NELSON MAREK YACHT DESIGN

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Report on Crew Weight and Stability

for

International Star Class Yachts

requested by Paul Cayard

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Overview

An analysis of the effects of fully-hiked crewmembers and partially-hiked helmsmen on the stability of International Star Class racing yachts was performed to accurately establish their relative contributions to stability and performance. A combined crew weight limit formula designed to provide similar performance potential over a wide range of helmsman/crew weight combinations is suggested. This formula is based on equal stability production at a sailing heel angle of 15 degrees with a crew leverage factor of 3.8 and a helmsman leverage factor of 3.2.

Discussion

A heeled body plan of a Star sailing upwind with crew hiking was created from Class plans and photos from recent Class World Championships. Righting arm levers at 15 degrees of heel of 3.77, 3.39 and 2.98 feet were calculated for a fully-hiked crewmember, a normally-hiked helmsman and a helmsman sitting on the deck edge, respectively. Computations of combined crew/helmsman weights of equal stability based on the calculated levers are provided for both the hiked and sitting helmsmen cases. Subjective considerations of additional performance benefits of crew weight (lower gyradius and windage) over helm weight suggested increasing the crew leverage factor to 3.8 with an averaged helmsman leverage factor of 3.2 for equal performance potential. The choice of a value for RM as a constant in the suggested formula can be adjusted to raise or lower the mean combined crew weight limit. The resultant increase in total combined weight for a heavy helmsman / light crew team is modest over a light helmsman / heavy crew team, however it should be recognized that the heavier total combined weight crew will produce a longer and more stable immersed hull form.

