How to Make Air Muscles!

by Honus

I needed to create some actuators for an animatronics project I'm working on. Air muscles are very powerful actuators that work very similar to a human muscle and have a phenomenal strength to weight ratio- they can exert a pulling force up to 400 times their own weight. They will work when twisted or bent and can work under water. They're also easy and cheap to make!

Air muscles (also known as a McKibben artificial muscle or braided pneumatic actuators) were originally developed by J.L. McKibben in the 1950's as an orthotic appliance for polio patients.

Here's how they work:

The muscle consists of a rubber tube (bladder or core) that is surrounded by a tubular braided fiber mesh sleeve. When the bladder is inflated the mesh expands radially and contracts axially (since the mesh fibers are inextensible), shortening the overall length of the muscle and subsequently producing a pulling force.

Air muscles have performance characteristics very similar to human muscles- the force exerted decreases as the muscle contracts. This is due to the change in the interweave angle of the braided mesh as the muscle contracts- as the mesh expands radially in a scissors like motion it exerts less force due to the weave angle becoming increasingly shallow as the muscle contracts (see the diagram below- figure A shows that the muscle will contract to a greater degree than figure C given an equal increase in bladder pressure).The videos show this effect as well. Air muscles can contract up to 40% of their length, depending on the method and materials of their construction.

Gas law states that if you increase pressure you also increase the volume of an expandable cylinder (provided temperature is constant.) The expanding volume of the bladder is ultimately constrained by the physical properties of the braided mesh sleeve so in order to create a greater pulling force you need to be able to increase the effective volume of the bladder- the pulling force of the muscle is a function of the length and diameter of the muscle as well as its ability to contract due to the properties of the mesh sleeve (construction material, number of fibers, interweave angle) and bladder material.

I constructed two different sized muscles using similar materials to demonstrate this principle- they both were operated at the same air pressure (60psi) but had different diameters and lengths. The small muscle really starts to struggle when some weight is put on it while the larger muscle has no problems at all.

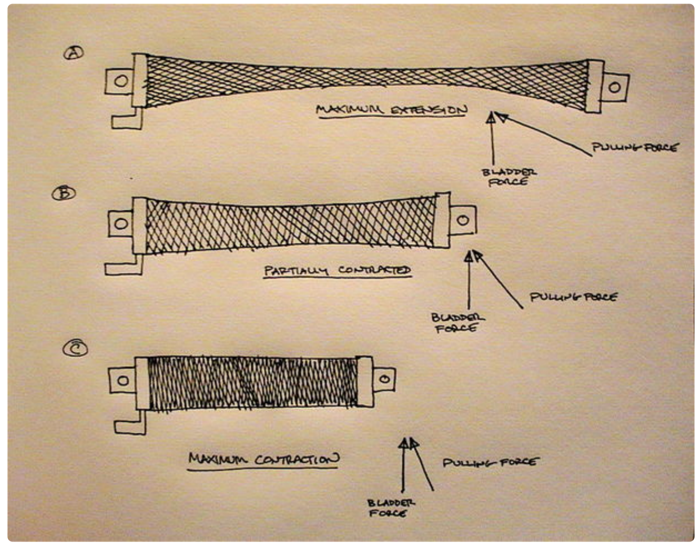
Here are a couple of videos showing both of the constructed air muscles in action.

//www.youtube.com/v/NgDPerAjVBw

//www.youtube.com/v/w77YDDTXfRc

Now let's go make some muscles!

