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Design and Manufacture of Wood Blades for Windtunnel Fans

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Contents

1.	**Introduction**		**1.1**
2.	**Historical Background**		**2.1**
	2.1	Fans for Small Windtunnels	2.1
	2.2	Fans for Medium Windtunnels	2.1
	2.3	Fans for Large Windtunnels	2.1
3.	**Different Types of Blades**		**3.1**
	3.1	Integral Two and Four Blades	3.1
	3.2	Detachable Blades (Fixed Pitch)	3.4
	3.3	Detachable Blades (Variable Pitch)	3.4
4.	**Design Concepts**		**4.1**
	4.1	New Fans	4.1
	4.2	Replacement Fans	4.3
5.	**Aerodynamic Design**		**5.1**
	5.1	Theoretical Study	5.2
	5.2	Design Computer Program	5.23
6.	**Materials**		**6.1**
	6.1	Historical Background	6.2
	6.2	Current Available Specifications	6.7
	6.3	Compressed Wood	6.12
7.	**Structural Design**		**7.1**
	7.1	Interaction with Manufacturing Design	7.2
	7.2	Stressing	7.3
	7.3	Root Design and Testing	7.7
	7.4	Transition Zone (Scarf) Design	7.27
	7.5	Detachable Tip Design	7.28
8.	**Manufacturing Design**		**8.1**
	8.1	Definitions	8.2
	8.2	Manufacturing Procedure	8.4
	8.3	Manufacturing Design	8.8

9.	**Manufacturing Techniques**		**9.1**
	9.1	General Gluing Techniques	9.3
	9.2	Lam Production	9.11
	9.3	Block Manufacture	9.18
	9.4	Shaping	9.23
	9.5	Covering	9.40
	9.6	Balancing	9.50
	9.7	Workshop Inspection	9.55
	9.8	Inspection (Acceptance)	9.73
	9.9	Packing and Transport	9.75
10.	**Repair Techniques**		**10.1**
	10.1	General	10.2
	10.2	Material Specifications	10.2
	10.3	Material Defects	10.2
	10.4	Manufacturing Damage, Defects and Repairs	10.2
	10.5	Inspection and Maintenance for Blades during Service Life	10.2
	10.6	Repairs	10.4
	10.7	Balancing	10.13
	10.8	Repair Records	10.13
11.	**Specification Preparation**		**11.1**
12.	**Relationship between Specification, Inspection and Acceptance**		**12.1**
	12.1	General	12.1
	12.2	Specification	12.1
	12.3	Inspection	12.1
	12.4	Acceptance	12.1
13.	**References and Definitions**		**13.1**
	13.1	References	13.1
	13.2	Definitions	13.2

Appendices

A. Adhesives

B. British Standards

C. Computer Program

F. Fatigue Test

G. Glues

S. S.P.S. Resin Systems

1. Introduction

Experience has shown (see Ref: 13.1.1) that wood bladed fans for Windtunnels can have an expected life span of over 50 years, consequently the need for new designs for existing or proposed windtunnels is practically zero, and the requirement for replacement fans or blades also very low. Therefore there is little, if any, incentive for any manufacturing contractor to maintain or set up a facility that would (in the future) have the necessary expertise to manufacture such blades. Unless the present day detailed knowledge and experience (particularly of the subtle minor points) is recorded for future use it will (quite possibly) eventually occur that the techniques will be lost for ever.

When (surely it must come one day!) replacement fans or blades are required it will be difficult, if not impossible, to find any organisation that will be in a position to contemplate considering to start up such a facility for this type of manufacture, involving the new learning curve that would arise. If such an organisation is found they would then have to include the escalation of costs that would arise and there would also be the possibility of mistakes occurring that could lead to a major failure of a fan or blades built.

This Report presents a survey of some aspects of the historical background of wood blades as used in slow speed windtunnel fans and gives information and details for future reference that would be invaluable for any future contractor. Emphasis is placed mainly on the practical and manufacturing aspects based on the author's 40 years of experience with such projects.

1.1 Notes on Presentation

The Report and consequently the spelling is written in U.K. English rather than with American terminology. There are some terms and expressions that do not have common names in the different forms of the language and are in any case unique to Wood Blade manufacture. Definitions and abbreviations for these expressions are given in Section 13.2. In the main if the text refers to a sketch or Figure this is then usually printed on the following or adjoining page or pages, but in some cases it may refer to a latter Section or Figure.

Sketches shown in the Figures are not drawn to true scale.

2. Historical Background

2.1 Fans for Small Windtunnels

The definition of Small windtunnels for this Report will be taken as mainly tunnels for instructional or academic purposes when generally the fans are about or less than 6ft. in diameter with power consumption in the region of 100 BHP.

Such tunnels had fans that were usually with integral 2 or 4 blades, based on the typical construction of fixed pitch aircraft propellers originating in the early days of flying. More details of the construction of this type of blade is given in Sections 3.1 and 9.

As the requirement for bigger tunnels arose and the fans consequently larger the same type of construction of the fans and/or fan blades was used.

2.2 Fans for Medium Windtunnels

The definition of Medium windtunnels for this Report will be taken as mainly tunnels used by industrial Companies or research establishments where generally the fans are of the order from 8ft. to 20ft. in diameter with limited power consumption, up to say 500 BHP.

Such tunnels had either similar fans as in Section 2.1 and 3.1 or because the need arose for multi bladed fans (i.e. more than 4 blades), it became necessary to have detachable blades. With this requirement the design of the blade had to incorporate suitable root retention facilities and new concepts in hub design.

The basic manufacturing design of the aerodynamic portion of the blade remained the same but new methods had to be incorporated for the root. More details are given in Section 9.

2.3 Fans for Large Windtunnels

The definition of large windtunnel for this Report will be taken as tunnels with fans over 20ft. in diameter or with power consumption of over 500 BHP. per unit. Some tunnels in this category have multiple unit fan systems. Theses tunnels are nearly always owned and operated by Government research establishments, although one particular example illustrated was built by a major motor car company (GM) for research into vehicle aerodynamics.

Such large fans were, of course, multi bladed and required detachable blades. This requirement then led to the expansion of the principle used for medium fans with the corresponding need to solve the problems associated when constructing larger units based on smaller scale designs.

One such fan unit, built during the 1950's, for the Aircraft Research Association, of Bedford, England was 21ft. in diameter requiring two impellers on a single shaft, the impellers being separated by stationary guide vanes. Twenty blades were required for each impeller, all blades being of identical aerodynamic design. Details of the Root Plate (Bracket) used for this design are given in Section 7.3.2.1.3.

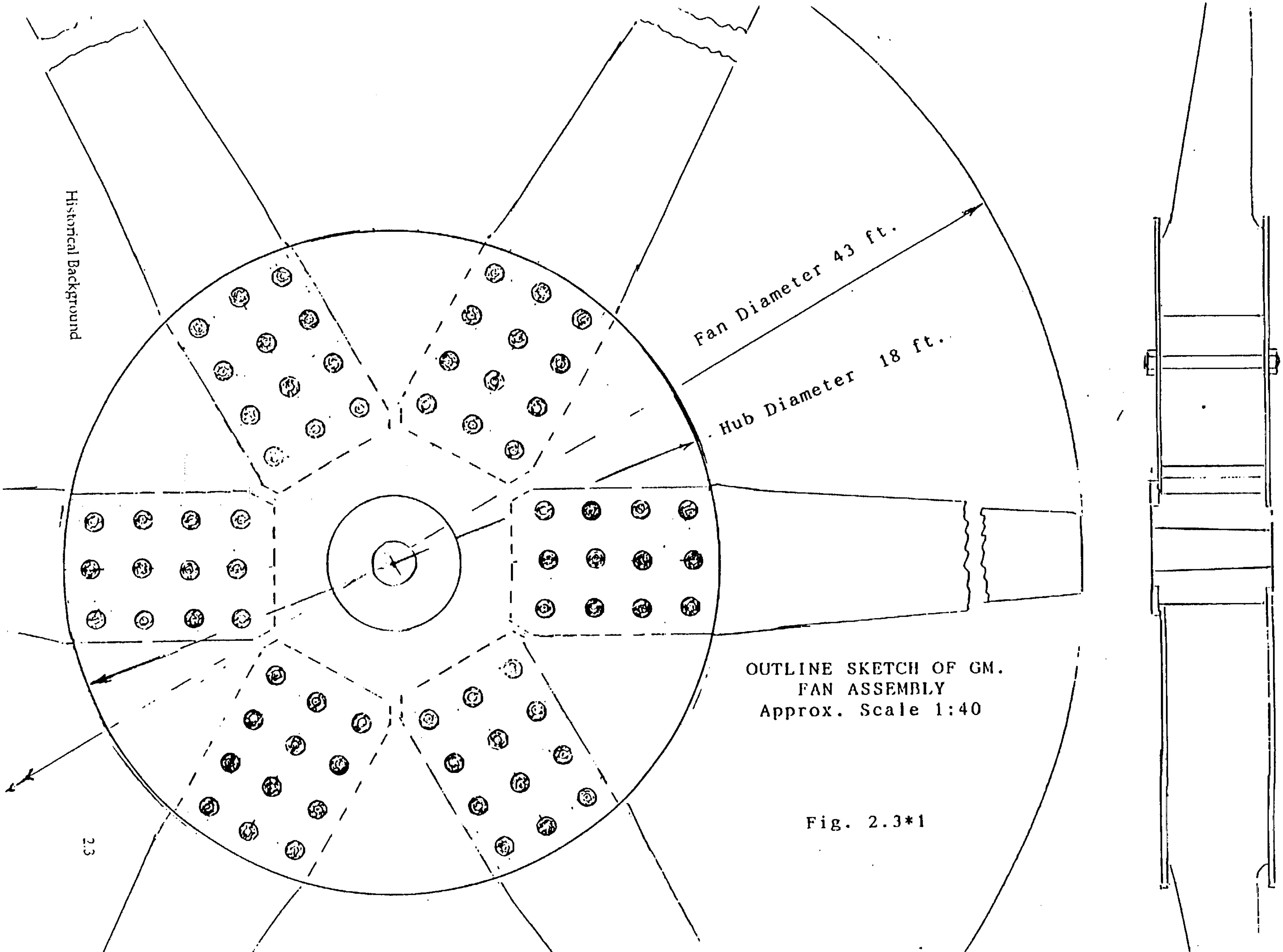
A large Motor Car Windtunnel built by General Motors at their Technical Center, Warren, Detroit has a fixed pitch fan of 43ft. diameter, the construction being six detachable blades with substantially rectangular roots bolted between two steel hub plates. See Figs. 2.3*1 and 2.3*2.

Other fans similar to this type are in use at three NASA Research Centers, (Ames, Lewis, and Langley).

The World's Largest Windtunnel, the (U.S.A.) National Full-scale Aerodynamic Complex at Ames Research Center, California has a multi unit fan system consisting of six fans each 40ft. diameter. Originally this tunnel was constructed during 1940 - 1944 and each fan then had six detachable blades, held between two steel hub plates, a similar design to many other large fans of the time and even since.

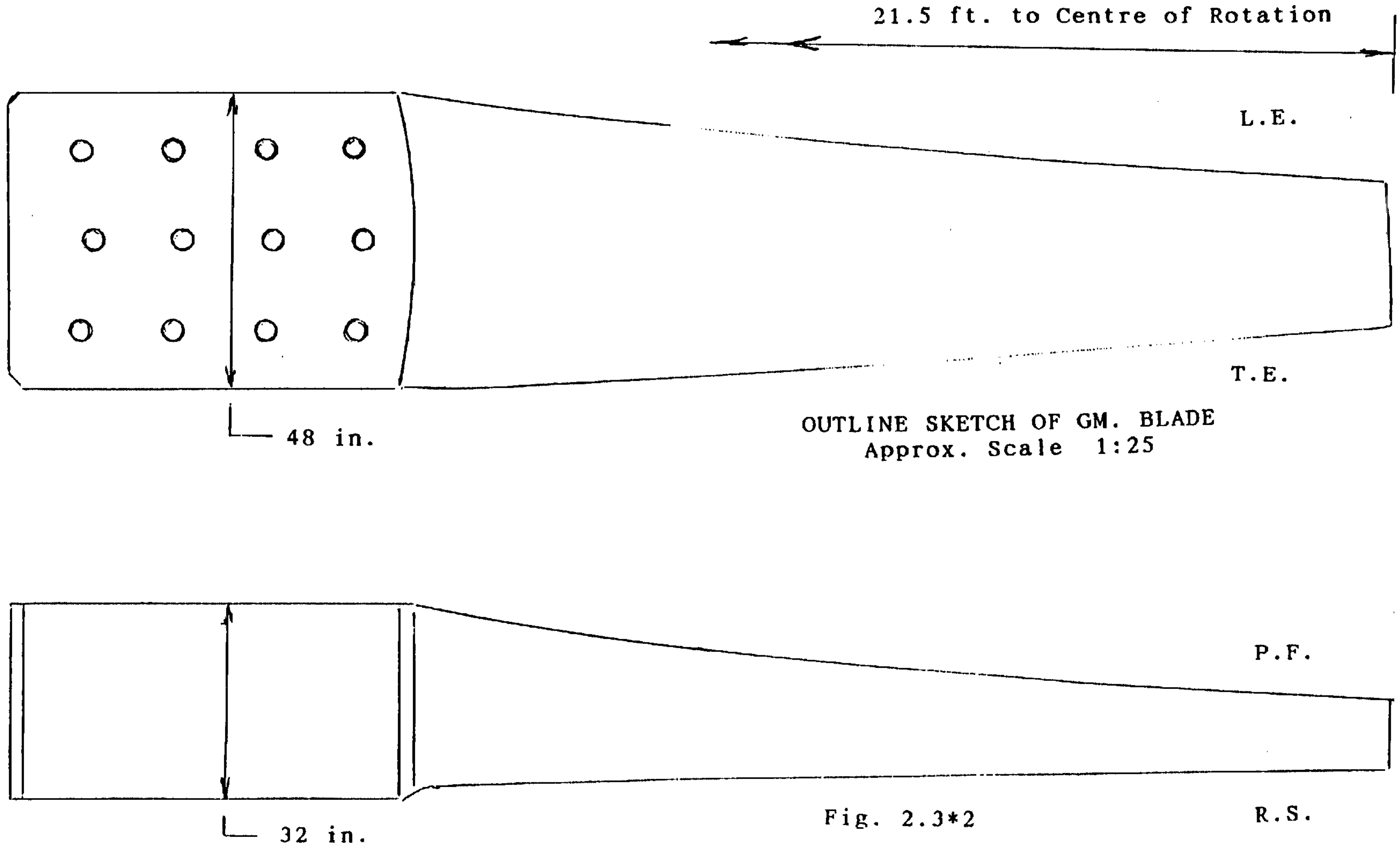
During 1978 - 1986 a major refurbishing project was undertaken on this Ames tunnel and the fan units were re-designed and re-built. The 6 fan units now (1990) consist of variable pitch fans with 15 blades per fan that are powered by 22,500 BHP motors, to run at variable speed at low power and variable pitch at a constant speed of 180 RPM at high power. The original diameter of 40ft. was not changed.

As a result of this re-design the fan blades were required to have "circular" root sections. Because the project for these blades was so important and of course the financial considerations so large it was deemed necessary to conduct a good deal of detailed testing of the proposed design before much of the manufacturing process was undertaken. See also Section 7.3.



OUTLINE SKETCH OF GM.
FAN ASSEMBLY
Approx. Scale 1:40

Fig. 2.3*1



OUTLINE SKETCH OF GM. BLADE
Approx. Scale 1:25

Fig. 2.3*2

3. Different Types of Blades

3.1 Integral Two and Four Blades

3.1.1 Two blade fans

Typical two blade fan construction is shown in Fig. 3.1.1*1.

A block has to be constructed/glued from a number of laminations (lams). Most lams are made continuous through the root, (into both blades), to achieve structural integrity.

Because of the symmetry of the fan the grain direction of each lam for each blade is the same although the grain direction of adjacent lams need not necessarily be identical.

To allow for the boss depth to be kept low it is permissible for a few lams (normally not more than 2) to be "floating" lams, i.e. lams that are dis-continuous at the root.

Reference should be made to Section 7 for aspects of the root design and lam shape.

3.1.2 Four blade fans

There are two solutions to achieving a 4 blade fan. The first is to have two 2-blade fans simply bolted together at the root, but this arrangement has the disadvantage of requiring twice the length or depth for the attachment to the driving shaft or motor leading to mechanical problems.

The alternative solution is to have an integral 4-blade fan where each of the four blades runs into the boss. This is achieved in the construction by having each lam from a pair of blades being "half lapped" with the corresponding lam of the other pair of blades. See Fig. 3.1.2*1, Fig. 9.2.3*1 and Fig. 9.2.3*2.

The consequence of this type of construction is that the root strength of each blade is reduced so that care is needed at the initial design stage that adequate strength is retained. See Section 7.2

However this construction has its advantages in that the boss depth can be kept low so that the hub or shaft attachment is also kept to reasonable proportions.

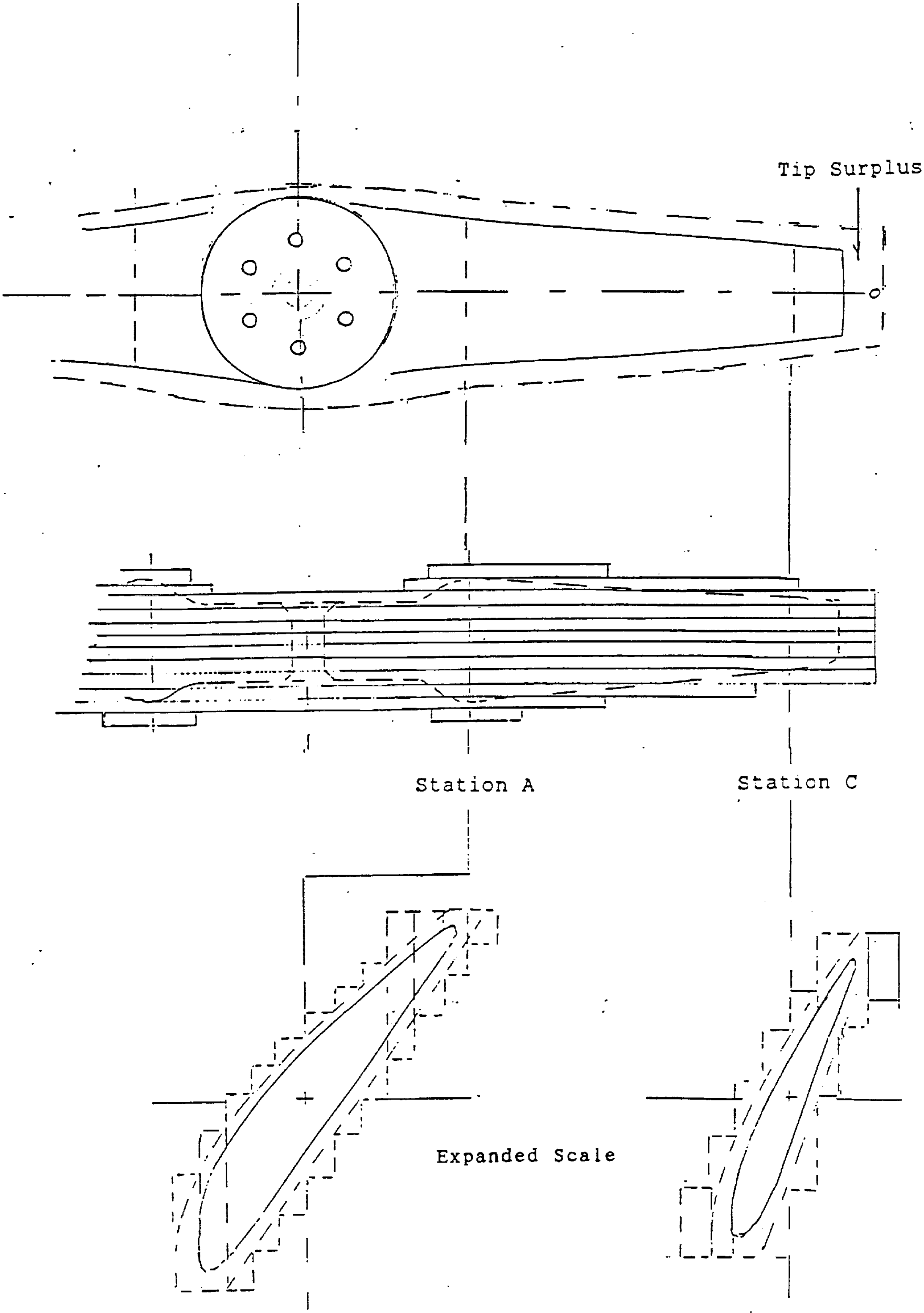


Fig. 3.1.1*1

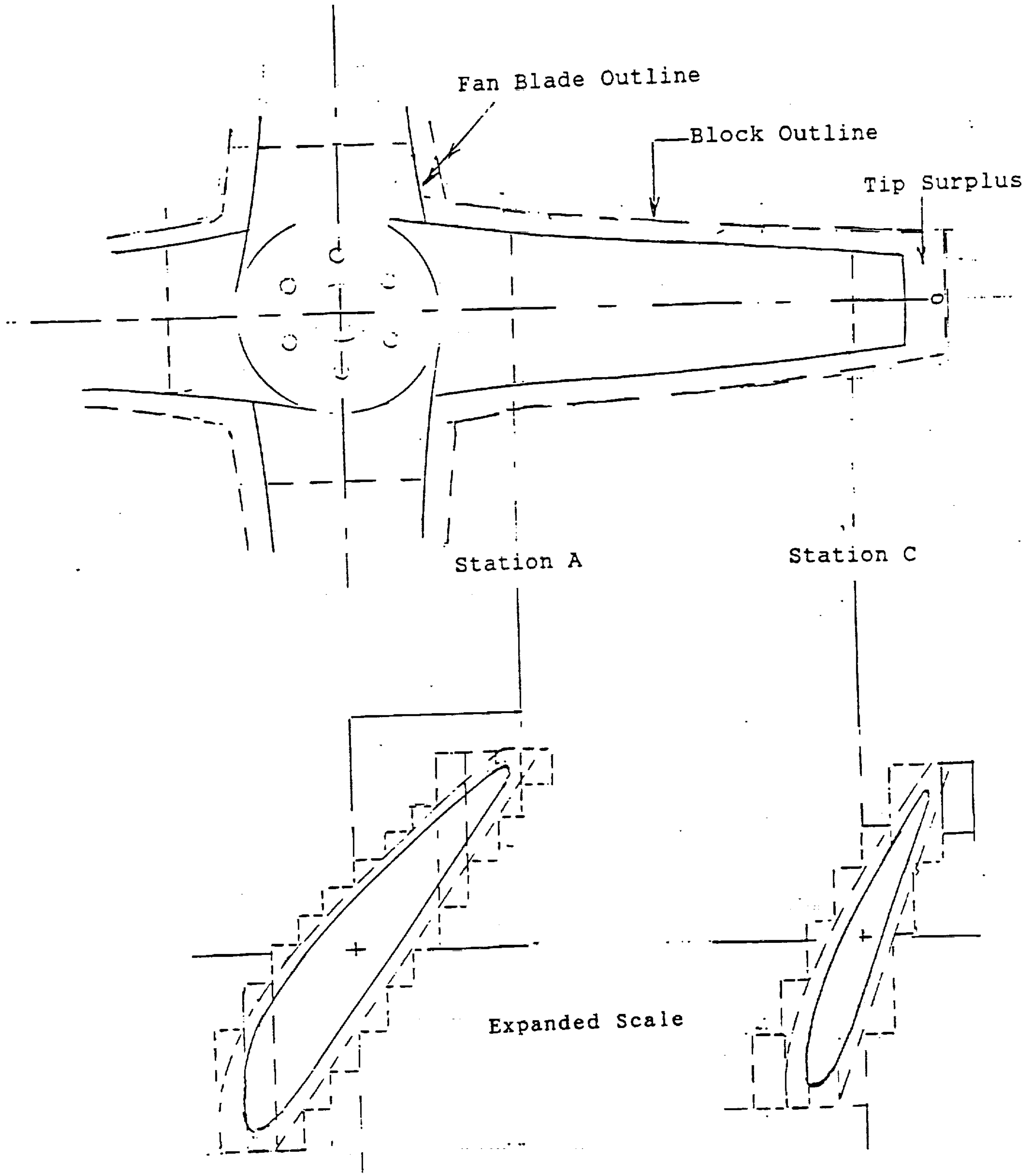

Fan Blade Outline
Block Outline
Tip Surplus
Station A
Station C
Expanded Scale

Fig. 3.1.2*1

3.2 Detachable Blades (Fixed Pitch)

Detachable blades for fixed pitch fans do not necessarily have the requirement of a circular root section, so a "rectangular" section at the root is possible, although the root plan form is frequently trapezoidal or segmental to fit neatly into a circle. Such roots may be retained by simple disc hub plates, which leads to simple hub design.

Various types of root retentions have been used. The simplest is for the blade root to be retained between the hub plates by bolt pressure and friction, sometimes the friction method being extended by having the root plates grooved so that the peaks of the plate grooves can actually bite into the wood surface of the blade root when assembled.

This method can sometimes lead to the requirement, on a sitka spruce root block, for different (harder) wood face lams to be glued each side to the root block to prevent excessive indentation by the metal root plates.

The second type (really an extention of the above) is where the bolts of the hub plates are proportioned to take some of the load by bearing directly on to the wood root through close tolerance holes.

The GM fan was a combination of these two methods of root retention.

A third type replaces the friction component by having a metal (usually high grade aluminium alloy) plates bonded to the blade and then these plates are retained between the hub plates by through bolts, or if the plates are part of a forged component retained by other means. See Section 7.

3.3 Detachable Blades (Variable Pitch)

Variable Pitch blades are virtually compelled to have circular root sections. The geometrical shape of the transition from an aerofoil shape to a circular section necessitates the circular root section to be relatively small, consequently a natural wood root is unable to cope with the high root loads and mechanical attachment to the hub.

This problem originally arose (mainly during World War II) with wood aircraft propeller blades and was solved by the development of what became known as improved wood or compressed wood. This solution to the problem has been applied to Windtunnel fan blades in a number of ways.

For small or medium sized blades it has been found possible to construct the complete blades from a suitable compressed wood that can successfully be used at the root retention. This solution is inappropriate for very large blades on two accounts Firstly the root loads become too high for large blades due to the large centrifugal forces developed and secondly the cost of the material reaches an unacceptable level.

Because improved or compressed wood has a higher density than natural wood (approximately twice the density) the centrifugal loads of large fan blades would be excessive if the whole blade were constructed of compressed wood. The practical solution to this aspect is to construct the main part of the blade with natural wood and only have the root portion in compressed wood. This can be achieved by producing the lams with the two materials scarf jointed at an appropriate position along the radial axis of the blade.

This method can and has also been used for small and medium sized blades where it was appropriate to do so.

The circular root section, continuing inboard to form a cylindrical or conical component has to be part of the root retention system which needs to fit into or on to the mechanical component of the hub.

The basic cylindrical or conical compressed wood root can be retained in a metal (usually steel) adaptor or ferrule by one of two methods. A conical wood root may be screw threaded to mate with an internal thread in the (metal) adaptor or a cylindrical root may be contained in a cylindrical tube adaptor and retained by screws. See Fig. 3.3*1 and Ref:13.1.10.

Both types of adaptor have been used successfully, the main consideration of which type is used usually being determined by the design of the hub.

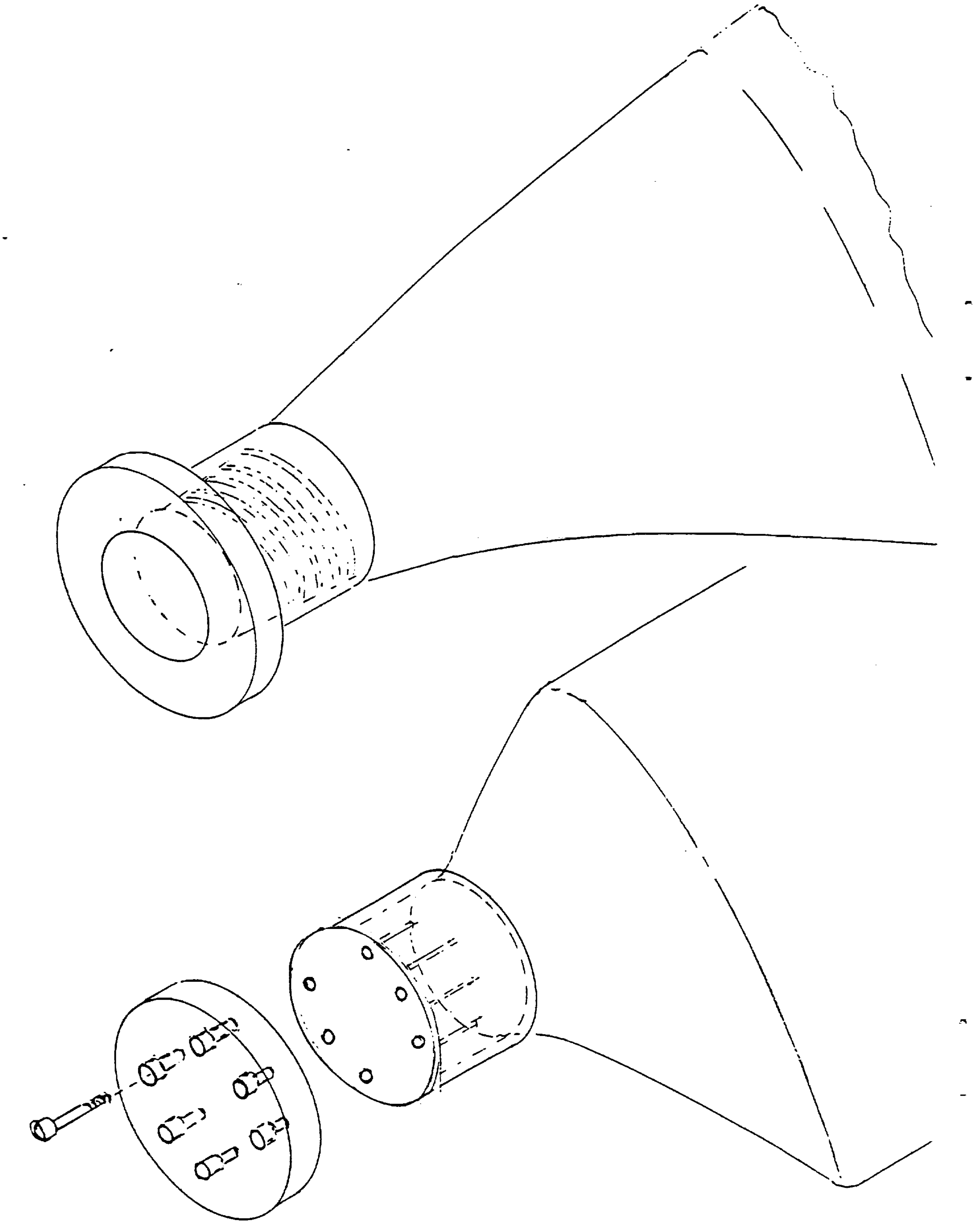


Fig. 3.3*1

4. Design Concepts

4.1 New Fans

4.1.1 Introduction

This Section gives an outline for the solution to developing a design for a completely new project.

The details of the design of a new windtunnel is not a part of this Report but an appreciation of what is involved is necessary if the detailed design of the appropriate fan is to be considered.

Various types of windtunnel may be involved, but only one type will be illustrated. The closed circuit of such a tunnel would consist of a closed loop of a suitable sized tube where the air is circulated round and round. Part of the loop, usually with a rectangular cross section, would be the Working Section where a model (either reduced scale or full sized), to be tested would be held for the circulating air to be passed over it. The majority of the loop will be of variable cross section so that the air velocity at any section will be less than in the Working Section. The fan is usually towards the largest cross section. See Fig. 4.1.1*1

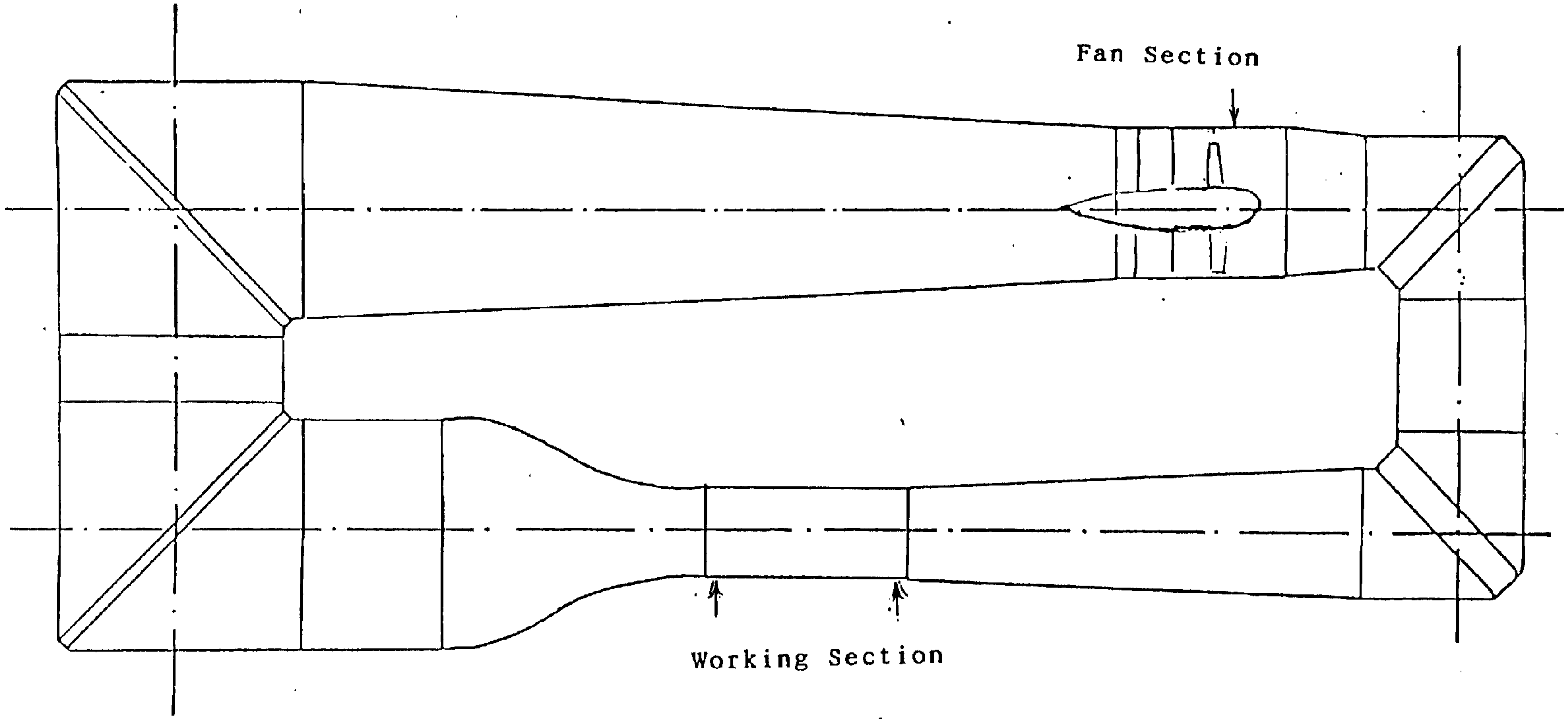
The windtunnel design usually starts by specifying the size of the Working Section to be used and the maximum velocity of air to be passed through this working section. From these starting points it is possible to determine the volume of air to be passed through the fan and the pressure drop round the wind tunnel leading to an estimate of the power required to be absorbed by the fan.

From the physical size of the Windtunnel the fan diameter is either determined or at least a close approximation can be arrived at.

Similar considerations apply to other types of tunnels so that the design of the fan has to be based on a known (or restricted limit) of the diameter, the volume of air to be passed through and the power to be absorbed.

4.1.2 Detailed Design

The detailed design has to be based on general well known aerodynamical principles (See Section 5 for a theoretical summary).



SKETCH OF CLOSED CIRCUIT
WINDTUNNEL

Fig. 4.1.1*1

As with the majority of practical engineering problems before a start can be made on a design study some idea of the end product and how it is to be manufactured has to be kept in mind. The design of the fan involves a number of other features, the main one being the type of motor to drive the fan. Most Windtunnels use an electric motor as the prime motor drive, although some windtunnels have been built using other power sources such as diesel engines or hydraulic motors. The fan designer either has to co-operate with the windtunnel designer so that an agreed solution is found or perhaps more frequently the fan designer is restricted to the system that the windtunnel design specifies or imposes.

Of course it has frequently occurred that the tunnel designer needs possible solutions to the fan design before being able to firm up on the tunnel hardware details which are essential to be known to the fan designer in the first place. (A typical "chicken and egg" situation).

In an attempt to simplify this problem a quick method (in the form of a computer program) of fan design has been developed (See Section 5) whereby alternative designs can be produced with alternative data input.

When an acceptable overall design concept has been achieved this method (the computer program) can be used to specify the detailed design. A refinement to the program can then give stress values and details of the material contents so that estimates of cost may be considered. (For further details see Section 5.)

4.2 Replacement Fans

Replacement Fans usually need little fundamental design change as a basic copy of an existing fan is often involved but some detailed consideration of the manufacturing design is sometimes required. The external shape and dimensions can normally be obtained from the original fan but the details of the lams and build up are not always apparent.

In some cases it may be that a change or new hub system will require design changes of the roots of replacement blades. There are small differences between the design concept for replacement or new blades.

Section 5: Aerodynamic Design

Index

5. Aerodynamic Design

- 5.1 Theoretical study
  - 5.5.1 Notation
  - 5.1.2 Standard Formulae
  - 5.1.3 Conditions for Stable Flow
  - 5.1.4 Practical Modification for Torque Grading
  - 5.1.5 Limitations of Analysis
  - 5.1.6 Input Data and Preliminary Calculations
  - 5.1.7 Main Calculations
  - 5.1.8 Pressure Calculations
  - 5.1.9 Blade Loading
  - 5.1.10 Blade Stresses
- 5.2 Design Computer Program
  - 5.2.1 Operating Instructions with Sample Design

See Appendix C

C1 BASIC Variables

C2 Program Listing

5. Aerodynamic Design

5.1 Theoretical study

5.1.1 Notation

As this Section provides a Computer Program listing (5.2) the notation is given in two forms: firstly in fairly conventional script form (including Greek letters) and secondly the corresponding requirements for the BASIC program language.

Script		BASIC	
π	standard value	PI	= 3.1459
π^2	standard value squared	PS	= 9.8696
r	radius (ft)	R	
R	tip radius (ft)	TR	
D	blade/fan diameter (ft)	D	
BD	blanking diameter (ft)	BD	
		(I)	used in BASIC program FOR..... NEXT loops as integer spaces of blade stations range 1 to 10
		(J)	used in BASIC program FOR..... NEXT loops as integer spaces of blade radius, mainly for 1% spacing in range 40 to 100
x	r/R	X(J)	
BHP	fan power	HP	
υ	blanking ratio	NU	= BD/D
Z	no of blades	Z	
c	blade cord (ins)	C(J)	blade chord for station J
t	blade thickness (ins)	TT(J)	blade thickness for station J
t/c	blade thickness/chord ratio	TC(J)	thickness ratio for station J
s	blade solidity = Z*c/12*x* π *D	S(J)	blade solidity at position I = Z*C (J)/(12*X(J)*:PI *D

Eqn 1

u	air velocity through fan annulus (ft/sec)	U	
n	rotor speed (revs/sec)	N/60	
Rpm	rotor speed (revs/min)	N	
Δv	rotational air speed (ft/sec)	DELV	(ft/sec)
kg	non-dimensional coeff for rotational air flow $= \Delta v/\pi nDx$	KG(X) =	60*DELV/(PI*N*D*X(J)) Eqn 2
W	mean air velocity at blade station	W1(J)	(ft/sec)
T	thrust force acting on blade	T	(lbsf)
Q	torque moment acting on blade	Q	(lbsf-ft)
C_L	lift coefficient	CL(J)	
CD	drag coefficient		
γ	drag/lift ratio	GAM	
Q_{sec}	quantity of air flow (cu ft/sec)		
Q_{min}	quantity of air flow (cu ft/min	V	= Q_{sec}/1000
ρ	density of air	RHO	= 0.00238 slugs/cu ft for standard condition
φ	non-dimensional flow coefficient	VI	= 4*KV/(PI^2*(1-NU^2)) Eqn 3
kv	non-dimensional volume coefficient	KV	= 1000*V/(N*D^3) Eqn 4
kq	non-dimensional torque/power coefficient = Power/$(2\pi\rho n^3 {*} D^5)$	KQ	550*60^3*HP/(2*PI*RHO*N^3*D^5) Eqn 5
kp	non-dimensional pressure coefficient = sp/nD	KP	3600* pressure/.00238*N *D
sp	static pressure		
Φ	inflow angle (degrees)	PH(J)	for station J

Gs	power coefficient	GS	= KQ/PI*KV Eqn 6
G	modified power coefficient at station J	G(J)	for station J = GF(J)*GS Eqn 7
Gf	power coefficient factor for station J	GF(J)	for station J = G(J)/GS Eqn 8

5.1.2 Standard Formulae

Velocity and force diagrams are given in Figs 5.1.2*1 and 5.1.2*2.

From these diagrams it can be seen that:

$$\tan\Phi = \frac{u}{\pi n D x - \Delta v/2} = \frac{\varphi/x}{1 - Kg/2} \qquad \text{Eqn 9}$$

and

$$W = \frac{u}{\sin\Phi} = \frac{(\pi n D x - \Delta v/2)}{\cos\Phi} \qquad \text{Eqn 10}$$

The torque on an increment of blade at radius r can be calculated in two ways.

From momentum considerations it can be found that:

$$dQ/dr = 2\pi r^2 \rho u \Delta v \qquad \text{Eqn 11}$$

From consideration of the lift and drag forces on the aerofoil section:

$$dQ/dr = ½W^2\, r\, Z\, c\, C_L \sin\Phi\,(1 + \gamma\cot\Phi) \text{ or} \qquad \text{Eqn 12}$$

$$dQ/dr = \rho W^2\, \pi\, r^2\, sC_L \sin\Phi\,(1 + \gamma\cot\Phi) \qquad \text{Eqn 13}$$

These can then be converted to non-dimensional form as:

$$dKq/dx^2 = \frac{\pi^3}{4}\,\varphi\, x^2\, Kg/2 \qquad \text{Eqn 14}$$

and

$$dKq/dx^2 = \frac{\pi^3}{16}\,\varphi^2\, x\, \frac{sC_L}{\sin\Phi}\,(1 + \gamma\cot\Phi) \qquad \text{Eqn 15}$$

which gives

$$Kg/2 = (1/4)\,(\frac{\varphi}{x})\,sC_L\,(1 + \gamma\cot\Phi)/\sin\Phi \text{ or}$$

$$sC_L = \frac{4x\ Kg/2 * \sin\Phi}{\varphi * (1 + \gamma\cot\Phi)} \qquad \text{Eqn 16}$$

or in BASIC notation:

dKQ/dx^2 = (1/8)*PI^3*VI*X(J)^2*KG and

dKQ/dx^2 =
(1/16)*PI^3*VI^2*X(J)*SCL(J)*(1+GAM/TAN(PH(J)))/SIN(PH(J))

Similarly the thrust force can be found to be:

$$\frac{dT}{dr} = sp*2*\pi*r \qquad \text{Eqn 17}$$

whereT is thrust and sp is static pressure

$$= \rho/2\ W^2\pi r s C_L \cos\Phi\,(1 - \gamma\tan\Phi) \text{ or} \qquad \text{Eqn 18}$$

$$kpx = \frac{\pi^2}{2}\,sC_L\,\frac{(\cot\Phi - \gamma)}{\sin\Phi} \qquad \text{Eqn 19}$$

where kpx is the coefficient of pressure at station x.

In BASIC notation this is:

KP(I)=.5*PS*VI^2*SCL(I)*(1/TAN(PH(I)) - GAM)/SIN(PH(I)) Eqn 20

5.1.3 Conditions for Stable Flow after passing through the Fan Rotor

Assuming that two adjacent cylindrical tubes of air have the same Bernoilli constant after passing through the rotor:

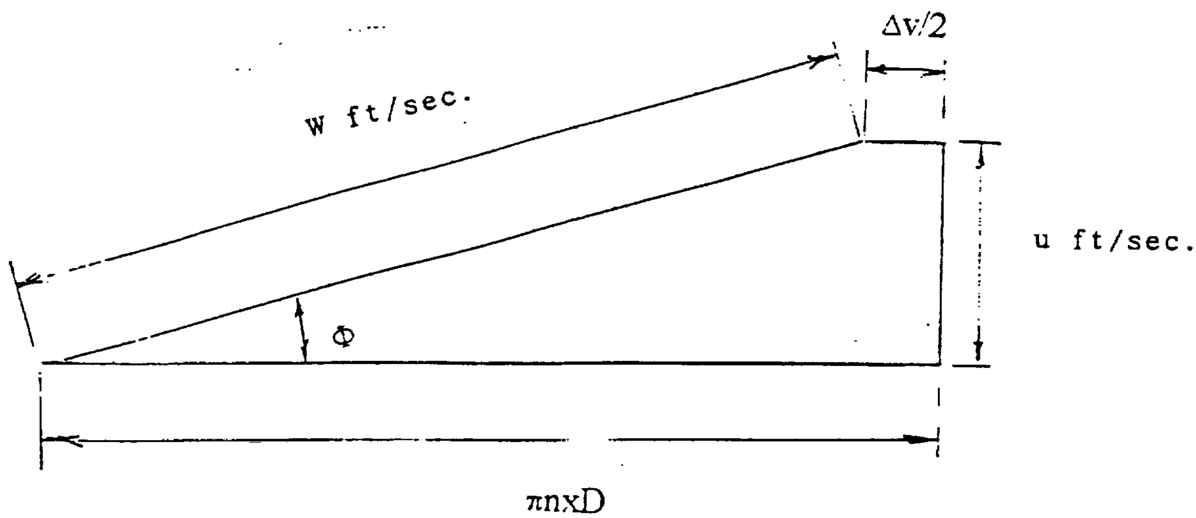
ie $p+1/2\,\Delta\,v$= constant

for this condition which is of a free vortex then:

$r^*\,\Delta\,v$= constant

Therefore $^{dQ}/_{dr} = 2\pi r^2 \rho u \Delta v = 2\pi\rho u * \text{constant } *r$

Velocity Diagrams



Non-dimensional
Representation

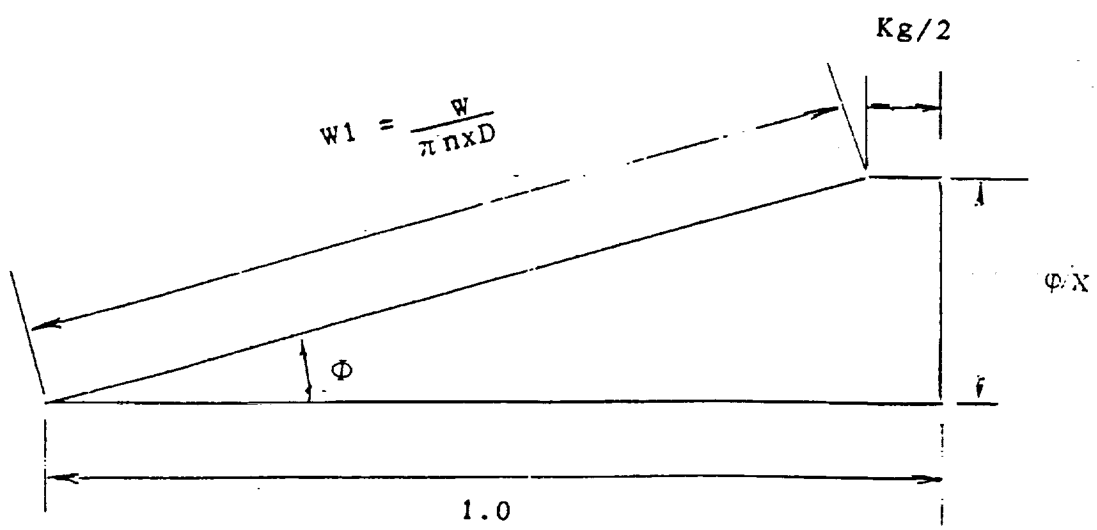


Fig. 5.1.2*1

Force Diagrams

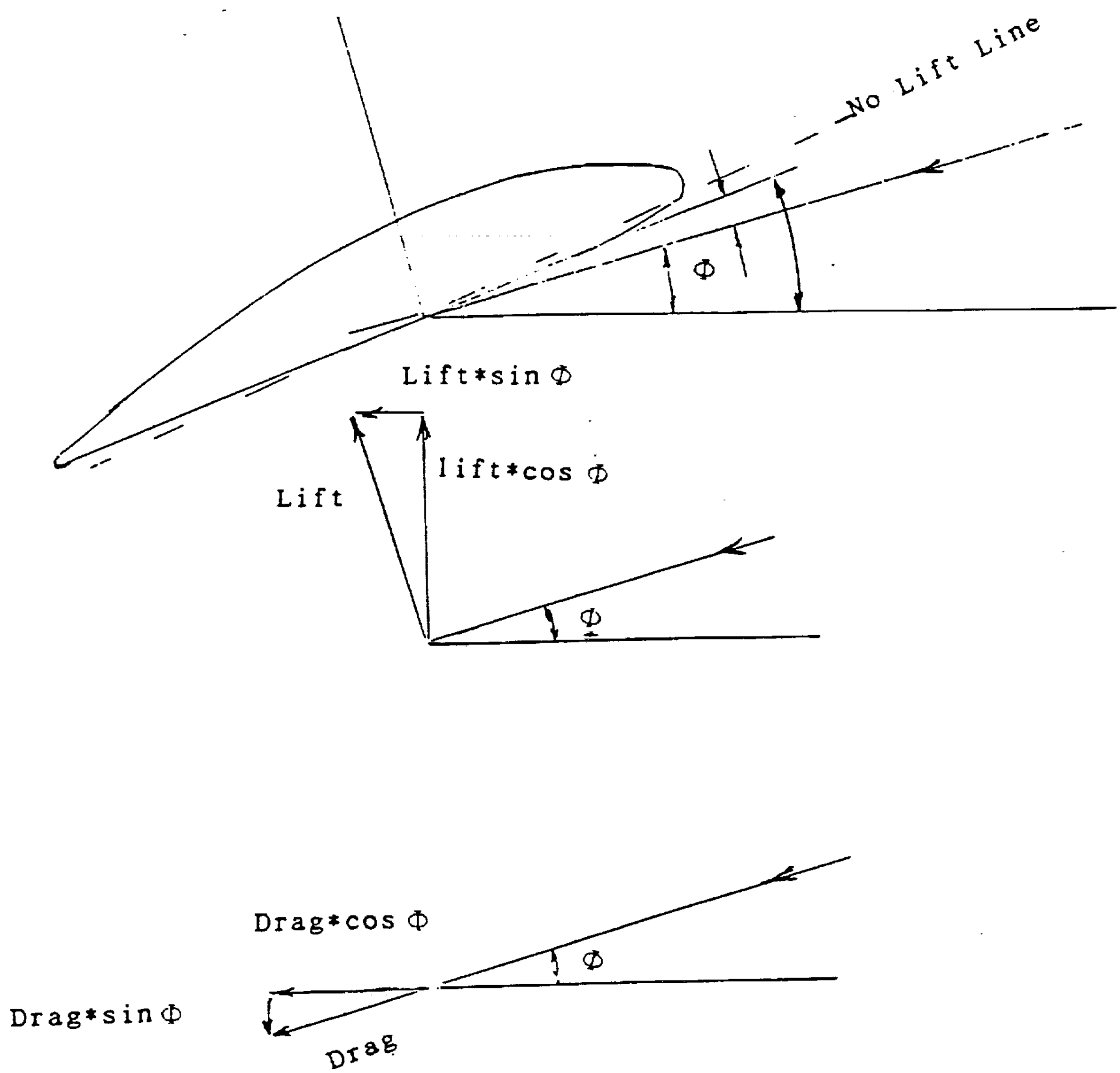


Fig. 5.1.2*2

ie a linear torque grading is required.

Converting to non-dimensional coefficients

$$x^2Kg/2 = Gs \text{ (a constant)} = Kq/\pi*Kv \qquad \text{Eqn 21}$$

or in BASIC notation:

(X(J))^2*KG(J)/2=GS   Eqn 22

5.1.4 Practical Modification to Torque Grading

Although it is theoretically desirable to have a linear torque grading, in practice it is usually necessary to have a reduced power (or torque) grading at the hub to restrict the value of sC_L below 1.0 over this region. It is also helpful for the power grading near the tip region to be increased slightly above the nominal linear grading to offset the increase in drag on the air at the tunnel wall.

Consequently if these requirements are to be taken into account, a power coefficient factor, somewhat lower than 1.0 at the hub and slightly higher over the tip region, should be included in the detailed calculations. This requirement can be illustrated as shown in Fig. 5.1.4*1

5.1.5 Limitations of the Analysis

The theoretical analysis presented has to be interpreted with certain limitations and the BASIC program will only apply within the following restrictions.

The resultant design must ensure that the solidity of the fan is relatively small (see Section 5.1.7) otherwise cascade theory would need to be included for the flow between adjacent blades.

The maximum tip speed of the fan design should be limited to below approximately 450-500 ft/sec, Mach 0.6, so that it is lower than the speed of sound and compressibilty does not have to be taken into account.

It is assumed that the aerofoil sections of the blades will be relatively conventional (normally flat undersurfaces) appropriate for wood blade manufacture. If highly cambered sections are used some modification in the theory may be required at certain stages of the analysis (i.e. the relationship of the slope of the curve for C_L vs. α incidence angle).

The final range of values for C_L along the blade must be limited to below 1.0 at the root, but preferably lower than 0.85 and the C_L at the tip below 0.65.

Typical Power Curve

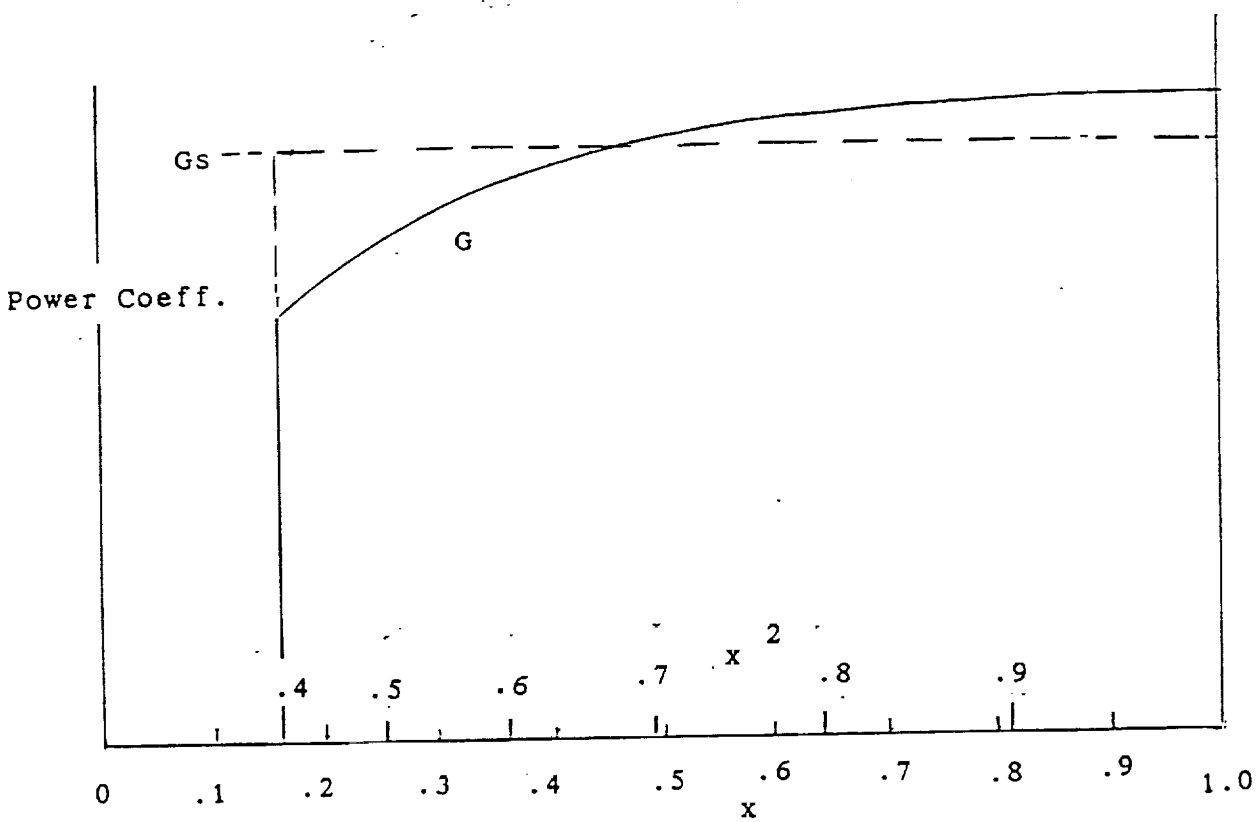


Fig. 5.1.4*1

This range of of C_L will enable a standard value for drag/lift, GAM = 0.067 to be used.

5.1.6 Input Data and Preliminary Calculations

The input data required for a fan blade design consists of:

Fan Diameter
Blanking (or Hub) Diameter
Volume of air flow
Fan power to be absorbed
Fan speed

From this data the required values of the air velocity, u ft/sec, through the fan annulus can be calculated, and it is assumed that this value is uniform over the whole annulus area so independent of the blade radial station. This then allows the non-dimensional equivalent, φ to be found. Eqn. 3.

Also from the input data the required (constant) power coefficient, GS, can be calculated and hence by using a standard practical range of power coefficient factors (see Section 5.1.1) suitable values for the (local modified) power coefficient at any radial station may be determined. This coefficient then enables values for the rotational air speed at any radial station to be found from the expression:

x^2 Kg/2 = Gs (see Section 5.1.3) see... Eqn.21

The range of power coefficient factors is given in the BASIC program as DATA at lines 140 through to 180 to be READ into the variable GF(J).

5.1.7 Main Calculations

The values for sC_L at any radial station can be obtained from the appropriate equation:

$$sC_L = \frac{4*x*Kg/2*\sin\Phi}{\varphi*(1+\gamma\cot\Phi)} \quad \text{see Eqn 16}$$

$$sC_L = \frac{4*G*\sin\Phi}{\varphi*x*(1+\gamma\cot\Phi)} \quad \text{Eqn 23}$$

or the BASIC equivalent:

```
SCL(J)=4*G(J)*SIN(PH(J))/(VI*X(J)*(1+GAM/TAN(PH(J)
```
Eqn 24

See Section 5.1.3.

It is necessary that the value of sC_L at the root is restricted to be below 1.0 and it is also advisable that both the solidity and the C_L values be restricted to be below 1.0. If in a detailed calculation it is found that at the root a value of sC_L above 1.0 is produced then the previously considered chord (hence solidity) will need to be increased. If this cannot be achieved without it being necessary to increase the solidity to above 1.0 then it is necessary that the fundamental input data be modified. This may be achieved by considering an increase in the Fan Speed but sometimes it may be necessary to consider an increase in the Fan Diameter which, of course, might entail a complete revision of the basic tunnel layout sizes.

It is advisable to restrict the required lift coefficient C_L, at the tip to somewhat lower than a value of 0.6 so it is possible to obtain a first approximation to the tip solidity from the calculated value of sC_L at the tip and this limit of required C_L.

The next stage is to choose an appropriate chord distribution to obtain solidity values at any radial station that will give a suitable range of lift coefficients (C_L) along the blade. It is necessary to limit the C_L value at the root, as previously explained so that preferably it is not greater than say 0.85.

Although theoretically there is little limit on the size or shape required by a blade, it has been found that a practical size of wood blade should have an aspect ratio of approximately 0.4. Taking into account the eventual stressing considerations it is advisable to specify a trapezoidal plan form with a somewhat larger chord at the root to that at the tip. A first approximation for a suitable (tip) chord can be obtained from the formula:

CS = 2.4* (D-BD), where CS is the chord in inches.

The plan form can be obtained from having the blade taper approximately 1 in./ft. length to a larger root chord.

From the two appropriate values of the tip solidity and tip chord, it is possible to find the minimum number of blades that would be required. This minimum value will usually not be an integer but, of course, for a practical design the number of blades must be an integer above this minimum.

Fans usually have an even number of blades, say 2, 4, or 8, but this is not essential, some windtunnel fans have been manufactured with 5 or 7 blades and the Ames fans have 15 blades per rotor.

An appropriate number of blades must be chosen for the fan and an actual tip chord specified. This will allow a revision to be made for the tip solidity and tip C_L values, the tip C_L being retricted to a suitable value lower than say 0.65.

A similar analysis for the root station gives values for the root solidity and root C_L. Provided that this calculated value for the root C_L is lower than the maximum of 1.0 (preferably in the region of 0.8) it is then appropriate to calculate the values for the chords at the other radial stations.

Taking into account the practical manufacturing considerations and the eventual stress requirements it is possible to suggest an appropriate aerofoil section thickness distribution along a blade by having a section thickness at the root of 19%, tapering to a section thickness at the tip of 10%.

These values of chord and thickness then define the aerofoil section sizes along the blade. From the values of thickness/chord ratios the value of the "no-lift" angle can be found.

$$\varepsilon = \text{const.}*t/c \qquad \text{Eqn.25}$$

For a fan design within the limitations as specified in Section 5.1.5 there is usually no need to use aerofoil blade sections other than standard flat pitch (under surface) Clark Y sections. If these are used then the C_L vs. α incidence angle diagram, see Fig. 5.1.7*1 shows that it is possible to use the following relationship between the two quantities:

$$\alpha + 0.11 = 11.76 * C_L \qquad \text{Eqn.26}$$

provided that C_L is limited to a maximum of 0.85. The "no-lift" angle constant may be taken as 40 (see Eqn. 25).

From the values of sC_L and solidity, s the values for C_L may be obtained and hence the incidence angles, α.

The design section angles may then be calculated from the values of α, ε and ϕ and the formula:

$$\theta = \alpha - \varepsilon + \Phi \qquad \text{Eqn 27}$$

TH(J)=ALP(J)-40*TC(J)+PH(J) Eqn 28

In the BASIC program (as listed) this "angle" equation (Eqn 28) is expanded so that the section blade angles can be printed out as "Degrees-Minutes" which will be the form required on the eventual Workshop Drawing.

5.1.8 Pressure Calculations

The pressure rise after the fan van be calculated from the thrust forces developed by the blades (See Eqns 17 to 20).

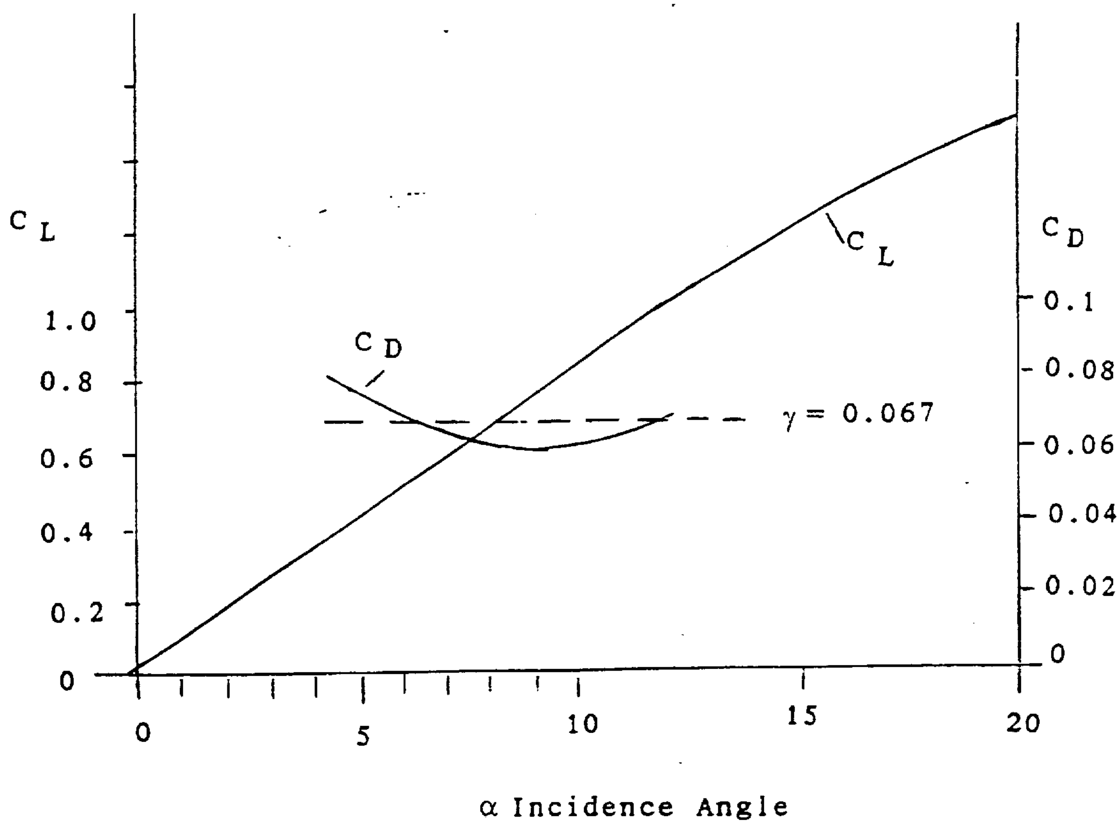

C L
C D
C D
C L
1.0
0.8
0.6
0.4
0.2
0
0.1
0.08
0.06
0.04
0.02
0
γ = 0.067
0
5
10
15
20
α Incidence Angle

Fig. 5.1.7*1

Integrating to obtain the total thrust, and dividing by the (annulus) area gives the pressure rise. Defining KP as:

$$KP = pressure/\rho\ n^2\ D^2$$

this leads to:

$$KP = \frac{1}{(1-\upsilon^2)} \int_{x=0.4}^{x=1.0} 2*x*kpx*dx$$

In BASIC notation with KP(I) = kpx, the integral can be calculated as:

KP = (.045*KP(4) + .1*KP(5) + .12*KP(6) + .14*KP (7) + .16*KP(8)
+ .18*(KP) + .095*KP(10)/NF Eqn 29

Note: A more accurate calculation could be made by using smaller intervals of the radius, e.g. using 1% spacing, but this is not really necessary for the pressure calculation.

From the value of KP found, the pressure rise can then be calculated as:

$$Pressure = \rho\ n^2\ D^2 *KP$$

In BASIC notation:

Pressure = .00238*(N) *D *KP
(60)
= .66*N^2*D^2*KP*10^-6 lbs/sq.ft.
WG = .127*N^2*D^2*KP*10 -6 "W.G.

The final Pressure value can be converted to other units if required.

5.1.9 Blade Loading

5.1.9.1 General

The aerodynamic design cannot be finalised until it is established that it is possible that the proposed design is capable of being manufactured and that in operation the stress levels are suitable for the type of construction.

The BASIC computer program has been extended so that, (at least for a first approximation), the stress levels can be readily and quickly obtained.

The main loading that has to be calculated for a blade is firstly the Air Bending Moments (ABM), i.e. the Bending Moments produced by the aerodynamic forces on the blade sections and secondly the centifugal loading produced by the rotational speed and the mass of the material of construction.

5.1.9.2 Air Bending Moments Calculations

By dividing the blade into elements with small radial length and by reference to the Force diagram, Figs. 5.1.2*1 and 5.1.2*2 it is possible to calculate that the loads on each element of 1% of the radius are as follows.

The Lift Force is given by:

$$L = \frac{1}{2}\rho W^{2}*C_L\frac{*c}{12}*0.01*D/2 \quad \text{(c is the chord in inches)}$$

$$= 0.00119*W^{2}*C_L\frac{*c}{12}*0.01\frac{*D}{2} \qquad \text{Eqn 30}$$

and the Drag Force is given by:

$$Dg = 1/2\rho W^{2}*C_D\frac{*c}{12}*0.01*D/2 \quad \text{or}$$

$$Dg = 1/2\rho W^{2}\gamma*C_L*c*0.01*D/24 \qquad \text{Eqn 31}$$

The relative air velocity is

$$W = u / \sin\Phi \qquad \text{Eqn 32}$$

The component of this Lift force gives a load in the axial (or thrust direction) of :

Element Thrust Lift Force, ETLF = $L*\cos\Phi$ Eqn 33

and a load in the plane of rotation direction of

Element Torque Lift Force, EQLF = ETLF/$\tan\Phi$ Eqn 34

Correspondingly the component of Drag force gives a load in the axial (or thrust) direction of :

Element Thrust Drag Force, ETDgF = EDgF*$\sin\Phi$ = $L*\gamma*\sin\Phi$ Eqn 35

and a load in the plane of rotation direction of :

Element Torque Drag Force, EQDgF = EDgF/$\tan\Phi$ Eqn 36

Combining these forces give a total load in the axial direction of :

Element Total Thrust Force, ETTF = ETLF - ETDgF   Eqn 37

and in the plane of rotation of :

Element Total Torque Force, ETQF = EQLF + EQDgF   Eqn 38

Inboard of the blanking or hub radius there are no air loads so that these total loads are zero for these positions.

In BASIC notation these equations can be expressed as:

ETLF(J) = L(J)*COS(PH(J))   Eqn 39

EQLF(J) = ELF(J)/TAN(PH(J))   Eqn 40

ETDF(J) = L(J)*GAM*SIN(PH(J))   Eqn 41

EQDF(J) = ETDF(J)/TAN(PH(J))   Eqn 42

ETTF(J) = ETLF(J) - ETDF(J)   Eqn 43

ETQF(J) = EQLF(J) + EQDF(J)   Eqn 44

5.1.9.3 Centrifugal Force Loading

The Centrifugal Force acting on a body can be expressed by the standard equation:

$C.F. = m * \omega^2 * r$

where m = mass
ω = rotational speed
r = distance from the centre of rotation

To calculate the Centrifugal loading on a blade, it should be considered as small radial elements, which can have their volumes found and then with an estimate of the mass density their individual masses calculated.

The rotational speed, ω, is a function of the Rpm and the distance from the centre of rotation found from the radial position on the blade.

The area of a "simple" aerofoil section is given by:

Area (sq. in.) = 0.7*chord *thickness with the chord and thickness values in inches — Eqn 45

Or in BASIC notation this can be given as:

Area AR(J) = .7*C(J)*TT(J) at postion J. — Eqn 46

The volume of a small element of blade of radial length 1% of radius is then :

Volume of element = Area *0.01*D/(2*144) cu. ft.

For a spruce blade the nominal density value of spruce material is approximately 30 lbs./cu.ft. However an allowance has to be made for the additional weight of glass cloth and resin covering. To simplify the calculations it is justified to assume that the material has a density of 40 lbs./cu.ft. and then converting this value to mass density this becomes approximately 40/32.2 or 1.25 slugs/cu.ft.

Hence the mass of an element of blade can be given by:

Elemental mass = 1.25*Volume
= 1.25*Area * 0.01 * D/288 slugs — Eqn 47

or in BASIC notation

Mass = .0125 * Area * D/288
= .0125 * AR(J) * D/288 — Eqn 48

Rotational speed is given by:

$$\omega = 2 * \pi * n = \pi * N/30$$
$$\omega^2 = \pi^2 * N^2/900 \qquad \text{Eqn 49}$$

In BASIC notation:

OM = PI*N/30 where OM is the rotational speed and

OS = OM*OM and OS is (rotational speed) squared

The distance of the element from the centre of rotation is given by:

Distance = x *D /2 ft.

In BASIC notation:

$$\text{Distance} = \frac{X}{100} * D/2 \text{ or } X * D/200 \quad \text{ft.} \qquad \text{Eqn 50}$$

Combining the above formulae this then gives:

C.F. on element = 0.0125*Area*D/288 * p^2 * N^2 *x*D/1800 Eqn 51

In BASIC notation this is:

CFJ(J) = .217 * AR(J)*OS*X(J)*D*D*10^-6 Eqn 52

The Centrifugal loading at any radial station (I) is then the sum of all the centrifugal loads of the elements outboard of this station. (Of course, the tip station where I=100 has no centrifugal loading.) This can be expressed as:

C.F. at station I = C.F. on all outboard elements. Eqn 53

In the BASIC program this can be achieved within nested FOR . . . NEXT loops as:

```
FOR I = 9 TO 4 STEP -1
FOR J = ( 10*I+10) TO ( 10*I+1 ) STEP -1
CA = CA + CFJ( J)
NEXT J
CFT(J)=CA
NEXT I
```

where CA = accummulated C. F. I oads for elements between stations
and CFJ(J) = expression as above.

Note: The above analysis is only valid for a uniform spruce blade. If a detachable blade with a compressed wood root is considered, further claculations will be needed to be made to include the extra weight (or mass) near the root of this heavier material.

5.1.9.4 Centrifugal Force Bending Moment Calculations

By suitable orientation of the main axis of the blade it is possible to induce the centrifugal force loading on the blade to give a bending moment (CFBM) that is opposite to the air bending moment (ABM) so that the result can be a lower Net Bending Moment (NBM) and hence lower stresses on the blade.

The value of the CFBM depends directly on the amount of TRACK and SWEEP (Definitions:13.2.45 and 13.2.43) that is built into the blade orientation. See Figs. 5.1.9.4*1 and 5.1.9.4*2.

Practical note: This relationship is only strictly true if the blade does not deflect under load. Deflection of the blade will increase the CFBM and hence reduce the maximum NBM during normal operation. Windtunnel fan blades will usually be fairly stiff and the deflection can be discounted (at least for a first approximation of CFBM).

It is appropriate to set the amount of track and sweep so that the CFBM is approximately 50% of the calculated ABM and then if the ABM is suddenly reduced to zero at the shut down the NBM has the same value (but opposite sign) to the maximum NBM.

As the CFBM depends directly on the amount of track and sweep it is appropriate first to claculate this CFBM for the standard values of 1 in. track and sweep and then scale for desired values to give the required ratio of 50% of the ABM

The same techniques as for the main C.F. loading can be employed with the suitable offset dimensions at each blade section used to obtain the Bending Moments.

The C.F. loading on a small element of blade is given by:

C.F. on element = 0.0125*Area*D/288 * π^2*N^2*x*D/1800 see...Eqn 51

In BASIC notation this is:

CFJ(J) = .217*AR(J)*OS*X(J)*D*D*10^-6 see...Eqn 52

With the track at the tip, set at a standard 1 in. the offset of the C.of G.of the element at position x or J is then given by:

tx = (x-0.4)/0.6 Eqn 54

In BASIC notation this is:

TX(J) = (J-40)/60 Eqn 55

See Fig. 5.1.9.4*1

The CFBM due to the 1 in. tip track on this element is then:

T.CFBM on element = C.F. on element *tx Eqn 56

In BASIC notation this is:

= CFJ(J)*(J-40)/60 Eqn 57

Similarly the CFBM due to the 1 in. tip sweep on an element is then:

Q. CFBM on element = T.CFBM Eqn 58

Note: By reference to Fig. 5.1.9.4*2 it can be seen that these sweep equantions are slightly incorrect as, in the Y-Z plane, the C.F. loading makes a very small angle to the blade X-axis. However this effect is so small that it may be neglected.

It has been found that the Sweep.CFBM (SCFBM) should be some 60% of the Track. CFBM (TCFBM) to give an appropriate final CFBM across the root sections which are the heaviest loaded.

The total CFBM (for a standard 1 in. track at the tip) at any station (x or J) can be found by summing the values of all elements outboard of that station.

To set this value of the track CFBM at x=.4 (J=40) as 50% of the ABM at that station the track dimension at the tip would-have to be ABM at x=.4/CFBM at x=.4

For the BASIC program this required track is then shown on the VDU and a "CHOSEN TRACK" input required.

Practical Note: For manufacturing drawings it is helpful if the "CHOSEN TRACK" is set at an easily recognised and measured value (such as 3/4 in. or 0.75 in.) and not as a multi-decimal value as will normally be calculated and then shown on the VDU.

The TCFBM can be recalculated with the new value of "Chosen Track" and the SCFBM calculated as 60% of these values for the 60% value of the tip sweep dimension.

By resolving these two values of CFBM at the appropriate blade angle the final CFBM across the section may be found as:

CFBM across section = T.CFBM $*\cos\theta$ + Q.CFBM $*\sin\theta$ Eqn 59

By subtracting these CFBM calculated values form the Air bending moments (ABM) as found in Section 5.1.9.2. the Net Bending Moments can be obtained and hence the final BM stresses. The details are dealt with in Section 5.1.10.

