This is my perspective and opinions as an Engineer on the pole vault pole.

This document contains some of the same information to a similar paper I developed while at Gill Athletics.

While I have been an Engineer all my professional life, much of my knowledge and understanding of pole construction I must attribute to Ralph Paquin.

Ralph was the Plant Manager at Gill Athletics when I first meet him. He had been instrumental in Skypole production when acquired by Gill. Ralph was the lead when Gill acquired the Pacer line (Spirit came from the Pacer family and those who did not move when it was acquired).

Ralph was also involved with the design, testing and production of the original carbon poles. There were some who did not give him his due because he did not have a degree. The man knows how to build poles. Ralph along with Ken Hursey (Lead Man in Pole Room) had a lot to do with Gill's successful pole building and advancements.

This document has more information included or added to take some of the mystery out of the pole.

The goal is to help people make a more informed decision.

Included are thoughts and ramblings on the following topics:

1. ***Pole design***
   a. ***Spirit***
   b. ***Gill Lines***
   c. ***Essx***
   d. ***Altius***
   e. ***Nordic***
2. ***Pole failure***
3. ***Pole bending***
4. ***What is the best pole***
5. ***Tools for understanding***
6. ***Column versus beam theory in relation to flex numbers and weight ratings.***
7. ***My Background as an Engineer and Track Junkie***

Basics of pole vault poles

All poles that I know of that are currently produced have some things in common.

1) ***Made using a mandrel***
   a) ***A hollow tube that usually as a small taper to it***
      i) ***Some are made of steel , some are made of aluminum***
      ii) ***A taper allows the finished product to be remove***
   b) ***Various basic diameter***
      i) ***With most Manufacturers as the number goes up the diameter is smaller***
      ii) ***The bigger diameter usually means bigger stiffer poles***
         (1) ***Same wall thickness – bigger diameter – bigger Section Modulus – stiffer pole – more on this later***
   c) ***Mandrel length***
      i) ***Many are the same length but this is as much an oven issue (process and manufacturing) as anything***
      ii) ***Your could have a 13', 14',and 15' pole all built on the same mandrel. You just use longer patterns of material***
2) ***Various layers of material***
   a) ***Inner wrap or layer***
      i) ***Spiral wrap***
      ii) ***Roving***
      iii) ***Tack layer or veil cloth***
   b) ***Body wraps***
      i) ***Set number (some chose they approach)***
      ii) ***Can vary based on sail deign and desired pole stiffness (some use this approach)***
      iii) ***Different material types intermixed (carbon poles)***
      iv) ***The rail or neutral axis***
   c) ***Sail piece***
3) ***Sail Patterns***
   a) ***Symmetrical versus unequal length***
   b) ***Number of wraps or height of the sail***
4) ***Cooked or cured***
   a) ***Flow phase***
   b) ***Cure or cook phase***
   c) ***Cool down***
5) ***Different materials and resins***

A more detailed discussion follows. These are my opinions on many of aspects. While I have had discussions with other pole vault manufacturers, if a point needs to be clarified or corrected – let me know.

1.) Let's look at mandrel sizes and what they mean:

The following is what I would imagine is pretty close to what the two biggest pole makers use.

Look at the UCS/Spirit or Gill Catalog and you will see the tip size given according to mandrel size – Since Spirit is an offshoot of the original Pacer line this is probably pretty close for both companies

Want to check yourself – measure the inside diameter at the tip and the top of the pole, check the mandrel size (usually marked near tip of pole) or ready the tip size and compare

Mandrel Chart

Size	Tip (Handle)	Butt (Planting End)	diff	Mandrel Length
21	0.95	1	0.05	180
18	1.03	1.08	0.05	180
17	1.05	1.1	0.05	180
16	1.075	1.125	0.05	180
15	1.1	1.15	0.05	180
14	1.125	1.175	0.05	180
13	1.15	1.2	0.05	180
12	1.175	1.225	0.05	180
11	1.2	1.25	0.05	204
10	1.225	1.275	0.05	204
9	1.25	1.3	0.05	204
8	1.275	1.325	0.05	204
7	1.3	1.35	0.05	204
6	1.325	1.375	0.05	204
5	1.35	1.4	0.05	204
4	1.375	1.425	0.05	204
3	1.4	1.45	0.05	204
2	1.425	1.475	0.05	204
1	1.45	1.5	0.05	204

Smaller number is bigger diameter. If you are 2m tall and run like the wind you might even get a "0" mandrel

2.) Let's look at material and layers:

a.) I believe the first layers are the most critical.

Why? If these inner layers are not applied properly, voids, folds or crevices can results. In the case of these layup issues, either resin must flow to fill these imperfections or you have a built in stress riser (weak spot).

