Airscape Structures

A Primer

There are three basic differences between Airscape's ***'Pressure Stabilized Cable Structures'*** and all other air supported structures:

1. Cables built into the seams of the cover material take the design loads.
2. The prime function of the film or fabric is to contain the air.
3. The internal pressure is regulated as a function of the outside wind velocity.

These three fundamental basic differences permit a wide variety of additional features only available with the Airscape system.

- The cover can be prefabricated in one piece for installation on a prepared site in less than a day.
- There is virtually no size limit; the distance one can string a cable sets the width, and the length can be anything required.
- A scalloped surface can be created, reducing the stress on the cover material, minimizing acoustic reflections and providing natural drains for rain and snow.
- The low stress in the cover material permits the use of films as well as fabrics, ranging from window clear to opaque.
- The ability to operate at low pressures permits one to economically ventilate the structure with the fans that also support it.
- A potentially high ventilation rate also permits the use of large doors without airlocks, since air lost through the open door is quickly replaced by the fans in the ventilation system.
- The system lends itself to automation, so that once set, it self-determines which fans are needed and operates them accordingly.
- Originally conceived as a greenhouse, the use of very light, highly translucent membrane materials not only permits the use of live plants, trees and grass, but enhances their growth beyond conventional greenhouse capabilities.
- The high light transmission through the membranes allows occupancy during daylight hours without the necessity for artificial lighting. Lighting at night can be provided by pole or ground mounted fixtures installed outside the cover.

Subjects Considered in this Primer

Design Techniques

If the enclosure is essentially a cylindrical shape with end walls, similar to the Portland YMCA, then the cables call all be parallel to one another and built into the the seams of the fabric. The size of the cable would be determined by the pressure contained, the radius of the cable curvature and the space between the cables. In this case, the plane of each cable would be perpendicular to the grade line and the cables would be taking the pressure loads.

Since each cable tends to become a part of a circle, it is necessary to determine the radius of that circle. The load in that cable is then: the radius of that circle in feet, x the design pressure in pounds per square foot x the space between the cables in feet.

From experience, it has been found that to design for an 80 mph wind, a design pressure of 16.5 pounds per sq ft (3 column inches of water) can be used. This includes a safety factor of ~1/3.

If the space between the cables is 5', the design load for the cable is 16.5 pounds x 5' x the radius of the the circle made by the cable. If the span of the cable is known and the height to span ratio is determined, formulas and charts have been developed to give the required radius. As an example:

> If the span is 65' and the span to height ratio is 3, the radius would be approximately 35'. This would give a cable design load of 16.5 pounds x 5' x 35' or 2888 pounds. Therefore, one would select a cable with a breaking strength greater than that and also define the load carrying requirements for the foundation, anchors and connectors. Make sure to take into account the angle the cable meets the anchor; in the case of a 3:1 span to height ratio, this will be ~67 degrees.

If the enclosure does not have end walls, and the cover itself is to form the ends, then a cable configuration is selected that tends to take the design pressure loads in the cables. As the the cover comes down to the ground on each end, the cables are arranged to be normal for the surface selected. The centerline of the cover is used as the design base, as the maximum fabric width and cable spacing is at that location.

The curvature selected for the end, from a side view, should be formed by a radius between the H (height) value used on the rest of the cables and a value of 2. If 2 is selected, the end will approach a quarter of a sphere, and all cables will terminated at on point. If a value less than 2 is selected, the end will tuck into itself. In the plan view, the cover should terminate in a curvature which will permit the lowest cable to be a practical size. (if the end were flat, the cable would tend to approach a straight line with an infinite radius and design load.)

Example

(see Chart 1)

Assume a structure with as 300' span (S) and 100' height (h)

H is the ration of span (S) to height (h) so H = 3

AL is the length of the cable; AL/S = 1.274: Therefore AL = 300 x 1.274 or 382.2 feet

β is the angle at which the cable meets the horizontal: ~67.4 degrees

R is the radius of the arc made by the cable; R/S = .541

Therefore, R = 300 x .541 or 162.3 feet.

CSA is the vertical area under the cable, or the area of the 'plane between the horizontal and the cable. CSA/S= .244

Therefore, CSA = 300 x 300 x .244 or 21960 sq ft (an autocad or drawing program may differ slightly in many of the calculations from these formulae, but they are very close)

How to use this information:

Assume S = 290'   h = 90'

H = S/h or 290/90 or 3.22

R/S = .56 Therefore R = .56 x 290 or 162.4 feet.

P = the internal pressure of the structure in pounds per square foot.

The load in the cover is P x R

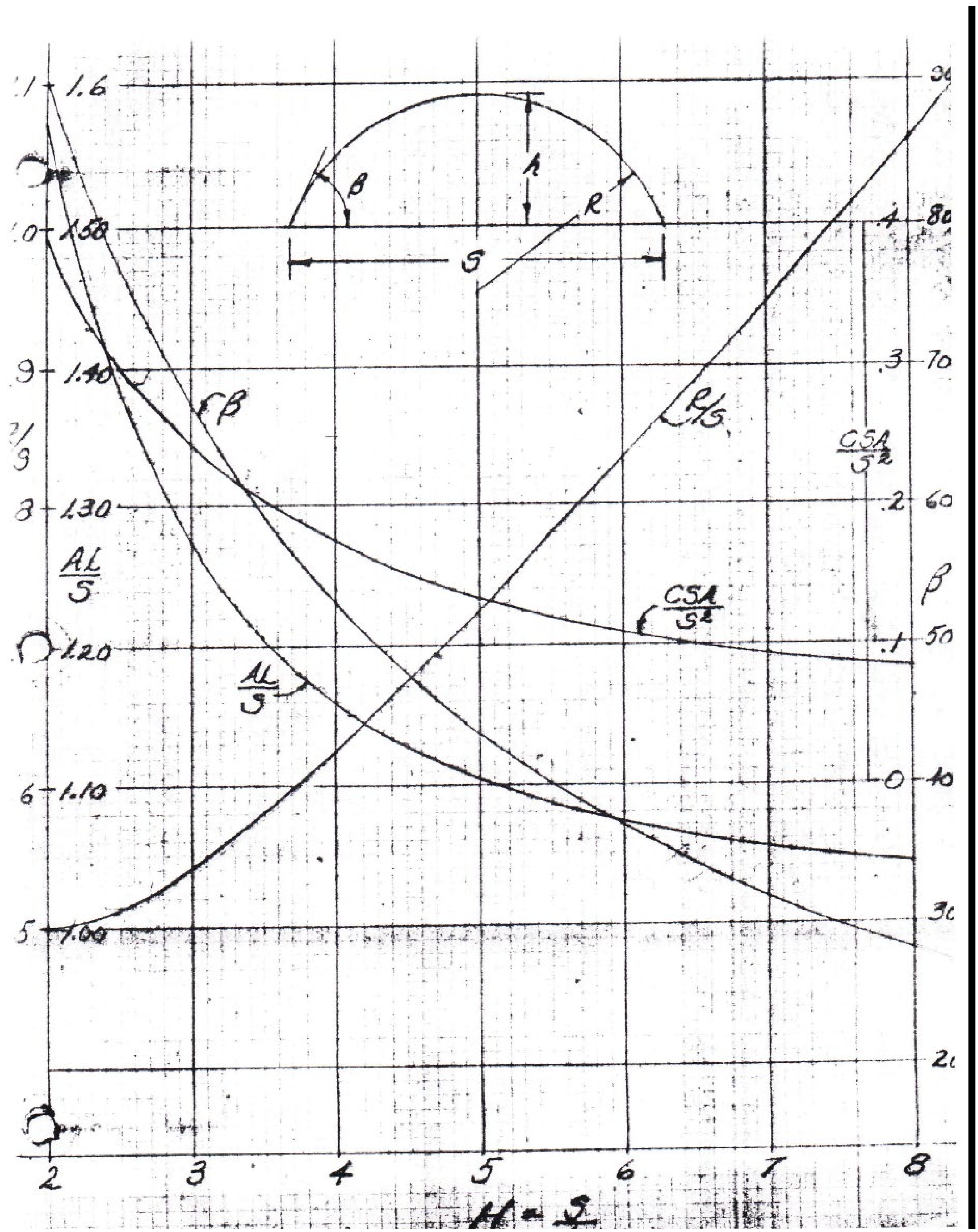
Using 16 for P, the load in the cover is 16 x 162.4 or 2598.4 pounds per foot (say 2600)

If the cables are spaced 50” apart, the load per cable is 4.167 feet x 2600 pounds per foot or 10,833 pounds per cable.

