Concept Generation and Selection

EML 4551C – Senior Design – Fall 2011 Deliverable

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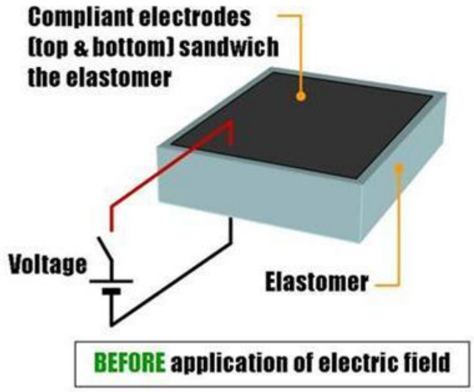
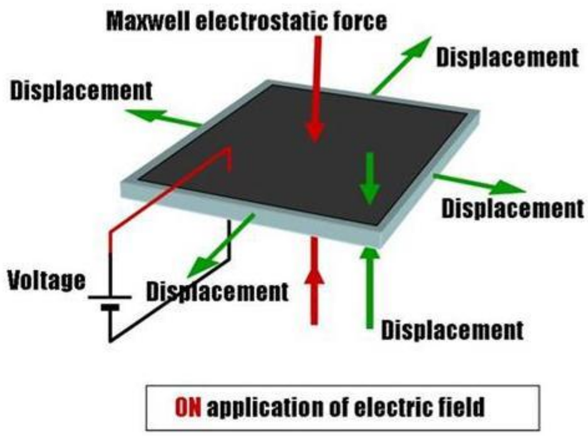
Introduction

Our project is sponsored by Air Force Research Laboratory Munitions Directorate at Eglin Air Force Base in Pensacola, Fl.

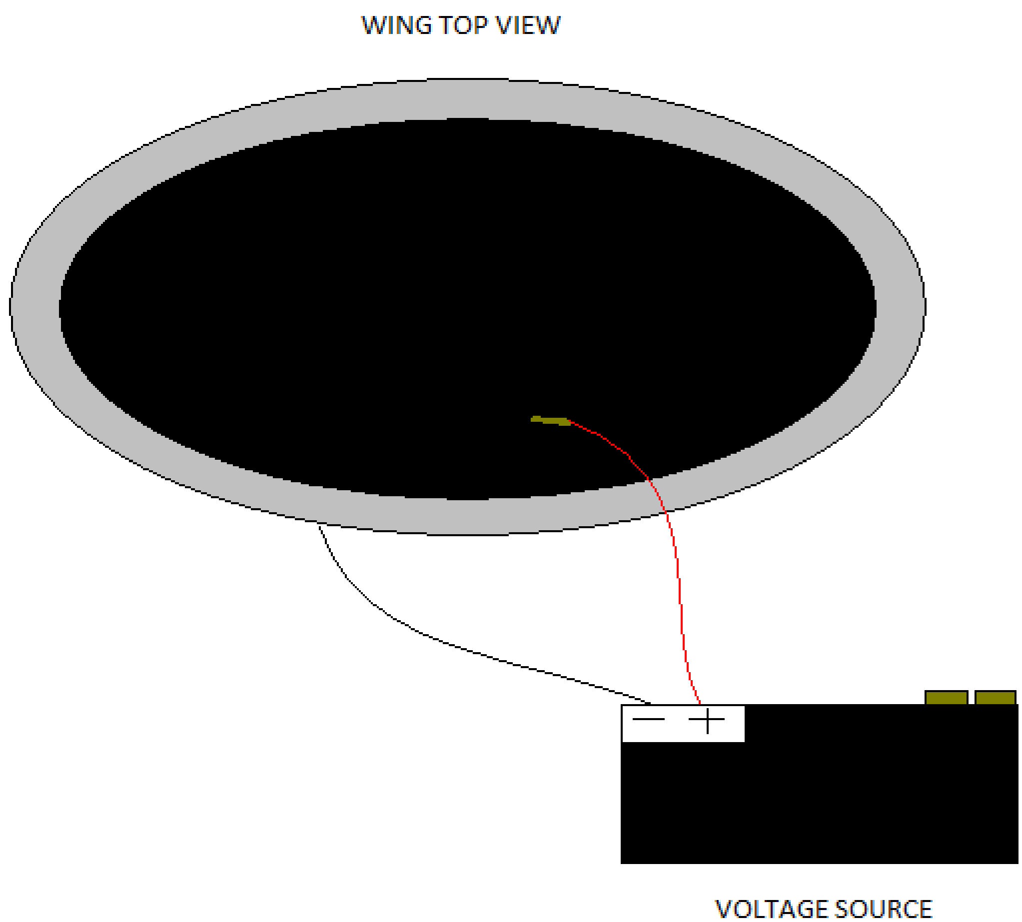
The purpose of this project is to design an electro-active membrane for micro air vehicles. We want design a light membrane that enhances the aerodynamic properties of the micro air vehicles. These electro active membranes, when voltage is applied, experience a force on both sides compressing it. This compression causes displacement throughout the surface. Throughout this report we will present multiple concepts which try to achieve better flight characteristics for micro air vehicles. We will compare these results to rigid wings, which are currently in use for these micro air vehicles, to determine the effectiveness of our membranes. A large increase in lift is something of great importance to us when considering designs.





