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Research Paper

Articulation & Analysis of Span Adaptive Wing Using Wind Tunnel

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ABSTRACT

- In this project we will analyse the forces during subsonic flight conditions, the concept of (SAW) span adaptive wing is to fold the outer portion of aircraft wing and there control surfaces to optimal angels in flight.
- The (SAW) project intends to obtain a wide spectrum of aerodynamic benefits in flight by folding wings.
- Where it has an ability to fold the outer portion of aircraft wing in flight during subsonic and supersonic manoeuvres, on-board controllers which helps folding of wing panel between the angles of 0-40 deg to bend completely.

Hence using span adaptive wing we can attain a superior stability.

Key words: span adaptive wing, wind tunnel, aerodynamic, stability.

1. INTRODUCTION

The Span wise Adaptive Wing (SAW) is a way to articulate the outboard portion of the wing in flight to effect a variety of multi-disciplinary, multiplatform benefits. SAW incorporates advanced actuation technology which allows the outboard portion of the wing to articulate in flight. The SAW concept could increase the subsonic aircraft efficiency by increasing stability and compression lift on the wing. It uses a mechanical joint, acting as a line of hinge providing the freedom of movement and eventually allowing the rotation. The concept of folding is pretty much similar to that of on-ground folding method used in carrier borne aircraft.

Fig:1 A-PTERA(prototype testing & evaluation research aircraft)

Wing folding capability have been around since decades and have generally been used as a method to optimize parking area and take less space in aircraft carrier hangar deck. The only milestone that was left upturned was the mid-air actuation of the outboard portion of wing. Now that NASA is re-looking into fold-able wing technology, it aims to use control surfaces through advanced actuation thus permitting the outboard portions of wings to adapt as much as 40 degrees. The shape memory alloy (SMA) enable the fold mechanism to be accommodated within the outer mould line of the outboard wing section. These solid-state actuators can be driven by an all-electric mechanism, "remember" the original shape, eventually return to the shape when heated electrically and might as well make possible a design that is less complex, compact and lightweight with respect to hydraulic systems used in conventional actuators.

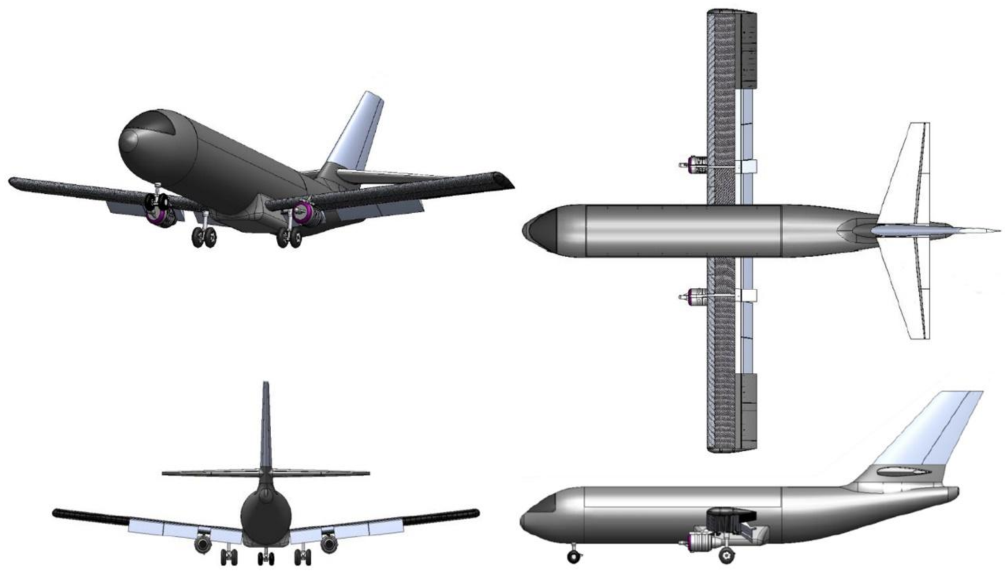

Fig:1B-layout for span adaptive wing model

This allows the outboard portion of wing (hinge span) and its corresponding control surface to be folded to the optimal setting for the flight condition. In doing so the aircraft sees significant increases in lateral-directional stability and control augmentation. The increase in lateral control enables increasing aircraft efficiency by reducing the rudder through the incorporation of SAW .Supersonic benefits include increased compression lift and reduced wave drag, and is an enabler for supersonic flying wing design.

