The Planing Hull Catamaran

TOBIN FISHER
MARCUS MALINOSKY

The Planing Catamaran Concept

Create a high performance sailboat that combines the best qualities of windsurfers and catamarans

Catamaran

Windsurfer

The Planing Catamaran Concept

The Two Modes of Sailing

1. Displacement Sailing

2. Planing

The Two Modes of Sailing

1. Displacement Sailing

- Volume of water that must be moved as boat moves through water creates "form drag"
- Total Drag = Skin Drag + Form Drag
- Total Drag $\propto V^2$
- Above the hull speed total drag $\propto V^4$
- Top speed effectively capped by the hull speed

The Two Modes of Sailing

2. Planing

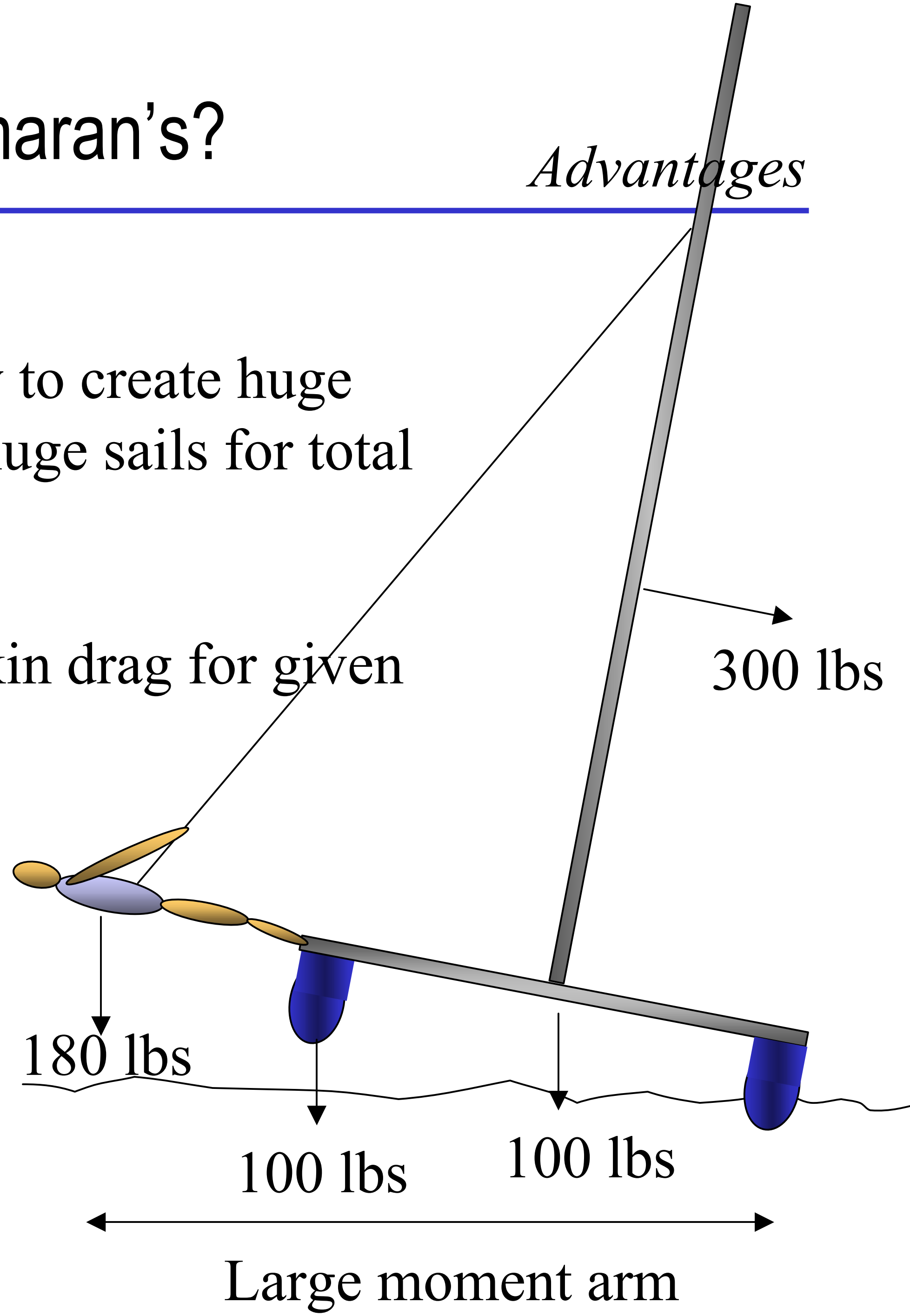
- Only skin drag, form drag becomes negligible
- Boat slides over surface of water like surfboard
- Wetted area decreases with velocity
- Drag $\propto$ V

What's Special About Catamaran's?

Advantages

✧ Wide beam (width) allows crew to create huge moments and thus boat can carry huge sails for total weight

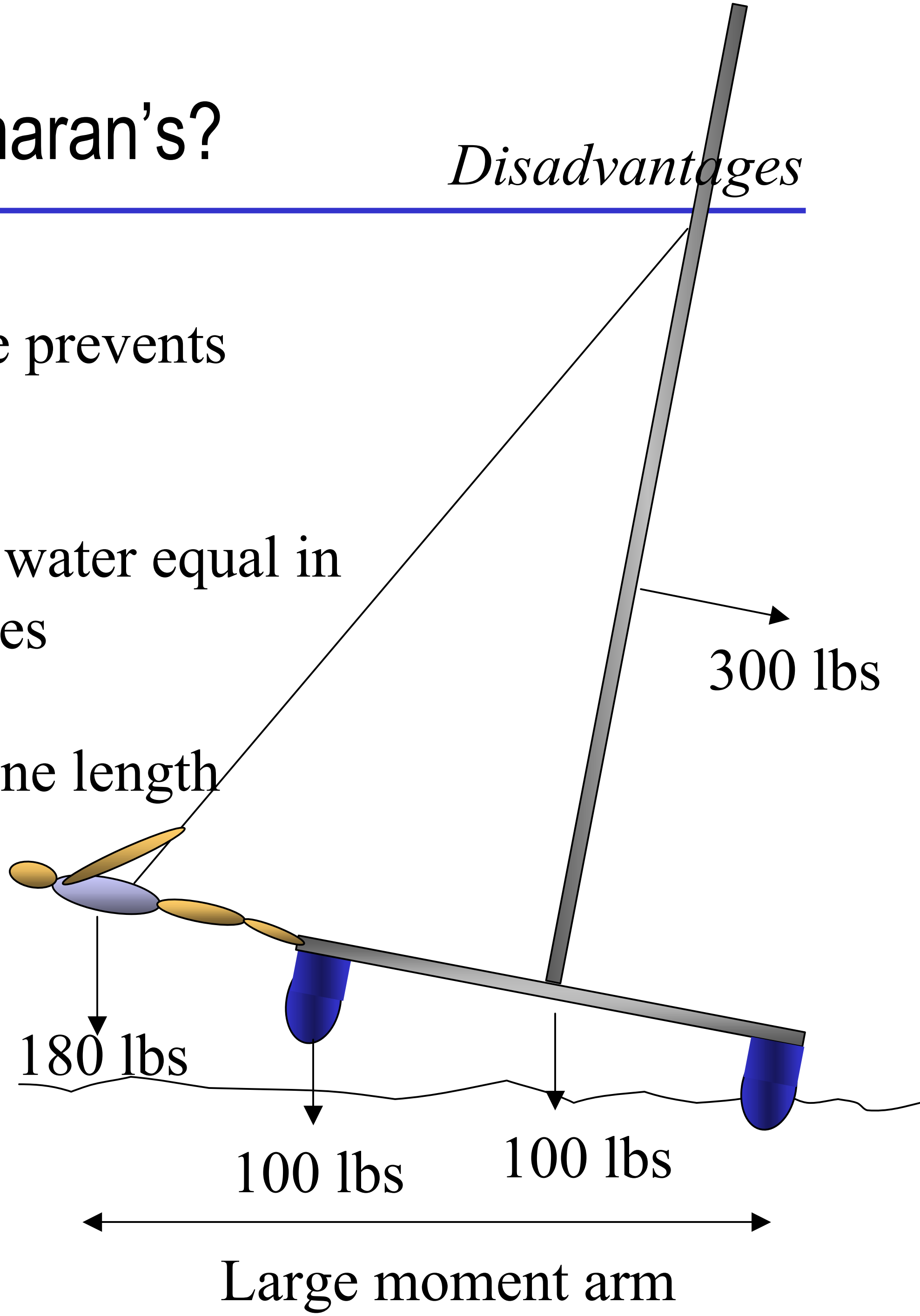
✧ Semicircular hulls minimizes skin drag for given buoyancy



What's Special About Catamaran's?