Suggested Crew Weight (lbs) vs Helm Weight for Equal Performance

Formula: Crew Wt = (RM - (Helm Wt * 3.2)) / 3.8

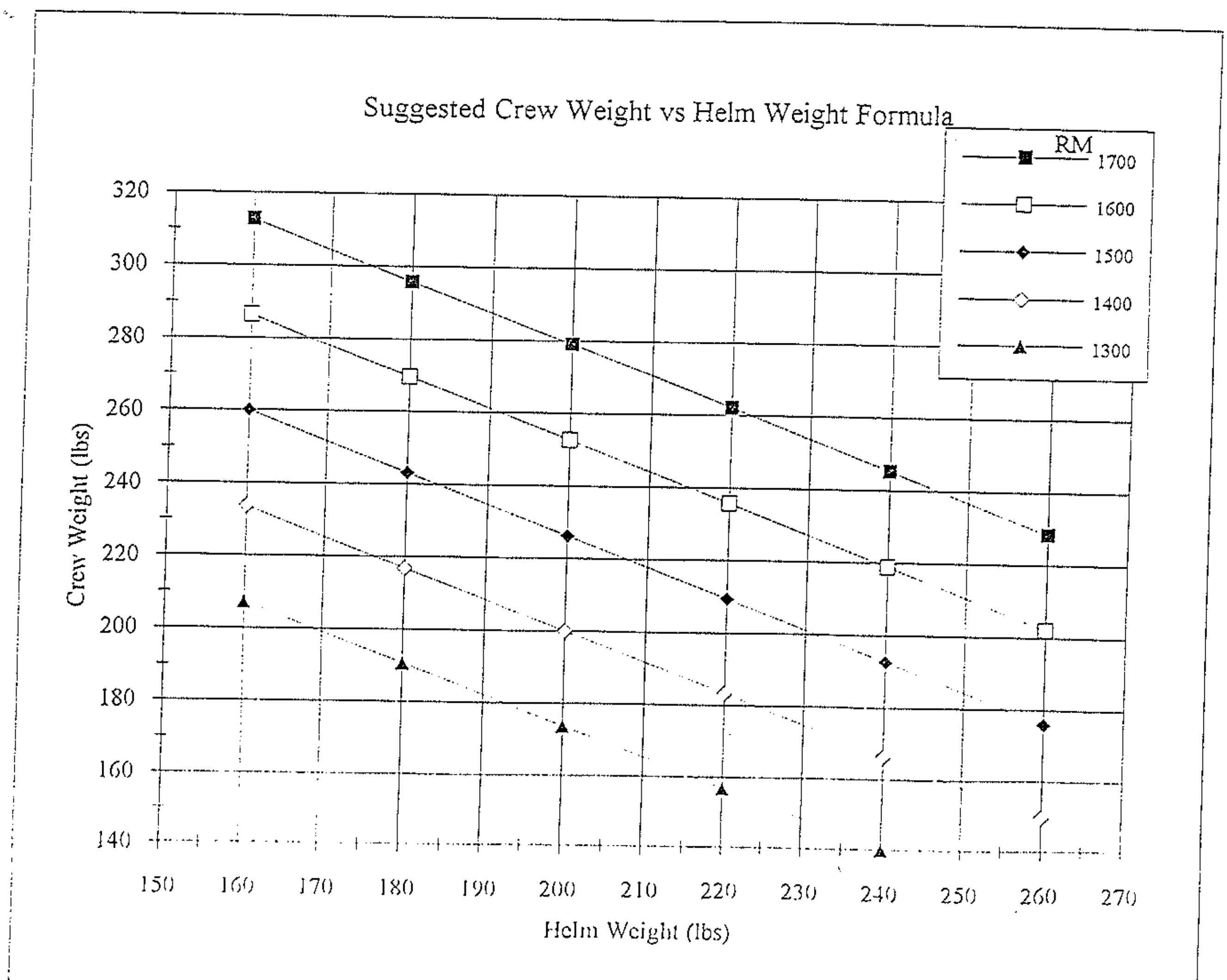
* Suggest RM=1500

RM (ft lbs)	160	180	200	220	240	260 Helm (lbs)
1700	313	296	279	262	245	228
1600	286	269	253	236	219	202
1500	260	243	226	209	193	176 *
1400	234	217	200	183	166	149
1300	207	191	174	157	140	123

Total Combined Crew and Helm Weight Table

*Suggest RM=1500

RM (ft lbs)	160	180	200	220	240	260 Helm (lbs)
1700	473	476	479	482	485	488
1600	446	449	453	456	459	462
1500	420	423	426	429	433	436 *
1400	394	397	400	403	406	409
1300	367	371	374	377	380	383



Crew Weight (lbs) vs Helm Weight for Constant RM (with Helm Hiking)

Formula: Crew Wt = (RM - Helm Wt * 3.39) / 3.77

RM (ft lbs)	160	180	200	220	240	260	Helm (lbs)
1700	307	289	271	253	235	217	
1600	281	263	245	227	209	191	
1500	254	236	218	200	182	164	
1400	227	209	192	174	156	138	
1300	201	183	165	147	129	111	

Total Combined Crew and Helm Weight Table (with Helm Hiking)

RM (ft lbs)	160	180	200	220	240	260	Helm (lbs)
1700	467	469	471	473	475	477	
1600	441	443	445	447	449	451	
1500	414	416	418	420	422	424	
1400	387	389	392	394	396	398	
1300	361	363	365	367	369	371	

Crew Weight (lbs) vs Helm Weight for Constant RM (with Helm Sitting)

Formula: Crew Wt = (RM - Helm Wt * 2.98) / 3.77

RM (ft lbs)	160	180	200	220	240	260	Helm (lbs)
1700	324	309	293	277	261	245	
1600	298	282	266	251	235	219	
1500	271	256	240	224	208	192	
1400	245	229	213	197	182	166	
1300	218	203	187	171	155	139	

Total Combined Crew and Helm Weight Table (with Helm Sitting)

RM (ft lbs)	160	180	200	220	240	260	Helm (lbs)
1700	484	489	493	497	501	505	
1600	458	462	466	471	475	479	
1500	431	436	440	444	448	452	
1400	405	409	413	417	422	426	
1300	378	383	387	391	395	399	

