

# Theoretical Calculation of Lift Force for Ideal Electric Asymmetric Capacitor Loaded by High Voltage

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## Abstract

Asymmetric capacitor like the so-called lifter can fly up from the ground. Some common characteristics exist in the asymmetric capacitor: high-voltage, capacitor, lift force. What are the accurate quantitative relations among them and how can we figure the lift force out? It's a thorny problem so far. In this article, we attempt to establish a model that can match the actual experimental data and theory derivation result. After checking, the calculation result is verified to be correct.

## Keywords

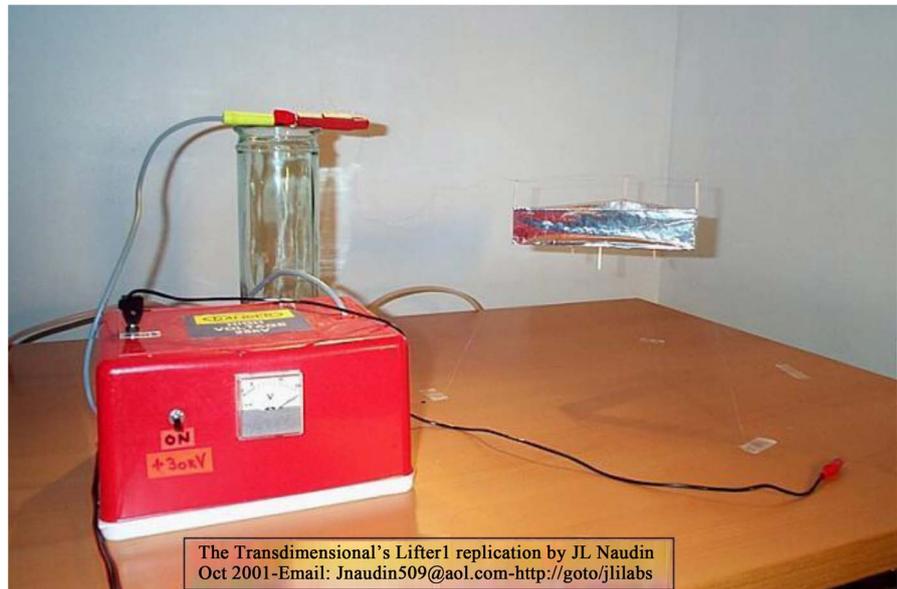
High-Voltage, Asymmetric Capacitor, Lift Force, Calculation

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## 1. Introduction

Hairs loaded high-voltage [1] can float up in air. Consisted of balsa wood, fine cooper, and aluminum foil, so-called lifter (refer **Figure 1**) can get off the ground after loading more than a high-voltage of 20 kV [2] [3]. We attempt to find out the rules hid behind the phenomena about what are the dominant factors that affect the lift force [4]. So we can further adjust the factors to enhance the force.

It is clear that the lift force tends to be positively correlated with the high-voltage in condition of under the breakdown voltage loaded between the 2 electrodes. There are two respects included in the words: 1) higher voltage input means greater force output; 2) the high-voltage loaded between the electrodes



**Figure 1.** A lifter flying up loaded with high-voltage power.

can't be too high leading to breakdown. The voltage is limited by the breakdown voltage in air, and so does the lift force. The important work is how to get the maximum force at the highest voltage below breakdown. Are there any other methods to break through the limit, so that we can enhance the output of force?

Different from the methods that exist nowadays [5], we provided a simpler and more accurate way. The method is established on hypotheses. By a series of theoretical derivation, we turn out a brief result for calculating the lift force. After comparing with experimental results, the validity of the calculation result is verified.