A 3/8” 7 x 19 **G**alvanized **A**ircraft **C**able (GAC) has a breaking strength of 14,400 #. It would give a factor of safety of 14,400/10,833 or 1.329

If the cables were spaced 25” apart, the load per cable would drop to 5417 pounds.

Chart 1



1.6
1.50
1.40
1.30
1.20
1.10
1.00
h
β
R
S
β
R/S
CSA/S²
AL/S
.4
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70
60
50
40
30
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4
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6
7
8

Cables

In an Airscape Structure, the cables are built into the seams of the cover material. The cover is usually made in one piece for erection on a prepared site in less than a day. This means the cables are folded up in the cover for transport to the site and must be flexible enough to act as though they are part of the cover.

It has also been found that over the life of a structure, the cables do move and therefore should be be flexible so as not to fatigue.

Alternatively, where the span of the structure dictates larger, less flexible cables, the cover may be manufactured in a temporary factory set up on site for that purpose. In this way, larger cables, up to 3/4" if necessary, may be used in the cover. Using larger cables allows us to maintain reasonable spacing of 3' – 5' between the cables, reducing the number of seams in a large cover.

From experience, it has been determined that for most applications, GAC does the job very well, even though it is slightly more expensive than other cables of the same strength. There are occasions where non-metallic cable or rope with low elongation properties may be used. This is an area where we intend to do more research. We see several potential advantages, particularly for ease of handling in temporary covers that may be moved and re-used several times.

In areas subject to high erosion or rust, such as near the ocean or covers for salt water pools, **S**tainless **S**teel **A**ircraft **C**able (SSAC) or non-metallic cable is recommended.

Aircraft Cables only go up to 3/8" diameter. Therefore, where the loads in the cables exceed those possible with this size, consideration should be given to placing the cables closer together. The fabric can be procured in a narrower width and the seams spaced closer.

Alternatively, additional cables can be placed between the seams and outside the cover and held in place with a tape installed for that purpose.

The tape can be made of the same material as the rest of the cover of any other easily obtained material which would have the same life span. If placed on the outside of the cover, its main purpose is to locate the cable at the right part of the cover panel, so it is under little or no load.

If only a few cables of a large size are needed, and they are in an area where not much folding is required, larger size **flexible** cable that is not aircraft cable may be used.

Each cable is premanufactured to the exact length required and fitted with an eye or a swaged end. If an eye is used, it is usually assembled with a nico-press type of joint and a thimble. Each cable is marked as to its number in the cover and carefully coiled so that no nicks or kinks are present.

Films and Fabrics

Since the Airscape Structures transfer the major design loads to the cables built into the seams of the cover, the film or fabric used is under very little load. It is possible then, to use just plain, unsupported film as the cover material. In the earliest structures, vinyl film was obtained in rolls 69” wide and 12 mils thick. The length of the rolls depended on the weight that could be handled. These materials were dielectrically seamed together. The normal elongation of the film stretched to form the scalloped surface. Materials as thick as 16 mils were also used.

These materials, when clear with no pigment, lasted from about 6 months – 2 years, depending on the location of the structure. The deterioration of the film was primarily due to UV in the sunlight and resulted in the material becoming brown and brittle. A system was devised for changing the cover periodically, without the need to disrupt the operations in the enclosure.

This material originally came with a frosty surface that let in the sunlight but was translucent rather than transparent. It provided a shadow-free interior light that was very good for plant growth. In order to get window clear material, it was necessary to order the vinyl immediately after it had been polished. Later, a way was found to flame polish the surface to eliminate the frosty appearance.

When longer life material was required, new film with a clear, Tedlar surface was developed and provided by DuPont. The Tedlar coating included a UV screen and prevented degradation of the cover.

The Tedlar surface was obtained in 1 mil of thickness and a substantial extension of film life was apparent. The Tedlar surface was also very slippery, making it a self-cleaning cover to which dust and dirt would not stick.

The Tedlar surface created some other challenges as well. It made the film stiffer so that it would no longer self adjust to the length of the cable. It would not elongate the same as earlier films and it became necessary to place extra material between the cables to provide the scalloped surface. The non-stick surface prevented the material from being welded or glued without first removing the Tedlar from the edge to be seamed.

A means of applying the Tedlar while leaving the edges untreated was developed. It was then possible to provide a clear, dielectrically seamed Film cover that had a lifespan of 10 – 20 years, depending on the location.

The disadvantage of using film materials is that if an accidental tear occurs and is not immediately repaired, it could progress to a larger hole. One way of getting around this is to produce **'Rip-Stop'** properties in the film by including a scrim made of polyester, nylon or other fiber. If damage does occur, these fibers tend to contain the damage. These fibers tend to cut down the light transmission in a clear material.

For definition purposes, a simple, unsupported material will be called a **Film** and when it includes cords in a scrim or cloth, it will be called a **Fabric.**

It is possible to manufacture covers of one layer, but from experience, we have found that the extra benefits of a double layer cover far outweigh the additional cost. Therefore, our standard practice is to include an inner layer with a dead air insulating space between the inner and outer liner. This inner liner can be of very light material as its sole purpose is to contain the dead air space.

If a window clear cover is required, the inner liner can be a lightweight, clear film. If the outer cover already includes UV protection, the inner liner is also protected.

To get Rip-Stop properties in the inner liner without restricting much light transmission, a very open scrim with thread spacing of 1/4” or more can be used.

In earlier buildings, where a lot of light was required to grow plants or grass inside, it was necessary to have as clear a vinyl as possible with very open scrim. More recent developments in light weight Woven Poly Fabrics allow up to 80% of the natural light to pass through the two layer cover. These are high strength fabrics treated against UV degradation, relatively inexpensive with life spans of 10 years or more. They provide excellent, shadow-free lighting that encourage both flora and fauna to not only live, but thrive.

Seams

One of the unique features of an Airscape Structure is the fact that cables sized to take the design loads are built into the seams of the cover.

There are several methods of sealing covers and various types of equipment to do so. They are all effective, depending on the type of material being used.

Because we initially used vinyl films for our covers, one of the first seaming methods was dielectric welding, a method capable of welding several layers of material together in as single process.

If the cover material can be dielectrically sealed, a double bar with an open space in the middle of the cable is used. Usually, the seaming bar is 4' long and the weld is 2" wide, made up of a 3/8" section and a 1/2" section. Most vinyl materials seal very well with this process provided the machine variables; heat, time, pressure; are set for each type of seam, thickness of material, number of layers, etc.

There are now various types of coatings available for vinyls and other materials. Tedlar is only one of them. Before specifying any welding or cementing system, ensure that they will work with the base material or the coating. If the coating prevents welding or cementing from taking effect, the material should be ordered with an edge that is free of the coating, or the coating removed from the area where the seam will be effected.

If a single layer cover is being made, the cable is placed between the two layers in the seam. If a double layer cover is being made, the inner liner is usually lighter in weight and can simple be added to this seam. With dielectric welding, it is possible to put the cable between the two outer layers in the seam and the two inner layers. It is important that the cable be located between the strong members of the cover, if there is a choice.

The cable exits the seam at its ends so that it can be attached to the anchor system. Whether it exits inside the enclosure, outside the enclosure or between the inner and outer layers of a double layer cover is a function of how the anchor system is designed. Care should be exercised to know this in designing and fabricating the cover, since it may vary around the perimeter.

A good dielectric seam is very strong and gas tight. It is, however, difficult to tell by looking at the seam if is is good or not. A test seam should be made and tested to destruction, and the machine values established for those materials and thicknesses. Usually, an experienced operator will be able to judge the integrity of the seam from the consistency of its appearance and 'feel'. Periodic sample seams should be made to ensure there have been no changes.

Because Airscapes are large structures with several long seams, it is more advantageous to move the sealing machine than it is the fabric and cable themselves. In this way, it is possible to produce any size of cover in one piece, either directly onto a shipping pallet, or if too large to ship, on the site itself, ready to deploy when completed. If being folded onto a pallet, the flexibility of the cable is essential as it is folded in with the rest of the cover.

