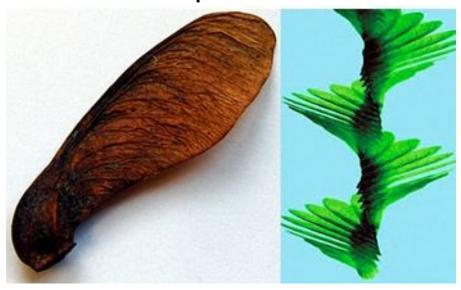


ESCAPING HELICOPTERS

THE PROBLEM

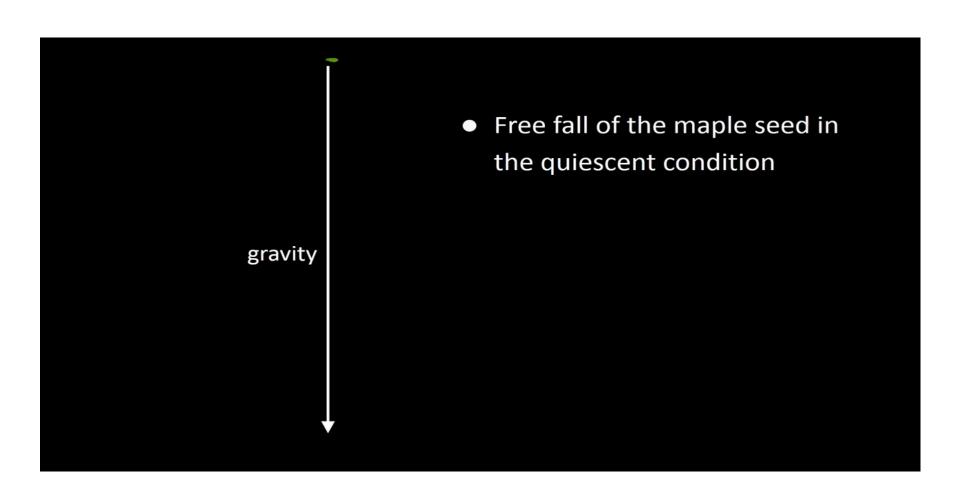
Certain species of trees produce a type of dry fruit known as a samara. It has a winged structure that allows the seeds to be carried by the wind. How does the terminal speed of a samara depend on the relevant parameters? Is it more efficient than a parachute?



1

THE PHENOMENON

Lee, Injae, and Haecheon Choi. "Flight of a falling maple seed." Physical Review Fluids 2.9 (2017): 090511.



TURBULENCE

To determine the regime of the fluid we have to calculate the Reynolds number

- Length scale is side of paper $L \approx 10$ cm
- Typical velocity is $U \approx 1 \text{ m s}^{-1}$
- Density of air is $\rho_A \approx 1.23 \text{ kg m}^{-3}$
- Viscosity of air is $\mu_A \approx 18.5 \,\mu\text{Pa}$ s

$$Re = \frac{UL}{\mu_A/\rho_A} \approx 10^4 \gg 1$$

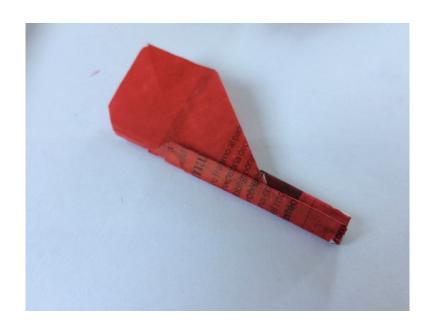
We have a turbulent flow

- Experimental setup
- Theoretical explanation
- Results
- Parachute comparison
- Conclusions

- Experimental setup
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OUR FLEET OF SAMARAS

We used samaras made of paper for the ability to change the <u>density</u> and the <u>size</u> in a <u>controlled</u> way.





- Our approach to the problem

- Experimental setup

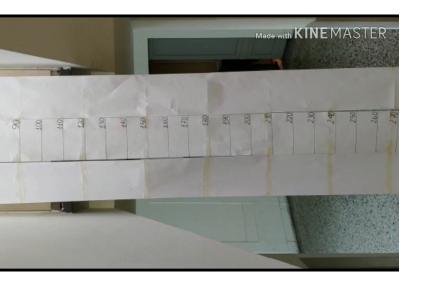
- Theoretical explanation

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EXPERIMENTAL SETUP



We built a graduated scale and we filmed in slow motion the fall of the various samaras.

