Hello, everyone. With all the different workshops available, thank you all for choosing this one.
Now, I'm going to start my workshop, "From Origami to IKAROS."

ABOUT ME

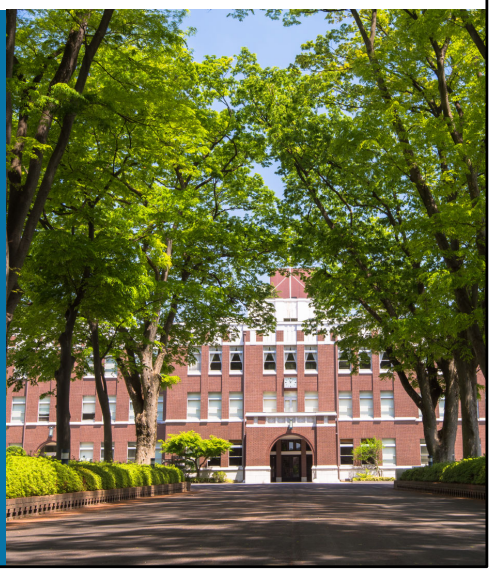
★ Name: Akira Yo

★ School: Seikei Junior High School

Seikei Senior High School

A private school founded in 1912. Part of Seikei Gakuen, a comprehensive academic institute, with many affiliated schools ranging from elementary school to university.

★ Subject: Mathematics



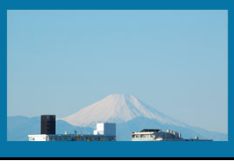
First, let me briefly introduce myself.
My name is Akira Yo. You can call me Akira.
I'm a math teacher at Seikei Junior High School in Kichijoji, Tokyo.

UNIQUE GEOSCIENCE EDUCATION 1

(1) We have our own weather station on the premises.

- It opened 95 years ago, in 1926, and weather observation has never stopped since.
- First-year junior high school students have weather observation lessons in this facility.

★For many years, a variety of things have been observed here, including some unique to the school.



Our School offer a unique geoscience education program.
First, we have a weather station on the school's premises. It has carried out meteorological observation every day since it opened 95 years ago in 1926.
Our first-year junior high school students take turns practicing weather observation here.
In addition to what people observe normally, there are also some things unique to our school, such as blooming cherry blossoms and whether or not we can see Mt. Fuji, the most famous mountain in Japan.

UNIQUE GEOSCIENCE EDUCATION 2

(2) Senior high school students observing the sky using the Subaru Telescope in Hawaii.

(3) A stargazing session at the school's observatory dome

Also, our senior high school students get to look at the stars using the Subaru Telescope in Hawaii, and we hold stargazing sessions in the school's weather station as well.

Today's Presentation

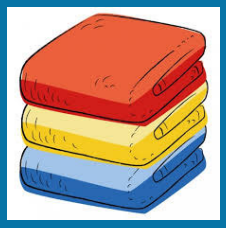
1. The World of Folding
2. The World of Origami
3. Applying Origami to IKAROS
4. Let's Create an IKAROS!!

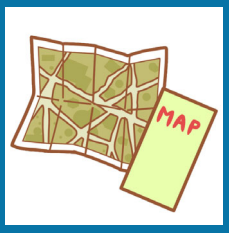
Now, let's get started with today's presentation.
This is what I'm going to cover.

1.THE WORLD OF FOLDING

Question

If I say “folding,” what objects do you think of?



etc.

Folding can make a big thing smaller.

To start, I'd like to ask you a question about the world of folding.
If I say “folding,” what objects do you think of?

What comes to mind?
When you look online, this is what you get:
Clothing, umbrellas, folding desks, and folding maps, for example...
I’m sure that some of you thought of other things as well.

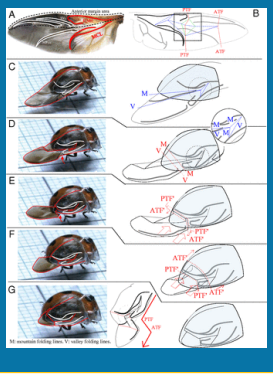
But the commonality is that you can make a large thing compact by folding it.
And actually, these aren’t the only examples of folding; there are also other things you can find in nature.

FOLDING IN THE NATURAL WORLD

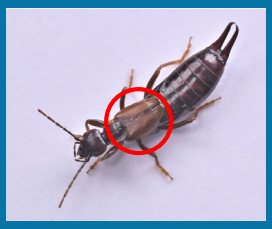
There are also many things in the natural world that are folded.

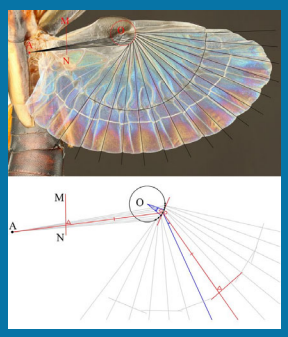
For example, insect fold their hind wings.

(1) A ladybug's hind wings



(2) An earwig's hind wings





Japanese researchers have clarified the mechanism by which these hind wings extend.

(Source:https://www.pnas.org/content/114/22/5624/tab-figures-data)

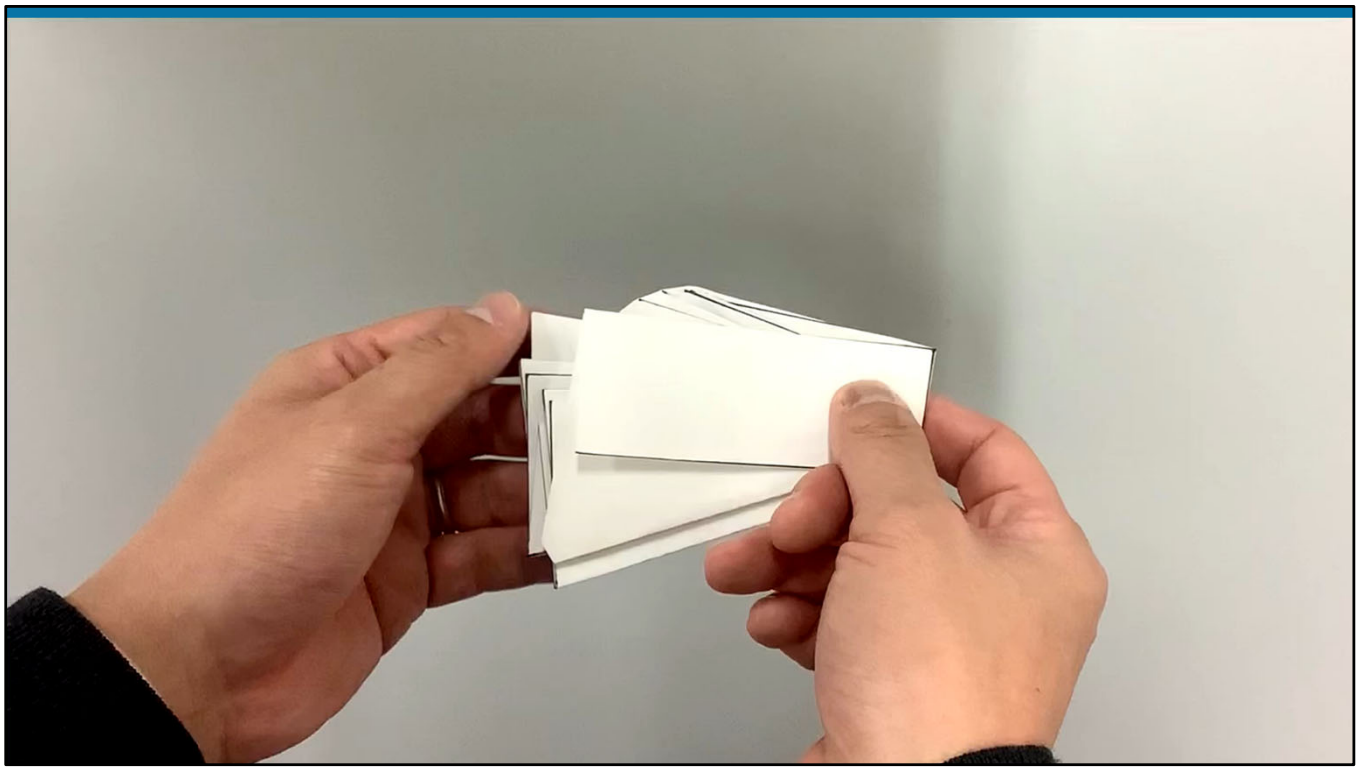
(Source:https://www.kyushu-u.ac.jp/en/researches/view/154)

