Basic Theories of Tensile Architecture

Membrane structures rely on double curvature to resist imposed loads efficiently.

Imagine a flat piece of fabric. An imposed download of snow can only be resisted by tension in the horizontal fibres – a bit like making the catenery cables on a suspension bridge horizontal and expecting them to still carry the weight of the road deck.

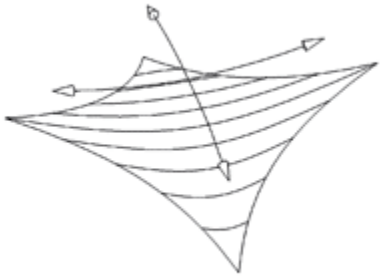

figure 1: a hyperbolic paraboloid

In Fig 1, a classic ***Hyperbolic Paraboloid***, any point on the membrane surface can be restrained by the corner points. The two high points pick up any downloads and the two low points resist the wind uplift.

The flatter the fabric, ie the smaller height difference between the high and low points, the greater the resultant loads will be at the corners.

Inflatable fabric structures are ***synclastic*** forms where constant air pressure balloons the fabric into shapes also exhibiting double curvature. ***Anticlastic*** forms like the ***Hyperbolic Paraboloid*** have ***opposing*** curvatures.

Other common ***anticlastic*** forms are the cone (Fig 2) and the arch form (Fig 3).

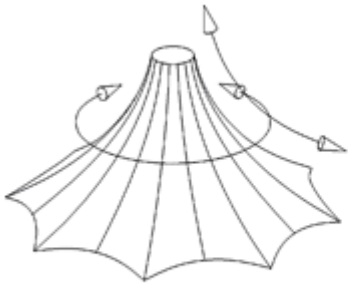

figure 2: a cone

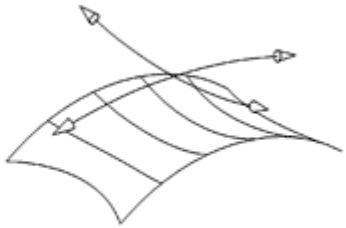

figure 3: an arch form

Nearly all tensile canopies are derived from either one or a combination of these three shapes. The surface of the membrane adopts a similar kind of characteristic double curvature.

The creative challenge to designers is to explore the development of striking new forms, which satisfy the structural requirements of the membrane's surface. Developing new shapes

of push-up elements, and varying the design of the perimeter connections enables dramatic variation in the appearance of a structure.

Membrane forms can be soft or spiky, rotund or leaf-like. They are frequently a combination of these forms.

***Pre-Stress*** is the tensile forces introduced in the canopy during erection.

The shape of a membrane surface is determined by the ratio of prestress in the two principal directions of curvature. These are established in the computer form generation process. The absolute values of prestress are calculated to be sufficient to keep all parts of the membrane in tension under any load case.

Any imposed live load will be carried by redistributing the stresses within the membrane. If this results in any section going into ***compression***, ie going slack, then creases will appear.

Similarly if the prestress is not high enough a snow load could cause ***ponding***.

Detailing of Tensile Membranes

LOAD RESOLUTION

Canopies fall into two main types, those that transfer tensile loads into adjoining structures and those containing the tensile loads within their own frame. The first type may generate large lateral loads which may result in the need for additional reinforcement in existing structures.
Likewise a typical 'lightweight' canopy with masts and cable tie backs to ground level will generally need large concrete foundations or screw anchors to resist the tensile loads. As part of the preliminary design process a provisional load analysis derived from a computer model will give typical loads directions and size of the design loads.

BOUNDARY DETAIL

The boundary of the membrane falls into two categories:

Curved/scalloped edge- This generally consists of a cable slid through a pocket on the edge of the membrane. In larger canopies webbing belts are added parallel to the edge to take out the shear loads. An alternative detail used for PTFE canopies is to have an exposed cable connected to the clamped edge of the membrane by series of stainless steel link plates.

Straight edge- The membrane would have a bead/***kedar*** edge formed by sealing a flexable pvc rod in a small pocket. This can then be trapped behind an aluminium clamp plate bolted directly onto the structural steel work or slid into an ***aluminium luff track extrusion***.

Canopies can be tensioned by hydraulically jacking up the mast with the base being housed in a ***sand pot*** or the mast can be extended with a ***telescopic*** section.

Corners can be pulled out with rigging screws, U bolts or by the shortening the perimeter mast tie back cables.