Disadvantages

- Slender semicircular hull shape prevents hulls from planing
- Hulls must displace volume of water equal in weight to boat and crew as it moves
- Top speed is limited by waterline length

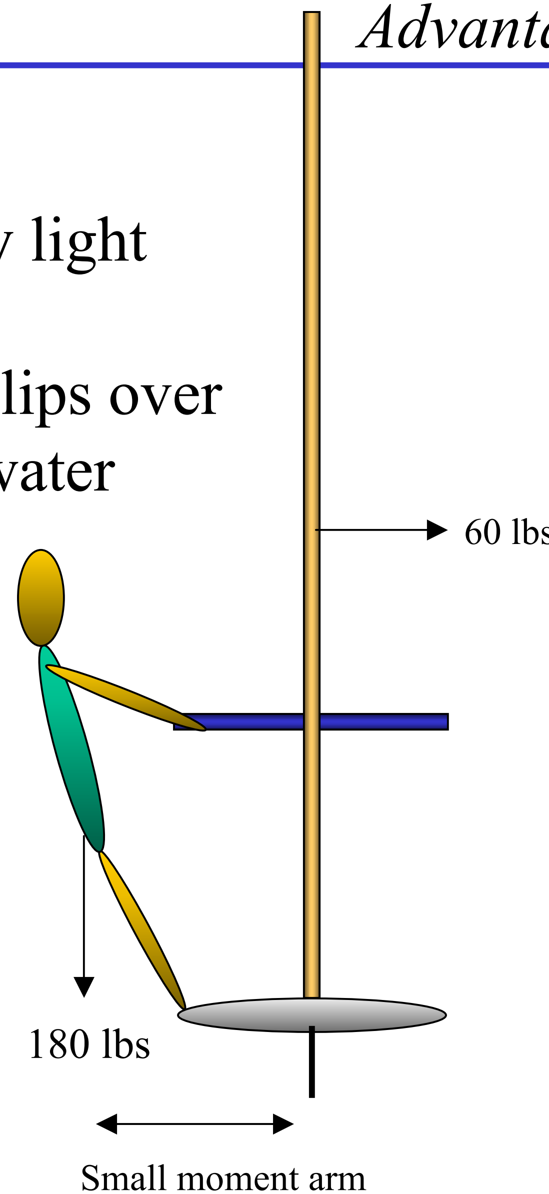


How About Windsurfers?

Advantages

- ✧ Simple design allows total rig to be very light
- ✧ Flat hull shape promotes planing--hull slips over surface of water instead of displacing the water

- Can travel very fast in high winds
- Drag increases linearly with velocity

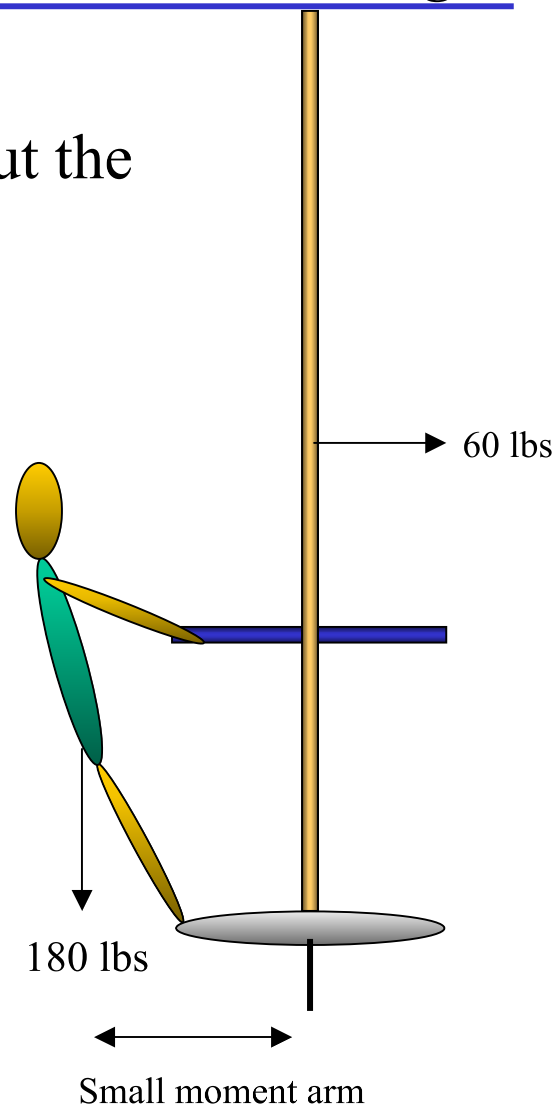


How About Windsurfers?

Disadvantages

Crew cannot generate a very large moment about the centerboard

- Rigs must have very low aspect ratios
  - Sails are not efficient
    - Poor light wind performance
    - Poor upwind sailing capabilities



Why A Catamaran That Could Plane?

Advantages:

- Unlike conventional catamarans, it's top speed is not limited by waterline length
- Excellent performance on all points of sail in medium to high winds (when it is strong enough for the boat to plane)

Disadvantages:

- poor light air performance--this is because the flat hulls have a large amount of surface area to buoyancy and have a large amount of skin drag when not planing

Critical Factors in the Design

Sail Carrying Power (SCP)

SCP = max lift generated by sails divided by total weight of boat and crew. This dimensionless number predicts planing ability and performance as a rough rule of thumb:

if SCP < .20		boat will not plane
if SCP > .20	→	boat can plane on some points of sail
if SCP > .30		boat can plane of most points of sail

The bigger the SCP, the better!

What helps create a high SCP? → Wide beam and light weight

Early estimates for our design yielded an SCP of 0.615!