2. HISTORY & OVERVIEW OF SPAN-WISE ADPATIVE WING

Air transport is increasingly becoming more accessible to a greater number of people who can afford travelling by aerofoil leisure and business purposes. This is evidenced by the fact that last year the air transport system moved more than 1 billion passengers and 14 million metric tonnes of freight through its airports whilst handling more than 12 million movements over the same period.

Despite the effects of 9/11, SARS, the IRAQ war and even the recent volcano problems, the sector forecasts that over the next decade, both passenger and freight traffic is expected to increase at an average 4-5% p.a., (with freight slightly higher) both significantly above global GDP growth: in air transport terms, this implies a doubling of traffic about every 16 years.

It is evident that space requirements, will play a dominant role in future transport aircraft development, becoming a driving force for aircraft design. This is the main reason for which ACARE, in the so-called Strategic Research Agenda 2, established the so-called span adaptive aircraft.

2.1 Attempts for Span Adaptive Wing Model

That honour goes to the XB-70 Valkyrie, an experimental supersonic bomber that NASA developed with the U.S. Air Force in the early 1960s. NASA's prototype isn't the first aircraft to have hinged wings purely for stability. The wingtips were completely horizontal during take-off and landing, and while the plane was flying at speeds under the sound barrier. At supersonic speeds, the wingtips were moved downward for stability, and to reduce drag from the wingtips interacting with the shockwave caused by the plane's air intake inlets.

Fig:2A-XB-VALKYIRE(first plane to adopt span adaptive wing concept)

The North American XB– 70 Valkyrie was a large, long-range strategic bomber so ahead of its time that it pushed the aeronautical engineering of the early 1960s well beyond what had been thought possible. The **North American Aviation XB-70 Valkyrie** was the prototype version of the planned **B-70**, deep-penetration strategic bomber for the United States Air Force Strategic Air Command. Designed in the late 1950s North America aviation, the six-engine Valkyrie was capable of cruising for thousands of miles at mach3+ while flying at 70,000 feet (21,000 m).

However, the development of this masterpiece reached its dead end, ultimately becoming a museum piece, partly because the research and design costs were enormous, and partly because it was being developed at a time when ballistic missiles were thought to be supplanting manned bombers (thus declaring it obsolete). That being said, the legendary XB-70 still lacked advanced technologies, the reason obviously being the fact that it was a wrong plane built in a wrong time.

Fig:2B-display at museum.

3. DESIGN & POWER SYSTEM USED IN PTERA

3.1 Materials Used

The material used in the project is high density foam, as it has light weight and easily available .It has a density range 0.27. The results of mechanical characterization by large and small deformation (mechanical spectrometry) tests have been compared to different modeling approaches.

It appeared that a correct description of the viscoelastic properties and of the yield stress needs to take into account the filler size compared to the wall size.

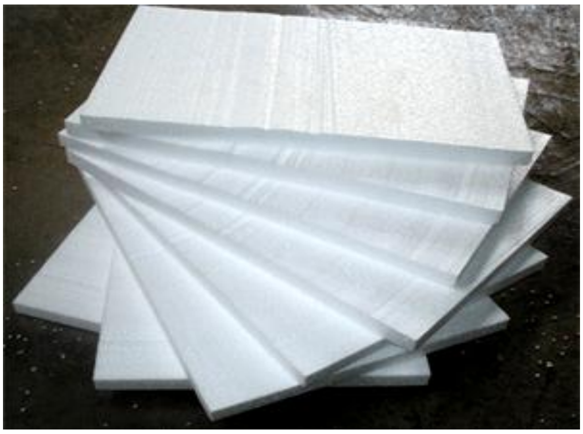

Fig:3A-foam(material used for making the model)

Two modeling hypothesis which consider the composite foam as either a filler dispersion in a foam or a void dispersion in a filled polymer have been made. The first one is adapted to the description of PU filled with the big carbonate fillers, when the second one is better to describe the PU filled with the small carbonate fillers.

The use of the crystallized silica particles gives composite foams with properties in between that of the two calcium carbonate composites, showing that the filler size in the range is a key parameter to take into account in the reinforcement level.

3.1.1 Power System Used In This Project

14OOKV out runner brushless motors- 2: The work of the motor is to provide torque as well as to change the electrical energy into mechanical energy which helps in movement of our model in & during in-flight condition .The brushless motors gives more torque when compared to normal D.C motors. A motor converts supplied electrical energy into mechanical energy. Various types of motors are in common use. Among these, brushless DC motors (BLDC) feature high efficiency and excellent controllability, and are widely used in many applications. The BLDC motor has power-saving advantages relative to other motor types.

