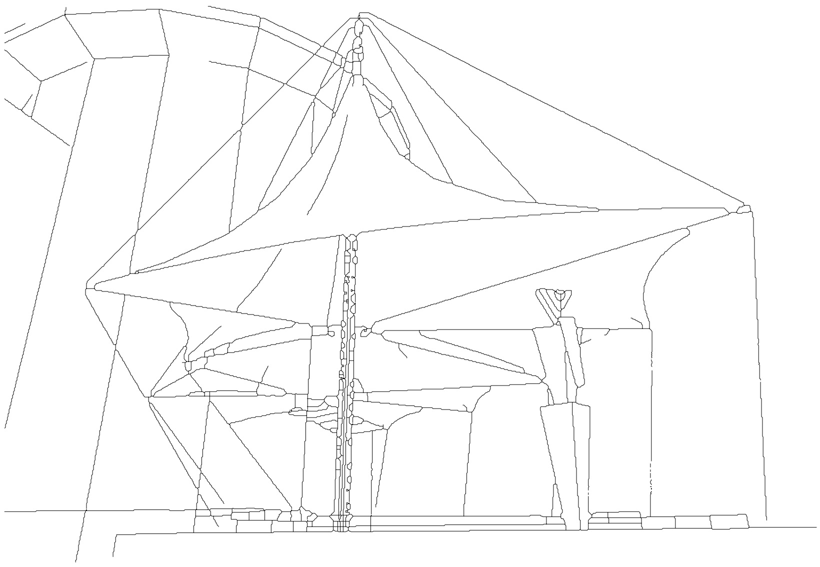
A TECHNICAL GUIDE TO SPECIAL STRUCTURES.



This document is intended to provide a technical overview of tension fabric structures. Many of the points made also apply to roofs using other materials. Obviously none of the technical details are specific to any particular project, but can be taken as a general guide to most projects. We are always willing to answer specific questions on any matter concerning the design, manufacture or installation of special structures.

We also show how the use of 3 dimensional forms can allow the realisation of structures that were considered impossible to build only a few years ago.

This use of complex forms can improve the performance of the structure while reducing complexity of installation.

This concept we call....

Strength through shape

INTRODUCTION

MoonBurst Structures Limited design, manufacture and install permanent and portable specialist structures for a wide variety of applications. In addition, MoonBurst Structures Limited provide a service to the events industry in the fields of music, hospitality, exhibition and advanced, portable structure hire. The very first MoonBurst structure was used for exhibition in 1990.

We build permanently engineered roofs for architectural installations where the loading criteria are the same as a conventional building and are required to meet local building codes. We provide complete installations to suit client wishes, or we can provide the membrane element of a construction project. We can work as nominated subcontractors on large projects and manage smaller installations ourselves.

MoonBurst have exclusive manufacturing rights to a wide range of existing pre-engineered designs which can be purchased 'off the shelf'. These include the Kayam, Valhalla (Tensile 1), Newtec, Domes, MoonBurst marquee, Space Structures and 'Walt Disney On Ice' structures available world wide. MoonBurst Structures Ltd bring all the skills and experience required to provide a complete service to the permanent and portable membrane structures industry.

MoonBurst project managers have many years of membrane design, manufacturing and installation experience. We have our own design office, Special Structures Lab of Sheffield UK to provide independent membrane structure design and analysis services.

We have our own fabric assembly shop with the capacity to assemble membrane roof sections to the highest quality standards. We have extensive experience of rigging, structural steelwork, ground works and other skills required to install membrane roofing systems.

- We have extensive experience of providing performance space in temporary and permanent membrane structures. For theme parks, leisure facilities, touring shows and music performance, our structures have provided many years of accommodation for organisations wishing to stage events in cost effective and quickly installed structures.

- We produce structures which have housed the largest one-night music event ever staged in a temporary structure, the most significant European rock tour ever housed entirely in temporary structures, the most expensive fashion show in the world, and the structure for the exhibition at the World Summit For Sustainable Development in Johannesburg, South Africa.

- MoonBurst structures provide staging accommodation for the leading festivals in Europe and world tours of ice shows, music tours, and exhibitions. We design and manufacture some of the largest, mechanically tensioned portable structures ever built, and our designs have worked on almost every continent. All of the projects shown in our literature have been either designed, manufactured or installed by our staff.

- We have the capability to design, manufacture, operate or install, and maintain fabric structures of all kinds. We have in-house 3D CAD/CAM and the ability to provide detailed presentations, cost analysis, and project building.

- Our architectural membranes are designed and installed to exacting quality levels. We provide a full engineering service to clients for product design, installation, and maintenance. We can provide ten year insured warranties for all permanently installed structures.

- We provide initial costing and timetable details on structures such as those shown in our brochures, (all of which were designed, manufactured or erected by our skilled management). We have a guidance document for those who wish to know more about the process of incorporating membranes into building projects.

We believe this team can provide all the skills required to undertake major projects.

Contents

STRENGTH THROUGH SHAPE

Using the "strength through shape principle", curved forms such as membranes and domes are stronger, more efficient, and more economical than the equivalent rectilinear structures. It is our policy to use this principle wherever possible when designing structures. This organic architecture can fascinate and inspire, and reflect the harmony of natural forms such a sand dunes or breaking waves.

The membrane is unique when compared to traditional structures in that it is extraordinarily efficient. All visible components have a structural purpose as well as visual. The double curvature of the surface provides structural stability. Upward curvature accepts downward loads, downward curvature accepts upward loads. Generally, the more curvature the surface has, the more it can accept loads. Large deformation is resisted by prestressing the membrane to a level that is not countered by external forces. Allowance must be made for water runoff and the collection of snow, particularly at valley areas.

Architectural membranes appeal to the designer because of their novelty, their lightness of touch and feel, and their ability to change the space under and around them. They rely on geometric form for their shape, not the designer's whim, which provides a challenge to the designer that other built forms do not. This also means that the designer or architect should work with the engineer at an early stage of the project to ensure the proposal uses a form that can be realised and built. As the surface form can only be (easily) generated in software, the realisation of the membrane shape is less easy than with traditional materials. This requires the structural design of the project to be totally integrated with the architectural concept.

There are no British Standards or building regulation guidance specifically for permanently installed membranes. Guidance on how to lay out the form of the roof is virtually non existent. For example, few permanent structures rely on the membrane as the primary load-bearing element against wind and other loads. In most cases, the designer breaks down the membrane into modules divided by the supporting structure for manufacturing, transport, installation and replacement reasons.

THE MEMBRANE - FORM AND FUNCTION.

With the rapid growth in the use of fabric structures in Architecture, Engineering and Recreation, the designer is able to make use of a methodology and family of materials not considered feasible before. The modern concept of the membrane structure, one that provides atmosphere as well as shade, is a concept that designers are keen to encourage. With the advent of materials that allow us to think of architecture in new and different ways, it is feasible to use large spans economically for the creation of architectural spaces never possible before.

The designer can use the shape to create an effect that is not just structural or form based. For instance, by combining the translucency of the membrane with the inclusion of (for example), light wells to achieve new dimensions in the use of space.

Computer technology can contribute significantly to understanding and managing special structure development. Fabric structures present designers with unique challenges; the designer must understand the principles that determine the form, as the shapes of membrane structures cannot be dictated by looks alone, and must follow engineering principle and practice to work successfully. In the design and engineering of fabric membranes architecture combines the talents of the artist and the artisan in a very pure and unique fashion. The artist cannot work on looks alone without considering the geometric form of the surface. The artisan cannot reasonably produce a decent form without considering the artistic considerations.

The computer is the tool that helps the artisan to create original forms without ignoring the geometric necessities.

(taken from "The Sky is Not the Limit" the book of tents – © Rudi Enos 1993-9).

Computers-A Corporate Issue

Computers and information technology are already providing a wide range of solutions to local, national, and global problems. We have a goal of achieving excellence in our field, mainly by the use of information technology to disseminate all knowledge requirements of a project to the relevant parties. Internet based communication systems, KBE (knowledge based engineering), 3D computer modelling, and FEA (finite element analysis), all help to further our knowledge of the engineering requirements of modern structures. Strategic alliances with our partner colleagues in structural engineering, in membrane manufacturing, in methods of steel fabrication and with educational establishments, widen our field of vision even further.

Site Information Monitoring - All Documentation and information is normally stored on site in digital format. This will include all correspondence, site diaries, surveys and work programmes. Surveys can use the latest version of Global Positioning System (GPS) using a local transponder, that can output a visual display to monitor progress. Data is normally stored on a server connected to the Internet, allowing access from anywhere world-wide to supervise the project status and view the administration.

Our company has a policy that provides our employees a safe and healthy work place, protects the environment and the community, and conserves natural resources wherever possible. This provides a corporate context for sustainable development, while maintaining a strong commercial focus to maximise operational productivity within the ultimate framework of safety.

Where we need new solutions to challenges, we often invent new concepts. We then work to the maxim "innovation is the application of invention".

Technology alone does not bring success. The challenge is to apply technology to the problems facing the customer, our co-workers, and the community. As a company and as individuals we welcome the challenge.

DESIGN AND MANUFACTURE

Our design and manufacturing staff have developed specialised techniques for shape modelling, material testing procedures, structural analysis, cutting pattern generation, membrane seaming machinery and manufacturing techniques.

