

The Science Behind
Christopher Columbus's
Voyage to the New World in 1492

By

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Christopher Columbus (Eng)

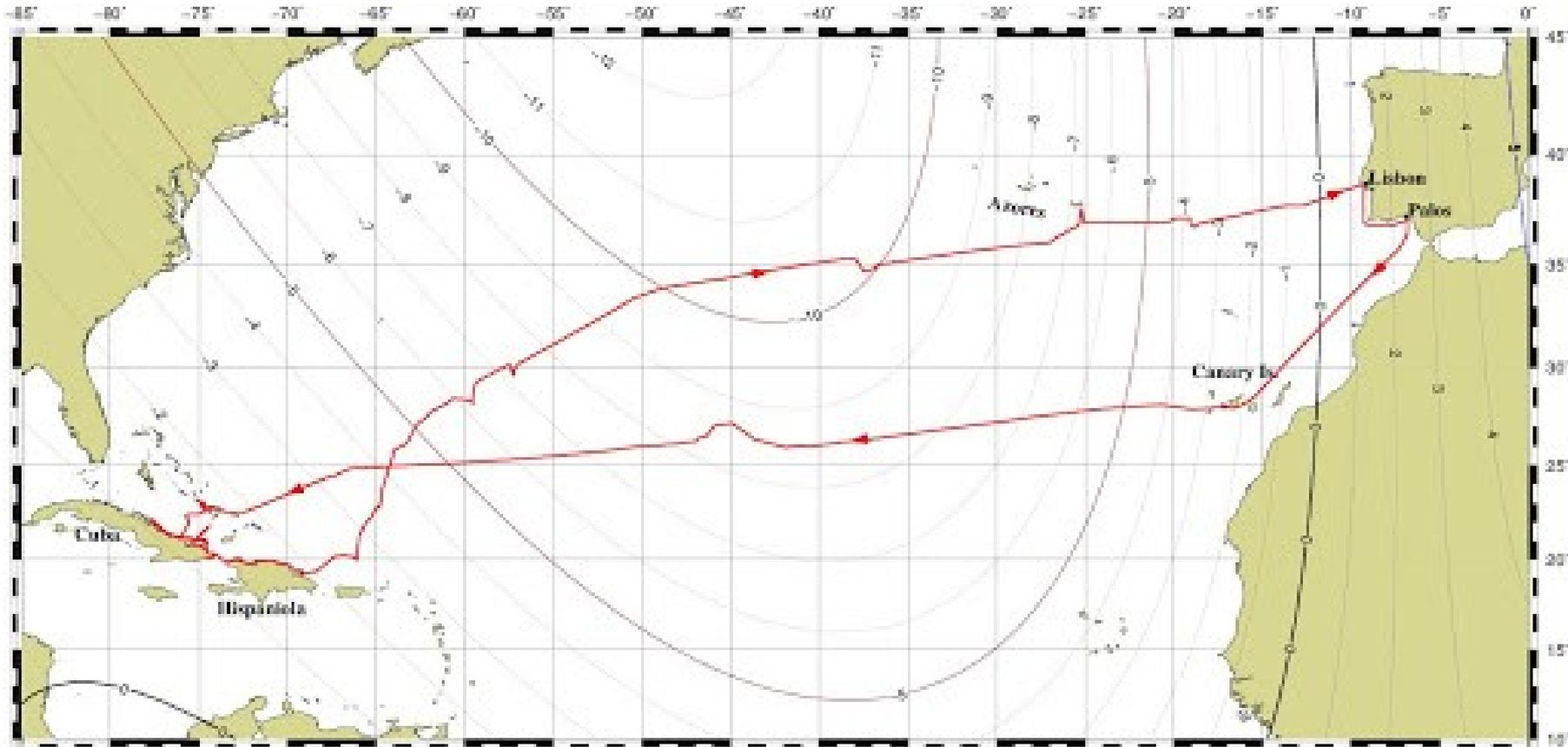


(1519)

Columbus's "La Empresa de las Indias", as he named his Enterprise to sail west to arrive in Japan to the east, opened up the New World to permanent European colonization.

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Why This Topic Interests Me?



Path of Columbus's First Voyage from Palos, Spain to Bahamas, Cuba, Hispaniola, and return to Palos (via Lisbon)

The Path of An Another Great Voyage



**Path of My Voyage in 1990 from
Road Town, BVI to South Miami, FL.**

Agenda

1. A summary of the state of Europe in the middle to late 15th century.
2. Examine Columbus the person, his family, his education, his sailing training and experience, his petitions to fund his Enterprise.
3. Look into voyages themselves focusing on the science.

Europe in the Late 15th Century

- A deep sense of despair pervaded the privileged classes; there was little sense of forward progress, and widespread decay of institutions.
 - Catholicism, a key element of Italian and Spanish society, was in decline.
 - The Crusades were long over (1291) but the goal had not been achieved.
 - The Western schism ended a short while ago.
 - Pope Alexander VI was blatantly corrupt.
 - Alexander VI's neglect of the spiritual aspects of the church would soon lead to the Reformation.
 - Christendom was shrinking in area while Islam was expanding.
 - University enrolment was dwindling; its content seemed increasingly irrelevant.
 - For over a century there had been no important advance in natural science.

Europe in the Late 15th Century (*cont.*)

- **Despair (cont.)**

- Unchecked environmental degradation was taking a significant toll.

- **On the other hand:**

- In 1439 Guttenberg developed the movable type printing press. As a result Columbus had an extensive library.

- Portugal was aggressively exploring the Atlantic off the coast of Africa and colonizing islands they found. Portugal was also trying to find a sea route to the far east around Africa.

- **Shipbuilding technology made rapid strides in seaworthiness and sailing capability in the early 1400's.**

- Spain was united by marriage of Ferdinand I and Isabella in 1469 which enabled them to wage war on Islam in Granada.

- On 2 January 1492, the leader of the last Muslim stronghold in surrendered. **This was critical to Columbus.**

- Italian Renaissance started to spill over into Spain in early 1400's

Columbus's Personal Info

- Born in Republic of Genoa in August-October 1451 time period to Domenico Columbo and Susanna Fontanarossa
 - Father was a master weaver of wool, lower middle class.
Mother was from a wealthy decidedly upper-class family.
 - **Genoa was one of the two major naval/trading powers in what was to become Italy.**
- He had two brothers.
 - Bartholomew (year or two younger), Skilled cartographer.
 - Giacomo (It.)/Diego (17 years younger).
- He was a devout and utterly committed Catholic.

Columbus's Personal Info *(cont.)*

- **Married Felipa Perestrello e Monis, daughter of a wealthy Portuguese nobleman.** Thus, Columbus became a nobleman.
- He had two children, one with his wife and one with his mistress (after his wife died)
- Physically, tall of stature, powerfully built, ruddy complexion, red hair, i.e., not the typical Italian attributes.
- Died May 20, 1506 Valladolid, Spain, a very wealthy man. Befitting his nature he continued to move around thereafter.

Childhood and Teen Years

- Little to no documented evidence of his activities.
- He had no formal education.
- Almost certainly spent time sailing as a seaman.

Possible Early Sailing Experience

- (~1461) In one of his writings he claimed he went to sea at the age of 10.
- (~1465) At 14 he may have sailed a small boat up and down the coast buying/delivering wool/cloth for his father.
- (1466-1472) The next six years are largely undocumented
- (1473) At age of 23 he known to have sailed to Khios, Greece as a business agent for the important Spinola family.
- (1474) Columbus begins a series of voyages over the next seven years which take him to faraway lands such as Guinea (Africa) and Iceland. He becomes a knowledgeable seaman, and learns of the Trade Winds.

His *Big Splash & Break in Life*

- In 1476, at the age 25, fate enters the picture and the ship he is on sinks off the coast of Portugal.
- Columbus jumps into the ocean, and swims 6 miles to shore in spite of being wounded.
- He travels to the “Genoa” enclave in Lisbon, his wounds are treated, and he recovers. He is thus thrust into the most advanced sailing community in Europe. Columbus soon proves to be a very apt student.
- He continues sailing briefly and then returns to Lisbon.

Sailing Education

- In 1477 he is back in Lisbon as a student learning navigation, seamanship, This is also when he learns to speak/read/write Portuguese, Spanish, and Latin. He reads widely about astronomy, geography, and history (Ptolemy, Polo, ...)
- Columbus was not a scholarly man, but he was intelligent, and ambitious. - ambitious to gain lots of wealth, a little glory, and a bit of Godliness. He studied intently the authors/books mentioned above, made hundreds of marginal notations and came out with clear ideas about the world.
- Maybe he was already thinking about the Empressa as something he could do.

Ancillary Life Experiences

- In 1479 he takes time out from sailing to marry Felipa Perestrello e Moniz, daughter of a wealthy Portuguese **nobleman**, sea captain, and colonizer.
- The idea of **HIM** doing the sailing west to the Indies must have occurred to him by this time. Columbus acquired from his father-in-law's widow the charts and documents describing his Atlantic voyages, and a list of contacts.
- He must have consulted with a number of “experts” to put together his Enterprise proposal. His father-in-law corresponded with Toscanelli, a well respected Florentine astronomer, who first made the proposal for the Enterprise to the king of Portugal in 1470. Columbus corresponded with Toscanelli, who died in 1481.

Sell the Enterprise to King John II of Portugal

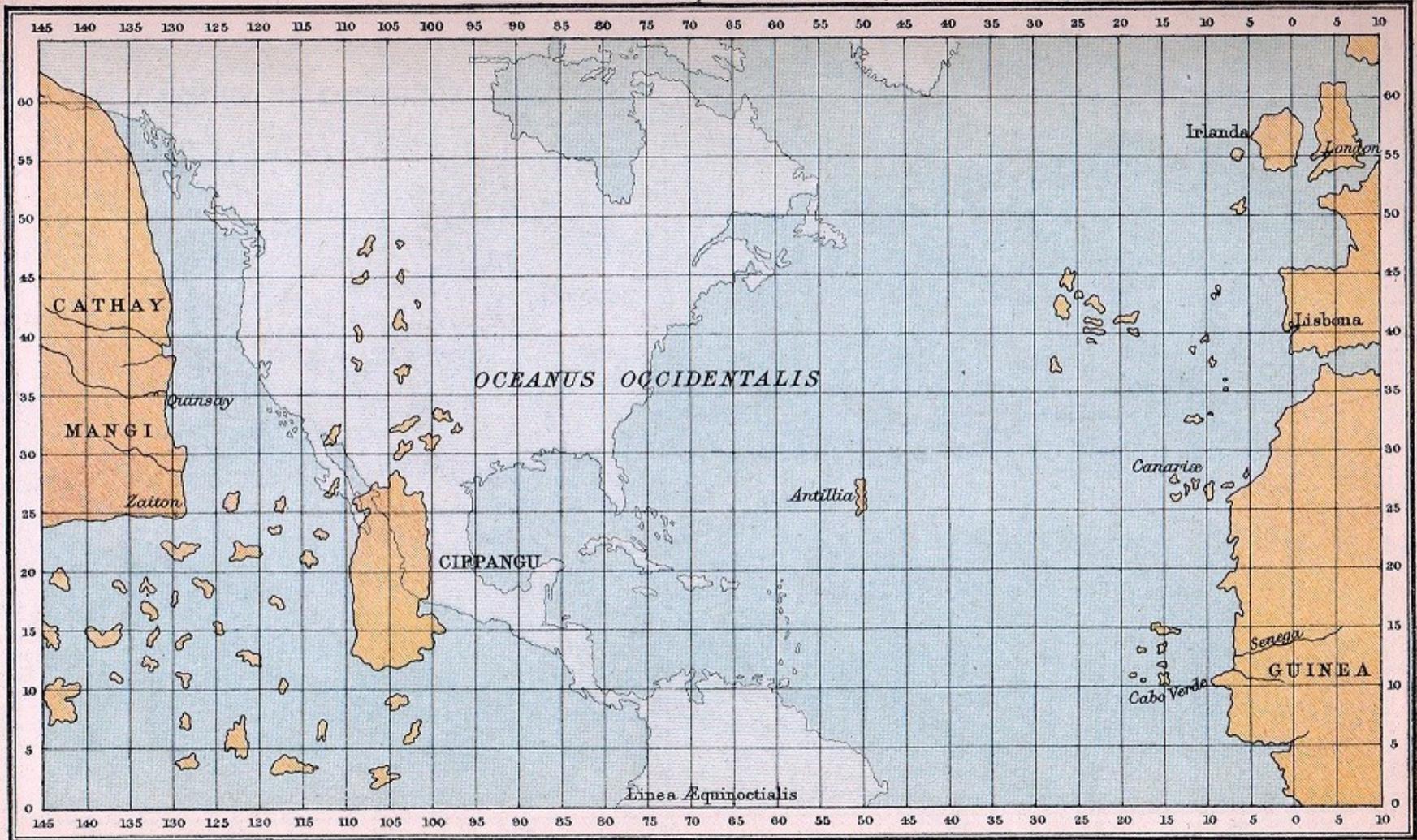
- As hinted at above no hard evidence exists concerning exactly when Columbus first thought of the La Empressa de las Indies as something he could do.
- From 1485 to 1488, Columbus presented his Enterprise to King John II of Portugal. It was sent to a succession of committees, and eventually rejected primarily due to his estimate of the distance. – 2,400 versus 10,000 nm.
- Somehow, the committees dismissed or underestimated the key difference in Columbus's proposal – the Trade Winds.
- In 1488 the famous explorer named Bartholomew Dias rounded Cape of Good Hope, i.e. the eastern route, so King John II turns down Columbus's proposal categorically. Columbus now leaves for Spain.