## 2. Description of Problem and Overview of Result

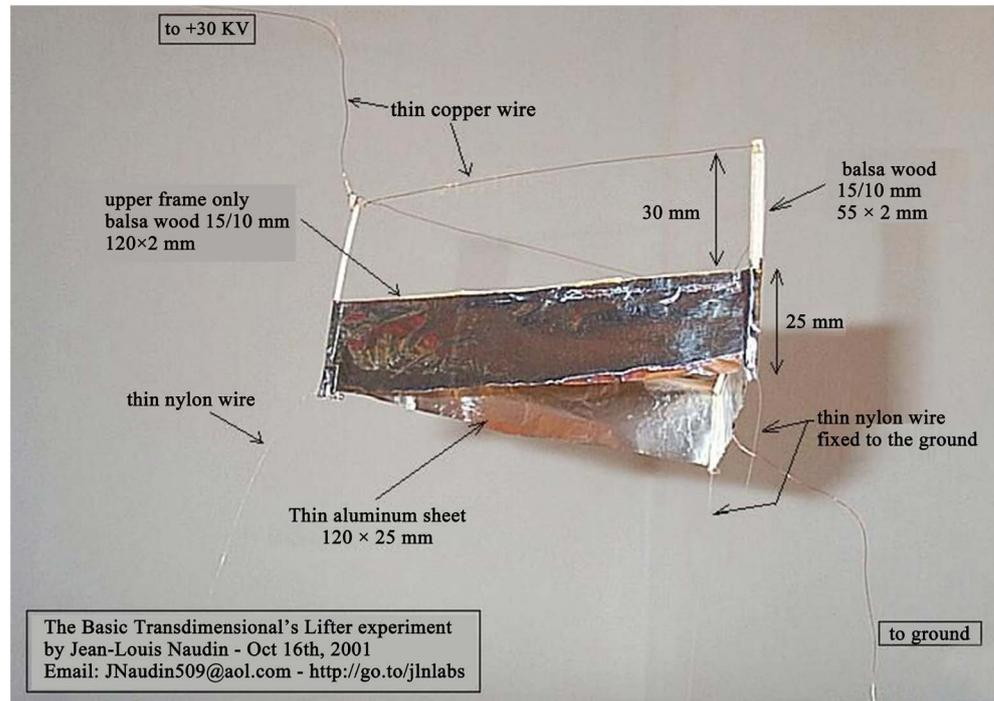
### 2.1. Problem Description

The original problem we described is as follows:

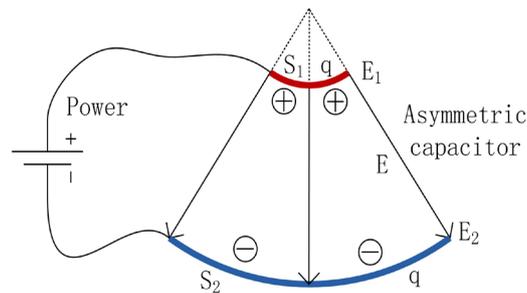
When we load 20 kV high-voltage on an asymmetric capacitor like as lifter (refer **Figure 2**), a thrust [6] is produced on the lifter. The force direction normally is from the big electrode plate to the small one [7]. It can make the asymmetric capacitor to move ahead. Just like the thruster of MIT ionocraft (Ion-propelled aircraft). But what is the detail value of the thrust force and how to figure it out, which is the task we want to solve in next content.

When the two electrode plates of asymmetric capacitor are loaded within a high-voltage circuit, the electric charge carried on the two plates is equal. The different surface areas, lead to the different the surface charged densities. Because of the surface charge distributions can be affected by their shapes and the space between the 2 plates, the calculation is very complex and difficult to establish a quantitative model.

For convenience sake, we plan to simplify the charged asymmetric capacitor model (refer **Figure 3**) into an ideal state firstly. After figuring out the quantitative



**Figure 2.** A lifter composed by asymmetric capacitors.



**Figure 3.** A simple asymmetric capacitor model.

relation by the ideal model, we further expand it into the general cases of complex distributed charged densities. The calculation and test result indicated that this is a feasible method to solve the complicated problem.

After simplification, we successfully figured out the force of uniform distribution of surface charge of asymmetric capacitor. Subsequently, we will give the deduced result firstly, and then show the derived process.

## 2.2. Result Overview

The result of the problem is as follows:

If the surface electric density is uniform under the ideal condition, the thrust force of an asymmetric capacitor charged with high-voltage electricity can be expressed as Equation (1):

$$f = \frac{q^2}{\epsilon} \left( \frac{1}{S_1} - \frac{1}{S_2} \right) \tag{1}$$

where  $f$  is the thrust force of asymmetric capacitor in a static environment [8],  $q$  is the quantity of electric charge on the capacitor plate,  $S_1$  is superficial area of the small plate,  $S_2$  is superficial area of the large plate and  $\varepsilon$  is the dielectric constant.

In Equation (1), the dielectric constant  $\varepsilon$  can also be written into  $\varepsilon = \varepsilon_r \varepsilon_0$ , where  $\varepsilon_r$  is relative dielectric constant and  $\varepsilon_0$  is vacuum dielectric constant.

In above content, the method of calculating thrust force is performed in ideal static environment [9] [10]. To further illustrate Equation (1), the details will be derived subsequently.