Most quality control measures centre around checking that the workshop has interpreted the manufacturing drawings correctly. This has been resolved by eliminating a whole level of manufacturing which was traditionally the 'black art' of tent making, i.e. the 'cut'. The three dimensional shape is turned into digital two dimensional cutting patterns and then exported into the cutter/plotter software, which automates the process, reducing potential errors.

SYSTEM ROOFS

Practical And Reasonable Value For Money

If you want to cover a space, and you want something that doesn't cost the earth but looks good, then MoonBurst Structures Ltd membrane system roofs are the answer, being both aesthetically pleasing and functional. This is when the MoonBurst specialists can come up with a design specially for you, custom-built to suit the locality and your own particular requirements. Single or double skin, small or large span, with guttering, apex ventilation, short term or long term tailored to meet your needs and stand up to your weather.

MoonBurst inflatable membranes are halls enclosed by an air supported membrane structure, erected using a proven modular system. They offer the ideal low-cost solution if you want speedy protection of large areas against the weather, e.g. warehousing at specific temperatures, open air exhibitions, tennis courts, etc. We can supply you with the complete infrastructure - membrane, blowers, heating, airlocks, revolving doors, anchorage, lighting and cooling. What's more, you only need a few hours to erect our inflatables or take them down, and storage is easy, too. Which makes them a very good option for seasonal users.

ARCHITECTURAL MEMBRANE ROOFS

MoonBurst specialist structures are state of the art, engineered permanent and portable building systems. We work with architects and engineers either as the prime contractor on stand alone contracts or as nominated subcontractors to supply the membrane element of a project. We are fully conversant with construction industry practice and meet all on-site health and safety requirements and CODAM. We use qualified installation crew for rigging (IRATA), and skilled erectors for the membrane elements. We can meet all local building codes specified.

Our architectural membranes are designed and installed to exacting quality levels. We provide a full engineering service to clients for product design, installation, and maintenance. We can provide ten year insured warranties for all permanently installed structures.

THE MEMBRANE IN ARCHITECTURE

Each year, the trend towards using membranes in an architectural context grows stronger. Many leading edge construction projects have a tented element or elements. Some, such as the Arabian Beach hotel in Dubai, would not even appear the same concept without the membrane shade structure soaring vertically, integrated into the shell of the building. Many membranes are used, not just to provide cover, but to fundamentally change the area beneath.

'Form follows Function' is a modernist ideal. With the membrane structure, the two concepts are indivisible. How the designer interprets the form while retaining function was best expressed by Picasso: " Some painters transform the sun into a yellow spot; others transform a yellow spot into the sun".

Architectural membranes appeal to the designer because of their novelty, their lightness of touch and feel, and their ability to change the space under and around them. They rely on geometric form for their shape, not the designer's whim, which provides a challenge to the designer that other built forms do not. This also means that the designer or architect should work with the engineer at an early stage of the project to ensure the proposal uses a form that can be realised and built. As the surface form can only be (easily) generated in software, the realisation of the membrane shapes is less easy than with traditional materials. This requires the structural design of the project to be totally integrated with the architectural concept.

There are no British Standards or building regulation guidance specifically for permanently installed membranes. Guidance on how to lay out the form of the roof is virtually non-existent. For example, few permanent structures rely on the membrane as the primary load-bearing element against wind and other loads. In most cases, the designer breaks down the membrane into modules divided by the supporting structure for manufacturing, transport, installation and replacement reasons. The method of determining the size and shape of the modules is usually arrived at from experience.

This overview intends to provide some details of the design, specification, purchasing, installation management, and contractual requirements for an architect, quantity surveyor (cost accountant), or contract manager wishing to specify such elements in the construction industry. It is not intended to be a finite statement of best practice for any individual project.

Introduction To Membranes

Compared with traditional buildings, designers and architects must incorporate a surface form created (usually) in software which is not subject to artistic desire or whim. This requires the designer to work with the engineer earlier than would be expected in the traditional building process. As the engineering requirements cannot be ignored, both architects and buildings that push the boundaries of design will need input from engineers at an earlier stage.

Compared to traditional buildings, fabric structures present a unique set of design challenges, as the shapes of membrane structures cannot be chosen at random. The absence of bending resistance requires designers to work within the constraints of feasible membrane equilibrium shapes, which can only be easily arrived at with the use of software. The structure can be considered in equilibrium when all forces and reactions balance each other out so that there is no net change.

Membrane forms are usually complex, doubly curved surfaces which must be pretensioned in such a way as to resist applied environmental loading such as wind and snow. A tensile membrane structure is prestressed and stabilised by the counteracting tensions of opposing curvatures of an anticlastic surface (two-directional curvature of opposite sign, as in a saddle surface), or the synclastic surface (two-directional curvature of equal sign, as in a spheroid such as an inflated dome or hemisphere).

Special non-linear techniques are necessary for the structural analysis of tension structures, since membranes undergo large shape changes under varying load conditions and fabric materials exhibit complex stress-strain response. Finite element techniques can be used to solve these non-linear problems. FEA or finite element analysis breaks down the surface into finite elements or areas and analyses the reaction effects and inter-relationships of the elements.

Engineered Roofing Fabric - The Advantages

Engineering fabrics can be used to provide a roofing material which offers unique properties to the designer. They can be translucent or blackout, single or double skinned for insulation, and are resistant to ultraviolet light degradation over periods of many years, sometimes longer than a traditional roofing material. Engineered roof fabrics can be self coloured or have a range of translucencies yet retain those properties over the service life of the structure, often 15 to 20 years. All materials used by MoonBurst Structures have guarantees of a minimum of five years with extended warranties available on all permanently installed structures.

Fabric membranes compare favourably with traditional roofing materials. In particular, flat membrane roofs are extensively used as part of current roofing systems. The significant difference to the flat roofing system is that while the flat roofing is mainly non load-bearing, tension membranes accept all environmental loads.

Most engineering fabrics use a base of high tenacity polyester or glass fibre with a high modulus to minimise extension under load. Both exhibit high tensile strength to weight ratios with resistance to tears and high shear strengths. Yarn stability is unaffected by changes in temperature and humidity which provides the dimensional stability that mechanically tensioned structures require. Specially formulated coatings provide extended performance characteristics for specific installations such as arctic or desert conditions. As well as resistance to chemical attack and the retention of flexibility in cold weather, the roof materials can be repaired in situ for economical maintenance.

Engineering fabrics have been extensively tested over a period of many years and meet building codes around the world. We have test results for flame resistance, colour fastness, fade resistance, flexibility and elongation under load.

WHOLE OF LIFE COSTS

In many cases the cost of a membrane can be further offset by savings made over the life of the structure such as by reduced maintenance or the daylight electricity savings of a translucent roof.

Modern membrane materials are a complex mix of chemical compounds which perform well under a wide variety of environmental conditions. They provide a high level of translucency, typically from 10% to 30% and even greater where required to special order. They provide many benefits to whole of life costs in many installations where savings can be made on reduced electricity costs, etc.

STRUCTURAL MORPHOLOGY

"Why not go out on a limb? Isn't that where the fruit is?"

Frank Scully

Early practitioners used models made from stocking material to generate the doubly curved forms in models. These could be measured and scaled to create the cutting patterns for manufacture. Obviously the accuracy of the full-scale form would generally be somewhat suspect, and many early structures had to be altered after manufacture to fit the intended space. Modern computer-based methods allow for accuracy that practitioners in the 1950's did not have. All elements in the project can be represented in software, analysed, and the results used for manufacture.

The membrane is one of the few types of structure that is extraordinarily efficient. All visible components have a structural purpose as well as visual. The double curvature of the surface provides structural stability. Upward curvature accepts downward loads, downward curvature accepts upward loads. Generally, the more curvature the surface has, the more it can accept loads with minimal deformation. Large deformation is resisted by prestressing the membrane to a level that is not countered by external forces. Allowance must be made for water runoff and the collection of snow, particularly at valley areas.

Visually, the membrane can be adapted into many different shapes. Mostly, the shapes are high in the middle and lower at the perimeter, but this does not need to be the norm. Wave forms such as sand dunes can be evocative and are often copied in membrane profiles. Modern architecture is moving ever closer to more organic shapes, which membranes can provide. The curved ridge lines can be induced by using curved members to provide the lift and soft valleys can be created. Cathedral-like towering shapes can be represented by using 'peaky' forms. Masts and tension cables can lean outwards to provide grace and movement to the concept.

Once a design has been approved in the design office it still has to be approved by the client. It is often difficult to acquaint the client with the complexities of a membrane based project. Sophisticated visual aids such as artists sketches and painted visuals can give the feel of the overall project but for accuracy the membrane forms are best represented with computer renderings. The true form of the surface can be exported from the design software into the rendering software, incorporating most physical details of the surrounding project and either printed out in colour or animated and issued on videotape or CD.

Overhead photographs can have the intended design 'perspective matched' onto them to show the final result. Shadows at different times of day and year can be represented and translucency defined.

Complex spreadsheet-based cost analysis is available as are costings from previous projects. Manufacturing quantities, bill of materials, and shop and installation times can be estimated with the depth of information available from the analysis output. All of this accurate information gives the client and the main contractor the confidence to initiate the project.