Estimated Distance from Canary Islands to Japan

	<i>Toscanelli</i>	<i>Martin Behaim</i>	<i>Columbus</i>	<i>Actual air-line*</i>
Canaries to Cipangu (Japan)	3000	3080	2400	10,600
Canaries to Quinsay (Hangchow) . . .	5000	4440	3550	11,766

Toscanelli Map of the (Known) World

ATLANTIC OCEAN, TOSCANELLI, 1474



The Correct outline of North America is shown in light blue tint

John Bartholomew & Co., Edinb.

GLOBE DE MARTIN BEHAIM (1492)



Columbus's Calculation of the Distance to Japan

- Ptolomy taught that the known world covers 180° (of 360°). This is already a 50% overestimate. Columbus (and other respected geographers to be fair) insisted this is too small.
- Columbus preferred to believe Marinus of Tyre (successor to Ptolomy) who stretched the known world to 225° .
- To this Columbus added 28° for the discoveries of Marco Polo and 30° for the distance from China to the eastern coast of Japan. (why not?)
- $225^\circ + 28^\circ + 30^\circ = 283^\circ$. He is planning to start from the Canaries (9°) so add this to 283° to arrive at 292° . $360^\circ - 292^\circ = 68^\circ$.
- $68^\circ * 45\text{nm}/^\circ = 3060\text{nm}$. Note 45nm (as opposed to 60) is the length of one degree according to a Roman expert. You would think this would do it, but Chris wasn't done yet.
- Inexplicably, Chris believed that Marinus of Tyre degrees were incorrect, so 68° is too large, and should be decreased to 60° . Again, why not?
- More reasonably, a degree is 45nm at the equator (0° latitude), so at 28° , where he expected to sail, it should be 40nm.
- Thus, we end up with $60^\circ * 40 = 2400 \text{ nm}$, i.e., the value in the table above.

Other Estimates of a Degree and the Circumference of the Earth

11. ESTIMATES OF THE LENGTH OF THE DEGREE AND OF THE CIRCUMFERENCE OF THE EARTH

	Unit of measurement	Value of unit in meters	Length of Degree		Circumference	
			in con-temp. units	in nautical miles	in con-temp. units	in nautical miles
Modern			*69.1	60.0	*24,876	21,600
Aristotle	stade of	99.8	1111 $\frac{1}{9}$	59.8	400,000	21,528
Eratosthenes	stade of	157.5	700	59.5	252,000	21,420
Ptolemy	stade of	185	500	49.9	180,000	17,964
Alfragan	mile of	2164	56 $\frac{2}{3}$	66.2	20,400	23,832
10th century						
Columbus	R. mile	1480	56 $\frac{2}{3}$	45.2	20,400	16,272
Spain and Portugal	league of	5920	17 $\frac{1}{2}$	55.9	6,300	20,124
16th century	4 R. miles					

How Eratosthenes “Estimated” the Earth's Circumference (276-194 BC)

- On the day the Sun shone on the bottom of the wells in Syene, Eratosthenes **measured** the Sun's position in the sky over Alexandria. It was seven degrees away from the zenith, meaning Syene must be seven degrees away from Alexandria as **measured** on the circle that is **Earth's** circumference.
- Multiply the distance between Syene and Alexandria by $360/7$ to get the circumference.
- He was about 1% off. Very impressive!

Sell the Enterprise to the Queen Isabela

- In 1486 Columbus sought an audience with the Spanish monarchs Ferdinand II of Aragon and Isabella I of Castile.
- On 1 May 1486, permission having been granted, Columbus presented his plans to Queen Isabella, who, in turn, refers it to committee.
- After the passing of time, the committee, like their counterparts in Portugal, reply that Columbus had underestimated the distance to Japan.
- In reality, the monarchy was absorbed with the attack on Granada, and Columbus was not going to get a final answer until Granada fell.
- To keep Columbus from taking his ideas elsewhere, and to keep their options open, the Isabella gave him an annual allowance of 12,000 maravedis.

(Almost Final) Thumbs Down

- The committees findings were not deterministic. The timing of the monarch's verdict was being delayed explicitly until Grenada was taken.
- Isabella gifted him 20,000 maravedis and continued free food/lodging when the battle for Granada was close to over.
- In 1491 Columbus made the first proposal of his remuneration demands: Admiral of the Ocean Sea, 10% of all proceeds, governor of all he finds (including the far east), kick in 1/8, get 1/8 of proceeds. Keep in mind we are talking about the Far East, not the Bahamas.
- Granada capitulated on January 2, 1492. The metaphorical axe wielded by Isabela fell on Columbus a short while later.

The Spanish Committee Findings

As you can see above Columbus's calculations picked the values most beneficial to his goal. This certainly seems suspect but were in accordance with other well respected astronomers/geographers.

Here are the precise findings of the royal committee assigned by Isabella.

- a. The accuracy of Marco Polo is doubted (*for no apparent reason*).
- b. The existence of Japan is doubted because Ptolemy mentioned no such place.**
- c. The commission estimated the distance to be 10,000nm (*which is actually close*).
- d. The commission doubted fair winds, i.e., the Trade Winds**

These points, except c, are just as half-baked as Columbus's ideas, so I don't think Isabella could base her decision on either

Isabella Finally Sees the Light and Green Lights the Enterprise

- Amazing good fortune smiles on Columbus once again:
 - Columbus made a friend (as he often did with royalty) of Luis de Santangel, none other the treasurer for King Ferdinand. Luis approached Isabella after the final verdict and pointed out the obvious fact that she was being shortsighted.
 - Isabella saw the light, summoned Columbus to return from his trip to France, and along with Ferdinand, ok'd the venture in short order.
 - Finally there was the matter of Columbus's steep demands – Admiral of the Ocean Sea, 10% of all the proceeds, Governorship of all discovered land, and 1/8 of all private proceeds. Isabela realized she didn't have much of a choice here either.
- The Queen then ordered, at Luis's suggestion, the town of Palos to charter two of the boats (eventually Nina and Pinta), and Columbus kicked in 1/2 of the charter fee for a third boat, the Santa Maria.

Chartering the Ships & Recruiting the Crew

- After a few months of ironing out the details, Columbus proceeds to Palos. The town is charged with providing two boats at taxpayer expense, which it does begrudgingly.
- Good fortune smiles yet again. Columbus teams up with a local named **Martín Alonso Pinzón**. It's safe to say that **Martín**, due to his prestige and exceptional expertise in nautical matters, played almost as important role in the Enterprise as Columbus. Without him it is doubtful that the Enterprise could have succeeded.
 - As a strong sign of his commitment to Columbus's plan, Martin put up half a million maravedís, ½ the sum put up by the monarchy.
 - He dismissed the two modest boats provided by Palos, and offered his own – the Nina and Pinta – both top of the line caravels.
 - He also dismissed the crew Columbus recruited, and was able to enlist a qualified crew. Each boat had a surgeon, and was very capable, e.g., able to make major repairs in the new world.
 - He sailed with Christopher Columbus on the first voyage as captain of the Pinta.

The Crew and Their Living Conditions

- Martins youngest brother Vicente Yáñez Pinzón was captain of the *Niña*, and the middle brother Francisco Martín Pinzón was *maestre* (first mate) of the *Pinta*.
- Prisoners – there were 4 in the crew. They received a pardon, one for murder. They must have been experienced seamen given the living conditions.
- The crew, except the captain, had to sleep on the very hard, curved deck; thus experienced seamen was a must.
- Food was consistent with the normal Spanish diet. Wine was in large casks. For food to last at sea, it needed to be dry.
- Food was cooked (if at all) on deck in something of a pit. There was not an official cook.

Caravel Characteristics

- In reality very little is known definitively about any of the ships.
- All major voyages of this period, including Magellan in 1522, used the caravel. As we shall see, they were sturdy, fast, and nimble.
- The Nina and Pinta were probably about 15m (~50') long with a beam a little over 4m (~14') or a ratio of about 3.5 to 1. This is about average. They have displacement hulls, and thus the theoretical hull speed is $(4/3 * \text{SQRT}(\text{LWL})) = 4/3 \text{ SQRT}(45') = 8.9$ knots.
- All had three masts. Nina was a *caravela latina*, which means she initially had 3 lateen sails, while the Pinta is a *caravela redonda*, which means she had square sails on the forward two masts.
- Ballast was a vital consideration. Typically, heavy cargo or some stones at the bottom of the boat served as the ballast, and thus got the center of mass as low in the boat as possible.
- No wind, no problem. These boats could be rowed quite easily at about 2 knots.



Model of Nina with original lateen (triangular) sails
Thus making her a caravel latina.



The ships of Christopher Columbus
Santa Maria in the center, Pinta to the right,
And Nina with her original rig to the left.

