Effect of Embedding Shape Memory Alloy (Cu-Zn-Al) in an Aircraft Wing Panel

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Abstract

Aircrafts that are designed with fixed wing structure have to sacrifice design efficiency. Most airplanes wings are designed to perform optimally at cruising speed in order to save on fuel consumption. Flight conditions that consume the most fuel are: take-off, ascending, descending and landing. At these instances, the aileron is expected to deflect, thereby using more energy. In this work, shape memory alloy, Cu-Zn-Al was used to simulate an aileron deflection, using the effect of temperature change in the behavior of this material. The rate of austenite and Martensite start and finish were first established. With that knowledge, a suitable dimension and the number of the alloy to be embedded for the desired aileron deflection was determined by iteration method, using MATLAB codes. The effect of temperature on the embedded material at different altitudes were determined and plotted.
It was observed that it is very easy to reach a down aileron with the shape memory alloy than it is to get the aileron up. It was also concluded that a shape memory, self-actuating material can be used to achieve this motion in an aircraft wings without additional energy.

Keywords: Aircraft, austenite, martensite, shape memory alloy.

Introduction

Smart materials are defined as materials that react to their surroundings, resulting either from the addition or removal of energy. Such surroundings includes changes in pH, temperature, pressure, light and also magnetism (Jahanzeb, 2012). Smart materials have inherent and induced capabilities. According to Akhras, smart materials respond to stimuli and changes in the environment. They can activate functions, such as deformation or deflection according to these changes (Akhras, 2000). Smart materials can be classified as follow: Thermo-to-mechanical, electrical-to-mechanical, and magnetic-to-mechanical and vice versa. The most common smart materials are: Piezoelecric Materials, Shape Memory Polymers (SMP) and Shape Memory Alloys (SMA). Advances in technology of smart materials provide an opportunity to make air flight more efficient(Amariei, Miclosina,Vela and Tufoi, 2010). By researching on the possibility of getting rid of the heavy actuators and changing the shape of the airfoil to suit different flight conditions, it is envisaged that there will be a reduction in fuel consumption and hence savings in energy. This will in turn increase the distance aircrafts can travel with the same amount of aviation fuel.

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Shape Memory Alloys (SMA)

Shape Memory Alloys (SMA) have the ability to return to their original shapes when heated and then cooled. Thus, the material remembers its previous shape. The deformation of SMA occurs at relatively low temperatures and when heated, the material will return to its original form (Callister, 2007). The material moves between austenite and martensite phases when cooled or heated. Figure 1. shows a fundamental characteristics of Ni-Ti as reported by Callister. Shape memory alloys can be used as actuators in the automotive industry. It is also used extensively in dentistry for certain dental corrections.