5.1.10 Blade Stresses

5.1.10.1 Section Areas and Moduli Values

The area of any section is given by:

Area of section = 0.7*chord *thickness sq. in. see...Eqn 45

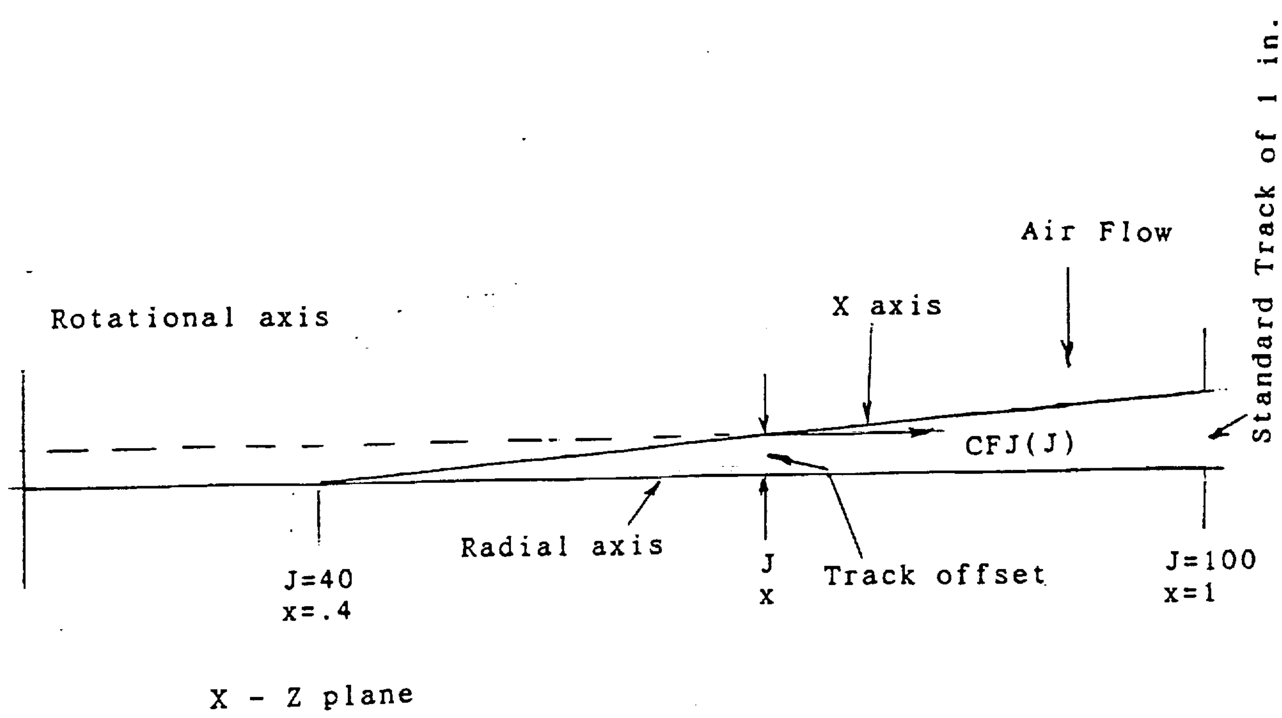


Fig. 5.1.9.4*1

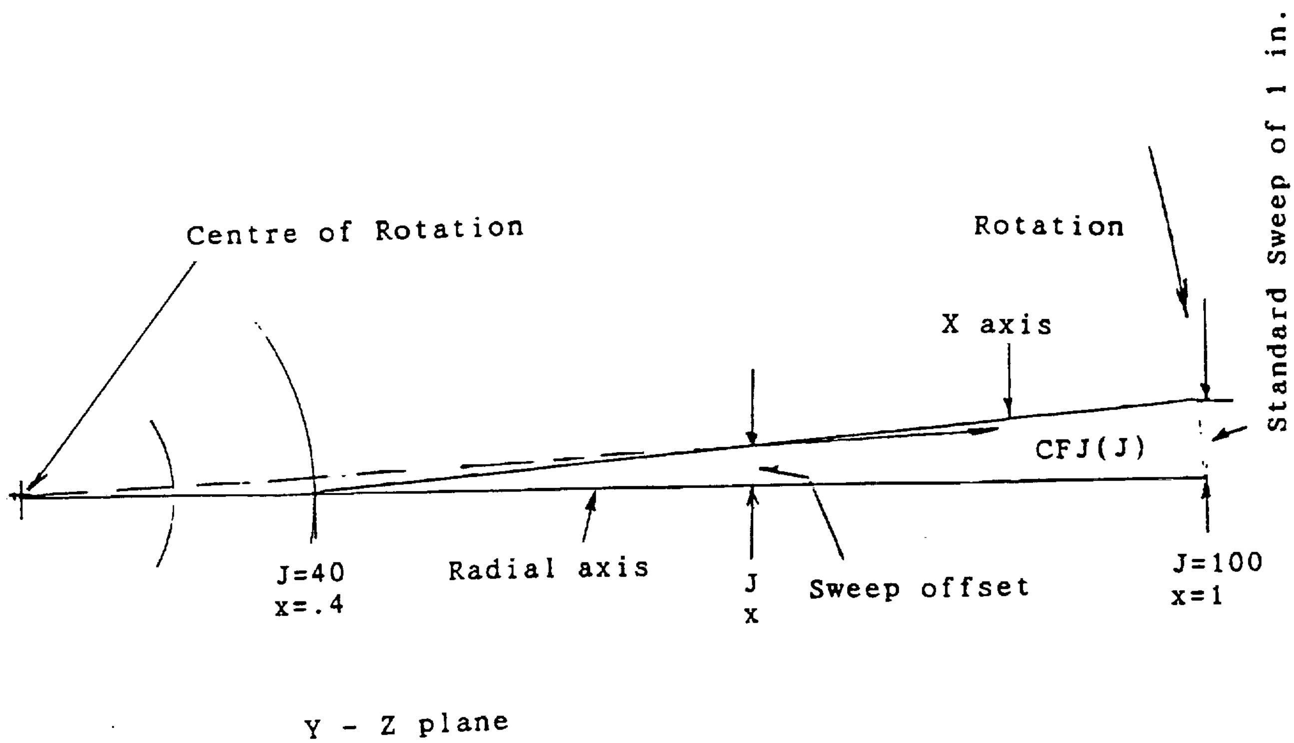


Fig. 5.1.9.4*2

The two values, for tension and compression, of the section moduli, Z, are given by:

Tension	Zt = 0.12* chord * (thickness) squared	in^3	Eqn 60
Compression	Zc = 0.08* chord * (thickness) squared	in^3	Eqn 61

In BASIC notation these are then :

AR (I) = .7*C(I)*TT(I) at position I	see...Eqn 46
ZT (I) = .12*C(I)*TT(I) at position I	Eqn 62
ZC (I) = .08*C(I)*TT(I) at position I	Eqn 63

5.1.10.2

The C.F. stress at any position x or J is then:

C.F. stress = Total C. F. load/Area at x   Eqn 64

The Bending stresses at any position x or I are then :

Tensile BM stress = +Net BM/Zt for the pitch face   Eqn 65
Compressive BM stress = -Net BM/Zc for the round side   Eqn 66

The final stresses at any position x or I are then:

Final tensile stress = C.F. stress + Net Tensile BM stress   Eqn 67

Final compressive stress = C.F. stress - Net Compressive BM stress   Eqn 68

In BASIC notation these are:

CFS(I) = CFL(I)/AR(I)   Eqn 69

TBS(I) = NBS(I)/ZT(I)   Eqn 70

CBS(I) = NBS(I)/ZC(I)   Eqn 71

FTS(I) = CFS(I) + TBS(I)   Eqn 72

FCS(I) = CFS(I) - CBS(I)   Eqn 73

5.2 Design Computer Program

The program was written in IBM BASIC to run on an IBM PS/Personal Computer.

A copy of the Program Listing is given in Appendix C.

5.2.1 Operating Instructions with Sample Design

Note: The Table references give the results of the sample design.

The Input data required to run the program is:

Fan Diameter	ft.
Blanking (or Hub) Diameter	ft.
Volume of air flow through fan	CFM/1000
Fan Power	BHP
Fan Speed	RPM

Usually the required Fan and Blanking Diameters will be specified by the Windtunnel design. The Volume flow can be obtained from the required design air speed through the Working section. The estimated Power to operate the Windtunnel will usually be specified by the Windtunnel design.

As a first approximation the Fan speed should be estimated from the proposed tip speed, which should be limited to about 500 ft./sec. If there is a requirement for the noise level to be kept as low as possible, a reduced tip speed will be required.

Before entering the DATA check that the proposed Diameter(D) and the Fan speed (N) are consistent with this requirement

After the Data has been loaded there is an opportunity to check that no mistake has been made and that the correct Data has in effect been entered. The loaded DATA is displayed on the VDU. Also shown are the values for the Blanking Ratio, the Volume and Power Coefficients. See Table 5.2.1*T1.

If the entered DATA is incorrect the program can be re-started by use of Key 1. If correct DATA is used the program can be continued by the use of Key 0 The VDU will display a suggested Tip Chord and the corresponding sC_L The VDU displays the theoretical minimum number of blades that will be required (usually not an integer number) and asks for the Input of a "CHOSEN NUMBER OF BLADES".

After the value for the "Chosen number of Blades" (which of course must be an integer number greater than the previously displayed minimum) has been entered the VDU will ask for the Input of a chosen tip chord and display the value of the "Tip C_L" that would result with this choice. If this "Tip C_L" is too large a "WARNING" sign will appear on the VDU with options to be selected by the use of different keys.

If the "tip C_L" value is satisfactory the VDU will then display a value for "ROOT SCL" and a suggested approximate "ROOT CHORD".

The operator then has to select a proposed root chord that would be appropriate for practical manufacturing purposes.

The VDU will then display "ROOT CL IS NOW" and the calculated value. (If this value is over 1.0 a "WARNING" will be displayed with alternative procedure options that can be selected by the use of appropriate keys. These options allow for different DATA to be chosen in an endeavour to have the Root C_L reduced below 1.0. See Table 5.2.1*T2

The program then carries out various calculations and eventually the VDU displays the option to "CALCULATE PRESSURE" or to "END".

If the "CALCULATE PRESSURE" option is selected there will be a pause in the operation until the VDU displays the request to "PRESS SPACE BAR" when the operator is ready for the "DATA INPUT AND RESULTS" to be displayed.

After the space bar has been pressed the VDU will again display the "INPUT DATA" and the "RESULTS" of the calculations in the following form.

The "NUMBER OF BLADES" chosen will be displayed and then a table showing for each Station, its Radius, the selected Chord and Thickness, the "INFLOW ANGLE", Φ, as shown in Figs.5.1.2*1 and 5.1.2*2, the calculated C_L values and finally the Design Blade Angles (θ).

The results can, if required, then be printed out on a hard copy for retention, (see Table 5.2.1*T3) before it is appropriate to "press space bar" when ready for "PRESSURE print out" and for the pressure results to be displayed on VDU.

Continuing with the program by the use of Key 0 the value of the C.F. loads and stresses will be displayed on the VDU.

[Note: the C.F. loads, as displayed, will only apply for blades to be manufactured with spruce. Some modifications will be needed by additional calculations for detachable blades with compressed wood roots.] See Table 5.2.1*T4 for Pressure and C. F. results.

The VDU will then display the option "FOR TRACK CALCS" which may be commenced by the use of Key 0. Provided that this option is selected the VDU will display an approximate value for a suggested track and request that a "CHOSEN TRACK" be entered. This chosen track should be an appropriate practical design value.

After this chosen value is entered the VDU will display a table giving the values of ABM, CFBM and Net BM at each station with the design values of the tip Track and tip Sweep chosen.

Also shown will be the ABMs at stations 2 and 3, these values being required for detachable blade designs. See Table 5.2.1*T5.

"FINAL STRESSES" both Tensile and Compressive can be displayed on the VDU by pressing the space bar. See Table 5.2.1*T6.

These final results will enable an assessment to be made as to whether the design will come within appropriate allowable stress values.

```
      INPUT DATA
      ***** ****
DIAMETER.      FT-? 24
BLANKING DIA. FT-? 9.6
VOLUME/1000  CFM-? 2500
FAN POWER    BHP-? 1800
FAN SPEED    RPM-? 350
   ***********
BLANKING RATIO IS .4
VOLUME COEFFICIENT = .248
POWER COEFFICENT = .0258
   *********
CHECK ABOVE INPUT DATA - IF CORRECT PRESS KEY 0
                         IF INCORRECT PRESS KEY 1
```

Table 5.2.1*T1

```
FAN SIZE INDICATES THAT TIP CHORD SHOULD BE ABOUT 34.56

TIP SCl = .087
No. OF BLADES NEEDS TO BE GREATER THAN  4.406793
CHOSEN No. OF BLADES Z=? 8
CHOSEN TIP CHORD TO BE =? 32
TIP CL IS NOW = .3
ROOT SCL = .393
FIRST TRY OF ROOT CHORD, ABOUT  39.2 Ins.
CHOSEN ROOT CHORD? 36
ROOT CL IS NOW  .49

PRESS KEY 0 TO CALCULATE PRESSURE
PRESS KEY 1 TO END
```

Table 5.2.1*T2

```
     INPUT  DATA
     *****  ****
DIAMETER           D= 24      FT                      .9         1.0
BLANKING DIA.  BD= 9.600001    FT                  129.6       144
VOLUME,            V= 2500    1000*CFM              32.66       32
FAN POWER.    BHP= 1800    BHP                      3.75        3.19
FAN SPEED.          = 350    RPM                    15.92       14.3

     RESULTS                                          .34         .3
     *******                                     15 - 14    13 - 50

   NUMBER OF BLADES = 8
STATION          .4          .5          .6          .7          .8
                                                     .7          .8
RADIUS           57.6        72          86.4        100.8       115.2
CHORD  Ins       36          35.33       34.66       34          33.33
THICK  Ins        6.84        6.18        5.54        4.92        4.33
INFL.ANGLE       35.05       28.54       23.92       20.52       17.93
   Cl             .49         .48         .45         .42         .37
                                                      .42         .37
BLADE ANGLE 33 - 9      27 - 8      22 - 46     19 - 33     17 - 5

Press Space Bar when ready for PRESSURE Print out
```

Table 5.2.1*T3

```
PRESSURE COEFFICICENT = .394

TOTAL PRESSURE= 3.52  INS. W.G.

EFFICIENCY = 76.9  %
Waiting for ABM Print out
PRESS KEY 0 TO CONTINUE

 STATION      ABM lb-in.
C.F. at Stn- 4  is  79005
C.F. at Stn- 5  is  66654
C.F. at Stn- 6  is  53341
C.F. at Stn- 7  is  39581
C.F. at Stn- 8  is  25834
C.F. at Stn- 9  is  12518
C.F.Stress at Stn- 4  is 458
C.F.Stress at Stn- 5  is 436
C.F.Stress at Stn- 6  is 396
C.F.Stress at Stn- 7  is 338
C.F.Stress at Stn- 8  is 255
C.F.Stress at Stn- 9  is 146
FOR TRACK CALCS. PRESS KET 0
```

Table 5.2.1*T4

PRESSURE COEFFICICENT = .394

TOTAL PRESSURE= 3.52 INS. W.G.

EFFICIENCY = 76.9 %
Waiting for ABM Print out
PRESS KEY 0 TO CONTINUE

STATION	ABM	CFBM	Net BM
			Net BM
4	48312	23235	25077
5	35724	16155	19569
6	24043	10311	13732
7	14149	5772	8377
8	6597	2559	4038
9	1778	654	1124

TRACK TO BE - .5
SWEEP TO BE - .3
ROOT ABM AT STN 2= 71484
ROOT ABM AT STN 3= 58659
Press Space Bar for FINAL STRESSES

Table 5.2.1*T5

FINAL STRESSES
***** ********

STATION	TENSILE STRESS	COM. STRESS
4	697	-100
5	656	-106
6	584	-114
7	481	-124
8	342	-124
9	178	-98

C.F. LOAD AT STN .4 = 79005
Ok

Table 5.2.1*T6

Section 6: Materials

Index

6. Materials

6.1 Historical Background

6.1.1. Hardwoods
6.1.2 Softwoods
6.1.3 Compressed Wood
6.1.4 Glues and Adhesives
6.1.5 Covering and Finishing
6.1.6 Root Attachment
6.1.7 Sundries

6.2 Current Available Specifications

6.2.1 Hardwoods
6.2.2 Softwoods
6.2.3 Compressed Wood
6.2.4 Glues and Adhesives
6.2.5 Covering and Finishing
6.2.6 Root Attachment (Metal)
6.2.7 Sundries

6.3 Compressed Wood

6.3.1 Veneers
6.3.2 Adhesives
6.3.3 Manufacturing Processes
6.3.4 Testing
6.3.5 Compressed Wood for High Temperature Use

6. Materials

6.1 Historical Background

The wood materials that have been used in the past are mainly:

6.1.1 Hardwoods[1]

Honduras Mahogany (Swietenia macrophylla King) was a popular choice for integral blade fans as this material has relatively high strength to weight values, particularly in shear, for a modest density (S.G.=0.5/approx.) and could be obtained in relatively wide board form with very few imperfections. It was very suitable for 2 and 4 blade integral fans. Unfortunately during the 1960's - 1970's commercial quantities of H. Mahogany became extinct so it is no longer a viable material.

Birch. (Betula lutea) This is a similar (for fan blades) material to Mahogany but slightly denser, (S.G.=0.56/approx.) not so easily worked and typical sized clean stock (boards) not so readily available.

Birch Veneer. This material although rather expensive was, and still is, the basis of the Compressed Wood suitable for fan blades.

Brazilian Mahogany. This began to be used as a replacement for H. Mahogany during the 1960's - 1970's and has proved to be an acceptable replacement. It is generally slightly more dense than Honduras Mahogany.

Balsa. Balsa comes from a "botanical hardwood" tree although the material is soft and very light. This material has been used in certain applications where a light weight breakaway tip that can readily be repaired or replaced is required. It has also been used as a light weight filler material, in zones where the stress is small.

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1 (See Section 6.2.1. for details of specifications of each type of material used up until approximately the 1960's)

6.1.2 Softwoods[2]

Sitka Spruce. (*Picea sitchensis*) This timber has been, perhaps, the most popular choice for wood blades, particularly so for large blades. It has the highest strength to weight ratio of any timber and has been readily obtainable at an acceptable standard in commercial quantities at a reasonable cost. Most Spruce blade fans that have been manufactured are of the type with large rectangular root sections.

There are two main sources of supply, either from Alaska or from Canada.

Douglas Fir. (*Pseudotsuga taxifolia Brit.*) This material has been used as a substitute for Spruce but its use has generally been limited to situations where Spruce was unobtainable, usually due to political conditions.

6.1.3 Improved or Compressed Wood

Improved or Compressed woods were developed mainly as a result of World War II for use in aircraft propeller blades. These materials are manufactured by bonding with heat and pressure veneers of a suitable hardwood (usually Birch) into a denser laminate that is denser and stronger than the natural wood.

There are various methods of achieving the necessary bond and the subsequent lamination can have various enhanced properties. For fan or propeller requirements the main essential is that the laminate has improved tensile, compressive and shear strength and a predictable fatigue resistant property.

Considerable R & D has been involved in producing this type of material, much of which is still kept confidential by the manufacturing companies from whom it must be obtained.

The fatigue resistant properties of Beech veneer based material has not been so well established as that of Birch veneer based material and consequently Birch based material, although much more expensive, is the favourite choice for fan blades.

Sections 6.3.1 and 6.3.2 give more details of the materials used and Section 6.3.3 gives an outline of the manufacturing process.

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2 (See Section 6.2.2. for details of specifications of each type of material)

6.1.4 Glues and Adhesives

See Section 6.2.4.1. for details of the Terminology for Glues and Adhesives used in this Report.

6.1.4.1 Glues

In the early days of wood aircraft propellers, the glues used were of natural occurring types, such as glues made from animal components (e.g. horses' hooves or casein based on milk products). All these types had the disadvantage that they were water soluble and consequently blades made with these glues could de-laminate if subjected to excess moisture or humidity. Although this feature was not so critical for Windtunnel blades which usually operated in a dry internal environment, these materials were somewhat unreliable.

At the time of World War II, chemical resin glues became available and were being developed to have enhanced properties consequently these types of glues superseded the old natural glues and became the standard for all wood blades, including fan blades.

In the U.K. a typical resin glue used was Aerodux made by CIBA-GEIGY. (See 13.1.5). In the U.S.A. a typical resin glue was Penacolite made by Koppers. (See 13.1.4).

Details of the currently available glues are given in Section 6.2.4.2.

6.1.4.2 Adhesives

There were very few "Adhesives" as distinct from wood to wood glues available until the development of chemical resins at the time of World War II.

6.1.5 Covering and Finishing

During the years since World War II great changes have been made in the materials available for covering wood blades.

In the early days of aircraft propellers the only protection used was a natural varnish, then as speeds increased extra protection was deemed necessary which led to the use of a linen fabric bonded on with varnish and ultimately with a number of special finishes developed by many of the then paint manufacturers.

Windtunnel fan blades do not have quite the same operational requirements as aircraft propellers so their protection needs are somewhat different, For small Windtunnels, particularly closed circuit, the air in the tunnel is normally clean and reasonably dry so limited protection for the fan blades was needed which only required a simple varnish or paint finish.

As larger tunnels were constructed, the power necessary increased, so did the tunnel temperature. Windtunnel models became more complex and the likelihood of small nuts or bolts becoming loose increased. These and other features led to the requirement for more protection of the fan blades so extra covering features became desirable, if not essential. At about the same time both glass cloth and resin systems were being developed for a number of uses and these two types of material then began to take over from natural linen cloth and the varnishes previously used on Windtunnel fan blades.

Initially polyester resins were used but eventually epoxy resins were developed and superseded the former type.

The extent to which covering of the fan blades, especially the L.E. was taken depended on the particular Windtunnel, and its main use.

6.1.6 Root Attachment (Metal)

6.1.6.1 Adaptors

An Adaptor (or sometimes referred to as a "Ferrule") is nearly always a steel component that has to mate up with the compressed wood of a blade and the other steel components of the hub.

The external design was always a function of the hub design whereas the internal design depended on the design of the blade root. The type of steel used had to be consistent with both design requirements and the specification standards at the time of manufacture. Usually a high strength steel was selected from the standard range.

As compressed wood is not perfectly dry and contains some moisture (approx. 5%) it was advisable that the steel adaptor was coated with an appropriate rust preventative, such as Cadmium plate or Nickel plate.

6.1.6.2 Root Plates

For blade designs that had rectangular roots with bonded root plates, it was always advisable to have these plates made from a high strength Aluminium alloy as this type of material was more suitable for the required bonding process. (See Section 6.2.4.3)

As the bonding process requires the plate to be flat, the particular specification for the Aluminium alloy was always chosen from the standard aircraft plate material, such as B.S.S. L70 (Ref: 13.1.5) which has an ultimate strength of 60 tons/ sq.in.

6.1.7 Sundries

6.1.7.1 Sealing Compound for Adaptor Assembly

It was found advisable to ensure that the Compressed Wood root was adequately sealed against moisture ingress at the assemble time. A suitable material for this purpose had to be flexible rather than one that became hard or rigid over time, consequently a modified "rubber" type compound was used. An example of this is a Polysulphide compound.

6.1.7.2 General Wood Sealing Material

During manufacture, particularly after the block gluing stage it is essential to be able to maintain the existing moisture content of the wood at a stable condition by coating the wood components with a sealing solution. An example of this is an epoxy based compound, S.P. 106 with Hardener S.P. 207 (Ref: 13.1.18).

6.1.7.3 Lead Wool

Standard Lead Wool (i.e. lead in the form of small strands similar to cut lengths of knitting wool) can be packed into suitable cavities in the wood body of the blades to achieve balance weight adjustment.

6.1.7.4 Low Melting Point alloy

An alloy of Bismuth, Lead and Tin can, depending on the proportions of each of the metals, be formulated to have a melting point below that of boiling water. Such an alloy can therefore be readily melted down to a liquid which may be poured into a suitable cavity and used for balance weight adjustment.

6.2 Current Available Specifications

At the date of this Report (mid 1990's) it is not very easy to forecast the likely Specifications that might be available in the future (how far ahead?) when a major windtunnel fan design could be required. Some of the previous Specifications have not really been in existence for some time but were taken as basis for use.

The following Sections give an account of what can be described as "currently available".

6.2.1 Hardwoods

The British Standard Specification for Hardwoods suitable for use in Windtunnel fan blades is B.S.S. 5V7 (Ref:13.1.6).

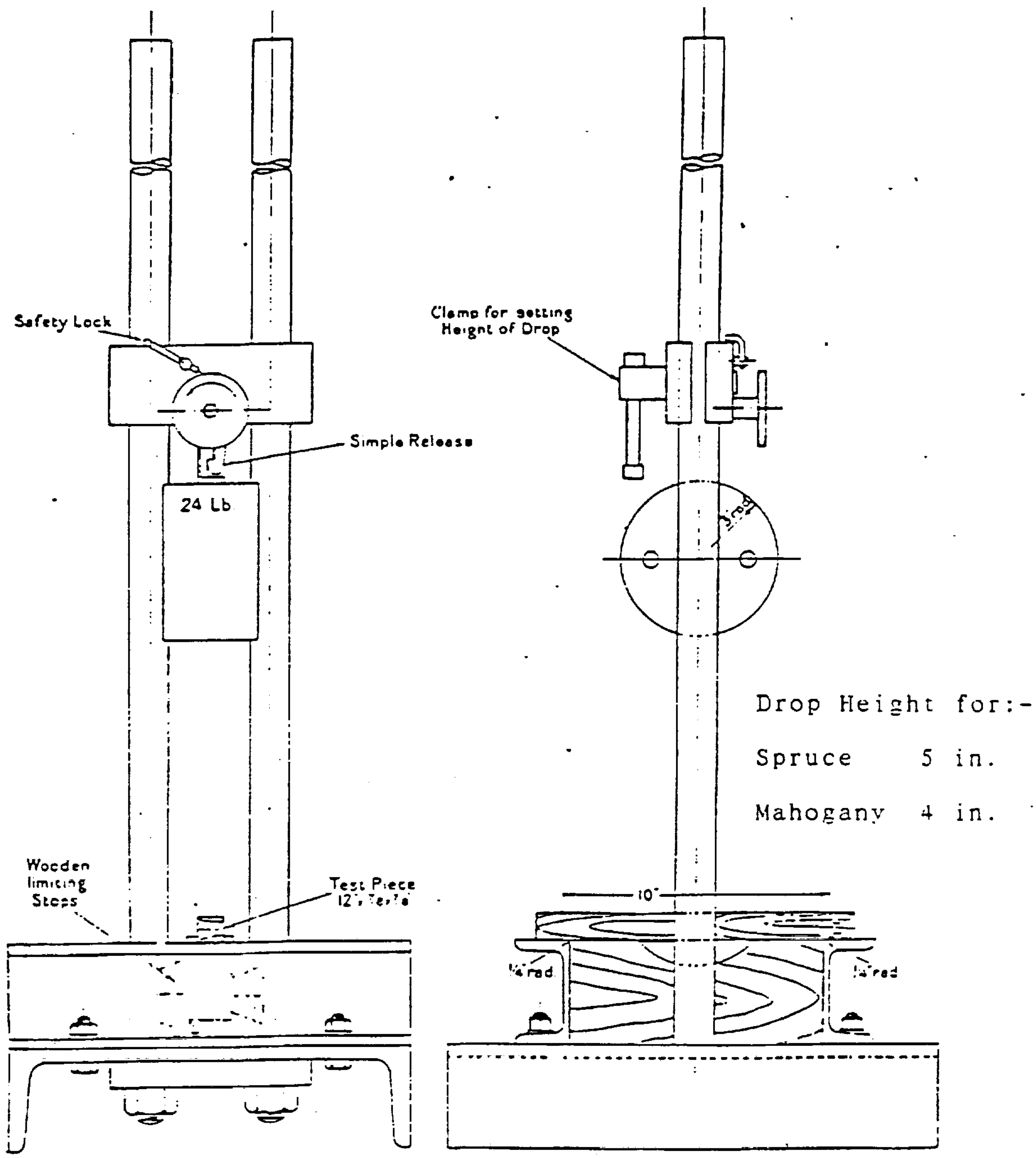
The material for which this Specification was written was Central American Mahogany (Swietenia macrophylla King) mainly from Honduras. However during the 1960-1970's this particular material was no longer available in commercial quantities, consequently an alternative material had to be used for fan blades. A fairly similar timber, Brazilian Mahogany was found to be suitable, provided that the actual material used met the same Specification strength requirements as 5V7.

Substitutes such as Canadian yellow Birch (Betula lutea) and Queensland Maple (Flindersia braylegaua) can be accepted to this Specification 5V7 but now, due mainly to commercial or supply reasons, are not really practical alternatives.

This Specification, 5V7, was not very tight and left much to the experience of the individual Inspector who was responsible for certifying any particular batch of timber.

The requirement for freedom from brittleness (Clause 7) was a case in point but the Inspector could be helped by means of a suitable test. A specimen of the material, 12 in. long x 7/8 in. x 7/8 in. was placed on a "Drop Impact Test Apparatus" as shown in Fig. 6.2.1*1 and the weight allowed to drop on to it from the appropriate height. For complete freedom from brittleness the specimem should not break, specimens that suffered small splits could be accepted as satisfactory but specimens that gave a brittle or "carroty" break were adjudged to have a brittleness that was not acceptable.

As with all tests or (visual) examinations of wood material it is relatively easy to be able to decide if a board or specimen is sufficiently near "perfect" for use or at the other extreme it contains so many defects that it is definitely not to be used. The main problem for an Inspector is to be able to make a decision on the majority of a batch that falls between these two extremes. There is always a very fine line between what is just acceptable and what standard is just not acceptable.



Drop Impact Test Apparatus.

Fig. 6.2.1*1

The British Standard 5V7 leaves much to the experience of the Inspector concerned and is difficult to interpret.

Much more detail concerning Mahogany and other hardwoods is given in "ANC-19" (Ref:13.1.7).

Balsa. There is no official specification for Balsa. For fan blade use it is necessary to specify that the material should be clean and free from defects, with a density between 4 and 9 lbs./cu. ft.

6.2.2 Softwoods

The British Standards Specification for Softwoods suitable for use in Windtunnel fan blades is B.S.S. V37, (Ref:13.1.8). The material for which this specification was written was Sitka Spruce (Picea sitchensis), with Douglas fir (Pseudotsuga taxifolia Brit.), Noble fir (Abies nobilis Lindl.), Western white spruce (Picea glauca var albertiana) or Western hemlock (Tsuga heterophylla Sarg.) as substitutes.

This Specification is in the same form as B.S.S. 5V7 for hardwood, leaving much to the experience of the Inspector concerned and similarly difficult to interpret.

Much more detail concerning Sitka Spruce and other softwoods is given in ANC-19 the bulletin described in Section 6.2.1. (Ref:13.1.7)

Another useful U.S.A. guide for Sitka Spruce and substitutes is the Standard Grading Rules No. 16 of the West Coast Lumber Inspection Bureau. (Ref:13.1.9) Material conforming to the "Ladder and Pole Stock Grade" is suitable for Windtunnel fan blades. But again this Specification needs careful interpretation by the individual Inspector involved.

There is much useful detail of many definitions and defects in this publication.

6.2.3 Compressed Wood

Compressed wood, being a manufactured material, does not have a universal Specification like natural woods, but is usually available from a particular manufacturer to their own internal Specification.

Permali Gloucester Ltd. manufacture various grades of compressed wood to a number of different specifications, the grade of material suitable for Windtunnel fan blades being Hydulignum to H.R. 210. (Ref:13.1.10)

An outline of the materials from which this is made and the manufacturing process is given in Section 6.3.

6.2.4 Glues and Adhesives

6.2.4.1 Terminology

In this Report the term "Glue" will be for material used for wood to wood bonding.

The term "Adhesive" will be for other types of material used for such processes as wood to metal bonding.

6.2.4.2 Glue

The most appropriate Glue for Windtunnel fan blades is a cold setting chemical hardening resin glue of the resorcinal-phenol-formaldehyde type which should conform to B.S.S. 1204 (Ref:13.1.11) or equivalent.

A typical glue of this type is manufactured by CIBA-GEIGY under the trade name of Aerodux. (Ref:13.1.3) This may be obtained in one of two forms, either with a powder hardener or with a liquid hardener. Experience has shown that marginally it is preferable to use the powder hardener type material, under the reference Aerodux 185 (Ref:13.1.3) (The powder hardener formulae gives slightly better gap filling properties.) Data sheets for this material are given in Appendix G.

Details of the necessary procedures for the use of this glue are given in Section 9.1.

An alternative used in the U.S.A. is a "Weldwood" product. (Ref: 13.1.12)

6.2.4.3 Adhesives

For wood to metal bonding cold setting adhesives are not satisfactory and hot setting materials have to be used.

The most suitable material is manufactured and marketed by CIBA-GEIGY under their trade name of "REDUX" (Ref:13.1.13). Data sheets for this material are given in Appendix A.

6.2.5 Covering and Finishing

6.2.5.1 Covering

If it is considered appropriate or necessary to protect fan blades by use of a cover, it is currently always carried out by the use of a glass cloth bonded to the blade by a suitable resin.

Glass cloth is manufactured in various types and different thicknesses. Experience has led to the view that a cloth thickness of approximately 0.010 in. (0.3 mm) is a reasonable compromise between being strong enough to give suitable protection yet not to be too "bulky" or heavy. A typical example of an appropriate cloth is Marglas E9700 (Ref:13.1.14).

It is important that the type of finish applied to the cloth is suitable to allow adequate "wetting out" by the subsequent resin, used for bonding to the blade. For small and medium wood blades only one layer of cloth would be required, but for larger blades it may be appropriate for multi layers to be used. Extra protection is usually desirable for the extreme L.E. (nominally up to say 25% chord) and at least three layers of cloth over this region is normally used.

6.2.5.2 Resin Systems

Glass cloth is bonded to wood blades by an appropriate resin, the most usual type being "Epoxy" of which there are a great number of different formulations by different manufacturers. Different forms give slightly variable results particularly in the reliability of the bond between the cloth and blade surface.

Manufacturers of this type of product are always endeavouring to improve the properties of their products so that at any one time it is not easy to forecast what will be the most appropriate formulation in the future. At the early 1990's one of the most satisfactory resins was SPS 110 with Hardener SPS 210 (Ref:13.1.15)

The final finishing of blades covered by both glass cloth and resin can, of course, be dependent on a particular customer's requirement. One possibility is that the final finish is left clear (glass cloth and resin give a virtual transparent finish so that the texture of the wood body may be seen) or alternatively it may be desired that the blades be painted with a suitable coloured paint. If a glass cloth and epoxy resin system is used and the requirement is for a coloured paint finish it is desirable that an epoxy based paint be used.

6.2.6 Root Attachment (Metal)

6.2.6.1 Adaptors

There is a wide choice of the exact type of steel that may be used. Usually a high tensile strength steel (over 50 tons/sq. in.) from the current standards would be chosen depending on the detailed design requirements. The final protective coating (e. g. Cadmium or Nickel plating) would be chosen depending on the availability of an appropriate sub-contractor at the time of manufacture.

6.2.6.2 Root Plates

Root Plates require to be made from high strength Aluminium Alloy plate material. There are a number of appropriate aircraft specifications for this type of material from which a suitable choice may be made. An example is plate to B.S.S. L70.

6.2.7 Sundries

6.2.7.1 Sealing Compound for Adaptor Assembly

A suitable Polysulphide compound is Sealant PR 1221-A2 (Ref:13.1.17).

6.2.7.2 General Wood Sealing material

An appropriate wood sealing material is S.P.207 (Ref:13.1.18).

6.2.7.3 Low Melting Point Metal for Balance Weight

An alloy of Bismuth, Lead and Tin with a melting point of approximately 200° F (see Ref: 13.1.19).

6.3 Compressed Wood

Compressed Wood, in its many forms, is used for various applications. Handbook No. 72, from the Forest Products Lab.,U.S. Dept. of Agriculture (Ref: 13.1.2) discusses compressed woods and their applications (including propellers.)

An outline of the base materials from which this is made and the manufacturing process is as follows.

6.3.1 Veneers

Although material manufactured and sold under the generic name of "Compressed Wood" can and is manufactured from veneers of a variety of timbers, as far as windtunnel fans are concerned, the only type of material that should be used must be manufactured from Birch veneers.

Considerable R & D was carried out during the development of compressed wood to establish which material would be suitable for use in aircraft propeller blades and it was found that Canadian Birch (Betula lenta or Betula likea) veneer material was superior to any other type bearing in mind that the criterion of "Airworthiness" was paramount.

(For other commercial uses it is quite acceptable and financially preferable to have material manufactured from other types of veneer, mainly Beech. Permali Gloucester manufactures other grades of commercial Hydulignum using Beech veneer. A detailed study of such materials is not within the scope of this Report.)

Apart from defining the species of the timber from which a suitable veneer should be cut, the specification for the veneer should include the standard of quality including limits of any defects such as maximum size of knots, areas of dote or decay, number and distribution of shakes, etc. and the length and thickness of veneer required. A typical thickness requirement would be that the veneers should be a nominal 0.7 mm (0.028 in) thick with a limit of +/- 0.005 in.

Veneer suppliers have a limitation on the maximum length of veneers available depending on the size of their peeling machine, a typical value being 76 in.

An appropriate moisture content of the veneer (maximum of 11%) has to be achieved just prior to assembly into packs.

6.3.2 Adhesives

Compressed wood may be manufactured using basically one of two types of adhesive resin. A liquid resin may be used by first immersing the veneer in the resin then after removal the resin is allowed to drain off, and the residual resin being partially cured to give impregnated dry veneers which can be assembled into packs. These packs are inserted into a press that is capable of being heated to the required curing temperature as well as imparting the appropriate pressure to bond the pack of veneers into a solid laminate. This type of compressed wood is mainly used for certain mechanical applications and has been developed for its excellent electrical insulation properties. However these materials are not appropriate for fan blade use, due to inadequate mechanical fatigue properties.

The alternative type of adhesive for compressed wood manufacture which is acceptable for fan blades consists of a special glue film. Such film is basically very thin kraft paper sprayed with an appropriate resin that is then dried so that the film may be conveniently handled. Packs of veneer inter-leaved with such a film may then be assembled and inserted into a press as previously described so that the resultant laminate has a uniform consistency.

Such a glue film is, of course, a proprietary article and can only be obtained from the appropriate manufacturer so that any specification for this type of film can only refer to its proprietary name and type.

In the past Permali Gloucester has used a glue film known as TEGO Special High Resin Film manufactured by a London Company This film had a resin content to give a film weight of 80 gm/sq.m. on a kraft paper of 20 gm/sq.m.

At the date of this Report (1994) this TEGO glue film was no longer available but had been replaced by SWEDOBOND glue film. (Ref:13.1.20)

6.3.3 Manufacturing Process

6.3.3.1 Assembly of Packs

The size of a compressed wood board that can be manufactured depends on the length of veneer that is available and the size of the manufacturing press to be used. The maximum typical length of a "board" is 72 in. due to the limitation of the veneer length at 76 in. (See below for the minimum length limit)

Experience has shown that the maximum practical pressed board width to obtain consistent properties is approximately 18 in.

The veneers as peeled and supplied to the compressed wood manufacturer are normally a nominal width of some 9 to 12 in., due partially to handling criteria and partially to quality considerations. It would be expected that veneers peeled much wider would then need to be cut into narrower pieces to eliminate any defects that are likely to occur. These narrow pieces of veneer can be edge jointed, by gluing, into larger wider sheets using a special type of machine for this purpose. Such a machine applies a liquid glue to the edge of two pieces of veneer which can then pass through the machine which applies both side pressure to these veneers at the same time curing or setting the glue by heat. The result is that the butt joint gives a width the sum of the widths of the original pieces. Although such butt joints have limited strength the combined width of veneer can be conveniently handled during pack assembly.

The veneer butt joints are arranged so that they have more than 4 in. stagger in adjacent veneers.

Permali Gloucester use a Diehl Veneer Splicing machine with a water based hoof liquid glue, Croda glue (Ref:13.1.21) Included in this liquid glue is a colouring agent so that during veneer jointing it may readily be seen that the glue has been applied to the full length of the veneer joint.

The glue film width as supplied (nominally 1 m.) is no problem as wider sheets can be assembled at the pack assembly stage if necessary by overlapping.

Veneers inter-leaved with sheets of glue film can be assembled into a pack of an appropriate size for the size of board required. The pack size has to be some 2 in. wider and 4 in. longer than the final board size to allow for side and end trim after pressing.

The number of veneers required for the particular thickness of board to be manufactured has to be carefully controlled so that the board density required is obtained. Due to slight variations in veneer density and hence weight, for any size the pack weight is measured and kept within a set tolerance to achieve the required density.

Experience has shown that due to heat flow limitations it is not possible to manufacture boards to a consistent standard if they are greater than 1 in. thick. This limit is convenient for it is appropriate to have the compressed wood boards the same thickness as the raw stock of any natural timber to which they will eventually be bonded.

For compressed wood suitable for fan blade roots the specification would call for a density of board of 82 lbs/cu.ft. (Sp.G.=1.31) with a tolerance of +/- 3 lbs/cu.ft.. (Sp.G.= 0.05).

It is not possible to compress veneers to give a density of compressed wood greater than a nominal 85 lbs/cu.ft.

Compressed wood can be manufactured to any density down to a density as low as 60 lbs/cu.ft.(This low density might be required for the major -aerodynamic- part of a blade). It is unwise to try to manufacture to give a lower density as the resultant material may not be consistent in properties and bonding failures may sometimes be present. For details of the variation in physical properties with various densities see Table 6.3.4*T1

6.3.3.2 Pressing Process

Permali Gloucester Ltd. have available multi platen presses so that more than one compressed wood (Hydulignum) board (Ref:10) can be pressed at any one time.

A number of packs depending on the number of "daylights" (see definition in Section 13.2.15) of the available press would be prepared and then inserted into the press. Care is needed in deciding the position of a pack on a press platen, particularly for short packs, so that they come symmetrical in relation with the ram position(s). Depending on the press to be used, this consideration can at times influence the minimum length of pack for a particular daylight.

The press would be closed and the heat applied. The main confidential element of the process is the relationship between the time and amount of pressure and temperature applied to the pack. The details of an appropriate pressure-temperature time cycle are not available for this Report, although it can be recorded that the maximum pressure required is approximately 2000 lbs/sq.in. and the maximum temperature needed would be in the region of 150° C with a cooling cycle down to 40° C.

After the boards have been cooled, normally to shop temperature they would be removed from the press and then stored in appropriate controlled conditions of humidity and temperature. (Relative Humidity between 45% and 55%, temperature 75° to 85° F.)

Each board would have the edges and ends, which after pressing are "raggged" trimmed off to give a smooth and truly rectangular board of the known required size.

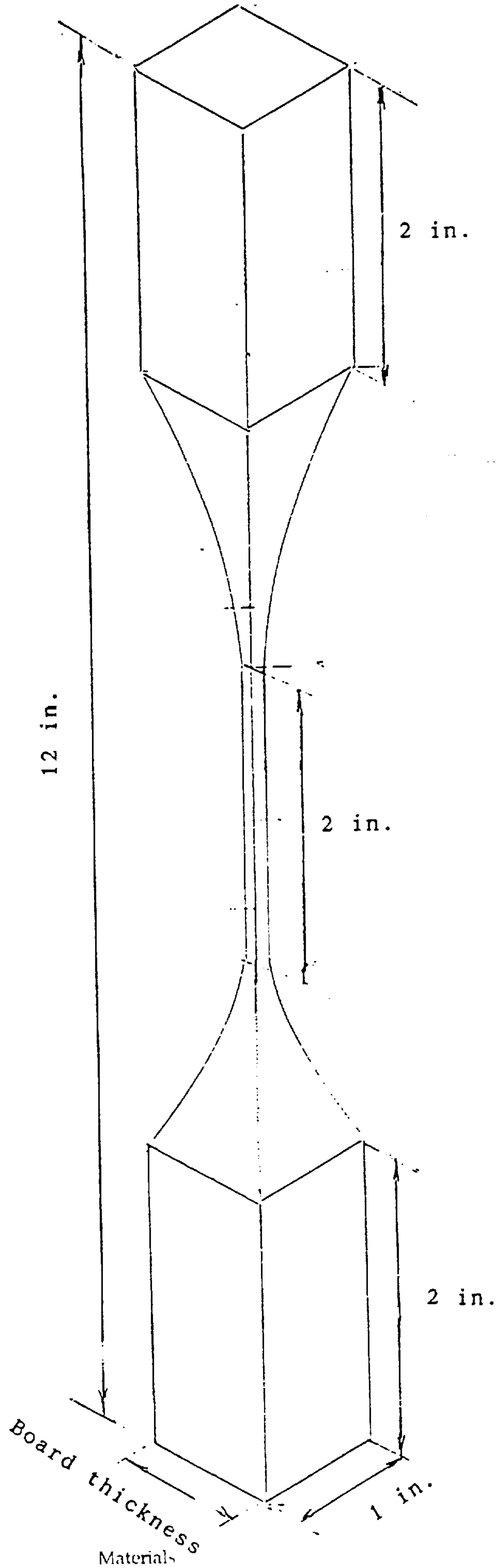
6.3.4 Testing

During the pressing cycle a record is kept of the applied pressure and temperature so that certification can be given that the process meets the declared specification.

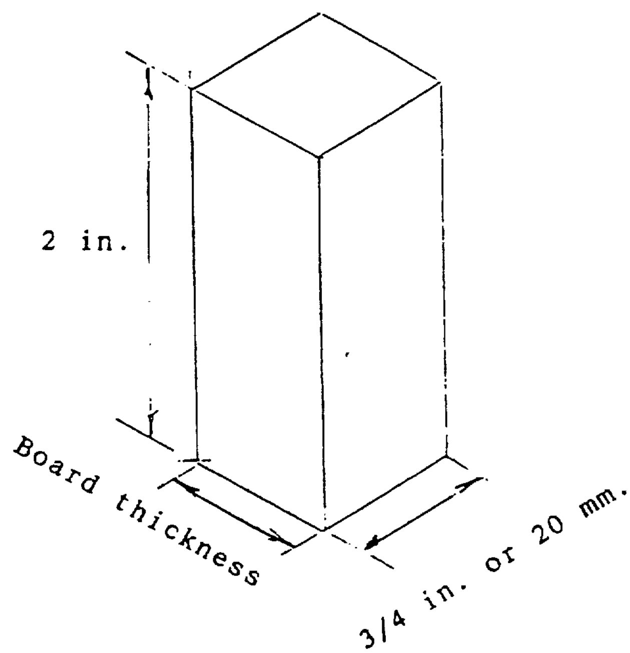
Each board would have its density checked and recorded by first weighing the board and then carefully measuring the thickness at a number of positions to obtain an average value for the purpose of calculating the overall volume. If any board is outside the density limits required it would not be accepted for fan blade use.

At least one board from each press load will have a suitable area,(normally 12 in. long by 2 in. wide) removed from which test pieces can be prepared. These test pieces would enable tensile strength, compressive strength and shear strength to be determined. There are two values for the shear strength, referred to as LT and LN shear. The codes for these being L for length or longitudinal, T for transverse and N for normal. See Fig. 6.3.4*2 for clarification of this feature.

Tensile strength is determined by preparing a test piece (shown in Fig. 6.3.4*1) and subjecting this test piece to a tensile load in an appropriate testing machine. The load should be applied at an approximate rate of 4000 lbs./minute until the



TENSILE TEST PIECE



COMPRESSIVE TEST PIECE

Fig. 6.3.4*1

specimum breaks. Compressive strength is determined by use of a test piece (as shown in Fig. 6.3.4*1) and subjecting this test piece to a compressive load at an approximate rate of 1000 lbs./minute until the specimum collapses and the load suddenly falls back.

Shear strengths are determined by preparing cubes (see Fig. 6.3.4*2) either of 0.75 in. or 20 mm. sides and testing these in apparatus shown in Fig. 6.3.4*3. The loads should be applied at a rate of approximately 4000 lbs./minute until the specimum cube fails. Usually 4 or 6 specimum cubes are prepared from each board test area so that 2 or 3 results for both LN and LT shear may be obtained.

Moisture Content is determined by first weighing small samples of broken test pieces then placing these samples in an oven at 110^0 C/220^0 F until of constant weight and all the moisture driven out (usually for about 3 hours) The moisture content may then be calculated from the relationship of weight lost to the original weight.

Compressed Wood manufactured by Permali Gloucester suitable for fan blades and known under the reference Hydulignum/ HR210 (Ref:13.1.10) is guaranteed to have properties as shown in Table 6.3.5*T1.

During the N.A.S.A. - Ames Fan Project a major fatigue test was undertaken on the blade root/retention system. The final report on this test is given as Appendix F.

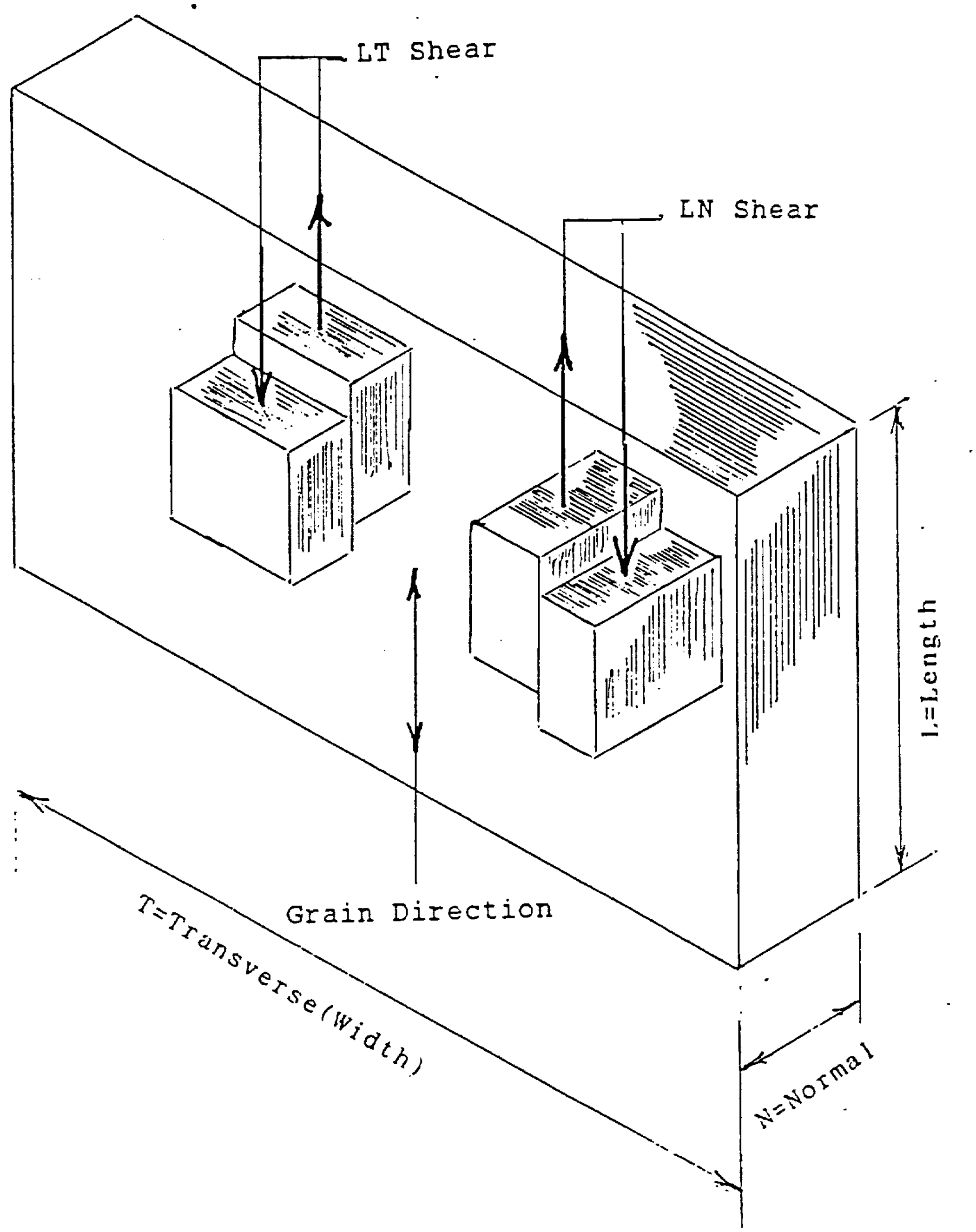

LT Shear
LN Shear
L=Length
Grain Direction
T=Transverse(Width)
N=Normal

Fig. 6.3.4*2

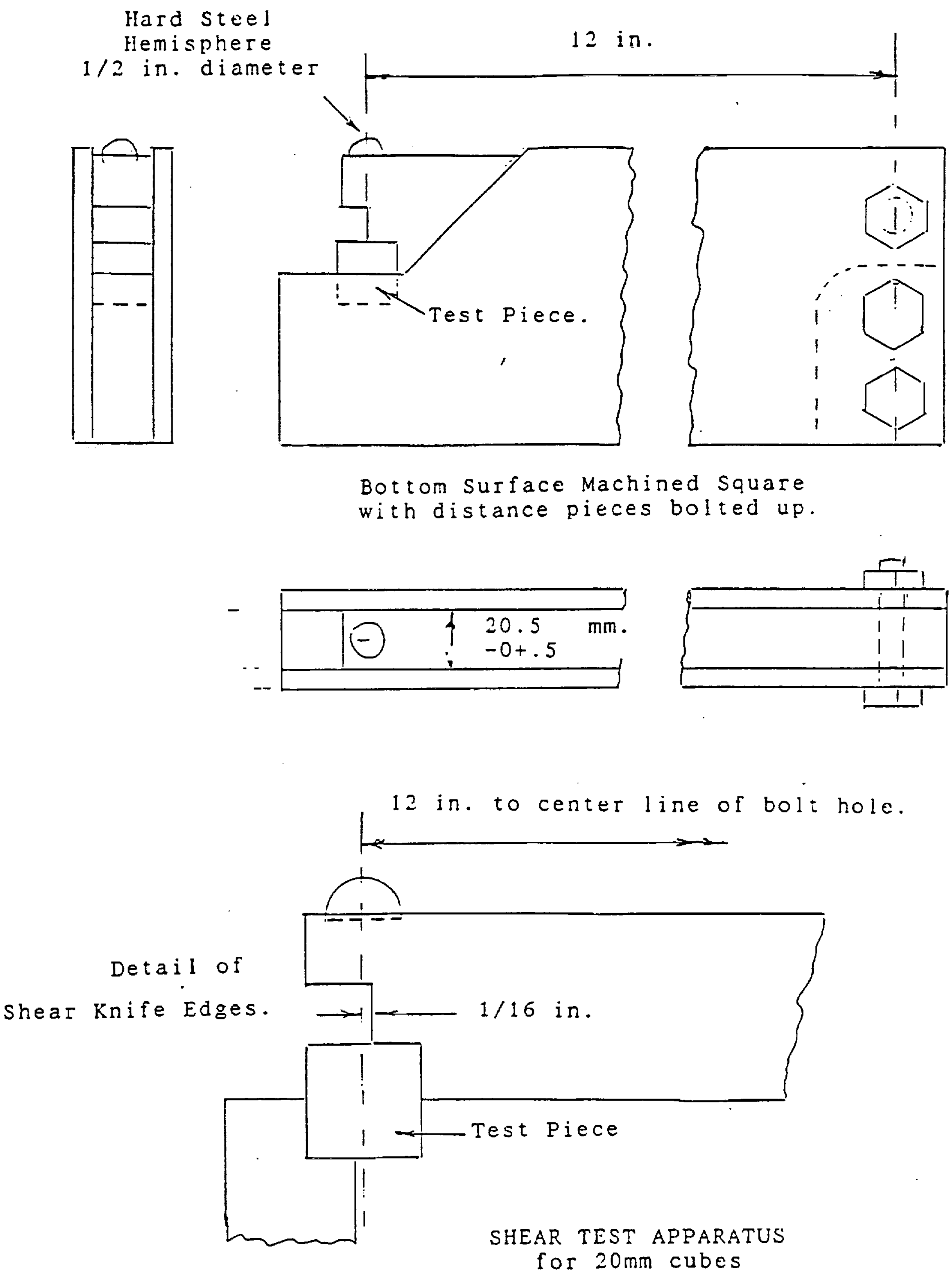

Hard Steel
Hemisphere
1/2 in. diameter
12 in.
Test Piece.
Bottom Surface Machined Square
with distance pieces bolted up.
20.5 mm.
-0+.5
12 in. to center line of bolt hole.
Detail of
Shear Knife Edges.
1/16 in.
Test Piece
SHEAR TEST APPARATUS
for 20mm cubes

Fig. 6.3.4*3

Table 6.3.4*T1					
Properties of Hydulignum/HR210					
Density	Ten.strength	Comp.strength	LN Shear	LT Shear	Modulus
lbs/cu.ft	lbs/sqin	lbs/sqin	lbs/sqin	lbs/sqin	lbs/sqin x 10^6
59	25,960	13,770	4275	2588	2.55
60	26,280	13,980	4350	2620	2.59
61	26,590	14,180	4425	2652	2.62
62	26,890	14,380	4500	2684	2.65
78	29,730	16,785	5681	3196	3.06
79	29,830	16,880	5754	3228	3.08
80	29,920	16,970	5828	3260	3.10
81	30,005	17,055	5901	3292	3.12
82	30,085	17,135	5975	3324	3.13
83	30,155	17,210	6048	3356	3.15
84	30,220	17,280	6122	3388	3.16
85	30,280	17,350	6196	3420	3.17

The normal value for the Moisture Content of pressed boards is approximately 5 to 8% and they should be stored in conditions that maintain this range.

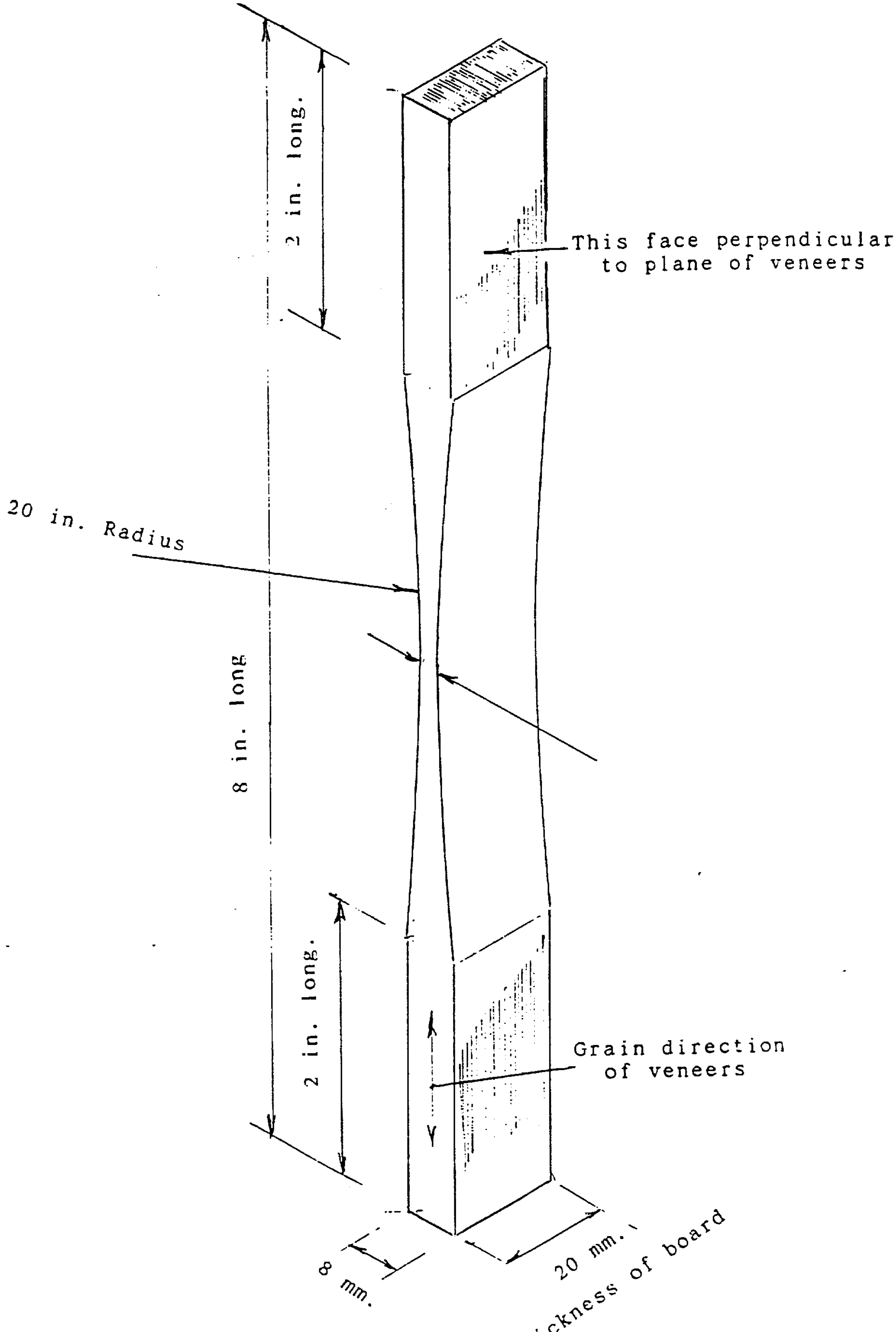
6.3.5 Compressed Wood for High Temperature Use

During the 1980's a requirement arose for compressed wood suitable for use at relatively high temperatures (up to 200 F). Normally straight grained compressed wood tends to shrink and split across the direction perpendicular to the grain, if subjected to high temperatures for some time, caused by excessive moisture loss. Cross grained material does not have these properties to the same extent. It was found that by modifying the specification for Hydulignum to HR210 to include 25% of cross ply veneers the resultant material had strength values only slightly lower than the straight grained type but was able to stand the raised temperature without deterioration. The results of this development are given in Table 6.3.5*T1.

Note: The results in Table 6.3.4*T1 are Minimum values whereas the results on Table 6.3.5*T1 are average values and the proposed specification values for this material.

The tensile test results were determined by the use of the Tensile Test Piece shown in Fig. 6.3.5*1

Table 6.3.5*T1			
Properties of 25 % Cross Grained Hydulignum			
Density 82 lbs/cu. ft.		Test Temperature 200° F	
	Mean	Min.	Proposed Spec. Value
	lbs/sqin	lbs/sqin	lbs/sqin
Tensile Strength	23,980	20,890	19,000
Compressive Strength	9,750	8,875	8,000
Shear LT, 1,810	1,640		
Shear LN	6,210	6,000	4,500
Cleavage	1,327	1,295	



TENSILE TEST PIECE.
for Cross-grain Material.

Fig. 6.3.5*1

Section 7: Structural Design

Index

7. Structural Design

7.1 Interaction with Manufacturing Design

7.1.1 General
7.1.2 Root Design
7.1.3 Main Body
7.1.4 Breakaway Tip Design

7.2 Stressing

7.3 Root Design and Testing

7.3.1 Fixed Pitch Integral Blade Root design
7.3.2 Detachable Blade Root Design
7.3.3 Root Testing

7.4 Transition Zone (Scarf) Design

7.5 Detachable Tip Design

7. Structural Design

7.1 Interaction with Manufacturing Design

7.1.1

Structural Design must cater for the working loads that will be imposed during operation, but must also be consistent with the proposed manufacturing techniques to be used. Of course, the reverse is also true. The proposed manufacturing techniques must allow for the eventual structural design necessary to cater for the working loads.

7.1.2 Root Design

The normal starting point of the design process is where the loads are highest, i.e. at the root and any root attachment considerations.

7.1.2.1 Integral Fixed Pitch 2 and 4 bladed fans

These have a well established system for the design of the fan hub and blade bosses. It is most unlikely that any major variation from this system needs to be considered and examples of the Structural Design parameters are dealt with in Section 7.3.1.

7.1.2.2 Detachable Fixed Pitch blades

There are basically two systems for retaining these types of blades, although the different types have aspects in common. "Large" rectangular roots can be held between two hub plates partly by friction and partly by the required hub bolt system. "Small" rectangular roots can have metal (usually Aluminium alloy) plates bonded on to the root blocks and then these metal plates held mechanically between hub plates by means of a bolt and or tube assembly. Design consideration for this type is dealt with in Section 7.3.2.1.

A combination of the above 2 systems can be used, mainly for small (but possibly for some medium) sized blades. The blades themselves can be manufactured with rectangular root type root blocks and then glued directly between prepared root plates which have had veneers of birch bonded in appropriate positions to their surfaces.

For more detail of bonding veneer to Aluminium alloy sheet see Section 7.3.3.2.

The design requirements of such blades are similar to any other blade held by the above 2 systems but the blade designer then becomes either associated with or responsible for the design of the hub plates and centre boss.

The advantage of this approach is that the manufacturing cost of the complete fan assembly should be lower than for a separate hub with truly detachable blades. The disadvantage, of course, is that the assembled fan (unless of only 2 blades) is more difficult to handle and its size may also cause transport problems. See Fig.7.1.2.2*1

7.1.2.3 Variable Pitch Blades

These normally require a circular root and this design consideration can be met by having the blade root being manufactured in compressed wood which can then be retained in a metal (usually steel) adaptor (or ferrule) that can be mechanically attached to a suitable hub component. Examples of this design type are given in Section 7.3.2.2.

7.1.3 Main Body

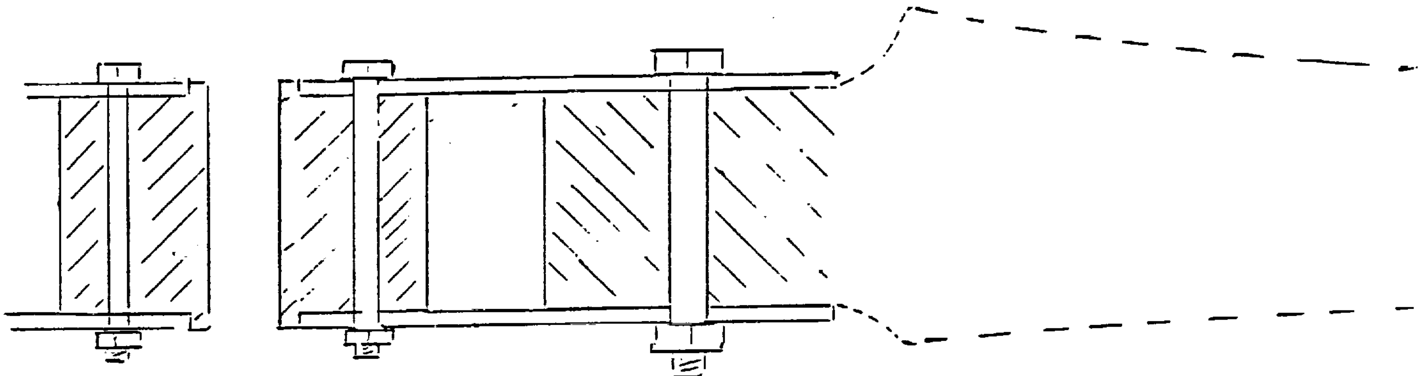
The well established techniques (see Section 8) for the manufacture of wood blades give little problems between Structural Design and Manufacturing Design for most blades. However for some very large blades there may be problems with the attachment of a large overhang of the T.E. body to the main load carrying body at approximately the centre of the chord. It may be necessary (as with the Ames blades) for separate T.E. bodies to be manufactured which have then to be attached to the main body. This attachment must cater, not only for the centrifugal loading which will result in a shear force between the two bodies but also for a bending moment across the proposed joint. See Fig.7.1.3*1

7.2 Stressing

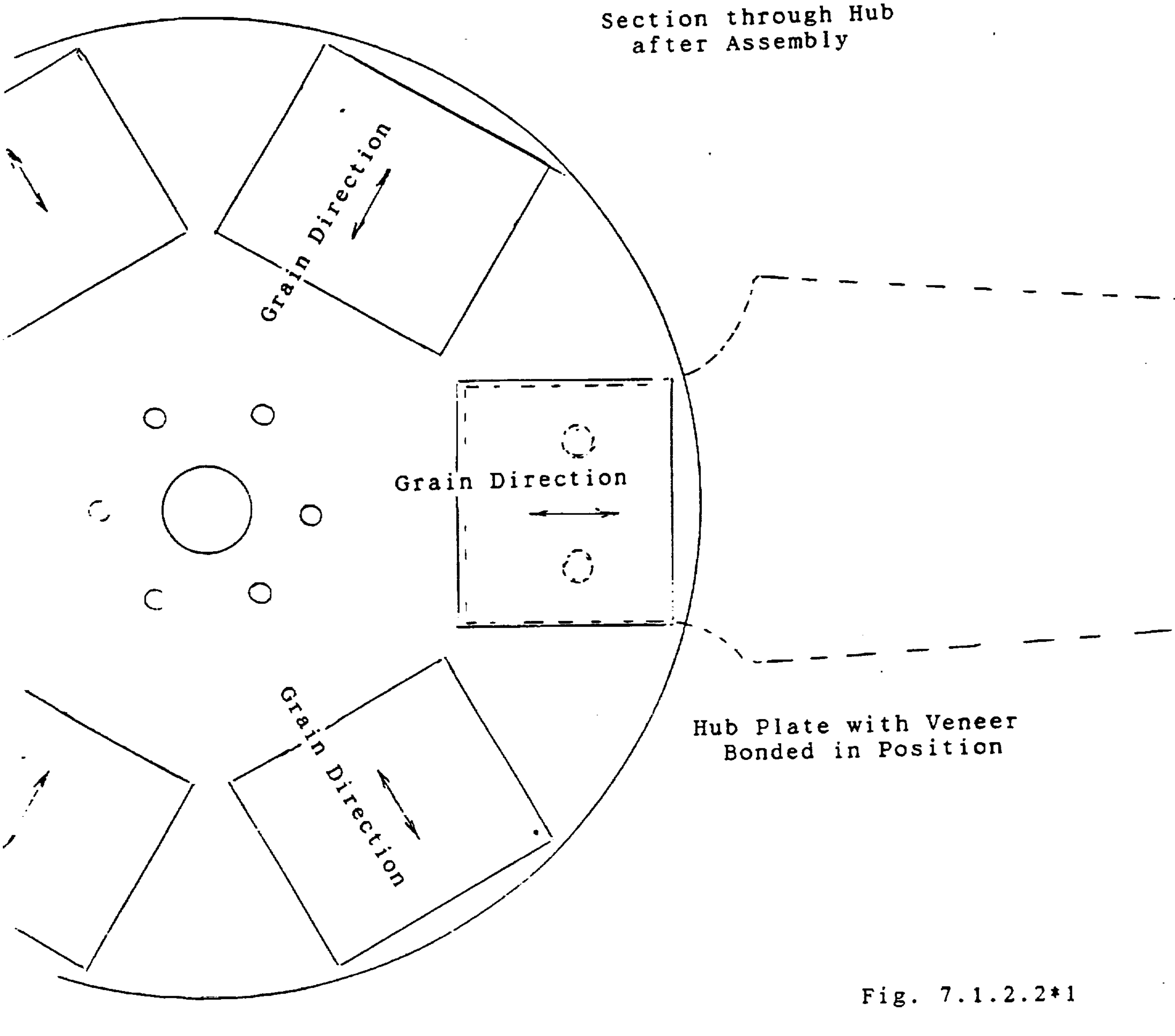
7.2.1 General

Stress calculations involve, first calculating the dynamic loading due to the Centrifugal forces and secondly calculating the aerodynamic loading.

Calculating the dynamic loading is nearly always the responsibilty of the blade designer and, apart from the fan rotational speed which may be decided by the requirements of the fan unit (including the drive system), the main data required after choosing the required material type for the blade, is its mass density.



Section through Hub after Assembly



Hub Plate with Veneer Bonded in Position

Fig. 7.1.2.2*1

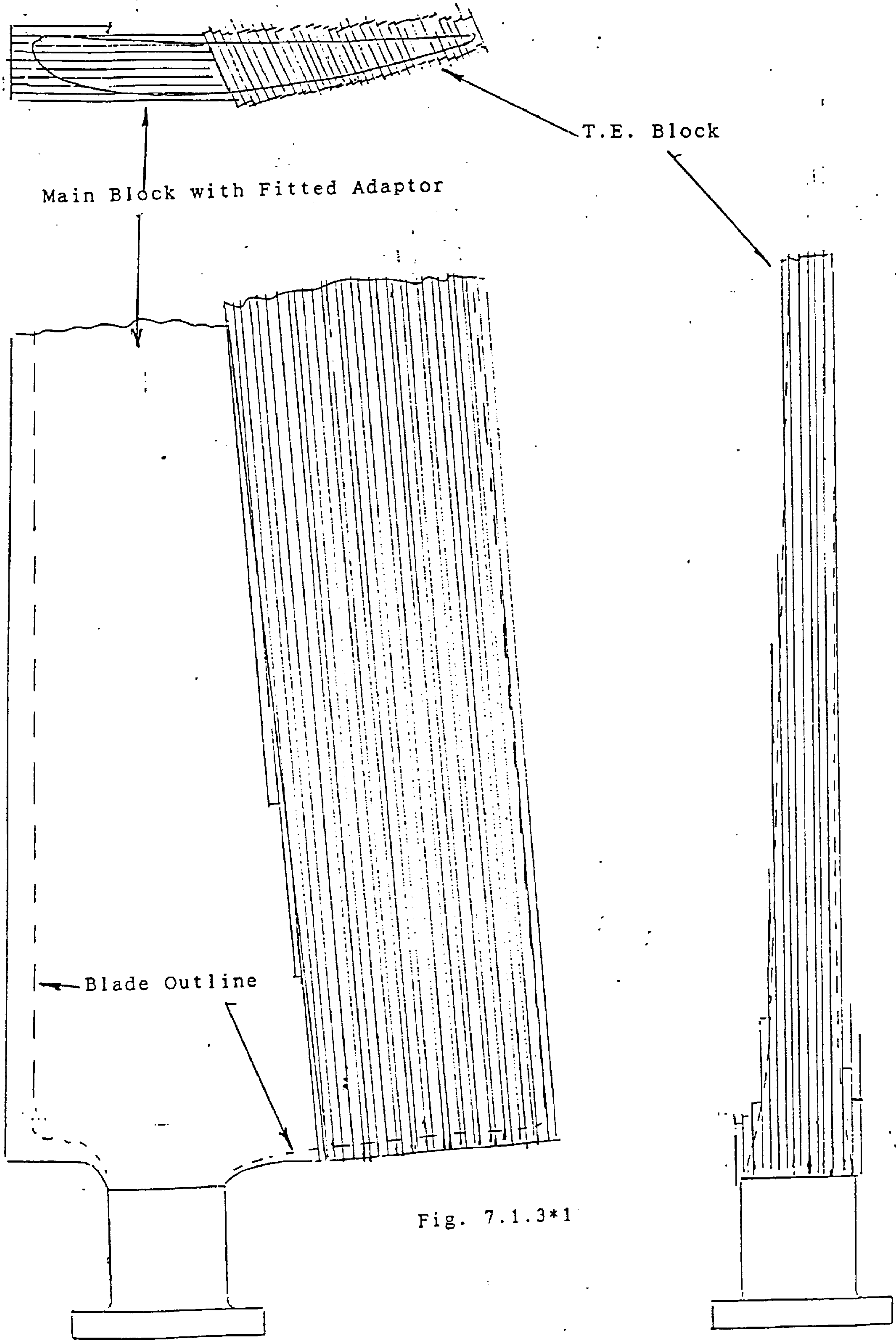


Fig. 7.1.3*1

The calculations for the aerodynamic loading may be made by the fan desiner or required to be made by the blade designer.

7.2.2 Dynamic (Centrifugal) Loading and Stress

The blade material type leads to the requirement for an estimate of the mass density of such material. The nominal density of suitable compressed wood will be 80 lbs/cu.ft. which, allowing for say 5% weight tolerance, gives a value of 84/32.2 =2.60 slugs/cu.ft. mass density, which should be used in the Centrifugal loading calculations.

Softwood, such as Spruce, has a nominal density of 32 lbs/cu.ft. but allowances for the extra weight of glue in a blade assembly plus the covering increases this value to an average of just over 40 lbs/cu.ft.

Consequently a practical value for the mass density for the Centrifugal calculations should be taken as 40/32.2= 1.25 slugs/cu.ft..

The Centrifugal loading can then be readily calculated from values of blade section finished chords, thicknesses and the above mass densities.

The Centrifugal stress values should be calculated on the basis of these loading values divided by the White Shape section areas.

The section areas may be calculated as:

Area= 0.7 * W.S.chord * W.S.thickness

7.2.3 Aerodynamic Loading and Stress

Aerodynamic loading calculations involve the overall design of the fan unit and these calculations may be made by the overall Windtunnel designer/customer and, the values supplied to the blade designer as data, to be incorporated in the blade design.

The blade designer then has the task of transferring such loading into Bending Moment values along the length of the blade. The Bending Moment stresses are then calculated by use of the formulae BM/Z where the Bending Moment, BM is divided by Z the Section modulus.

For most flat face sections the value of Z can be taken as:

Compressive Face (Round Side) = 0.12 * Chord * (Thickness)^2

Tensile Face (Pitch Face) = 0.08 * Chord * (Thickness)^2

(As before White Shape values should be used for the Chord and Thickness).

7.2.4 Final Stresses

The final Tensile Stress is then the sum of the Centrifugal Stress and the Tensile Bending Stress.

The final Compressive Stress is then the Compressive Bending Stress minus the Centrifugal Stress.

7.3 Root Design and Testing

7.3.1 Fixed Pitch Integral Blade Root Design

Fixed Pitch blades with 2 or 4 blades have an integral circular boss as shown in Figs. 3.1.1*1, 3.1.2*1 and 7.3.1*1 which is then contained in a metal (usually steel) hub. See Fig. 7.3.1*2.

In these cases it is conventional to refer to the blade Root as a "Boss" (Definition 13.2.10) which incorporates either the 2 or 4 blades.

(Very occasionally fans with 6 blades have been manufactured in this form but the manufacturing process of joining lams in 6 different directions is rather involved and it is more usual for multi-bladed (more than 4) fans to have detachable blades.)

The design of a 2 or 4 blade boss and hub is usually the responsibility of the blade designer, even if, in practice, a standard hub design is available the blade designer must be satisfied that such design is appropriate for the proposed blade.

The diameter of the boss has to be related to the chord of the root section being approximately the projected length of the chord. The diameter of the hub plates must give sufficient area so that there can be a friction drive between the hub and boss.

Similarly the thickness of the boss has to be related to the depth of the projected root chord.

Any size variations in these requirements should be kept to a reasonable minimum. The thickness limitation should restrict the number of any "floating" lams on each face to 2 or fewer.

These requirements are illustrated in Fig. 7.3.1*1

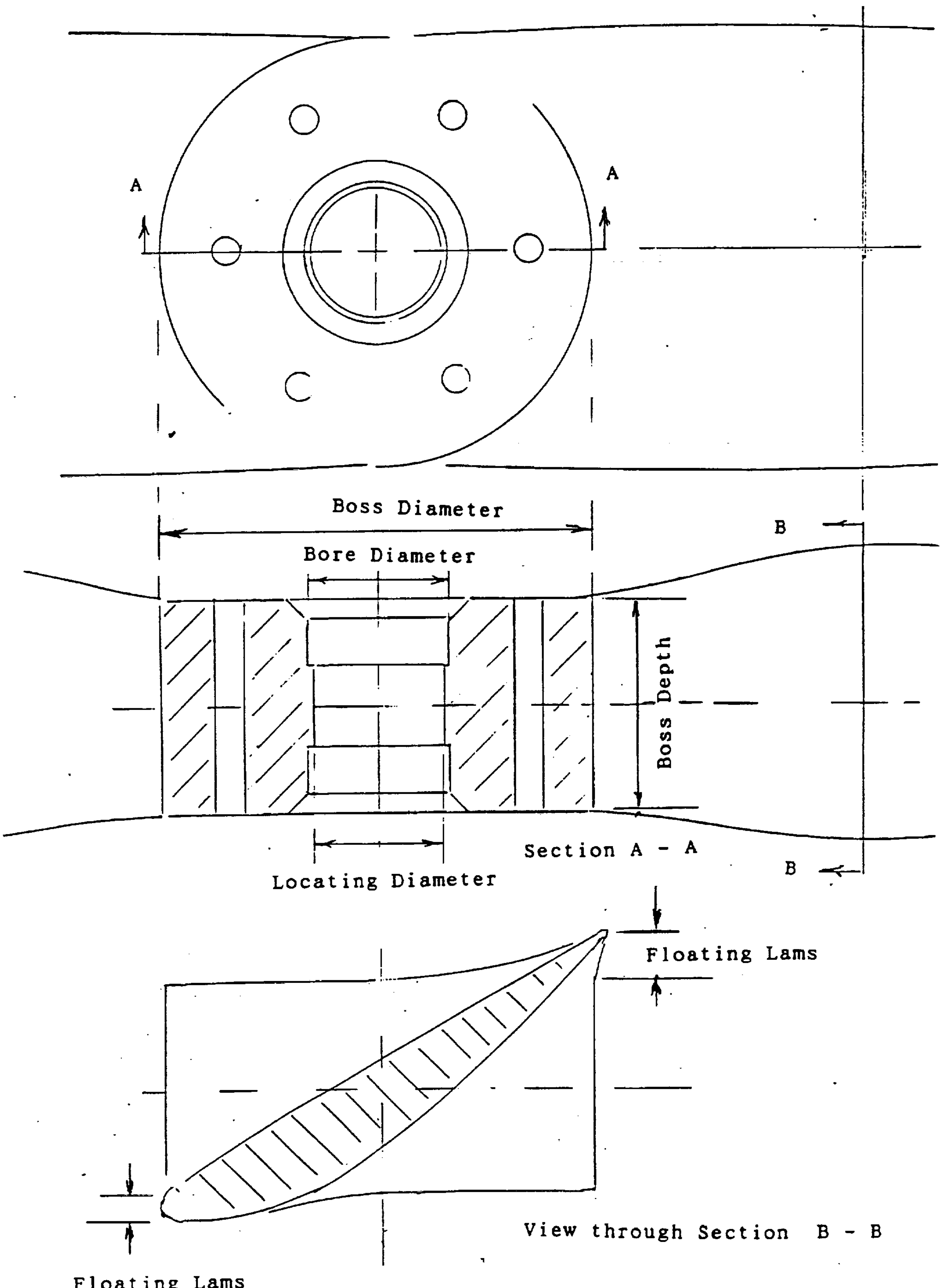
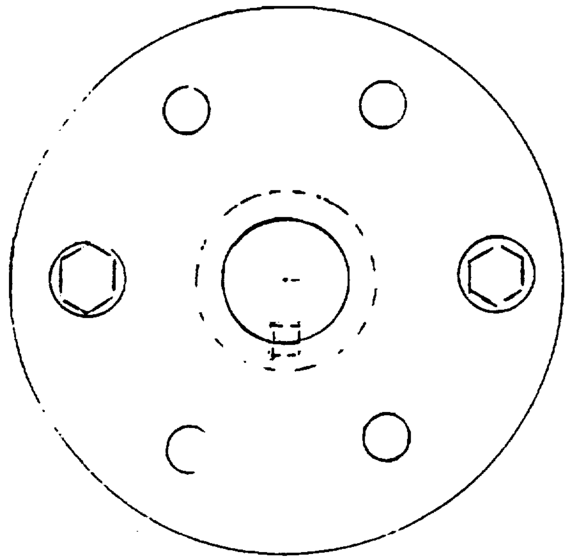

A
A
Boss Diameter
B
Bore Diameter
Boss Depth
Section A - A
B
Locating Diameter
Floating Lams
View through Section B - B
Floating Lams

Fig. 7.3.1*1



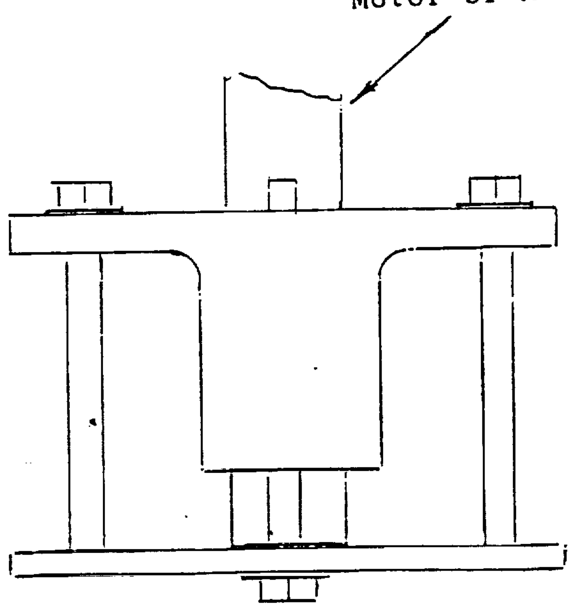


Fig. 7.3.1*2

The other main consideration for the design of the 2 or 4 blade boss is that there is sufficient shear area along the critical lines as depicted in Fig. 7.3.1*3.