The undisputable fact is a void that gets filled with resin does not have fiber distribution like a section that was smoothly applied.

It is just a matter of how much any of these issues affect the pole.

The first layer needs to get applied to the mandrel, be wrapped tightly and serves as a tack point for next layer.

Spiral Wraps

In examining the original spiral wrap and the patent **(US Patent 3,969,557, Herbert Jenks)** *you will see the concept, why it was done, and how brilliant the man (Jenks) was.*

Much of the concept dealt with how to increase hoop strength, reduce splintering (old glass vaulters will remember this) and as always control cost.

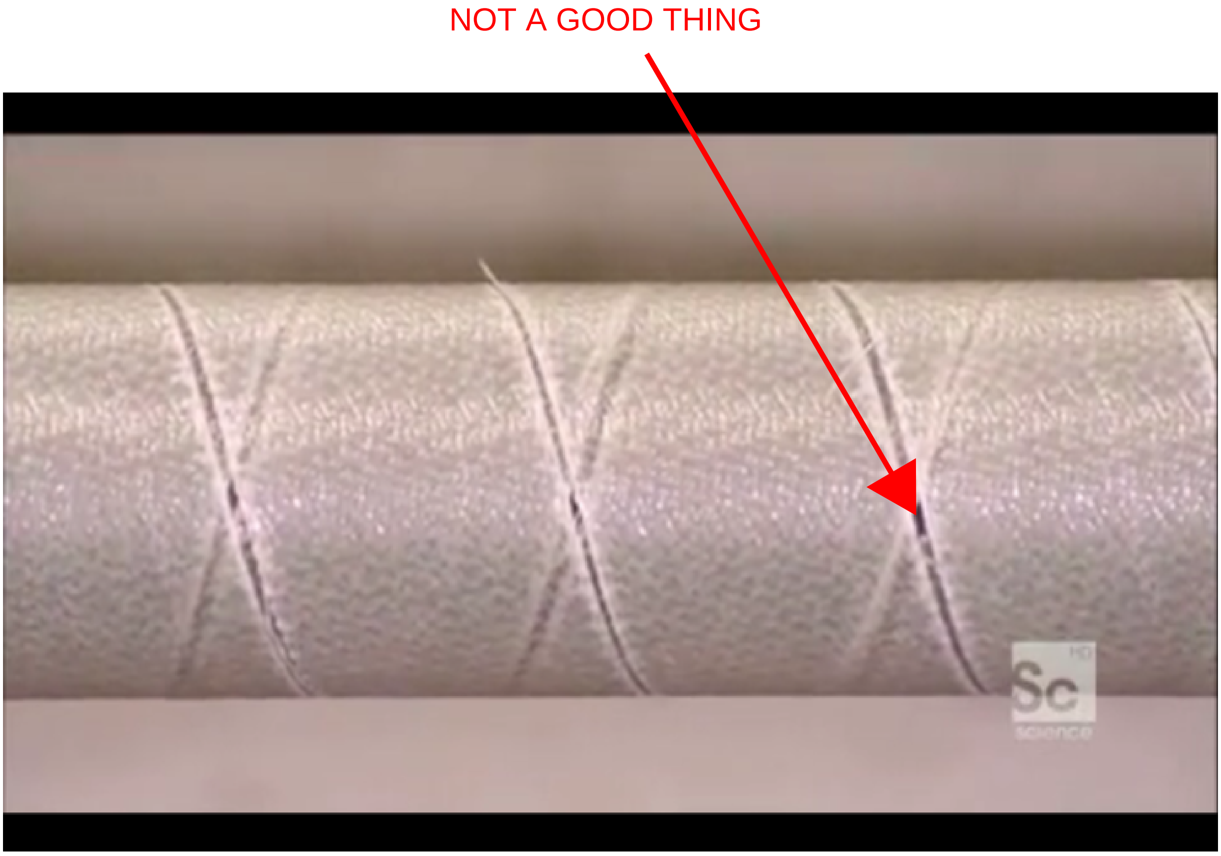
Herb Jenks also states in this patent "That is to say, to the greatest extent possible, woven tapes and cloths are avoided." Material advances have gone on to minimize many of these concerns.

E-mail me if you want in depth comments on this point.

The original spiral wrap was to get more fibers running in the direction to increase hoop strength. This spiral wrap (helically wrapped narrow piece of material) was the solution.

One of the subtle points was the separation of the two spiral wraps by a layer of material. While the concept of having opposite wind directions spiral wraps is more obvious, the reason for a separation layer is not.

If you have spiral layers that are next to each other, there is an edge intersection point or crossing point (actually numerous). This is in effect a two layer void or pin hole (ideal world the butting of the spiral wraps is perfect) - hence if you have any gap – you have built in a void or very small weaker spot (no fiber) that must be filled with resin flow. If this gap is big enough, and you do not have enough extra resin to flow and fill this – you could have a dry spot, void, pin hole, or stress riser.