1. 4" long air muscle
2. 8" long air muscle



Step 1: Materials

All of the materials are readily available on Amazon.com, with the exception of the 3/8" braided nylon mesh- it is available from electronics suppliers. Amazon does sell a braided sleeving kit with several sizes of braided mesh but the exact material is not stated-
Amazon

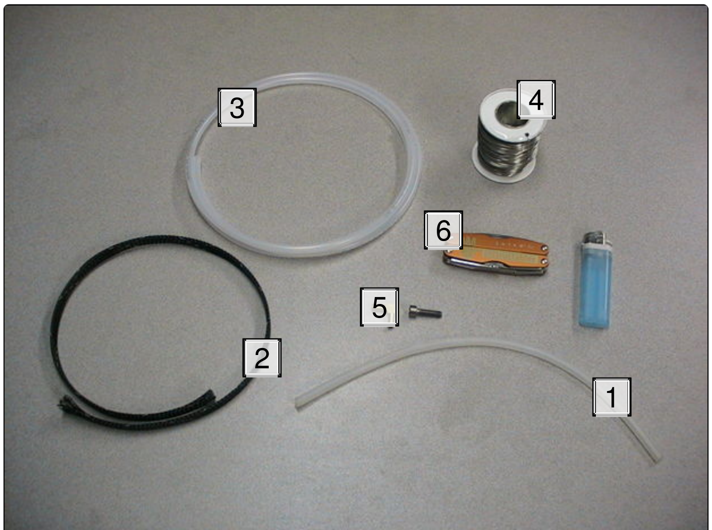
You'll need an air source:
I used a small air tank with a pressure regulator but you can also use a bicycle air pump (you will have to make an adapter to make it work with the 1/4" poly hose.
Air tank- Amazon
Pressure regulator (will require a 1/8" NPT female to 1/4" NPT male adapter)- Amazon

1/4" high pressure poly tubing- Amazon
multitool (screwdriver, scissors, pliers, wire cutters)- Amazon
lighter

for the small muscle:
1/4" silicone or latex tubing- Amazon
3/8" braided nylon mesh sleeve (see above)
1/8" small hose barb (brass or nylon)- Amazon
small bolt (10-24 thread by 3/8 in length works well)- Amazon
steel safety wire- Amazon

for the large muscle:
3/8" silicone or latex tubing- Amazon
1/2" braided nylon mesh sleeve- Amazon
1/8" or similar sized drill bit- Amazon
21/64" drill bit- Amazon
1/8" x 27 NPT tap- Amazon
1/8" hose barb x 1/8" pipe thread adapter- Amazon
small hose clamps- Amazon
3/4" aluminum or plastic rod to construct the muscle ends- Amazon

Safety note- make sure you wear safety glasses when testing your air muscles! A high pressure hose that pops off a loose fitting could cause a serious injury!



1. silicone tubing
2. braided nylon sleeve
3. high pressure poly tubing
4. safety wire
5. hose barb and bolt
6. handy dandy instructables multitool

1. 3/8" latex tubing
2. 1/2" braided nylon sleeve
3. hose clamp
1. 3/8" latex tubing
2. 1/2" braided nylon sleeve
3. hose clamp

1. adjustable air regulator

Step 2: Making the Small Muscle

First cut a small length of the 1/4" silicone tubing. Now insert the small bolt into one end of the tubing and the hose barb into the other end.

Now cut the 3/8" braided sleeve about two inches longer than the silicone tube and use a lighter to melt the ends of the braided sleeve so it doesn't fray apart.

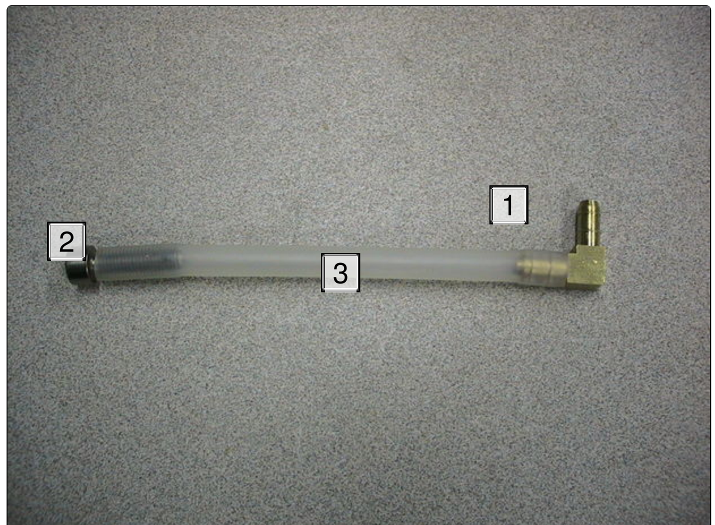
Slide the braided sleeve over the silicone tubing and wrap each end of the tube with the safety wire and tighten it.