Concept 1

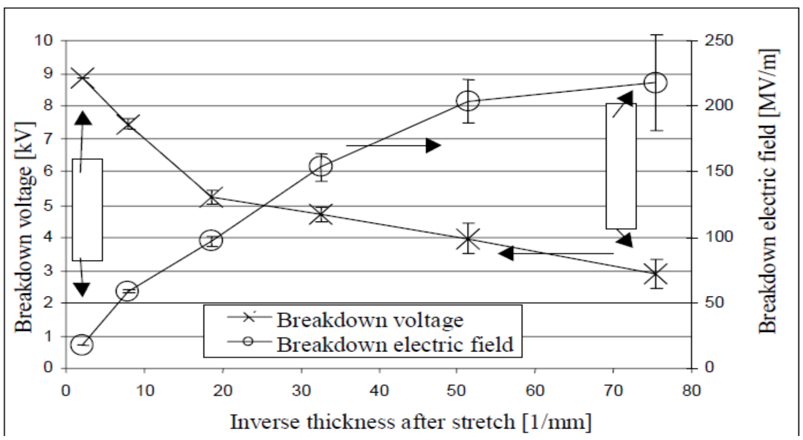
Concept 1 consists of the same aluminum elliptical frame that will be used for each concept. It has dimensions of 20cm by 10cm along the major and minor axis. The elliptical shape closely resembles a combination of an airfoil and an MAV wing and is appropriate for testing purposes. VHB (Very High Bonding) 4910 tape will be used as the dielectric elastomer because it is extremely elastic, has a high elastic energy density, high electric breakdown strength and through past research deems the best material for this experiment. This will be the medium for the carbon conductive grease, which is electrically conductive and will allow voltage to flow across the VHB tape. The carbon grease will be applied to the top and bottom of the VHB tape and a will have a positive and negative charge hooked up to the top and bottom layers of carbon grease. The carbon grease will be applied in a centered elliptical shape similar to the frame but with less area.



Concept 2

This concept involves a variation of the VHB pre-strain from the concept 1 value of 300%. Concept 1 data indicates a significant increase in flight characteristics (specifically the coefficient of lift) with increasing voltage, however applied voltage is limited by the potential for catastrophic failure of the membrane due to electric breakdown. A basic relationship between the strength of the dielectric ( ), strain ( ), membrane thickness at pre-strain ( ), and breakdown voltage ( ) is given as:

This relationship is empirically verified for VHB 4910 and the plot is depicted below.



(**Site for image:** http://130.226.56.153/rispubl/POL/polpdf/spie4329.pdf)

This indicates an increase in pre-strain will both increase the dielectric strength (i.e. resistance of the membrane to failure via electric breakdown) and decrease in the voltage required to incite this breakdown due to reduced membrane thickness.