7.3.2 Detachable Blade Root Design

7.3.2.1 Rectangular Root Design

7.3.2.1.1 Plain (Bolt) Type Root

For a design of blade to have a rectangular type root block that it is proposed to be retained clamped between two hub plates by relying partially on a friction joint, the required area of contact of the root block faces must be large enough to ensure that the friction stress level at these surfaces is somewhat lower than 50 lbs./sq.in.

This friction stress level is made up mainly of the total centrifugal force loading of the blade divided by the two block surface areas (upper and lower faces).

The block surface area is frequently limited by the design and hence area of available hub plate surface, and is not always at the disposal of the blade designer.

Another feature to be considered is that the larger the root block surface area the larger the volume of the root block and hence the larger the Centrifugal load on the joint, so it can occur, particularly with very large blades, that an increase in size of the root block does not always result in a lower stress value.

This type of design may be improved if it is possible to have the hub plates grooved to increase the friction coefficient between them and the root block.

This type of design is only appropriate if some of the loading is taken by the bolts passing through the hub plates and through the root block. The critical stress in the wood root is the result of shear loading as shown in Fig. 7.3.2.1.1*1.

Extreme care has to be taken in specifying the manufacturing limits of both the bolts and the corresponding holes. The fit between the bolts and the holes in the wood root block should be such that when the bolt is inserted, it tends not to split the wood.

Ideally the diameter and limits should be such that the bolt and wood hole are only in contact over the bearing area between them produced by the blade loading. See Fig. 7.3.2.1.1*2.

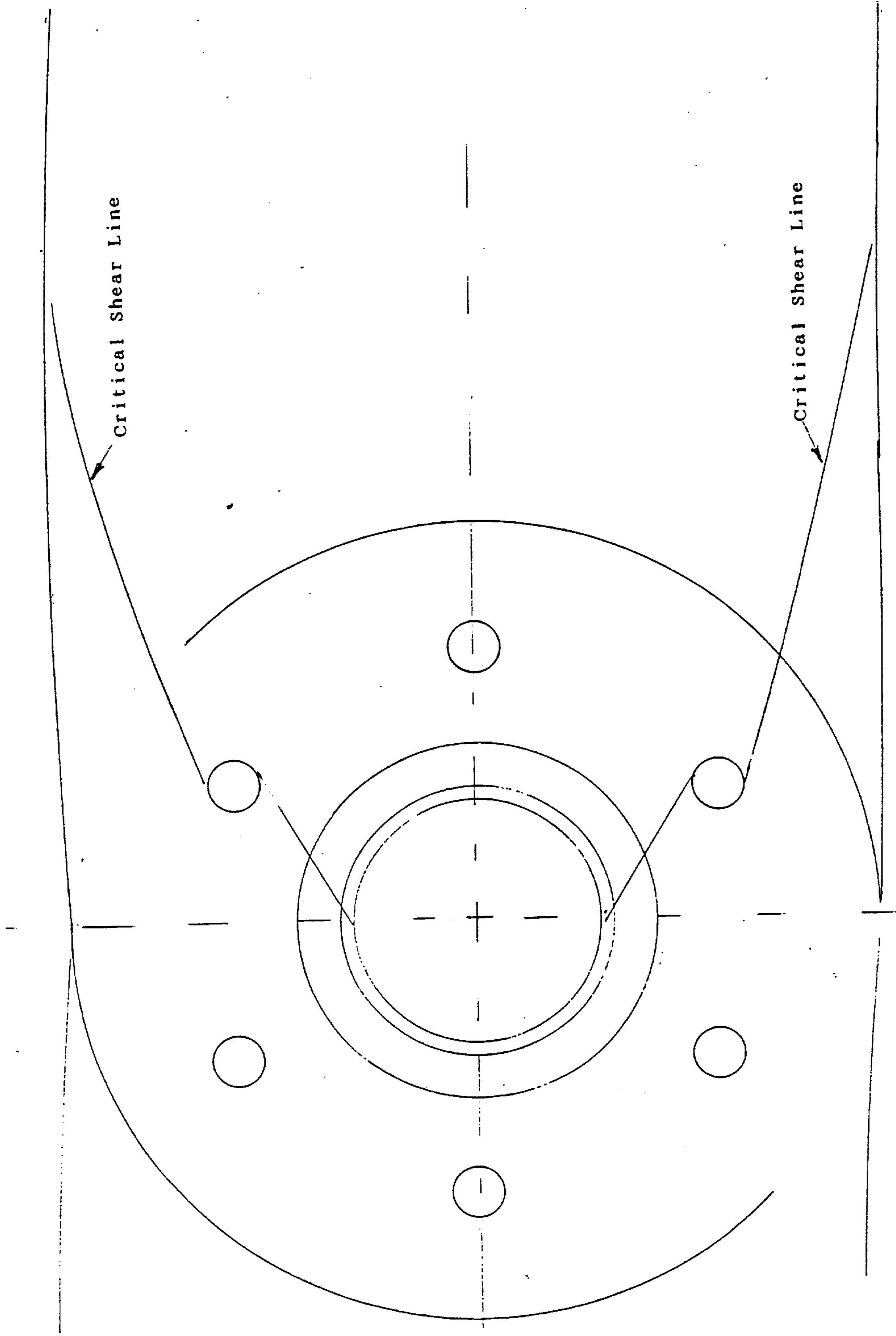


Fig. 7.3.1*3

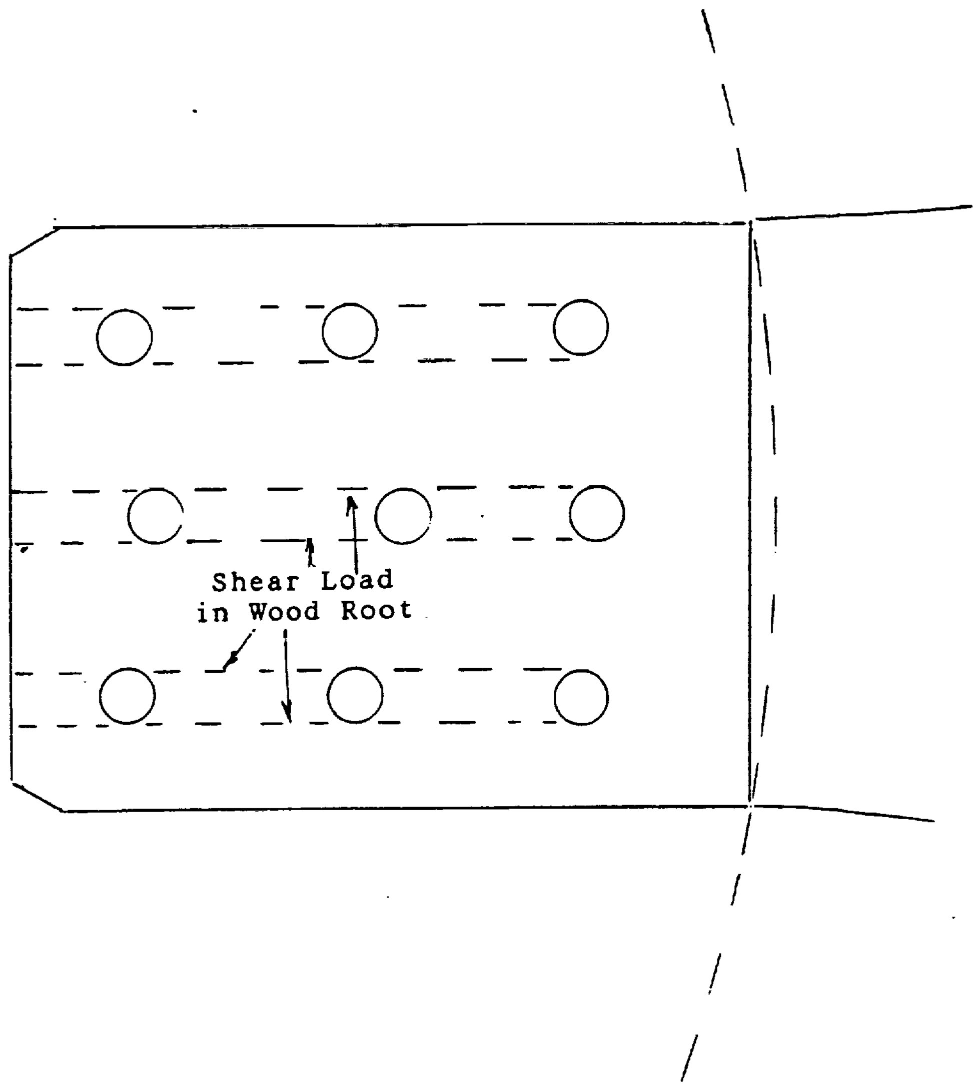


Fig. 7.3.2.1.1*1

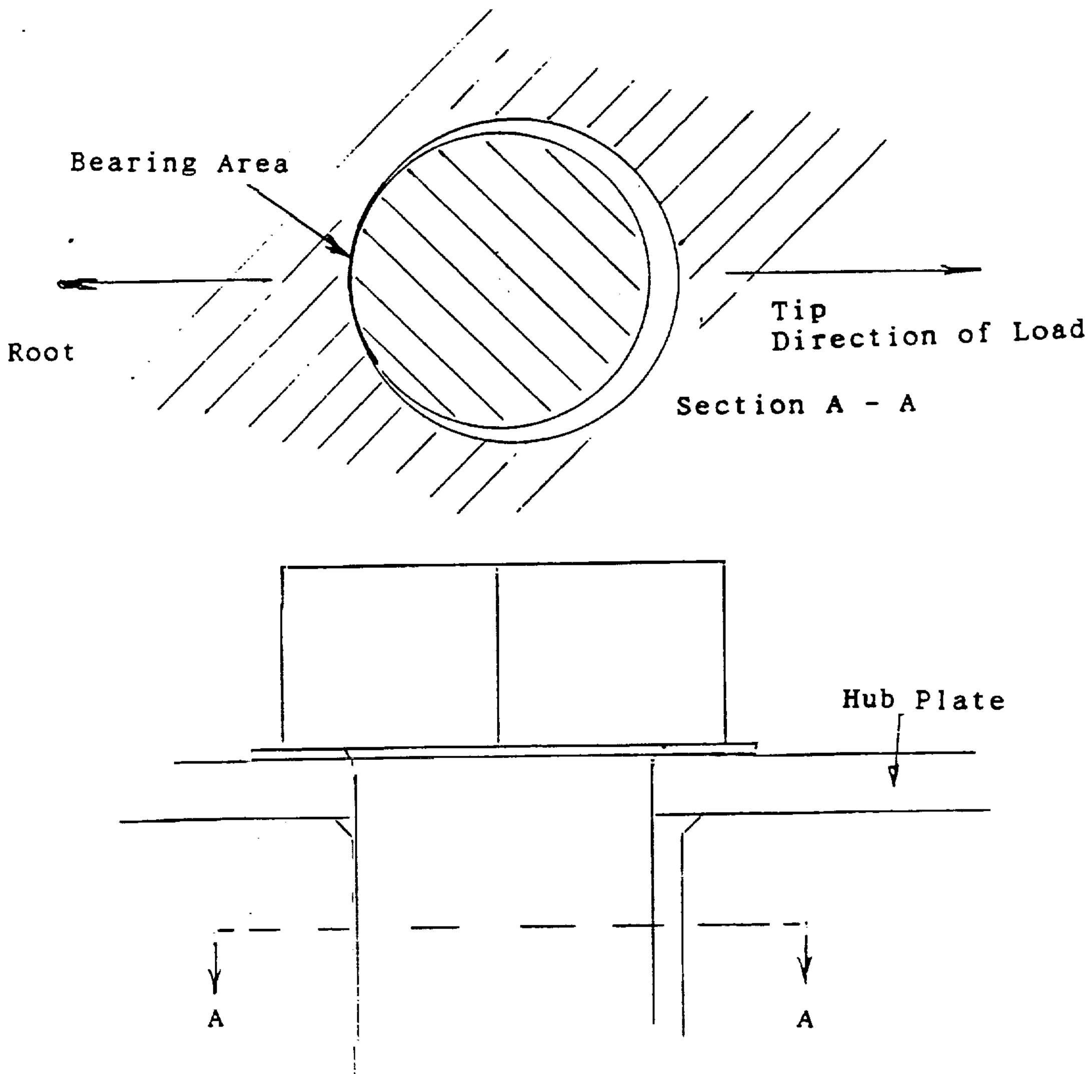

Bearing Area
Root
Tip
Direction of Load
Section A - A
Hub Plate
A
A

Fig. 7.3.2.1.1*2

A practical note: It is extremely difficult to ensure very close tolerances for drilling holes in very large root blocks. If this can be achieved in the root block by standard workshop practice it is then essential that such a root is kept stable. A case has occurred where blades were manufactured and a trial assembly into the corresponding hub successfully achieved before the complete fan had to be dis-assembled for transport and kept in store for some years before it was convenient for the fan to be re-assembled at the windtunnel site.

Owing to storage problems some dimensional change took place in the blade root blocks with corresponding difficulty with the re-assembly process that resulted in the need for some rework of the root block holes.

7.3.2.1.2 Root Plate Type

An alternative method for holding a blade with a rectangular root design between hub plates is to have root plates bonded to the root block and then bolt this complete assembly by through bolts between the hub plates. See Fig. 7.3.2.1.2*1.

The blade load is transferred to the root plates by shear at the bonded joint and the subsequent load in these root plates is taken by the through bolts (and/or tubes) into the hub plates.

To produce a completely detachable blade it is necessary in practice that a tube and bolt combination be provided for the through attachment, as shown in Fig. 7.3.2.1.2*1.

The detailed design first requires that the shear area between the root plates and the root block be limited to give a stress level of less than 100 lbs./sq,in. and that secondly the bearing loads between the root plates and bolt/tube combinations be limited to a suitable value depending on the strength of the root plate material. See Fig. 7.3.2.1.2*2

The bonding of wood to metal involves the Redux process (see Section 8.) This method is more suited for bonding Aluminium alloy than other metallic materials so it is preferable for the root plates to be of such material. A suitable specification of these is high strength aluminium sheet to aircraft standard L70.

(See Section 7.3.2.1.3. for an alternative approach to a design with other types of root plates.)

Practical notes; A tube which has to be inserted into a hole through the root block should preferably have a slightly reduced outside diameter over the majority of its length, where it will come inside the wood hole. This will allow for a tight tolerance fit at the junction of the tube with the root plates, the position where the operating shear load will occur, but clearance and hence no or limited loading between the wood and the tube. Correspondingly the main through bolts should

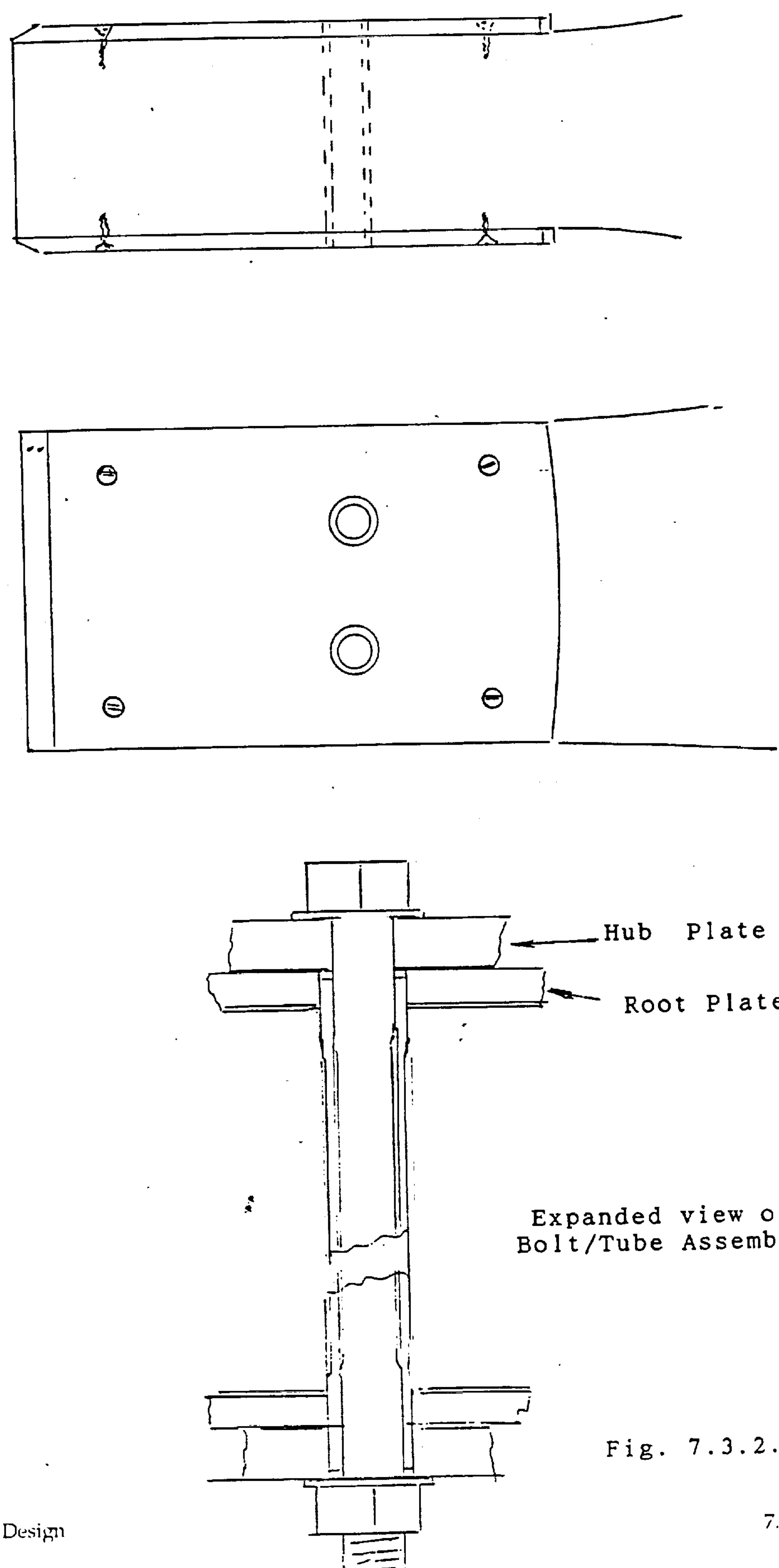
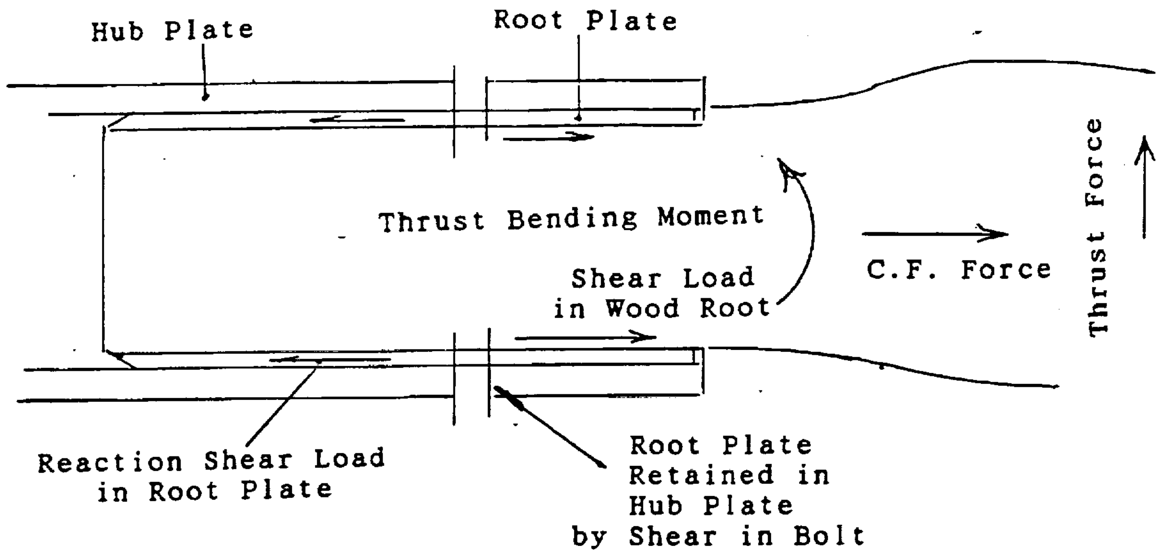


Fig. 7.3.2.1.2*1


Hub Plate
Root Plate
Thrust Bending Moment
Thrust Force
C.F. Force
Shear Load
in Wood Root
Reaction Shear Load
in Root Plate
Root Plate
Retained in
Hub Plate
by Shear in Bolt

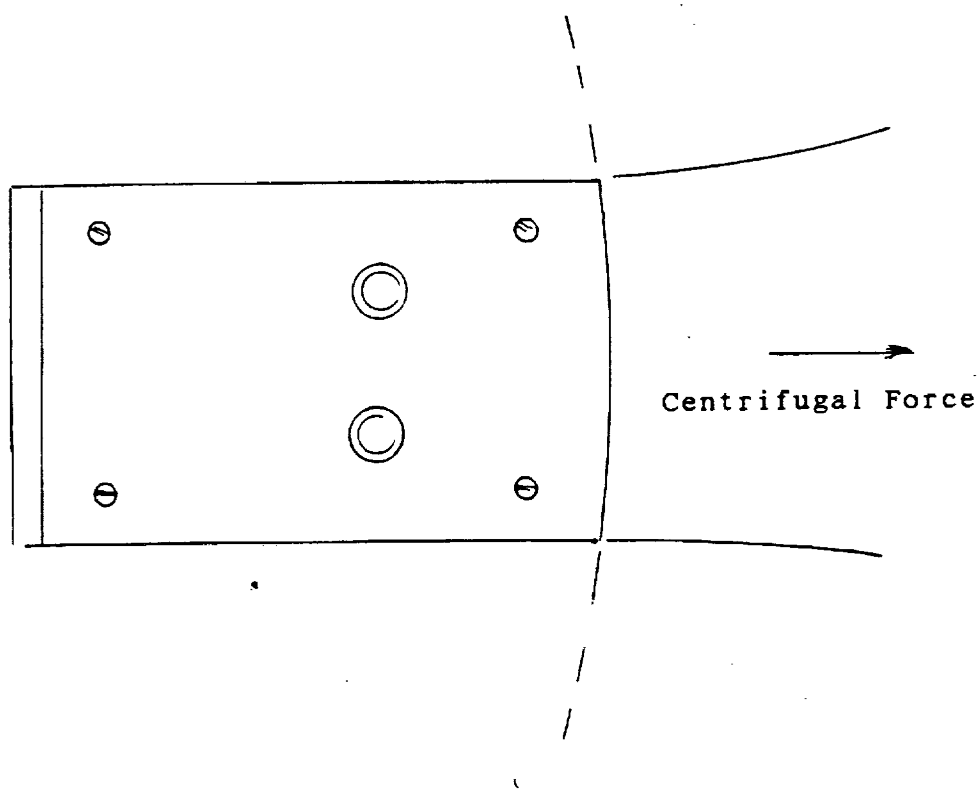

Centrifugal Force

Fig. 7.3.2.1.2*2

also have slightly reduced outside diameter over the central portion to allow for easy fitment along the majority of the length but a tight fit tolerance at the important loading positions. see Fig.7.3.2.1.2*1.

It is important that this type of bonded root plate is also held down by either wood screws or other type of through bolts. This requirement is to ensure that no tension or peeling load is imposed to the bonded joint during handling before the complete blade can be firmly clamped between the hub plates at the assembly stage.

7.3.2.1.3 Bracket Root Plate Type

An alternative design type is to have the root plates in the form of a forged bracket that can be bolted to the main hub members. This type of design will, however, normally involve steel forged bracket/root plates with the then practical difficulty of bonding a veneer to the steel plate portion so that the unit may be glued to the blade block. See Section 8. for details of the manufacturing techniques of using the Redux process with a steel component.

It is, of course, desirable that through bolts are also included, firstly to ensure that the glue/adhesive joints between the plates and the block are never subjected to any peeling or tension loading and secondly that should any slippage occur in these joints during operation the blade would still be retained by the bolts.

The blade material for this type of root assembly would be Mahogany.

A typical design for this type of assembly is shown in Fig. 7.3.2.1.3*1.

7.3.2.2 Circular Root Design

Variable Pitch fans require detachable blades with suitable (usually circular) roots that can be joined to metal components for assembly to the fan hub. For wood blades that require a circular root the only practical design is for the blade root to be of compressed wood and this contained in a metal (normally steel) adaptor (or ferrule). The design of such a retention system is, of course, vital to the reliability of the blade. The first decision to be made for such a design is the size of the Root Diameter. A record of the tests made for previous designs is available from which it is possible to prepare data to be able to forecast the required diameter of the root for any known loading.

A summary of these results is presented in the form of a graph showing Root size versus Centrifugal Load. See Fig. 7.3.2.2*1.

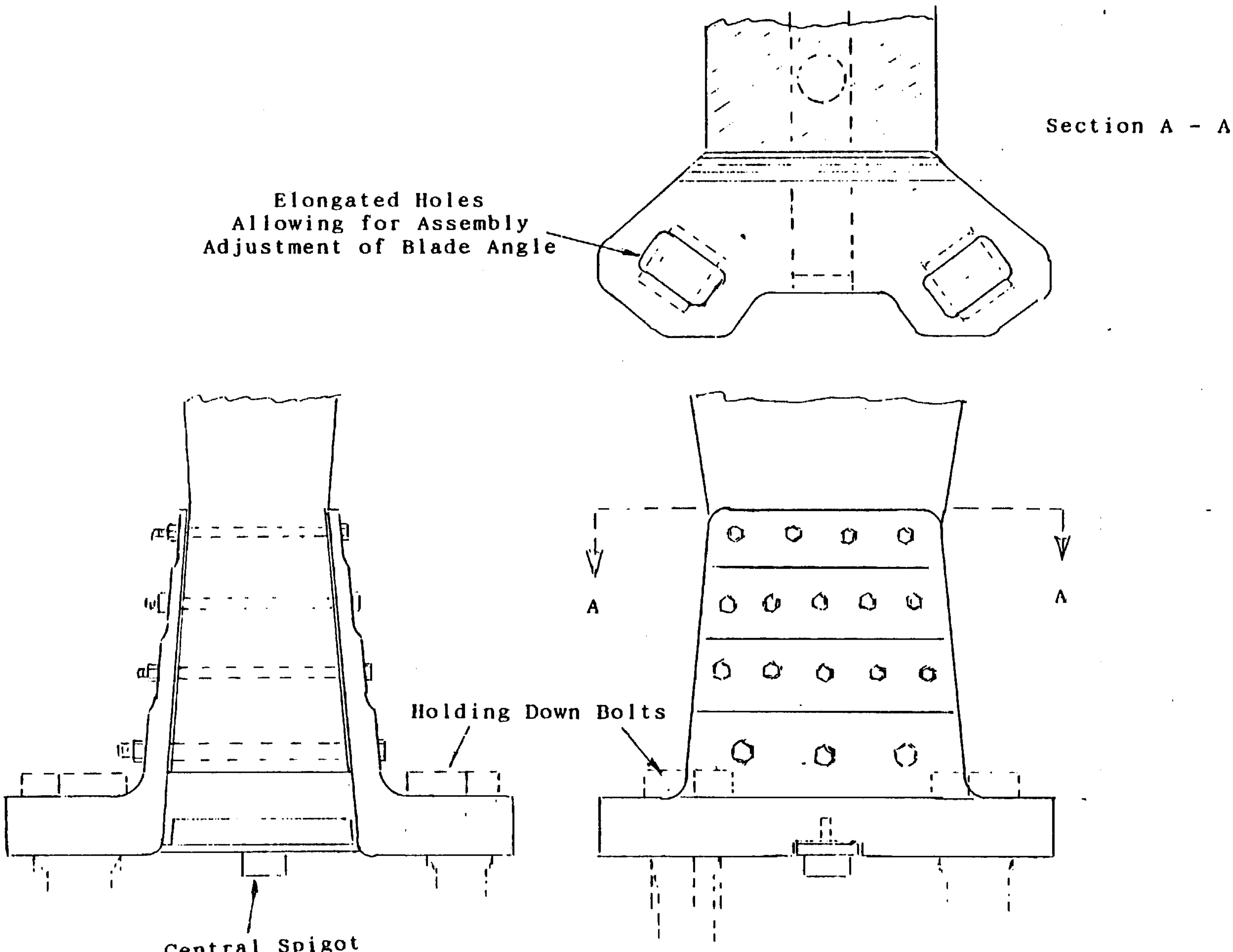

Section A - A
Elongated Holes
Allowing for Assembly
Adjustment of Blade Angle
A
A
Holding Down Bolts
Central Spigot

Fig. 7.3.2.1.3*1

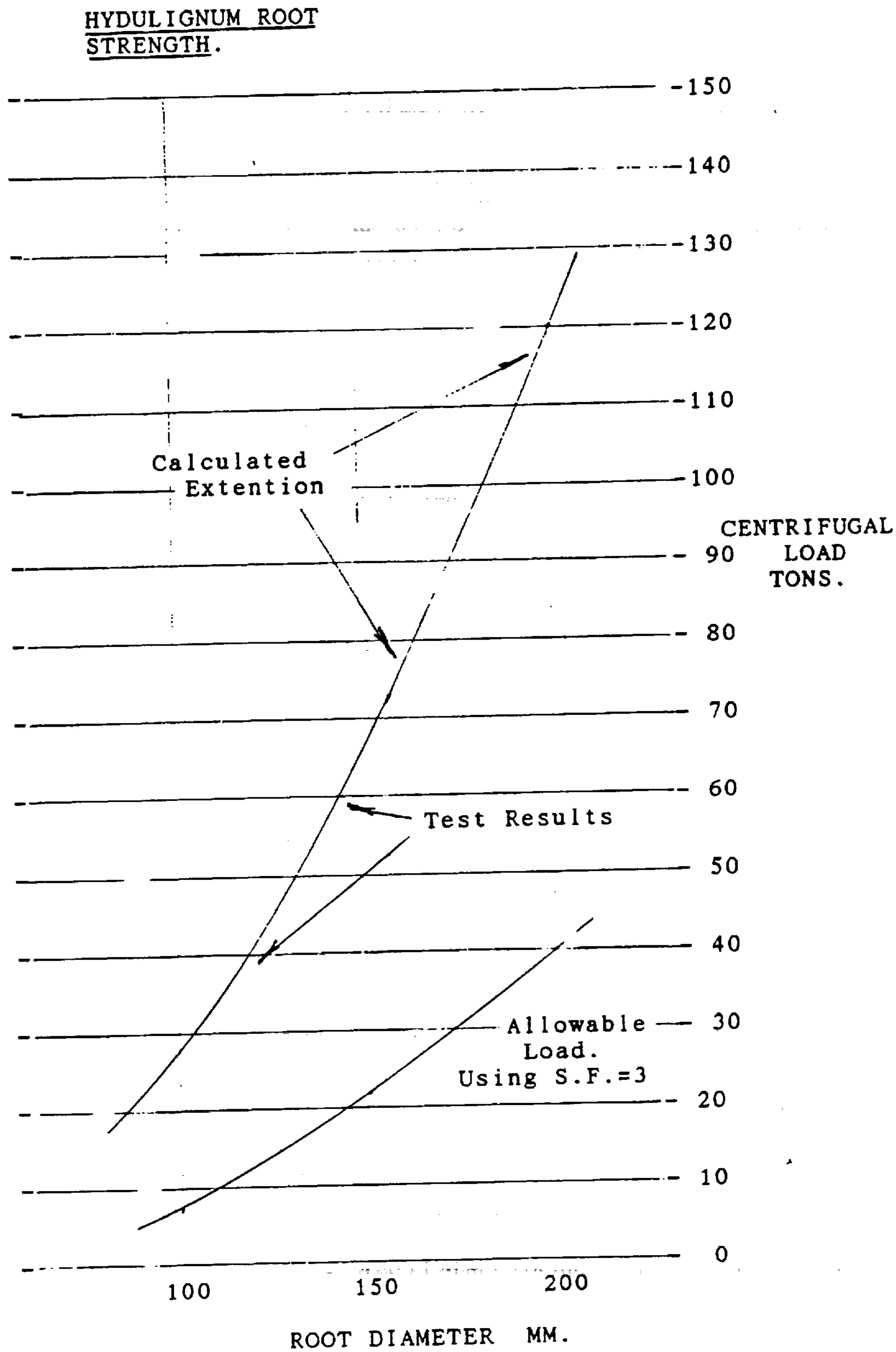

HYDULIGNUM ROOT
STRENGTH.
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
CENTRIFUGAL
LOAD
TONS.
Calculated
Extention
Test Results
Allowable
Load.
Using S.F.=3
100
150
200
ROOT DIAMETER MM.

Fig. 7.3.2.2*1

The load on a blade root is a combination of Centrifugal Force and Bending Moment forces. It is usual, but not universal, that the Bending Moment on the blade root is approximately equal to the Centrifugal Force x 1 in. and in the past most root tests have been conducted using this assumption. Hence the results that are presented were based on this relationship.

Some of these tests were originally carried out to establish the airworthiness of aircraft propeller blade roots where the normal Safety Factor requirement was 1.5, but for Windtunnel fan blades where weight of the final assembly is not so critical it is advisable to require a Safety Factor of not less than 3. The Allowable Load curve shown in this Fig. 7.3.2.2.*1 is based on this requirement. From this data the diameter of a Windtunnel fan blade root may be decided after the Centrifugal Loads have been calculated.

It is usual for the root length to be equal to or slightly longer than the diameter.

There are two types of adaptor that have been used, viz. Screw type or Bolt type as previously shown in Fig. 3.3*1

For roots with screw type adaptors the root form has to be of a conical shape so that the adaptor has a positive stop position when it is assembled and tightened. The normal conical root form used has a 5^{o} taper.

Although normally screw threads are cut as Right Handed it is advisable that the handing of the adaptor thread should take into account the effect of the Twisting Moment on the blade, which may be quite high, partly due to centrifugal loading.

The Twisting Moment should tend to tighten the blade root into the adaptor.

7.3.2.3 Detailed Thread Design for Screwed Adaptors

The tread form on the adaptor screw should be similar to the American Standard 60 -degree Stub Thread although the thread depth and the pitch will not necessarily meet this standard. The mating thread form on the compressed wood root should not contain any sharp corners and have appropriate manufacturing clearance over the adaptor thread.

The depth of the mating thread x the total thread length giving the total bearing area on the compressed wood must be used in relation to the maximum required working centrifugal load to ensure that the Bearing Stress on the compressed wood is lower (by a suitable safety factor) than the value (for a Hydulignum root) given for the end grain compression in Table 6.3.4*T1.

For practical reasons the manufacturing thread depth of the compressed wood root has to be slightly larger than the manufacturing size of the adaptor thread so the mating thread depth referred to above has to be the manufacturing thread depth of the adaptor.

The thread pitch must conform to the requirement that the shear stress on the compressed wood between each thread form is lower (by a suitable safety factor) than the LT shear value given in Table 6.3.4*T1. For practical reasons (to suit available thread cutting machines) the manufactured thread pitch should be chosen to be a standard value but the value of the eventual choice must conform to the above requirement.

The length of the root must be such that the total thread length gives sufficient area of thread engagement to conforms to the requirement that the Bearing Stress on the compressed wood is lower than the appropriate End Grain Compressive Strength.

The width of each thread form on the adaptor must also be sufficient so that the shear value is appropriate for the grade of steel to be used. This width dimension is not usually critical as practical considerations of manufacture will always give more than an adequate size on the metal thread.

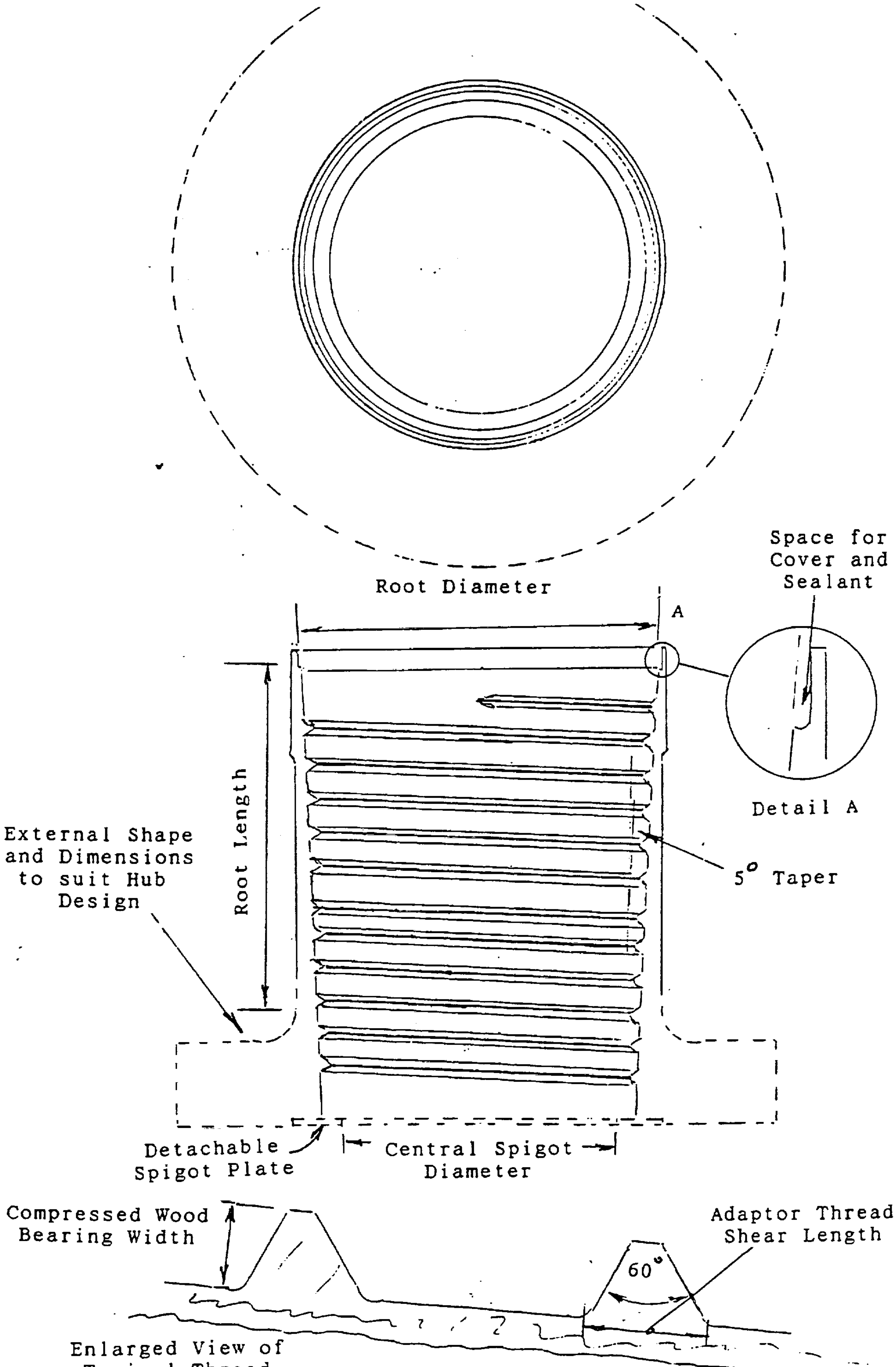
A typical adaptor is shown in Fig. 7.3.2.3*1 and further details of the thread form for both adaptor and the compressed wood root are given in Fig. 7.3.2.3*2 and Fig. 7.3.2.3*3. The main dimensions given were typical for roots with (large) diameters of the order of 8in./200 mm. to 11 in./280 mm. using threads with a pitch of 1 in. such as the Ames blade roots.

7.3.2.4 Design of Roots with Bolt Retained Adaptors

It is appropriate for Adaptors retained by bolts to be of cylindrical form. The basic Root Diameter and length should conform as previously specified. See Fig. 7.3.2.4*1

The base of the adaptor will need to be thick enough so that no distortion takes place under the working loads. The critical and important feature of such a design is the size and number of retaining bolts.

If a single bolt is inserted into the end grain of compressed wood and then subjected to increasing longitudinal load, it will eventually fail in one of two ways. Either the bolt will fail in tension or the bolt will pull out of the compressed wood due to shear failure in this compressed wood. The form of failure will depend on the relationship between the strength of the bolt due to its diameter and the shear area of the bolt engagement (due to the depth of engagement and hole diameter).



Root Diameter
A
Space for
Cover and
Sealant
Detail A
Root Length
External Shape
and Dimensions
to suit Hub
Design
5° Taper
Detachable
Spigot Plate
Central Spigot
Diameter
Compressed Wood
Bearing Width
Adaptor Thread
Shear Length
60°
Enlarged View of
Typical Thread

Fig. 7.3.2.3*1

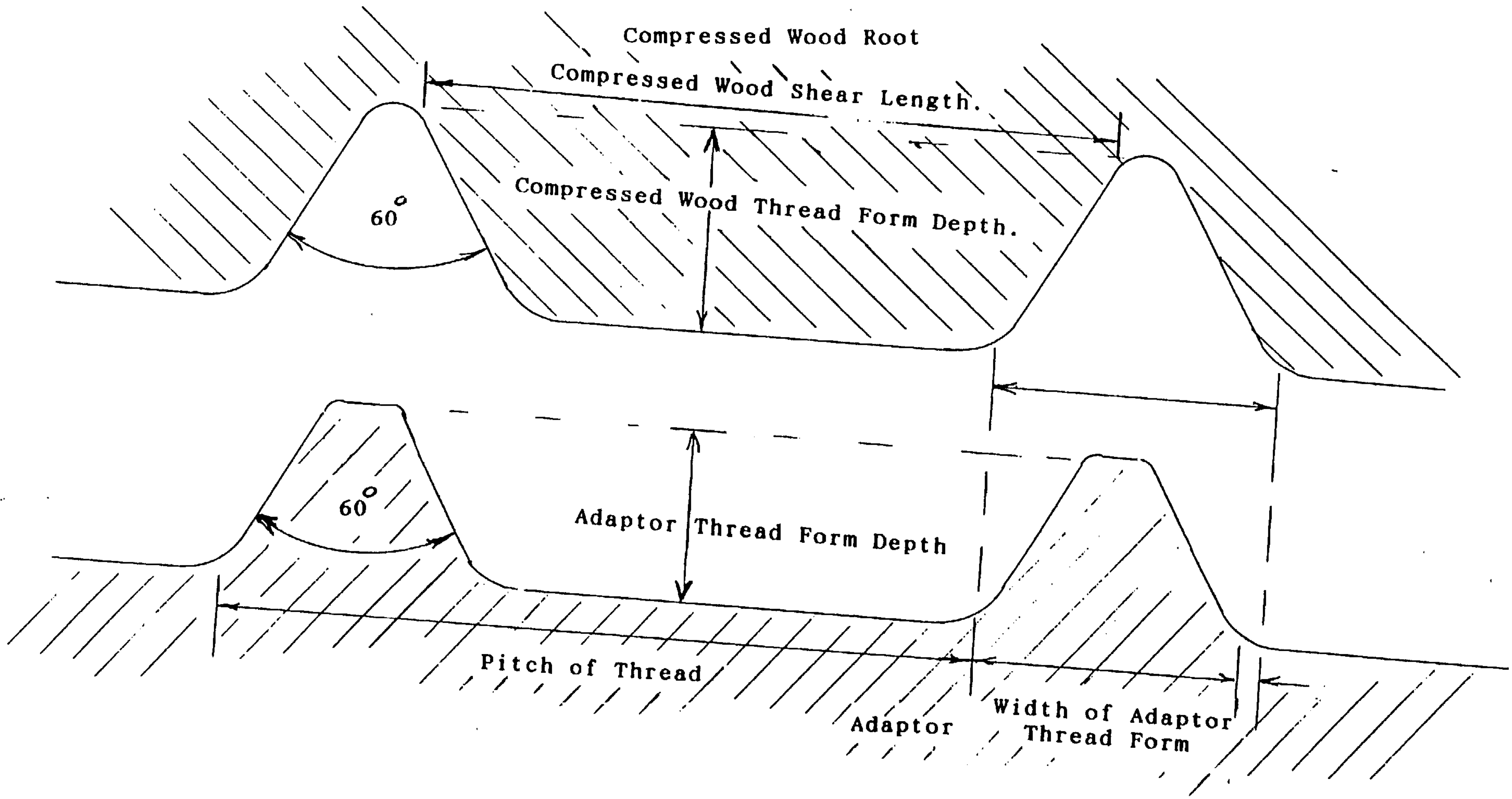

Compressed Wood Root
Compressed Wood Shear Length.
Compressed Wood Thread Form Depth.
60°
60°
Adaptor Thread Form Depth
Pitch of Thread
Adaptor
Width of Adaptor Thread Form

Fig. 7.3.2.3*2

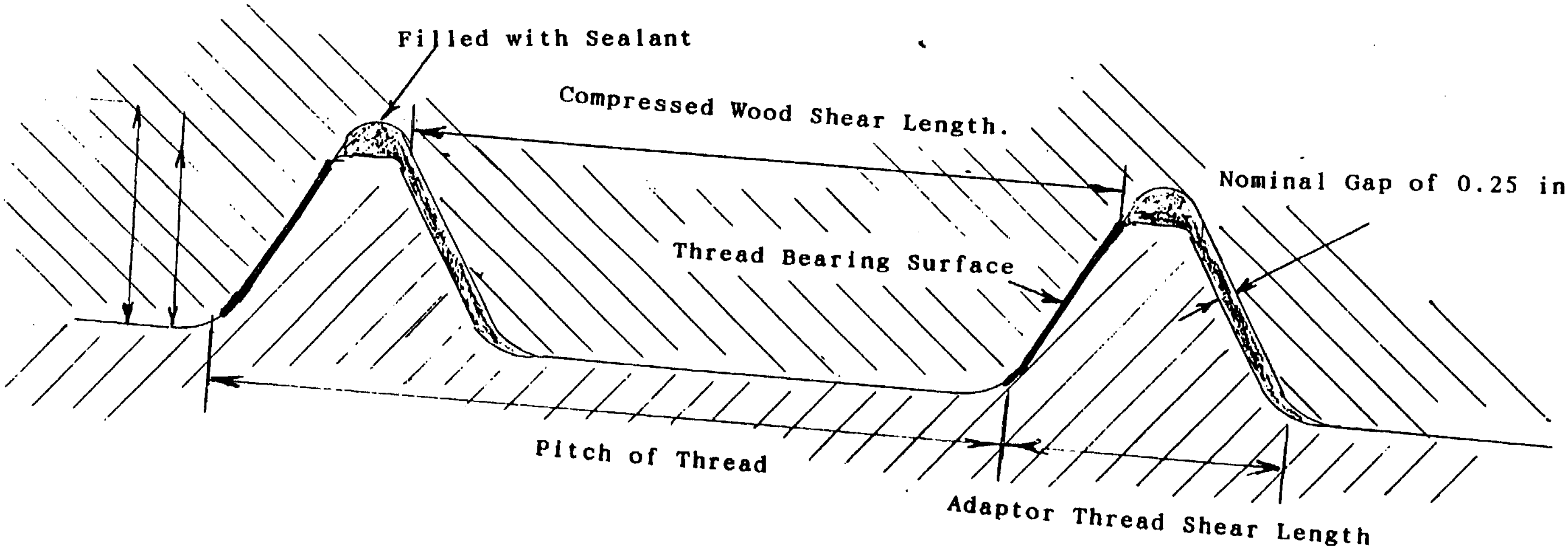

Filled with Sealant
Compressed Wood Shear Length.
Nominal Gap of 0.25 in.
Thread Bearing Surface
Pitch of Thread
Adaptor Thread Shear Length

Fig. 7.3.2.3*3

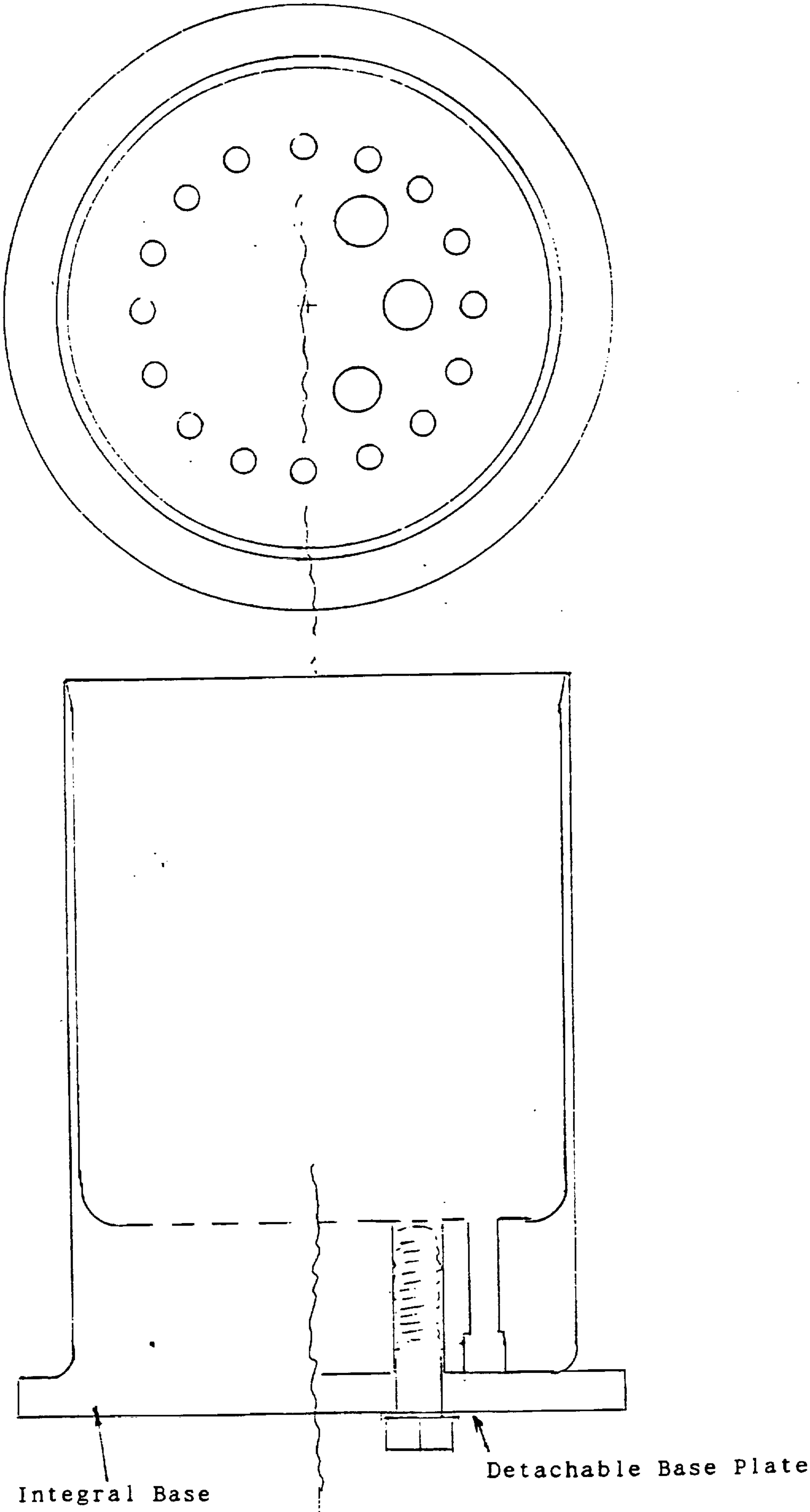


Fig. 7.3.2.4*1

The number and size of appropriate bolts to be used with such a bolt retained adaptor may then be determined from this relationship, also taking into account a suitable value for the safety factor.

A practical note: Normally standard high tensile bolts will be specified for this type of design. Coarse threaded bolts, giving greater bearing area for the thread, are more suitable for insertion into the compressed wood than bolts with fine threads.

The compressed wood can be drilled and tapped by standard workshop methods.

It is advisable to have a safety factor of approximately 3 on the total bolt failing load in relation to the root diameter failing load.

The outside shape of this type of adaptor will depend on the requirements of the hub design as will the exact details of the final retention feature. Examples of these are shown in Fig. 7.3.2.4*1.

7.3.3 Root Testing

7.3.3.1 Static Tests

If a new circular (compressed wood) root design, (outside the range of previous established designs) is required, particularly for a major project or new windtunnel, it may be advisable to consider that a test on a full scale replica of the root be undertaken. The tests previously carried out have consisted of manufacturing suitable holding shackles that can be attached to a double ended specimum of the proposed root and these shackles then being capable of being fitted to the jaws or other similar features of a standard tensile testing machine. The design of the shackles allowed for the double ended test specimen to be offset (usually by 1 in.) from the main line of action of the subsequent load pull to be imposed.

Because the Centrifugal loading and the Bending Moments that were calculated to be present for the Ames blades, the design of these blades did not conform to the general pattern of only requiring a 1 in. offset, it was deemed necessary that an offset of 8 in. would be more appropriate for the test for this project.

7.3.3.2 Fatigue Testing

There is sufficient data already available to assess the fatigue limitations of likely future designs of a compressed wood root assembly and it is most unlikely that a project of major importance will again justify the expense and the time involved in carrying out a full scale fatigue test.

As an historical note, the design and importance of the Ames blades did justify such a major test. A copy of the Report dealing with this test is given in Appendix F.

7.4 Transition Zone (Scarf) Design

The Transition Zone, for Spruce to Compressed Wood, will need to be positioned between the circular root at the adaptor and the main (aerodynamic) blade.

From stress considerations the zone should allow for the gradual increase of the stress levels that occur over this region. Preferably there should be, therefore, a gradual change between spruce and the compressed wood. This may be achieved by having the scarf joints in individual lams at different radial positions.

There is no absolute grading system that is required along this zone so it is usually convenient to start with the practical necessities and base the original proposed scheme on the manufacturing considerations, eventually checking that these then cater for the resultant loading and stress values obtained.

It is more convenient when setting up compressed wood manufacture that batches of the same size of boards are considered. This then leads to a preferred length of board of 72-74 in. to be assembled from the maximum 76 in. length of veneers available. It is very unlikely that the length of compressed wood portion in any one lam will need to be any longer than this even in a large blade, such as the Ames blades.

The minimum length of compressed wood in any lam will normally be the root length plus the scarf length and some allowance for manufacturing tolerances, giving a total of say 18 in. or 24 in. Boards of 72 in. can be conveniently cut into lengths of 24 in., 36 in., 48 in. with no waste in length and even if a length of 60 in. is required this only involves a relatively small off-cut from a 72 in. board.

It is preferable, although not absolutely essential, for scarf joints in adjoining lams not to overlap, which entails that the difference in length of the compressed wood portions should be the scarf length, (approximately 12 in.)

All these considerations than lead to a very convenient position that the length of compressed wood in adjacent lams may be specified as the same as is convenient for manufacturing.

As the stress levels in a blade tend to be higher on the surface lams than in the internal lams, the compressed wood should be disposed in a corresponding configuration, the shorter lengths to be used for the centre lams of the main block, with increasing lengths of compressed wood for the lams towards the outer sides of the block.

A block for a large blade (similar to that required for the Ames blades) showing a typical layout of the compressed wood and spruce portions is shown in Fig. 7.4*1. For medium size blades the full length of compressed wood of 72 in. may not be required but the same principle should be adopted, using decreasing lengths of compressed wood (for adjoining lams) that may be cut from a common length of manufactured board.

7.5 Detachable Tip Design

It is frequently required (or advisable) to have a low density breakaway tip block incorporated on to the main body. There is always the possibility that, during operation, a relatively large foreign body may pass into the fan and become wedged between the tip end of a blade and the tunnel wall causing considerable damage to such a solid blade.

For a blade with a breakaway tip block, although this block will be damaged, the main part of the blade should easily escape any major damage. The design of such a block should, of course, allow for it to be readily replaced.

The normal solution for this contingency is to have a breakaway tip block of say 3 in. length for a large blade or 2 in. or even down to 1 in. for the purpose of protecting the main area from major damage due to a foreign body.

Such a tip feature can be simply a block of balsa, virtually to the full chord of the blade width required at the tip of the blade.

The structural design problem is merely to ensure that the tip block is retained in position against the centrifugal and the aerodynamic loading it will eventually experience in operational use.

The practical and manufacturing requirements are that the balsa should be reasonably light but still firm enough not to sustain normal operational and handling damage. It has been found that material of a density range of 6-9 lbs./cu.ft. has these suitable properties.

It is important that an adequate retaining system is specified. This can be a simple plywood tongue retained both in the tip block and the main structure of the blade or alternatively for medium and small blades perhaps the strength of the subsequent cover system may be adequate. It may be appropriate if the extreme L.E. is part of the main body to ensure that this part is adequate to resist normal wear.

These alternatives features are illustrated in Fig. 7.5*1.

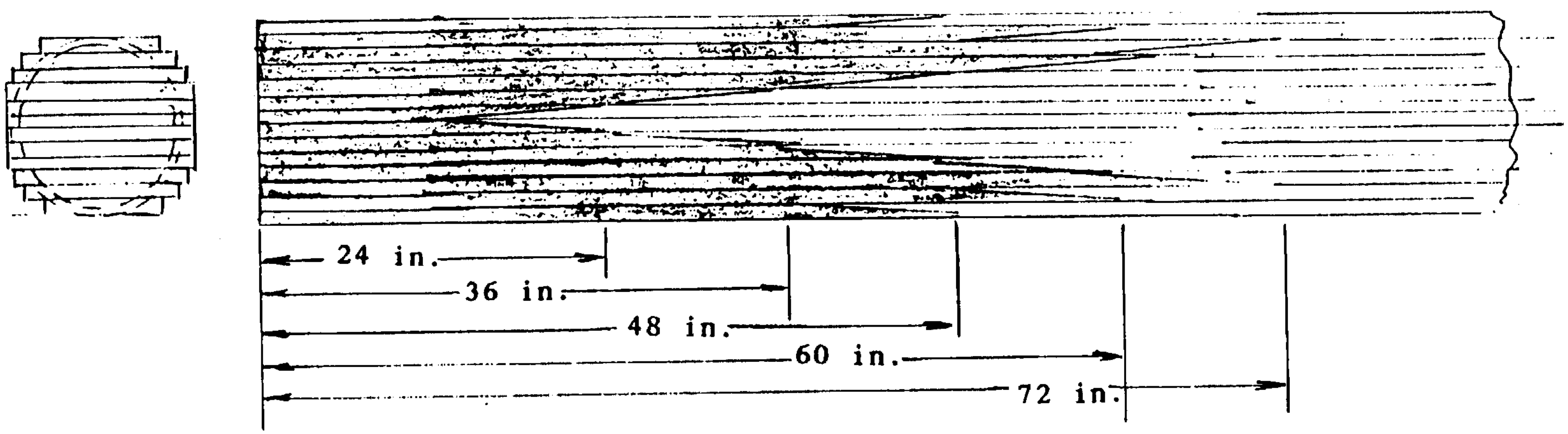
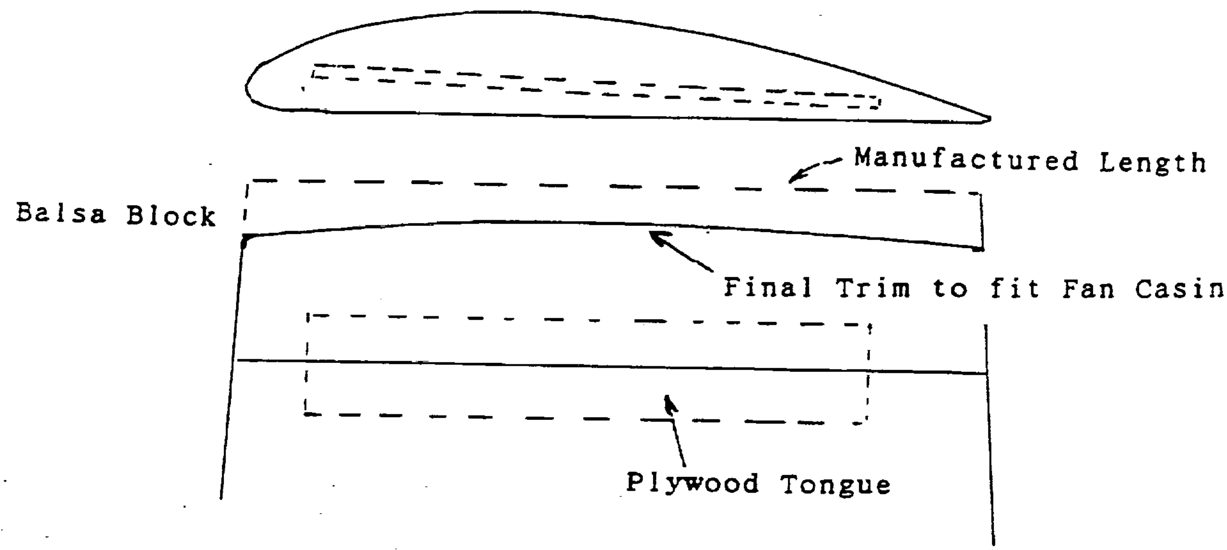


Fig. 7.4*1


Manufactured Length
Balsa Block
Final Trim to fit Fan Casin
Plywood Tongue

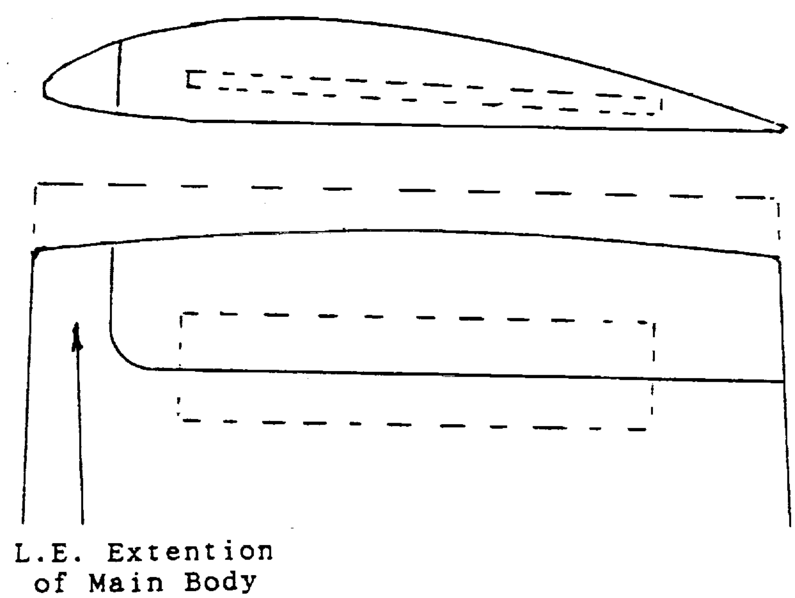

L.E. Extention
of Main Body

Fig. 7.5*1

Section 8: Manufacturing Design

Index

8. Manufacturing Design

- 8.1 Definitions
- 8.2 Manufacturing Procedure
- 8.3 Manufacturing Design
  - 8.3.1 Lams and Block
  - 8.3.2 Manufacturing Design Considerations for Root Design
  - 8.3.3 Manufacturing Design for Shaping
  - 8.3.4 Covering - Manufacturing Design Requirements
  - 8.3.5 Balance Adjustment

8. Manufacturing Design

8.1 Definitions

Aerodynamic Design:	A method for arriving at the aerodynamic design comprising details of the aerofoil shapes required at a number of stations along the radial length of a blade is dealt with in Section 5. Alternatively this information may be supplied by the major customer to a prospective blade contractor who may then be required to undertake translating these details into a practical manufacturable product. Although not strictly exclusively aero-dynamic any track or sweep of the blade is included in this definition.
Manufacturing Design:	The detailed manufacturing information, finally in the form of working drawings, specifying all aspects of dimensions, special tools and templates, and manufacturing limits to be applied.
Root Design:	That part of the manufacturing design that refers to the root area and the correlation to the hub details.
Blade Axes:	In order to be able in the text of this Report to make reference to positions and directions on a blades it is convenient to define appropriate axes and their origins. The X-axis, along the Radial axis, extends from the Root end along the length of the blade to the tip. A practical origin is usually at the root end station of the blade whereas the origin of the Radial Axis co-incides with the axis of rotation. The Y-axis is normally in the plane of rotation to correspond to the chordwise direction. The Z-axis, at right angles to the other two axes, corresponds to the thickness of the sections and/or block, and is parallel to the axis of rotation. The origin is usually on the radial axis. Illustrations of these axes are shown in Fig. 8.1*1
Section Angle:	The aerofoil angle at a particular section relative to the Y-Blade Axis
Section C. of G. Point:	The theoretical position of the Centre of Gravity of the particular section.
Radial Axis:	The true axis of the blade at right angles to the axis of rotation, as defined by the fan hub.

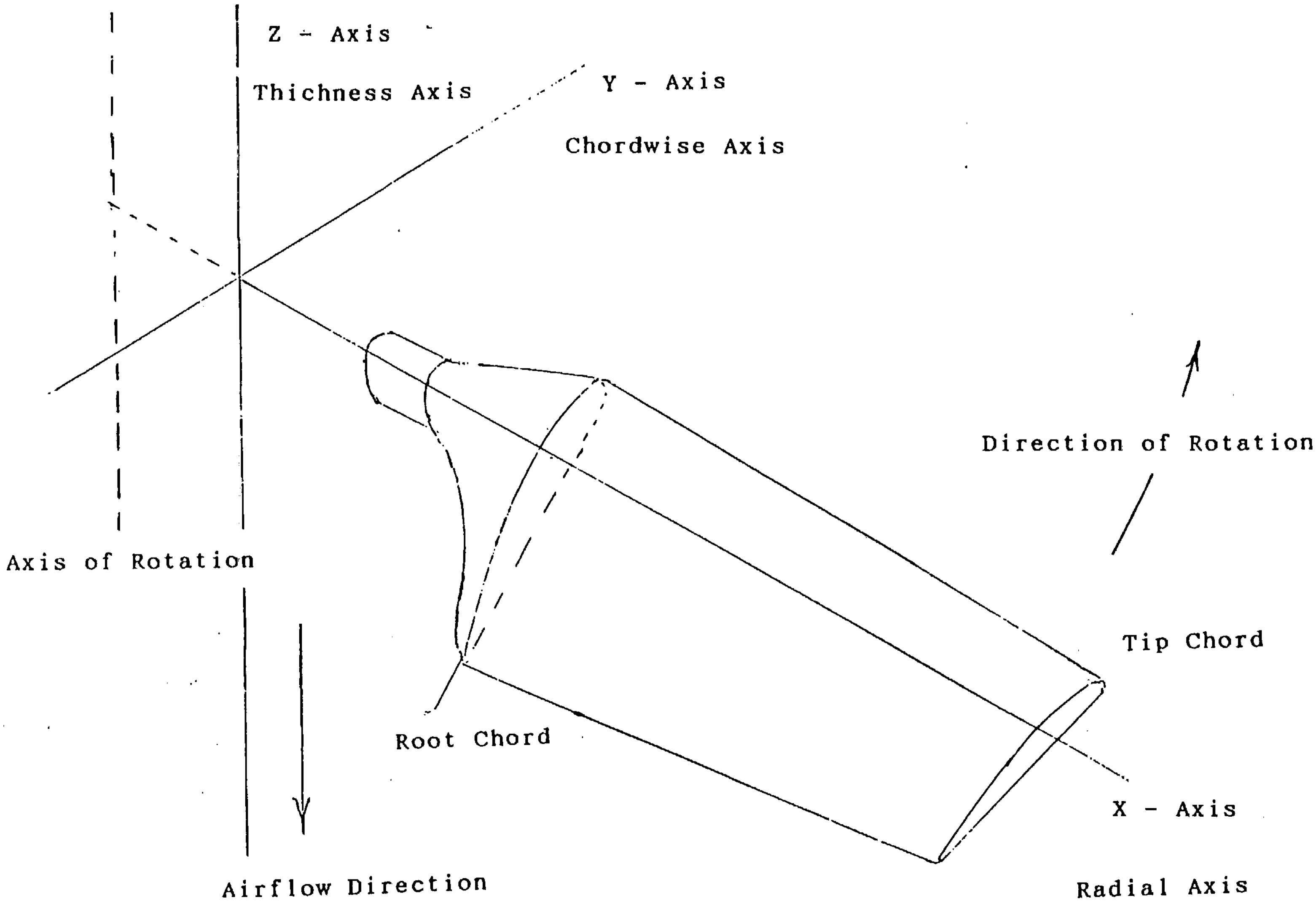

Z - Axis
Thichness Axis
Y - Axis
Chordwise Axis
Direction of Rotation
Axis of Rotation
Tip Chord
Root Chord
X - Axis
Radial Axis
Airflow Direction

Fig. 8.1*1

Radial Block/ Lam Angle: The angle between the fan radial axis and the plane of the lams.

Lam and Block Face Angle: The angle between the plane of the lams and the Y-Axis.

Track (or Rake): At a particular section is the Z directional distance between the X-Y plane and the C. of G. point.

Sweep: At a particular section is the Y directional distance between the X-Z plane and the C. of G. point.

These definitions are illustrated in Figs. 8.1*1, 8.1*2, 8.1*3, and 8.1*4.

8.2 Manufacturing Procedure

A brief outline of the manufacturing procedure (based on a detachable blade) is as follows:

(Slight modifications to these procedures are necessary for integral blade fans.)

a. Select appropriate raw boards, long enough to preclude any joint in their length required, and clean up one surface.

b. Inspect these cleaned up boards, rejecting any that are not to standard.

c. Plane edges of boards and then (for large blades) side glue to achieve necessary width of board required.

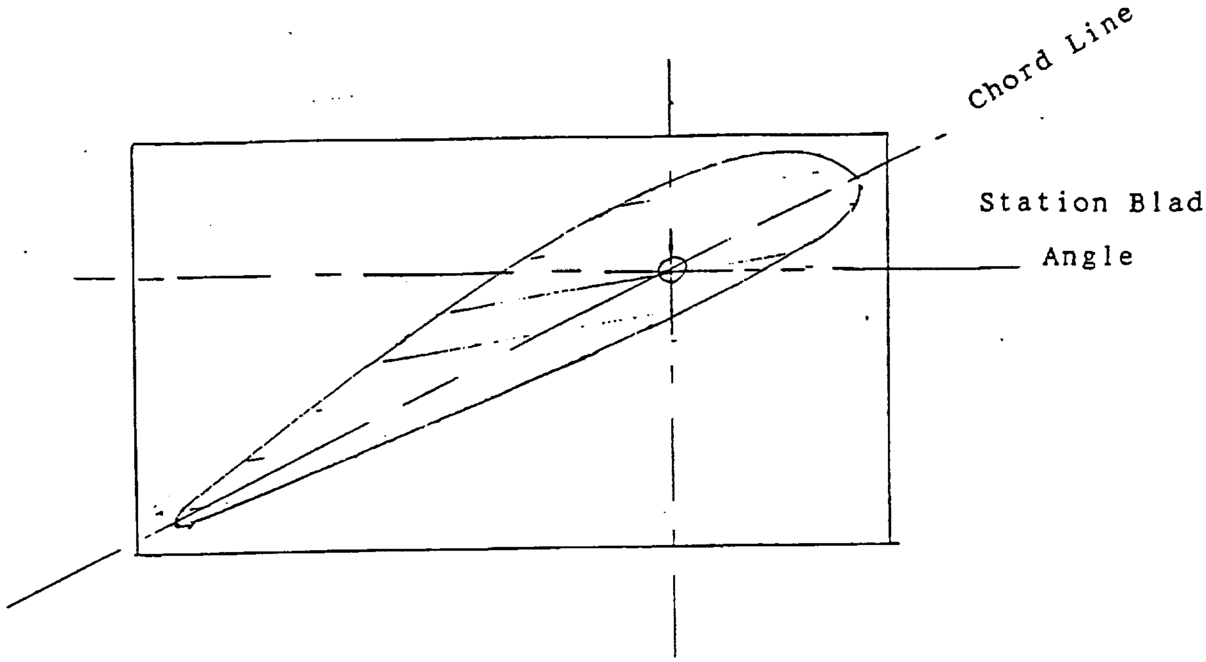
d. Mark out, using appropriate lam pattern or template the lam profile and cut lam to rough plan form shape.

e. If necessary scarf joint (with 15 :1 scarf joint) on to root end (compressed wood) material.

f. Plane rough sized lam to final thickness. Weigh or balance individual lams so that a selection may be made for balance purposes.

g. Dry assemble all lams required to form a blade block. Drill for and insert dowells to retain lams in correct relationship to each other during gluing process. Check all lam fits.

h. Dis-assemble dry block, apply glue to all appropriate surfaces and re-assemble block under pressure (approximately 50 lbs/sq.in.) in a suitable glue press. Check that all glue joints are mating.


Chord Line
Station Blade
Angle

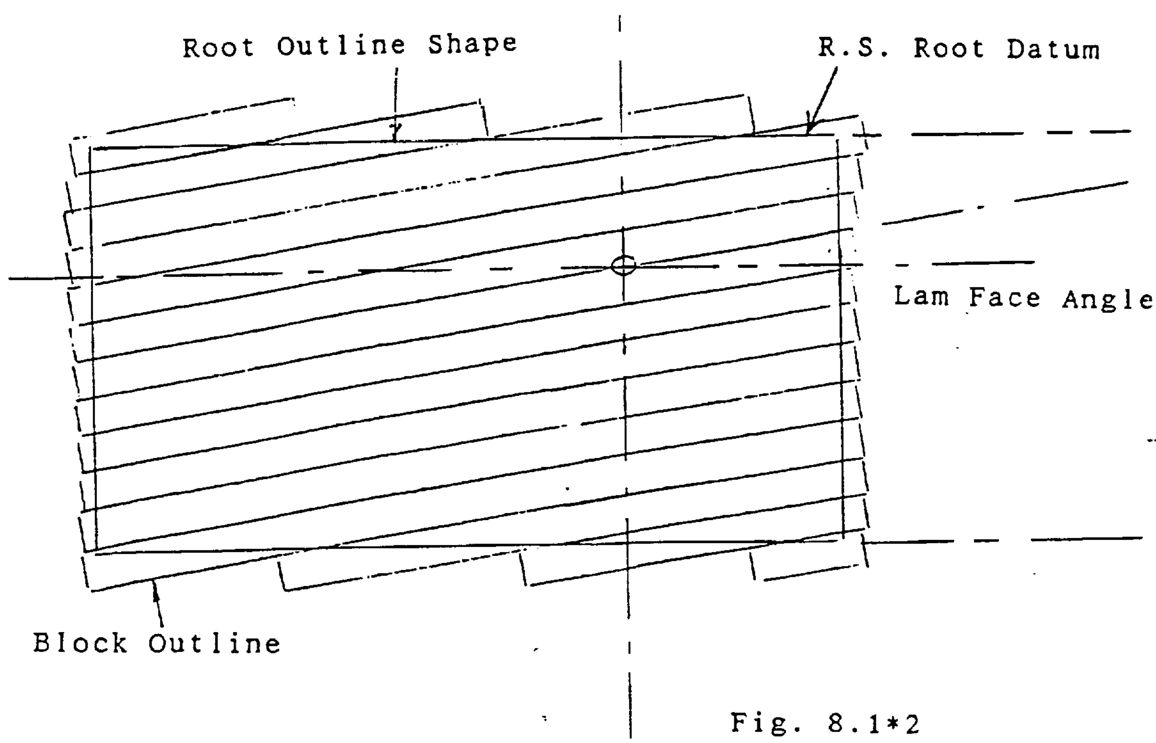

Root Outline Shape
R.S. Root Datum
Lam Face Angle
Block Outline

Fig. 8.1*2

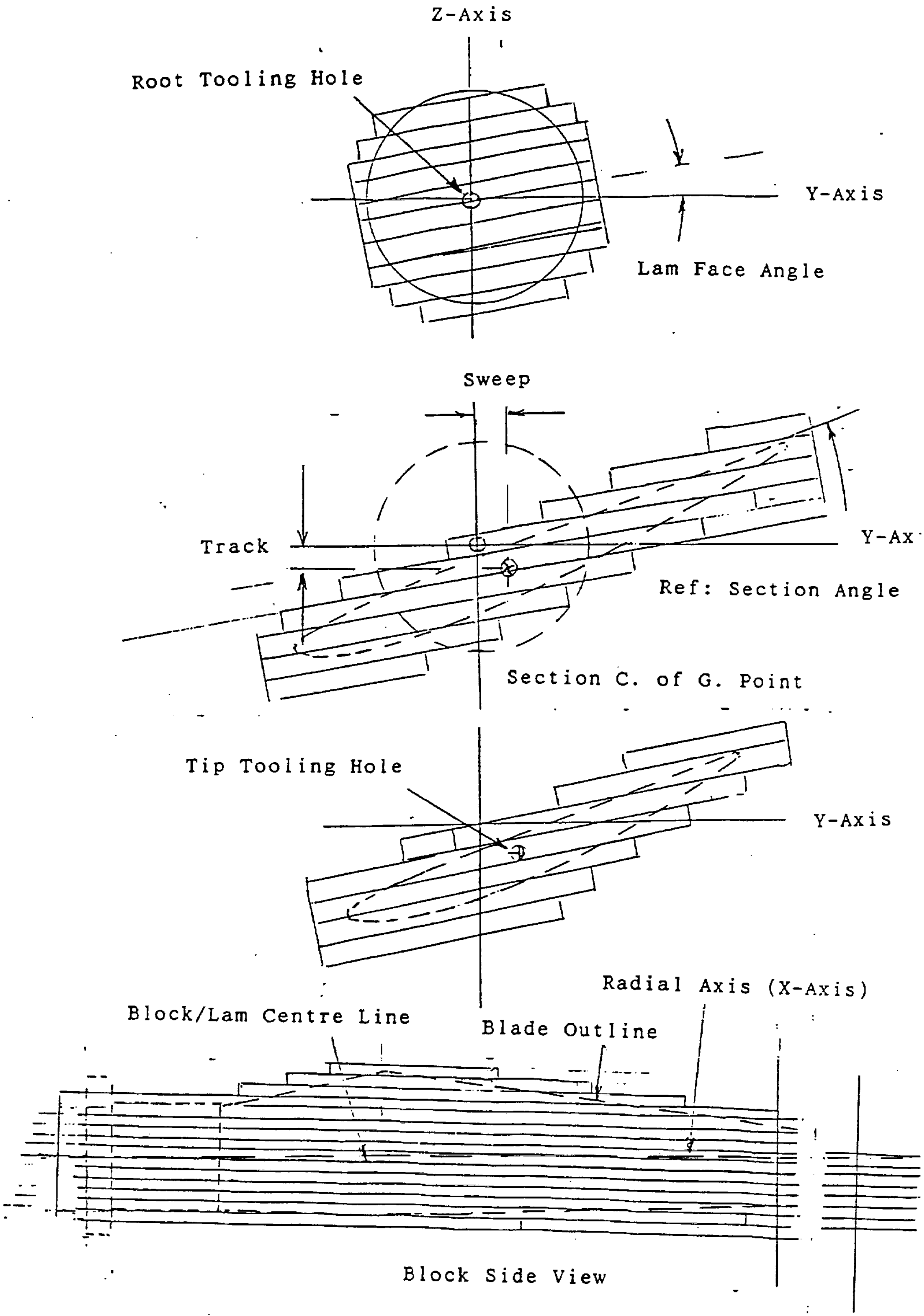
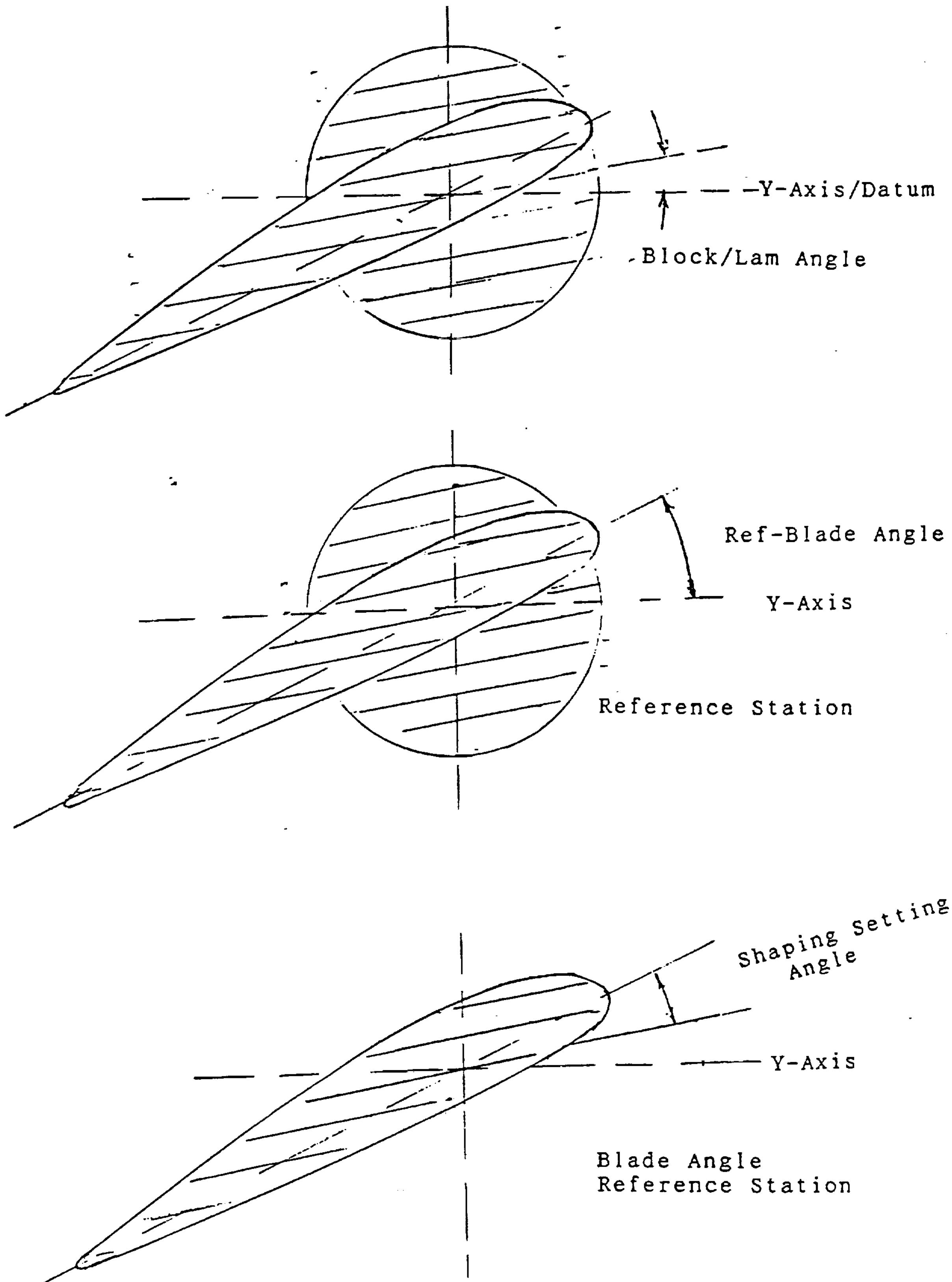

Z-Axis
Root Tooling Hole
Y-Axis
Lam Face Angle
Sweep
Track
Y-Ax
Ref: Section Angle
Section C. of G. Point
Tip Tooling Hole
Y-Axis
Radial Axis (X-Axis)
Block/Lam Centre Line
Blade Outline
Block Side View

Fig. 8.1*3



Y-Axis/Datum
Block/Lam Angle
Ref-Blade Angle
Y-Axis
Reference Station
Shaping Setting Angle
Y-Axis
Blade Angle
Reference Station

Fig. 8.1*4

i. After appropriate glue setting time (usually overnight) remove pressure from block. Then remove block from press and store for required glue hardening time.

j. Machine appropriate surface, or drill suitable tooling hole(s), or mark block to achieve working datum(s) prior to shaping block to desired profile.

k. Shape block to give required "White Shape" (see definition in Section 13.2.48) form all over. Check that all dimensions are within the specified tolerances. (Further information for blade shaping tolerances is given in Section 9.7)

l. Check balance details of each blade in comparison with others of same fan or set.

m. Apply covering and finishing materials as required.

n. Check final dimensions, including balance requirements.

