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Highlights

In the New Spectrum of Space Law

High Altitude Science Experiments

Will Biden Favor the Moon Treaty

WB-57 Airborne Research Platform

Discovering Thoughts, Inventing Future

VOLUME 21 ISSUE 1 VERSION 1.0

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High Altitude Science Experiments aboard NASA's WB-57 Airborne Research Platform

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Abstract- Purpose: Exposure to space radiation may place astronauts at significant health risks. This is an under-investigated area of research and therefore more knowledge is needed to better plan long-term space missions. The purpose of this study was to assess the effect of radiation on murine naïve and activated T lymphocytes (T cells) and to test the effectiveness of thermal, radiation and flight tracking technology in biological scientific payloads. We cultured cells in specific cytokines known to increase their viability and exposed them to either flight or had them as ground controls. Flight cells were kept under proper environmental conditions by using an active thermal system, whereas the levels of radiation were measured by NASA's Timepix radiation sensor during ascent, cruise at 60,000 feet, and descent. In addition, an Automatic Dependent Surveillance Broadcast (ADS-B) device was utilized to track the state vector of the aircraft during flight.

Keywords: WB-57 flight, ADS-B, suborbital radiation, payload integration, T-cells, naïve cells, airborne research.

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HIGHALTITUDESCIENCEEXPERIMENTSABOARDNASASWB57AIRBORNERESEARCHPLATFORM

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High Altitude Science Experiments aboard NASA's WB-57 Airborne Research Platform

Pedro Llanos [α], Kristina Andrijauskaite [σ] & Sathya Gangadharan [ρ]

Abstract- Purpose: Exposure to space radiation may place astronauts at significant health risks. This is an under-investigated area of research and therefore more knowledge is needed to better plan long-term space missions. The purpose of this study was to assess the effect of radiation on murine naïve and activated T lymphocytes (T cells) and to test the effectiveness of thermal, radiation and flight tracking technology in biological scientific payloads. We cultured cells in specific cytokines known to increase their viability and exposed them to either flight or had them as ground controls. Flight cells were kept under proper environmental conditions by using an active thermal system, whereas the levels of radiation were measured by NASA's Timepix radiation sensor during ascent, cruise at 60,000 feet, and descent. In addition, an Automatic Dependent Surveillance Broadcast (ADS-B) device was utilized to track the state vector of the aircraft during flight.

Results: Radiation levels reached about 1.5 μGy during ascent, 9.5 μGy during the cruise and near 1 μGy during descent. The recorded temperature of the cells was between 21 °C to 26 °C during the cruise. Our results show that exposure to radiation at 60,000 feet increased the expression of cytotoxic T cells (CD8) but decreased the expression of T-helper cells (CD4). Thus, it modulated the cell cycle and led to the enhanced expression of the IL2 receptor CD25. Furthermore, we observed the differences in various cytokines expression patterns detected from T cell culture supernatants. During the flight, the ADS-B device unit provided partial flight data, which was concurred with the flight team during ascent and descent, but it was locked above 50,000 due to the Federal Aviation Administration (FAA) regulations, so no ADS-B data were obtained during the cruise.

Conclusions: Our results demonstrate that exposure to various radiation doses may have led to cellular alterations in both naïve and activated T cells. These cells received about six and five times more radiation levels than the ground controls during ascent and descent, respectively, and over 16 times more during the cruise. However, we suggest that treating cells with cytokines (IL-2, IL-12) may reverse some of these changes. Knowledge gained from this study could be adapted to assess the short-term effects of radiation on individuals conducting prospective suborbital missions.

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Keywords: WB-57 flight, ADS-B, suborbital radiation, payload integration, T-cells, naïve cells, airborne research.

I. Introduction

Humans have made significant progress in space exploration over the last decades. However, there are still many aspects requiring attention and scientific investigation, such as exposure to radiation. Space is a hostile environment, and technological advances coupled with scientific research could accelerate the development of interventions aimed to alleviate spaceflight induced side effects. Moreover, training new generation scientists and engineers could enable to meet future research and development challenges. The Embry-Riddle High-Altitude Science and Engineering Rig (ERHASER) team flew several NanoLabs aboard NASA's WB-57 aircraft at 60,000 feet (18.29 km) on December 1, 2017to obtain scientific data and to enhance students' knowledge of Science Technology Engineering and Mathematics (STEM). The WB-57F "Long-Wing" aircraft has been used for decades for airborne research, including weather studies and aerospace technology demonstration. There were four objectives of this flight: 1) technology demonstration of an Automatic Dependent Surveillance-Broadcast (ADS-B) system, 2) characterization of flight conditions using various state-of-the-art sensors, such as temperature and Timepixradiation monitoring sensor, 3) assessing radiation effect by using in-vitro biological experiment involving naïve and activated murine T cells, and 4) testing the specific life support system.

The first aim was to study the position of the aircraft using the ADS-B device for subsonic or supersonic flights through triangulation from communication nodes along the Gulf of Mexico, which had never done before. We aimed to get insights into some challenges the Federal Administration Aviation (FAA) is facing with integrating the newly emerging era of suborbital space vehicles into the National Air Space. The second objective was to test the effects of radiation using the Timepix, a sensor that had flown on NASA's Exploration Flight Test (EFT)-1 On December 5, 2014, and that had never flown before aboard this aircraft to study the radiation levels at 60,000 ft.

Next, we wanted to assess the radiation levels on the immune cells, also called T cells. We used both

Global Journal of Researches in Engineering (D) Volume XXI Issue I Version I Year 2021

naïve and activated murine T cells, which were supplemented with cytokines IL-2 and IL-12, as well as treated with the novel supercritical CO2 extract of neem tree Azadirachtaindica (SCNE). Interleukin-2 (IL-2) is a potent T cell growth factor used for T cell expansion and treatment several types of cancer [23]. IL-12 is involved in the differentiation of naive T cells into the T helper cells. It is also known as a T cell-stimulating factor, and a promising agent in cancer immunotherapy [24]. These two cytokines facilitate their effect by targeting the immune system. We sought to investigate whether exposure to radiation and other flight stressors would have any effect on these cells, especially at the 60,000 feet, where peak galactic cosmic rays (GCR) scattering of secondary particles occur. Given the cytokines' ability to alter the cellular processes and the role of supercritical extract as the natural compound with pluripotent properties, we wanted to test whether supplementing cells with these additives would rescue the cells of radiation damage. We performed the phenotypic analysis of the cells and assessed their ability to release cytokines.

The fourth objective included the development of an Environment Control Life Support System (ECLSS) NanoLab, which could be used to host and sustain the cells at the desired temperature while other variables are being tested. Given the ambitious nature and complexity of the project, students worked closely with faculty and other collaborators from other universities to mature and make this project ready for flight in 6 months.

Space travel, including exposure to radiation, induces many challenges to the human body, especially to the immune system [6].Cosmic radiation is thought to have a significant down regulation effect on many different types of cells of the immune system short-term with B cells being the most affected, then T cells, and finally natural killer (NK) cells being the least affected. Even during the shortest trip to Mars (7-8 months), radiation levels would be of the order of >0.6 Sv, which is close or above the dose limits proposed by NASA for a single astronaut's entire career. [6]. An open question would be to understand the effects of radiation (heavy ion exposure) on various types of T cells which was the epicenter of this multidisciplinary study. Radiation effects can be related to the loss of cell functionality. Only some heavy ions contribute to GCR –these ions are delivered sequentially rather than concurrently. Very few research platforms provide the capability of exploiting the 60,000 feet region and provide insights about the radiation dose. Although several commercial research platforms (e.g., Blue Origin's New Shepard, Virgin Galactic's SpaceShipTwo) are sending unmanned missions to suborbital space (100 km), they are planning to send more frequent manned missions after 2021 This opens a window to further increase our understanding of the potential risks associated with radiation and the suborbital environment. Heavy ions that interact with molecules in the upper atmosphere generate cascades of secondary particles such as electrons, pions, and muon, and the intensity of these particles increases, which creates a peak in ionization rate around 60,000 feet. Below this altitude, there is a secondary particle flux that decreases steadily toward ground level, which is approximately 3 orders of magnitudes lower than the peak [22]. The reason we had chosen to focus on T cells is that they represent one of the main defense mechanisms to fight space travel (radiation) induced immune system alterations. This is usually achieved by reprogramming naïve cells into specialized T cells that can combat infections and other spaceflight induced damage. Naïve cells are characterized by small cell size, low proliferative rate, and low basal metabolism. For quite some time, naïve T cells were thought to be homogeneous and quiescent, however, recent studies demonstrated significant differences between naive T cells in terms of phenotype and function [8]. These new insights make them very valuable for studying immune system dysregulation and designing prevention strategies. In the human body, they are generated in the thymus and each naïve T cell recirculates from the blood through a lymph node and back to blood every 12 to 24 hours until it encounters the appropriate antigen and gets activated [9]. For the T cells to begin their immunological work, they first must be activated. Most commonly, mouse naive cells are activated by engaging the T Cell Receptor (TCR) (signal 1) and CD28 co stimulatory molecule (signal 2) with antibodies against CD3 and CD28, respectively, followed by culture with interleukin-2 (IL-2) [10]. However, recent studies suggest that naïve cells cultured in interleukin IL-2 without TCR engagement could also elicit a unique pattern of signaling associated with proliferation and up-regulation of different markers [11]. Given the significant importance, T cells play in fighting (radiation/flight) induced damage, here we provide insights into new T cell culture methods which might be used in future research for assessing cellular consequences of cosmic radiation exposure. This pilot study provides guidelines used by faculty and students from different backgrounds (Spaceflight Operations, Aerospace Engineering, and Biological Sciences) to propel their knowledge in the design, fabrication, integration, and testing of airborne research payloads [1] and allowed us to collect valuable scientific data.

II. Material and Methods

a) *Timeline Operations*

The EHRASER team followed a very tight schedule to meet the Test Readiness Review (TRR) before the actual flight. TRR was conducted about 4 hours before the flight (bottom left, Figure 1). After TRR was finalized, the AOD team secured the payload onto the pallet (bottom center, Figure 1) and attached under

Global Journal of Researches in Engineering (D) Volume XXI Issue I Version I Year 2021

the belly of the aircraft (top center, Figure 1). Early daily (7:00 AM) aircraft operations started with the AOD team meets with the U2 pilots to discuss mission routing and go/no-go decision for the weather. The aircraft was then towed and loaded with 20,000 lbs of fuel at 9:00 AM. Aircrew aircraft preflight U2 suit operations (top left, Figure 1) were conducted at 9:45 AM or about 1h and 15 minutes before the flight. Aircraft engine started at 10:30 AM, and aircraft taxed at 10:50 AM. Takeoff of aircraft was at 11:00 AM (top center, Figure 1). The landing of the aircraft was at 14:30 PM. Aircraft post-landing flight operations included the AOD team delivering (top right, Figure 1) the payload to the ERHASER team at Landing + 30 min. After payload was retrieved about 1 hour after landing, the ERHASER team started immediate analysis (bottom right, Figure 1).