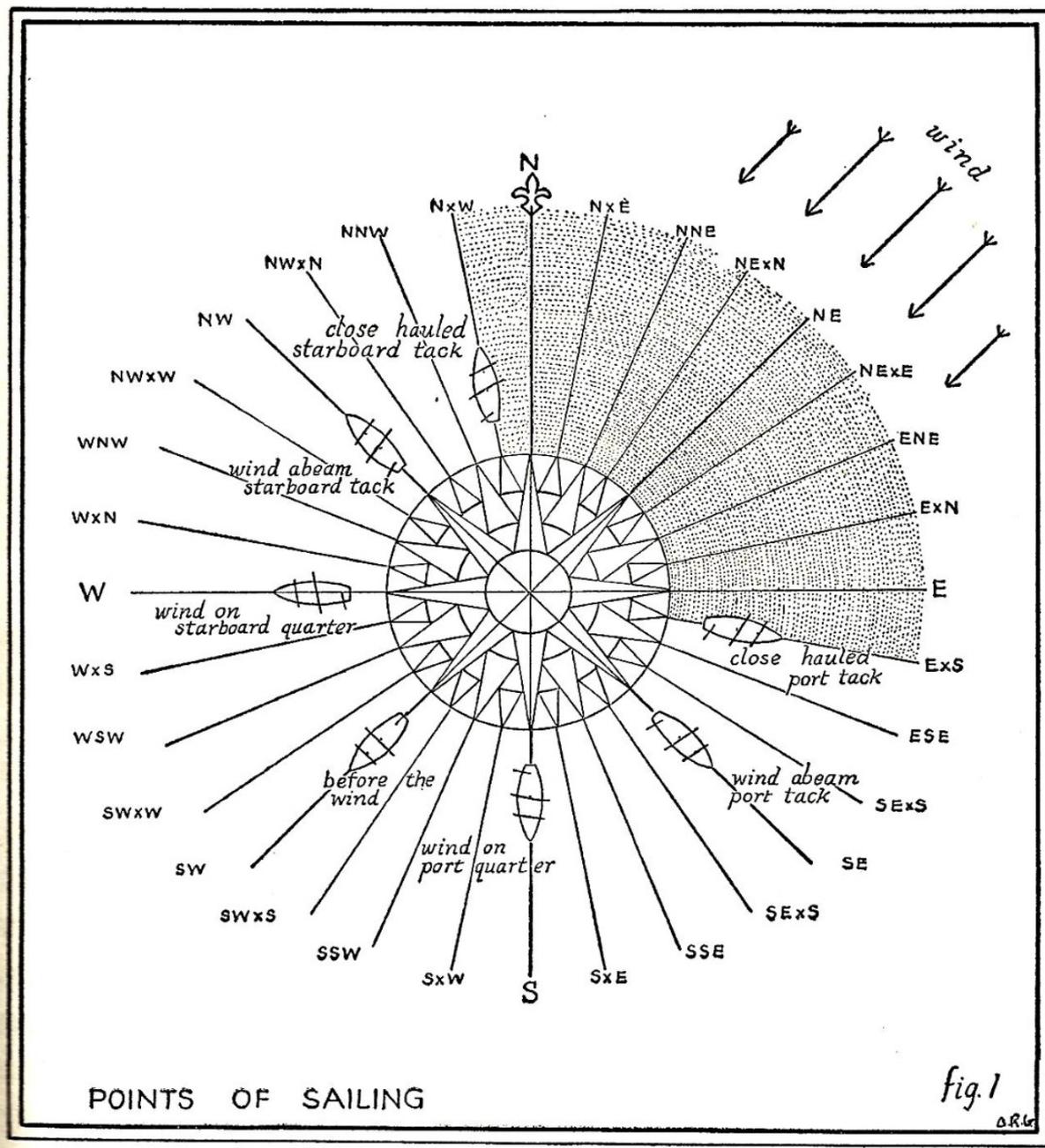
Construction Improvements to the Caravel That Enabled Ocean Voyages

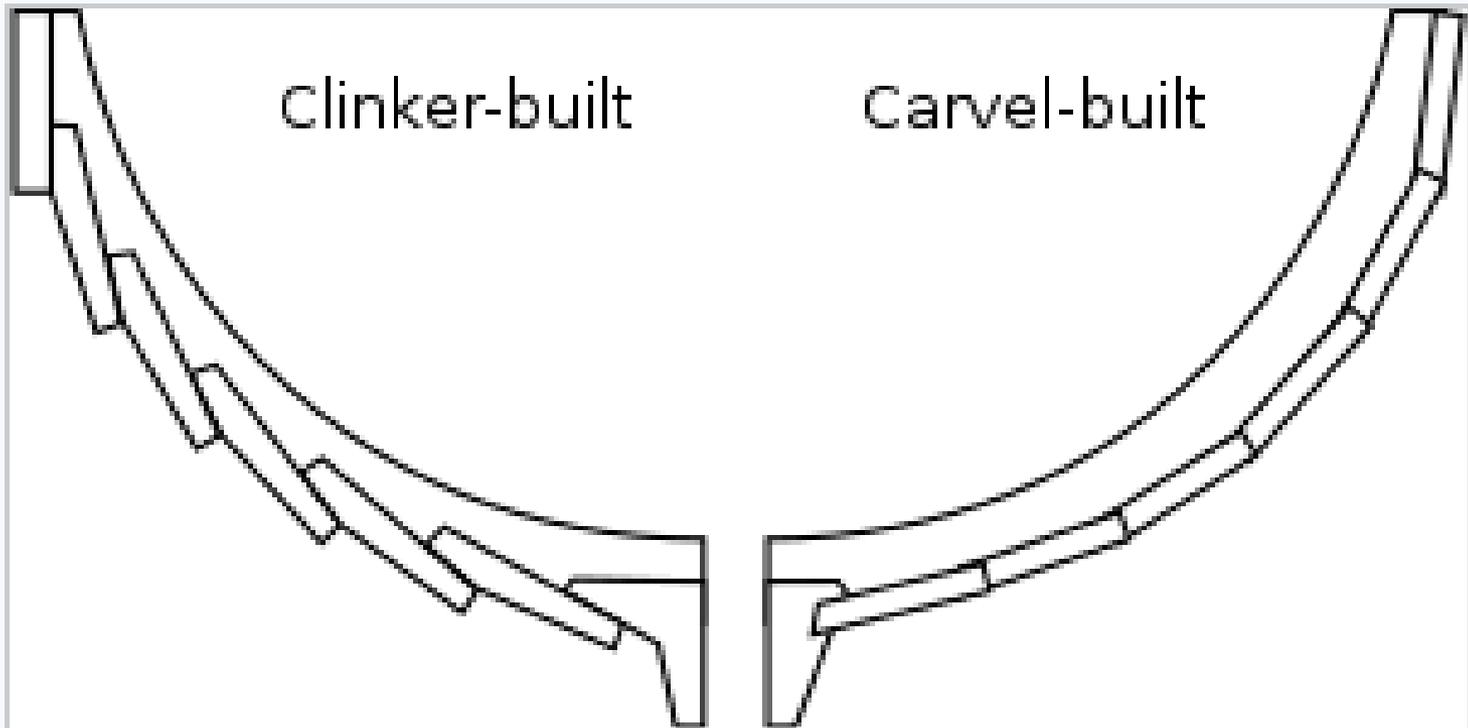
A caravel capable of an offshore ocean voyage was developed around 1450. Major improvements that enabled it to withstand even severe conditions were:

- The rudder was moved from the side to the rear of the ship allowing more precise control in heavy or following seas.
- The keel, ribs, and planks were made substantially heavier, and thus sturdier. For example, the planks (sides) were 3-5 inches thick.
- The ribs were fashioned to give the boat an elliptical shape below the waterline.
- The sides were attached using the “planking”, or non-overlapped, method, as opposed to the clinker method (see diagram next page). These boats were used to round the Cape of Good Hope, which demands very sturdy construction.
- The length over all was increased from a ratio of 2:1 to a ratio of about 3.5 to 1. This is critical to reasonable upwind performance.

Compass Rose Circa 1490's –

A modern boat
tacks thru 90°'s
while a caravel
of this era tack
thru 120°.





A comparison of clinker and carvel construction.
Carvel frames are much heavier than clinker ribs.



One important advantage ..

The Science of Sailing into the Wind

How is It Possible?

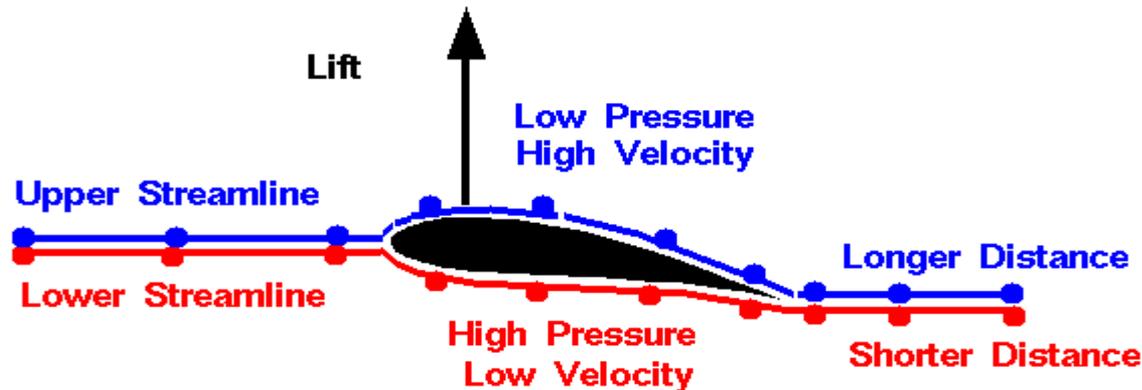
- The physics of sailing into the wind can be summarized in one word - LIFT. Obviously air, a compressible fluid, flowing around a wing, i.e., an airfoil, somehow provides lift.
- A wing and a sail are both an airfoil, and thus achieve lift using the same physical principles.
- The remaining question (for me) is why doesn't a sailboat go sideways when going upwind, i.e., go downwind? The answer is once again LIFT – this time provided by the water (an incompressible fluid) flowing over the keel.
- Slides below show the three favorite incorrect theories for lift. The first one shows the most common theory, and one that I have accepted for years. But it has bothered my intuition my entire sailing life. The fourth page shows the true theory in abstract fashion.

The Most Popular Incorrect Theory of Lift – Equal-Transit-Time and Bernoulli Effect



Incorrect Theory #1

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"Longer Path" or "Equal Transit" Theory

Top of airfoil is shaped to provide longer path than bottom.
Air molecules have farther to go over the top.

Air molecules must move faster over the top to meet molecules
at the trailing edge that have gone underneath.

From Bernoulli's equation, higher velocity produces lower
pressure on the top.

Difference in pressure produces lift.

Wind Tunnel Picture

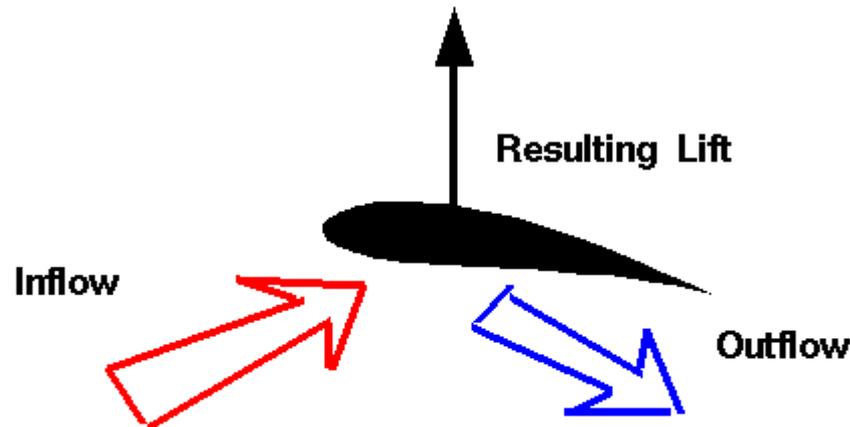


Another Popular Incorrect Theory of Lift – Newtonian Theory



Incorrect Theory #2

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"Skipping Stone" Theory

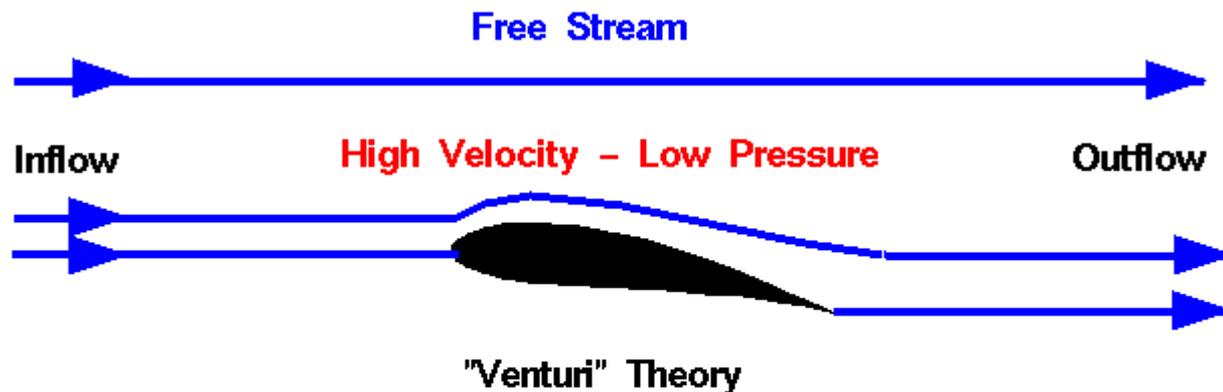
Lift is the result of simple action <--> reaction
as air molecules strike bottom of the airfoil
imparting momentum to the foil.

The Third Incorrect Theory of Lift – Venturi Theory



Incorrect Theory #3

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Upper surface of airfoil behaves like a Venturi nozzle constricting the flow.

