VI-11 - STUDY OF THE STRESSES IN THE MAST

We approach here the true nut of the problem which will lead us to apply the theory which has just been developed, namely that we will use the aerodynamic load developed by each sail to analyse its action on the rigging. I had formerly used this method for calculation of the mast and rigging of origin of *Pen Duick III* whose very particular geometry of the sails, with its foresail with wishbone, did not make it possible to use the usual methods of calculation. Exposed here is the development that shows its limits. It implies of course the estimate of certain data, or of simplifications, that can be easily adjusted by simple observation.

Let us recall that the case studied is that of the close-hauled condition where the loads are greatest. A priori it appears simple to calculate the value of these forces by the usual aerodynamic formulas, unfortunately the coefficients of bearing pressure and real drag are too poorly known to offer sufficient precision. However studies based on the theories of aerodynamics are currently undertaken in this direction and are already applied to the layout of the sails.

One will be able however to use this method when one wants to calculate the loads due to the lighter sails. In this case one will be able to take for the side force:
$\mathbf{F_y = 0{,}0625 \times V^2 \times S \times C}$ where:
V = speed of the wind in m/s;
S = surface area of the sail in m^2;
C = variable coefficient of bearing pressure according to the shape and hollow's of the sail but which we will consider equal to 1,2.
On the other hand we can determine rather well the share of the total force developed by the yacht of the jib, the mainsail, and also the resistance of the rigging and the hull.
In addition we also know rather well the value of the lateral component of the total force since its moment compared to the centre of the immersed canoe body is at any moment equal to the righting moment.

Thus, from the righting moment practically all calculations of rigging are carried out.
The process will thus consist, from the most significant [maximum] righting moment, which produces maximum loads in the rigging, to determine the lever arm of the moment of capsizing and to calculate the corresponding total lateral force.
The second stage will lead us to define the share from each element of the rigging and to deduce from them the forces that they exert to their points of connection with the mast and the hull.

VI-II - 1. - CHOICE OF THE RIGHTING MOMENT

All the methods of calculation of the rigging start from this data, but all do not agree on the value to be taken into account. Some, such as Sparkman & Stephens, take a value equal to 1,5 times the righting moment at 30°, others the moment with 45°, others finally 45 times the moment at 1°. In fact, if one has the stability curve it will always be preferable to record on this the maximum value; table VI-II indeed shows the disparities that can occur with the approximate formulas.
Yacht I is a traditional beam cruiser with moderate freeboards and ratio of ballast of 45 %;
yacht II is a modern half-tonner with beam and high freeboards and low ratio of ballast.

TABLEAU VI-II
COMPARISON OF RIGHTING MOMENT IN m-daN,
ESTIMATED ACCORDING TO DIFFERENT METHODS

	1,5 x Mr_{30}	Mr_{45}	45 x Mr_1	Mr maximum
Yacht I	2908	2495	3403	3214
Yacht II	2143	1793	2511	1852

From knowing the maximum righting moment exactly it seems that the righting moment at 30° gives the closest result to reality. For a first approximation for yachts up to approximately 12 m of floating length and 15 tons of displacement when fully loaded one will be able to estimate it at:
$Mr = (b^4 \times P_l)/(0{,}01 \times \Delta)$ where:
b = average of the maximum beams at the floating line;
P_l = weight of the ballast; with
Δ = displacement.
In all the cases the righting moments will be established for a mid-displacement.

VI-II - 2. - EVALUATION OF THE LATERAL FORCE

One starts with the height, H, between the centre of area of the sails and the immersed canoe body. Sparkman & Stephens estimate the centre of the hull at 40 % of the draft under the floating line. It seems that this value, higher than that corresponding to the centre of area from the plan of the hull, at least for the modern aileron yachts, is close to reality if one takes account of the difference in output of the various elements.
In addition, the influence of the hull on the output of the sails, the less favourable orientation of their lower part and the gradient of the wind lift the centre of pressure on the sail generally higher than the geometrical centre. On the other hand the presence of the hull reduces it and one can estimate that one compensates for the other.
One will thus take for the lever arm of the moment of capsizing to be the height of the centre of area of the sails above the floating line plus 40 % of the draft.
There will be thus $F_{y\,tot} = Mr / h$
One will be able to deduce the driving power from F_x knowing that the ratio: $F_{y\,tot} / F_x$ is approximately 4.

VI-II - 3. - DISTRIBUTION OF THE EFFORTS BETWEEN THE SAILS

It will initially be necessary to determine for which configuration of sails we want to carry out the study. For a sloop it will generally be with the maximum heavy genoa and the entire mainsail. They are conditions corresponding in general to navigation in a force 3 wind [7 to 10 knots] and relatively flat sea but where one is likely more to be laid down by a gust while carrying any top. In stronger weather, the state of the sea will generally result in the yacht being held down on its side more easily.
Of course, all other configurations can be adopted to study particular cases. A typical example is that of the sloop lying under spinnaker after a yaw. The F_y force then will be almost completely developed by the spinnaker.
As the sail's centre of pressure is about at middle height of the front triangle, the load exerted at the head of the mast by the halyard will reach $F_y / 2$.
Another interesting configuration can be that of the ketch sailing under jib and mizzen, without mainsail.

For these defined conditions, it is necessary to determine now the proportion, of the calculated force, between the hull unit + rigging and each sail.
According to the resistance of the hull and rigging share of F_y assumed to be 7,5 to 10% and 90 to 92,5 % for the sails.
The share returning to the rigging only (without the hull) is approximately 4 %.
In the longitudinal direction, resistance acts negatively, it accounts for 3,5 to 4 % of F_y including 3 % for rigging. The force F_x developed by the sails alone is thus equal to approximately 30 % of F_y.
By convention we will give to F_x and F_y negative values when the forces are directed backward or leeward.
The distribution of the effort between the sails depends on the output of these. In the lateral direction, the mainsail made little more than the jib; one will thus apply a coefficient of 1,05 to the mainsail against 0,95 for the jib. A mizzen will have a coefficient of 1,1, when it is used with the mainsail, 1,05 without it.
In the longitudinal direction it is the opposite; a jib will have a coefficient of 1,2 against 0,8 for the mainsail and 0,5 for a mizzen.
All these values are not arbitrary but rest on wind tunnel tests, in particular those carried out at the university of Southampton [1].

At this stage we will recapitulate to an example.

That is to say, a sailing ship whose characteristics are shown in (fig. VI-13):
Righting Moment at 30° = 3360 m-daN
Main Sail Surface = 20 m^2
Genoa Surface = 42 m^2
Height CV (*centre of sail area*) on floating = 5,85 m
Draft from waterline = 1,90 m

One will deduce:
Maximum Righting Moment: 1,5 x 3360 = 5040 m-daN
Arm of capsizing lever: 5,85 + (0,4 x 1,9) = 6,61 m

Laterally:

Total F_y:	5040 / 6,61 = -762, 5 daN of which
F_y sails:	-762,5 x 0,9 = - 686,25 daN

Surface area of sails for calculation:

Mainsail:	20 x 1,05 = 21 m^2
Genoa:	42 x 0,95 = 39,9 m^2
Total sail area:	60,9 m2
F_y Main sail:	686,25 x 21 / 60,9 = - 236,64 daN
F_y genoa:	686,25 x 39,9 / 60,9 = - 449,61 daN
F_y rigging:	762,5 x 0,04 = - 30,5 daN

Longitudinally *:

F_x aerofoil:	762,5 x 0,3 = 228,75 daN

Sail surface areas for calculation

Mainsail:	20 x 0,8 = 16 m^2
Genoa:	42 x 1,2 = 50,4 m^2
Total:	66,4 m^2
F_x Main sail;	228,75 x 16/66,4 = 55,12 daN
F_x genoa:	228,75 x 50,4/66,4 = 173,63 daN
F_x rigging:	762,5 x 0,03 = 22,88 daN

* These forces are not used in this part of the calculation but are interesting to be known for other uses.

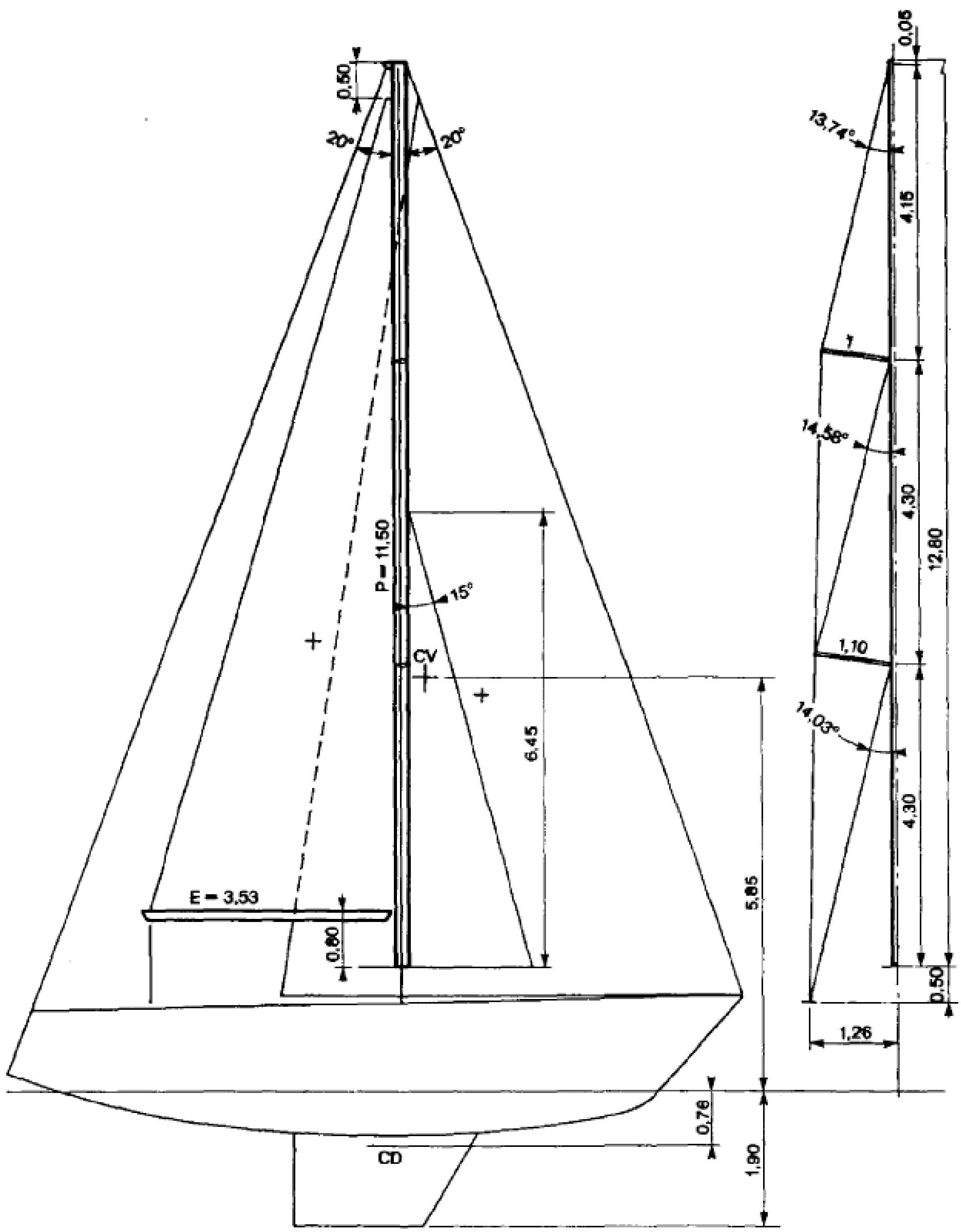

Fig. VI-13. Plan du gréement de l'exemple développé.

VI-II - 4. - EFFORTS OF THE SAILS ON THE MAST

Now that we know the efforts developed by each sail we can determine how these will be distributed on the rigging in the transverse and longitudinal directions.

VI-II - 4.1. Mainsail

Being unable to know exactly the distribution of the efforts in the sail, such as it was explained at the beginning of this chapter, we will adopt the following simplification.
We will consider the mainsail (fig. VI-14) as a juxtaposition of bands parallel with the leach and we will suppose that the whole surface is subjected to a uniform pressure.
The curve which the sail under the effect of this pressure will take will be constant and the whole of the sail will constitute a conical surface whose top will be the point of tack.
We know little about the curvature of this surface and we will consider initially that it is an arc of a circle. On the other hand it is relatively easy to observe the angle β_g, which forms the luff and the leach, it depends on the cut and the adjustment of the sail and generally lies between 30° and 40° in the plane of the boom and the mast. It is this plane which we will take for reference for the moment. Because of its flexibility, the fabric is aligned obligatorily with the force of the load that it transmits. The direction of this is thus given by the tangent to the sail to the point where it meets the spar.

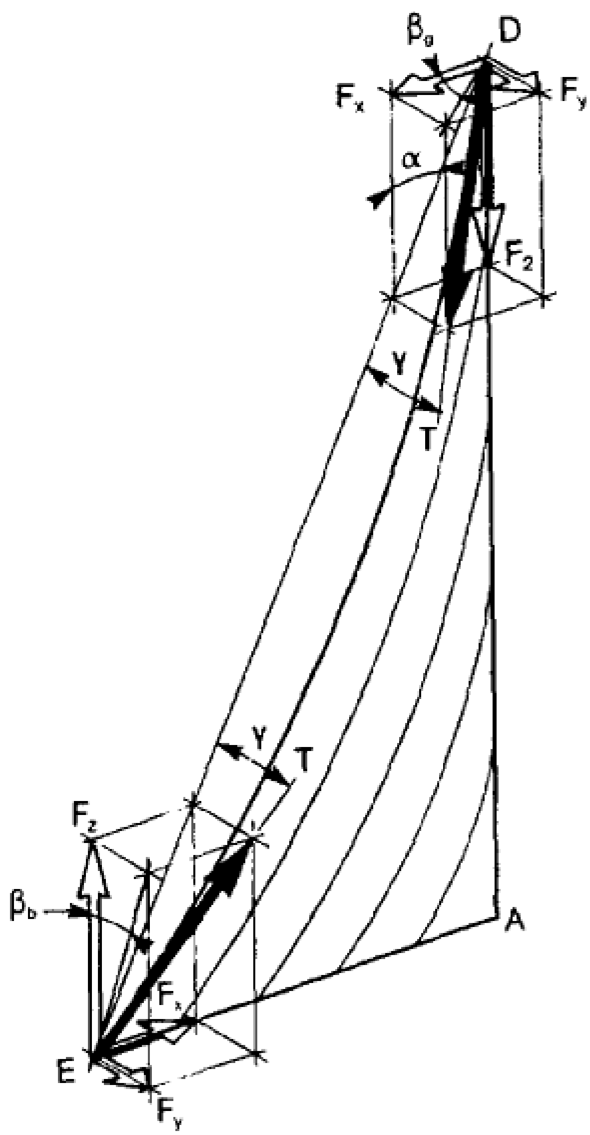

Fig. VI-14. *The mainsail is comparable to a series of bands parallel with the leach. Knowing the angle, β_g, which the sail forms from the luff to the end of the boom it is possible to determine the tensions T in these bands.*

The angle γ which results is given there by the formula $\tan\gamma = \tan\alpha \tan\beta_b \cos\alpha$ where $\tan\alpha = E/P$*

* P being the length of the luff and E that of the foot (symbols of IOR).

Taking again the formula of the sag of a cable, one will have as a total tension between mast and boom:

$T = F_{yg-v} / (2 \sin\gamma)$ which will give us:

- Transverse force on the mast and the boom

$P_y = T \sin\gamma = F_{yg-v} /2$

- Longitudinal force on the mast and compression in the boom:

$P_{xm} = P_{xb} = T \cos\gamma \sin\alpha = F_{yg-v} \cos\gamma \sin\alpha / (2 \sin\gamma)$

Compressive force on the mast and vertical on the boom:

$P_{zm} = P_{zb} = T \cos\gamma \cos\alpha = F_{yg-v} \cos\gamma \cos\alpha / (2 \sin\gamma)$

To see what that will give for our example by taking $\beta_g = 40°$, P = 11,50 m, E = 3,53 m, from where $\alpha = 17{,}07°$:

$\tan\gamma = \tan 17{,}07° \times \tan 40° \times \cos 17{,}07° = 0{,}246$

$\gamma = 13{,}84°$

$P_y = - 236{,}64/2 = -118{,}32$ daN

$P_{xb} = - P_{xm} = (236{,}64 \cos 13{,}84° \sin 17{,}07°) / (2 \sin 13{,}84°) = 141$ daN

$P_{zb} = - P_{zm} = (236{,}64 \cos 13{,}84° \cos 17{,}07°) / (2 \sin 13{,}84°) = 458{,}74$ daN

Knowing the distribution of these forces on the mast and the boom we will adopt a triangular distribution with a maximum at the points of the halyard and the clew and zero at the point of the tack. Sometimes this will be close to reality, at least for the mast because, for the boom, the cut of the low part of the sail can result in approaching the sail with a free edge where all the effort is concentrated on the clew.

VI-II - 4.2. Boom

We will suppose that the mainsheet is attached at the clew end of the boom and that the vang is not tensioned. When the mainsheet is not attached at the point of the clew, the efforts on its level will be E/x times those calculated at the clew, 'x' being its distance from the tack.

The resultant of the vertical and transverse efforts being at the third of the boom starting from the point of clew, one will have two thirds of the efforts on the clew and a third on the tack (fig. VI-15) is:

- at the clew: $p_{ye} = - 118{,}32 \times 2/3 = - 78{,}9$ daN *
  $p_{ze} = 458{,}74 \times 2/3 = 305{,}8$ daN

The load in the clew will be equal to: $T_e = \sqrt{(78{,}9^2 + 305{,}8^2)} = 315{,}8$ daN

The corresponding angle at the clew is given by $\tan\varepsilon = 78{,}9 / 305{,}8$ from where $\varepsilon = 14{,}46°$.

This angle is greater than that which one can observe in reality and which is around 10°.

It results owing from the fact that we chose for the curve of the sail an arc of a circle whereas actually the curve is flatter on the back, with perhaps too large a β_{g-v} angle. The side force remaining constant, it is the vertical force and the load in the clew, which will increase.

If one takes $\varepsilon = 10°$ one will have: - at the clew:

$T_e = p_{ye} / \sin 10° = 78{,}9/\sin 10° = 454{,}2$ daN $\quad p_{ze} = p_{ye} / \tan 10° = 447{,}3$ daN

- at the tack:

$p_{ya} = - p_{ye} / 2 = - 78{,}9 / 2 = - 39{,}4$ daN $\quad p_{za} = p_{ze} / 2 = 223{,}7$ daN

* One can also regard the mainsail as a triangular surface articulated on the luff. Its centre of area being located at one third from this edge to the clew: $p_{ye} = Fy/3 = - 236{,}64/3 = - 78{,}9$ daN, identical result.

As for the load in the halyard it will be equal to $P_{zb} = p_{ze} + p_{za} = 447{,}3 + 223{,}7 = 671$ daN
These modifications of load on the boom will be reflected of course on the mast since
$P_{zm} = P_{zb} = - 671$ daN, one thus has
$P_{xm} = - 671 \tan \alpha = - 206$ daN and
$P_{xb} = 206$ daN
One notes whereas the load on the boom
$P_{zb} = - 671$ daN is appreciably equal to $3\ F_{yg\text{-}v} \cos \alpha = 678{,}5$ daN and
$P_{xb} \approx 3\ F_{yg\text{-}v} \sin \alpha = 194{,}5$ daN.

We will start from cm values for the calculation of the boom.
Attention, the pressure P_{xb} exerted by the boom on the mast can be much higher when the vang is tensioned, it then relieves vertical effort on the mainsheet but, taking into account the advanced position of its point of attachment on the boom and of its loading angle, the compression which it induces is important and modifies the equilibrium between the panels of the mast, influencing adjustment of its curve.