8.3 Manufacturing Design

8.3.1 Lams and Block

Manufacturing Design starts with the design of the blade block, which involves detailed design of the lams, defining the block data for future manufacturing reference and specifying the gluing procedure including details of the glue press that will need to be made available.

The first detail to be decided for the block design is the lay-out of the lams.

The start is the lam thickness. Usually this is chosen as 0.75" or 20 mm., as the timber, in board form is normally supplied or available and purchased from a Timber Merchant at a nominal thickness of 1 in. (or 25 mm.) This then allows a practical tolerance for cleaning up of both faces to give a smooth true surface for gluing.

For strength and timber stability reasons it is essential that the tip section, being of the smallest chord and lowest angle contains a minimum of, but preferably more than, two lams. These lams running through the tip section should run continuously through from the root or boss to the tip and will normally be the centre lams of the block. From this requirement the Radial Lam Angle of the lams relative to the angle of the finished blade may be decided.

From the root size the total number of lams can be assessed to achieve the desired root thickness. Normally the Radial Lam Angle coincides with the radial axis of the blade (for 2 or 4 integral blade fans this is, of course, essential) but for detachable blades, particularly where the blade has a considerable track dimension, it may be appropriate for the lams to run at a small angle to the Radial Axis so that the centre lams are contained within both root and tip sections. See Fig. 8.1*3.

After the decision has been made for the value of the lam angles relative to the blade orientation it is possible to arrange where further lams may be added to the draft lay-out scheme so that all of the proposed blade design is contained within the block.

The width of any lam at a particular radial station is assessed by reference to the aerofoil sections required, by drafting out the section superimposed on a lam thickness lay-out.

The lam widths are dependent on the relationship of the Lam Face Angle (which eventually becomes the Block Face Angle,) and the Blade Angle Datum.

A Ref:Blade Angle Datum, usually the aerofoil angle at either 0.7 or 0.75 radius station, is chosen as the eventual reference angle from which all section angles are related.

For small or medium sized blades the Lam Face Angle is usually taken as zero to the blade datum (Y-Axis). Of course for integral blade fans where the lams run through the boss into opposite blades this is the only option, but for detachable blades this is not essential, although desirable for large fixed pitch blades where a rectangular root section and rectangular root block are used. Fig. 8.1*2 illustrates a small value for this Lam Face Angle on a large detachable fixed pitch blade with a rectangular root block.

For large Variable Pitch fan blades with circular root sections there is considerable scope for arranging the Lam Face Angle and the Ref:Blade Datum Angle at a convenient difference so that the lam width may be kept within an appropriate limit.

The centre lams normally require the maximum width. Although theoretically there is no need to restrict this width, in practice all lams have to be planed to a final thickness and the width of any lam must be restricted below the capacity of the thickness planer available at the manufacturing plant to carry out this operation.

In extreme circumstances for very large blades with rectangular root blocks (this was the case with the G.M. fan blades) this requirement may not be able to be met and the maximum width lams have to be assembled from part width lams at the block gluing stage. This is a difficult and undesirable production process and not used unless absolutely necessary.

At the lam lay-out stage it is important that the correct amount of surplus material is allowed on the lam size, normally 3/8 in. (10 mm.) should be allowed as surplus round each blade section face. At the L.E. and T.E. a nominal 1 in. surplus should be allowed. See Fig. 8.3.1*1.

If too little surplus is allowed any slight manufacturing tolerance error in the block production may result in the block being undersized and the required aerofoil section not being achievable at the shaping stage. Alternatively if too much surplus is allowed there are problems that perhaps excess material will be used or excess manufacturing time be spent to remove it. Either of these alternatives could lead to extra cost.

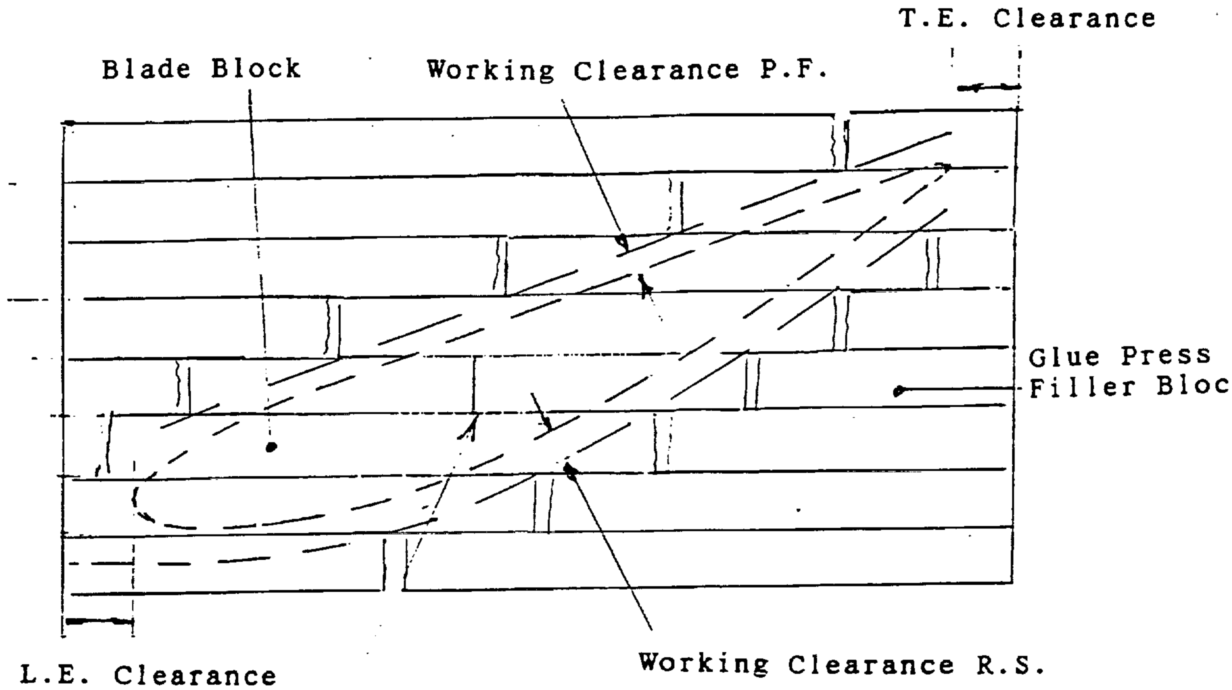
An important consideration in the design of the block is to ensure that a datum (or more than one data) are provided for use as reference when the block is converted to the "White Shape" (Ref:13.2.48) blade.

For integral blade fans the basic datum has to be the face of the root boss. If the block has sufficient thickness at the boss, implying that the number of lams in that region must be more than a specified minimum, then at the manufacturing stage a datum face can be machined on the boss. Because integral fans are usually small, certainly not greater than medium as defined in this Report, a datum face over the boss area is usually sufficient for the whole fan.

For detachable blades it is usually necessary to have a datum at both ends of the block. Fixed Pitch blades with rectangular root blocks can normally have one face of such a block specified as a root datum, but even then before this face can be machined it is advisable to allow for a dummy datum to be prepared on the block inboard of the final blade which frequently means that an "extra" tooling root block be incorporated necessitating that extra length be allowed on some (or perhaps all) of the lams at both ends. See Fig. 8.3.1*2.

For Variable Pitch blades with circular root sections, a similar datum will be required although in not quite the same form. It is frequently more appropriate that the root datum of Variable Pitch blades should be tooling holes in each end of the block to specify the position of the centre of the circular root and as a tip datum. These tooling holes can be used for the lathe setting when turning the root end. See Fig. 8.1*3.

Because wood has a unidirectional feature in that its strength depends on its grain direction it is, of course, most important that this is taken into account when designing the lams and the block lay-out.



Note: Internal butt joints should preferably be confined entirely within the aerofoil section.

Fig. 8.3.1*1

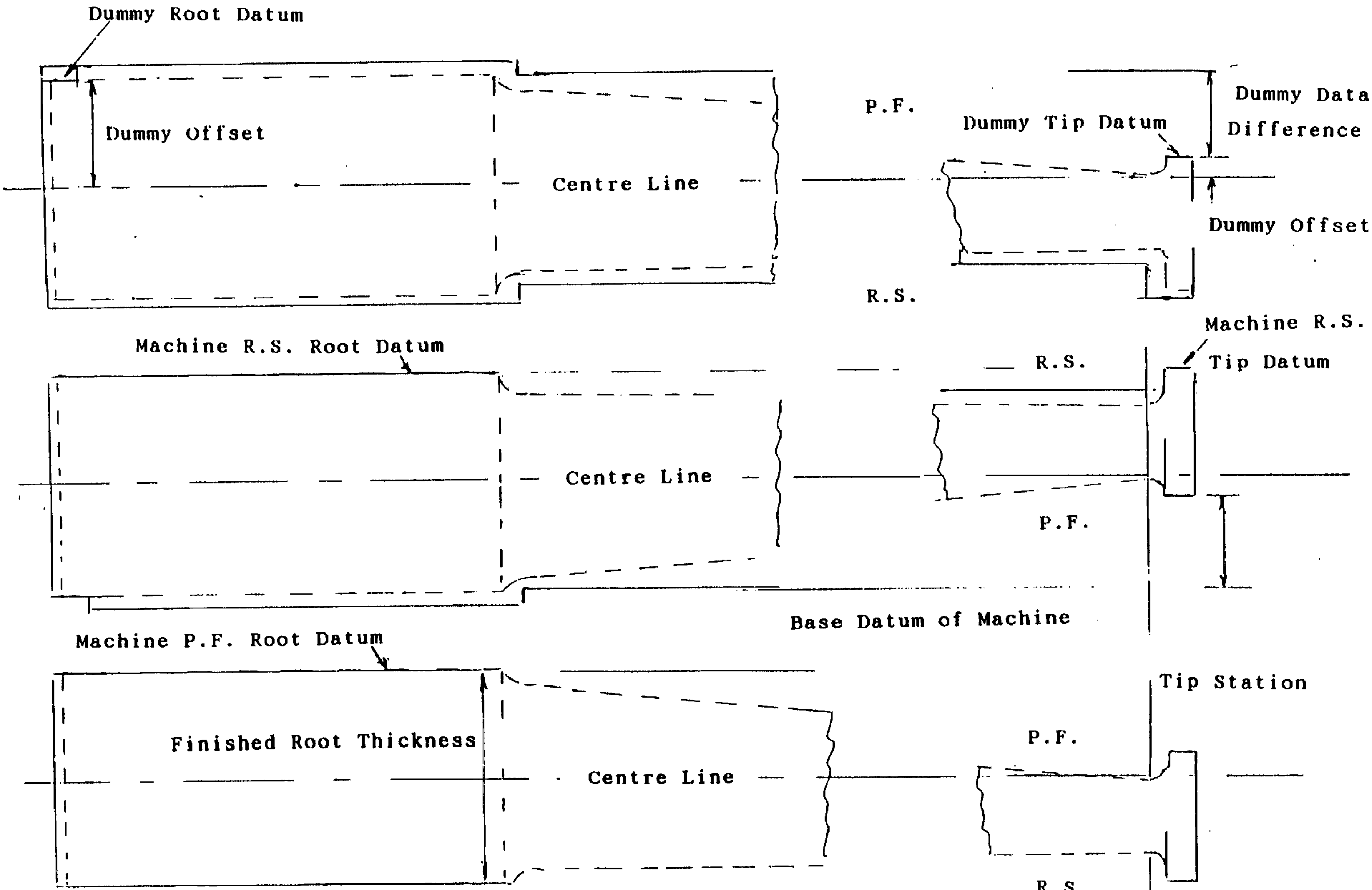


Fig. 8.3.1*2 Machining Sequence for Root Block

Nominally the grain of the lams and block has to be along the blade radial axis to take advantage of the tensile strength of the timber, but in practice there can be some slight variation to this requirement. It can be shown by tests that the tensile strength of timber is approximately as shown in Fig. 8.3.1*3 and that little loss of tensile strength is found if the grain direction is not greater than say 10° or 11° from the direction of the load. The grain direction can therefore be along the centre of a lam provided that this is less than 10° from the radial axis of the blade. Also it is sometimes possible for alternate lams to have the grain direction staggered by up to 10° on each side of the radial axis. During the block design stage the lam axis/grain direction must be decided for each lam.

This system of staggered grain direction also has the advantage that where lams are produced with side by side gluing of narrow strips, these glue lines are then at a significant angle to the similar joint on the adjacent lams and can never be directly over or along adjacent joints.

The complete lam plan form profile can be assembled from the details at each radial station and the requirements for the root and tip blocks. This information is then eventually required to be presented as a full scale lam pattern or template for use by the manufacturing department.

During the gluing process it will be essential that the correct lam positions relative to each other be maintained and to stop any sliding on the wet glue before pressure is applied. This is normally done by having adjacent lams dowelled together, the dowel positions being in the surplus lam areas that are outside the finished blade so that the dowels are cut away during the shaping stage and not left in the final blades. It is, therefore a requirement during the preparation of the lam patterns to specify these dowel positions with adequate tolerances to ensure that the dowels do come outside the final blade. See Fig8.3.1*4.

One reference dowel should always be specified for all lams on the lam axis near the inboard end of the lam and just inboard of the final root end station.

During the lam pattern design and preparation, frequently by drawing office personnel, it is important that the block datum references and grain direction are included on each pattern. The blade (& block) axis should be included and each blade radial station marked. A sample of a typical lam pattern is shown in Fig. 8.3.1*5.

For a limited production, e.g. in the case of one fan requiring a small number of blades, it is appropriate to have these lam patterns made from thick drafting paper, but in the (rare) cases where a medium or large number of the same blades are to be manufactured it is preferable to have lam patterns made from a more durable material such as commercial hardboard or other similar material.

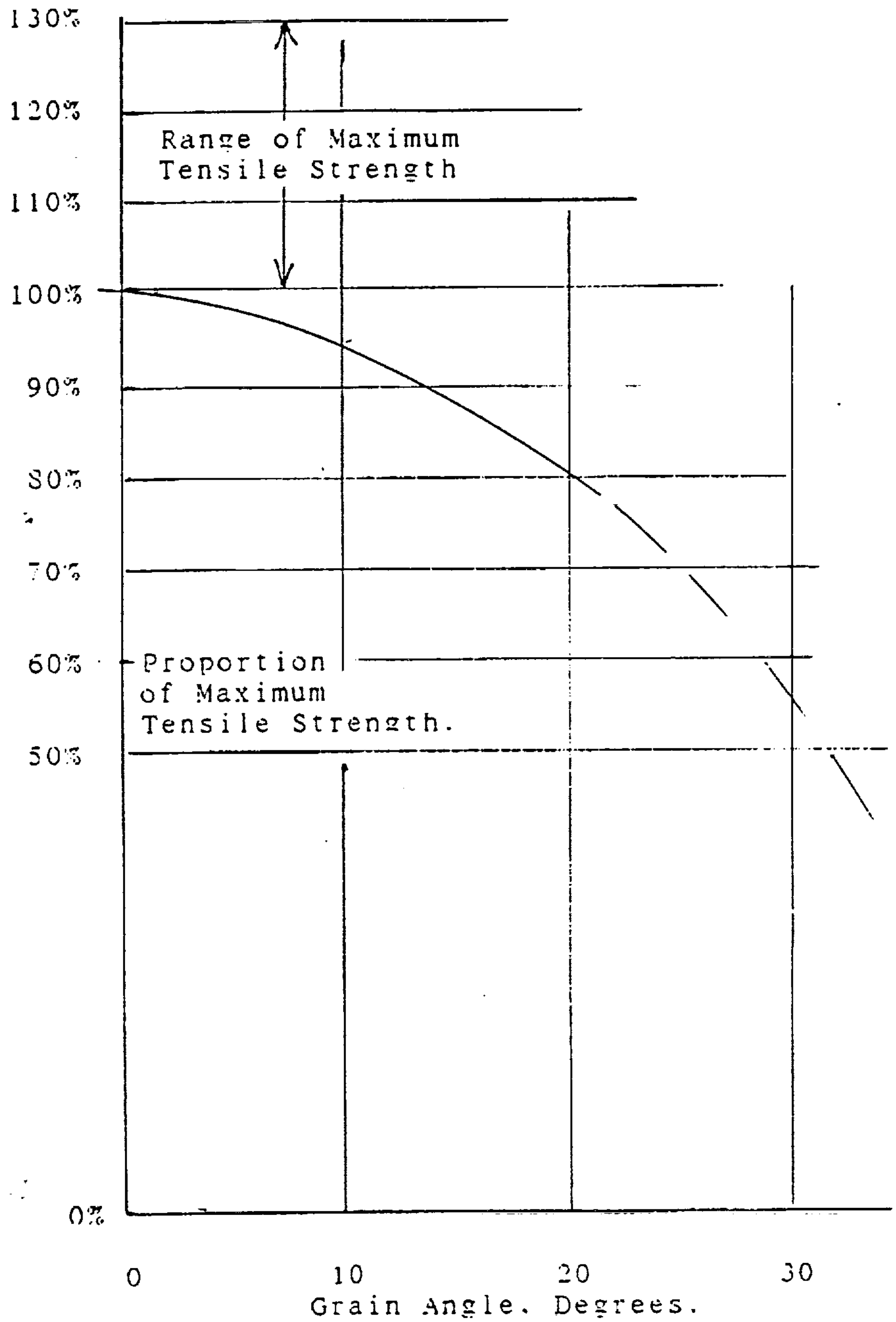
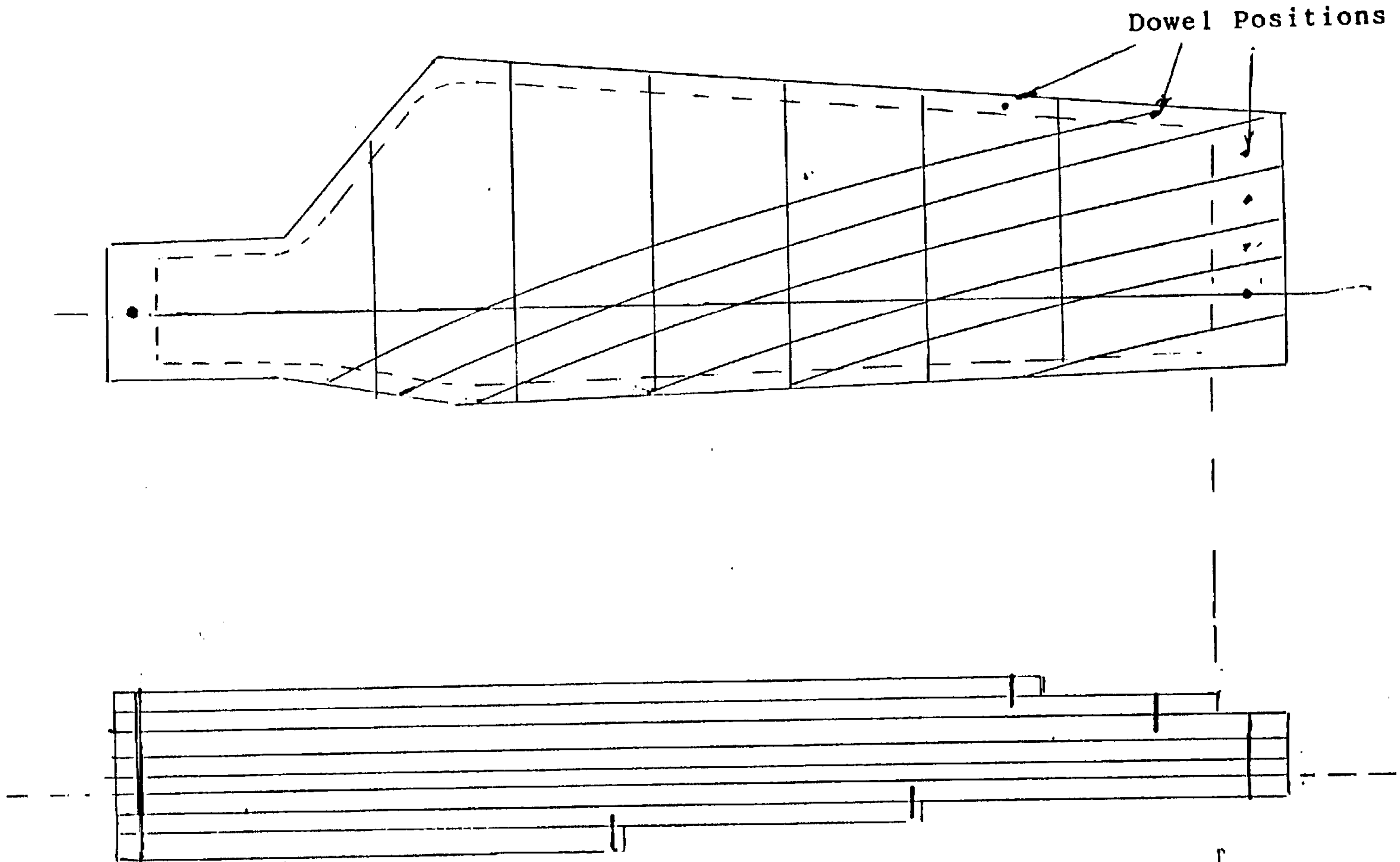
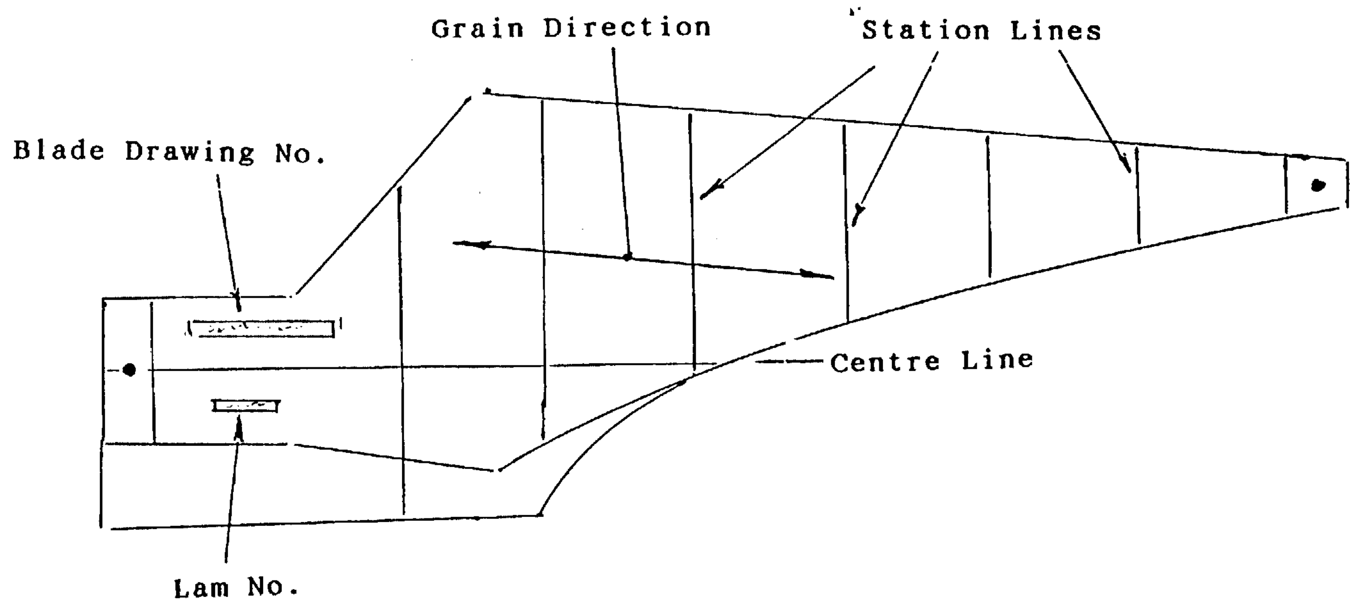

130%
120%
110%
100%
90%
80%
70%
60%
50%
0%
Range of Maximum
Tensile Strength
Proportion
of Maximum
Tensile Strength.
0
10
20
30
Grain Angle. Degrees.

Fig. 8.3.1*3



Part Block showing Dowel Positions

Fig. 8.3.1*4



Typical Lam Pattern

Fig. 8.3.1*5

8.3.2 Manufacturing Design Considerations for Root Design

The fundamental Root type is decided with reference to the type of Hub into which the blade has to be fitted or attached.

8.3.2.1 Rectangular Roots

For hubs consisting of two root plates or discs the blade root then has a Rectangular Root form, either a plain bolt type or a root re-inforced with bonded root plates.

The Manufacturing Design considerstion required for the plain bolt type root depends mainly on the required size of such a root block.

Consideration has to be given firstly to the layout of the lams. This does not cause problems for small or medium blades where the lam width will be limited but for large blades it may be necessary to make some arrangement for the manufacture of extra wide lams. Consideration has also to be given to specifying the required manufacturing data points on the glued block. Details of this are given in Section 8.3.1.

For Bonded Root Plate type roots, the size of the Root Plate is not a manufacturing design consideration but must be dealt with as a stressing problem. As with plain bolt type roots consideration has to be given to specifying the required manufacturing data points, possible alternatives being special machined areas of these blocks or direct on the face of the bonded plate. Details of the design requirements for this type are given in Section 7.3.2.1.

8.3.2.2 Circular Roots

A blade that requires a circular root with a fitted adaptor will then require a compressed wood root so that the lam material will need consideration.

It is not very usual for small blades to be of this type, but if so then the whole length of lam would be of compressed wood.

For medium and large blades it will nearly always require that the extreme root area be of compressed wood with the outer portion of the blade of a softwood such as spruce. Although the design of the transition zone is partly controlled by the stressing requirements of the blade, the manufacturing design involves the details of each lam design and in particular the positioning of the scarf joint.

Roots for screw type adaptors need the details of the threads, both internal of the adaptor and external of the compressed wood root to be specified. Such design considerstions are dealt with in Sections 7.3.2.2. and 7.3.2.3.

Details for plain bolt type adaptors are given in Section 7.3.2.4.

8.3.3 Manufacturing Design for Shaping

In the past there were a number of features that had to be specified and incorporated into the Workshop Drawing (Ref:13.2.41) at the Manufacturing Design stage depending on the method that would be required for shaping the blade.

For small and medium blades where the only practical method was virtually complete hand shaping, the main requirement was to define the necessary tooling components, consisting of the section templates, the back pattern and the drop pattern.

The start of the process was to have drawn out the aerofoil sections at each blade station with reference to the main block axes taking into account the requirements for the Track and Sweep. From theses section drawings the required back pattern (Ref:13.2.4) and drop pattern (Ref:13.2.17) dimensions can be obtained.

For medium and large blades, when a degree of preliminary machine shaping was considered appropriate, the same approach as above was necessary, but also required would be a following model to be used on the copying machine. This model was in one of two forms. It might have been an actual blade (usually from the first block to be processed, hand shaped to the appropriate oversized dimensions). The hand shaping process would have required a suitable oversized back pattern and possibly a similar drop pattern with corresponding oversized section templates.

(Practical Note: Oversized back and drop patterns could have been made from correct sized versions with temporary additions to give the oversize required)

Alternatively, depending on the number of blades required for a particular order, it may have been economically appropriate to produce special machine models for fitment to the shaping machine that would be used . Such models would have to be dimensionally correct (or identical with) a finished blade, but not, of course, to the same structural standard so could be made from distinct components assembled to represent the desired shape.

An important requirement, necessary for the shaping process, at the Manufacturing Design stage is that the data positions are clearly defined.

8.3.3.1 Future Possibilities

It is extremely difficult to predict possibilities for shaping at an unknown future date.

At the date of this Report (mid 1990's) computer controlled machines were available that could have been brought into use. Such machines were capable of being programmed to cut the required shapes for windtunnel fan blades but had not been used for such purpose. It is not known what practical difficulties may have arisen particularly with the fine details such as producing the small section at the T.E. with the complication that the material to be cut has the one directional grain characteristic which could lead to unwelcome splitting.

8.3.4 Covering - Manufacturing Design Requirements

The details required for the Covering System have to be considered during the Manufacturing Design stage.

The first decision to be considered is whether the blade needs or requires a simple coating or a full cover.

For a simple coating system the details of the resin and or paint will need to be specified. See Sections 9.5/9.5.2.2. for typical materials.

(Practical Note: The availability of any particular resin or paint maybe an influence on the final decision of what is - or can be -specified.)

For a full cover system (i.e. usually a glass cloth / resin laminate system) the availability of a particular glass cloth has to be considered. Not only the exact type of cloth but also the finish standard of the glass has to be considered and specified.

Although it will be most likely that epoxy resin will be chosen, it is important that the exact formulation to be used is specified. Typical materials that have been used successfully for previous designs are given in Section 6.2.5.2.

(Practical Note for future designs: If the exact resins previously used are not available - what ever the reasons - it will be advisable to consult with the likely suppliers for alternative types and consider what testing needs to be carried out to ensure that any alternative suggested will give equivalent results to previous used resins.)

The details of the glass cloth layout needs to be specified. See Section 9.5.3. and Figs. 9.5.3.2*1 through to 9.5.3.2*9 for an example of the stages of a typical layout procedure.

Eventually at the conclusion of the Manufacturing Design procedure all these details will need to be included in the appropriate part or sheet of the Workshop Drawing.

8.3.5 Balance Adjustment

The method of Balance Adjustment has to be decided at the Manufacturing Design stage and the details incorporated in the Workshop Drawing.

8.3.5.1 Integral Fans

Apart from the use of the shaping tolerances it is usually only necessary to adjust balance by the application of extra coats of resin or paint at the finishing stage and in these cases it is not required to make special reference to this method on the appropriate drawing. (See Sections 9.6.1. and 9.6.2.)

8.3.5.2 Medium Blades

These can usually have balance adjustment made in a similar manner to integral fans by the use of the shaping tolerances and the application of extra coats of paint or finishing resin.

If necessary extra balance adjustment can be made in similar manners as for large blades.

8.3.5.3 Large Detachable Blades

It is frequently (nearly always) necessary to make special arrangements to be able to add weight(s) to the blade. The root block size of fixed pitch blades with rectangular roots can be specified to be between a minimum size for strength and attachment purposes to a maximum size that allows extra weight for increase of balance moment if required. It is also necessary to have some control on the weight of the aerodynamic part of the blade by shaping between normal limits. These means may not give enough tolerance and it may be appropriate to consider the need for adding weight(s) at appropriate places.

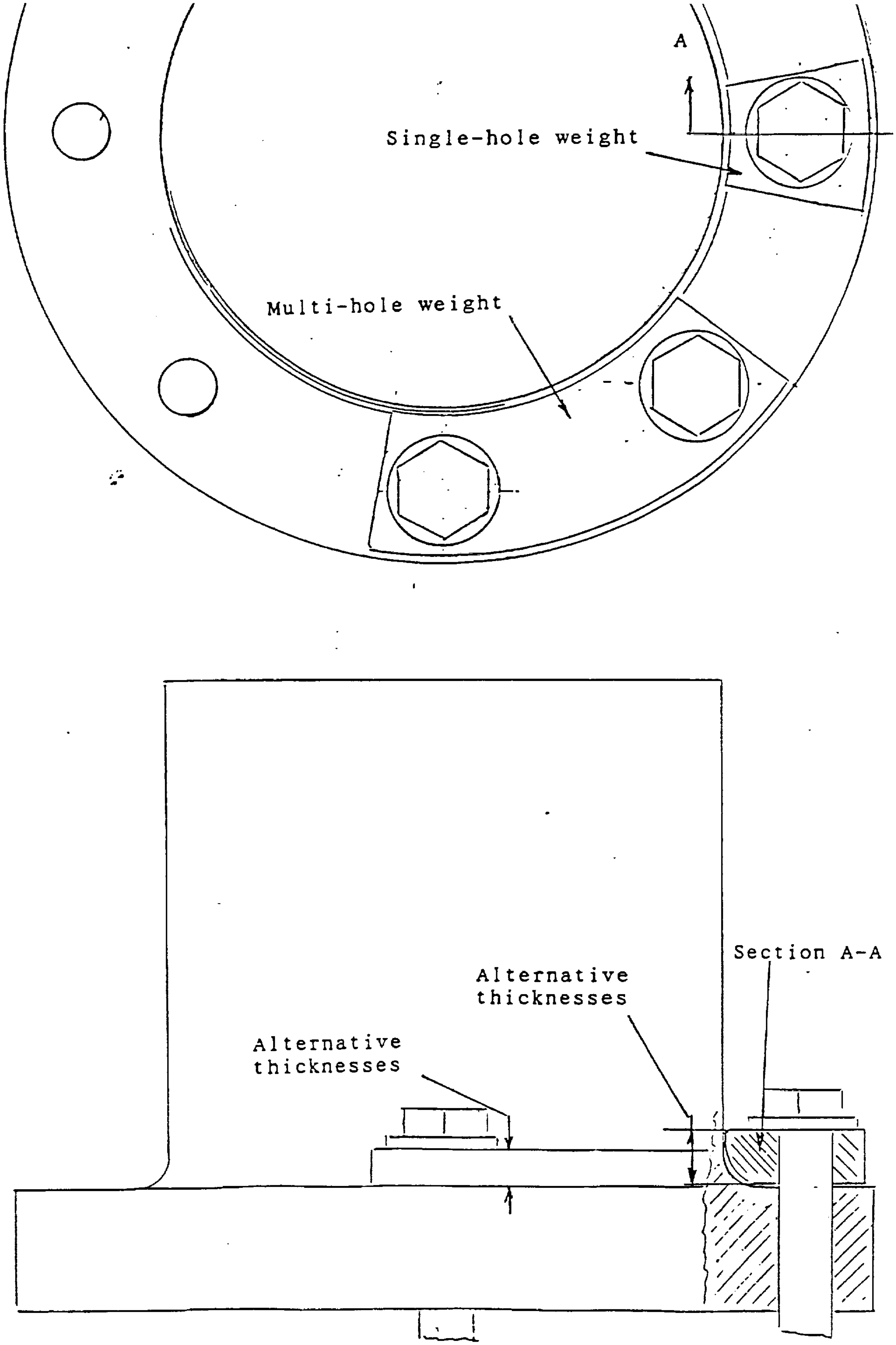
Large detachable variable pitch blades with circular roots do not lend themselves to weight adjustment at the root by size variation so it is necessary to make provision to be able to add metal weight(s) at some places. How and where such weights may or can be added depends on the type and size of the (metal) adaptor or root fitting. A typical solution is to consider adding weights to the fan hub rather than the blade itself as it is normally easy to retain metal weights to a metal hub unit by mechanical means such as bolts or welding. For blades with flanged adaptors it is possible to add weights under the retention bolt heads.

These weights can be of various thickness and/or length to be held by one or more retention bolts. A typical arrangement is shown in Fig. 8.3.5.3*1. More details of the balance adjustment for the Ames blades are shown on the Balance Data Sheets 9.6.3*6 and 9.6.3*7.

Alternative means of retaining metal balance weights to the adaptor can be considered depending on the detailed design of such adaptors. Care must be taken that any fixing is capable of withstanding the (possibly high) centrifugal forces likely to be experienced in operation.

If balance weight adjustment beyond that available by extra paint or resin at the covering stage is required at the tip end of a blade, this can be achieved by the insertion of a metal "plug" into a suitable cavity. These "plugs" can be formed by packing lead wool into the cavity or by the use of a Low Melting Point alloy (Ref:13.1.19) poured in whilst liquid and allowed to solidify.

In either case such metal plugs will require to be retained, mainly against centrifugal loading, by an extra wood plug glued into the end of the cavity. Care must be taken that the retaining wood plug is long enough to give an adequate gluing area so that the glue line stress is low (normally less than 100 lbs./sq. in.) See Fig. 8.3.5.3*2.



Balance Weights for Flanged Adaptor

Fig. 8.3.5.3*1

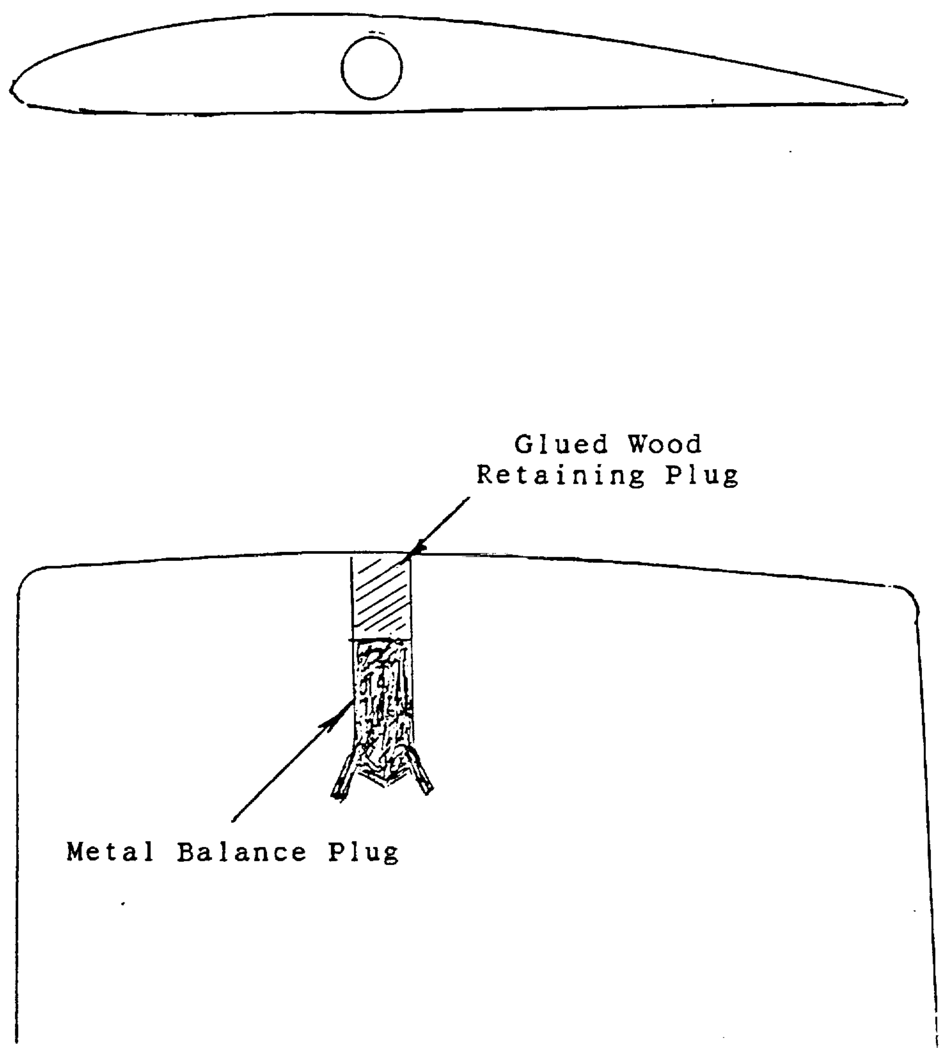


Fig. 8.3.5.3*2

Section 9: Manufacturing Techniques

Index

9. Manufacturing Techniques

- 9.1 General Gluing Techniques
  - 9.1.1 Assembly Shop Conditions
  - 9.1.2 Surface Preparation
  - 9.1.3 Materials and Mixing
  - 9.1.4 Assembly
  - 9.1.5 Scarf Gluing
  - 9.1.6 Glue Press Design
- 9.2 Lam Production
  - 9.2.1 Edge Gluing
  - 9.2.2 Scarf Preparation and Gluing
  - 9.2.3 Lam Preparation for 4 Blade Fans
  - 9.2.4 Profile Cutting
  - 9.2.5 Lam Balancing
- 9.3 Block Manufacture
  - 9.3.1 Dry Block Assembly
  - 9.3.2 Block Gluing
  - 9.3.3 Summary of Process
  - 9.3.4 Block Maturing
- 9.4 Shaping
  - 9.4.1 Original Techniques.(Small Blades)
  - 9.4.2 Medium and Large Blade Shaping Techniques
  - 9.4.3 Datum Considerations for Large Blades
- 9.5 Covering
  - 9.5.1 Historical Background Notes
  - 9.5.2 Covering Systems
  - 9.5.3 Glass Cloth Application Sequence

9.6 Balancing

9.6.1 Integral Blades
9.6.2 Detachable Blades
9.6.3 Balance Measurement Methods

9.7 Inspection (Work Shop)

9.8 Inspection (Acceptance)

9.9 Packing and Transport

9.10 Installation

9. Manufacturing Techniques

This Section gives details of how the manufacturing techniques have, in the past, been carried out and, in some instants, give a few suggestions as to future possibilities.

Many of the operations do not lend themselves to being performed by automatic machinery and merely require hand working possibly with power tools. For the cases where large automatic machinery might be used, it is not possible to foresee every eventuallity in the development of (such) machine tools, particularly computer controlled machines but it is almost certain that the large capital expense of such future machines will be too great to be employed by some contractors interested in the limited amount of windtunnel fan blade production needed. Consequently this production will most likely be confined to what, in the future, will appear to be "primitive" techniques.

This Report is primarily a record of past established techniques so will not give much detail of many (or any) of possible hi- tech developments that may occur in the distant future.

9.1 General Gluing Techniques

This Section is based on the techniques required for the use of resin glue consisting of a basic liquid resin and a chemical hardener (either powder or liquid) that can be water soluble before glue setting, such as Aerodux 185 (Ref:13.1.3)

Data Sheets for this glue are given in Appendix G.

The exact temperatures and times quoted may need to be varied depending on the particular glue material to be used after reference to the manufacturer's data sheet involved.

9.1.1 Assembly Shop Conditions

Gluing should be carried out in a draught free area, free from dust, fumes, dirt or any other condition which may be harmful to gluing. The temperature of the assembly shop should at all times during gluing be between the limits of 20^{o} C (68^{o} F) and 28^{o} C (82^{o} F) which should give a pot life of 2-3 hours.

9.1.2. Surface Preparation

Surfaces for gluing must be clean, flat and scarified. Platen finished compressed wood material must be skimmed and scarified over the whole area to be bonded. Surfaces must be free of oil, grease, dirt dust or other foreign matter.

9.1.3. Materials and Mixing

Measure out into seperate containers enough basic resin and the corresponding hardener that when mixed is sufficient for say 10 minutes working time. For block gluing the amount of each and the number of mixings required depends on the size and number of lams in the block.

Retain these measured amounts of the two types of material until the wood components are ready for the glue application. When actual gluing is ready to start, mix a pair of glue sets together and thoroughly stir until a uniform consistency is achieved.

9.1.4 Assembly

Apply a coat of the glue mix evenly at the rate of 3/4 oz./sq. ft. When large areas of an impermeable nature are to be bonded it is important to allow sufficient open assembly time, up to a maximum of 5 minutes.

Particular attention should be paid to glue pot life and assembly time to avoid skinning before application of pressure. Glue near the end of its pot life should not be used at the start of an assembly of a large number of components. The joints should be assembled and pressure finally applied within one hour at a temperature of 21° C or within 30 minutes at 25° C.

(Immediately after the actual gluing process there will be the requirement to dispose of any wet glue and clean up the equipment. Surplus glue should be poured into a special container that may eventually be collected by a suitable waste disposal organisation or company. Other equipment should be washed with water to be free of any glue residue. Contaminated water should be disposed of in a similar manner to surplus glue.)

9.1.5 Scarf Gluing

9.1.5.1

The general conditions and techniques have to be similar to that described in Sections 9.1.1 to 9.1.4.

9.1.5.2 Scarf Preparation

Details of this are described in Section 9.2.2.

9.1.5.3 Special Scarf Glue Press

See Section 9.1.6.3.

9.1.5.4 Testing

It is always essential that evey scarf joint be tested to verify that the process has been carried out correctly and that the resultant glue joint is capable of satisfactory service. At the scarf preparation stage (see Section 9.2.2) sufficient width of material must be allowed so that a suitable Test Piece, such as shown in Fig. 9.1.5.4*1 may be prepared.

After the appropriate curing time for the glue joint this test piece must be cut from the assembly and tested in a suitable tensile testing machine. The main criterion to be met is that the test piece should fail in tension and that the glue joint does not fail in shear. Any joint that does not meet this standard should either be rejected (or re-worked if a further test piece is possible.)

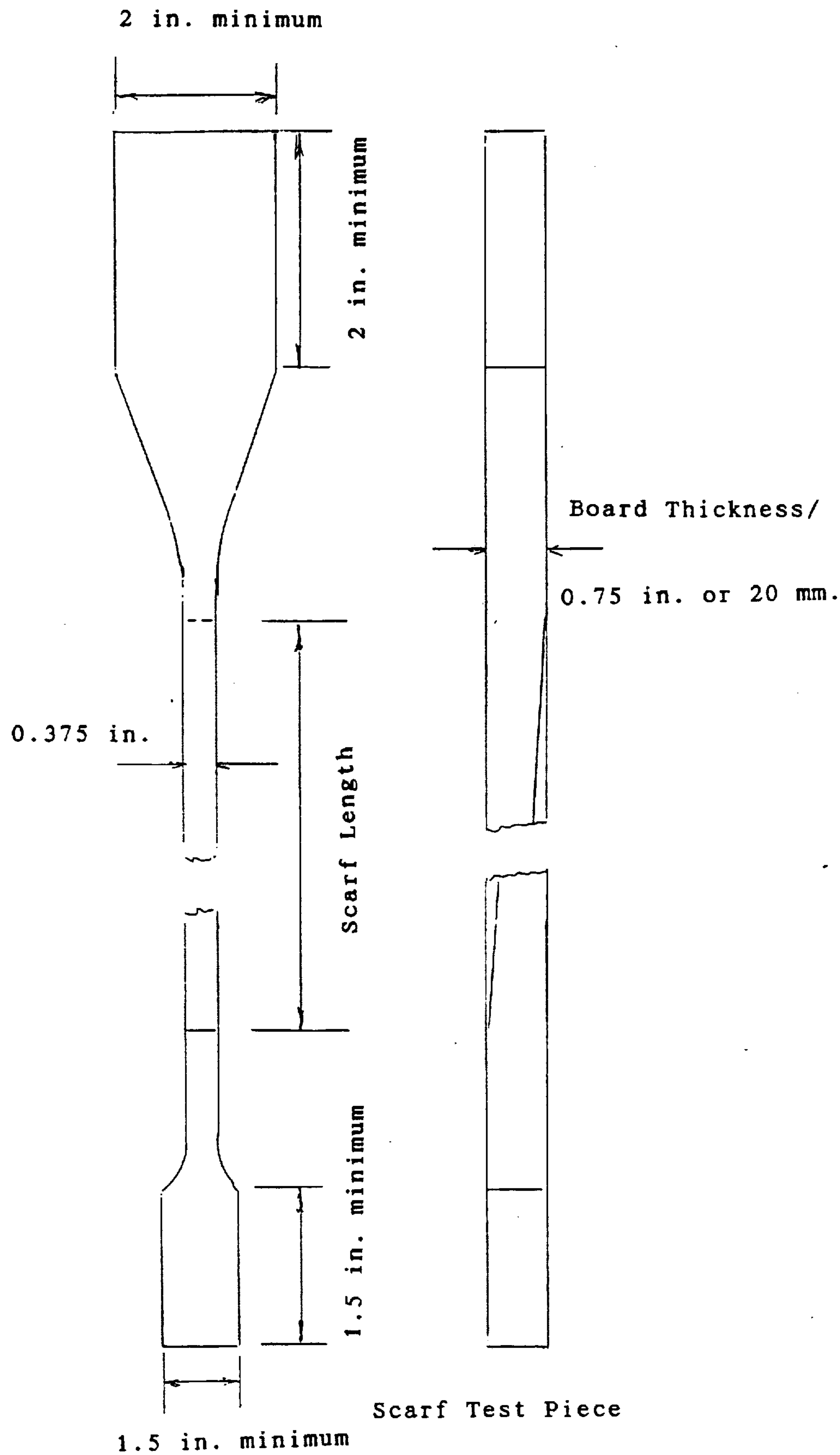
9.1.6 Glue Press Design

9.1.6.1 Main Block Glue Press

The gluing process requires that the components to be glued are firmly held together for a number of hours while the glue sets. For block manufacture where a number of lams are to be glued together this then requires equipment by which suitable pressure can be applied to the components in the relatively short time that is available before the glue starts to set.

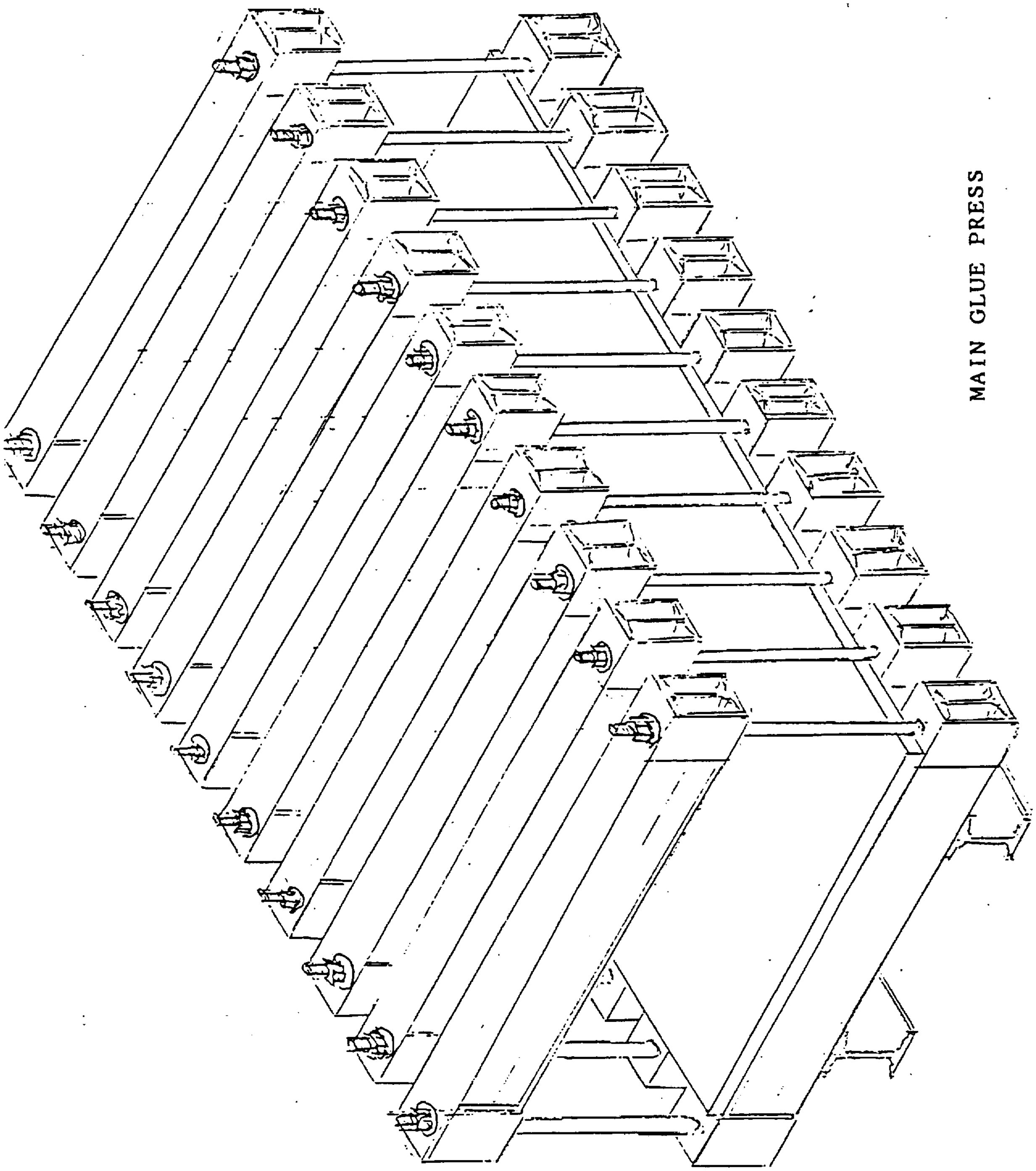
The design of such equipment is based upon the (arbitary) value for the appropriate gluing pressure. It has been established that the average pressure should be of the order of 50 lbs./sq. in. and that this pressure should be uniform over the entire block. A convential glue press (or glue stool) consists of a very firm base, on to which the block or compenents may be placed, with side bolts placed along the length of such a base so that individual strechers may be fitted across the block and pressure applied by tightening of the nuts on the side bolts. (See Fig. 9.1.6.1*1)

The design of a suitable block glue press requires that the maximum size of blade for which it is needed, must first be established.



Scarf Test Piece

Fig. 9.1.5.4*1



MAIN GLUE PRESS

Fig. 9.1.6.1*1

For small 2 blade integral fans or even up to medium sized detachable blades, the main consideration is the maximum length although normally a glue press for this type of blade would lend itself to be readily extendable to any length by the addition of extra parts.

For large detachable blades, the basic design requirement of the glue press does not depend on the length (although the cost of manufacture does) but on the width. This width requirement is of course, a function of the maximum chord of the blade. Up to the 1980's the maximum chord of any windtunnel blade has rarely exceeded about 48 in. so that it has only been found necessary to design a glue press for a block width of some 50 in.

It should be noted that the design calculations are not an exact science but should give an overall assessment of suitable sized components which need to be considered.

The main problem to be solved or decided with such a design is the size of the top stretchers. The pressure to be applied by these stretchers is 50x50 lbs/in. (length along the press) and this 2500 lbs/in. load has to be applied by the two end bolts or 1250 lbs. per in. spacing of the stretchers.

The compromise has to be made between having the bolt spacing as close as possible to be able to keep the applied load "low" or having a minimum number of bolts and nuts to be tightened during use. It has been found that for a large glue press a bolt spacing of approximately 10 in. is a reasonable compromise.

Assuming this requirement the bolt load becomes 12,500 lbs. per bolt which can be applied by a steel bolt of say 2 1/2 in. diameter which then leads to a stretcher width of somewhere between 5 and 10 in.

The important consideration for the design of the stretcher is the stiffness rather than the strength, The stretcher being a simple beam, although loaded at each end will have a deflection at the centre based on a beam uniformly loaded if the pressure is to be applied uniformly across the press and this deflection must be restricted to a value consistent with the required glue line thickness.

Although in practice the loads applied by the stretchers are spread by intermediate boards and package, it is still desirable that the stiffness of the strectchers are such that, theoretically at least, they conform to this principle.

The final glue line should not be greater than approximately 0.006 to 0.007 in. thick and the stiffness of the stretchers should conform to this requirement.

A steel beam 50 in. long with an applied load of 25,000 lbs. restricted to a central deflection of 0.007 in. will then need a Moment of Inertia value of approximately 200 in ^{*4}.

A standard "I" beam, 10 in. deep by 7 in. wide has an M. of I.= 220 in*4 so that this size of beam is suitable for the basic stretcher. Another equally important practical requirement is that the stretcher should be readily handled by two men and this sized of "I" beam at 50 lbs/ft. give a weight of stretcher at 200 lbs. just within the limit.

For practical reasons each end has to be drilled to take a 2 1/2 in. diameter bolt so that at the ends, the web of the beam being drilled away it can be replaced by two side plates welded on to the flanges.

For symmetry the base should also contain identical cross beams to those at the top which will be under a suitable flat plate. The final design then becomes as shown in Fig. 9.1.6.1*1.

Length wise stability of the press can be achieved by fixing the lower stretchers to two longitudinal beams, preferably bolted to a solid floor.

The side bolts at 2.5 in. diameter for a load of 12,500 lbs. give a working tensile stress of approximately 2550 lbs./sq.in. which is acceptable for mild steel bolts. The bolt length will need to be sufficient to cover the depth of the proposed block plus both top and bottom strechers with space to spare for nuts at each end. A reasonable bolt length is then approximately 60 in. which means that these bolts would weigh some 80 lbs. so it is not practical to have these portable and they have to become a fixed part of the glue press. (See Fig. 9.1.6.1*3)

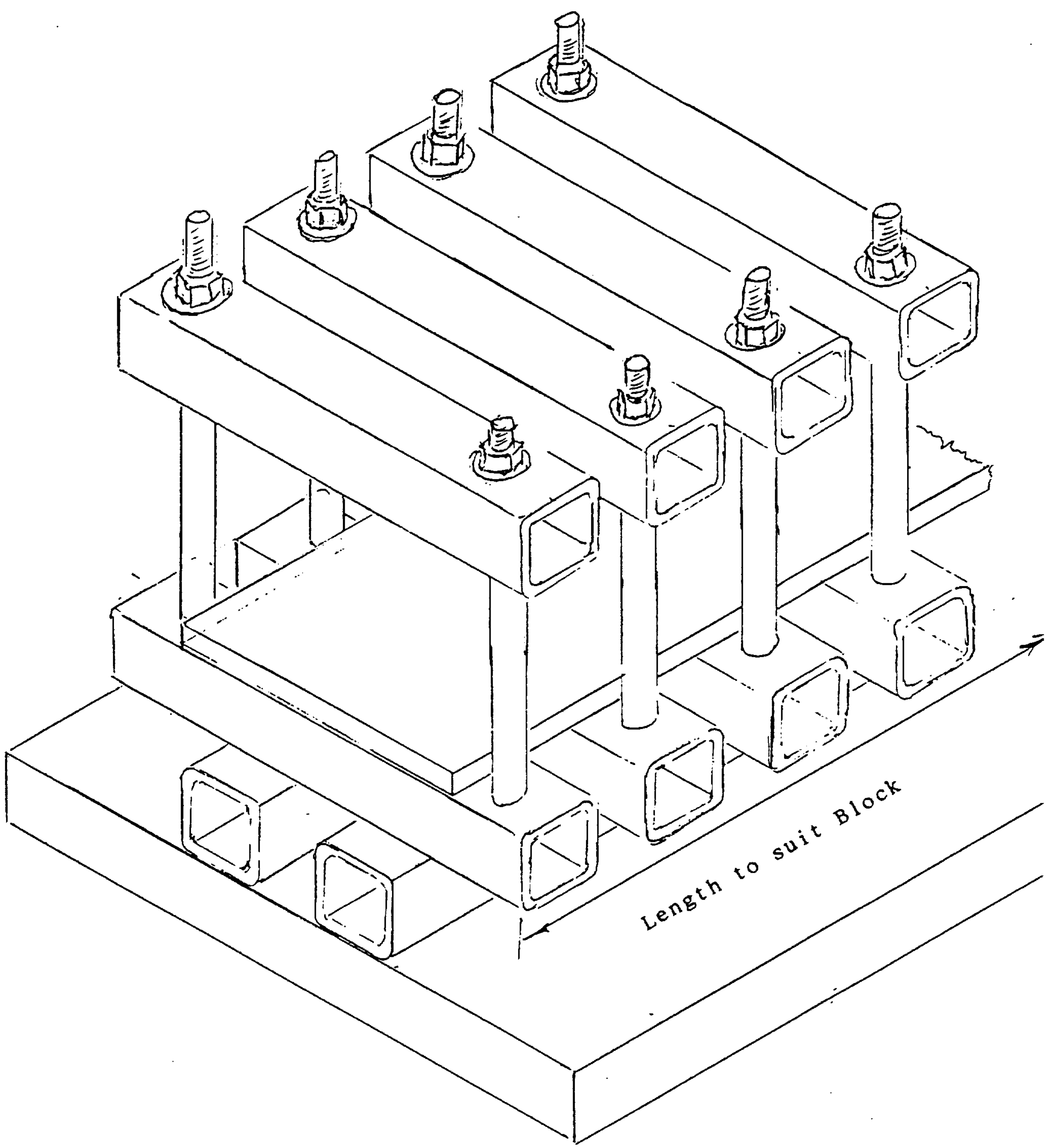
9.1.6.2 Small Glue Press

A similar analysis for a smaller glue press suitable for small and medium blades would assume that the maximum chord to be accommodated would be say 15 in. with the press catering for a maximum block width of 16 in. This analysis could lead to a square box beam of say 4 in. weighing approximately 11 lbs. with side bolts of 1.5 in. diameter spaced at 7 in. Alternatively for such small glue presses it may be more convenient to have solid cast stretchers.

For 4 blade integral fans a special press is required that not only caters for 2 through blades but also can accommadate the two "side" blades. A similar analysis as for the upper stretchers above is required but the base needs to consist of a solid plate of sufficient size to cover all 4 blades which could be supported on benches arranged in a cross.

9.1.6.3 Scarf Glue Press

A scarf joint at the root end of a lam between compressed wood and natural wood needs to have a slope of 15 to 1, therefore the joint itself in a 3/4 in. or 20 mm. thick lam will be approximately 12 in. long. If the need arises that a special glue



SMALL GLUE PRESS

Fig. 9.1.6.2*1

press for this operation will be required, it would then only need to have two stretchers of say 5 in. wide. The maximum width of lam likely to be required at this station will be (for practical purposes) less than 24 in. so a glue press with a practical width of 30 in. should be capable of catering with this size of lam. To apply a load of 50 lbs./sq.in. over an area of 30 in. wide by 7 in. long or a total of 4200 lbs. a 5 in. wide stretcher would need to be of minimum depth to have a suitable stiffness. The actual minimum depth of a standard "I" beam is 8 in. with a stiffness that would give a deflection in the order of 0.0001 in. for such loading.

These considerations then lead to a design as shown in Fig. 9.1.6.3*1.

9.2 Lam Production

9.2.1 Edge Gluing

Because lams are frequently wider than available timber stock (nearly always in the case of Stika Spruce) it is usually necessary to produce wide boards by edge gluing narrow stock side by side to achieve this required width. The raw stock as purchased normally has a sawn finish which will be too rough for gluing. These stock strips are first planed on one face to give a true surface and then planed on the opposite face to give maximum thickness. Each edge has to be planed square to the faces to produce a strip with a truly rectangular section. At this stage it is possible to inspect each strip for quality (see Section 6.2.2.) If any unacceptable defect is found the strip may either be discarded (if the defect is "large") or the strip reduced in width to remove the defect. An alternative might be to repair the defect in the strip by a technique as described in Section 10.

The length of a number of strips are selected so that when side by side they conform to the overall size of a particular lam. These strips then have to be glued together. Sash clamps spread approximately 12 in. apart are laid on a bench with the jaws uppermost. Mixed glue is applied to the appropriate edges and the strips laid on to the clamps and light pressure applied. Further clamps are placed over the strips and similar pressure applied. A check should then be made to ensure that the strips are not offset to each other and that there is uniform thickness to the lam board. Maximum pressure should then be applied by means of the clamps. At this stage it will be found that surplus glue will tend to squeeze from the joints over the face of the lam board. It is advisable that this surplus glue be wiped away with a damp (not wet) cloth before the glue has set. These assemblies should be left under pressure for the appropriate glue setting time (normally over-night) before removing the clamps.

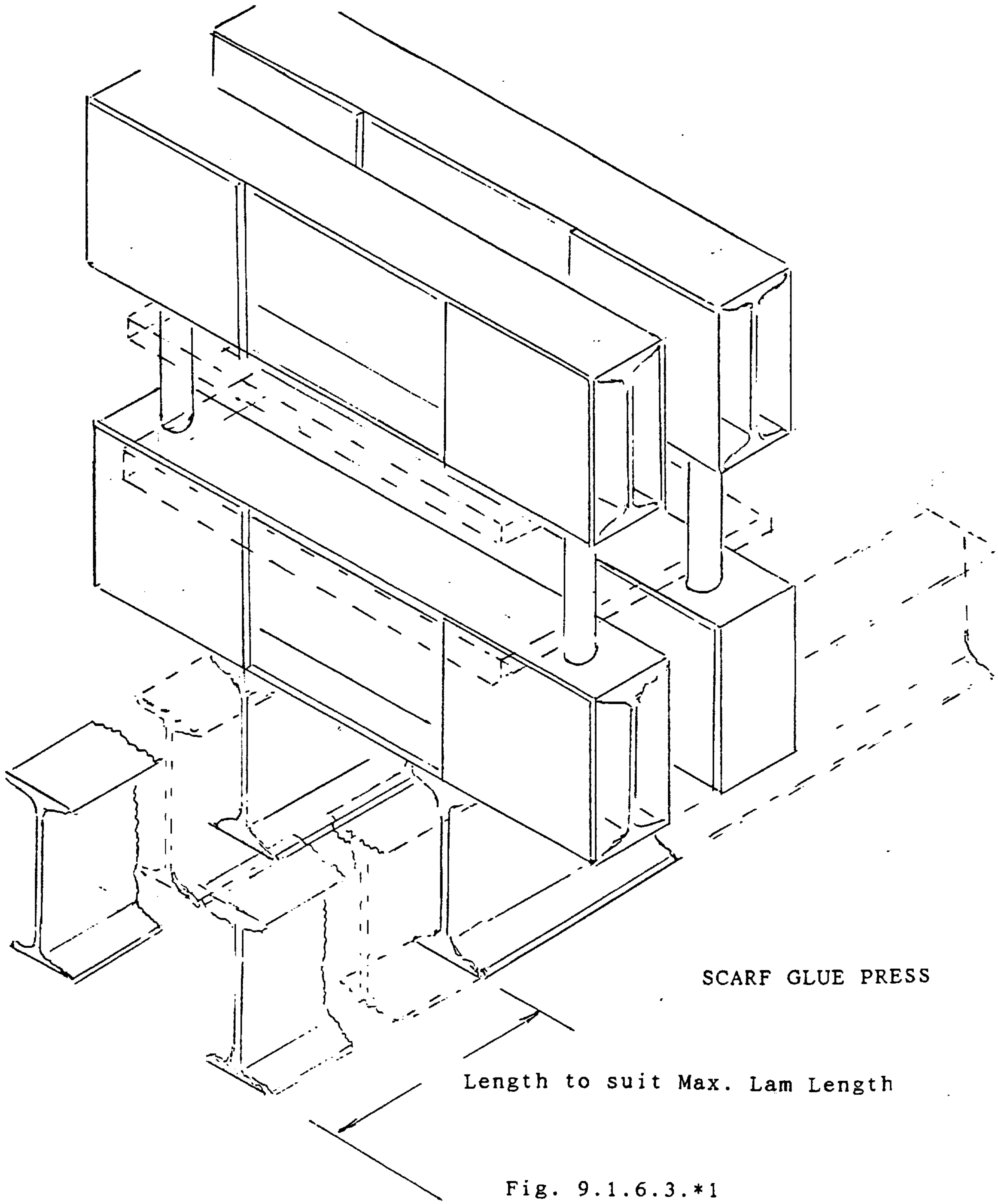


Fig. 9.1.6.3.*1

9.2.2 Scarf Preparation and Gluing

For medium and large blades that have a compressed wood root,some if not all lams will need to be produced by having a compressed wood portion scarf jointed to an outer natural wood portion. Depending on the actual size of an individual lam this should be achieved allowing for sufficient material from which the Test piece may be prepared before the lam has been profiled to final size or shape. It has been established that scarf joints for this purpose have to have a slope of 15 to 1 so that the length of a scarf in a lam prior to final thicknessing would be some 12 to 15 in. long.

The actual method of producing such scarves will depend of course on the machine tool available to the manufacturer. A typical method using an articulated arm router would be to have a suitably tapered block or stand mounted on the machine table so that the board or lam to be processed may be clamped to it. The router cutter can then be passed over the component to produce the required scarf. (See Fig. 9.2.2*1)

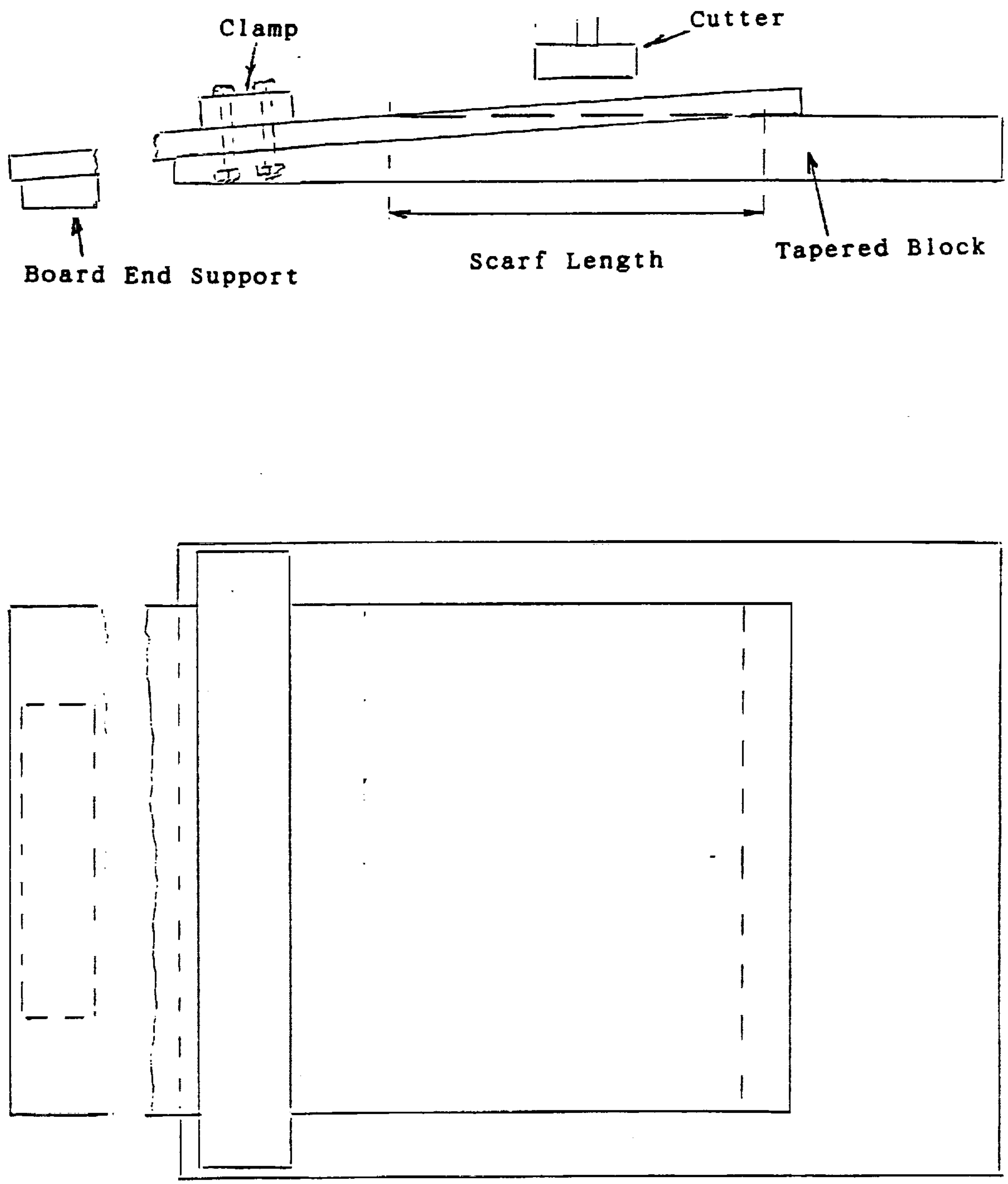
The two parts of the assembly, root end compressed wood and main portion, are then positioned and clamped together dry and two dowel holes drilled at one edge so that dowels may be inserted at the gluing stage to hold the two parts in the correct relationship. Although it is preferable for a special scarf glue press to be used for the gluing process, it may be necessary for manufacturing and commercial reasons to use a main glue press (See Section 9.1.6.1.)

It is always essential to have a surplus allowance of material on the side of a scarf joint from which a tensile test piece may be prepared and tested. (See details in Section 9.1.5.4.) The result from such a test should be that a failure occurs in the material and not in the glue joint itself, otherwise the scarf joint assembly should be rejected.

9.2.3 Lam Preparation for 4 Blade Fans

Lam preparation for 4 blade fans is similar to that for simple 2blade fans except for the boss region where the 2 pairs of blades cross over and the lams need to be half jointed to give a 4 blade lam. It is not appropriate for the half joint edges to be positioned so that these edges on adjacent lams are directly in line. A lam "centre line" should be established on each lam running between the mid chord points at the tip chords on opposite ends of a lam through the centre of the fan. These centre lines on adjacent lams are then at a small angle to each other. The true radial axis of each blade will be approximately at the mid point of this group of lines. See Fig. 9.2.3*1 and Fig. 9.2.3*2.

The half lap joints then have to be cut at right angles to these lam centre lines, the width of the half laps being determined from the profile of the lam running into the boss. SeeFig. 9.2.3*1 and Fig. 9.2.3*2.