Through the constriction, flow speeds up
(velocity times area equals a constant).

From Bernoulli's equation, high velocity gives low pressure.

Decreased pressure on upper surface produces lift.

Correct Theory – Too Complicated to Explain



Euler Equations

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2 - Dimensional, Steady Form:

Coordinates: (x,y)	Continuity:	$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} = 0$
Velocity Components: (u,v)	X - Momentum:	$\frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} = -\frac{\partial p}{\partial x}$
Pressure: p	Y - Momentum:	$\frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho v^2)}{\partial y} = -\frac{\partial p}{\partial y}$
Density: ρ		

Incompressible Form:

Continuity:	$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$
X - Momentum:	$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial x}$
Y - Momentum:	$u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial y}$

Finally, Sail Into the Wind

- Actually, the first two incorrect theories, i.e., Bernoulli and momentum with the proper angle of attack. contain most elements of the correct theory, and in reality, Euler's equations are simplifications of the more general Navier-Stokes equations of fluid dynamics.
- However, even the Euler equations are typically too complex to solve, so simplified approximations are used.
- It is clear from wind tunnel picture that the air molecules do NOT meet up at the end of the wing/sail/foil. Thus, the molecules traveling over the longer distance can go very much faster and thus provide **substantial** lift.
- More to the point, this answers my question of how can the air on the leeward side of a very thin sail be going considerably faster than the air on the windward side.

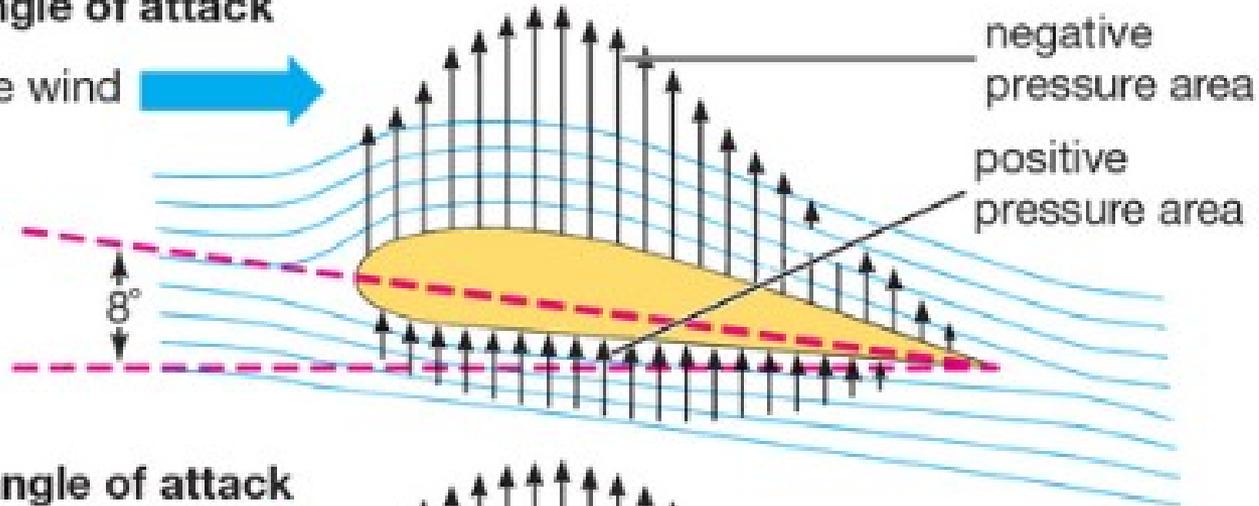
(More Intuitively)

How Most Lift Is Actually Developed

How lift varies with angle of attack

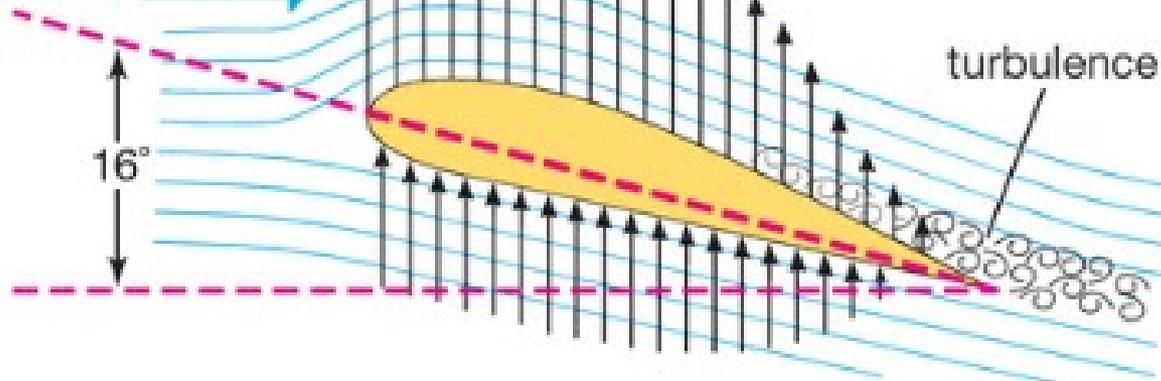
low angle of attack

relative wind 



high angle of attack

relative wind 



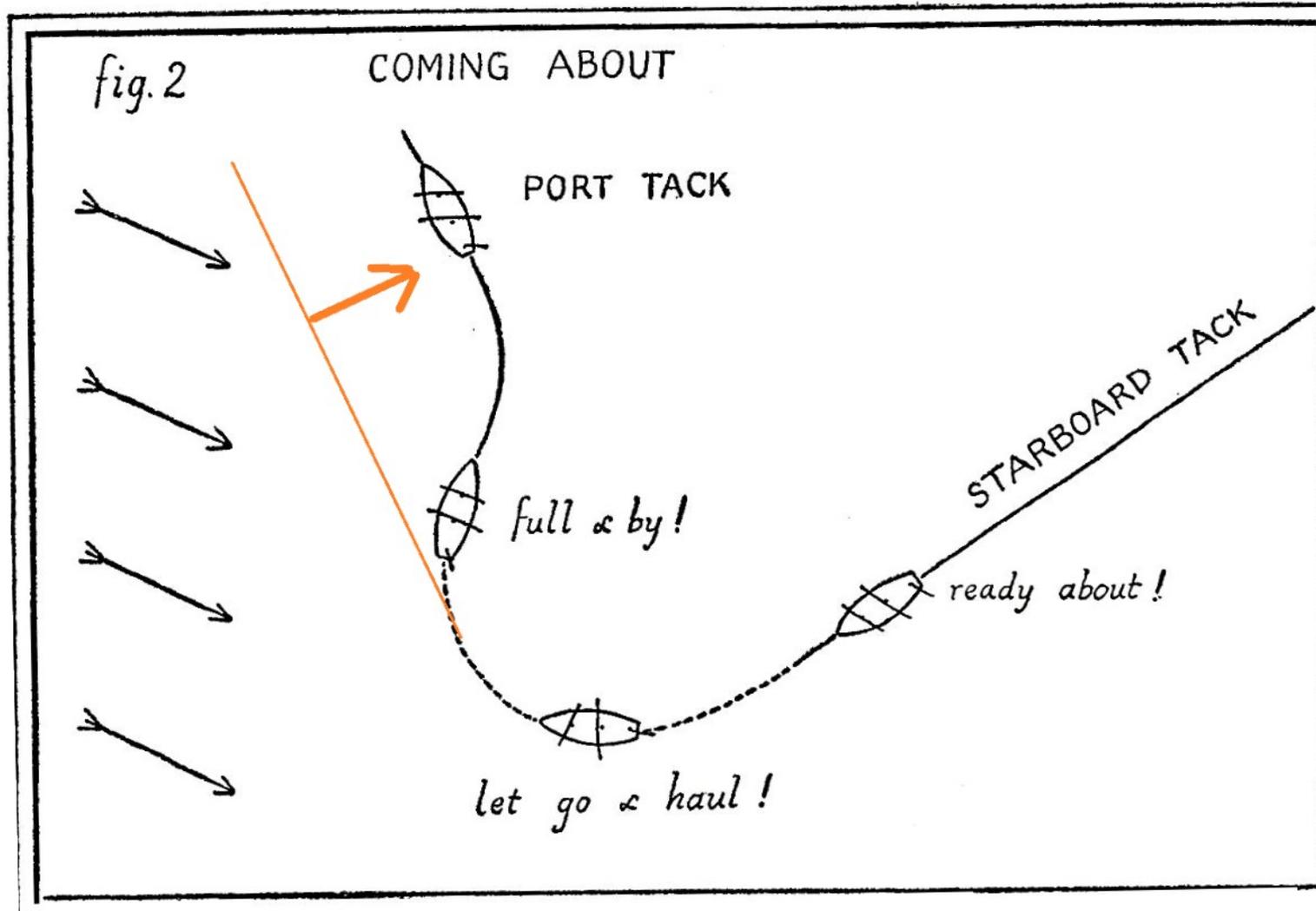
Finally, Why Does the Air On the Longer Side Go So Fast

- This article on Wikipedia gives an extensive discussion of every aspect of lift:
 - [https://en.wikipedia.org/wiki/Lift_\(force\)](https://en.wikipedia.org/wiki/Lift_(force))
- It seems to me that NASA left out why the air on the longer side goes much faster than the air on the shorter side. The Wiki answer is that the deflected air at the leading edge creates a vacuum that pulls the air in.
- There is also the Coanda effect.

Sailing Into the Wind – the Hull/Keel

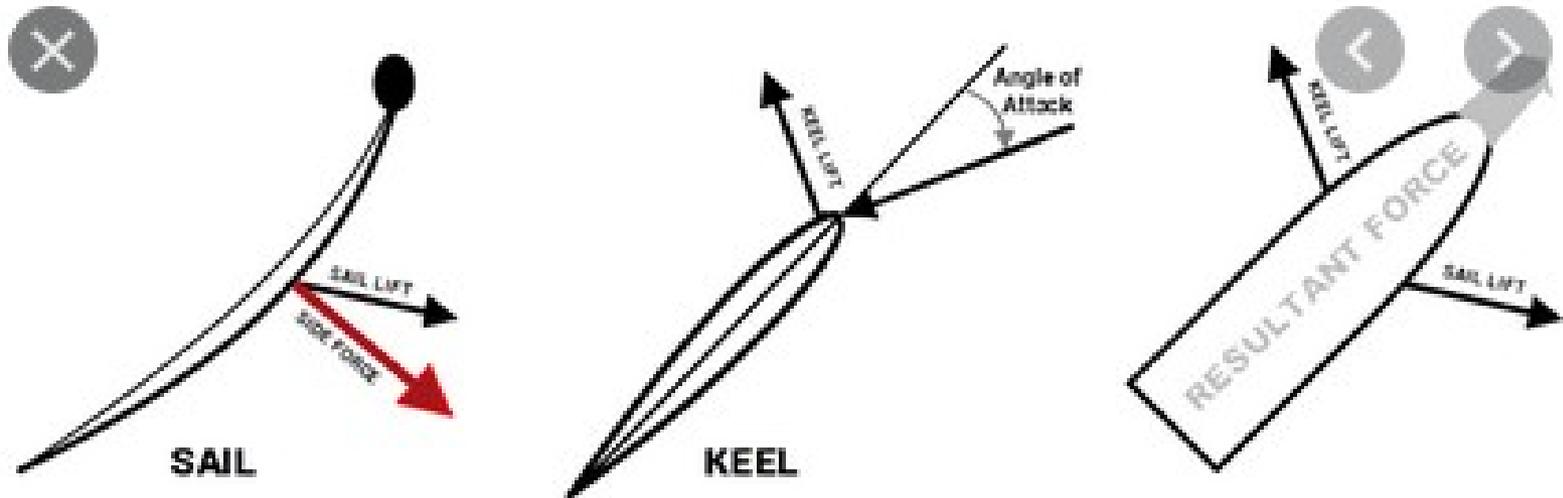
- The final question is why doesn't a sailboat sailing close hauled go sideways downwind? Again LIFT is the answer.
 - Keep in mind that air is a compressible medium and water is not. Separate versions of Euler's formula apply to each.
- The next slide demonstrates that there is indeed lift. Then we look at why is so? We will see that it is due to the "angle of attack" which turns the symmetrical keel into an asymmetric foil.