### 3. Solution

We use two ways to prove the thrust force calculation formula separately.

For an ideal equal charge density distribution model, from surface charge density  $\sigma = \frac{q}{S}$ , we can get the surface charge density of the plate 1 (we normally call the small one plate 1 and the large one plate 2) is  $\sigma_1 = \frac{q}{S_1}$ , and the plate 2 is  $\sigma_2 = \frac{q}{S_2}$ .

#### 3.1. The First Way

The first way to calculate the thrust force of an asymmetric capacitor is shown as follows:

Assuming the charge density of the plate 1 is equal to plate 2, the positive charge carried by plate 1 is

$$q_{1h} = S_1 \sigma_2 = S_1 \frac{q}{S_2} \quad (2)$$

At this moment, the electric field strength nearby plate 1 is equal to plate 2

$$E_{1h} = E_2 = \frac{\sigma_2}{\varepsilon} = \frac{q}{\varepsilon S_2} \quad (3)$$

Because of actual electric charge  $q$  is  $n = \frac{q}{q_{1h}} = \frac{S_2}{S_1}$  times of the hypothetical electric charge  $q_{1h}$ , it needs  $n$  electric fields  $E_{1h}$  to superpose each other to compose the actual field strength on plate 1.

The residual electric charge  $q_{1r}$  removed the assuming charge  $q_{1h}$  from actual charge  $q$  is

$$q_{1r} = q - q_{1h} = q - S_1 \sigma_2 = q \left( 1 - \frac{S_1}{S_2} \right) \quad (4)$$

We need  $n$  residual electric charges  $q_{1r}$  to superpose each other to compose the actual field strength on plate 1  $E_{1r} = q \left( 1 - \frac{S_1}{S_2} \right) \cdot n$ . So we can get the electric field force  $f$  of the  $n$  residual electric charge  $q_{1r}$  in assuming electric field

$$E_{1h} = E_2$$

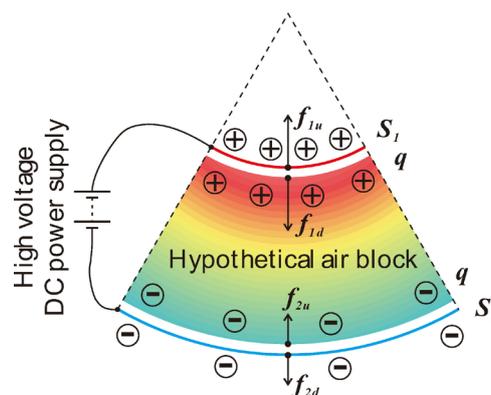
$$\begin{aligned} f &= q \left( 1 - \frac{S_1}{S_2} \right) \cdot E_2 \cdot n \\ &= q \left( 1 - \frac{S_1}{S_2} \right) \cdot \frac{q}{\varepsilon S_2} \cdot \frac{S_2}{S_1} \\ &= \frac{q^2}{\varepsilon} \left( \frac{1}{S_1} - \frac{1}{S_2} \right) \end{aligned} \quad (5)$$

Therefore we get the right result of the thrust force of practical asymmetric capacitor.

### 3.2. The Second Way

We assume the air medium between the two plates of the asymmetric capacitor as a whole block in physical shape, and electrical non-conduction at the inner (refer **Figure 4**). The gaps between the air block surfaces near to the plates are infinitesimal. So the molecular collision between them causes to charge exchange, and then leads to the upper surface positively charged and the lower surface negative charged. As the reason of like charges repelling, there is a pair of reaction forces produced on the surfaces of air block and the plates. You can further find the force loaded on the upper plate is larger than the lower plate for reason of different plate areas causing to different electric densities. That is to say their sum is positive. It is exactly the reason that an asymmetric capacitor like as lifter loaded by high voltage DC power can produce an upward lift force. Then, we can attempt to figure out the strength of the levitation force.