Up to now we had taken for reference the plane included by the mast and the boom, it is necessary for us now to bring back this plane to the axis of the sailing ship. We will take for the angle of the boom a value of 5°. The problem is quickly solved while passing by a polar/rectangular conversion in a computer. The corrected values will be established as follows:

$P_{xm} = - 206 \Rightarrow - 194{,}9$
$P_{ym} = - 118{,}32 \Rightarrow - 135{,}8$
The compression on the boom p_{xb} will break up at the point of tack into
$p'_{xa} = 206 \cos 5° = 205{,}2$ daN
$p'_{ya} = 206 \sin 5° = 18$ daN
The lateral force at the point of tack p_{ya} will break up into
$p''_{xa} = 39{,}4 \sin 5° = 3{,}4$ daN
$p''_{ya} = - 39{,}4 \cos 5° = - 39{,}3$ daN
And in total:
$p_{xs} = 205{,}2 + 3{,}4 = 208{,}6$ daN
$p_{ys} = 18 - 39{,}3 = - 21{,}3$ daN

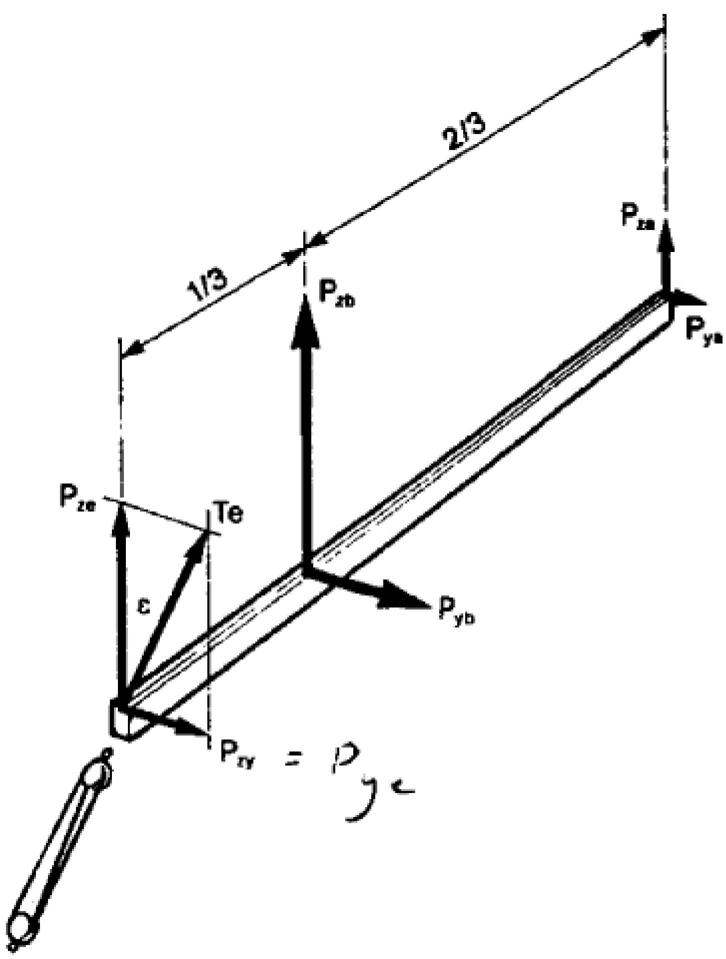

Fig. VI-15. Les efforts sur la bôme.

VI-II - 4.3. Genoa

On the boat used in the example, the clew jib car is at 1,50 m off the centreline of the yacht.
By observation we know that the clew lies in a plane appreciably parallel with the axial plane of the yacht and that the angle of attack of the genoa β is approximately 45°, finally we will allow for a deflection for the luff, envisaged by the yacht, of 0,43 m, in our example, 3,18 %, and a sail hollow of 10 %. We can thus trace a section perpendicular to the stay and passing by the clew (fig. VI-16).

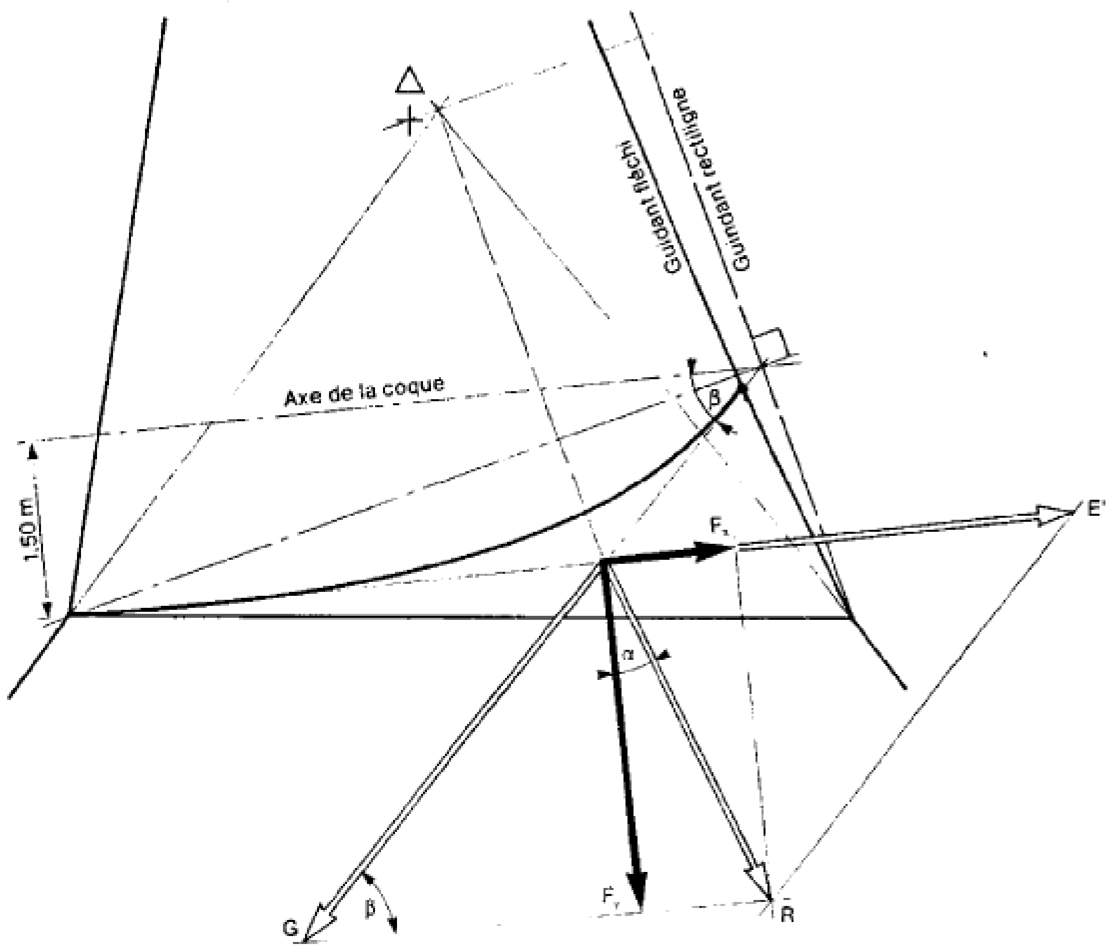

Fig. VI-16. Décomposition de la résultante du foc selon les directions perpendiculaires au guindant dans le plan de celui-ci et dans le plan de l'écoute.

The resultant of F_y and F_x pass by the intersection of the two tangent plans at the luff and the clew. This intersection is thus a place of the point of convergence of the three forces balancing the resultant. This cuts the line joining the clew to the stay at 3/10 of this, that is to say a little in front of the third, which is normal. It will be also noted that it is located a little in front of the perpendicular to this line, which is also normal if one takes account of a certain cant (inclination) of the sail on the whole his height.
By breaking up the resultant according to two tangent planes we will have load E' in the plane of the clew and the load G distributed on the luff.
$E' = F_y (\sin \alpha + \tan \beta) = 449{,}61 (\sin 19{,}95° + \tan 45°) = 603$ daN
$G = Fy / \sin \beta = 449{,}61 / \sin 45° = 636$ daN

We can now trace a side projection of the genoa on which we will carry the position of the point of convergence of the forces (fig. VI-17). We will place it at the same height as the geometrical centre of area and on the straight line parallel with the luff previously seen.
From this point we have the direction of the three forces A, D and E passing respectively by the three points of tack, halyard and clew.
From E', projection of E on the perpendicular with the luff, we obtain E = 709,46 daN, as the load in the clew.
By composition of E and F_x and decomposition of their resultant we obtain projections on the axial level of D and A.
A folding back on a transverse plane will give us, starting from F_y, the projection of the three forces from this point of view. We can measure or calculate their full-scale value and their angles in the longitudinal and transverse planes.

For our example one will find as follows:
A = 812 daN
D = 1226 daN
α = 9,94°
γ = 10,06°

One notes, within sight of these angles, the importance that to provide the points with high and low attachment of the stay and the point of tack of an articulation with sufficient clearance and to correctly draw the exit of the halyard that these do not wear on the edges of the sheave box.
Up to now we reasoned as if the genoa were not affixed to a stay.
The presence of the stay and its natural tension will balance a part of the normal forces in the luff and will reduce much of the component in the load of the halyard. It is very difficult to define this proportion exactly the more so as it is eminently variable since it is dependent on the cut and the adjustment of the sail and of the rigging. The distribution along the luff is also poorly known. We will estimate, a little arbitrarily, I recognize, that the force on the luff G will be distributed for 2/3 on the forestay and 1/3 on the luff.
The tension in the stay which results from it will be then T = G / 12 x c, where c is the curve expressed by the deflection/luff ratio.
In our example:
T = 636 x 100 / 12 x 3,18 = 1667 daN.

The reduction of the tension in the halyard, that shares only part of the corresponding tension in the luff, will be estimated to be 1/4 of the tension of the luff. We will thus have:
D = 1226 x 0,75 = 919,5 daN
The sum of the two tensions will determine the total efforts with the rigging of the stay on the mast and the fitting of the stem.
At the head of the mast we will have then: Halyard + stay = 919,5 + 1667 = 2586,5 daN which will break up into:

Mast Compression	$Fz = \sqrt{(2586^2 / (\sin^2\gamma + 1/\cos^2\alpha))} = 2511$ daN
Side Force	$Fy = 2511 \times \sin\gamma = 438{,}5$ daN
Longitudinal Force	$Fx = 2511 \times \sin\alpha = 433{,}5$daN

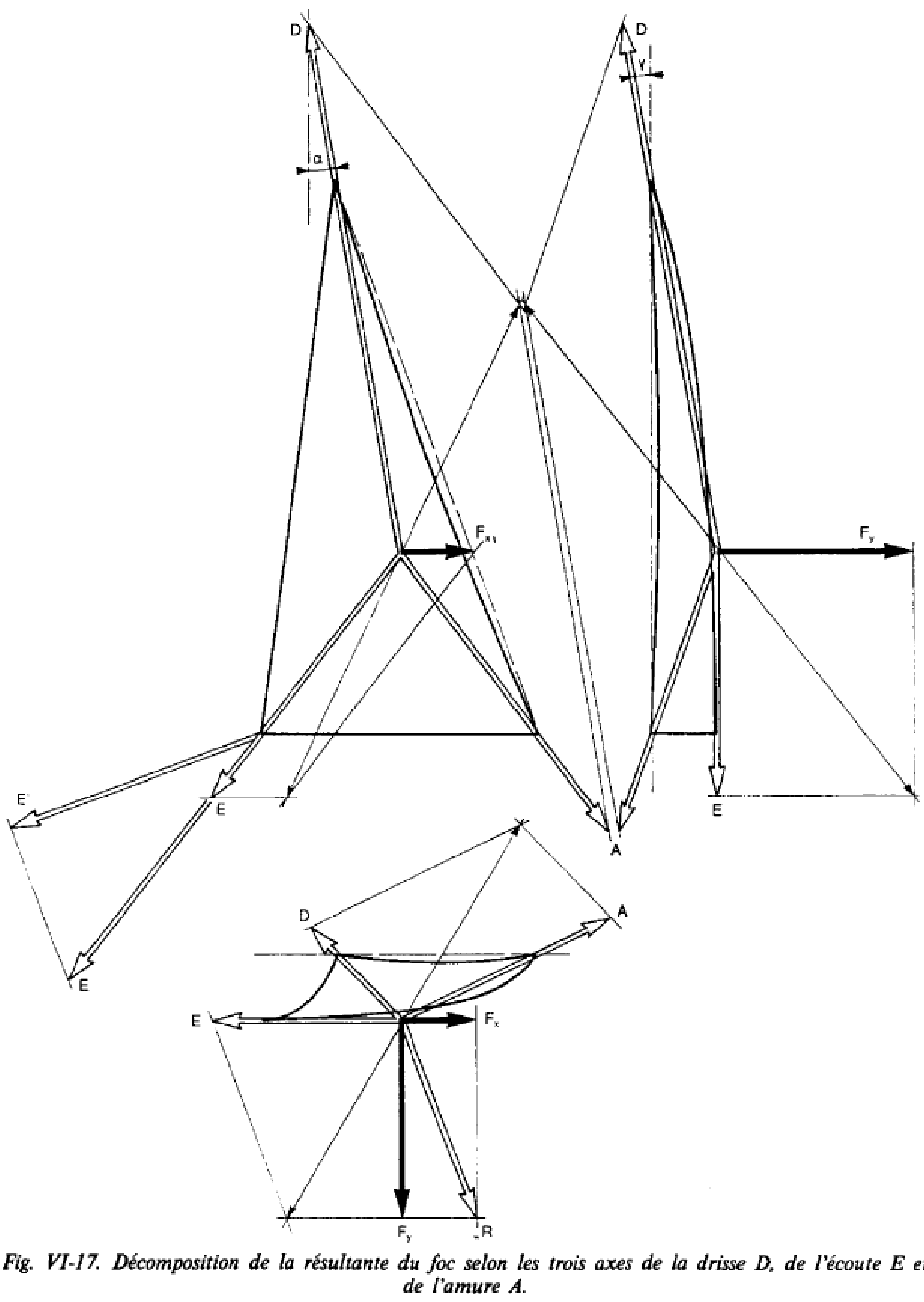

Fig. VI-17. Décomposition de la résultante du foc selon les trois axes de la drisse D, de l'écoute E et de l'amure A.

VI-II - 4.4. Distribution of the effort of the sails on the mast

We can now represent the distribution (which we have triangulated) of the efforts of the mainsail on the mast in the longitudinal and transverse planes (fig. Vl-18 a and b) by considering, as for all the calculations, that the mast remains straight. For a triangular distribution of the load of the mainsail, the value of the load exerted per unit of length, on the level of the point of the halyard is equal to **2F/P** is:

Longitudinal: $p_x = 2 \times 194{,}9 / 11{,}5 = 33{,}90$ daN/m
Transverse: $p_y = 2 \times 135{,}8 / 11{,}5 = 23{,}62$ daN/m
From the site of the points of attachment we can draw up a first table of the loads that are exerted there:

	Longitudinal	Transversal
Head of mast	433,5 - 75,86 = 357,64	
Babystay	-79,43	
Cap shroud		- 470,93
2nd spreader		- 69,00
1st spreader		- 36,05
Foot of mast	168,98	- 25,72
	447,19	- 601,70

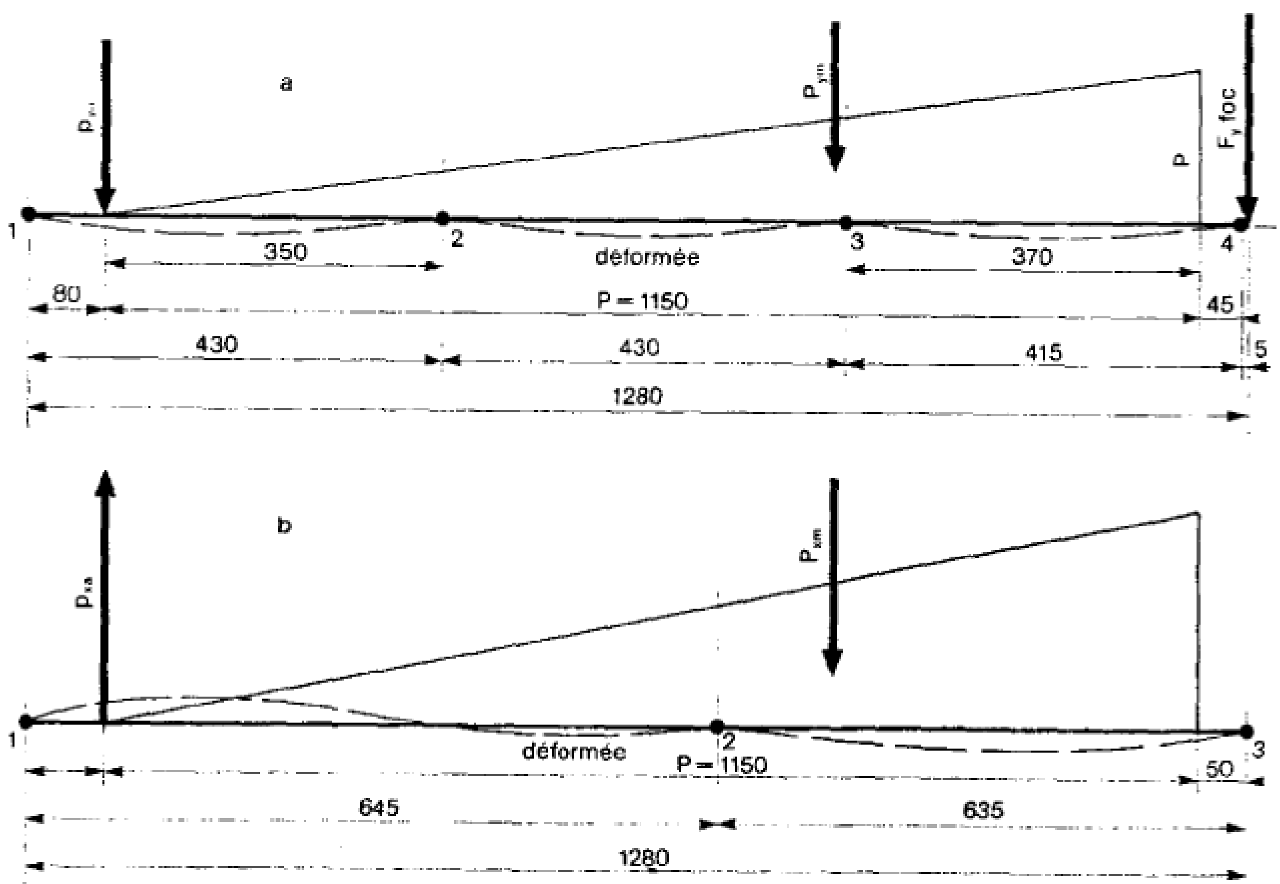

Fig. VI-18. Géométrie du mât dans le sens transversal (a) et longitudinal (b).

If the mast were made up segments articulated at each point of fixing these are the loads which act on the shrouds. But actually the mast is a continuous profile. At each node will be created equal bending moments of opposite direction which will modify the load that is exerted there. The calculation, which can be solved by "the three moments theorem" is extremely complex and I will not develop it here.
For our example one leads to the corrected table:

	Longitudinal	Transversal
Head of mast	362,54	
Babystay	-89,16	
Cap shroud		-464,14
2nd spreader		- 77,98
1st spreader		- 43,32
Foot of mast	173,81	- 16,26
	447,19	- 601,70 1

In the case of a keel-stepped mast the results would be a little different because of the presence of an additional section between the partners and the foot of the mast.

VI-II - 5. LOADS IN THE STAYS

From knowing the load in each point we will be able to calculate those of the stays and the compression that they will induce in the mast.

VI-II - 5.1 longitudinal Staying (fig. VI-19)

The load at the head will be balanced by the load of the backstay:
$T = F_x/\sin\alpha$ inducing a compression in the mast:
$F_z = F_x/\tan\alpha$
The same formulas will apply to runners and the inner forestays.