How To Prevent Sailing Sideways When Coming About



Sailing Into the Wind – the Hull/Keel

- A keel is a symmetric foil, rather than an asymmetric foil. Lift is produced because the keel has a certain angle of attack relative to the flow of the water. As the boat moves forward, it is also moving a bit downwind. This creates an asymmetric flow, and thus the lift.



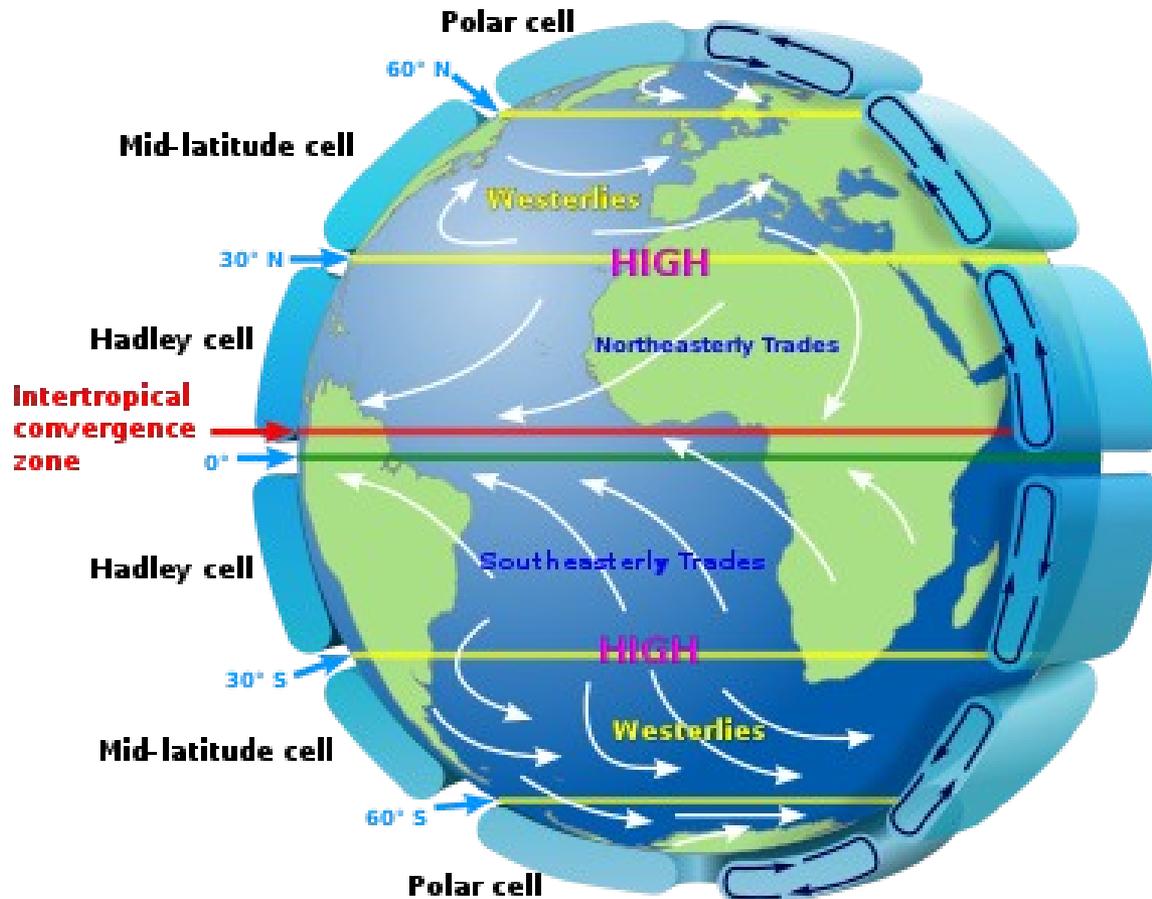
First Voyage to the New World

- The three ships leave from Palos, Spain on 2 August 1492 for their 10 week voyage.
- The first leg of the voyage is SSW to the Canary Islands. This lines him up with the insight that enabled success – sailing far enough south to pick up the Trade Winds (or easterlies)
- In the Canaries, Columbus took 10 days to refit the Nina with square rigging, and restock provisions.
- On 6 September, the 3 ships leave San Sebastián de La Gomera, C. I. for the Far East.

The Science Behind the Trade Winds

- The three ships depart the Canaries and pick up the Trade Winds, which hold for almost the entire voyage, thus proving Columbus correct and the Portuguese/Spanish committees incorrect.
- Exactly why do the Trades blow east, and the Westerlies blow west? The basic answer is uneven heat from the sun and Coriolis Force.

Trade Winds and the Hadley Cell



A More Detailed Explanation of the Trade Winds

- As part of the Hadley cell, surface air flows toward the equator while the flow aloft is towards the poles.
- The **Hadley cell**, named after George Hadley, is a global scale tropical atmospheric circulation that features air rising near the Equator due to heating by the sun, flowing poleward, then descending in the subtropics, and then returning equatorward near the surface.
- The surface air that flows from these subtropical high-pressure belts toward the Equator is deflected toward the west in both hemispheres by the Coriolis effect.
- Westerlies originate from the high-pressure areas in the horse latitudes and trend towards the poles and steer extratropical cyclones in this general manner.

The North Atlantic Gyre (or Currents)

- There is a clockwise circular flow to the currents in the North Atlantic as well.
- Columbus probably had the current in his favor 100% of the time, although they would have been weak.
- The gyre is usually considered to begin with the Gulf Stream which is very impressive indeed.
- Note that currents make estimating your speed difficult unless the current is very weak. Luckily for Columbus they were.

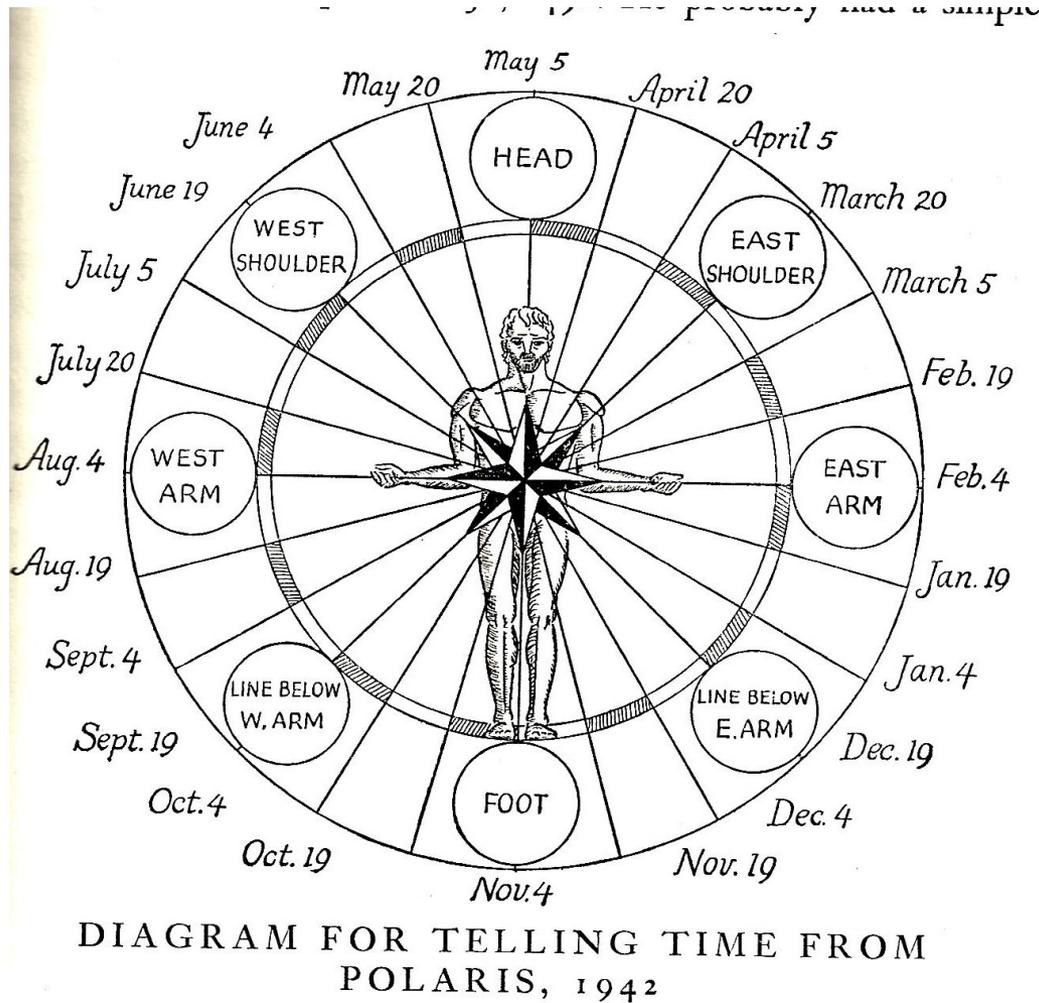


North Atlantic Gyre

Overview of Navigation in 1492

- Columbus used dead reckoning with a compass and an hourglass (1/2 hour).
- Basically Columbus guesstimated the boat speed accurately.
- Columbus did use celestial navigation by simply looking at the North Star which should be on his right. One can also determine the time within 15 minutes using the North Star (at night).
- He also tried using a quadrant, a precursor to the sextant, but determined that he was in Cape Cod (obviously he didn't know this). No sea captain of this era was proficient with the quadrant.
- He also tried to use eclipse to determine his longitude (details below), but failed dismally. My guess is that he failed intentionally – he was easily smart enough to get it right.
- Wind, current, waves, water depth

Columbus Knew This Trick to Determine the Time Using Polaris



Pictures of Common Navigation Devices



Quadrant



Astrolabe

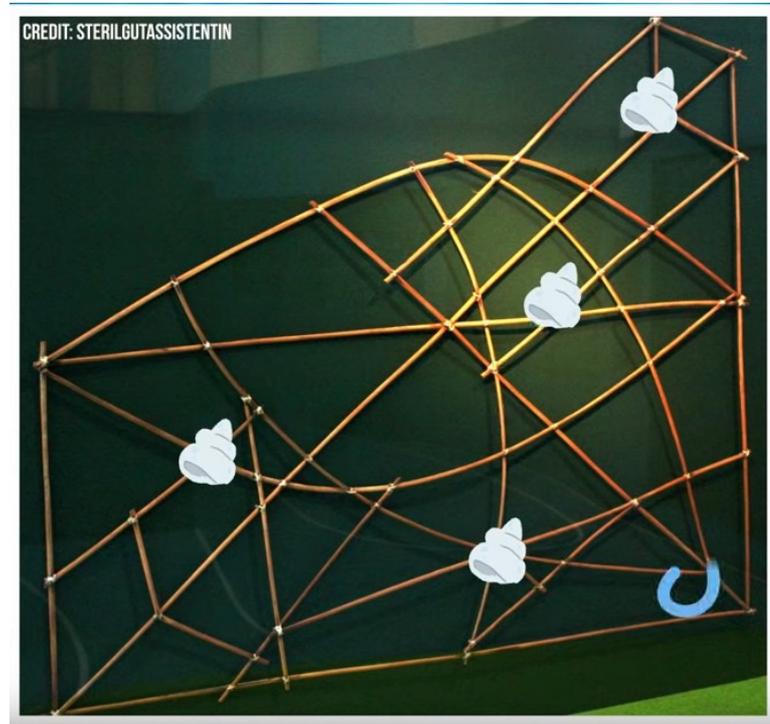
Note that you don't need the horizon to use these devices.