The forces of the top and bottom surfaces of the air block exerted by the asymmetric capacitor are different. Because of different areas  $S$  lead to different charge densities  $\sigma$ , combining  $E = \frac{q}{\sigma}$  and  $f = qE$ , we can find that the sum force of the air block is not equal to zero. It gets a total trend to downward by the electric field force exerted, and makes the asymmetric capacitor to get the trend to upward which is from the large plate pointing to the small plate. So, the lift force produced by the asymmetric capacitor is



**Figure 4.** Air block analytical approach of asymmetric capacitor.

$$\begin{aligned}
 f &= f_{1u} - f_{2d} = f_{1d} - f_{2u} = qE_1 - qE_2 \\
 &= q \frac{q}{\epsilon S_1} - q \frac{q}{\epsilon S_2} = \frac{q^2}{\epsilon} \left( \frac{1}{S_1} - \frac{1}{S_2} \right)
 \end{aligned}
 \tag{6}$$

### 4. Brief Analysis of Result

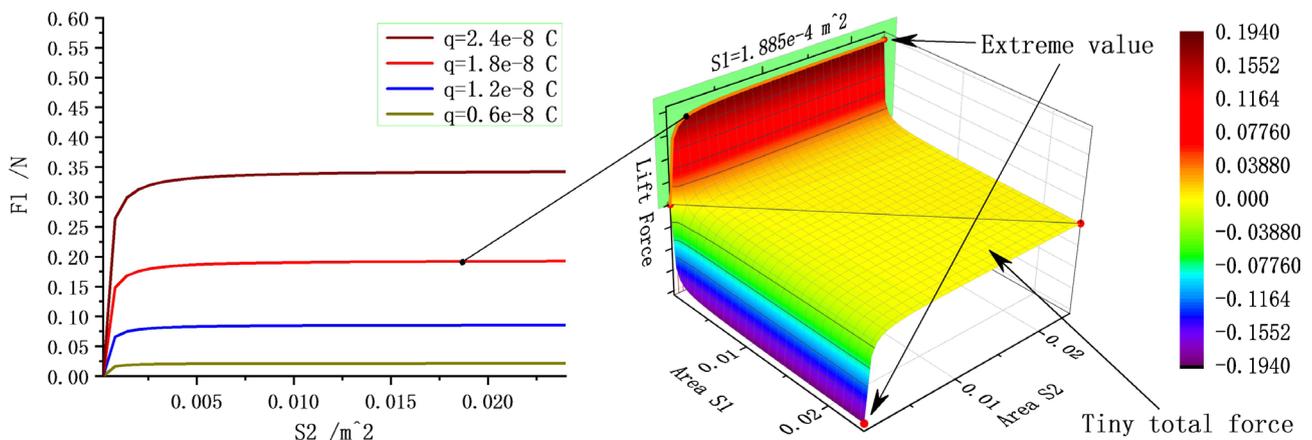
The results by above methods are the same. Except  $q$ , the other three variables  $\epsilon$ ,  $S_1$  and  $S_2$  are known. So, before we can calculate the final lift force, we must to figure out the carried charge firstly. If when

$$\begin{aligned}
 \epsilon &= 8.854187817 \times 10^{-12} \text{ F/m}, \\
 S_1 &\in [1.89 \times 10^{-4}, 240 \times 10^{-4}] \text{ m}^2, \\
 S_2 &\in [1.89 \times 10^{-4}, 240 \times 10^{-4}] \text{ m}^2, \\
 q &= 1.8 \times 10^{-8} \text{ C},
 \end{aligned}$$

and using above formula  $f = \frac{q^2}{\epsilon} \left( \frac{1}{S_1} - \frac{1}{S_2} \right)$ , we can get the lift force produced by the asymmetric capacitor that is between the maximum 0.2 N and the minimum -0.2 N. The trend of  $f(S_1, S_2)$  is drawn in **Figure 5**.

We can see that smaller small-plate than the large-plate means stronger force output. But too smaller dimension may lead to structural strength problem. In other works, by reference to kinds of lifters, we found that thinner copper wire can produce more lift force. The trend reflected by the formula is verified to be correct.

From Equation (1) and **Figure 5**, we can find the lift force  $f$  is sensitive to amount of the charges carried on asymmetric capacitor. As  $q = UC$ , the amount of the charges  $q$  is proportional to the load voltage  $U$ . Through an asymmetric capacitor in lifter form (refer **Figure 6**), we test the relation between load voltage  $U$  and force  $f$ , and achieve a data table (refer **Table 1**). This trend of force change reflects (refer **Figure 7**) that  $f$  is assuredly sensitive to  $U$ . As the voltage is increased, the lift force increases quickly with charge growing on the plates.