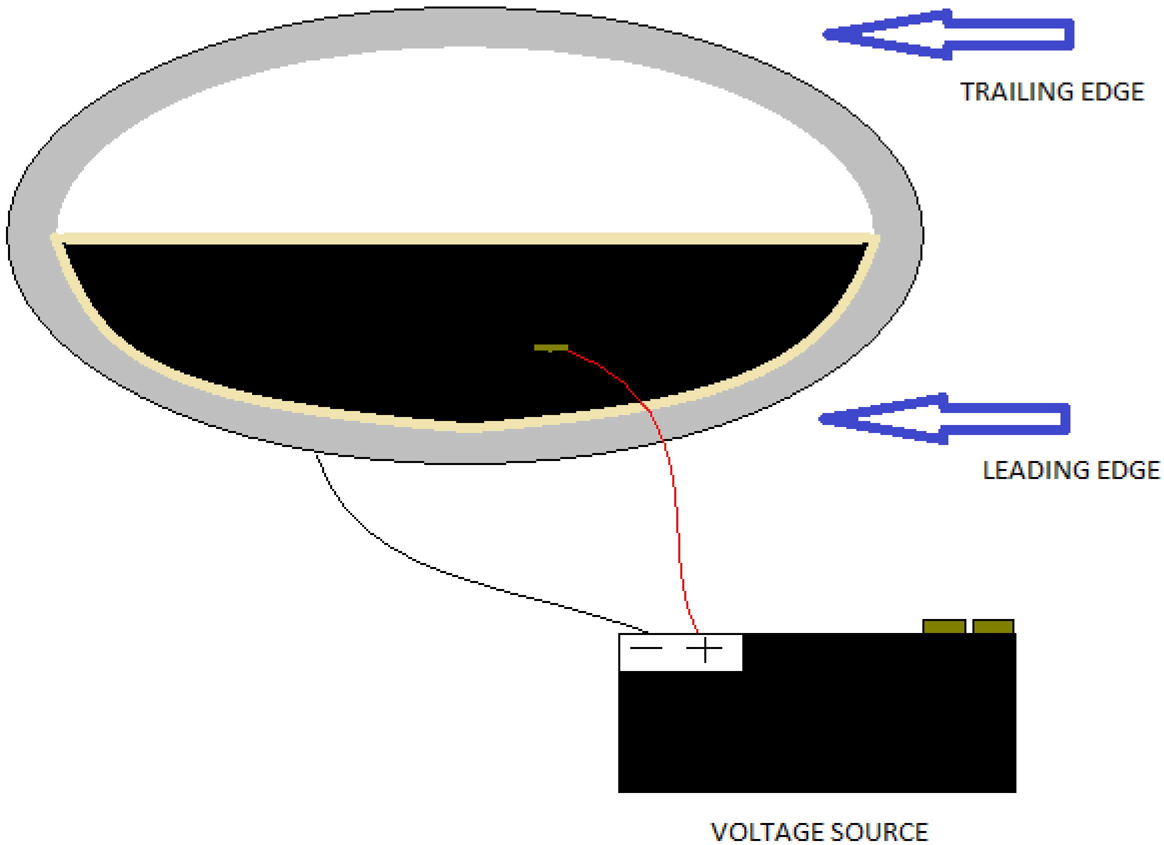
Ensuring the breakdown voltage is greater than the applied voltage at the onset of electromechanical or "pull-in" instability is vital in avoiding catastrophic membrane failure. Thus, we may optimize the pre-strain value by noting empirically the failure strain to pre-strain ratio, and plotting it against varying values of pre-strain. The maximum of this plot will occur at the optimized value of pre-stretch, and will ensure that the membrane will sustain the greatest amount of voltage and deformation before failure, thereby maximizing the potential for change in flight characteristics