There have been huge advances in architectural fabrics over the years and many of the better materials cannot be dialectrically sealed. Instead, we have migrated to mechanical means to fasten the fabrics together.

The earliest method was to sew the materials together and a system of making a sewn seam including the cable was developed. It utilized a double needle sewing machine, a fel seam folder and a wide spacing for the needle holes. The cable was fed over the shoulder of the operator into the sewing machine set up to run on a track.

This makes a good seam and was used for many years on temporary type structures using a woven poly material. Cables can easily be added if closer spacing is required, by adding them to the outside of the cover using narrow strips of compatible material to hold them in place.

In one instance, for an unknown reason, some of the seams opened up and no thread was present. The seam was not torn, the thread was just missing. We were unable to determine if heat melted the thread or if was chemically destroyed somehow. Not knowing the reason, caused a search for a substitute mechanical seam.

The stapled seam is a mechanical seam that we are using with woven poly materials to make temporary structures. The original staples had copper colored appearance and tended to rust; the rust would then stain the fabric, effecting the overall appearance of the structure. A galvanized staple was obtained that has a life span equivalent to the material used in temporary structures. We have also used stainless steel staples but they are not readily available. They are much harder than the galvanized and cause operating problems.

The advantage of a mechanical seam is that it is easy to inspect to see it is all intact. It also enables one to mix materials since they do not have to be compatible. The disadvantage is that it punches holes in the cover. Some of these tend to leak during periods of rain or snow. This can be pretty well eliminated if some pressure is added to the structure prior to the rain or snow. The pressure seals the fabric against the staples, and forces any droplets to the outside instead of inside of the structure.

A new fabrication system is under development for faster production and longer service buildings. It is a automated welding process that will provide a continuous vapor proof seam. There is an automated Quality Assurance monitoring system that ensures the integrity of the seam.

Fabrication Methods

The basic concept on which Airscape Structures are designed is that cables built into the seams take the design load so that the film or fabric merely have to contain the air. Therefore the seam is fabricated with a cable as an integral part of it.

In early structures, the seams were made by hand. The edge of the film or fabric was wrapped around the cable and an enclosing type of clamp used. This clamp took a number of different forms but usually a spring clip that was set in place with a special tool.

The basic idea was that a structure of any size could be built by hand by 'slack labor' on a farm, for instance, providing a low cost enclosure.

As time progressed, it turned out that more often than not extra labor was not available and labor became very expensive. It was found that the early vinyl films could be dielectrically sealed by someone who could afford the welder. Therefore, a seaming system was developed that utilized a double head with space between the sealing components for the cable. This eliminated the need for clamps and dramatically reduced the labor requirement.

The seaming machines were very heavy but it was determined it would be better to move the machine along the seam rather than taking the fabric and seam to the machine. A system that moved the equipment on a track allowed for the fabrication of very long, parallel seams (wide structures). The structure could be almost any length simply by adding more panels of film next to each other.

This same basic method has been successfully used with both sewn and stapled seams. The cover is fabricated a panel at a time and accordion folded onto a shipping pallet, usually placed in the middle of the panel length.

The package is longer than the pallet, so it is tied into a 'sock' and then either rolled up on to the pallet from each end or again, accordion folded so that it all fits on the shipping pallet.

The use of this basic technique lets one use a manufacturing room that is long and narrow. The length has to be at least as long as the longest cable in the finished structure, plus whatever fabric tail is included to provide the perimeter seal. The width has to include the fabricating machine on its track, the width of the pallet and a small working space in between that sometimes includes a table.

The determining factor that limits the size of the cover is the shipping weight, since the folded material is quite dense and does not take up a lot of room.

The new welding system will require a similar configuration.

Where larger covers that are not readily shipped are required, a long narrow Airscape can be set up on the project site as a temporary factory. The cover can be manufactured on site and deployed without folding or shipping.

Folding Techniques

It has been found that very large packages can be made of fabricated fabric pats if, when folded, an accordion type of fold is made so that the material is not stretched over itself. By accordion folding back and forth, the panel lengths are averaged out. For smaller packages, it is often possible to roll up the fabric. In this case, the fabric must slide on itself or crumple up to keep the material from stretching. This is possible without damage on the smaller covers.

Normally, it is recommended to use a protective sock or cover over the finished fabricated part to protect it from getting dirty or damaged during transit. This sock or cover is usually made of a sheet of inexpensive fabric large enough to cover the fabricated part when it has been initially folded accordion style, full length panel on panel, back and forth until the entire cover is stacked on the pallet. The sock is a great way to use up roll ends of miscellaneous fabric.

The basic procedure is to first place the shipping pallet so that its centerline is in the center of the fabricating process. Then lay lengths of rope on the floor about 10' apart so they can later be used to tie up the cover sock. The cover sock is then spread out on top of the ropes.

As the cover is fabricated, it is accordion folded on top of the cover sock. Care must be exercised to not extend the folds beyond the width of the pallet. The pallet should be quite a bit wider than the fabric, and the folds slightly staggered so the panels and cables do not lie right on top of each other. Care must be taken so the cables in the seams do not pile on top of one anther but are side by side so they are easier to fold and roll up in the next step. This is easy to do by changing the width of the folds.

After the cover has been completed, the sock is folded over the entire pile and the ropes tied so that it makes one long bundle.

There are a number of ways to pile the fabric in its sock onto the pallet and often a determination must be made depending on the size of the part, the manpower and the equipment available. If it is a relatively small package, and the people are available, it may be easiest to simply start at one end of the package and roll it onto one half of the pallet. Tie this side down, go to the other end of the package and repeat. Both halves should be tied down to the pallet to prevent movement. **The pallet should be carefully and clearly marked to show how the cover was fabricated so that it can be properly oriented and opened on site.**

If one has a fork lift available, with forks almost as long as half the length of the pallet, it is possible to work from each end of the sock and pile it accordion folded on half at a time. Tie the sock and package down to the pallet before starting to fold. Pace off where the folds should be and start by lifting one end of the package, moving toward the pallet. Continue this until all that half is placed on the pallet. Then go to the other side and repeat the process. Tie everything down securely and **mark the pallet!**

If the component is very large and heavy, it is accordion folded across the entire pallet. In order to do this, it is necessary to have some mechanical assistance such as a tractor or a winch. After tying the sock to the pallet, one end of the package is clamped securely so that it could be pulled over itself and beyond that part of the pallet. It is pulled until the folded end moves up on the pallet. The other end is then tied to the pallet and the process repeated in the opposite direction. This process continues until the entire end is on the pallet. The other end of the package is then clamped and the process repeated, pulling that end of the package over the part that is already stacked on the pallet. Continue stacking accordion style back and forth until the entire cover is palletized and fastened down. Care should be exercised that the fabric does not overhang the pallet on any size. **Be sure to mark the pallet so that they will know how to unpack it in the field.**

Deployment

There are many different ways to deploy the cover, depending on its size, the condition of the area, how it was folded onto the pallet, the manpower and tools available, etc.

The cover is usually accordion folded onto the pallet, so it is deployed opposite to the way it was folded. The pallet should have been marked to indicate this. The method of deployment is normally determined before the cover is folded onto the pallet.

If small, the pallet with the folded cover may be placed at one end of the site, and the sock containing the cover is unrolled in each direction so the cover is now accordion folded with the cables extended. If the sock has been accordion folded instead of rolled, the cover with the sock around it should be grabbed with a clamp and pulled away from the pallet to get the cables in extended condition.

The cords around the sock should then be taken off and the sock folded back to expose the cover. **This step should not be done unless the wind is very calm** and the intent is to continue the deployment and erection. If necessary, it is possible to leave the cover in its sock to hold for better weather or for other reasons. If you untie the sock, it is possible for the wind to unpack the cover and destroy it.

Once the decision has been made to deploy the cover, people distributed along the available end can pull it across the site until each cable, which has been numbered, reaches its correspondingly anchor, which has also been numbered. Since the cover area is larger than the area made by the anchor lay out, it should be possible to now attach each cable to its anchor without need to move the cover very much. If the cover is over a flat area such as black top or grass, having air between the cover and the base will permit it to be moved easily. This air can come from a fan or can be created by fanning the cover up and down to force air under it.