Now make some wire loops and wrap them around each end of the braided sleeve. As an alternative to using wire loops on the ends of the muscle, you can make the sleeve longer and then fold it back over the end of the muscle, forming a loop (you have to push the air fitting through)- then tighten the wire around it.

Now connect your 1/4" high pressure tubing and pump a little air into the muscle to make sure it inflates without leaking.

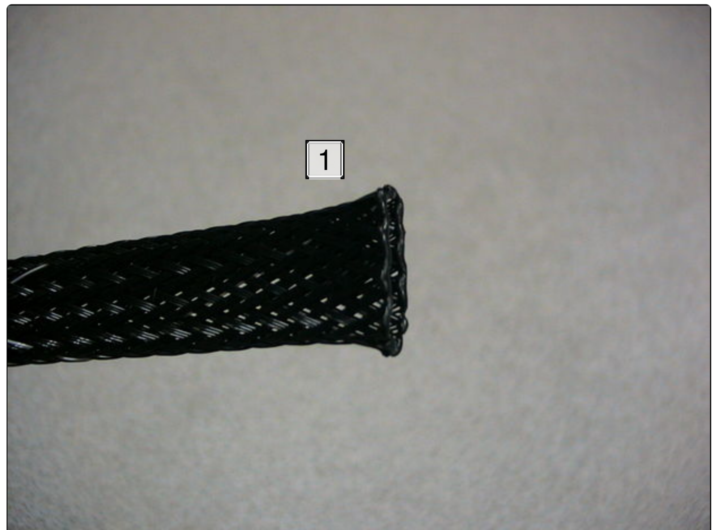
To test the air muscle you have to stretch it to its full length by putting a load on it- this will allow it maximum contraction when it's pressurized. Start adding air (up to about 60psi) and watch the muscle contract!