Critical Factors in the Design

Flat planing surface

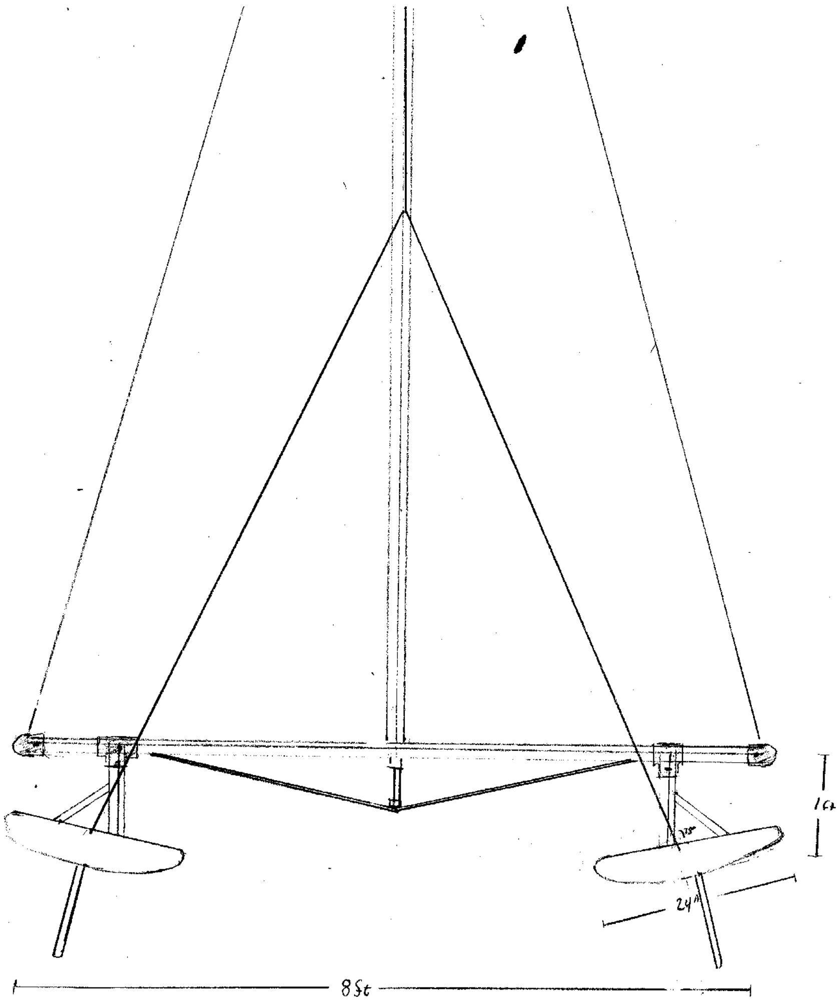
Stability

Control

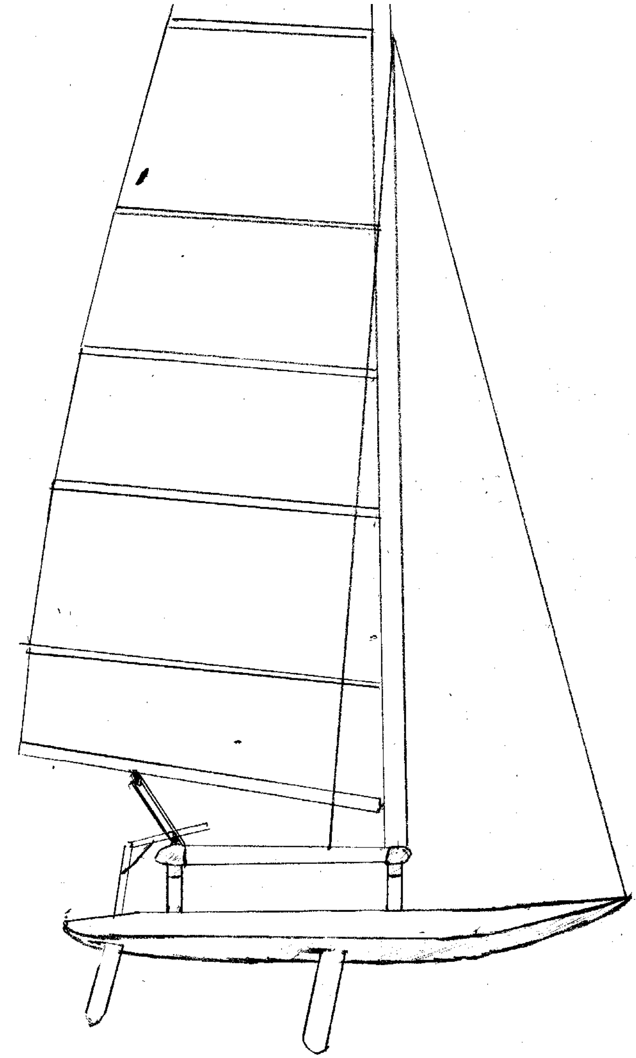
Strength

The Design

Early Sketches



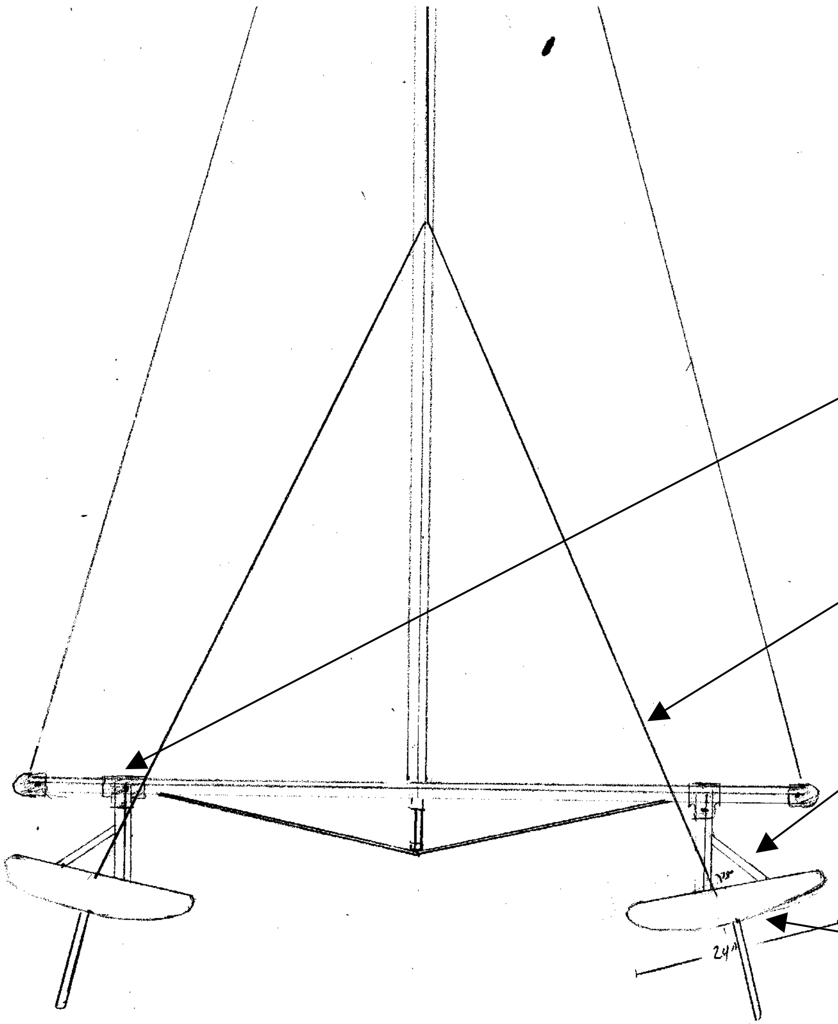
Front View



Side View

The Design

Innovative Features



Front View

Tubing connectors enable easy adjustment of beam

Use spectra line instead of wire to reduce weight

Wide trampoline supports

Hulls canted at 12^{o} so hull is flat when “flying a hull”

Flat hull bottom promotes early planing

How Did We Build A Sailboat In Thirteen Weeks?

Learned as much as possible from similar existing designs

✧ studied several conventional catamarans of similar size

✧ met with professional catamaran designer and national champion catamaran racer

Used pipe connectors for tubing connections

✧ enables connection of aluminum tubing without time consuming and permanent welding

✧ aid experimentation by making adjustments and part replacement relatively fast and easy

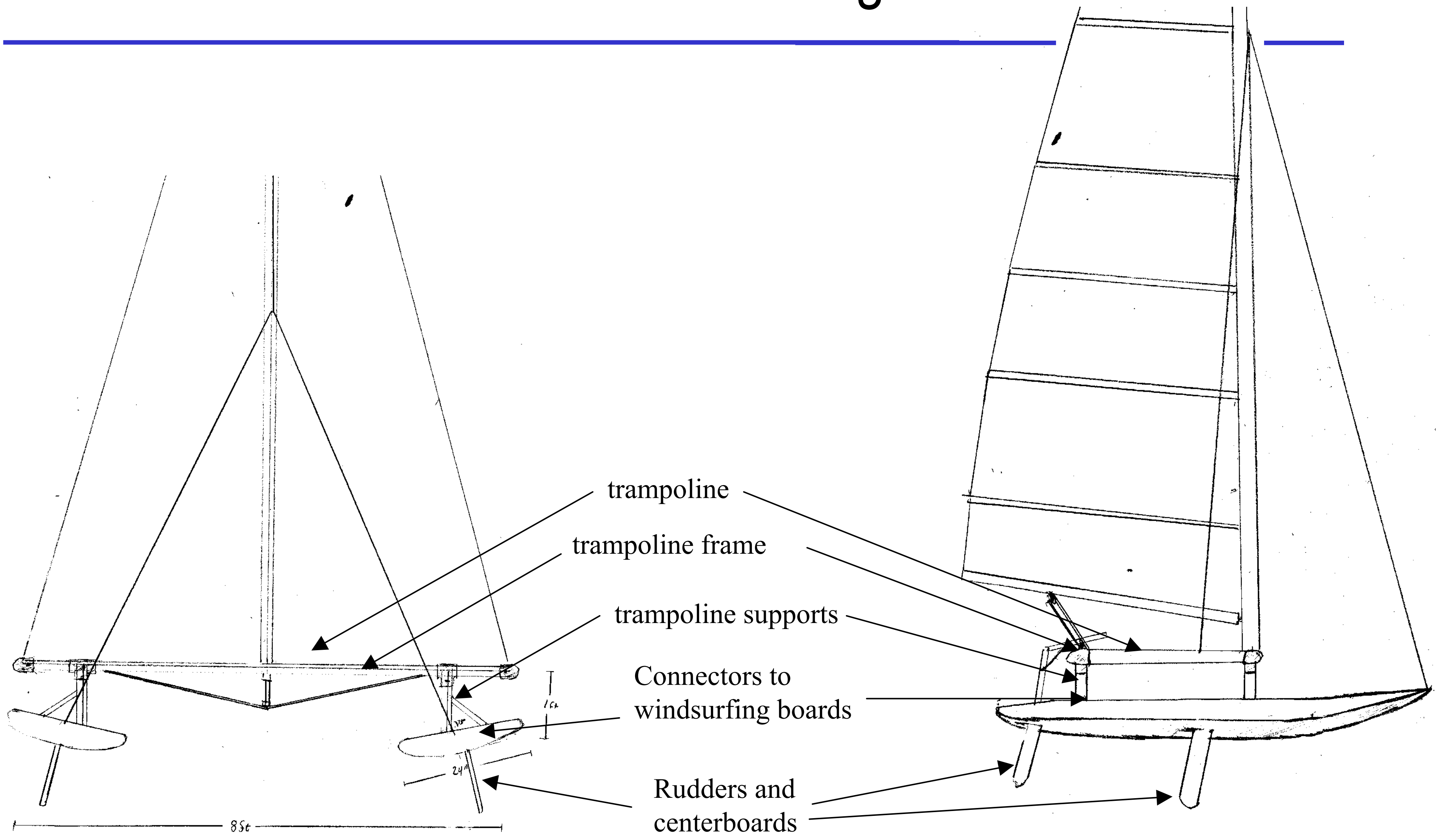
Know what you have to make yourself and what you can buy

✧ Use windsurfers for the hulls

✧ Take mast, sail, and hardware off an old catamaran (Prindle 16)