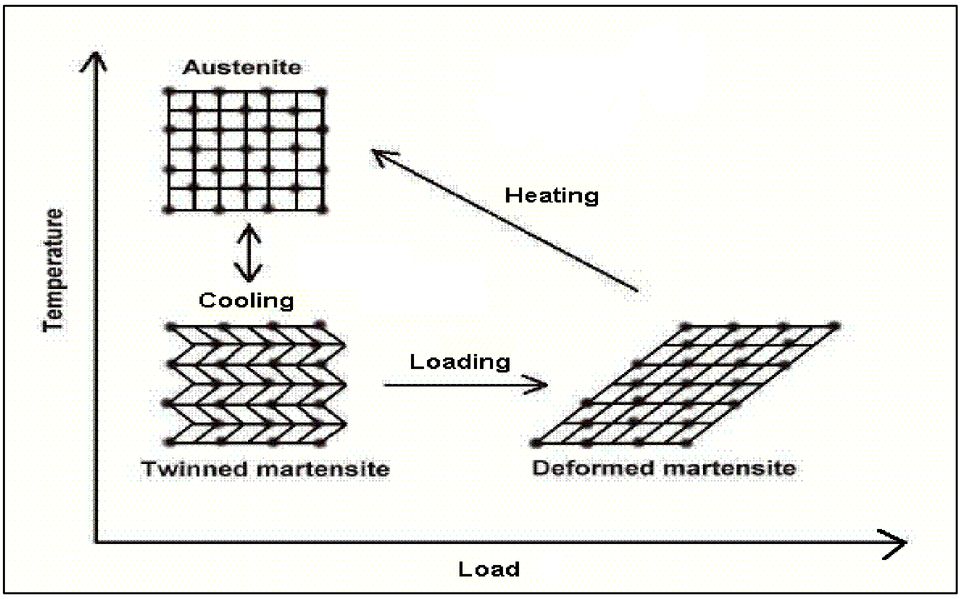

Figure 1. Material moving between the two phases austenite and martensite (Herkules, 2013)

Deflection in SMA can either be a one-way- memory or a two-way memory. In a one-way memory, the material deflects only when it is heated. When it is cooled at a low temperature, it does not change in shape. Conversely, a two-way memory alloy is able to deform when heated and reverse when cooled beyond certain temperature (Otsuka and Wayman, 1999.).

Phase Transformation of Cu-Zn-Al

The material used for the simulation is Cu-Zn-Al. The composition of the alloy used was Cu-25.63%, Zn-4.2% and Al-70.17%.

Table1. Input Parameter

Symbol	Value
D	6mm
A	18.06 x 10^{-6} $^{o}C^{-1}$
U	0
S	1
σ^{+}	6 ^{o}C
σ^{-}	3 ^{o}C
μ^{+}	290
μ^{-}	270
Austenite Start	289 K
Austenite finish	290 K
Martensite start	287 K
Martensite finish	270 K

The input data were taken from the experimental data of (Lexcellent and Bourbon, 1996)

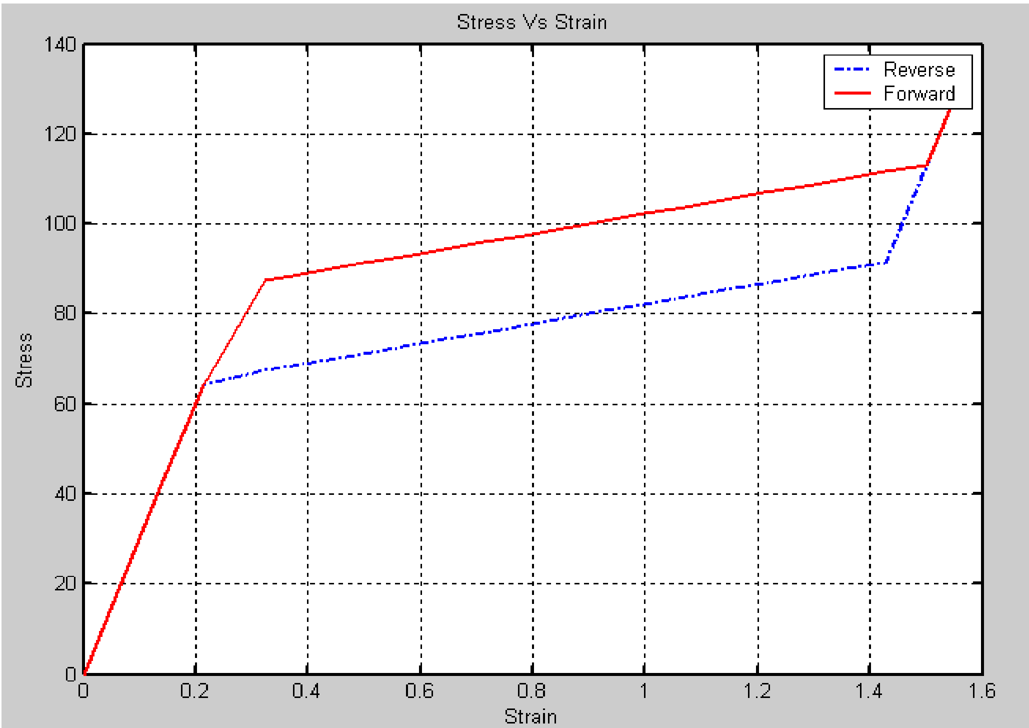

Figure 2. Rate of Phase transformation

Modeling of the Wing

The material used for this Simulation is Cu-Zn-Al. The composition of the alloy used was Cu-25.63%, Zn-4.2% and Al-70.17%. A wing panel was drawn in Solidworks of 1000mm in length and 300mm in with. The thickness of the carbon fiber weave was 8mm. The wing design that was used is Wortmann FX60-126airfoil.