Once the cover has been deployed and the cables connected to their respective anchors, the erection can be performed by turning on fans.

The same same general approach is used for all deployments, however, variations are used depending on site conditions and equipment available.

Very Large Site

In this case, if the site is flat and hard, the pallet is sometimes placed on wheels and provision is made to support the unfolded sock across the entire width of the site, also on wheels. A truck can then pull the sock the length of the site, deploying the cover as it goes. By sealing the space between the sock and the ground, it is possible to inflate the cover as it is deployed, if the fans are in position and if workmen attach the cables to their respective anchors as the cover is being deployed.

This can also be done on a smaller scale by having a fork lift hold the pallet and back through the site with manpower handling the part of the sock not being supported by the forklift. In other words, a number of variations of this method of deployment are possible.

Usually, if the site is large and it is not practical to drive through the area, the pallet is placed in the approximate center of the area and the sock is deployed from that position. Sometimes it is important to unload the pallet onto some type of support such as 4 x 4's so that lifting cables can be installed or removed and so that air can be passed under the pallet.

Mechanical equipment, such as a tractor or winch is used to pull the folds out of the sock, by attaching to a clamp on the available end. The sock is pulled in both directions until all the cables are extended.

After unfolding the sock, the cover is pulled in the direction which corresponds to the cable and anchor numbering until half of the site is covered. The cover left on the pallet is then turned over, one panel at a time, by people disbursed along its width, until the bottom panel is on top and can be pulled to cover the opposite half of the site. This can be done by manpower or by winches or equipment attached to the cover with clamps. **Do not pull on the ends of the cables, but on the panels themselves, perpendicular to the cables.** Again, supporting the cover with air helps considerably with deployment.

Since the cover is larger than the site, care has to be exercised to avoid the fans, doors, etc distributed around the perimeter of the site. **It is also important to ensure that the cover does not get dirty during the deployment process.** If the area is covered with snow, grass, concrete or asphalt, it may be possible to let the cover lay directly on the base. However, if it is mud or dirt, you might have to use a protective layer of some sort. A ground cloth can be used, bales of hay or straw; generally, whatever is most economically available for the location.

Do not walk on the cover. If it is necessary to walk on the cover, use protective, paper booties, or shoes that have been thoroughly cleaned, or socks.

Inaccessible Sites

In the event that the area to be covered might be a pond or an area that contains items difficult to traverse, such as a full warehouse, it is possible to blow the cover over the area using the sill channel and trolleys made to ride on it. In this case, the pallet with the cover is placed in the center of the width and at the end of the area that has fans available.

The sock is spread out across the pallet in the normal manner. Sill channel placed along the length of each side is used to guide the trolleys and make a seal between the cover and the ground or wall. Provision for air to go under the pallet is usually provided. Once the suck is untied, it is important to check and see if the panes on top are those to be carried to the far end of the enclosure.

As each cable is taken from the pile, it is attached to a trolley that is placed on the sill channel. Attachments between the trolleys prevent the trolleys or cables from separating enough to put loads on the cover material. By making a 'tail' to seal the cover to the ground and inflating the cover as it is deployed, it is possible to “blow” the cover over the site.

By pulling on the trolleys and monitoring the amount of air under the cover, it is possible to float the cover right out of the sock into its position over the site. The normal tail along the sides forms the seal with the sill channel.

When the cover is in place, the cables are taken off the trolleys and connected to their respective permanent anchors. The trolleys separate and can be removed from the sill channel.

This same system can be used to replace a cover without disturbing the contents of a building. First, the existing cover is disconnected one cable at a time from its permanent anchor and the cable is attached to a trolley. The new cover is placed at one end of the building and attached to the new one. As each cable is taken from the sock, it is attached to a trolley and as the old cover is removed, the new one moves into place. When the new cover completely covers the site, the cables are taken off the the trolleys and attached to their respective permanent anchors. The trolleys are removed and the cover sealed to the sill channel.

It is possible to install sill channel temporarily next to the existing anchors, and use it as described above. The trolleys and sill channel can then be removed once the new cover is properly attached.

Erection

Before starting the erection of the cover, it is important that all of the doors and mechanical components are installed and checked to make sure they are properly located and in working condition. All of the anchors need to be numbers so that they can be easily identified for attachment to the cables, also labeled. This is a good way to check the installation against the drawings. If any part is found incorrect, it should be corrected before attempting erection.

The electrical system should be checked to see if the controls operate each fan and that the blades are turning in the direction to blow air into the structure. Since the fans are equipped with gravity operated shutters, this check can be made by observing whether the shutters open when the fan is turned on. Care should be exercised that each fan in a tandem fan system is checked individually. If a three phase electrical source is used, it may be necessary to switch a couple of wires to get the proper rotation of the fan.

The emergency power source should be checked to see that it comes on automatically when the public power is off, and that it goes back to public power once it comes back on. **It is important to check the rotation of the fans during operation of the emergency power source.**

The control panel should be checked to see that all fans operate by the 'ON' and 'OFF' switches. The auto switch will probably turn the fans on since there is no pressure in the structure at this time. All switches should be in the 'OFF' position before deploying the cover. The tandem fans will probably not operate in the auto position at this time unless there is a high wind.

If a high wind exists, no attempt to erect the cover should be made!

The actual erection should take place on a calm day. Sometimes the best hours are early in the morning before the winds begin. This also gives one the opportunity of having the rest of the day for sealing up and trimming the cover. Once started, the erection should not be stopped until the cover is secure, even if it means working overtime hours.

After the cover has been deployed, each cable attached to its respective anchor and the skirt pushed underneath to make a seal, a cut out should be made for the fan and the fabric sealed around it. If it is possible to seal around a door at this time, that should be done, or someone will have to get inside under the cover to get to the control panel.

When making any cut outs, care should be exercised to leave excess material so that the film or fabric is not under load when inflated.

Depending on the fixture, and whether or not it has been earlier done, it may be necessary to add more fabric to the cover, or make a 'boot' around the fixture to ensure lots of slack in the fabric.

Start by turning on one fan to let the air enter slowly, and watch to see that there are no 'hang ups' where the material may have snagged on something or where there is a fold that does not open. This can best be done from the inside, once air starts to lift the cover on the ground. If the inflation process progresses smoothly, it is possible to turn on more fans and speed it up. As the cover approaches full inflation, all but one fan should be turned off to prevent an overloading shock on the cover or anchors.

While inflating, workmen can go around the perimeter and pull in the tail to make a good seal. During this process, it may be necessary to leave the large doorways sealed off until the cables have been extended to their full length and are carrying the inflation load. This portion of the erection should be done as quickly as possible, since the cover is vulnerable to damage while not in its inflated shape.

Once the cover is fully inflated, it is capable of taking wind loads, so the rest of the erection can progress at a practical rate. Since the cover has now taken ins inflated shape, it is possible to make the cut outs for the doors and other equipment, allowing sufficient excess material so that it can be sealed without putting stresses in the film or fabric.

When sealing the cover to the aluminum extrusions, try and do so in a manner that not only leaves the cover loose and without stress, but also lines up the cables in the cover with their respective anchors.

Usually it is a good idea to seal up the entire cover using small pieces of seal strip widely spaced. Then go back and seal up the cover completely using long sections of the seal strip. This makes the process quite fast and gives one the opportunity of adjusting the cover before trimming it and at the same time retaining the integrity of the structure.

After the cover has been installed, the control panel should be checked to make sure it is operating properly. Each fan can be switched to 'AUTO' to see if it goes on or off when it should. This can be tested by opening and closing doors and watching at which pressure the fans function. Some of the fans will have delays built in so care should be taken to see that the time delays are not too long. Both the pressure values and the time delays are adjustable.

The operation of the fans due to the wind should be checked the first time winds are experienced. The wind gauges have been preset, but are adjustable and they should be set so that sufficient pressure is developed so waves in the cover are not formed. If they start to form at a particular wind speed, the gauge should be set to turn on the tandem fan to eliminate the waves.

It is normal for the building to move with the wind, and this movement can appear excessive. However, as long as the extra fabric around the fixtures is enough to prevent stress on the cover material, and there are no waves or ripples forming in the cover, this movement should not be a cause of concern.(this note added by wp as it was in other docs written by Dr. Ross.)