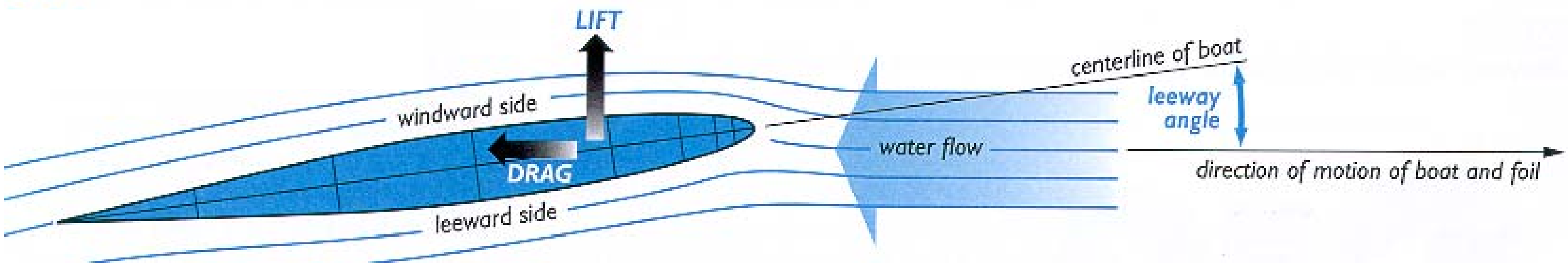
✧ buy other stock sailing hardware (travelers, shackles) to meet needs

Elements That Needed To Be Designed



The Rudders

How A Rudder Works

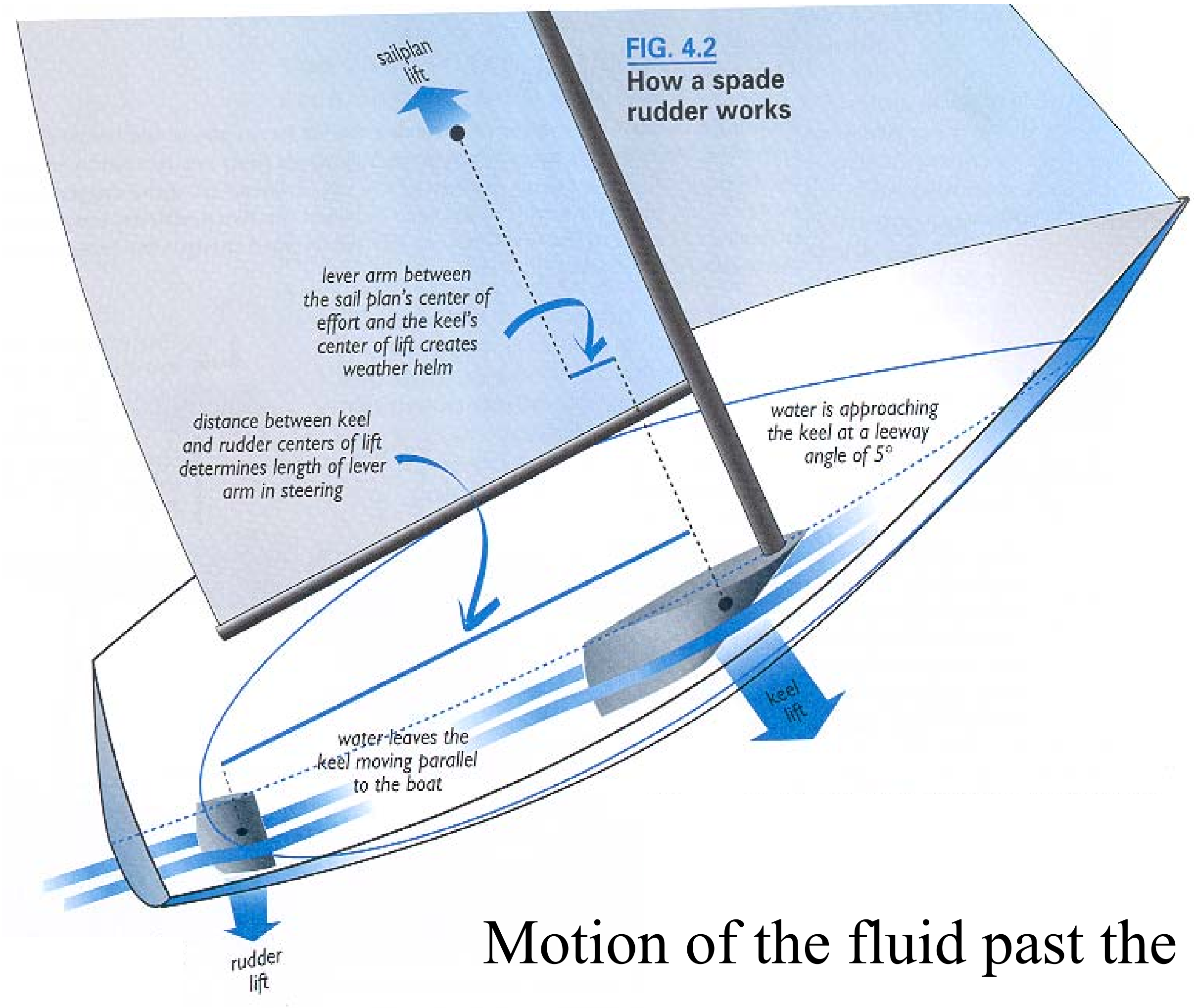


As boat slips through the water, lift is produced according to Bernoulli's Principle. A high and low pressure region are created on either side of the foil because of the different velocities of the fluid. This pressure difference creates lift.

Without leeway, there is no lift generated by the foil.

You will always have leeway no matter how good your centerboard is. A good centerboard will make the leeway angle as small as possible.

The Rudders



Motion of the fluid past the centerboard and rudder

Design Of Rudder

To design a rudder and centerboard system that will allow the boat to go the fastest while still being able to keep the vessel under control.

Optimization Goals:

1. Drag of the system

2. Weight of the system

Design Of Rudder

Choice Of Foil

NACA 0009 Foil

- 0 – Foil is symmetric
- 0 – Location of asymmetry
- 09 – Thickness in percentage of chord

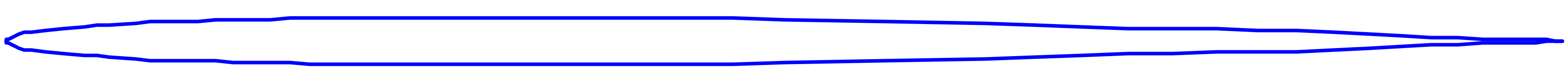
Properties

$C_{L\ MAX} \approx 1.20$

$\alpha_{at\ max} = 17.5^{o}$

Had to choose a shape that would produce enough lift and minimize drag while still turning the boat. Wanted smooth leading edge and sharp trailing edge. Smooth leading edge will create extended laminar flow and delay stalling

I looked to see what foil shapes were used in industry by boats that were comparable in size to ours. Found that most companies use the NACA 0009 or NACA 0012 foil shape (the thickness of the foil is proportional to the chord length) .



Placement Of Rudder

Options

1. Hang rudders off the stern of the boat

2. Attach rudders below the hull near the stern of the boat

Placement Of Rudder

1. Hang Rudders Off Stern

- Susceptible to ventilation
- Great for pleasure craft where boat has to be pulled up on sand, etc.
- Easy to attach turning system
- Has largest possible moment arm for steering

