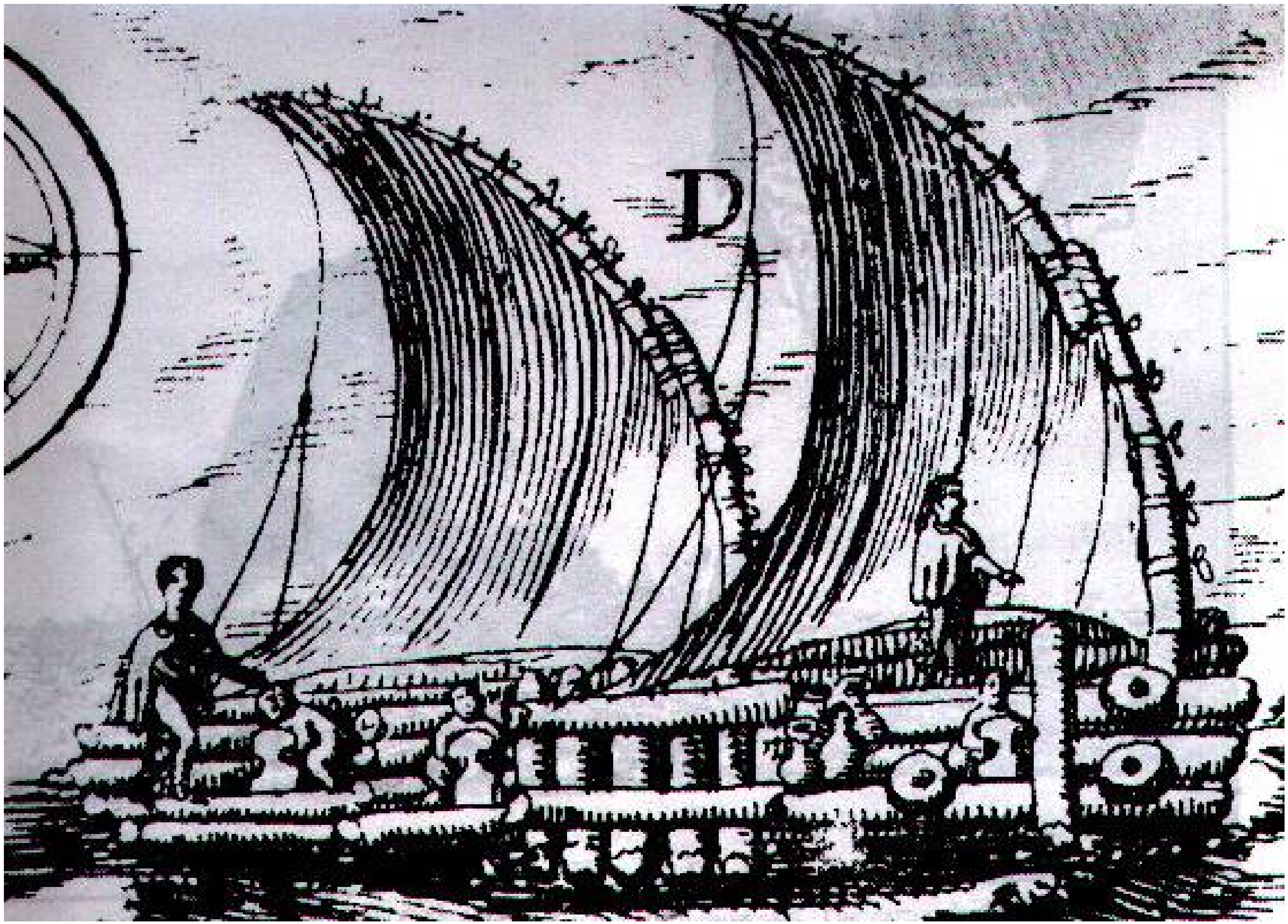
Ecuadorian Balsa Raft Construction and Design Analysis



Leslie Dewan

- Hosler's research in 1980s proved there was contact

- Indirect evidence for maritime exchange routes
- Mechanical and materials analysis of ancient Ecuadorian balsa rafts: determine whether maritime exchange was feasible using available technology
- To what degree were the Andean and Mesoamerican peoples in contact with one another?

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BOLIVI
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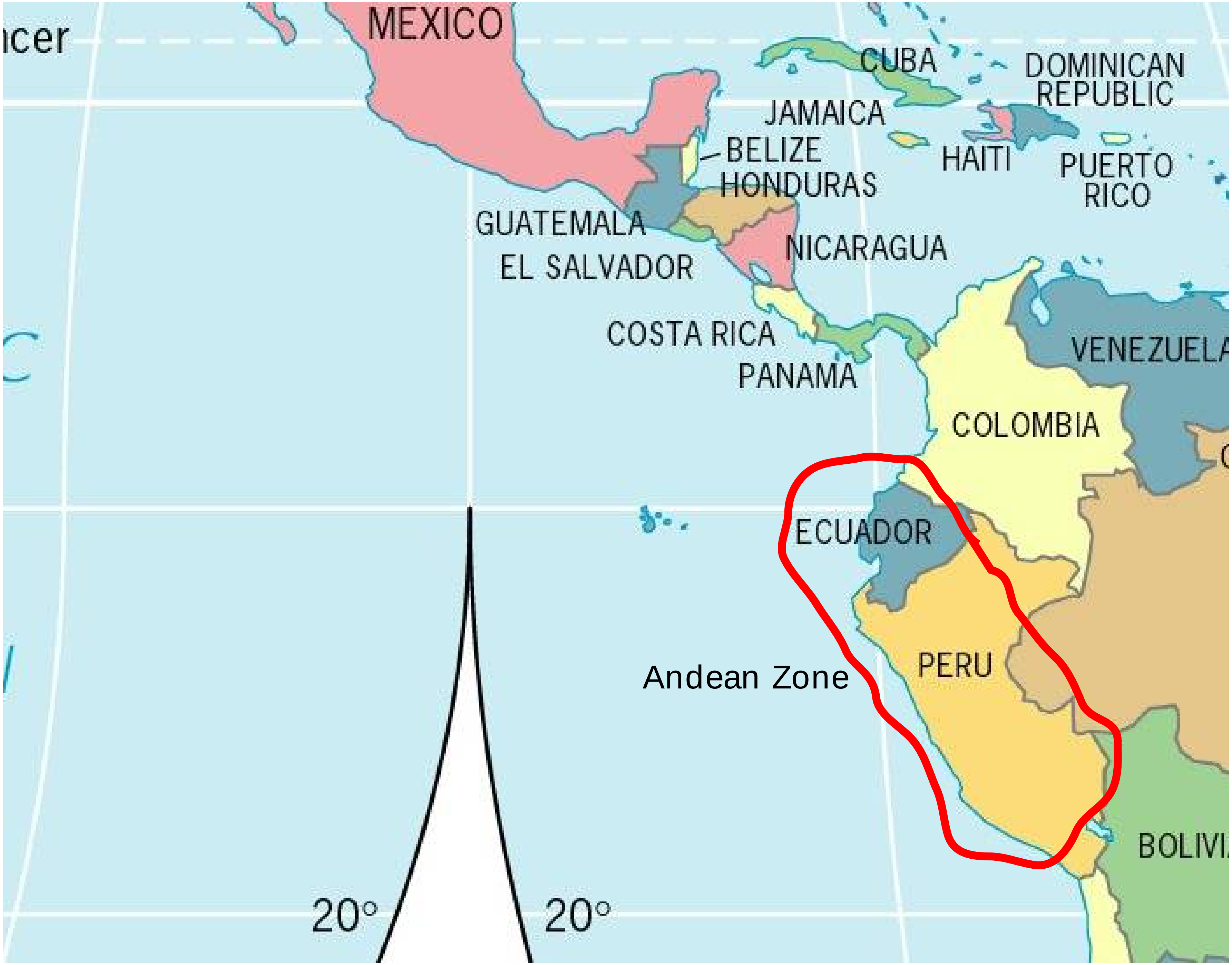