Longitude During a Lunar Eclipse

- The only practical method for determining longitude precisely in the fifteenth century was a well-known method of timing lunar eclipses. The eclipse timing method is simple: first, you determine the local time that the lunar eclipse starts or ends by direct observation. Then you compare your local time for that event against the local time at some distant place. The difference in the two times is the difference in longitude.
- Observers can tell the moment a lunar eclipse starts or ends to within a few minutes. That means that the biggest source of error would have been finding the correct local time. But this is also easy (he was on land): in the tropics, the sun rises at nearly 6:00 a.m. and sets nearly 6:00 p.m. every day.
- Using these clues and a sandglass, Columbus should have been able to determine the correct local time of an eclipse to within ten minutes. However Columbus's eclipse timing longitudes are off by much greater amounts than this..
- My guess is that the error was intentional. Hard to believe he could screw up this badly, and if he got it right he would know he wasn't anywhere near Japan, China, or India.

Other Navigation Device I

- Stick chart. Used in Pacific among islands to show islands, currents.



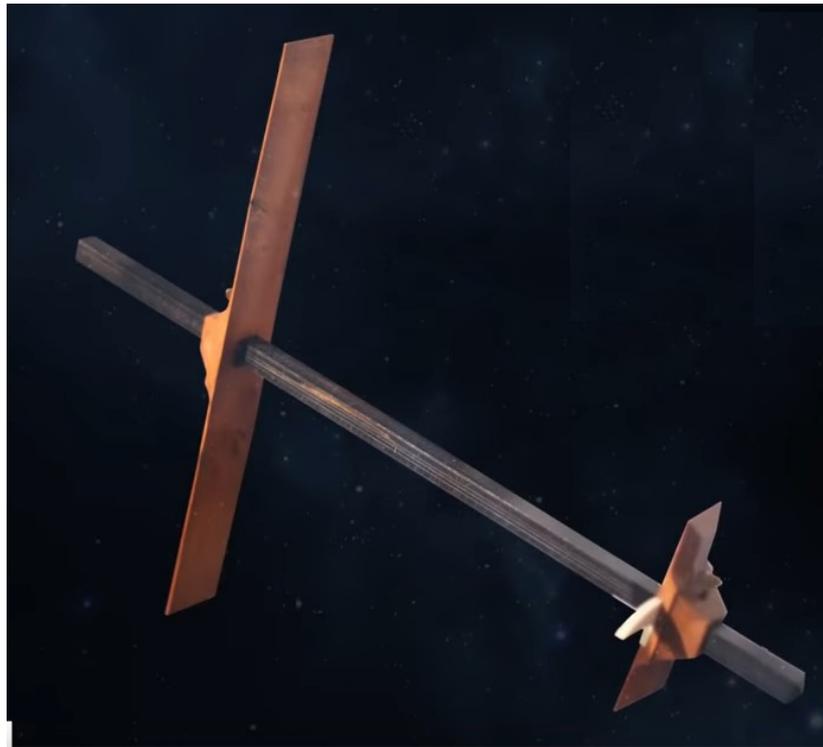
Navigation Device II

- Kamal, used to determine latitude. Put board at arms length, i.e., arms are bent, such that bottom touches horizon and top touches Polaris.



Other Navigation Devices III

- Cross-staff. Similar to Kamal with sliding cross bar. Easier to use on a tossing ship.

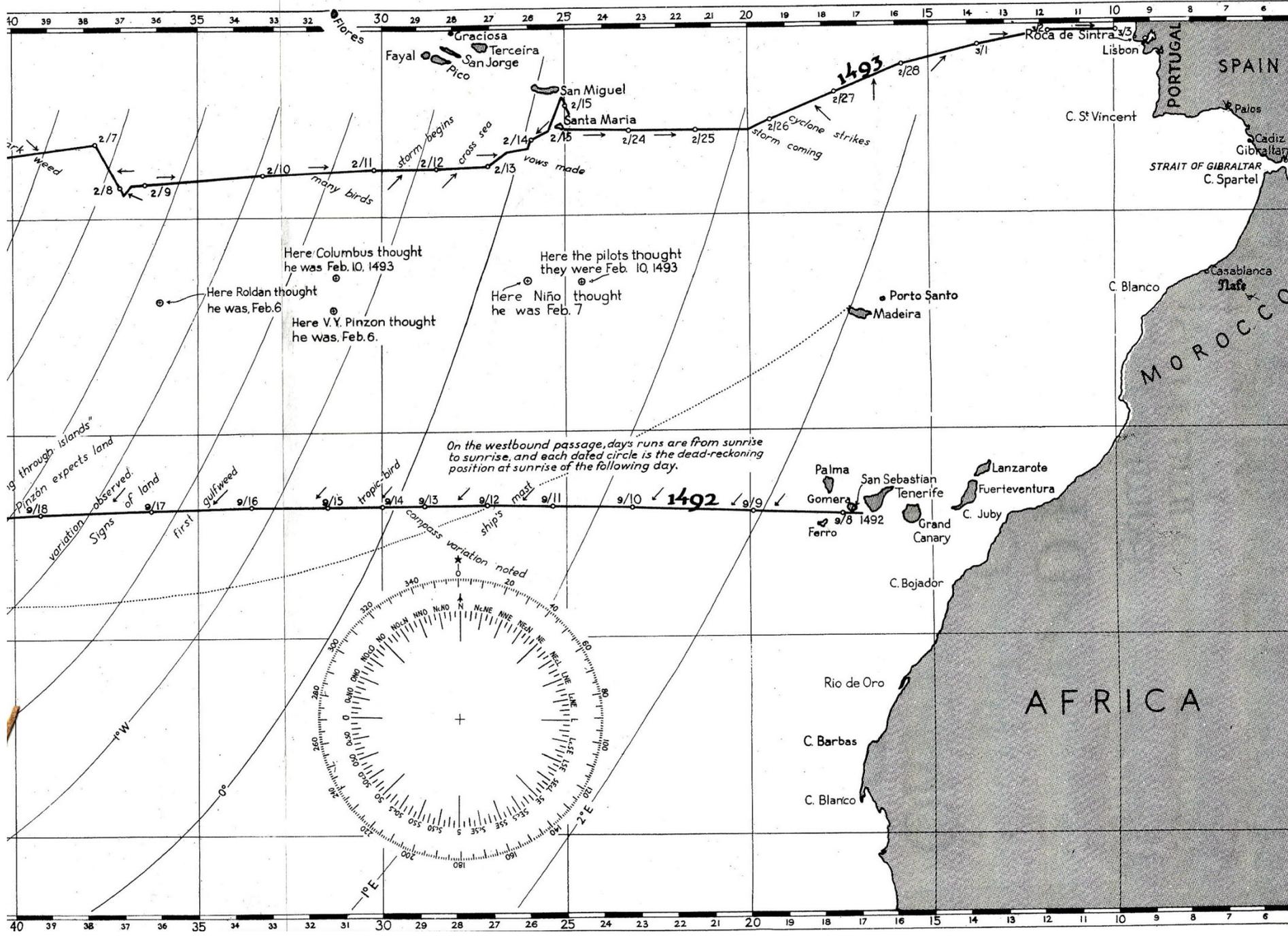


Digression: A Modern Technique to Determine Longitude Without a Clock

- In fact, there is a way to determine the time and longitude precisely without any aids other than a sextant. It is called “**Longitude by the Method of Lunar Distance**”.
- Basically, you determine the angular distance between the moon and the sun and then do a sequence of complex calculations.
- Joshua Slocum, the first person to solo circumnavigate the world, claimed he did it with no time piece. A number of years later he admitted he knew the Lunar method.

First Voyage to the New World (cont.)

- Voyage I proceeds in uneventful fashion.
- Columbus didn't know it, but he was far enough north that he should have found the horse latitudes descending on him, but once again it he was fortunate.
- He continued to navigate west using dead reckoning.
- We now look at a chart recreated from his log.

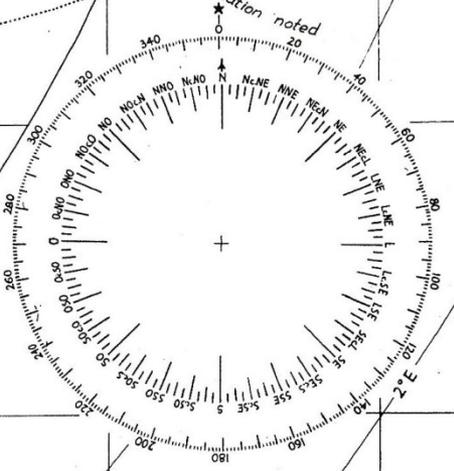


40 39 38 37 36 35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6

40 39 38 37 36 35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6

2/7
2/8
2/9
2/10
2/11
2/12
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2/14
2/15
2/24
2/25
2/26
2/27
2/28
3/1

9/18
9/17
9/16
9/15
9/14
9/13
9/12
9/11
9/10
9/9
9/8 1492



Here Columbus thought he was Feb. 10, 1493
Here the pilots thought they were Feb. 10, 1493
Here Rolan thought he was, Feb. 6
Here V.Y. Pinzon thought he was, Feb. 6
Here Niño thought he was Feb. 7

On the westbound passage, days runs are from sunrise to sunrise, and each dated circle is the dead-reckoning position at sunrise of the following day.

Pinzon expects land
variation observed
Signs of land

weed

storm begins
cross sea
vows made

cyclone strikes
storm coming

through islands
first
gulfweed

tropic bird
compass variation noted
ships

Palma
Gomera
Ferro
San Sebastian
Tenerife
Grand Canary
Lanzarote
Fuerteventura
C. Juby

C. Bojador
Rio de Oro
C. Barbas
C. Blanco

Porto Santo
Madeira

C. St. Vincent

STRAIT OF GIBRALTAR
C. Spartel

C. Blanco

Casablanca
Marrakech

PAIDOS
Cadiz
Gibraltar

Roca de Sintra
Lisbon

PORTUGAL
SPAIN

MOROCCO

AFRICA

Height Above Sea Level in feet	Distance to horizon in nautical miles	Height Above Sea Level in feet	Distance to horizon in nautical miles
40	7.2	150	14.0
50	8.1	160	14.5
60	8.9	170	14.9
70	9.6	180	15.3
80	10.2	190	15.8
90	10.9	200	16.2
100	11.4	300	19.8
110	12.0	500	25.6
120	12.5	1000	36.2
130	13.0	1500	44.3
140	13.5	2000	51.2