Fig:3B-BLDC motor(brushless D.C motor)

Fixed brushes supply electric energy to the rotating commutator. As the commutator rotates, it continually flips the direction of the current into the coils, reversing the coil polarities so that the coils maintain rightward rotation. The commutator rotates because it is attached to the rotor on which the coils are mounted.

Servos- 6[4 plastic geared] [2 metal geared] : As long as the coded signal exists on the input line, the **servo** will maintain the angular position of the shaft. A very common use of **servos** is in Radio Controlled models like cars, airplanes, robots, and puppets. They are also **used** in powerful heavy-duty sail boats. **Servos** are rated for Speed and Torque.

Fig:3C-servos

Servos come in different sizes but use similar control schemes and are extremely useful in robotics. The motors are small and are extremely powerful for their size. It also draws power proportional to the mechanical load. A lightly loaded servo, therefore, doesn't consume much energy.

Servos are constructed from three basic pieces; a motor, a potentiometer (variable resistor) that is connected to the output shaft, and a control board. The potentiometer allows the control circuitry to monitor the current angle of the servo motor. The motor, through a series of gears, turns the output shaft and the potentiometer simultaneously. The potentiometer is fed into the servo control circuit and when the control circuit detects that the position is correct, it stops the motor. If the control circuit detects that the angle is not correct, it will turn the motor the correct direction until the angle is correct. Normally a servo is used to control an angular motion of between 0 and 180 degrees. It is not mechanically capable (unless modified) of turning any farther due to the mechanical stop build on to the main output gear.

2200-3000 3s lipo: A **lithium polymer battery**, or more correctly **lithium-ion polymer battery** (abbreviated as **LiPo**, **LIP**, **Li-poly**, *lithium-poly* and others), is a rechargeable battery of lithium-ion technology using a polymer electrolyte instead of a liquid one. High conductivity semisolid (gel) polymers form this electrolyte. These batteries provide a higher specific energy than other lithium battery types and are being used in applications where weight is a critical feature - like tablet computers, cellular telephone handsets or radio-controlled aircraft.

Fig:3D-LIPO battery (Lithium polymer battery)

30 amps ESC -2 Battery: An **electronic speed control** or **ESC** is an electronic circuit that controls and regulates the speed of an electric motor. It may also provide reversing of the motor and dynamic braking. Miniature electronic speed controls are used in electrically powered radio controlled models. Full-size electric vehicles also have systems to control the speed of their drive motors.

Fig:3E-ESC (Electric speed controller)

PROPELLLERS (8INCH): A **propeller** is a type of fan that transmits power by converting rotational motion into thrust. A pressure difference is produced between the forward and rear surfaces of the aerofoil-shaped blade, and a fluid (such as air or water) is accelerated behind the blade. Propeller dynamics, like those of aircraft wings, can be modelled by either or both Bernoulli's principle and Newton's third law.

Fig:3F-Propellers

A propeller of this type is sometimes colloquially known as a ***screw propeller*** or ***screw***, however there is a different class of propellers known as cycloidal propellers – they are characterized by the higher propulsive efficiency averaging 0.72 compared to the screw propeller's average of 0.6 and the ability to throw thrust in any direction at any time. These are the equipment's used in this project which together constitute a power system of PTERA.

3.2 Wind Tunnel Model Specifications

- Closed circuit wind-tunnel.
- Good flow quality (mean flow variation, turbulence intensities & temperature variation).
- Contraction ratio, CR, of 9.
- Test section aspect ratio of 1.5 and the maximum test section length possible in the available space.
- Maximum flow speed in the test section of at least 40 m/s.

Fig:3G-Low speed wind-tunnel

3.2.1Experimental setup:

The experiments concerning flow quality in the test section, e.g. mean flow, temperature and turbulence intensity measurements, were performed at a position 250 mm from the inlet of the test section. A special traversing arm was built, see figure 11, made of three joints connected by two beams. The beams are made of extruded aluminum with a laminar airfoil profile.

Trip tape was applied to the beams to eliminate flow instability induced noise, see e.g. Nash et al. (1999). The axes were all orientated in the stream wise direction allowing movements in the cross stream plane of the traversing arm. One joint was mounted on the test section wall, one joined the two beams and one was located at the far end of the outer beam allowing rotation of a 500 mm long sting. This was a necessary feature to allow control of the rotational direction of the probe.