And we got the speed with:

$$v = k \frac{\Delta x}{\Delta t}$$

And k is a conversion factor from slow motion to real time

- Our approach to the proble	em
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- Experimental setup

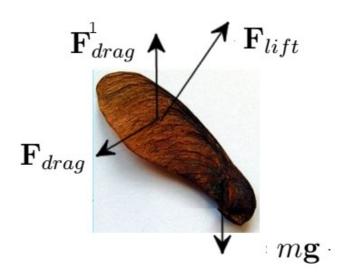
- Theoretical explanation

- Results

- Parachute comparison

- Conclusions

THEORETICAL EXPLANATION



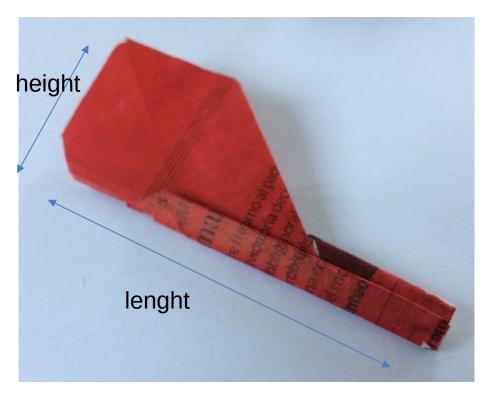
- The first Drag force is due to the fall
- The second Drag force is due to the rotation
- The lift is caused by the rotation.

$$\frac{d\mathbf{p}}{dt} = m\mathbf{g} + \mathbf{F}_{drag} + \mathbf{F}_{lift}$$
$$\frac{d\mathbf{L}}{dt} = \mathbf{Q}_{drag} + \mathbf{Q}_{lift}$$

At the equilibrium we find that exist the following relations:

$$\left[\begin{array}{c} mg \\ 0 \end{array}\right] = \mathbf{A} \left[\begin{array}{c} v^2 \\ \omega^2 \end{array}\right]$$

THE PARAMETERS



R is the characteristic length of the samara

$$h \propto R$$

$$l \propto R$$

$$S \propto hl$$

IMPORTANT PARAMETERS

From this model, ignoring the small terms and using the Taylor formulas, we can extract this relation:

$$v = \sqrt{\frac{\rho_m Sg}{\frac{1}{2}\rho h(c_d l + \frac{5c_l h^2 \alpha}{3s_p})}}$$

So we can say for the density of the paper:

$$v \propto \sqrt{\rho_m}$$

For the size of paper

$$v = const$$

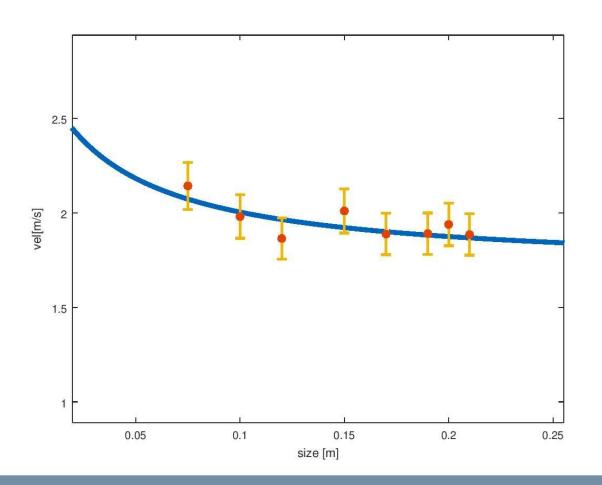
- Our approach to the proble	em
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- Experimental setup
- Theoretical explanation

- Results

- Parachute comparison
- Conclusions

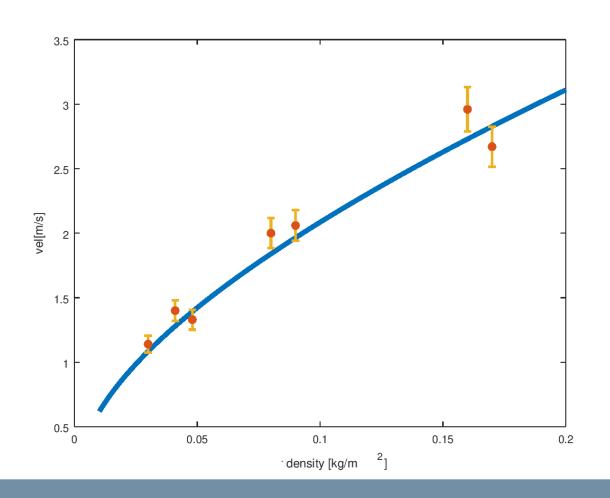
RELATION SPEED-SIZE



The blue line represents the theoretical relation we previously discussed beetwen the size of the samara and the terminal speed.

The red dots represent our data.

RELATION SPEED-DENSITY



We plotted with the blue line the theoretical relation beetwen the speed and different density of samaras.

In our experiment we build samaras made of different materials like alluminum or paper of different density.