Doors

The most popular personnel door for an air supported structure is the revolving door, since it prevents loss of air, yet allows passage of people and is relatively insensitive to pressure differences between the inside of the enclosure and the outside. It has drawbacks, though, limiting the size of what can pass through, and its cost compared to a simple door. It also can not be considered an emergency exit, according to codes, so another exit must be provided. Although a couple of sizes are available, it would take a very large one to be used for wheel chair access.

When using a revolving door, usually it intersects one or more cables and a frame is provided to take the cable loads so as not to load the door and possibly hinder its movement. Often, a pad is provided as a base so that the door and its housing remains level and operates smoothly.

The next most popular entrance is a small airlock with both doors opening outward so it can also be considered an emergency exit. If one door is opened at a time, ordinary doors can be used with conventional hardware, since during the opening process, the pressure of the domed area is negated. The size of the doors and the airlock can be varied to match the need. If the width of the airlock is greater than the space between the cables, a frame to take the cable loads must be provided at the dome side to prevent cable loads from effecting the operation of the the door at that end. Both doors must be strong enough to handle dome pressure. They can be automatically inter-locked or signs can be posted saying that one at a time may be opened. To take in long items, both can be opened at one time, but a draft will be created and the fans must be capable of handling the lost air.

Where vehicle traffic is concerned, the air lost through an open door is not a concern as long as the fan system is capable of handling it. Therefore, on large truck doors, a frame is provided to handle the cable loads and with an adequate fan capacity, no airlock is required. The fans are set to go on when the door opens and go off when it closes. This has been done automatically either with limit switches on the door or with regulation of the pressure in the structure.

The emergency exit doors are usually a balanced type with panic hardware so that they can be opened or closed against the dome pressure. For low cost applications, sometimes a conventional door is used along with a balance weight to prevent it from opening too fast and to make it possible to handle easily against the dome pressure. Usually, these are narrow enough to fit between the cables and heavy structural frames are not needed. When these are opened a draft is created dependent on the pressure in the dome.

Vents

One of the unique capabilities of an Airscape Structure is that it can be economically ventilated. This means that summer comfort can be provided. It also means that the structure can be used in applications that require a large amount of air movement. This is possible because the system uses propeller fans that produce ah high volume of air movement at low pressures. (**H**igh **V**olume **L**ow **P**ressure or HVLP fans) The structure operates most of the time at very low internal pressures. The only time higher pressures are needed is during periods of high winds, storms or when heavy snow is expected. At those times, the extra pressure is provided by tandem fans or blowers.

Air movements up to an air change per minute or more are possible. These are required in a greenhouse operation for instance, where the maximum sunlight is desired for growth, but the plants must not overheat. The general arrangement is to bring the air in on one side of the structure and vent it out the other, providing a uniform flow across the entire area covered.

In order to accomplish this, a large opening is required. It can be manually opened or actuated automatically, but it must be monitored so as to retain the internal pressure required for the structural integrity of the building. This is usually a function of wind velocity; the higher the wind velocity, the greater the internal pressure required.

Sometimes, to minimize cost or when ventilation is not required often, doors are used as vents and opened when needed. When this happens, it is important for the operator to see that there is sufficient fan capacity to handle the amount of opening. When an automatic control panel is incorporated into the system, it will usually handle the open door situation automatically, turning on a sufficient number of fans to handle the air loss through ventilation.

If a large truck door is used without an airlock, it can serve as a vent by placing it opposite to the fans bringing in the air. If this door is electronically operated, it might ever be set up to operate as an automatic vent, opening at a particular temperature, for instance.

An automatic vent is normally made up of a curtain over an opening that has been carefully located to provide the ventilation required. The vent is opened by a lifting and rolling action of the curtain, which is insensitive to pressure differences in the structure and is friction free. It is usually operated by an electronically powered screw tied to a control switch that can be manually or automatically operated. The system often includes a safety device, made up of an air cylinder that will release the curtain so that gravity will close the vent, in the event of a power failure, or if the pressure in the structure drops below a preset safe value.

Controls

The Airscape Structure operates on the principle that a minimum pressure is maintained between the inside and outside so as to be able to ventilate and operate most economically. In order to do this, a wind sensor is used and an automatic system employed to turn fans on and off to maintain the required internal pressure. The actual value of internal pressure vs wind velocity varies with each structure and location, so the pressure sensors are set in the field to prevent waves or ripples from going through the cover because of the wind. If a wave occurs, the pressure is raised until it is prevented from happening.

The control panel usually includes pressure sensors that activate switches which turn fans on and off. One of these is a low pressure switch that activated fans to replace air lost through doors or other openings. The structure should not go below this value, even if there is no wind. Sometimes this is connected to a light and/or horn to give a visible and audible indication that this condition exists. It may be caused by a power failure, an open door or an accidental tear in the cover. Whatever the cause, the situation should be corrected, if possible, as soon as practical, so the operator needs a warning.

If a large door is included or if ventilation is a part of the system, the control panel often includes several pressure sensors which turn on fans as needed to maintain the pressure in the structure. Depending on the size of the opening, these pressure sensors may operate one or several fans. If they turn on more than one fan at a time, often time delay switches are included to provide a 'soft start' and prevent overloading the circuits with starting loads.

Sometimes the wind sensor is a pressure reading instrument. In this case, a couple of specific wind velocities are selected and tandem fans are turned on to increase the pressure in the enclosure. As mentioned above, the settings are selected according to the environment where the structure is located. To eliminate turning fans on and off quickly (cycling) when the wind is gusty, timers are included in the circuits to keep a fan on for a period of time once it is activated. These are used in each step of the selected wind settings.

Usually the outside of the control panel only, has indicators such as wind velocity, building pressure, low pressure indicator, high wind indicator and power failure warning. Inside the panel, it is possible to turn on and off every fan individually or set it on automatic so that it is operated by the system.

Emergency Power

In the event of a public power failure it is important that a supplementary source is provided to maintain the structural integrity of the enclosure. This is usually done by means of an automatic transfer panel and a back up emergency generator. This unit senses the loss of public power, starts the generator and transfers the load from public power to the generator without any need for attention on the part of the operator.

If is is possible to operate the generator on natural gas, one does not have to worry about keeping a tank full and the length of power outage is not critical. Usually the maintenance on the generator is minimal if gas is used as the fuel, since it is cleaner burning. If LP is used, one gets a little better performance out of the generator but must keep track of the amount of fuel available. Diesel and gasoline generators are also used, depending on the size needed, the availability of fuel, etc.

Most of the generators can come with a weather housing that permits them to be kept outdoors. In cold areas, they are also equipped with heaters to assist in winter starting. If the generator is mounted indoors, care to vent the exhaust outdoors should be exercised. Many transfer panels are equipped with a timing system that will start the generator periodically to exercise it and keep it in good running condition. A system for keeping the battery charged should also be included.

Depending on the applications, the generator can be sized to just run critical support equipment to prevent the cover from coming down, or it can be large enough to support the entire operation as if there were no power failure. Where the integrity of the building or operation is absolutely critical, there can be a back up generator to the back up generator, in case one or the other refuses to start when called up.

If the generator is of any size, usually it is possible to have the manufacturer's representative check it out when it is first installed. Usually, 3 phase power will be specified. **Be sure to check the direction that the equipment is rotating when operating on the emergency generator, as it may be wired opposite the public power. This can be corrected by changing a couple of wires.**

Evaporative Cooling

Since it is possible to ventilate an Airscape enclosure with large quantities of air, it is economical to cool the structure by merely adding a small amount of water in a fine spray at the air intake. If the droplet size is small enough, it will completely evaporate leaving no remaining water and all of the heat of vaporization will go into cooling the air.

Obviously, the lower the humidity of the ambient air, the greater the potential for cooling. However, this system has been found effective across the country, since even in areas of high humidity and high temperatures, often these do not occur at the same time.

Usually in highly ventilated enclosures, the support and ventilating fans are located on one side or end of the building and the the vents located opposite. The water spray nozzles should be placed outside the structure at the fan inlets. Sometimes it is necessary to provide a protective screen at the inlet to keep unwanted objects from entering the fans. This screen can be made of an expanded metal or plastic sheet which collects any stray droplets, and the passage of the air over the moistened screen enhances the evaporative cooling effect.