This very concept is why all layers need to be wrapped tightly, no wrinkles, voids or folds. Each can lessen the safety factor built into a pole.

Why would both layers of a spiral wrap be next to each other? Cost! The ease of manufacturing and time are reduced.

Roving

A* roving *is a long and narrow bundle of fiber. If the roving is applied or wound around the mandrel to be used as a base layer and provide hoop strength, it has the same precautions that apply to a spiral wrap.

A dry roving also requires adequate flow of resins from the layers above it.

Much of early use of this type application was to avoid patent infringement issue and cost issues.

Ralph and I had many a discussion about the merits and drawbacks.

If I was starting from scratch – today – I would not use a roving.

Tack Layer or Veil Layer

Advantage is less joints/seams so less chance of voids.

Basically a long rectangular piece than would be applied and have a complete wrap around the pole.

Width would be roughly the circumference of the mandrel at the larger end (π x d).

Example - #9 mandrel is let's say 1.3 inches in diameter

- *the one wrap would be 1.3 times 3.14159, or 4.08 inches*
- *I would probably cut about 4 1/8" since cutting patterns is still the labor equation part and a gap in a wrap is a bigger problem than a small overlap.*

Braided Fiberglass Sock

If I had the time and resources – this would have been one area that I would like to have done testing on.

The concept of no seams or wrinkles on the inner layer is greatly desired.

The cost, ease of application and the availability of the right resin impregnated material would all need to be researched.

Part of the issue is the stigma of this is the way we have always done it.

b.) Body Wraps

Most poles you will see on the market today will have either three or four body wraps.

How are they tacked on before going through rollers to roll on tightly?

- *A hot iron run over the edge will do the trick*
- *Some people use heat roller assemblies also when rolling on body and sail*

An example works best – so 4m pole (just over 13') on a #9 mandrel (pole for a slow "solidly built" guy) – body piece would be as follows:

> *This could be one large rectangle piece – starts out just over 4m long since needs to be trimmed after pole is finished.*
>
> *Width if a four (4) body pole on a #9 mandrel would be 4 x π x d or roughly 16 ½ inches wide.*

I will not get into how much extra in width you add because the diameter gets larger with each layer added – but you get the idea.

Most training poles add body wraps and do not have a sail or not much of one.

Some carbon pole will also have a body wrap of straight carbon plus body wraps of fiberglass (usually s-glass)

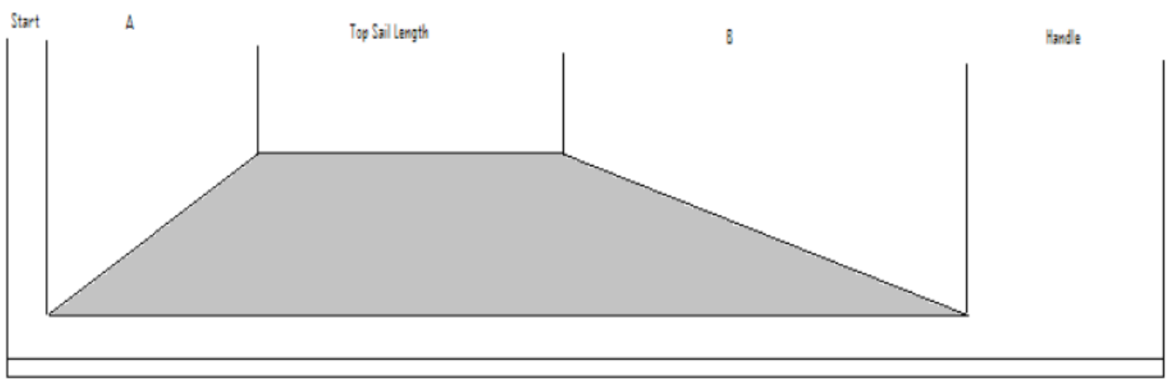
The start point along the long axis of the pole – what I call the neutral axis and some refer to as the rail. Below is how I identify areas:

- *Tension side - the side that bends away – thus fibers and glass on that side stretch or are in tension – 12 O'clock*
- *Compression side – side you see – inside of the bend – in compression – 6 O'clock*
- *Neutral axis – would be the 3 and 9 O'clock position – least amount of strain*

The neutral axis is where you always tack the start of the next layer.

3.) Let's look at Sail Patterns:

Below is a diagram we can use for reference:



- *Skypole and Essx tend to have sails where A is smaller than B – result is a lower sail piece and the pole is stiffer near the bottom – top of pole bends easier*

Some might keep the "top sail length" the same and vary the height while others might vary the top sail length but always keep the height (width of material and resultant home many wraps on the pole) the same.