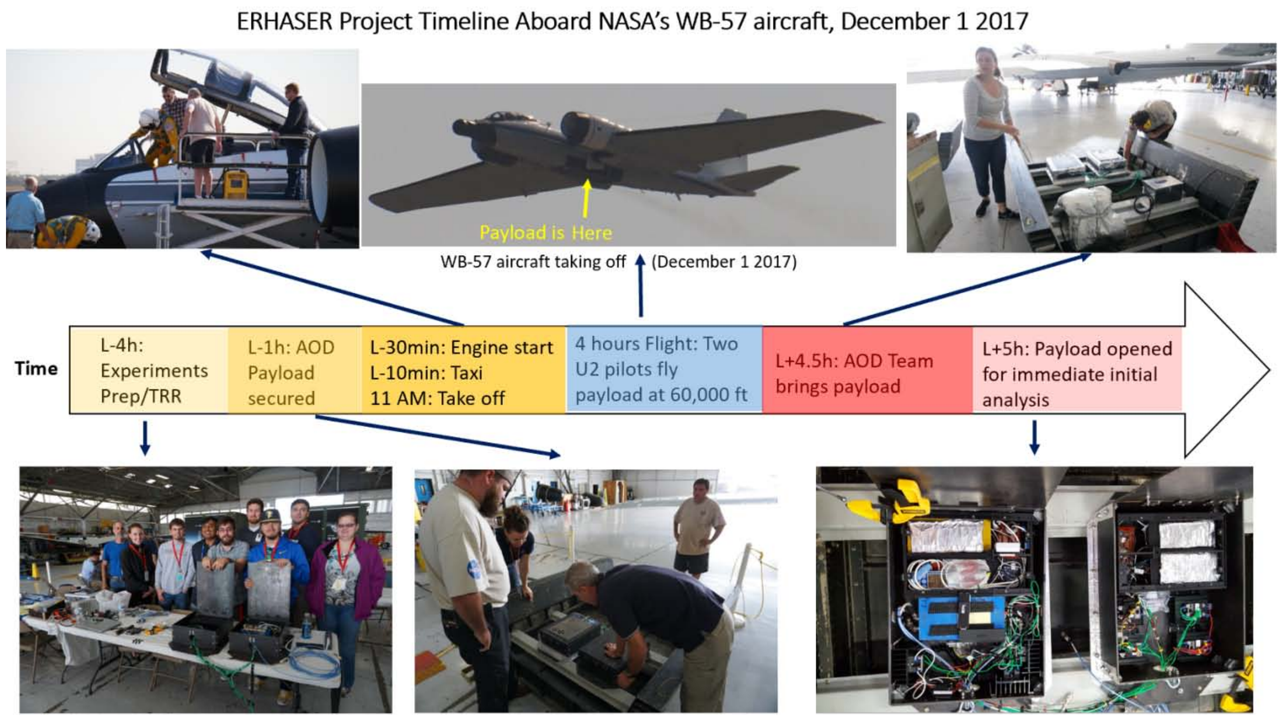


Figure 1: Timeline of the airborne research experiment

Figure 1 shows the operations' timeline for the WB-57 #927 flight including loading and unloading of the payloads by the AOD team. Two prior test flights flew on November 29 and November 30, 2017, of duration 2.2 hours and 4 hours, respectively. The actual flight (Figure 2) took place on December 1, 2017, departed at 11:00 Z and landed at 14:51 Z in KEFD, and logged 3.8 hours of flight. ERHASER's Test Readiness Review (TRR) was conducted on November 30.

b) Flight Path and Tracking with ADS-B

After several private communications with the WB-57 chief pilot Tom Parent, the ERHASER team deemed the path below in Figure 2 to be the optimal flight path for the mission. The WB-57 aircraft departed from Ellington Field Airport in Houston, where the temperature was about 15℃, and the flight reached a maximum altitude of 63,600 feet (19.39 km), right past the Armstrong line (62,000-63,500 feet), indicating that any unprotected exposure above this level causes body fluids to boil.

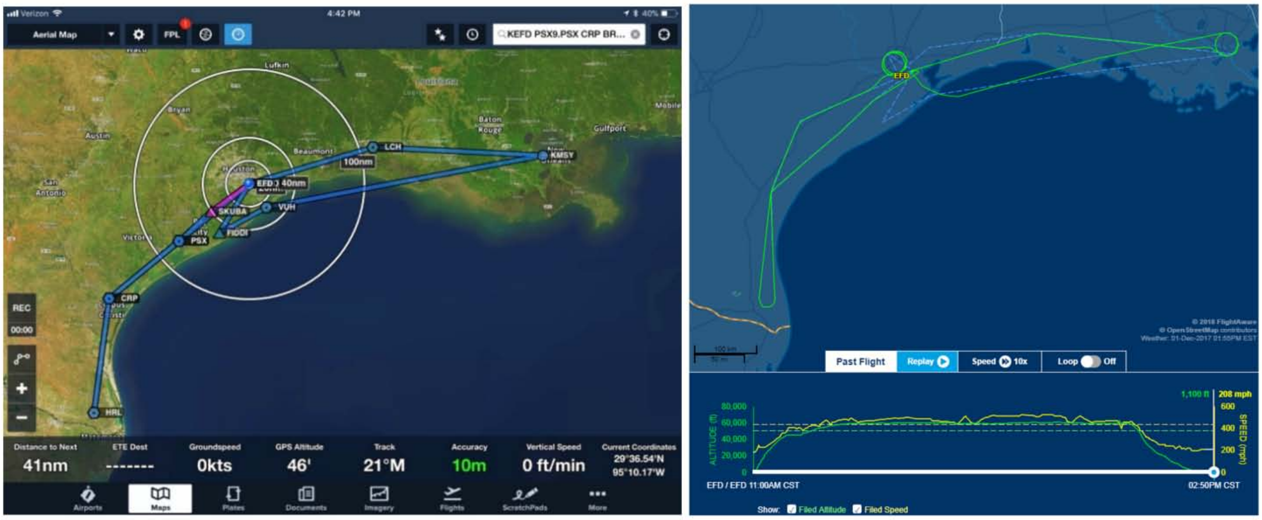


Figure 2: WB-57 flown path from Ellington field airport, Houston

The flight (Figure 2) started from Ellington field airport in Houston (KEFD), and flew over several preselected locations (airports for triangulation) in the following order: KEFD to Palacios Municipal Airport (PSX), Corpus Christi International airport (CRP), Valley International airport (HRL), back to CRP, back to PSX, back to KEFD, then Lake Charles Regional Airport (LCH), Louis Armstrong New Orleans International airport (KMSY), VUH, FIDDI, and back to KEFD.

Crewmembers wore a U2 suit (top left of Figure 1) as mandated by the FAA flight rules, weighting 14 kg. Wearing this suit prevented crew members from any physiological deficiency while flying between 12,500 feet (3.81 km) and 50,000 feet (15.24 km). The stratosphere starts at 50,000 feet, and the WB-57 flew in the lower region of the stratosphere where the temperature is about -55 degrees Celsius with little water vapor, jet streams, and little turbulence. WB-57 pilot recorded the following temperatures during the flight: -47 ℃ at 52,200 feet, -52 ℃ at 59,000 feet, -48 ℃ at 59,200 feet, -44 ℃ at 59,000 feet, -43 ℃ at 60,400 feet, and -44 ℃ at 60,400 feet and 63,600 feet.

Figure 3: ADS-B configuration

Figure 3 accurately displays the fully assembled ADS-B system. The ADS-B has two endplates: the right plate has the UAT transmitter antenna and 1090 ES receiver antenna connections (Figure 3b); the left plate has the power and GPS connections (Figure 3c). All the antennas used on the ADS-B were the 1090 ES the UAT and the GPS receiver, attached to the WB-57 through the antenna farm. The connections used included the power cord shown in Figure 3d. The power cord shown in Figure 3d was changed by splicing directly to the power regulators because the connector from the factory was unsatisfactory in maintaining a stable connection.

c) *NanoLabs Design, Contents and Active Thermal System*

The ERHASER team designed and 3D printed various NanoLabs. The size of these NanoLabs was a 12 U, being a 1U a 10 cm x 10 cm x 10 cm. The NanoLabs were designed to house the in-vitro biological experiment, and various sensors to monitor the environmental conditions, such as temperature, relative humidity, accelerations and carbon dioxide inside the payload. Since the operational thermal limits of these sensors had a various range of temperatures, a thermal system was designed for heating and cooling so that the sensors could function nominally.

Two 6U NanoLabs consisted of 30 Eppendorf 5.0 mL tubes containing immune T cells derived from mice. 20 tubes had cells that were maintained with or without cytokines IL-2 and IL-12, while the remaining 10 tubes consisted of T cells grown in the supercritical extract of Azadirachta Indica (SCNE). The liquid was contained within the sealed tubes, which were further vacuum sealed for containment against leaks. With the 6U NanoLab structure, it provided three levels of containment in the event of a leak. Tubes were sealed using parafilm medical tape and vacuum-sealed in Ziploc bags. Ground control conditions were kept at the NASA facility.

The NanoLab sho used the edl-4S (placed in the first NanoLab), and the EL-21 CFR TP LCD (second NanoLab) sensors, which had operational thermal limits of 0 ℃ to 50 ℃, and -35 ℃ to 80 ℃, respectively. The biggest challenge was to keep the edl-4S within the operational thermal limits from -60 ℃ to a few degrees above 0 ℃, for what the team decided to use aerogel space loft 5 mm thick insulation covered with thermal tape (Figure 4). Also, the operational thermal limit of the ADS-B device was -20 ℃ to 55 ℃. This instrument was placed in a smaller 2U Nano Lab (blue) inside the main 12 NanoLab (black), and everything housed inside the metal box (Figure 4).

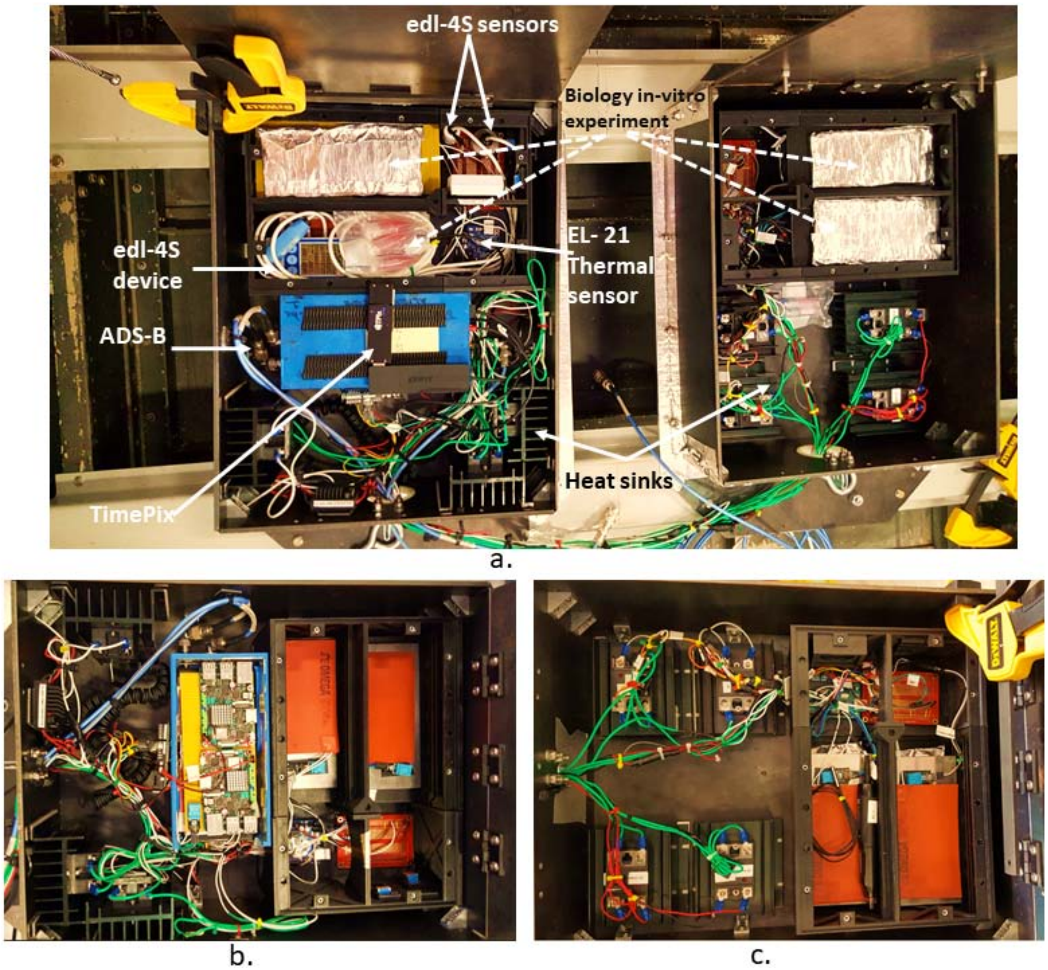


Figure 4: ERHASER payload highlighting all the subsystems. a: Payload showing both chambers with an active thermal system, ADS-B unit, Timepix radiation sensor, edl-4S unit and sensors, EL-21 thermal sensor, heat sinks, rest of avionics, and the in-vitro biological experiment. Payload was verified and approved by the AOD team at Ellington Field Airport. b: left chamber showing heating pads inside the 4U NanoLab, and inside the 2U NanoLab where the ADS-B device was located, and three heat sinks. c: right chamber showing heating pads inside the 4U NanoLab, and four solid-state relays assembled on top of the heat sinks.

