Freedom 21 Rudder Design Notes

Summary of Rudder Design/Performance Information

Rudder T/E Cut-off Effect: One can "cut-off" up to around 10% of the rudder trailing edge chord with no appreciable effect on drag but with a significant increase in lift. For example, a 5% trailing edge chord cut-off on an NACA aerofoil produced a 10% increase in lift and a higher stall angle for the foil. *(Ref 1 – p223)*

Rudder Tip Shape (Cross Section): The best C_L/C_D ratio is given by a cross section tip shape consisting of "knife blade" edge, next best is a simple square cut tip & worst a rounded tip. *(Ref 2 - p 52)* Also the tip cross section has an influence on the tendency of the rudder to vibrate at high speed. A square cut tip has a relative vibration amplitude (RVA) of 1.0, a 45^o included angle tip section rudder has an RVA of 0.43 and a 30^o included angle tip section rudder has an RVA of zero. Poor tip shapes can have RVA values as high as 3.8. *(Ref 3 - p128)*

Rudder Blade Tip Profile (Planform): A simple square cut tip profile works well as does a tip profile consisting of a shallow elliptical tip over the first 75% of the chord blending into a square tip. Other "clever" tip end shapes tend to increase drag. *(Ref 2 - p51*) The leading edge sweep angle should be minimised – preferably no more than 10^o and the rudder blade taper ratio should be in range 0.4 to 0.6. *(Ref 4 - p87)*

Rudder Area: Should be in the range 8% to 10% of the total lateral plane area. If the rudder is a deep, high aspect ration design & transom hung the area could be reduced to around 7%. *(Ref 4 - P87)*

Rudder Balance: Balanced rudder blades minimise tiller loads and make steering easier – best balance found to be around 17%. (*Ref 5 - p80)*

Aspect Ratio: "Normal" aspect ratio for sailing boat rudders is 2.2 to 3.5. *(Ref 5 – p77)*

Aerofoil Shape: NACA 4-digit simple foil sections are best since the higher performance laminar flow sections are very critical of manufacturing accuracy and are not as "robust" in performance terms & toleration of non-optimum surface roughness & fouling. Also the leading edge profile and accuracy of the first 35% of laminar flow blade sections are critical. The best compromise of highest lift angle, best lift coefficient and minimum drag is given by a foil with a thickness/chord ratio in the range 9% to 12%. One should consider 9% as the minimum thickness/chord ratio for a rudder. The 4-digit NACA sections also give a more gradual stall characteristic. (Ref 4)

References

1. Marchaj C A, *Aero-Hydrodynamics of Sailing*, Adlard Coles, London 1988, ISBN 0-229-11835-6.
2. Gutelle P, *The Design of Siling Yachts*, Macmillan, London 1984, ISBN 0-333-322681.
3. Larsson L & Eliasson R E, *Principles of Yacht Design*, Adlard Coles, London 2000, ISBN 0-7163-5181-4.
4. Vacanti D, *Keel & Rudder Design*, Professional Boatbuilder Magazine, June/July 2005
5. Gerr D, Steering Systems Fundementals - Part 1, Professional Boatbuilder Magazine, Dec/Jan 2006

Comparison of the Freedom 21 Rudder with Rudder Design Recommendations

Characteristic	Recommendation	Freedom Rudder
Rudder Area	8% to 10% of TLP	12.9% (Normal Fin Keel) 13.2% (UK Tandem Keel) 15.0% (UK Twin Lift Keel)
Rudder Balance	17% optimum	17%
Aspect Ratio	2.2 to 3.5	2.3
Taper Ratio	0.4 to 0.6	0.7
Leading Edge Sweep	10 degrees max.	10 degrees
Tip Cross Section	Minimise RVA	Square cut (RVA 1.0) – worst case RVA is 3.8 (RVA denotes "relative vibration amplitude")
Aerofoil Section	NACA 0009 or 0010	Production F21 rudder section not known