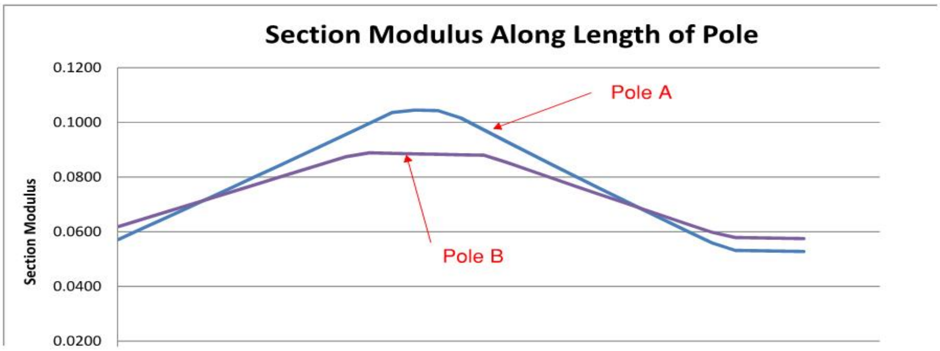
- *Original Pacer and Spirit want the Sail to start and stop on a rail (Neutral axis) - so to add stiffness without changing mandrel size – make the top sail length longer.*
  - *Since there is a limit to how long the top can get, relative to overall sail length, otherwise it becomes a training pole –*
  - *Option is then to increase mandrel diameter – but if that would then make the tops sail length to short (for guidelines you use) to achieve the desired flex – your option is to drop a mandrel size and add a body wrap. Look at the Spirit tables and you can tell what they do.*
  - *I will go into this more when discussing individual poles*

If you are real curious – you can take the protective/decorative tape of a pole and see the sail design (have to be a real anal engineer or real curious to go that far).

Since there are many ways to come up with a composite having a certain overall stiffness – it is in this complete "composite" design where small differences in design are evident. Sail design is part of that.

Some poles had a body wrap over the sail so then you are out of luck.

Model	Mandrel	Sail Height	Length in Inches	Top Sail Length	Sail Layers	Total Moment of Inertia	Total Section	Total Estimated Weight	[redacted]	Total Cross Sectional Area	[redacted]	[redacted]	I for Average	Estimated F
Pole A	16	14.94	162	11.5		0.0470	0.0776	2.2683		0.2697			0.0504	21.65113
			Max Section		3.9223	0.0649	0.1047		[redacted]	0.3581				
			MIN			0.0308	0.0529			0.191164277				
			MAX		3.9307	0.0647	0.1045			0.358103446				
			Max/Min			2.1	1.975							
Pole B	12	8.21	162	30		0.0480	0.0744	2.0421		0.2400			0.0504	21.65377
			Max Section		2.0001	0.0580	0.0890		[redacted]	0.2834				
			MIN			0.0362	0.0576			0.191127043				
			MAX		2.0127	0.058	0.0889			0.283390008				
			Max/Min			1.601	1.542							



The above is taken from little program than calculates all kinds of interesting things.

What is illustrates is two 13'6" (415-66) 145 lb poles with a flex of approximately 21.6 as noted in the light blue on the right.

Both have different sail design concepts.

Pole B:

- ***Sail starts and stops on the rail thus 2 sail layers.***
- ***Top side sail length is 30 inches and height to get two wraps is just over 8 inches***
- ***Is on a 12 mandrel and the upper handle of the pole is stiffer***

Pole A:

- ***Sail starts on rail but makes not quite 4 wraps – not concerned about that is this concept***
- ***Top side sail length is 11.5 inches and height is almost 15 inches.***
- ***Pole is on 16 mandrel – is actually stiffer in the middle but has a softer handle***

There are some many variables and variation in pole design. Even the overall length of the sail has variations:

- *Sail is always a certain percentage of overall pole length.*
  - *90% of 4m pole would be 3.6 m length sail*
- *Sail is always runs from bottom to a certain distance from the top.*
  - *If 15cm then sail would be 400 – 15 or 385 or 3.85m*
- *I have seen on pole manufacturer where I tested two identical length and flex poles but the sail was about 20 cm different in length – so they are using a floating design and are more concerned about final flex – or where in a design change mode*

The example above showed two poles with basically same weight rating and flex – yet this was achieved in markedly different approaches.

Many of the columns and information are not displayed – but – it does illustrate the point.

Which is the best – this I will repeat over and over – the one that works for you.

