ANSYS Solutions simplify additive manufacturing – the example of a drone

Concept becomes reality

Drones are one of the interesting products which require reduced weight and high strength. 3D printing, which is the most powerful manufacturing technique for making light structures, can be efficiently combined with topology optimization. For this project, Taesung S&E created a real drone with an organic, biological cellular lattice shape. ANSYS topology optimization and Discovery Live were used at the design stage to reduce weight and increase aerodynamic performance. ANSYS Additive Print was used to minimize the thermal deformation and residual stress, prevent blade crash and increase the manufacturing effectiveness. It also provides a compensated model for accurate dimensioning.

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Objective

In general, additive manufacturing (AM) (also known as 3D printing) has special advantages for

- making structures with complex shapes that were impossible to make in the past
- reducing the number of parts as a one body

This project was initiated to prove the merits of metal additive manufacturing by creating a real product, a Racing Drone. Four detailed objectives were set:

1. Topology Optimization

- Improve the body rigidity as the first priority to maximize the responsiveness of the racing drone's flight controls for rapid maneuverability;
- Evaluation with the Light Weight Index to ensure maximum mass efficiency
- Organic and Biological design

2. Lattice structure

- Additional weight reduction by using a lattice structure
- Styling considerations

3. Titanium (Ti64)

- A difficult material to produce with conventional processing methods
- High corrosion resistance, light weight and high strength compared to steel
- No immunorejection by the human body (while this was not critical for the drone it is a consideration for the next project)

4. Feedback from AM field

- Easy to remove supports
- Support optimization

Development process

It was decided to create an easy process that any common designer, and not only a CAE specialist, could follow after taking some simple training. This was achieved by skipping the digital verification step usually conducted by experts.

ANSYS mechanical was used for the Design for Additive Manufacturing (DfAM) and topology optimization at the design stage.

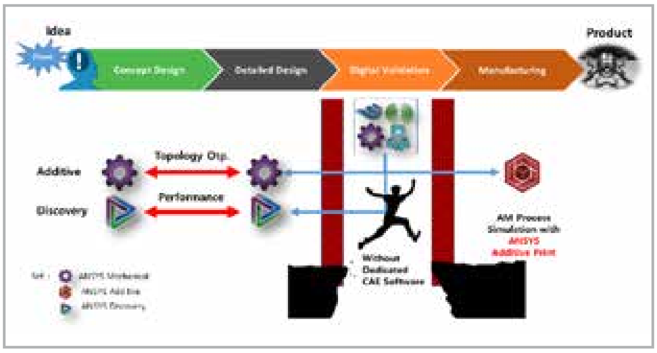


Fig. 1 - Development process

ANSYS Discovery Live was used for initial virtual validation and ANSYS Additive Print was used for the manufacturing process.

Topology optimization

There are many load cases and constraints which should be considered when performing topology optimization, such as forces, moments, vibration and so on. Fig. 2 shows the final topology shape which has an organic and biological appearance.

Based on the STL file from topology optimization, the mounting design and some modifications for the wire harness path were conducted directly in ANSYS Spaceclaim. To achieve a lighter design, a lattice structure was considered for the drone body center and cover. Important considerations were the reduction of mass and the ease of removing the supports.