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Andean Zone
BOLIVIA
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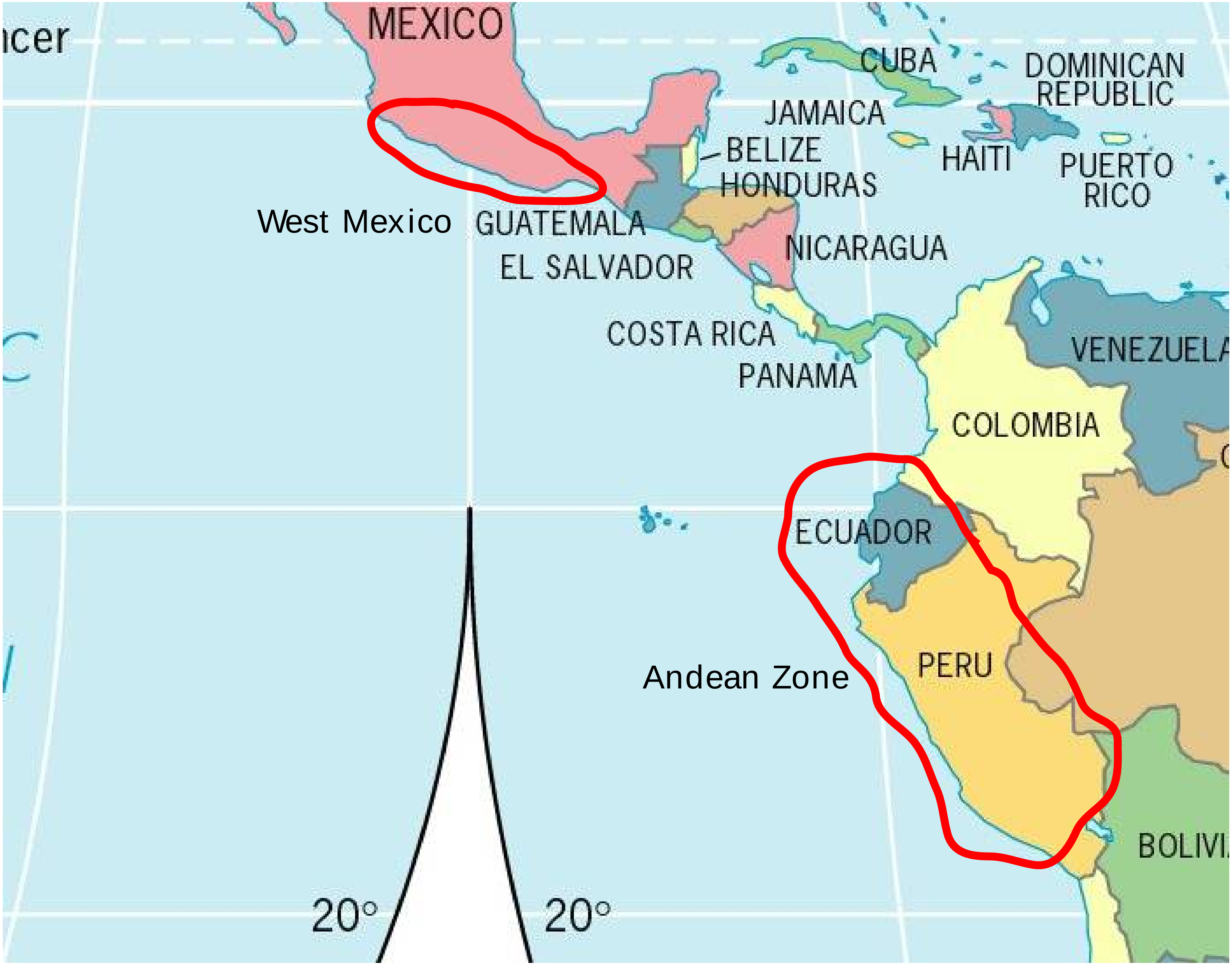

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EL SALVADOR
COSTA RICA
VENEZUELA
PANAMA
COLOMBIA
ECUADOR
PERU
Andean Zone
BOLIVIA
20°
20°

Proof of Contact: Metallurgy technology set

- Hosler's research in the 1980s proved that **metallurgy** was introduced to west Mexico from the Andean Zone ~**700 CE**
- 400 CE: metallurgy thriving in Andean Zone

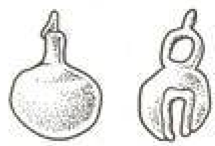
Lost-wax cast: Colombia

Cold-worked: Peru/Bolivia

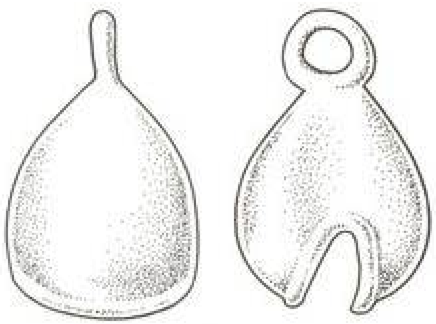
Proof of Contact: Metallurgy technology set

- Sudden fluorescence of high-level metallurgy in west Mexico ca. 700 CE
- Same object classes, fabrication methods (cold working and casting), and design characteristics as Andean metallurgy
- Trace element analysis: some ores were directly transported, most were mined locally