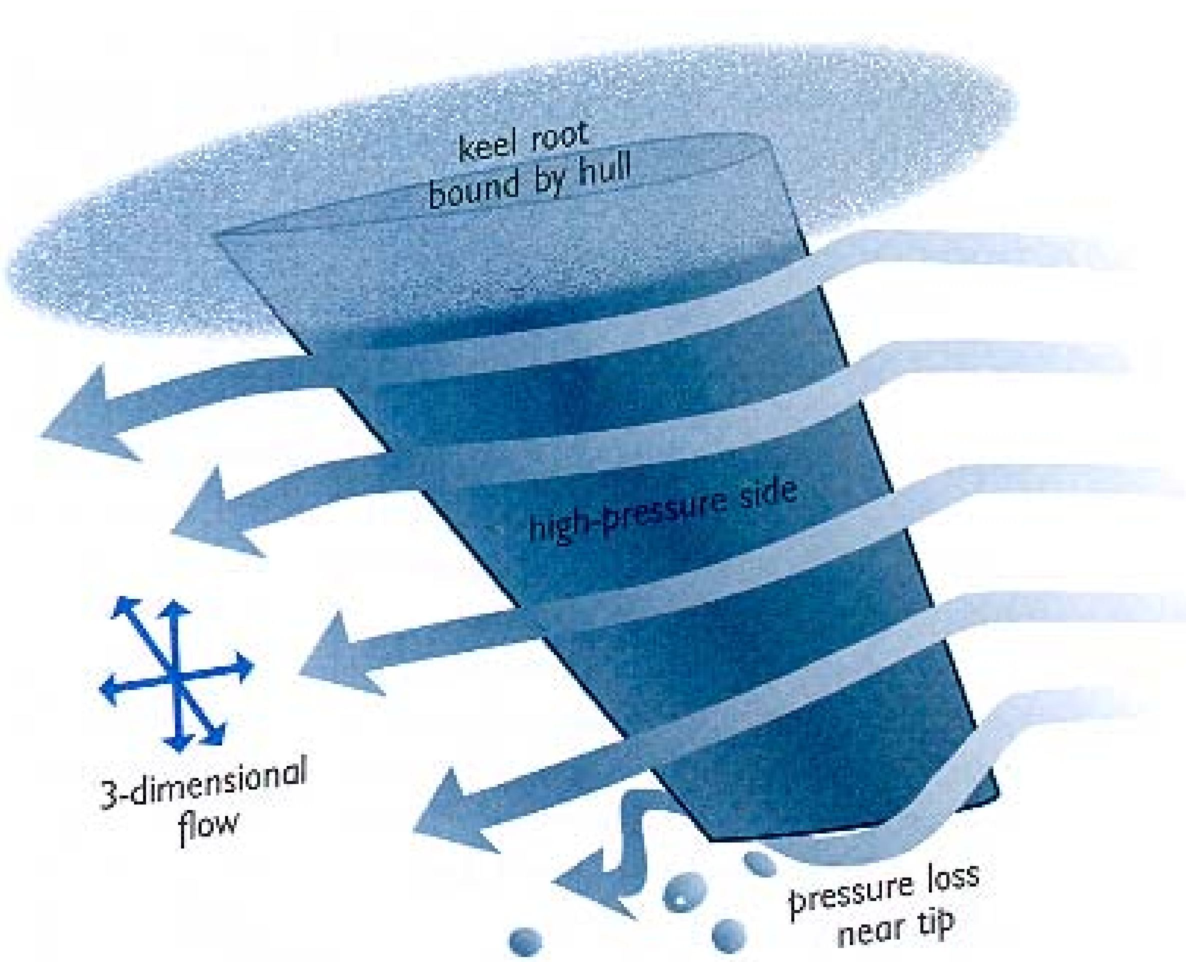
Placement Of Rudder

2. Attach Rudders Below Hull

- Creates ‘end plate’ effect
- No ventilation
- Hard to attach turning system to rudder

Placement Of Rudder

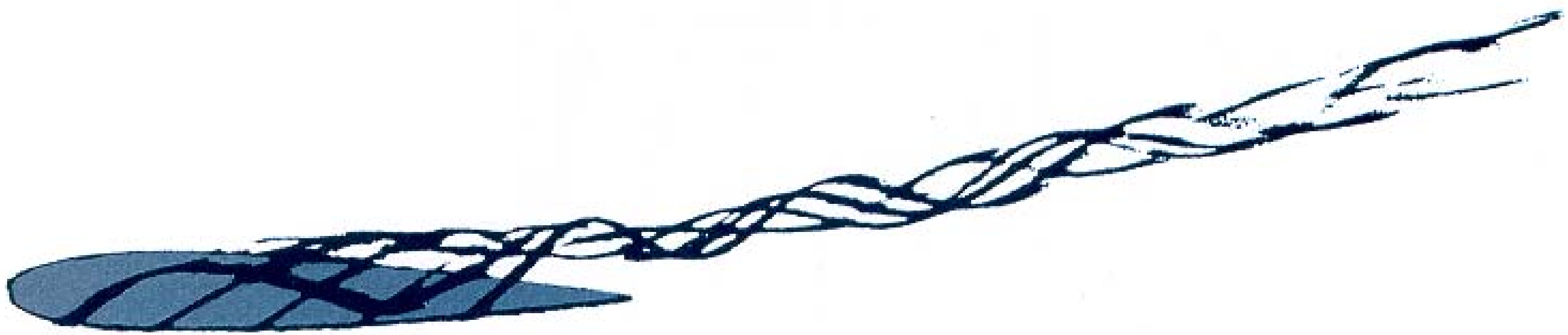
End Plate Effect



Tip vortices at the end of the rudder reduce lift and increase drag. By having one end placed against the hull the rudder can be smaller and lighter. Combat this effect with high aspect ratio.

Placement Of Rudder

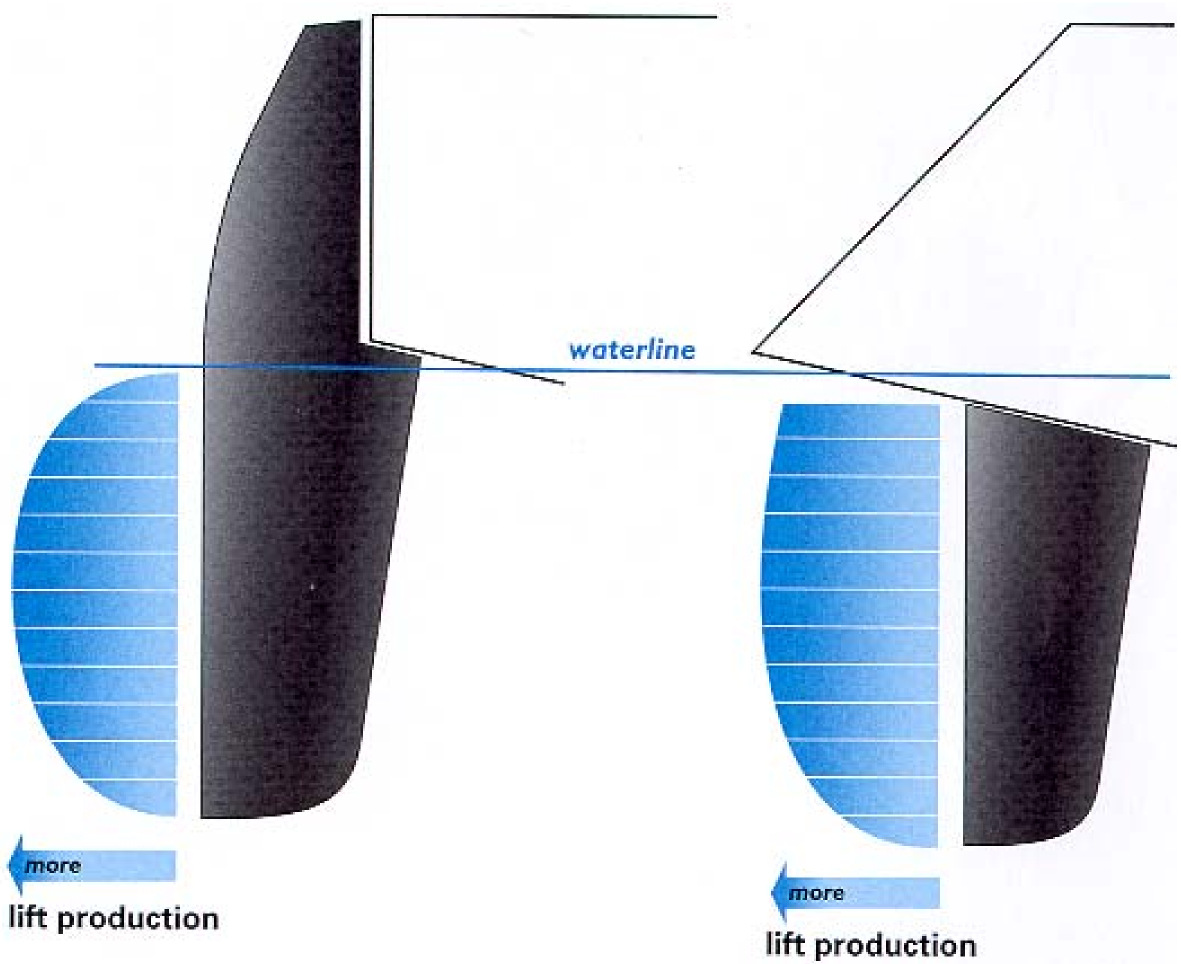
Tip Loss In Wind Tunnel



Top View Of Tip Vortices In Wind Tunnel

Placement Of Rudder

Effective Keel



The end plate effect increases the surface area of the rudder by approximately 20%. Therefore the rudder can be smaller and lighter

Placement Of Rudder

Decision

We decided that it was better to place the rudder under the hull and take advantage of the "end plate" effect. This allows our rudders to be smaller and lightweight while still producing an adequate amount of lift to keep the sailor in control of the craft.

Picture of rudder in place under the hull

Design Of Rudders

We made three sets of rudders so that they could be compared to one another and the optimum shape could be extracted from the results of the tests.

Shape	Average Chord	Span	Aspect Ratio
Small	5.5''	15''	2.7
Medium	5.5''	17''	3.0
Large	5.5''	22''	4.0

Aspect Ratio = Span / Average Chord

Design Of Rudders

Marine Grade Plywood was chosen for the the core of the rudder because of it’s low cost and ease to work with. Other materials used for the core in industry include hard woods and foams.

We used a mill to create the airfoil shape in the plywood then sanded it down until eventually the rough shape was achieved.

