THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
One World Trade Center, Suite 1369, New York, N.Y. 10048
Paper to be presented at the Chesapeake Sailing Yacht Symposium, Annapolis, Maryland, January 15, 1983.

Design and Engineering Aspects of Free-standing Masts and Wingmasts

Eric W. Sponberg, Life Associate Member, Sponberg Yachts, Newport, RI 02840

ABSTRACT

Since their appearance in the mid-1970's, free-standing masts and wingmasts have become available on a number of production and custom sailboat designs. Being made primarily of composite materials, their engineering and development is complex and subject to much trial and error. Yet practically nothing of this development has been written down outside of what the various manufacturers have recorded for themselves.

This paper outlines the basic criteria for free-standing mast and wingmast engineering and design, discusses current rig arrangements, materials and manufacturing methods, and gives two design examples. Weaknesses in the engineering process are also delineated, and guidelines are given for future research which could eliminate those weaknesses.

NOMENCLATURE

A_s	Sail area
A_{cs}	Area of mast cross-section
A_{le}	Area of cross-section of wingmast leading edge
A_{te}	Area of cross-section of wingmast trailing edge
a	Half wingmast chord length to outside surface
a_1	Half wingmast chord length to inside surface
B	Beam
b	Half wingmast section width to outside surface
b_1	Half wingmast section width to inside surface
C	Mast circumference, wingmast section chord length
CHA	Geometric center of underwater profile
CSA	Geometric center of sail area
D	Diameter of mast cross-section
Δ	Displacement
E	Mainsail base
F_{mh}	Equivalent force at masthead
F_s	Shear force in mast
F_{wb}	Equivalent force at wishbone boom
GM	Metacentric height
I_{cs}	Moment of inertia of the mast cross-section about its centroid
I_{ycs}	Moment of inertia of wingmast cross-section about the y-y axis
I_{yle}	Moment of inertia of wingmast leading edge about the y-y axis
I_{yte}	Moment of inertia of wingmast trailing edge about the y-y axis
L_{oa}	Length over all
L_{wl}	Length on waterline
M_b	Mast bending moment
M_h	Heeling moment
M_r	Righting moment
M_y	Moment of wingmast section area about y-y axis
N	Number of carbon fiber strips
P	Mainsail height
R	Radius of mast cross-section
R_b	Reaction force at base of mast
R_d	Reaction force at deck
SM_{cs}	Section modulus of mast cross-section about its centroid
T	Draft

t	Wall thickness of mast cross-section
t'	Thickness of carbon fiber strip
V_{aw}	Speed of apparent wind
V_h	Boat hull speed
V_{tw}	Speed of true wind
w	Width of carbon fiber strip
$\overline{X}_{cs}$	Distance of centroid of wingmast cross-section area from y-y axis
$\overline{X}_{le}$	Distance of wingmast section centroid of leading edge shape from y-y axis
$\overline{X}_{te}$	Distance of wingmast section centroid of trailing edge shape from y-y axis
ϕ	Heeling angle
σ	Design bending stress

Subscripts

aw	apparent wind
b	bending, base
cs	cross-section
d	deck
h	hull, heeling
i	to inside surface
le	leading edge
mh	masthead
oa	overall
r	righting
s	sail, shear
te	trailing edge
tw	true wind
wb	wishbone boom
wl	waterline
y	to y-y axis

BACKGROUND

Free-standing sailboat masts date at least as far back as the Chinese junk rig, a design so old there is no record of its initial use (ref. 1). Structural limitations prevented the junk rig's use on boats larger than about 100 feet long, but it was easily handled on all points of sailing by a small crew.

Elsewhere in the world, various types of stayed rigs predominated, reaching a peak of development with the clipper ships of the 19th century. Steam power put an end to sail in commercial shipping, but recreational sailing came to life, continuing the development of stayed rigs up to the sophistication of present-day ocean racers. In fact, conventional stayed rigs are so well established in the yacht racing industry today that free-standing masts and wingmasts are implicitly prohibited from most races by the racing rules.

Reference 2, rule 802.6A states: "To qualify for measurement under this rule, a yacht must be fitted with a bonafide forestay." Reference 3, rule 07.01.05 states, "All yachts, including those not having a mast head rig, shall be equipped with a permanent backstay extending to the mast head...." Other features inherent to free-standing masts and wingmasts are also prohibited or penalized, as follows:

Wrap-around luffs & rotating masts	Prohibited by IOR rule 802
Spars built of anything but wood, aluminum alloys, steel alloys, and glass fibre reinforced plastics	Penalized by IOR rule 802.4
Spars built of anything but wood, fiberglass, aluminum alloys, brass, bronze, or steel (including stainless steel alloys)	Prohibited by MHS rule 03.03.01
Battens exceeding 4 or 5 in number of specified lengths	Penalized by IOR rules 845.5 & 848

Why are free-standing masts and wingmasts restricted in this manner? It may be that the aerodynamic efficiency and superiority of these rigs on all points of sail has to be more widely shown and accepted than at present. Also, if the rules were changed overnight, owners, designers, boatbuilders and equipment manufacturers would face an expensive, chaotic situation trying to take advantage of the new allowance for as yet unproven benefits. One thing is certain: if free-standing masts and wingmasts were allowed under the racing rules, development of these types of rigs would be faster and more sophisticated than it is today.