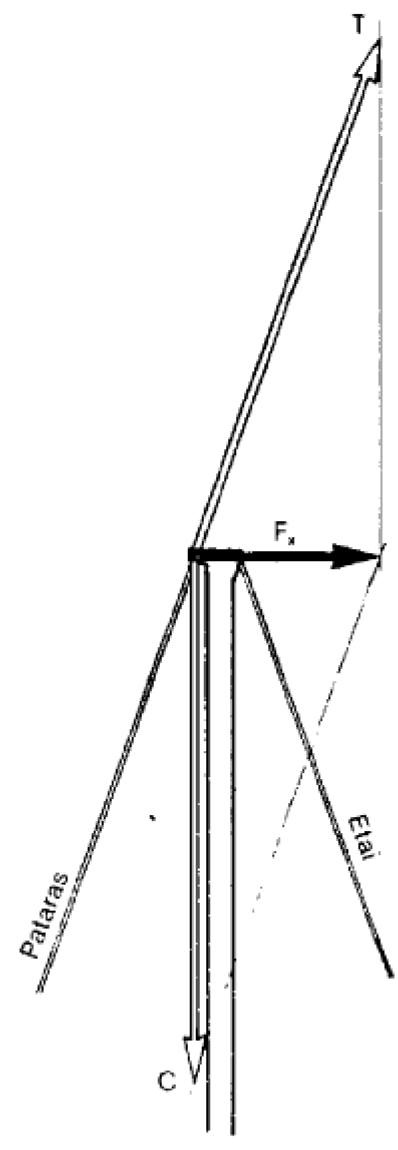

Fig. VI-19. *Load at the head of mast F_x generates a load in the backstay T and a compression in the mast C. According to their distance from the axis of the mast, compressions due to the forestay and the backstay can generate a bending moment in the top part of the mast.*

VI-II - 5.2. Transverse staying (fig. VI-20)

The spreaders are fixed according to the bisection of the angle which the stay makes at its end.
When the stay goes down again parallel to the mast, its angle is:
$\alpha = 2 \sin^{-1} (f/(2 \times l))$ has, with f: the length of the spreader.
In this case the angle of the spreader $\beta = \alpha/2$
The compression induced in the mast is:
$F_z = F_y / \tan \alpha$ and force in the stay:
$T = F_y / \sin \alpha$
On the level of the spreader one has
- Compression in the spreader: $C = (2 F_y \sin \alpha/2) / (\sin \alpha)$
- Lateral Component on the mast $f_y = F_y$
- Vertical Component on the mast: $f_z = (2 F_y \sin^2\alpha/2) / (\sin \alpha)$

When the stay does not go down again parallel to the mast (case of spreaders length gradually reduced) but formed with the vertical an angle β, angle α practically does not change. That of the spreader is increased by γ/2.

One has then on the level of the spreader
$c = (2 F_y/\sin \alpha) \times \sin((\alpha-\gamma)/2)$
$f_y = F_y (\sin \alpha - \sin \gamma)/\sin \alpha$
$f_z = F_y (\cos \alpha - \cos \gamma)/\sin \alpha$
The influence of the angle γ is very large and can involve important reductions of c and F_y with a corresponding transfer of the load in the higher shroud when one gradually reduces the length of the spreaders from the lower stages towards the higher stages.

For the shrouds in the plane of the mast, the formulas are the same ones as for the backstay. In the case of double lower shrouds, forward lower will support the transverse load, but also the longitudinal loading reserved previously for the baby stay. It will thus have a double vertical component and its load will increase the resultant longitudinal loading.

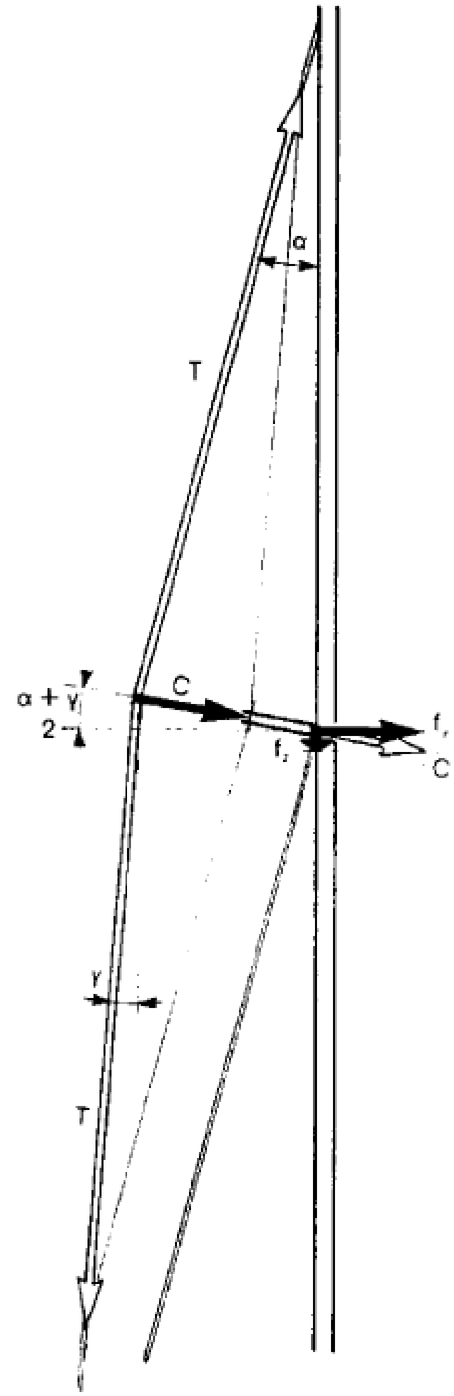

Fig VI-20. *The tension of the cap-shroud transmits to the mast, via the spreader, a force 'c' which breaks up into a compression f_z and a transverse force f_y the value of 'c' varies very quickly when the angle γ is modified.*

The resultant of the transverse load will be also distributed between the two lower shrouds and will be increased by taking account of their angles γ fore and aft.
One will have thus for the aft lower Shroud:

$T_{AL} = F_y / (2 \sin \alpha \cos \gamma)$

and for the forward lower shroud:

$T_{FL} = F_y / (2 \sin \alpha \cos \gamma) + F_x / \sin \gamma$

We will now be able to draw up a table (below) making it possible to define all the components of compression in the mast and loads in the shrouds.

POINT OF RIGGING	LOAD ON THE ELEMENT OF INTEREST*		LOADS ON THE MAST*			
			Longitudinal Rigging		Transverse Rigging	
			F_x	F_z	F_y	F_z
Head of mast	Forestay	1667	362,5	-2511		
	Jib Halyard	919,5				
	Jib Halyard Return			-919,5		
	Main halyard	671		-671		
	Main Hal. Return			-671		
	Backstay	*1059,9*		-996		
	Cap Shroud	*1954*			- 464,1	*- 1898*
2nd spreader	spreader	*406,5*			- 402,7	*- 55*
	Inter. Shroud	*1909,7*			- 56,37 - 402,7	*- 1848,2*
Babystay	Babystay	*344,6*	- 89,2	*- 332,9*		
1st spreader	spreader	*435*			- 430,7	*- 60,8*
	Lower Shroud	1954			- 28,98 - 430,7	*- 1895,6*
Gooseneck			208,6		- 27,4	
				- 6101,4		***- 5757,6***

*The figures in normal font result from preceding calculations, those in italic are due to the load of the staying which results from it. Not to complicate the demonstration too much, the resistance of the mast and rigging is not taken account of, in any event being small.

Compression in the three panels of the mast will thus be distributed as follows:

Higher panel:	- 2511 - 919,5 - 2 x 671 - 996 - 1898	= - 7666,5 daN?
Intermediate panel:	- 7666,5 - 55 - 1848,2	= - 9569,7 daN above the baby stay?
Intermediate panel:	- 9569,7 - 332,9	= - 9902,6 daN below the baby stay?
Lower panel:	- 9902,6 - 60,8 - 1895,6	= - 11859 daN.

VI-II - 6. - SAFETY COEFFICIENTS

Up to now we considered only the static loads. It is quite obvious that usually the coefficients intended to take account of the tolerances of the mechanical characteristics; the loads on the stays and the mast will undergo significant variations due to the dynamic stresses from the movement of the yacht.
At the time of studies carried out in Sweden at the higher Technical training school Chalmers de Malmoe one measured the following variations by ratio with the average loads. The sailing ship used, L-32, measured 9,81 m H.T., displacement 4,6 t; the sloop sail area of 47,85 m^2 was supported by rigging at the head with one set of spreaders and a pair of fore and aft lowers.

Tension in the Shrouds	Forestay	+ 32 %
	Cap-shroud	+ 45 %
	Aft lowers	+ 71 %
	Forward lowers	+ 42 %
Stresses in the mast	Higher Panel	+ 133 %
	Lower Panel	+ 34 %

One will note the important variations of the tension of the aft lower and the load in the higher panel of the mast. They are explained very well by the fact that decelerations are much higher than accelerations; the mast then tends to bow forwards, from where an important overload of the aft lower and a release of the forward lower. As for the higher panel of the mast, being further from the centre of gravity it is subjected to higher decelerations, while at the same time, the high part of the sail flogs, it is now not supported.

Nevertheless the variations measured in the stay appear small compared to those of the higher part of the mast and I think that reality must be closer to their average.
It should be noted in addition that accelerations to which the rigging is subjected vary by the square speed. One imagines what can be the consequences for a multi-hull sailing in 30 knots.
All in all, by including the mechanical, dynamic factors and of fatigue one will be able to adopt the safety coefficients of the table below, for a monohull. For the multi-hulls, the coefficients of longitudinal rigging could be doubled.

	1 spreader	2 spreader
Forestay, backstay, runner, 7/8 rigging	3 -3,5	
Baby stay	2,2 - 2,4	
Cap Shroud	2 - 2,2	1,9 - 2,1
In line lowers	2,1 - 2,3	2,2 – 2,4
Forward lower	1,8 - 2	1,9 – 2,1
Aft lower, check stays	2,2 - 2,4	2,3 - 2,5
halyards	2,5	
Sheets	5	

The margin indicated takes account of the conditions of use. The lowest value corresponds to small yachts for coastal cruising, the highest values for deep-sea yachts. It will be noted that the coefficients are lower for a single in line lower, little bothered by decelerations, than for an aft lower which, supports all the effects of decelerations to the mast.
If we apply these coefficients to the loads in the stays calculated above we will find respectively:

Forestay:	1667 x 3,5	= 5834 daN
Baby stay:	344,6 x 2,4	= 827 daN
Cap-shroud:	1954 x 2,1	= 4103,4 daN
Intermediate:	1909,7 x 2,1	= 4010,4 daN
Lower:	1954 x 2,4	= 4689,6 daN

VI-II - 7. - CALCULATION OF THE MOMENTS OF INERTIA OF THE MAST

The formula most usually allowed for the calculation of the masts is that of Euler * which gives:
$I_G = (P\ L^2) / (k\ \pi^2\ E)$ with
P: axial loading;
L: free length of the section;
k: coefficient of fixture;
E: modulus of elasticity.

* See page 122.

This formula can however apply only to little curved masts, whose deflection - within each panel - does not exceed the corresponding width of the profile. When the bending of the mast becomes too great it should be considered that the bending moment causing bending is balanced by the load of the sail. The mast does not work any more in compression, but its stability depends only on the sail. When the sail is not set (taking in a reef, bad adaptation of the sail to the mast by its cut or its adjustment, flogging, etc.) the mast comes to work in combined compression and deflection. It is a very different mode of calculation, in which all rigging must be considered to be hyper-static (lengthening of the shrouds and shortening of the profile), which would be far too involved for us here.
We will thus leave it for the moment with simple calculation of buckling, by taking account nevertheless of the transverse loads.

VI-II - 7.1. Coefficient of fixture

In the case of a mast, the coefficient of fixture is difficult to determine because, except at the head or at the foot where one can regard the support as articulated, at the other nodes, the presence of the adjacent panels will introduce a moment of resistance which will constitute a partial fixture.

A variable coefficient will result according to the relationship between the loads and the lengths in the panels.
The form of the deformation of the mast resulting from the provision of the points of anchoring of the staying will also have importance in the fact that it will allow or not, in one direction or the other, the participation of the adjacent panels. Theoretically, if the load were constant top to bottom of the mast and that it is perfectly straight one should have K = 2 for the end panels and 4 for the intermediate panels.
Taking into account in respect of the above conditions, the coefficient of fixture will lie between 1 and 2.
For example, for a mast with only one set of spreaders and stepped on the deck, the coefficient would be 1 if the load were equal in the two panels. However the higher panel, loaded differently, will bring to this an additional rigidity that will increase its critical load. The graphics of figure VI-21 give the value of K, according to the ratio of the loads in the upper (superior) and lower (inferior) panels and, P_i/P_s.

In the same way, the coefficient of fixture of a mast passing through the deck and stepped on the keel will depend on the l_2/l_1 ratio of lengths of the panels ranging between the deck and the keel and the lower spreaders and the deck. The graphics of figure VI-22 give the values of k_2 under these conditions.

The two coefficients apply to the lower panel.

If for example the P_i/P_s ratio = 1,25, one will have k_1 = 1,1 (fig. VI-21).
If, however, it is stepped at a height equal to 1/3 of the lower panel, there will be k_2 = 1,29 and the coefficient of fixture K = k_1 x k_2 = 1,1 x 1,29 = 1,42.

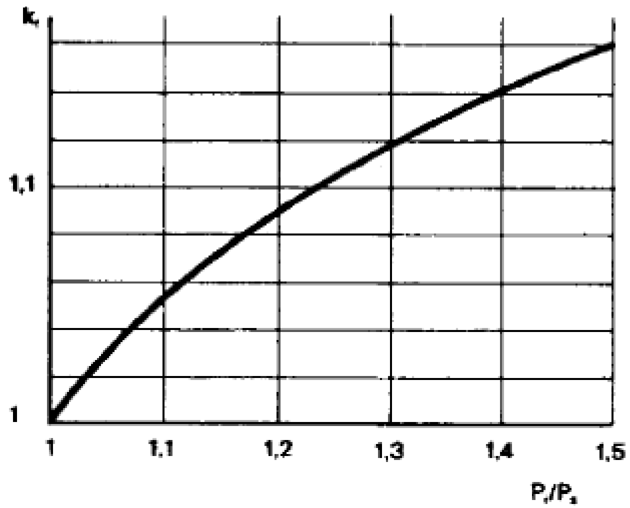

Fig. VI-21. Courbe du coefficient k_1 correspondant au rapport entre les forces de compression dans les panneaux adjacents.

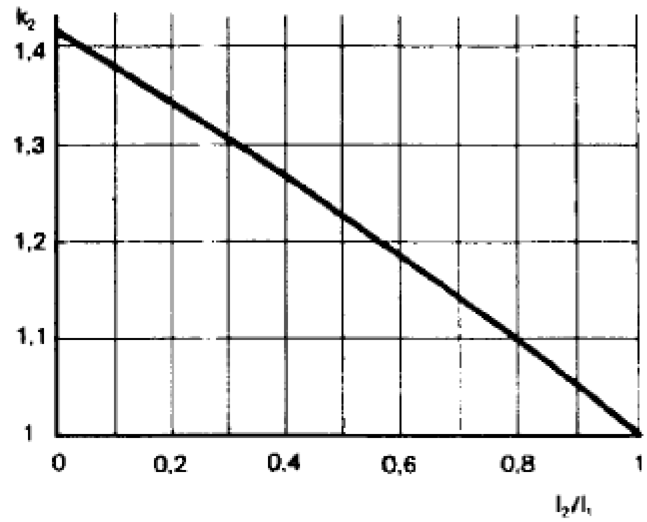

Fig. VI-22. Courbe du coefficient k_2 correspondant au rapport des longueurs des panneaux adjacents.

By combining these two coefficients one can about cover all the cases.
In our example we will have thus

Longitudinal:
The loads are not constant in all the height of the panels so we will take the averages of those located at the head and above the spreaders, and below and at the foot. One will thus have:
Pi/Ps = [(9902,60 + 11859)/2] / [(7666,5 + 9569,7)/2] = 10880,8 / 8618, 1 = 1,26 from where k = 1,05 for the lower panel and 1/1,05 = 0,95 for the higher panel.
The two panels being of equal length there is not another coefficient to apply. If it were not thus one could use the coefficient k_2 corresponding for the longest panel and $1/k_2$ for shortest.

Transverse:
In the first stage we will regard the mast as fixed between the spreaders and the deck. We will have:
Pi/Ps = 9902,6 / 7666,5 = 1,29 from where,
for the intermediate panel, a first coefficient k_1 = 1,11.
Likewise l_2 / l_1 = 4,3 / 4,3 = 1, k_2 = 1
For the higher panel k = $1/k_1$ = 0,90.
In the second stage one will consider that the whole is reversed and that it is the higher panel which is fixed. We will have then;
Pi/Ps = 9569,7 / 10880,8 = 0,88 from where,
for the intermediate panel, a second coefficient k'_1 = 0,94. Likewise l_1 / l_2 = 4,15 / 4,3 = 0,97, there will be k'_2 = 1,02.
The coefficient of total fixture of the intermediate panel will be:
$k_1.k_2.k'_1.k'_2$ = 1,11 x 1 x 0,94 x 1,02 = 1,06
For the lower panel one will have k = $1/k'_1$ = 1,07

These coefficients of fixture are in fact very pessimistic and would correspond to an alternate deformation of the panels. This case can nevertheless occur when there is no mainsail. Under normal conditions it would not be thus, at least in the transverse direction, and the coefficients of fixture would be practically doubled. We will preserve them despite everything, considering that these low values correspond to a safety coefficient.
Knowing the coefficients of fixture, we will be able to calculate the minimum moments of inertia necessary in each panel.
To reduce the numbers to be treated, one takes the centimetre as the unit of length. This will give for the alloy A-SGMT6, $E = 7 \times 10^5$ and for the yield stress $Re = 2400$ daN/cm^2

Longitudinal:
Lower panel: P = 11859 daN, l = 645 cm, k = 1,05
$I_L = (11859 \times 645^2)/(1{,}05 \times \pi^2 \times 7 \times 10^5) = 680$ cm^4
Higher Panel: P = 9569,7 daN, l = 635 cm, k = 0,95
$I_T = (9569{,}7 \times 635^2)/(0{,}95 \times \pi^2 \times 7 \times 10^5) = 588$ cm^4
Transverse:
Lower panel: P = 11859 daN, l = 430 cm, k = 1,07
$I_T = (11859 \times 430^2)/(1{,}07 \times \pi^2 \times 7 \times 10^5) = 297$ cm^4
Intermediate Panel: P = 9 902,6 daN, l = 430 cm, k = 1,06
$I_T = (9902{,}6 \times 430^2)/(1{,}06 \times \pi^2 \times 7 \times 10^5) = 250$ cm^4
Higher Panel: P = 7 666,5 daN, l = 415 cm, k = 0,90
$I_T = (7\,666{,}5 \times 415^2)/(0{,}9 \times \pi^2 \times 7 \times 10^5) = 212$ cm^4

The most similar profiles that we will find will be Francespar F 380 A or Z Spar Z 500, whose characteristics are as follows:

	Francespar F380 A	Z Spar Z 500
External Dimensions mm	186 X 130	185 x 125
e mm	3,6	3,3
S (area) cm^2	19	18,5
I_T cm^4	380	350
I_T / v	58,5	56
I_L cm^4	730	730
I_L / v	78,5	77

We will calculate the buckling critical load,
$P_{crit} = k \times \pi^2 \times E \times I / l^2$ and working stress
$\sigma_a = k \times \pi^2 \times E / \lambda^2$ in the various panels for the Francespar profile.
For that, one will calculate initially the radius of gyration
$\rho = \sqrt{(I / S)}$ and the slenderness $\lambda = L / \rho$.