1. silicone tubing



1. hose barb
2. bolt- this should be a snug fit
3. 1/4" silicone tubing

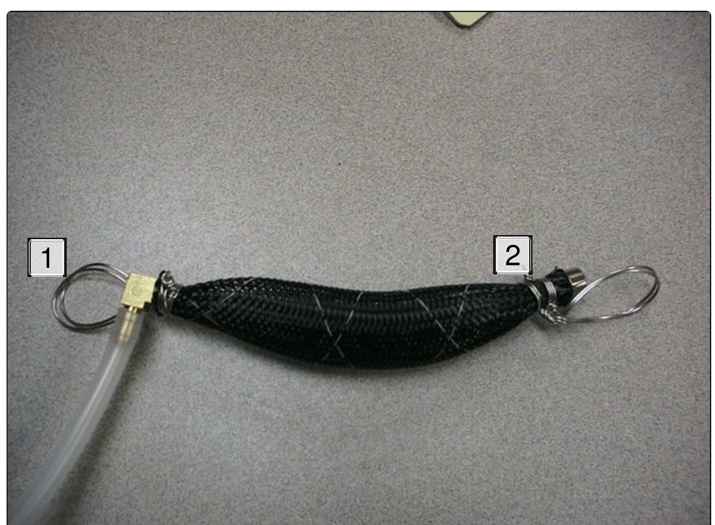
1. 3/8" braided nylon sleeve



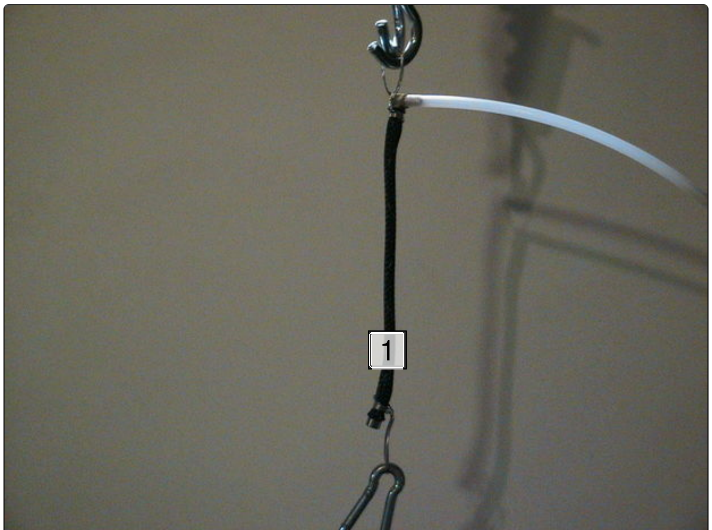
1. melt ends of sleeve with a lighter

1. wrap ends with safety wire and tighten

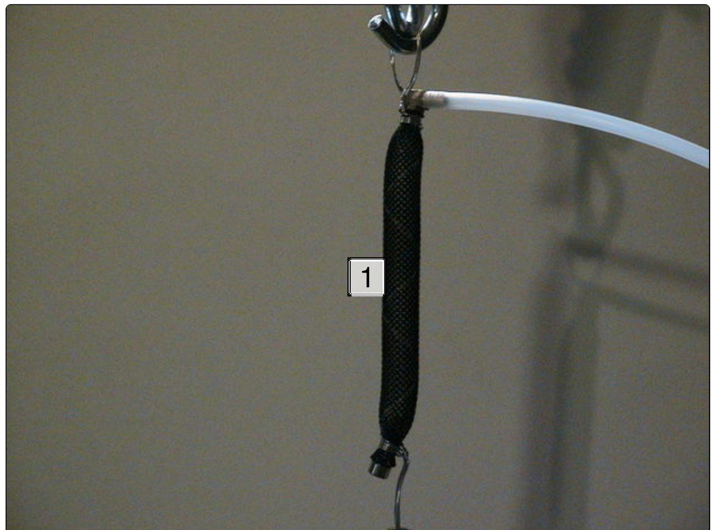
1. make loops from safety wire



1. connect high pressure poly tubing
2. wrap safety wire loops around ends of muscle



1. muscle fully extended under tension



1. air muscle fully contracted @60psi

Step 3: Making the Large Air Muscle

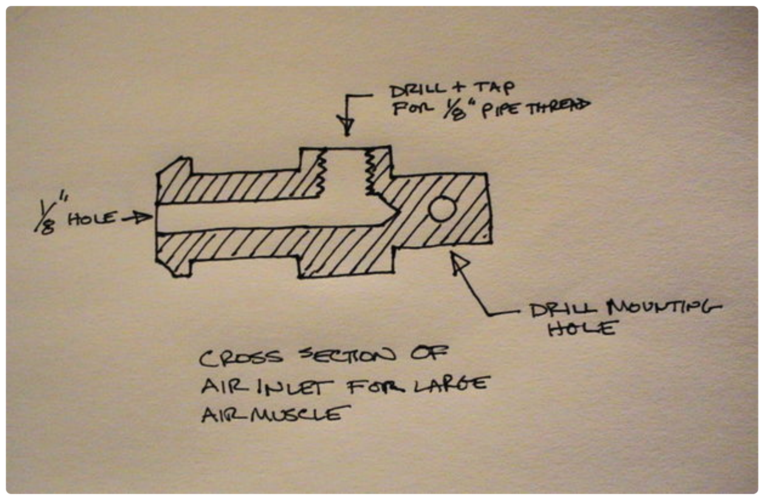
To make the large muscle I turned some barbed ends from some 3/4" aluminum rod- plastic will also work. One end is solid. The other end has a 1/8" air hole drilled in it and then is tapped for a 1/8" hose barb pipe thread adapter. This is done by drilling a 21/64" hole perpendicular to the 1/8" air hole. Then use a 1/8" pipe thread tap to tap the 21/64" hole for the hose barb fitting.