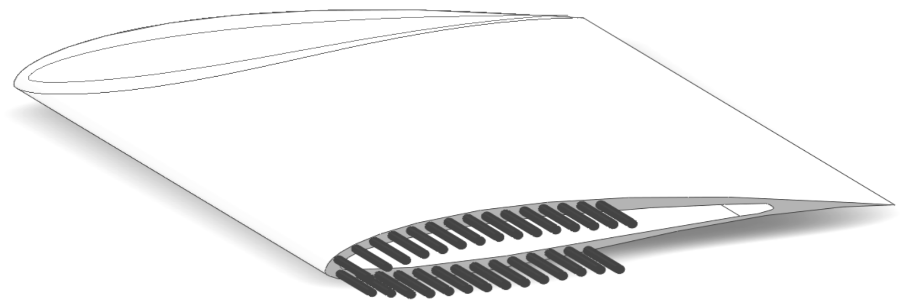

Figure 3. Simulated version of a full wing with infused 6mm diameter Cu-Zn-Al SMA wire.

The deflection of the wing, due to its own weight, was calculated using the beam deflection equation. The wing was analyzed as a cantilever beam. Practically, the in-flight deflection of a full wing for a Boeing 787 is about 7.62 m with a full length of about 30 m long (Paur, 2010). Using a 1 m long wing and mimicking an in-fight condition gave a maximum deflection of 0.254 m using equation 1.

$$\frac{UAV}{7.62} = \frac{1}{30} \qquad (1)$$

Iteration of the Number of SMA Wire

A script was written in order to iterate the number of Cu-Zn-Al SMA wires required to obtain a way deflection of a 1000 mm long wing, as shown in the figure above. The result is plotted in figure 4.

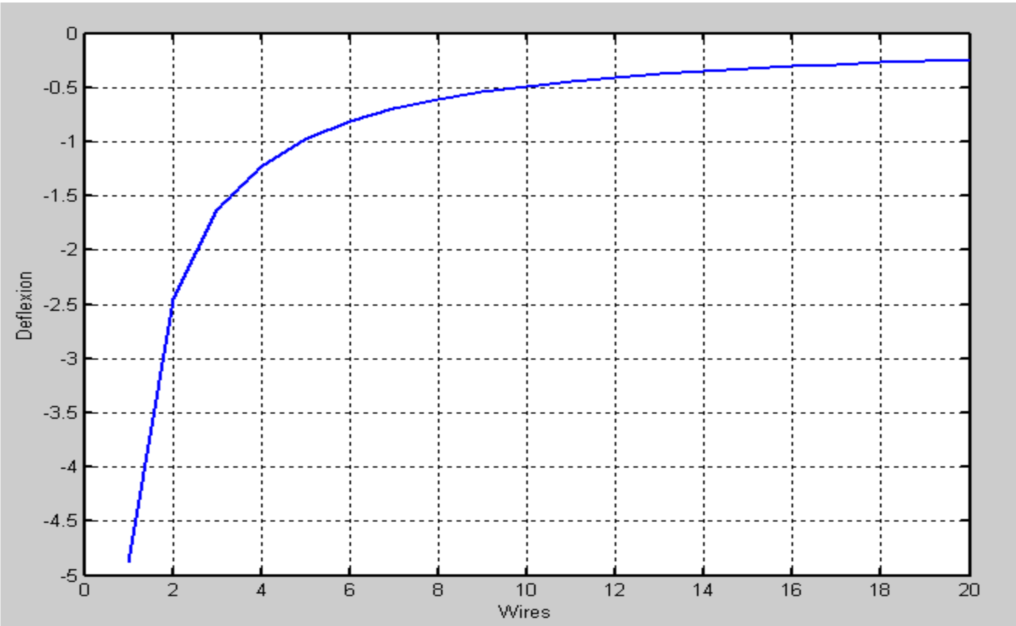

Figure 4. The number of wire required for the maximum deflection of the 1 m length wing

It can be seen from Figure 4 that the number of wires required to obtain a deflection of the wing to 0.254 m are 20 wires.