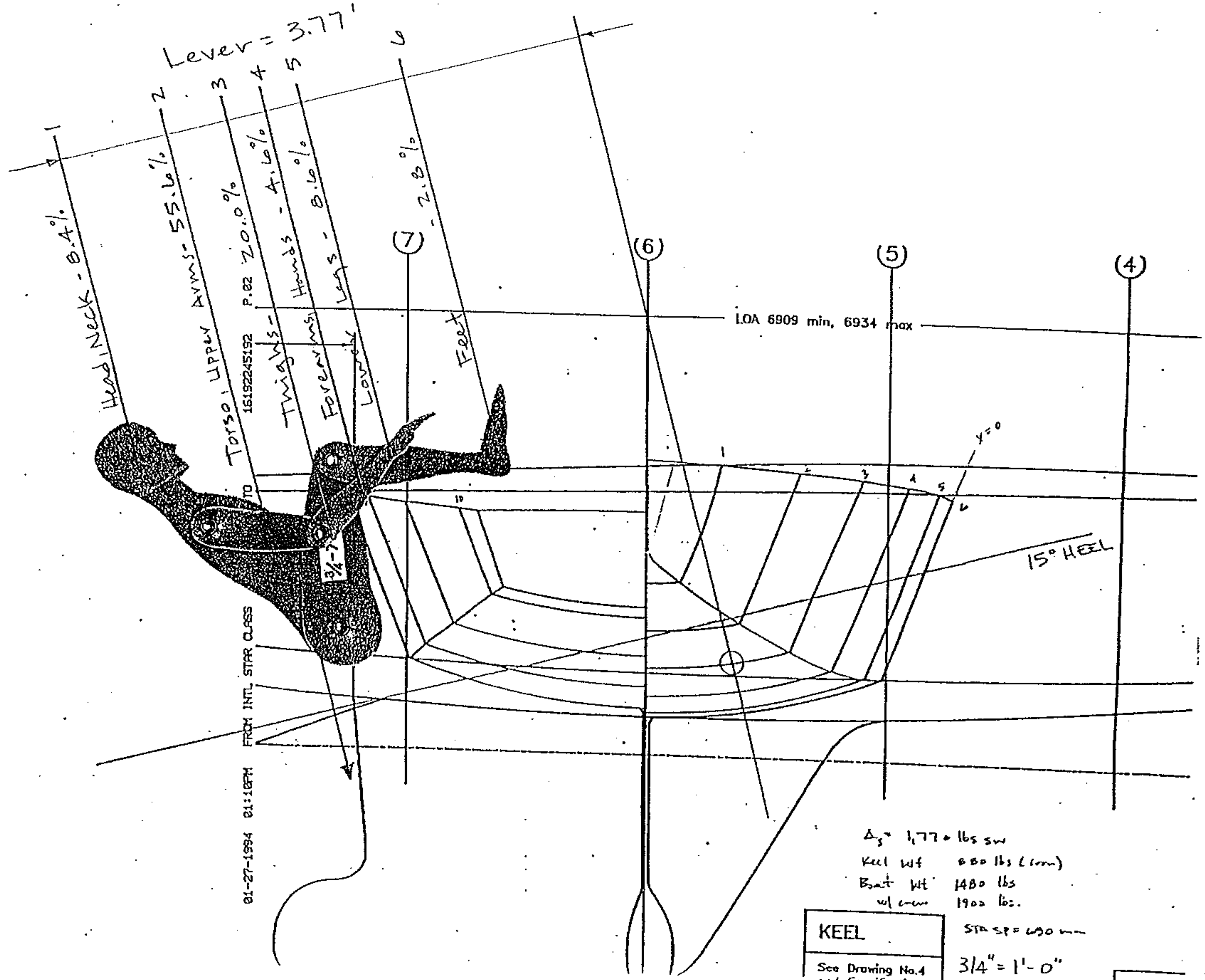
Star Crew and Helm RM Lever (feet) at Heel=15

	Total	1	2	3	4	5	6
Crew	3.77	5.06	4.02	3.44	3.06	2.71	1.71
Helm - Hike	3.39	3.85	3.63	3.10	2.79	1.86	1.00
Helm - Sit	2.98	3.35	2.96	2.67	1.58	0.83	