Scarf Cutting

Fig.9.2.2*1

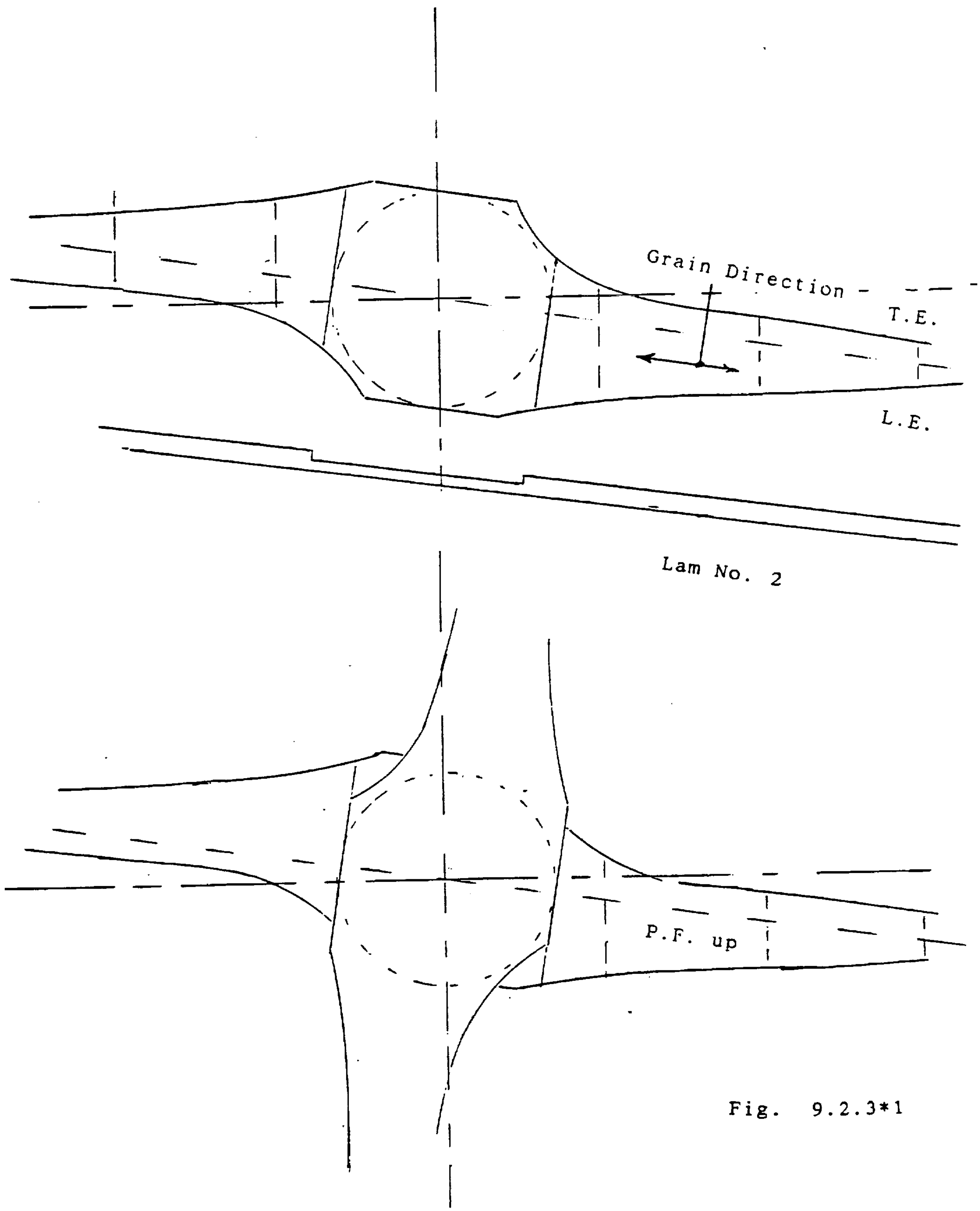


Fig. 9.2.3*1

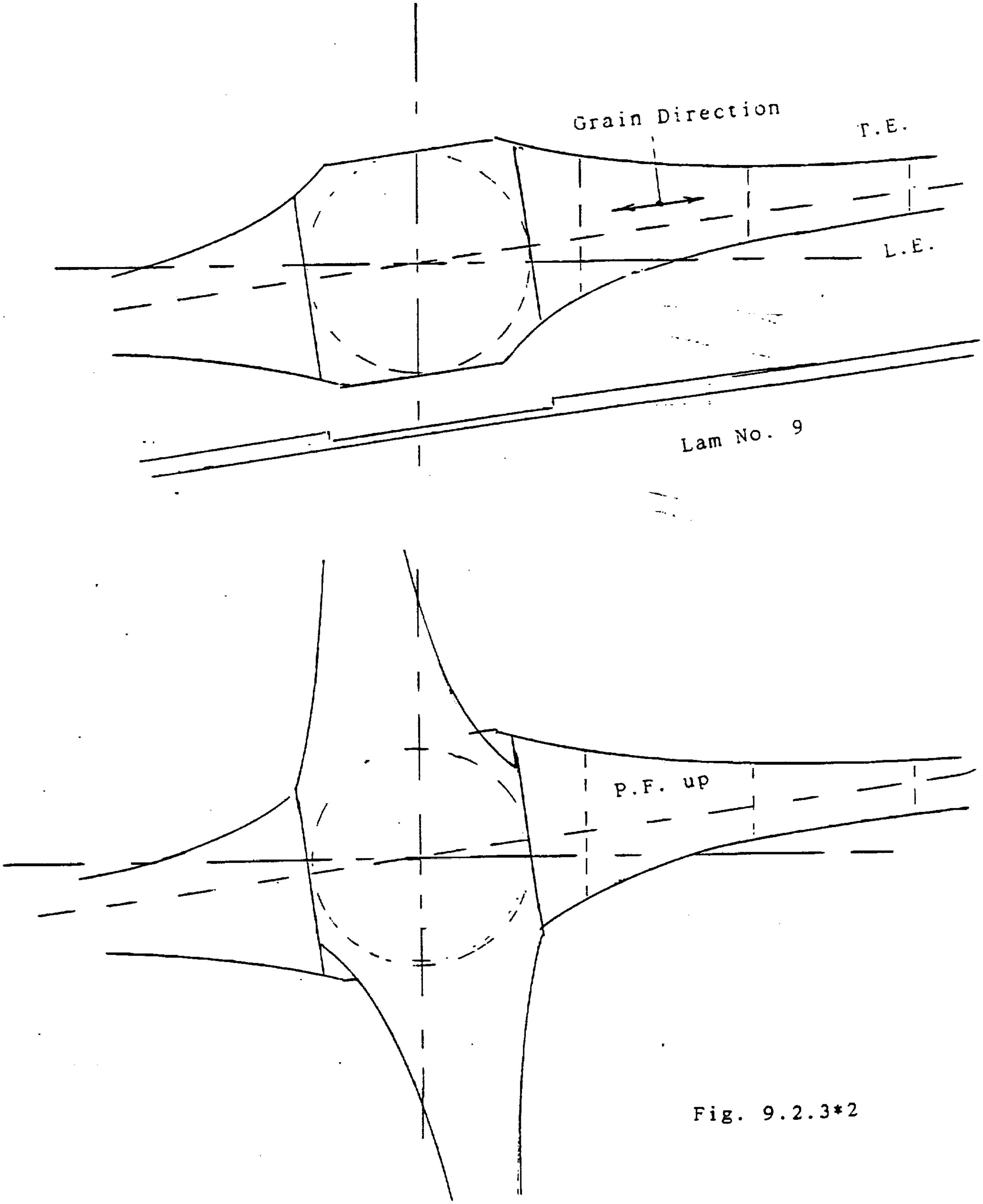


Fig. 9.2.3*2

Each half lap joint of one lam set should be glued together and allowed to set before the finished 4 blade lam is ready for assembly into the final block.

9.2.4 Profile Cutting

After the lam boards have been prepared, with or without root compressed wood portions depending on the design requirements, the overall profiles and data lines have to be marked using the previously prepared lam patterns. (See Section 8.3.1.)

The profiles may then be cut, normally with the use of a work-shop bandsaw, or for small lams a hand power jig saw may be appropriate. It is important that, for the first few lams at least, some of the side offcuts are retained for future use. These offcuts must be planed to thickness at the same time and with the thickness planer still set as for the lams. They are required to be used for building up the "Glue Press Filler Blocks" needed in the main block gluing process. See Sections 9.3.2. and 9.3.3.

After the lams of medium or large blades with compressed wood roots have been profiled to shape they then need to be re-planed to final thickness, this thicknessing will eliminate any slight step at the feather edge of the scarf joint between the two portions. As the lam surfaces will have been removed at this stage it is necessary (using the lam patterns) to remark the datum lines on the lams. Any such marking must be carried out with a marker that does not adversely affect the subsequent glue joint.

9.2.5 Lam Balancing and Selection for Block Assembly

Although compreesed wood can be manufactured to reasonably close tolerances of density, natural wood has a much wider variation in the order of 15%. It is therefore very desirable that account be taken of this situation at an early stage in the manufacture of wood blades and some consideration to the ultimate balance requirement should be given at the lam stage. If the following procedures are used there will not be a large variation in the balance moment values of the final shaped blades.

For simple 2 blade integral fans the lams to make up one fan block should be dry assembled and checked for balance in that state. If the block does not balance then individual lams may be rotated by 180^{0} to obtain the best result achieveable with that set of lams. If more than one such fan is manufactured at the same time it may be appropriate to change lams from one block to another.

For 4 blade integral fans a similar situation applies, lams may be dry assembled into a block and a balance check made. If the block does not balance individual lams may be rotated by either 90^0, 180^0 or 270^0 to obtain the best result achieveable with that set, or lams may be changed from one block to another.

For single detachable blades the requirement will either be that blades of one fan set need to be balanced against each other or that all blades are made to a master moment value. It would be most unususal if all the same lams of different block sets had the same fundamental balance moment value so it is advisable to check and record appropriate values for all lams before allocating them to a known block.

For the (rare) cases where a large number of blades are to be manufactured for one order, it is desirable, although not always practical, to manufacture the total number of lams required for the order before measuring any for balance. It may be found necessary to consider a limited number of lams to be processed at one time.

Because lam profiles are not cut to close limits it is only necessary for an approximate value of the balance moment for any one lam to be obtained. A method that has been found successful is to weigh each lam on two scales spaced apart by a known distance, the lams being set at the appropriate radial stations on these scales.(See Fig. 9.2.5*1) The radial balance moment of each lam may then be calculated. By sorting each lam balance moment into an ordered list of increasing values it is possible to select items from each list to give the blocks of a set, these sets having very little variation in total moment.

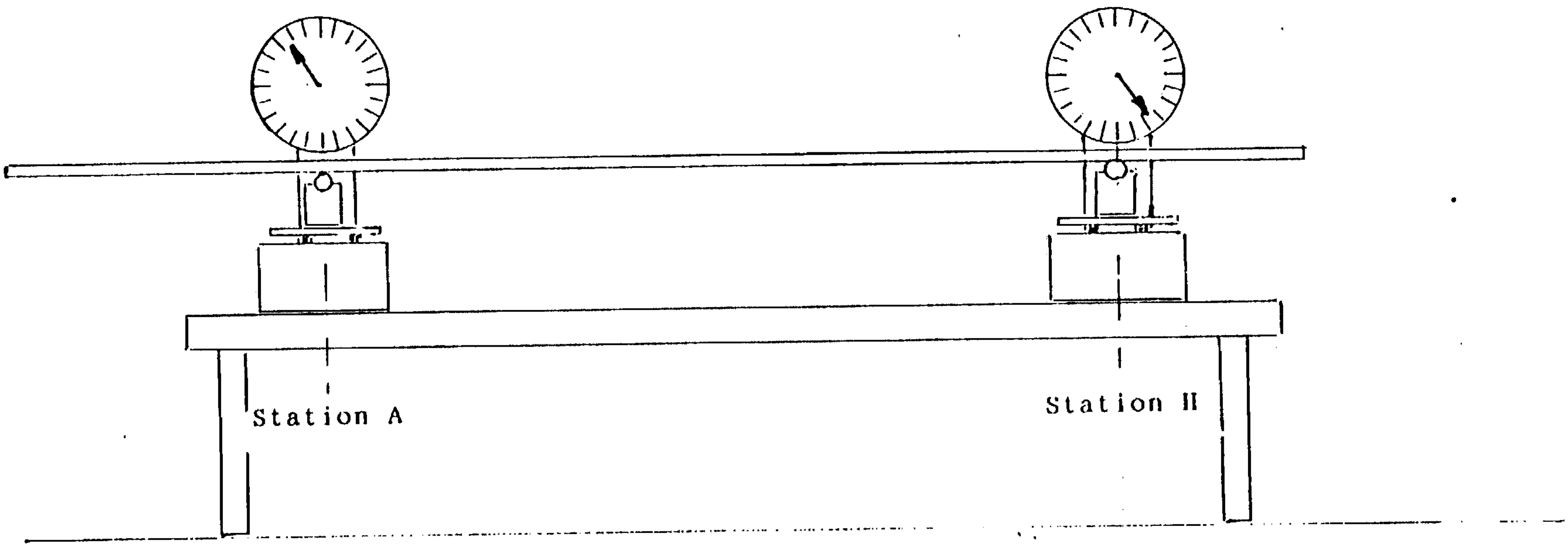
9.3 Block Manufacture

9.3.1 Dry Block Assembly

Before attempting to glue all lams together to produce a finished blade block it is essential to make a trial assembly in the dry state . It is also a convenient time in the process to drill the lams for and insert dowels into adjacent lams to ensure that no slippage occurs over the wet glue. Checks can be made at this stage that the flatness of each lam is such that the eventual glue line thickness will be less than the nominal say 0.006 in.

The part face areas of all lams not covered by the adjoining lams, where no glue will be required to be applied, should be marked with crayon so that these areas can be readily seen at the glue application stage.

The first block of a set should also be fully assembled dry in the appropriate glue press with the part lams of the side Filler Blocks so that all features can be checked to ensure that they are correct and that there will be no hold up once



LAM BALANCING

Fig. 9.2.5*1

thegluing process starts. This becomes more and more important the larger the block. It is usual to conduct this trial by assembling the lams in the glue press to be used.

After the block has been dry assembled and checked it should be broken down and each component placed in a position so that it can be readily available and convenient for handling during the actual gluing process.

9.3.2 Block Gluing

An important consideration to be borne in mind for the block gluing process is that there is a maximum Open and Closed Assembly Time laid down by the glue manufacturer, e.g. see CIBA- GEIGY data sheet in Appendix G. These times are the maximum that should be taken between applying the glue to the components, assembling these mating components and then applying the pressure. (For resorcinol glue this time will be approximately 20 minutes.) The planning of the Block Gluing Process must take into account that all the details of the process must be achievable within the appropriate time limits.

During the gluing proces of the first block of a new design it will be necessary to include the gluing of the part lams for the Filler Blocks.

9.3.3 Summary of Process

Lam 1 should be positioned in the appropriate glue press with its Pitch Face side upper most. The first glue mix should be made and then a coat of glue applied to the required area of the upper face (Pitch Face) of this Lam 1.

At the same time, or within the Open assembly time, a coat of glue should be applied to the Round Side face of Lam 2. Lam 2 should be placed with the Round Side face (i.e. the face on which glue has been applied) down on to Lam 1. If applicable insert required dowel(s).

Glue should then be applied to the required areas of the upper face (Pitch Face) of this Lam 2. At the same time, or within the Open Assembly time, a coat of glue should be applied to the Round Side face area of Lam 3.

This process needs to be continued until all Lams of the block have had glue applied and been placed together, with any dowels inserted if required. Of course the top most Lam does not require glue applied to any areas of its Pitch Face side at the top of the block.

At this stage it will be appropriate to add the Filler Blocks at both sides of the block to complete the "rectanglar" form under each stretcher position. See Fig. 9.3.3*1.

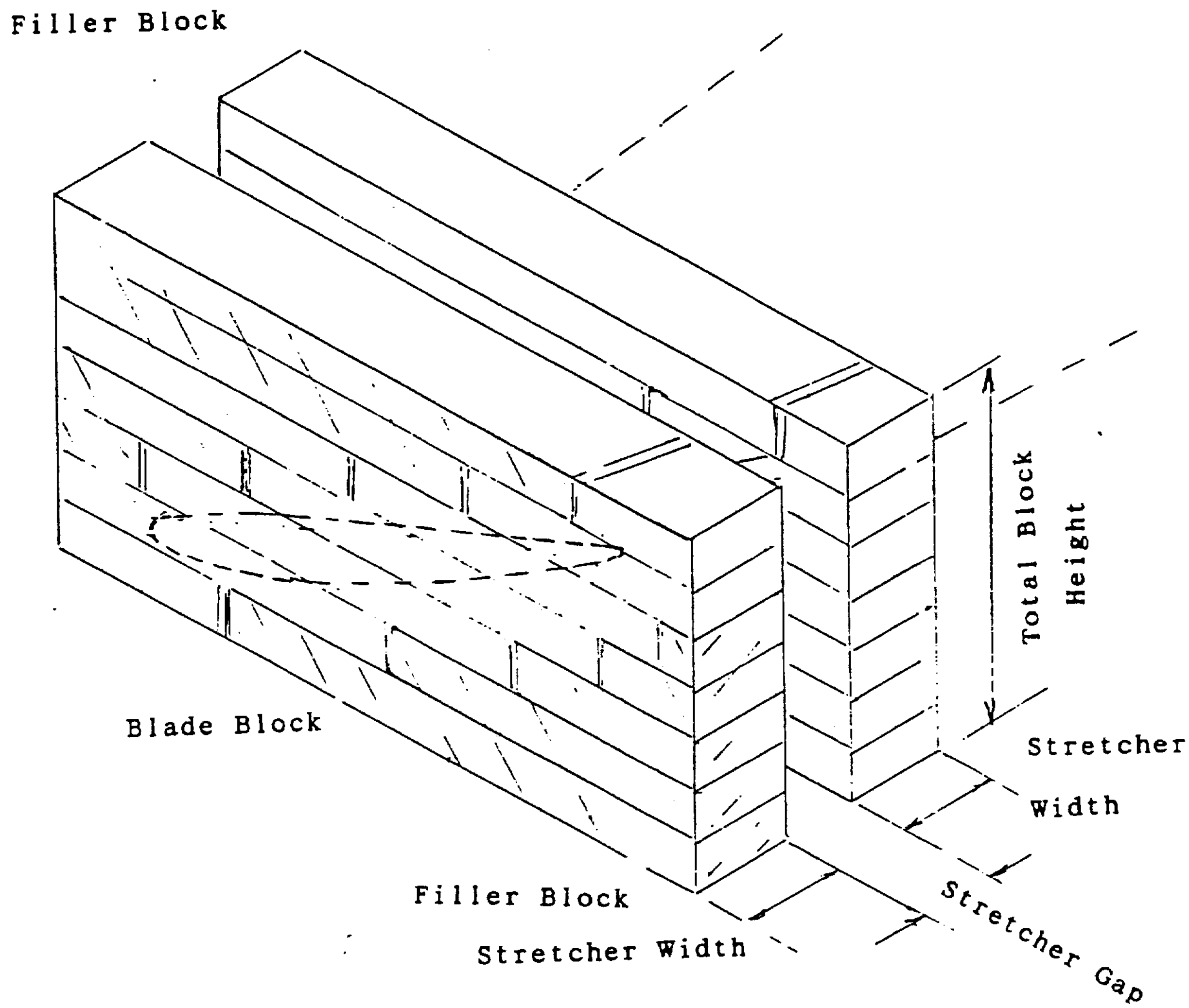

Filler Block
Blade Block
Total Block
Height
Stretcher
Width
Filler Block
Stretcher Width
Stretcher Gap

Fig. 9.3.3*1

The top packing boards are then placed over the assembled block and the top stretchers loosely assembled. The nuts should be screwed on to the side bolts and hand tightened.

Starting at approximately the centre stretcher the nuts should then be tightened, on both ends of any stretcher at the same time. To ensure that it can be seen that a stretcher remains horizontal it is appropriate to have a bubble gauge on top of the stretcher and the nuts tightened accordingly. The tightening process should continue working from the centre of the block towards each end.

When all nuts have been tighened using "standard length" spanners, the process should be repeated using spanners with extension arms to be able to apply further torque to the nuts. During the tighening process it can be seen that surplus glue will commence to ooze out from the joints. If this feature does not occur at any particular spot it may indicate that insufficient pressure is being applied and that extra bolt load, hence extra nut torque is required at that zone.

At this stage checks should be made to verify that the glue line thicknesses are less than say 0.006 in. by endeavouring to insert a feeler gauge between the joints.

A practical hint is that a standard 0.006 in. feeler gauge should be mounted at the end of a suitable rod so that it is reasonably easy to apply, through the gaps between the glue press bolts, this feeler gauge to the joints between the lams.

If the joints accept such a feeler gauge further pressure needs to be applied by means of the stretchers.

After allowing the glue to ooze out for a few minutes (say 5) all stretchers should be re-tightened again.

9.3.4 Block Maturing

The block should be left under pressure for a minimum time according to the Glue Instructions (Section 9.1) Normally this specified time is 8 hours but in practice this minimum period is not very convenient and it is usully appropriate to leave a block in the press over night. After removal of the stretchers from the press the glued block can also be removed but, particularly for large blocks, care must be taken in handling the block so that no excess load is imparted to the glue joints.

After removing the block from the glue press and before transferring it to a storage position the block should have a coat of suitable sealer (such as Ref.13.1.18.) applied to prevent any rapid change in moisture content and/or splitting.

9.4 Shaping

9.4.1 Original Techniques

This initial section to be presented is a record of how propeller blades and subsequently small fan blades were first manufactured by hand shaping means. These initial methods were gradually superseded by more and more use of machine power tools but some of the principles were still retained, particularly for the close tolerance for the final "White Shape" finish. In the early days of aircraft and propeller manufacture it was found that flat pitch face aerofoil sections were suitable for propeller design and this type of section was fairly easily produced by the simple hand methods then available. Although the methods illustrated in this section show that the aerofoils have flat pitch faces, these methods could and were extended to sections without flat faces.

As explained in Section 8./8.3.1. a blade block originally has no accurate data points on which to base the final shape and dimensions of the blade. The data points developed (as illustrated in Section 8.3.1.) are then the starting points from which the shaping process has to begin. These data points in effect accurately define the X,Y, and Z axes referred to in Section 8.1.) The blade block was then mounted on a suitable base or stand (depending on the type of blade) with the pitch face upwards and the datum face horizontal.

The first step after the axes had been defined was to produce the plan form of the blade. This was done by having a template or Back Pattern produced to the dimensions of the plan form projection of the blade shape. By mounting the blade block with such a back pattern parallel to the datum axis (plane X,Y) it was possible to shape the profile of the blade block to match this pattern and give the required plan form to the block. (Fig. 9.4.1*1)

The second step required was to shape the trailing edge (T.E.) drop defined as the Z dimension of the T.E. radius. For workshop convenience it was usual to produce a drop pattern, as shown in Fig. 9.4.1*2) that could be placed along the profiled T.E. of the block. The position of the T.E. drop could then be marked on the already cut profiled edge so that this mark could be used as a guide from which to create a dummy T.E. position on the block. See Figs. 9.4.1*3 to 9.4.1*6 for clarification of this requirement.

At this stage the blade block mounted with the pitch face side up has a dummy T.E. position cut giving a vertical face to define the T.E. plan form and a horizontal face to define the T.E. drop dimension. It was then required to mark a datum line, (on this horizontal face) to define the position that the pitch face intersected it. See Fig. 9.4.1*5.

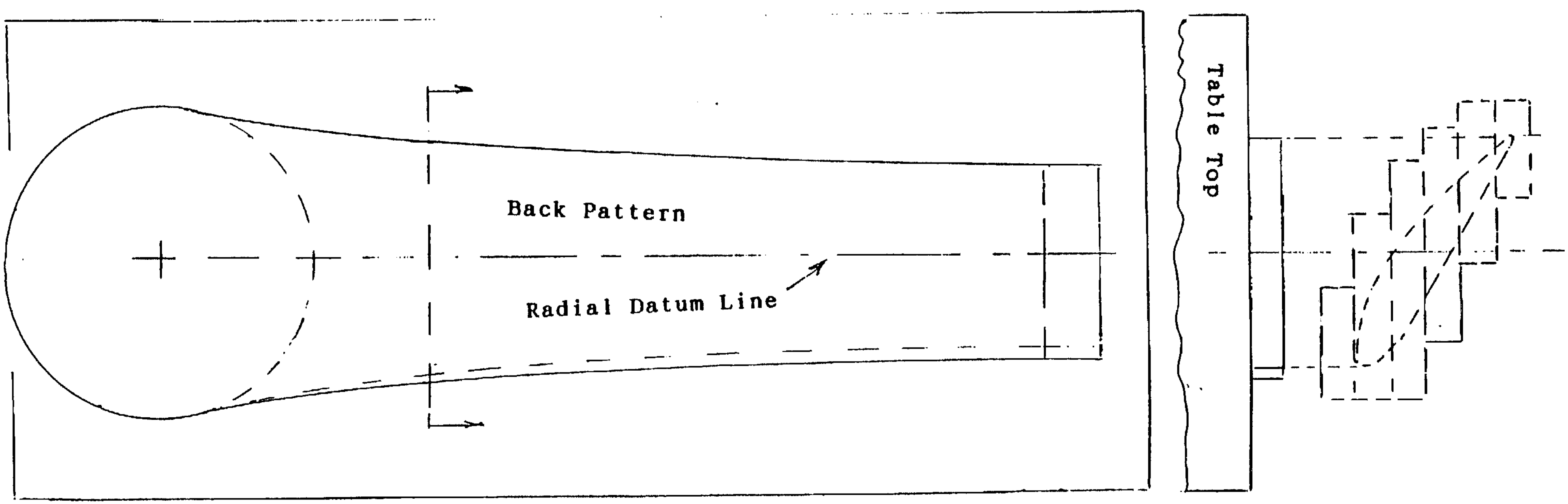


Fig. 9.4.1*1

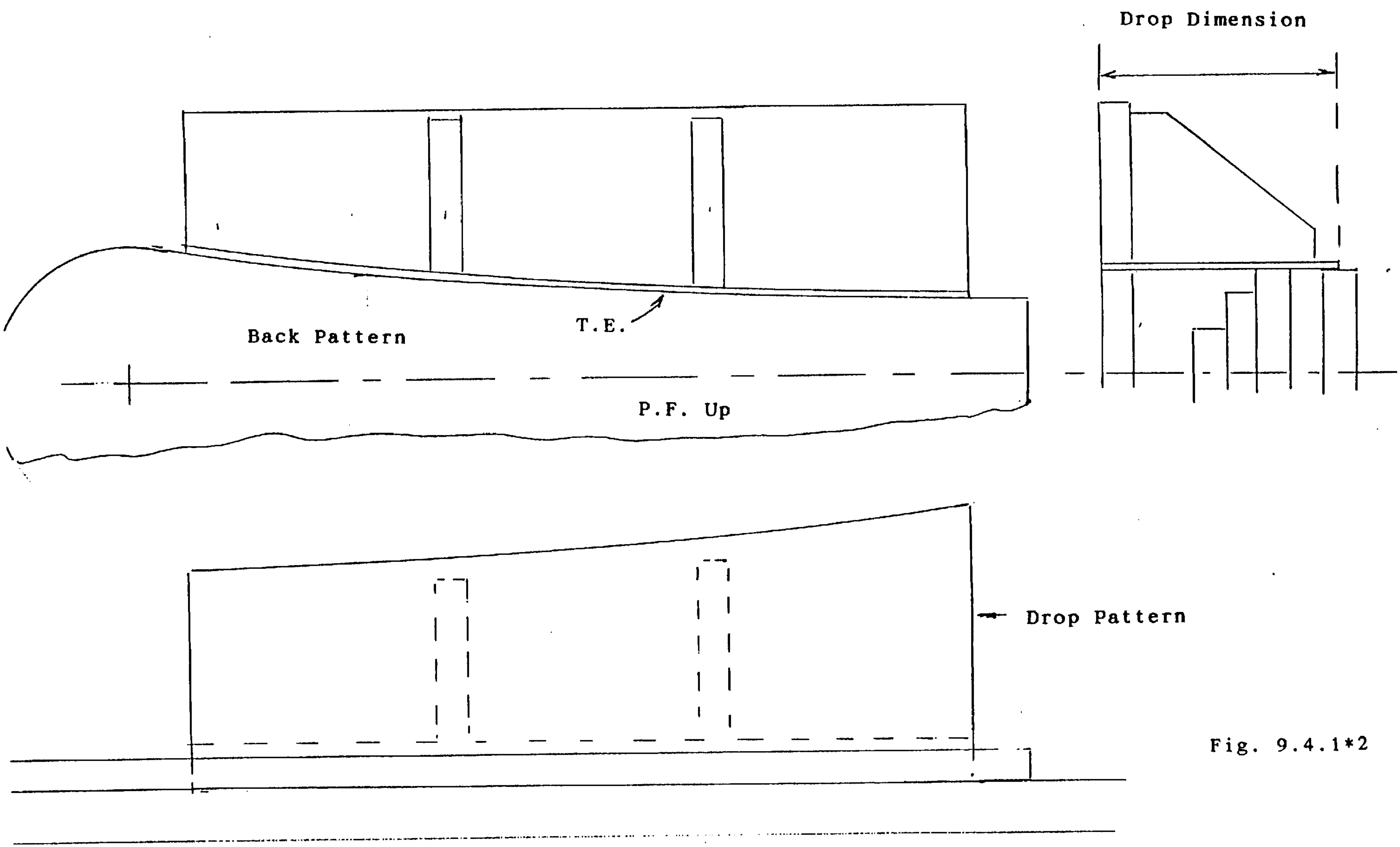


Fig. 9.4.1*2

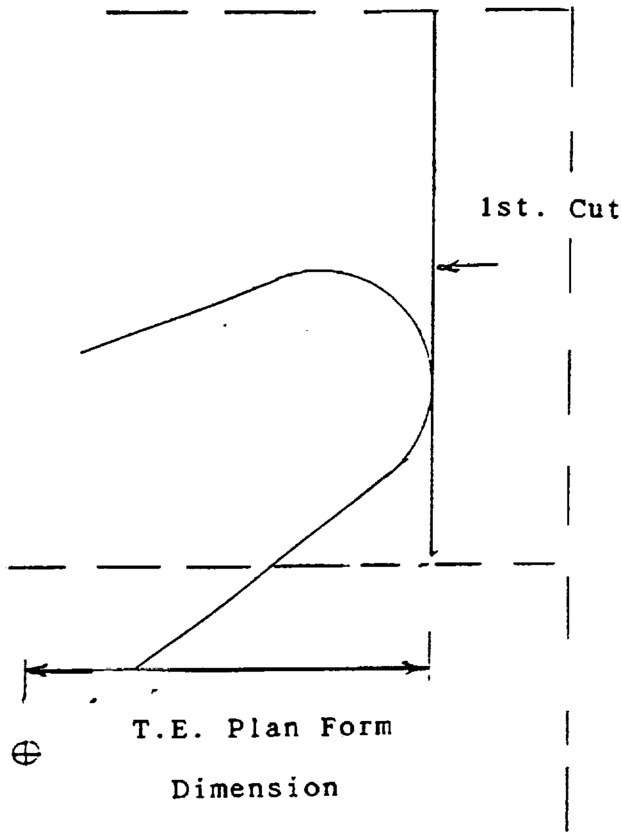


Fig. 9.4.1*3

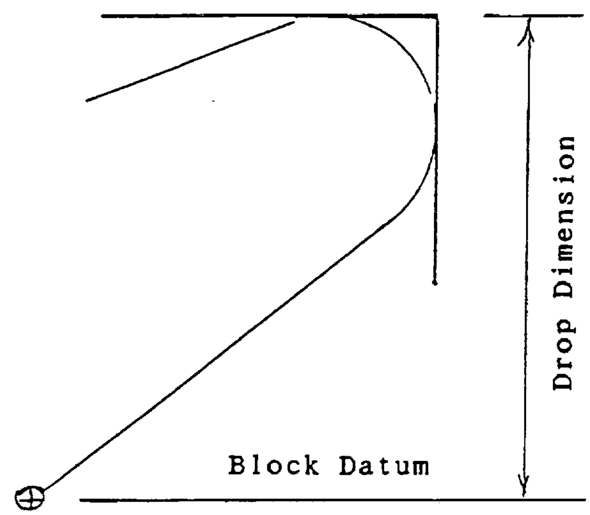


Fig. 9.4.1*4

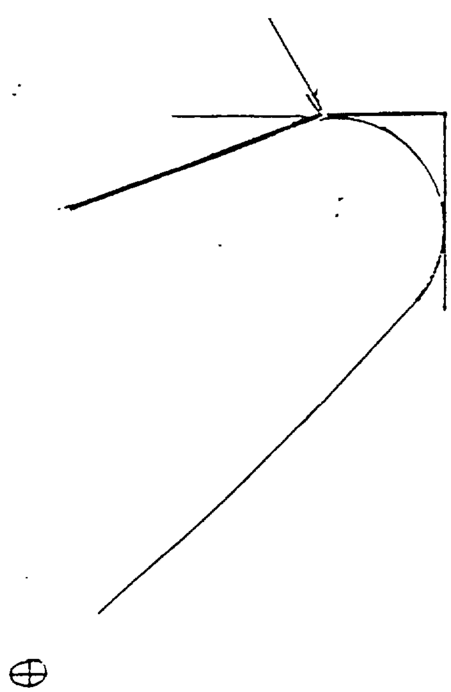


Fig. 9.4.1*5

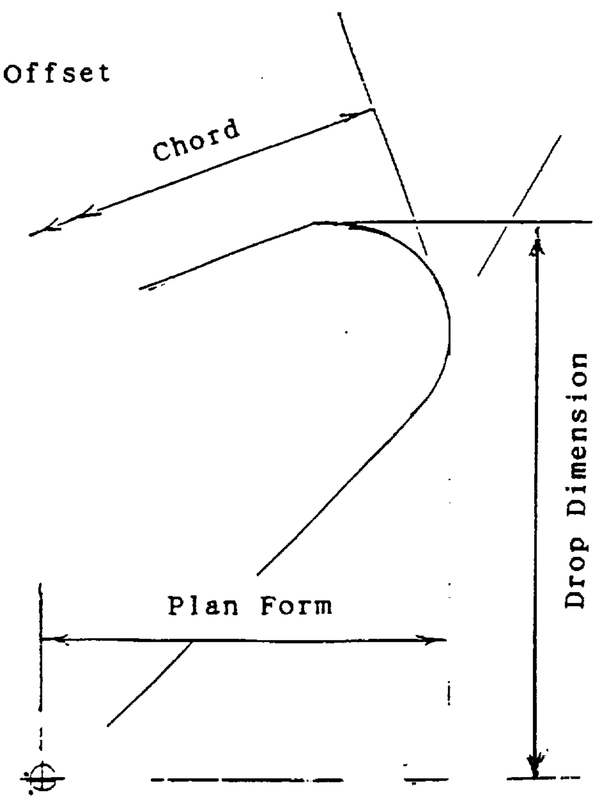


Fig. 9.4.1*6

This datum line had to be positioned at a distance forward of the vertical plan form face already cut to allow for the TE radius. If the T.E. radius was very small (as initially with the small chords of propeller blades) the appropriate workshop dimension used was assumed to be equal to twice the T.E. radius, but for larger chords of windtunnel fan blades the actual dimension was usually specified on the workshop drawing.

9.4.1.1 Pitch Face Shaping

For each radial station material could then be cut away to give the angle to the horizontal datum (Y axis) as specified by the design and for the pitch face to intersect the datum line marked on the top face. A series of angle templates as shown in Fig. 9.4.1.1*1 and Fig. 9.4.1.1*2 would be provided for this operation. These templates could be used with the help of a standard bubble level gauge.

The shaping of the pitch face was completed by removing the surplus material between each radial station to give a smooth transition along the length of the blade. It was possible to achieve a smooth flow between the stations and to judge the result by reference to the visible glue lines. With experience skilled blade shapers and inspectors could ensure that there were no uneven defects visible in the glue lines flow.

The penultimate process was to produce the part of the T.E. radius along the blade to define the true T.E. position.

The final process for the pitch face (if required by the design of the aerofoil section) was to shape the leading edge (L.E.) turn up (i.e. the part of the pitch face forward of approximately 30% chord that was not flat). This final process could be left until the Round Side (or Camber Face) had been completed. This was achieved with the use of templates of this part of the pitch face, material being removed until the appropriate template fitted the face. See Fig. 9.4.1.1*3

9.4.1.2 Round Side Shaping

The Round Side (Camber Face) shaping required the use of suitable cloaking template sets. The lower or pitch face template of such a set (see Fig. 9.4.1.2*1) was held at the appropriate radial station under the the pitch face of the blade with the T.E. mark to coincide with the T.E. of the blade. The upper or round side template could be placed over the blade to judge wether or how much material needed to be removed at that station.

It was required that eventually both legs of the round side template had to mate with the lower pitch face template and that the round side section of the blade fitted the profile of the template. Care had to be taken that excess material was not removed to leave any gap between the template and the blade.

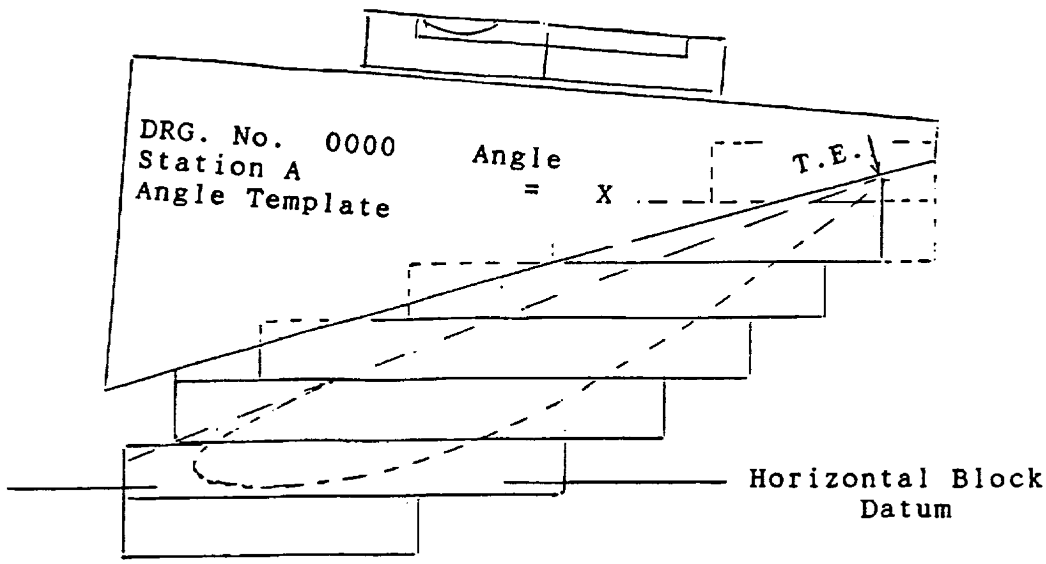


Fig. 9.4.1.1*1

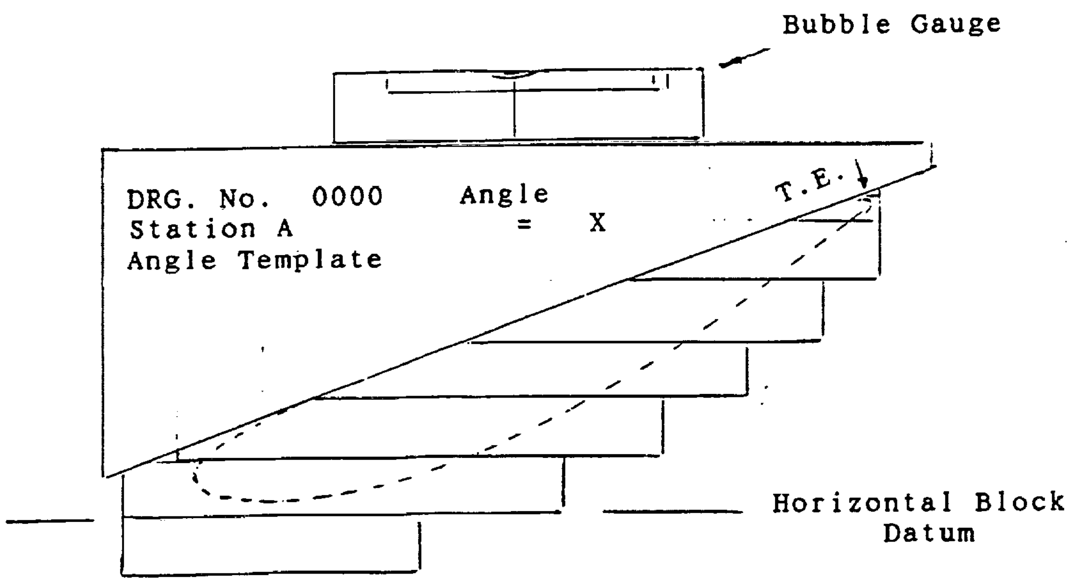


Fig. 9.4.1.1*2

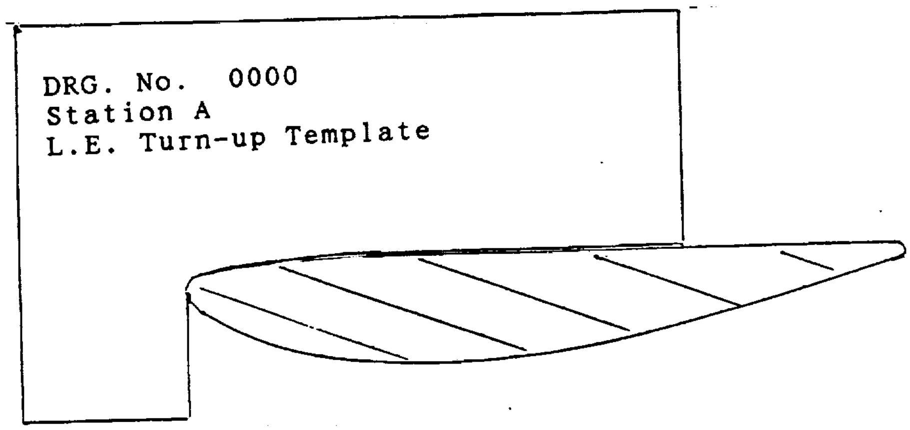


Fig. 9.4.1.1*3

It was usual initially to fix (temporarily with adhesive tape) a packing piece of 0.02/0.03 in. thickness on to the legs of the round side template (shown in Fig. 9.4.1.2*2) so that the section shape could be achieved to within this limit of the packing piece before attempting (with the packing pieces removed) the final operation of removing this last 0.03in. of material from the section.

The practical technique used was to coat the mating edge of the template (defining the aerofoil section shape) with coloured wax from a pencil (or marker) and when this coated template was rubbed against the blade the high spots would be marked with the wax and show where material needed to be removed.

Final checks could be made with a feeler gauge to judge the gap between the template and the blade. (See also Section 9.6. dealing with balance considerations).

As with the pitch face the round side shaping was completed by removing material between each radial station to give a smooth transition along the length of the blade.

9.4.1.3 Datum Considerations

The original method of hand shaping propeller blades with the T.E. position as datum was devised and very convenient for relatively large numbers of small blades to be manufactured as the method required very limited tooling or fixtures. All that was required were simple stands on to which the (normally fixed pitch) propeller blades could be bolted with the datum face horizontal and the orientation of this face could be checked with a standard bubble level gauge. A number of skilled wood workers could be trained to use this method to sustain a steady production flow. The final tolerances to which the blade section position were shaped depended on the tolerance of the T.E. position and the tolerance of the blade angle, usually +/- 0.25 degrees.

As the chords of these blades were quite small somewhere in the order of 6 in. or 150 mm. the tolerance of the section datum position relative to the required datum axis could not differ by more than some 0.005 in. or 0.08 mm. from the true position.

This method was continued to be used for windtunnel fan blades when only small blades were involved but the method had serious drawbacks as larger fans were required. The position tolerance of the section, depending directly on the value of the chord, became too large and it was found necessary to develop a more positive technique but with the disadvantage that large accurate working tables were required.

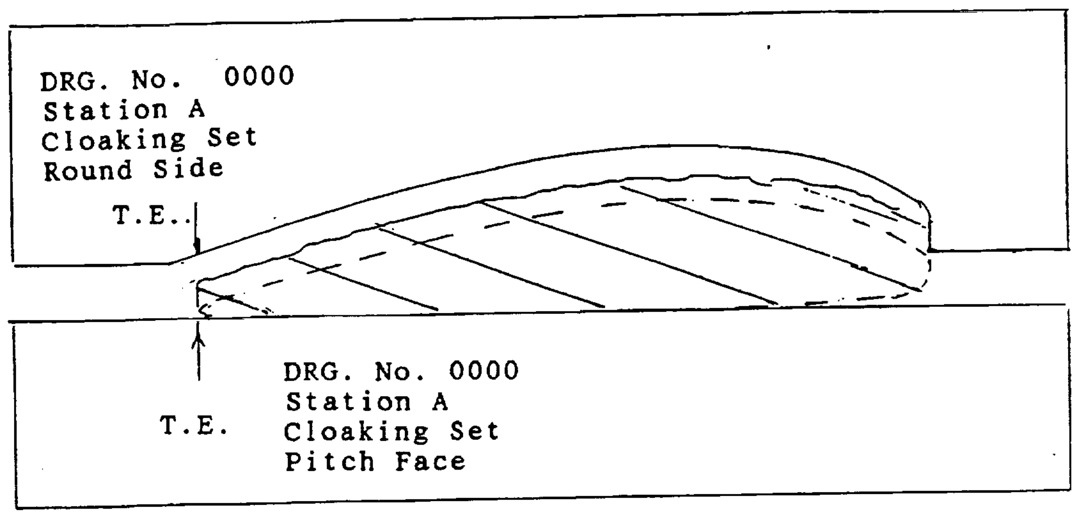


Fig. 9.4.1.2*1

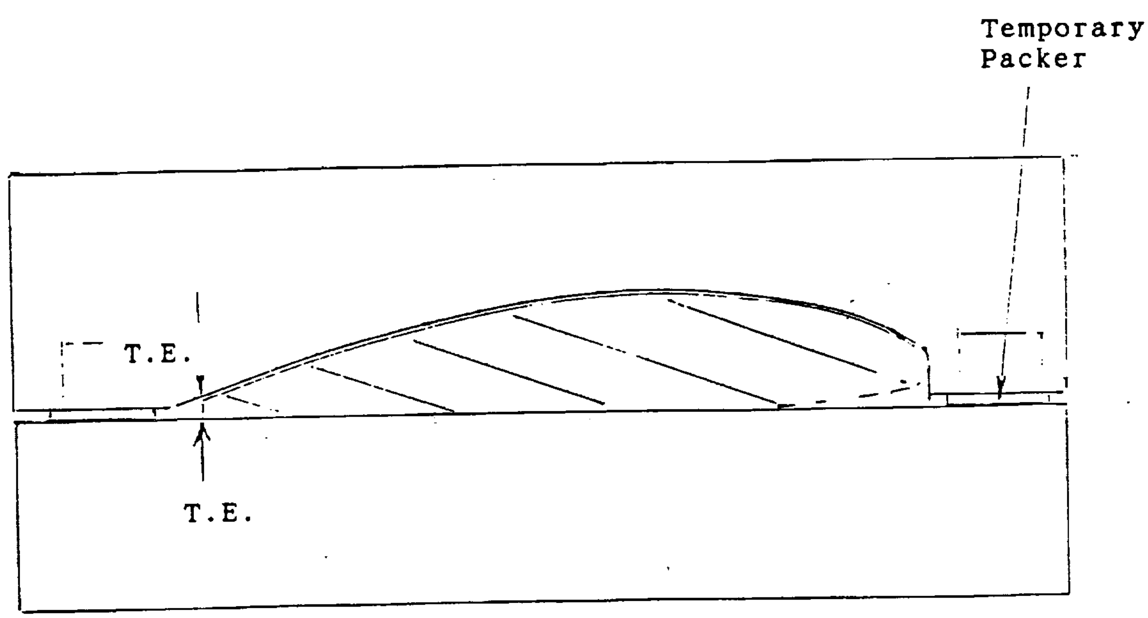


Fig. 9.4.1.2*2

It is usually only possible for a manufacturer to have available a very limited number of such tables (possibly only one) and consequently there will be a restriction on the rate of production for blades requiring such a facility but it is unlikely that any windtunnel fan blade order will involve a time scale that makes this critical.

9.4.2 Medium and Large Blade Shaping Techniques

The method for large blades required the use of "Leg Templates" as illustrated, in Fig. 9.4.2*1. For convenience the original sequence of shaping was retained, the Pitch Face first and subsequently the Round Side.

There are a number of reasons why this method is preferred. It leads to a closer control on the section angle, provding that the feet of each leg comes within say 0.03 in. (1 mm.) of the datum table face, the section angle is then restricted to a maximum of 0.25 degrees, within any design or contractrual limit. This type of template is easier to use if the aerofoil section has a non flat pitch face such as with NACA 65— series sections.

Equally the section position, both in the Y and Z directions can be controlled by such a leg template to the final working position needed.

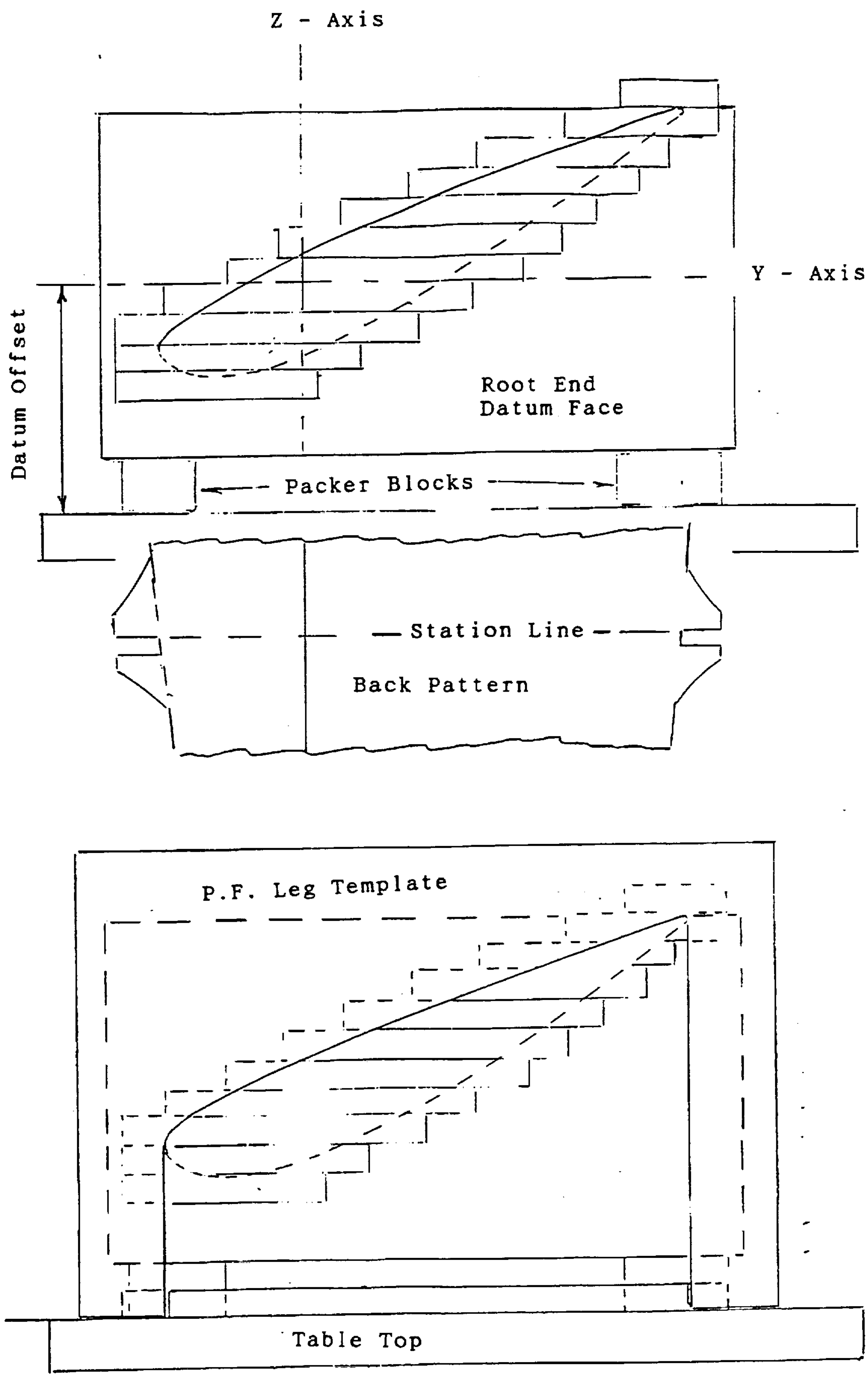
Either the actual template used by the shapers or other special inspection templates may be used by the inspection personnel to measure the dimension of the final blade and to verify the tolerance achieved. (See also Section 9.7)

The original blade block has to be mounted on or by suitable supports so that the blade X and Y axes are at specific distances from and parallel to the Table Datum Face. A suitable "Back Pattern" must be fixed under the block and on to the face of the table, similarly to that shown in Fig. 9.4.1*1 but with slots into which the legs of shaping templates can fit.

9.4.2.1 Large Blades with Rectangular Roots

The start of the shaping process (for all types of blades) depends on setting the block into an appropriate position and establishing the correct data for the X, Y and Z-Axes. The required manufacturing data points or positions will have been decided at the Manufacturing Design stage (see Section 8.3.1.) and in the case of Large Blades with Rectangular Roots this will possibly have involved machining dummy root and tip surface data. These surfaces will establish the X-Y plane of reference.

The position of theses dummy data surfaces will be initially established with reference to one or more block glue lines as specified by the manufacturing design. Once theses surfaces are machined, they then become the new reference



Z - Axis
Y - Axis
Datum Offset
Root End
Datum Face
Packer Blocks
Station Line
Back Pattern
P.F. Leg Template
Table Top

Fig. 9.4.2*1

data position for the direction of the X-axis and the X-Y plane. Further machining as described in section 8.3.1. then finally establishes the X-Y plane and the direction of the Z-axis at right angles to this plane. The normal tolerance limits for measuring the radial position along the X-axis of a large blade would not be less than say 0.010 in. or the thickness of a pencil line so it is usually not necessary to require a close tolerance tooling hole to define the origin of the X-axis on the block. Measurements along this axis can usually be made by defining and making one known station, preferably near the root, as the datum and then measuring all other stations from this datum station.

The datum for the Y-axis can also be a simple marked line on the face of the root block or if more convenient for tooling purposes a toling hole can be established on such root face. The direction of the X-axis is established in relation to the centre line of the block, and may need to be re-defined accordingly.

The datum for the Z-axis would be established from the thickness of the root block.

9.4.2.2 Large Blades with Circular Roots

As with Large Blades with Rectangular Roots the data points positions for, in this case, root and tip tooling holes will have been specified at the Manufacturing Design stage and for actual manufacture will need to be drilled (and possibly bushed) These holes then define the Radial and X-axis but not the origin, which can again be achieved from a known Station line previously marked on an outer lam. This enables the inboard end of the circular root to be defined and cut to length if appropriate. The root end can then be turned and the adaptor fitted as per the next Section 9.4.2.3. The final positions of the X, Y, Z-axes then have to be defined in relation to the Adaptor data. It will be necessary to check the relationship of the tip tooling hole with the axes (as now defined by the Adaptor and it may be found necessary to make some adjustment if any discrepancy has occurred due to tolerances of the Adaptor

9.4.2.3 Root Turning and Adaptor Fitting

Detachable blades with compressed wood roots are designed to have a metal (usually steel) adaptor (or ferrule) fitted that can be mechanically attached to the hub, either in a fixed configuration to give a fixed pitch fan or to a rotatable member to give a variable pitch fan. In both cases the compressed wood root has to be turned to give a cylindrical or conical form that can then be inserted into the internal corresponding shape of the adaptor.

This is a straight forward turning operation on a conventional lathe, the requirement being that the block has to have two data points, one at each end, to define the axis of rotation for the root. See Section 9.4.2.2. for details of establishing the Block Data.

There are two types of attachment for the adaptor. It can have an internal thread that mates with a thread cut on the compressed wood root in which case a conical root is used or alternatively the adaptor can be retained on to the root by means of bolts or set screws, when a cylindrical form is used. (See Fig. 3.3*1) The external form of the adaptor and its retention on to the hub depends on the hub design and is generally only an issue for the blade manufacturer in that this part of the adaptor design will define the requirements for the holding fixtures and possibly the datum from which the blade angles have to correspond.

As an example of the fitting of a "screw type" adaptor, the following procedure was used for the Ames 80x120 tunnel fan blade roots.

The block was set into a lathe and the root cone turned to within approximately 0.25 in. of the required diameter. The block was then removed from the lathe and left for 72 hours before the next operation which involved the finish turning of the cone, as specified by the design, and the cutting of the appropriate thread form.

A practical note is that as these operations were carried out in a standard "metal working" shop floor environment the blade blocks were always kept fully covered by polythene sheet during turning and storage to keep the block clean.

After the root turning and thread cutting the adaptor was tried on to the root cone and checked for fit. This was achieved by first making chalk marks approximately 1 in. wide on the wood root cone in an axial direction in three circumferential positions. The adaptor was screwed on to the root until just hand tight and then removed, care being, taken to avoid contact of the adaptor on the chalk until the adaptor began to tighten.

After removal of the adaptor these chalk marks were examined to determine that they had been disturbed all along the root and that the fit was satisfactory.

The adaptor was then replaced hand tight and left in this position until the next operation, final fitting, was able to be started.

The block was securely clamped to a firm stand with the root end and adaptor hanging clear of one side.

The position of the end of the thread of the root end was marked on the block so that it could be seen when the adaptor was fully tightened.

Also marked on the outside of the adaptor was the position of the end of its thread.

The two thread end marks must then show an allowed clearance suitable for the draw on final tightening of the adaptor.

The adaptor then was removed from the root end cone.

After mixing a batch of the appropriate Sealer Compound (Ref: 13. 1. 17, see section 6.2.7.2.) a coat of this material was applied all over the root end making sure that all the thread was completely covered. The adaptor was then immediately screwed on to the root and hand tightened.

The appropriate fitting lever was attached to the adaptor and clamped in a position suitable for the connection of the spring balance and to an overhead crane.

Load was applied by the crane up to the value as specified by the design requirement. As the load was being applied it had to be noted that a suitable draw was being achieved. See Fig. 9.4.2.3*1.

After the final draw had been obtained with the maximum load, this maximum load was maintained for a further 5 minutes, to ensure that any settling down had taken place, before being reduced back to zero and the assembly dismantled.

The assembled block with adaptor was then ready for the next operation of drilling the retention holes. This was a straight forward operation with a horizontal boring machine and appropriate drill jig.

The datum master retention hole had to be in the correct angular position relative to the block face datum and this then subsequently became the new datum from which the Y-axis was re-defined and consequently the blade angles derived and measured.

Similarly the root end face of the adaptor now defined the position of the radial (X-axis) origin position.

This general procedure has to be adopted for all screw type adaptor fitting but, of course, there may need to be some variations depending on the actual design of the adaptor, particularly in regard to the eventual angular datum to be achieved.

The fitting of a "bolt type" adaptor can be carried out by turning the compressed wood root end to the required cylindrical dimensions, similarly in a two stage operation as for the conical root, allowing a waiting period of 72 hours between 0.25 in. over size and turning to the final size.

The adaptor should be a tight push fit on to the root, but before final fitting a coat of Sealing Compound (Ref:13.1.17) must be applied to the root.

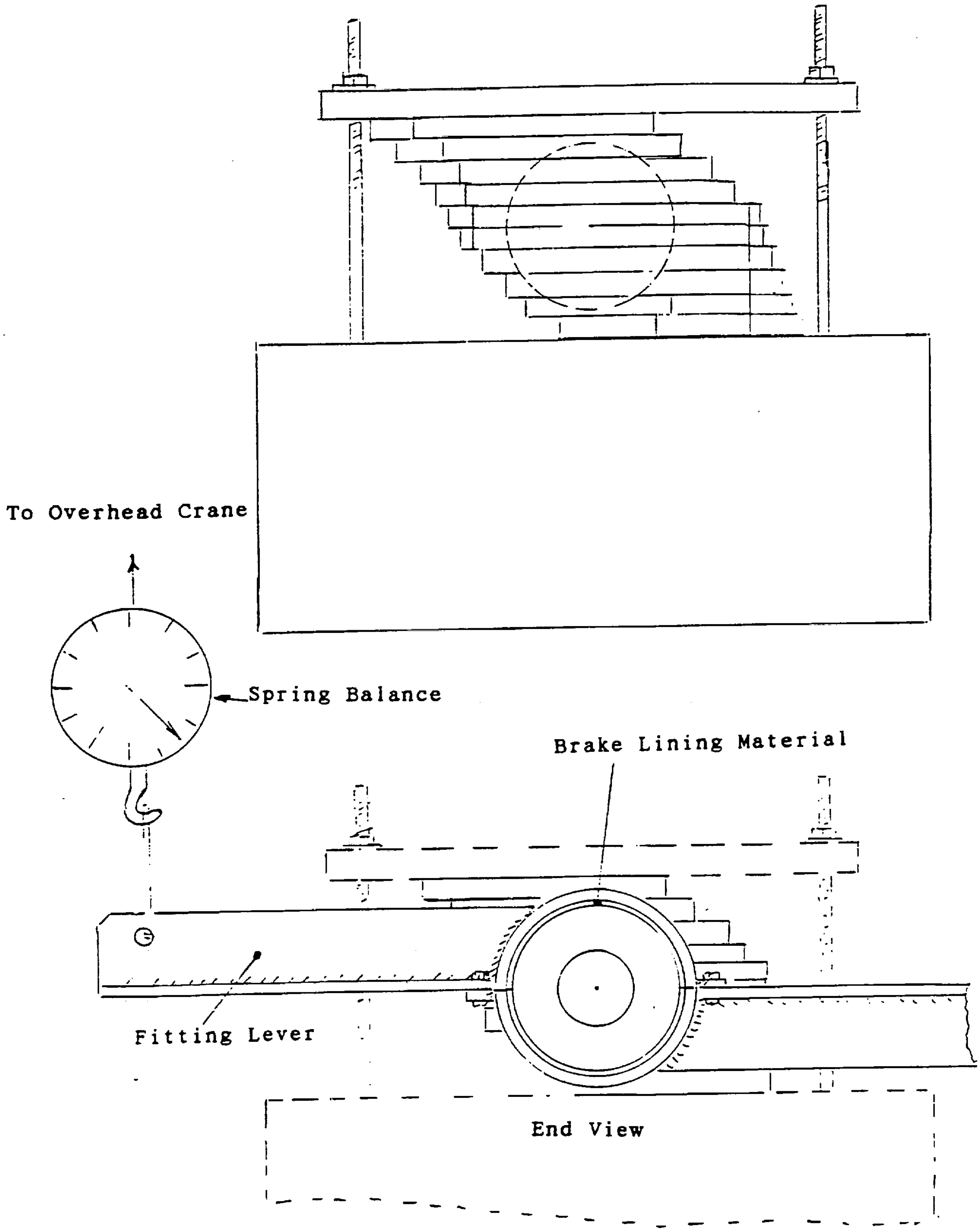

To Overhead Crane
Spring Balance
Brake Lining Material
Fitting Lever
End View

Fig. 9.4.2.3*1

After fitting of the adaptor the compressed wood root has to be drilled and tapped so that the bolts or set screws can be inserted and tightened. It is advisable to have these bolts coated with similar Sealer Compound just before insertion.

9.4.3 Datum Considerations for Shaping

See Section 8.1 for Definitions of Axes.

A block after removal from the glue press and being held for an appropriate maturing time has only approximate reference points from which true data for the whole of the shaping process into a finshed blade must start.

Some of the station lines marked on the outer lams will still be visible and give an indication as to the longitudinal (or radial) postioning to be used and from which the origin of the X-axis can be specified.

The initial datum for the thickness (or Z)-axis can be established from one of the glue lines and by reference to the block design.

The datum for the chordwise (or Y-) axis can be made either from the radial axis lines marked on the outer lams or by reference to the width of the block, preferably at the tip end.

The final exact data points to be established depend on the type of blade.

9.4.3.1 Data for Integral Blades

For 2 blade integral fans a datum face, to define the X-Y plane, will first be required and from this face the origins and postions of all the axes can be made.

The block thickness at the boss will have been decided to give some surplus material at that position so it is usual for the (rough) block to be machined flat at the boss to be an appropriate datum face.

The lams will have been produced with centre holes so that the glued block will retain this centre (rough) hole. This hole can then be re-drilled to a slightly larger size to give an accurate centre point and consequently define the origins of both the X- and Y-axes.

Corresponding data faces in the tip surplus, to "line up" with the centre datum face can also be machined. (These tip surfaces need not necessarily be in exact line up with the centre datum, but may be at a known distance from the centre datum.)

An appropriate tooling hole at each tip, finally to define the X-axis, should be drilled.

The Y-axis is then defined from the centre hole, along the datum face, and at right angles to the X-axis. The Z-axis is then defined from the other two axes.

9.4.3.2. Datum for Detachable Blades with Rectangular Roots

The X-axis (Radial centre line) will normally be required to be defined first.

At the inboard end of the block a point specified on the workshop drawing and relative to both the thickness or glue lines and width will need to be selected as the first position on the X-axis.

Similarly at the tip end of the block a further point (also specified on the workshop drawing) will need to be selected as the second position on the X-axis and so complete the defination of this axis. Its origin will be defined as at a suitable distance, to allow for final trimming, from the end of the block.

The Y-axis can then be defined as being at right angles to this established X-axis and parallel to the face of the root block (or at the appropriate design angle if the block is manufactured with this requirement) The Y-axis origin then usually coincides with the X-axis.

The Z-axis can then be defined in relationship with the other two axes. See also Fig. 8.3.1*2 for possible machining sequence of the root block.

9.4.3.3 Data for Detachable Blades with Circular Roots

The main consideration for data points to be marked on to a block with a compressed wood end that will subsequently have to be turned (posibly threaded) for the fitment of an adaptor, is that these marks must establish the axis for the root turning. This turning axis is usually the X-axis.

The root end position is normally found by referance to an appropriate glue line specified at the Manufacturing Design stage for the Z-co-ordinate and on the centre of the root end block for the Y-co-ordinate.

Similarly the tip end position is found by reference to an appropriate glue line for the Z-co-ordinate and on the centre line of the block at the tip end for the Y-co-ordinate.

The origin of the X-axis, to establish the station positions along the block and the position of the root cylinder or cone, can be defined by reference to the original station lines on the outer lams.

9.5 Covering

9.5.1 Historical Background Notes

"Covering" for early (aircraft propeller) blades was limited to coating by natural materials such as varnishes and other types of lacquers. Improvements were made by applying linen cloth with dope and then paint finishes.

As initially windtunnel fans were usually only used in an interior enviroment it was not necessary for the majority of fans to have a covering to protect against rain or excess moisture. Some early windtunnel blades were only finished with the application of suitable lacquers or paint but eventually as aircraft windtunnels were used for more extreme climatic conditions it was found necessary to have more durable protective finishes.

An exception to this requirement still applies in the case of some motor car windtunnels where testing is usually only for aerodynamic efficiency and the air may be classified as dry and clean. In these cases the fan blades may not need extensive protection and perhaps only limited reinforcement protection on the extreme L.E. is sufficient requirement beyond a straight forward resin finish. (This does not apply for motor car climatic windtunnels where the fan blades do need protection)

After World War II when glass clothes were generally available and chemical resins were developed, it became possible to develop practical systems using these materials. The main problem to overcome with this type of covering is to achieve a satisfactory bond between the resin/glass cloth laminate formed and the wood surface. Polyester resins could be used to produce a satisfactory cover laminate but did not always give an entirely acceptable bond condition.

Eventually epoxy resins were used with greater sucess but even then not all epoxy formualtions were completely satisfactory.

9.5.2 Covering Systems

9.5.2.1 Surface Preparation

For any system of covering it is first necessary to ensure that the blade body surface is of a suitable standard on which to apply the chosen type of covering. Frequently during the shaping process very minor surface defects, such as lifting of grain, leaving a slight indentation in the surface may occur when it is not possible completely to eliminate these at that stage. Such minor defects should prior to covering be filled with a thixotropic resin system (such as Pregel SP 210) which can then be sanded down to produce a smooth blade surface. (See SPS Data sheets in Appendix S for further details.)

9.5.2.2 Coating

A suitable coating resin (such as SP 110, see Appendix S) may be applied to a blade either by brush (or spray) Because coating resins are normally formulated to produce a relatively thick coat, they are normally applied by brush rather than by spray. Even for large blades brush application can be a reasonable efficient manufacturing procedure giving an acceptable finish standard.

Some details of suitable application techniques are given in the SPS Data Sheets, see Appendix S.

One or more coats of resin may be applied, allowing overnight curing between coats. Any identification labels may be applied at this stage and then a final flow coat applied. This coat, being relatively thick, will leave a smooth even gloss finish. After a minimum of 16 hours for this coat to dry and cure, the surface gloss finish can be matted down to obtain a smooth matt surface.

The final finish needs to be allowed to stand for 14 days before it is fully cured.

The main disadvatage of this type of finishing is that it is not very appropriate for the extreme L.E. of the blade and it is normally required to reinforce this area by the addition of 1 (possibly more) layer(s) of glass cloth, similarly as Stage 3 detailed in the Section 9.5.2. dealing with Reinforced Covering Systems.

An alternative technique that has been used is to have a renewable tape system. Self adhesive polyurethane tape can be fixed to the L.E. and each new application should be satisfactory for 10 or more hours of use depending on the operational conditions that are encountered. The disadvantage of this system is that care must be taken in laying down and keeping to appropriate maintenance standards. The installed fan blades must be readily accessable for the tape to be renewed.

9.5.2.3 Reinforced Covering Systems

Much the same techiques as above are required for a reinforced covering system except that after the surface preparation and then the first coat of resin has been applied and left to dry and cure, glass cloth, (typically as specified in Ref:13.1.14) has to be layed over an appropriate area as shown by the corresponding sequence drawing or specification. A further coat of resin should be brushed over this glass cloth making sure that all air initially trapped by the glass/resin coat is allowed to escape and the glass cloth is left in intimate contact with the previous resin coat(s) and the wood body.

9.5.3 Glass Cloth Application Sequence

As an example of the sequences required for the application of the glass cloth to a blade, the procedure for the NASA-Ames blades manufacture during 1983-1984 is given in this Section 9.5.3.

9.5.3.1 Materials Used

9.5.3.1.1 Glass Cloth: E9700 2x2 Twill 0.30mm thick 290 gm/m*2 Supplied by Marglass Ltd. (Ref:13.1.14)

9.5.3.1.2 Epoxy Resin SP110 Supplied by:-

9.5.3.1.3 Hardener SP210 S.P.S Ltd.

9.5.3.1.4 Pre-gel Resin SP110 Cowes, I. of W.

9.5.3.1.5 Fast Hardener SP210F Ref:13.1.15.

9.5.3.1.6 Epoxy solvent SP FAST (See Appendix S.)

9.5.3.2 Covering Sequence (Cloth Application)

Stage 1

Cloth size : to suit Balsa insert.

The tip cloth was positioned to extend 2" inboard of the Balsa insert, with a simple 1" turnover joint on to the P.F. at the T.E.

45^0 mitres were cut on both faces at the L.E. See Fig. 9.5.3.2 *1

Stage 2

Tailored root end pieces were positioned on the leading and trailing root shoulders, giving 1" clearance around all edges. See Fig. 9.5.3.2*2

Stage 3

Cloth size 16" wide x 140" long.

The cloth for the L.E. sheath was wrapped equally on to both P.F. and R.S. giving approximately 7in. chord width coverage on each face and then 45 mitres were cut at the tip end to suit the previously layed tip cloth, excess cloth was allowed to drape over the root shoulder. See Figs. 9.5.3.2*3 and *9

Stage 4

Cloth size 39"/1m. wide x 150" long. (Note: This width of 39" /1m. was due to supply consideration)

The R.S. / T.E. cloth was positioned, allowing a 2" overlap on to the P.F. at the T.E. The tip end of the cloth was allowed to overlap the existing tip cover by 1". At the root end cloth was folded over the root shoulder creating a 1" overlap on to the existing root end piece. See Fig. 9.5.3.2*

Stage 5

Cloth size 39"/1m. wide x 150" long.

The P.F. / T.E. cloth was positioned as shown, draping excess cloth over the T.E. The tip end of the cloth was allowed to overlap the existing tip cover by 1". At the root end the cloth was folded over the root shoulder creating a 1" overlap on to the existing root end piece. See Fig. 9.5.3.2*5

Stage 6

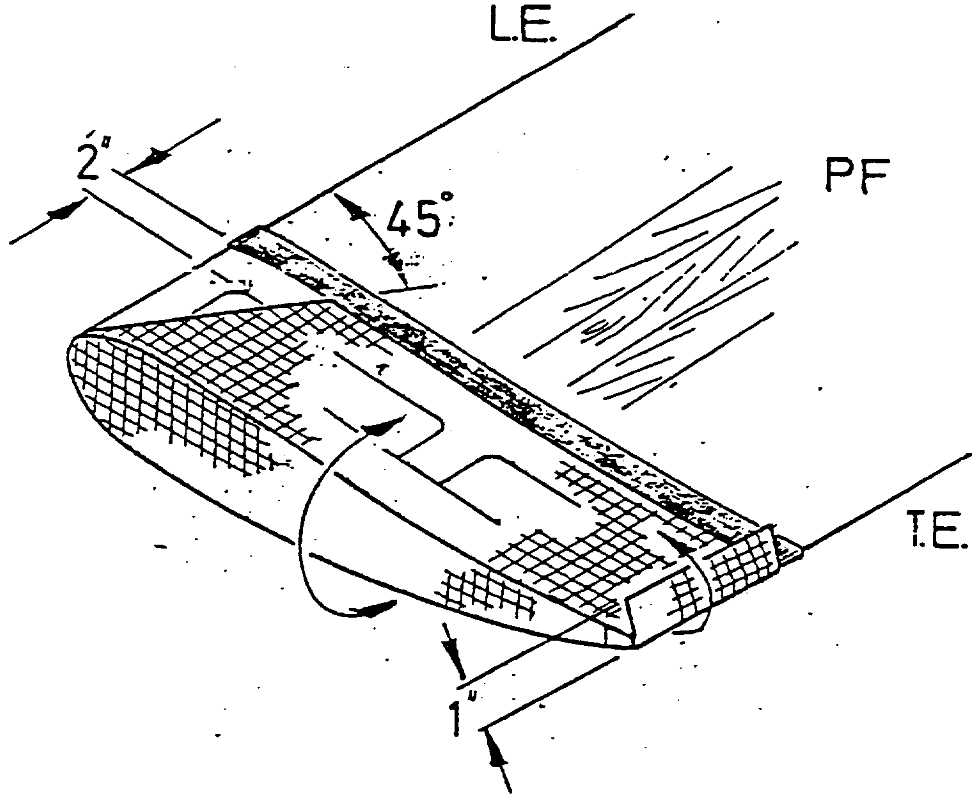
Cloth size 39"/1m. wide x 150" long.

Cloth was layed on to the P.F. and around the L.E. to give an 11" overlap on to the R.S. At the root end the cloth was folded over the root shoulder creating a 1" overlap on to the existing root end pieces. At the tip end the cloth was allowed to overlap the existing tip cover by 1" with a 9" step-out at the L.E. See Fig. 9.5.3.2.*6 During this stage the test sample was prepared. (See Section 9.7.2.6)

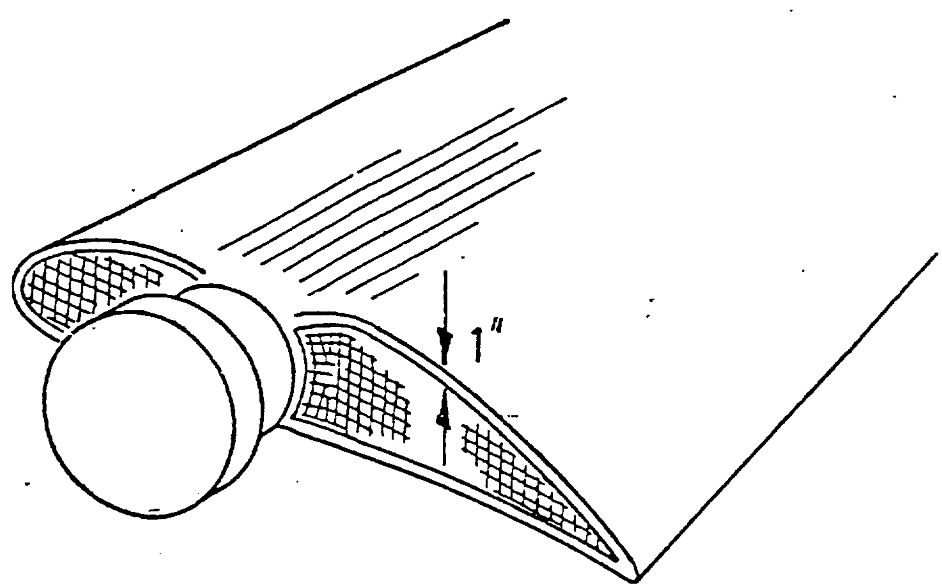
Stage 7

Cloth size 39"/1m. wide x 150" long.

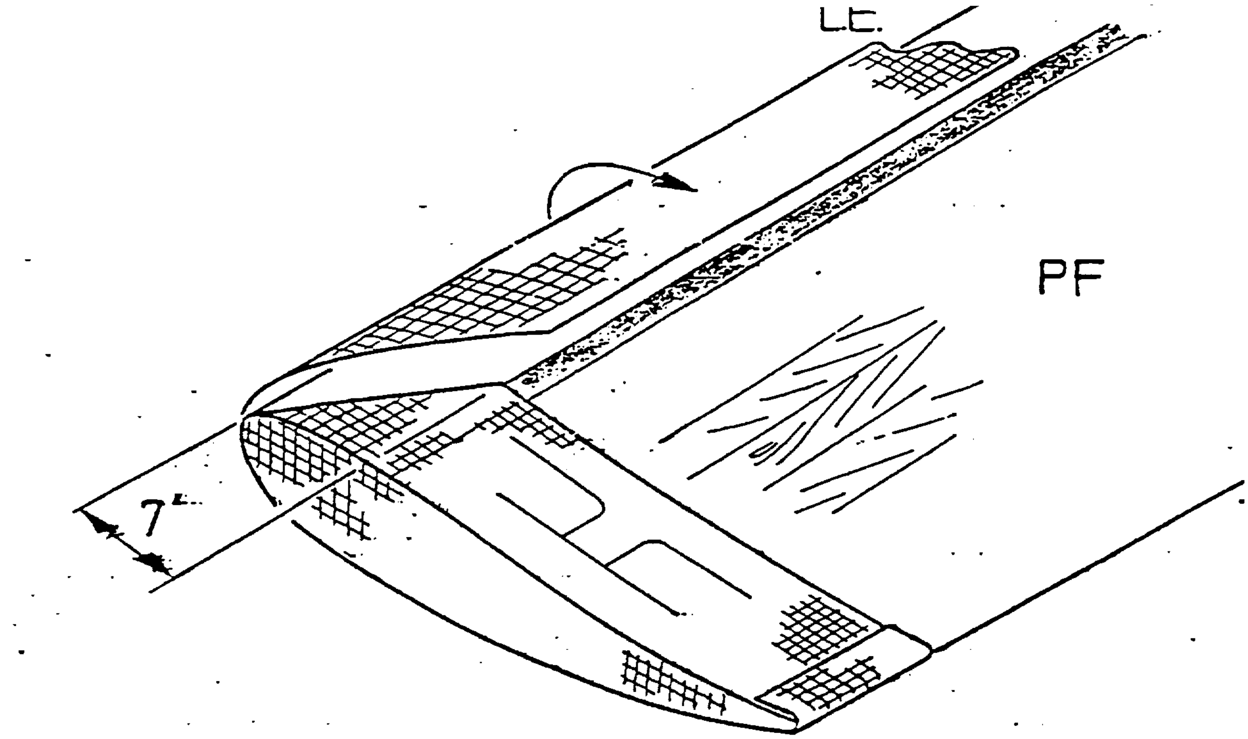
Cloth was layed on to the R.S. with an 11" overlap on to the P.F. At the root end the cloth was folded over the root shoulder creating a 1" overlap on to the exisitng root end pieces. At the tip end the cloth was allowed to overlap the previously applied tip cover by 1" with a 9" step-out at the L.E. See Fig. 9.5.3.2*7.