Let's take a look at those.
For example, many insects fold their hind wings when they're not using them.
The left photo is a ladybug, and the right one, which may be less familiar to you, is an earwig.
These insects fold their hind wings when they're not using them, using mechanisms that have been clarified by Japanese researchers.

Ladybugs hide their hind wings under a sheath. Their hind wings actually fold like this. (Demonstration)
When they unfold, they extend smoothly like this. (Demonstration)

Earwigs hide their hide wings here, and the mechanism to extend them was clarified last July.
Their wings actually fold like this. (Demonstration)
When they unfold, they extend smoothly like this. (Demonstration)
You can actually draw the expansion diagram using a ruler and a compass.

We know that they hide their wings in a folded state like this. For Japanese people, folding is something very familiar because we have origami.

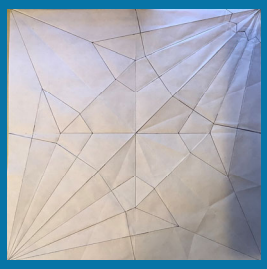


(Demonstration movies)

2. THE WORLD OF ORIGAMI

What is origami?

- Origami is the traditional Japanese play of folding squares of paper to make animals, vehicles, and various other things.
- It involves geometric elements.



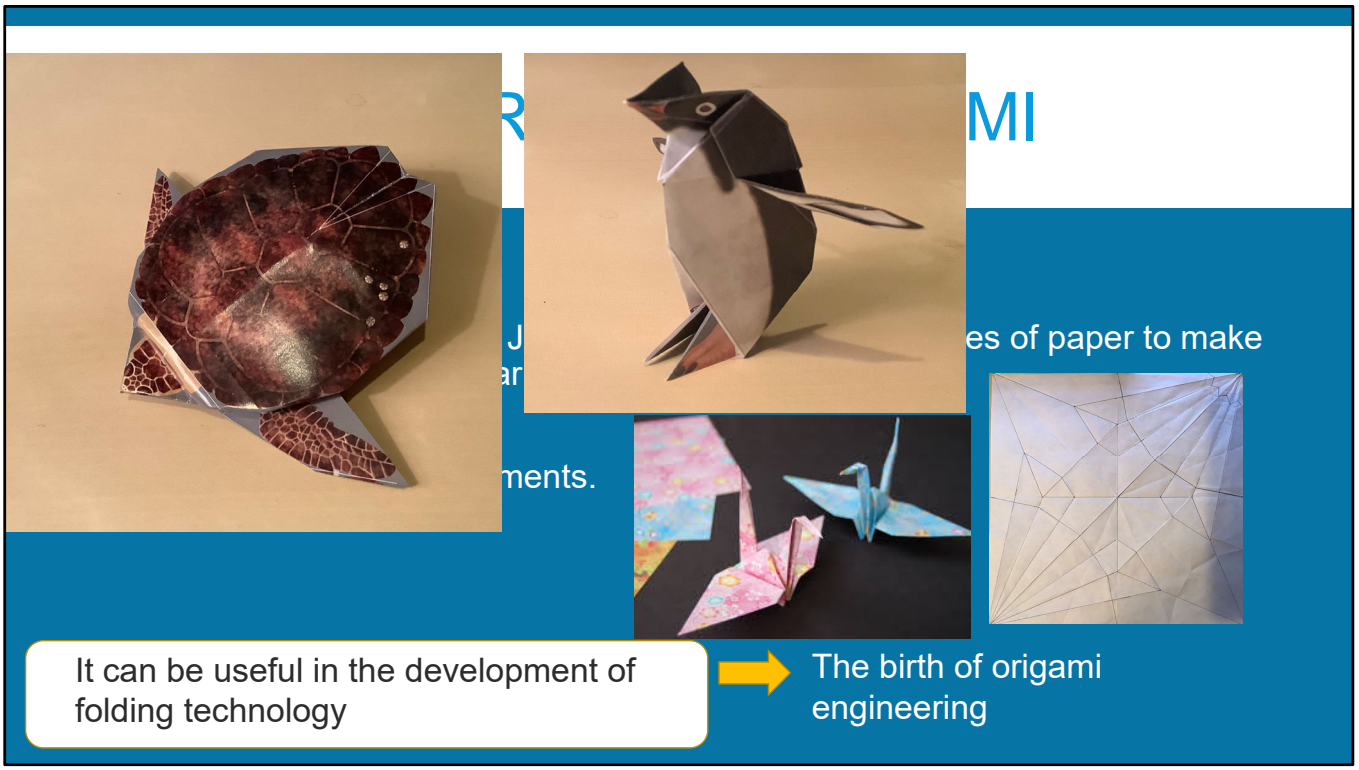
It can be useful in the development of folding technology → The birth of origami engineering

Origami is the traditional Japanese play of folding squares of paper to make animals, vehicles, and various other things.
For example, you can make such cranes, turtles, penguins, etc.

Origami also involves geometric mathematical elements.

look at the expansion diagram for that origami crane from a moment ago. The fold lines show congruent triangles or similar triangles.

Origami helped to develop folding techniques, and in 2002, a new field called origami engineering was born.
Now let's look at examples of how origami is applied to technological development.



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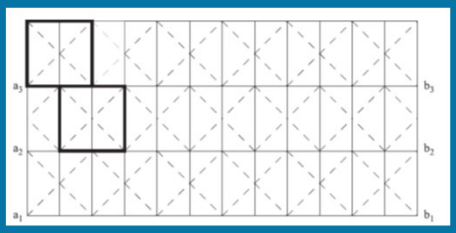
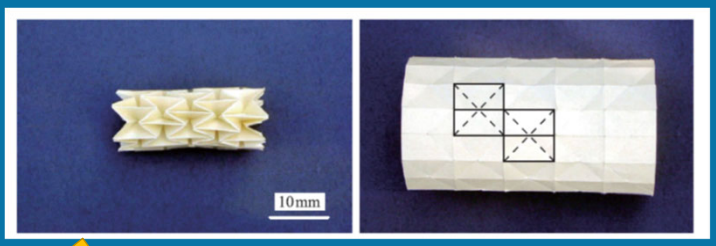
APPLYING ORIGAMI TO THE MEDICAL TECHNOLOGY FIELD

The sea cucumber fold is applied to artificial blood vessels.