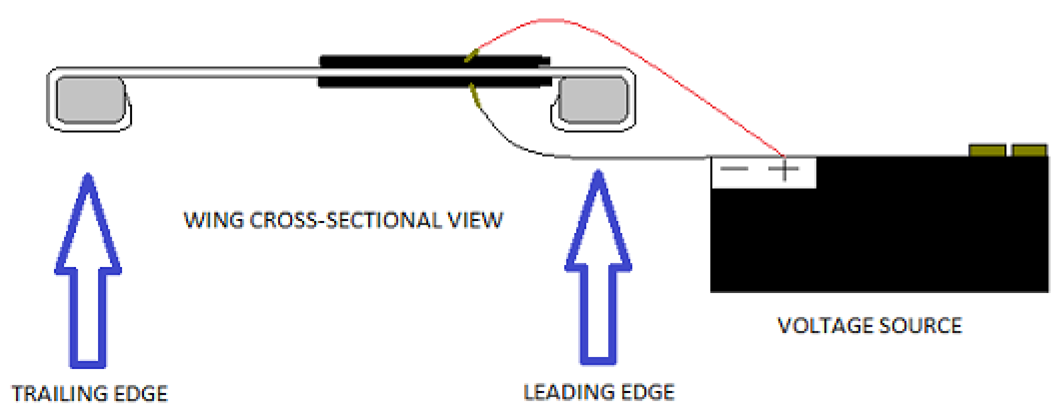
Concept 3

Similar to the Concept 1 design, Concept 3 continues to build off of the elliptical frame. Like Concept 1, VHB tape is stretched to a strain of about 300% over the aluminum elliptical frame. However, in contrast to the design for Concept 1, Concept 3 takes a variable approach to the application of the carbon grease. Rather than applying the carbon grease to the entire top and bottom surfaces of the wing membrane, the carbon grease will be applied only to a certain area of the wing. Localizing the carbon grease to a certain area, it is our intention to concentrate deformation only to specific areas of the wing. However, despite the simplicity of this approach, in practical application simply applying the carbon grease to a certain area is insufficient. Doing this, any deformation felt by the area affected by the carbon grease will simply displace into the rest of the membrane, thusly the concentrated deformation we sought to observe becomes indistinguishable. In order to achieve localized deformation, the creation of a boundary around the area of desired concentration is needed. Using an adhesive like glue, we can bound the area of desired deformation which will prevent any unnecessary displacement from the concentrated area of deformation. Through basic aerodynamic principles, we know that the geometry of an airfoil plays a large role in flow separation and flow reattachment. Any geometry towards the leading edge of the airfoil will play an important role in flow separation and reattachment. So it is our intention to localize carbon grease towards the leading edge of the wing in order to capitalize on the membrane deformation to achieve reattached air flow.

Some positive aspects of this design are control over the application of carbon grease. This allows us to control the location of deformation in order to appropriately influence air flow. In theory, this could increase the critical angle of attack before stalling and help with gust alleviation. In a cost effective sense, this concept will most likely use less carbon grease than the original design, so the cost of carbon grease should reduce. A negative aspect of this design is that the glue needed to bound the area of deformation could increase the weight of the structure, however it is important to note that the weight reduced by using less carbon grease could counteract this effect. In addition, this concept has no preliminary empirical data because this concept has not been tested before. Therefore it is important to conduct some experimentation on this design to see where it truly places amongst the other concepts.

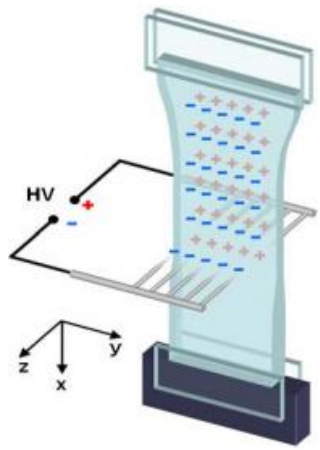
WING TOP VIEW





Concept 4

The concept of Röntgen's electrode-free stimulation of a membrane allows for many benefits. The technology, as we would apply it, would incorporate impingement of oppositely charged ions into opposing sides of the pre-stretched elastomer under the influence of an applied voltage (to maintain polarity of impinging charges). This is accomplished using corona discharge technology as illustrated below.