Now cut a 8" length of 3/8" rubber tubing for the air bladder and slide one end over one of the machined fittings. Then cut some 1/2" braided sleeve 10" long (remember to melt the ends with a lighter) and slide it over the rubber tube. Then slide the opposite end of the rubber tube over the remaining machined air fitting. Now securely clamp each end of the tubing using hose clamps.

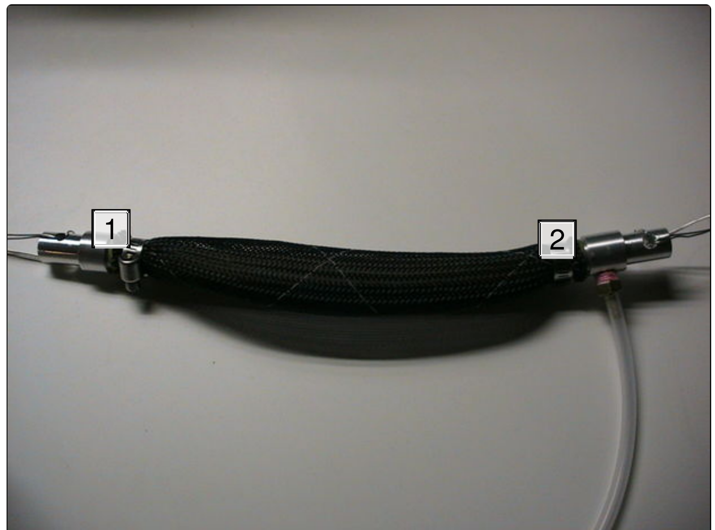
The larger muscle works just like smaller version- just add air and watch it contract. Once you put it under load you'll immediately realize this larger muscle is much stronger!

1. solid end machined from aluminum but plastic will also work
2. This hole is for mounting the air muscle

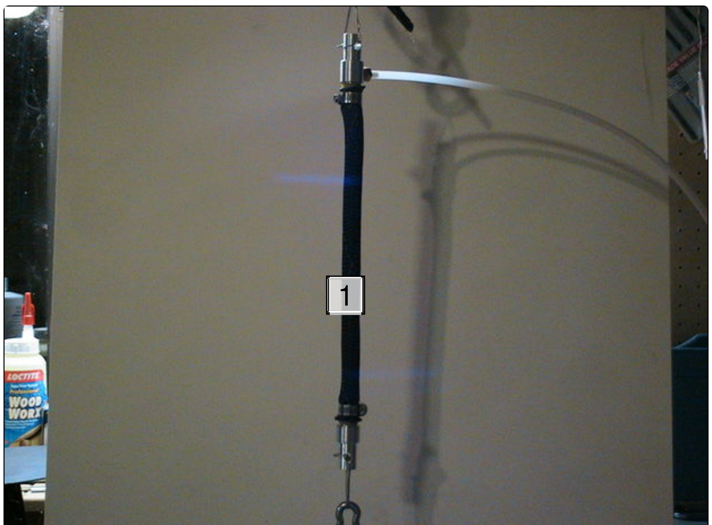
1. drill 1/8" hole for air entry- make sure the hole is deep enough to allow for air entry from the barbed fitting