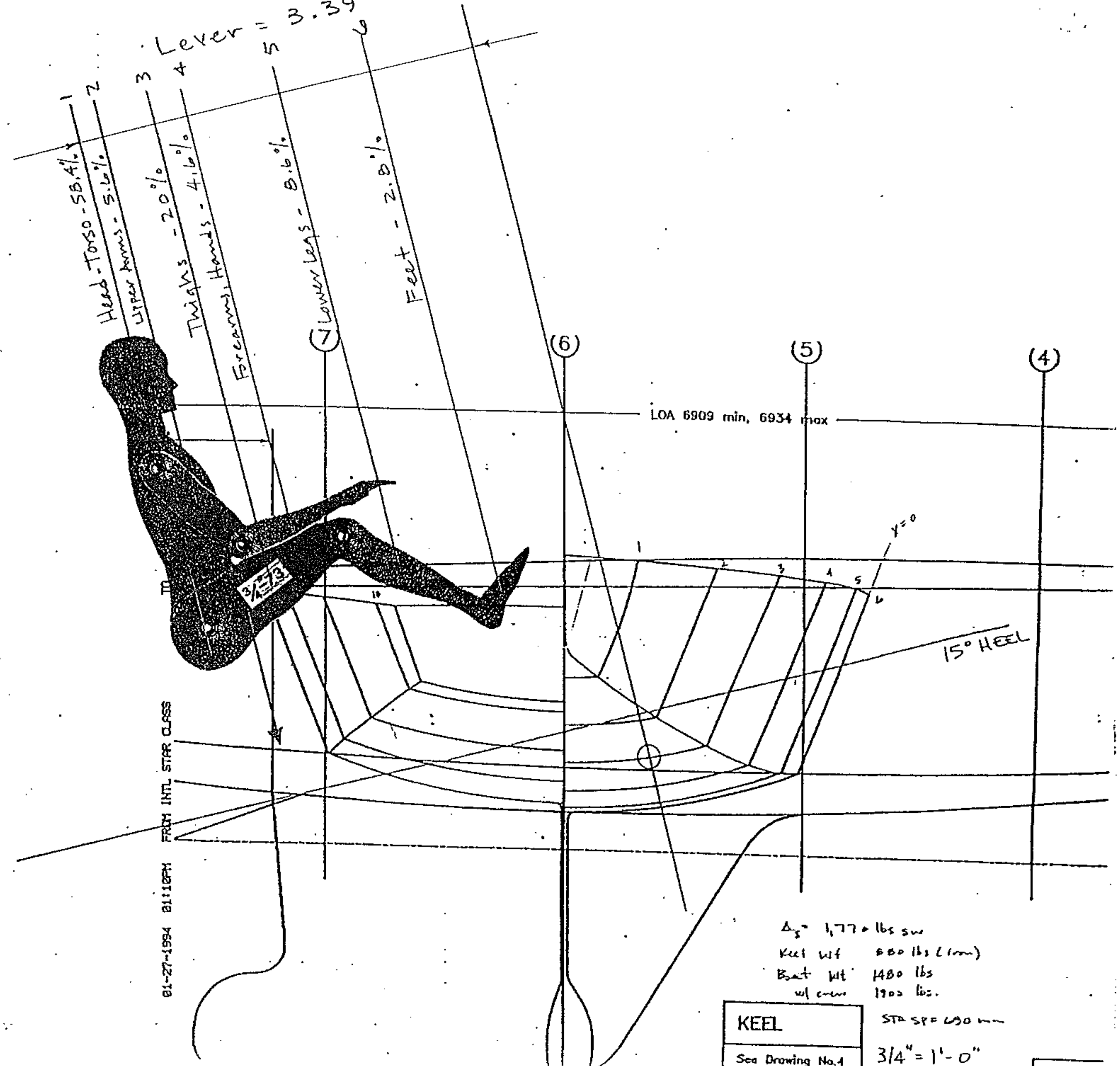
Percentage Weight Breakdown (%)

	Total	1	2	3	4	5	6
Crew	100	8.4	55.6	20.0	4.6	8.6	2.8
Helm - Hike	100	58.4	5.6	20.0	4.6	8.6	2.8
Helm - Sit	100	64.0	4.6	20.0	8.6	2.8	

CREW - FULLY HIKED:



HELM - HIKING :



Lever = 3.39'
1 Head-Torso - 58.4%
2 Upper Arms - 5.6%
3 Thighs - 20%
4 Forearms, Hands - 4.6%
5 Lower Legs - 8.6%
6 Feet - 2.8%
(7)
(6)
(5)
(4)
LOA 6909 min, 6934 max
y=0
15° HEEL
3/4=73
FROM INTL STAR CLASS
01-27-1994 01:18PM
Δs = 1,770 lbs sw
Keel wt 880 lbs (min)
Boat wt 1480 lbs
w/ crew 1905 lbs.
STA SP = 690 mm
KEEL
See Drawing No.4
3/4" = 1'-0"