PROJECT DESIGN PARAMETERS

British building codes do not specifically cover membrane roofs. There are parts of the Institute Of Structural Engineers, 'Guide To The Design And Installation Of Temporary Structures', and other industry codes which are relevant. Basically, the permanently installed membrane roof must prove to be able to handle safely the same environmental loads as a traditional roof.

It is possible for a contract manager or architect to specify architectural membranes, or construction industry projects with a membrane content, without extensive knowledge of the genre. The following are the main points.

STRUCTURAL CERTIFICATION

Design, analysis and certification of membrane structures is a branch of engineering which cannot be undertaken by most structural engineers due to the specialised knowledge, experience and software requirements. The manufacturer/installer will know of suitable engineers to provide the technical and design warranties. Factors of safety must be determined for each disparate part of the structure. The stretch correction characteristics of each material in the project must be allowed for in the manufacturing drawings. Special Structures Lab provide this service to many manufacturers.

Permanently installed membranes will have to meet the same environmental loads as a traditional building. Pressure coefficients, and loading criteria are normally taken from local or national building codes.

TRADITIONAL WORKS

Much of the membrane project can be assessed in the same way as traditional construction industry projects. Foundations are usually poured concrete, tensile forces in cable stays or guys are a known quantity, and much brick or blockwork use current working practices. As in most projects, ducting, pipe work, and damp proofing will need to be specified prior to going on site.

When membranes need to be integrated with other elements of the project, potential problems arise. Connecting membranes which can exhibit large deformation, with brickwork or concrete elements which do not, can be problematic if not addressed at an early stage.

COMPONENT QUALITY

Quality standards of all goods supplied for a particular job must be stated prior to contract, and effective inspection methods carried out to ensure compliance. For example, stainless steel rigging is almost always preferable from a visual and maintenance point of view, but costs often dictate using galvanised steel rigging instead.

The membrane material can vary in specification and must be chosen for its intended use. Some membrane materials can have design lives greater than traditional materials. A specific design life should be a negotiated with the designers, and a specific manufacturer's warranty agreed. Tests should ideally be made to check material properties.

Structural steelwork specifications must meet the required codes for the locality. Surface finishes must be laid down and specified in the design brief. Type and quality of fixings should be agreed.

PROJECT DURATION

Typically, a medium sized membrane project will cover 12-16 weeks. The bulk of the design work takes place in a concentrated period during the first month. As most membrane materials are custom made for the project, delivery of the membrane in roll form from the factory is usually 4-6 weeks. By then the cutting patterns will be available in digital form to allow cutting in 4-6 days. Registration marks and system points are marked on the membrane automatically during cutting.

While the membrane seams are joined (usually by radio frequency welding, taking 2-3 weeks), the membrane compression fittings (which collect catenary and membrane forces at pressure points) are being manufactured (often laser cut) and plated or galvanised. Cables are ordered to the correct specification (delivery 2-3 weeks) and delivered to site with the membrane.

STRUCTURAL STEELWORK

Structural steelwork is also delivered to site and any drilling/fixing of base plates or fixtures to other elements of the project completed before commencing erection. Prior to fixing any part of the project, it is advisable to undertake a full survey of project geometry.

WARRANTIES AND GUARANTEES

The specifier should obtain manufacturers' quality statements and warranties on materials (including those obtained from their suppliers), workmanship, and all other fittings used on the structure. This will be used to provide an 'audit trail' of suppliers guarantees to generate the overall manufacturers warranty.

The specifier should also obtain suitable structural assessment and certification of the design from the structural engineers.

MEMBRANES - DESIGN LIFE

Membrane materials are generally maintenance free (apart from normal cleaning) for periods of many years. The design life of a structure depends mainly upon the environment. If pollution from road or industrial sources is nearby, it can affect the life of the roof. The pre-tension of the membrane also affects the life span of the installation through greater stability. Materials with improved coating standards also extend the life of the structure. Many varieties of coating are available such as acrylic and PVDF (fluorine as used on non-stick appliances). The colour of the membrane also affects the life span of the structure.

It can be good practice to use materials with an increased factor of safety (strength over potential maximum load) to prolong life.

Typical design lives are:

Portable structures, typically 10 years with a 5 year guarantee. Much depends on the way the structure is operated and the wear and tear involved.

Permanent structures using PVC/PVDF, typically a minimum of 10 years with more in the right conditions. If the building is to be used long term, a higher specification of coating is required. Some of these coatings need to be removed where the membrane is welded together, which increases cost, so a careful decision needs to be made when specifying roof materials. For extreme long life situations, where the roof needs to be installed for 20 years and more, PTFE coated glass fibre is often specified for maximum life.

ERECTION

The erection process comprises three elements;

1) laying out and fixing

2) erection of steelwork and membrane

3) dressing out and post tensioning.

The supplier should provide a risk assessment and erection method statement for the structure to the client prior to going on site. Where cranes are to be used, as much initial work as possible should be done to prevent costly delays. (Ideally, a spare day or days should be allocated at this point in case of delays).

The weather can play a part in the erection programme. As in most roofing, even slight winds can cause delays, so this must be allowed for in the programme.

Once the membrane has been hoisted, it must be gradually tensioned to 95 % of the final prestress tension. When this point has been reached, every part of the project must be checked for compliance with the specification. Finally, the membrane will be fully tensioned, checked again and signed off. It may be necessary to return to site to further tension the roof at a later date.

PAYMENT SCHEDULES

As in any project, the client wants to know that he gets value for money and the correct quality of work. The supplier wants to know that he will be paid. While there are many ways of arranging payment, the following has been shown to work.

In any bespoke product, it is normal to make an initial payment or at least pay for the design proposal. At that point, a finite specification can be given a finite project duration and cost. Further payment triggers can occur when the membrane materials arrive at the factory, when structural steelwork is delivered to site, when the whole structure is delivered to site (on smaller projects), and when the structure is erected. It is possible to consider monthly payments or fixed stage payments. In all cases, a small residual should be held back until final handover.

The inclusion of a membrane element in a construction project need not be greatly different from traditional projects if simple guidelines are followed.

TRANSPORT AND INSTALLATION

In almost all cases the main construction elements are fabricated off site. This allows for reduced installation times when compared with traditional works, giving substantial time and cost savings. Major roof installations can be completed in remarkably short time spans.

The on site installation of the membrane commences in the workshop. The rolled sections can be damaged by contact with hard or sharp objects while being transported so the packaging of the various fields of the membrane in the correct manner is vital, as is marking and orientation of the rolled sections.

Here we will concentrate on a permanent membrane installation as packaging of temporary structures varies enormously with the specific design. While individual designs will change the specific installation procedures of a permanently installed roof, there are many common tasks and parameters.

In any project there will be initial pre-site meetings to plan the integration of the membrane specific parts of the site. Inevitably, modern construction site planning involves many differing trades all working in effectively the same space within the same time frame. The installation of the membrane often takes up the entire floor area of the building and perhaps more, which means that other trades have to stop work, involving much planning and project management.

The anchors need to be integrated into the building works such as foundations or other elements. The structural steelwork will need to be installed and erected in much the same manner as any other building type. The cables, rigging and lifting gear will require positioning and installation. Only then can the membrane be brought to site.

If the membrane can be hoisted up the masts as in sailing ships, the site will need to be cleared and protective covers laid where the membrane is to be laid. In some installations, the rolled sections are hoisted by crane over the supporting steelwork and rigging and unrolled in the air. In all cases, it is better to undertake this procedure on the ground, but it then stops all other work on site. Any job undertaken in the air will raise project costs and slow the work rate as this usually requires the use of skilled riggers using industrial roped access techniques.

When installing PTFE glass fabric membranes, the whole process is made harder as a result of the materials inability to bend easily requiring the use of special supporting rigs to unroll the membrane either on the ground or in the air.

The extra work and cost of handling PTFE glass is offset by the long life of the material.

DESIGN TASKS - TYPICAL PROJECT

MEMBRANES - THE DESIGN PROCESS

Engineering of fabric membranes requires expertise in two primary areas; in the conceptual design and analysis of stressed skin structures and in the use of advanced geometry manipulation in the manufacture of the built form. In order to realise the complex three dimensional forms, it is necessary to use predominantly computer modelling techniques. Complex three dimensional shapes can be generated in special software suites which simulate applied environmental loads such as wind and snow. The software can compensate for different loads and component properties such as fabric stiffness and cable forces. At each stage of the design and analysis process the geometry can be checked for suitability for manufacture. The software can output not only technical information such as readouts of forces at node level to assist in specifying supports, but design aides such as graphic output of deflections and contours, in addition to membrane, cable, and vector forces. Cutting patterns are output from the three dimensional form to ensure the design information is optimised.

Compared to traditional buildings, fabric structures present a unique set of design challenges, as the shapes of membrane structures cannot be chosen at random. The absence of bending resistance requires designers to work within the constraints of feasible membrane equilibrium shapes, which can only be easily arrived at with the use of software. The structure can be considered in equilibrium when all forces and reactions balance each other out so that there is no net change. Membrane forms are usually complex, doubly curved surfaces which must be pretensioned in such a way as to resist applied environmental loading such as wind and snow.

With a wealth of information at hand, every performance characteristic can be assessed. The post analysis form can be exported to visualisation packages to create photo realistic visuals and animated fly-through's which provide an unparalleled opportunity for a potential client to assess the project.