Individual scallops can be tensioned by shortening the edge cable where the swaged studs connect onto the membrane plate.

A very common detail is to pull panels into parallel ***luff tracks*** and tension by drawing out the corner plate that slides inside the luff track.

**The Materials of Tensile Architecture**

A coated structural fabric consists of a woven base cloth stabilised and protected by a coating on both sides. The base cloth consists of ***warp*** threads running the length of the roll and ***weft*** threads running across the width.

A mesh fabric is a coated cloth with spacing between the thread bundles. With some meshes for interiors use the threads are coated before weaving.

A typical structural fabric would have a tensile strength of 10 tonnes in the warp and weft direction. A factor of safety of 6 on a maximum design loads is used to select a cloth although this may be reduced if the circumstances are well understood.

ie if the Maximum Strength of the membrane is 10 tonnes/linear metre the **Maximum Permissible Load** would be 1.7 tonnes/metre, and the typical ***Prestress Load*** would be 150-350kg/metre.

All fabrics will stretch under load although some exhibit different characteristics as a function of time. A structural fabric would not creep under load once it has reached full pretension.

Each roll of fabric is tested in a biaxial rig to measure the stretch in both thread directions at load ratios derived from the form generation computer model.

These figures would then be used as compensation percentages to be factored into the patterning software. The canopy is manufactured undersize so that when installed to its final dimensions it tensions out correctly.

For External Use: - Coated Fabrics

For External Use there are two main choices – **PVC (Poly Vinyl Chloride) coated polyester** cloth and **PTFE (Poly Tetra Fluro Ethlene) [Teflon] coated glass** cloth.

The PVC coating contains additives that include **UV stabilisers, fire retardants, colouring** and **antifungicides.**

There is a choice of protective **PVDF (Fluorinated Polmer)** lacquers that enhance the cleanability of the pvc membrane. With the **Non weldable PVDF** version we remove the lacquer before welding the seams. It will give a 15-20 year lifespan compared to 10-15 years for the **Weldable PVDF** type.

Although a PVC/ Polyester fabric will have a **structural** lifespan in excess of 20 years its quoted lifespan is based on visual appearance. **Plasticisers** in the PVC will migrate towards the surface over a period of time making the surface harder to clean.

The French Fabric supplier Serge Ferrari will coat the fabric whilst keeping the warp and weft threads in tension known as the **Precontraint** method. This will result on more even stretch characteristics in both thread directions than a conventional coated fabric.

The components of PTFE/ glass are inert and are therefore the natural choice for permanent structures with a design life over 15 years. When new PTFE is a buff colour that will bleach white in strong sunlight in a matter of weeks, weld discolourations will also disappear in a similar period. The anticipated lifespan of the membrane is 25-30 years.

**Meshes** are available in both PVC/Polyester and PTFE/ glass. They are essentially shading fabrics but a version of the PTFE/glass mesh is available with a clear laminate on both sides giving a weatherproof fabric with a translucency of 50%.

***ETFE foil*** is not a coated woven cloth and is not covered in these notes.

For External Use: - Uncoated Fabrics

**Natural canvas** is used where texture is important but is less stable than synthetics and is difficult to clean. A compromise is to use a fire rated **modified acrylic canvas** that has a similar texture but it is more dimensionally stable. Neither is suitable for large span canopies.

For Internal Use:-

For interiors there are three main fabrics:

**Cottons** are the most economical and are available in a wide range of colours. Due to their susceptibility to staining and shrinkage they are ideally suited for short term use or where a softer and more natural texture is required.

**PVC coated glass** mesh is very durable and acts like a theatre gauze or sunscreen.

**Polyurethane coated glass cloth** which has the benefits of durability and a similar appearance to cotton.

Silicone coated glass cloth is being used for its high fire resistance and low relative fore toxicity but tends to attract dirt.

All these fabrics meet **BS476 Part 7 class 1** and **Part 6 class 0** which is normal requirement for internal finishes. In some instances other fabrics with a lower fire rating such **pvc/polyester, CS trevira** and **cotton lycra** and **silk** have been approved.

Pure glass cloth meshes can be used in exhibition halls when fire standards are very stringent. Some ceiling systems demand open meshes that allow water sprinkler systems to operate through them. Unfortunately other exciting fabrics such as rip stop nylon and mylars do not achieve an adequate fire rating.