Many different forms of adding moisture to the inlet air are possible and each has its advantages and disadvantages. It was found that the use of an extremely fine spray with a minimum for needed evaporation from surfaces, tends to require the least maintenance.

Usually the cooling system is set up so that as the temperature in the enclosure rises, additional vents are opened and fans start automatically to maintain the pressure. When all of the fans are operating and the temperature sensors still call for more cooling, an electric valve opens the water flow to the nozzles an the evaporative system is made operational.

As the temperature drops, the water flow is turned off first and then successively, the ventilation is reduced. This may be done by closing vents that will automatically increase the pressure, causing fans to turn off, or vice versa; turning fans of that will reduce the pressure, causing vents to close. The control system may be set up either way. ***Note: Can we decide on a standard for this or is there good reason for it to differ between locations/applications?***

An Airscape enclosure with high ventilation rates normally tends to dry the inside environment so adding the small amount of moisture to the inlet air for cooling is both effective and inexpensive.

End walls

There are times when it is expedient to attach the air supported enclosure directly to an existing or planned hard structure. In doing so, that end of the enclosure can be considered an 'end wall'. It is essentially a flat or wall-like termination of the air supported structure.

Once in a while this type of structure is used to provide a good place to mount mechanical equipment or large doors. There are also times when it provides the most useful interior space for the available land. In other words, it can be a useful way to terminate a structure, depending upon the specific application.

The end wall is sometimes a part of a building and would be made up of whatever is there. A means would have to be provided to attach the cover itself. If the end wall is parallel to the cables, very little load is imparted to the wall and only a seam is required. If cables terminate in the end wall, the wall must be built to sustain those loads.

When the end wall is not a part of another structure, it is often made by building a framework which is skinned in film or fabric. The framework must be designed to not only handle the loads from the internal pressure, but also wind loads. Usually the framework is made of ESI extrusions to which film or fabric can be attached, or it can be made of other materials and the extrusions added.

Often window clear film is used to skin the framework and this gives the effect of a large picture window. With clear film both in and out, it is possible to create a double layer, insulated panel, merely by placing a small hole in the inner layer, on the bottom of each panel. This lets the internal air pressure bleed through the hole and act on the outside panel, bulging it outward. At this time, there would be no pressure differential across the inner panel and it would hang straight down. This results in a double layer window with a dead air insulating space in between the layers.

Since the end wall is essentially a framework, it is easy to design it so the doors and mechanical components can be mounted into it. (Our version of this is the Building in a Box)

If the air supported enclosure is part of another structure, the end wall can be made of materials that will aesthetically match.

If the air supported structure is small, end walls are relatively simple to make and often more convenient to use than making separate frames for the hard components. They can also be used as an emergency support for the cover in the event of a power failure. A cable cable strung from end wall to end wall can act as an emergency cable, holding the cover up if the power goes out.

Anchor Systems

An air supported enclosure is dependent on the integrity of the anchor system, since the internal pressure is trying to raise it off the ground and the anchor system must hold it down. This is just opposite to the type of foundation needed in a conventional structure where it must support the weight. There is a tendency to want to use an existing foundation and attach an air supported structure to it. This could be a big mistake unless it is determined that uplift loads can be handled.

For more permanent types of air supported structures, concrete grade beam around the perimeter of the structure is part of a good anchor system. Here, enough concrete is used as ballast to balance out the uplift forces of the cover. In an Airscape structure, the uplift loads are taken in the cables. A uniformly distributed beam of reinforced concrete, or a series of individual anchors can be used. The cables are usually terminated in an eye, and an anchor embedded in the concrete is also provided with an eye. Each cable can be attached to its corresponding anchor with a shackle. Each anchor should be numbered to match its cable in the cover, also numbered.

A seal is also required between the cover and the anchor system. This is often supplied by a 'tail' on the cover that is held in place with internal pressure. On more permanent structures, a sill channel is provided, held down by the anchor eyes, and the cover is attached to the sill channel with a special sealing system of rubber strips and spring clips. When a double layer cover is used, this sill also acts as a header for control of the air between the layers.

Since an Airscape needs to be held down by merely holding the cables built into the cover, a wide variety of individual type anchors can be used. One needs to know the loading of each cable and supply an anchor capable of handling that load. This makes a temporary structure very feasible where it is necessary to install the anchors quickly and possibly even remove them when the project is completed.

Many different types of anchors have been used. If we wish to remove the anchor after the fact, a helical anchor suited to the load and soil type might be a good option. Simple concrete blocks available just about everywhere, can be uses as simple ballast for surface installations on parking lots or other ground conditions where screw or driven anchors might not be practical. Large blocks of ~4000 pounds are an acceptable anchoring system for structures up to ~120' wide.

Expanding type anchors such as arrowhead, manta-rays and others are cost efficient but cannot be recovered. They are also subject to soil conditions.

There are lots of options for anchors. We have recently considered using shipping containers around the perimeter, ballasted enough to take the load but also modified to provide offices, storage and utility rooms around the perimeter of the enclosure.

In one case where marshy conditions were unsuited to anchors or blocks, a log with cables around it was sunk into the mud and made a primitive but effective temporary anchor.

The determining factors are the integrity of the anchor system to handle the loads and the economy of the system for that area. Don't be afraid to think outside the box.

Walls

There are times when it is advantageous to mount the cover on top of a wall rather than have it come clear to the ground. Again, there are times when a curtain wall is included which can serve a number of purposes, such as defining the interior useful space, acting as a vent, etc.

If the cover is mounted on top of a wall, regardless of height and the wall must act as the anchor system, it is important that the wall be designed to take the cable loads. This means both the vertical and horizontal components, and it often consists of reinforced concrete to withstand these loads. Usually the anchors are buried in the wall and a sill channel is placed on top of the wall for attachment of the cover material.

A wall like this serves several purposes. It is not only the anchor system, but it provides a place for installation of doors and mechanical equipment. If high enough, it provides a secure base from the standpoint of vandalism. In snow areas, when the snow slides off the cover, it has a place to go without pressing on the cover itself. Sometimes this type of wall is fitted with a berm, inside or outside, to add to the aesthetics of the installation.

There are times when the cover is terminated on top of the wall, and the sill channel is placed there, but the loads are carried down to an anchor system in the ground. In this case, the wall is essentially a curtain wall and does not need to be very substantial, although it may be made of cement blocks for other reasons. It could also be made of a framework of aluminum extrusions or steel studs skinned with film or fabric. As mentioned earlier, it might just be a support for a venting system.

In order not to place any cover loads into the curtain wall, the load of each cable must be carried down to the anchor system in the ground. This can either be done by each cable or extension of it going directly to the ground or providing some form of collecting the cable loads in a beam and then transferring these loads to the ground. Often is is necessary to use this latter system to bridge mechanical equipment of doors.

Care must be exercised to properly anchor the collecting beams and size the extensions to the ground to handle both vertical and horizontal loads when the cover is under internal loading and wind loads, when it tends to move. This is done with additional vertical components in the curtain wall between the anchor system and the collecting beams.

Sometimes the sill channel can be used as the collecting beam, if each cable load is carried to the ground, and sometimes just supplementing it with a strength member will suffice.

Pallets

The Airscape system for manufacturing and shipping the covers usually involves making the cover in one piece directly onto the shipping pallet. This has been done up to shipping weights of ~65,000 pounds and enclosures up to 3.5 acres. These are not an upper limit but what has been done to date using a flat bed trailer to transport the covers.

In the early days, the pallets consisted of articulated panels of plywood which formed a movable floor which could be towed from a dock right onto a flat bed trailer. Inflatable rollers under the panels facilitated this movement and distributed the weight. Therefore, the pallet did not have to support the weight of the cover except to act as a floor underneath it.

When smaller covers are made, it becomes easier to actually build a weight carrying pallet which can be picked up by a fork lift. Although standard wood pallets were used at first, the sizes of covers grew and the pallet requirements also grew. The pallets were first made of two x fours with a plywood top, but soon required two x eights and two x tens and plywood on top and bottom. As the weights and sizes of covers grew, the pallets had to be made to handle them. The wood was doubled up and reinforced with steel angles. The largest size pallets are made of steel I-beams and channels, with heavy plywood floors. Some pallets are merely truck beds without wheels.