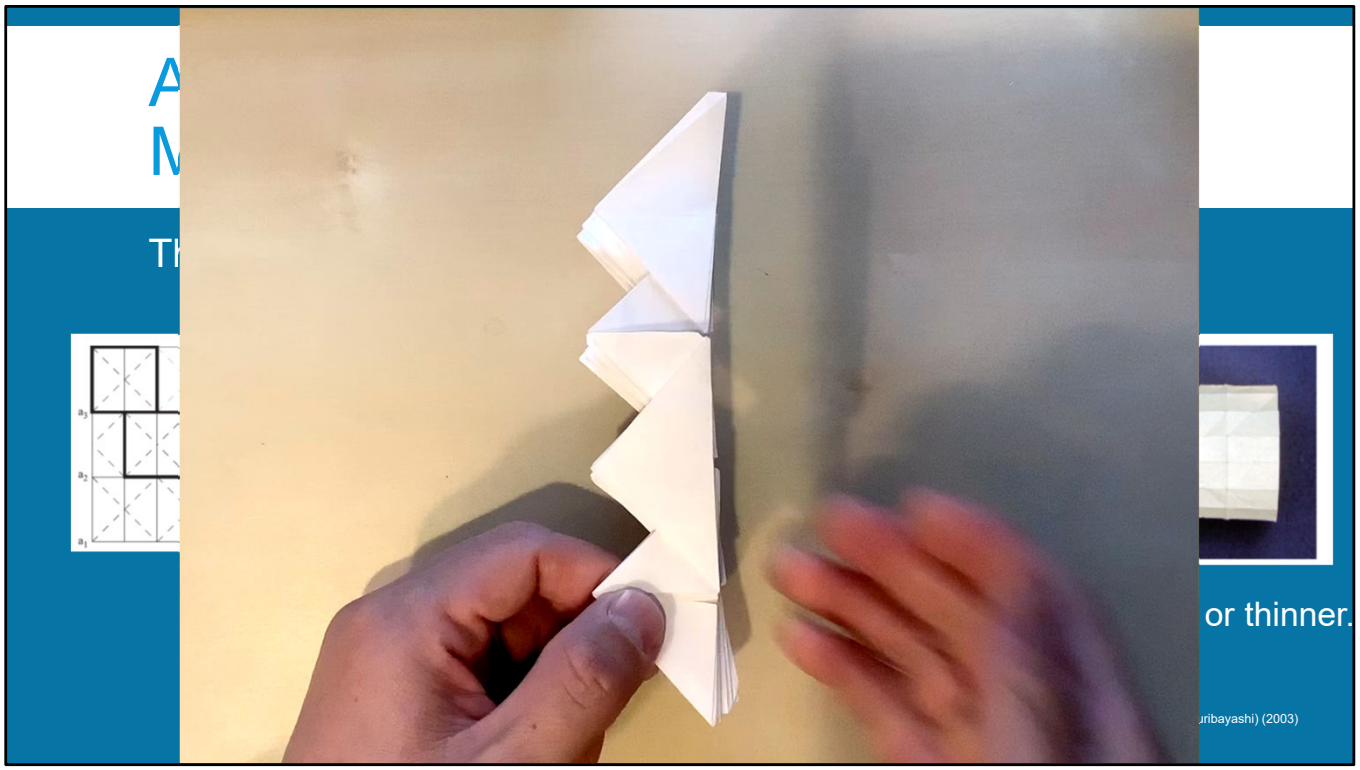


It can make blood vessels thicker or thinner.

Fold it along the line and put them together.

Source: Shigetomi (Kuribayashi) (2003)

Let's start with applications in the medical technology field. When you fold the paper along the lines in the left-hand diagram, you get something like this. (Demonstration)
This is called a sea cucumber fold, and it's applied to stent grafts (artificial blood vessels).
It can be made thicker or thinner. At first, it's placed in a blood vessel in a thin state and then expanded inside the body to push out a vessel that has become narrow.

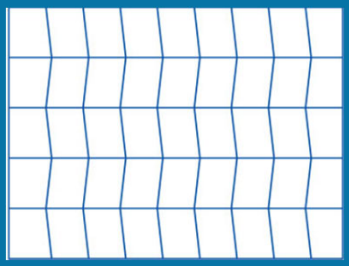


(Demonstration movie)

APPLYING ORIGAMI TO THE SPACE TECHNOLOGY FIELD

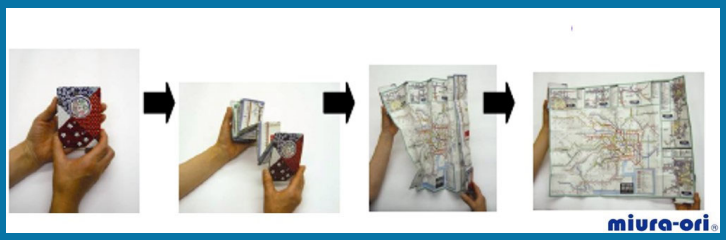
The Miura fold is applied to the solar sails of artificial satellites

Fig. 1



Fold it along the line.