1.17 X the square root of height of eye = distance to the horizon in nautical miles.

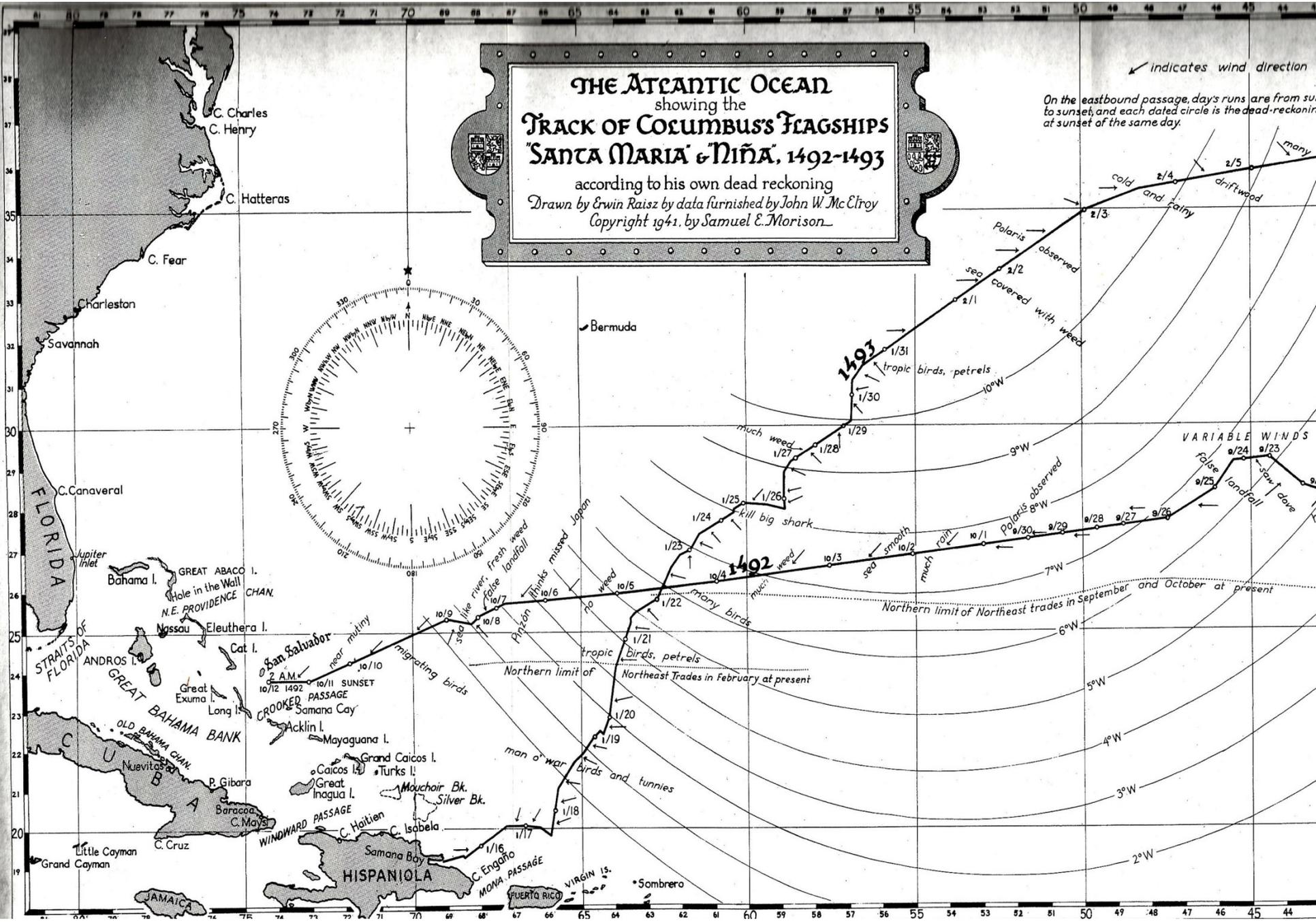
THE ATLANTIC OCEAN

showing the
TRACK OF COLUMBUS'S FLAGSHIPS
"SANTA MARIA" & "NIÑA", 1492-1493

according to his own dead reckoning
 Drawn by Erwin Raisz by data furnished by John W. Mc Elroy
 Copyright 1941, by Samuel E. Morison

↙ indicates wind direction

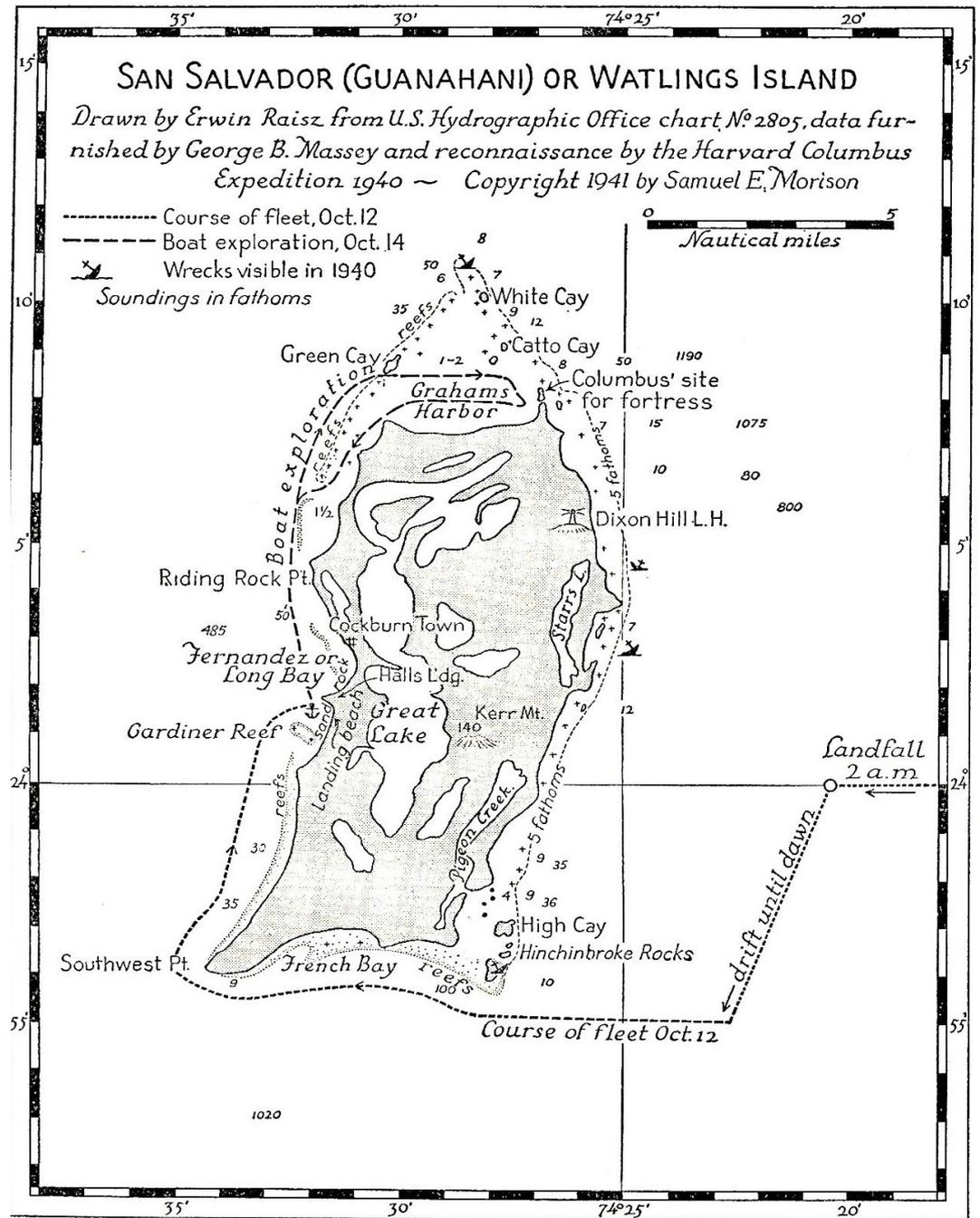
On the eastbound passage, day's runs are from sun to sunset, and each dated circle is the dead-reckoning at sunset of the same day.



Voyage I (*cont.*)

- On 9/22-9/23 you saw the jog to the NW but Columbus was presumably following the compass due west. Columbus duly observed that the North Star is now closer to being directly ahead instead of on the starboard beam as it should be.
- He correctly identifies the issue as magnet declination, a new discovery, and heads west once again.
- The voyage thence proceeds uneventfully for a couple of weeks.
- However, there were a few near mutinies. The day after the last and most serious one on Oct 11 when he promised to turn back within 2-3 days, they spot grass, other debris, and land birds.
- All ideas of mutiny evaporate, and they proceeded to follow the grass/birds to the Bahamas the next day – Oct 12, 1492. They land on Watlings Island.

Landfall in the Bahamas on Watlings Is



On to Cuba, Hispaniola

- Columbus quickly realizes there is no gold on Watlings Is. The natives suggest Cuba/Hispaniola.
- Columbus proceeds to explore other Caribbean Islands – notably east end of Cuba and Hispaniola (D.R. and Haiti today). He is primarily looking for gold, but is also encountering the indigenous population who he labels “Indians” (Indios in Spanish). He finds no pot of gold.
- On Hispaniola, the Santa Maria runs aground on 25 December 1492. Columbus was apparently asleep. This forces him to leave 39 men behind in a settlement named La Navidad, but he obtains permission to do so.
- He establishes good relations with the indigenous people (Lucayan, Taíno, and Arawak), who are naked, friendly, and weaponless. Remember, he ultimately wants to convert them to Christianity at this point.

Remember this Slide?

