The Future of Aerospace Design and Manufacturing through Self-Assembly and 4D Printing

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The design and manufacturing of aerospace systems and components has remained relatively unchanged for the last few decades. However, two new innovations that could change the status quo are Self-Assembly and 4D-printing. Both are based on the idea that the changing stimuli of the environment of certain materials could alter their physical size, shape, and position. These ideas, which have normally been associated with biological and chemical processes, can now be applied to the aerospace industry. Three examples will be developed to demonstrate the potential applications including physical assembly by vibration platform environment[1], jet engine inlet and outlet nozzle design, and control surface design. These designs along with strategies for manufacturing will be presented in the final paper to further demonstrate the potential opportunities for future aerospace designs and manufacturing.

I. Introduction

Most aircraft designed and built today follow many of the same principles as the days of the Wright Brothers. An engine of some kind generates thrust to move the plane forward against the air to generate lift from the shape of the wings and body to overcome the weight and drag of the plane. The difference lies in the shape of the plane, the type of engine, and the construction material. The most common construction materials used today have been narrowed down to either metals (aluminum, titanium, and steel), or more recently composite materials (fiberglass and carbon fiber). The most common engines are either turboprop or turbojet/fan engines. And, the although plane fuselages can vary wildly based the function of each plane, they all feature a similar arrangement for their control surfaces: ailerons, flaps, elevator, rudder, etc. Planes have changed dramatically over the last 100 years. 40 years after the Wright Flyer, Grumman came out with the F-4F wildcat one of the first all metal fighter planes. About 40 years after came the F-14 Tomcat, also a Grumman product. A massive airframe carrying large turbojet engines capable of over Mach 2 with the most sophisticated radar and flight control systems of the time. And 40 years after that, we have the Lockheed Martin F-35 Lightning. Another fighter jet but this time with advanced stealth technology, even more sophisticated electronics and on-board sensors and computers, and on the F-35B variant, capable of vertical take-off and landing (and yes Grumman which is now Northrop Grumman does produce the forward fuselage of the F-35). If we follow this trend, 40 years from now, the next generation of planes will be even more unrecognizable with technologies we could never have thought of today, until today. The technologies that will become commonplace in the aerospace industry in the future are still in their infancy today, and often times they're technologies which weren't even conceived with aerospace in mind such as composite materials. Two new technological concepts that aren't very well known in the aerospace industry are self-assembly and 4-D printing. Self-assembly or self-organization is defined as the process by which individuals, organisms, or objects automatically organize their behavior to create order by

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interacting with themselves on their own without any external intervention such as by observing humans[2]. This concept is used a lot in biological fields such as studying bacteria cultures, the central nervous system, and egg fertilization but not much else outside of this field. 4-D printing is another new concept similar to 3-D printing except instead of just static pieces being produced, the printed parts can change their shape with external stimuli such as light, heat, electricity, etc., with the extra dimension being time. Like Self-Assembly, 4-D printed materials behave on their own without human intervention. Because of their unique characteristics I propose that these new technologies could be applied to the aerospace industry in several innovative new ways.

II. Vibration Self-Assembly

Self-Assembly can be described in using a design strategy. A design strategy is basically the algorithm of all the rules that the objects participating in a self-assembly also known as agents must follow. These include the effect of boundaries conditions and external stimuli on the objects as well as how they bond or create patterns with each other. In Dr. Sanjay Sarma's research of Systems Design Concepts Mimicking Bio-inspired Self-Assembly, he presented his case study of a self-organization system through the use of a Vibration Simulation Platform using Unity 3D software and various CAD models to represent the physical agents. This case study was meant to show the Free-Agent design strategy where the user can select which physical process is taking place.