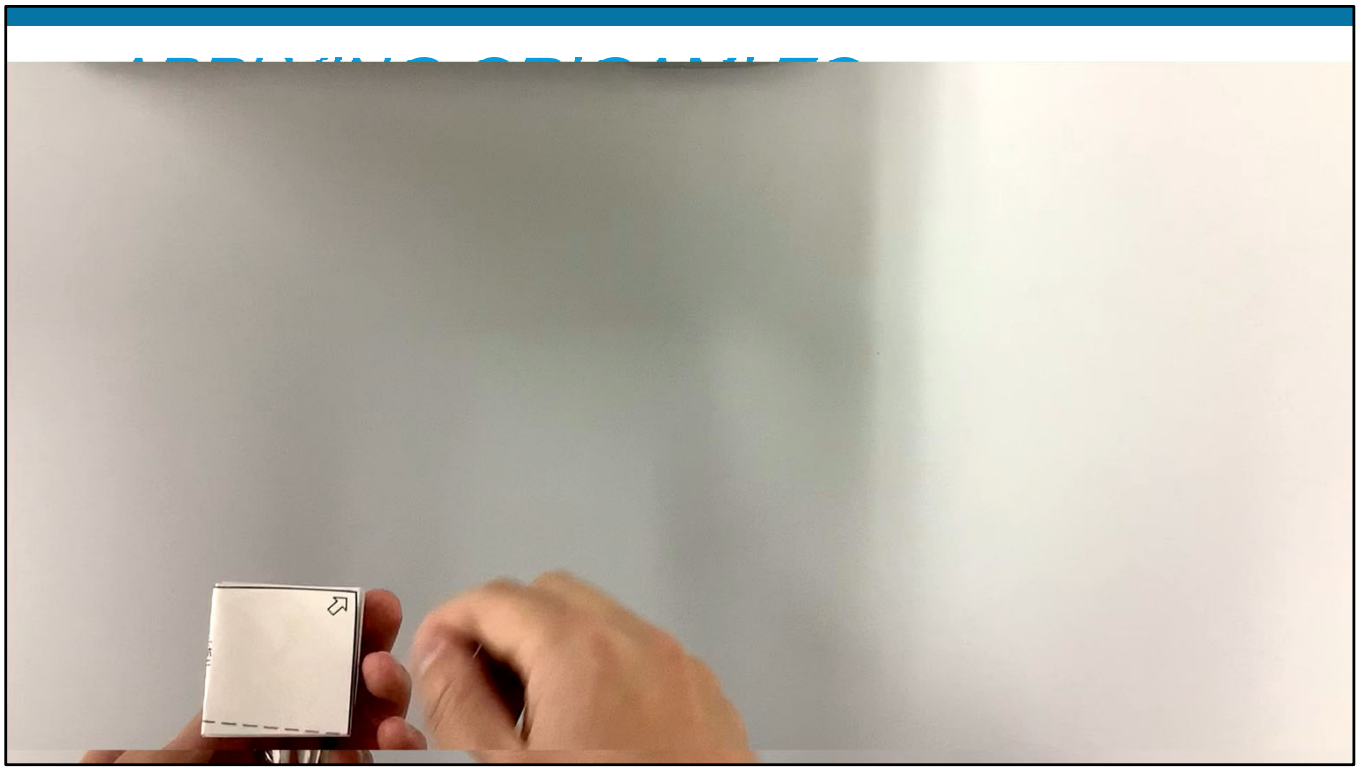
Fig. 2



Source: Fig. 1 (https://miuraori.biz/feature/); Fig. 2 (http://edu.jaxa.jp/lessonplanimg/,iuraori.jpg);

Next, let's look at applications in the space technology field.

Continue to fold it along the line shown in Fig. 1, and you can furl it like this. (Demonstration)
Pull the end, and you can extend it smoothly. (Demonstration)
This is called the Miura fold.
Incidentally, this expansion diagram is made up of parallelograms, and if you make all of them rectangular, you won't be able to unfold it smoothly. (Demonstration)



(Demonstration movies)

APPLYING ORIGAMI TO THE SPACE TECHNOLOGY FIELD

(1)

Space Flyer Unit (SFU)

Launched in 1995 and recovered in 1996, SFU was used for space experiments called the Two-Dimensional Solar Array Experiments.

Fig. 1

(2)

Microsatellite Hirogari

Scheduled to launch in 2021
The plan to demonstrate two challenges in space for the first time ever. One is to unfold a thick, Miura-fold structure, and the other is to measure its shape using an optical surface shape measurement system.

Fig. 2

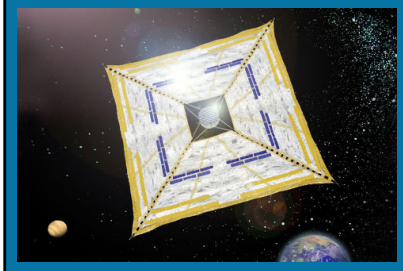
Source: Fig. 1 (http://spaceinfo.jaxa.jp/ja/sfu.html); Fig. 2 (https://www.osakafu-u.ac.jp/osakafu-content/uploads/sites/428/pr20201019.pdf)

This smoothly unfolding technology is applied to space technology.
This folding method was used in space experiments called the Two-Dimensional Solar Array Experiments, in the observation satellite Space Flyer Unit, which was launched in 1995.
There are plans for a demonstration experiment to unfold a thick plate using the Miura fold using Hirogari, a microsatellite that will be launched this year.

As I explained, origami is used in unfolding solar sails.

3. APPLYING ORIGAMI TO IKAROS

What is IKAROS?



It's spacecraft that travels by capturing the sun's energy to propel itself using an extended thin membrane sail.

The first in the world!!

Small Scale Solar Powered Sail demonstrator Satellite

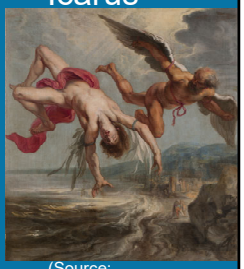
IKAROS

(Interplanetary Kite-craft Accelerated by Radiation Of the Sun)

It was launched in 2010, and it has gone into hibernation mode since 2012

(Source:https://www.jaxa.jp/projects/sas/ikaros/index_j.html)

Icarus



(Source: https://en.wikipedia.org/wiki/Icarus#/media/File:Gowy-icaro-prado.jpg)

Technology using origami is also used in IKAROS, so I'll tell you about that now.

IKAROS is a spacecraft that travels by capturing the sun's energy with an extended thin membrane sail. It was launched in 2010.
Its name is an acronym: Interplanetary Kite-craft Accelerated by Radiation Of the Sun.

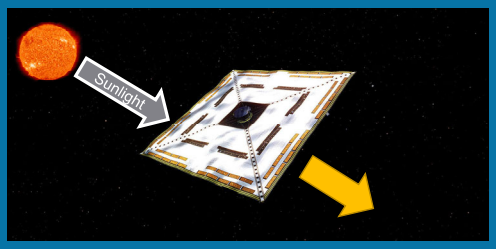
When you heard the name IKAROS, some of you may have thought of "Icarus," but the difference is that IKAROS is still up there.

THE MECHANISM OF IKAROS

There's air on the Earth.

A yacht has a sail that turns wind force into propulsion.

But not in space.



An experiment was conducted to make sure that IKAROS can obtain propulsion as it captures solar power (energy).

(Source: http://www.isas.jaxa.jp/missions/spacecraft/current/ikaros.html, with some additional description)

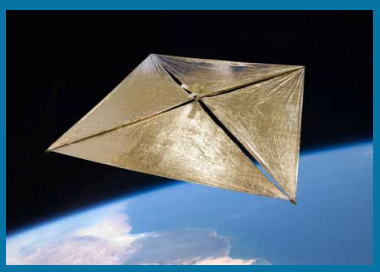
Let's see how IKAROS travels.

Because there is air here on the Earth, a yacht with its sails extended in the wind can travel using wind force.
But there is no air in space, so they conducted an experiment to see if IKAROS could travel using the solar radiation pressure on its sail.

DEVELOPING A SOLAR SAIL

Solar sails are being developed all over the world.

NanoSail-D2 (NASA)



Launched on November 20, 2010

(Source: https://www.nasa.gov/centers/marshall/pdf/484314main_NASAfactsNanoSail-D.pdf)

CubeSail (NASA/Univ Ilinoi)

Launched on December 16, 2018

(Source:https://www.cubesail.us/)

LightSail2 (Planetary Society (USA))

Launched on June 25, 2019

(Source:https://www.planetary.org/space-images/lightsail-2-with-sail-1)

Other solar sails like IKAROS are being developed outside of Japan as well. NASA has launched the NanoSail-D2 and CubeSail, the Planetary Society has launched LightSail2. They study how to unfold solar sails.

DEVELOPING THE TECHNOLOGY FOR UNFOLDING IKAROS'S LARGE SOLAR SAIL

The challenge was how to unfold a large solar sail smoothly.

How to unfold a sail

- Spin type: The sail assembly spins to extend the sail.
- Mast type: A mast is attached to the sail, and it extends to eventually unfold the sail.