Design Of Rudders

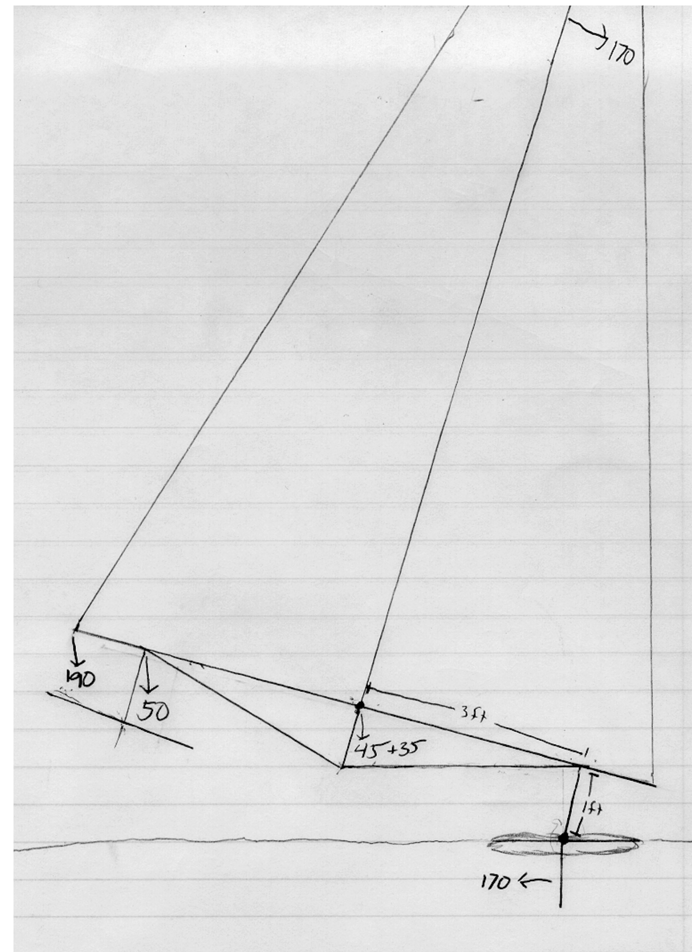
Problem: *The steering rod would twist and rip out of the rudder*.
We tested the rudders and found that the steering rod could not support the load. To get around this we drilled a hole 11’’ into the rudder for the tiller to sit. We added a layer of Kevlar in order to increase the rudders resistance to bending and hold the threaded rod in place and eliminated the problem.

The Connection System

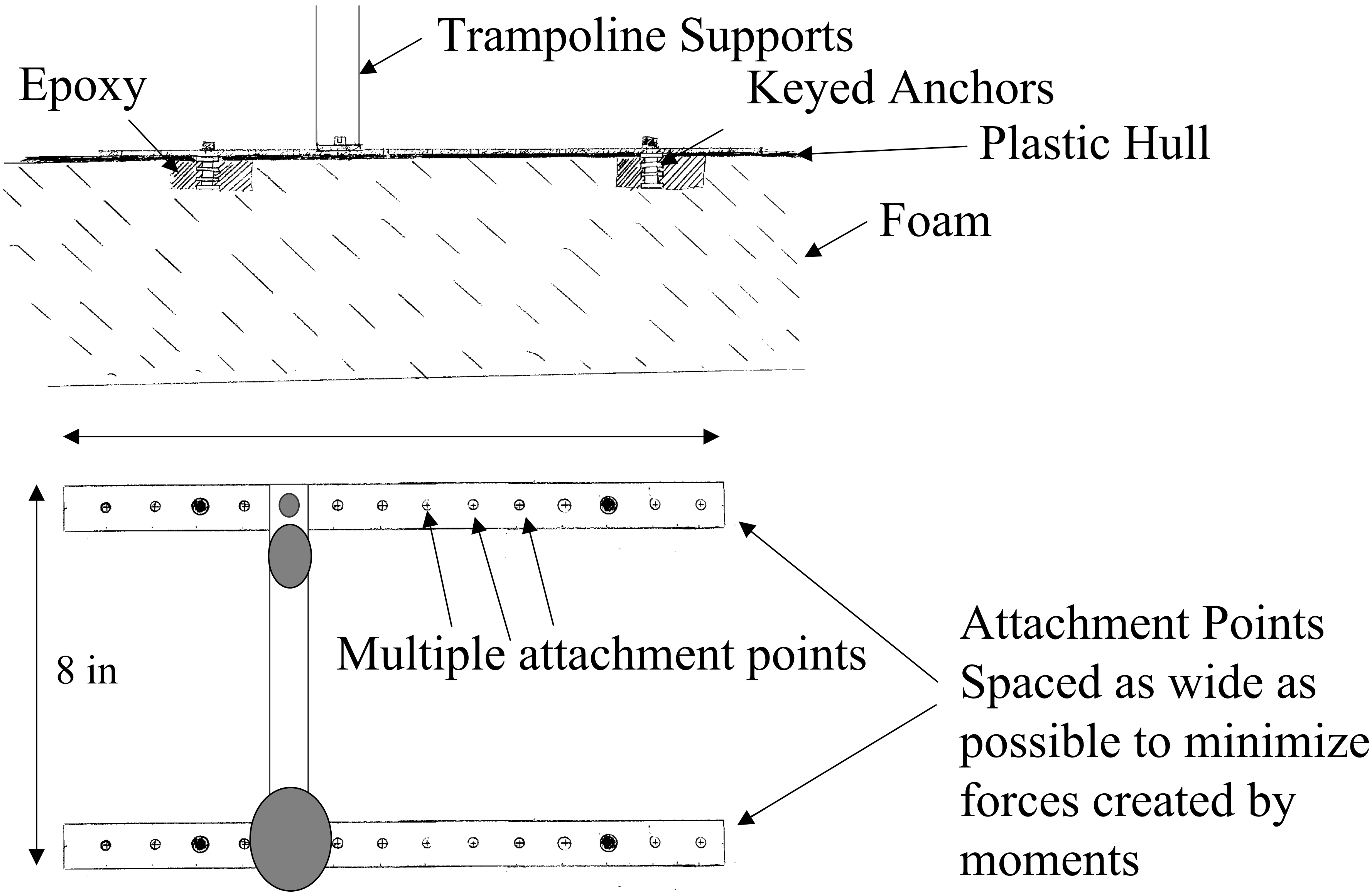
Main Design Issues

Connects windsurfer boards to trampoline supports and trampoline frame

- Needed to estimate loads so connections could be tested accurately
- How do you make rigid connection with foam and plastic board?
- Connection needs to be adjustable so the rig can be moved forward and backward