**Figure 5.** A lifter composed by asymmetric capacitors.

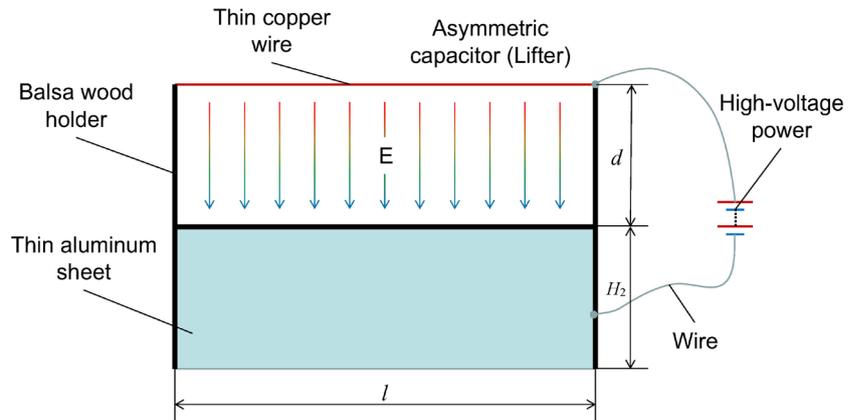


Figure 6. Test lifter of asymmetric capacitor.

Table 1. The relation table between voltage and lift force of a lifter.

Power output (mW)	56	288	814	1768	4448	7200
Loop current (uA)	4	16	37	68	139	200
Applied voltage (kV)	14	18	22	26	32	36
Charge carried on polar plate (C)	4.83E-09	5.80E-09	7.73E-09	9.91E-09	1.30E-08	1.52E-08
Lift force measured (N)	0.05493	0.06592	0.08789	0.11261	0.14832	0.17304
Experiment condition	Diameter of thin copper wire (as plate 1) $d_1 = 0.3$ mm , gap between two plates $d = 60$ mm , width of plate 2 $H_2 = 40$ mm , length of plates $l = 100$ mm .					

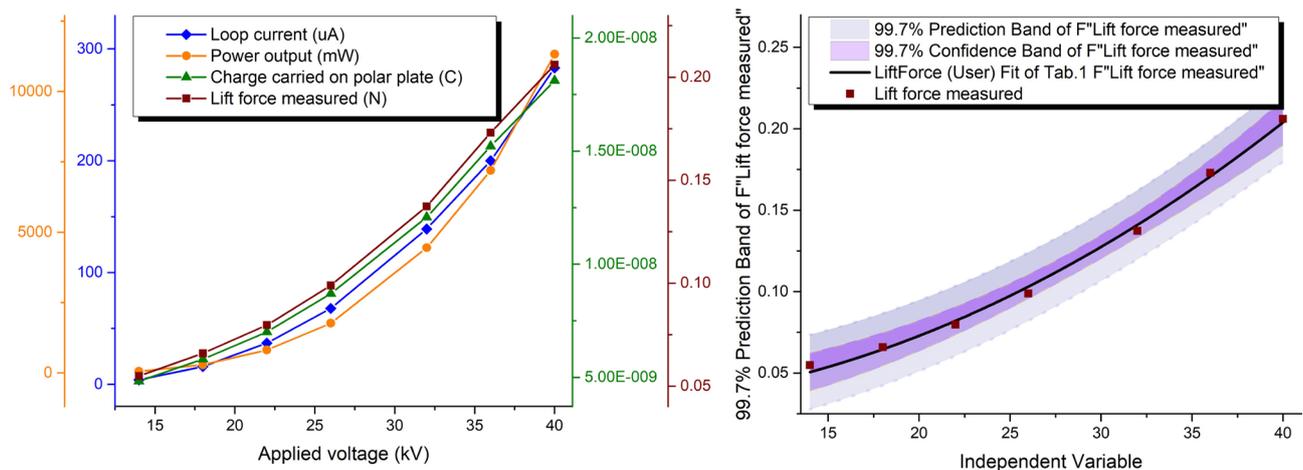


Figure 7. Relative changing trend between voltage and lift force of a lifter.

## 5. Conclusion

Through two methods, we achieved lift force formula of asymmetric capacitor successfully. But how to obtain the value  $q$  of the asymmetric capacitor, which needs much more content to present the derivation details? So including the experiment verification of the calculating method for the lift force of asymmetric capacitor, we plan to write them in the follow-up papers. In this one, we mainly completed the lift force calculation established on some theoretical assumptions

by two ways, the results by both ways point to the same form formula. It hints us that the calculation may be right, as for the exact verification of the formula, we will continue to achieve it at next papers to thoroughly resolve the lift force problem of asymmetric capacitor loaded by high voltage.

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### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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