→ IKAROS uses the spin type.

One of its advantages is that it weighs less because no mast is used.
It can be applied to unfold a larger sail in the future.

Source: Mori (2011)

Now let's see how IKAROS unfolds its sail.
There are two methods of unfolding a solar sail: the spin type and the mast type.
The spin type was chosen for IKAROS because weight was an issue.

APPLYING ORIGAMI TO IKAROS

It was decided that IKAROS would use a spin type solar sail.

The challenge was how to produce a solar sail that was **bilaterally symmetrical and could extend smoothly.**

How was this solved?

Origami played a pivotal role.

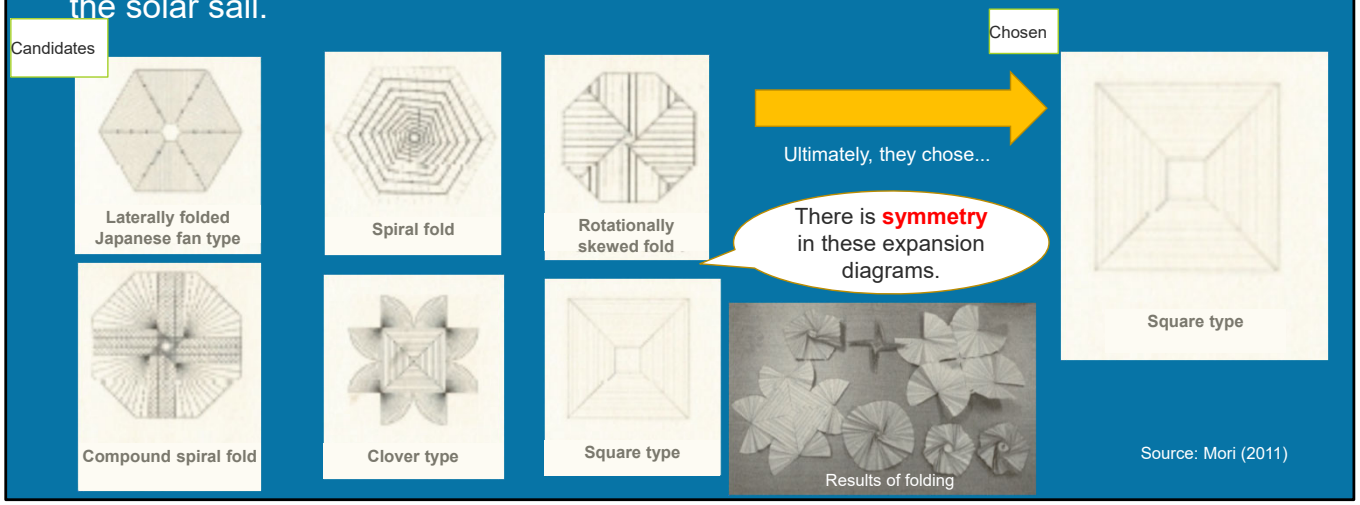
Through trial and error, many methods were tried out using folding technology from origami.

Source: Mori (2011)

Origami played a pivotal role as a tool for thinking about what could make a large solar sail unfold symmetrically and smoothly.

SELECTING CANDIDATES FOR SOLAR SAIL UNFOLDERS USING ORIGAMI

Many experiments were conducted actually using origami to determine the shape of the solar sail.

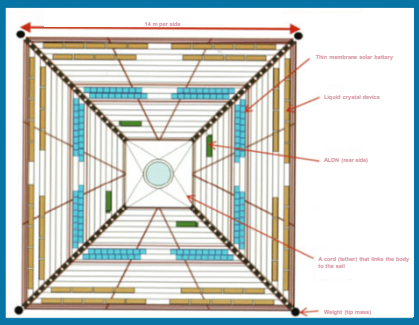


On the left is what was actually folded.
These expansion diagrams have symmetry.
The one that was chosen was this square shape.

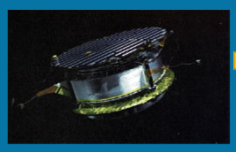
UNFOLDING IKAROS'S SOLAR SAIL

After the shape of the solar sail was determined through trial and error using origami, the sail was completed.

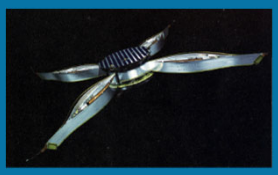
IKAROS with its sail extended



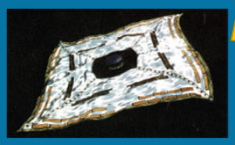
Unfold



(1) Weight (separation of the tip mass)



(2) Move the guide to extend the sail, which folded into four parts.



(3) Lay the guide to extend the sail in one

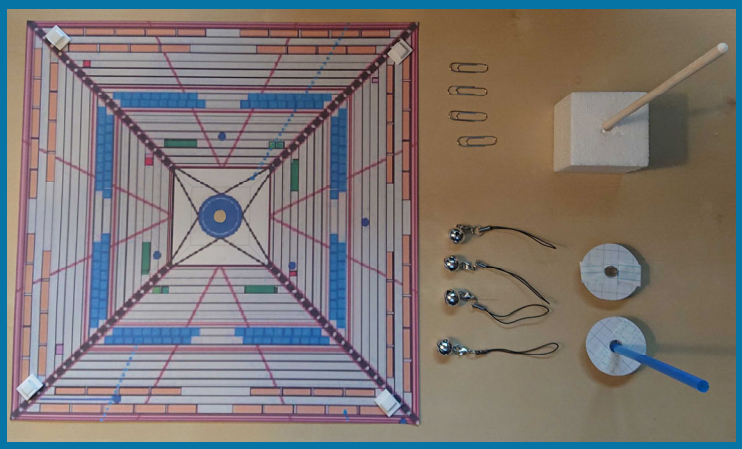
Centrifugal force, which performs an important role, comes into play here.

Source: Yamashita (2016)

The solar sail of IKAROS is a square whose sides are each 14 m in length. Its sail is wrapped around a cylinder.
As the cylinder rotates, the weighted sail unfolds as shown in the illustration on the right.
Centrifugal force is important in this unfolding action.

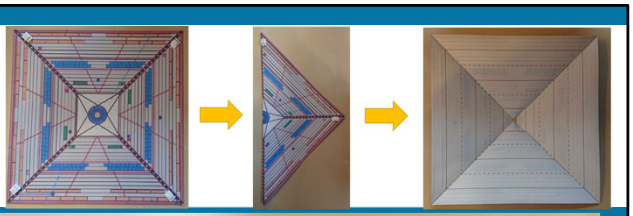
4. LET’S CREATE AN IKAROS!!