4.) Cooked or Cured

a.) Flow phase

- *Portion of the process where the temperature of the material is raised to a point the resin becomes viscous.*
- *Each resin type has a certain specific temperature range it flows best – or is recommended to be brought to during this phase*
- *This is the time when you need to wet all the layers and fibers so you eliminate any voids and take a step in turning the multi-layer tube into a composite pole*
- *Heat and low pressure are applied during this phase*

b.) Cure phase

- *Portion of the process where the temperature is raised beyond where the resin is viscous and flows to a point where it becomes solid/glass.*
- *Temperatures of over 240 F and higher pressures are used.*
- *To cure properly it is a combination of pressure, temperature and time.*

Typical information of resin – same resin as original Herb Jenks Patent

Cytec ENGINEERED MATERIALS

Cycom® 7409 Epoxy Resin

INTRODUCTION

Cycom® 7409 is a 250°F (121°C) curing epoxy resin with good 160°F (71°C) dry service capability. Cycom® 7409 is formulated mainly for autoclave processing, but has been successfully processed by press molding. Unidirectional tape and woven fabric impregnated with 7409 resin will retain excellent tack and drape for at least 10 days at RT. Standard cure is 2 hours at 250°F (121°C). No post cure is required for 160°F (71°C) dry service capability.

Typical applications for 7409 resin include recreational products such as tennis racquets, pole vaulting poles, fishing rods, etc.

FEATURES AND BENEFITS

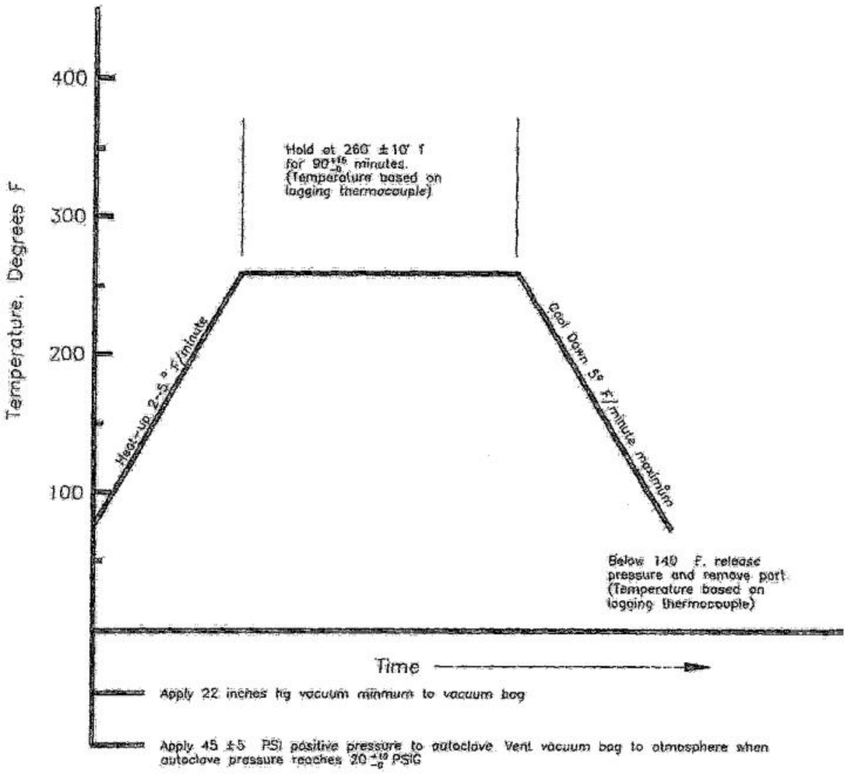
- 250°F (121°C).
- Available in aramid, glass, and carbon fabrics.
- 160°F (71°C) dry service temperature.
- Autoclave, press and vacuum bag moldable
- 10 days tack life/minimum
- 12 months shelf life at -18°C

Information about flow and cure –this is recommendation – manufacturer may find slightly different times and temperatures work well for them:

Cytec ENGINEERED MATERIALS

Cycom® 7409 Epoxy Resin

Recommended Cure Cycle:



Information or assistance is provided for your consideration without legal responsibility
Users are expected to perform adequate verification and testing to satisfy themselves that the product suits their purposes.

b.) Cool down phase

An often overlooked part of the process that can if done properly finish the making of a good pole.

If not cooled in a proper manner you can damage the composite and the pole may fail prematurely.