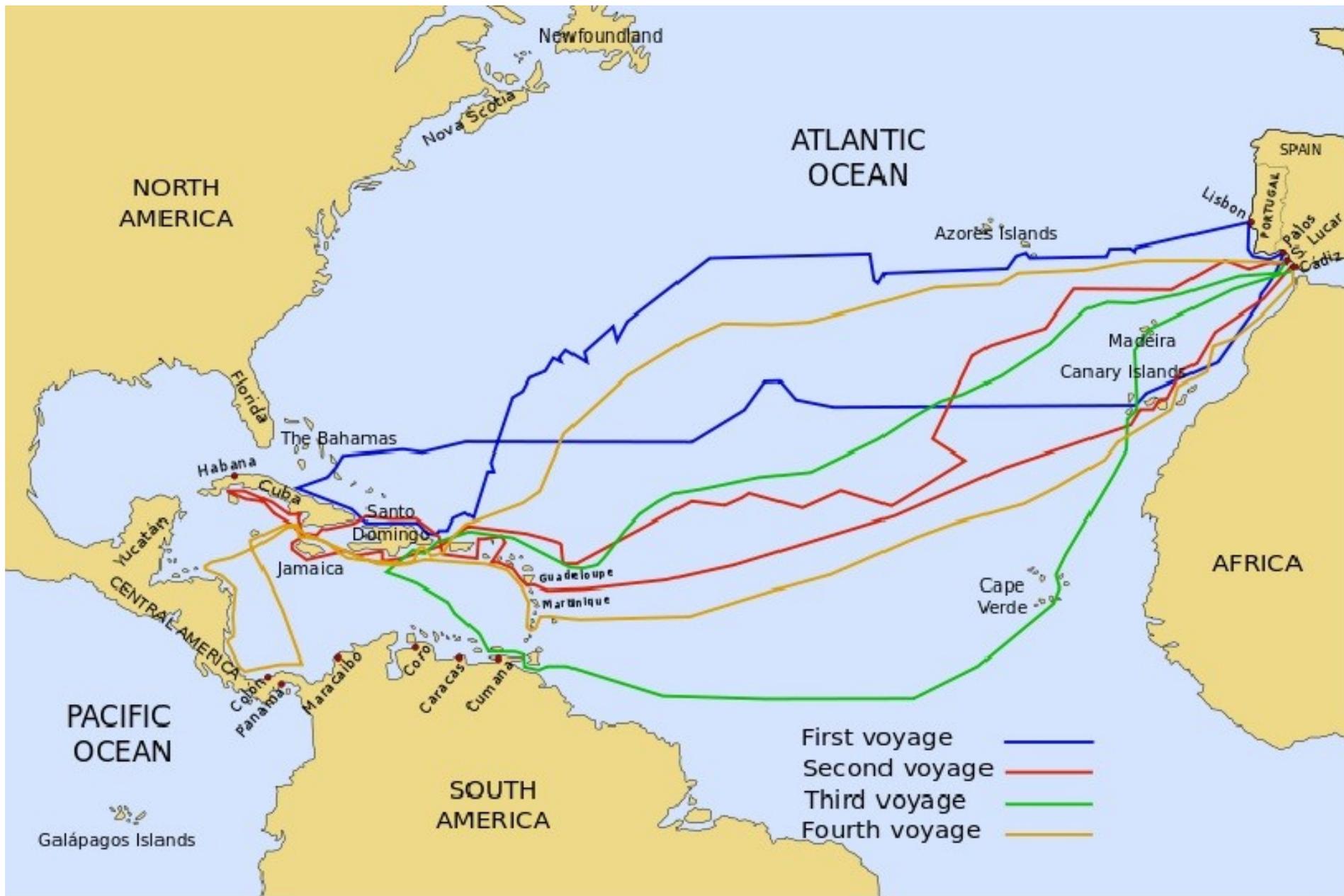


Departure from Hispaniola

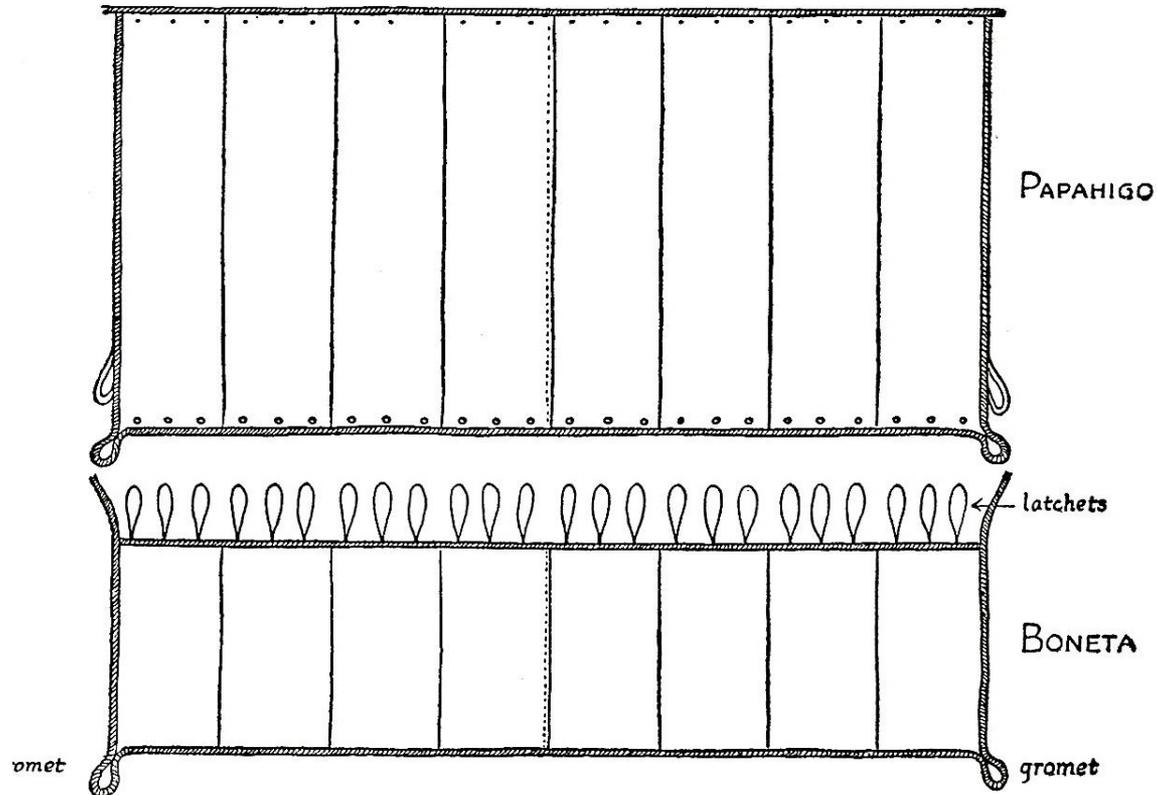
- On 13 January 1493, Columbus made his last stop of his first voyage in the New World, in the Bay of Rincón at the eastern end of the Samaná Peninsula in northeast Hispaniola.
- There he encountered the warlike Cigüayos, the only natives who offered violent resistance during his first voyage to the Americas. They shot at the boats using bow and arrow. Do not make light of bows and arrows.
- Columbus captured about 25 natives and took them back with him (only seven or eight of the natives arrived in Spain alive).

Return Voyage

- After his run in with the warlike Cigüayos, Columbus decides to head for Spain in mid January 1493. He is now captain of the Nina. The Pinta has rejoined by the Nina at this point.
- Sailing close haul at first on a NW course the ships get far enough north to catch the westerlies and turn east. Either Columbus continues to have superb sailing instincts about the Trade Winds and the Westerlies, or he is lucky. From the tracks of his other three voyages, it's not clear.
- A minor hurricane separates him from the Pinta, and forces the Niña to stop on the way back at the island of Santa Maria in the Azores to pray, catch their breath, and be imprisoned. A minor sailing miracle.
- Science tidbit: This reminds me that Columbus had to deal with The Center of effort vs center of mass on a continuous basis. One way to manage center of effort is reefing. The next screen shows is how it was done, although he probably went to bare poles during the storm.



Reefing or Controlling the Center of Effort



COURSE AND BONNET

From García Palacio, Instrucción Náutica (1587)

Reception in Europe Upon Return

- He returns to Spain the conquering hero. Lands in Lisbon, not by plan but there was another storm. After meeting with King John II, an enemy orders him killed, but as usual someone in a high place, this time the King, saves him.
- Thence, he returns to Palos, and is feted like royalty (which he actually is). His report claims he reached outer islands of the Far East and vast wealth awaits.
- News of his accomplishment spreads thru Europe like wildfire.
- Columbus quickly plans second voyage to claim the riches he believes are there, and colonize with people who think they are going to get rich quick. He also brings live-stock.
- Note that his reception went downhill from there on subsequent voyages. On the third voyage he returned in chains.

Second Voyage to the NW

- Columbus left Cadiz on 24 September 1493 with more ships (17) and colonists in the form of priests, farmers, soldiers (in addition to the crew members).
- Brought many plants - barley, wheat, leeks, beets, onions, radish, cucumber, broad beans, citrus fruits, olives, melon, parsley and vine cuttings - and animals - horses, cattle, sheep, goats, pigs, and others. Thusly, began the Columbian Exchange.
- Spaniards also brought disease, e.g., small pox, that would ultimately cause a pandemic that would kill many millions of people.

Return From Second Voyage

- He brought back maize, sugar, tobacco, chocolate, potatoes. Science: Long term genetic engineering had gone into these plants, particularly maize..
- Also, the New World returned the disease favor by gifting Europe a much more virulent strain of syphilis than those already found in Europe.
- Many of the colonists wanted to make a quick about face when they realized they were not going to get rich quick. His exaggerations quickly begin to catch up with him.

**WIDESPREAD TRANSFER OF ANIMALS,
PLANTS, CULTURE, HUMANS,
TECHNOLOGY, DISEASES, IDEAS
BETWEEN OLD AND NEW WORLD IN THE
15TH & 16TH CENTURIES**



Fourth Voyage – Weather Acumen

- Columbus was persona-non-grata in the NW at this point due to his disciplinary excesses. He was not allowed into any major ports in the New World.
- Shortly after his arrival in the Caribbean he realizes that a hurricane is about to hit. One would guess that his personal weather acumen was pretty finely tuned. He finds safe harbor near the capital of Hispaniola.
- He knows 25 ships are about to leave for Spain from the capital, and sends warning of the hurricane by messenger.
- They powers that be mock the idea of a hurricane, and the fleet leaves for Spain at the appointed day and hour.
- One day out the hurricane hits as Columbus predicted. 500 people die in short order. Probably should have listened to Columbus.
- One ship makes it to Spain.
- As you might guess it is the ship with Columbus's gold. In some quarters, he is accused of causing the hurricane.

Smallpox Pandemic in Mesoamerica and Peru

- It is well established that smallpox brought by the Spanish invading army killed many millions of the Indians of Central & South America. This was a major factor in the Spanish defeat of the the Indians. Horses, guns, and allies helped, but the Spanish were almost defeated until Smallpox broke out.
- It appears that over 90% of the Indians died of smallpox. This is unheard of in epidemics in Europe, e.g., the black/bubonic plague, which was the worst ever, killed one third of the European population.
- Why did such a high percentage of Indians die?

Smallpox Pandemic in Mesoamerica and Peru

(cont.)

- Why did such a high percentage of Indians die?
 - One theory is that there is not as much genetic diversity in the Indian population as in Europeans since all Indians are descended from a few thousand Asians who crossed over Bering Land Bridge around 12,000 years ago.
 - For example almost all South American Indians have type O, while in Europeans it is split evenly between O and A. And South American Indians are almost free of a number of genetic disorders.
 - To go to a depth I don't understand, the problem lies in human leukocyte antigens (HLAs). These are molecules inside most human cells that are key to one of the body's main means of defense. In the 1990's Black reviewed thirty-six studies of HLA, and he discovered that overall Indians have fewer HLA types compared to populations from Europe, Asia, and Africa.

Smallpox Pandemic in Mesoamerica and Peru (*cont.*)

- Another explanation for the high percentage
 - In 2004 it was proposed that Native American susceptibility to infectious disease might have a second cause: helper-T cells, which like HLAs help the immune system recognize foreign objects.
 - To simplify considerably, helper-T cells occur in two main types, one that targets microorganisms and one that targets parasites. The body cannot sustain large numbers of both. Hence adult immune systems tend to be skewed toward one or the other.
 - Indians have historically been burdened by flukes, tapeworms, and nematodes, so they long had majorities of **parasite-fighting** helper-T cells. Europeans, who grew up in a germ-filled environment, usually lean the other way. As a result adult Indians are more vulnerable to infectious diseases than adult Europeans.

An Aside, How Did Colonists Defeat the Superior Indians in New England?

- American history (at least as I was taught) claimed that the colonists of 1616 were superior to the Indians in most respects, i.e., weaponry, tactics, housing, clothing, etc.. In fact the Indians were more advanced in all areas, particularly weaponry. The bow and arrow was superior to the rifles of this period in distance and accuracy.
- A recently developed theory is that almost all Indians near the coast in 1616-1618 died due to an outbreak of viral hepatitis.

Charges of Tyranny, Brutality, and Genocide Against Columbus.

- Columbus's modern reputation has taken a big hit in recent years. To me, some of it smacks of political correctness.
- As governor he certainly did some horrific acts.
 - Capturing Indians to be sold into slavery to pay back his supporters. Spanish law prohibits this unless the person is a prisoner of war.
 - Severe punishment – hand, tongue removal – for minor crimes.
 - Forced labor of Indians. Many were thrown into indentured servitude with a quota of gold to be handed in each week. Gold was not abundant so the work was hard.
- Basically, he was an incompetent/disinterested administrator and governor. He would much prefer to go exploring.

Charges of Tyranny, Brutality, and Genocide (*cont.*)

- Defense:
 - Compared to the punishment handed out by Spain, France, and England he was close to the norm. Routinely, mass executions of 100 would be staged as entertainment and be attended by 10,000 to 12,000 exuberant fans – many woman and children.
 - Slavery was commonplace. He was not a crusader. Also some of the slaves were prisoners of war, and some were trying to eat him.
 - There would seem to be little defense for the level of forced labor, particularly given the lack of gold.
 - It doesn't appear he committed genocide to me other than with disease, and this is not usually considered genocide.

Summary of Columbus's Place in History

- Between 1492 and 1503, Columbus completed four round-trip voyages between Spain and the Americas, each voyage being sponsored by the Crown of Castile. On his first voyage, he proved this belief that the Trade Winds blew consistently eastward, (re)discovered the Americas and discovered magnetic declination. These voyages marked the beginning of the European exploration and colonization of the American continents.
- Columbus always insisted, in the face of mounting evidence to the contrary, that the lands that he visited during those voyages were part of the Asian continent, as previously described by Marco Polo and other European travelers. Thus, America became America when Amerigo Vespucci suggested as much.

Who Discovered America?

- In my opinion, the controversy over who discovered America is pointless. It's obvious (to me) that the Indians discovered America, and Columbus simply opened the Americas to Europe colonization at a time when Europe was very ready for a change.

The End

Sailing Trivia

- What is the fastest point of sail? *Easy*
- Can a sailboat go faster than the wind? *Harder*
- What is the fastest a boat has ever sailed? *Trick question*

Sailing Trivia

- What is the fastest point of sail? **Beam Reach**
- Can a sailboat go faster than the wind?
- What is the fastest a boat has ever sailed? *Trick question*

Sailing Trivia

- What is the fastest point of sail? **Beam Reach**
- Can a sailboat go faster than the wind? **Yes, a non-displacement hull on a beam reach.**
- What is the fastest a boat has ever sailed? *Trick question*

|



Sailing Trivia

- What is the fastest point of sail? **Beam Reach**
- Can a sailboat go faster than the wind? **Yes, a non-displacement boat on a beam reach.**
- What is the fastest a boat has ever sailed? (trick question)
 - **Modern designs of iceboats are very efficient, utilizing aerodynamic designs and low friction, and can achieve speeds as high as ten times the wind speed in good conditions**
 - **The rumored, but unconfirmed, top speed of an iceboat is over 130 knots (240 km/h; 150 mph)**

Main Sources

- **Admiral of the Ocean Sea, A Life of Christopher Columbus** by Samuel Eliot Morison (2 volume edition)
- **1491** by Charles C Mann
- Several other books from the Lexington Library, but the library is closed so I can't find out their names/authors.
- Numerous wiki pages