The Connection System

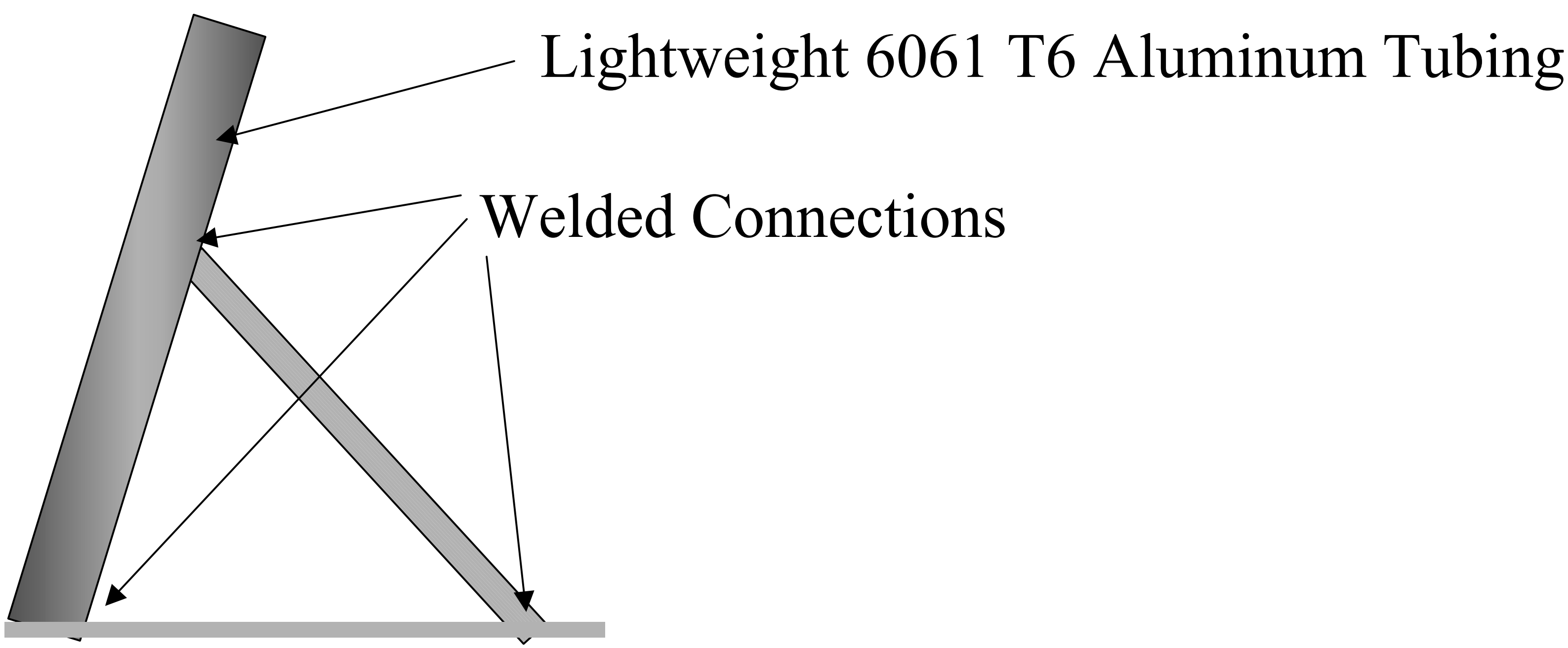


Trampoline Design

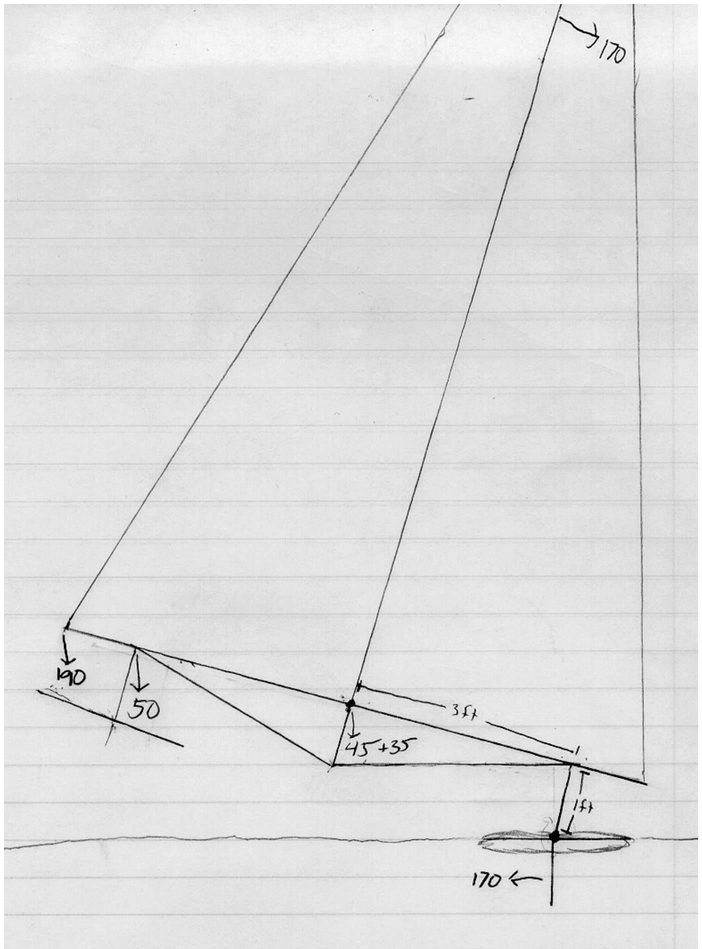
Supports

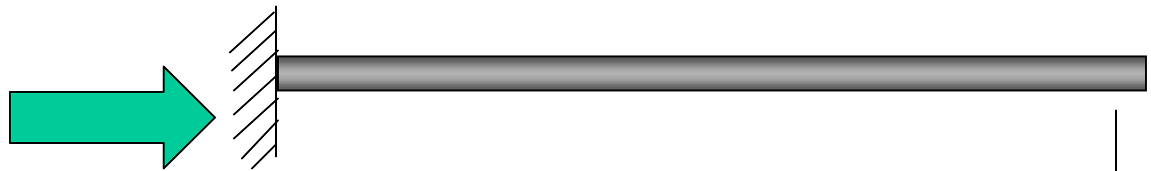
Lifts the trampoline above the hulls and the water and hold the board at a fixed cant angle

Went with design that had a fixed cant angle of 12 degrees and held the trampoline 1’3’’ over the surface of the water



Trampoline Frame





Deflections at tip should be < 1 inch

250 lbs

$y = -(1/3)(Wl^3)/(EI)$

$EI = 1.086\times10^7$ lb × in^2

For 3” diameter steel tube:

wall thickness must be .0044 in

total weight for 7 foot tube = 2.01 lbs

For 2” diameter steel tube:

wall thickness must be .015 in

total weight for 7 foot tube = 4.76 lbs

For 3” diameter aluminum tube:

wall thickness must be .0128 in

total weight for 7 foot tube = 2.05 lbs

Trampoline Design Final Decisions

Cost for 14 feet 3” diameter aluminum tube: $200
Total weight: 2.05 lbs

Cost for 14 feet 1.9” diameter aluminum tube with .145 wall thickness from the student shop: $43
Total weight = 7.47 lbs
Deflection = 1.5 inches

Other Advantages of 1.9” tubing

- thicker walls means that bolts can be threaded directly into tube walls
- 1.9” tubing fits in standard pipe connectors
- it was available right away
- lower aerodynamic resistance

Trampoline Design

Key Features

The trampoline is tightly stretched fabric that the sailor can sit on

- polypropylene fabric is strong, light, has minimal stretch and does not absorb water
- coarse basket weave allows waves to pass through fabric without collecting
- stainless steel grommets will not corrode and prevent fabric from ripping
- nylon thread used to support grommets is light and will not stretch when wet
- twists in the lacing help keep grommets from pulling out

Design Of Steering System

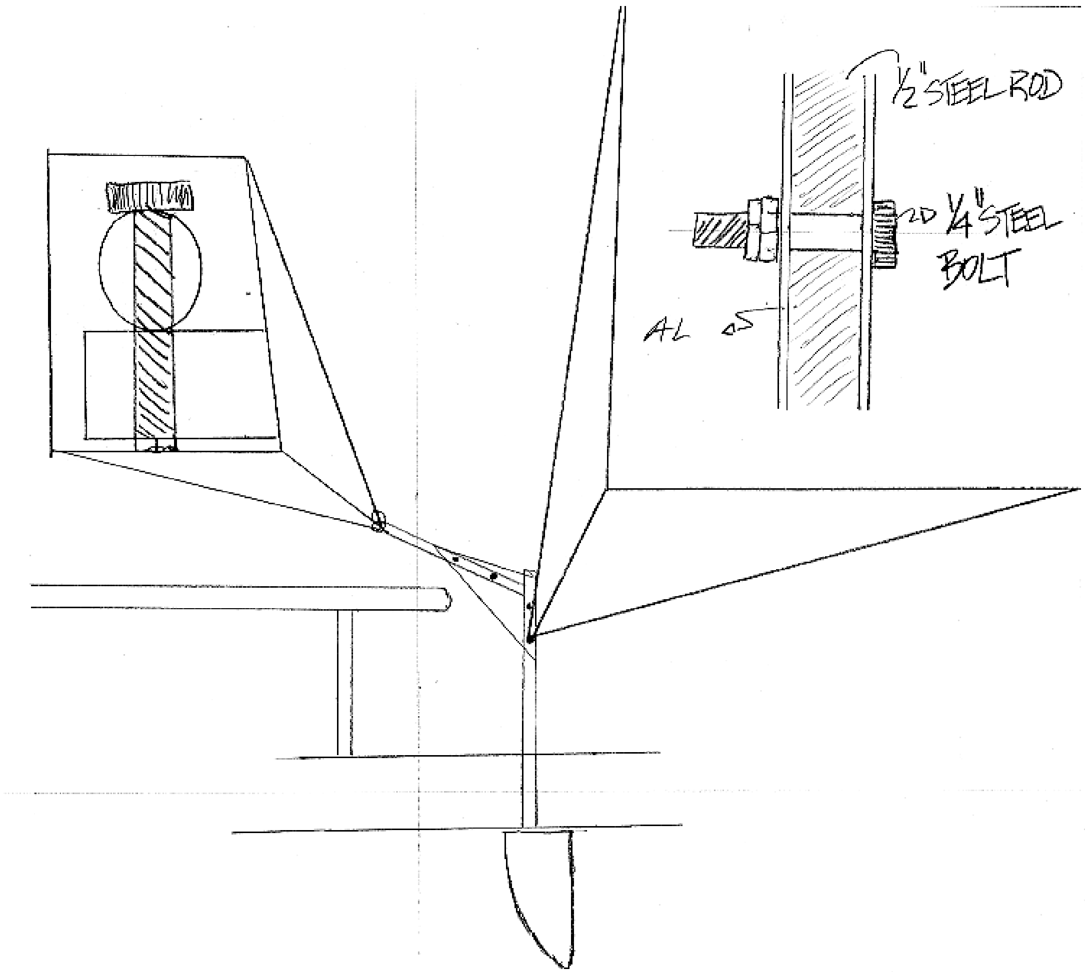


Diagram of 4-Bar Linkage

We decided the best way to build the steering system was to use a traditional four-bar linkage. The major requirement was that the rudders could be easily taken in and out for testing.