As it is, the restrictions imposed by the racing community have forced the development of free-standing masts and wingmasts into the cruising sailboat market where money and the driving incentive of competition are much more scarce. Nevertheless, there are today in the United States at least seven manufacturers building fifteen different production sailboats with free-standing mast and wingmast rigs. A growing number of custom designs are also available with these types of rigs. Where once racing sailors were the pioneers of sailboat technology, now cruising sailors can claim that role, thanks to the racers' own rules. This situation is very rare in the history of yachting.

For cruising sailors, safety, simplicity, and ease of handling have been the primary incentives for building boats with free-standing masts and wingmasts. Obviously, compared to conventional stayed rigs, free-standing rigs comprise much less equipment that requires maintenance or can give trouble at sea.

Aerodynamic efficiency, though it has played a secondary role, is no less important. References 4, 5, and 6 all discuss assorted model test programs which attest to the improved lift/drag characteristics of streamlined sail sections as found in free-standing mast and wingmast rigs. Reference 7 discusses similar advantages found during full-scale testing and racing of C-class catamarans as well as the reasonable correlation of the test results with computerized performance predictions. For free-standing mast and wingmast rigs to become more widely accepted, their aerodynamic superiority will have to be displayed to a greater degree than it is at present. This can best be done by test sailing identical boats against each other, each fitted with a different type of rig, and by greater participation of boats equipped with free-standing masts and wingmasts in the few organized races open to them.

No further discussion is required on the practicalities of free-standing masts and wingmasts, or on their aerodynamics. What remains is to discuss the masts themselves: what are the different types available, what are they made of, how are they engineered and built, and where is more research required to improve their engineering and manufacture?

BOAT	DESIGNER	BUILDER	RIG TYPE	MAST TYPE FREE-STANDING (FSM) WINGMAST (WM)	MAST MAT'L ALUM. (AL) FIBERGLASS (FG) CARBON FIBER (C.F.) WOOD-EPOXY (WE)	BOOM TYPE CONVENTIONAL (C) WISHBONE (W)	SAIL TYPE 1-PLY (1-P) 2-PLY (2-P) FULLY BATTENED (FB)	COMMENTS
PRODUCTION								
F-21	G. HOYT	FREEDOM YACHTS	CAT	WM	CF	C	1-P, FB	FREEDOM YACHTS ORI-
F-25	G. HOYT	"	"	WM	CF	C	1-P, FB	GINALLY HAD 2-PLY SAILS
F-28	K. BURGESS	"	CAT-KETCH	FSM	CF	C	1-P, FB	W/ WISHBONE BOOMS.
F-33	J. PARIS	"	"	FSM	CF	C	1-P, FB	PRESENT ARR'G'T WAS
F-39	R. HOLLAND	"	SCHOONER	FSM	CF	C	1-P, FB	EFFECTIVE 1982
F-40	H. HERRESCHOFF	"	CAT-KETCH	FSM	CF	C	1-P, FB	
F-44	G. HOYT	"	"	FSM	CF	C	1-P, FB	
F-70	G. HOYT	"	"	FSM	CF	W	2-P	
NONSUCH 26	M. ELLIS	HINTERHOELLER	CAT	FSM	AL	W		2 WOOD-EPOXY MASTS HAVE
NONSUCH 30	M. ELLIS	"	"	FSM	AL	W		BEEN MADE FOR NONSUCH 30
TANTON 43	Y. TANTON	OFFSHORE YACHTS	CAT-KETCH	FSM	CF	C	1-P	
WINGS 33	FREEWING GROUP	FREEWING	"	FSM	AL, CF	W	1-P, 2-P	
PEARSON 23C	PEARSON GROUP	PEARSON	CAT	FSM	AL	C	1-P	
WHISTLER 32	C. PAINE	ABLE	CAT-KETCH	FSM	CF	W	2-P	
AMA 45	R. NEWICK	AMA	SLOOP	WM	WE	C	1-P, FB	PRODUCTION TO BEGIN
CUSTOM								
SPONBERG 38	E. SPONBERG	UNDECIDED	SCHOONER	WM	WE	C	1-P, FB	
A.J. LUCIANTONIO	H. HERRESCHOFF		CAT-KETCH	WM	WE	C	1-P, FB	
ROGUE WAVE	R. NEWICK	GOUGEON	SLOOP	WM	WE	C	1-P, FB	
LADY PEPPERELL	HUNTER GROUP	HUNTER	CAT-KETCH	FSM	FG	C	2-P	MASTS ROTATE

TABLE I: CURRENT PRODUCTION & CUSTOM DESIGNS WITH FREE-STANDING MASTS & WINGMASTS