Materials for IKAROS

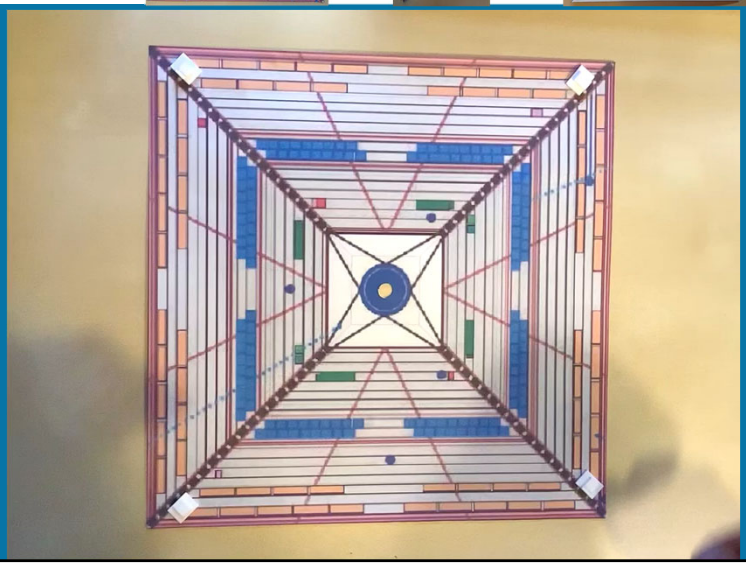


All right, let's create an IKAROS and unfold its sail.
Here are the materials you’ll need.
Do you have them all prepared?

STEP 1



Fold the sail in half along the diagonal so that the illustration remains visible. Then make a crease.
Make the opposite diagonal crease in the same way, and turn it over.

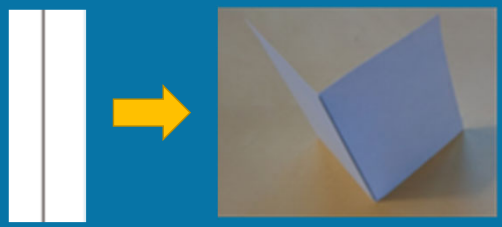


First, fold the sail in half along the diagonal so that the illustration remains visible.
Then make a crease.
Once that’s done, make another crease line for the other diagonal.

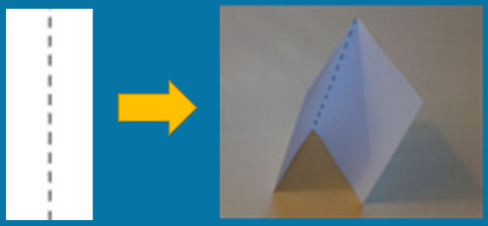
RULES OF SAIL FOLDING

Follow the rules below to fold the sail.

★Ridge fold



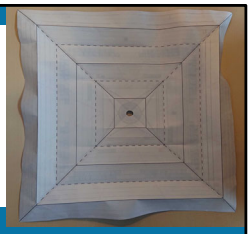
★Valley fold



Now I’m going to explain the folding rules.
Fold the solid line into a mountain like this.
And fold the dotted line into a valley like this.

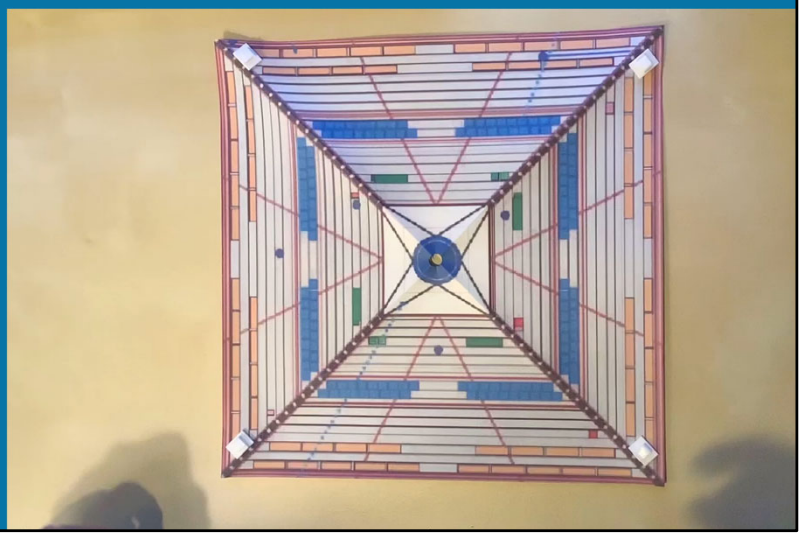
STEP 2

Fold it along the lines parallel to other sides.



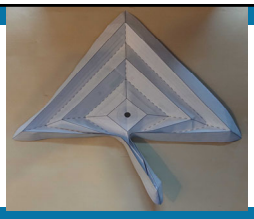
Following the previous folding rules, fold the sail along the lines parallel to the four sides, and make creases.

Fold it along the lines parallel to one side.

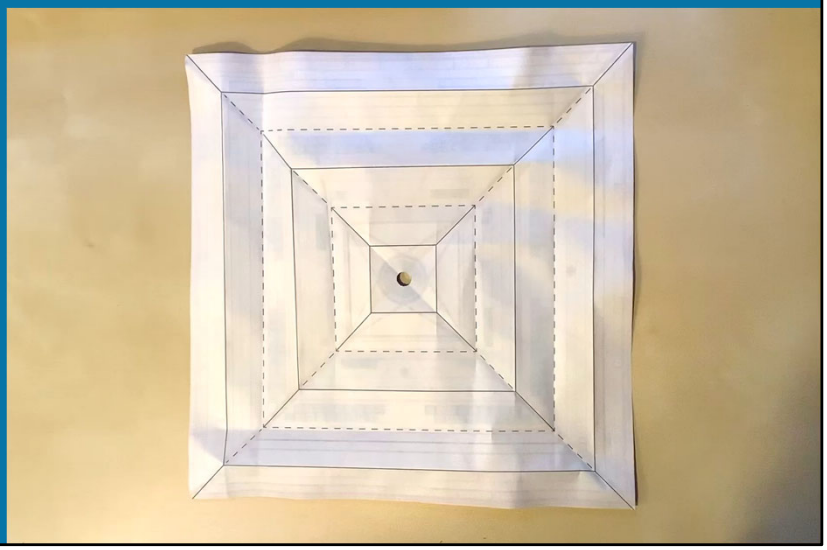


Starting from the outside, make mountain folds and valley folds in alternation, working along the lines parallel to each side of the sail.
It should look like this.
Do the same for the other parts.

STEP 3

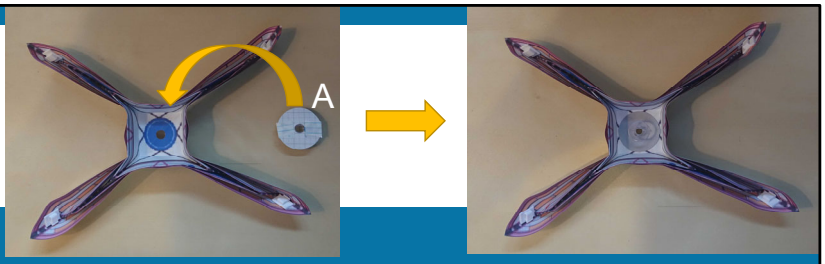


Following the previous folding rules, fold it along the diagonal from each corner point and furl it.



Next, make mountain folds and valley folds in alternation along the diagonal of the sail, following the lines drawn from each corner point.
It should look like this.