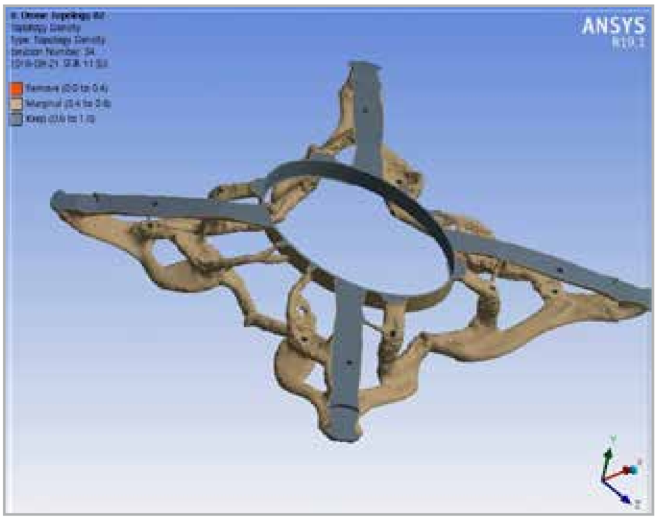


Fig. 2 - Topology optimization result

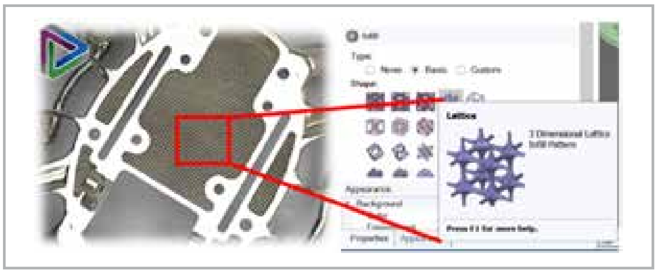
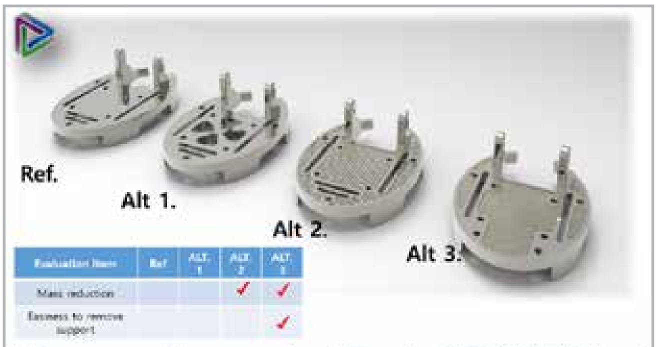


Fig. 3 - Lattice design function in ANSYS Spaceclaim



		Ref.	Trim	3D Lattice Infill Pattern	
			ALT. 1	ALT. 2	ALT. 3
Lattice	Length(mm)	-	-	1.6	0.8
	Thickness(mm)	-	-	0.4	0.2
	Fill Rate	-	-	14.7 %	14.7 %
Mass (g)		70.3	60.6	41.2	41.2
Mass reduction ratio		-	-13.8%	-41.4%	-41.4%

Fig. 4 - Alternative candidates and evaluation results of body design

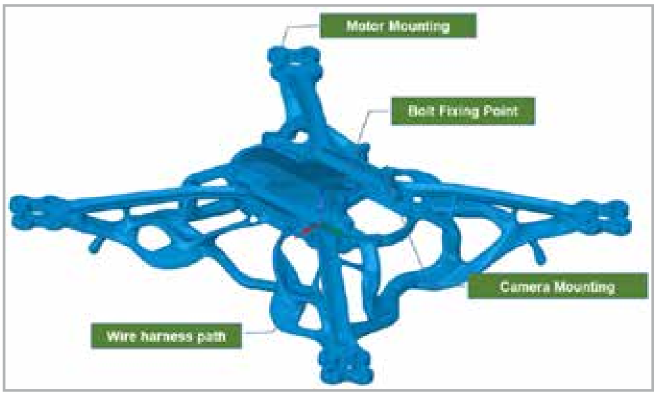


Fig. 5 - Final body design (AM result)

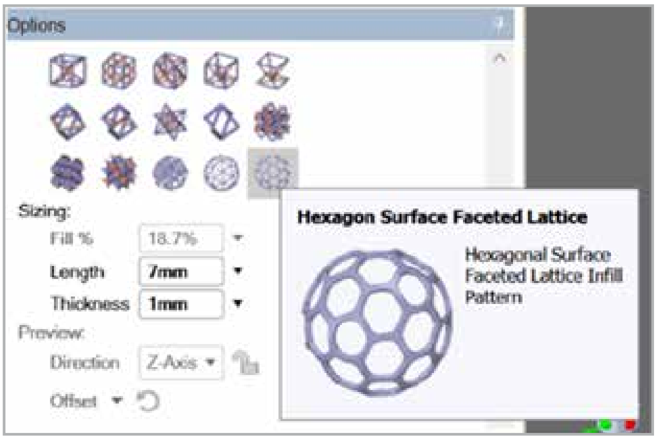


Fig. 6 - Hexagon surface function in ANSYS Spaceclaim

Evaluation item	ALT. 1	ALT. 2
Mass reduction	✓	
Styling	✓	
Easiness to remove support		✓

		Ref.	Hexagon Surface Faceted Lattice	
			ALT. 1	ALT. 2
Lattice	Length(mm)	-	7	5
	Thickness(mm)	-	1	1
	Fill Rate	-	18.7 %	24.9 %
Mass (g)		122.9	64.4	73.8
Mass reduction ratio		-	**-47.6%**	**-40.0%**

Fig. 7 - Alternative candidates and evaluation results of the cover design

Compared to the reference model of the body, alternative 2 (Alt. 2) and alternative 3 (Alt. 3) show similar weight reduction -- about -41%. But body design alternative 3 (Alt. 3) was selected for its convenience of removing the supports. Next, a hexagon surface faceted lattice structure was applied to reduce the cover weight. Even though candidate Alt 1 offered good weight reduction, Alt 2 was selected because it offered the same convenience of support removal as the body design.