This design loop of feasibility study, cost analysis, structural analysis, design for code provision, manufacturing detailing, and transport and erection documentation forms a specialised branch of engineering which is practiced by a select few engineers in the world. A simple example that can be shown is that a typical membrane has single and multi layered fabric, reinforcing belts, and steel wire rope cables all bound together in a complex interaction of forces. These materials all exhibit different stretch characteristics which have to be allowed for in the manufacturing geometry. The materials have to be tested in the laboratory and the compensations included in the production drawings so that when the structure is installed all components in their loaded state arrive at the correct point in three dimensional space.

An important part of the design process is final certification of the project. Certification and insurance are required for the safe use and operation of leading edge buildings and rely upon a high standard of engineering. As all potential, performance parameters can be assessed, most project information can be extracted.

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Most quality control measures centre around checking that the workshop has interpreted the manufacturing drawings correctly. This has been resolved by eliminating a whole level of manufacturing which was traditionally the 'black art' of tent making, i.e. the 'cut'. The three dimensional shape is turned into digital two dimensional cutting patterns and then exported into the cutter/plotter software, which automates the process, reducing potential errors.

GEOMETRY AND ANISOTROPIC BEHAVIOUR

The membrane should ideally have double curvature, as in a saddle, where the centre of radius of curvature in two principle directions is on opposite sides of the surface. This forms a shape known as an anticlastic surface. Tension structures use a double curvature that is anticlastic (in opposite directions), while the air supported structure is synclastic (curved in the same direction).

The membrane will be in equilibrium when the radius of curvature of the surface is small enough to resist out of plane forces.

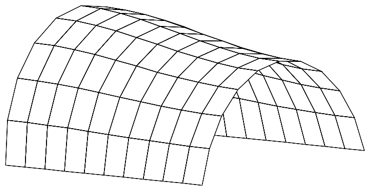
The fabric panels are generally laid across the surface in direct alignment with the principle axis of curvature. This ensures that the fibres of the woven base cloth can act in the most effective way.

With the warp and weft of the fibres (X and Y directions of weave), being inserted in and out of each succeeding layer, the fabric exhibits complex behaviour in the bias direction (at 45 degrees to the warp and weft). This loading and unloading of the scrim is called the 'crimp interchange'. The material is said to exhibit anisotropy because it behaves differently across the two orthogonal axis, and yet differently again when strained across the bias. Biaxial strengths of 60-70% of the warp and weft values can normally be expected.

One of the most difficult parts of the manufacturing process is not always exactly understood by the layman and that is the stretch factor. To achieve the required geometry for the final structure, every single component, whether it be cables that support the boundaries of the membrane or the membrane surface itself, have to be designed and manufactured to a size equal to the unstretched state of the material. This is achieved through calculation of the materials to be used. These calculations are extremely complex and not easily undertaken as all of the materials stretch by different amounts. The reduction in size will be exactly equal to the amount that each material stretches under load. Obviously compression members do not have to be made larger as they do not compress enough to make any difference. Therefore, the structure in question has to be modelled, usually with the help of 3-dimensional computer aided design software, to give finite and precise measurement of the structure in its intended state.

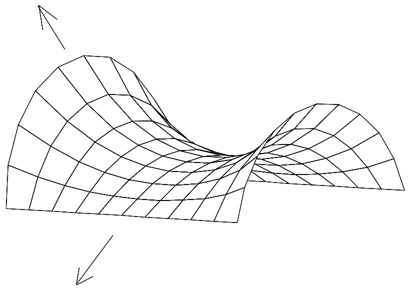
FORM FINDING

The single most important factor in the load bearing capabilities of a surface is it's shape. It is only with anticlastically shaped surfaces such as a saddle that it is feasible to produce structures that resist loadings despite deflection, (ignoring air supported structures). The surface has two opposing curvatures, (concave and convex), at every point. Thus, all forces, irrespective of which side they come from, can be transferred as a tensile force into and along the catenary's. If the axis of the two opposing curvatures coincide with the patterning, not only has the material the highest load bearing capacity, but variables that come from loading the bias disappear.



A

A simple surface that will not transfer loads into the opposing curvature due to the minimul shape change.



B

The same surface after shapefinding exhibits much better capabiity to carry surface loads Positive and negative loads are both restrained by the opposing curvature.

Three dimensional surfaces of membrane structures can be made from any shape that allows the surface to counteract the forces applied upon it. It is desirable to design the surface so that only tensile forces are present. Such a surface may have one of two similar but differing forms, either a surface curving in the same direction (as a sphere), or in two opposing directions (such as a saddle surface). The extreme and seldom used example of this is the minimum surface. This shape is defined by the smallest area between discretionarily formed closed lines. Each point of the surface equates the negative or positive curvatures at zero values.

Some of the simplest structures are based upon square boundaries or bases rising to a point, or variations thereof. A simple hyperbolic paraboloid can be created by four or more straight boundaries, the shape can be added to, and more or less boundaries created to alter the plan of the intended shape. The three dimensional surface can then be 'nudged' and pushed or pulled, with the use of conical rings or curved members to give the surface an arch instead of a point. Variations of this technique are used to create almost any surface. As a rule of thumb, the larger the shape change, the more efficient the surface will be. Analysis regularly shows that areas needing higher rigidity also need greater curvature.

Membrane structures can be defined as light-weight, load-bearing or fabric structures, on steel supports, mechanically stretched or inflatable, with loading according to DIN or BS, or any other international standard, for dead weight, snow and wind load, stress and applied forces. MoonBurst Structures Ltd is able to provide installations to the highest possible standards, - anywhere in the world. With our high level of engineering back-up, we are confident of complying with local and international standards, wherever the structure may be sited.

MoonBurst Structures Ltd synthetic membranes are made of a carrier material polymer coated on both sides to produce waterproofing systems that have been used with great success in civil and constructional engineering projects all over the world.

ANALYSIS

MoonBurst Structures use the Easy NT suite of analysis tools at our associate company Special Structures Lab Ltd, also in Sheffield.

Typical membrane structures defy classical analysis. Modern engineers use sophisticated software tools to generate virtual models which can represent the real world project. Every part of the virtual model can have properties simulated to represent forces and structural components in software. The model can then have surface pressures defined from projected wind patterns and assigned. There are two main methods used to determine equilibrium shape in the commercial world of membrane roof manufacture. These are the 'dynamic relaxation' method and the 'force density method. SSL use the force density method with Easy NT.

Membrane surfaces exhibit both geometric non-linearity due to large deflections in addition to fabric non-linearity. Non linear analysis is used where displacement may not equal the applied force depending on scale. The surface is normally represented as a mesh. The representative mesh is analysed using non linear FEA (finite element analysis) to determine the forces in the membrane, the perimeter cables and the loads to the main supporting elements. The elements are usually masts and cables, but beams, concrete members or even timber can provide support.

The research engineer tries to develop new principles and processes by using mathematics, scientific concepts, and experimentation. For instance, large computer simulations developed by research engineers permit the prediction of the performance of the structure prior to manufacture. It is possible to predict the deformation of the membrane under varying environmental conditions using non linear Finite Element Analysis tools, depending on the stiffness and stretch characteristics of the materials chosen.

By testing a representative sample of test pieces in the laboratory, a reference configuration for the structural fabric is arrived at. This reference configuration is modelled and simulated in software, then analysed using different parameters until the software model exhibits deformation and stress/strain results similar to the real world tests. The software can then be said to be calibrated to the material being analysed.

The development of tensioned fabric membranes has gone from the use of early stocking models and 'soap bubble' tests to the current use of multi programme software suites. Special non linear techniques are necessary for the structural analysis of tension structures, since membranes undergo large shape changes under varying load conditions and fabric materials exhibit complex stress-strain response. Finite element techniques can be used to solve these non-linear problems. FEA or finite element analysis breaks down the surface into finite elements or areas and analyses the reaction effects and inter relationships of the elements. The main processes that generally need to be undertaken are as follows;

Simulated application of loads

Even with a rectilinear building it is difficult to asses the loads that may be imposed due to the variables of weather and in particular wind, which can exhibit unpredictable eddies and turbulence. When the force calculation is made more difficult due to the three dimensional form of a membrane there are only three ways to assess the potential forces. One is to apply an overall pressure co-efficient (uniform load) which makes allowance for most conditions. While factors of safety are a vital part of engineering, over engineering can be detrimental to a project and not just on the grounds of cost. We use software applications which break down the surface of the membrane, sector by sector and apply a simulated load determined by direction of force and angle of approach. This provides a more accurate method of determining potential force.

Validation of fabric properties

To provide accurate analysis of membrane structures, it is necessary to accurately asses the performance characteristics of the engineering fabric chosen, within the software. Once the chosen fabric exhibits the same performance characteristics in software as the physical tests, analysis can begin.

Finite element analysis

Typical membrane structures defy classical analysis. Modern engineers use sophisticated software tools to generate virtual models which can represent the real world project. Every part of the virtual model can have properties simulated to represent forces and structural components in software. The model can then have surface pressures defined from projected wind and snow patterns as above and assigned. The analysis provides output forces and geometry. The output forces are used in the design of supports.