- *Cooling to fast can result in micro fractures*

5.) Different Materials and resins:

Basic overview of materials:

- **E-glass** *(electrical) is the most commonly used glass for fiber reinforcement and continuous fibers, in particular. An electrical grade glass good insulative properties and a relatively low cost. E-glass is a lime-aluminum-borosilicate glass.*
    - *When used today it is because of cost reasons*
    - *Will result in a slightly heavier pole*
- **S-glass** *(high-strength) has an extra high strength-to-weight ratio, is more expensive than E-glass. S-glass is a magnesia-alumina-silicate glass.*
    - *Used in the majority of top end competition poles*
    - *Different fabric/fiber counts*
    - *Gives a lighter carry weight.*
- **Carbon Fiber** *-Following taken from Toray Carbon Fibers America*
    - *Standard Modulus Carbon Fibers*
        - *T300 - Baseline carbon fiber used in aerospace applications with over 20 year service history. Has 30 year production history and is known for balanced composite properties, high quality and consistency, reliability and availability of supply. Available in 1K, 3K, 6K and 12K tow sizes*
        - *T700S - The highest strength, standard modulus fiber available, with outstanding processing characteristics for filament winding, weaving and prepregging. This never-twisted fiber is used in a variety of industrial and recreational applications, including pressure vessels such as natural gas vehicle (NGV) storage tanks and SCBA breathing tanks. Available in 6K, 12K, and 24K tow sizes.*
    - *Many use material in a tape form or all fibers in one direction*
    - *Woven material available – patent on use in pole vault poles*
    - *High Modulus Carbon Fiber not typically used – cost being one factor*

Resin Systems:

- *General Points*
  - *Elongation to fracture is greater than fiber*
  - *Supplies much of the compressive strength on the inside of the pole bend*
  - *Cure temperature easily achieved for production type environment*
- *7409 Epoxy Resin*
  - *Listed in Herb Jenks Patent*
  - *Commonly used in some vaulting poles today*
  - *Toughened resins are preferred*
- *Some 977 Series have been used*
  - *Compatibility with other systems must be verified*
  - *Toughened Epoxy Resin system*

Fabric portion: (Fiber Glass Cloth)

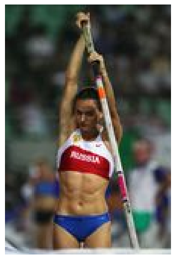
- *Fiberglass cloth is a woven fabric.*
- *In this most simple weave pattern, warp and fill yarns are interlaced over and under each other in alternating fashion. The Plain weave is the easiest to handle since it does not unravel as much as the other weaves when cut.*
- *The satin and twill weaves are slightly stronger and more pliable than the plain weave and are easier to conform to curved surface. They are more difficult to handle than the plain weave.*
- *The twill weave is more drapeable than the plain weave and maintains more fabric stability than a four or eight harness satin weave. This weave pattern is characterized by a diagonal rib created by one warp yarn floating over at least two filling yarns*

Again you can see the many variables in the material allow. What resin system with what fiber (carbon or fiberglass) and straight fiber versus woven and which woven pattern.

Different Pole Designs/Manufacturers

The following are my comments on different poles. I am an engineer, sometimes coach, Masters Multi-event person and just enjoy the sport.

I have used and coached people who have used Spirit, Skypole, Pacer, various carbon poles, Essx, some old Catapoles and even an old Gill Big Red.



Spirit (UCS)

Established manufacture that had origins with some of the original AMF Pacer guys – Steve Chappell is the big driver and big supporter of vault. Ex-vaulter.

All glass poles that are used at all levels. S-glass on most I have seen. State they have one pole design for all.

Overall, a very good product. ***Group I am working with has a mix of poles including Spirit. I would not hesitate to fill a gap in a series with another pole of this design.***

As an Engineer – dropping to a smaller diameter mandrel while going up in weight in your standard design Series is "interesting".

Petrov is a bigger backer of these poles -

Gill

Skypole ***- Been around for a long time – originally had flex numbers in inches***

Since the switch to all s-glass a few years ago, should move up on many people charts for a very good all around pole for all levels of athletes.

Lower sail center design gives stiffer lower portion – higher bend – also little more forgiving for those who take off flat or under.

Pacer FX ***– a very good durable 4 body design s-glass pole. More of a neutral sail design and placement.***

I have used and liked them and have some in our current arsenal. In some cases a slightly heavier pole than a Spirit pole.

Pacer in my opinion is an equal as far as overall poles go. Remember Bubka set his first records on Pacer.

Mystic – *similar to Pacer accept slanted towards shorter poles and lighter weights. Originally targeted for girls market, but with slight change in color now marketed for smaller vaulters and High School market.*

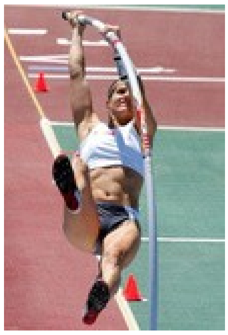
Carbon FX – *Steve Hooker, Toby Stevenson and a slew of others have used them. Very response, fast pole – uses straight carbon material along with s-glass. Lighter than all S-glass poles unless the s-glass pole is on a much bigger mandrel.*

Carbon Weave – *Anna Rogowska (Polish Record Holder), Kate Dennsion (UK Record Holder), Steve Lewis (UK top guy), some NCAA champs, a pushing the envelope pole and a pole design to minimize ovalling of the pole for a more consistent feel while taking advantage of the carbon materials steeper stress strain curve. A pole design that is more stringent in construction requirements, and thus harder to build properly. I personally like and have a bunch. More forgiving at take-off than the straight carbon Carbon FX.*

Essx

Makes vaulting poles of both all glass design and variations of carbon poles designs.