The active thermal system (Figure 4) was designed to meet all the operational thermal limits of the sensors [1]. The rest of the avionics in Figure 4 included an Arduino, a pressure sensor, thermocouples and cables to provide power to the heating pads that actively controlled the temperature inside each NanoLab. The temperature inside the chambers was maintained using OMEGA® silicone heating pads mounted to the bottom of the chamber. One of the heating pads (orange) is visible on the left side chamber in Figure 4 where the edl-4S device and part of the biology experiment touches on, which was used to provide heating to both the device and the cells (Figure 4b). Another heating pad (Figure 4b) was placed inside the 2U NanoLab (yellow) where more cells were touching it, and the top was the aerogel covered with thermal tape to insulate theNanoLab from the flight conditions. Similarly, the other two heating pads (Figure 4c) were housed in the other 2U NanoLabs inside the right chamber (Figure 4c) for heating of the in-vitro biological experiment, and aerogel covered with thermal tape on top (visible in Figure 4a).

The NanoLabs needed to be designed in a manner that different containment areas maintained different temperatures while the instruments and avionics mounted inside could suitably log the data from sensors and keep the active thermal system operational for the duration of the flight.

d) Radiation Sensor Timepix, Arduino, and OMEGA Heating Blocks

We used the Timepix Radiation Environment Monitor to measure the dose rate and the overall dose and the high-Linear Energy Transfer (LET) on the experiment.

Radiation sensor Timepix [4] was mounted on the NanoLabs(Figure 5) and flown inside the unpressurized pallet of the WB-57.

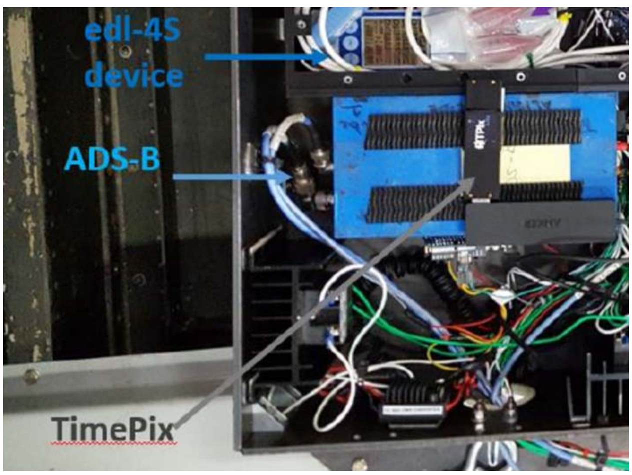


Figure 5: Timepix radiation detector. Zoom of Figure 4a

To maintain the temperature within a few degrees Celsius in each section of the 6U NanoLab, the thermocouples were mounted in each section and their data was fed into an Arduino Uno that controlled each heater. The Arduino gathered the temperature readings from each section of the 6U NanoLab and directly controlled power given to the OMEGA® heating pads. Since the Arduino only outputs 5V, it couldn't supply the power needed to operate the heating pads (12V). Thus, solid-state relays connected to the Arduino regulated the power running to the heating pads. Once heating pads heated the tubes to the desired temperature the Arduino would turn off the power going to the heating pads using the transistors. As an added precaution, the Arduino contained a complete shutdown command for the experiment if the temperature in any of the NanoLabs reached more than 45° C.

e) Splenocytes Isolation and T cell Activation

T cells were generated from mice spleens which were dissected from euthanized C57BL/6 mice (2013044AR) which were bred and maintained at the UT Health Science Center specific pathogen-free facility according to the Institutional Animal Use and Care Committee (IACUC) at UT Health Science Center standards. Animals of the female sex (n = 5) with the age of 6-8 months were used. Single cell-suspensions of lymphocytes were achieved by sterile dissociation of whole spleens with syringe plunger through a cell strainer and by lysing red blood cells with the ACK (Ammonium-Chloride-Potassium) lysing buffer (Life Technologies). Isolated splenocytes were plated in 24-well plates at 1 × 106 cells per ml concentration in 1.5 ml and activated with anti-CD3 mAb (145-2C11 clone, plate-bound, 1 μg/ml) and anti-CD28 mAb (37.51 clone, soluble, 2 μg/ml) from Bio X Cell in RPMI media containing 10 % fetal bovine serum (FBS) for 48 hours. After 48 h, cells were washed and supplemented with or without human (h) IL-2 (200 ng/ml, recombinant human interleukin-2 (rIL-2)) from NCI at Frederick Repository or mouse (m) mIL-12 (10 ng/ml) from Shenandoah Biotechnology, both or without cytokines every three days. Naïve cells were isolated as described above and supplemented with or without cytokines. Cells were also treated with 10 ug/mL of the Supercritical Extract Neem Extract, SCNE (Nisarga Ltd., Satara, Maharashta, India).

f) Flow Cytometry

Cells were analyzed by flow cytometry using standard procedures as previously described [12]. Briefly, cells were washed in staining buffer (PBS, 2% bovine growth serum and 0.01% sodium azide) and stained with fluorescently labeled antibodies. The fluorescently conjugated monoclonal antibodies (mAb) used in this study included: anti-mouse (m) CD4 mAb (RM4-5, dilution 1/500), anti-mCD8 mAb (53-6.7, dilution 1/500), anti-mCD25 mAb (PC61, dilution 1/250) from Biolegend. Samples were acquired on Celesta and data were analyzed using the FloJo software (Tree Star, Ashland, OR, US).

g) Cell Cycle Analysis

Naïve and activated T cells were washed with cold PBS and fixed overnight at 4°C in 70% ethanol. Cells were then pelleted, washed and re-suspended in 1 ml PBS with the propidium iodide (PI) at a final concentration of 20 μg/ml, ribonuclease at 20 μg/ml and EDTA at 2mM. The cells were incubated at 37°C for 30 min in the dark. PI content was assessed by flow cytometry using FL-2 channel.

h) T cell Viability Assay

T cell viability was assessed by using the Trypan Blue dye (Sigma) to determine the number of viable cells present in a cell suspension. Calculations were made using the hemacytometer with a light microscope.

i) Multiplex Immunoassay

Cell culture supernatants were collected from flown T cells and ground controls and stored at -80 °C until further processing. Cytokine secretion assay was performed using Thermo Fisher Procarta Plex Multiplex Custom-Made mouse cytokine 5-plex assay kit following

Global Journal of Researches in Engineering (D) Volume XXI Issue I Version I Year 2021

the manufacturer's instructions and analyzed with the Bio-Plex 200 Luminex-based multiplex analysis system (Bio-Rad, Hercules, CA). All samples were analyzed using duplicates. The expression of different cytokines was determined by the fluorescence intensity (FI) minus the background.

j) Statistical Analysis

Data were graphically displayed using prism 6 software. Differences in various markers expressions across different conditions were determined and compared using standard error mean (SEM) or ± standard deviation (SD). Statistical analyses are represented in Table 1.

III. Results

a) Flight Path and Tracking with ADS-B

The ADS-B provided the state vector of the aircraft during the ascent and descent phases (Figure 6). There was a cut-off in the transmission over 50,000 feet due to the commercial origin of the instrument which locked above a certain altitude due to FAA regulations. The ADS-B unit provided flight information during the first 40 minutes of ascent and last 40 minutes of descent. The ADS-B returns concurred with the data provided by the Flight team. WB-57 aircraft flight path was obtained from the Flight Aware to map the proposed ADS-B ground-based transceivers along the Gulf of Mexico as shown in Figure 6. There were no returns from the open source or commercial offshore assets, which could be used to triangulate the location of the aircraft. Exploring the options and analyzing the returns led to the conclusion that other aircraft flying over the Gulf of Mexico would be better source of obtaining flight parameters and trajectory although it might heavier the computations to account for accuracy due to Doppler shift in the radio signals caused by the significant difference in velocity and altitude between the two entities.

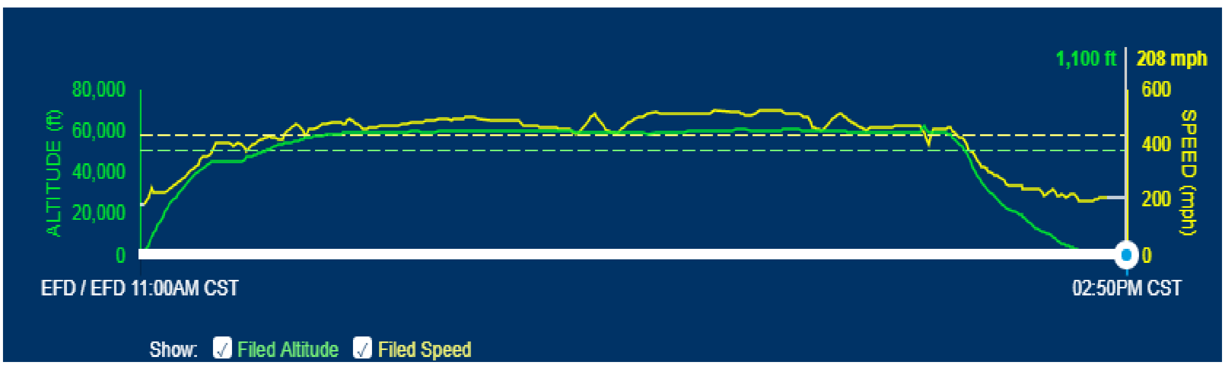
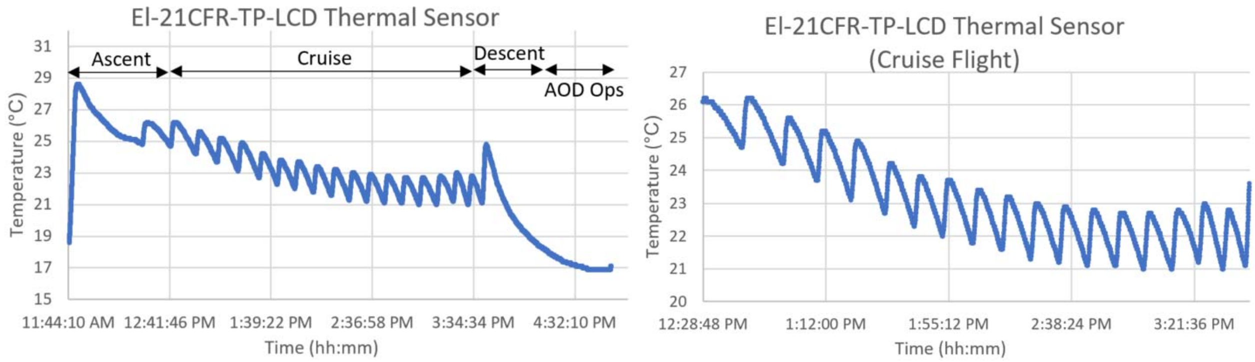


Figure 6: WB-57 flight. Yellow trajectory depicts the filed speed of the aircraft. Green trajectory displays the filed altitude of the aircraft from Flight Aware.

b) Passive and Active Thermal System

Two sensors, the edl-4S (first NanoLab) and the EL-21-CFR-TP-LCD (second NanoLab) provided information on the temperatures. Figure 7 displays the temperature data logged in the second NanoLab. The temperature was initially maintained between 25 °C and 26 °C which degraded overtime before the Arduino device instructed the heating pads to start working. This resulted in the short spikes of increasing temperature over time. Note that Figure 7 shows the Eastern time indicating one hour needed to be subtracted to compare with the Central time. The edl-4S had a temporary power interruption when pilots switched over to USB power from the battery power for testing, leading to instrument reset and loss of data. Thus, the temperature, accelerations, relative humidity and carbon-dioxide levels were not collected to avoid interferences with ground operations. The active thermal system kept the cells between 21°C and 26 °C during cruise (Figure 7), temperature decreased from about 26 °C to about 21 °C during the first 90 minutes of cruise, and then maintain it from 21 °C to near 23 °C in the last 90 minutes of cruise, showing a good stability of the active thermal system.



a. b.