Cutting pattern generation

The form has geodesic lines generated on the surface in the position of the seam lines. This positioning is configurable to meet production requirements and to match fabric roll widths. Seam lines are the jointed edges of the individual panels that make up a membrane section. The geometric information is used to provide 2D cutting patterns. The 3 dimensional form is broken down into fields divided by the geodesics. These fields are then split into triangles which are opened up along their common edges and unfolded flat in software. The node points are then treated as co-ordinates for manual marking or to drive an automated cutter/plotter.

Building code compliance

Most structures around the world need to meet some form of local authority standards. The manufactured design must be checked for compliance.

Prestress

Prestress is applied to the membrane surface sufficient to resist environmental loads. The prestress used in the structure must be high enough that the internal tensions in the membrane are never zero when loaded with external or environmental forces. When the prestress is zero, the membrane may wrinkle which does not allow the membrane to distribute the forces in another direction.

Patterning

The form has geodesic lines generated on the surface in the position of the seam lines. This positioning is configurable to meet production requirements and to match fabric roll widths. Seam lines are the jointed edges of the individual panels that make up a membrane section. The geometric information is used to provide 2D cutting patterns.

The 3 dimensional form is broken down into fields divided by the geodesics. These fields are then split into triangles which are opened up along their common edges and folded flat. The node points are then treated as co-ordinates for manual marking or to drive an automated cutter/plotter.

Factors of safety

Typical factors of safety for membrane components can be:

Membrane	5:1
Webbings	2.5:1
Structural steelwork	3:1
Wire rope cables (pre stretched)	2:1
Shackles and rigging	2.5:1

DESIGN PROCEDURES

The following design procedures are generally used to undertake most projects. The design tasks for a typical membrane project can be broken down into the following categories.

- To model the structure in three dimensions on the computer to provide the 3D geometry (system points) for use by all aspects of the project.
- To determine 'registration points' to enable all parts of the project to interact.
- To layout the structure and provide a GA. (general arrangement).
- To provide visuals and animations of the final specification.
- To determine the pressure coefficients (wind loads, positive and negative), and to assess the performance capabilities of the proposed form.
- To provide the equilibrium form of the surface in its pre-stress state, using the appropriate software, and to analyse and assess the resultant reaction loads from environmental loads to the membrane and the corresponding supports.
- To assess the resultant geometry and its bearing on the structural supports, the way the structure interacts with surrounding features (if necessary), and determine an appropriate specification.
- To detail the steelwork, fabrication drawings, and rigging.
- To establish a database of the project components, to log revisions, and to provide the project office with this information to distribute.
- To plot and print all drawings and specifications to the detail level required to instruct the workshops and to issue them to the project manager for distribution to possible subcontractors such as steel fabricators.
- To determine erection procedures.

Upon completion of the full design proposal, the client usually has the right to change, amend or append any part of the proposal but may be charged for these changes.

MANUFACTURING

- To determine material specification, manufacturing standards and design life for the structural steelwork and rigging.
- To provide the cutting patterns, from the patterning software, to allow the manufacture of the membrane.
- To detail cables, webbing inserts and catenaries.
- To specify the detail of the clamping plates at lacing and catenary ends.
- To specify the detail of the neck construction and fittings.
- To specify protective covers for all fabric sections where required.
- To provide all fabrication drawings, laser cutting templates, and weld specifications where needed.

- To specify instructions to the steelwork engineers in respect of design, operation, and lifespan of the structural steelwork, the rigging, the winches, and the winch control gear (if used).

INSPECTION

- To agree a material specification with the fabric supplier/coater.
- To check fire retardancy certificates.
- To visit each manufacturing site during fabrication for a quality check.
- To determine quality levels and specifications.
- To specify quality and inspection methods.
- To layout a quality and inspection schedule for steelwork.
- To layout a quality, inspection schedules, and test certificates for lifting gear.

COST ANALYSIS

- To determine a Bill of Materials for the project.
- To assist in the choice of sub contractors in order that the client can appoint them.
- To provide a cost analysis of the project costs.

LIABILITIES, WARRANTIES AND GUARANTEES

- To assess the manufacturing liability, and obtain manufacturers warranties.
- To assist in negotiations with the insurers in order that the best cover be provided.
- To specify material and manufacturing guarantees in order that they be obtained by the client from the suppliers.
- To, provide structural assessment and certification of the design.
- To provide an 'audit trail' of suppliers' guarantees to generate the overall manufacturers warranty.

MEMBRANES - MANUFACTURE

The use of computers in membrane architecture extends to manufacturing the built structure. We use large scale x-y cutter plotters for the creation of the cutting patterns, and predominantly laser cut parts for structural steel components, for which the information is generated by our in house specialist software.

Fabric structures rely on their geometry to work structurally. The difficulty in manufacturing the membrane is to translate the three dimensional geometry of the finished and installed shape to the flat workshop floor, or in reality the other way round. The workshop is presented with a series of instructions which are not always clear, which is understandable when you think how difficult it is to represent overlapping layers of cloth in a complex layout. Fabric manufacturers and assemblers tend to use available production materials (apart from special mixes of colour) as the warranties could be an issue with special weaves and finishes.

The making of parts and components (sometimes with the help of robots), is usually considered a subspecialty of mechanical engineering. Fabric workshops increasingly use automated machinery for the assembly of materials.

The knowledge of 3D CAD-CAM, engineering design, fluid mechanics, structural computation, machine design, controls, robotics, operations, maintenance, and logistics are all involved in a project. All parts are designed with the aid of computer graphics. The computer carries out all the technical computations needed to make a part meet performance requirements. This aspect of computer-aided design (CAD) is frequently coupled with computer-aided manufacture (CAM) to produce parts automatically.

MANUFACTURING TECHNIQUES

Designers and manufacturers have developed specialised techniques for shape modelling, material testing procedures, structural analysis, cutting pattern generation, membrane seaming machinery and manufacturing techniques.

Most quality control measures centre around checking that the workshop has interpreted the manufacturing drawings correctly. This has been resolved by eliminating a whole level of manufacturing which was traditionally the 'black art' of tent making, i.e. the 'cut'. The three dimensional shape is turned into digital two dimensional cutting patterns and then exported into the cutter/plotter software, which automates the process, reducing potential errors.

The making of parts and components (sometimes with the help of robots), is usually considered a subspecialty of mechanical engineering. The knowledge of 3D CAD-CAM, engineering design, fluid mechanics, structural computation, machine design, controls, robotics, operations, maintenance, and logistics are all involved in a typical membrane project. All parts are designed with the aid of computer graphics. The computer carries out all the technical computations needed to make a part meet performance requirements. This aspect of computer-aided design (CAD) is frequently coupled with computer-aided manufacture (CAM) to produce parts automatically.

In addition to the modelling, (which provides 3D co-ordinates to allow the project to be broken down into discrete parts, yet still interface through pre-defined 'registration points'), the geometric information is used in manufacturing. Although many differing computer aided manufacturing techniques are used, two examples can be shown:

1./ Using traditional woodworking practises, laser cutters can be used to create metal parts that not only allow complex shapes not easily attainable, such as slots or compound curves, but to ensure a perfect fit to the co-components. Lugs and grooves are used to register the parts together, in a way not possible with normal fabrication techniques. These shapes are transmitted to the laser cutter by MODEM or disk to provide geometrical information without traditional paper dimensioning.

2./ The two dimensional co-ordinates of the tents are passed to a large scale X-Y plotter, (some as large as 3 metres by 25 metres, {10 feet by 80 feet}), which draws and marks or cuts by knife-edge or by laser, the fabric panels for seaming.

These are registered by marks down the seams to ensure perfect seam match on every panel. Other marks identify the panel, (panel number, orientation, left hand, right hand etc.) to avoid confusion. These panels are obviously easily scaled down to allow the manufacture of a model for wind tunnel analysis, thereby completing the circle from design to manufacture.

MEMBRANE MATERIALS

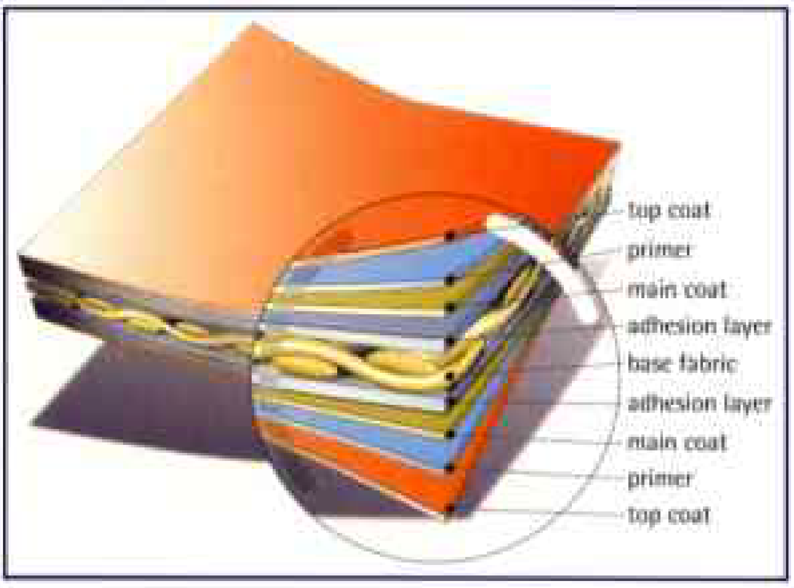
The generic term "fabric" refers to a wide assortment of materials: cotton canvas, nylon, polyester, glass fibre and ethyltetrafluoroethylene (ETFE) foils; and their many coatings, such as polyvinyl chloride (PVC), polyurethane (PU), Polyvinylidene fluoride (PVDF), polytetrafluoroethylene (PTFE), (otherwise known under it's trade name of Teflon), Acrylic, and other less common coatings.