HELM - SITTING:

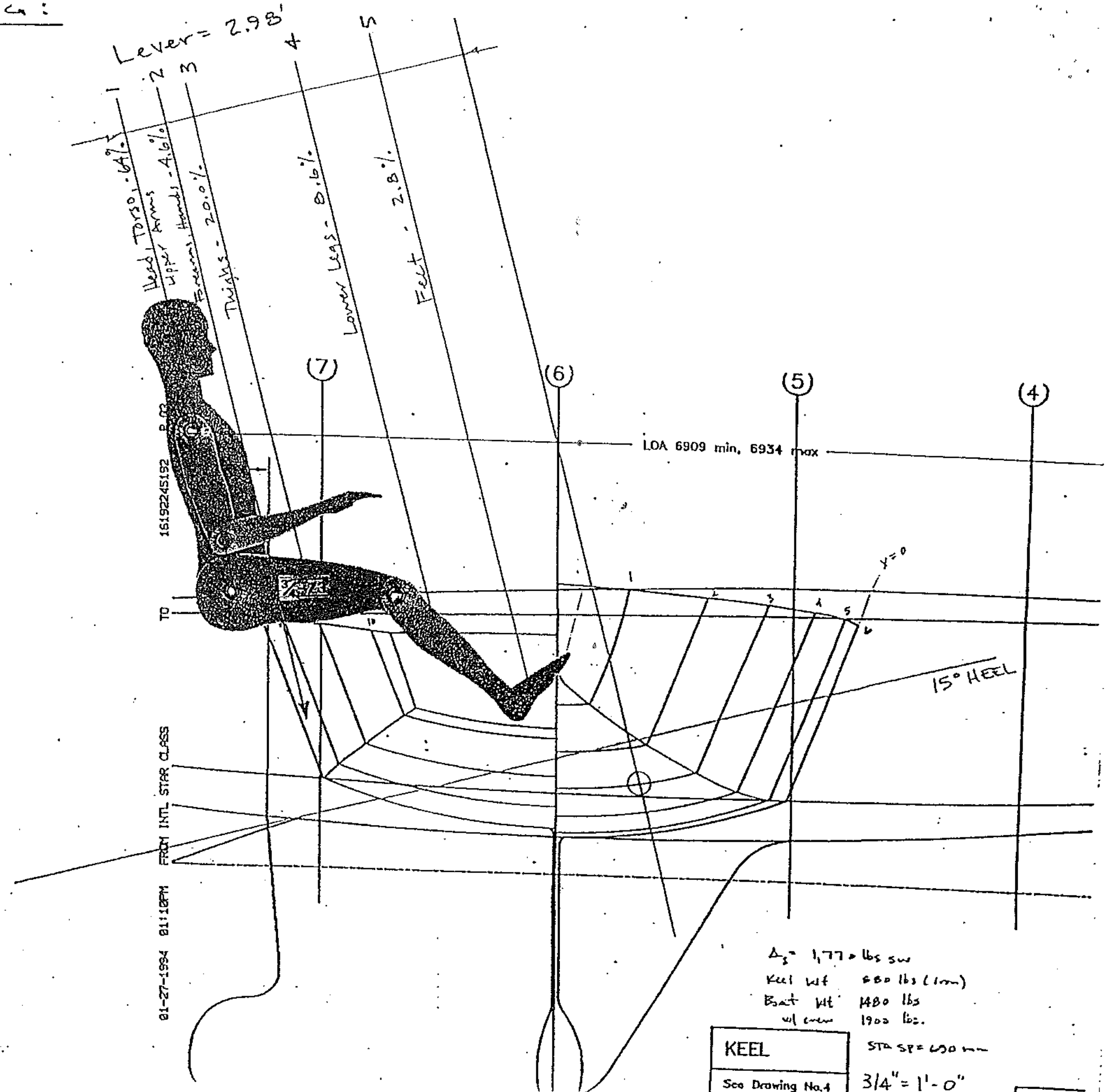


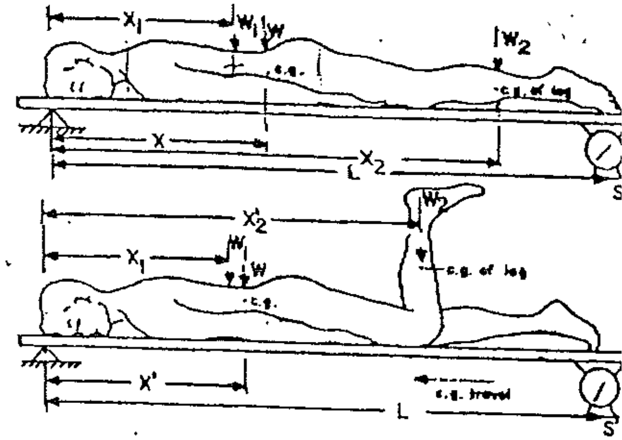
TABLE 3.5
Percentage Distribution of Total Body Weight According to Different Segmentation Plans (from Webb Associates, 1978)

Grouped Segments, % of Total Body Weight	Individual Segments, % of Grouped Segments Weight
Head and neck = 8.4%	Head = 73.8%
	Neck = 26.2%
Torso = 50.0%	Thorax = 43.8%
	Lumbar = 29.4%
	Pelvis = 26.8%
Total arm = 5.1%	Upper arm = 54.9%
	Forearm = 33.3%
	Hand = 11.8%
Total leg = 15.7%	Thigh = 63.7%
	Shank = 27.4%
	Foot = 8.9%

regardless of the orientation of the segment in space? The resulting point on the segment is known as its *mass center* (referred to in some earlier books as the *mass center-of-gravity*).

Body-segment mass center locations have been measured on cadavers by a number of investigators using a suspension technique (Roebuck, Kroemer, and Thomson, 1975). The frozen section was suspended from a pin that was systematically reinserted until a point of balance was determined. In living subjects, two methods can be used. The more traditional method requires the subject to assume various positions while supported on a force platform (see Chapter 5 for operating details of a force platform). The force platform provides a means to determine the location of the segment mass centers by applying the static equilibrium principle that requires the sum of moments around any point in a force system, while in equilibrium, to be zero. By having a person assume two different positions on the force platform and by knowing the segment weights, one can solve for the segment center of mass using a procedure described in detail by Williams and Lissner (LeVeau, 1977). Figure 3.5 presents the basic procedure for determining the mass center location for the combined shank and foot segments.