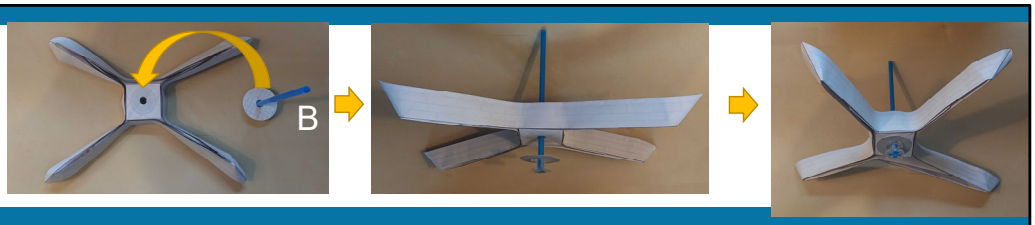
STEP 4



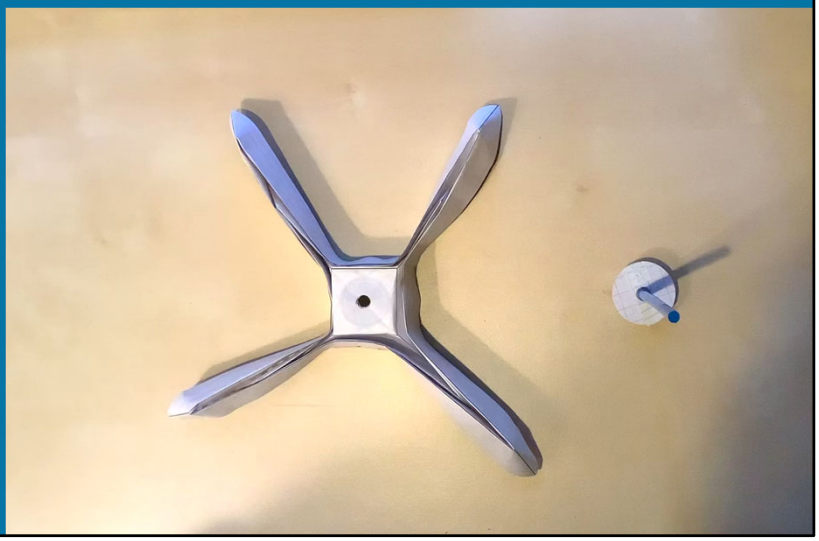
Turn the sail over, peel off the double-sided tape on Part A, and stick it so that the holes in Part A and the sail overlap.

Turn the sail over, peel off the double-sided tape on Part A, and stick the tape so that the hole is visible.
It should look like this.

STEP 5

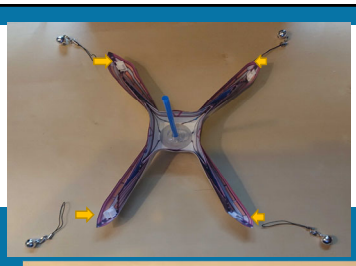


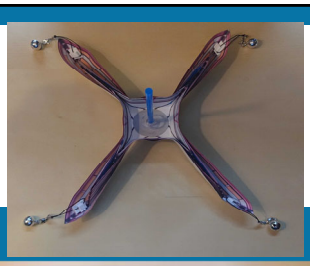
Turn the sail over, peel off the double-sided tape on Part B, insert a straw through the hole of the sail, and stick it together.



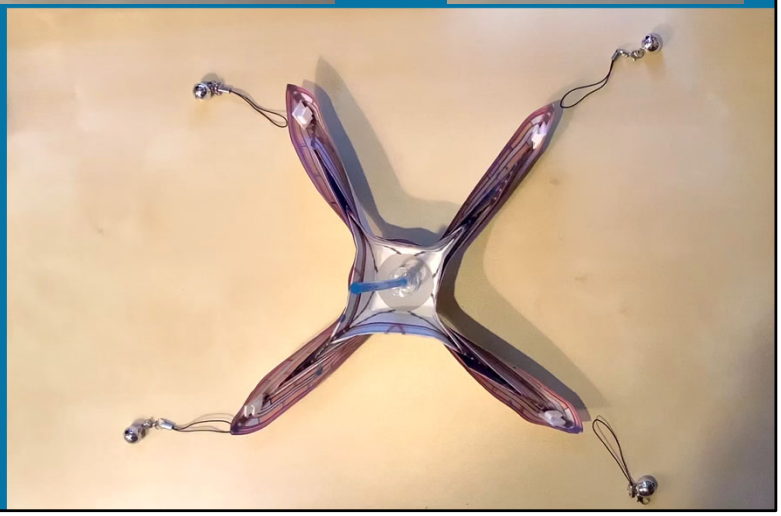
Turn the sail over, peel off the double-sided tape on Part B, insert a straw through the hole of the sail, and stick it together.
It should look like this.

STEP 6



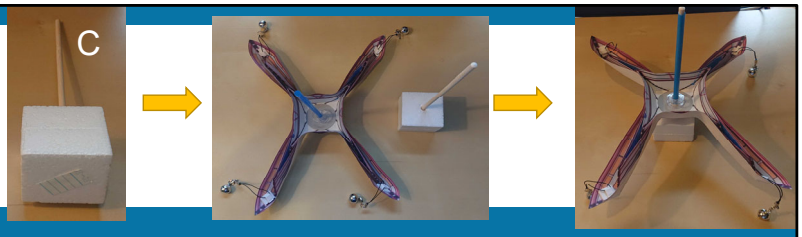


Take a bell by its string and hang it on the hook of the sail. Repeat this for each hook.

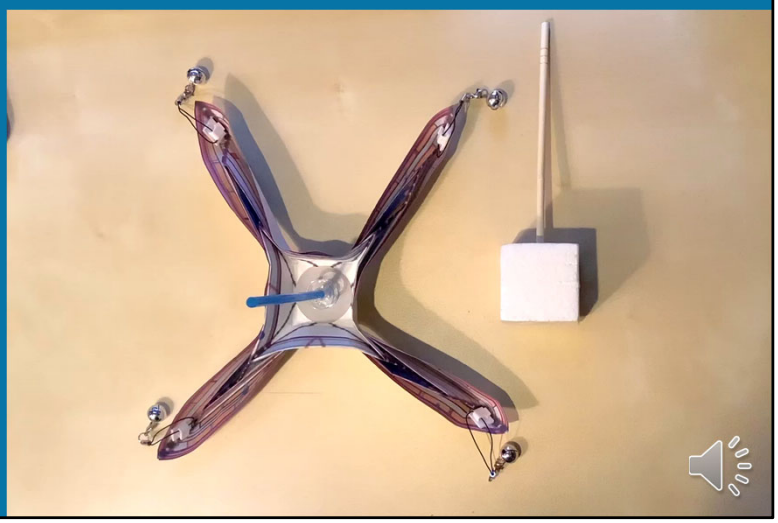


Take a bell by its string and hang it on the hook of the sail. Repeat this for all four hooks.
It should look like this.

STEP 7

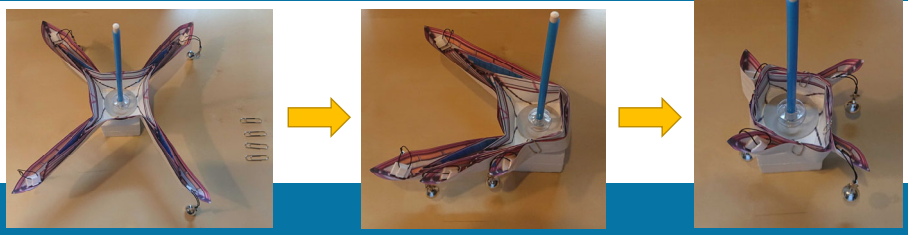


Peel off the double-sided tape on the rear of Part C and stick it to the desk. Put the sail straw from earlier through the bar of Part C.