Longitudinal: $\rho = \sqrt{(730/19)} = 6{,}20$ cm
Lower Panel: $\lambda = 645/6{,}20 = 104{,}1$
$P_C = 1{,}05 \times \pi^2 \times 7 \times 10^5 \times 730 / 645^2 = 12\,729$ daN
$\sigma_a = 1{,}05 \times \pi^2 \times 7 \times 10^5 / 104{,}1^2 = 669{,}4$ daN/cm^2
Higher Panel: $\lambda = 635/6{,}20 = 102{,}4$
$P_C = 0{,}95 \times \pi^2 \times 7 \times 10^5 \times 730/6352 = 11\,882$ daN
$\sigma_a = 0{,}95 \times \pi^2 \times 7 \times 10^5 / 102{,}4^2 = 625{,}9$ daN/ cm^2

Transverse: $\rho = \sqrt{(380/19)} = 4{,}47$ cm

Lower Panel: $\lambda = 430/4{,}47 = 96{,}15$

$P_C = 1{,}07 \times \pi^2 \times 7 \times 10^5 \times 380/430^2 = 15\,192$ daN

$\sigma_a = 1{,}07 \times \pi^2 \times 7 \times 10^5 / 96{,}15^2 = 799{,}6$ daN/ cm^2

Intermediate panel: $\lambda = 430 / 4{,}47 = 96{,}15$

$P_C = 1{,}06 \times \pi^2 \times 7 \times 10^5 \times 380/430^2 = 15\,050$ daN

$\sigma_a = 1{,}06 \times \pi^2 \times 7 \times 10^5 / 96{,}15^2 = 792{,}1$ daN/ cm^2

Higher Panel: $\lambda = 415 / 4{,}47 = 92{,}8$

$P_C = 0{,}9 \times \pi^2 \times 7 \times 10^5 \times 380/415^2 = 13\,719$ daN

$\sigma_a = 0{,}9 \times \pi^2 \times 7 \times 10^5 / 92{,}8^2 = 722$ daN/ cm^2

VI-II - 7.2. Side load

The critical load which a column can accept working with buckling can be considerably reduced if a side load is applied to it. It is unfortunately the case of a mast, which is subjected to the load of the mainsail and the boom push.
It is hardly easy to introduce this additional element into a formula to make it possible to obtain the moment of inertia directly. It will be easier to check afterwards, once the profile of the mast is chosen from the calculation of the moments of inertia due to buckling alone.
One will first of all calculate the bending moment in the panel from the plan considered. To simplify, one will take account only of one concentrated resultant force for the lower panel, or a force uniformly distributed for the intermediate and higher panels and without fixture at the ends. Once again these conditions are definitely more unfavourable than reality since they do not take consideration of the adjacent panels. For the calculation of the moment one will use the following formulas:

Concentrated loading, $M = (p \sin k \times b \sin k \times a) / (k \sin kl)$

Distributed loading, $M = q/k^2\ ((1/\cos (kl/2))-1)$, with

p: specific side load;

q: load per unit of length = p/l;

a and b: distances to the ends from the concentrated loading;

L: length of the panel;

k: $\sqrt{(P/EI)}$

From this moment one will deduce the maximum stress by the formula:

$\sigma_{max} = P/S + M/[(I/v)(1-P/Pcrit)]$ and the safety coefficient its $Cs = \sigma_a / \sigma_{max}$

For our example one arrives at the following results:

Longitudinal, I = 730 cm, I/v = 78,5 cm^3, S = 19 cm^2

Lower Panel:

P = 11859 daN,	P_c 12729 daN,	l = 645 cm
p = 161,6 daN,	a = 29,8,	b = 615,2,
k = 0,0048	M = 80,68 daN-cm	
σ_{max} = 639,2 daN/cm^2		Cs = 1,05

Higher Panel:

P = 9569,7 daN,	P_c = 11882 daN,	l = 635 cm
p = 147,86 daN,	q = 0,23 daN/cm	
k = 0,0043	M = 3,53 daN-cm	
σ_{max} = 504 daN/cm^2		Cs = 1,24

Transverse, I = 380 cm^4, I/v = 58,5 cm^3, S = 19 cm^2

Lower Panel:

P = 11859 daN,	P_c = 15192 daN,	λ = 430 cm
p = 40 daN,	a = 153,3,	b = 276,7
k = 0,0067	M = 68,85 daN-cm	
σ_{max} = 629 daN/cm^2		Cs = 1,27

Intermediate panel:

P = 99026daN,	P_c = 15050 daN,	L = 430 cm
p = 49,9 daN,	q = 0,12 daN/cm	
k = 0,0061	M = 0,82 daN-cm	
σ_{max} = 521 daN/cm^2		Cs = 1,52

Higher Panel:

P = 7666,5 daN,	P_c = 13719 daN,	l = 415 cm
p = 73,3 daN,	q = 0, 18 daN/cm	
k = 0,0054	M = 1,16 daN-cm	
σ_{max} = 403,5 daN/cm^2		Cs = 1,79

All stresses are substantially lower than the critical stresses; therefore the mast works well with buckling.

The safety coefficients can appear low, in particular in the longitudinal direction. In reality it will be very rare to reach these values, because, if the mast is slightly curved forwards by the baby stay, there is a balance between the moment thus created and that, of the direction opposed by the load of the mainsail creating a stabilization of the mast corresponding to a coefficient of fixture higher than those calculated.

When this stabilizing effect of the mainsail disappears, for example when taking in a reef, a moment when, moreover, the balance between the moments of the forestay and the mainsail and of the cap-shroud is not ensured any more, accidents can occur.
With the study of the results one also sees that those could be improved by displacement of certain points of anchoring of the shrouds. As a whole, a descent of those would make it possible to better balance the stresses in the panels, but it should be known that small modifications can have large consequences. In addition it is good to have higher coefficients in the upper panels where the dynamic stresses are greater.

VI-11 - 7.3. Local buckling

Thin tubes, like the profiles of a mast, can fail at a rate of constraint lower than that determined by a general buckling. It is normally in the curved part of the section that local buckling occurs; for an elliptic profile it will be the sidewall of average radius ‘r’.
Working stress for a tube will be: σ_{co} = Re/[1 + 3 (r/e) (Re/E)]
In our example, with: Re = 24 daN/mm^2, r = 122,5 mm and e = 3,6 mm one has σ_{co} = 17,78 daN/mm^2, which remains much higher than the working stresses of general buckling.
This checking is nevertheless necessary, in particular for the large profiles or when, wishing to increase the moment of inertia, leads one to too low wall thicknesses.

VI-III SIM IFIED METHOD

The method of calculation that we have just studied is long, even if relatively precise, and this precision is not always necessary, the more so as the safety coefficients applied offer a rather broad guarantee. In fact, I considered developing it primarily to show, by progressive analysis, the factors that constitute the total stresses on the mast and it's rigging.
In practice it will generally not be necessary to resort to it or, in the extreme cases, it will be preferable to use the lenient method with the proviso of introducing the correct data with regard to the loads exerted by the sails.
In the majority of the cases one will use a simplified method, development by the office of Sparkman & Stephens and whose most up to date version was published in 1982 in the report of the 12e symposium of the AIAA [2].
This method is applied by many architects with some alterations resulting from personal experience. It is completely adapted to the traditional cruising yachts with, for the masthead rigging, a ratio of areas of the genoa to mainsail in the neighbourhood of 2. It calls for some comments, shown by an index, which we will develop here.

The process is as follows:

a) Loads in the mast and rigging

$P_t = (MR_{30} \times 1.5)/e$ with:
P_t: vertical effort on chainplates and the mast due to the transverse rigging;
MR_{30} (1): righting moment at 30° heel with mid-displacement;
e (2): chainplate distance from the axis of the mast;
1,5: coefficient for maximum heel.

b) Compression in the mast

P = 1,85 x P_t where: 1,85: coefficient to take account of the longitudinal rigging. (3)

c) Burden-sharing in the various elements of rigging **(Table VI-II)** (4)

d) The Safety Coefficients for the rigging

Cables: cap-shrouds: 2,5 - 2,75;
Lower shrouds and stays: 3.
Rods: shrouds and cap-shrouds: 2,25 - 2,5
Stays: 3.
Chainplates: 4.

e) Masts and Rigging of the mizzen

$Pt = (MR_{30}/e) \times 1{,}5 \times C$ with:
C = 1/3 for the normal yawls and ketches;
C = 1/2 for the ketches with large mizzen.
P = Pt
Coefficients safety of rigging
Yawls: shrouds 1,5, chainplates 2;
Ketches: shrouds 2, chainplates 2,5.

f) Moment of inertia of the masts

$I_{cm}{}^4 = (Cs \times P \times L^2) / (K \times \pi^2 \times E) = C \times P \times L^2 \times 10^{-8}$ with
P: compression on the mast in daN;
L: length of the panel of mast in cm;
C: coefficient given in Table VI-III.

TABLEAU VI-II

RÉPARTITION DES EFFORTS DANS LE HAUBANNAGE TRANSVERSAL

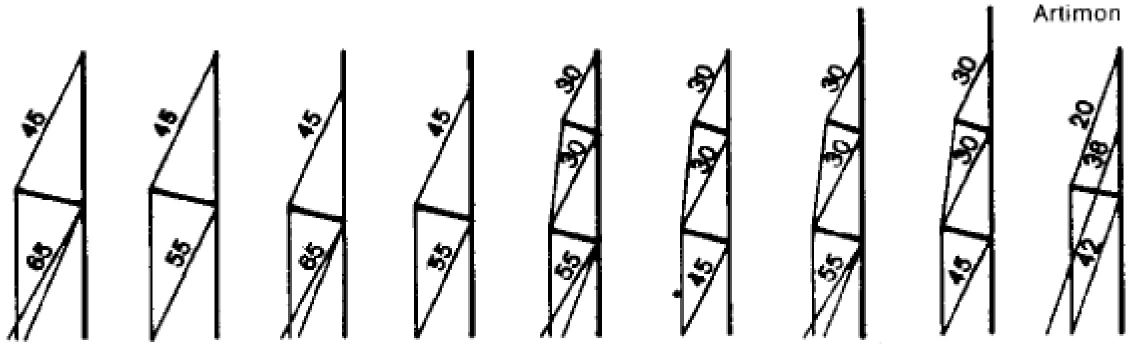

TABLE VI-III

VALUES OF 'C' FOR A LIGHT ALLOY MAST STEPPED ON THE KEEL

	Euler Coefficient, k	TRANS-VERSAL		LONGITUDINAL						
		Single Spreader	More than one Spreader	L to the stay			L to the stay			
				All Lengths $L_f < 10$ m with releasable baby stay			10 m < L_f < 14 m			$L_f > 14$ m
				Mast Head		7/8	Mast Head		7/8	Mast Head
				Double Lowers	Single Lower and baby stay	Double Lowers	Double Lowers	Single Lower and baby stay	Double Lowers	Double Lowers
C_s		2.1	2,5	1,2		1,15	0,8		1,15	
Lower Panel	2,25	1,34	1,61	0,77	0,64	0,74	0,51	1 spreader 0.51	0,74	0,43
Upper Panels	1,5	2,16	2,4					2 spreader 0,43		

Note:

- For rigging with only one lower in the plane of the mast and without baby stay, to add 10 % to the longitudinal moment of inertia calculated for double lower-shrouds.
- For a yacht of more than 14 m of waterline length with a releasable baby stay take L of the rigging to the baby stay with C = 0,45.
- For a deck stepped mast, one uses an Euler coefficient lower by 20 %:

C deck stepped = 1,25 x C keel stepped.

- For a mast in spruce $I_{SP} = I_{alu}/0{,}139$. (5)

g) Forestay (6)

The graph of Figure VI-23 directly gives the diameter of the forestay according to MR_{30}/h where 'h' is the vertical distance between centre of sail and centre of the immersed canoe body, this being taken to be 40 % of the draft.

The strength of the cable or the rod is counted to 125 daN/mm^2 [=1250 MPa = to Dyform] on the nominal diameter.

A reduction is not envisaged for a material of higher strength.

The ends must have a strength 5 % greater than that of the cable.

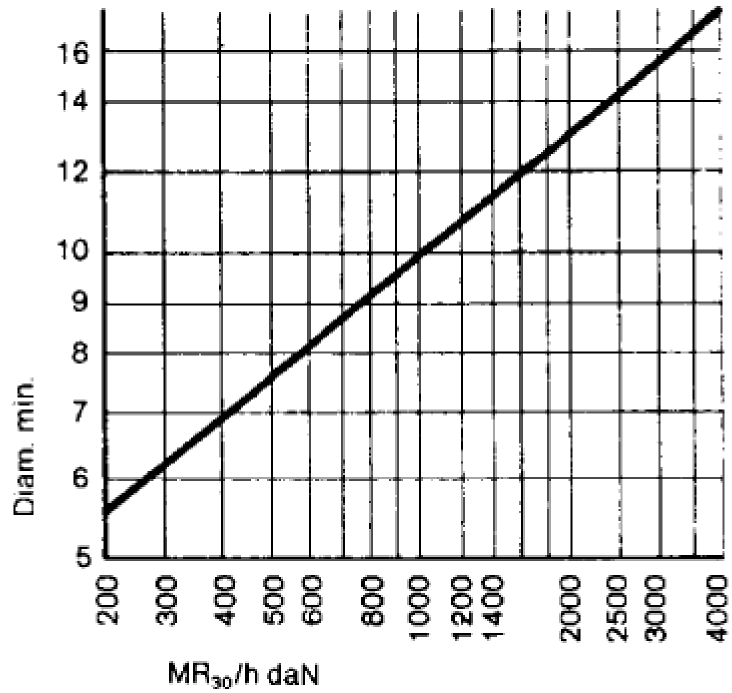

Fig. VI-23. Diamètre de l'étai en fonction de MR_{30}/h, basé sur une résistance à la rupture R_r = 125 daN/mm², la section étant calculée à partir du diamètre extérieur, qu'il s'agisse de câble 1 × 19 ou de monofil.

h) Running Rigging

For the halyards of the jib and mainsail, Stephens gives a table of correspondences with the dimensioning of the forestay. Table VI-IV is the metric adaptation to which were added the sheets of the genoa and of the mainsail as well as the halyards, spinnaker brace and sheets. It is valid for cruising boats having unit surfaces of mainsail, maximum genoa and spinnaker in ratios close to 1, 2 and 4.

The breaking strengths in daN/mm^2 indicated correspond to the Sarma cables, the ropes Glenstein Cup for the halyards and the spinnaker braces, with the ropes Glenstein Gemini for sheets.

One will be able to also refer to the tables of the pages 346 and 347 of Sails and Rigging (éd. of 1982), in particular for the correspondence with Kevlar ropes.

For the ropes, strength alone is not taken into account because one cannot go down below a certain diameter if one wants to preserve a correct handhold; the diameter of 8 mm is then an extreme minimum. As for the diameter of the sheet of the mainsail it depends of course on the purchase of the tackle; the diameter indicated here would be that of a direct load (1:1), without purchase.

TABLEAU VI-IV
CORRESPONDANCES BETWEEN STAYS, HALYARDS AND SHEETS

Stay - 1 x 19		Genoa and Spinnaker Halyard		Mainsail Halyard		Genoa sheet	Mainsail sheet	Spinnaker sheet	Spinnaker Brace	
∅	R_f	7 X 19	Cup	7 X 19	Cup				7 x 19	Cup
19	27000	11,2								
15,9	22000	9,6	18	8	16	16	16	16	9,6	18
14,3	17800	8	16	8	16	16	16	16	8	18
12,7	13600	8	16	8	16	14	16	16	8	18
11,2	10800	8	16	6,4	16	14	14	14	8	16
9,6	8200	6,4	14	5,6	14	12	14	14	-	16
8	5800	5,6	14	4,8	14	12	12	12	-	14
7	4650	4,8	12	4	12	10	10	10	-	12
6,4	3650	4	10	3,2	10	8	8	8	-	10
5,6	2850	4	10	3,2	8	8	8	8	-	10
4,8	2050	3,2	8	2,4	8	8	8	8	-	8
4	1450	3,2	8	2,4	8	8	8	8	-	8
3,2	900	2,4	8	2,4	8	8	8	8		

BREAKING STRENGTH OF THE CABLES AND ROPES in daN/mm^2

Cables mm	2,4	3,2	4	4,8	5,6	6,4	8	9,6
Cable 7 x 19	350	660	950	1350	1900	2500	3900	5700

Cordages mm	6	8	10	12	14	16	18
Glenstein Cup	565	1040	2040	3120	3920	5780	6900
Glenstein Gemini	755	1160	2270	3140	4000	4890	6200

[

VI-III - 1. - REMARKS ON SIMPLIFIED METHOD (1)

(1) We know that the righting moment is equal to the moment of capsizing, itself produced from F_y x H, lateral force of the sails by the vertical distance of the centres of the sails and immersed canoe body. However, the moment of the rigging compared to the horizontal plane of deck collar is F_y x h', h' being the height of the centre of the sails above the deck collar. One can think that there is the need to introduce a certain safety coefficient or to compensate for other additional components increasing the moment of the rigging loaded on the chainplates, such as the moment exerted by the vertical component of the jib sheet load, or the weight of the mast.

(2) The cap-shrouds and the lower shrouds do not always lead onto isolated chainplates on the side of the hull. In this case it is necessary to calculate an 'e' intermediate such as:

$$e = (\sum C_{cap}\, e') + (C_{low}.\, e'')] / [(\sum C_{cap} + C_{low})]$$ where

C is the percentage of P_T corresponding to the stay concerned and given in table VI-II;
e' and e'' are the respective spacings of the chainplates of the cap-shroud and the lower shroud.
For example if, in a rig with two sets of spreaders, the chainplate of lower is e'' = 1,25 m and that of the cap-shroud is with e' = 1,20 m

$$e = [(30 + 30) \text{ x } 1,20 + 45 \text{ x } 1,25] / (30 + 30 + 45) = 1,22 \text{ m}$$

(3) The coefficient 1,85 appears a little small even for yachts where one seeks a minimum angle of the forestay and it does not seem to take account of the load of the return of the halyards. One can thus change it to 2. In the example analysed previously it reached 2,05 by including the returns of the halyards.

(4) For the lower shroud, it should not be forgotten that it acts off the vertical component of the load on the chainplate, the resultant in the stays will be thus F/cos α, α being the angle of the stay with the mast in the transverse plan.
In the case of double lowers, the forward lower has a higher load than that of the aft lower since it balances the aft load of the sail, a role filled alternatively by the baby stay. Nevertheless as the safety coefficient of the aft lower must be higher, one will also share the load on the two lowers. The larger coefficient compared to the single lower probably takes account of the increase due to their angulation in the longitudinal plane and to the greater variations due to the dynamic effects.
The table does not give the loads in the intermediate fore stay. One will be able to estimate that the longitudinal loading that they have to balance will be equal to:

- for the baby stay: 1,3 % of the load of the lower shroud, -
- for the intermediate stay : 2,4 % of the load of the intermediate shroud.

If there is only one baby stay, between the two sets of spreaders, as in our example, one will take the sum of the two preceding loads.
Finally it should be noted that these coefficients do not take account of the respective lengths of the spreaders and the spacing of the chainplates. One can thus think that one considers these a constant dimension. Under other conditions one indeed notes transfers of the load of one shroud to the next, which partly explains the differences in the coefficients between the cap-shroud and the lower shroud while there was not much in the example studied, the undervaluation of the proportion of the loads due to the forestay representing the balance of the difference.

(5) For a material of a modulus of elasticity E' different from light alloy one has

$I_{E'} = I_{alu}$ x 7000 / E'

Here, the modulus of elasticity of the spruce is taken for 975 daN/mm^2.

(6) The value of the load is not given for the backstay. One will be able to use 70 % of the forestay, in the same way for runner balancing the forestay in a 7/8 rig. For this one will be able to take account of the difference in angle.

VI-III - 2. - APPLICATION TO THE PRECEDING EXAMPLE

Let us point out the characteristics necessary for the simplified calculation and compare with the preceding results.
RM_{30} = 3360 daN-m;
H = 6,61 m;
e = 1,26 m

a) P_T = 3360 x 1,5 / 1,26 = 4000 daN

b) P = 4000 x 1,85 = 7400 daN against 11859 is, for this last an initial safety coefficient of 1,6 compared to the simplified method.

c) Load in the stays:

Cap-shroud: (2,75 x 4000 x 30) / (100 cos 13,74°) = 3397 daN, against 4103,4 daN
Intermediate Shroud: (2,75 x 4000 x 30) / (100 cos 14,58°) = 3410 daN, against 4010,4 daN
Lower-shroud: (3,00 x 4000 x 45) / (100 cos 14,03°) = 5566 daN, against 4689,6 daN

The differences, less on the upper shrouds and more on the lower shroud, correspond to the transfers of load that occurs with the progressive shortening of the spreaders.
The totals are appreciably equal with: 12373 daN against 12803,4 daN.