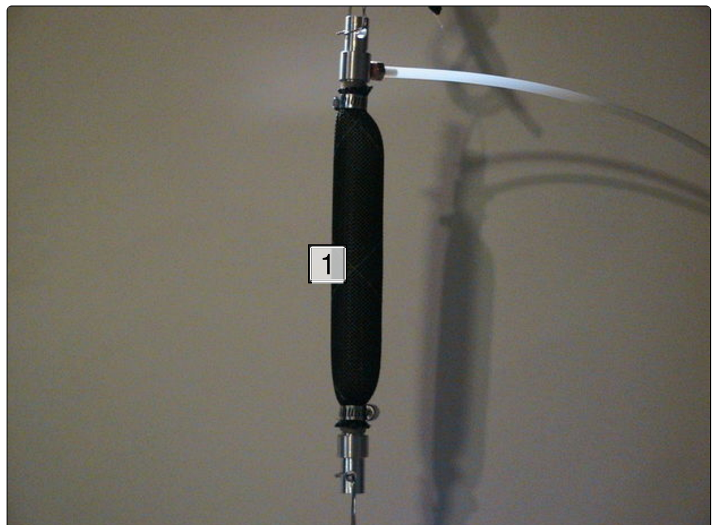
1. drill and tap for 1/8" pipe thread hose barb- make sure air flows through into tube!
2. This hole is for mounting the air muscle



1. ends clamped with hose clamps
2. connect high pressure poly tubing to hose barb



1. air muscle fully extended under tension



1. air muscle fully contracted @ 60psi

Step 4: Testing and Additional Info

Now that you've made some air muscles it's time to put them to use.

Stretch out the muscles so they reach their maximum extension by adding weight. A good test rig would be to use a hanging scale- unfortunately I didn't have access to one so I had to use some weights. Now slowly start adding air in increments of 20psi until you reach 60psi.

The first thing you notice is that the muscle contracts a progessively smaller amount with each incremental increase in air pressure until it fully contracts. Next you'll find that as the load is increased the ability of the muscle to contract decreases at an increasing rate until it can no longer lift the increased load. This is very similar to how a human muscle performs.

It is immediately noticeable that a change in the size of the muscle has a huge effect on the performance of the muscle. At 22lbs. @60psi, the smaller muscle can still lift, but it is nowhere near obtaining full contraction while the larger muscle can very easily obtain full contraction.

The dynamics of air muscles are fairly difficult to mathematically model, especially given the number of variables in their construction. For further reading I recommend having a look here:
http://biorobots.cwru.edu/projects/bats/bats.htm

Several applications of air muscles include robotics (especially biorobotics), animatronics, orthotics/rehabilitation and prosthetics. They can be controlled by microcontrollers or switches using three way solenoid air valves or by radio control using valves operated by servos. A three way valve works by first filling the bladder, holding the air pressure in the bladder and then venting the bladder to deflate it.

The thing to remember is that air muscles must be under tension to work properly. As an example two muscles are often used in conjunction to balance each other to move a robotic arm. One muscle would act as the bicep and the other as the tricep muscle.

Overall, air muscles can be constructed in all sorts of lengths and diameters to suit a wide variety of applications where high strength and light weight are critical. Their performance and longevity varies according to several parameters regarding their construction:

1) Length of muscle
2) Diameter of muscle
3) Type of tubing used for bladder- testing I've read states that latex bladders tend to have a longer service life than silicone bladders, however some silicones have greater expansion rates (up to 1000%) and can hold higher pressures than latex (much of this will depend on the exact tubing specification.)
4) Type of braided mesh used- some braided meshes are less abrasive than others, improving bladder life span. Some companies have used a spandex sleeve between the bladder and mesh to reduce abrasion. A tighter woven mesh allows for more even pressure distribution on the bladder, reducing stress on the bladder.
5) Pre stressing of the bladder (the bladder is shorter than the braided mesh)- this causes a reduction of contact area (and hence abrasion) between the bladder and braided mesh sleeve when the muscle is at rest and allows the braided mesh to fully reform between contraction cycles, improving its fatigue life. Pre stressing the bladder also improves the initial contraction of the muscle due to initial lower bladder volume.
6) Construction of muscle end housings- radiused edges reduce stress concentrations on the bladder.