Metalworking Technology as Indirect Evidence for Trade



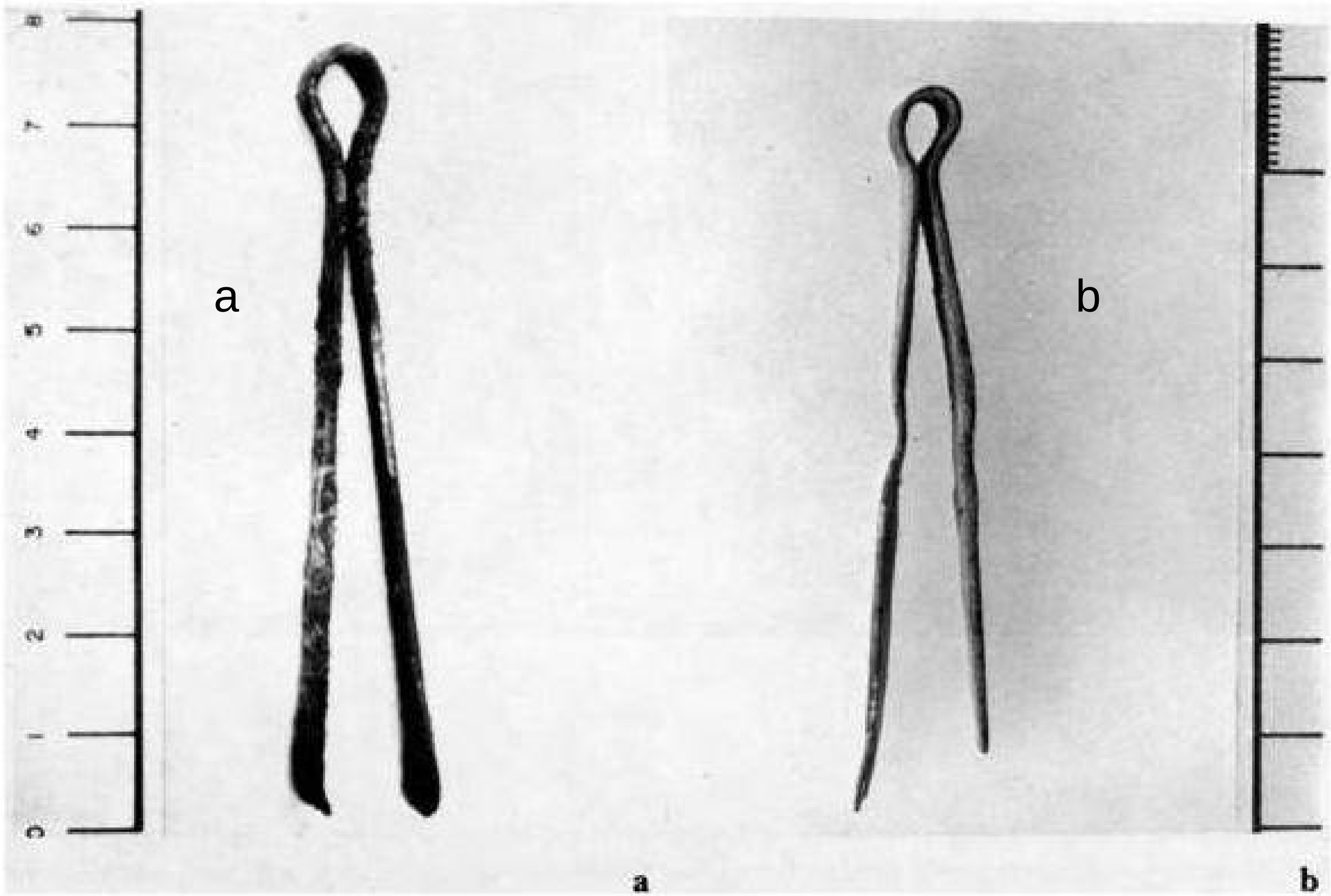
1b



9a

0 1 2cm

10b

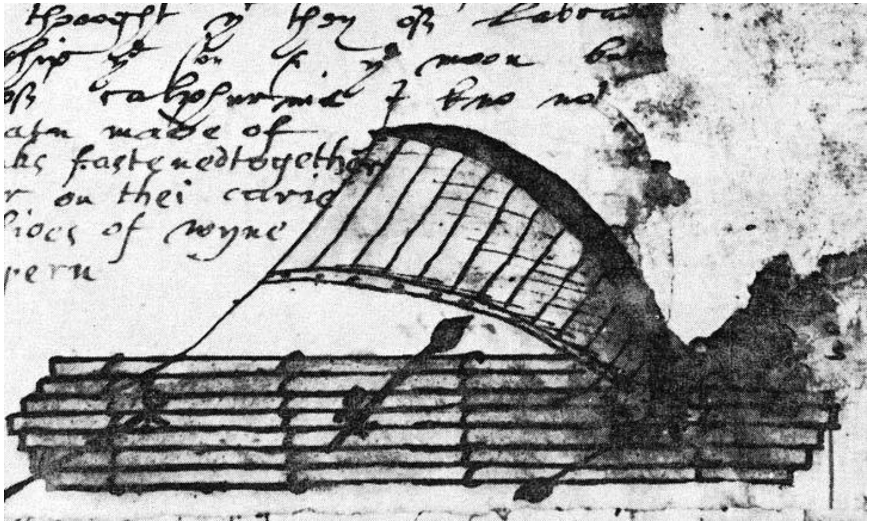


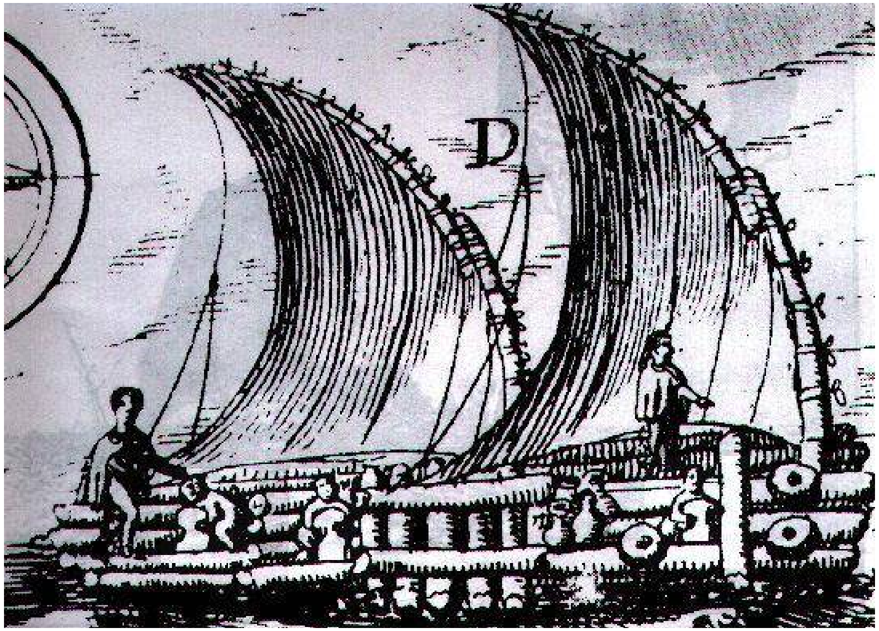
Beam tweezers from West Mexico (a) and Ecuador (b).

Marine routes?

- Indirect evidence for maritime trade
- 100 BCE: Ecuadorian traders had marine routes from Chile to Colombia
- Merchandise transported on balsa rafts
- No metal goods found in intermediate region
- Ethnohistoric evidence

Ethnohistoric data set





...these balsas are of some very thick and long wooden logs, which are as soft and light on the water as cork. They lash them very tightly together with a kind of hemp rope, and above them they place a high framework so that the merchandise and things they carry do not get wet. They set a mast in the largest log in the middle, hoist a sail, and navigate all along this coast. They are very safe vessels because they cannot sink or capsize, since the water washes through them everywhere.

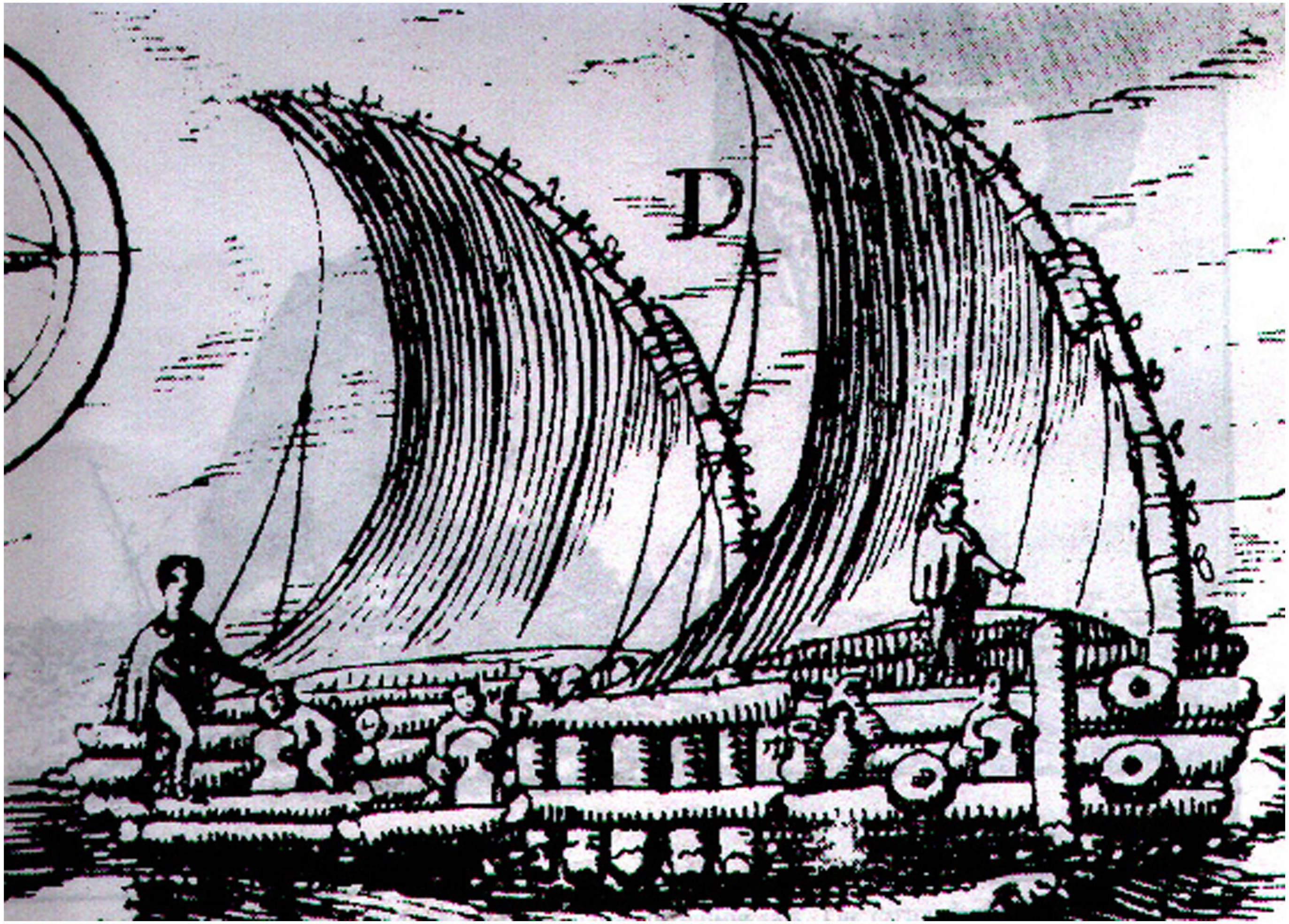
(de Estete, *Noticia del Peru* 1535)

Ethnohistoric data set

- Agustín de Zárate (Spanish chronicler, Peru 1543): logs forming the base of the raft are always of an odd number, commonly five, and sometimes seven or nine
- And: logs were laid out such that the middle one is longer than the others, like a wagon tongue, ... thus the balsa is shaped like an outstretched hand with the fingers diminishing in length
- Girolamo Benzoni (Italian trader, Peru 1550s): rafts are made of three, five, seven, nine, or eleven very light logs, formed in the shape of a hand, in which the middle one is longer than the others

- Used this data set as basis for analyzing raft design. Tells us about materials and technologies in use on rafts.
- Such as: Balsa hull logs
- Density ~ 150 kg/m3