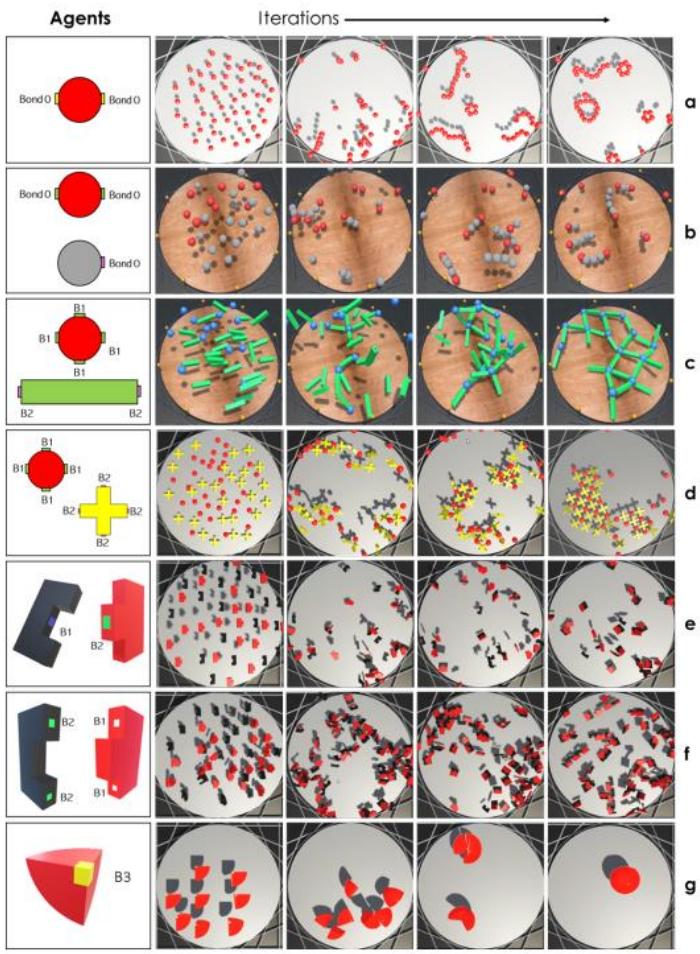

Fig. 1 Free Agent Simulation Examples

As seen in this image of Dr. Sarma's simulation, the various agents which are in essence the building blocks in this simulation all eventually formed into some pattern after being exposed to the vibration platform with the only changing stimuli being the vibration platform's frequency, amplitude, and pattern type: linear or elliptical [1]. These patterns and assemblies were meant to simulate real life molecules and chemical bonds and how they might self-assemble on their own. This simulation could be expanded upon to more accurately portray the material properties of aircraft component materials such as titanium and aluminum alloys. We could use this research to study the ways of how these allows are made and how to improve upon them such as better understanding what stresses and strains they could withstand and fatigue loading over time. This principle could also apply to composite materials in the same way by using different agents to represent the different fibers and resin types. Finally, this data can be used to better understand the chemicals used by aircraft. These include the fuels, hydraulic fluids, lubricants, etc. By better understanding how they function based on these stimuli, we can have a better understanding of how they're made, how they can degrade, and how to improve and manufacture more of these fluids to be cheaper, longer lasting, and above all much safer in the future.

III. Jet Engine Design

All aircraft except gliders need some kind of engine to power them. Otherwise, they couldn't get off the ground. The most common type of engine seen on aircraft of today is the turbojet engine. This type of engine uses the combustion in a turbine to create thrust to power the aircraft. Ever since the first mass produced jet aircraft, the ME-262 made its debut in WW2, the jet engine has undergone quite a few upgrades and mods to stay relevant in today's world. For example, many military jet engines have after-burners to help the engine generate additional thrust to reach super sonic speeds. Many passenger jets have a version of the turbojet called the turbofan engine where some of the inlet air bypasses the combustion chamber and exits the rear of the engine contributing the thrust without using extra fuel. But perhaps the newest and most unique modification to the jet engine is the use of thrust vectoring[3].

Fig. 2 P&W F119 Thrust Vector Engine

Thrust vectoring is the technology that allows turbo-jet engines to allow the direction of the thrust created by the hot exhaust to travel in other directions besides straight out. It's primary application has been fighter aircraft either to improve maneuverability in addition to the control surfaces or in VTOL aircraft which must operate in confined areas such as military bases with small airstrips and small aircraft carriers. The problem is that it's very expensive to both build and maintain. They have only been limited to the newest and most expensive military fighter jets such as the American F-22 and F-35 and the Russian Sukhoi Su-35 and Su-57. Part of this comes down to the complexity of their designs. With so many moving parts such as rods, levers, gears, sensors, etc. it's no wonder that only a handful of planes even have them. In order for more planes to use them and help unlock their future potential, the basic design of thrust vectoring needs to be improved by drastic simplification, and 4D printed engine components could be the answer. We'll use an F-22 as our example.

Fig. 3 F-22 Raptor, Fighter Aircraft

The F-22 currently uses the Pratt and Whitney F119 engine which are designed to shift the direction of thrust up or down by as much as 20 degrees. Although the exact design specifications for this engine and many thrust vectoring engines is highly classified, we can presume that the thrust vectoring mechanism consists of hundreds if not thousands of moving rods and levers to angle the exhaust nozzles in the correct direction wanted by the pilot. If we were to invent a new 4-D printed material that could deform its shape at will using only heat, it could be used in the exhaust nozzle section of a thrust vectoring engine, so that it wouldn't need as many rods and linkages to mechanically move it. The whole nozzle could move on its own based on how much heat or the stimuli of chosen is applied to it.