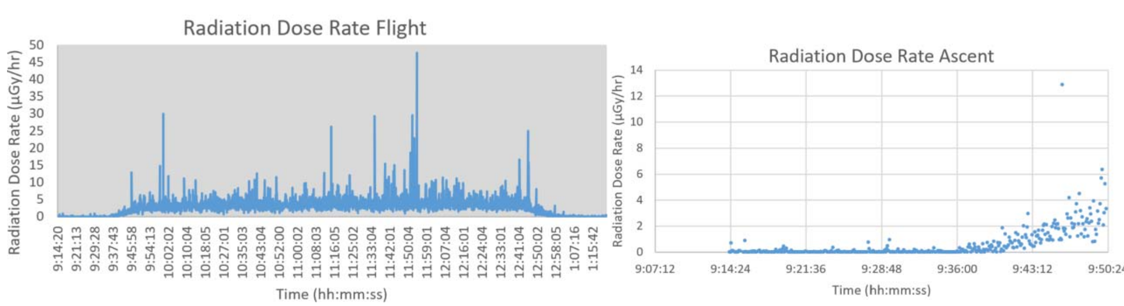
Figure 7: Temperature measured by the EL-21CFR-TP-LCD sensor during flight. a: temperature profile. b: zoom-in of cruise phase

c) Timepix Radiation Sensor

Throughout the flight, we observed a high trend in atmospheric radiation (Figure 8). This radiation trend behaved similarly to the total dose rate trend [3] measured by the ARMAS system during various flight scenarios (Figure 8e, 8f, 8g). This trend can be explained by the much thinner atmosphere seen at 60,000 feet altitude where the WB-57 cruised for near 2.5 hours. At this altitude, the atmospheric pressures measures close to a hundredth of what we experience around a sea level. With the lack of atmosphere, ionizing particles are free to fly until they strike whatever surface they may encounter. Most of the time this atmosphere consists of denser and lower altitude air, but sometimes these particles will strike aircraft or other objects at these altitudes. Because of the randomness of these particle strikes, the data (Figure 8) takes on a fuzzy, static appearance as there is no steady flow of particles, but a perpetual bombardment to the sensor by ionized particles once it leaves the protection of the lower atmosphere. μ

During the ascent, the average radiation dose rate measured by the TimePix sensor was about 2.22 μGy/hr. Since the ascent lasted near 40 minutes, the total amount of radiation dose was about 1.48 μGy during ascent. During the cruise, the average radiation dose rate was about 3.83μGy/hr. Since cruise lasted approximately 2.5 hours, the total amount of radiation dose that the cells received was about 9.58 μGy. Finally, during the descent the average radiation dose rate measured was about 1.24 μGy/hr, thus, during the 40 minutes descent, the total radiation dose was about 0.83 μGy, or about twice than the radiation amount that cells received during ascent. According to the American Nuclear Society, the average yearly human dose is about 0.71μSv/hr

At sea level, the minimum measured cosmic background radiation dose [7] that reaches Earth's surface is about 0.06 μGy/hr. Cells on the ground received approximately 0.24 μGy during the 4 hours. This means that flight cells received more radiation dose levels than ground control samples. These larger radiation levels were 6 times higher during ascent, 16 times higher during the cruise, and over 5 times during descent when compared to ground levels of radiation.



a. b.

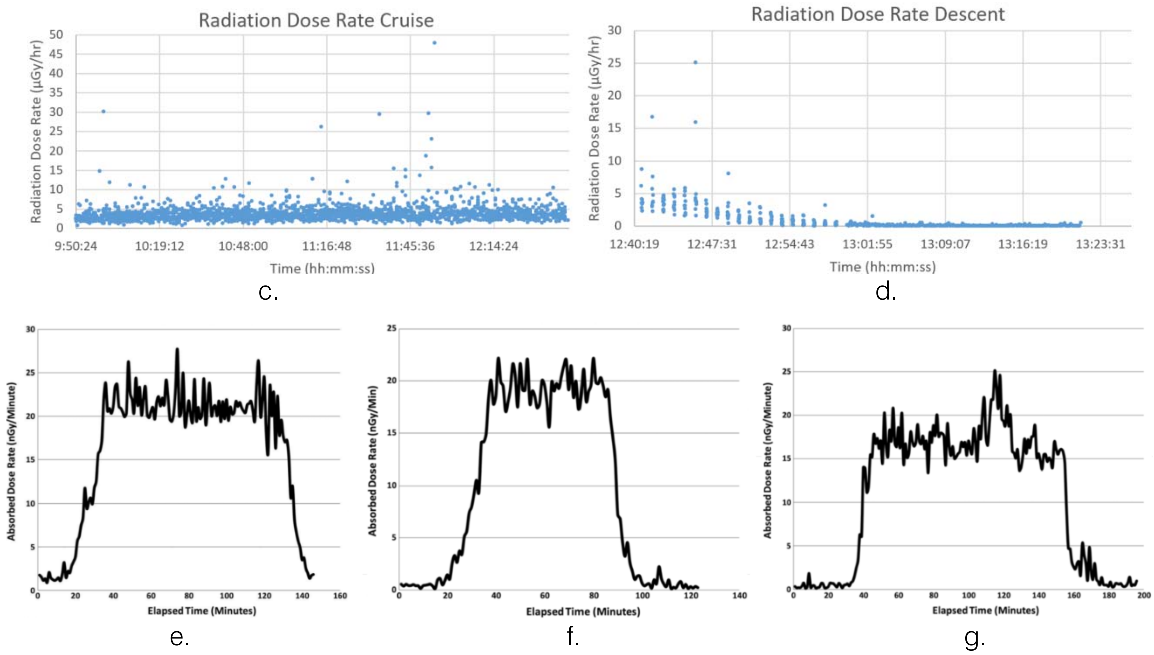


Figure 8: Total radiation dose rate. a. Flight. b. Ascent. c. Cruise. d. Descent. e. For comparison, we show the TEPC absorbed dose rate for Holbrook to Memphis as measured by the ARMAS system. f. TEPC for Holbrook to Indianapolis. g. TEPC for Houston to Los Angeles, August 2011.

There is a clear trend line at the beginning and at the tail end of the data suggesting that the strength and the frequency of particles strikes raise and lowers at a time coinciding with the WB-57 aircraft's ascent and descent phases. The maximum dose during those spike moments was recorded to be 48 μGy. This can be explained by the particles, which strike parallel to the surface and track across the length of the instrument. This results in the particle leaving a longer trace on the sensor than what would be observed if the particle was to strike the sensor head-on.

For comparison, previous studies [3] provide evidence of tissue-equivalent proportional encounters (TEPC) radiation doses of about 3.29 μSv/h (Figure 8e), 2.70 μSv/h (Figure 8f) and 1.81 μSv/h (Figure 8g), respectively during cruise at about 9.8 km (32,152 feet) for various flights in 2011 (Figure 8) using the Automated Radiation Measurements For Aerospace Safety (ARMAS) system. These radiation dose rates translate to total dose equivalent of 5.88 μSv (Figure 8e), 2.63 μSv (Figure 8f) and 3.96 μSv (Figure 8g), respectively, or total absorbed doses of 2.34 μGy, 1.19 μGv and 2.20 μGv, respectively.

d) In-Vitro Experiment Visual Inspection

Given our biological payload consisted of sensitive cells, we inspected the cells as soon as we were given them back. On a preliminary inspection done at the Hangar, the Eppendorf tubes which had been cataloged pre-flight (Figure 9a) were laid out. It was noticed that 10 of the 32 cell mediums exhibited a change in color, which can be attributed to the temperature change. The cells which underwent temperature alterations were the ones placed in the avionics section of the NanoLabs and not directly over the heating pad. This can be attributed to the lack of heat transfer by convection due to the low density of air at the cruising altitude of the WB-57 aircraft. The two Eppendorf tubes (top right corner in Figure 9c) placed on the outside of the NanoLabs and exposed to the outside air temperature had the same indication of temperature change.

a. b. c.

Figure 9: Cells (a) before and (b,c) after the flight after immediately taking them out of the NanoLabs

Our goal was to keep the cells at 30 °C (with the heating pads) because that is their preferential temperature. However, the actual measured temperatures ranged from about 21 °C to 26 °C. Given the tubes containing the cells were sealed and placed on top of the heating pads, it is plausible to assume that the actual temperature inside the tubes was about 3 °C to 4 °C higher.

i. *Effect of Flight Stressors on the Expression of CD8 and CD4 Populations*

Exposure to flight led to an increased expression of CD8 cells in all conditions for naïve cells population with the most robust effect observed in IL-12 alone or in combination with IL-2 condition (Figure 10a). SCNE also led to a profound increase. There was a decreased expression in the CD4 population in flown cells compared to the ground controls, except for the SCNE treatment (Figure 10b). Overall, the CD4/CD8 ratio was decreased, except for the cells treated with SCNE. A similar pattern of CD8 expression was observed in activated T cells (Figure 11a). CD4 expression was decreased in all flight conditions compared to control cells (Figure 11b). The difference of CD4/CD8 expression between flown and control cells was higher in activated cells (Figure 11c) as compared to naïve cells. Interestingly, we observed a very noticeable increase in CD4 expression in activated T cells treated with SCNE (Figure 11c).

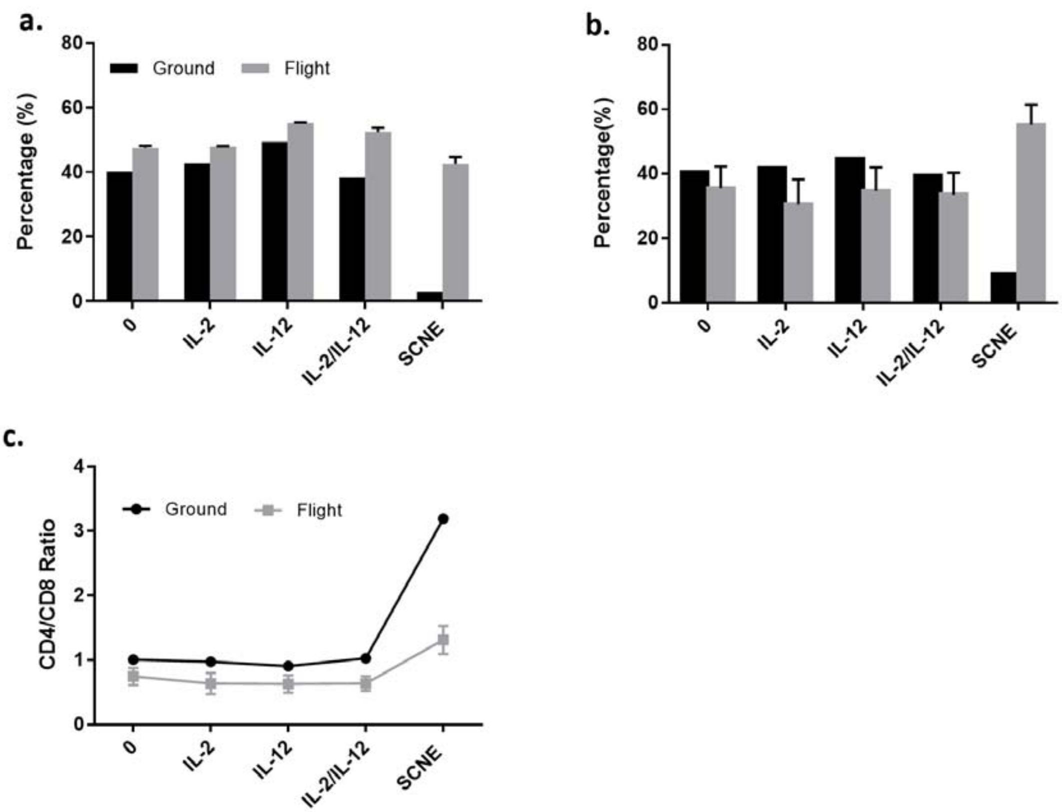


Figure 10: Assessment of naïve cells exposure to 60,000 feet flight on (top left) CD8, (top right) CD4, and (bottom) CD4/CD8 ratio expression with indicated cell culture conditions. Data represented as means +/SEM.