While a lot of stuff put out is marketing hype – the pole designs and construction have evolved into a very good pole. Tested some carbon poles of the later designs and they performed extremely well.



S-glass poles will behave similar to Skypole's

Essx Vaulting Poles are now being made in the same production facility as Altius vaulting poles.

Bruce Caldwell is if nothing else, a diehard track guy and vault supporter supreme. Former vaulter and owner of various vaulting pole endeavors over the years.

Altius

Much like Essx and Gill in that they have glass poles and poles that have carbon material in them.

Original roots in one of the Skypole family tree lines. Has had some ownership changes and now helps produce ESSX poles

Vaulting Poles are built in Texas and have a strong presence in Texas, Louisiana and Oklahoma.

Nordic

Also make glass and carbon poles. Poles made in Sweden, so vaulting poles are not as widely distributed in US as some of the other players.

While best known for their javelins company is making a bigger presence in the pole market.

Nordic Pole designs have had 6 meter vaults on their poles in the past just like Spirit and Pacer. Pole is being used by some of the top up and coming vaulters in Europe and Australia.

Alex Parnov who coaches Hooker, who is on Pacer Carbon FX, has his youngest daughter on Nordic poles.

Hope to have further input since the facility I will train at and help coach at will allow me to vault and observe others on the various poles as well as measure poles made by Gill, Spirit and Nordic.

Conclusion:

All of the above aim to make a good product that athlete's can use to maximize their potential.

Still come down to use what works best for you. Sometimes it may be use what is available.

Pole Failure

How and why the Pole Fails:

Poles commonly fail due to these reasons:

- ***Pole was damaged***
    - ***Spiked***
    - ***Hits standard***
    - ***Throw against something (athletes can be their own worst enemy)***

- ***Pole was overbent/overloaded***
    - ***Localized overbend***
    - ***Continued overbending – numerous times***

- ***Pole had a defect***
    - ***Usually hidden like a void or wrinkle***
    - ***Micro cracks from rapid cooling or handling before adequate cooling***
    - ***Material issue used in pole construction***

Here are some things that may give a clue or indication to what happened.

1. ***Pole fails in a single point.***
    a. ***Almost assuredly damage***
        i. ***Probably from spiking or impact with something***
        ii. ***Could be internal flaw during construction - especially if one of first vaults on pole***
        iii. ***If you miss the box and go under pit or pallets – duh***
2. ***Pole fails in two points***
    a. ***Pole was fairly heavily loaded or stressed***
    b. ***Pole could fail at a moderate bend but had been damaged or over-stressed on a previous occasion – which was really the start of the failure cycle –***
    c. ***The 2nd break usually near the hands is a result of the shock wave/energy release from the lower break – unless you have high speed camera appear to happen at same time***
3. ***Pole fails in three or more points***
    a. ***Highest probability is major overload***

Single point break – early in vault – pole not overload or overbent
Clear indication of damage like standard ding or a defect in the pole from manufacturing process