The pallets are not only lifted by forklifts, but also by cranes, so the pallets have to be made strong enough to handle point load supports. Sometimes lifting lugs are included.

Since most of the pallets are shipped on flat bed trailers, they are made 8' wide and up to 40' long. Many times, however, it is necessary to ship by van, so those pallets are made 6.5' wide and as long as necessary. For instance, for overseas shipment by container, the pallets should be narrow enough to fit in the container.

On the smaller covers, the pallets are considered expendable and usually not returned; the cost of the pallet is simply included in the price. On the larger structures, the cost of the pallet is substantial, so consideration should be given to the return and reuse of the pallet. If the customer is going to erect the structure once and use it for its whole life, he probably does not need the pallet and it can be returned. If, however, he plans to move the structure, he may need the pallet and its cost would have to be included in the sale.

Care must be exercised to design the pallet for how it is handled to prevent problems from breaking the pallet in the field.

Sizes and Weights

The Airscape system of enclosures can be applied to very small back yard units or very large ones covering many acres. Formal bids have already been made on structures up to 120 acres without exceeding any engineering or manufacturing limits. The major determining factor regarding the size is the width which designs the cable loading. The length is merely a modular addition and can be as continuous as desired. So far, widths up to 1000' have been investigated and are practical using existing cables and fabrics.

As the width increases, the cable loads also increase. This means that either larger cables are required or the cables must be placed closer together. If the cover is to be manufactured in the Airscape manufacturing facility, and transported to site, it means that it will have to be folded. It has been found that galvanized aircraft cables up to 3/8 inch diameter can be folded without great difficulty and therefore, multiple cables up to this size, rather than larger ones should be used.

If the structure is so large that it should be made on site, consideration for using larger diameter cables is in order. Flexible cables should still be used to minimize problems from fatigue and vibration.

It has been found that these covers can be packaged to be quite compact, and can then be transported by truck, train, boat or aircraft. Usually, the size of the package can be varied to match the carrier. The weight, however, can be substantial and often defines how it will be handled or how large a unit can be transported by that method. A cover for a three acre site might easily fit on a 40' flat bed trailer, but its weight, including the pallet, might be 65,000 pounds or more, over the normal loading for that truck. Usually, this can be handled by a one time overload permit, which is not too expensive.

A cover tightly bundled might have a density of 35 pounds per cubic foot. Be sure to leave space around it for protection during shipping. Usual packages are probably half that density.

Often the cover can be shipped on a pallet with no other protection than the sock in which it is made and then it is transported by a dedicated carrier. If it goes to standard commercial carrier, it will probably need to be boxed to prevent damage during transit. This could add to both the size the weight.

If the pallet is to go inside a van, it should not be over than 7 feet wide. If it is to be transported by trailer, it could go up to 8' wide. In all cases, the package on the pallet should be inside the pallet dimensions and not hang over it.

Multi-Layer Covers

Although Airscape Structures can be made in a single layer thickness, there are many advantages to using a double layer cover once installed. In fact, the benefits are so great that double layer covers are now considered our standard.

In a double layer cover, the outer layer material is selected to handle the environmental conditions such as weathering, while the inner liner is primarily selected to create a dead air space for insulation. If the outer layer is clear or translucent for the passage of sunlight, the inner layer should be selected to minimize the reduction of light transmission. It might be window clear to translucent with a minimum of scrim for tear resistance.

During the manufacturing process, when the seam is made, both layers as well as the cable are included. In that case, both layers are obtained in the same width. There are times, however, when cables are included in the outer layer and the inner linger is skipped so that it is attached at every other cable. This is done when the cables are closer together than about 4 feet, since the cables are located for strength purposes and the inner liner is just for insulation. If a protective surface such as Tedlar or some other UV treatment is used, the inner layer material does not require it, since the protection from UV rays is already provided.

In order to obtain a dead air insulating condition when a double layer is used, it is necessary to make sure that the space between the layers is either vented to the inside so that there is no pressure difference between the layers and the inside of the enclosure, or it is greater between the layers than in the inside of the enclosure. The former condition is sometimes done by terminating the inner liner before the cover seal is made with the outer layer, or a hole can be made near the bottom of each panel of the inner liner. This way the inside pressure can get between the layers and there is no differential pressure. Gravity will then separate the two layers.

If a sill channel is used, each layer is attached to its respective side and the channel can act as a header to control the pressure between the layers. If a double layer is required, a small fan or blower can be used to blow air between the layers to keep them separated. If it is desired to have the two layers together (for example, to use the heat inside the building to melt snow off the cover) the fan can be turned off (or reversed) and the internal pressure will push the layers together. (Usually, the sill channel includes condensation drain holes and the air between the layers can escape through these)

The double layer is used both as thermal insulation and as a means of preventing condensation on the inside of the enclosure. Control of it during freezing rain or wet snow periods eliminates the weight by letting heat through to melt it off the cover.

Make-up-air Heaters

When heating an Airscape enclosure, the air which is lost through leakage and ventilation should be replaced with warm air, if possible, and this is done on the more permanent structures with a make-up-air heater. On the more temporary enclosures, sometimes it is more expedient to just bring in cold air and direct it into an area which is being warmed.

Since the pressure in an Airscape enclosure is usually regulated in accordance with the velocity, it is important that this make-up-air, which is being warmed by the heater, is regulated. The air input to the enclosure is usually furnished by a tandem fan that is turned on and off by the Airscape Control Panel. Therefore, a tandem fan system is often incorporated in the make-up-air heater.

Some of the larger make-up-air heaters have been designed to use a tandem fan system that usually contains two fans, although three have also been used. At other times, when it has been necessary to use existing furnaces, these have been supplemented with a tandem fan system.

On the larger size heaters, it is most efficient to use direct fired heat sources. When utilizing gas as the heat source, these heaters have a safety system that is sufficiently costly to preclude their us on small heaters. In those cases, a standard root top furnace heat exchanger is modified to use a tandem fan system as the air source. This can then be operated by the Airscape Control Panel.

In the case where a standard roof top furnace heat exchanger is modified to use a tandem fan system, so as not to affect the warranty of the heater manufacturer, the standard blower is also used. The tandem fan just supplements the air supplied by the blower. In this way, the variation of pressure in the enclosure does not effect the heater operation.

Added Note by WP: Although the blowers in these units are more costly to operate than fans, they have the advantage of higher operating pressures and can be used to increase the pressure in the enclosure against higher velocity winds. The blower can be operated in sequence with the other fans but without the heating component. The unit can operate as both a heater and a high pressure back up for storm conditions.

When a direct fired make-up-air heater is used, it adds moisture to the air in the enclosure. This should be taken into account when determining the ventilation requirements. Unless the extra moisture is a benefit, extra ventilation may be needed to evacuate it.

Usually, the heat that is lost through the cover is handled by a separate recirculating heater system. There are times however, when it is more appropriate to just oversize the make-up-air heater and let this unit supply both the heat for the make-up-air and replace air lost through the perimeter and cover. This is done by bringing the air into the enclosure at a higher temperature than the internal temperature desired. Otherwise, the make-up-air heater can be set to bring the outside air in at whatever temperature desired, such as 70 degrees F, by a thermostat in the heater supply and a modulating burner.

Recirculating Heaters

The heat loss through the cover and perimeter of an Airscape enclosure is usually replaced by the use of recirculating heaters which pass the air inside the enclosure through heat exchangers or over electric coils, depending on the type of heat source available. Since the entire movement of air is internal, it is independent of the pressure in the enclosure as a function of wind velocity.

The key elements in selecting a heater, therefore, are the source of heat, the amount that must be added and the distribution of the heated air. Electric heaters are clean and easily distributed wherever needed, dependent upon the contents of the enclosure. If steam or hot water heat exchangers are used, the source of the energy usually helps dictate how it will be distributed. Often the units are placed along the outside walls, spotted so that each handles a particular area.

If oil, natural gas or LP is used, then the outside of the perimeter is almost required as the location, since these units must be vented in order to burn fuel. They may draw combustion air from inside or outside, but the exhaust should be to the outside. The inside air merely passes through the heat exhanger and is not concerned with the location. Sometimes the heaters themselves are mounted outside the structure and ducts are used to carry the air back and forth to the heat exchangers.