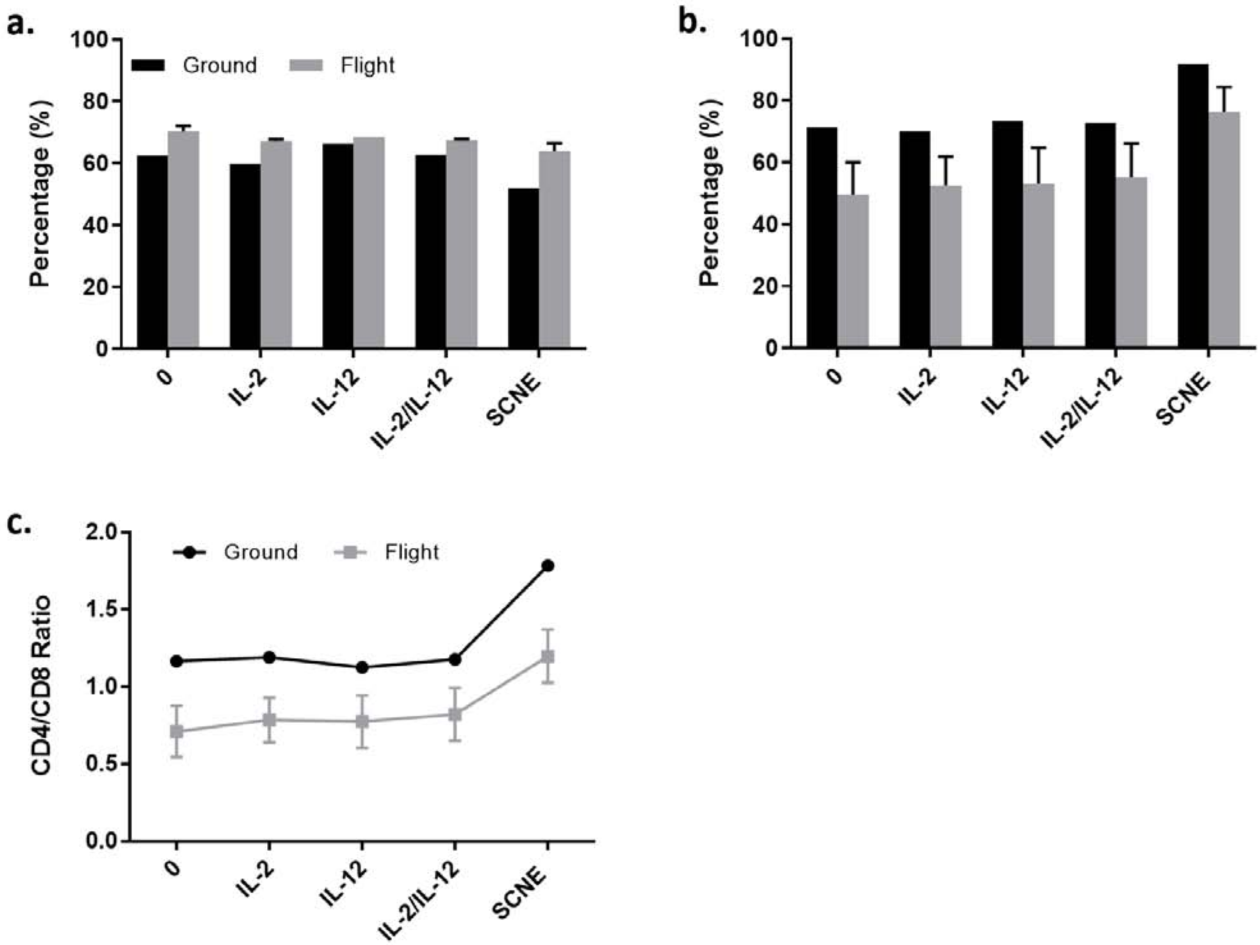


Figure 11: Assessment of activated T cells exposure to 60,000 feet flight on (top left) CD8, (top right) CD4, and (bottom) CD4/CD8 ratio expression with indicated cell culture conditions. Data represented as means +/SEM.

ii. *Flight Stressors Effect on the influence of the Cell Cycle*

T cell proliferation is essential for an effective adaptive immune response. A key element of proliferation is the entry of cells into the cell cycle, by transitioning from G1 into the S phase (Figure 12b), a complex process that is tightly controlled by the expression of cyclins and other enzymatic activities. There are several growth factors, known to induce T cell proliferation, such as interleukins IL-2 and IL-12. Therefore, we sought to determine, whether exposure to flight would modulate the cell cycle for T cells and whether the addition of cytokines and SCNE would have any effect on cell cycle. Usually, naïve cells stay in GO/G1 cell cycle phase. However, naïve cells treated with cytokines are known to enter other phases of the cell cycle [25]. Our data suggest that naïve cells treated with cytokines entered S and G2 phases and there was a slight difference in ground and flight conditions (Figure 12 a). Also, exposure to flight altered the cell cycle in T cells depending on the T cell culture conditions (Figure 12b).

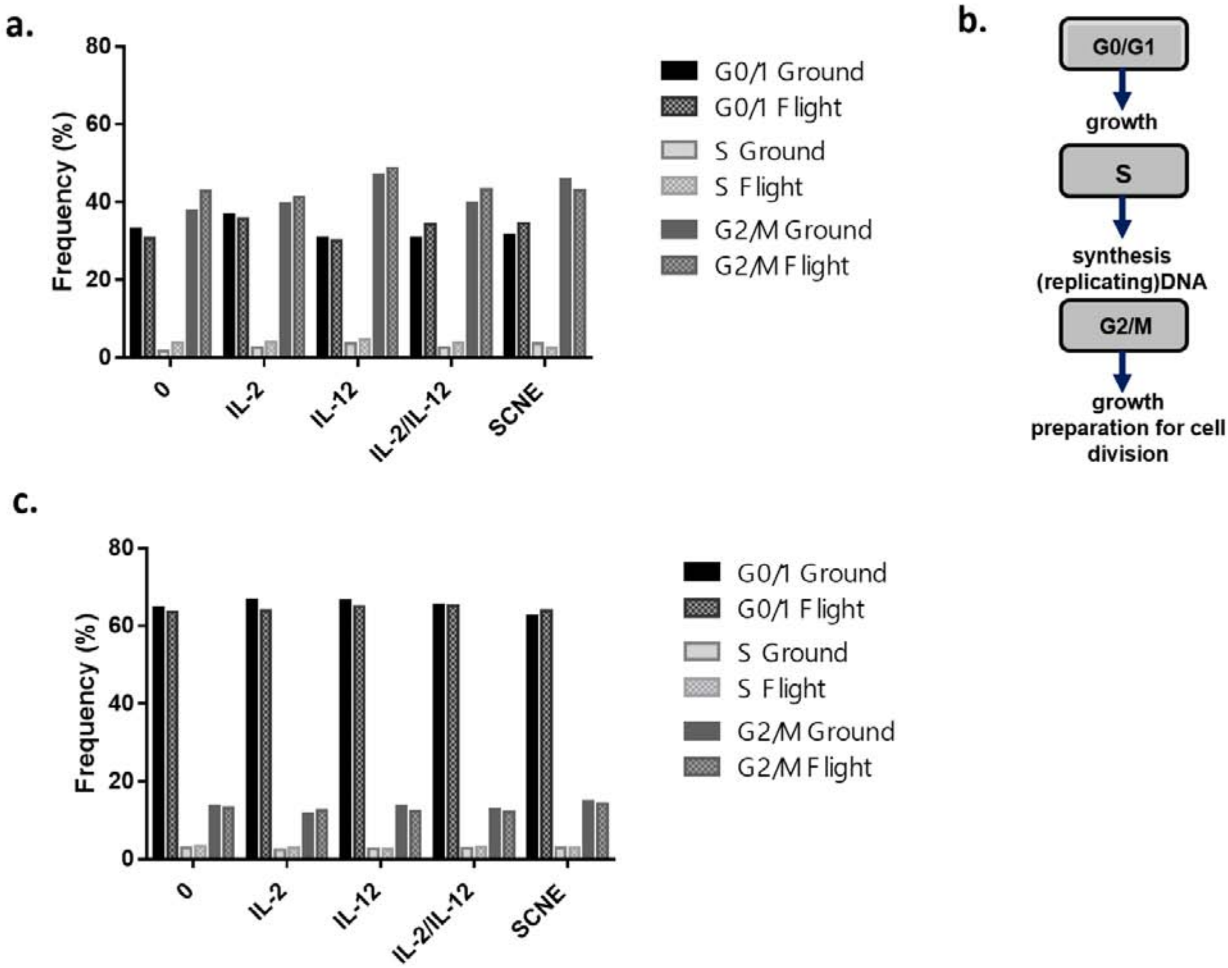


Figure 12: Cell cycle analysis of T cells exposed to 60,000 feet flight and their corresponded ground controls. Cells were harvested, fixed, stained with propidium iodide (PI) and analyzed by flow cytometry. (Top left) indicates % of frequency of naïve cells in GO/G1, S, and G2/M phases for each condition. (Top right) shows the diagram of cellular processes happening in each cell cycle phase. (Bottom) shows the distribution of activated T cells.

iii. *Flight Stressors and T Cell Proliferation Data*

We next assessed cell proliferation capabilities (Figure 13). We counted flown and ground cells post-flight. Our data indicate that adding IL-2 and IL-12 cytokines into T cell cultures leads to an enhanced T cell proliferation. We saw an uncommon decrease in cell numbers in activated ground T cells cultured in IL-2 and an increase in IL-12 (Figure 13 b). Thus, an increase in naïve ground cells cultured in SCNE (Figure 13 a). Except for the conditions mentioned above, there was not a profound difference in the ground and flown cell viability.