- Cocobolo crosspieces
- Density ~ 1100 kg/ m3



crescent-shaped sail

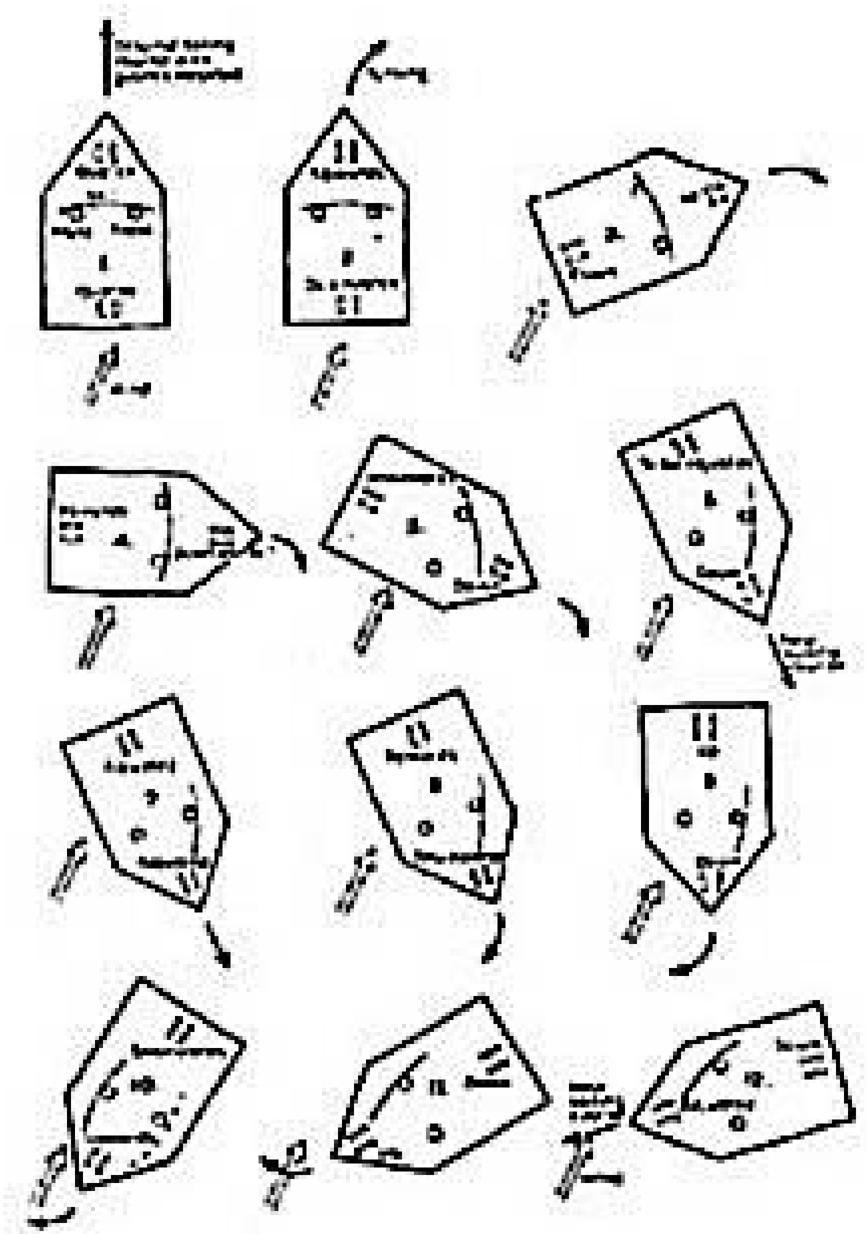
sailor
manipulating sail

sailors manipulating
centerboards

Centerboards

- Are they paddles? Are they shovels?
- No. They are centerboards.
- Used for steering in tandem with sail
- Uniquely New World invention

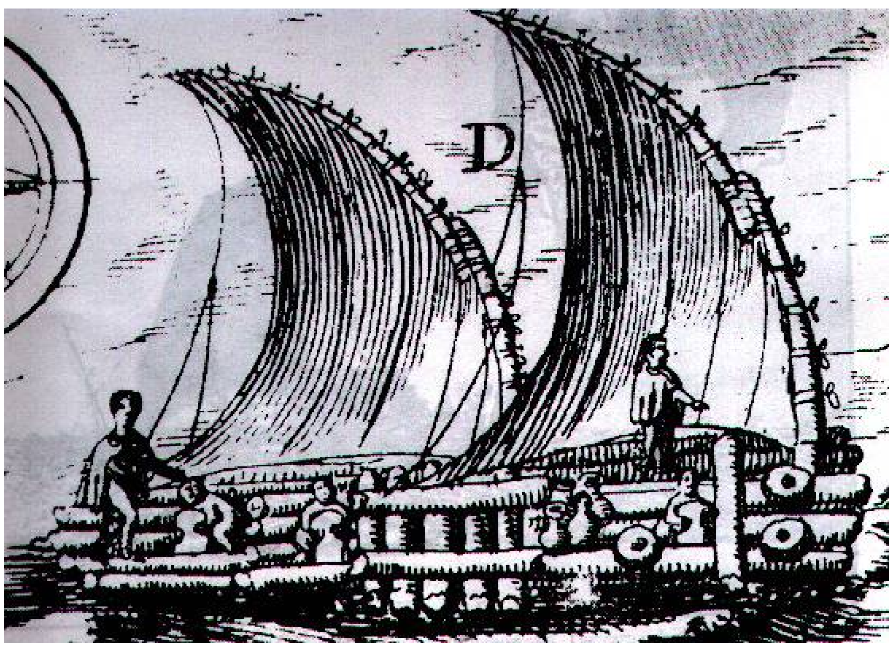
Centerboards



- Steer using sail and centerboards in tandem
- Turning into the wind: lift stern boards out of the water; wind force (acting on the sail) makes raft pivot on the bow boards
- Reverse procedure for turning away from the wind

Elliptical Sails

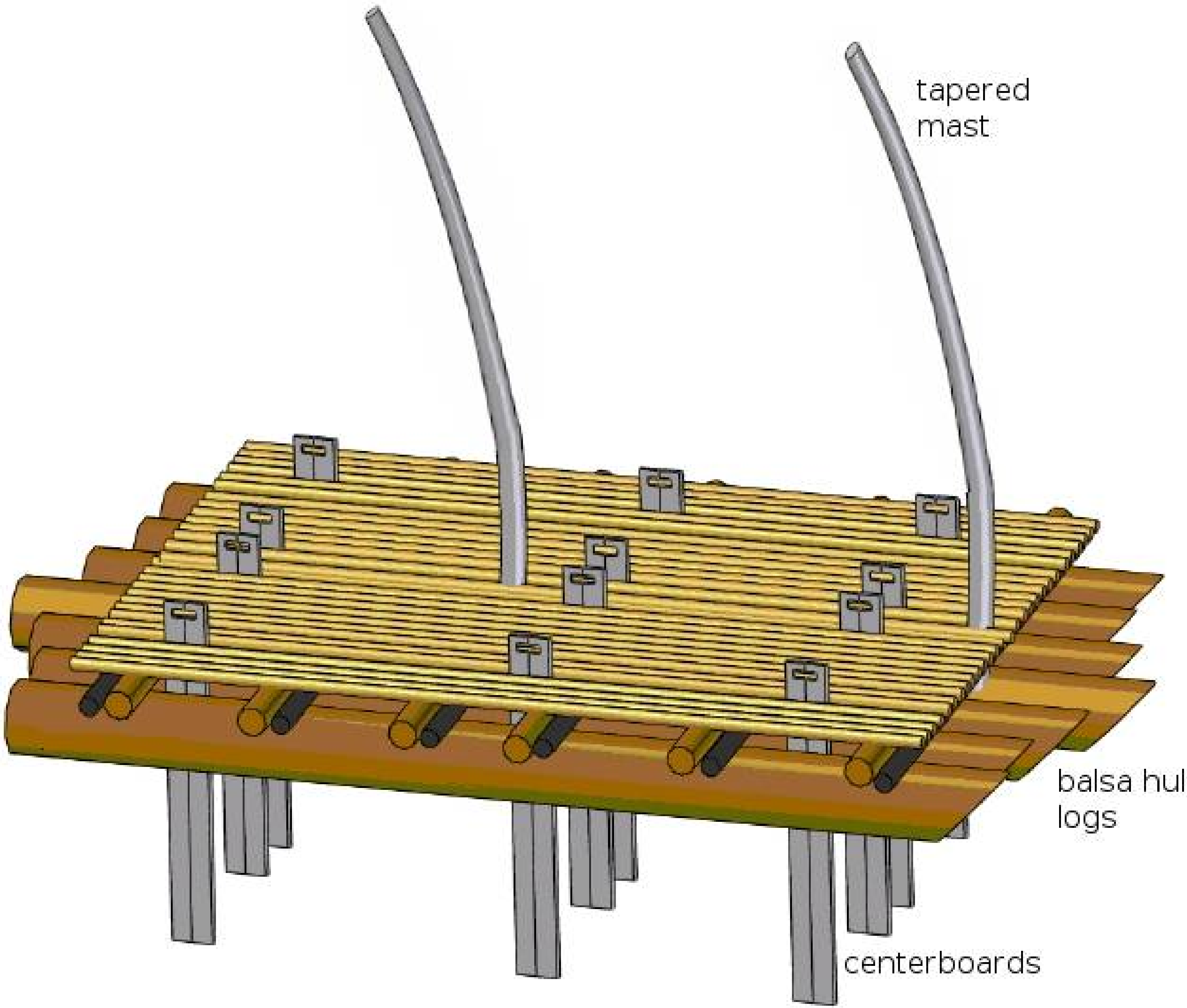
- Vary curvature to change sail efficiency
- Significant limiting factor on raft size



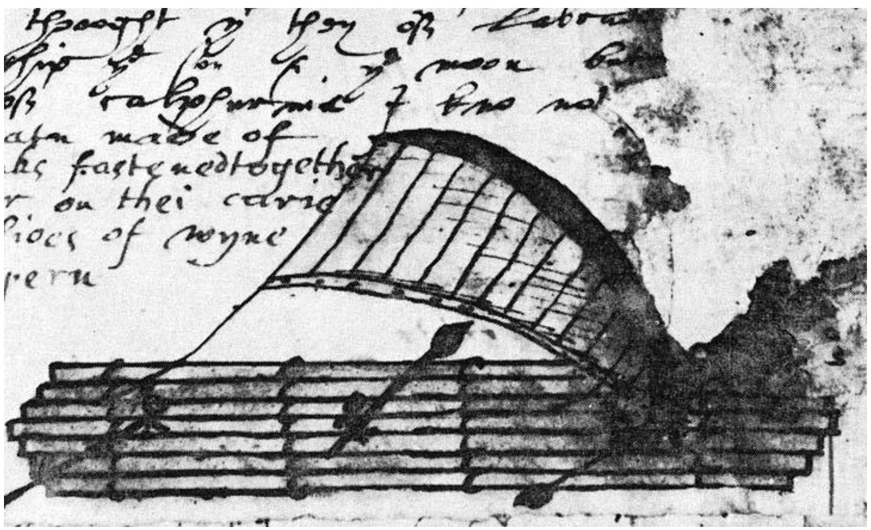
- Handling; maneuverability
- Substitutions
- Results 60 degrees into wind, successful turning. Capacity: 1 metric ton
- Mathematical modeling