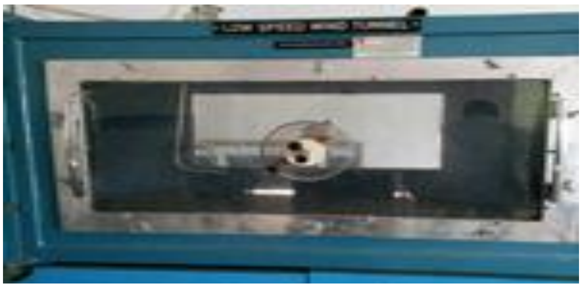

Fig:3H-Test section of wind tunnel.

The sting is long enough to keep the probe upstream of the flow field influenced by the traversing arm. All three axes were equipped with DC servo controlled motors that could be operated from a computer, automating the traversing process. On the inner axis there was also a balance weight mounted to counteract the gravitational force on the traversing arm. Two coaxial cables and two pressure tubes that can be connected to a probe run inside the beams and the sting, thereby minimizing flow disturbances.

3.2.2wing Configuration Used In Wind Tunnel

Wing used for wind tunnel test has been scaled down to 35% of the original model.

SPAN - 20 inch, the span of the wing from tip to root.

CHORD - 8 inch, the chord of the wing.

3.2.3 Wind Tunnel Testing Procedure

STEP: 1 the model which has to be tested is fit into the test section of the wind tunnel.

STEP: 2 Ensure that all the nuts & screws are joined properly, as any lose joint may cause disturbance during test.

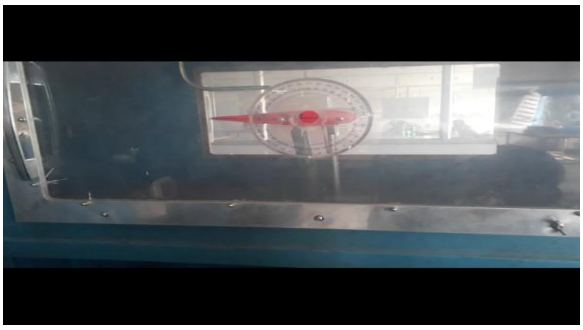

Fig:3I-wing placed in test section.

STEP: 3 Switch on the digital control panel of the wind tunnel, & set all the reading of digital meter to zero.

STEP: 4 Set the velocity to zero & gradually increase it, the maximum velocity of our wind tunnel is 30m/sec^2.

Fig:3J-Calibration of wind tunnel.

STEP: 6 check the values of different lift & drag at different angle of attack.
STEP: 5 set the angle of attack of the wing & check the values of lift & drag at zero angle of attack.

Fig:3K-Results obtained from display of wind tunnel

STEP: 7 Articulate the wing at different angles from 0-40 at different angle of attack & note down the lift & drag co-efficient articulation.
NOTE: tabulate all the reading & compare the values before & after

After the successful wind tunnel test we have applied it in a practical sense which has been a successful maiden flight. Here we are going to discuss about the mission profile for our PTERA.

MISSION PROFILE:
A graphical or written plot of a flight level f rom the start to the end of the mission.The fi rst letter indicates the height during the ingr ess mode; thesecond indicates the height to f ly when near the target, and the last letterind icates the height to fly during the egress, or r eturn, to the base flight.

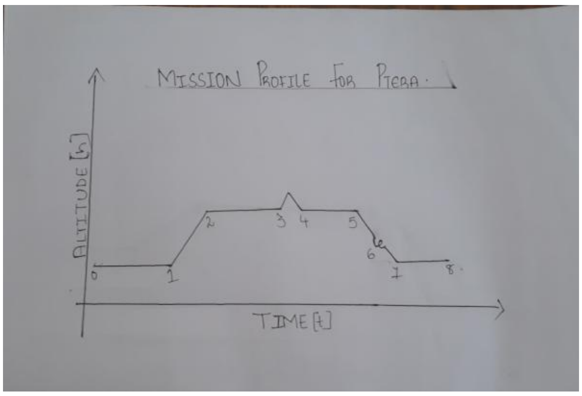

Fig:3L-Mission Profile.

Taxing: also sometimes written "taxying", is the movement of an aircraft on the ground, under its own power, in contrast to towing or push-back where the aircraft is moved by a tug. The aircraft usually moves on wheels, but the term also includes aircraft with skis or floats (for water-based travel).