All in all, given their power to weight ratio, ease/low cost of construction and ability to mimic the dynamics of human muscles, air muscles offer an attractive alternative to traditional means of motion for mechanical devices.

Have fun building them! :D

Also to make up air, same as electric car braking, high pressure air pump in legs. May be use the air out to the pump's intake too.

Not sure if my post went up or not but make a voltage controlled air regulator. A solenoid coil pulling on the spring or acting like the spring of a regulator.

What solenoids would you recommend to use these with?

I've thought about doing this for the past 30 years. After seeing how a building automation systems works and control the air. You'll have to control the air pressure. Make a voltage controlled regulator for air. A small coil controlling a regulator spring, now you'll have to make many one for each muscle. You might have to make a pilot type valve so you can move much more air faster.

Also the paint ball air high pressure tanks (4500 psi) hold more air than co2 I think. Don't forget about pressure safety use a pressure relief valve 4500 in most things = bad!!!!!!! Even from co2 at 800 or 900 psi can bad very bad!!!!

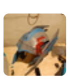
To get more air added to your tank think about adding a high pressure pump to legs???? It could pump air if going down stairs like electric car braking, right? Even take air coming out of muscles to intake of pump or have a higher than outside air tank for pump intake to help pump. Even having air at 20 or 40 psi will help the pump. Now this might hurt in other ways and you may need to dump air in that tank over 20 or 40 psi to keep air moving as fast as it needs.

I have been thinking of building an exo-suit, and these might just be the ticket. I bet paintball CO2 tanks would work great for this too.

i've been working on prototypes for over 5 years now. designing and redesigning parts. the problem with these is they need constant replenishment of lost air, because when the muscle deflates, the air escapes, it doesn't return to the tank. having more power with these would require a fair amount of pressure. which means a more powerful compressor. how are you not only gonna carry it, but power it as well? in all honesty, a linear motor design for the joints still works best. the only limiting factor here being how are you gonna carry enough power with you for extended use? and let me know if you figure that one out...

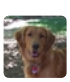
Hmm, these are interesting points. Thank you for the advice! I don't know much about these, but I would assume a regulated SCUBA or CO2 tank would last at least a little while. With linear motors, you would still have to carry a battery pack, and linear motors move much slower than air muscles. I guess each has there pros and cons. Thanks again!

A faster displacement can be achieved with a wider thread. this would come at the cost of power. In creating such a suit you'll have to balance power and speed. imho, if the actuators used can support running at roughly 18 km/h (or 11 mph) they are fast enough, the rest of the gears should be configured to provide additional strength. it's all about how much energy can you pack on board and how you convert it. assuming you're wanting the same as me, about the size of medieval armor, the most efficient way we know goes out the window, fuel, next in line is electricity, which comes in batteries, which can packed in pretty much everywhere, and linking them in a specific way can make 2 1,5V batteries 1 3V battery, etc. if you'd like to discuss the topic further, i'm on facebook, my name is Kevin Kuyl, i'm from the netherlands. that should be enough to find me. there's just way too much material to cover and i'd love to talk about this with some one, all my friends think i'm nuts :P



That's a lot simpler than I thought it would be. I can't imagine how I'd find a use for those, but someone is gonna figure out how to put those to work!

Hey there, I made an exo arm in which is like to include a pneumatic muscle. Probably the small one. But I was really wondering if I could you co2? Mainly because I can fit the cartridges right into the arm. Please let me know and I greatly appreciate it.



I can't see any reason why that wouldn't work.

Okay great! This is my first attempt as this air muscle stuff, so I was wondering if you could please tell me how I'd go about the co2 cartridges instead of air tank? Sorry for being a pest, I just want to make sure it's done correctly. Thank you!

Ok I get how to make the muscle but how do you go abouts making an exo-arm

They should easily handle 2 bar pressure.