A [illegible] method for determining mass center locations is more involved. [illegible] of the immersion method of determining the volume of [illegible], described in detail by Miller and Nelson (1976), [illegible] while the volume [illegible] the procedure and calculations. [illegible] method of determining the approx[illegible] the limb [illegible] the volume of water



IF MASS CENTER LOCATIONS ARE KNOWN, THEN SEGMENT WEIGHT PREDICT FOR FOOT AND SHANK BY:

$$W_2 = \frac{L(S - S')}{(X_2 - X_2')}$$

IF SEGMENT WEIGHT IS KNOWN, THEN MASS CENTER (C.G. LOCATION) C PREDICTED BY BALANCING SEGMENT OVER JOINTS, WHICH FOR FOOT SHANK YIELD:

$$X_2 = \left[\frac{L(S - S')}{W_2} + X_2'\right]$$

[illegible] 3.5 Estimation of body segment weights and mass center locatio[illegible] [illegible] method described by Williams and Lissner (LeVeau, 1977, p. 21[illegible]

[illegible]aced. Withdraw the limb slowly until half the volume fir[illegible] [illegible]ed. The water level at this point on the limb, assuming uni[illegible] [illegible]y, bisects the mass center.

[illegible] mass-center locations have been obtained for se[illegible] [illegible] using these methods. In general, because the shap[illegible] [illegible] greatly altered from one person to another, though size [illegible] [illegible] practice is to present the data as a proportion o[illegible] [illegible]ength. Table 3.6 does this for three different studies, a[illegible] [illegible] (1977). The differences can be attributed to different [illegible].

[illegible]4 Body-Segment Inertial Property Measurement

[illegible] of the mass center location in a body segment, [illegible] and link length is sufficient to perform a static analysi[illegible]