Temperature and Altitude on Cu-Zn-Al SMA Wire

Temperature changes from day to night in summer and in winter. Also, as the altitude increases, the temperature drops. Table 2 shows the average temperatures (during the two seasons of the year) over South Africa and the drop in temperature for every 1000 meter in to the air.

Table 2. Data used to calculate temperatures at various altitudes (Gratz, 20013).

Season	**Day**	**Night**	**Temperature drop for every 1000m increase in altitude**
Summer	28°C	8 °C	-9.8 °C
Winter	18 °C	1 °C	-6 °C

After about 11 000m, the temperatures average out and the formula is no longer necessary which is in Table2.

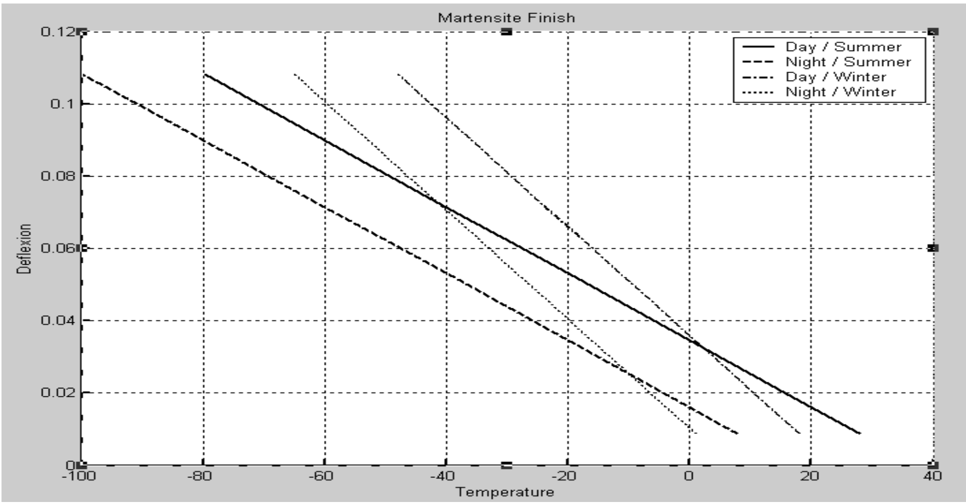

Figure 5. Wire temperature of 6.85 °C

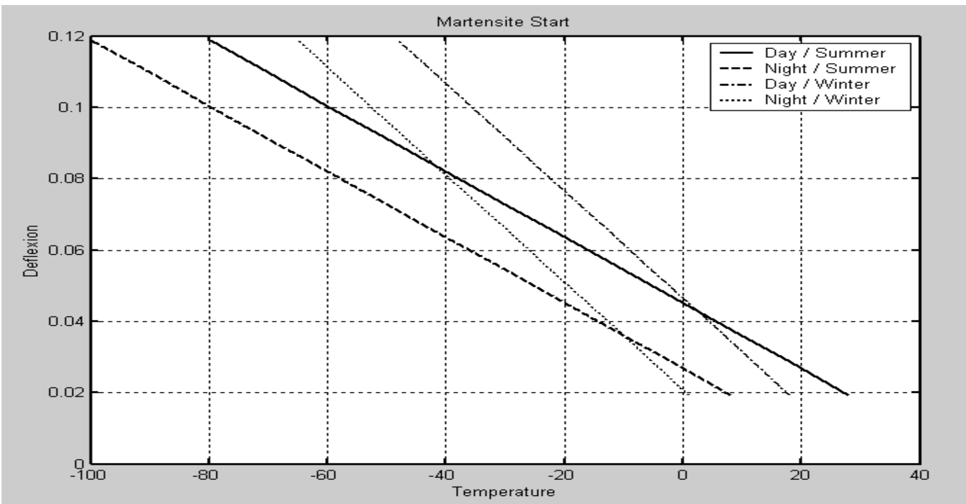

Figure 6. Wire temperature of 13.85 °C

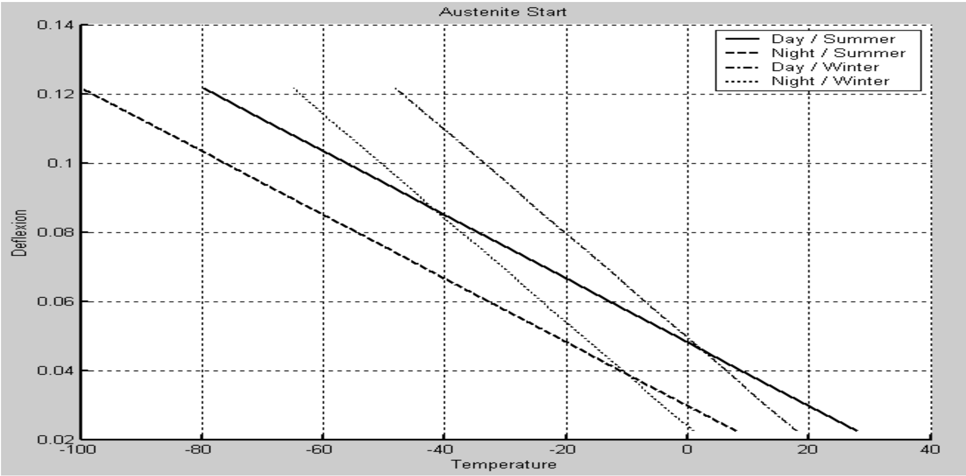

Figure 7. Wire temperature of 16.85 ^{o}C

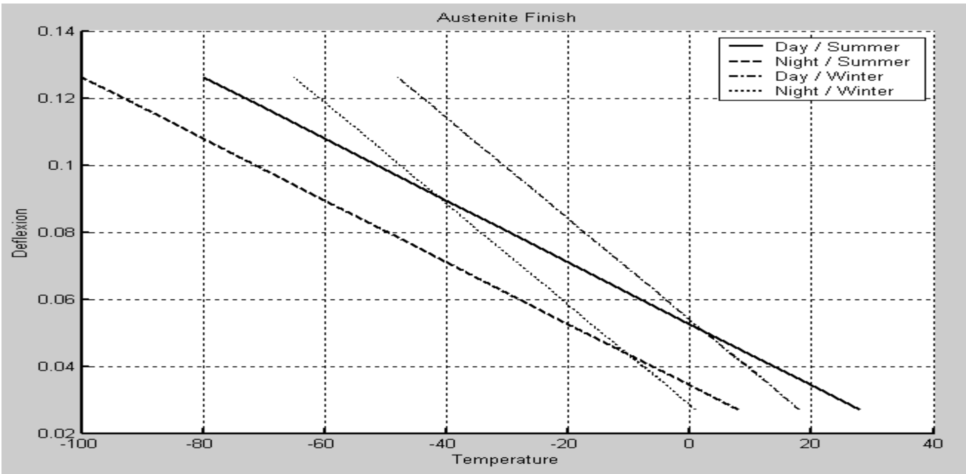

Figure 8. Wire temperature of 18.85 ^{o}C

By making use of the surrounding temperatures of the wing at different altitudes, the wing wild deflection due to the temperature outside the plane, can be determined. Most of the deflections will take place at Austenite finish temperature. However, it can be seen that the change in temperature due to altitude deflection will also take place at martensite start temperature.

Conclusion

This study shows that it is possible to actuate a UAV wing by making use of the environments temperature and altitude. The higher the altitude of the UAV and the higher the temperature of the shape memory alloy, the greater the deflection of the wing. For this system to perform at its best an on board computer should calculate the desired deflection of the wing and change the temperature of the shape memory alloy accordingly for optimal performance.

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