Most of these heaters are equipped with a fan or blower to help distribute the heated air. The size of the air move is dependent upon how far and how fast the heated air must move. For instance, in a greenhouse 100 feet wide, it has been found that a 2 hp blower can pass the air across the top of the enclosure from one side to the other, and let it return along the ground in a very uniform flow. In this way, all heaters can be placed along one side, minimizing installation problems and still result in very uniform heat distribution. Otherwise, it is possible to mount the heaters around the perimeter and blow the heated air towards the center.

Sizing the heaters depends on many factors, some of which are the use of the structure, how it is made, time of use, geographic location and the climate in that location, etc. A formula for initiating the determination of the amount of heat loss through a double layer enclosure is:

- *The BTU input required is ~ 1.2 x the ground area covered x the temperature differential desired in degrees F. Regardless of the form of heat source used, this is a good start point for defining how large and how many units would be required if all heat lost, not counting the make-up-air, is provided by the recirculating heaters.*

The number of units and the size of each to obtain the heat needed becomes an economic matter as long as a good distribution can be achieved.

Combination Heaters

In some installations, it has been found to be advantageous to modify conventional recirculating heaters so that they can be used as both recirculating heaters and make-up-air heaters. This is particularly true in smaller structures where two separate heaters would be uneconomical.

Usually a recirculating heater is fitted with an outside inlet to bring in outside air supplemented with fans to raise the pressure to what is needed by the structure. This is often done with a fan system tied to the control panel so that these added fans are operated as a function of the wind velocity.

At the time the system is used as a make-up-air heater, the added pressure of these fans close a damper to the return side of the recirculating heater, making it a true make-up-air heater with the outside air passing directly through the heat exchanger into the enclosure.

In the event that a storm calls for a tandem fan ti raise the internal pressure, this added pressure closes another damper in the inlet from the outside, preventing any air from entering from the outside. At that time, it opens the damper is the return section of the system and the heater becomes a recirculating heater. This is important, because at this time, during the storm, cold air is being brought in directly through the tandem fan and the heater can now apply all its capabilities to heating the inside air. During this period, the fans in the make-up-air section are running without effect, since they are being overpowered by the tandem fan.

The entire system is extremely simple and self regulating and does not violate any warranty on the heater. The only losses are the extra operation of the fans in the make-up-air section when overpowered by the tandem fans. At these times, the extra cost is overwhelmed by the benefits of system simplicity and the added heat to the interior.

The fans included in the make-up-air section are sized to add pressure to the system, retaining the volume flow through the blower. Therefore, the heat exchanger sees the same flow through it but at different pressures. This insensitivity to pressure differences lets an Airscape Structure operate most effectively at various pressures.

Airlocks

In order to pass to and from an enclosure with a pressure higher than the ambient without experiencing an air flow from the higher pressure to the lower pressure, one of the most common means is the use of an airlock. This is nothing more than a passageway between the inside of the enclosure and the outside ambient conditions, with a door at each end. Usually this passageway is small in size compared to the maine enclosure and its main purpose is to prevent the loss of air from the enclosure when people or equipment go in or out. Only one door at a time is opened. Sometimes they are inter-locked to prevent both from being opened at once. (A revolving door is a unique form of airlock)

If this is a personnel entrance and it is also to be used as an emergency exit, then both doors should swing outward. They should be wide enough for a wheelchair to pass throught. Sometimes this passageway can serve other purposes as well, such as a vestibule or lobby.

If large equipment is to pass through, the door size and length of the passageway is determined by the largest piece of equipment. Often in this case, electrically operated roll up doors are used. Usually a 12' x 14' door can handle anything that travels on the highway. An airlock must be strong enough to handle the same internal and external pressure loads as the enclosure.

If the ventilating system in an Airscape Structure is capable of replacing the air lost through an opening as fast as it is lost, an airlock is not required unless the resulting flow is a problem. For example, a truck would not be bothered by the air movement since it encounters more than that in normal operation on the highway. Many Airscape Structures do not use airlocks, even for their large doors. This is a significant advantage if a lot of traffic is expected or if the loads are long and would require a very long airlock.

Extrusions and Sealing Systems

There is a very fundamental difference between Airscape Structures and conventional air supported structures that effects the way the covers are sealed. Airscapes take the design load in the cable built into the seams of the cover material so as to leave film or fabric essentially unloaded, except to contain the air. This means that when the film or fabric is attached, it should not be stretched tight, but left loose yet be gas tight.

In order to provide a seal in a simple manner, a number of aluminum extrusions were developed, all having a specially shaped edge to which the film or fabric is to be sealed. A sealing strip is also provided that is pressed over the fabric once it is folded over the aluminum edge. This sealing strip is made of vinyl with a metal segmented base so it is easy to bend. It comes in continuous rolls about 100' long and is cut to size as needed. To cut it, one needs a metal cutting tool, a heavy pair of scissors or a knife will do if cuts are made between the parts of the metal base.

The sealing strip is easy to install; therefore, it is also easy to remove. To prevent accidental removal of the sealing strip, a spring clip is provided that is periodically slipped over the sealing strip to lock it into place. A special tool is provided that is used to open the spring clip and locate it over the sealing strip. Since the gas tight seal is already made by the sealing strip, the number and spacing of the spring clipls is a function of the expected tendency to pull off the strip. Average spacing is about one foot apart.

When installing the sealing strip, there are times when the length of the film or fabric is greater than the extrusion and folds are needed. If possible, an attempt should be made to not pile one fold on top of the another, or the amount of cover material that has to fit into the sealing strip becomes excessive and tends to spread it apart, reducing its functionality.

During installation of the cover the first time, often the sealing strip is cut into small pieces about 3” long and the cover is sealed temporarily with these widely spaced strips, to shape the cover. Once the cover is in place, the continuous strip can be applied and these short strips removed as one progresses, until the whole cover is properly sealed. The trimmin of the excess material can then take place after examination that none of the cover is under load, but only being used to retain the air.

As mentioned above, the cover is not to be under load except to provide a seal. Therefore, there are other ways to seal the perimeter, such as:

- just leaving a long tail on the bottom of the cover, laying it on the ground and letting the pressure hold it in place.
- The tail can be buried, nailed or screwed to boards, etc
- Sand bags or other weights can be set around the outer perimeter to hold the outer layer down; this is not necessary for the inner liner as the pressure in the enclosure will seal it to the ground for an adequate seal.

Repair Kits & Techniques

A repair kit is usually provided as part of an enclosure system, and it contains a small amount of material as well as any special tools that might be required. Since the covers are made of different materials, each repair kit is matched to the materials used. Repair techniques also vary with the material, so that must be taken into consideration when assembling the kit.

The purpose of the kit is to provide sufficient materials and tools to permit a repair of a small damaged area before it grows into a large one.

All the repair kits include scissors to cut the material, because although a common tool, there is never a pair around when you need one. If the enclosure utilizes the Airscape sealing system, a length of sealing strip, a few spring clips and a clipping tool are included. These are not readily available so having them on hand is advisable.

If the cover is made of a film material, the repair technique requires that any patches be cemented on, so a can of a clear vinyl adhesive is included. **This material degrades over time so should be replaced periodically to remain effective.** Also included is a cleaning solvent, such as MEK (methyl ethyl ketone) to clean the material before making a cement patch. **Both the cement and the solvent are very volatile so care should be exercised that they are not used near anything that could ignite them.** Also included are paint brushes to apply the cement, clean up rags, etc so all materials are available when needed.

If the cover material is woven or contains a cloth or scrim, it is possible to make a repair by sewing or stapling a patch into place. In those cases, a stapler with an extra box of staples is included. The stapling technique can be used for all those types of materials.

In some cases special attachments are used that might require cables assembled with cable clips. In those cases, a few extra clips and any necessary tools should be included.

To make a temporary repair, often it can be accomplished with simple duct tape or a special clear vinyl fabric tape designed to work with these types of fabric, making a near invisible repair. A roll of one or both of these should be included.

Although they are sometimes lost, instructions for making repairs are also included in the repair kit. Repair techniques are usually described in the operating manual, but it is good to have the instructions handy where the repair is being made.

All of these items along with two or three yards of cover material are packaged in a repair kit, either a tool box or bag, clearly marked for the purpose. Since this is a handy item to walk off with, it's a good idea to specifically hand it to the building operator and emphasize the importance of having it handy and on site at all times.