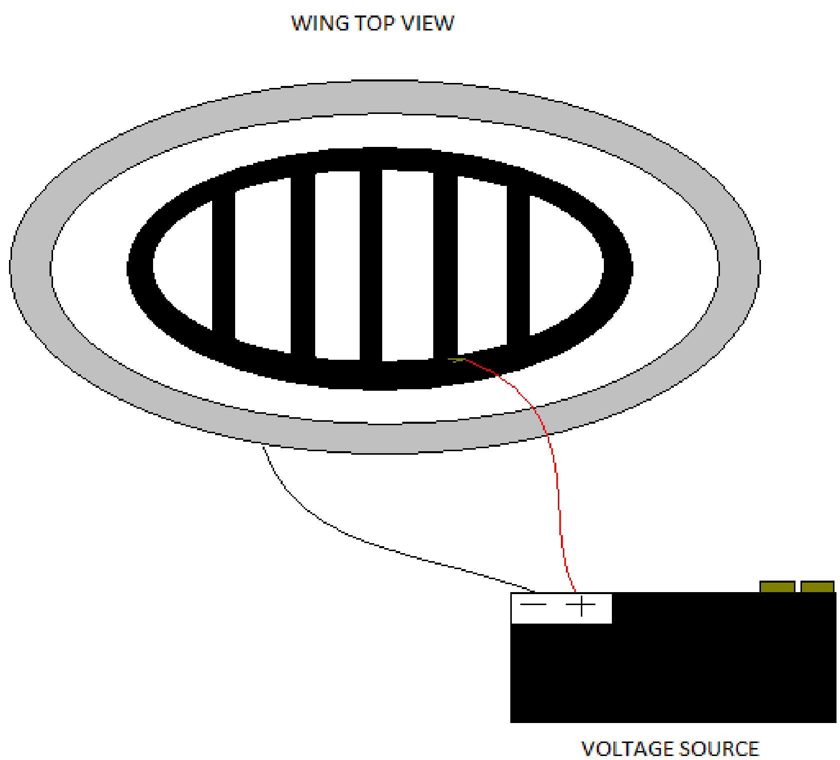


(**Site for image:** http://www.pnas.org/content/107/10/4505.full)

The electrode-free design would greatly improve the capacity for cyclic loading of the membrane, as the embedded charges would be far more compliant than the carbon grease. The potential for degradation of the electrodes is non-existent, and much higher voltages and electric fields would be encountered before breakdown due to the nature of the "trapped" surface charges. Electromechanical instability should also be substantially reduced. Disadvantages of the concept include the increased difficulty of the modeling equations (charge symmetry about membrane not as concise) and access to the corona discharge technology would likely put us well beyond our budget and experimental capabilities. Also the process of the corona discharge results in hazardous bi-products such as ozone and nitrous oxide.

Concept 5 (Failed Concept)

This concept utilized an alternative application of carbon grease to try and achieve superior aerodynamic and structural properties. We wanted to do this by applying less carbon grease to attain similar results to Concept 1. In doing so, we would also be using less carbon grease making the membrane lighter. After speaking with Dr. Oates, he suggested this concept would not be ideal because without bounding the carbon grease, there would still be displacement felt throughout the whole surface. We did not consider this when originally designing this concept, we did not think of constraining the carbon grease to localize the displacement. Because we did not consider the displacement that would occur throughout the whole surface, this concept itself was deemed a failure by our group. Even though this concept failed, it allowed for a new concept to flourish in Concept 3 and allowed us to learn more about how our membrane would behave.



Decision Matrix

	Weight	Concept1	Concept 2	Concept 3	Concept 4	Concept 5
Assembly	0.15	7	5	6	7	6
Material Availability	0.15	9	9	9	3	9
Cost	0.1	8	8	8	5	9
Total Weight (Excluding Frame)	0.2	6	6	7	9	7
Electric Breakdown	0.15	6	9	5	8	6
Deformation	0.25	7	9	4	8	1
Total	1	7.05	7.7	6.2	7	5.7

Conclusion

Due to the amount of preliminary empirical data at our disposal, we are unable to narrow down which concept is truly the ideal concept to choose for optimizing our sponsor desired needs such as gust alleviation and improved modal frequency. Certain concepts have only material data such as with Concept 2 and 4, where only data on material properties have been research. This data displays no indication of its actual performance when it is implemented as a membrane for an airfoil under and induced air flow. There is little empirical data for Concept 3 as well since it has not been tested before. In addition, Concept 5 is obviously an impractical concept considering without creating boundaries, the deformation effects will simply displace into the rest of the membrane and would achieve less deformation than the original design. However, based off of the limited preliminary data we currently have, theoretically Concept 2 has the greatest potential out of all the current concepts. At this point Concept 2 would be the ideal choice. Since the basis of the project is to improve upon the original design, experimentation on each concept we have generated is necessary in order to truly narrow down an ideal design for our sponsor. In addition, this field of research is relatively new having been around for only a few years. Any results or data we may gather from these experiments may prove to be valuable to this particular field of research.