Glass Cloth Application Stage 1. Fig. 9.5.3.2*1



Glass Cloth Application Stage 2. Fig. 9.5.3.2*2



Glass Cloth Application Stage 3. Fig. 9.5.3.2*3

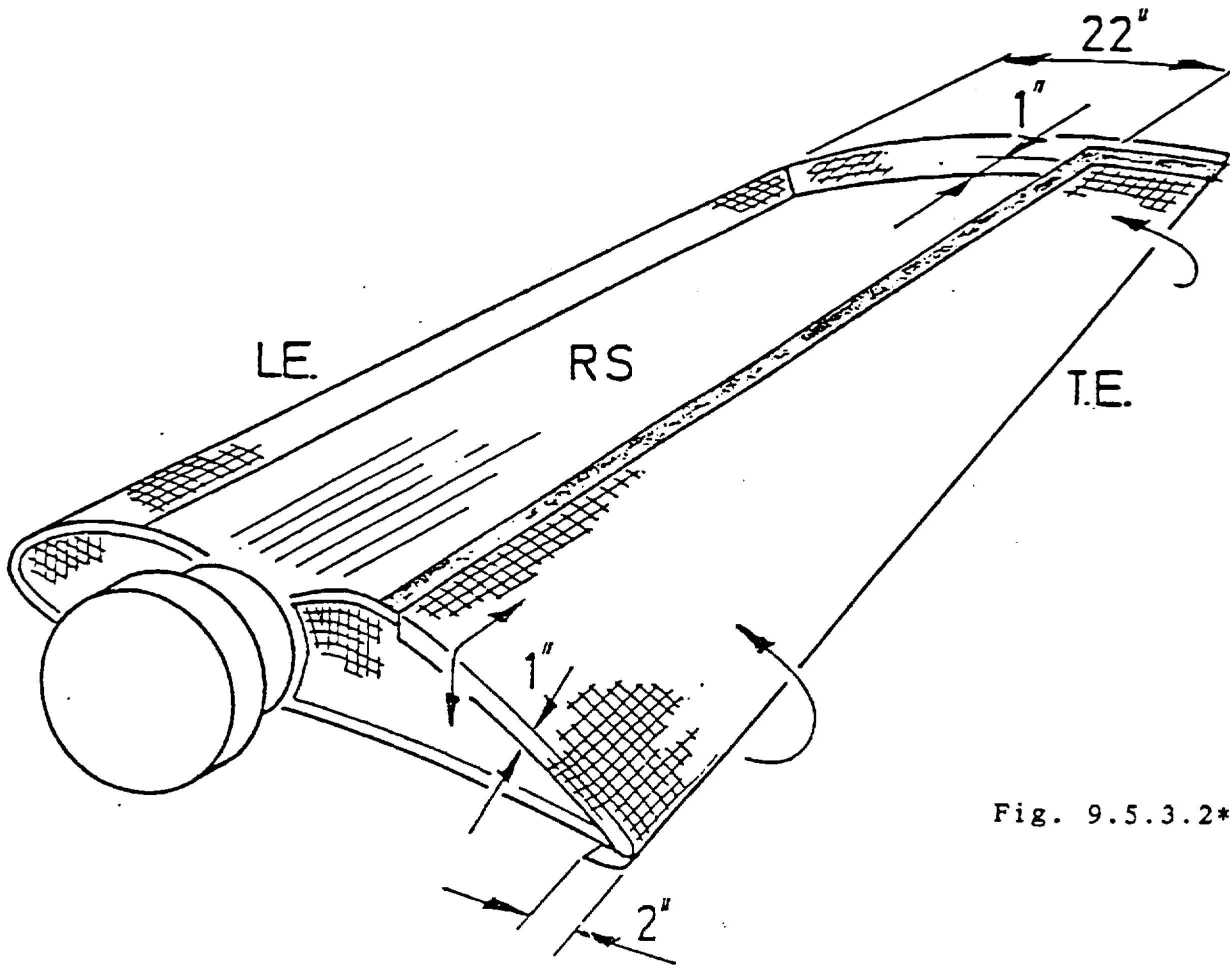
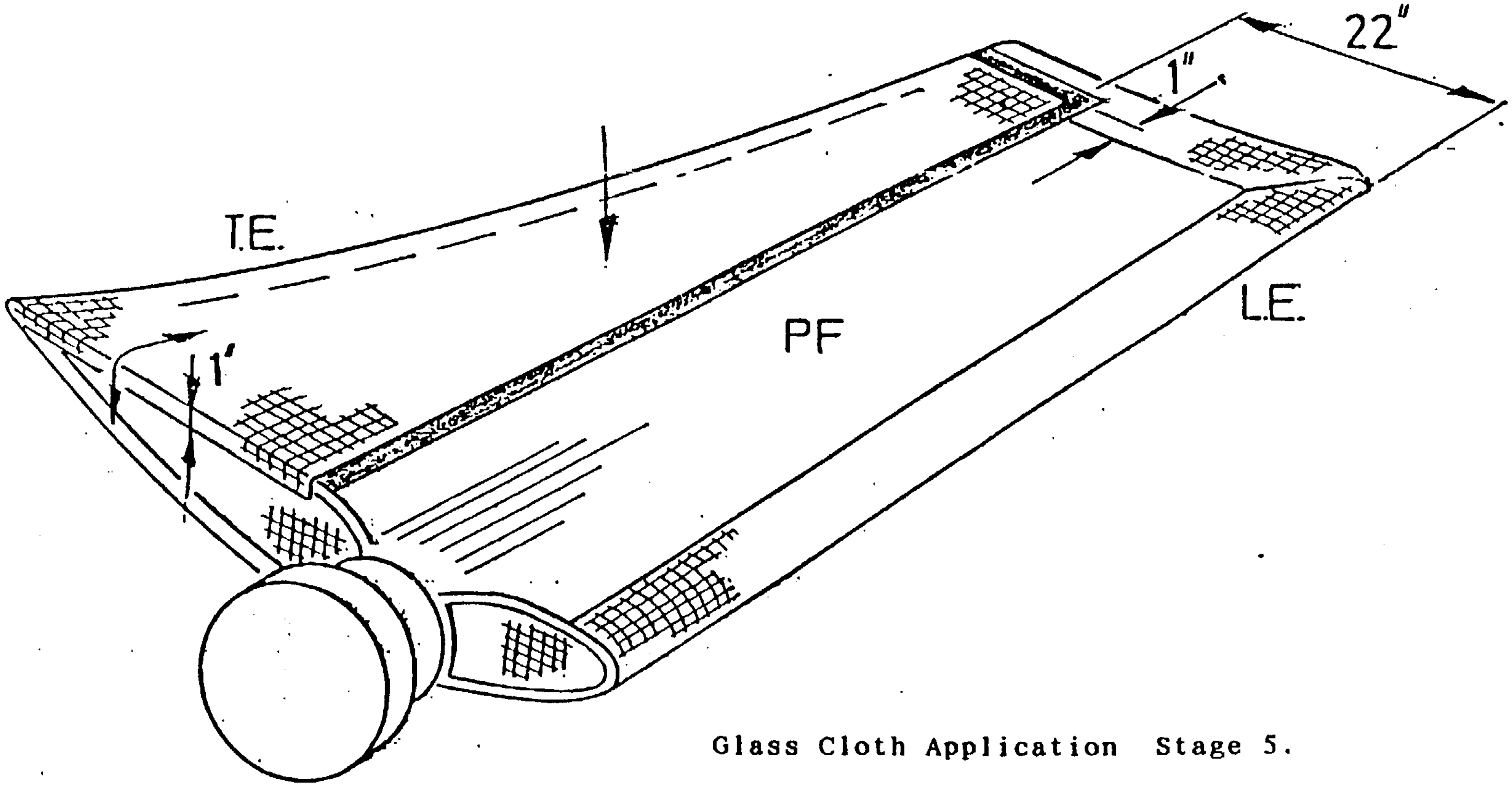


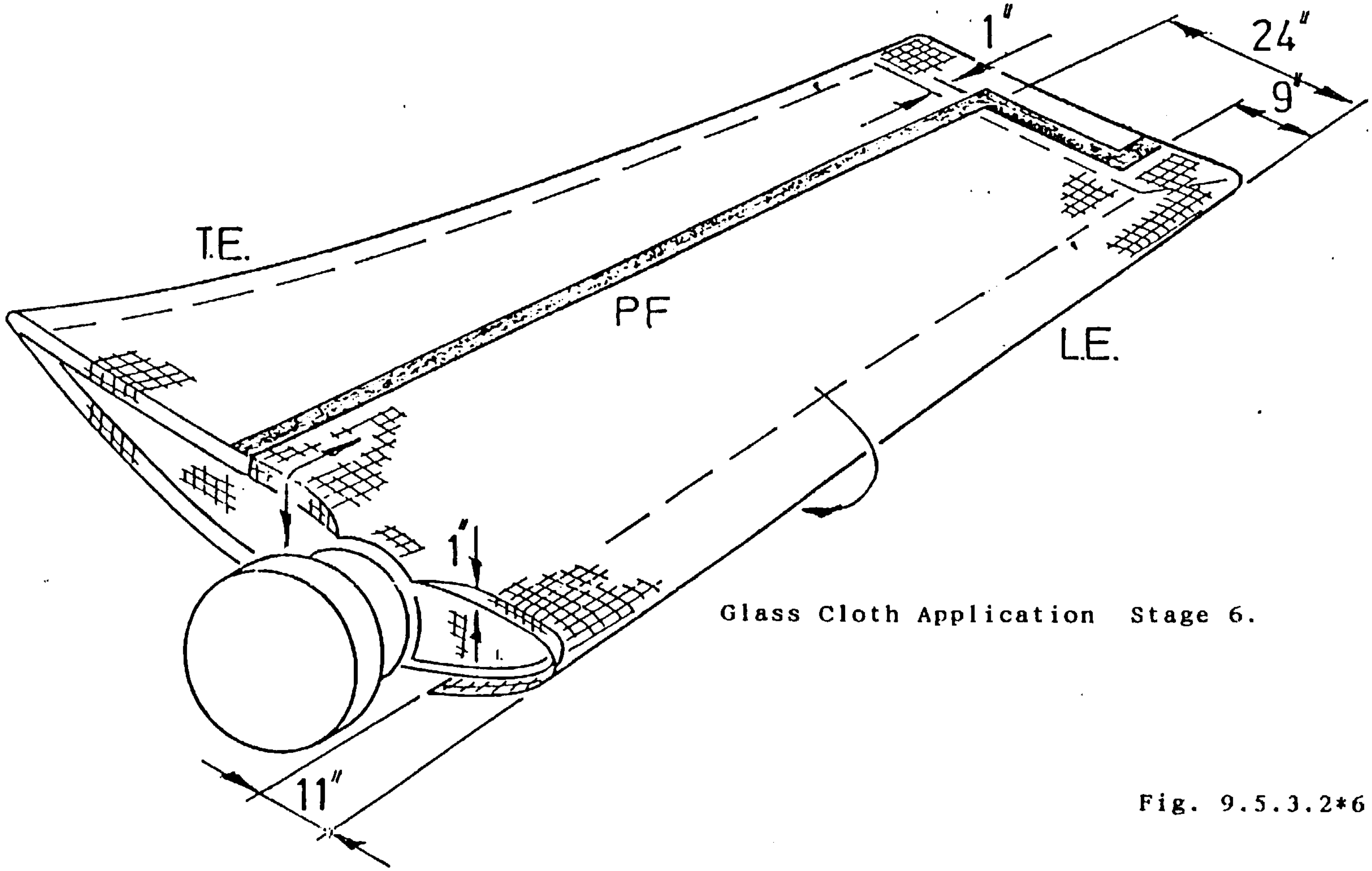
Fig. 9.5.3.2*4

Glass Cloth Application Stage 4.



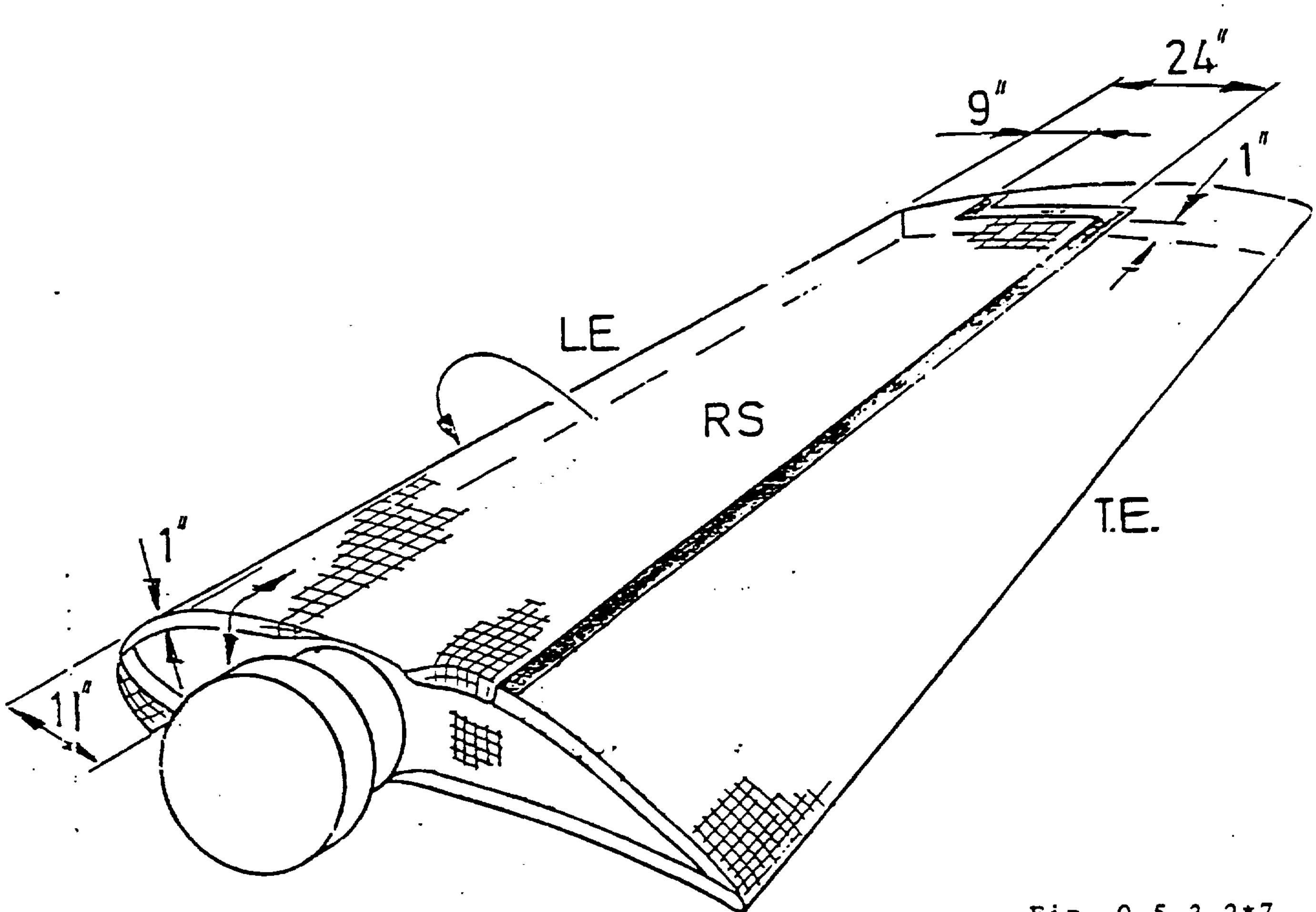
Glass Cloth Application Stage 5.

Fig. 9.5.3.2*5



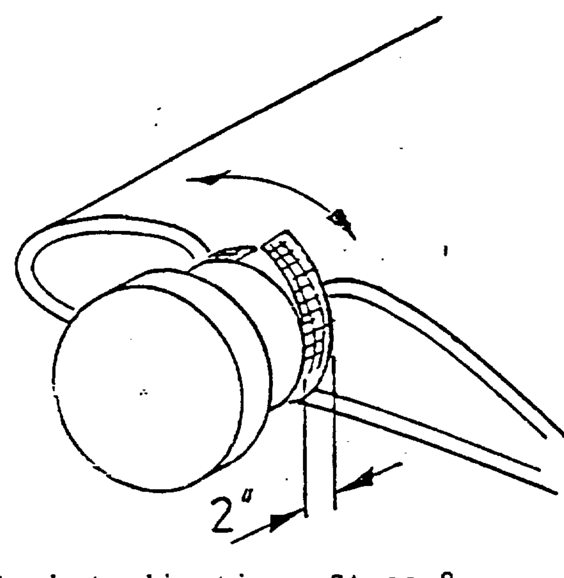
Glass Cloth Application Stage 6.

Fig. 9.5.3.2*6



Glass Cloth Application Stage 7.

Fig. 9.5.3.2*7



Glass Cloth Application Stage 8.

Fig. 9.5.3.2*8

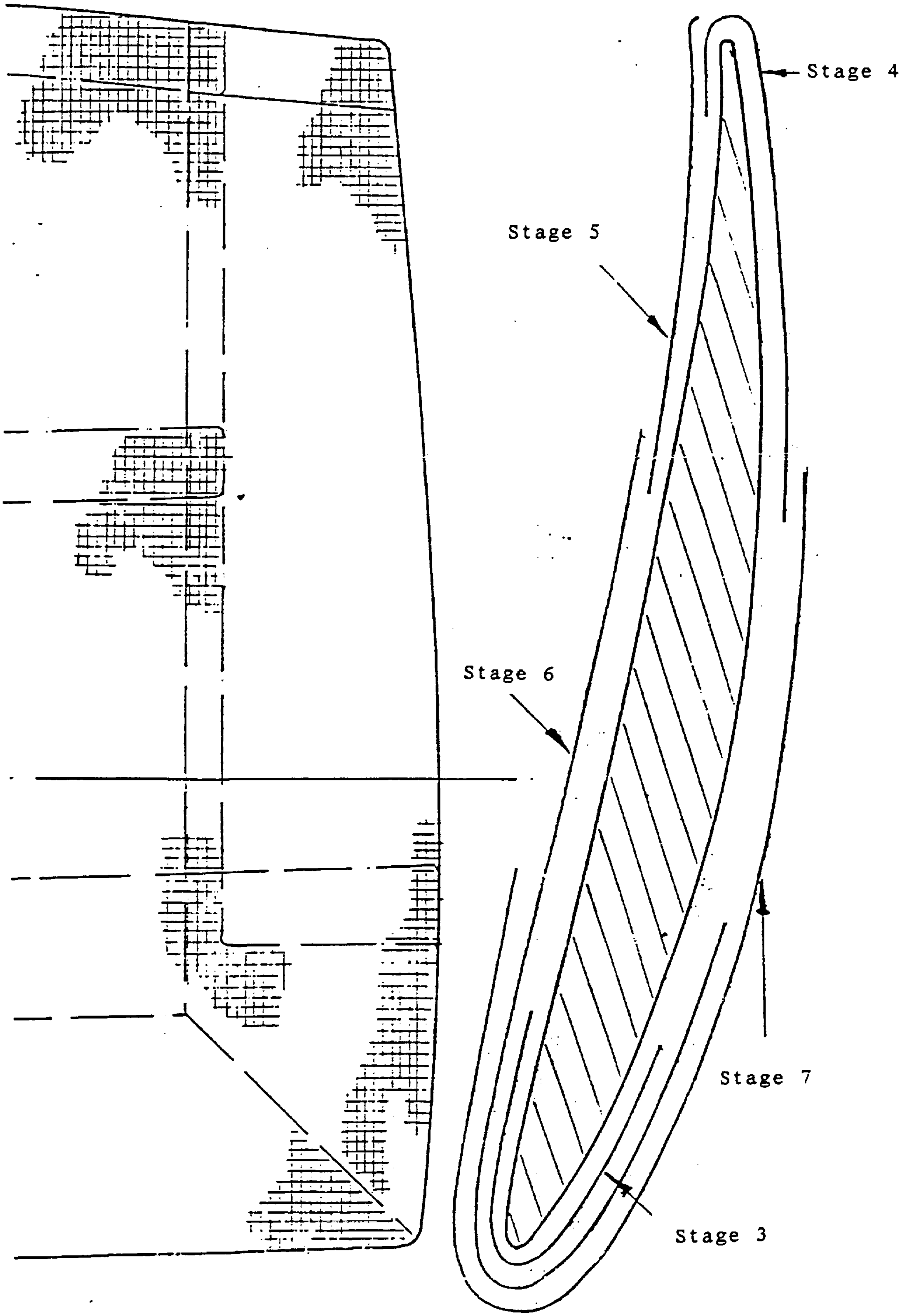


Fig. 9.5.3.2*9

Stage 8

Cloth size 2" wide x 40" long.

A root collar 2" wide was wrapped around the mouth of the adaptor. See Fig. 9.5.3.2*8 and Fig. 9.5.3.2*9 for further details.

9.6 Balancing

It is, of course, necessary that the completed fan be balanced as accurately as possible. This involves both dynamic and aerodynamic balancing.

9.6.1 Integral Blades

For 2 and 4 blade integral fans the balance feature is under the direct control of the blade manufacturer. The process starts at the block stage (see Section 9.2.5.) and continues with the White Shape stage. It is normal to endeavour first to shape all (either the 2 or 4 blades) to the maximum design limits and then make a balance check.(See Section 9.6.3.) If an acceptable balance tolerance is not achieved it is then possible to reduce the heaviest (heavier) blade below the maximum limits to reduce its weight so that the balance moment difference may be reduced or eliminated. If this method does not achieve a correct balance (within the final acceptable design tolerance) consideration will have to be given to the amount of balance change that will be available at the covering or finishing stage. For small blades it is usually found that extra coats of finishing resin or paint that can be applied will be sufficient to give a final acceptable design balance value.

Aerodynamic balance is catered for by the design tolerances of the dimensions of the blade sections.

9.6.2 Detachable Blades

For detachable blades it is always preferable that the blades of a fan or even a series of the same type of fan have the same or master balance moment value. Unfortunately this is usually very difficult to achieve or sometimes impossible merely by use of the shaping tolerances. Consideration should be given to the following possibilities.

For a one-off detachable bladed fan with a limited number of blades, possibly only 2, 4 or 8, as for integral fans the balance process must start at the lams and block stages. It is advisable to process each stage of the production on the whole batch of blades at the same time so that lam selection and then dry block balancing for all the batch can be undertaken together. This will enable the glued blocks of the batch to be maintained within reasonable limits of each other.

It is preferable that the first block selected to be shaped should be the one with the heaviest balance moment. This can then be shaped as with integral blades to the maximum dimension limits and become the most likely heaviest moment achievable by the batch.

As subsequent blades are shaped and their balance moments determined the range of tolerances for the batch will be established. Eventually the blade with the lowest balance moment will be found. At this stage the heaviest blade will need to be assessed and it will be necessary to establish by how much this blade can be reduced in moment by shaping down.

This method will usually result in the batch of blades being within reasonable (and acceptable) limits of balance moment for the white shape stage so that the covering and finishing processes can be used to complete the balancing pocedure to achieve final balance.

However the above method assumes that the batch of blades is small (ususally 8 or less) which is not always practical from a manufacturing point of view if a large batch number is to be manufatured at any one time.

Permali has been involved with a number of contracts where the order size has been 40, or even 100 blades of the same design. It was found to be impossible to arange the manufacturing sequences to cater for batches of this size so that smaller batch sizes (approximately 10) were processed at the same time. This then required that although the above balance procedure was adopted, the resultant batch balance moments were required to be the same for each batch. As before aerodynamic balance is achieved by keeping within the dimensional tolerances laid down at the manufacturing design stage.

9.6.3 Balance Moment Measurement Methods

Small integral 2 and 4 blade fans may have their balance checked by attaching a circular shaft through the centre hole and then placing the assembly on to a Balance Fixture consisting of two parallel and horizontal bars or knife edges held rigidly at a convenient height to give clearance above the floor or over a pit. To cater for various sizes of centre holes for different fans the balance shaft should be provided with two adjustable Cone Sleeves that may be pushed into the fan centre hole. See Fig. 9.6.3*1.

The balance fixture must be rigidly fixed to a stable floor and the bars or knife edges kept truly horizontal.

The measurement of any out-of-balance moment is achieved by the use of a "Spider" assembly. This assembly consisting of a centre collar with 4 rods at right angles is fitted on to the balance shaft. The rods, approximately 15 in. (400 mm.)

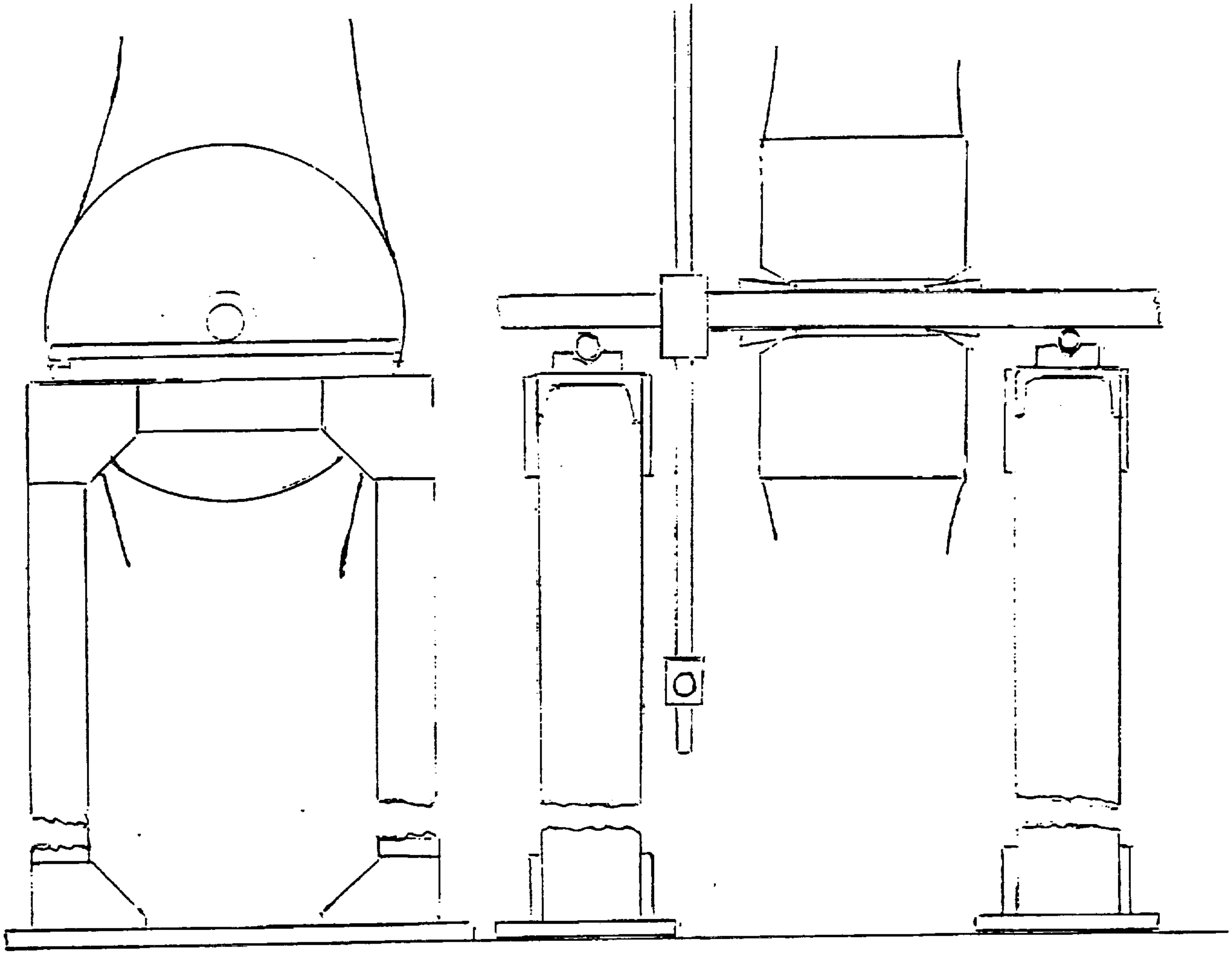
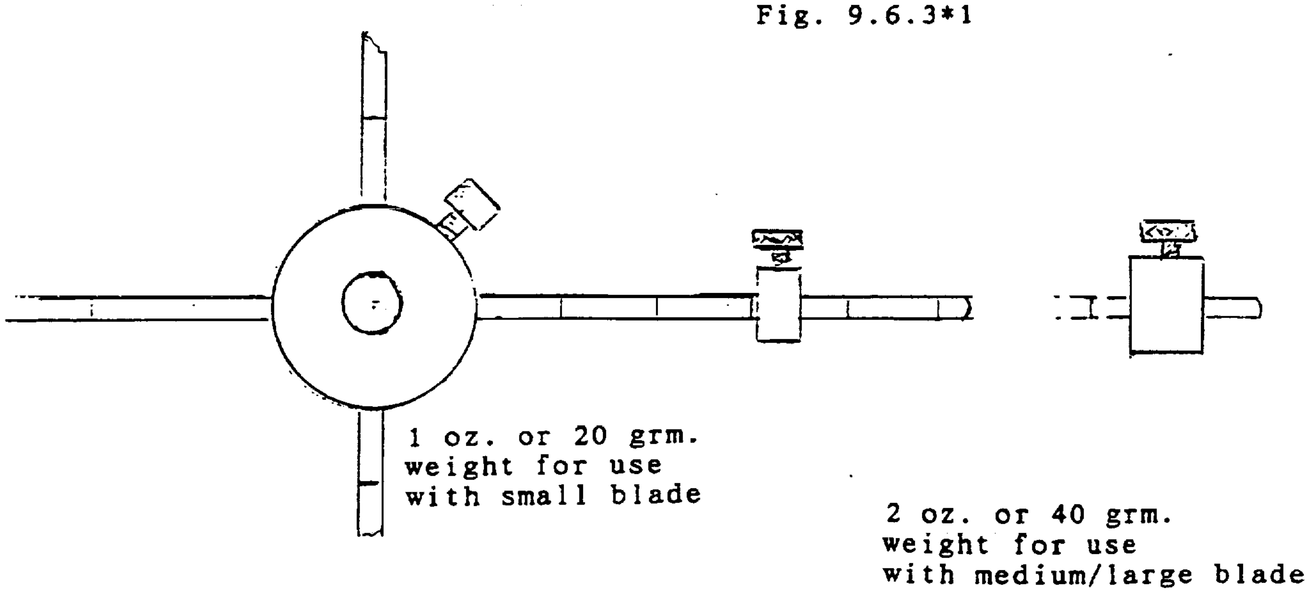


Fig. 9.6.3*1



Balance Spider

Fig. 9.6.3*2

long carry small adjustable weights that may be slid along and then retained by hand screws on one of the rods in a position to give a true balance of the assembled unit (fan, balance shaft and spider) See Fig. 9.6.3*2.

For practical convenience the small weights should be either 1 oz. or 20 gm. with the spider rods marked from the centre of the balance shaft every 1/2 in. or 10 mm., enabling direct readings within every 1/2 in-oz. or 200 mm-gm. of the out-of-balance moment.

Integral 2 blade fans need to have a balance check first with the blade in a horizontal position and then with the blade in a vertical position.

Integral 4 blade fans need to have a balance check with each of the pair of blades horizontal.

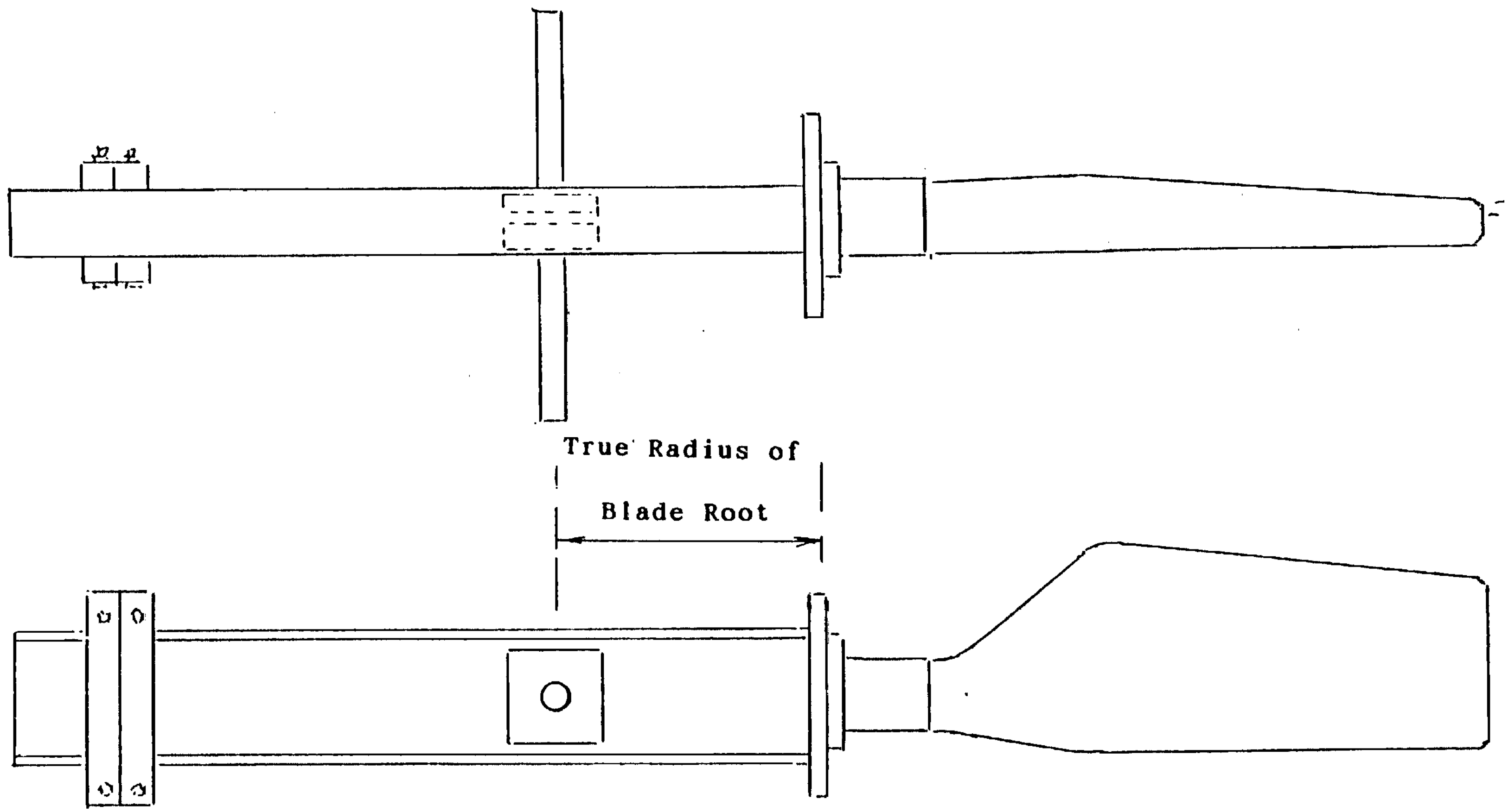
For single detachable blades a corresponding system may be used but this then requires a suitable Balance Frame, one end of which requires to have a replica or substitute for the fan hub to which the test blade can be fitted. The opposite end needs to be weighted to counter balance the test blade. It is preferrable that the counter weight be adjustable for different designs of blades.

The same or similar measurement spider as for the integral blade balance fixture is also required, although it may be helpful if some what larger adjustable weights are available when large blades are tested. See Fig. 9.6.3*3.

The main disadvantage of this method for medium and large blades is that the balance frame usually needs to be a special piece of equipment for any particular design and with large blades the centre balance shaft needs to be at the appropriate position to simulate the centre of rotation of the fan. These requirements makes the frame rather large. Consequently the balance fixture has to have the horizontal bars or knife edges at a substantial height above any floor (or a pit) to give clearance for the counter weight arm when either of the vertical balance moments are measured.

An additional feature that would be required on the balance frame is for the blade attachment to be moveable so that the test blade may be rotated through 90 degrees for both vertical (chordwise and axial) balance moments to be determined.

Another practical disadvantage for the use of such a balance frame for very large blades is the consequent handling difficulties. It can be extremely difficult to hold such a heavy balance frame, already placed on the balance fixture, in a rigid position while the test blade is then moved and attached on to the the frame.



Counter Balance Weights
to suit

Single Blade Balance Rig

Fig. 9.6.3*3

Alternatively if it is more convenient for the balance frame to be held in a position away from the balance fixture for fitment of the test blade, then moving the whole assembly (test blade affixed to balance frame) back to the balance fixture can become a handling problem.

Another alternative method, particularly applicable for very large blades can be used. This is in effect a means by which the weight and centre of gravity of the test blade can be found in one operation.

A special balance frame is required for variable pitch blades but such a frame can be made to cater for more than one design. This balance frame requires a blade holding fixture (preferably able to be rotated through 90 degrees) at the end of a balance arm with two cross arms, the ends of which may be hung from supports standing on two standard weighing machines. The balance arm should be provided with a weight pan.

After attachment of the test blade, the rig is balanced into a horizontal position by the addition of weights to the pan, then 3 measurements are taken, the two scale readings and the pan weight. This procedure is carried out for the two positions of the test blade, with the chord horizontal and the chord vertical. The resultant 5 readings (although 6 are taken the pan weight for both cases are the same) enables the blade weight and the position of the centre of gravity to be calculated. (Of course intially readings are required to determine the effect of the balance frame to give a zero from which the blade readings alone must be assessed.) (See Fig. 9.6.3*4 and Fig. 9.6.3.*5). Note: The dimensions shown in these Figs. refer to the Y-Frame used for the Ames project.

A suitable computer program was written for this Ames project so that by inputting the 5 weight readings obtained, the out put gave the required values for the blade weight, the position of the Centre of Gravity and the balance moments. Examples of the "output" sheets are shown as Balance Data Sheets 9.6.3*6 and 9.6.3*7.

9.7 Workshop Inspection

9.7.1 Personnel Organisation

For the satisfactory manufacture of windtunnel fan blades the manufacturing company should have an appropriate Inspection capability. The requirements are that an Inspector independent of the manufacturing department should be capable and allowed to assess that all operations are carried out to the required standard as specified and that the dimensional limits of components are maintained. The Inspector must be able to keep appropriate records and information.

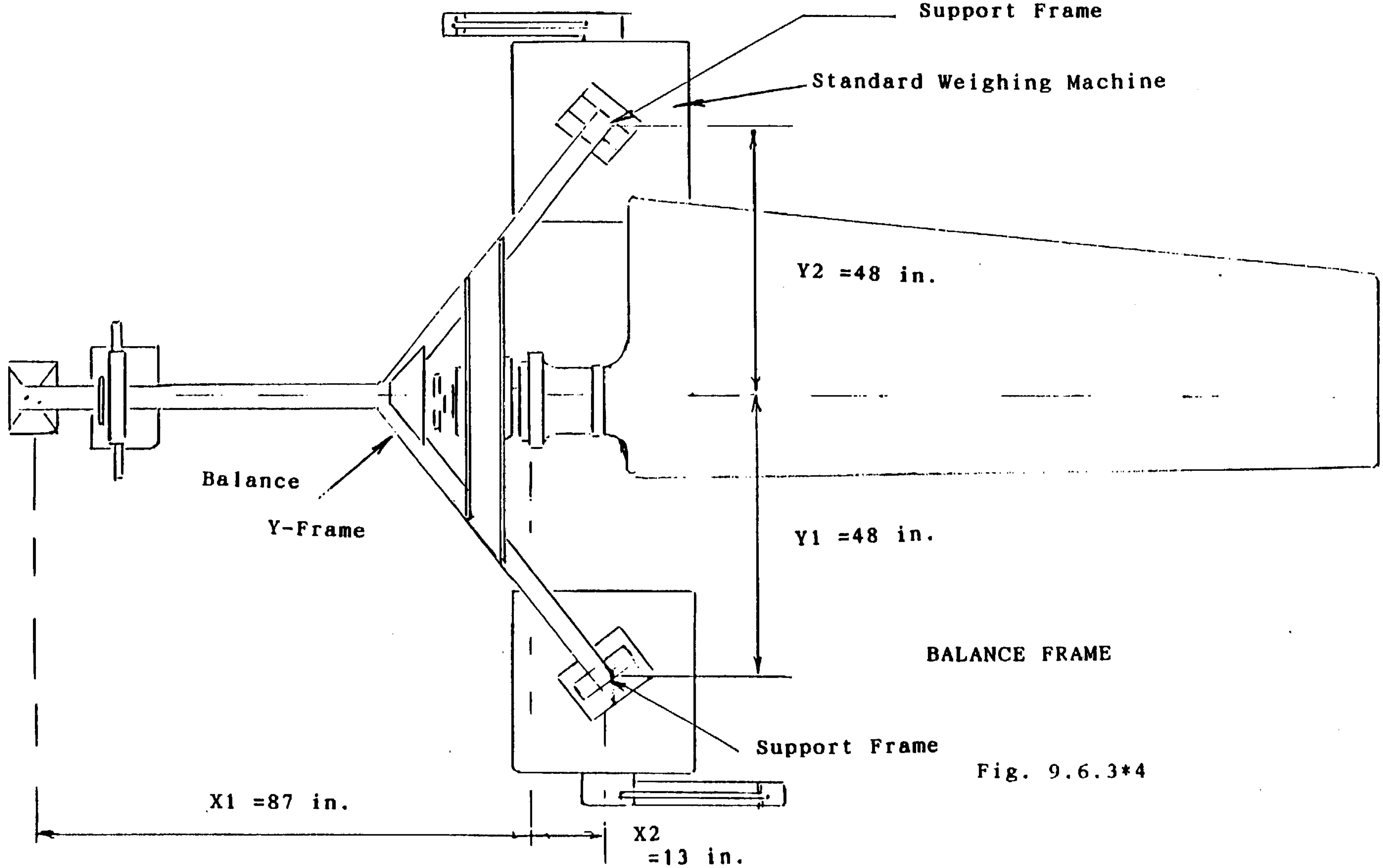

Support Frame
Standard Weighing Machine
Y2 =48 in.
Balance
Y-Frame
Y1 =48 in.
BALANCE FRAME
Support Frame
X1 =87 in.
X2
=13 in.

Fig. 9.6.3*4

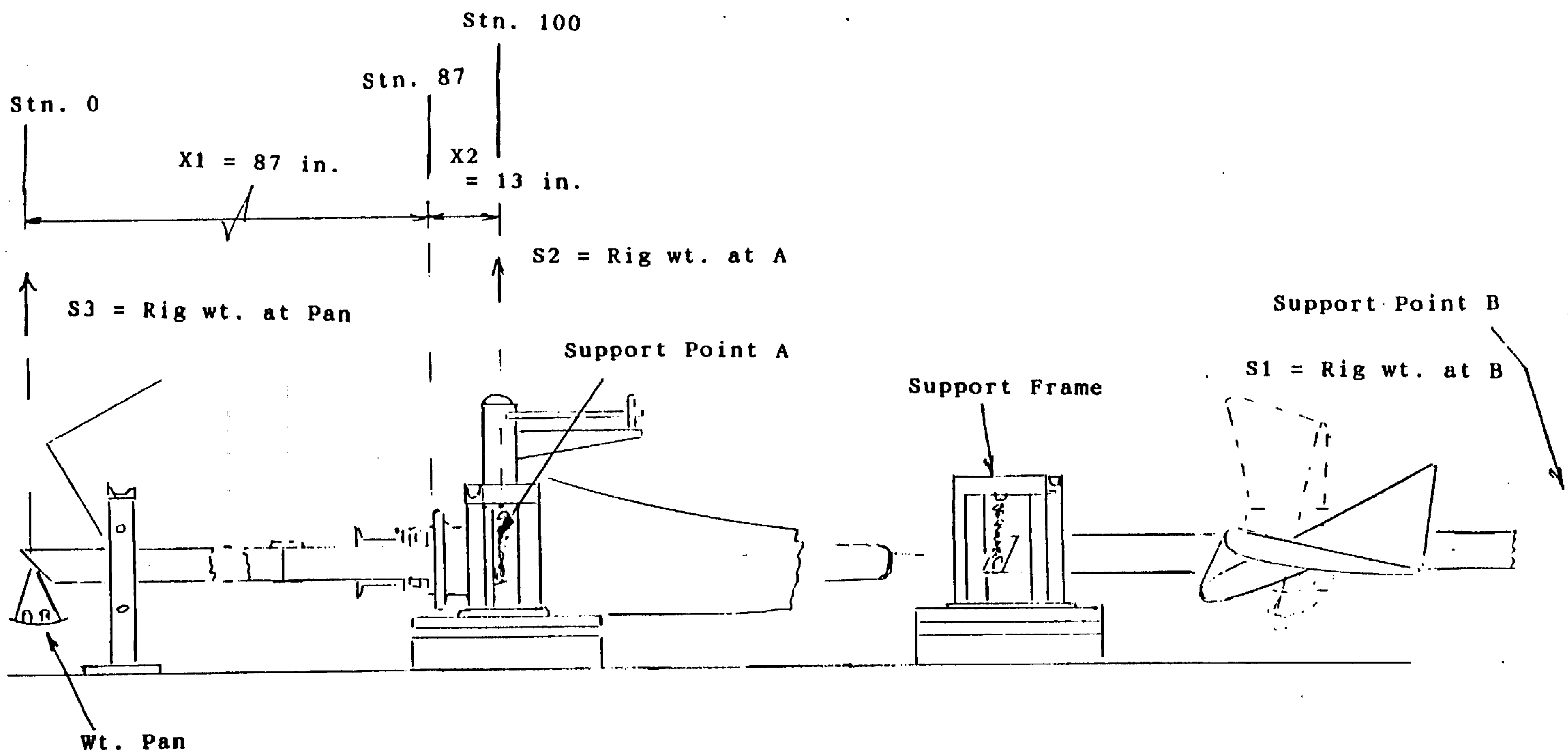

Stn. 100
Stn. 87
Stn. 0
X1 = 87 in.
X2
= 13 in.
S2 = Rig wt. at A
S3 = Rig wt. at Pan
Support Point B
Support Point A
S1 = Rig wt. at B
Support Frame
Wt. Pan

Fig. 9.6.3*5

Permali Gloucester

NASA-Ames Fan Project 1983/84

FINAL BALANCE RECORD

NAB Nº	195
84/SET Nº	7

NAB	195	
SB		
LE. SCALE	347.9	kgs.
TE. SCALE	352.0	kgs.
PF. SCALE	350.8	kgs.
RS. SCALE	349.1	kgs.
PAN WT.	16.7	kgs.
STANDARD	7	
BALANCE WT.	2.86	lbs.
ANGLE	7	deg's.
RADIUS	5.99	ins.

Nº OF WTS	3
Nº 1 WT.	2
at	12
Nº 2 WT.	W
at	5
Nº 3 WT.	1
at	1
Nº 4 WT.	
at	
Nº 5 WT.	
at	
Nº 6 WT.	
at	

	NETT	GROSS
BLADE WT lbs	745.1	822.9

C of G POSITION

	NETT	GROSS
RADIAL ins	128.5	124.6
CHORDWISE "	.69	.62
THICKNESS "	-.14	-.03

MOMENT ERROR

	NETT	GROSS
RADIAL in-lbs	-261	-2
CHORDWISE "	10	0
THICKNESS "	-14	0

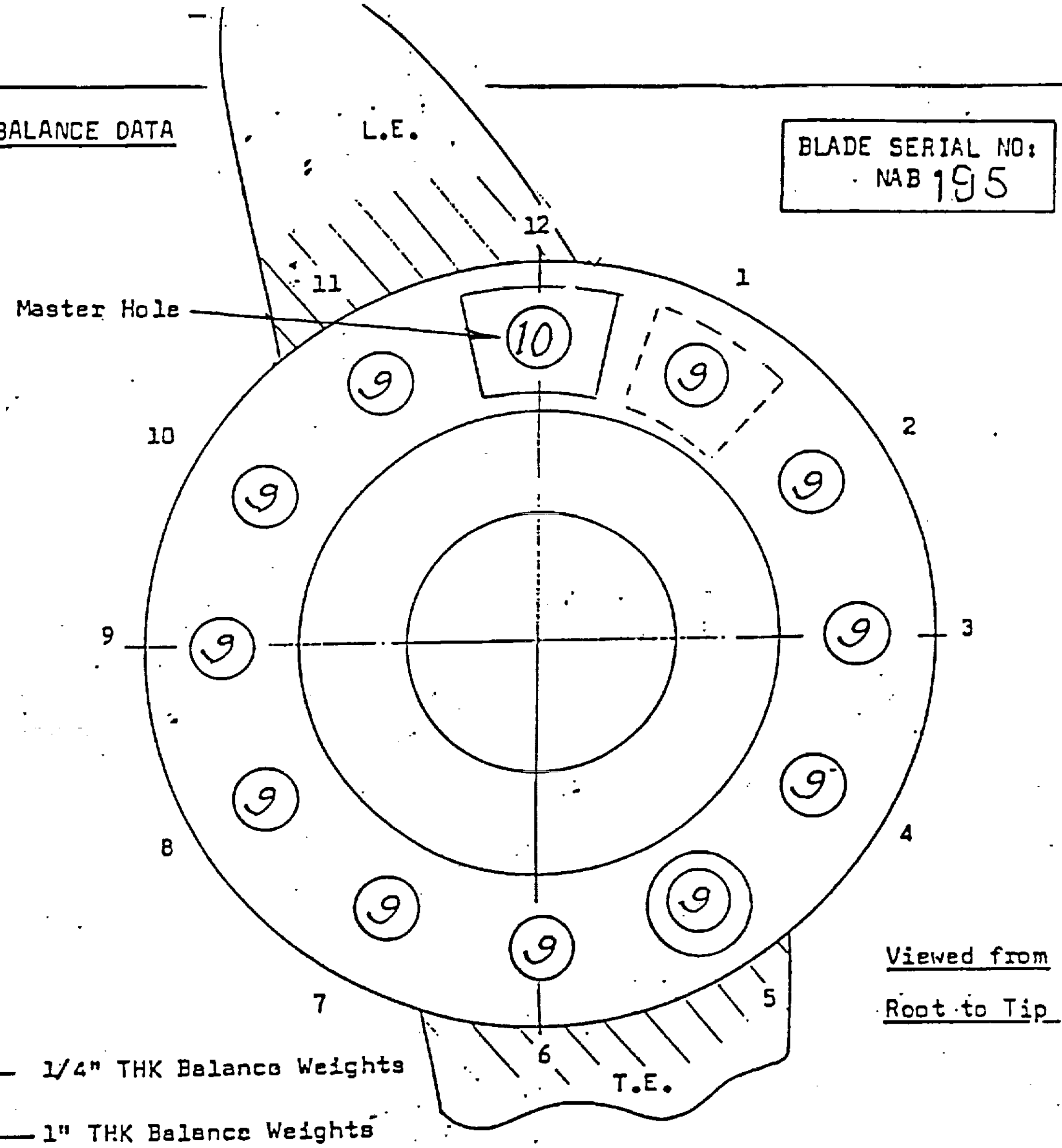
ITEM Nº	
BATCH Nº	

Balance Data Sheet 9.6.3*6

DATE : 18 FEB 85

BALANCE DATA

BLADE SERIAL NO:
NAB 195



- - - 1/4" THK Balance Weights

——— 1" THK Balance Weights

QTY PER BLADE

11	9" long DRG: HRF 2064 ITEM 1A
1	10" long DRG: HRF 2064 ITEM 1B
—	~~11" long DRG: HRF 2064 ITEM 1C~~
1	DRG: HRF 2063 ITEM 1 - 0.44 lb
1	DRG: HRF 2063 ITEM 2 - 1.78 lb
—	~~DRG: HRF 2063 ITEM 3 - 1.01 lb~~
—	~~DRG: HRF 2063 ITEM 4 - 4.25 lb~~
—	~~DRG: HRF 2063 ITEM 5 - 1.50 lb~~
—	~~DRG: HRF 2063 ITEM 6 - 6.50 lb~~
Extra Balance Washer: 1	DRG: HRF 2064 ITEM W - 0.20 lb

Balance Data Sheet 9.6.3*7

It may be more appropriate if some functions and/or tests are carried out by Laboratory or Test House personnel, (as distinct from purely Inspection Department staff). In this case the same conditions should apply to both Departments.

In subsequent text reference to "the Inspector" should be taken as including any Test House personnel, if appropriate.

9.7.2 Material Checks

All in-coming materials should be checked by the Inspector as being certified by the suplier to the agreed specification.

Of course the main material, the actual raw wood, is the most important and must be certified to being to its required standard. As well as being the most important it is usually the most difficult material to judge, as an appropriate standard cannot be specified solely in relation to strict dimensional checks. Physical tests are a means of assessing some properties, but any destructive test (such as tensile, compressive or shear tests) can only be used on representative samples that are taken from adjacent or nearby material from the batch or board to that actually used. Further information is given in Section 6.2.

9.7.3 Lams and Block Preparation

9.7.3.1 Gluing

All gluing processes should be recorded by the Inspector as conforming to the required specification. Records of Shop Temperature and Humidity should be made.

Samples of surplus glue from a process should be retained for at least one day and then checked to ascertain that the glue has fully cured.

The majority of gluing operations should also be checked by removing from excess material of the work piece a sample which may be processed into suitable shear cubes that may then be tested, using apparatus as shown in Fig. 6.3.4*3 so that the glue line is postioned in the critical zone. Such cubes should fail in the material and not show a glue line failure.

9.7.3.2 Lams

Lams should be checked for dimensional size before being released for gluing. This can be carried out with the use of the corresponding lam patterns.

The last process for the manufacture of lams is that of planing to final thickness. This will then show the actual gluing surface and may reveal minor surface defects previously internal to the lam.

All lam surfaces must be examied to ensure that no such defects are included in a finished block. (The repair procedure for defects, if appropriate, is shown in Section 10).

A sample of a suitable History Sheet for Lam Manufacture is given as Fig. 9.7.3.2*1.

9.7.3.3 Block Gluing

During the Block Gluing stage it is most important that a check be made that all glue lines are less than the recommended thickness. Refer to Section 9.3.3. for details of Block Gluing and the method of carrying out this check.

A sample of a suitable History Sheet for Block Gluing is given as Fig. 9.7.3.3*1.

9.7.4 Dimensional Records (White Shape)

9.7.4.1 Chords

The limits for the chord dimensions will be laid down on the Workshop Drawing (Ref:13.2.49) Measurement of each defined chord value will need to be taken. For small or medium sized blades chords may be measured by standard caliper gauge, but large blades (with correspondingly large chords) may need alternative equipment. Templates (for chord measurement) may be appropriate but this approach is not all that convenient for providing the final dimensions achieved that need to be recorded. A typical example for such a template/gauge is shown in Fig. 9.7.4.1*1.

A sample of a suitable History Sheet for White shape is given as Fig. 9.7.4.1*2.

9.7.4.2 Section Thickness

Similar conditions apply for measuring and recording the Section Thickness as for the chords. Small or medium sized blade with flat under (or pitch) faced sections may be measured directly with (long jawed) calipers, but large blades are not readily dealt with by this method as the maximum thickness position is usually beyond the reach of standard (even long jawed) calipers. It is usually more convenient to produce special thickness gauges for such cases. For blades with

Inspection Department History Sheet

FAN BLADE | LAMINATION MANUFACTURE

DRAWING NO. ________ SERIAL NO ________

OPERATION/PROCESS	DATE	INSPECTOR	MANUFACTURERS/ MATERIAL REF
Inspection of Timber after preliminary planing.			
Edge glueing of boards			Glue Ref Hardener Ref
Planing to thickness			
Cut to lamination profile			Lam No

REMARKS:

Fig. 9.7.3.2*1

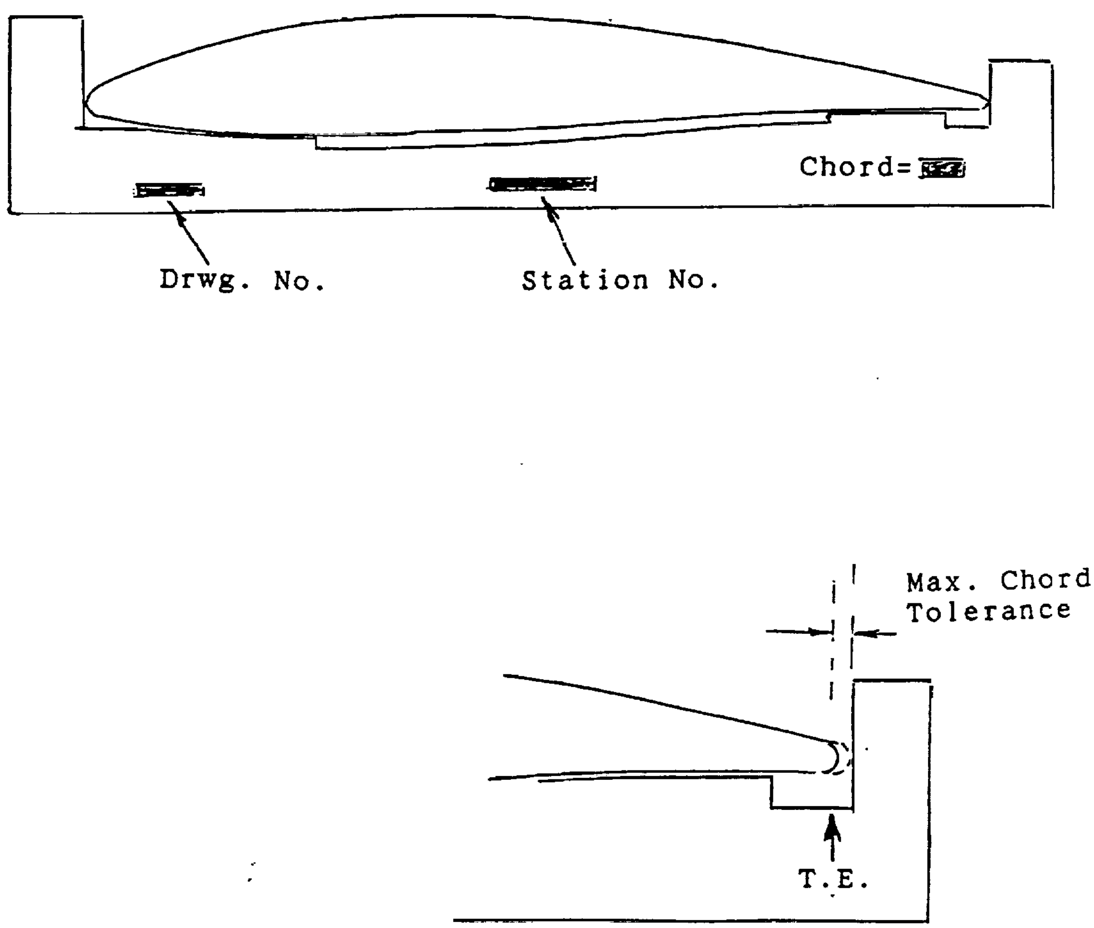
Inspection Department History Sheet

FAN BLADE BLOCK GLUEING

DRAWING NO. SERIAL NO.

LAM NO	SERIAL NO	INSPECTOR	MANUFACTURERS/ MATERIAL REF.
1			
2			Glue Ref
3			
4			
5			Hardener Ref
6			
7			
8			Date
9			
10			
11			Time In
12			Time Out
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			

Fig. 9.7.3.3*1



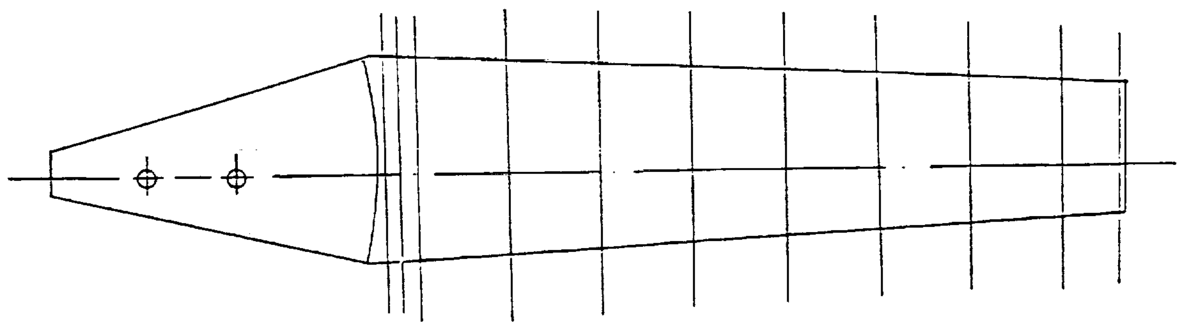
Expanded View of T.E.

Fig. 9.7.4.1*1

Inspection Department History Sheet.

FAN BLADE	WHITE SHAPE INSPECTION
DRAWING NO.	SERIAL REF:

OPERATION/PROCESS	DATE	INSPECTOR	COMMENTS
Check Pitch Face Set Up			
Check Pitch Face White Shape Sections			



OPERATION/PROCESS	DATE	INSPECTOR	COMMENTS
Check Round Side Set Up			
Check Round Side White Shape Sections			

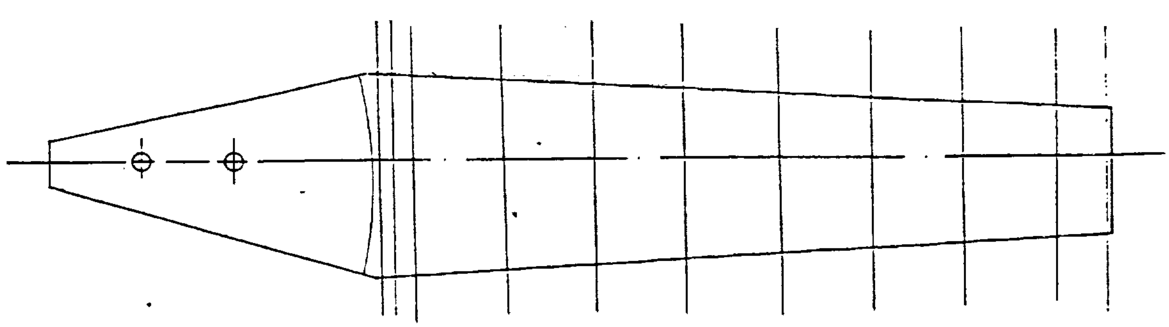


Fig. 9.7.4.1*2

concave surfaces caliper measurements are rarely satisfactory and special gauges are always preferred. A typical example of an appropriate gauge is shown in Fig. 9.7.4.2*1.

9.7.4.3 Section Angles

All section angles need to be checked and the measurements recorded by the Inspector.

Except for flat pitch face sections, it is usually necessary to have available special templates for measuring section angles. Templates for this purpose can be similar (or identical) to those used in the "White Shape" shaping process. See Section 9.4.

9.7.4.4 Section Shape

For non-machined shaped blades the section shape needs to be checked by the use of approved section templates. An inspection set of cloaking templates should be made available and reserved for this operation. These templates should be in the form as shown in Fig. 9.7.4.3*1 manufactured to the top limits specified. The exact dimension may then be deduced with the use of standard feeler gauges.

9.7.4.5 Section Position

The section Position needs to be ascertained. Theoretically the Section Position is specified as a relationship of its C. of G. point to the Radial Axis. However the C. of G. point at any section is only at a position internal to the blade and so cannot be directly located.

For small and medium blades, it is possible to use the equivalent methods as for manufacture (see Figs. 9.4.1*3 to *6) with special templates reserved for inspection use if necessary. For large blades with rectangular roots similar conditions apply using templates as shown in Fig. 9.4.2*1.

For blades with circular roots and adaptors it is usually convenient to have a special head stock to hold the adaptor so that the blade may be turned to make any station Section angle parallel to the table and direct measurements may be more readily taken. See Fig. 9.7.4.5*1.

A sample of a suitable History Sheet for White Shape is given as Fig. 9.7.4.1*2.

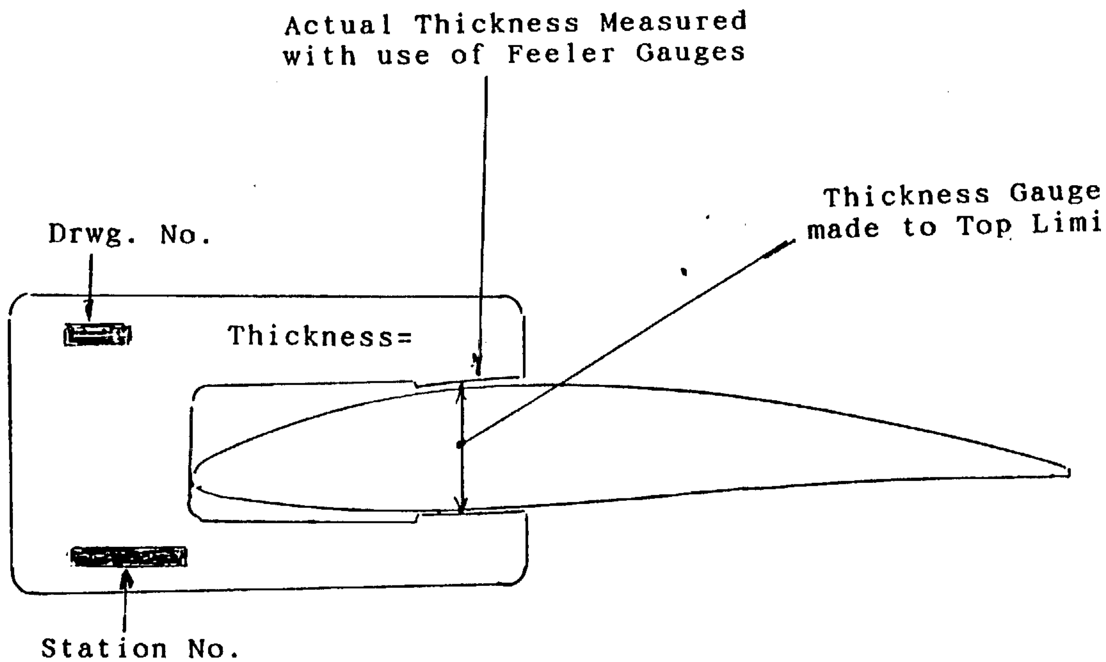
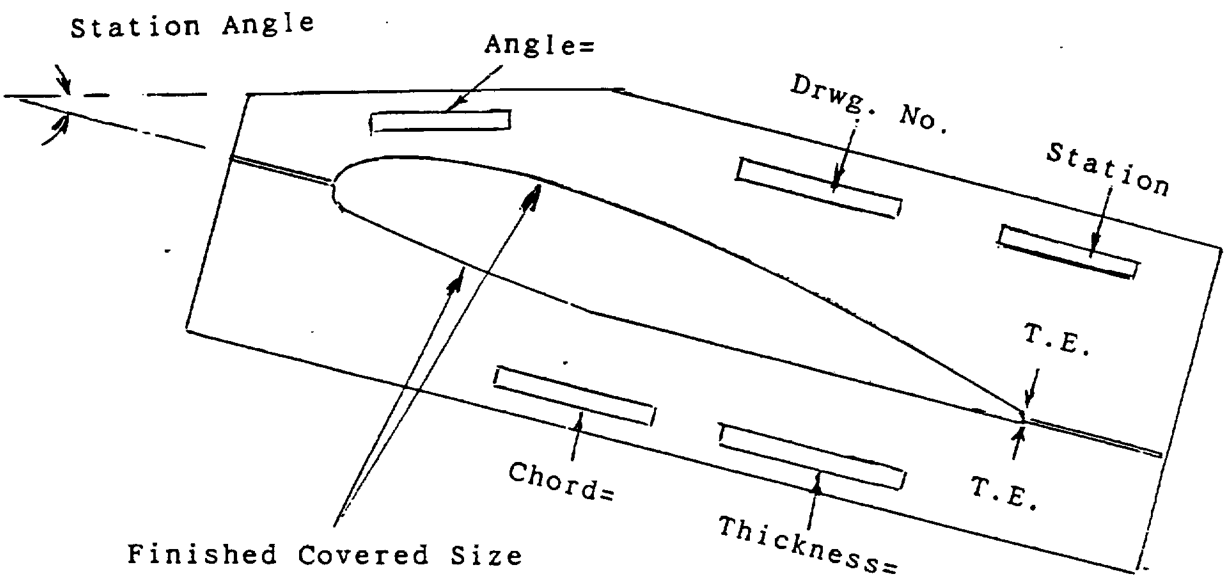

Actual Thickness Measured
with use of Feeler Gauges
Thickness Gauge
made to Top Limit
Drwg. No.
Thickness=
Station No.

Fig. 9.7.4.2*1


Station Angle
Angle=
Drwg. No.
Station
T.E.
Chord=
T.E.
Thickness=
Finished Covered Size

· Fig. 9.7.4.3*1

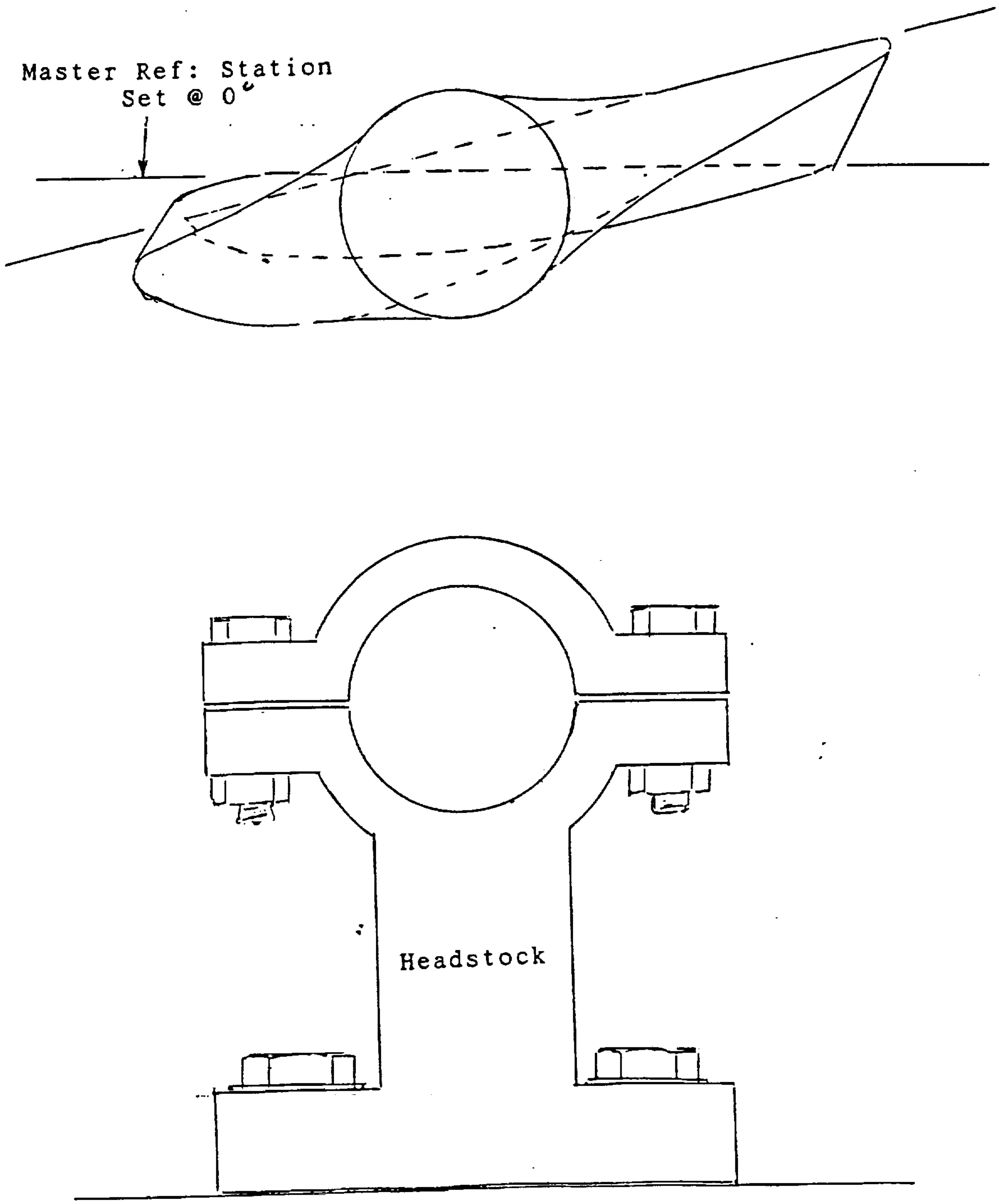


Fig. 9.7.4.5*1

9.7.4.6 Future Machined Shaped Blades

If in the future computer controlled machines are used for shaping it is likely that such machine tools will be more accurate than other methods of making and recording measurements. No doubt these methods would be put to use if the need arose.

9.7.5 Miscellaneous Checks

9.7.5.1 Balance Checks

For small blades the balance inspection checks can usually be carried out subsequent to but in similar manner to those used during manufacture.

For medium and large blades the inspection checks and the recording of results will normally be made at the same time as the balance procedures are actually made.

The record of Blade Weight and C. of G. position could be included in the Packing Record as given on a sample History sheet for these stages, see Fig. 9.7.5.1*1.

9.7.5.2 Covering

Most of the covering procedures need to be carried out with the Inspector present to be able to certify and record that all processes are to specification. It is also advisable for a small quantity of surplus resin to be retained in a mixing pot to check that it will cure satisfactorily after the appropriate time (usually over night).

The Bond strength of the cover must also be checked by preparing at the time (for example see Section 9.5.3.2. Stage 6) and with the production materials being used, a suitable test specimum. This specimum should consist of a board (approximately 8 in. x 6 in. - previously obtained from the offcut of a lam) on to which a sample of the glass cloth is applied using the standard application technique and method.

When the resin has cured, preferably 3 days after application, the test cover should be cut through to the base wood board to give one or more strips 1 in. wide.

The strength of the cover bond may then be tested by peeling a strip of cover away from the board, measuring the load required to do so. A satisfactory standard should require a load of over 10 lbs. to peel away the cover. There should also be evidence of wood fibre left adhering to the resin film left on the detached cover. See Fig. 9.7.5.2*1.

Inspection Department History Sheet

FAN BLADE IDENTIFICATION & PACKING

SERIAL REF: ______________

OPERATION/PROCESS	DATE	INSPECTOR	COMMENTS
Blade Identification and Drg. Ref.			
Blade Weight			
C of G position			
Packed and Sealed with Dessicant			
Crate Identifications			
Blade Secured for transportation			

Fig. 9.7.5.1*1

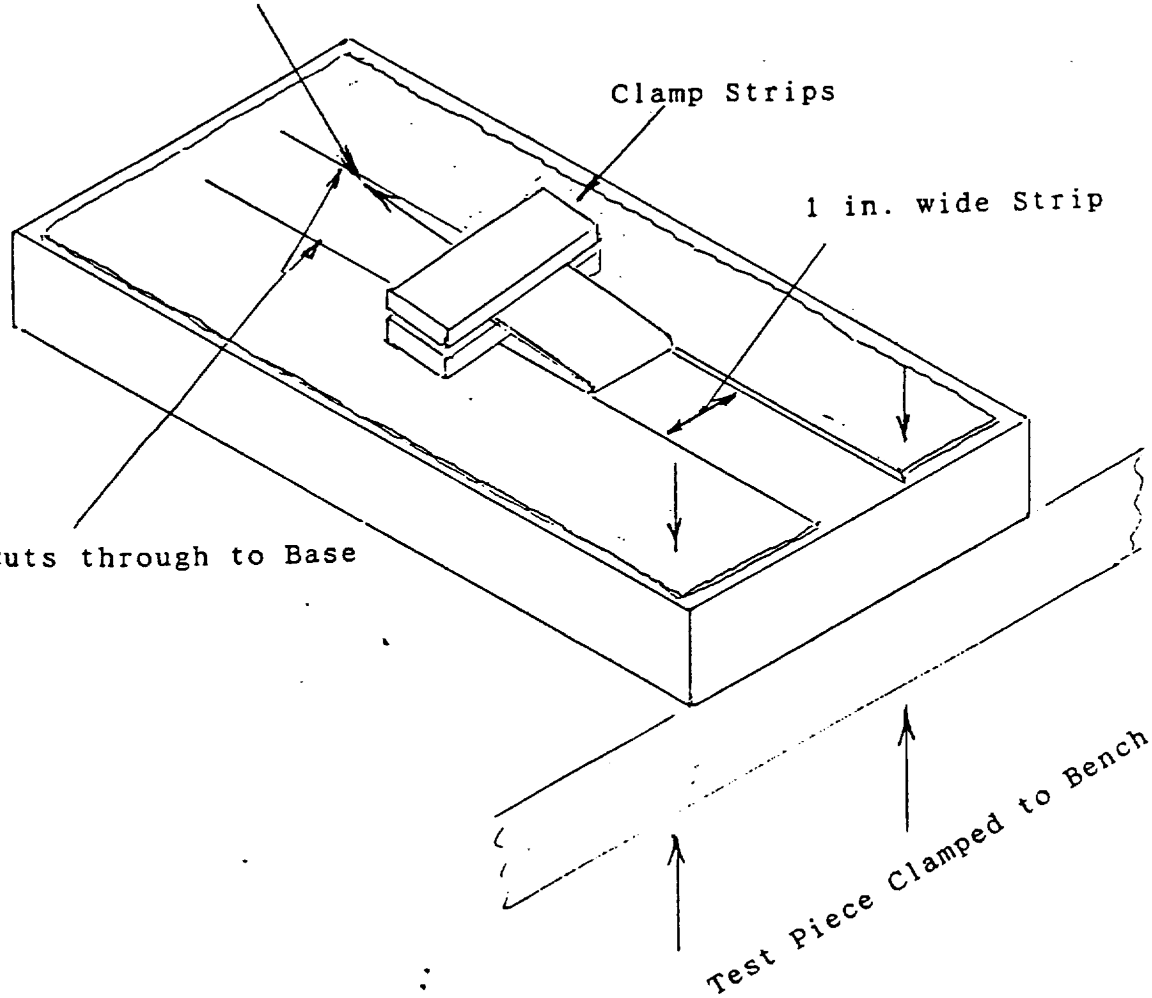

To Hand Spring Balance
Clamp Strips
1 in. wide Strip
Cuts through to Base
Test Piece Clamped to Bench

Fig. 9.7.5.2*1

9.7.6 Final Inspection

After a blade has been completely manufactured a final inspection check should be made. This check mainly covers the finished dimensions and balance readings as all process checks will have been carried out during the manufacturing stages. The dimensional checks need to be similar to those listed in Section 9.7.4. and the balance checks to those of Section 9.7.5.1. Any special templates required will have to be suitable for the final covered size and shape. It is important that detailed records are made of all measurements and information taken so that these are available, if required, for the customer or windtunnel user. An example of a Finished Blade History Sheet is shown in Fig. 9.7.6*1 as being certified by the suplier.

9.8 Inspection (Acceptance)

Acceptance Inspection is normally carried out by the customer or the customer's representative on a completely finished blade.

All records (e.g. copies of the History Sheets) of workshop checks as carried out according to Section 9.7 should be made available to the customer, if required, for vetting.

Apart from these records the practical Acceptance Inspection consists of a repeat of the final workshop inspection and is usually caried out in similar manner on one or more blades of an order.Some customers will require these checks to be made on their behalf at the manufacturer's plant whereas some customers may make their own checks afetr delivery of the blades.

Problems can arise if the customer's method of measurements differ from that of the blade manufacturer. If possible it is better to be able to reach agreemnet on the extent and methods of final measurements at the start of the manufacturing process rather than leaving this question until the blades have been completed and there is then no possibility of coming to an agreed common system.

From the manufacturer's point of view this would involve their inspector being able to have direct contact with the personnel of the customer's organisation who will eventually be given the responsibility for carrying out the acception inspection.

Unfortunately this is not always possible, due sometimes partly to the difference in time between the start of the design/manufacture and the completion of manufacture.

Inspection Department History Sheet

FINISHED BLADE INSPECTION

RECORD OF DEVIATIONS

SERIAL REF: ____________

STATION	SURFACE	DEVIATION	POINT OF MAX DEVIATION	SPREAD

(ALL DIMS. IN INCHES)

SIGNED ____________

DATE ____________

Fig. 9.7.6*1

9.9 Packing and Transport

9.9.1 Packing

9.9.1.1 Small and Medium Blades

Small and Medium Blades that are readily manhandled do not usually require special packing, particularly if they are able to be delivered to the Windtunnel site from the manufacturer by their own transport. Blades can be wrapped in plastic sheet to protect against moisture and dirt and then further wrapped in felt or equivalent protective material.

A conventional rigid type case into which a blade may be lowered (as an example see Fig. 9.9*1) can be appropriate for a small or medium blade that can be manhandled but due to limited space is difficult to use for large and heavy blades, see next Section 9.9.1.2.

9.9.1.2 Large Blades

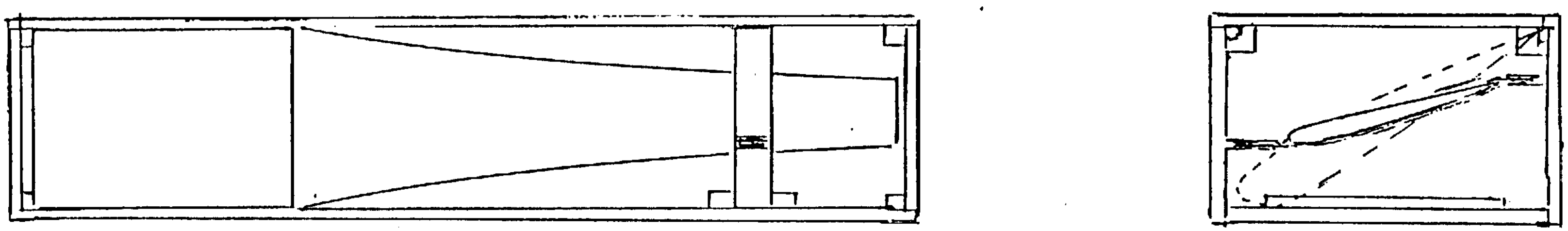
Large Blades that need to be mechanically handled due to their weight can sometimes be transported to the Windtunnel site from the manufacturer by having special holding equipment bolted to the base of the transport vehicle. This possibility depends on the design of the root adaptor and whether such adaptors lend themselves to fairly simple or straightforward clamping devices. Blades with Bracket type Root Plates (see Section7.3.2.1.3.) can be dealt with in this method.

The majority of Large Blades and in particular blades that have to be delivered to a foreign country or overseas customers will need to be transported wrapped in plastic sheet and then contained in a suitable packing case.

It has been found that the most convenient type of packing case for this condition is of the "Top Hat" type. This type consists of a solid rigid base on to which holding cradles are attached so that a blade may be lowered into an appropriate position (with the help of mechanical means if required) and then the blade clamped into a firm position. Access to the clamping positions is readily available so that the packers can be sure that the blades have been securly clamped but not damaged. Before a blade is positioned on to the holding cradles it should be covered in plastic sheet for protective purposes. A suitable quantity of dessicant should be included with the blade under the plastic sheet to keep the blade dry.

After a blade has been clamped into position by the holding cradles the whole assembly can be covered by a light weight "Top Hat" cover to complete the packing case. Inspection procedures for this stage are given in Section 9.7.6.

Tip Support Cradle
with Foam Rubber



Internal Side View

Plain "Rigid" Case

Fig. 9.9*1

It is always desirable if such cases have eventually to be delivered overseas by ship that the cases should if possible be such that they are of convenient size for loading into standard ship containers.