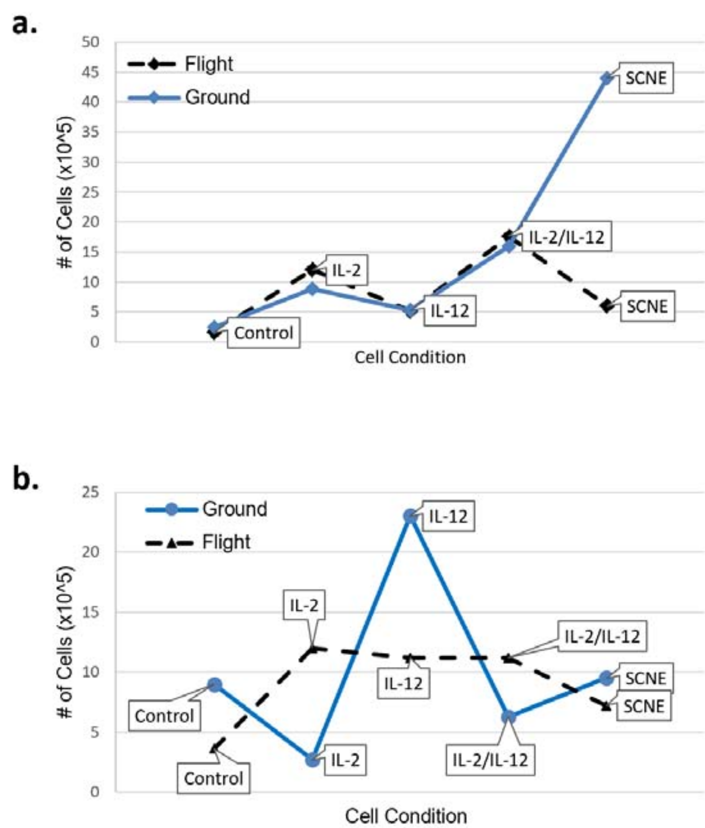


Figure 13: Assessment of (a) naïve and (b) activated T cells viability by staining cells with the trypan blue dye

iv. *Effect of Flight Stressors on the T cell Activation Marker CD25*

We next looked at the activation marker CD25. T cell activation is associated with the early synthesis of IL-2 and up regulation of IL-2 Receptor (R) CD25. Because CD25 expression requires T cell activation, IL-2R expression on resting naive T cells is limited to the low-affinity βγ IL-2R. Recent findings [11] indicated thought that IL-2Rβγ on naive CD8 T cells is functional and allows the cells to respond vigorously to moderate concentrations of IL-2 as manifested by proliferation and differentiation into effect or cells, both in vitro and in vivo. Our data on T cells show the increased expression of CD25 in all flight conditions compared to ground controls (Figure 14a). A similar pattern of expression was observed in naïve cells too (Figure 14b).

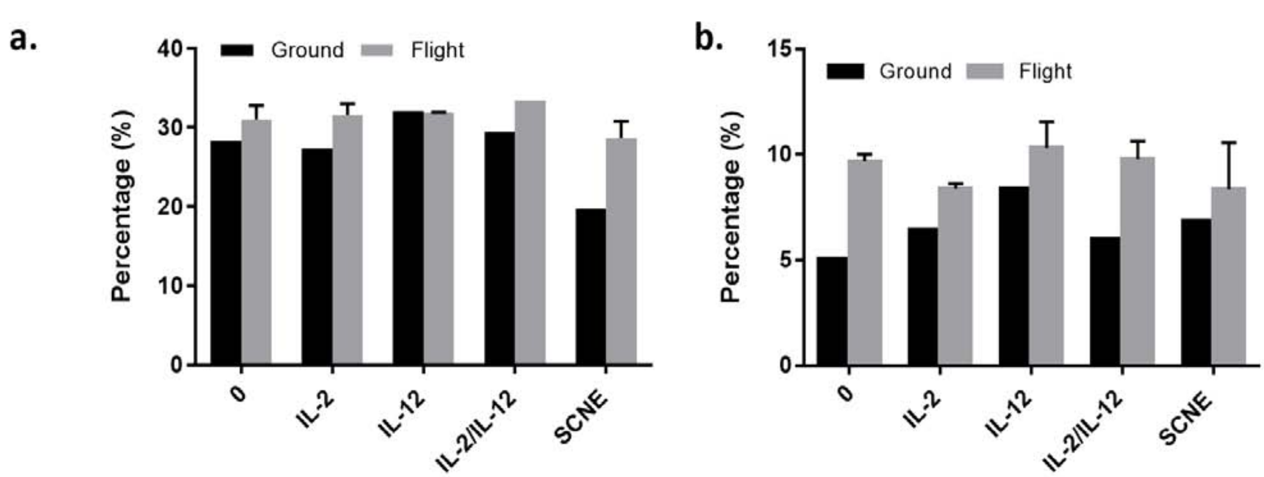


Figure 14: Assessment of CD25 expression on (left) activated T cells and (right) naïve cells for the indicated conditions. Data represented as means ± SEM

v. *Exposure to Flight Stressors Alters the Expression of Multiple Cytokines Detected from T Cell Culture Supernatants*

T cells are usually classified by the expression of glycol proteins and by the ability to produce cytokines within specific groups, such as Th1- or Th2-. Therefore, we assessed an array of different pro- and anti-inflammatory cytokines released to the cells' culture media of flown cells and their ground controls. Given IL-2 stimulated cells are unable to produce IFN-γ, we did see its expression in IL-2 conditions (Figure 15a). However, our data indicate that IFNγ expression was elevated in both naïve and activated T cells across all IL-12 culture conditions compared to ground controls. Supplementing IL-2 with IL-12 also led to strong induction of IFN-γ expression. TNFα expression was decreased in all naïve cell conditions in almost all flight conditions, except for the IL-12 condition (Figure 15b). The up-regulation of TNFα by IL-12 has been reported before [17]. IL-2 expression was elevated in nearly all activated T cell conditions, except for the IL-2/IL-12, whereas in naïve cells IL-2 was decreased except for the IL-12 and SCNE conditions (Figure 15c). As expected, IL-12 expression was elevated in IL-12 conditions (Figure 15d).

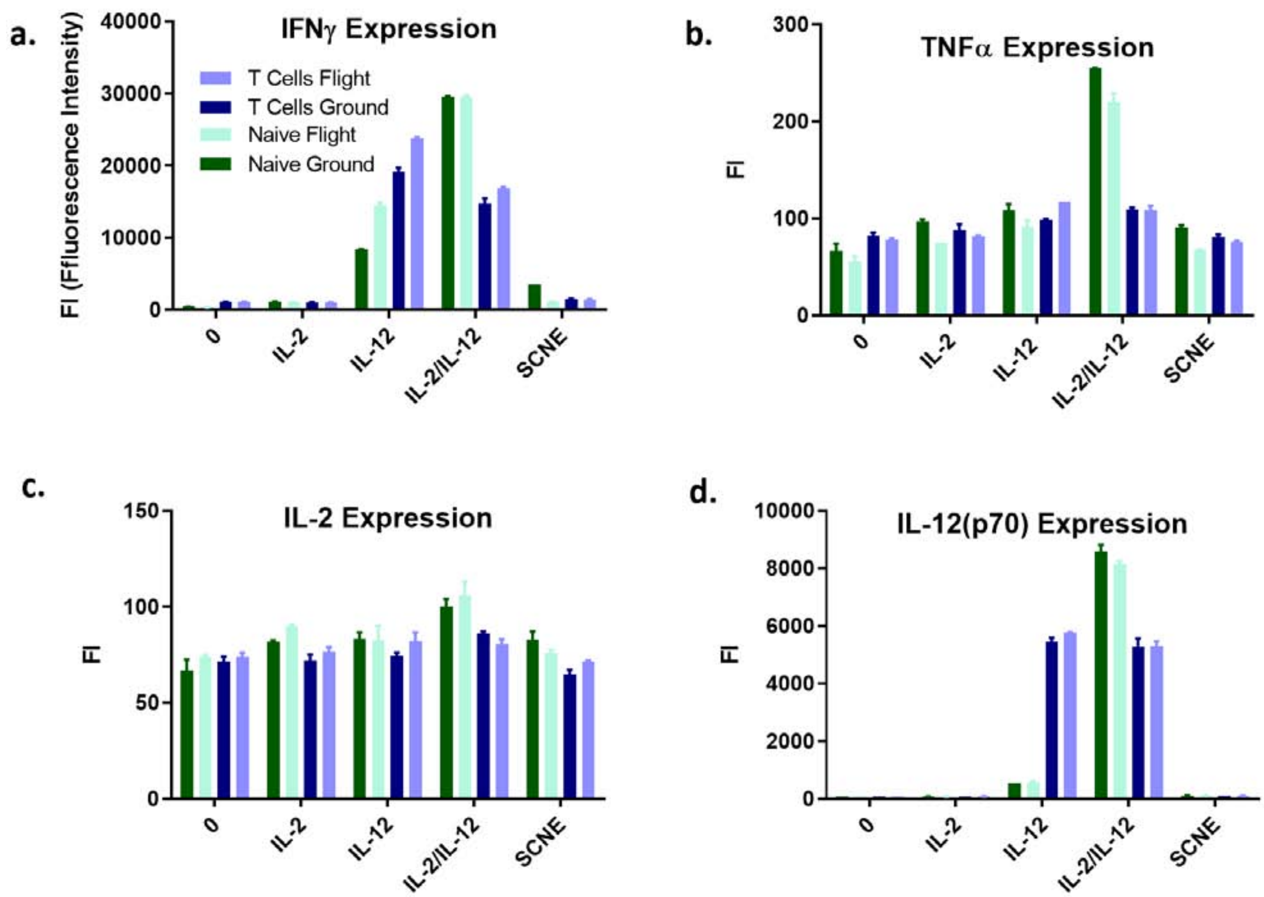


Figure 15: Th1 type cytokines expression on naïve and activated cells including (top left) IFNɣ, (top right) TNFα, (bottom left) IL-2, and (bottom right) IL-12 (p70). Expression of cytokines is displayed as the Fluorescence Intensity (FI). Data represented as means +/SEM.

The pro-inflammatory cytokine IL-6 expression was elevated in all flight conditions for both naïve and activated cells except for SCNE in naïve cells (Figure 16a). The colony-stimulating factor (G-CSF) was elevated in most flown cell conditions, apart from naïve cells not cultured with any cytokines and SCNE as well as T cells either cultured with IL-2 alone or in combination with IL-12 (Figure 16b). IL-5 expression was elevated in all flight conditions for T cells (Figure 16c) and it was the opposite effect in leukemia inhibitory factor (LIF) expression (Figure 16d).Next, we looked at the expression of IL-3, IL-4, IL-5, and IL-17 (Figures 17a,b,c,d). We saw mostly elevated expression in all of them in flown conditions, except for the IL-3 and IL-17 expression in cells cultured in IL-2 and SCNE for the latter.