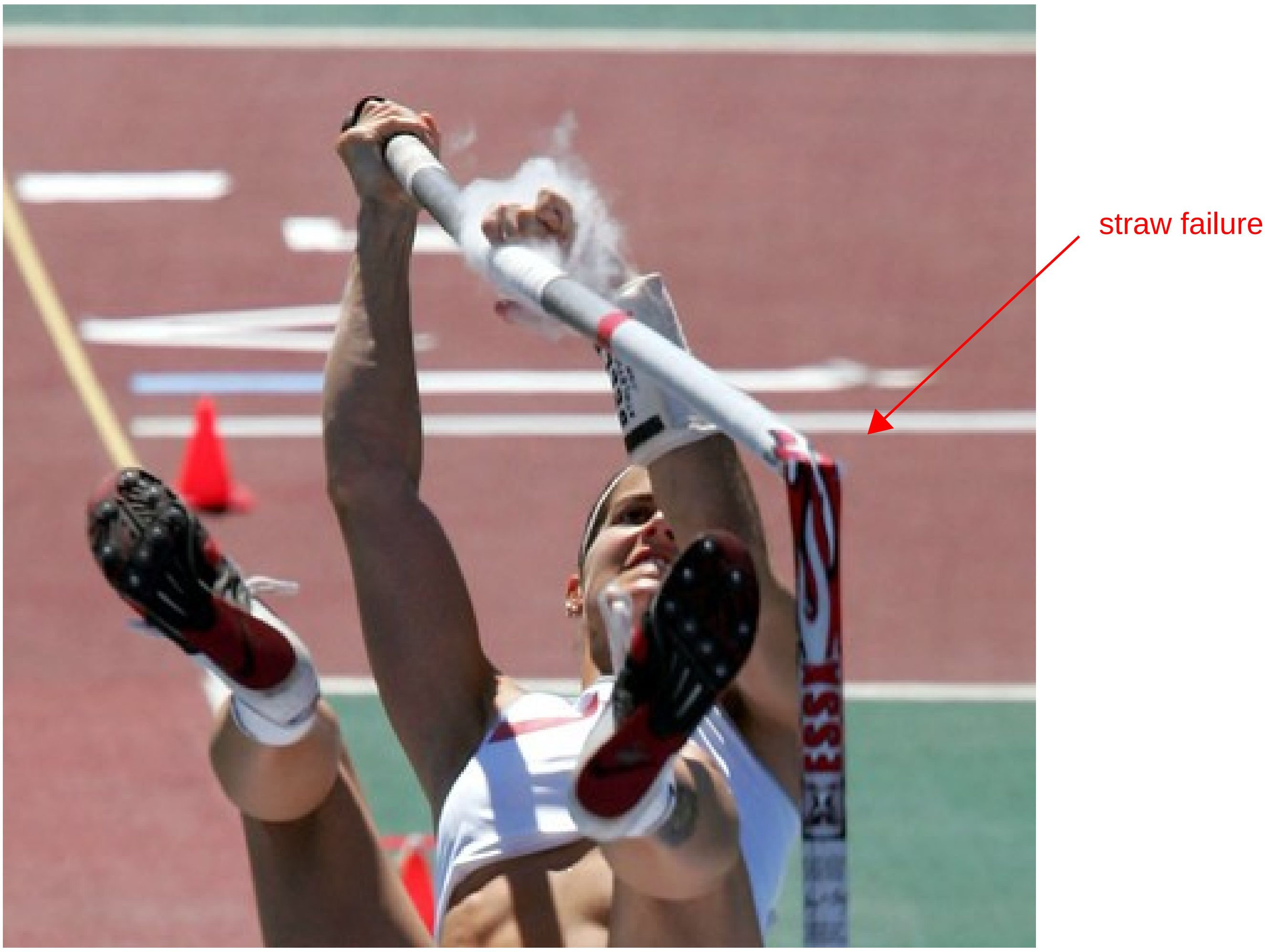
Single point break – early

Engineering View of failure:

Types we will review

- *Hoop failure*
- *Compression side cracking*
- *Fiber failure on the tension side.*

Hoop Failure: *Discussions about higher hoop strength and how a pole is constructed are common. A simple way to look at it is, as the pole bends and the load exceeds the capability of the pole to maintain its shape, as with pole or slender columns, the compression side has a tendency to collapse inward (buckle StrawFailure).*



What could have helped start this failure?

- *Damage on a previous vault – spiked – kicked*
- *Bad take-off and loaded pole beyond what hoop strength could handle*

- *Second break at hands do to first break – see previous section comments.*

Since the geometry of the pole changes when it ovals, it also serves to decrease the Moment of Inertia in the primary bend direction. Thus, as the bend gets bigger the pole actually loses strength.

This is the reason you want high hoop strength. The higher the hoop strength the more stress or load that is put on the compression and tension sides when bent. This compression, tension and ovaling is discussed in depth in the next section (pole bending).

Compression Side Cracking: *Crack the resin/glass/fibers on the Compression Side: This cracking has been observed to happen when the pole bend is large (shortening of the chord length to under 65%) and the pole has very high hoop strength, high tensile loading capability, and the compression side loads cause a crack in the resin system on the compression side.*

This pole would then fail after the pole begins to recoil or unbend. This condition of compression side cracking has been duplicated in testing and in some cases cracks are formed without total failure.

You could get this also if you damage the pole on the compression side by spiking or kicking it. You have help start a crack. While a hoop failure typical has material folding in toward the center of the pole. This type cracking gives a cleaner break.

Fiber Failure on the Tension Side: *Fiber failure has been observed to happen in dynamic test conditions when the chord length was shortened well under what any vaulter would be expected to bend or shorten a pole. In some cases the fiber failure did not result in total failure. In fact, in some of the test cases the pole recoiled or unbent, but did show some internal failure of fibers. This*

S-glass poles have a hard time stretching fibers enough for tension failure since the fiber and resin can handle more elongation than you should be able to able – unless you really localize the bend – take off real flat and drive all the bend low.