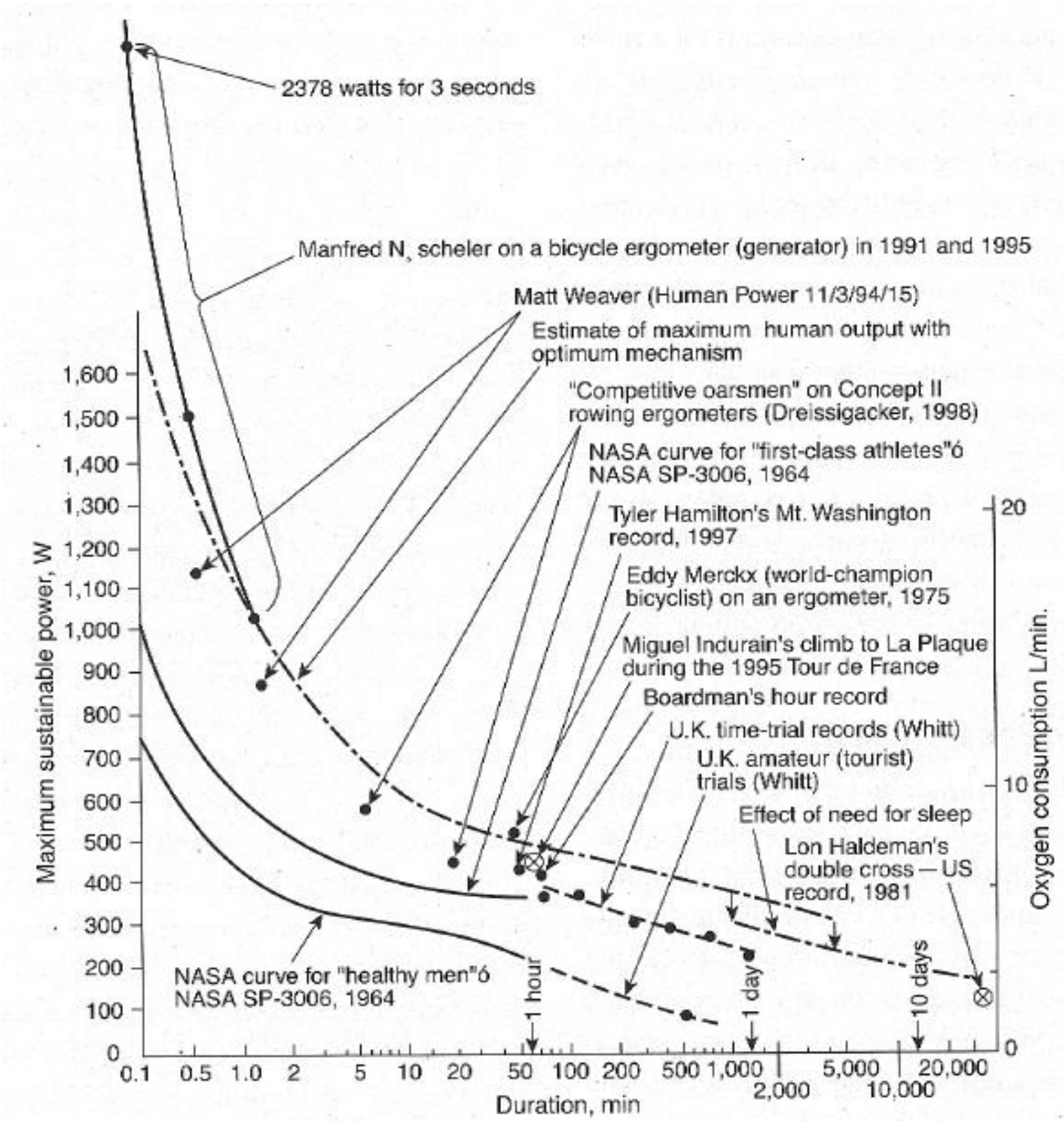

Figure 11– Human Power Output. T. Dean, *The Human-Powered Home* (2008) Figure 2.2, p. 66

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