Guys can someon tell me if it's possible to connect ot to the human body?

i've actually done such a thing. You can see a video of it here: https://www.youtube.com/watch?v=ehh1Idim8H4

HII AIDAN

you could have two velcro straps on the limbs and it would pull them together

Ola Im brasilian..minha duvida e se a capa de nailon tem que ser espesifica

how can i conect it to the human body?

Does anyone have any ideas/pointers on how the system could be made quieter?

You could put something like a small filter or a baffle over the air exhaust port to quiet it.

Maybe even a closed-loop system of some sort?

Do you have any info on how to control multiple air muscles via a micro controller, such as an Arduino?

The easiest method would probably be to connect multiple solenoid air valves to the Arduino output pins with a transistor to turn each valve on and off.

Do you know of anyone that sells VERY SMALL solenoid valves for use in this way? I looked in my Jameco Electronics catalog, and they only have ONE solenoid valve for sale, and it's like 1.2". Looking for something much smaller that also uses less power.

ALSO, do you think "air muscles" could be used with water inside rather than air? My intention is to make an extremely smooth operating cluster of "muscles", that mimic biological organisms accurately.

Thanks sooo much for your help!!!

i see you are trying to build a muscular system for an robot of some sort that moves and function like the real thing. EXCELLENT! do you have any interests what so ever in exo-suits?

I would just do a search for micro or subminiature solenoid valves. Most really small valves can't handle high pressure though.

You might be able to use water inside but I really don't see any advantage as you're adding a fair bit of weight and you would need a pump. If you want to go that route it would probably just be better to use traditional hydraulic cylinders.

Wow, amazing Instructable, wonder why they were never used in robotics.

Several companies have use them (Festo immediately comes to mind) but they are nowhere near as common as traditional electric motors or even hydraulics. You have to have an application that specifically requires their particular properties.

Because they are very hard to control.

Expanding on something mentioned here, would it be possible to run these using water? What sort of pump would you need? My thoughts are that a small pump would be more portable than an air compressor and a tank.

if accurate-yes

I don not know where to buy materials in Peru. Maybe try a hardware store or a place that sells aquarium supplies?

as it would be for you to bring it to the silicone tube peru because I find

Sorry I don't understand. Are you looking for silicone tubing in Peru?

Honus thank you tell me where each material conseguistes especially the silicone tube and not the meeting and thanks in advance

could give me the exact link of the materials or detallarmelos nesecito thanks in advance what to draft an exoskeleton

All of the materials are listed in Step 1.

me podrian dar exactamente el link de los materiales o detallarmelos gracias de antemano lo nesecito para un proyecto de un exoesqueleto

what does the strength of the muscle depend on?

The pulling force of the muscle is a function of the length and diameter of the muscle as well as its ability to contract due to the properties of the mesh sleeve (construction material, number of fibers, interweave angle) and bladder material.

Hi i was just wondering how you managed to get the aluminium at the ends of the muscle into the shape they are, did you buy them like that or what?

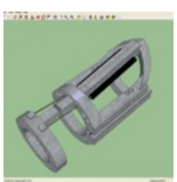
Thanks in advance

I turned them from Aluminum rod using a lathe.

i remember seeing this instructable when it was first shown in the email send out as a featured ible and i favorited it, i have now come back and am designing a "gauntlet" that someone puts their arm into and the muscle will hopefully add to the strength of their motion, thank you for the inspiration.

That sounds like a really cool project- make sure to post pics or video when it's done!

here is what i have so far for a design for a bicep, what do you think?



I think it needs a rotational joint at the elbow. And the cables should be attached to a disk or something to translate the contraction of the muscle into torque.

If this works out, do you plan to extend the exoskeleton to more body parts? I just read Wearable Robots: Biomechatronic Exoskeletons and I suppose I'm interested in working on the same sort of thing. Also, I just found this website, are other people here working on exoskeletons?

I would love to turn this into an exoskeleton (and hope to), the problem I' ve had is cost so far, so a decent amount of time is taken saving up for the different parts.

You should enter the Jack Daniel's contest. $25,000 would buy a lot of parts.