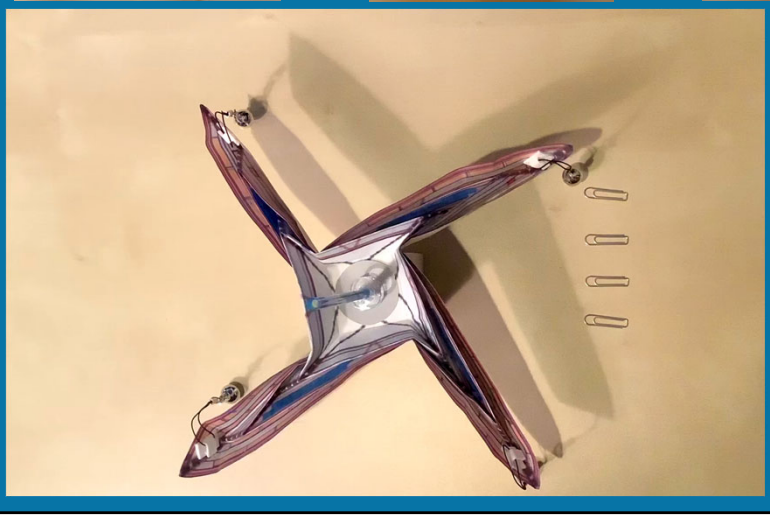


Peel off the double-sided tape on Part C and stick it to the desk.
Then, put the straw of the sail through the bar of Part C.
It should look like this.

STEP 8



Wind the straps clockwise around the cross part of the sail and fix it at four locations with clips.



All Done!!

Wind the straps around the cross part of the sail clockwise and fix them with clips.
IKAROS is now complete!!

LET’S UNFOLD THE SAIL OF IKAROS.

Let's try

Use your hands to rotate the straw counterclockwise.

How do you think the sail will unfold?

Now, let’s unfold its sail.
Remove the clips and use your hands to rotate the straw counterclockwise.
Let's Try!!

So what happened?
Did the solar sail unfold symmetrically and smoothly?

When I unfold its sail, it looks like this.

It’s possible that some of you couldn’t extend the middle part of the sides of the solar sail.
That would be because the centrifugal force was not transmitted well.

(Demonstration movie)

WHAT DID YOU THINK?

Folding technology from origami allows IKAROS to:

- ◯ Tuck in the solar sail compactly
- ◯ Extend it symmetrically and smoothly using centrifugal force.

Did you actually get a sense of this in the experiment?

What did you think?

Did this experiment give you a hands-on sense of how the solar sail of IKAROS unfolds?

WRAPPING UP

Technological development using origami technology is still underway.

Development in Japan (JAXA)

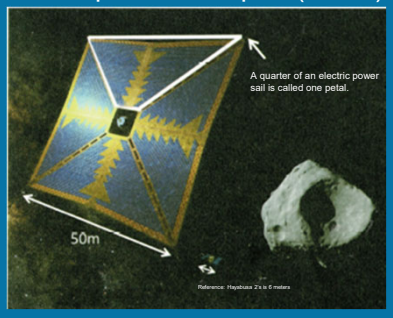


Fig. 1: Conceptual diagram of a next-generation solar power sail
(planned to explore the Jupitar trojans)
(Source: Yamashita 2016)

Development in the USA (NASA)

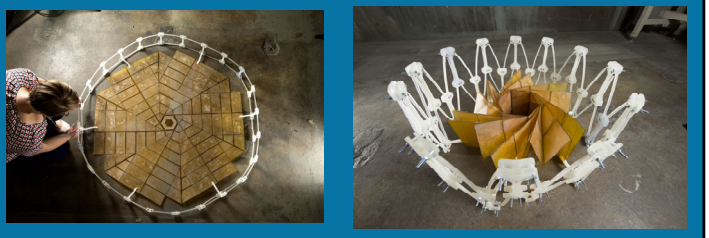


Fig. 2: Preparing a prototype solar array
(Source: https://www.nasa.gov/jpl/news/origami-style-solar-power-20140814)

The development of solar sails using origami technology is ongoing today.
As you can see here, new solar sails are being developed in Japan and the USA.

Did you experience the traditional Japanese play "origami" being applied to various technologies?
Especially in the application to space technology, it is used for efficient unfolding solar sails and is still under development.

Everyone, Please try out different ways of folding origami.
And I hope that the students will think about unfolding other than the solar sails introduced today in the classroom.

That’s all for my workshop.
Thank you for participating today.

I look forward to meeting you in person someday and exchanging ideas about space education.

REFERENCES AND WEBSITES

- Shigetomi (Kuribayashi) Kaori (2019): Bio-origami Engineering: Applications in the Medical Field, The Journal of the Institute of Electronics, Information and Communication Engineers, **102**, No. 4, pp. 335 - 341
- Osamu Mori (2011): Let's Travel the Solar System with a Space Yacht - The First in the World! The Challenge of IKAROS, Iwanami Shoten
- Miki Yamashita (2016): The World's First Space Yacht, IKAROS - Use Sunlight and Sail Through the Great Ocean of Space, supervised by Osamu Mori, Bunkeido
- Microsatellite Hirogari, Jointly Developed by Osaka Prefectural University and the Muroran Institute of Technology https://www.osakafu-u.ac.jp/osakafu-content/uploads/sites/428/pr20201019.pdf
- Kyushu University, "Design of insect-inspired fans offers wide-ranging applications" https://www.kyushu-u.ac.jp/en/researches/view/154
- CUA CubeSail HP https://www.cubesail.us/
- JAXA "Research on Space Science - The Small Solar Power Sail Demonstrator 'IKAROS'" https://www.jaxa.jp/projects/sas/ikaros/index_j.html
- JAXA Institute of Space and Astronautical Science (ISAS) - IKAROS, the Small-Scale Solar Powered Sail Demonstration Satellite http://www.isas.jaxa.jp/missions/spacecraft/current/ikaros.html
- JAXA Space Education Center website http://edu.jaxa.jp/lessonplanimg/.iuraori.jpg
- JAXA Space Information Center website http://spaceinfo.jaxa.jp/ja/sfu.html
- miura-ori HP https://miuraori.biz/feature/
- NASA "Solar Power, Origami-Style" ESPLORE SPACE TECH, Aug. 15, 2014 https://www.nasa.gov/jpl/news/origami-style-solar-power-20140814
- NASA facts "NanoSail-D" https://www.nasa.gov/centers/marshall/pdf/484314main_NASAfactsNanoSail-D.pdf
- Planetary Society "LightSail 2 During Sail Deployment Sequence" https://www.planetary.org/space-images/lightsail-2-with-sail-1
- PNAS " Investigation of hindwing folding in ladybird beetles by artificial elytron transplantation and microcomputed tomography" https://www.pnas.org/content/114/22/5624/tab-figures-data
- Wikipedia Jacob Peter Gowy's *The Flight of Icarus* https://en.wikipedia.org/wiki/Icarus#/media/File:Gowy-icaro-prado.jpg