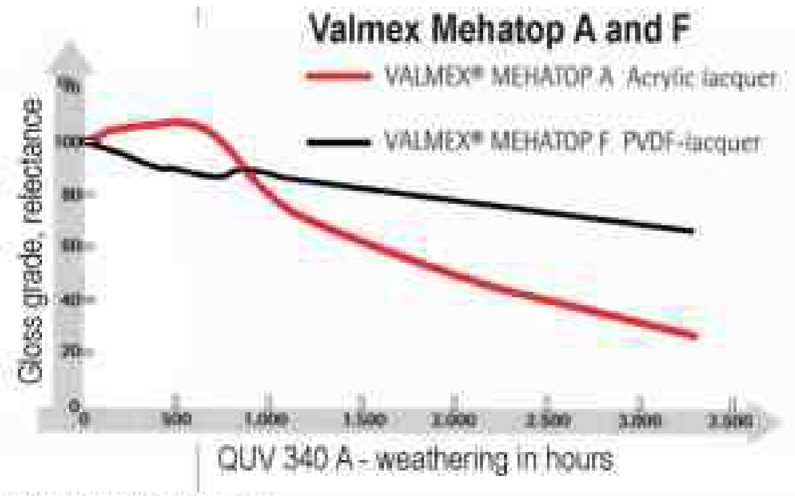
All of the materials used by our company are chosen carefully for their ability to meet the requirements of the intended design life of the roof. As most fabrics are coated with complex chemical compounds, each of which provide specific solutions to engineering requirements, it is vital that the correct specification is used.

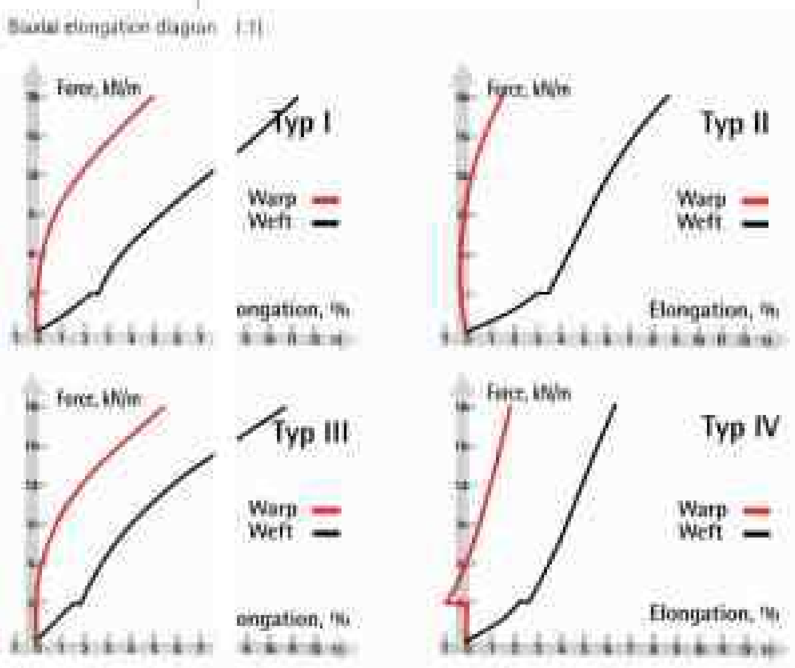
Most roof materials generally use woven Polyester base cloth, with a coating of P.V.C. (Polyvinylchloride), that includes additives for material stabilisation under Ultraviolet (U.V.), Anti Fungoids, special Plasticisers to stop surface 'creep', and Flame Retardants. Finally the surface is treated with a coating of either Acrylic high gloss Lacquer, or Fluorine type lacquers of PVDF. Blackout structures require a first coat of black opaque P.V.C. before the final colours are applied. For long life external applications PTFE coated glass is the preferred option. Internal membranes can use silicon coated polyester for improved fire resistance.

PVC / POLYESTER MATERIALS

PVC / Polyester is the most widely used membrane material for architectural use. The material and the project are able to be covered by a 10 years warranty backed by an insurance company. This provides an unconditional cover that is not available with traditional building methods. These membrane materials are based upon 'polyvinyl chloride' (PVC) coated woven polyester base cloth. The cloth provides tensile strength and dimensional stability. The coating is chemically bonded to the cloth and provides the mechanical strength of the membrane. Additives are included to prevent the hardening and degradation of the material under UV, to stop fungoids attacking the membrane, and to provide the fire retardancy required under building codes.







MoonBurst Structures Ltd PVC membrane comes predominantly in five types:

Membrane Type 1		
Carrier material	DIN 600001	PES

Weight per unit area g/m2 - (untreated material)		200
Type of coating	PVC on both sides	
	DIN 4102 B 1 fungicidal	
Weight per unit area g/m2 (treated material)	DIN 53332	850
Tensile strength (N/5cm) K/S	DIN 53354	3000/3000
Tear strength (trapezium) (N) K/S	DIN 53363	300/350
Membrane Type 2		
Carrier material	DIN 600001	PES
Weight per unit area g/m2 - (untreated material)		280
Type of coating	PVC on both sides	
	DIN 4102 B 1 fungicidal	
Weight per unit area g/m2 (treated material)	DIN 53332	900
Tensile strength (N/5cm) K/S	DIN 53354	4500/3800
Tear strength (trapezium) (N) K/S	DIN 53363	500/500
Membrane Type 3		
Carrier material	DIN 600001	PES
Weight per unit area g/m2 - (untreated material)		380
Type of coating	PVC on both sides	
	DIN 4102 B 1 fungicidal	
Weight per unit area g/m2 (treated material)	DIN 53332	1050
Tensile strength (N/5cm) K/S	DIN 53354	6000/5500
Tear strength (trapezium) (N) K/S	DIN 53363	1000/1200
Membrane Type 4		
Carrier material	DIN 600001	PES
Weight per unit area g/m2 - (untreated material)		470

Type of coating	PVC on both sides	
	DIN 4102 B 1 fungicidal	
Weight per unit area g/m2 (treated material)	DIN 53332	1400
Tensile strength (N/5cm) K/S	DIN 53354	7500/6500
Tear strength (trapezium) (N) K/S	DIN 53363	1200/1200
Membrane Type 5		
Carrier material	DIN 600001	PES
Weight per unit area g/m2 - (untreated material)		600
Type of coating	PVC on both sides	
	DIN 4102 B 1 fungicidal	
Weight per unit area g/m2 (treated material)	DIN 53332	1600
Tensile strength (N/5cm) K/S	DIN 53354	9000/8500
Tear strength (trapezium) (N) K/S	DIN 53363	2000/2000

PTFE COATED GLASS FIBRE

Polytetrafluoroethylene

Fluorine is used in many commercial and industrial products for it's 'non stick' properties. The glass fibre substrate has excellent structural properties and resistance to ultraviolet. The composite of these materials provides the best solution for long term and high profile projects. The first structures made with these materials are still in use after some thirty years. Long guarantees, reduced maintenance, excellent whole of life costs and the ability to provide high light transmission make this material an ideal choice for most installations. Glass fibre is more expensive and difficult to handle during manufacture, transport and installation. This increases the cost by 50% to 100% compared to PVC.

ETFE FOILS

Ethyltetrafluoroethylene

ETFE has a lifespan of over 25 years, transmits UV light, is non-stick, self-cleaning and weighs less than 1% of the equivalent area of glass.

LIGHT DIFFUSION CHARACTERISTICS

Membrane roofs are often chosen for the way that they diffuse light. Typically, tension structure fabrics have a translucency of 10 to 40 % compared to 90% of glass. Shade netting can be installed to meet the same design and loading criteria as other tension structures and are available in a wide variety of meshes to give maximum or minimum shade. Many different effects can be created with the use of the membrane to reflect light.

Our company uses several suppliers of membrane fabric. The details listed here are from one of our preferred suppliers, Mehler Haku of Huckelhoven, Germany.

VALMEX® FR - membrane structure materials - Light And Thermal Properties

	Colour	A	B	C	D	E
Solar transmission (at 550 nm)	Approx	5%	0%	0.5%	0%	12%
Solar reflection (at 550 nm)	Approx	85%	85%	70%	40%	85%
Solar absorption (at 550 nm)	Approx	10%	15%	30%	60%	3%
UV-transmission	(<380 nm)	0%	0%	0%	0%	0%
UV-reflection	(<380 nm)	100%	100%	100%	100%	100%

A = translucent, standard white

B = opaque white

C = colour 141 pearl white

D = colour 852 sandstone

E = highly translucent, white /008

Thermal conductivity:	approx 0,18 watt/meter x Kelvin
Heat transfer co-efficient (U-value):	approx 5,7 watt/sqm x Kelvin

ACOUSTIC PROPERTIES

There are two main problems that must be considered during acoustic design of fabric structures. First the long reverberation time caused by the lack of sound absorbing materials, which results in loud background noise. Secondly the focussed reflection caused by the geometrically shaped roof. Hanging banners or linings can help sound quality. Due to the low mass of the membrane, sound absorption is minimal. Consideration has to be made on the impact of external noise and the structures ability to contain potential intrusion, and the sound diffusion to the outside of the building.