Fore Stay:
RM_{30} / 6,61 = 508,72 giving, according to graph VI-23, a diameter of 7,7 correspondent to a load of 5820 daN, against 5834 daN.

Baby Stay:
[3 x 4000 x 45 x 1,3 / 100^2] + [2,5 x 4000 x 30 x 2,4 / 100^2] = 142,2 / sin 15° = 549,4 daN, against 827 daN
The diameter of the most similar 1 x 19 cable will be 8 mm for the whole of the shrouds and the forestay, 7 mm for the backstay and 3,2 for the baby stay.

d) Moments of inertia of the mast (Table VI-III)

Transverse:
Lower panel: 1,61 x 7770 x 430^2 x 10^{-8} x 1,25 = 289 cm^4
Higher Panels: 2,4 x 7770 x 415^2 x 10^{-8} = 321 cm^4

Longitudinal:
Lower panel: 0,64 x 7770 x 1280^2 x 10^{-8} x 1,25 = 1018 cm^4
Against 380 and 730 for the selected profile.

It is noted that the longitudinal moment of inertia is stronger than for the selected profile. But a coefficient 0,64 relates to only the rigging with one set of spreaders, but we here have two of them. If we take, as for the boats from 10 to 14 m, a coefficient of 0,51, the moment of inertia falls to 811 cm^4, which is much closer. The difference confirms the higher stress in the longitudinal direction already noted.
In fact one notes that the majority of the profiles of the trade have a ratio of the moments of inertia in the neighbourhood of 2.
For flexible masts working in compression and inflection, and either in buckling, the moments of inertia of the profiles should be closer to a ratio = 1.

e) Running Rigging

From the diameter of the forestay (8 mm), table VI-IV gives us:

Genoa and spinnaker halyards:	cable 7 x 19 - 5,6∅,	and rope - 14∅;
Mainsail halyard:	cable 7 x 19 - 4,8∅,	and rope - 12∅;
Sheets:		12∅;
Spinnaker Brace:		14∅.

It is quite certain that these diameters of the sheets correspond to the maximum of the heaviest sails and that other sizes must be planned for the lighter sails.

VI-III - 3. - PROCTOR GRAPHIC

The mast manufacturer, Proctor, established a graph allowing the quick determination of the profile type to use according to two characteristics of the yacht: the floatation length and the height of the fore-triangle. I recalled it as from [Je l'ai retracé à??] the transverse moments of inertia. The longitudinal moment of inertia is almost double the transverse (fig. VI-24).
This graph is practical for a quick determination, at the level of the draft for example, but is not sufficient, in my opinion, when one requires a precision or better-defined safety.

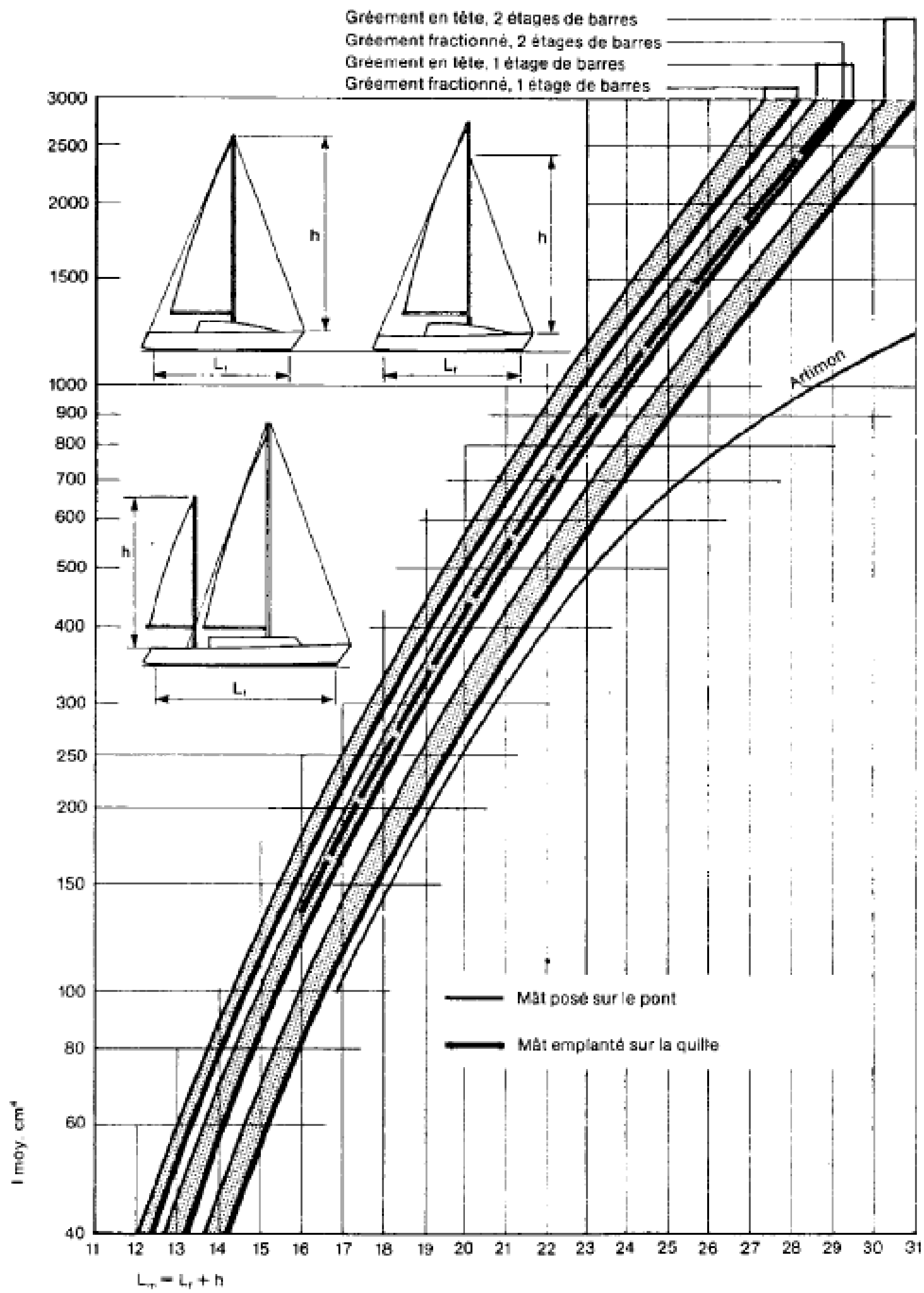

Fig. VI-24. Graphique donnant une première approximation du moment d'inertie moyen $I_{moy} = \frac{I_x + I_y}{2}$, *en fonction de la somme de la longueur de flottaison et de la hauteur du capelage de foc ou du mât d'artimon.*

VI-III - 4. - MIZZEN MAST

The force developed by the sail having been determined from the distribution coefficients defined at the beginning of this chapter the calculation is the same as the one of a big mast without a jib. In the simplified method one has

$P_T = [(MR_{30} \times 1,5) / (e \times C)]$ with

C = 3 for a yawl; C = 2 for a ketch with a big mizzen.

The safety coefficients are the following:

Yawls: shrouds 1,5; chainplates 2;

Ketches: shrouds 2, chainplates 2,5.

The loads in the shrouds are valued at:

20% of P_T for the Cap-shroud;

42% of P_T for the lower shroud;

38% of P_T for the intermediate fore stay.

VI-III - 5. - CALCULATION OF THE BOOM

The boom is held at the gooseneck, to the point of attachment of the mainsheet and to the point of attachment of the vang.

The first analysis suggested is that the normal effort to the boom followed a triangulated distribution with a maximum at the point at the clew and 0 to the tack. The cutting of the modern large sails moves the load distribution a lot more towards the clew. On the other hand, the main sheet constitutes a more and more important fixing point especially, of course, as soon as it is separated from clew.

To take account of these considerations one will define the boom as a beam working in bending under the effort of a resultant situated 4/5 of its length from the gooseneck (0,8 E) and subjected to a compression axial force applied at the clew. We will estimate that the moment generated by this force is balanced instrumentally by the moments generated by the mainsheet and the vang.

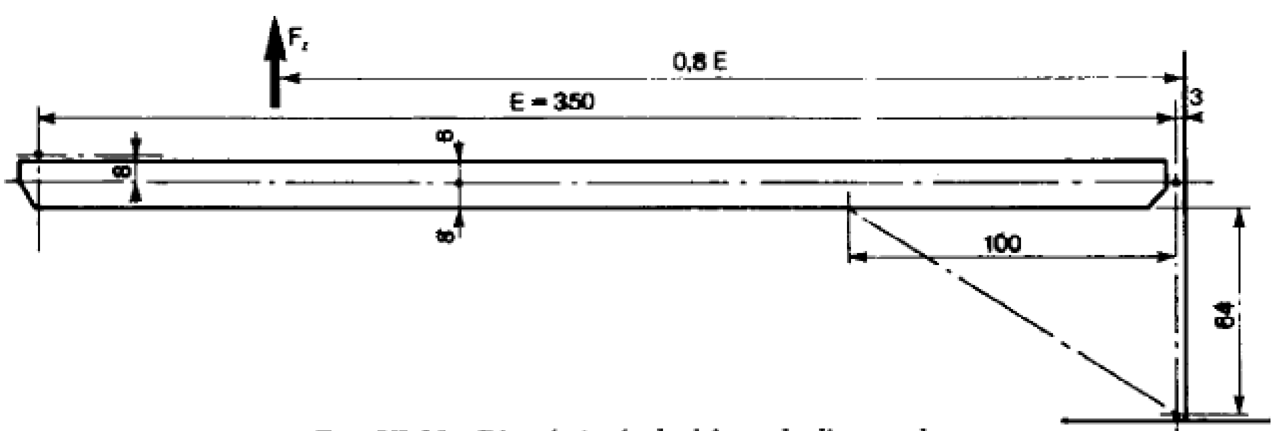

Fig. VI-25. Géométrie de la bôme de l'exemple.

In certain cases these conditions can be again harder, as for example for a big transocean sailer, for which one will be able to consider that the mainsheet can be brought to bear the entire the effort of the sail.

Having determined the value of F_y of the main sail by the method established in section V-II-3, we estimate the forces at:

$3\ F_{yg-v} \cos\alpha = F_z$
$3\ F_{yg-v} \sin\alpha = F_x$
with $\alpha = \tan^{-1}(E/P)$

For our example (fig. VI-25) will have us with

E = 353 cm, e = 100 cm and $\alpha = 17{,}07°$
$F_z = 3 \times 236{,}6 \cos 17{,}07° = 678{,}5$ daN
$F_x = 3 \times 236{,}6 \sin 17{,}07° = 194{,}5$ daN

The moment of F_z in comparison with the gooseneck will be:

$M = F_z \times 0{,}8 \times E = 678{,}5 \times 0{,}8 \times 350 = 189980$ cm-daN

and the vertical load on the vang:

$F_{h\text{-}b} = 189980 / (2 \times 100) = 950$ daN

This effort will generate an additional compression in the forepart the boom:

$C = 950 \times 100 / 64 = 1484$ daN

Under the effect of the load of the vang, the boom will bend. The maximum moment bending will be situated in the point of attachment of the vang and will be:

$M_{f\,max} = F_{h\text{-}b}\,(0{,}8\,E - e) \times e / (0{,}8\,E)$
$= 950\,(0{,}8 \times 350 - 100) \times 100 / 0{,}8 \times 350$
$= 61071{,}4$ cm-daN

With $R_p = 2400$ daN/cm^2 one will have to have:

$I/v \geq 61071{,}4 / 2400 = 25{,}45$ cm^3.

The profile F 340 of Francespar will give us the following characteristics:

- dimensions: 101 x 140 mm
- section: 13,7 cm^2
- Iy = 150 cm^4
- Iz = 370 cm^4

The clew attachment will be at about 8 cm above the centreline, giving an $I_z/v = 370/8 = 46{,}25$ cm^3 for the underside, working in tension, and $I_z/v = 370/6 = 61{,}67$ cm^3 for the topside, working in compression.

The critical load that the boom can bear will be:

$P_{cri} = \pi^2 \times 700000 \times 370/350^2 = 20867$ daN

The bending moment applied to the boom will be the sum of the due moments to the vertical load and to the off centre position of the compression load.

This off centre position will be equal to the distance between the point of clew and the horizontal axis of the gooseneck, in our case about 8 cm. One will therefore have:

$M = 61071{,}4 + (194{,}5 \times 8) = 62627{,}4$ cm-daN

Using the same calculation method as for the mast, one will have:

$\sigma_{max} = [194{,}5 / 13{,}7] + [62627{,}4 / [46{,}25\,(1 - 194{,}5 / 20867)]] = 1381$ daN/cm^2 for the underside and

$\sigma_{max} = [194{,}5 / 13{,}7] + [62627{,}4 / [61{,}67\,(1 - 194{,}5 / 20867)]] = 1039{,}3$ daN/cm^2 for the topside, with at least a coefficient of 1,9 in comparison with elastic limit of the alloy.

The loads on the boom situated between the point of attachments of the vang and gooseneck is subjected to an additional compression.

The point of application of this load being situated underneath the section will induce a bending moment opposite to the direction of the compression from the clew. The section concerned being, moreover, rather short, the generated stresses will be compression only and equal to P/S, that is to say in our example:
$\sigma c = 1484 / 13,7 = 108,3$ daN/cm^2
that be added to add to σ_{max} of the top of the boom to give 1039,3 + 108,3 = 1147,6 daN/cm^2 while the stress on the bottom part will be reduced to be: 1381 - 108,3 = 1272,7 daN/cm^2.

In the transverse direction the normal efforts on the boom are weak but can accidentally become large, for example, with the aft wind, if it engages on a roll and the mainsheet withholds it. These loads being difficult to determine, one will take for the transverse moment of inertia of the boom between 0,5 and 0,6 of the vertical moment of inertia.
The bending moment diminishes almost linearly from the point of attachment of the vang towards the clew; it is tempting to reduce the boom by the cutting of openings in its sides. These will have to be progressively increased in width and the remaining alternate braces will have to be inclined to 45° to withstand the shearing loads (fig. VI-26).

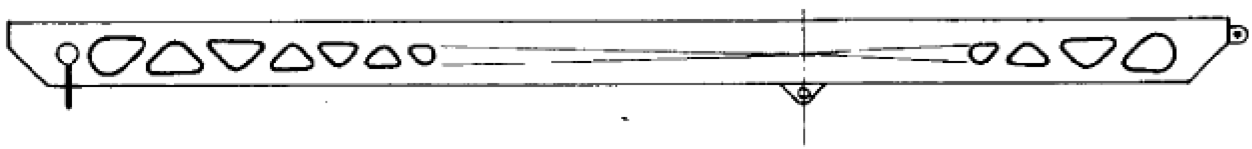

Fig. VI-26. Allègement de la bôme.

VI-IV - MATERIA S AND ROFI ES OF MASTS

Today, almost all the masts are made of aluminium alloy with heat treatment, with alloys magnesium, silicon and manganese - A-SGM treated to T6. The differences of characteristics that one can note originate essentially from the silicon content and other ingredients and the process of heat treatment.
Nevertheless other materials were or will be used for the manufacture of masts: wood, steel, composite, etc.
The interest of a new material in compared to another is measured primarily by the ratio E_f/d^3* owing to the fact that the modulus of elasticity defines the critical load. But one must take account of the resistance in compression and of the ratio R_{ec}/d since the deflections depend on it and that the local stresses in a mast are always in compression - at least for a stayed mast.
* See section IV-II-2
It is interesting to recount then the values of the figure IV-XI:

	R_{ec}/d	E_f/d^3
Spruce	8,7	11742
Alloy A-SGM T6	10,74	356
Stainless Steel	3,4	37,5
UD R glass fibre with epoxy	33,3	734
UD HT carbon with epoxy	98,6	3844

One will note the excellent performance of spruce that, even with a wide safety factor to take account of the possible structure irregularities, comes practically equal to carbon fibre. The resistance in compression of this is often superfluous except for sections of large dimension and too thin a wall where the local buckling becomes the more critical factor. This will not be the case with a mast in spruce given the thickness of the walls.
It is necessary to take equal account, for masts in composite, of the fact that the fibre to the adhesive bond will not allow it to attain theoretical performances. To the other extremity one sees that the stainless steel, sometimes envisioned for the manufacture of masts, presents no interest.
For the moments of inertia of a mast being defined, there remains an infinity of possible dimensions according to the thickness that one gives to the wall. Nevertheless the section of the profile - therefore its weight - growing as the square of its dimensions while the inertia moments grow to the power four, the larger the exterior dimensions the more the thickness must be reduced to preserve the same section and the local buckling of the walls quickly becomes critical. For the same reason, a material with high resistance in compression allowing a reduction in the section of the profile will not be able, most of the time, to be used to the maximum of its possibilities.
In the Volume I studied the form of the aerodynamic sections. From the mechanical standpoint do not forget that the value of the moments of inertia according to different axes of the section follows an elliptic curve of which the axes have for length the longitudinal and transverse moments of inertia (fig. VI-27).

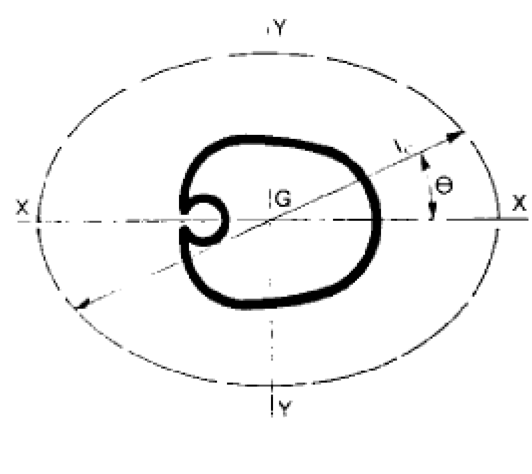

Fig. VI-27 Knowing the moments of inertia of a section, Ix and Iy, it is possible to know the moment of inertia I_θ for any inclined axis of the angle θ, it suffices for that to trace the ellipse having for axes the values Ix and Iy.

In addition the bending of the mast occurs in an intermediate direction - and variable in its height - between these two axes.
When one wishes to modify the bending characteristics of a mast by the addition of internal reinforcements, do not forget that their position will not be unspecified; one will favour the axis on which they will be located. And when one wants to stiffen the two directions simultaneously, rather than to place reinforcements on the two principal axes, one will locate them on the diagonal axes.
Local internal reinforcements can be also planned for the fixing of the fasteners of stay.
In the drawing of the sections one will avoid flat parts whose local buckling strength would constitute a weak point. From this point of view an elliptic section represents the best compromise.
For the same reason, on an open section (for the passage of a rope or a sail with roller) the internal wall will be always curved (fig. VI-28).

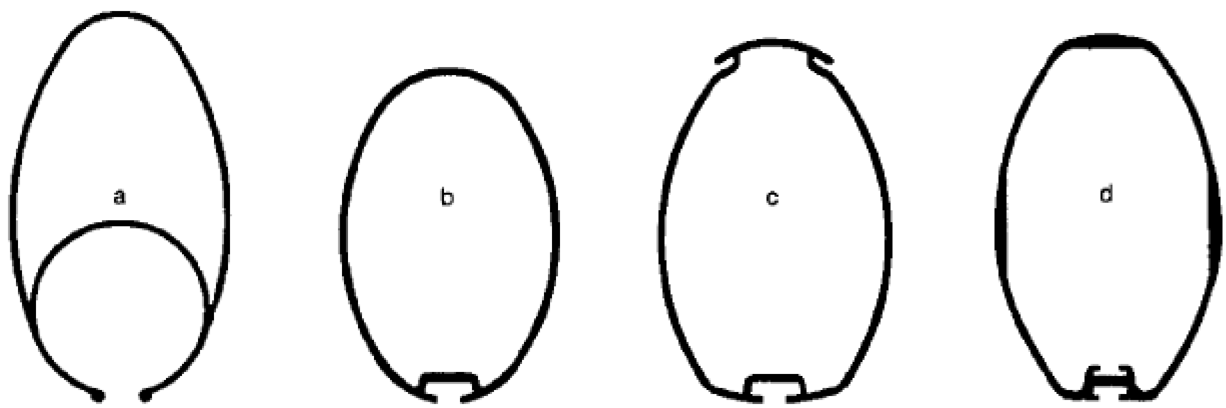

Fig. VI-28. Different examples of mast sections.
a - section Francespar for furling sails;
b - section Francespar classical elliptic;
c - section Z-Spar with rail of integrated pole track;
d - section Marechal to report high moments of inertia and reinforcement on the axes; the internal rail is destined to receive a plastic conduit for the electric cables.