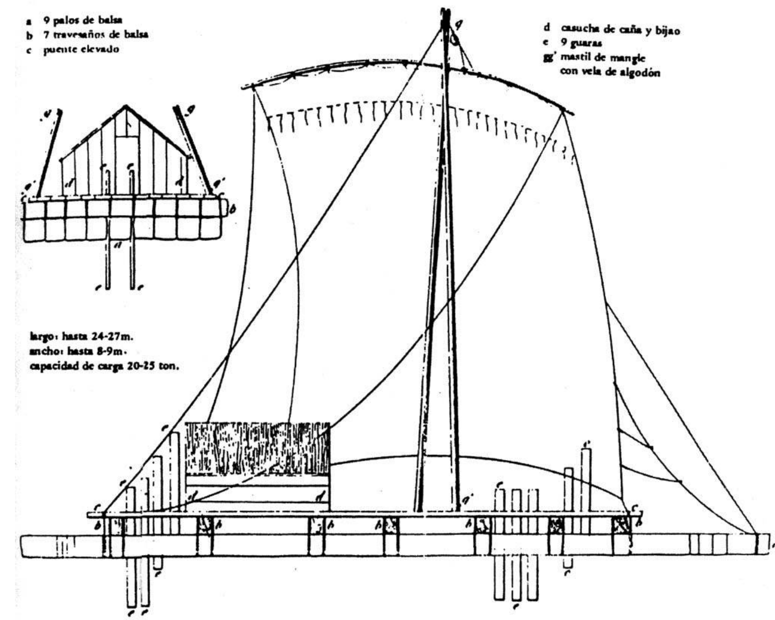
Formal Design Analysis: Feasibility Requirements

- What makes a raft functional? How do we model this?
- Components must have correct dimensions and material properties to withstand applied stresses
- Sufficient buoyant force to support cargo and crew
- Aerodynamic and hydrodynamic considerations
- Sufficiently long functional lifetime


tapered
mast
balsa hull
logs
centerboards

Stress-Strain Evaluation: Rigging Style, Mast Height and Consequent Raft Size

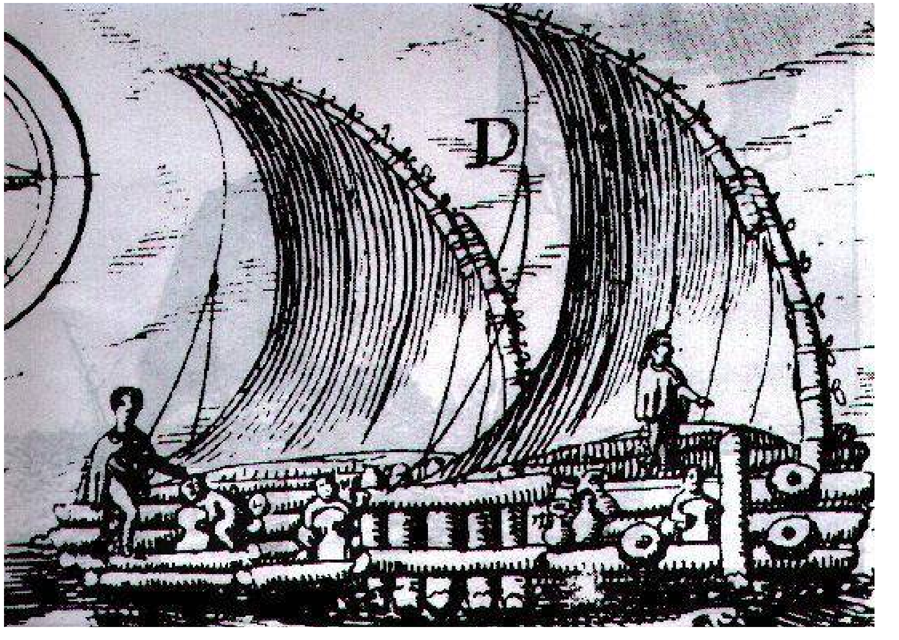




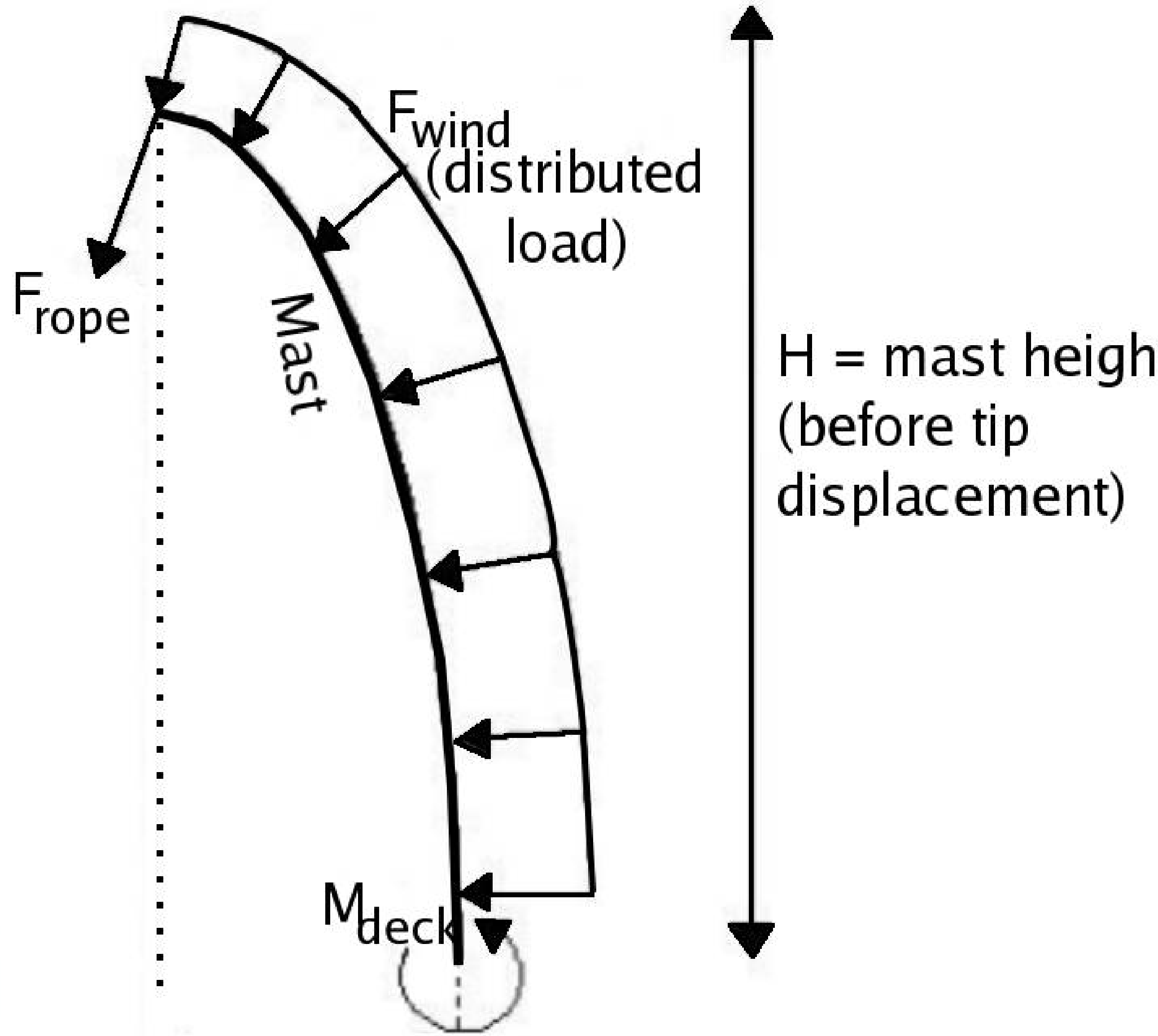
- Before the 1700s: rafts had a curved mast and were at most ~11 m in length
- After the 1700s: rafts had European-style square sails (and therefore taller masts) and had lengths up to ~22 m