There are four main acoustic considerations with fabric structures: reverberation-time, echoing, focussed hot spots and noise transmission.

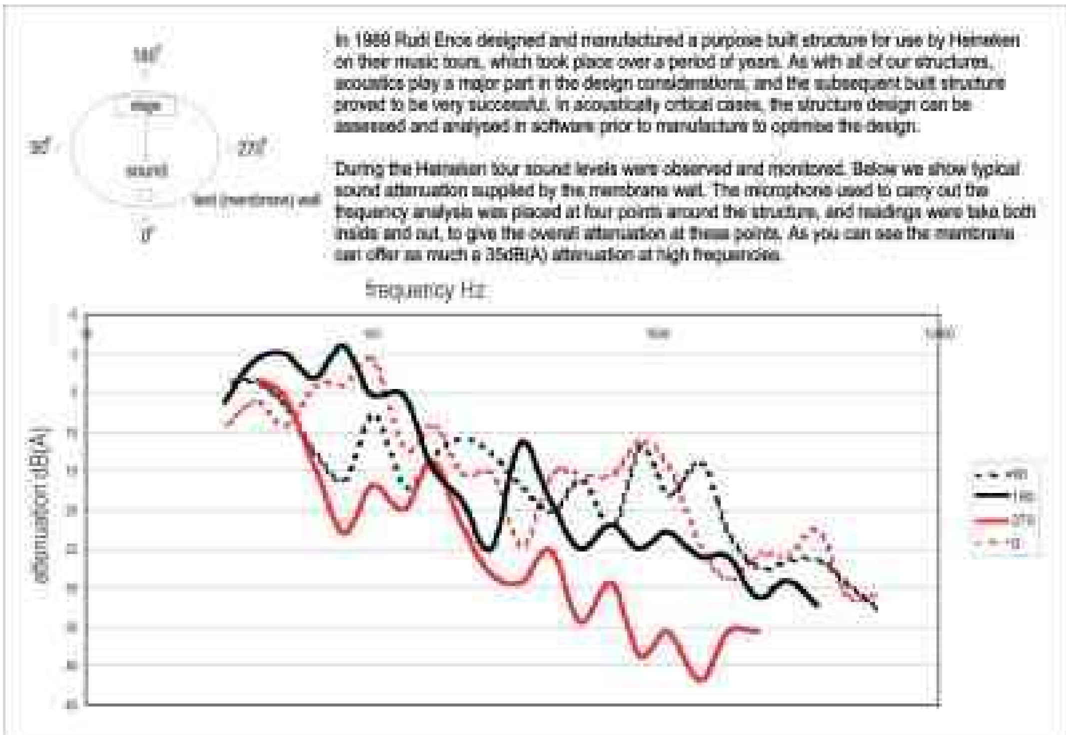
Membrane structures with large smooth surface areas tend to have long reverberation times which will increase with the size of the structure. This makes such structures suitable for certain kinds of orchestral and choral performances, but may be "too live" and undesirable in other situations (such as amplified concerts). Where the reverberation time does need to be reduced, absorbent materials need to be added - Typically in the form of hanging baffles or linings.

Tension structures tend to have a highly anticlastic doubly-curved surface for structural reasons. This has an interesting acoustic side-effect of reducing the incidence of "hot spots" and echoing, these are typically caused by large flat or concave surfaces - Often entirely absent in a well-formed membrane structure.

A tension membrane is practically transparent to low frequency sound. Consideration needs to be made for the impact of external noise (such as aircraft) and containment of internal noise (such as concerts) - These can be mitigated by incorporation of absorbent liners and/or a suitably spaced double skin.

In 1989 Rudi Enos designed and manufactured a purpose built structure for use by Heineken on their music tours, which took place over a period of years. As with all of our structures, acoustics play a major part in the design considerations, and the subsequent built structure proved to be very successful. In acoustically critical cases, the structure design can be assessed and analysed in software prior to manufacture to optimise the design.

During the Heineken tour sound levels were observed and monitored. Below we show typical sound attenuation supplied by the membrane wall. The microphone used to carry out the frequency analysis was placed at four points around the structure, and readings were take both inside and out, to give the overall attenuation at these points. As you can see the membrane can offer as much a 35dB(A) attenuation at high frequencies.



THERMAL PROPERTIES

In general, single skin fabric roofs exhibit similar thermal characteristics as glass. The performance can be much improved with the use of double layers and an air barrier. Most fabric roof materials reflect a certain amount of energy and absorb the remainder. Contact us for more details.

FIRE PERFORMANCE

Industrial fabrics perform extremely well under conditions of fire. The composite materials are chemically compounded to inhibit the spread of flame. Hot gases tend to locally melt the fabric allowing the area to vent. The membrane will shrink back venting the fire to the atmosphere.

FIRE STANDARDS

International flame retardancy standards vary from country to country but differ mainly in test methods. Appropriate test results are;

- UK - British Standards - 5438 Parts 2A & 2B - BS5867 TYPE B, BS7837 (washed)
- Italian - class 2
- French - Classment - M1, M2
- German - DIN 4102 - B1 + B2
- USA - NFPA 701 small and large scale - NFPA 92503, ASTM E84 and ASTM E108 standard - or California Fire Marshall standards.

PORTABLE-STRUCTURES-PORTABLE-ARCHITECTURE

MoonBurst design, manufacture and install for sale or for hire, the largest portable structures in the world.

While this may seem an outrageous statement for a relatively small company, over the last twenty-five years our designers and engineers have pioneered the movement of mechanically tensioned structures in which the membrane entirely carries the environmental loads. New systems of design, manufacture, installation, certification, mechanical handling, motors, winches and controls, installing ground anchors and maintenance have been implemented to the point where the current structures barely resemble the circus tent of 1980. Our structures are 'state of the art' and generally out perform other large span structures.

In the 1980's many changes happened to the design, erection methods and installation of these structures. Canvas was being replaced by PVC coated synthetic cloths. Modern methods of mechanical handling were being introduced. Clients started to use the circus tent for performances where it's image did not really fit, such as choral competitions and classical concerts.

In 1987 a new kind of event started to be staged in the UK. A few adventurous DJ's had seen the start of a new wave of club music with an insistent beat and fanatical followers. These people wanted to dance all night and no venue would risk their license by housing the events. Illegal, unlicensed events started to be staged in warehouses and eventually tents. Some of the jobs were like the days of prohibition in the USA, with a phone call telling the erection crew to meet at a motorway service station and from there go on to the site. The big top would be erected in a few hours and the event would take place that night. Many people, including myself thought that these events would not last long. This was the birth of the dance music genre. This area of music is now many years later a part of the mainstream of popular music and directly responsible for our company building of some of the largest portable tented structures the world has ever seen. The structures developed for the dance scene are now being used for a wide variety of other functions, from product launches to corporate days to film sets.

We have extensive experience of providing performance space in temporary and permanent membrane structures. For theme parks, leisure facilities, touring shows and music performance, our structures have provided many years of accommodation for organisations wishing to stage events in cost effective and quickly installed structures. We provide initial costing and timetable details on structures such as those shown in this brochure. We have a guidance document for those who wish to know more about the process of incorporating membranes into building projects.

Our product line includes aluminium portal frame structures which range from 5 metre span to 40 metres span, domes, and air supported structures.

TENSILE 1

Tensile 1 was awarded a Guinness World Record for this incredible five acre portable venue which is available for sale or hire. The structure is 86 metres or 282 foot wide extendable in 15 metre or 50 foot sections, with an internal height of 18 metres or 60 feet. In 1999 'Tensile 1' (a version of our 'Valhalla' structure) was erected in Don Valley athletics stadium in the UK for Millennium Eave, with an occupancy of 32,000 in the sole structure. This is believed to be the largest one night event of its kind in the world. The original contract for Tensile 1 was in excess of 28,000 square metres or 302,000 square foot (feet?). Tickets were on sale at £110 UK (approximately $160 US) making the event one of the biggest grossing one night events of all time.

The Valhalla was used in November 2001 for the 'Victoria's Secret' fashion show, staged on 42nd Street in Manhattan, possibly the most expensive one night fashion show ever staged. The event was broadcast nationwide in the USA for one hour at prime time. Tickets were auctioned for charity and 2 million dollars was raised for the victims of the terrorist attack on 11th September 2001 in New York.

In August 2002 the Tensile 1 structure with a surface area of 14,520 square metres was erected for the Ubuntu village exhibition accompanying the World Summit For Sustainable Development in Johannesburg, South Africa.

The Valhalla is used for one of the main stages at the Roskilde festival, one of the premier music festivals in the world, in addition to providing staging at many other events.

It is believed to be the largest portable structure available for hire in the world.

KAYAM

The 'Kayam' is a revolutionary minimalist structure, the first version of which was built in 1991. Since then, these market leading structures have been used by most major music and cultural festivals in Europe, and in the year 2000 housed the performance of 'Radiohead' for their European tour, the first time that a market leading band had shunned traditional venues. The tour sold out, with more than 150,000 people going to the performances.