In addition to engine exhaust, we should also not forget the engine inlets. Several jet aircraft design for supersonic speeds such as the f-15, SR-71 and the Concorde have adjustable intake ramps. Although their designs were all different, their main goal is the same: to slow the speed of supersonic air to subsonic speeds which the het engine can handle by adjusting the internal geometry of the engine inlet.

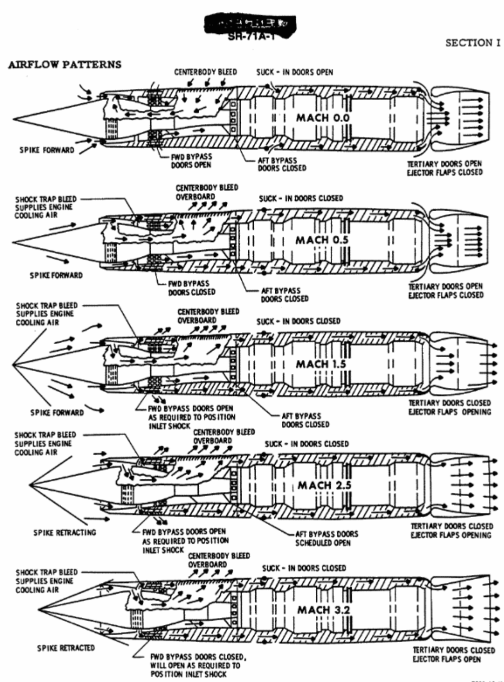

Fig. 4 SR-71 Adjustable Inlet Engine

With the SR-71 engine as an example, 4-D printed materials could be implemented for use in simplifying engine intakes such as intake cones and ramp doors that could be self-adjusted by various factors around them such as airspeed, temperature, and pressure. They could be applied to future Hypersonic aircraft prototypes as well as subsonic commercial aircraft to test for improved fuel efficiency[4].

IV. Control Surfaces

Another area where 4-D printed materials could be applied is in the control surfaces of an airplane. Specifically, one type of control surface that would greatly benefit from this new material. Flaps are designed to increase an aircraft's lift during takeoff and landing. They are no used during flight as it would induce too much drag, thus it is only used during those two events. So much heavy and complex machinery such as hydraulic lines and linkages must be used to mechanically control flaps despite being only a small part of an aircraft that is only used during takeoff and landing. A 4-D printed flap could improve aircraft performance by not only saving weight from the removal of hydraulics lines and actuators in the area of the wing, but also reduce maintenance costs by having less parts.

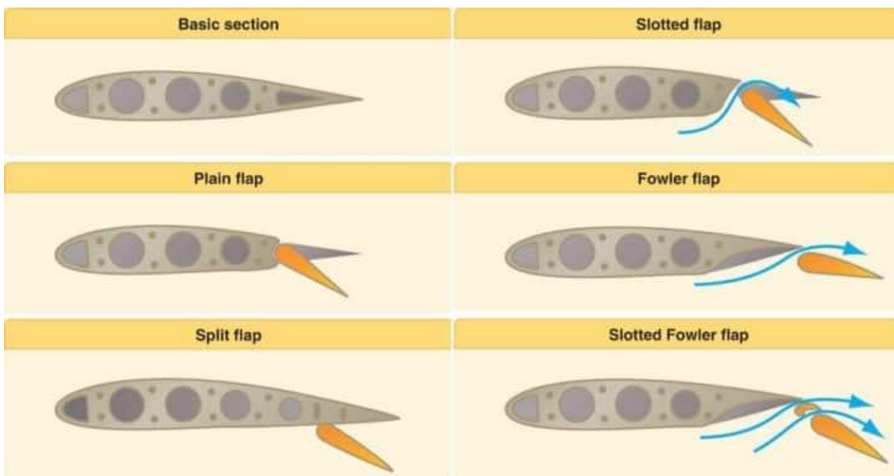

Fig. 5 Flap Designs

Just like using 4-D printing for jet engine air inlets and exhaust control, 4-D printed flap materials can also be controlled by the surrounding airspeed, temperature and pressure to automatically deploy and retract at the right times. They could be used in the exact same way as all current flap designs on aircraft to accommodate for different types of aircraft from small fighter jets to larger passenger jets. The possibilities are endless and could eventually be applied to other control surfaces as well[5].

V. Conclusion

Although all of the topics in this report are hypothetical and still in the concept phase. They serve as examples of new and forward thinking in the aerospace industry. Their potential is yet to be untapped because we still need to research them today. Very few researchers have found practical uses for self-assembly and 4-D printing right now for any industry application let alone aerospace, but maybe in the next 40 years, that won't be true. Maybe in 40 years we will finally understand these technologies and what they're truly capable of. The real question is what will Self-Assembly and 4-D printing's real impact on the future of aerospace be?

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