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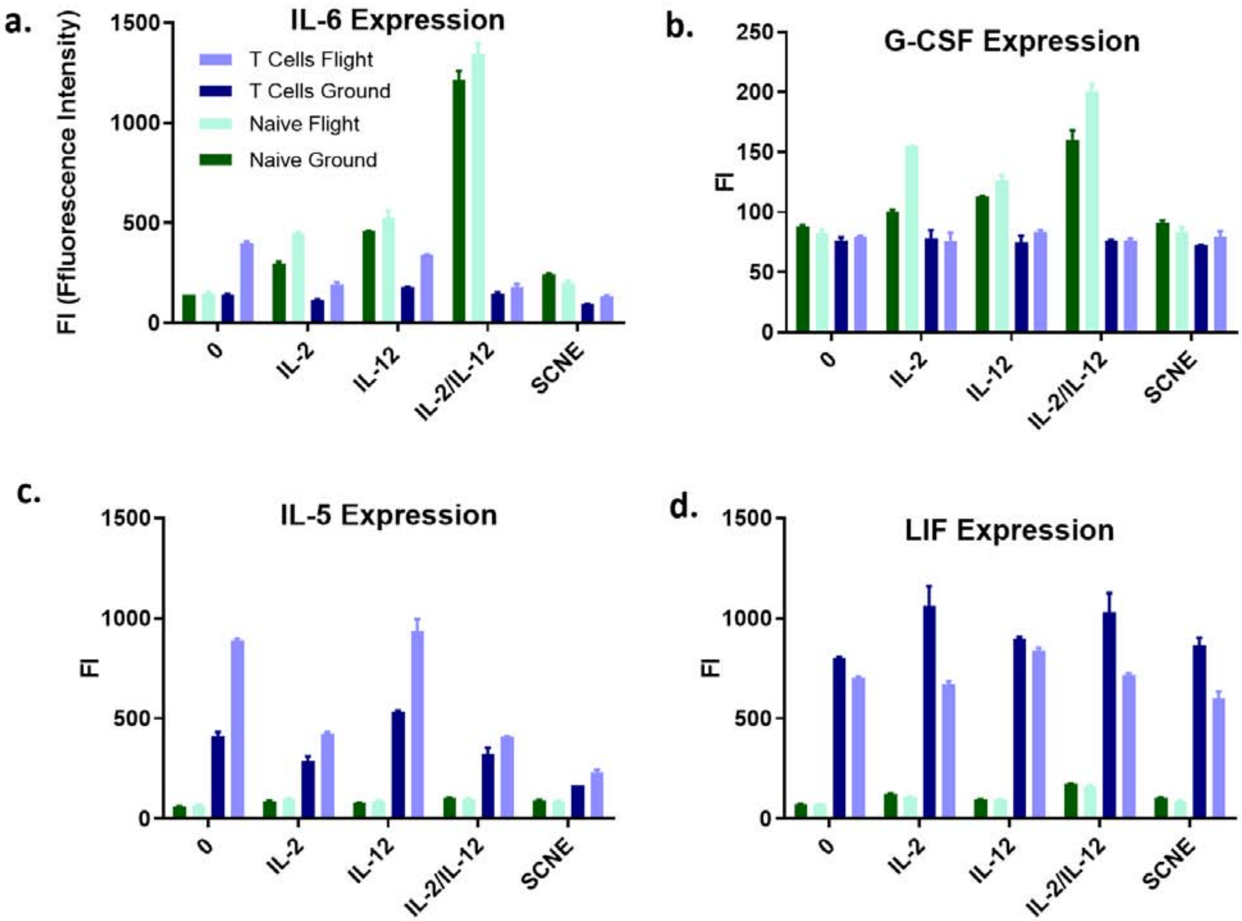

Figure 16: Cytokines expression on naïve and activated cells including (top left) IL-6, (top right) G-CSF, (bottom left) IL-10, and (bottom right) LIF. Data represented as means +/SEM

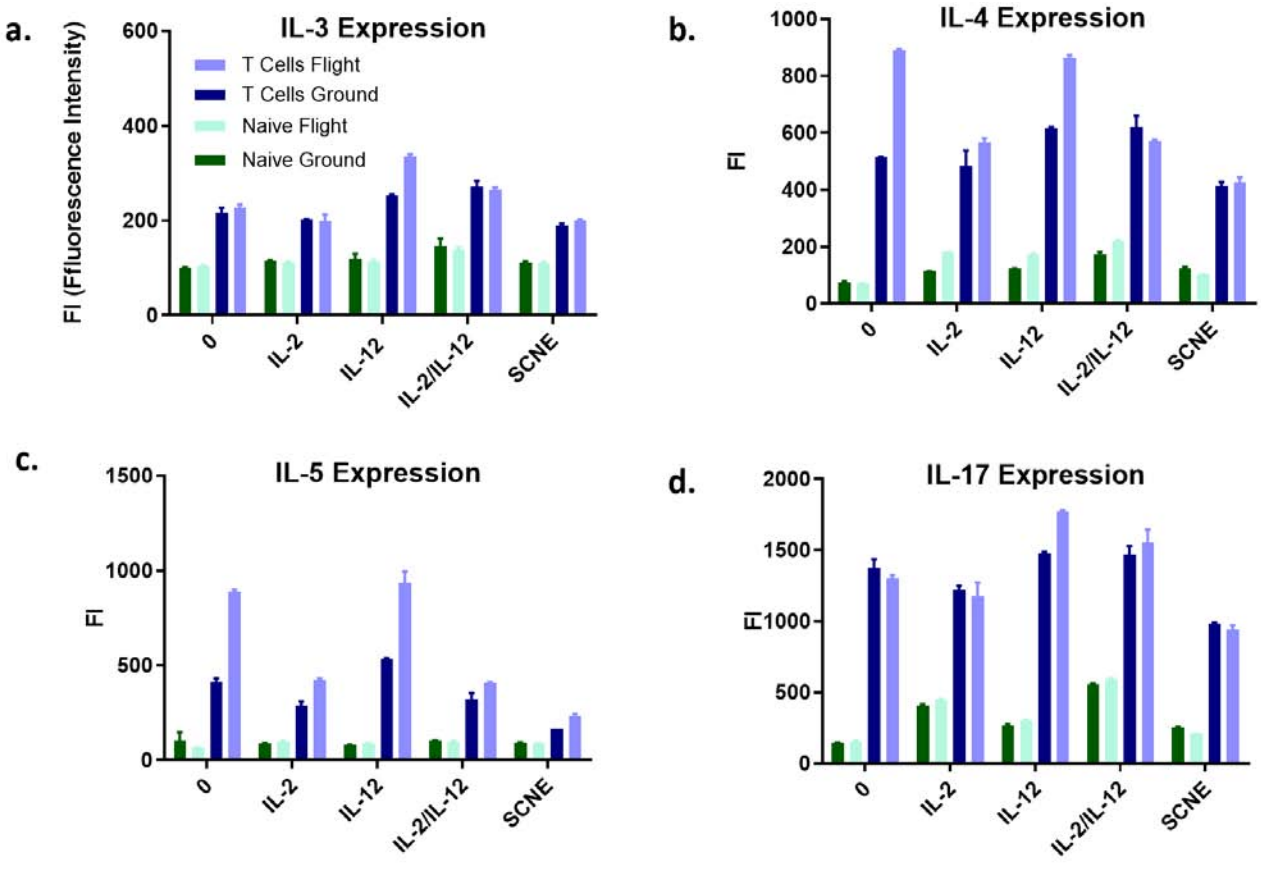

Figure 17: Cytokines expression on naïve and activated cells including (top left) IL-3, (top right) IL-4, (bottom left) IL-5, and (bottom right) IL-17. Data represented as means +/SEM

Our data show that exposure to flight leads to decreased expression of recombinant human macrophage inflammatory protein MIP-1α (Figure 18a) but decreased expression of MIP-1β (Figure 18b) in naïve cells in most conditions. Also, decreased expression of MIP-2 (Figure 18c), and RANTES (Figure 18d), except for the IL-12 condition.

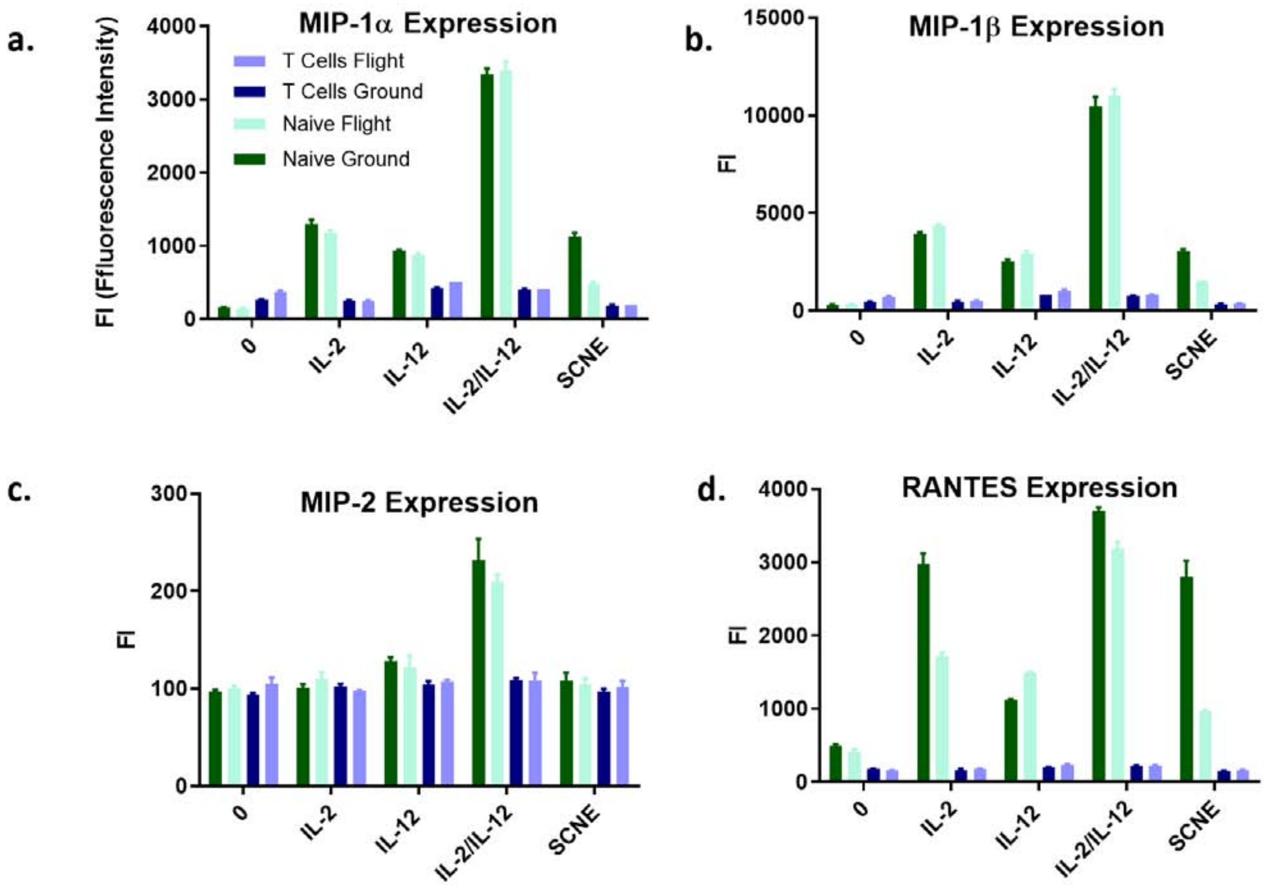

Figure 18: Cytokines expression on naïve and activated cells including (top left) MIP-1α, (top right) MIP-1β, (bottom left) MIP-2, and (bottom right) RANTES. Data represented as means +/SEM

Finally, our data show the decreased expression of chemokine IP-10 in naïve cells, except for the IL-12 condition (Figure 19a). An opposite trend was observed in neutrophil chemokine (KC) expression (Figure 19b). The expression of monokine induced by interferon-gamma (MIG) was decreased in all naïve cell conditions (Figure 19c) and similar pattern observed in vascular endothelial growth factor (VEGF) expression (Figure 19d), except in activated T cells treated with IL-12. Our data highlight the differences in the responses of different cell culture conditions to exposure of flight stressors, including cosmic radiation.