An illustration of such a typical "Top Hat" case is shown in Fig. 9.9*2

9.9.2 Transport

9.9.2.1 Small and Medium Blades

The transport of small and medium blades for "local" delivery can usually be made by the manufacturer's own facility. If other transport is required such as public road or rail then suitable packing arrangements must be made.

9.9.2.2 Large Blades

Large Blades packed in cases can be transported by alternative means, such as road rail or by sea if necessary. For overseas delivery when sea transport is require it is preferable to be able to load the cases into standard ship containers. The dimensions of such cases should if possible be appropriate for the ship container size.

9.10 Installation

The Blade Manufacturer is not normally responsible for the installation of blades, this being for the windtunnel user/owner to carry out. However for very large and heavy blades it can be that the Manufacturer is asked to provide suitable holding fixtures that are capable of being clamped to a blade and then being used for attaching to a mechanical lifting device.

Holding fixtures clamped to the adaptor or even root end, over major portions of the blade are usualy straight forward, but care has to be taken in the design of holding fixtures for the tip end where the section is small, there is limited strength and if excess load is applied it may cause damage. Clamping fixtures have to be lined with an adequate thickness of foam rubber or other soft material.

Typical designs for both adaptor end and tip end fixtures are shown in Fig. 9.10*1.

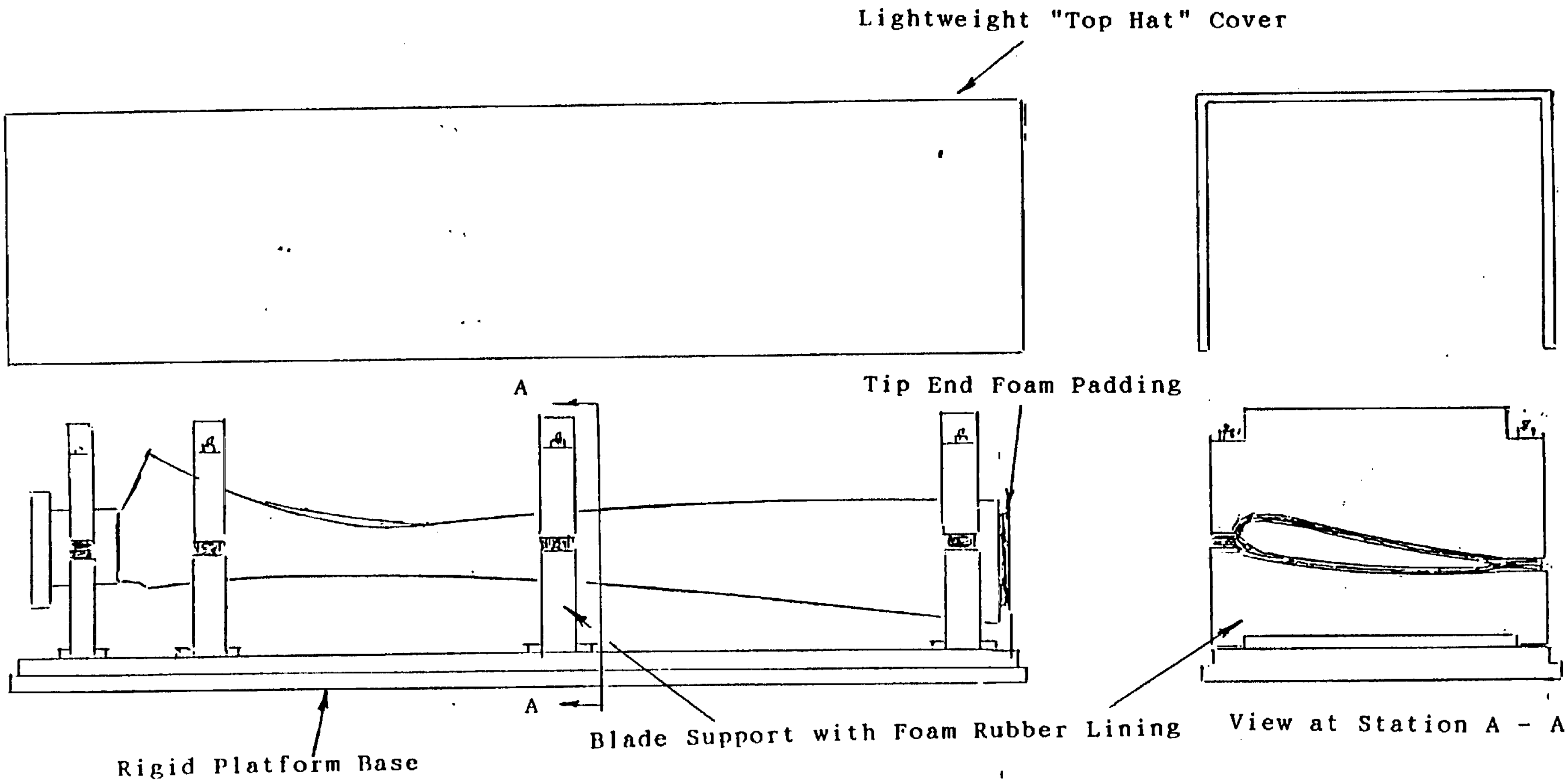
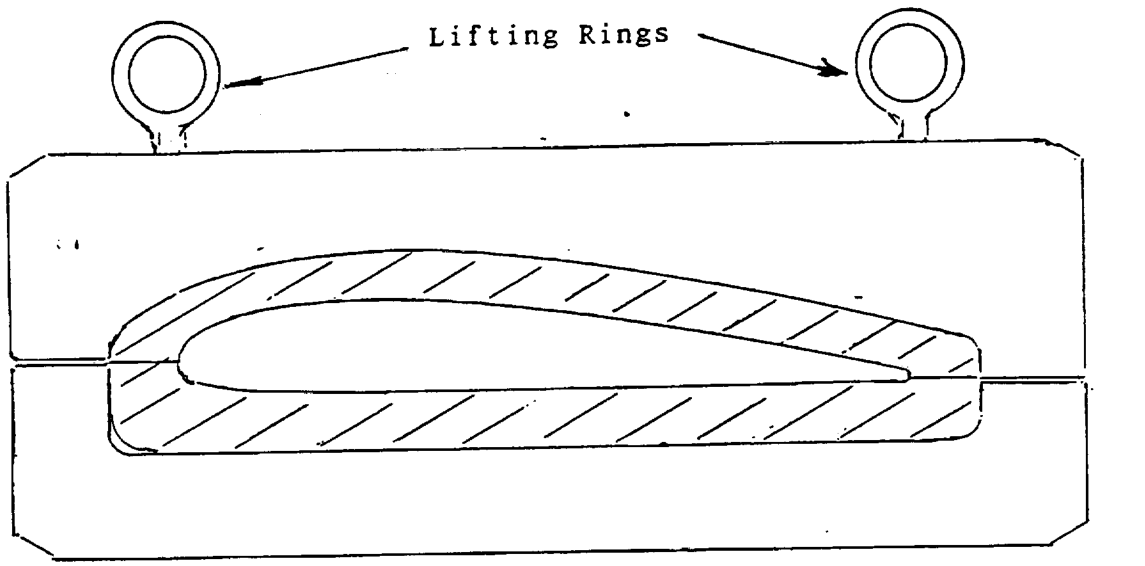
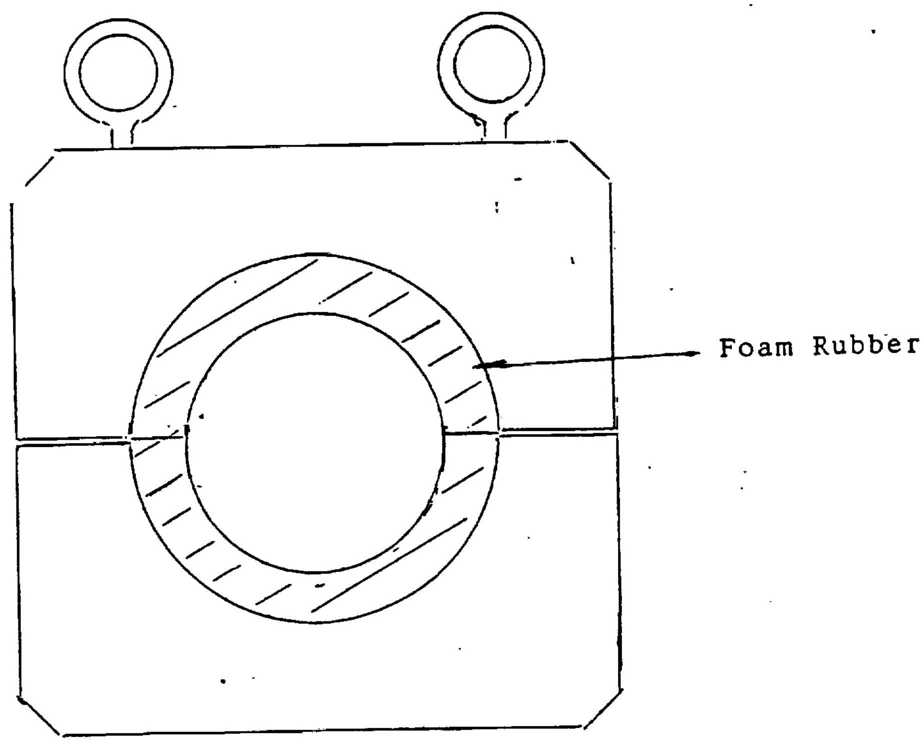

Lightweight "Top Hat" Cover
A
Tip End Foam Padding
A
Blade Support with Foam Rubber Lining
Rigid Platform Base
View at Station A - A

Fig. 9.9*2



Tip End Support



Adaptor End Support

Fig. 9.10*1

Section 10: Repair Techniques

Index

10. Repair Techniques

- 10.1 General
- 10.2 Material Specifications
- 10.3 Material Defects
- 10.4 Manufacturing Damage, Defects and Repairs
- 10.5 Inspection and Maintenance for Blades during Service Life
- 10.6 Repairs
- 10.7 Balancing
- 10.8 Repair Records

10. Repair Techniques

10.1 General

A Blade Manufacturer will require to have a suitable Specification for Repair of any defect encountered during manufacture and a Specification for Maintenance and Repairs required for reference by the Windtunnel operator.

This Section 10 presents standard maintenance and repair techniques recommended to be carried out on Windtunnel Fan Blades. The required Specifications should be prepared generally in accordance with the techniques recommended in this Section. Some of these techniques are only applicable during manufacture, others refer to blades after being in operational service.

10.2 Material Specifications

Materials used for maintenance and repair should conform, as far as possible, to the specifications as called for in the manufacturing processes. (See Section 6.)

10.3 Material Defects

10.3.1 Softwood strips (see Section 9.2.1.) found to have minor defects may be repaired by cutting away the defective material and repairing in accordance with Section 10.6.1. (See also Fig. 10.3.1*1).

Defects on the face of complete lams may also be repaired in a similar manner.

10.3.2 Defects in Compressed Wood material should not be acceptable.

10.4 Manufacturing Damage, Defects and Repairs

10.4.1 Damage or defects that occur during manufacture may be repaired within the limits of Section 10.6.

10.5 Inspection and Maintenance for Blades during Service Life

10.5.1 Routine inspection and maintenance Specifications should be prepared generally in accordance with the following recommendations.

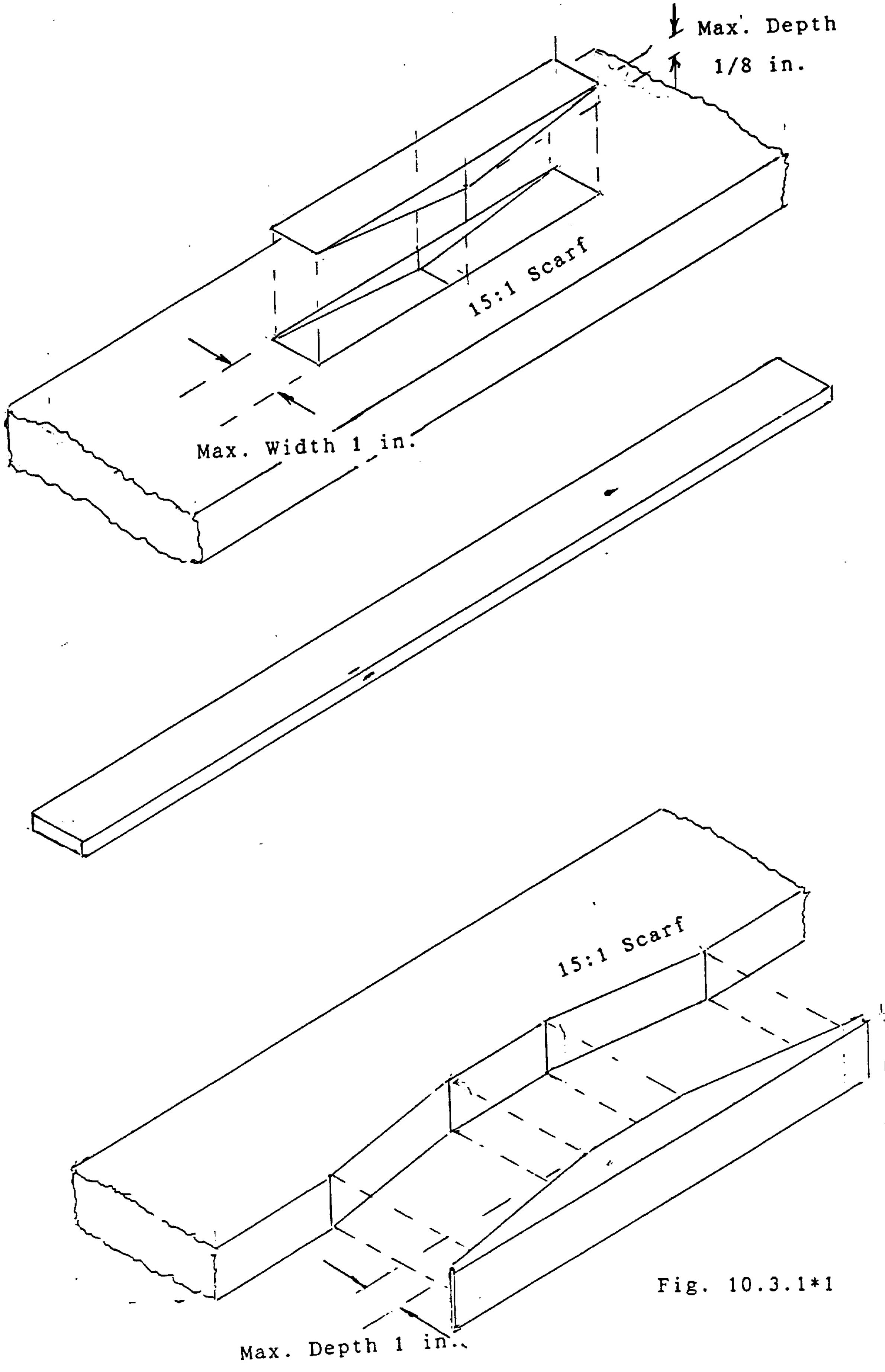

Max. Depth
1/8 in.
15:1 Scarf
Max. Width 1 in.
15:1 Scarf
Max. Depth 1 in.

Fig. 10.3.1*1

10.5.2 Covered Blades

10.5.2.1 If the blades are covered by glass cloth bonded by and finished with an epoxy resin giving a transparent finish so that the wood substrata can be examined, it is advisable that periodic checks be made to ascertain that no damage has been sustained and that the cover is still sound. Particular attention should be given to the tip area.

10.5.2.2 The surface of the covered blade should be kept clean by wiping with a clean rag dampened with water containing a detergent cleaner. Excess water should not be used. Particular attention should be paid to the extreme L.E. to prevent build up of dirt and grease over this portion of the blade. If any defect or tear has occurred in the cover exposing the wood body under no circumstance should water or any dampness be allowed to come into contact with the wood body.

10.5.2.3 After wiping the blade with a damp cloth, the blade should be wiped down with a dry cloth and all surplus moisture removed.

10.5.2.4 If any scrape or scuffing through to the glass has been sustained by the resin surface, this should be recoated with the appropriate resin mix.

10.5.2.5 If the cover has been torn or the blade suffered any wood damage, repairs should be made according to Section 10.6.4.

10.5.3 Adaptor and other Metal Parts

10.5.3.1 Normally no maintenance is required on metal parts apart from keeping them clean.

10.5.3.2 Retention bolts should be examined periodically to ensure that no fatigue cracks develop and that any preload applied at the initial assembly is maintained.

10.5.3.3 Checks should be made that any locking devices remain sound.

10.6 Repairs

Note re presentation: Most of the Figures show repairs as recommended on the Ames blades, but of course these repairs can be related to any design of blade.

10.6.1 Softwood/Spruce Repairs

10.6.1.1 In making wood repairs the defect should be entirely removed.

10.6.1.2 All patches and new material should match the existing component and with the grain direction similar.

10.6.1.3 In all cases where patches and new material are added, excess material should be used and shaped to contour after ageing of the glue. Normally very small patches and balsa patches may be worked after 1-day, but larger patches may need 3-days for the glue to harden.

10.6.1.4 Small defects, dents or gouges up to 1/4 in. deep may be repaired by insering matching patches with 15:1 scarf joints at each end. (See Fig. 10.6.1.4*1)

10.6.1.5 Defects may be routed out to a 20 included angle to a depth of 1/2 in. with 1/16 in. radii on the bottom corners. Scarf 15:1 on the inboard and out board ends unless the patch is at the end of the blade when it may run out without a scarf. The exposed width of the patch shall not exceed 1 in. more than the exposed width of the lamination being repaired. (See Fig. 10.6.1.5*1)

10.6.1.6 Defects up to a maximum depth of 1 in.in the trailing edge may be repaired by insering a patch with a 15:1 slope on the inboard and outboard ends, unless the patch runs through to the root end when the inboard scarf is not required. (See Fig. 10.6.1.6*1)

10.6.1.7 Defects up to a maximum depth of 1 in. in the leading edge may be repaired by insering a patch with a 15;1 slope on the inboard and outboard ends, unless the patch runs through to the root end when the inboard scarf is not required. (See Fig. 10.6.1.7*1)

10.6.1.8 Gluing control should conform to the standards of the gluing control specified for manufacture, see Section 9.1.

10.6.1.9 The blade surface on which a repair is to be glued must be clean, free from dust, dirt or grease and present a suitable matching surface to the repair block.

10.6.1.10 The repair block must also be have its matching surface clean and free from dust dirt and grease. The moisture content of the repair block should be within the range of 8-12%. Normally this moisture content can be checked by a suitable meter.

10.6.1.11 The two surfaces to be glued should fit within 0.006". The fit can be checked by feeler gauge.

10.6.1.12 Clamping pressure should be applied by "G" clamps or other suitable mechanical means.

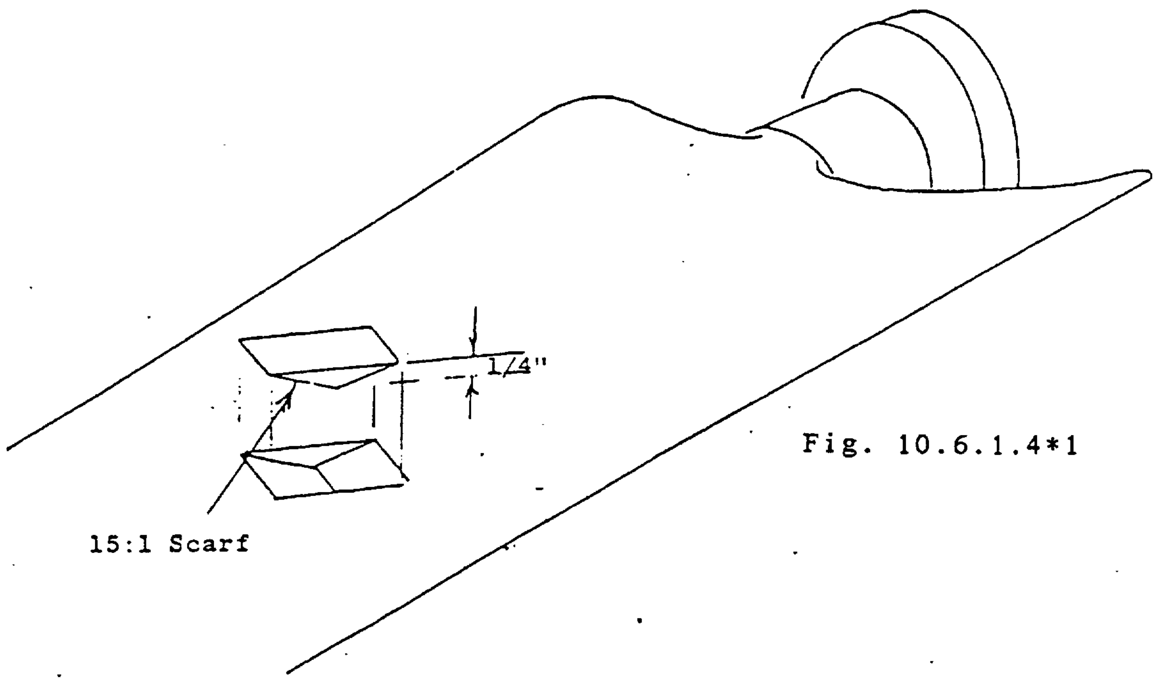


Fig. 10.6.1.4*1

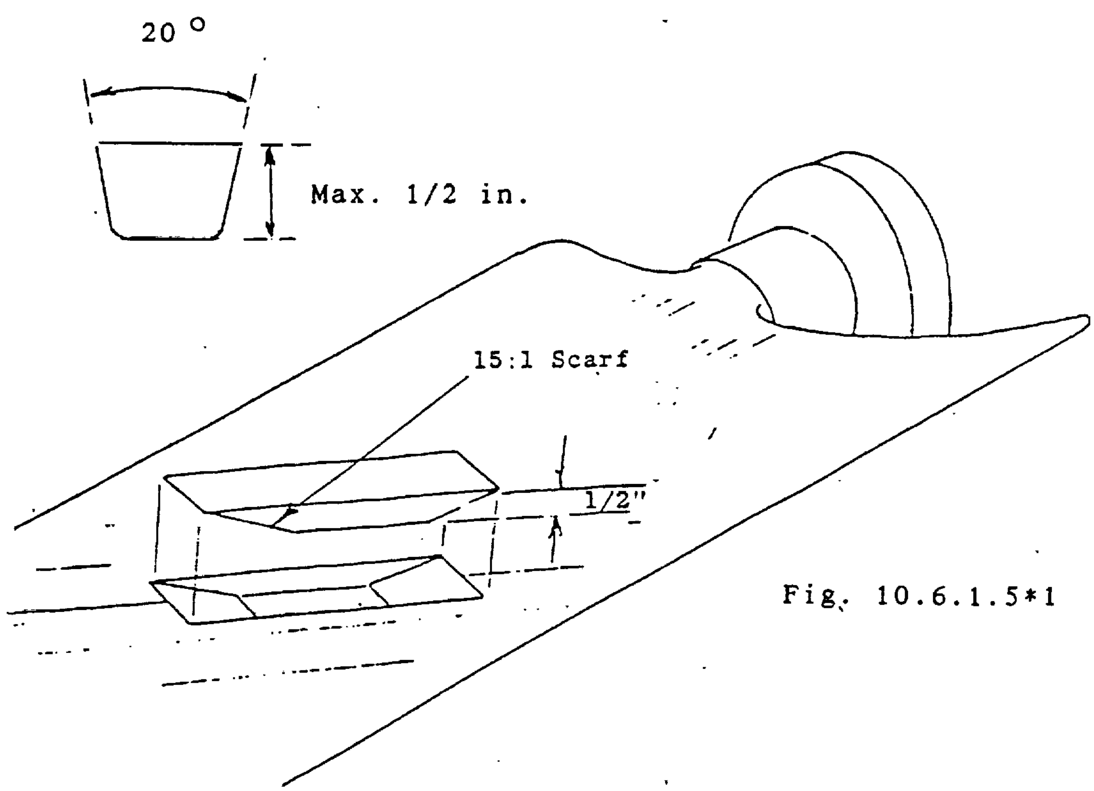


Fig. 10.6.1.5*1

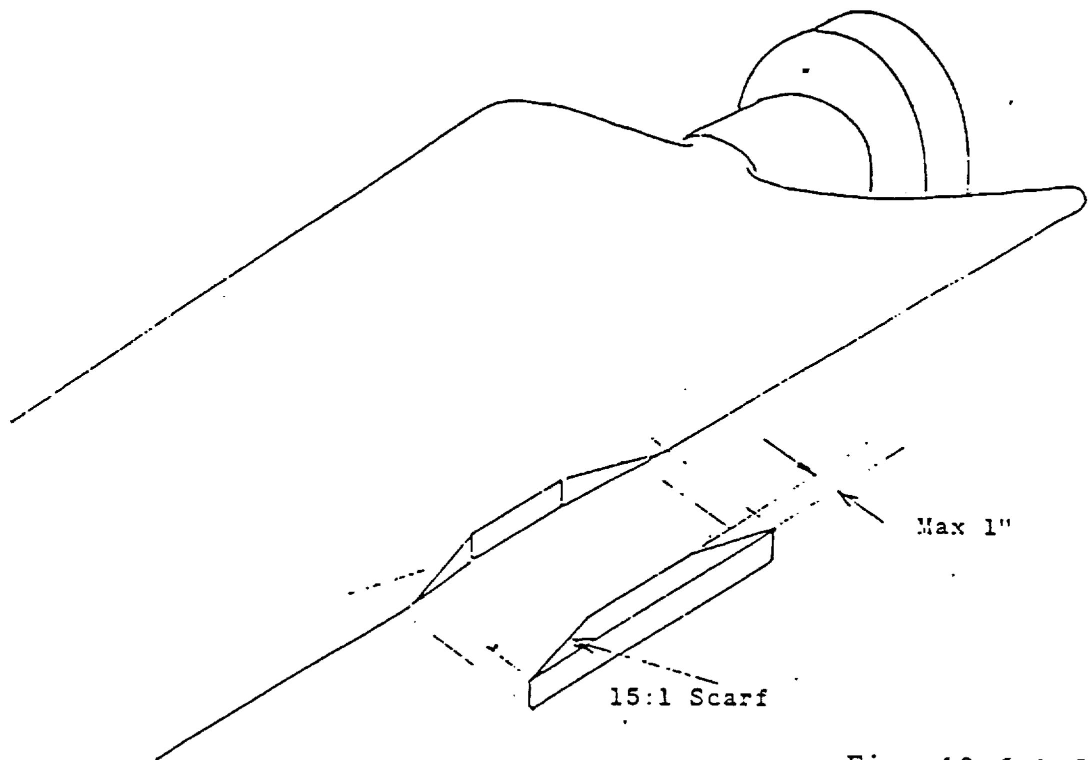


Fig. 10.6.1.6*1

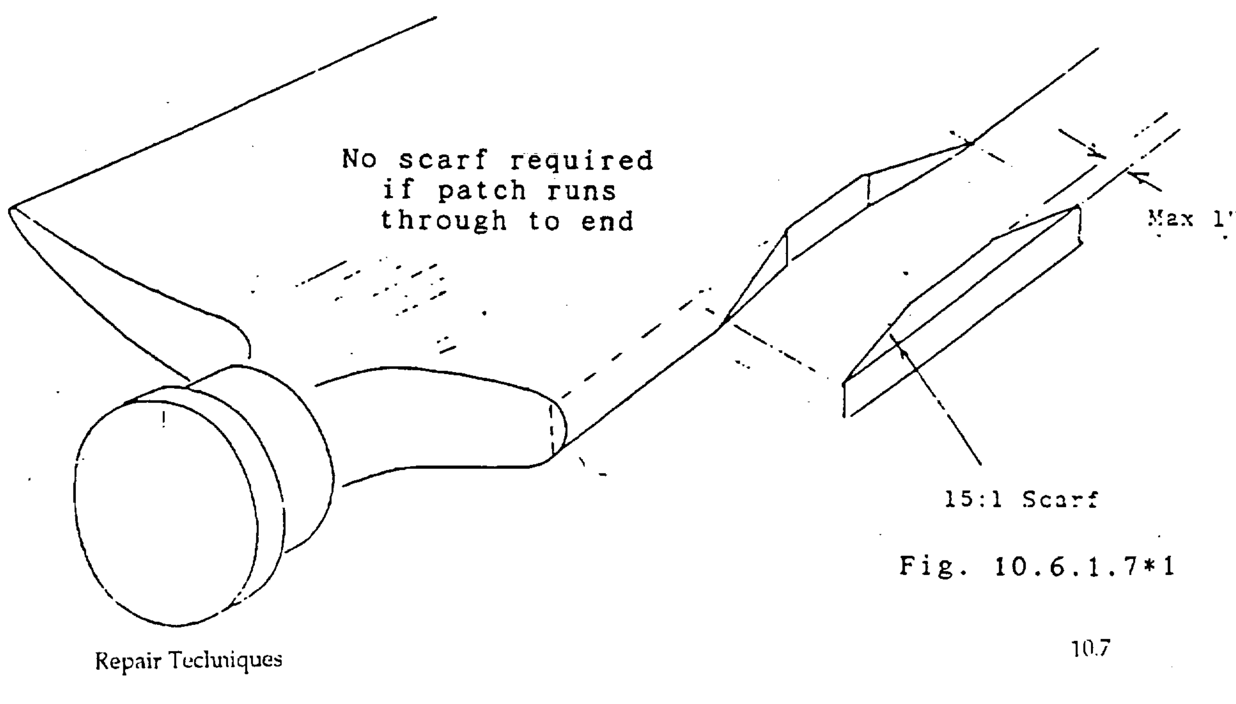


Fig. 10.6.1.7*1

10.6.1.13 The amount of pressure that should normally be applied for wood repairs (except for Balsa) will be the maximum that is practically achievable.

10.6.1.14 Clamps should not be applied directly to any part of a covered (undamaged) blade. If necessary a spreader pad between the clamp and the blade should be used.

10.6.1.15 Clamping pressure should be maintained for at least 8-hours: normally overnight is a practical period.

10.6.1.16 Small patches and balsa repairs may usually be re-worked after 1-day curing. However extreme care is needed not to apply excess load to the glue joint before the glue has fully cured.

10.6.1.17 Large patches should be left for 3-days or more before being shaped to contour.

10.6.2 Compressed Wood Repairs

10.6.2.1 Small defects or gouges up to 1/8 in. deep may be repaired by inserting matching patches with 15:1 scarf joints at each end (See Fig. 10.6.2.1*1)

10.6.2.2 Larger defects, up to 1/4 in. deep may be repaired by inserting matching patches with 15:1 scarf joints at each end. (See Fig. 10.6.2.2*1). Patches that run through to the root end section do not require an inboard scarf joint. (See Fig. 10.6.2.2.*2)

10.6.3 Balsa Repairs

10.6.3.1 In most cases the "repair" of tip Balsa blocks will entail the replacement, to the manufacturing specification,of the complete block (or sub-block if only this part is damaged. See Fig. 10.6.3.1*1.

10.6.3.2 If only very limited damage is involved a section as shown in Fig. 10.6.3.2*1 may be replaced.

10.6.4 Cover Damage and Repairs

10.6.4.1 General. If any damage is suffered by the cover ensure that the wood body is sound before attempting any cover repairs.

10.6.4.2 Materials. A full list of materials for cover repairs is given in Section 6.

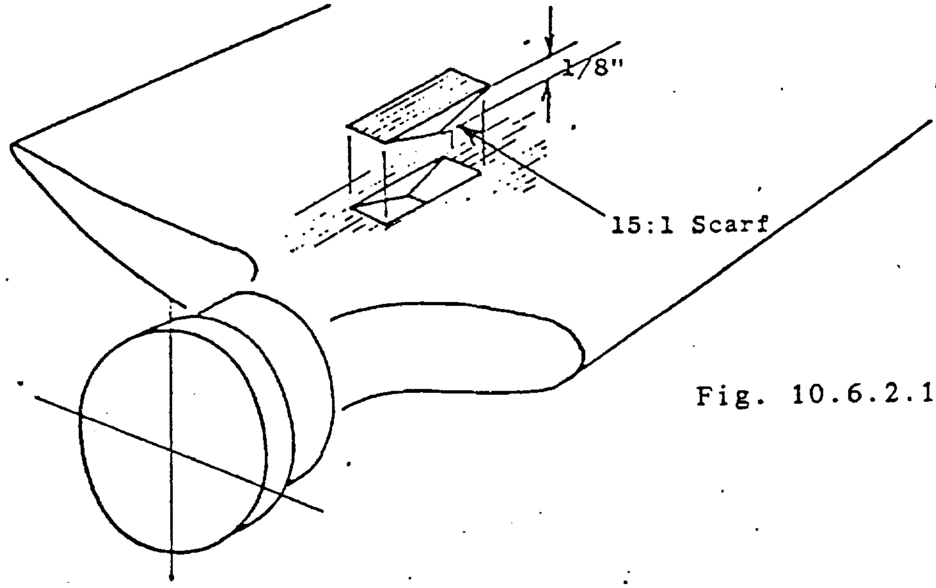


Fig. 10.6.2.1*1

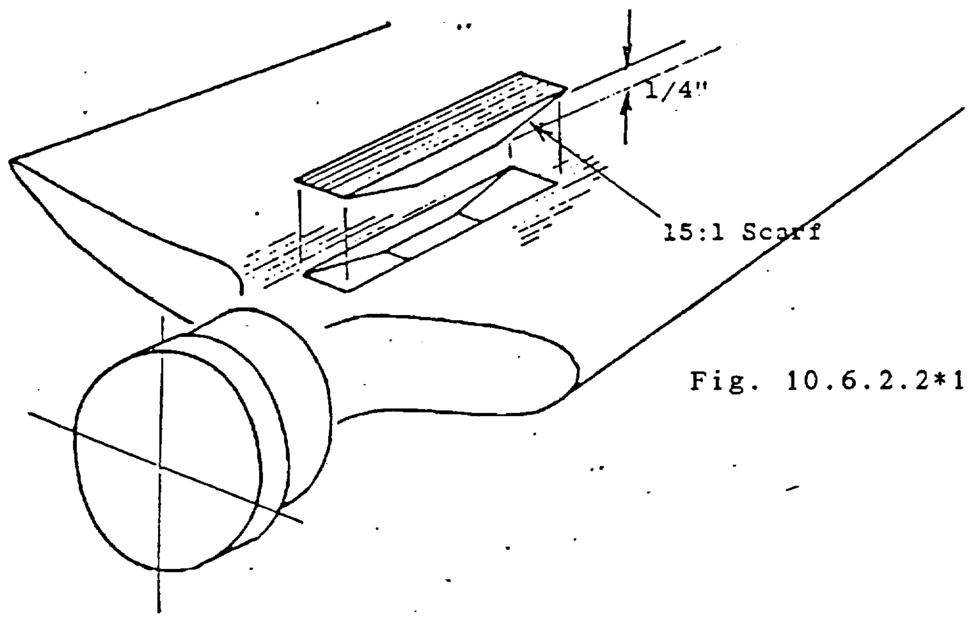


Fig. 10.6.2.2*1

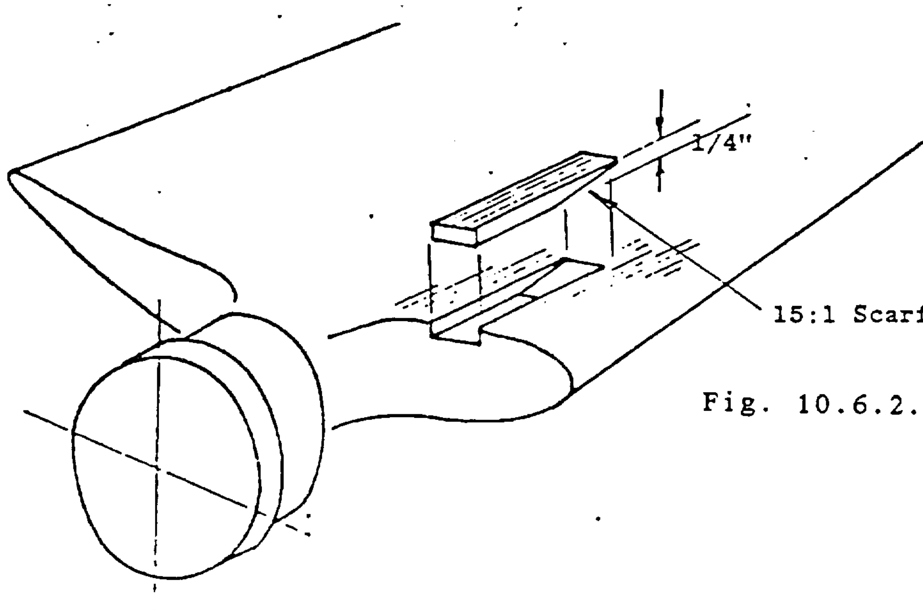


Fig. 10.6.2.2*2

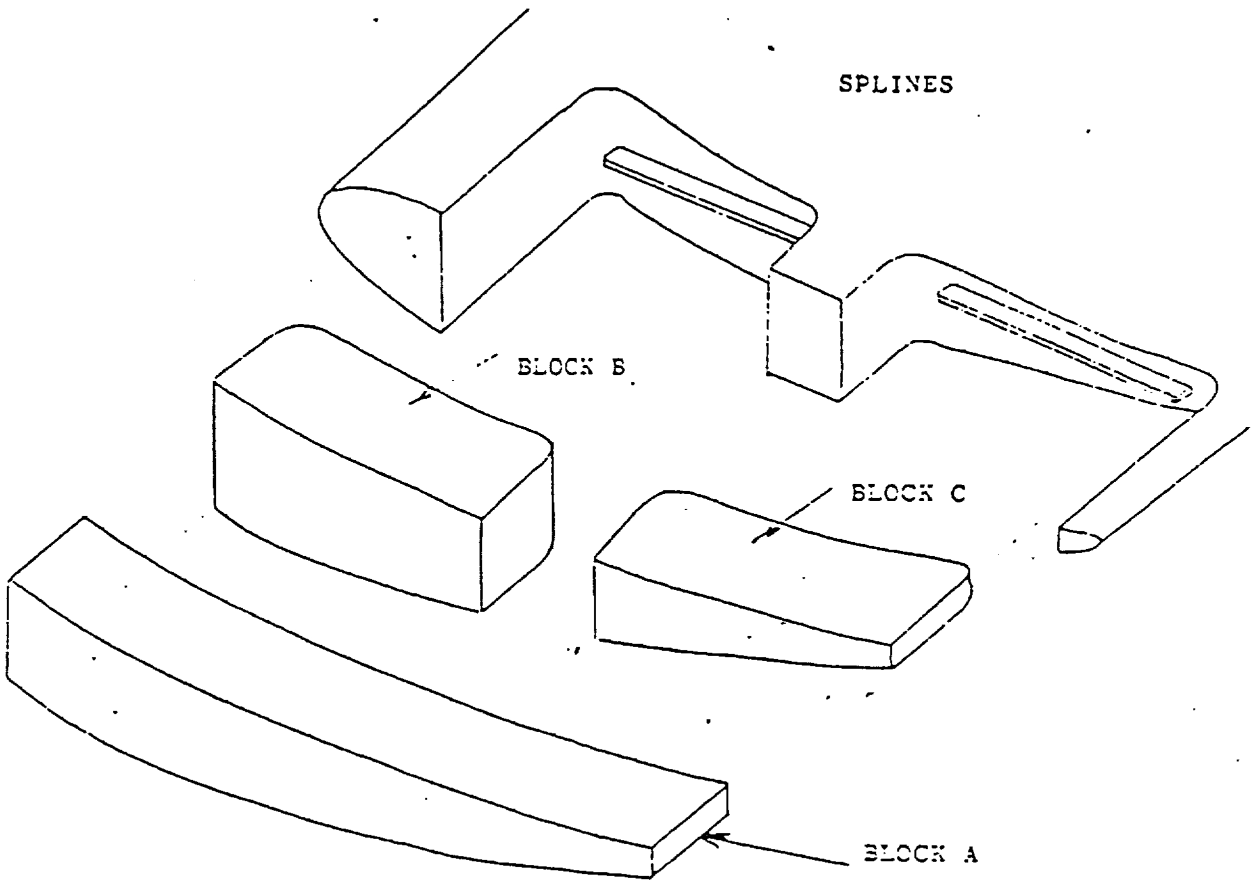


Fig. 10.6.3.1*1

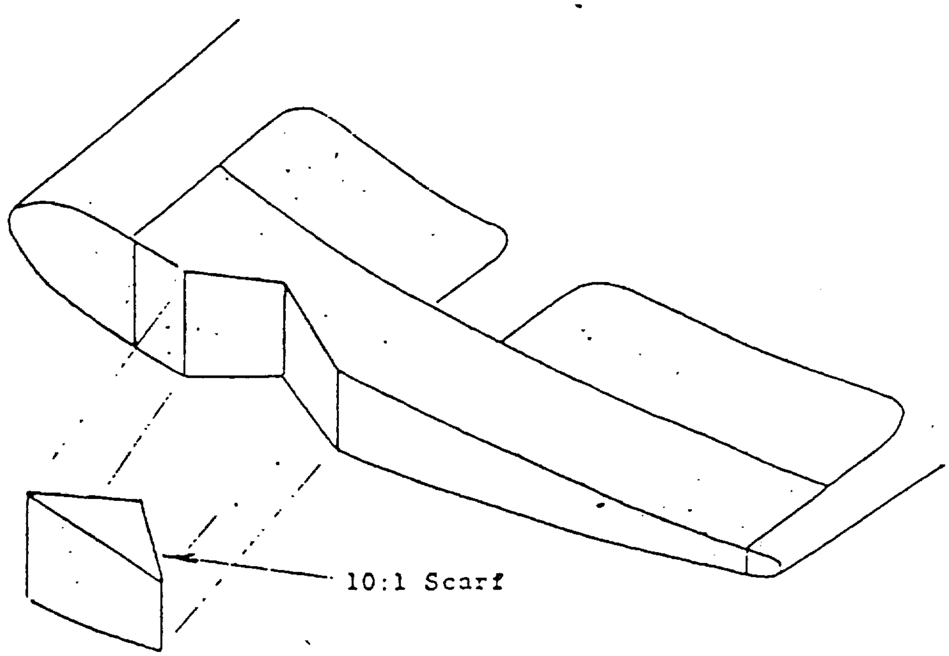


Fig. 10.6.3.2*1

10.6.4.3 Repairs. Allow approximately 3 days after completing any wood repairs before attempting to repair the cover.

10.6.4.4 Mask off an appropriate area round the defect with masking tape. A regular shape, such as rectangular,should be chosen. (See Fig. 10.6.4.4*1)

10.6.4.5 Remove the defect cover by cutting away so that a border 1 in. wide remains inside the masking tape. Ensure that when making a cut into the cover to produce a side to the regular shape chosen that the wood body is not touched.

10.6.4.6 Scrape away the resin coat on these 1 in. borders down to give a champfer and a minimum feather edge at the inboard side. (See Fig. 10.6.4.6*1)

10.6.4.7 Ensure that the wood body at the patch is smooth. Remove all loose particles and dust. Ensure that the area is clean, dry and free from oil and grease.

10.6.4.8 Cut a piece of glass cloth to fit the repair area to the outside edge of the masking tape and have it available for application.

10.6.4.9 Apply resin mix by spatula to the wood area and the champered edges of the sound cover.

10.6.4.10 Apply the cloth, dry, to the resin coated area and smooth to fit close to the wood body. The resin mix will penetrate the glass cloth during the process of smoothing down, Make sure that all the entrapt air under the glass cloth is squeezed out. (See Fig. 10.6.4.10*1)

10.6.4.11 Apply a further coat of resin mix over the glass cloth. ensure that no air bubbles are trapped beneath the cloth.

10.6.4.12 During the initial curing of the resin, for the first two hours, it is advisable to observe the patch to verify that the cloth remains in contact with the wood body. Some smoothing down of the cloth during this time may be necessary or advisable.

10.6.4.13 The resin will cure overnight provided the temperature is kept over 70° F after which time the surplus edges, over the masking tape, may be cut away. The masking tape should then be removed.

10.6.4.14 Scrape and sand the extreme edges of the patch to fair into the cover surface. Care must be taken not to penetrate the glass cloth through to the wood body.

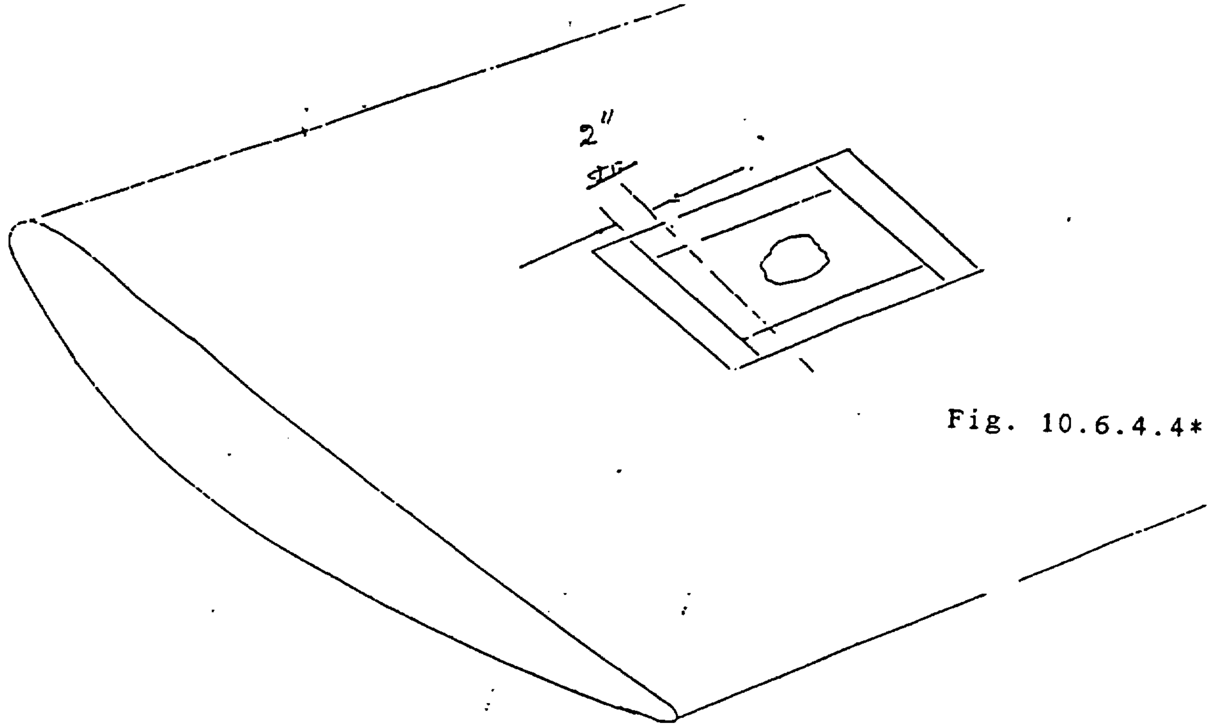


Fig. 10.6.4.4*1

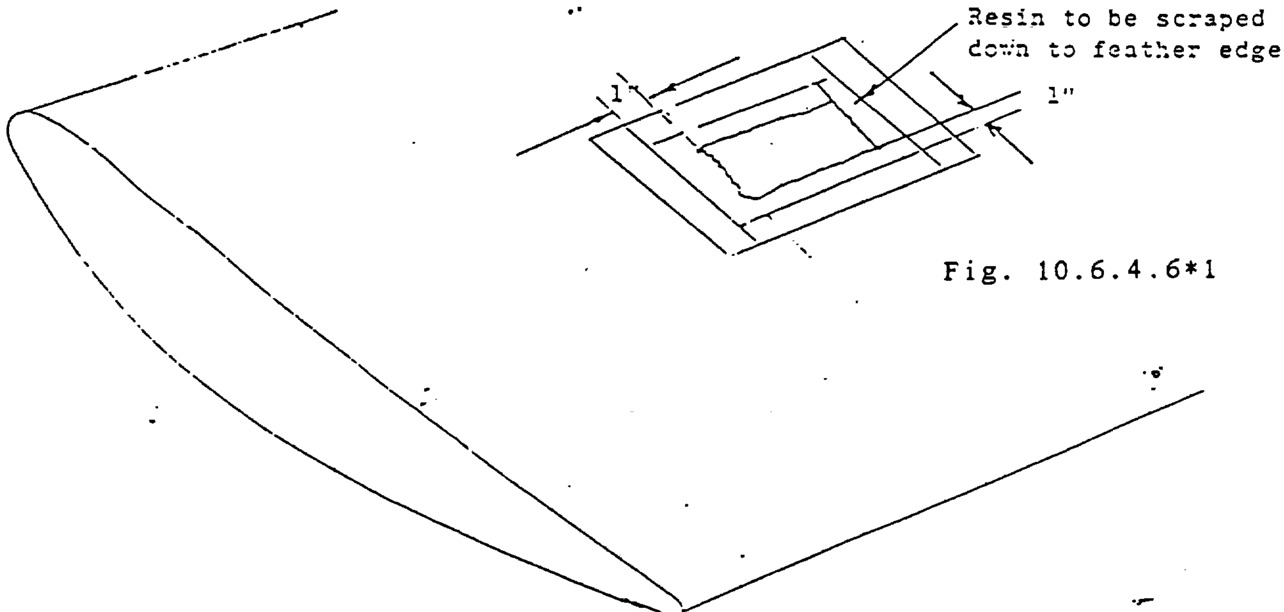


Fig. 10.6.4.6*1

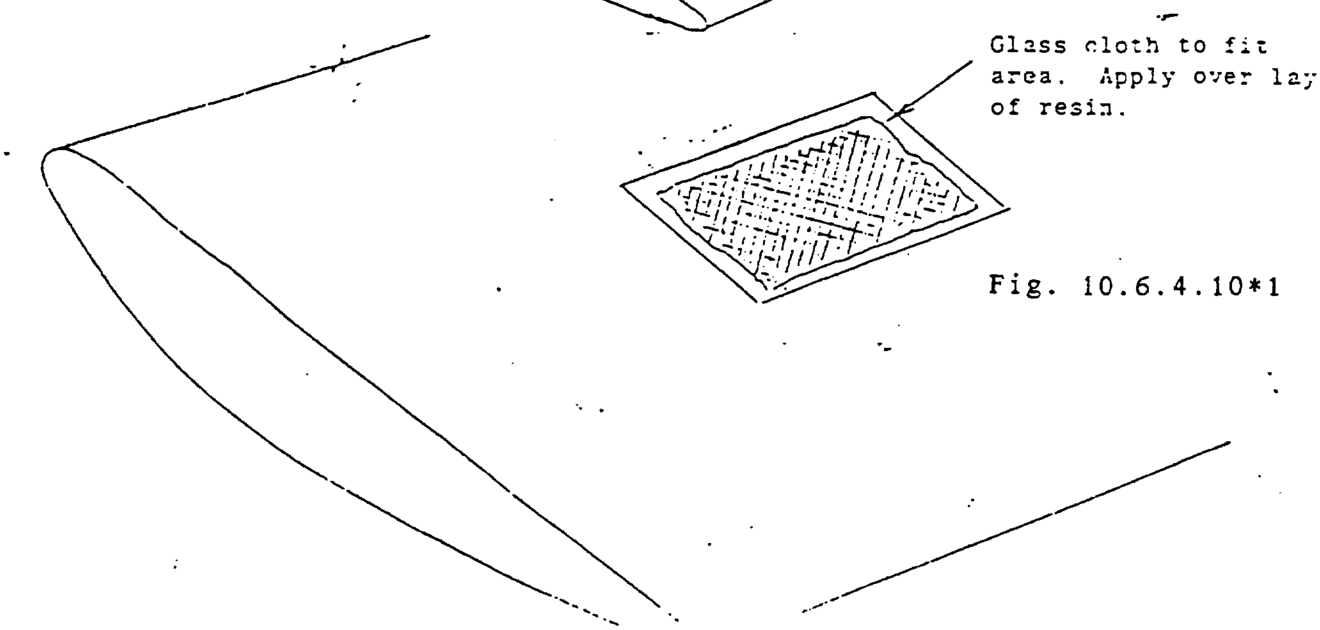


Fig. 10.6.4.10*1

10.6.5 Finishing

10.6.5.1 Materials. A full list of materials for finishing is given in Section 6.

10.6.5.2 Method.After applying the glass cloth patch and scraping down the edges to fair with the original cover, sand the surface of the patch and surrounding cover to give a smooth contour.

10.6.5.3 If the surface being treated is held horizontally pour on a small quantity of resin mix over the patch and flow the resin to give an even thichness coat brushing out the edges for a smooth transition to the original surface.

10.6.5.4 If the surface being treated is not held horizontally apply a thick coat of resin to the patch to achieve a similar result.

10.6.5.5 Maintain a temperature over 70 F for at least 4 hours after which time the resin will have become touch dry. The component or blade on which the repair has been made should not be used for at least 8 hours or until the resin has fully cured.

10.7 Balancing

10.7.1 The scope of these recommendations, limited to small repairs, should not normally affect the balance of any blade by a significant amount and therefore the balance moment need not be rechecked.

10.8 Repair Records

10.8.1 Any repair made to a blade in the course of manufacture should be recorded and the details included with the other information of the Final Inspection History Sheet. Normally a brief sketch of the repair should be made on a (repair) History Sheet, such as the example shown in Fig. 10.8.1*1.

Inspection Department History Sheet.

BLADE REPAIR

SERIAL REF: ____________

DESCRIPTION/SKETCH OF REPAIR:

GLUE REF. ____________

HARDENER REF ____________

Approved By: ____________

Authorised By: ____________

Date: ____________

Fig. 10.8.1*1

11. Specification Preparation

11.1 A potential Windtunnel user or Windtunnel operator who needs to consider the supply of a suitable fan, whether as a new project or a replacement for an existing fan will initially be faced with the problem of preparing or having prepared a specification for the supply of such equipment.

There will nearly always be conflicts of interest between what is preferred by the windtunnel user and what can actually be manufactured or even allowed by financial limitations. As an example the user will normally prefer the fan to be of a specific design of fixed dimensions whereas the ultimate manufacturer and supplier must be allowed some latitude in what dimensions are actually achieved in the manufacture. Eventually after the hardware has been completed and supplied there may be other personnel who have the responsiblity of certifying what exactly is the manufactured result and the Specification should be clear to them.

It is important from both points of view, that the original specification for the supply is prepared so that there is no ambiguity and that disputes, difficult to settle, do not arise. It is most unlikely that the major features of the proposed design such as the types of material to be used, the main dimensions etc. will lead to mis-understandings but many of the apparently minor details such as dimension limits or tolerances can be mis-interpreted and lead to disputes if the original specification is not appropriately prepared and worded and agreed by both user or customer and the chosen manufacturer and supplier.

11.2 The following notes give a summary of the most likely topics that need careful consideration but not necessarily need to be included in a specification.

11.2.1 Section Chords, Thicknesses and Angles limits and tolerances.

11.2.2 Chords: The method of ascertaining the dimensions of the chords may be critical, e.g. by calipers or by comparison with approved templates. (Who is authorised to approve such templates?)

Should the chords be defined at the "White Shape" (Ref:13.2.48) or is the final chord after covering, finishing or painting to be used as the acceptance standard. Tolerances and limits need specifying.

11.2.3 Thicknesses: Similar considerations as for Chords.

11.2.4 Angles: The actual definition of the Section Angles may be critical particularly for sections that do not have a flat pitch face and this may lead to the method of measurement also being critical.

11.2.5 Section Shape/Surface Dimensions: Any limits or tolerances on the section shapes or surface dimensions must be defined clearly.

11.2.6 Blade Data Points: These must be defined very clearly.

11.2.7 Blade Tip Radius: The datum point from which the Blade Tip Radius is to be measured must be defined very clearly and the tolerance on the actual White Shape or finished dimension must be clear.

11.2.8 Balance Limits/Tolerances: The balance Limit or Tolerance for individual blades (if applicable) need to be clearly defined.

11.2.9 Attachment Holes: The diameters and positions of any attachmen (bolt holes or others) must be defined clearly to eliminate any problems at the installation stage.

11.3 As a guide the following manufacturing tolerances, which should be achievable, may be specified by the Windtunnel operator.

11.3.1 Chords

Blade Size	Chords	Tolerance
Small Blades	up to 10 in.	+/- 0.10 in.
Medium Blades	10 in. to 30 in.	+/- 0.15 in.
Large Blades	30 in. to 40 in.	+/- 0.20 in.
Very Large Blades	over 40 in.+/- 0.25 in.	

11.3.2 Thicknesses

Blade Size	Thickness	Tolerance
Small Blades	up to 1 in.	+/- 0.05 in.
Medium Blades	1 in. to 3 in.	+/- 0.08 in.
Large Blades	3 in. to 4 in.	+/- 0.10 in.
Very Large Blades	over 4 in.	+/- 0.15 in.

11.3.3 Angles

Blade Size	Tolerance
Small Blades	+/- 15′
Medium Blades	+/- 15′
Large Blades	+/- 25′
Very Large Blades	+/- 25′

11.3.4 Tighter Tolerances

11.3.4.1 Tighter toelances than those given above may be requested, but there would then be the possibilty that a proposed manufacturer could find them difficult to achieve and hence require, or at least expect, a higher price for the manufacture of such blades.

11.5 Load Prediction

11.5.1 If the Specification Preparation, by the Windtunnel operator, includes estimation of the aerodynamic blade loads that will be expected, there will occur the reliability of these estimates. If for example the Windtunnel operator knows, or surmisses, that the load estimation can be somewhat uncertain it is obvious that this situation should be be passed to the blade designer who must then ensure that the blade design will be suitable for any reasonable increase of loads above that originally specified.

12. Relationship between Specification, Inspection and Acceptance

12.1 General

The original Specification should have been prepared and then accepted by both the Blade Manufacturer and the Windtunnel Operator/Customer as the basis of any manufacturing contract. (See Section 11.)

Final Inspection by the Blade Manufacturer should verify that the basic requirements of the Specification have been satisfied. (See Section 9.7.6.)

Acceptance by the Windtunnel Operator/customer (see Section 9.8.) should then confirm that both they and the Blade Manufacturer are satisfied with the manufactured result.

12.2 Specification

The details of the original Specification should have been agreed with all concerned. (See Section 11.) This Speicification should have included the details of the measuring techniques and, if necessary, the differences to be used by each of the customer and manufacturer.

12.3 Inspection

The manufacturer should carry out, at each stage, all the necessary inspection requirements and record the final values (or deviations) for every blade such dimensions as section chord, section thickness and section angle on an appropriate History Sheet. (An example of such a History Sheet is shown in Fig. 12.3*1)

These History Sheets, for every blade, should be made available to the customer so that it can be agreed that the resultant standard is acceptable.

12.4 Acceptance

The customer having available copies of the Manufacturer's final History Sheets for every blade will then be in a position to decide which, if any, blade should be re-checked by them to verify the results as presented by the manufacturer.

If there has been any agreement (or understanding) at the time of the preparation of the Specification, that differences in measuring techniques will be employed, this must be taken into account when comparing the particular results.

13. References and Definitions

13.1 References

1. NASA Technical Momorandum 104059. Structural Integrity of Wooden Wind Tunnel Fan Blades. April 1991. By Young, Wingate, Mort, Rooker and Zager. NASA. Langley Research Center, Hampton, Virginia.

2. Anon: Aircraft Propeller Handbook, Issued in U.S.A. by Department of the Air Force, Navy, and Commerce. ANC-9, First Edition, Sept. 1956, Erratum Supplement, Sept. 1957.

3. Aerodux. Resorcinol-phenol-formaldehyde resin glue. Meets British Standards Specification 1204 (Ref:13.1.11) Manufactured by CIBA-GEIGY of Duxford, Cambs. U.K. Type 185 with powder hardener 151. Type 500 with liquid hardener. Note: After mid 1990's this material was supplied by DYNOCHEM UK Ltd. a subsidary company of CIBA-GEIGY. See Appendix G.

4. Penacolite. Glue with similar properties to Aerodux. Manufactured in U.S.A. by Koppers.

5. High tensile aluminimum alloy plate that meets Britsh Standards Institution Specification L70.

6. 5V7. British Standards Institution Specification for "Mahogany for use in Airscrews." Sept. 1952.

7. ANC-19 Bulletin. "Wood Aircraft Inspection and Fabrication" Munitions Board Aircraft Committee. U.S.A. Department of Defense. April 1951.

8. V37. British Standards Institution Specification for "Sitka Spruce for use in Aircraft" Sept. 1952.

9. West Coast Inspection Bureau, P.O.Box 23145, Portland, Oregon, U.S.A. Standard Grading Rules.

10. Hydulignum to Specification HR 210. Birch based compressed wood manufactured by Permali Gloucester Ltd. to their own internal specification, which has been approved for use in Aircraft flying blades and is suitable for use in windtunnel Fan Blades.

11. B.S.S. 1204. Britsh Standards Institution Specification for Resin Glues.

12. Weldwood. U.S.A. Glue suppliers from whom a type of glue with equivalent properties to Aerodux may be obtained.

13. Redux. Adhesive for Metal to Metal or Metal to Wood bonding.Manufactured by CIBA-GEIGY, Duxford, Cambs. U.K. Approved for Aircraft structural bonding. See Appendix A.

14. Glass Cloth E9700. 2x2 Twill 0.3mm thick 290 gm/m*2 Manufactured by Marglas Ltd. (Now C.S. Interglass, Sherbourne, Dorset, U.K.)

15. SPS 210. Epoxy resin system manufactured by Structural Polymar Systems Ltd. Cowes, I.of W., U.K. See Appendix S.

16. (Not allocated)

17. PR 1221-A2. Polysulphide Sealer compound. Manufactured by Berger, Newcastle-on -Tyne, U. K.

18. Sealing Material S.P. 106/Hardener S.P. 207 Epoxy resin manufactured by Structural Polymar Systems suitable for general woood sealing use.

19. Low Melting Point Alloy. Alloy of Bismuth, Lead aand Tin which has a melting point lower than 100 C. suitable for use as Balance Weight material.

20. SWEDOBOND Glue Film, Type GP 177. Manufactured by Casco Nobel Industries of Stockholm, Sweden. Used in the manufacture of Hydulignum Compressed Wood.

21 Croda Glue. Skin glue to B.S.S. V11 or other chemically suitable glue having equivalent strength properties.

13.2 Definitions

1. Adaptor (or Ferrule): Metal (usually high tensile steel) member in the form of a sleeve or tube into which a compressed wood root end may be inserted and retained. The outside shape and dimensions depend on the hub design.

2. Adhesive: Term reserved for metal to metal or metal to wood bonding agent. (See also 13.2.21. Glue for wood to wood bonding.)

3. Aerodynamic portion of Blade: Part of blade excluding, the root end, with aerofoil sections.

4. Back Pattern: Pattern cut to the shape of the profile of the aerodynamic portion of a blade. See Fig. 9.4.1*1

5. Blade Axes: See Section 8.1. and Fig. 8.1*1 for full description of these terms.

X-Axis

Y-Axis

Z-Axis

Radial Axis

6. Blade Root: The portion of a blade by which it is held during operation.

7. Blade Sections: The fundamental aerofoil forms at appropriate Stations (13.2.42) along the Radial Axis (13.2.5).

8. Block: The assembly of glued Lams (13.2.26) from which the finished blade may be manufactured.

9. Block Face Angle: See Section 8.1 for a full description.

10. Boss: The centre portion of an integral 2 or 4 blade fan. For this type of blade it replaces the alternative term of Blade Root.

11. Circular Root: A blade root in the form of a cylinder or cone that is retained in an adaptor.

12. Closed Circuit Windtunnel: A windtunnel consisting of a closed loop through which air is made to pass. See Fig. 4.1.1*1

13. Compressed Wood: Material made by bonding a number of veneers together under heat and pressure.

14. Cover: The external layer of a blade, usually a laminate of glass cloth and resin.

15. Daylight (of a Press): The space between two platens of a press.

16. Detachable Blade: A single blade consisting of an aerodynamic portion and root end that may be attached to a suitable hub mechanism.

17. Drop Pattern: An appropriate device from which the T.E. (13.2.44) position of a blade may be measured. See Fig. 9.4.1*2

18. Ferrule: An alternative term for an Adaptor.

19. Finish: The surface state of a completed blade.

20. Fixed Pitch Fan or Propeller: A fan or propeller with blades that cannot have their aerodynamic angle changed.

21. Glue: A material for bonding wood to wood.

22. Glue Film: Thin kraft paper coated with special semi-cured resin, used for the bonding of veneers into compressed wood. See Section 6.3.2.

23. Hardwood: Wood derived from a botanical deciduous tree. Does not necessarily imply that such wood is hard in itself. (For example: Balsa is a botanical hardwood although as a material it is relatively soft.)

24. Impeller: That part of a fan unit (hub and blades) which actually rotates.

25. Integral 2 or 4 Blade Fan: A fan consisting of 2 or 4 baldes that have common integral roots built into a solid Boss (10).

26. Lamination (Lam): An appropriately shaped wood board of limited thickness (usually 0.75 in. or 20 mm.) a number of which when glued together form the required shape from which a Blade Block (8) may be manufactured.

27. Lam Angle: Section 9.1

28. Lam Pattern: The appropriate full sized representation of the required shape with other information required by a manufacturing department to be able to mark out and produce a lam. Lam patterns are usually drawn on thick drafting paper but sometimes it is preferable to have them made from thicker and more durable material. A typical Lam Pattern is shown in Fig. 8.3.1*5

29. L.E.: Abbreviation for the Leading Edge of the aerodynamic portion of a blade.

30. LN Shear: See Section 6.3.4. and Fig. 6.3.4*2 for detailed description of this term.

31. LT Shear: See Section 6.3.4. and Fig.6.3.4*2 for detailed description of this term.

32. Multi-Bladed Fan: A fan with more than 4 blades which requires detachable blades.

33. P.F.: Abbreviation for the Pitch Face of the aerodynamic portion of a blade. Pitch Face is a term equivalent to Pressure Face, Flat Face and Lower Surface of an aerofoil section of a blade.

34. Radial Block Angle: See Lam Angle (13.2.27)

35. Rake (or Track): The dimension that the C. of G. points of the blade sections are positioned forward of the plane of rotation so that the centrifugal force creates a bending moment on the blade in the direction to help offset the bending moment created by the aerodynamic loads. See also Track (13.2.45) and Fig. 8.1*3. Normally this term may refer only to this dimension at the tip section

36. Rectangular Root: The root end of a blade which has a rectangular section. This Rectangular term does not apply to the shape of the plan form of such roots, which may be segmental, multi-sided or other appropriate shape to fit into the hub circular form.

37. Root Plates: Metal plates (usually Aluminium alloy) bonded to the rectangular root of a detachable blade.

38. R.S.: Abbreviation for Round Side of the aerodynamic portion of a blade. Round Side is a term equivalent to the Suction Face or Upper Surface of an aerofoil section of a blade. (Historical Note: Round Side was derived at the time when the shape of early propeller blades had aerodynamic sections of flat under surfaces and curved or round upper surfaces.)

39. Section Angle: See Section 8.1 for full description of this term.

40. Section C. of G. Point: See Section 8.1 for full description of this term.

41. Softwood: Wood derived from a softwood or evergreen tree. Usually implies that the wood material itself is soft and some deformation may take place if excesss load is imparted to the surface of a component made from such material.

42. Stations: Distinct positions along the Radial Axis (13.2.5) where the blade aerofoil shapes are specified.

43. Sweep: The dimension that the X-Axis of the C. of G. points of the blade sections are positioned from the true Radial Axis of the blade. Positive Sweep implies that the position of the C. of G. points lag behind the Radial Axis so that the centrifugal force creates a bending moment in the direction to offset the bending moment in the plane of rotation created by the force due to aerodynamic drag. See Fig. 8.1*3. Normally this term may only refer to this dimension at the tip section.

44. T.E.: Abbreviation for the Trailing Edge of the aerodynamic portion of a blade

45. Track (Rake): Equivalent term to Rake(13.2.35)

46. Veneer: Very thin layer (in the range of 0.01 in. - 0.1 in.) of wood produced by peeling from a log. Used for the manufacture of compressed wood

47. Veneer Pack: The appropriate number of veneers interleaved with Glue Film (13.2.22) which after assembly can be inserted into a suitable Press Daylight (15) for pressing into a compressed wood board.

48. White Shape: The completed wood shape of a blade before any cover or coating is applied. The White Shape section dimensions have to be such that they allow for the thickness of any subsequent cover (13.2.14) that will be applied. (Historical Note: During the period when propeller blades were finished with black paint, the complete blade was referred to as being its Black Shape and the unfinished wood blade was known as the White Shape)

49. Workshop Drawing: The Manufacturing Design stage leads to the preparation of the Workshop Drawing to specify all the information required by the Manufacturing Department to be able to produce a blade within the specified limits of the correct dimensions and materials layed down.

APPENDICES

Index

A. Adhesives. (Redux)

B. British Standards.

C. Computer Program.

F. Fatigue Test.

G. Glues.

S. S.P.S. Resin Systems.

CIBA-GEIGY

Advance information sheet

Bonded Structures
Ciba-Geigy Plastics
ford Cambridge England CB2 4QD
phone: Cambridge (0223) 833141 Telex: 81250

TER COPY ISSUE DATE:
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7/11/95

Redux 775

Vinyl phenolic structural adhesive in film form or in two component, liquid and powder form

Description

Redux 775 was adopted as the world's first metal-to-metal bonding process to be officially approved for use in the manufacture of aircraft primary structures in 1943. Now used as the yardstick by which all other structural adhesives are measured, Redux 775 is still in great demand.

It is available either as a film or as a two component system, Redux 775 "Liquid" and Redux 775 "Powder", both systems requiring heat and pressure for curing.

Main Features

* Outstanding long term weathering and corrosion resistance
* Outstanding resistance to commonly used aircraft fluids
* Insensitive to atmospheric moisture before and after curing
* High shear and peel strength in the temperature range -55 to +70°C
* Minimum pressure of 7 kg/cm^2 required for bonding
* Suitable for bonding a wide range of materials, including steel, rubber, plastics and wood, as well as aluminium

Applications

Bonding reinforcing stringers and doublers to aircraft wing and fuselage skins
Bonding 'Z'-sections and multi-laminations in the construction of metal spars
Bonding reinforcing plates in helicopter blades
Bonding aluminium to balsa wood in aircraft floor panels
Bonding steel to rubber and steel to friction linings in miscellaneous applications

Information Sheet
No RTA 150a
September 1985

Form

Redux 775 Film

A white, slightly tacky film of 0.46 mm minimum thickness and a weight of 366 ±37 gm/m^2 protected on both sides during transit, storage and handling by polythene film. The width of the film is 61 cm and it is supplied in standard rolls containing 25 m^2.

Redux 775 L & P (Liquid and Powder, two component system)

Redux 775L is an amber-to-red phenolic resin solution with solids content 69-73% and viscosity 3.0 to 6.0 poise at 25°C*. It is supplied in 25 kg or 1 kg standard packs.

Redux 775P is a white, free-flowing vinyl powder of bulk density 0.3 kg/litre and particle size 300 to 500 μm. It is supplied in 65 kg or 1 kg standard packs.

* Brookfield model RVT, spindle 3, speed 100 rpm.

Instructions for Use

Surface preparation

All surfaces to be bonded must be completely free from grease and should have a uniform matt (or slightly roughened) surface.

For aluminium and aluminium alloys, surface pretreatment as specified in British Defence Standard 03-2/1 is recommended as follows:-

1. Degrease thoroughly in trichloroethylene vapour bath

2. Immerse for 30 minutes in a solution of

Demineralised water	880 pbw
Sulphuric acid (density 1840 kg/m^3)	276 pbw
Chromic acid flake	50 pbw

   at a temperature of 60°C

   N.B. Extreme care is required when making up this solution. Always add sulphuric acid slowly to water - never add water to the concentrated acid. Chromic acid should be added after the sulphuric acid and water have been mixed.

3. Wash thoroughly in clean running water (preferably soft or demineralised water for final wash)

4. Dry in warm air flow - do not allow temperature to exceed 60°C

For optimum corrosion resistance in aluminium alloy bonds, the above procedure may be followed by chromic acid anodising to British Defence Standard DEF 151 type II

If pretreated aluminium is to be stored temporarily before bonding, a light coating of Redux 101 should be applied as soon as possible after the pretreatment process. Redux 101 will protect the prepared bonding surfaces for up to two weeks and need not be removed before the bonding operation.

Details of surface preparation methods for other materials to be bonded with Redux 775, such as steel, rubber, wood, plastics etc can be found in Ciba-Geigy manual no A.15, available on request.

Application

Redux 775 Film

1. Cut the film to shape and size required
2. Remove one protective polythene cover and position the exposed film surface against the prepared bonding surface
3. Remove the second polythene cover
4. Complete the joint assembly and secure against relative movement of the parts while the adhesive is being cured

Redux 775 Liquid & Powder

1. Apply Redux 775 Liquid at the rate of approximately 100 gm/m^2 to both of the prepared adherend surfaces, using a brush or roller to give as uniform a coating thickness as possible
2. Immediately, apply Redux 775 Powder either by dipping the coated component into a powder reservoir or by sprinkling enough powder onto the liquid coating to cover completely. In either case, excess powder should then be removed by lightly tapping the inverted component.
3. The coated surfaces must then be left for at least 30 minutes at 22°C to allow solvent evaporation before closing the joint. Coated components may be stored for periods up to 72 hours at 22°C before completing the bonding process.

This procedure results in an application rate of approximately 100 to 120 gm of powder per m^2 of adherend surface. After solvent evaporation from the liquid component, that should result in a Powder:Liquid ratio of 1.25:1 to 1.4:1 and the total weight of adhesive in the joint will be approximately 400 gm/m^2.

The above conditions are recommended to achieve an optimum balance between tensile shear and peel properties of the cured joint. If, however, applications exist where higher peel strengths are required, they may be achieved (though at the expense of shear strength) by applying a thinner film of liquid, effectively increasing the Powder:Liquid ratio to a maximum of 2:1.

Further advice on application of the Liquid & Powder system may be obtained from the Adhesives Product Manager at the address on the back page of this information sheet.

Curing

Redux 775 (both Film and Liquid & Powder) emits some water vapour during cure so it is essential that a pressure of at least 7 kg/cm^2 is maintained on the joint during the curing process. Higher pressures are recommended for thicker adherends to ensure complete mating of the two surfaces.

To complete the curing process, 30 minutes at 150 $\pm$ 5°C is required in the glue-line. Curing schedules should allow time for heat to penetrate through the adherends to the glue-line. When the cure schedule is complete it is recommended that components are cooled to below 70°C before releasing pressure. If cured in an autoclave, it is necessary to apply vacuum throughout the curing process to remove volatiles.

Properties

Both Redux 775 Film and Redux 775 L & P have been used for bonding aircraft primary structures for many years and, as a result, a vast amount of design data has been generated and published in technical literature. The properties shown below are intended as a guide to the general performance levels achievable; they are typical figures obtained during routine inspection and are not guaranteed minima for specification purposes. For further information on design data please contact Ciba-Geigy Bonded Structures.

Redux 775 Film

	Test method specification	
Tensile shear at 22°C	DTD 5577	37 MN/m^2
" " at 70°C	DTD 5577	21 MN/m^2
Metal-to-metal peel at 22°C	DTD 5577	275 N/25.4 mm
" " " " at 22°C	Pr EN 2243/2	240 N/25.4 mm

Redux 775 L & P (P:L ratio = 1.3:1)

Tensile shear at 22°C	DTD 775	31 MN/m^2
Metal-to-metal peel at 22°C	CIBA(ARL)	270 N/25.4 mm

Qualifications

Both Redux 775 Film and 775 L & P are qualified to US Federal Specification MMM-A-132 type 1 class 2.

Both Redux 775 Film and 775 L & P meet the requirements of UK Ministry of Defence Specification DTD 5577 type 2 class 2P.

Handling Precautions

Redux 775 Film

In film form Redux 775 is relatively free from handling hazards since it is virtually dry (tack free) and protected on both sides by polythene. Nevertheless the usual precautions when handling synthetic resins should be observed - avoid direct contact with skin and clothing. In case of accidental contact wash with plenty of warm soapy water.

Keep away from food and food containers.

In compliance with the Health & Safety at Work Act (1976), Ciba-Geigy has prepared a Product Safety Information Sheet which is available to medical/safety officers on request.

Redux 775 Liquid

Redux 775 Liquid is highly inflammable. It should be kept well away from all sources of heat and must not be exposed to naked flames or sparks.

Redux 775 Liquid is toxic if swallowed, keep well away from food and food containers.

Avoid contact with skin, eyes and clothing, avoid breathing vapours. In case of accidental skin contact wash with warm, soapy water, in case of eye contact give prolonged irrigation with water and summon medical aid. If the operator feels unwell, seek medical advice.

Full safety information is combined in the Product Safety Information Sheet which is available to medical/safety officers on request.

Redux 775 Powder

Observe the usual precautions when handling synthetic resin materials. Avoid contact with skin and clothing, avoid breathing dust, and keep away from food and food containers.

Full safety information is contained in the Product Safety Information Sheet which is available to medical/safety officers on request.

Volatiles

Redux 775 Film and Redux 775 L & P emit volatile constituents during the curing process. Ensure that hot press or autoclave areas are well ventilated.

Storage

Redux 775 Film

Store in original packaging whenever possible. If stored at 0–5°C in a refrigerator the adhesive will maintain performance characteristics for 12 months. After removal from the refrigerator the film may be stored in the workshop at temperatures below 25°C for up to 6 months.

Redux 775 Liquid

Storage at 0–5°C is recommended. At this temperature the product will maintain its performance characteristics for up to 12 months. At room temperature (15 to 25°C) the product gradually increases in viscosity and, whilst adhesive performance characteristics may be maintained for up to 6 months, a change in processing characteristics may become evident after 2 to 3 months.

Redux 775 Powder

Provided it is kept dry and free from contamination Redux 775 Powder has an indefinite storage life at normal room temperature.

CIBA–GEIGY

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Tel: Cambridge (0223) 833141
Telex 81250

5 V. 7, September, 1952
(Replacing British Standard 4 V.7 and Ministry of Supply Aircraft Material Specification D.T.D. [illegible])

BRITISH STANDARDS INSTITUTION
24 VICTORIA STREET, WESTMINSTER, LONDON, S.W.1

INCORPORATED BY ROYAL CHARTER
Sales enquiries: Telephone, VICTORIA 0522
Other enquiries: Telephone, ABBEY 3333

BRITISH STANDARD SPECIFICATION FOR

MAHOGANY FOR USE IN AIRSCREWS

SCOPE

1. This British Standard covers the requirements for Central American mahogany (*Swietenia macrophylla* King) for use in airscrews.

Information relating to timbers used as substitutes for Central American mahogany as an emergency measure is given in Appendix A.

QUALITY

2. The timber shall be of the best description of Honduras, Nicaraguan or Tabasco mahogany, or of equal quality.

SEASONING

3. The timber shall have been either naturally or artificially seasoned to the satisfaction of the Inspector to a moisture content, determined by the method described in Appendix B, of 12 ± 2 per cent.

FREEDOM FROM DEFECTS

4. The timber shall be free from sapwood, knots, gum veins, compression failures, shakes and splits, spongy heart or other forms of rot. Occasional pin worm holes and fine drying checks are permissible.

DENSITY

5. When the moisture content, calculated on the weight of the oven-dry wood, is 12 per cent, the weight per cubic foot of each sample of timber, determined by the method described in Appendix C, shall be not less than 30 lb.

This minimum value shall be increased or decreased with the moisture content within the range of 10 to 14 per cent, at the rate of 0·16 lb. per cubic foot, for each 1 per cent increase or decrease respectively in the moisture from 12 per cent.

STRAIGHTNESS OF GRAIN

6. The inclination of the grain as indicated on a quartered or near-quartered face or edge by the lines marking the growth rings shall not exceed 1 in 12. Slight interlocked grain is allowed, but markedly oblique grain ('fiddle back', 'roe', 'stripe', 'curly figure') or [illegible] direction of vessel lines on fla[illegible] showing as elliptical dots on [illegible] not permitted.

BRITTLENESS

7. The freedom of the timber from brittleness shall be to the satisfaction of the Inspector.

APPENDIX A

TIMBERS USED AS SUBSTITUTES FOR CENTRAL AMERICAN MAHOGANY

As an emergency measure, the following timbers have been used as substitutes for Central American mahogany in designs based on the mechanical properties of that timber:—

Canadian yellow birch (*Betula lutea* Michx.)