It is not always possible to obtain a mast in one length, generally for transportation reasons or of manufacture, but also because the manufacturers are limited by the length of the heat treatment ovens or of the anodising plant. In this case, the joint of the sections must carry out an important effect on the profile. It is necessary to look for the points where the bending moment is low and that correspond to the modulation points of the distorted mast. They are situated in the vicinity of the quarter of the panel above and below the spreaders. In any case it will not be necessary to place the joins too far from this as one too often sees.
The join will be effected by glue and fastened sleeve. The joint between the two extremities must be perfect, with no false support, in a manner to transmit uniformly the compression loads without introducing parasitic bending moments. In order not to create a too hard change, the internal sleeve, constituted of a rolled sheet of the same thickness as the wall, would be taper cut (fig. VI-29).

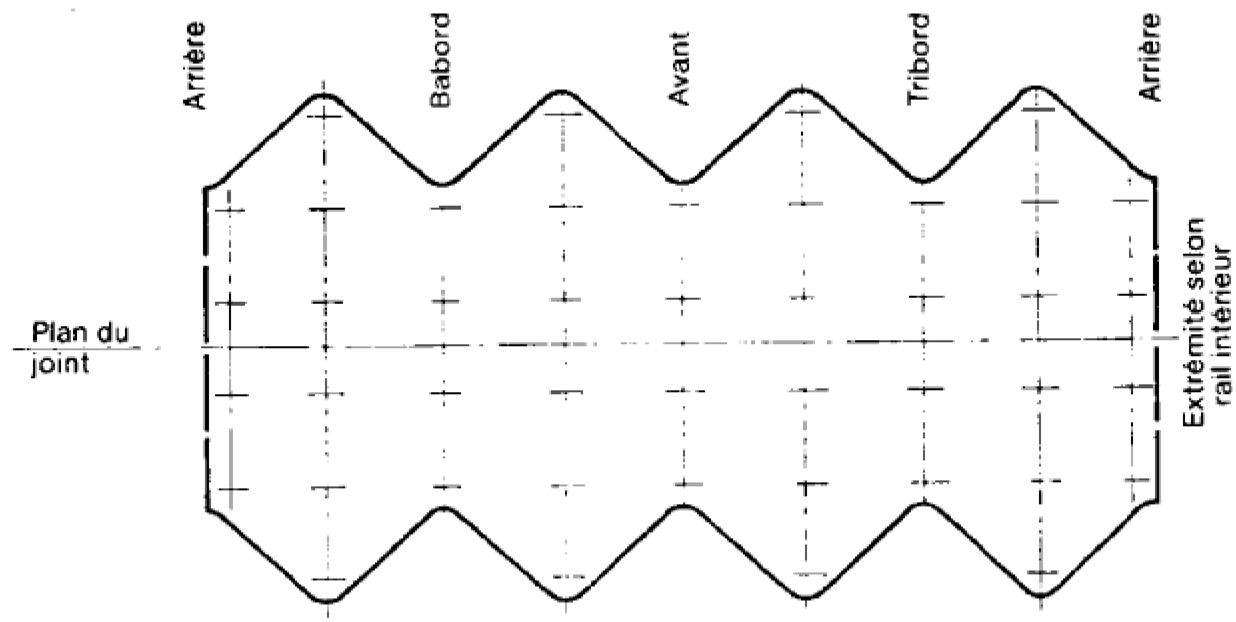

Fig. VI-29. Connection Collar for elements of mast. The height is equal at least to half of the interior perimeter of the mast; the "horns" are placed on the diagonal axes of the section; fixing is ensured by epoxy joining and Pop rivets counter-drilled with the mast. The joint, placed on the back face comes to butt against the luff rail; it is wise to bring back a guide out of U on the outside of this rail to avoid any risk of misalignment which would cause the blocking of the slides.

The alloy A-SGM having undergone a heat treatment, all operations of welding will reduce its mechanical characteristics. One will forbid oneself therefore all welding in a plane perpendicular to the axis of the mast, except of course, to the ends where only compression and shearing loads exist, for which the section is widely overabundant. In particular one will reject the spreader mountings fixed on a transverse plate and welded to the mast wall. The taper in the masthead necessitates a weld along the mast wall. This is admissible provided that the weld is carried out with the maximum of precautions to reduce the heat-affected width as much as possible.

These tapers are interesting not only from the viewpoint of the easing of the top end of the mast, but also to reduce the width presented to the wind and the harmful effects that result for the main sail. The cut will begin mid-way up the last panel for a masthead rig and the exterior dimensions will not be reduced by more than half. The bend of the reduction in dimensions will be parabolic. For a 7/8 rig, the cut will start mid-way up the last panel under the hound, but it is not possible to give a proportion and a reduction form of precise dimensions for they depend on the cut of the mainsail. This is the reason it is practically always necessary to foresee a jumper of which the angle of the struts should be adjustable to be able to absorb the bending of the mast in the two planes.

VI-V - A   ESSORIES AND E   UI   MENT

It is rare that one is brought to draw the various incidental mast fittings. The serious manufacturers propose a range that allows manufacturing almost for all the possible configurations of Rigging. It will be nevertheless important to study the equipment and to choose it according to a number of criteria.
It is not, of course, possible to review here all the proposed solutions and one will have to obtain the catalogues oneself.
Unfortunately these are mostly of a rarity, especially as for the description of the equipment. One is happy when one finds all the essential pieces of information to the choice of the profile: dimensions, thickness, surface of the section, moments of inertia and position of the centre of area.

VI-V - 1. Head of the Mast

One of the first qualities of a masthead must be the lightness since it is placed in a particularly unfavourable place not only for stability but especially for the cushioning of the rolling of the yacht. It will therefore be manufactured in welded alloy at the top of the mast.
The bracket on which the backstay is set up must present a sufficient rigidity vertically as well as transversely. The reach of the clevis pin must resist hammering. For that it is often necessary to double the thickness by a disc or a welded shape and, in the biggest sizes, a hollow pin of large diameter will allow associated lightness and large surface support. The same considerations apply to the fixing of the forestay but, for this it will be necessary to take account of variation of its initial angle that, as we saw, it can attain about ten degrees or less in the longitudinal direction and as much to each side. A double joint is therefore essential.
I could not impress too much on the importance of the diameter of the sheaves for the halyards. These are never rather large and practically all the premature rupture problems of halyards are due to too small a sheave. This was the case in particular of *Club Mediterranee**. All textile halyards, often used on the cruising yachts up to a dozen meters, suit themselves to smaller but wider sheaves. On the other hand, the halyards in Kevlar ask for sheaves at least as big as for steel wire. Such sheaves require, in order not to be too heavy, a carefully studied lightening. Transverse rigidity must be preserved so that they cannot foul themselves. The hub must be wider than the rim by some fraction of a millimetre so that it does not wear on the side of the housing, which would slow its rotation. The light alloy sheave will be provided with a bearing in poly-acetal, or equivalent material, preferably lubricated, with graphite or molybdenum. In the big dimensions, bearings with rollers or balls are necessary. In all the bores, the pin of the sheave must be able to be removed, without dismantling any other elements; the sheave of the jib halyard, for example, must be able be gotten out without being bothered by the forestay. The rollers or the balls of the bearings must be retained in cages. It should not be forgotten that these disassemblies will be often carried out with the mast in place.

The halyards must equally be able to be passed without removing the sheaves, this that implies a housing width at least equal to the diameter of the rope.
The rail or the boltrope throat of the main sail will always have to be provided with a headboard, even if the yacht is not destined for races. It is indeed always necessary to provide a minimum height between the axis of the sheave and the head of the sail so that it can easily orient itself without being prevented by too short a free length of the halyard.
This height must be of at least 6 times the [horizontal] distance between the back of the mast and the eye of the halyard point.

The lips of the sheave and housing of the jib halyard must allow an orientation around its static axis in a cone of 10° of half angle to the summit, with no fouling.

The halyards of the spinnaker must be able to orient themselves at least in a quarter of sphere unlimited by a perpendicular or horizontal plane to the mast and the transverse plane. The simplest solution consists in mounting a pulley to swivel on a fixed eye at the end of a small bracket. The eye will be inclined at 30° to the vertical and the bracket will be shifted to one side in a manner that the pulley does not come in conflict with the forestay (fig. VI-30).

When one desires internal halyards, this mounting is usable while allowing these to enter the mast by an exit hole at a certain distance under the head. The exit hole must be fitted with round edges on its perimeter or provided with a sheave to reduce the wear that one nevertheless cannot totally avoid. On the other hand the exit hole weakens the section of the mast in a particularly critical place.

If one is not limited by gauge problems one can use, for the spinnaker halyards, a sheave mounted in a cage pivoting around a vertical hollow hub in which passes the return of the halyard. This mounting is placed above the forestay allowing a lateral clearance of 180° with a single cage, but is a lot more limited with two cages. It is more inconvenient to lengthen the mast. It is the same with the use of spinnaker halyards exits consisting of vertical rollers. To tell the truth, still no one has found a satisfactory solution to this problem.

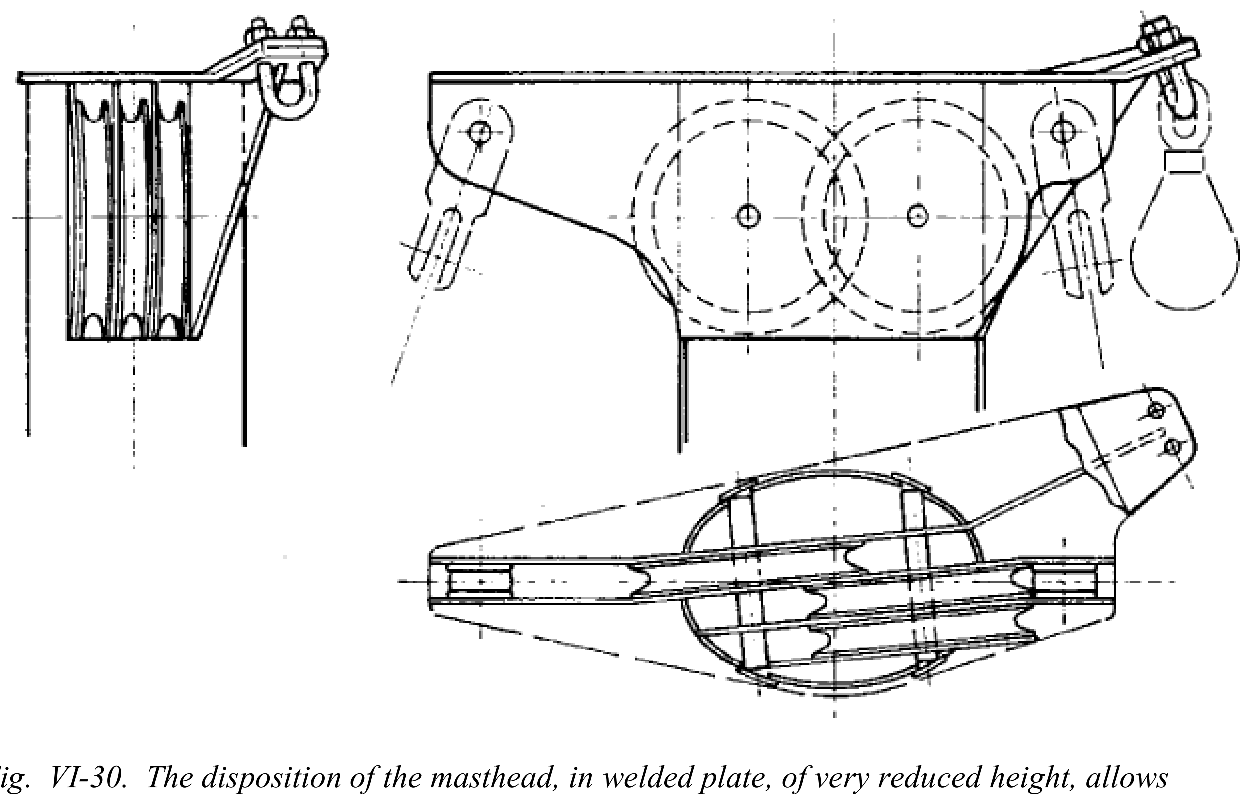

Fig. VI-30. The disposition of the masthead, in welded plate, of very reduced height, allows nevertheless the use of large sheaves, with the exit of the principal halyards on the centreline; the auxiliary jib halyard is the only one off centre; one will note that the joint of the forestay is only at an angle of 10°. The only inconvenience lies in the fact that the sheaves can only be dismantled by the removal through the opposite side to the halyard exit; the pins are kept by screwed on small plates. The thickness of the plate is doubled, in way of the forestay and backstay pins, by internal welded discs; as against double veneers welded equally to the extremity of the bracket.

VI-V - 2. FIXING OF THE SHROUDS

The classical system of chainplates fixed on the gunnels is an inheritance from the wooden masts. This remains perfectly valid so long as one does not seek optimal aerodynamic qualities. It must however respond to a number of stresses.

The free part of the chainplates must be long enough to leave space at the end of the axis for the assembly of its pin. Its play with the lug must allow a reduction of the initial angle of at least 2°, when the mast is curved. The chainplate can be single when the shroud is provided with a toggle, or double in the case of an eye, the most frequent solution.

In both cases one must check the bearing load and it will be often necessary to double the thickness by a disc or a welded plates. When the chainplate is two plates, the spanning of the two plates must be symmetrical in order not to create a false loading. The tang is generally taken on a bolt through the mast. It is essential that this bolt is provided with a spacer to join the two walls, thus reducing the secondary stresses (fig. VI-3 1). Here again it is necessary to verify the bearing load, not only between the tang and the bolt but especially between the bolt and the wall of the mast.

A hollow tube or a socket of big diameter generally allows the resolving of this problem at the level of the tang but a doubling in stainless steel must be fastened on the wall to distribute the load and to support the bulk of the bearing load. In any case the pieces do not bear on a threaded part of the pin and the nuts_must be provided with a lock system.

To diminish the aerodynamic turbulences on the mast, but often also by preoccupation with a reduction of the cost price, the manufacturers adopted clash of systems of fixing the stay to the mast wall. These systems do not have anything basically bad with the proviso of respecting a number of rules.

In no case should the fixing be carried out directly on the light alloy wall but on a part of reinforcement, generally in stainless steel, able to support the stresses of the bearing load. This part must relate to the thickness of the wall of the mast to transmit the compressive forces, fastening rivets or screws alone not being able to provide this function. Nevertheless the opening in the partition must be as small as possible because it is always located at the level of a large bending moment. Especially, the system of fixing of swaging on the cable and its tang must allow a clearance under tension of several degrees in all directions. This condemns the ends in T of which the bar is only a simple cylinder. The reach always must be spherical. In order to align the cable with its range, the end is sometimes bent, it will be necessary to watch that the play between the wall and the heel is sufficient that in any case it does not come to rest on it, otherwise one can be assured to provoke a rupture of the cable at the entry into the end, that is to say latter to height of the heel. Moreover, the section on the bent part must be such that it cannot distort under the load. Without any doubt it is the combination of these two defects that caused the failure of the trimaran of Kersauzon, Jacques Ribourel. Lastly, is it necessary to specify it? A security system must prevent the end from escaping its housing.

The attached shroud being located, usually, in proximity of the root of the spreader, ensuring the liaison between the walls. If it is not , a tie must link the two opposed parts.

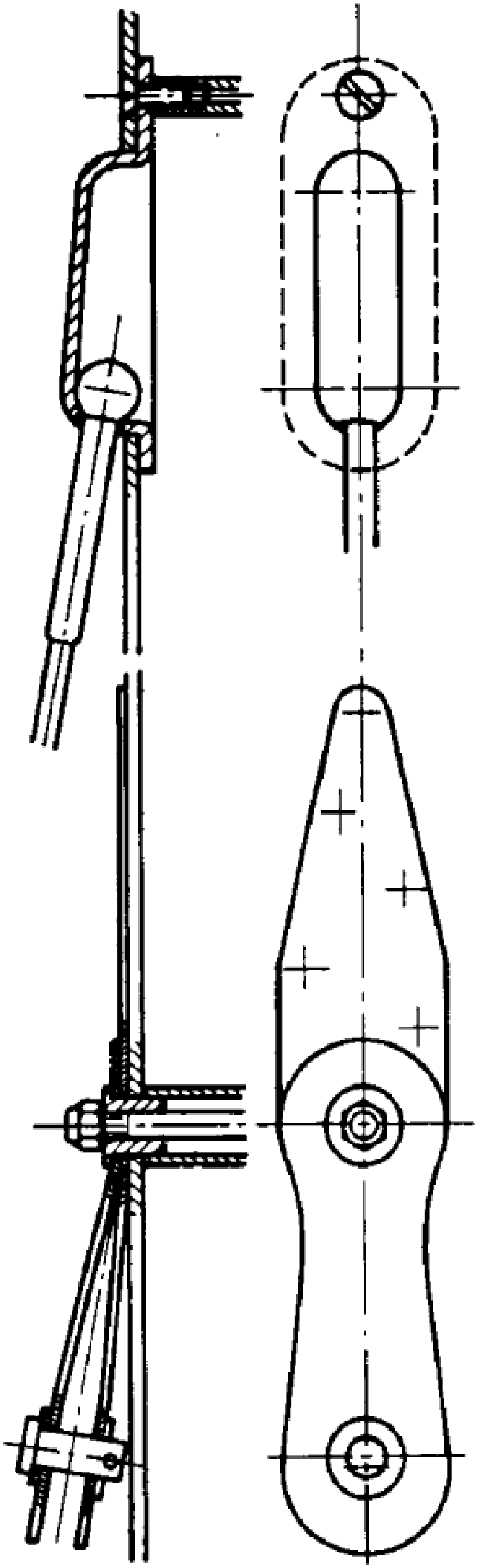

Fig. VI-31. Two systems of shroud attachment. *Top: a spherical end is retained by a pressed stainless steel cup. The articulation is excellent; as well the range on the mast. The retaining screw is screwed in the spacer transferring the lateral load to the two walls. When two shrouds attach themselves to the same place it will be necessary to shift the attachment in height of a distance equal to at least three times the length of the opening.*

Below: classical tang in the shape of blanket. One will note the socket increasing the diameter of the wall in the mast and on which comes to be centred on the spacer, and the gap of the fixing holes of the distribution plate.