Mast Stress-Strain Analysis

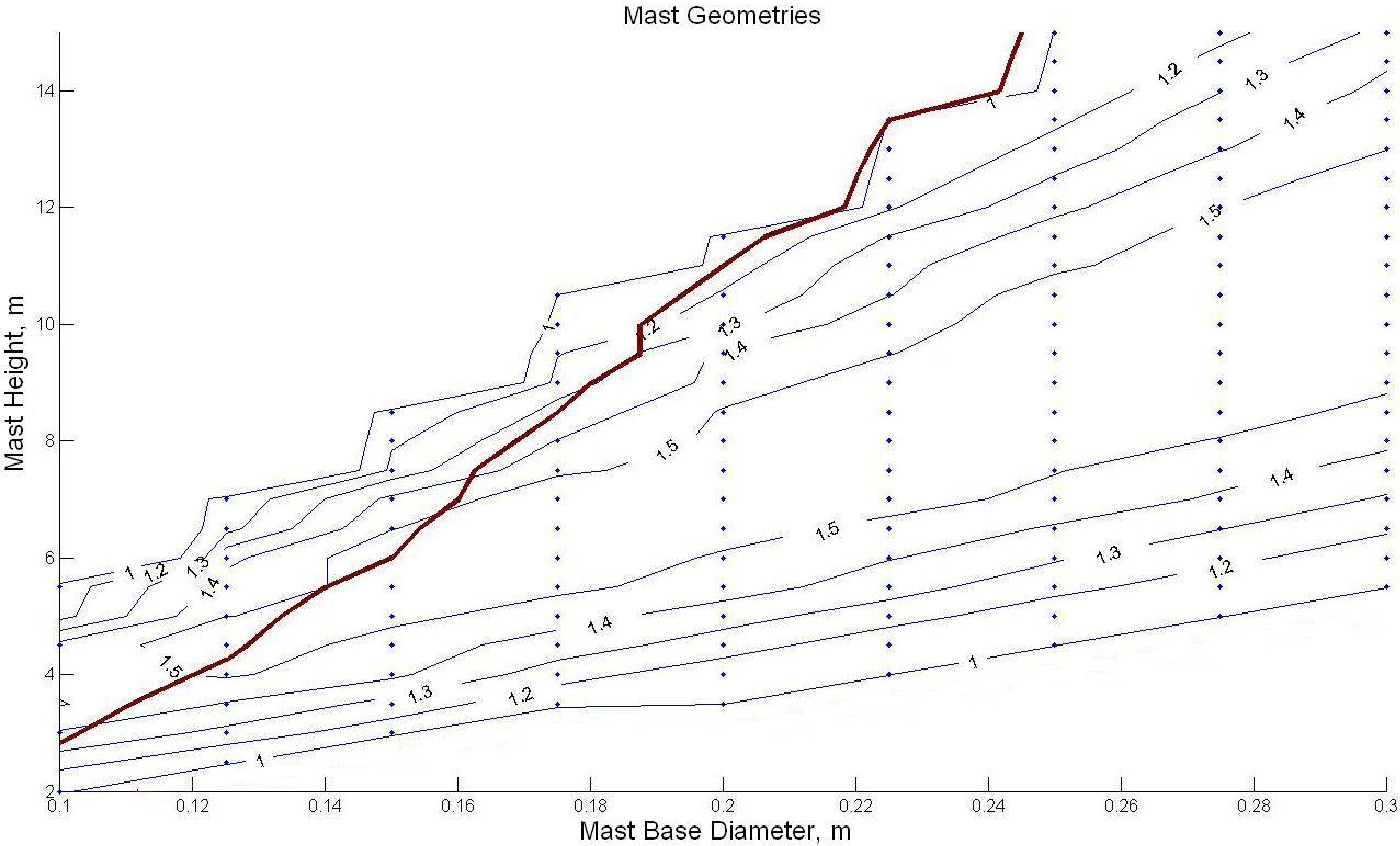
- Two main sources of stress in the mast:
  - Force of wind on the sail
  - Force of rope on tip of mast
- Rope force is significant.
- Crescent-shaped sails
- Taller, thinner masts can more readily bend a given fraction of their height
- Shorter, thicker masts can withstand a greater wind force.



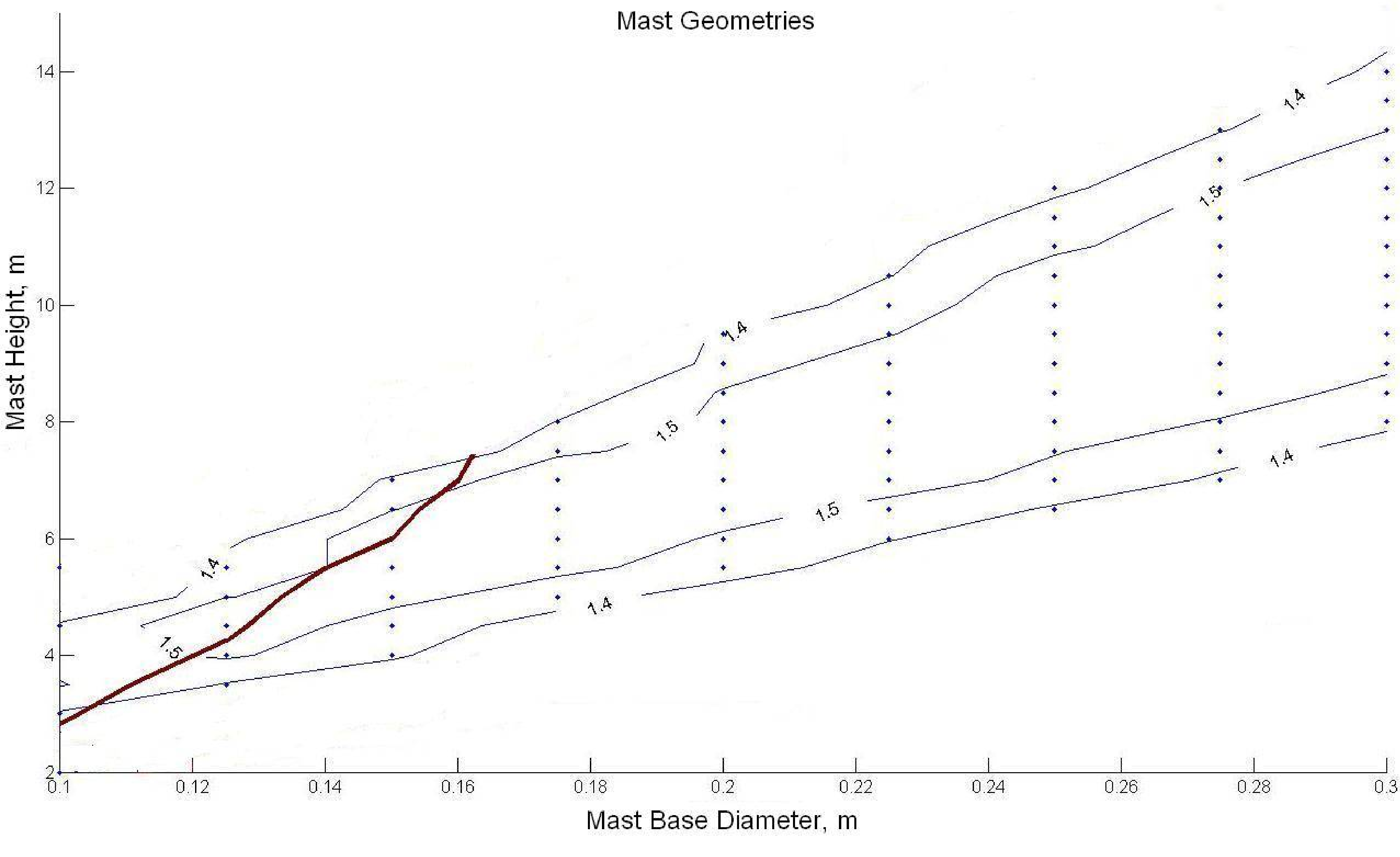

Mast


F_wind
(distributed
load)
F_rope
Mast
H = mast height
(before tip
displacement)
M_deck