0-1: TAXI & TAKE-OFF:
TAKE-OFF: A rise or leap from a surface in making a jump or flight or an ascent in an aircraft or in the launching of a rocket advantage of wind direction of a different altitude, particularly with balloons.

1-2 CLIMB:
to rise slowly by or as if by continued effort, to attain certain altitude.
2-3 CRUISE: after a successful take-off the flight moves with constant speed at a high altitude that stage of mission profile is known as cruise.
3-4 ARTICULATION OF WING: folding the certain portion of wing upto certain angle during high maneuvers.
4-5 CRUISE: sail about in an area without a precise destination, in aircrafts; it is the travelling of the aircraft in air.
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5-6 LOITER: The phase of flight consists of cruising for a certain amount of time over a small region. The loiter phase occurs, for general aviation, generally at the end of the flight plan, normally when the plane is waiting for clearance to land.
6-7 DESCEND: descents might be undertaken to land, avoid other air traffic or poor flight conditions (turbulence, icing conditions, or bad weather), clouds (particularly under visual flight rules), to see something lower, to enter warmer air, or to take
7-8: LANDING: Landing is the last part of a flight, where a flying aircraft,

or spacecraft returns to the ground. When the flying object returns to water, the process is called **alighting**, although it is commonly called "landing", "touchdown" or "splashdown" as well. A normal aircraft flight would include several parts of flight including taxi, take-
off, climb, cruise, descent and landing.

3.3 Wing Configuration

The wing used in our model is span adaptive wing, which means the wing folds its outer portion to maintain its directional stability of the air craft.

The case is applicable for both subsonic & supersonic speed, but in this project we are going to focus on subsonic proto type model.

The aerofoil used in the ptera aircraft wing is NACA-0017, it is symmetric aerofoil which has equal lift distribution on upper & lower surface of wing.

Fig:3M-Wing which was tested in wind tunnel (scaled down).

The dimensions of the aircraft wing are:

3.3.1 Specification of our Model:

- Aerofoil used NACA 0017
- Wing total length – 57.3 inches, the total length of the wing from tip to tip.
- Control surface(span to adapt) length -8 inches , the wing which has to be articulated is 8inch from each side, during in-flight condition it folds up to 40'which gives maximum lift even after articulation .
- Span length- 60.5 inches, it defines the total width of the wing from tip to tip.
- Height – 20 inches, the total height of the aircraft from ground.

4. RESULTS & IMPLEMENTATIONS

The main part in any of the project is results which analyses the aim of the project.

1. The experimental results obtained by wind tunnel testing &

Here in our project we will be providing two results for the span adaptive wing which are:

2. The conclusion made after the maiden flight.

Fig:4A-Take-off View of our model.

As we have already discussed about the wind-tunnel test procedure, here we are going to discuss about the results obtained from wind tunnel test .In wind tunnel test we obtained maximum lift & drag values at different angle of attack.

4.1 Wind Tunnel Experiment Results:

First we will go through the lift & drag co-efficient without articulation.

TABLE:4.1 RESULTS OF WIND TUNNEL TEST WITHOUT ARTICULATION

ANGLE OF ATTACK (α)	LIFT CO-EFF (C_L)	DRAG C0-EFF (C_D)	AIR VELOCITY (V)
	0	0	0
5'	0.2	0.2	4
	0.9	0.5	8
	0.14	0.10	15
	0.17	0.04	0
15'	0.24	0.04	4
	0.32	0.08	8
	0.46	0.12	15
	0.5	0.02	0
30'	0.11	0.04	4
	0.23	0.08	8
	0.66	0.13	15

The above table describes the maximum & minimum lift and drag variation by varying angle of attack. Now we are going to describe the lift & drag variation in accordance with articulation angle & we will verify the directional stability of the aircraft.

TABLE:4.2 RESULTS OF WIND TUNNEL TEST WITH ARTICULATION

ANGLE OF ATTACK (α)	LIFT CO-EFF (C_L)	DRAG CO-EFF (C_D)	AIR VELOCITY (V)	ANGLE OF ARTICULATION
	0	0	0	0
	0.2	0.05	4	20
5’	0.12	0.06	8	30
	0.16	0.12	15	40
	0.17	0.06	0	0
	0.29	0.09	4	20
15’	0.36	0.11	8	30
	0.47	0.13	15	40
	0.6	0.01	0	0
	0.31	0.10	4	20
30’	0.46	0.29	8	30
	0.93	0.41	15	40

The above tables gives a clear idea about the lift & drag variations, from the maximum lift at 40’ angle of articulation we can maintain a stable directional stability of a aircraft at higher altitudes & the span adaptive wing concept (saw) can be implemented in both sub sonic & supersonic flight.