VI-V - 3. SPREADERS

Today spreaders are mostly manufactured in profiled tubes. It is unfortunate that the manufacturers do not profit from it to wedge them to a negative angle of incidence of about ten degrees, which would reduce their windage a lot. All the big classical architects knew that.
In the vertical direction, the spreader must be fixed according to the bisection of the angle of the shroud to its passage at its end in order to avoid all parasitic loads. Its fixing nevertheless must possess a certain flexibility to take account of the small errors that can introduce themselves to the mounting of the shrouds, due to variations to their lengthening when the mast works and bends.
In the longitudinal direction, the loads on the fixing can be very high when the mast is curved forwards. It is therefore good that this fixing is secured in two points as distant as possible, forward and behind the spreader bar, rather than to the centre, to reduce the stresses on the band fastened on the mast, a certain flexibility is nevertheless favourable. This band will be developed enough to divide up the compression load over a large area and, if need, the two opposite fittings will be connected up by a tie-bar with spacer. A good system consists in articulating the fixing on a horizontal axis of which the bearings are combined with the band while the spreader's plate is done with interposition of a sheet of neoprene (fig. VI-32 a). Nevertheless, for the yachts up to about eight meters, a fixing on a bolt through the mast is admissible, provided that this applies the same criteria as that for the fixing pin of the tangs (to brace and distribute the load). Besides, they are able to be confused.
The spreader working in buckling can be reduced in section from the centre towards the extremity. Nevertheless the manufacturers sometimes use longer sections than necessary to have a big fixing width on the mast, in this case the taper is done on the whole length of the spreader.
The extremity comprises of an end in which movement of the cable is locked. In any case it must not concern the extremity of the tube and, rather than a locking by an exterior screw, it is preferable that the screw be interior to the end and bears on a shoe receiving the cable and making it possible to round off with sufficient angle (fig. VI-32 b).
This assembly is imperative for the stays leaving the spreader. The shoe will have sufficient play to let the stay orient itself and the end of the thumbscrew will be spherical.
One will avoid of course any system containing parts welded to the mast, in particular those using a broad horizontal flat part crossing the mast and onto the ends of which the spreader section is fixed; with such a system the side resistance of the mast is often reduced by more than 30 % by the reduction in the characteristics of metal.
With rigging on several sets of spreaders, does one have to take all the upper shrouds to the deck or not? Without any doubt - yes.
One gains there initially in facility of adjustment, it is never very easy to go aloft to adjust a turnbuckle at the end of a spreader. One also gains there on wind resistance because two smaller cables in tandem will have less wind resistance than a larger cable *. It will simply have to be taken care that they are placed one behind the other.
This implies that all the shrouds pass by the ends of spreaders although only the upper shroud correspondingly will be locked. It is the only disadvantage of the system when the mast curves but then the spreader is subjected to longitudinal loading whose effect on its fixing can be very high. Still this is a disadvantage only from this point of view because, for the behaviour of the mast, that is very favourable since the points of support thus made up in the longitudinal plane make it possible to reduce the moment of inertia of the mast in this direction.
One does not lose in weight since the single cable should have a section equal to the sum of both others and one will not have the weight of the articulated fitting at the end of the spreader; as for the turnbuckle its weight will be placed better at the deck.
If nevertheless, for various reasons, one preferred the solution of the single cap-shroud, the articulations at the end of the spreaders should allow a certain freedom of the cables not only on the transverse level but also in the longitudinal direction.

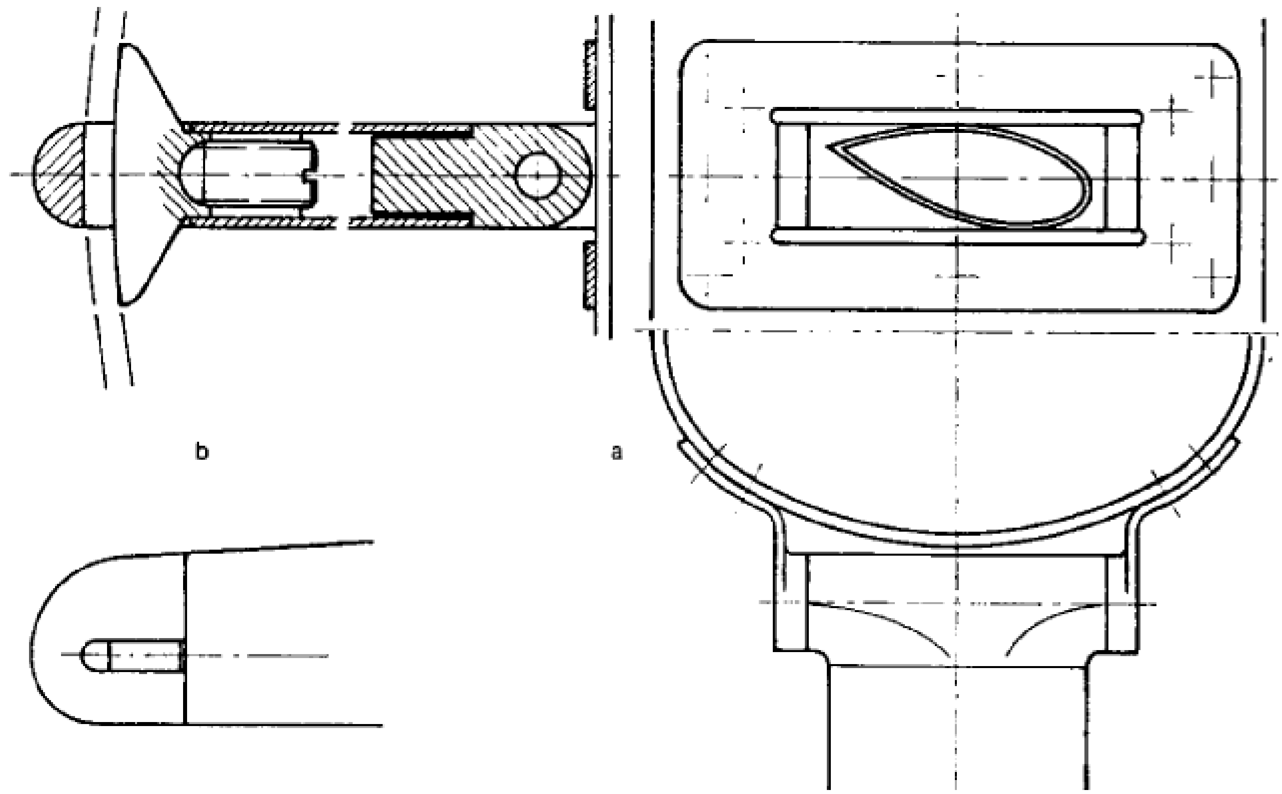

Fig. VI-32 Details of assembly of spreaders. On the left, end with tightening of the cable by an interior clamp. For the cables up to 6 mm one can also use a clamp or a hook with the wire passing by outside, provided that the range of the cable in the end is with the suitable radius, taking into account the angle of the stay and the width of the end. On the right, fixing articulated on the mast; the hinge fitting consists of a plate of steel cut out and reinforced with the ranges of the axis; taking into account the important envelopment of the section of the mast, a spacer is not necessary. One also can, on the largest profiles, use bearings screwed spacers crossing the axes. Note the negative incidence of the shaped bar.

VI-V - 4 FOOT OF MAST, EXITS OF ROPES AND OTHERS

One often pays little attention to the foot of mast, however this has at least two important functions, its behaviour in the horizontal plane and the definition of the point of support compared to the centre of area of the section. This last point calls for some explanations. If the foot of mast and its baseplate are flat, there is little chance but that they are parallel, the least difference in angle, and the foot will bear to fore or the aft, introducing a bending moment and thus a bending into the lower part of the mast. For a mast on the deck, if the support is on the fore this moment can balance that of the boom, it is thus not unfavourable. It will not be the same if the support is to the aft, which unfortunately is the most frequent case; it is the reverse for a mast on the keel. Under the baseplate, a clamp should then be placed compensating for the variations in the angle.

One also can, as on the 12 m J.I to interpose between the two parts a very hard rubber plate distributing the pressure. But best is still to give to the foot of mast a round form with a centre of curve placed forwards of the centre of the section profile (or to the back for a keel stepped mast), one will thus obtain a shift according to the rake which will be more progressive.

It is essential that the mast is fixed in, or on, a base-plates of a sufficient height to avoid any risk of exhaust as we saw that that had probably arrived at the time of the first dismasting of PEN Duick VI. However, if the mast is stepped on the deck one should not ensure this connection by an axis crossing the two parts because, in the event of dismasting, the wrenching of the base-plate could cause a water way. This plate must be bolted, through the deck, to the plate of the pillar and not simply "fixed" by four drive screws as it is too often seen.
The openings in masts provided for the passage of various items are as many entries offered to the rain, it is thus essential that a drainage hole be envisaged at the base.
If the mast is stepped on the deck the hole will be bored in the foot. If it is stepped on the keel another hole will be bored above the deck collar, on the front face, and a polystyrene foam stopper will be inserted below.
The sealing of the deck collar of a keel stepped mast is ensured by a mast boot, rubberised cloth held on the mast and on a pad on the deck collar by metal clamps. One should not forget, of course, to seal the throats and rails.

Two other harmful effects of the light alloy masts affect comfort: noise of the ropes and electric cables to the interior and heat exchange. This last disadvantage can be tiny by coating the part of the mast located under the deck with an insulating coating as one uses some for piping. Stuck inside a fabric sleeve closed by a zipper, it will be easily removable for the dismasting.

The noise of the halyards is much more difficult to eliminate. One can however use the following method. One cuts out rigid foam plates to the interior profile of the section, which one bores to thread them and stick them on rigid PVC tubes as light as possible. The whole being then slipped inside the mast before the installation of the fittings. One can be satisfied with two conduits only if they are large enough to pass several ropes. Their ends will be largely widened and their position will be calculated to be in line with the passage of the halyards. The electric cables will be simply wedged in notches spared on the circumference of the holds. The spacing of those will be 1,50 to 2 m and the exits of cables will be provided with a grommet.
The mast must be blocked in the deck collar by hard rubber chocks placed in front of and behind and whose covered sector will be for each one, equal approximately to the quarter of the circumference of the profile.
The exits of ropes can be located either in the foot of mast, or with height. This solution is however very dangerous because the mast is weakened at a particularly vulnerable place.
At a certain time much of masts of Arpeggio perished by strong wind for this reason. If this solution nevertheless is adopted, the passage through the wall will be reinforced and the halyard protected from chafing by round lips or a cage with two sheaves in tandem.
The openings in the mast will end in round-offs and they will be shifted in height of at least three times their length, in order to not ever have two openings in the same plane. Alignment with the winches is always difficult to ensure correctly. Plates on which they are fixed should not be parallel with the mast but be directed so that the axis of the winch forms an angle of approximately 100° with the halyard turned on the basis of headstock. In the same way, a wedge must never be placed on the axis of pull of the rope that comes to moor but form there with it an angle of 15° with 20° in its plane.

Bases of winches must be firmly fixed, if possible with a row of rivets in the axis, and more on the edges of the support. The nuts of the attaching bolts of the winches must nevertheless remain accessible to a spanner.

The rollers, little used nowadays, must be placed sufficiently far from the exit sheave of the halyard so that the its angle does not vary by more than 3° between the two ends of the drum.

VI-V - 5 ARTICULATION OF THE BOOM

The majority of the articulations of the boom are assembled on a carriage in order to allow a taught sail by a hoist of tack. These carriages slide, generally rather badly, in the throat or the rail used for the boltrope, or in a brought back rail. To improve the slip it would be necessary that these carriages are provided with trimmings out of charged Teflon or poly-acetate, but the throats and the female rails, of too small section, do not allow it. That becomes however possible when the rail is used only as guidance and that the carriage runs, on both sides, directly on the mast. This solution is besides by far the best to balance the important overhang of thorough of the boom to the bearing paces.

The two axes, vertical and transverse, must be as close as possible one to the other and the back face of the mast so that the position of the boom has the minimum of influence on the tension of the ropes. Nevertheless, the clearance of the boom must be able to reach 90° each way, 20° to 30° upwards and downwards.

The tack shackle fixing and the hooks of the reef points will be up on the vertical axis and articulated in the vertical plane.

VI-V - 6 - EQUIPMENT OF THE BOOM

Those are summarized primarily with the attachments at the clew and of vang and with the reefing device.

The first must be sufficiently resistant not to become deformed while leaving with the pulley which is fixed there a liberal side clearance at the bearing paces. It is preferable that the clamp is articulated on a transverse axis. Their fixing must be as distributed as possible, in particular for the vang.

Additional anchoring points must be planned for the reserves used with the back wind.

The vang can consist of a jack, hydraulic or mechanical, which makes it possible to remove the balance or, more generally, of a hoist.

Its point of fixing will be always on the mast or its baseplate. If it is fixed on the deck, which is often the case for a deck stepped mast, it is imperative that an interior tie connects the deck to the baseplate. This is valid for all the keel stepped mast yachts that do not have a bulkhead in the immediate vicinity.

A tackle of the vang will be always as short as possible. A pendant in sheathed cable will connect it to the boom. It will be always preferable to reduce the number of purchases of the tackle for the benefit of a winch. The speed of manoeuvre will be perhaps a little less but the output higher.

The lower fastening point of the vang must have all the freedom of orientation necessary. One too often sees shackles or pulleys to relate to an incorrect fitting at the foot of mast. In the case of a rigid vang in particular, the lower point of fastening must be an articulation similar to that of the boom, their vertical axes being aligned.

The same considerations on the length and the number of purchases are valid for the hoist of the main sheet.

The reef lines like that of the clew tension, are almost always returned, via sheaves placed in the end of the boom and by the interior of this one, towards jammer cams placed below the in-board end. It will have to be checked that the provision of the exit sheaves does not cause a relaxation of the line when one manoeuvres the locking cams, which unfortunately is often the case. From a surface of mainsail of a score of square meters one uses a winch placed under the boom or on the back of the mast for easier hoisting. In the second case the winch base must be held off the mast to leave the passage for the tack line.

The lazy end of the reef lines can be fixed on an eye placed on the side of the boom. If this eye is assembled on an adjustable slide in a rail it is still better because its position is critical for the adjustment of the sail. But if the boltrope is equipped with slides, it will be enough to tie the lazy end around the boom, which eliminates the always-dangerous protuberances.

For the clew tension, which requires precision and force, the first reduction could be obtained while passing the line in a pulley with swivel attached on the sail, the lazy end coming to fix itself on the end of the boom. With mainsails of more than 40 m^2, the pulley will be assembled on a ball or roller carriage on which the clew will be shackled. Not to forget that the end of the boom must be equipped with a point of fixing for the mainsheet.

VI-V - 7 SPINNAKER POLES

The first thing to be defined will be the process of gybing which will determine the type of ends of the pole and the fixing to the mast *.
For the small yachts one generally uses the method of the reversible boom. The two ends are identical and there is a point of fastening on the mast, either one or more bales fixed, shifted in height, or an eye or a fork articulated on a carriage. It will have to be checked that clearance is possible in all the portion of sphere delimited by the deck and the shrouds, without the end being able to be wedged causing its inevitable failure. Because of the reversibility, the topping lift and downhaul must be attached to the middle of the pole, but it is only on the very small yachts (with the spinnaker less than approximately 30 m^2) where the bales can be fitted directly to the mast. Beyond the bending stresses to the loose end, when the pole comes to touch the fore stay, would be too high and manoeuvres will come to stick on goose legs in cable fixed on the ends in order to make the pole work only in compression. Their angle at the ends must be at least 15° and one will use a sheathed cable to avoid it being caught the hair.
From 80 m^2 it is not possible any more to plan to take down the pole from the mast by wind or sea efforts. The reversibility of the boom can nevertheless preserve an interest for the facility of manoeuvre when one pole is used. In this case the ends have a conical external form allowing their fitment in a bell fixed on a carriage with balls, rollers or slides ensuring a sliding motion without effort when it is in service. One should not forget that the push of the pole, very high, almost always occurs with an important offset. The design of the carriage and the rail, and its fixing, must take account of it.
The height adjustment of the carriage must be ensured by a means having an effective blocking [tackle].
The topping lift and downhaul are fixed on the end of the boom, the downhaul, in general, passing through a pulley fixed on the deck, behind the forestay. The effectiveness is thus greater at the loose end , where the load is highest.
For the spinnakers of large surface area or when rigging does not allow gybes with only one pole (fixed baby-stay, cutter...), two poles are used. Their symmetry is not any more of interest. One then uses sometimes, on the carriage, a gooseneck engaging in the end of the pole where it is retained by a bolt. This system is simple, light, offers less protuberance on the mast than the bell but it can be extremely dangerous for the hand of the crewmember that must direct it to engage it.

The choice of the ends and the system of locking of the brace is more within the competence of the user than of the architect. Nevertheless this one will have to take care of its solidity (in particular its fixing on the pole) and of its maintainability (disassembling). The order will place by the interior of the pole and will arise, is in the middle if the boom is symmetrical, that is to say towards the mast. With spinnakers exceeding 50 m^2, the jockey-pole being used to hold out the clew sheet becomes essential. Its fixing on the mast must be provided for.

VI-VI - THE RI IN AN

This plan must provide all the elements making it possible to carry out the mast and rigging, standing and running, of the yacht.
For the masts, it must provide the characteristics of the minimum profile necessary: section, moments of inertia, all dimensions, nomenclature and sites of the accessories and equipment, positions, lengths and angles of the spreaders. In the same way for the booms.
In return, the manufacturer of the mast should provide the exact position of the fastening points of the rigging in order to allow the rigger to calculate exactly the length of his cables.
For standing rigging, one must indicate minimum strengths of the cables (or their diameter in a given grade), their type as well as the type of ends, turnbuckles, etc.
For running rigging, the diameters and specifications of the ropes must be provided but one generally leaves to the rigger the responsibility for calculation of the lengths. Which sometimes surprises!

VI-VI - 1. TRANSVERSE RIGGING

The first option to be defined in the drawing of the transverse rigging is the number of spreaders. Two preliminary decisions will determine this choice: on the one hand the relationship between the maximum spacing of the chainplates and the height of the mast, on the other hand the minimum angle of the shrouds.
The first will be dictated by the desire to return the jibs to the maximum to tighten the wind as much as possible. It is certain that this factor will be more important for a competition yacht than for a cruiser.
As departure bases one will be able to take a distance ‘e’ from the centreline equal to approximately 7 % of ‘I’ for the first and to 9 to 10 % for the second.
For the second decision, it will have to be acknowledged that, for equal transverse efforts, the angle being reduced, the load in the shrouds and compression in the mast will be high. A larger section and thus weight will result from this, as well as a greater difficulty of adjustment.
For a long time it was considered that an angle of 15° was a minimum below which it was not possible to go down without risk. Today, under the influence of the competition yachts produced which sail with increasingly small angles of incidence, one finds sometimes angles lower than 10°. In theory nothing would be opposed to it if everyone were conscious of the increase in loads that results from it, not only on the mast and the stays, but also on chainplates and the structure of the hull, transverse and longitudinal, with increasing height of the mast.
It can be wise to point out that, on the basis of an angle of 15°, the efforts will be increased approximately 25 % for 12°, 50 % for 10° and 90 % for 8°!
One should not forget either that, for the same lengthening of the stay, the angle is reduced; the displacement of the point of attachment is greater which involves in its turn a new reduction of the angle. The adjustment is thus more difficult and it would be logical, under these conditions, to increase the safety coefficients. This is also the reason for which, with rigs of this type, one often uses, for the Cap-shroud, rod of which the stretch is lower and more linear than the cable.
Personally I estimate that one should never go down below 14° for a cruising yacht* and 10° for a racing yacht taking part in races being able to profit from a closer jib.
The two preliminary choices being carried out, one will realize that the number of sets of spreaders is related to the ‘I/e’ ratio that will have to remain lower than the values below.

* Nevertheless a certain tolerance for the mast head cap-shroud for, these masts being practically never hammered, the top panel is less solicited than it could be, which corresponds to a higher safety factor.

	1 stage	2 stages	3 stages
Cruising	7,5	10	15
Race	10	13	20

The number of spreaders being defined, their position will determine the length of the mast panels. The position of the points of attachment should be such that the angles of the tangential to the distorted axis of the mast, be there any, so that it does not produce any imbalance between the panels and therefore an undesirable deformation of the mast. And of these points, particularly important is: the cap-shroud attachment at the head. It has in fact to be situated underneath attachment of the forestay in a manner to obtain a balance between the moments generated above by the Genoa and that moment below generated by the main sail. One sees there, the impossibility of a perfect solution since these two moments will vary according to the size of the jib and the reefing of the main sail. Precise calculations could be carried out only in a body completely hyper-static (mast and shrouds) and for all the possible cases. This problem cannot be determined elegantly by the elemental method.
The table below gives a first approximation of the bases that one can adopt for every panel from the bottom as a percentage of I for a mast stepped on the deck.

	1 spreader		2 spreaders			3 spreaders			
14°	52	48	40	35	25	28	29	25	18
10°	55	45	42	33	25	30	30	25	15

This allows for a progressive reduction of the length of the spreaders. For a mast stepped on the keel one will increase the percentage of the lowest panel by two points.
These heights are taken from the level of the chainplates. If the mast foot or the deck collar are located on the summit of a deck house, the height of this will be deducted from the lowest panel.
The distance between the forestay attachment and cap-shroud will be equal to about 6 S_f / S_{g-v} one for thousand of the top panel.
In our example we had 6 x 42 / 20 ‰ of 415 cm length, becomes 5,2 cm rounded to 5 cm.
The progressive shortening of the spreaders is intended to facilitate the passage of the leach of the Genoa. One should not forget, however, that it leads to a reduction of the load on the lower shroud and consequently to an increase of the load on the cap-shroud and that these change very quickly.