If the hole size were small, the structure could be manufactured without supports. But if the hole size is larger than a specific dimension, many supports are required to prevent deformation during AM processing.

In Fig. 8, one can see many supports directly attached to Alt 1's hexagonal surface. But, by using Alt 2, we could manufacture the entire lattice structure at once without any inside supports attaching to the hexagonal surface.

Fig. 9. was made with ANSYS Spaceclaim's Keyshot module and enabled the design and styling of the drone to be finalized. The next steps were to check the strength and the aerodynamic performance and to create the product without any defects (deformations, cracks, etc.)

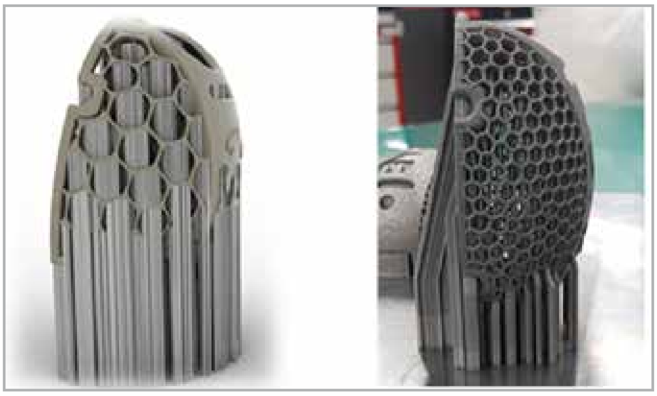


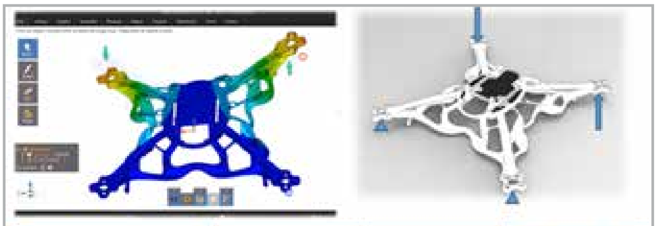
Fig. 8 - Supports in Alt 1 (left) and Alt 2 (right)

Fig. 9 - Rendering with ANSYS Spaceclaim

Virtual validation

The simplest and most common way to check structural safety is with a static stiffness analysis. Among several static stiffness analyses, we conducted a torsional stiffness analysis (also known as rigidity) which is usually used for bodies that rapidly accelerate/decelerate, like racing drones. In general, when the drone changes direction rapidly, a low rigidity drone would distort.

The purpose of the topology optimization was to reduce the weight while increasing the stiffness, but sometimes these two requirements conflict. Using a light weight index (mass/torsional stiffness) is one way to evaluate how well the optimization was done. Sometimes area (A) is used to compare the model size: the lower the index value, the better the design. The model with topology optimization only showed no weight/



Item	Ref.	Topology	Topology & Lattice
Mass (M)	1 (295g)	1.2 (354g)	1.09 (323g)
Size (Diagonal Length)	1 (210mm)	1.2(260mm)	1.2(260mm)
Mass/Size	1.00	0.97	0.88
Torsional Stiffness(C_t)	1	2.2	1.7
Light Weight Index	1.00	0.44	0.52

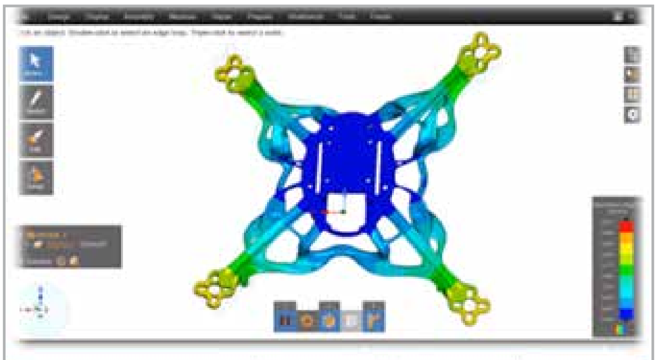
$$\therefore Light\ Weight\ Index = \frac{M}{C_t \times A}$$

Fig. 10 - Torsional stiffness and light weight index

size reduction, but the stiffness doubled, resulting in an index of 0.44. After applying the lattice, weight was reduced by -12% and a torsional stiffness increment of 70% was achieved (index=0.52). This meant the design was almost two times better than the reference model.