Design Of Steering System

Conceptual Design

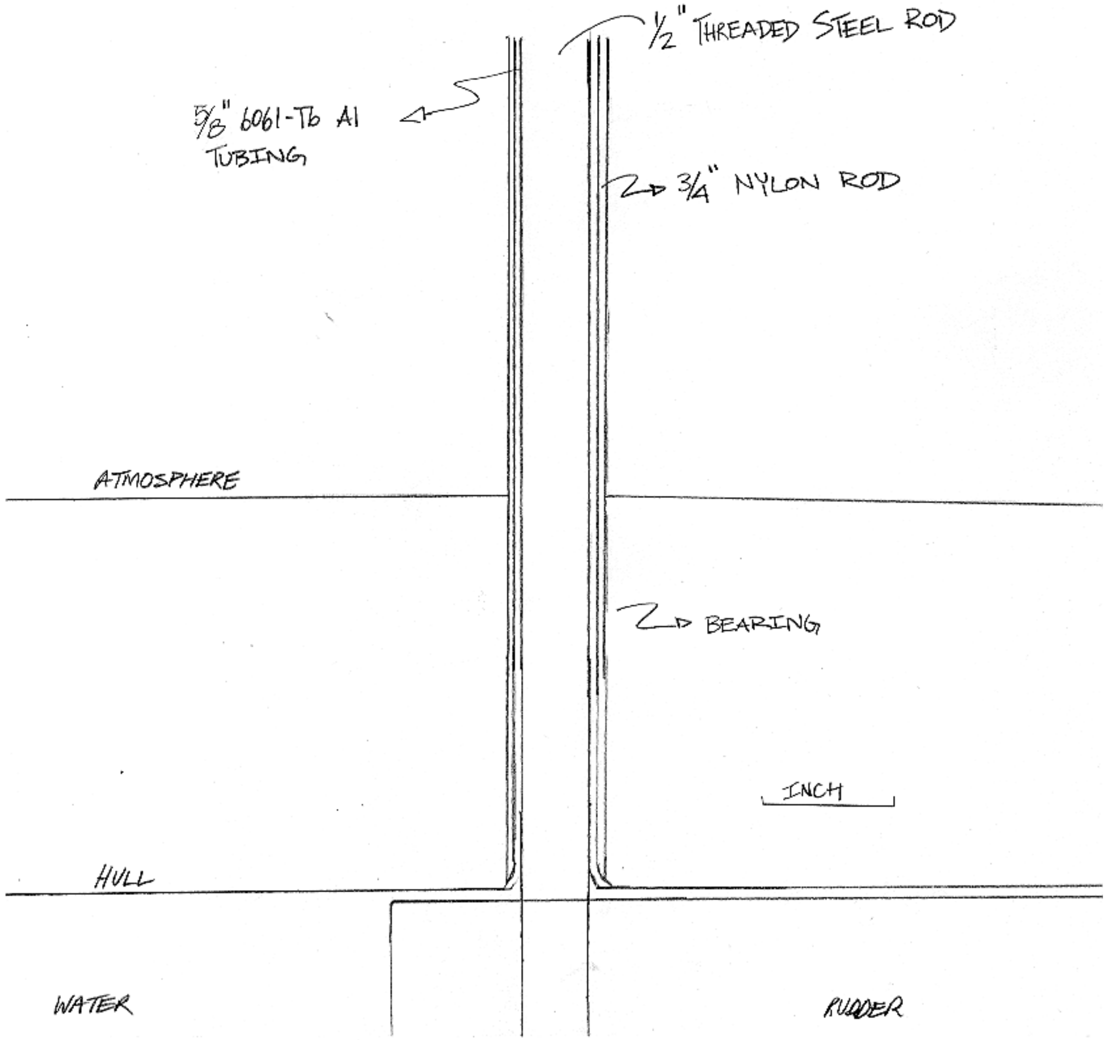


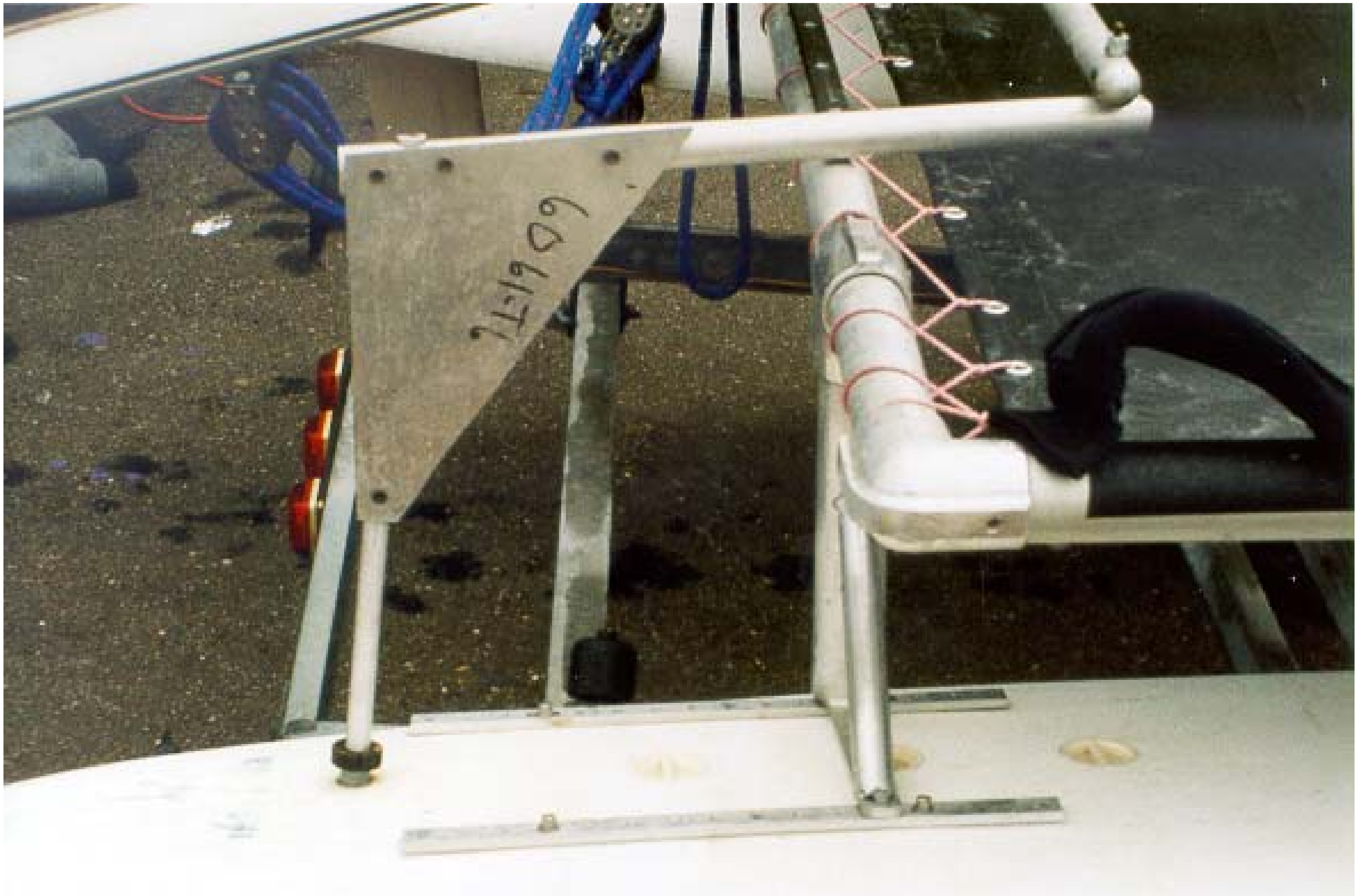
Diagram of bearing

Bearing through the hull of the boat

Design Of Steering System

Rear View of 4-bar linkage

Design Of Steering System



Side view of tiller and tiller extension

Design Of Steering System

Problems:

- Too much stress at point were tiller leaves rudder
- Had to put tiller through center of lift of rudder, can’t feel the force on the rudder.
- Bearing surface needs to be better.

Solutions:

- Use a bearing of Teflon on Teflon
- Will be easier to make since the rudders won’t be interchanged

So How Did It Work?

It Did Have Some Problems …

Problems And Solutions

Boat pitches bow over stern when tacking in strong wind

Solutions:

- ✧ move rig forward
- ✧ keep weight forward when tacking
- ✧ decrease mast rake
- ✧ add buoyancy to stern
- ✧ cut mast down or use lighter mast

Boat Gets Stuck “in irons” when tacking

Solutions:

- ✧ move rig forward
- ✧ move centerboard back
- ✧ move rudder back
- ✧ make rudder bigger
- ✧ add jib

Problems And Solutions

Hulls twist and flex in waves

Solutions:

- use fiberglass poles to stiffen hulls
- use bracing wires to prevent flexion of trampoline frame
- use stiffer beams for trampoline frame

Thanks !

Dr. Nathan Delson

Dr. Sandros Gomez

Dr. Juan De La Mora

Dr. Gary Povirk

Dr. Kailasnath Purushothaman

Christopher White

and special thanks to:

Nick Bernardo