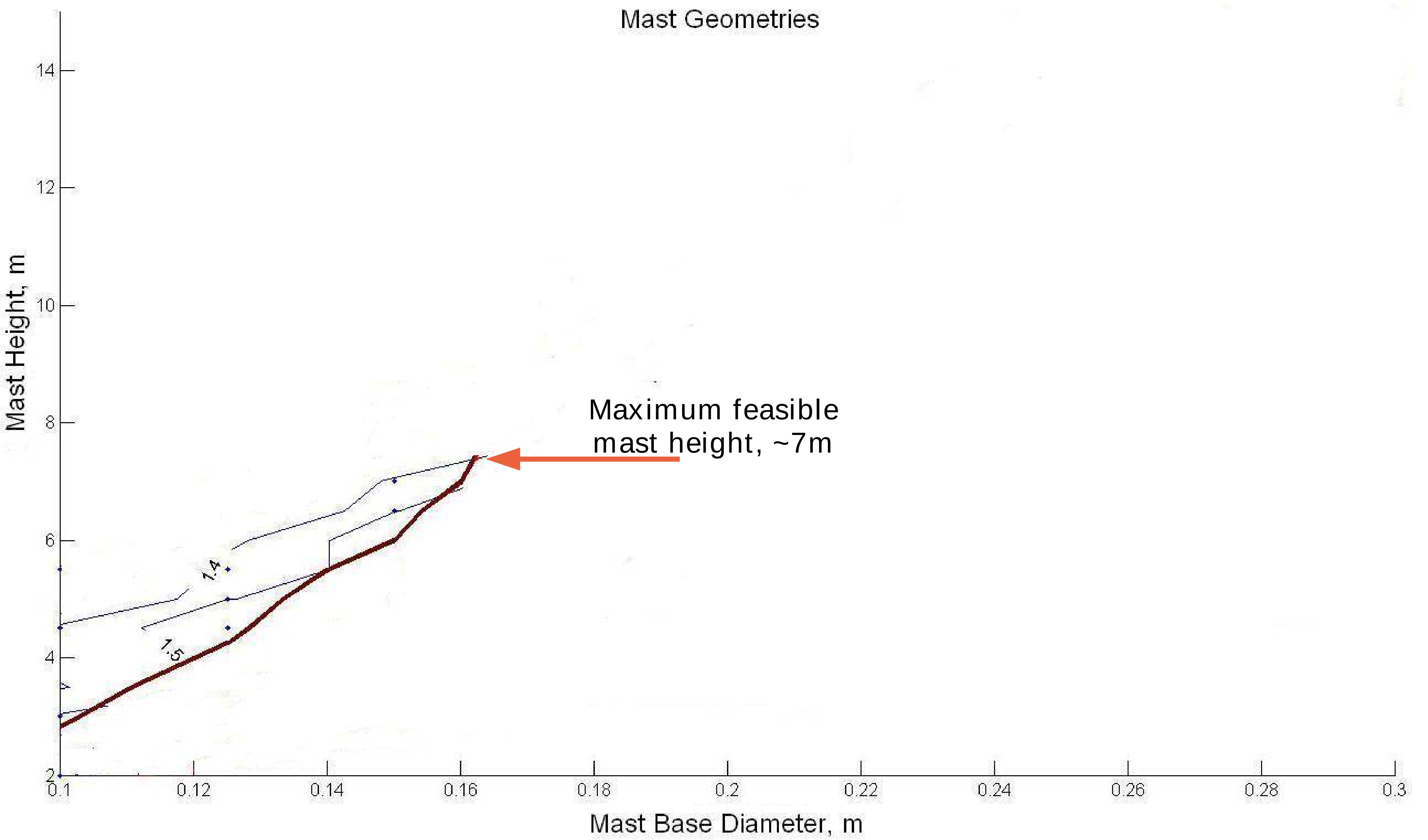
Mast Stress-Strain Analysis

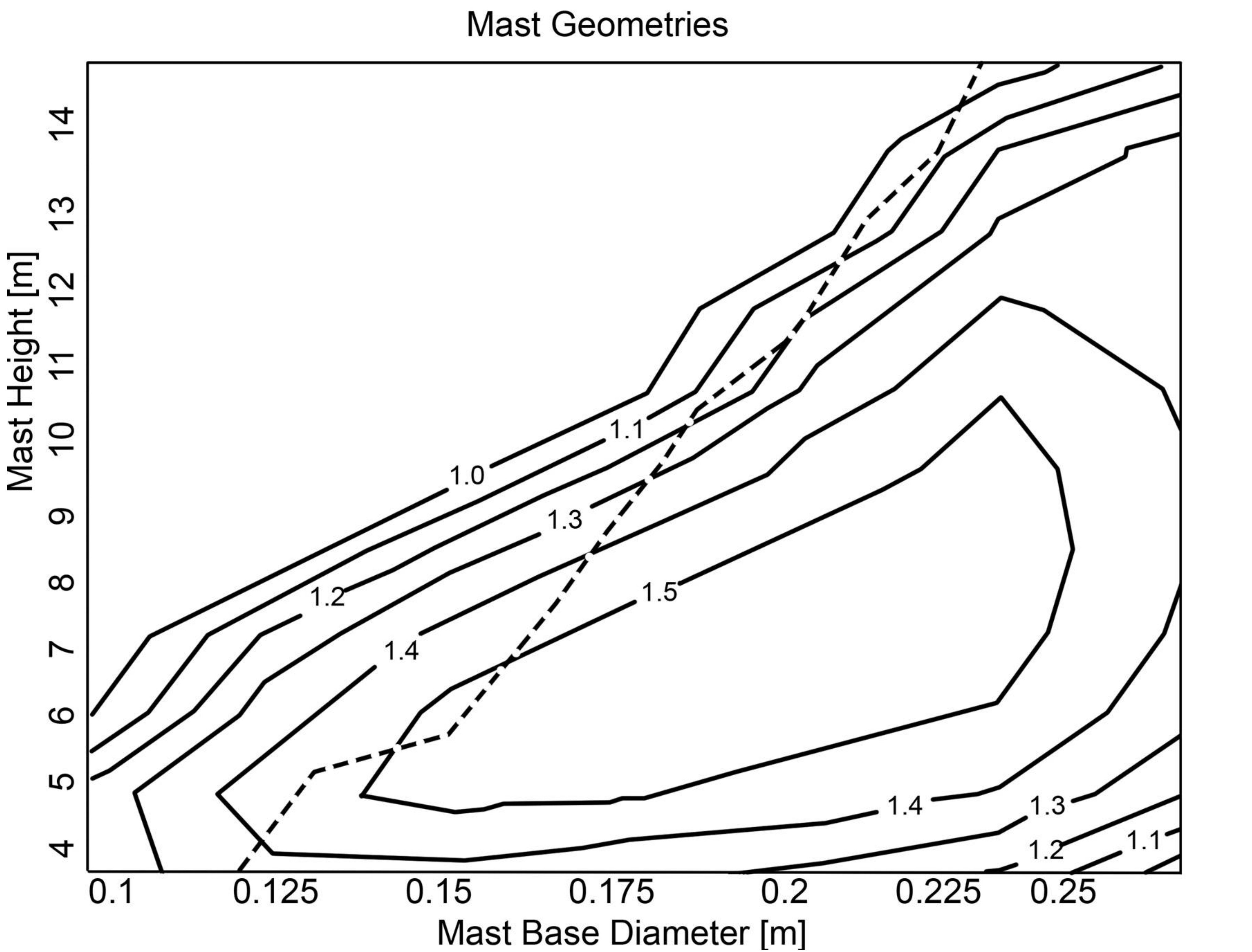


Mast Stress-Strain Analysis



Mast Stress-Strain Analysis

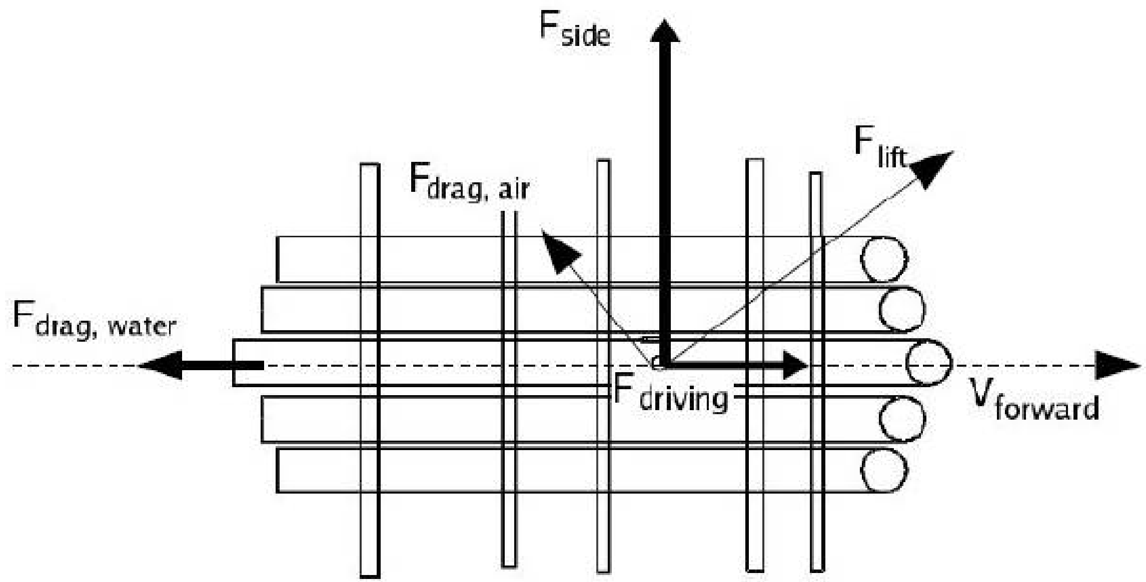




Mast Geometries
Mast Height [m]
Mast Base Diameter [m]
0.1
0.125
0.15
0.175
0.2
0.225
0.25
4
5
6
7
8
9
10
11
12
13
14
1.0
1.1
1.2
1.3
1.4
1.5
1.4
1.3
1.2
1.1

Consequences of Maximum Mast Height

- Limits sail area.
- Limits raft base area, length.
- Constrains centerboar dimensions.