It is important to emphasize how easy this simulation process is. With ANSYS Discovery Live, it only took 1 minute from importing the STL file to obtaining the post-stress and deformation results.

Next, the dynamics stiffness (modal analysis) was checked.



Item	Ref.	Topology	Topology & Lattice
1st Mode (Hz)	167	250	214
Ratio	1	1.5 ✓	1.3

Fig. 11 - Dynamic stiffness

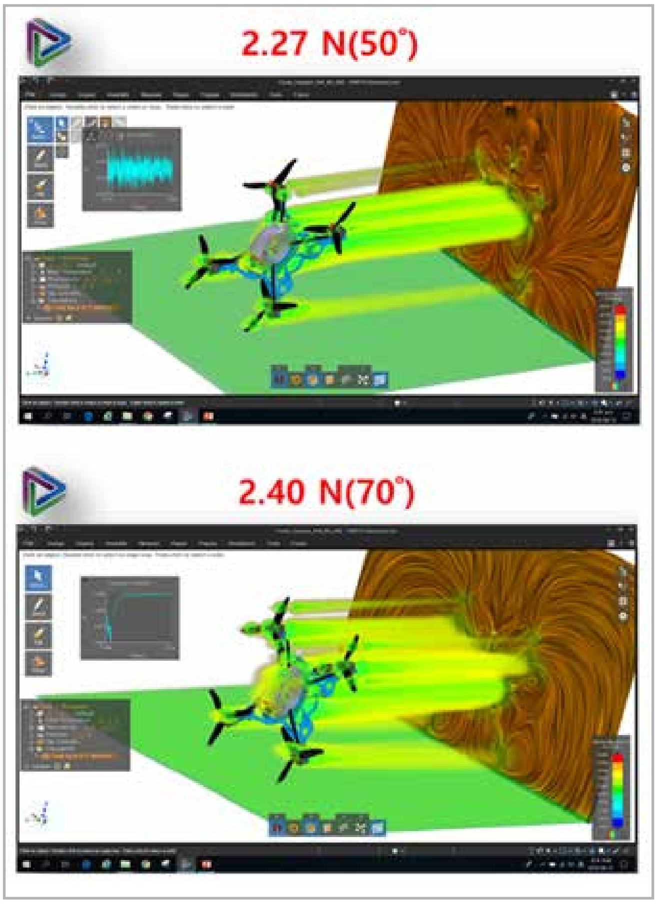


Fig. 12 - Aero-dynamic performance (drag force)

In conclusion, the topology model was superior to the additional lattice mode for both static and dynamic stiffness. We selected the "Topology and Lattice" application model just for an experimental application of the LATTICE structure.

Finally, an external flow analysis was conducted in ANSYS Discovery Live to check the drag force at several attack angles. This analysis was completed in 10 (s) without any additional geometry modification or meshing operations.

AM build

ANSYS Additive Print was used to pre-check possible thermal deformation, blade crash, high strain severity and residual stress during the AM process. Blade crash means a Z-directional deformation. If the value is large, the product will be hit by the recoater blade and the product could be broken during processing. If strain severity is high, a crack could easily occur. If residual stress is high, there could be durability problems during use. The After cut off displacement plot shows the product's deformation after cutting the supports this is related to the product's precision. All of these elements can be checked in ANSYS Additive Print immediately.

In addition, ANSYS Additive Print offers optimal support design which minimizes previous problems.

The role of the supports is to support the product and prevent thermal deformation during AM processing. They can also serve as thermal paths to the base plate to facilitate dissipation of high temperatures. On the