NOTES

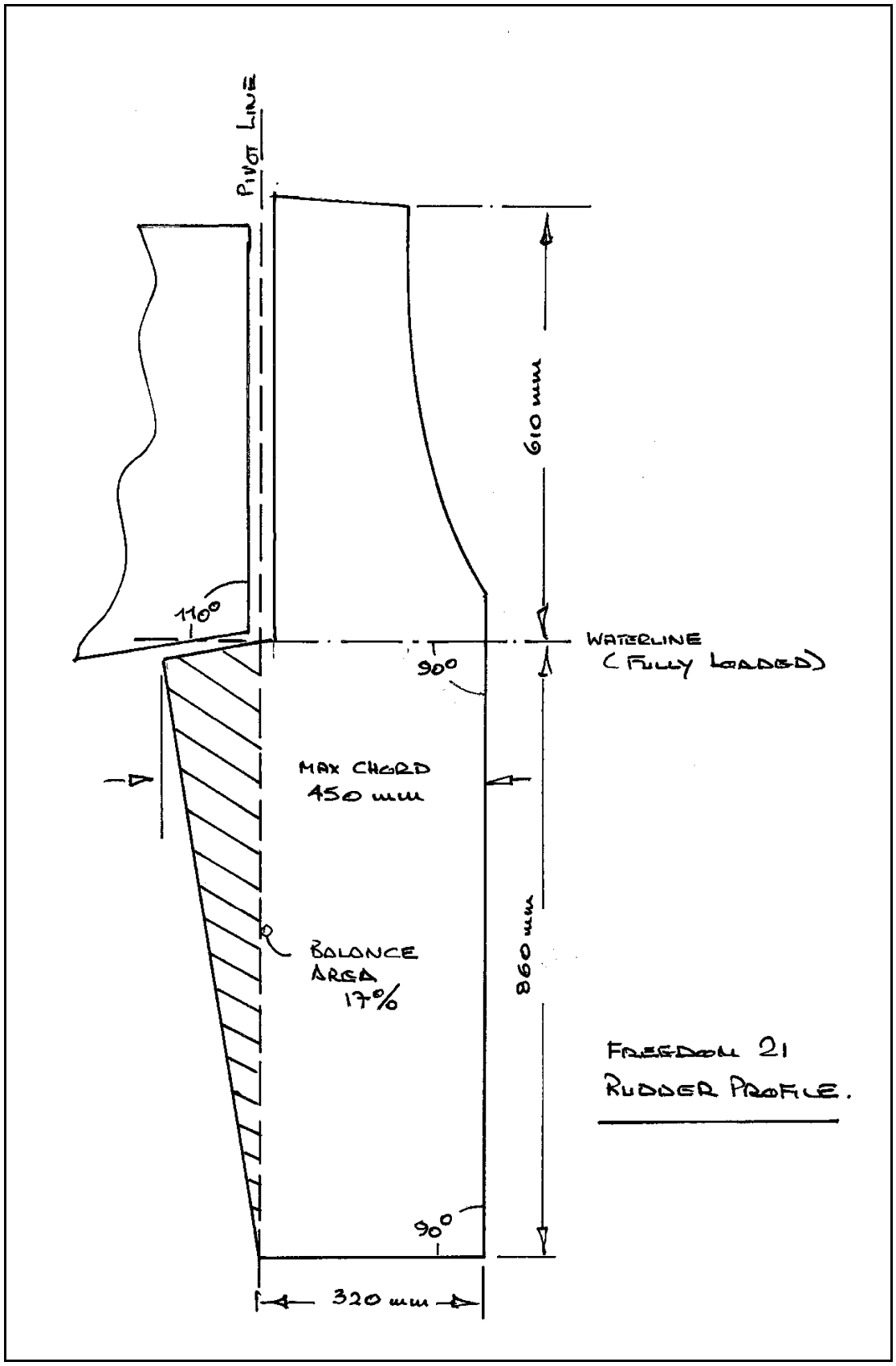
From the above table we can conclude that the Freedom 21 rudder is a relatively large, highly tapered rudder, with excellent balance and an appropriate degree of leading edge sweepback.

I intend to make my replacement lifting rudder for my UK twin lift keel F21 to the standard F21 planform to an NACA 0009 section with a 45^{o} degree knife-edge "vee" cross section to the rudder tip and a 5% trailing edge "cut-off". I also intend to fit a small anti-cavitation plate to the rudder to prevent entrainment of air at high speed which can evidently reduce rudder lift and cause rudder vibration to develop.

I have measured a number of F21 rudder blades and the attached sketch gives these dimensions.

Perhaps these notes will be of interest to other F21 owners planning to replace their rudder blades?

Wilf Bishop
DAYDREAM – Sail No 205
29th October 2007



FREEDOM 21
RUDDER PROFILE.