Queensland maple (*Flindersia brayleyana* F. Muell. and *F. pimenteliana* F. Muell.)

The minimum densities specified for the substitute timbers at 15 per cent moisture content are shown in the following table:—

Timber	Density	Increase or decrease of density for 1 per cent change in moisture content
	lb/cu. ft.	lb.
Canadian yellow birch	39	0·11
Queensland maple	32	0·05

APPENDIX B

METHOD OF DETERMINING MOISTURE CONTENT

A small sample of the timber shall be removed from an appropriate position and weighed (W_1). The sample shall then be desiccated in an oven at a temperature of approximately 100 to 105°C. (212 to 221°F.) until the weight is constant (W_0).

The percentage of moisture shall be calculated as follows:—

$$\text{Percentage of moisture} = \frac{W_1 - W_0}{W_0} \times 100$$

Great care should be taken to prevent any change in moisture content between the cutting of the sample and the first weighing and also between removal from the oven and the subsequent weighing.

APPENDIX C

METHOD OF DETERMINING DENSITY

The density of the piece shall be determined by weighing and measuring the volume of representative samples.

The samples, approximately 1 in. long and of the full cross-section of the boarder plank, shall be cleanly cut, one from each end of the piece at a position clear of weathering, where the moisture content is known or is about to be determined.

To ascertain the volume of the sample a series of measurements shall be made of the length, width and thickness of each sample and the arithmetic mean of each dimension obtained.

Each sample shall be weighed in grammes to an accuracy of 0·3 per cent of its weight and the following formula used:—

$$\text{Density in lb/cu. ft.} = \frac{\text{Weight in grammes} \times 3{\cdot}81}{\text{Volume in cubic inches}}$$

This Britain Standard, having been approved by the Aircraft Industry Standards Committee and endorsed by the Chairman of the Engineering Divisional Council, was published under the authority of the General Council on 2nd October, 1952.

ACE/2

V. 37, September, 1952
(Replacing Ministry of Supply Aircraft Material Specification D.T.D. 36B)

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BRITISH STANDARD SPECIFICATION FOR

SITKA SPRUCE FOR USE IN AIRCRAFT

SCOPE

1. This British Standard covers the requirements for Grade A and Grade B Sitka spruce (*Picea sitchensis* Carr) for use in aircraft.

Information relating to timbers used as substitutes for Sitka spruce as an emergency measure is given in Appendix A.

SEASONING

2. The timber shall have been either naturally or artificially seasoned to the satisfaction of the Inspector to a moisture content, determined by the method described in Appendix B, of not less than 10 or more than 17 per cent.

In laminated assemblages the difference in moisture content between any two of the laminae shall not exceed 3 per cent.

FREEDOM FROM DEFECTS

3. The timber shall be clean, free from rot, dote and all forms of incipient decay and/or discolouration, deleterious shakes, knots resin pockets and compression wood.

DENSITY

4. When the moisture content, calculated on the weight of the oven-dry wood, is 15 per cent, the weight per cubic foot of each sample of timber, determined by the method described in Appendix C, shall be:

Grade A—not less than 24 lb.
Grade B—not less than 22 lb.

These minimum values shall be increased or decreased with the moisture content within the range of 10 to 17 per cent at the rate of 0·11 lb. per cubic foot, for each 1 per cent increase or decrease respectively in the moisture from 15 per cent.

STRAIGHTNESS OF GRAIN

5. The timber shall be free on all faces from cu[illegible] wavy grain, undulating and irregular grain, or a[illegible] grain disturbance which may constitute a weak[illegible]

The maximum inclination of the grain to the [illegible] the piece shall not exceed one in fifteen (see App[illegible]

BRITTLENESS

6. The freedom of the timber from brittleness s[illegible] the satisfaction of the Inspector.

APPENDIX A

TIMBERS USED AS SUBSTITUTES FOR SITKA SPRUCE

As an emergency measure the following timbers have been used as substitutes for the Sitka spruce covered by this British Standard in designs based on the mechanical properties of that timber:

- *Douglas fir (*Pseudotsuga taxifolia* Brit.)
- Noble fir (*Abies nobilis* Lindl.)
- Western white spruce (*Picea glauca* var *albertiana*)
- Western hemlock (*Tsuga heterophylla* Sarg.)

The minimum densities specified for the substitute timbers at 15 per cent moisture content are shown in the following table:

Timber	Grade A	Grade B	Increase or decrease of density for 1 per cent change in moisture content
	lb/cu. ft.	lb/cu. ft.	lb.
Douglas fir	29·5	[illegible]	0·14
Noble fir	24	22	0·10
Western white spruce	26	24	0·10
Western hemlock	24	22	0·11

* The reference here is to low-density Douglas fir. Douglas fir [illegible] high density [illegible] covered by British Standard [illegible]

APPENDIX B

METHOD OF DETERMINING MOISTURE CONTENT

A small sample of the timber shall be remov[illegible] from an appropriate position and weighed (W_1). The sample [illegible]

APPENDIX C. COMPUTER DESIGN PROGRAM.

C.1. BASIC Variables.

The Variables used in the BASIC Program are as follows:-

AB(I) Air Bending Moment
AC(J) $1/2 \rho W^2$ at J
ALP(I) Incidence angle at I
AM(I) Minutes of blade angle
AQ Accumulator -Torque
AQ(I) Accumulated torque
AT Accumulator -Thrust
AT(I) Accumulated thrust

BD Blanking Diameter
BM(I) Bending Moment

C(I) Blade chord at I
CA Accummulated C.F.
CB Accumulated C.F.
CB(I) C.F. Bending Moment
CFJ(J) C.F. of element at J
CFT(I) C.F. total at I
CGR Chord gradient
CL(J) Lift coeff.
CLS BASIC function
CS Suggested tip chord
CT(I) C.F. on element

D Fan diamter

EF Calculated efficiency
EQDF(J) Element torque drag force
EQLF(J) Element torque lift force
ETDF(J) Element thrust drag force
ETLF(J) Element thrust lift force
ETQF(J) Element total torque force
ETTF)J) Element total thrust force

FC(I) C.F. stress at I
FG Flag

FM(I) Total compressive stress
FT(I) Total tensile stress
F$ BASIC Function

G(J) Power coeff.
GAM Drag/Lift coeff.
GF(J) Power coeff. factor
GS Power factor

HP Fan Power, BHP.

I Integer spacer for stations.

J Integer spacer for elemnets.

K Pressure coeff.
KG Power coeff.
KP(I) Pressure coeff.
KV Volume coeff.

L Lift on element.

M Rpm/1000

N Fan speed, Rpm.
NF Annulus ratio.
NU Blanking ratio.

OM Rotational speed, rads/sec.
OS OM squared.

PH(J) Inflow angle (Φ)
PI
PS PI squared.
PZ Possible no. of blades.

R(I) Radius at station I
RC Suggested root chord.
RHO Air density

S(J) Blade solidity
SCL(J) Solidity*Lift coeff.

SC(I) Compressive bending stress
ST(I) Tensile bending stress

TC(J) Section thickness/chord
TEM1 Temporary variable
TG Design track value
TH(I) Blade angle ( ) at I
TK Suggested track value

TR(I) Blade angle (θ) in radians at I
TS(I) Track/Sweep distance factor
TT(J) Section thickness
TX(J)

U Air velocity thro' annulus.

V Volume flow, CFM/100
VI Air speed coeff.

W1(J) Mean air velocity at blade section.
WG Air pressure, (in. water gauge)

X(J) Position "x" coressponding to J.

Z Number of blades chosen.
ZC(I) Section compression Modulus.
ZT(I) Section tension Modulus.

C.2. Program Listing.

```
10 REM Program FANABMS6(FAN Aero Bending Moment and Stress)
20 REM This is my main fan design program.
40 PI=3.1459 : PS=PI*PI
50 DIM GF(100),C(100),TC(100),TT(100),X(100),PH(100),SCL(100)
60 DIM W1(100),AC(100),G(100),LT(100),S(100),CL(100)
70 DIM        AR(100),TX(100),ETLF(100),ETDF(100),EQDF(100)
80 DIM ETTF(100),ETQF(100),EQLF(100),CFJ(100)
90 FOR J=40 TO 100
100 READ GF(J)
110 NEXT J
120 FOR I=4 TO 10
130 READ CL(I)
140 NEXT I
150 DATA .721,.734,.748,.761,.774,.789,.801,.815,.828,.84 ,.854
160 DATA .864,.875,.885,.895,.905,.914,.923,.933,.942,.952
170 DATA      .958,.966,.974,.981,.99 ,.995,1.01 ,1.007,1.013,1.019
180 DATA  1.023,1.027,1.031,1.035,1.038,1.041,1.044,1.047,1.05 ,1.05
190 DATA 1.054,1.056,1.058,1.06 ,1.062,1.063,1.064,1.065,1.067,1.068
200 DATA 1.068,1.069,1.069,1.07, 1.07, 1.071,1.071,1.072,1.073,1.073
210 DATA .85,.795,.74,.695,.63,.575,.52
220 CLS
230 PRINT"     INPUT DATA":PRINT"     ***** ****"
240 INPUT "DIAMETER,     FT-";D
250 INPUT "BLANKING DIA. FT-";BD
260 INPUT "VOLUME/1000  CFM-";V
270 INPUT "FAN POWER    BHP-";HP
280 INPUT "FAN SPEED    RPM-";N
290 PRINT    "   ***********  "
300 GAM=.067
310 M=N/1000:NU=INT(BD*1000/D)/1000
320 PRINT"BLANKING RATIO IS";NU
330 NF=1-NU*NU
340 VI=INT(4000*V/(PI*PI*M*D^3*NF))/1000
350 PRINT"VOLUME COEFFICIENT =";VI
360 GS=2528800! *HP/(N*N*D*D*V)
370 PRINT "POWER COEFFICENT =";INT(GS*10000)/10000
380 PRINT "   *********       "
390 PRINT"CHECK ABOVE INPUT DATA - IF CORRECT PRESS KEY 0"
400 PRINT"                       IF INCORRECT PRESS KEY 1"
410 Z$=INKEY$ :IF Z$=""  THEN 410
420            IF Z$="0" THEN 450
430            IF Z$="1" THEN 220
440 PRINT"WRONG KEY PRESSED": GOTO 410
450 CLS
```

```
460 CS=2.4*(D-BD)
470 PRINT"FAN SIZE INDICATES THAT TIP CHORD SHOULD BE ABOUT";
          CS;"INS."
480 PRINT
490 I=10
500 GOSUB 2830
510 PRINT"TIP SCl =";INT(SCL(10)*1000)/1000
520 PZ=12*PI*D*S(10)/CS
530 PRINT"No. OF BLADES NEEDS TO BE GREATER THAN ";PZ
540 INPUT "CHOSEN No. OF BLADES Z=";Z
550 INPUT "CHOSEN TIP CHORD TO BE =";C(100)
560 S(10)=C(100)*Z/(PI*D*12)
570 CL(10)=SCL(10)/S(10)
580 PRINT"TIP CL IS NOW =";INT(CL(10)*100)/100
590 IF CL(10)<.65 THEN 710
600 CLS
610 PRINT"     ******* WARNING  *******"
620 PRINT"     Cl IS TOO LARGE";
630 PRINT"PRESS KEY 0 TO RECALCULATE...."
640 PRINT"PRESS KEY 1 TO CALCULATE ROOT STATION"
650 PRINT"PRESS KEY 2 IF NEW RPM REQUIRED"
660 Z$=INKEY$: IF Z$=""  THEN 660
670            IF Z$="0" THEN 540
680            IF Z$="1" THEN 720
690            IF Z$="2" THEN 280
700            IF Z$="3" THEN END
710 I=4
720 GOSUB 2830
730 PRINT"ROOT SCL =";INT(SCL(4)*1000)/1000
740 RC=.5*(D-BD)+C(100)
750 PRINT"FIRST TRY OF ROOT CHORD, ABOUT ";RC;"Ins."
760 INPUT "CHOSEN ROOT CHORD";C(40)
770 S(4)=C(40)*Z/(4.8*PI*D)
780 CL(4)=SCL(4)/S(4)
790 PRINT"ROOT CL IS NOW ";INT(CL(4)*100)/100
800 IF CL(4)<1  THEN 930
810 CLS
820 PRINT" **** WARNING ****"
830 PRINT"   *** Cl IS OVER 1 *** "
840 PRINT"PRESS KEY 0 TO RE-CALCULATE ROOT STATION"
850  PRINT"PRESS KEY 1 TO CHANGE RPM"
860 PRINT"PRESS KEY 2 TO RE-CALCULATE TIP STATION"
870 PRINT"PRESS KEY3 TO END PROGRAM"
880 Z$=INKEY$ :IF Z$=""  THEN 880
890            IF Z$="0" THEN 750
900            IF Z$="1" THEN 280
910            IF Z$="2" THEN 540
920            IF Z$="3" THEN END
930 CGR=(C(40)-C(100))/60
940 FOR J=41 TO 99
950 C(J)=C(100)+CGR*(100-J)
960 NEXT J
970 FOR J=40 TO 100
980 TC(J)=.25-.0015*J
990 TT(J)=C(J)*TC(J)
1000 NEXT J
```

```
1010 FOR J=40 TO 100
1020 X(J)=J/100
1030 G(J)=GF(J)*GS
1040 PH(J)=ATN(VI*X(J)/(X(J)^2-G(J)))
1050 SCL(J)=4*G(J)*SIN(PH(J))/(VI*X(J)*(1+GAM/TAN(PH(J))))
1060 S(J)=C(J)*Z/(X(J)*PI*D*12)
1070 CL(J)=        SCL(J)/S(J)
1080 NEXT J
1090 FOR I=4 TO 10
1100 ALP(I)=11.76*CL(10*I)-.11
1110 TH(I)=ALP(I)-40*TC(10*I)+PH(10*I)*57.296
1120 TR(I)=TH(I)/57.296
1130 AM(I)=INT(60*(TH(I)-INT(TH(I))))
1140 TH(I)=INT(TH(I))
1150 PH(I)=INT(5729.6*PH(10*I))/100
1160 R(I)=X(10*I)*6*D
1170 C(10*I)=INT(100*C(10*I))/100
1180 TT(10*I)=INT(100*TT(10*I))/100
1190 CL(I)=INT(100*CL(10*I))/100
1200 SCL(I)=SCL(10*I)
1210 NEXT I
1220 PRINT
1230 PRINT"PRESS KEY 0 TO CALCULATE PRESSURE"
1240 PRINT"PRESS KEY 1 TO END"
1250 Z$=INKEY$: IF Z$=""  THEN 1250
1260            IF Z$="0" THEN 1280
1270            IF Z$="1" THEN END
1280 CLS
1290 FOR I=4 TO 10
1300 TEM1(I)=0
1310 TEM1(I)=2*SIN(PH(I)/57.296)
1320 KP(I)=PS*VI*VI*SCL(I)*(1/TAN(PH(I)/57.296)-GAM)/TEM1(I)
1330 NEXT I
1340 FOR I=4 TO 10
1350 PRINT"STN =";I/10;"  KP(";I;")";INT(KP(I)*1000)/1000
1360 NEXT I
1370 K=((.9*NF -.711  )*KP(4)+.1*KP(5)+.12*KP(6)+.14*KP(7)
     +.16*KP(8)+.18*KP(9)+.095*KP(10))/NF
1380 WG=INT(.1267*N*N*D*D*K/10000)/100
1390 EF=INT(V*WG*1000/(6.35*HP))/10
1400 PRINT"WAITING FOR DATA INPUT AND RESULTS. Press Space Bar
           when ready"
1410 Z$=INKEY$:IF Z$=""  THEN 1410
1420 FG=0
1430 CLS
```

```
1440 PRINT"     INPUT  DATA":PRINT"     *****  ****"
1450 PRINT"DIAMETER          D=";D;"   FT"
1460 PRINT"BLANKING DIA. BD=";BD;"   FT"
1470 PRINT"VOLUME,           V=";V;"  1000*CFM"
1480 PRINT"FAN POWER,    BHP=";HP;"   BHP"
1490 PRINT"FAN SPEED,        =";N;"  RPM"
1500 PRINT
1510 PRINT"     RESULTS":PRINT"     *******"
1520 PRINT
1530 PRINT"   NUMBER OF BLADES =";Z
1540 PRINT"STATION";TAB(14)".4";TAB(24)",5";TAB(34)".6";TAB(44)".7";
          TAB(54)".8";TAB(64)".9";TAB(74)"1.0"
1550 PRINT"RADIUS";TAB(13)R(4); TAB(23)R(5);TAB(33)R(6);
TAB(43)R(7);TAB(53)R(8);TAB(63)R(9);TAB(73)R(10)
1560 PRINT"CHORD  Ins";TAB(13)C(40);TAB(23)C(50);TAB(33)C(60);
      TAB(43)C(70);TAB(53)C(80);TAB(63)C(90);TAB(73)C(100)
1570 PRINT"THICK  Ins";TAB(14)TT(40);TAB(24)TT(50);TAB(34)TT(60);
          TAB(44)TT(70);TAB(54)TT(80);TAB(64)TT(90);TAB(74)TT(100
1580 PRINT"INFL.ANGLE";TAB(13)PH(4);TAB(23)PH(5);TAB(33)PH(6);
      TAB(43)PH(7);TAB(53)PH(8) ;TAB(63)PH(9) ;TAB(73)PH(10)
1590 PRINT"   Cl      ";TAB(14)CL(4);TAB(24)CL(5);TAB(34)CL(6);
         TAB(44)CL(7);TAB(54)CL(8);TAB(64)CL(9);TAB(74)CL(10)
1600 PRINT"BLADE ANGLE";TAB(12)TH(4);"-";AM(4);TAB(22)TH(5);"-";
 AM(5);TAB(32)TH(6);"-";AM(6);TAB(42)TH(7);"-";AM(7);TAB(52)TH(8);
   "-";AM(8);TAB(62)TH(9);"-";AM(9);TAB(72)TH(10);"-";AM(10)
1610 PRINT
1620 PRINT"Press Space Bar when ready for PRESSURE Print out"
1630 Z$=INKEY$:IF Z$="" THEN 1630
1640 PRINT:PRINT
1650 PRINT"PRESSURE COEFFICICENT =";INT(K*1000)/1000
1660 PRINT
1670 PRINT"TOTAL PRESSURE=";WG;" INS. W.G."
1680 PRINT
1690 PRINT"EFFICIENCY =";EF;" %"
1700 PRINT"Waiting for ABM Print out"
1710 PRINT"PRESS KEY 0 TO CONTINUE"
1720 PRINT
1730 Z$=INKEY$: IF Z$=""  THEN 1730
1740            IF Z$="0" THEN 1760
1750            IF Z$="1" THEN END
1760 IF FG=1 THEN 2590
1770 FOR J=40 TO 100
1780 W1(J)=(VI*PI*N*D)/(60*SIN(PH(J)))
1790 AC(J)=.00119*W1(J)*W1(J)
1800 ETLF(J)=(AC(J)*CL(J)*C(J)*.01*D*COS(PH(J)))/24
1810 EQLF(J)= ETLF(J)*TAN(PH(J))
1820 ETDF(J)=(AC(J)*.067 *CL(J)*C(J)*.01*D*SIN(PH(J)))/24
1830 EQDF(J)=ETDF(J)/TAN(PH(J))
1840 ETTF(J)=ETLF(J)-ETDF(J)
1850 ETQF(J)=EQLF(J)+EQDF(J)
1860 NEXT J
```

```
1870 FOR J=11 TO 39
1880 ETTF(J)=0
1890 ETQF(J)=0
1900 NEXT J
1910 FOR I=2 TO 9
1920 AT=0:AQ=0
1930 FOR J=(10*I) TO 100
1940 AT=AT+ETTF(J)*(J-10*I)*.06*D
1950 AQ=AQ+ETQF(J)*(J-10*I)*.06*D
1960 NEXT J
1970 AT(I)=AT
1980 AQ(I)=AQ
1990 AB(I)=AT(I)*COS(TR(I))+AQ(I)*SIN(TR(I))
2000 AB(I)=INT(AB(I))
2010 NEXT I
2020 PRINT" STATION";"     ABM lb-in."
2030 FOR I=I TO 9
2040 PRINT TAB(4)I;TAB(14)AB(I)
2050 NEXT I
2060 OM=PI*N/30
2070 OS=OM*OM
2080 FOR J=40 TO 100
2090 AR(J)=.7*TT(J)*C(J)
2100 CFJ(J)=D*D*OS*J*AR(J)*.00217*.0001
2110 NEXT J
2120 CA=0
2130 CFT(10)=0
2140 FOR I=9 TO 4 STEP -1
2150 FOR J=(10*I+10) TO (10*I+1) STEP -1
2160 CA=CA+CFJ(J)
2170 NEXT J
2180 CFT(I)=INT(CA)
2190 NEXT I
2200 FOR I=4 TO 9
2210 PRINT"C.F. at Stn-";I;" is ";CFT(I)
2220 NEXT I
2230 FOR I=4 TO 9
2240 FC(I)=INT(CFT(I)/AR(10*I))
2250 PRINT"C.F.Stress at Stn-";I;" is";FC(I)
2260 NEXT I
2270 PRINT"FOR TRACK CALCS. PRESS KET 0"
2280 F$=INKEY$: IF F$=""  THEN 2280
2290            IF F$="0" THEN 2300
2300 FOR J=40 TO 100
2310 TX(J)=(J-40)/60
2320 NEXT J
2330 FOR I=4 TO 10
2340 TS(I)=(I-4)/6
2350 NEXT I
2360 CB=0
2370 FOR I=9 TO 4 STEP -1
2380 FOR J=100 TO (10*I) STEP -1
2390 CB=CB+CFJ(J)*(TX(J)-TS(I))
2400 NEXT J
2410 CB(I)=INT(1.155*CB)
2420 CB=0
2430 NEXT I
```

```
2440 TK=.5*AB(4)/CB(4)
2450 PRINT"TRACK TO BE APPROX.";TK
2460 INPUT "CHOSEN TRACK -";TG
2470 SWP = .6*TG
2480 FOR I=4 TO 9
2490 CB(I)=INT(CB(I)*TG)
2500 BM(I)=AB(I)-CB(I)
2510 ZT(I)=.12*C(10*I)*TT(10*I)^2
2520 ZC(I)=2*ZT(I)/3
2530 ST(I)=AB(I)/ZT(I)
2540 SC(I)=AB(I)/ZC(I)
2550 FT(I)=INT(ST(I)+FC(I))
2560 FM(I)=INT(SC(I)-FC(I))
2570 NEXT I
2580 FG=1 :GOTO 1430
2590 PRINT
2600 PRINT TAB(1)"STATION";TAB(12)"ABM";TAB(22)"CFBM";
2610 PRINT TAB(32)"Net BM"
2620 FOR I=4 TO 9
2630 PRINT TAB(3)I;TAB(11)AB(I);TAB(21)CB(I);TAB(31)BM(I)
2640 NEXT I
2650 PRINT"TRACK TO BE -";TG
2660 PRINT"SWEEP TO BE -";SWP
2670 PRINT"ROOT ABM AT STN 2=";AB(2)
2680 PRINT"ROOT ABM AT STN 3=";AB(3)
2690 PRINT"Press Space Bar for FINAL STRESSES"
2700 Z$=INKEY$ :IF Z$=""  THEN 2700
2710 PRINT TAB(10)"FINAL STRESSES"
2720 PRINT TAB(10)"***** ********"
2730 PRINT
2740 PRINT TAB(2)"STATION";TAB(13)"TENSILE STRESS";
2750 PRINT TAB(31)"COM. STRESS"
2760 PRINT
2770 FOR I=4 TO 9
2780 PRINT TAB(4)I;TAB(17)FT(I);TAB(34)FM(I)
2790 NEXT I
2800 PRINT
2810 PRINT"C.F. LOAD AT STN .4 =";CFT(4)
2820 END
2830 G(I)=GF(I*10)*GS*(1+.2*(.4-BD/D))
2840 X(I)=I/10
2850 PH(I)=ATN(VI*X(I)/(X(I)^2-G(I)))
2860 SCL(I)=4*G(I)*SIN(PH(I))/(VI*X(I)*(1+GAM/TAN(PH(I))))
2870 S(I)=SCL(I)/CL(I)
2880 RETURN
2890 -48669!
```

Appendix F Fatigue Testing

F. Fatigue tests for NASA Ames Blades

F.1 Introduction

Static tests had previously been undertaken on a representative Root Pull specimen to establish the static strength of the proposed blade root design. The test had shown that the static strength was not less than 3.5 times the calculated operational loading.

The Ames fans are designed to run at a maximum speed of 180 RPM or 3 revs/sec. so that the blades will be subject to a cyclic loading of 3 per sec. NASA Ames had laid down the requirement that the blades should be capable of 1000 hours running per year for 25 years. Hence a total number of 3 x 25,000 x 60 x 60 equal to 2.70 x 10^8 loading cycles would be achieved.

Joining the two points, 3.5 x load for the static strength and the required fatigue limit of 1.0 x load for 2.7 x 10^8 cycles on a log.log. axes graph configuration an S N line can be plotted as shown in Fig. F.1*1 and Fig. F.1*2.

The fatigue test would then require to show that the test specimen could attain at least one point above this S N line. Of course, a loading condition near to the proposed operational load and the test being run for the required maximum cycles is the ideal test condition, but was impractical due the extensive time it would take to perform.

It was decided that to meet the above conditions the fatigue tests attempted should be firstly for 15 x10^6 cycles at a loading equivalent to 1.2 times the calculated maximum loading of the Ames H2/H4 design case (Point D on Fig. F.1*2) and secondly at 1.3 times the same load for (nomimally) another 15x10^6 cycles (Point C on Fig. F.1*2).

This Appendix F gives a summary of the tests involved and a resume of the reports by the subcontractor who carried out the actual work.

F.2 Test Specimen

The specimen, see Fig. F.2*1, consisted of a full size root end of the blade up to Station 130 in. with the tip being faired into a built up block contained between two Aluminium alloy plates so that it was possible to apply the appropriate loading from the testing machine yokes to the loading pins when the specimen was installed in the test rig (see Fig. F.2*1).

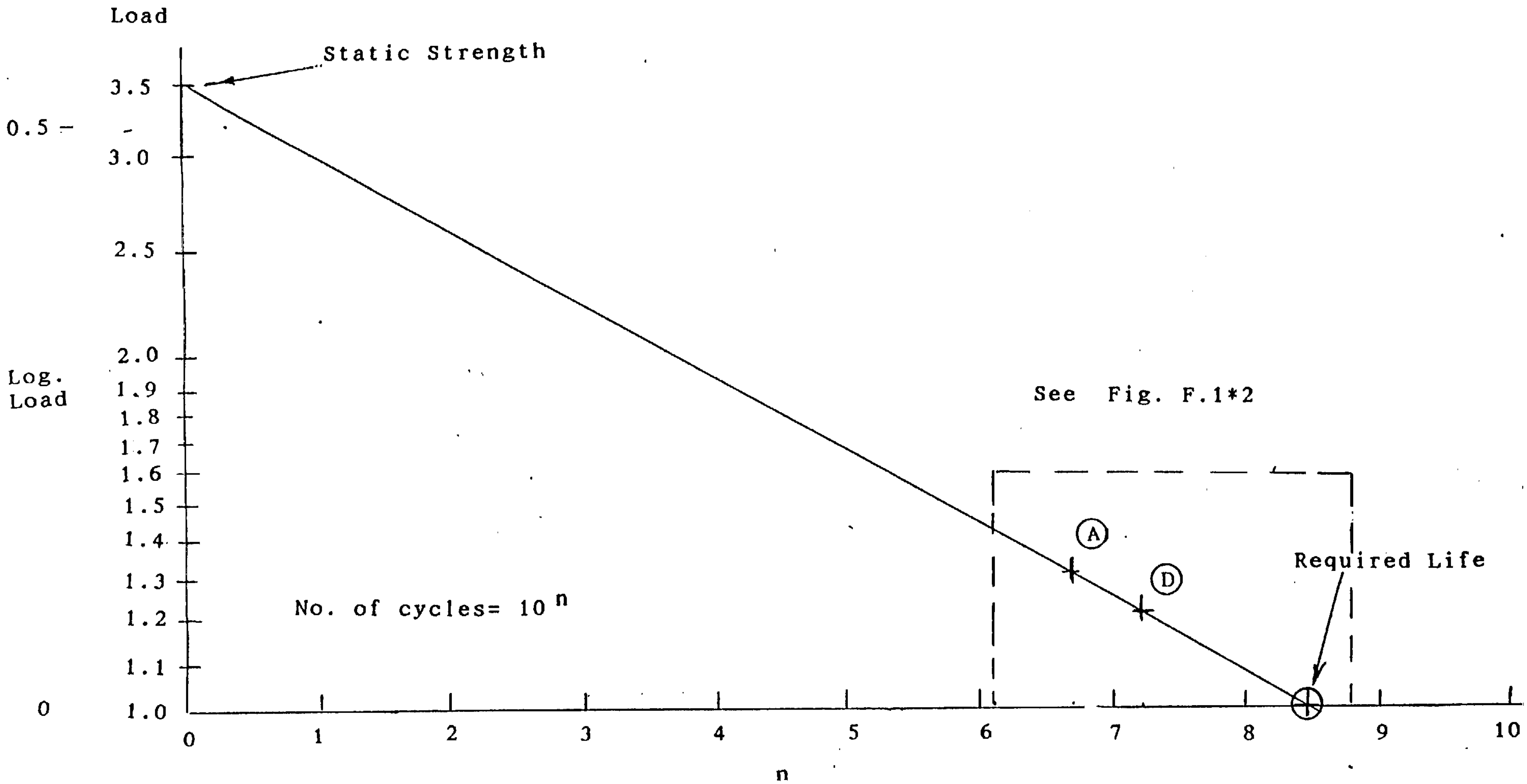

Load
Static Strength
3.5
0.5
3.0
2.5
2.0
Log.
Load
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
0
1.0
See Fig. F.1*2
A
D
Required Life
No. of cycles= 10 n
0
1
2
3
4
5
6
7
8
9
10
n

Fig. F.1*1

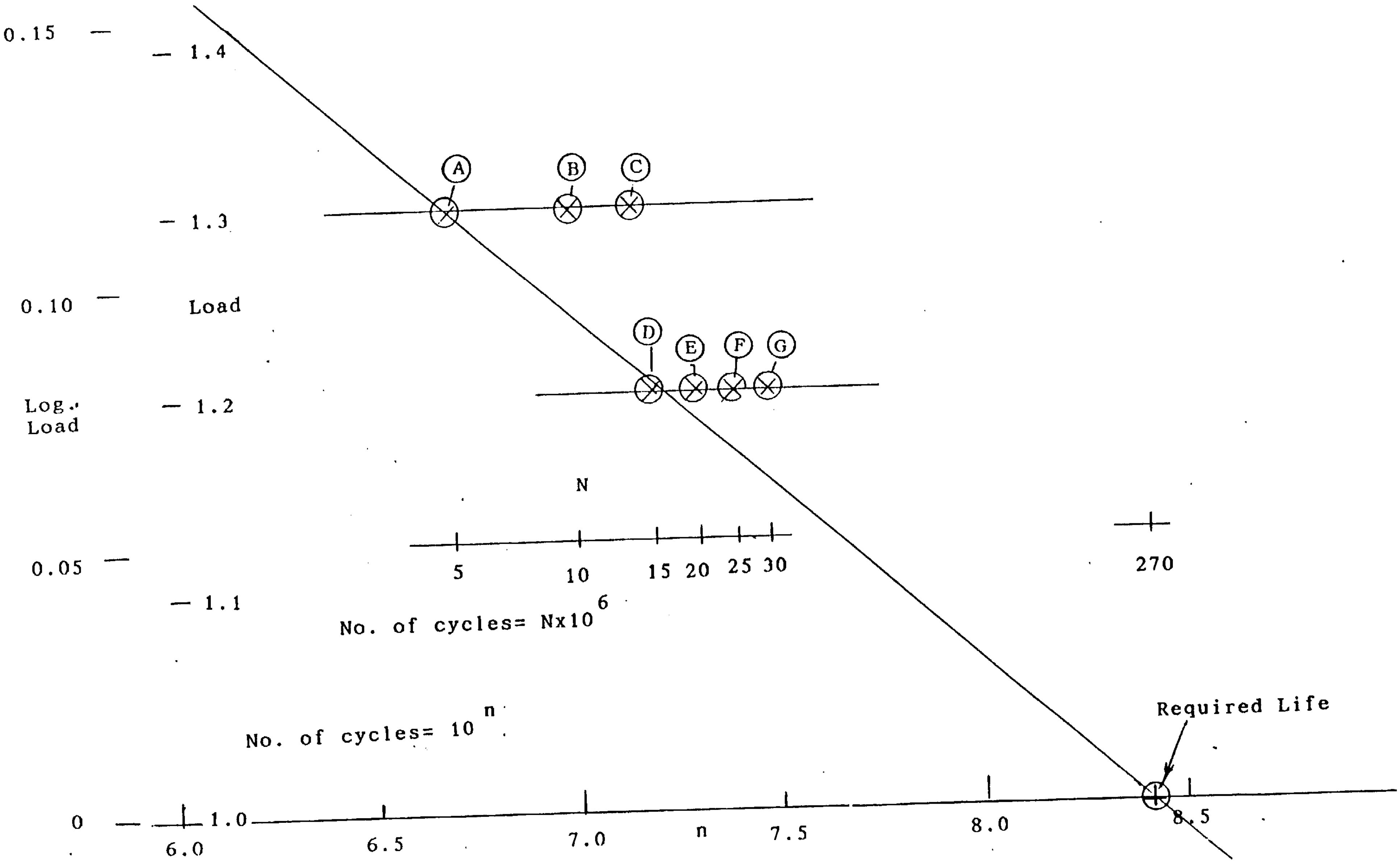

0.15
0.10
0.05
0
1.4
1.3
1.2
1.1
1.0
Load
Log. Load
A
B
C
D
E
F
G
N
5
10
15
20
25
30
270
No. of cycles= Nx10 6
No. of cycles= 10 n
Required Life
6.0
6.5
7.0
n
7.5
8.0
8.5

Fig. F1*2

F.3 Test Rig and Method

F.3.1 The specimen was tested in a specially designed test frame as shown in Fig. F.3*1. The specimen was attached to the frame via the blade end adaptor using a steel plate drilled to accommodate a set of production retention bolts, which were preloaded, prior to testing, to the same value (30 tonf) as they would be for operation in the fan assembly.

F.3.2 The centripedal end load was transferred from a Maclow Smith frictionless jack using columns and a yoke system via a large loading pin. (The jack had, pior to testing, been calibrated to BS 1610 Grade A). The end load was maintained constant using a Losenhausen UHP 35 tonf machine with a built in load maintaining system.

F.3.3 The lift/drag loads were applied using a 20 tonf UPZ jack, the positive and negative loads required being measured with a calibrated load cell at the loading yoke position. (These loads were monitored with an oscilloscope throughout the whole test programme and the loads adjusted when necessary). The jack was piped into the Losenhausen system 100 tonf testing machine, the dynamic loads being applied with the 300 CC Pulsator system.

F.3.4 The cycling speed was kept constant through out the whole test series at 333 cpm, somewhat higher than the operational speed.

F.3.5 Suitable safety systems were built into the test frame to switch off the whole test rig and unload the specimen should one or more loading system fail.

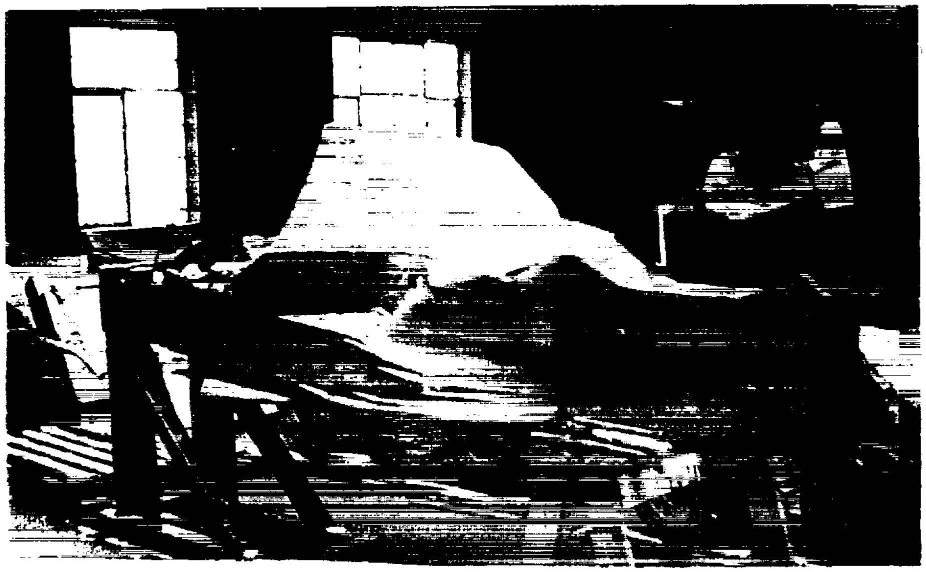
F.4 First Stage Tests

F.4.1 First static test. The specimen was loaded to 60,000 lbf on the centrifugal load jack whilst strain gauge readings were taken.

F.4.2 Second static test. The specimen was loaded to 60,000 lbf on the centrifugal jack and then loaded vertically to +3,950 lbf.

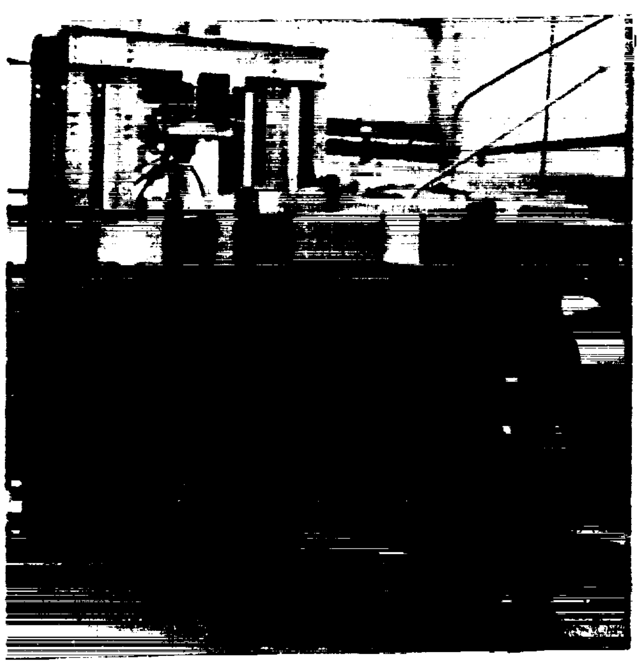
Further strain gauge readings were taken (N=1).

F.4.3 The vertical jack was disconnected, the specimen loaded to 72,000 lbf on the centrifugal jack, then vertical loads of +5,000 lbf and 3,650 lbf were applied with the centrifugal load kept constant. Strain gauge readings were taken and recorded.



Specimen
Fig. F.2*1

Specimen
in Rig
Fig. F.2*2



Test Rig
Fig. F.3*1

F.4.4 Dynamic test commenced with the specimen loaded to 72,000 lbf on the centrifugal jack with vertical loads of +5,000 lbf and 3,700 lbf applied.

F.4.5 After 3.04 x 10^6 cycles were completed, further strain gauge readings were taken before the specimen was statically loaded to 72,000 lbf on the centrifugal jack with +6,000 lbf and 4,500 lbf loads applied on the vertical jack.

F.4.6 Dynamic test resumed with original loads.

F.4.7 The specimen had completed 5.06 x 10^6 cycles at the above loading case.

F.4.8 Further strain gauge readings were taken with the specimen loaded to 72,000 lbf on the centrifugal jack and to +5,000 lbf to 3,700 lbf on the vertical jack.

F.4.9 Static load/deflection tests carried out. Further strain gauge readings were taken with 72,000 lbf on the centrifugal jack and +5,650 lbf to 4,350 lbf on the vertical jack. Dynamic testing resumed with these loads.

F.4.10 The specimen had completed 5,916,840 cycles.

The centrifugal jack loading pin was modified to give a single point loading and the loads changed.

F.4.11 After the specimen had completed 15,031,510 cycles, (Point D Fig. F.1*2) static load/deflection tests were carried out with 72,000 lbf on the centrifugal jack and +5,000 lbf to 3,700 lbf applied on the vertical jack. Further strain gauge readings were taken.

During this stage of testing slight movement between the steel adaptor and the compressed wood blade root was observed.

It was also noticed that the top surface of the steel adaptor felt warm whilst the test was in progress. The temperature was measured, the maximum being 26° C.

F.5 Preliminary Assessment after First Stage Tests

F.5.1 After the nominal 15 x 10^6 cycles had been completed (Point D Fig. F.1*2) it was considered that the test had demonstated that the specimen had a fatigue life of more than the 2.7 x10^8 cycles as required for a 25 year working life. This decision was influenced by the fact that the specimen was not damaged at the end of this run.

F.5.2 However it was decided that further tests should be subsequently carried out at a loading of 1.3 x the H2/H4 case and run for another 5 x10^6 cycles. (To achieve Point A Fig. F.1*2).

F.6 Second Stage Tests

F.6.1 Continuation of the dynamic test with 78,000 lbf load applied on the centrifugal jack with +5,500 lbf to 4,000 lbf applied on the vertical jack. Deflections were checked and recorded during the load up stage.

F.6.2 The second stage test discontinued after the specimen had completed (a further) 5,049,060 cycles. (Point A Fig. F.1*2) Load/deflection test carried out.

During the latter part of this stage of testing it was observed that hair line cracks had appeared on the tension side of the blade adaptor fillet. These cracks were only visible when the dynamic test was in progress or when load was applied statically in the upward direction.(See F.10.1.)

F.7 Assessment after Second Stage Tests

F.7.1 After the discontinuation of the test as at F.6.1. it was decided that a further 5 x10^6 cycles should be attempted at the same loading to see if any appreciable change would take place in the observed cracks.

F.8 Third Stage Tests

F.8.1 A natural frequency check was carried out giving a result of 12.9 cycles/sec. A load deflection check carried out.

F.8.2 Dynamic test recommenced with specimen loaded to 78,000 lbf on the centrifugal jack and +5970 lbf to 3530 lbf. on the vertical jack.

F.8.3 The second stage test discontinued after completing 5 x 10^6 cycles, (Point B Fig. F.1.*2). The specimen checked but no further damaged could be noted.

F.9 Assessment after Third Stage Tests

F.9.1 It was decided to repair the cracks before attempting further running.

F.10 Repair of Cracks

F.10.1 An illustrtion of the position and extent of the cracks is given in Fig. F.10.1*1.

F.10.2 Small cuts were made with a portable electic circular saw to remove the material adjacent to the cracks. These slots were then filled by inserting and gluing in pieces of new compressed wood material. Details of these slots and inserts are shown in Fig F.10.2*1.

F.11 Final Tests

F.11.1 Dynamic test restarted at loading of 78,000 lbf on the centrifugal jack and +5970 lbf to 3530 lbf on the vertical jack.

F.11.2 After the test had run for a further 4,231,830 cycles, (Point C Fig. F.1*2) the centrifugal jack loading columns failed in fatigue.

The specimen was checked for damage but no further damage had occurred.

F.11.3 Natural frequency check made with the results being 12.79 cycles/sec. (cf. 12.9 cycles/sec. as at F.8.1.).

F.12 Final Assessment

F.12.1 As the specimen had completed a total of 29.3 x 10^ 6 cycles (and this result gives Point G well above the required SN line, see Fig. F.1*2) and the specimen was still undamaged it was decided that no further fatigue tests would be required.

F.12.2 Further examination of the repairs to the specimen was made after it had been removed from the test frame, but it was noted that no further damage had occurred to these repairs that could be associated with this last test running.

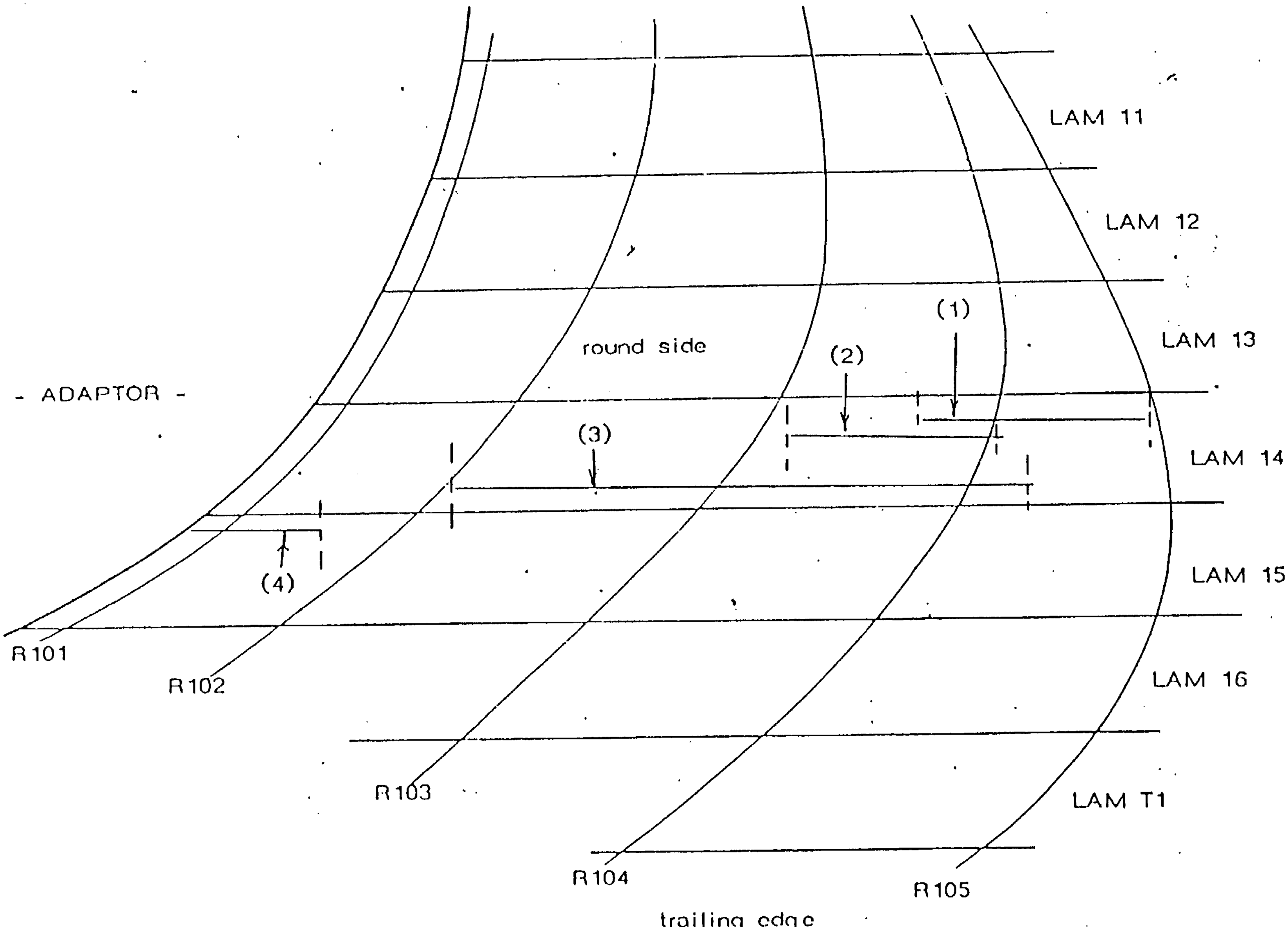


Fig. F.10.1*1

TRUE VIEW OF PART TRANSITION ZONE

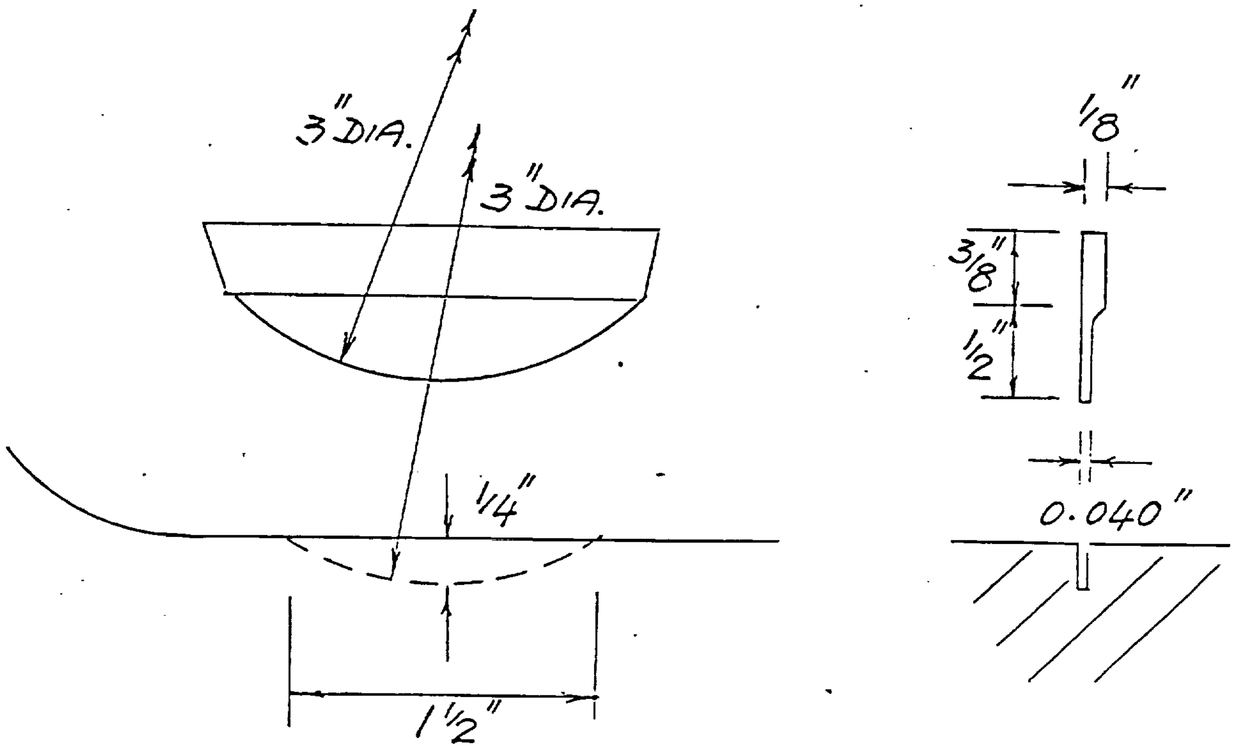
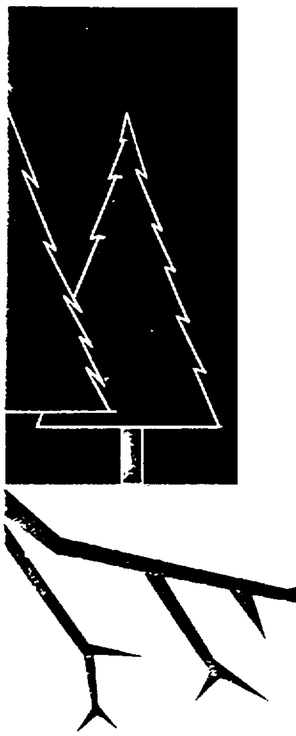


Fig. F.10.2*1

F.12.3 The total period of the test on these cracks (before and after repair) was very nearly equivalent to Point D Fig. F.1*2 the full required life of the blades.

It was therefore concluded that, if such repairs have to be made on any blade no loss of fatigue life would result.

DYNO



®Aerodux 185 with Hardener HRP.150 or HRP.155

Resorcinol-Phenol-Formaldehyde

Aerodux 185 liquid resorcinol-phenol-formaldehyde resin mixed with powder Hardener HRP.150 or HRP.155 provides cold-setting weatherproof and gap-filling adhesives. The adhesives are also suited to the production of heat resistant composite structures, e.g., fire-resisting doors.

Aerodux 185 with HRP hardeners, when fully cured, is resistant to acids, weak alkalis, solvents and boiling water.

Aerodux 185 is suitable for bonding a wide range of materials to porous substrates. These materials include:

Wood, improved or densified woods, e.g. 'Hydulignum'.

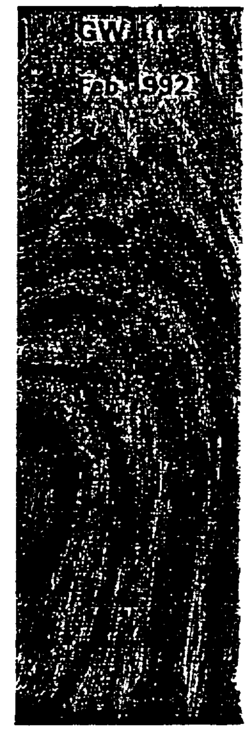
Mineral fibre reinforced boards, brick, concrete, unglazed porcelain.

Rigid expanded plastics, e.g., expanded polystyrene, polyurethane and PVC.

Industrial and decorative laminates (phenolic resin-based or phenolic resin backed).

Leather, cork, linoleum and nylon.

Aerodux 185 may also be used to bond natural and synthetic rubber (other than silicone rubber) and sheet metals to wood (see Preparation of Materials for Bonding).



Specifications

Aerodux 185 liquid resorcinol-phenol-formaldehyde resin mixed with powder Hardener HRP.150 or HRP.155 meet the requirements of BS 1204: Parts 1 and 2 (Type WBP), BS 1203 (Type WBP), DIN 68 141, DIN 68 705 (AW 100). It is also approved under DIN 1052 for the manufacture of load bearing building components, and by FMPA, Stutgart, for the manufacture of structural building elements.

The adhesives are also suited to the production of heat resistant composite structures, e.g. fire-resisting doors.

Typical Properties of Aerodux 185

Appearance	Reddish-brown liquid
Viscosity at 25°C	0.25 - 0.50 Pa s (2.5 - 5.0 poises)
S.G. at 25°C	1.14 - 1.16
Solids Content	57 ± 2%
pH	7.0 - 8.0
Flashpoint	52°C

Instructions for use

Choice of Hardener

Hardener HRP.150 gives a high-viscosity glue mix which dries out faster than mixes containing HRP.155. Its use is recommended for joints where a viscous mix is required to limit flow, e.g., for thick glue lines, uneven surfaces, etc.

Hardener HRP.155 provides a medium-viscosity glue mix, suitable for most gluing applications, especially timber structures. This glue mix tolerates longer assembly times than a mix using HRP.150.

Mixtures

Mixing proportions are the same for each hardener.

	Parts by weight
Aerodux 185	100
Hardener HRP.150 or HRP.155	20

Viscosity of mixture

Viscosity at 20°C, 15-20 minutes after mixing, is as follows:

Aerodux 185 + HRP.150	8-10 Pa s (80 -100 poises)
Aerodux 185 + HRP.155	4.5-6 Pa s (45 - 60 poises)

Use of Extenders

Wood flour or some mineral fillers may be added to increase viscosity and reduce glue costs.

Lightly-filled mix

	Parts by weight
Aerodux 185	100
HRP Hardener	20
China clay	20

Heavily-filled mix

	Parts by weight
Aerodux 185	100
HRP Hardener	20
China clay	100

The lightly-filled mix still complies with the requirements of BS 1204: Parts 1 and 2 (Type WBP), and BS 1203 (Type WBP). It may be necessary to adjust the viscosity of the heavily-filled mix with water but the water addition should be kept to a minimum. This mix is suitable for bonding uneven-surfaced boards, such as mineral fibre reinforced boards, and where maximum strength and full weatherproof properties are not required.

Mixing

Add the hardener to the resin and mix until the hardener is fully dispersed. Then, if required, add the filler, stirring it thoroughly into the resin-hardener mixture.

Pot Life (see table 1)

Resin and hardener remain usable for approximately the times given in table 1.

Preparation of Materials for Bonding

Surface Preparation

The surfaces to be bonded should be free from dust or other deposits. Wood, panels, laminates, etc., should be of uniform thickness. The surfaces to be bonded - except expanded plastics and mineral fibre reinforced boards-should also be thoroughly sanded.

Metal surfaces should be abraded, degreased and coated with Primer L.62 before bonding to porous materials (such as wood). Directions are given in Dynochem Instruction Sheet No AD 4.

Moisture Content

Satisfactory results may be obtained when the moisture content of the surfaces to be bonded is within the range 6-25%, but for best results 12-16% is preferred. Artificial drying will be required to reduce the moisture content to 16% or lower. Adjacent surfaces should not differ by more than 3% moisture content.

Effect of Preservative Treatments

Gluing preservative-treated timber

Before gluing timber that has been treated with a preservative, it is advisable to machine or vigorously sand the surfaces to be bonded. Also the timber should be checked for moisture content, since this can be increased beyond acceptable levels by water-borne preservatives and may need to be reduced before gluing. Further advice on the gluing of preservative-treated timber is available on request.

Preservative treatment after gluing

Beams and components should be allowed to stand for at least seven days after gluing, before being subjected to water--borne preservative treatment in pressure cylinders.

Application

Spread rates

Apply an even coating of mixed adhesive to both the surfaces to be bonded at a rate of about 225 grammes per square metre (4 ½lb/100ft²).

Open/Closed Assembly (see table 2)

When large areas of an impermeable material are being bonded, it is important to allow sufficient open assembly time. For most applications, however, it is advisable to restrict open assembly time to a maximum of 5 minutes.

Joints must be assembled and pressure finally applied within the times laid out in table 2.

These are average times. Slightly longer times are possible with Hardener HRP.155. Although the adhesive has gap-filling properties, it is important to bring surfaces into firm contact. It is essential that the joint should be made before the adhesive gels.

Control of Spread to Counteract Drying-Out

The defect known as drying-out is influenced mainly by relative humidity, temperature and thickness of glue spread. In conditions of high ambient temperature and low relative humidity, higher spreads may be necessary to limit drying-out. Under average conditions (65% r.h. and 18°C), a spread of about 225 g/m² (4½ lb/100 ft²) to each face of a joint is sufficient.

Pressing or Clamping

Cold Pressing (see table 3)

Table 3 gives the minimum time of application of pressure. Aerodux 185 does not cure adequately below 10°C (50°F).

Hot Pressing (see table 4)

The press should be loaded and closed as quickly as possible to avoid pre-curing. Basic setting times are given in table 4.

Heat penetration (see table 5)

The basic setting times stated refer to glue line temperatures only and allowance must be made for the heat to travel from the press platen. Heat penetration time will vary according to the density of the wood, moisture content and distance to the farthest glue line. Table 5 is a guide to the additional time required for low and medium density timbers.

The pressing times apply when bonding absorbent materials such as low and medium density wood. The pressing time must be considerably extended when bonding less absorbent materials.

RF Heating

Resorcinol adhesives heat up less rapidly under glue-line or stray-field heating than UF resins but curing may be accelerated by the addition of common salt (sodium chloride) at a rate of 1-2 parts by weight of salt to 100 parts by weight of resin. Precautions should be taken against arcing which may lead to tracking and burning in the glue line. Arcing can be avoided by low spread, low moisture content and good jig design to ensure no air gaps between electrode and glue line, and sufficient and even pressure on the joint during curing.

Cleaning of Equipment

Mixers, spreaders etc. should be cleaned by washing with warm water. The use of a warm dilute washing soda solution will help to remove persistent residue. Equipment should be cleaned before the glue has time to set. Further information is given in Dynochem Safety Manual AD2.

Notes

Accelerator for use with Aerodux 185

An accelerator (XDF 694) is available which can sometimes be used to speed curing at low ambient temperatures and accelerate heating and curing with radio frequency or warm pressing. Our Technical Service Department will be pleased to discuss this further in detail, if required.

Staining on absorbent boards

Light-coloured absorbent boards, e.g., mineral fibre reinforced cement boards, bonded with resorcinol-phenol-formaldehyde adhesives may tend to show signs of staining when subjected to exposure to weather or very wet conditions. This is because certain soluble materials in the uncured resin are absorbed and retained by the board and may subsequently be leached out by soaking. These materials appear as dark stains on the surface of the board but disappear with further weathering.

Storage

The resin and hardeners should be stored separately in a cool (ideally 5-20°C) dry place. In these conditions Aerodux 185 has a storage life of at least 18 months, and Hardeners HRP.150 and HRP.155 at least 3 years.

Note At a temperature of 25°C Aerodux 185 has a storage life of 12 months.

Quantities Available

Aerodux 185 and Hardeners HRP.150 and HRP.155 are available packed as follows:-
Aerodux 185: 225 kg (495 lb) and 25 kg (55 lb) Tighthead Plain Drum, 5 kg (11 lb) and 1 kg (2.2 lb) Polypail.
Hardener HRP.150: 20 kg (44 lb) and 5 kg (11 lb) paper sack with inner polythene liner.
Hardener HRP.155: 25 kg (44 lb) and 5 kg (11 lb) paper sack with inner polythene liner.

Table 1 - Pot life

Temperature of mixture	10°C	15°C	20°C	25°C	30°C
Pot life (time in hours)	6-8	4-5	2-3	1-2	¾-1

Table 2 - Open/Closed assembly

Glue-line temperature	10°C	15°C	20°C	25°C	30°C
Closed assembly time (hours)	2½	1½	1	½	¼

Table 3 - Cold pressing

Glue-line temperature	10°C	15°C	20°C	25°C	30°C	35°C	40°C
Minimum pressing or clamping time (hours)	12	6	4	2½	1½	1¼	1

Note: Pressing or clamping time quoted, is the time required by the adhesive, tested to BS 1204:Part 2, to give a failing load of 300 lbf (1.33kN). For dense or high moisture content timbers, where a component is impermeable or if the joint is liable to be strained immediately after removal of pressure (e.g., as in the manufacture of laminated bends), the above times should be increased. Aerodux glues will continue to gain strength but full water-resistant properties are developed only after several days.

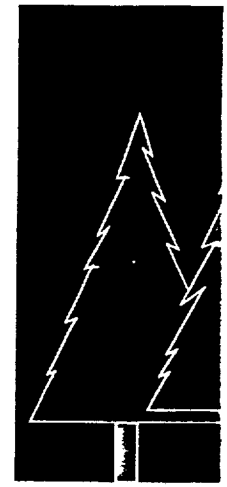
Table 4 - Hot pressing

Glue-line temperature	50°C	60°C	70°C	80°C	90°C	100°C
Basic setting time (minutes)	30	15	7	3-4	2-3	1½

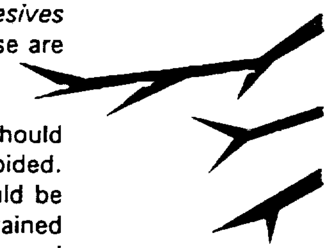
Table 5 - Heat penetration

Distance to the glue line	Heat penetration time in minutes per mm distance to the glue line				
	80°C	90°C	100°C	110°C	120°C
Less than 5 mm	1.2	1.0	0.9	0.8	0.8
5 - 10 mm	1.7	1.4	1.2	1.1	1.0
More than 10 mm	2.0	1.7	1.4	1.3	1.2

Caution



DYNOCHEM resins and hardeners are generally quite harmless to handle provided that certain precautions normally taken when handling chemicals are observed. The uncured materials must not, for instance, be allowed to come into contact with foodstuffs or food utensils, and measures should also be taken to prevent the uncured materials from coming into contact with the skin, since people with particularly sensitive skin may be affected. The wearing of impervious rubber or plastics gloves will normally be necessary; likewise the use of eye protection. The skin should be thoroughly cleansed at the end of each working period by washing with soap and warm water. The use of solvents is to be avoided. Disposable paper - not cloth - towels should be used to dry the skin. Adequate ventilation of the working area is recommended. These precautions are described in greater detail in DYNOCHEM Manual No. AD 2 *Handling Precautions for Formaldehyde-based Products, Vinyl Emulsions and Hot-Melt Adhesives* and in Material Safety Data sheets for the individual products. These are available on request and should be referred to for fuller information.



Aerodux 185, Hardener HRP 150 and HRP 155 These materials should be handled with care: contact with the skin and eyes must be avoided. If contact with the eyes does occur, the eyelids - held open - should be thoroughly flushed with water, and medical attention should be obtained immediately. If skin or clothing comes in contact with the uncured materials, the affected skin area should be thoroughly washed with soap and warm water, and the contaminated clothing removed and washed before re-use. Avoid breathing the vapour from Aerodux 185 and the dust from the hardeners - good ventilation of the working area is recommended. Aerodux 185 and its vapours are flammable. Due precaution must be taken against all possible fire risks. Keep the uncured materials (resin and resin-hardener mixture) away from open flames, electric elements, etc., and firmly seal the resin containers when not in use. If the resin catches fire either a water fog or carbon dioxide or dry powder extinguisher should be used.

ISO 9002 Lloyd's Quality Assured Firm

Erkend door de Raad voor de Certificatie

DYNO

ISO 9002 Lloyd's Quality Assured Firm

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SP 110

Epoxy Laminating System

FEATURES

- **High strength laminating system**
- **Suitable for use with glass, aramid and carbon reinforcements**
- **Good room temperature curing properties**

INTRODUCTION

SP 110 is a versatile high strength epoxy laminating system which is ideal for the manufacture or repair of lightweight, high strength composites, using glass, aramid or carbon fibres. SP 110 system is ideal as a laminating resin for the production of high performance sailing and power boats; high performance vehicle structures, such as racing car, rally car, and all-terrain vehicle components and body parts; and other industrial mouldings requiring high strength and stiffness, light weight and durability.

DIRECTIONS FOR USE

Workshop Conditions

SP110 should be used at a temperature of between 15°C - 30°C. As at lower temperatures the product thickens, it is essential to pre-warm resin, hardener and mould surface before use to achieve good fibre wet-out and to maintain laminate quality. Small scale work can be carried out in colder conditions but a warm air source is essential to provide local heating. A warm, dry environment is necessary for the development of a full cure.

Metering Resin and Hardener in the Correct Ratio

Combine SP 110 resin with either Fast, Standard, Slow or Extra Slow hardeners in the ratio:

3 parts resin : 1 part hardener by volume

or

100 parts resin : 30 parts hardener by wt.

If using the SP mini-pump dispensing system ensure that the pumps are fitted and used according to the pump instructions. For volumes in excess of 200 ml use graduated plastic mixing pots (available from SP Systems)

with Fast hardener, measure no more than can be used in 5 - 10 minutes
with Standard hardener, measure no more than can be used in 10 - 20 minutes
With Slow hardener measure no more than can be used in 15 - 30 minutes

Mixing Resin & Hardener

The resin and hardener should be mixed thoroughly in the pot for at least one minute to ensure a good cure. Use from pot quickly. Transferring mixed epoxy to a shallow tray will help dissipate the heat of the reaction and prolong its usable life.

Surface Preparation

When laminating into a mould or onto a plug use a suitable mould release (see section on Mould Release) ensure that the surfaces are clean, dry and dust-free. Use only SP Solvent A (SP Fast Epoxy Solvent) for surface cleaning.

■ QUICK GUIDE TO APPLICATIONS

Function		Notes
Gluing & fillet bonding to:		Use with SP filler powders. Other SP products may be equally suitable and less expensive.
Wood	■	
GRP	■	
Metals	▩	
Stone, ferrocement, brick	■	
Fibre reinforcement: laminating with glass, aramid and carbon.	■	Ideal for high performance applications.
Filling and fairing: many substrates	■	Use with SP filler powders.
Core materials, e.g. balsa, foams, honeycombs	■	
Coating: wood or GRP	□	Other SP products recommended.

Key: ■ Ideal
▩ Suitable but other SP products may give better performance
□ Not recommended

■ USAGE

Whilst primarily designed for laminating, SP 110 can be used for general bonding and filling operations particularly where long working time is required.

Fibre Reinforcement

When laminating aim for minimum resin use consistent with good wet out and apply good consolidation techniques using a rubber squeegee or roller. As a general guide use no more resin than the weight of fabric being laminated e.g. use less than 210gm/m^2 with SP RE210 (210gm/m^2) glass fabric.

Cure Schedule

The minimum cure required before demoulding is 16 hours at 20°C - 25°C (standard hardener) but laminate is not fully cured for a further 14 days at these temperatures.

While a moulding will have adequate strength and stiffness after a room temperature cure, an elevated temperature post cure is necessary to fully stabilize the laminate for higher service temperatures. It also gives the finished composite the maximum mechanical properties, particularly a higher heat deflection temperature and increased toughness. A typical post cure schedule is 5 hours @ 80°C.

Gelcoat Systems

Use either SP 127, SP 531 epoxy gelcoats or Ampreg Pregel.

Ampreg Pregel

Ampreg Pregel is a thixotropic resin which, when used with the appropriate hardener, can be added to, or used in place of, SP 110 resin/hardener mixes. Mix Ampreg Pregel resin with any of the SP 110 hardeners at a ratio of 100 : 27 **by weight**. Use as:

(i) A clear gelcoat for an SP 110 laminate using SP 110 fast hardener.
(ii) An adhesive mix for core bonding.
(iii) For secondary bonding of preformed laminates.
(iv) As an addition to SP 110 resin/hardener mixes to make them more thixotropic.

A separate data sheet is available describing this product's use in more detail.

TECHNICAL DATA

Mechanical Properties (clear casting of SP 110 resin & SP 110 Standard Hardener)

Property	[1]RT Cure	[2]Post Cured
Tensile strength	62.0 MPa	82.1 MPa
Tensile modulus	3.35 GPa	3.34 GPa
Elongation at break	2.85%	6.81%
Flexural strength	101.2 MPa	122.6 MPa
Flexural modulus	3.65 GPa	3.52 GPa
Compressive strength	121.6 MPa	119.2 MPa
Compressive modulus	4.7 GPa	3.92 GPa
Coefficient of linear thermal expansion	56.7×10^{6} °C	52×10^{6} °C
Heat deflection temperature	55°C	78 - 80°C

[1]14 days at 23°C
[2]16 hours at 23°C + 8 hours at 80°C

Mould Release Systems

From smooth metal or grp moulds use 5 - 6 waxings of a carnauba based wax eg: Polywax. Use PVA for less well prepared or complex surfaces.

Vacuum Techniques

SP 110 with Slow or Extra Slow hardeners are best suited. Do not expose wet laminates to excessive vacuum pressures (0.8 bar+).

Bonding

Use nylon peel ply over areas of laminate where subsequent bonding is anticipated. Use SP 110, with either Pregel or thickened with fillers, for bonding core materials, including honeycombs, end grain balsa, pvc foam, etc.

■ **WORKING PROPERTIES**

Hardener	Typical Uses	Lam. working @ 20°C
'Fast', 110F	Core bonding	0.3 - 0.5 hr
'Standard', 110 STD	Laminating at room temperature	0.75 - 1.0 hr
'Slow', 110 SL	Large lay-up, working at 25°C	1.5 - 2.0 hr
'Extra Slow', 110 XS	High ambient temperatures Large components	3.0 - 4.0 hr

■ **HEALTH & SAFETY**

- Avoid skin contact by using rubber or plastic gloves. Use SP barrier cream if possible.
- Protect eyes.
- Avoid inhaling sanding dust.
- Wear protective overalls and a face mask when sanding.
- Wash skin immediately if in contact with resin or hardener.
- Do not use solvents to wash skin.
- Use SP hand cleaner to clean skin after using epoxy.

■ **TRANSPORT & STORAGE**

The resin and hardeners should be kept in securely closed containers during transport and storage. Any accidental spillage should be soaked up with sand, sawdust, cotton waste or any other absorbent material. The area should then be washed clean (see appropriate Safety Data Sheet).

Adequate long term storage conditions for both materials will result in shelf lives of 2 years or more for the resin and 1 year for the hardeners. Ideally, storage should be in a warm dry place out of direct sunlight and protected from frost. The temperature should be between 15°C and 30°C. Containers should be firmly closed. Hardeners, in particular, will suffer serious degradation if left exposed to air. Providing the above storage conditions are met this resin and its fast and slow hardeners have a guaranteed shelf life of one year.

A full material safety data sheet (MSDS) covering usage, transport, storage and emergencies, is available upon request.

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SP Solvents Selection Guide

■ INTRODUCTION

Solvents are organic liquids which are indispensable for obtaining the best results with resin system. Solvents have many uses besides the obvious ones of cleaning surfaces and equipment. Indeed, many resin systems, particularly epoxy coatings, already incorporate one or more solvents, where they assist in providing easy application properties. When a high quality finish is to be produced, the same solvents are essential to provide additional thinning as low viscosity gives a better surface finish.

SP Systems supply a wide range of solvents blended for specific tasks and to work with specific products - unfortunately there is no one 'universal' solvent which suits every project!

Many of the problems which are experienced by users of epoxy resin, particularly when coating, can be attributed to the use of an inappropriate or even incompatible solvent.

The following notes are aimed at helping the user of SP products to understand the function of various solvents and how to use them.

■ FEATURES & BENEFITS

SP Solvent A (SP Fast Epoxy Solvent)
Solvent A is an extremely fast evaporating solvent and the only one recommended for cleaning all types of surfaces prior to applying a solvent- free product such as SP 320, SP 106, SP Speedipack, SP Handipack, SP 120, and SP 110, whether bonding, coating, filling or laminating.

Solvent A will clean brushes and equipment if the epoxy is still in a liquid state, but if the epoxy has started to gel, it is not effective. In this case, SP Solvent B is superior.

SP Solvent B (Standard Epoxy Solvent)
Solvent B is a slow evaporating solvent and the only one specifically designed for cleaning brushes and other application equipment which has been used with products such as SP 106, SP 320, etc. Under no circumstances use Solvent B for cleaning surfaces to be bonded, coated, etc. Solvent B can dissolve partially gelled resin system, but cannot break down a fully cured resin.

Solvent C (SP Cleaning Fluid)
Solvent C is designed specifically for applying to the surface of cured or hard-but-not-cured epoxy surfaces, to remove surface by-product which develops as a 'greasy' film, particularly in cold curing conditions or in high humidity environments. Use with SP 106, SP 120, SP 110, SP Speedipack or SP Handipack; **do not use with SP 320 epoxy.**

Unlike normal organic solvents such as Solvent A, Solvent C will not soften or attack plastic surfaces or those recently coated with epoxy. As a result, Solvent C is not effective as a brush cleaner or for removing semi-cured epoxy from brushes, surfaces or equipment. However, it may be used for cleaning individual resin or hardener components from plastic mini-pumps without causing damage to the plastic components.

Solvent C is therefore ideal as a surface cleaner for all types of plastic surfaces, for cleaning glass and for general grime or dust removal.

Solvent D (SP 301/SP 302 Brushing Solvent)
A fairly fast evaporating solvent to be used specifically with the epoxy coating systems Epocoat 301 and Hibuild 302 when brush applying. Use for:

(i) Wiping surfaces prior to coating, to remove sanding dust or slurry, etc.
(ii) Thinning by addition of 5-10% of solvent by volume to maintain a "wet edge" in warm conditions.
(iii) Thinning by addition of 5-10% of solvent by volume for the first coating on bare wood (not with Hibuild 302 which should not be used on bare wood).
(iv) As a brush cleaner.

Solvent E (SP 2000/Fastcote Brush Cleaner)
A fast evaporating solvent to be used specifically with 2 pack polyurethane coating products, Ultravar 2000 and SP Fastcote. Use for:

(i) Wiping surfaces prior to coating, to remove sanding dust or slurry, etc.
(ii) Thinning by addition of solvent up to 20% by volume for priming bare wood.
(iii) Thinning by addition of solvent up to 10% by volume for using the above products in warm weather and to maintain a "wet edge" when brush applying.
(iv) As a brush cleaner.

Solvent F (SP 301 Spraying Solvent)
A very fast evaporating solvent to be used specifically with Epocoat 301 epoxy for:
(i) Wiping surfaces prior to coating.
(ii) Thinning by addition of solvent up to 20% for spray application.
(iii) To clean equipment.

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Solvent G (SP302 Hibuild Spraying Solvent)
A very fast evaporating solvent (faster than Solvent D) to be used with Epocoat 301 epoxy and Hibuild 302 epoxy for:

(i) Wiping surfaces prior to coating.
(ii) Thinning Hibuild 302, by addition of solvent up to 20% by volume for spray application.
(iii) Thinning Epocoat 301, by addition of solvent (up to 100% by volume if necessary) for brush or spray application and particularly for coating bare wood to ensure good penetration.

Solvent H (SP2000 Ultravar Spraying Solvent)
A very fast evaporating solvent to be used only with 2 pack polyurethane coating products for:

(i) Wiping surfaces to be coated.
(ii) Adding solvent up to 20% by volume for spray application.
(iii) Cleaning equipment and tools.

■ GENERAL NOTES ON SOLVENTS

Most solvents are highly volatile, so keep them away from sources of ignition (naked flames) and do not breathe in the fumes.

Do not use solvents for cleaning skin as this may eventually lead to sensitisation and dermatitis. Solvents penetrate the skin very quickly and only serve to assist the penetration into the skin of the substance being removed.

Keep containers securely closed and out of direct sunlight.

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SP Ampreg Pregel

Thixotropic Resin Modifier

■ APPLICATIONS

- **Reduce drainage of laminating resins**
- **Core bonding adhesive**
- **Secondary bonding**

■ MIXING AND HANDLING

SP Ampreg Pregel can be used with the following resin systems and curing agents thereof:-

Curing Agent	Mix Ratio (by weight)
SP Ampreg 20	100 : 25
SP Ampreg 25	100 : 30
SP Ampreg 26	100 : 30
SP 110	100 : 27
SP 115	100 : 32

It is strongly recommended that a balance is employed in order that the resin and hardener components can be measured out by weight. The resin/hardener mixture should be well mixed paying particular attention to the sides and bottom of the mixing vessel. The mixture should then be transferred to shallow trays in order to reduce the exothermic heat build up which would reduce pot life and working time. Accurate measurement of the components and thorough mixing are essential. Deviating from the prescribed mix ratio will not speed the cure and can seriously degrade the properties of the system.

When used to thixotrope any of the above laminating resins (for example to reduce resin drainage in thick, vertical laminates) it is important that the Ampreg Pregel is first mixed with the chosen hardener. This resin/hardener mix is then added to the laminating resin/hardener mix.

NB. The use of Pregel will result in reduced potlife and working times when compared to the standard resin components.

■ HEALTH & SAFETY

The following points must be considered:

1. Skin contact must be avoided by wearing disposable rubber gloves. The use of barrier creams is also recommended.

2. Care must be taken to avoid the risk of splashing resin or hardener into eyes. If this occurs the eye should be immediately well flushed with water for 15 minutes and medical advice sought.

3. The inhalation of sanding dust should be avoided and, in particular, care should be taken not to rub the eye area when exposed to sanding dust. After any sanding operation of reasonable size a shower or bath should be taken and should include hair washing.

4. Overalls or other protective clothing should be worn when laminating or sanding. Contaminated work clothes should be thoroughly cleaned before re-use.

5. Any areas of skin coming into contact with resin and hardener must be thoroughly cleansed. This should be achieved by the use of resin removing creams and washing with soap and water. Solvents should not be used on the skin.

This cleaning should be routine:

- before eating or drinking
- before smoking
- before using the lavatory
- after finishing work

6. Ensure adequate ventilation and avoid excessive contact with solvent vapours which may cause dizziness and headaches.

TRANSPORT AND STORAGE

The material should be kept in securely closed containers during transport and storage. Any accidental spillage should be soaked up with sand, sawdust, cotton waste or any other absorbent material. The area should then be washed clean (see appropriate Safety Data Sheet).

Adequate long term storage conditions for the material will result in a minimum shelf life of 1 year. Ideally, storage should be in a warm dry place out of direct sunlight and protected from frost. The temperature should be between 15°C and 30°C. Containers should be firmly closed. Hardeners, in particular, will suffer serious degradation if left exposed to air.

A full material safety data sheet (MSDS) covering usage, transport, storage and emergencies, is available upon request.

SALES INFORMATION

For further details regarding this product and its uses please contact one of our sales engineers.

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Many windtunnels use wooden fan blades, however, because of their usual long life (often in excess of 50 years) wooden blades typically do not have to be replaced very often; therefore, the expertise for designing and building wooden windtunnel fan blades is being lost.

The purpose of this report is to document the design and build process so that when replacement blades are eventually required some of the critical information required is available. Information useful to fan-blade designers, fabricators, inspectors, and windtunnel operations personnel is included. Fixed pitch and variable pitch fans as well as fans which range in size from a few feet in diameter to over 40 ft. in diameter are described. Woods, adhesives, and coverings are discussed.

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