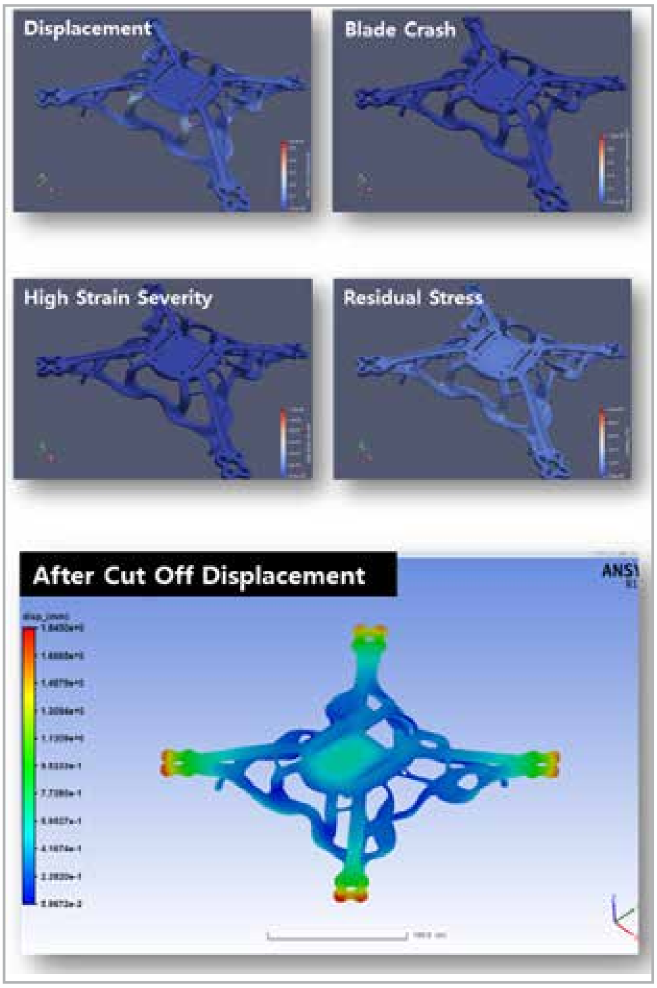


Fig. 13 - Problem estimation during AM processing

other hand, many supports are difficult to remove and increase product costs, material and time wastage. So, the most effective support locations and methods must be selected.
Alt 1 is a general 45-degree type for reducing the supports, and Alt 2 is a parallel type with many check points. We selected the Alt 2 type after considering the manufacturing speed, the surface quality and the price of titanium powder. Fig. 14 below shows the supports created with the thick wall method as suggested by ANSYS Additive Print. The black-looking area is the area of most inter-supports due to the lack of variation in thermal stress.

In summary, ANSYS additive print generates an optimal support design based on a prediction of thermal deformation, unlike other programs that consider geometry only.

Finally, the drone body was successfully created. Fig. 15, top, shows the products taken directly from the Metal AM and the image below shows it after removing the supports and thermal treatment.
The cover was created with two different orientation angles. One was for minimizing the number of supports and the other was for the surface finishing. Both were successfully produced.

Fig. 17, left, is a rendering of the drone model in ANSYS SpaceClaim's Keyshot. The concept was developed with computer simulations considering topology optimization, lattice design and AM processing

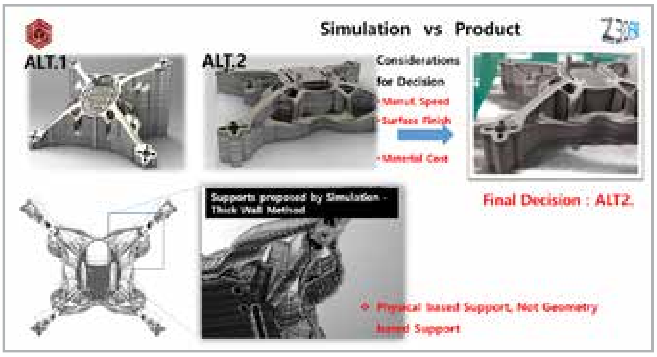


Fig. 14 - Parallel dupport (top), thick wall method (below)

Fig. 15 - Before and after removing the supports (body)

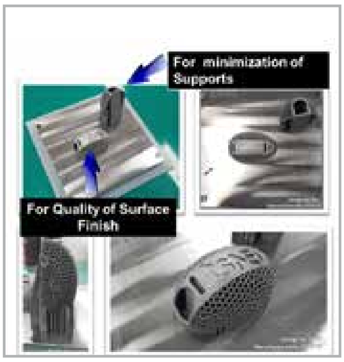


Fig. 16 - Cover

in ANSYS Product. On the right is the final product. The entire process was completed in two weeks. In the meantime, we created a plastic version for possible assembly.

Isn't it amazing?

This Drone project made us realize that all design processes

Fig. 17 - Before and after removing the supports (body)

can be undertaken in a CAE-environment and that concept design can create real designs without any complex or real tests. ANSYS helped us to realize all this process.
The real flying drone we made can be seen at the link below.
www.youtube.com/watch?v=WAjpd_0jpwE

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