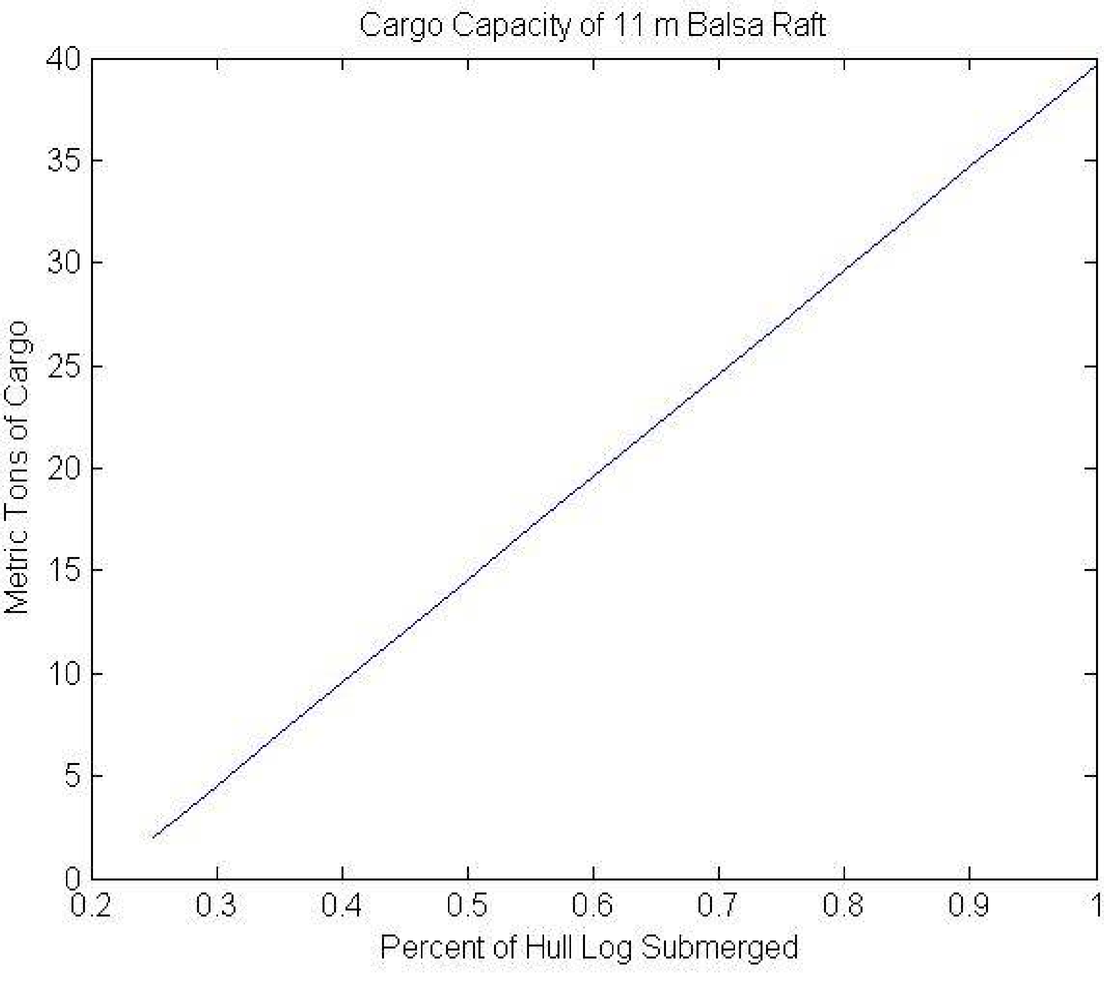


Wind and water forces on raft

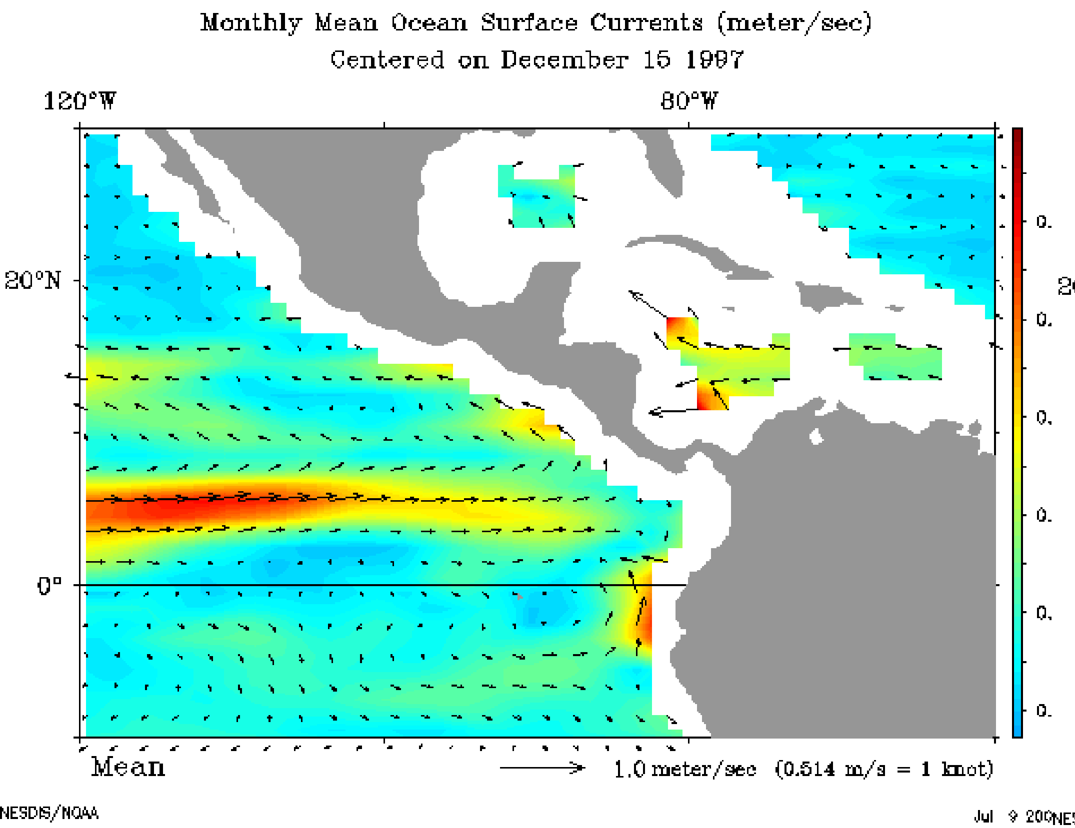
7 m mast → 11 m raft

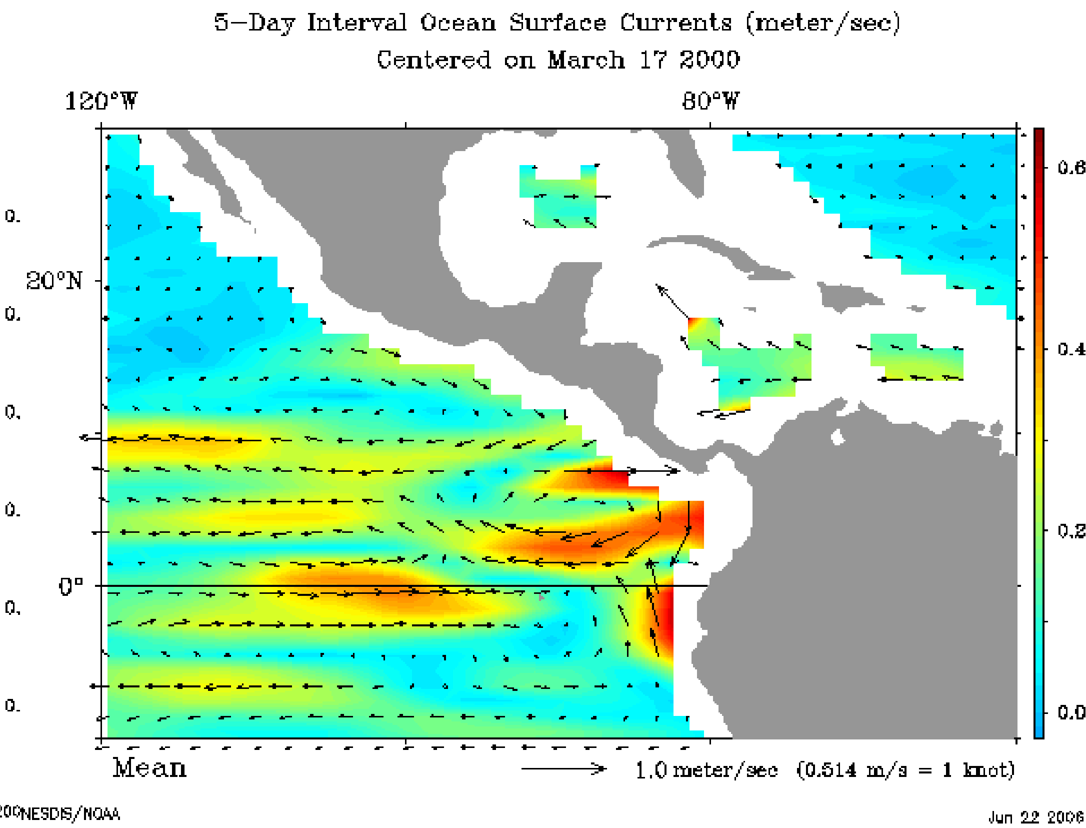
Buoyancy and Cargo Capacity

- Buoyancy and cargo capacity are directly correlated with raft size.
- An 11 meter long raft (maximum length as calculated in previous section) could carry **30 metric tons** of goods if the logs were 75% submerged.



Determining Feasible Sailing Times

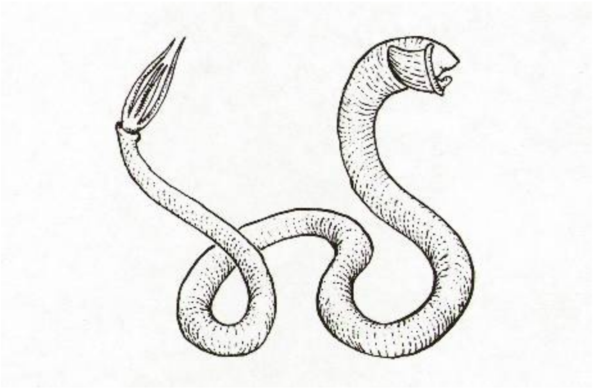




December: good time for sailing north.

March: bad time for sailing north.

Determining Functional Lifetime



Teredo navalis, gnawing worm of the sea

Conclusions

- Maximum mast height: ~ 7m
- Maximum raft length: ~ 11m
- Maximum cargo capacity: 30 metric tons
- Most feasible sailing times: north in December or January, south in late March or April
- Functional lifetime: ~ 8 months in water

Questions?