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ANGULAR VELOCITY

Looking at the angular velocity instead we can say that the faster is rotating the slower is the fall.

A typical value we got from the theoretical analysis is 50 rad/s or 7.5 complete rotations per second.

In this video we obtain around 7 rotations per second as we expected.



-	Our	approad	ch to	the	problem
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- Experimental setup
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PARACHUTE VS SAMARA

A simple analysis on the limit speed of a parachute gives us:

$$v = \sqrt{\frac{2mg}{\rho C_d S}}$$

We can compare to our theoretical formula for samaras:

$$v = \sqrt{\frac{\rho_m Sg}{\frac{1}{2}\rho h(c_d l + \frac{5c_l h^2 \alpha}{3s_p})}} = v_{parachute} \sqrt{\frac{1}{1 + \frac{5C_l \alpha h^2}{3s_p}}}$$

As we can see the trend is similar but samaras have an added term due to the rotation.

PARACHUTE VS SAMARA

- We have shown that theoretically samaras are more efficient. But we did not consider some relevant factors that comes into play like a changing center of mass.
- Experimentally we observed that for bigger samaras entering in auto rotation was unlikely. We hypotesized that it was due to the decreasing stiffness of the wing.
- For small sizes the samaras are more stable than a parachute.
- Samaras cannot be reliably used to slow down an heavy object.

-	Our	approach	to the	problem
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CONCLUSIONS

- We built the samaras to test the influence of the various parameters.
- We built a model using the cardinal equation.
- We extract a formula that showed all the relevant parameter that comes into play in our regime.
- We observed that our experimental result agree with the theoretical one .
- Finally we compared the parachute and the samara and we found that theoretically the latter is more efficient.

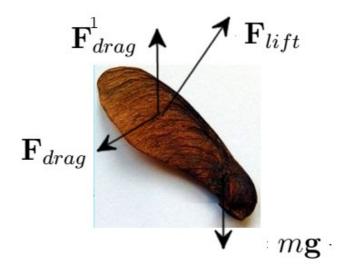
HOW TO IMPROVE OUR RESULTS

-Study different parameters like the density of air, other types of samara or different geometries

- From a theoretical point of view we should use the Blade Element Theory or Navier Stokes equation

- From an experimental point of view we have to increase the accuracy in the measurement of the speed

THEORETICAL EXPLANATION



$$\frac{d\mathbf{p}}{dt} = m\mathbf{g} + \mathbf{F}_{drag} + \mathbf{F}_{lift}$$
$$\frac{d\mathbf{L}}{dt} = \mathbf{Q}_{drag} + \mathbf{Q}_{lift}$$

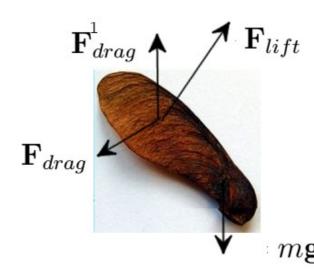
$$\mathbf{F}_{drag}^{1} = \frac{1}{2} \rho S v^{2} c_{d} \mathbf{u}_{s}$$

$$\mathbf{F}_{lift} = \int_{S} \frac{1}{2} \rho v_{blade}^2 c_l dS \mathbf{k}$$

$$\mathbf{F}_{drag} = \frac{1}{2} \rho S v_{rotation}^2 c_d \mathbf{u}_s = \frac{1}{2} \rho S r^2 \omega^2 c_d \mathbf{u}_s$$

$$\mathbf{Q}_{lift}(\omega) = \mathbf{r} \times \mathbf{F}_{lift}(\omega)$$

THEORETICAL EXPLANATION



$$\mathbf{F}_{lift} \qquad \mathbf{Q}_{drag}(v) = \mathbf{r} \times \mathbf{F}_{drag}(v) = \frac{1}{2} \rho c_d v^2 \int_S \mathbf{r} \times \mathbf{u}_S dS$$

$$\mathbf{Q}_{lift}(\omega) = \mathbf{r} \times \mathbf{F}_{lift}(\omega) = -\frac{1}{2}c_l\rho\omega^2 \int_S r^3\mathbf{u}_r \times \mathbf{u}_S dS$$

$$\mathbf{Q}_{drag}(\omega) = \mathbf{r} \times \mathbf{F}_{drag}(\omega) = -\frac{1}{2} c_d \rho \omega^2 \int_{S\perp} r^2 \mathbf{r} \times \mathbf{u}_\omega \times \mathbf{u}_r dS$$

At the equilibrium we find that exist the following relations:

$$\left[\begin{array}{c} mg \\ 0 \end{array}\right] = \mathbf{A} \left[\begin{array}{c} v^2 \\ \omega^2 \end{array}\right]$$