For cruising yachts of which the foot of the jib does not descend to the deck one can gain by separating the lower shrouds more than the cap-shrouds, the crossroads corresponding to the height of the foot.

VI-VI - 2. LONGITUDINAL RIGGING

The angle of the forestay is situated generally in the vicinity of 20° with very rarely small variations seldom greater than ± 1°. This explains for two reasons, the first one aerodynamic for this angle corresponds to an axis of the appreciably vertical Genoa, the second mechanical for, as we saw, it can reduce by half - and even less with a 3/4 sail plan and a supple mast - in the top panel, between the halyard point of the Genoa and the attachments on the mast head. One will consider with great circumspection the sail plan or of rigging of which the angle of the forestay would be less than 18°.
The balance of the load of the forestay is taken up mostly by the backstay. The lengthening of the forestay under load that is applied being responsible for the importance of the direction that it takes under the load, it is essential to be able to recover this lengthening by a shortening of the backstay. It is therefore necessary, even on the cruising yachts, that this has access to a means of powerful and precise adjustment if one wants to preserve a good balance of the mast. If, on the racing yachts, one adopted almost everywhere the hydraulic actuating cylinder, on a cruising yacht all sorts of systems of hoists and of turnbuckles with wheel or crank are available.
One does not find a double backstay anymore today. This did nothing but to increase the weight and the windage. The one advantage could be to balance a little of the torsion provoked by the offset, on the before profile, of the forestay attachment. Again it was necessary for this, that it is the leeward backstay that is solicited. When, on a cruising yacht, one desires to release the rear deck of the presence of the backstay, one installs a bridle rather high to leave the passage of an adult. The tension system will be brought up on the bridle but, if it is not symmetrical, the backstay there will have to be secured by a cable pulley of the same strength or a bridle plate, in order not to provoke imbalance in the tension of the two sides of the bridle.
The behaviour of the middle of the mast is always a delicate problem; the only really effective means being furnished by one or two intermediate stays or a baby-stay balanced by a check stay and aft lower shrouds. But this provision has many disadvantages of a practical nature. The intermediate stays obstruct the passage of the sheets for tacking, the operation of the check stays is random with a reduced crew, they add more weight, windage and complexity in the upper rigging. As for the aft-shifted lower shrouds, they prevent the boom from properly swinging outboard for down wind sailing, which can be dangerous by causing involuntary gybing.
We will see that some vary the rigging plan according to the size of the yacht and the sail plan.

- Yachts of less than 7 m with 7/8 or ¾ rigging 7/8 or 3/4 (fig. VI-33)

Masthead rigging is practically unknown in this size of yacht. The rigging will consist therefore in a cap-shroud and a lower shroud, both aft swept, as well as the spreaders. The mast is held aft, then by the angle of the spreaders. This is assured only if the two cap-shrouds remain taught. In fact, if the leeward lower shroud relaxes, the resultant push of the spreaders quickly falls behind perpendicular to the load of the main sail and the mast is held more by the balance of the moments exerted by the main sail above and below the attachment of the forestay.
The lower shroud has a role essentially to limit the action of the push of the spreaders; they are therefore less loaded than the cap-shroud.
Attention should be paid, in this type of rig, to the position of the spinnaker halyard take-off. Too far above the attachment of the cap-shroud, can cause the mast to invert, its effect adding to the effect of the top of the main sail.
The tension of the forestay is balanced by the cap-shroud and also by the load of the main sail. In the larger yachts it can become necessary, especially on the 7/8 rig, to use a backstay. Too near, and it can help to bend the mast forwards, the surface of the main sail above the attachment being smaller. With the wind from behind it is essential to balance the load of the spinnaker. The angle of the transverse rigging towards the aft that, normally, at about thirty degrees can be reduced with use of a backstay.

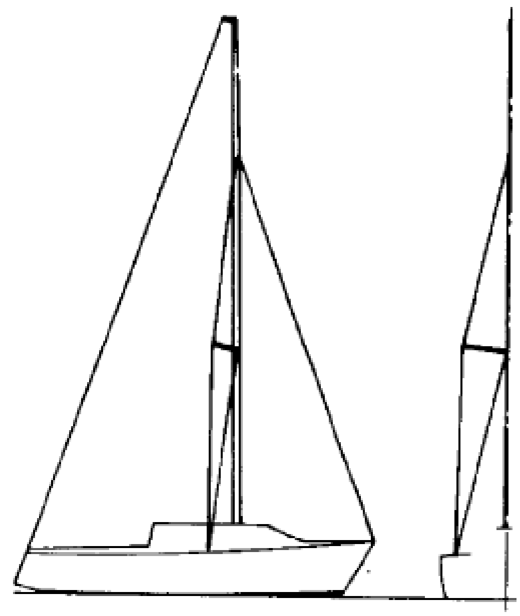

Fig. VI-33. Gréement 3/4 d'un voilier de moins de 7 m.

- Cruising Yachts with masthead rigging and one set of spreaders (fig. VI-34)

It is undoubtedly the simplest case. The longitudinal behaviour of the middle of the mast is set either by a pair of fore and aft lower shrouds, or by a baby-stay and aft lower shrouds.
The angle of the lower shrouds will be approximately 6° on both sides of the vertical, and that of the baby stay at least 10°. Attention, the jolts to the baby stay can be very strong and its chainplate will have to be connected to a solid structure on the hull.
On yachts that are not intended for the deep-sea cruising, the lower shroud can be in the same plane as the cap-shroud, and the baby stay, which remains essential, can be releasable under quiet sea conditions.

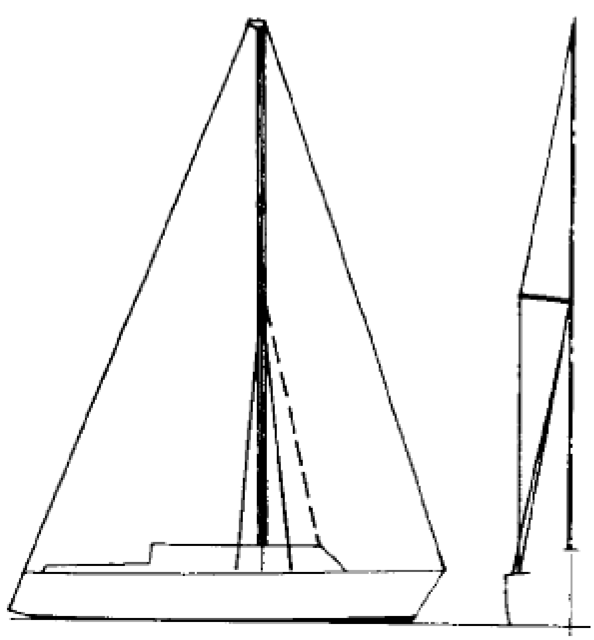

Fig. VI-34. Rigging at the head of a yacht of 8,50 m with one set of spreaders; the pair of front lower shrouds can be replaced by a baby stay.

- Cruising Yachts with masthead rigging with two or more sets of spreaders (fig. VI-35)

It is with these rigs with several panels that the longitudinal behaviour presents the most difficulties. If the sail is that of a cutter, an inner forestay is taken to the higher spreaders. This can be sufficient to prevent mast inversion, but it needs to be balanced by a running backstay.
If the boat length exceeds ten meters, one will be able to place a pair of fore and aft lowers or a baby stay and an aft lower shroud. But today rigging of a cutter is often mixed, i.e., with moderate wind; one rigs only a genoa of a sloop. The inner forestay and the runners can then be released if the state of the sea allows it, but the behaviour at the level of the first spreader must be preserved.
When the sail plan is a sloop, one will use an inner forestay coming to hold the mast between the two spreaders. The forward behaviour is normally secured by the mainsail but one will be able to supplement it by a check stay when the conditions of the sea require a firmer hold.

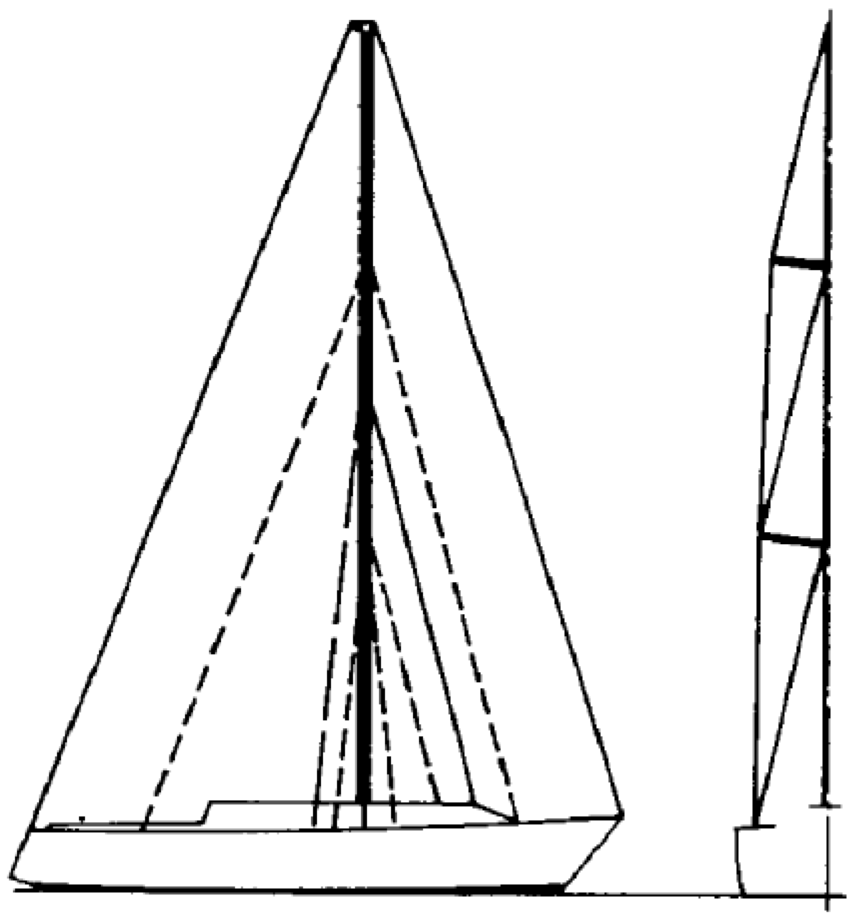

Fig. VI-35. Rigging at the head of a yacht of 10,50 m with two set of spreaders. For a larger yacht or a cutter, the baby stay will be replaced by an inner forestay (which can be releasable), balanced by the runners, and two fore and aft lowers, or aft swept lowers and a baby stay.

- Split Rigging (fig. VI-36)

Two requirements of balance are essential in this type of rigging: that of the load of the forestay and that of the bending of the mast. That the transverse rigging comprises of one or two set of spreaders, there will always be a runner at the height of the forestay and possibly a second at middle height of the fore-triangle. Except on the larger yachts, where the behaviour backwards will have to be resisted by at least a releasable inner forestay, the whole of the transverse rigging is placed in the plane of the mast in order to allow its bending.

The balancing of this bending is controlled by three elements, the backstay, the check stay and possibly a jumper. The reciprocal action of the sail and the mast can thus be regulated at will. The jumper is a rhombus laid out between the head of the mast and the top panel and whose struts are swept forwards so that it acts on the higher panel of the mast in the two directions longitudinal and transverse.

To be able to correctly distribute the action between these two directions it is necessary that the angle of the struts is adjustable. But the presence of the jumper obstructs the passage of the leach of the genoa.

When, as in the preceding case, no former staying is envisaged, it is necessary to pay great attention to the behaviour of the lower panel of the mast when one is with loose under spinnaker. At this time indeed, the push exerted by the boom becomes very high, and that while at the same time there is no more bending of the mast. On units of certain importance it becomes necessary to envisage a releasable baby stay.

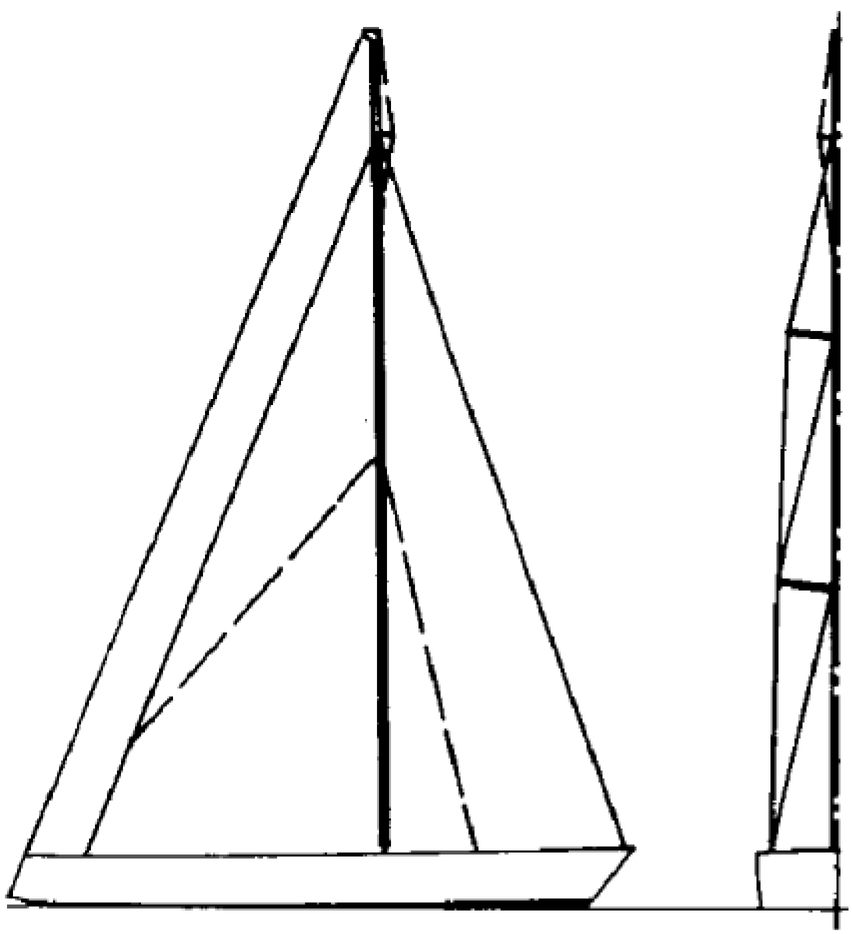

Fig. VI-36. For a 10-15 m yacht with a 7/8 rig, the runners are essential; the longitudinal behaviour is controlled by a baby stay and the check stay.

VI-VI - 3. THE MIZZENS (fig. VI-37)

Except to the bearing paces where they can support a staysail, these masts are subjected only to lateral and fore-aft forces.

Their lateral behaviour is thus ensured by traditional rigging with cap-shrouds, one or two sets of spreaders, and a lower shroud. The transverse rigging can be shifted backwards to compensate for the bending of the mast.

The longitudinal behaviour is ensured, in general, by an intermediate stay at two-thirds height of the sail and having a forward angle of ten degrees. It should be taken care that this does not obstruct the clearance of the boom of the mainsail.
The halyard of the staysail is provided with a thrust to the head of the mast and returns, as far as possible, to be useful as a running backstay.

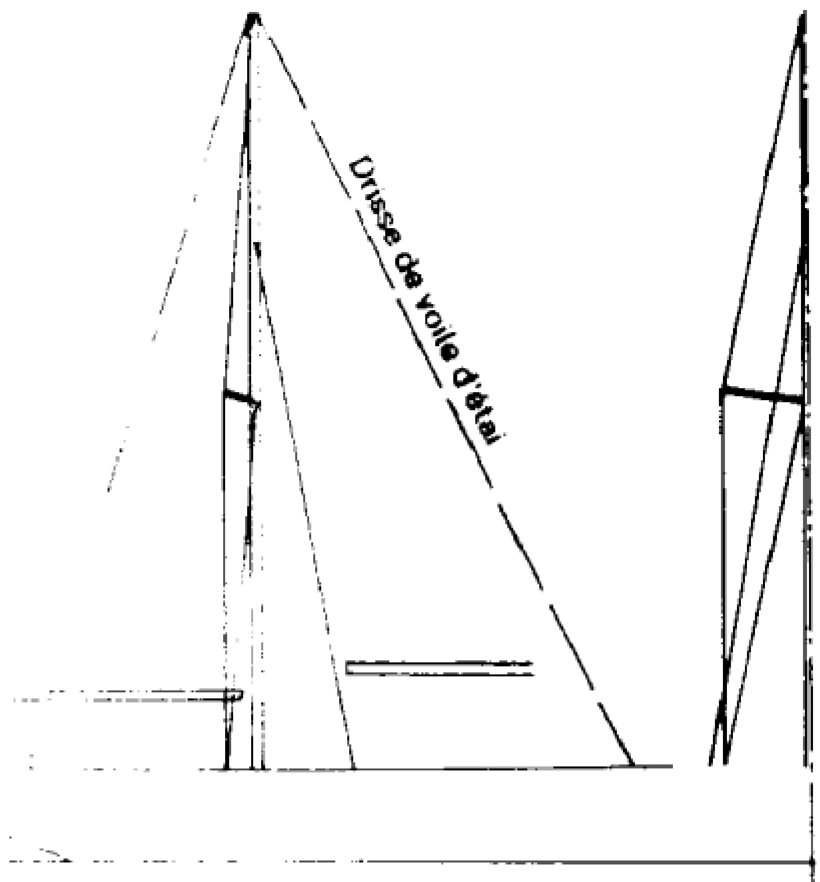

Fig. VI-37. Gréement d'artimon.

VI-VII - THE SAI AN

I will not extend here on the choice from the type of rigging which is treated in the first volume and sails and rigging. It however remains to see some practical problems of adaptation or interference with the hull and rigging.
The surface area of the sails having been determined according to displacement and of the program of the yacht, the distribution between the fore triangle and the mainsail will determine the position of the mast. And it is there that the first difficulty emerges. That the mast is deck stepped and supported by a pillar or that it goes down on the keel, its site and the associated structure must be integrated in the movements without harming itself.
It will often be necessary to move one or the other to lead to an acceptable compromise, which is far from always being easy.
One will then carry out the first control of the relative position of the centres of sails and hull, given according to the methods shown in chapter III. It then remains to measure the horizontal distance between the centres of sails and hull and to check if this variation corresponds to the values given in the volume I (Ch VIII-B-1-c).

It will probably be necessary to carry out an installation of the plan of the hull without harming the distribution of the weight.
The architect will thus be brought successively to make a circular step reviewing: the sail plan - position of the mast – movements - variation of the centres of sails and hull - plan of the hull - ballast – sail plan, etc., as many times as it will be necessary to arrive at a satisfactory result.

Some points remain to be checked. For example, it is always preferable that the end of the boom cannot be caught in the backstay at the time of an unforeseen gybe. That for an arc of circle having for its centre the gooseneck and for radius the overall length of the boom should not cut the backstay.
When sailing down wind, that the higher batten will not comes in conflict with the cap-shroud.
The sail plan will have to include all the necessary indications to the yacht and the particular specifications such as reef points, slides of mast and boom, jib hanks.
It will have to be specified, if dimensions correspond to the sail slackened or normally hoisted, which is generally the case, in particular for the yachts measured for racing. For lack of this precision one is likely to lead to a too large sail that one cannot hoist normally and a boom that hangs lamentably. All measurements of gauge concerning the sails and the mast must be given.
When the jib halyard is metal, its hoisted position must be constant which that is the length of the jib luff in place. It is thus necessary to provide each sail with a halyard pennant, and possibly tack, in order to keep a constant overall length.

The architect should also determine the fabric weights of the various sails. Unfortunately it often rests for that on the yacht. It is certain that this one is perfectly able to define it but at the time of consultations near several yachts it is essential to provide them common data if it is wanted that the proposals are comparable.
Certain foreign architects, like the office of Sparkman & Stephens provide to their customers a diagram of reduction of sail according to the real wind.

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