The Kayam (which is named after Hassan Omar Khayyam, the Persian poet, whose name means 'the little tent maker'), is constructed to be tensioned over its anticlastic surface by the use of compression fittings in the edge of the membrane joined to the ground anchors. This modular structure is able to be used in many different layouts and for a wide variety of events. The Kayam is the first large scale portable structure to feature a triangular section to allow expansion in three directions.

MT66

We also design and manufacture the 'Walt Disney On Ice' 10,000 seat portable structure to house the famous international ice shows of Feld Entertainments in South America, the Middle East and in Asia. This structure is totally self contained with seats, dressing rooms and the ability to suspend 22,000 kilograms or 48,000 pounds from the roof of the structure.

The structure travels in standard ISO shipping containers which can be handled by any transport method.

MOONBURST MARQUEE

The MoonBurst marquee is a visually stunning and unique fabric structure. Despite being innovative in design, the MoonBurst takes no longer to erect than similar frame structures. The product has been well proven over the last ten years with the mark 1 and 2 versions. The new MK3 structure uses established structural elements with new roof, wall, and ceiling elements to provide a visually striking and technically superior product.

If you need top class temporary structures for exhibition, hospitality or road shows, the MoonBurst has advanced levels of equipment to suit each. We will be happy to quote for sale or hire for any requirements.

The MoonBurst structure is ideal for exhibitions of all kinds, either as a stand alone unit, such as at agricultural and other shows. Many installations have been undertaken by our project managers in many different disciplines, including complete exhibition halls of almost any size.

The MoonBurst also has a unique structurally underpinned floor system that allows the roof structure to free stand almost anywhere, (without the use of stakes or ground anchors), and self levels the floor. With the addition of solid sides, glazed panels, flooring, carpets, linings and specialist lighting, we are able to cater for all types of events. The MoonBurst mk 3 also has a triangular plan which creates totally original layouts.

THE FLYING SAUCER

This structure is unique among portable membranes as it has no external visible means of anchoring or support when erected. Manufactured in metallic silver fabric with purple interior, the structure provide a totally new method of housing avant garde performance.

NOVA FRAME MARQUEES

Aluminium portal frame structures have formed an important part of our manufacturing efforts. We have used them for industrial storage, hospitality marquees, portable grandstand roofs, and they form the basis of our ground breaking MoonBurst marquee.

PORTABLE STRUCTURES FOR DISPLAY

MoonBurst structures have been used for many portable exhibitions over the years. Either as an exhibit at an agricultural show, or a roadshow for corporate clients, our portable systems use state of the art structures, flooring and wall systems which reflect the high standards the clients portray. Smooth white glass fibre walls accept branding, logos and other graphics.

STANDARD STRUCTURES

While standard structures can be hired or purchased, they can also be modified or specifically engineered for their purpose. We have extensive experience of providing performance space in temporary and permanent membrane structures. For theme parks, leisure facilities, touring shows and music performance, our structures have provided many years of accommodation for organisations wishing to stage events in cost effective and quickly installed structures.

All structures can meet local building codes for permanent or temporary installations, or as a minimum, the accepted local standards for marquees and tents. They meet, and many cases exceed, the technical standards of competitors products.

RELOCATABLE BUILDINGS

It is possible to relocate a structure during its life with repeatable results. These are available with Steel side walls and roller shutters for access. They can be bought or leased for any period.

Our designers have produced many different trussing systems over the years. We have extensive experience of manufacturing long span trusses many of which fold for transport. For example, we use 30 metre span trusses which carry a safe working load of 20,000 kilograms universally distributed (with a factor of safety of 1.5 to 1, tested to 36,000 kilograms) yet which weigh only 2,000 kilograms.

We are developing a new range of composite trussing and spaceframes which can be used in many differing applications for event, construction and display purposes.

SPACE STRUCTURES - PRODUCT NOTES

Space Structures allows fabricators to produce standard systems for construction of space frame structural members which overcome the current constraints on weight/strength/stiffness/cost. A UK patent has been granted, ADP number 6477723003. The products development goes back to the mid 1990's. The patent was applied for in 1998.

The invention is in response to perceived market demand. The goal is the commercial realisation of an economic and simply produced range of trussing systems which can be used in several rapidly expanding market areas. Our aim is to manufacture structural systems that can be used within pre defined performance parameters, as a kit of parts to assemble anything from exhibition stands to major structural components. We hope to provide a paradigm for the use of composites in construction and to allow their use in day to day industry.

For example, geodesic frameworks are the only form of mainstream construction invented this millennium. Yet to date, commercially available and desirable composite manufacturing methods to match this modern construction form are not available to maximise the inherent benefits of the form. If a commercially available, easily assembled system of trussing and framework can be bought off the shelf, it will be more commercially acceptable.

THE INVENTION

In world market terms, the product is innovative because for the first time it allows the economic commercial use of composite materials in off the shelf solutions for lightweight engineering structures. It will enable structures to be realised which are not economically feasible with current systems.

Most composite spaceframes are assembled using traditional and costly hand assembly methods. The Space Structures system provides a method of using mass produced components in a variety of materials which can provide solutions for many market segments. The system consists of nodes and chords which can be connected in an unlimited number of ways. Using only three components, the socket, the spigot and the ball, all of which can be produced using a variety of manufacturing methods, circular tubes can be joined in either a temporary or permanent manner. The ball can have the spigots inserted at the required angle to accommodate many different geometries.

THE SYSTEMS

The product can be broken down into three basic systems;

The Display System - (DS) - using moulded polymer components with chrome plated extruded UPVC tubes for economic assembly of frameworks for exhibition, display and commercial interiors.

The Composite System - (CS) - using many differing mixes of poltruded, filament wound, or pull wound members which can be tailored for specific structural properties. The nodes are manufactured using methods similar to those employed on formula one racing cars or military applications. This provides an optimum solution for non conducting, non corrosive and low maintenance applications.

The Alloy System - (AS) - using drop-forged aluminium alloy components which are welded into aluminium tubes using existing fabrication techniques.

Initially, 25 mm, 50 mm and 75 mm tubular members will be offered for each system. All of the systems use identical connectors for given tube sizes and are interchangeable between systems. The three systems can be interconnected at given tube sizes. Alternative tube diameters will be available at extra cost. The system is scalable to virtually any size.

POTENTIAL USES

DS - The display system can be used to assemble intricate geodesic frameworks for exhibition stands and displays. It can be used in car showrooms, retail outlets (such as supermarkets) suspended and free standing displays, commercial interiors for permanent or temporary signage, and most lightweight applications. It can accommodate rigid or flexible infill panels. The components can be assembled using existing manufacturing techniques. For example, a two storey exhibition stand could be manufactured using high strength CS or AS components to form the main structure and all external, visible members using DS parts. This provides the perfect mix of structural integrity with economic use of the display elements. Tubes can be extruded with integral support for accepting rigid infill panels.

Potential Clients - Exhibition stand design and build companies, display manufacturers, signage suppliers and commercial interior companies.

CS - Initially, we have identified several main uses for the CS system.

The rail industry require a non conducting trussing system for crash decks and for access equipment generally. When used in the power generation or rail industries, light weight, minimum down times, including minimum track possession time, and non conductivity will be the main determining parameters. In the field of industrial access, uniformly distributed loads of 2.5 kN/m2 are considered adequate combined with long spans of 15-25 metres, while in, for example, the music business, stages use higher load figures but on short spans.

For military use, current improvements in radar technology provide an increasing imperative for the use of polymeric frameworks for all sorts of installations. With the development of radar absorbing and reflecting fabrics, further requirement for non reflecting frames is expected.

Airports have a need of non radar reflective, structural components for lighting pylons, fence posts, and other structures.

Lightweight temporary roofing for buildings where traditional steel or aluminium scaffolding type roofs simply weigh too much for the existing structure to carry. There are many examples of problems of self weight on older buildings where the total weight of the access solutions prohibits the use of existing solutions.

In many industrial situations, for example where spark free environments exist, non metallic access equipment, platforms, and other industrial equipment are required.

Space decks, three dimensional, triangulated structural grids, can be used in many industrial access applications. Suspended platforms for use in maintenance under bridges, on the side of buildings or even complete custom built rigs for major projects.

Where highly corrosive environments exist, the use of corrosive components is not viable. Major structural decomposition due to chemical action on metals and alloys often results from contact with industrial environments. Non corrosive components allow for many uses of a flexible system in these situations.

In the architectural field, there are many applications where a low maintenance framework is required to carry a variety of cladding. Snow load plus the self weight of glass panels will need to be accommodated.

Potential Clients - Fabricators of composite structures, specialist access companies, dome and barrel vault manufacturers, glass curtain wall suppliers, manufacturers of composite pylons, plastics fabrication companies, chemical plant suppliers, manufacturers of temporary structures, military structures manufacturers.

AS
The use of structural aluminium frameworks in the live music, theatre and club industries is wide spread and well established. Structural grids tend to be made from assemblies of prefabricated aluminium trusses, but there is no practical reason why different geometries and assemblies should not be used, such as the AS system.

Potential Clients - Rigging suppliers, theatre, music and club suppliers, access companies, dome manufacturers.

All systems can suspend loads from each node, or alternatively complete frameworks can be suspended from any node. Decking can be fitted to the nodes as can handrails or other attachments.

Much of the content of this document comes from 'The Sky Is Not The Limit' written by Rudi Enos. Any errors or omissions in this transcript are apologised for.

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