In subsonic aircraft, such as commercial airliners, the potential aerodynamic benefit of folding the wings includes increased controllability. Which may result in a reduced dependency on heavier parts of the aircraft, including the tail rudder. This may result in a more fuel-efficient aircraft, as well as the ability for future long-winged aircraft to taxi in airports.

4.2 Test Made To Complete This Project

During initial stages of our project, the design made was very presentable & was having a ease of manufacturing as we have done more & more experiments on the R.C aircrafts.

Attempts for Wind-Tunnel Test

After replacement we again went through wind tunnel testing, which was the successful attempt and we were delighted to see the results & the stability of wing.

Later on we replaced the plastic servo with metal geared servo which was providing enough torque & was best suited to fulfill the aim of our project.

During first wind tunnel test we were disappointed as the test was not successful due to fluttering of wing, the main cause behind it was we used a plastic servo which could not bear the load of articulation.

Attempts for Successful Maiden Flight:

As we were ready with the complete airplane model the only thing which we were waiting was the first maiden flight.

The results & comparison of lift & drag values will be studied in another chapter which will give us a clear idea about the articulation of wing in this project.

The first maiden flight was made as there were electrical retracts to PTERA, they created a problem during flight take-off.

So we were left with only alternative of hand launch, the flight was successful but the only problem faced was, we tried to articulate the wing at lower altitudes.

4.3 Advantages of Span Adaptive Wing

Additionally, pilots may take advantage of a number of different flight conditions, such as wind gusts, by folding their wings to adapt to any particular condition experienced in flight. There’s a lot of benefit in folding the wing tips downward to sort of ‘ride the wave’ in supersonic flight, including reduced drag. This may result in more efficient supersonic flight,” SAW Principal Investigator Matt Moholt said. “Through this effort, we may be able to enable this element to the next generation of supersonic flight, to not only reduce drag but also increase performance, as you transition from subsonic to supersonic speeds. Due to the servo failure we could not maintain the stability of the aircraft, it started banking to left & was end up by crash landing.

As every flight is not a successful flight, but the one which is successful is more joyous, the second attempt maid by us for our maiden flight was successful .It fulfilled the main aim our project, in this attempt we made all the necessary replacements for the successful test flight. The first thing which we replaced was landing gear, instead of electrical retracts we used a normal tri-cycle landing gear. Another replacement was servo which was used for articulations of wing.

The servo used is of configuration Mg995 weigh about 25gms & produces about 2kg of thrust.

5. CONCLUSION

As we did the flight test, we observed that when we did the articulation the aircraft was really stable that we can assure not to give any control inputs.

We were able to land it successfully. Hence we conclude that span adaptive wing technology can be implemented to real life size aircrafts which will give more stability & will have more improved performance.

The Span-wise Adaptive Wing concept can uplift the concept of wing morphing, altogether, the world of aeronautics to a whole new level.

Fig:5A-Successful landing of our model.

What can be concluded from the above is that there has been a large amount of activity investigating different morphing concepts, but that this has been rather haphazard and there is no clear way to determine which the best concepts are.

Also, most of the concepts have been applied to either small wind tunnel models or UAVs, in particular to structures that don't have stressed skins. What is needed is an approach to decide the best way to apply local morphing concepts, in particular applied to more realistic sized civil aircraft with full size construction and operating conditions. & a way we opted may be the best suitable for even real sized aircraft.

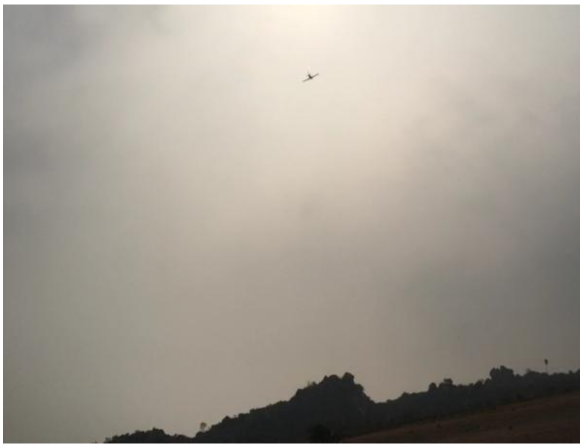

Fig:5B-Airborne view of our model.

After all the corrections a successful flight was made & the aim of the project was fulfilled.

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