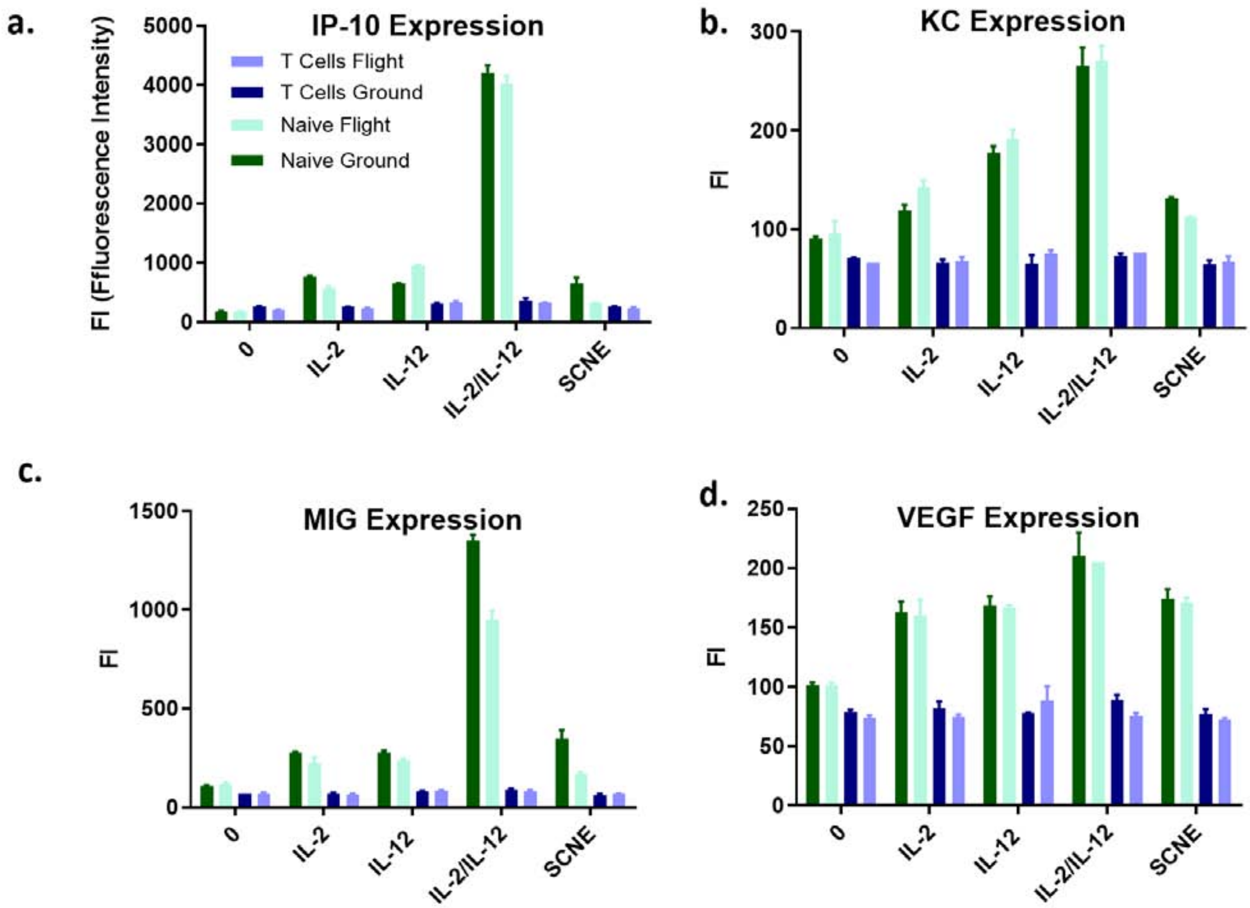

Figure 19: Cytokines expression on naïve and activated cells including (top left) IP-10, (top right) KC, (bottom left) MIG, and (bottom right) VEGF. Data represented as means +/SEM

Table 1: Statistical Analyses on Naïve and T Cells expressed as Mean ± SEM

Naïve Cells and T Cells vs. Ground Samples. Value as Mean ± SEM.					
Expression	Control	IL-2	IL-12	IL-2/IL-12	SCNE
Percentage % Naïve Cells Flight vs. Ground					
CD8	43.8 ± 3.8	45.3 ± 2.6	52.2 ± 3.8	45.4 ± 7.1	43.8 ± 3.8
CD4	38.0 ± 32.4	36.1 ± 5.6	39.7 ± 5.0	36.5 ± 2.9	32.1 ± 23.1
CD25	7.4 ± 2.3	7.4 ± 1.0	9.4 ± 1.0	7.9 ± 1.9	7.6 ± 0.8
Fluorescence Intensity Naïve Cells Flight vs. Ground					
IFN-ϒ	387.0 ± 15.5	1040.6 ± 87.9	11395.1 ± 3023.1	29556.4 ± 7.9	2254.3 ± 1200.0
IL-6	142.3 ± 2.3	372.4 ± 74.9	492.1 ± 34.6	1279.9 ± 64.4	222.3 ± 21.8
Il-17	150.4 ± 5.4	426.9 ± 22.1	284.3 ± 18.8	575.3 ± 16.3	234.0 ± 20.0
Percentage % T Cells Flight vs. Ground					
CD8	66.3 ± 3.9	63.4 ± 3.7	67.4 ± 1.1	65.0 ± 2.2	58.0 ± 6.1
CD4	60.5 ± 10.9	61.3 ± 8.7	63.2 ± 10.1	64.0 ± 8.9	64.0 ± 7.8
CD25	30.8 ± 0.5	30.9 ± 2.7	32.7 ± 1.4	34.6 ± 1.1	32.5 ± 3.6
Fluorescence Intensity T Cells Flight vs. Ground					
IFN-ϒ	1060.8 ± 16.3	992.5 ± 4.0	21385.3 ± 2315.3	15794.6 ± 1077.9	1475.3 ± 25.8
IL-6	270.6 ± 128.4	154.0 ± 40.5	259.8 ± 80.5	162.1 ± 17.4	113.4 ± 19.9
Il-17	1339.0 ± 35.5	1196.6 ± 21.4	1624.5 ± 146.0	1509.5 ± 42.0	963.4 ± 23.1

IV. Discussion

This multidisciplinary research project was a collaborative effort across different disciplines and universitiesnation wide to enhance students' experience in STEM and to obtain valuable technological and scientific data. Several space agencies including ESA, NASA, and the Chinese space agency, as well as private sectors such as Space X and Blue Origin are pursuing human activities in deep space. Space X is currently building several spaceports in Brownsville, Texas. Therefore, the technology tested in our payloads (e.g. ADS-B) can enhance the understanding of current and probable future operational procedures of spaceflight operations in the Gulf of Mexico region and to improve surveillance over the region. Understanding suborbital requirements, procedures, and ADS-B performance are critical to better assess prospective point-to-point suborbital flights [2]. This was a valuable opportunity to observe the WB-57, due a high-altitude performance aircraft, which flies at high speeds (756 km per hour or about 0.6 Mach) and is of interest in testing the functionality of ADS-B technologies during these analog suborbital trajectories. The Sky Guard TWX Vision-Pro Plus kit was the ADS-B used for this experiment.

Numerous challenges are facing space industry today. Exposure to radiation is one of the main concerns about space travel [20, 21]. Short-term radiation effects can be originated from intense solar energetic particles (SEPs) which could induce acute radiation syndrome (ARS) or sickness, poisoning or toxicity if the body is exposed to high radiation doses at the Gy level [20]. We suggest conducting further research and expose these cells to space environment during various solar activities to further assess the effects of radiation on the immune system since varying radiation intensities may derive from different solar cycles.

There were some previously reported studies examining the effect of radiation on the T cells. For example, previous research [5] used the T cells derived from the same strain of mice as ours which were exposed to-low-dose/low-dose-rate (LDR) (57) Co γ-rays (0.01 Gy, 0.03 cGy/h), with and without acute 2 Gy proton (1 Gy/min) or γ-ray (0.9 Gy/min) irradiation; analyses of which were done on days 21 and 56 post-exposure. Our results are consistent with reported literature which showed the significant increase in CD4 expression in human T cells of HIV patients treated with neem tree derived extract [13]. Previous studies [14] investigating the effect of radiation on lymphocytes reported CD4 population being more sensitive to radiation than CD8 which is in alignment with our findings. Also, some reports [15] suggested that CD8 population might be resistant to radiation of lower doses, but very sensitive to 2 Gy. However, most past studies were conducted using whole animal radiation exposure, therefore the comparison of our results with previous studies might be not comparable. Thus, our data suggest that adding IL-12 to naïve cell cultures leads to a higher expression of CD8, whereas adding SCNE leads to a higher expression of both CD8 and CD4 in flight but not in ground conditions.

We also saw an increased expression of CD25 which is in alignment with the previous report [16] showing the increased expression of CD25 in irradiated mice using a much higher dose of radiation than in our recordings, but from the same strain mouse as ours. The difference between ground and flight conditions were more evident in naïve cells.

Finally, we looked at the expression of many cytokines released in the supernatants of T cells. T cells' ability to release cytokines plays a critical role in their functional activity, as it determines the nature and the outcome of the immune response. Thus, their ability to produce multiple cytokines has been associated with beneficial immune responses. Previous studies [19] have shown that exposure to high-LET iron ion radiation on immune T cells induces pathological changes – relevant to assess the long-term potential effects on astronauts that may experience during their long exploratory missions in space. The expression of most cytokines was shown to decrease after low doses of radiation and to increase after high doses. For example, IL-6 was reported to react at early times and IL-10 at later times, whereas IL-5 levels were consistently elevated indicating the differences in the responses to a low and high dose of radiation [15]. Our data show very high levels of IL-5 in all flight conditions.

It is important to note that most other previous studies used the whole-body radiation exposure on the immune cells in mice, therefore comparing our study findings with past studies might be complicated. In our study, we report differences in T cell subpopulations, cell cycle alterations, and cytokine release possibilities in flown cells compared to ground controls. Although unlikely, but these changes might have been also influenced by the temperature changes as we saw color changes in the cells. Also, we were surprised to see the decreased expression of cells in ground cells cultured in IL-2. This could be due to the technical error or due to the different temperature the cells were exposed at the NASA Hangar. Our previous feasibility studies [26] conducted by exposing cells to different temperatures revealed that cells are capable to survive and proliferate at the temperatures experienced during this flight. Finally, we got insights into the effect of neem tree extract on naïve and activated T cells' behavior. Given the beneficial properties of this extract [18], further research is needed to elucidate its mechanism of action.

V. Conclusions

Space travel induces numerous health hazards and technical challenges. In this study, we designed and tested the various technologies to maximize scientific findings. Our results indicate that the maximum dose of radiation was 48 μGy with ten instances of high radiation dose above 15 μGy/hr during the cruise, totaling about 9.5 μGy during the cruise, and radiation doses of about 1.2 μGy and 0.8 μGy during ascent and descent, respectively. These radiation doses are about six times, sixteen, and five times larger than the radiation dosed experienced by the ground control samples. This radiation data was accurately measured by NASA's Timepix instrument. Thus, we obtained valuable scientific data on naïve and activated murine T cells exposed to the 60,000 feet flight and cosmic radiation. Our findings demonstrate that flown cells showed fewer CD4 positive cells, but an increased number of CD8 cells. Herein, we observed a beneficial outcome of adding cytokines IL-2 and IL-12 to the T cell cultures. This finding presents a simple strategy to enhance T cells' behavior in future studies.

T cells exposed to this flight environment expressed slightly higher than ground samples for CD8, but these flight T cells expressed approximately 20% less than the ground samples for every single condition when using CD4. However, naive cells showed a significant yield for both CD 4 and CD8. For CD4, when naïve cells were manipulated with SCNE or IL-2/IL-12 combined, flight samples showed much higher expression (near 90% higher for SCNE and near 25 % higher for IL-2/IL-12). For CD8, when naïve cells manipulated with SCNE, yield expression was about 85% higher than for ground cells, and it was nearly 10% lower for every other condition. As for CD25, a larger % expression is observed in the T cells versus the naïve cells, but relative % expression seems to be larger for the naïve cells.

Looking at the fluorescence intensity (FI), we observed that it is significantly larger for naïve cells, both flight, and ground than for T cells, especially for IL-6, G-CSF, IP-10, KC, MIG and VEGF, MIP-1α, MIP-2, and RANTES expressions when using IL-2 and IL-12 combined. Another important observation is that T cells, both flight, and ground, are significantly higher for IL-3, IL-4, IL-5, and IL-17 expressions for every single condition (no cytokine, IL-2, IL-12, IL-2/IL-12, and SCNE).

Our research findings indicate that the various levels of radiation doses may have had a significant impact on the cells, since cellular alterations of both flight naïve and activated T cells were noted. These cells received about six and five times more radiation levels than the ground controls during ascent and descent, respectively, and over 16 times more during the cruise. Temperature variations may have contributed to the cellular alterations, these variations were maintained within ± 6 °C to 7 °C of the desired 30 °C during the cruise for cells. Temperature variations during ascent and descent were within a few °C for approximately 40 minutes of flight for each segment. The temperature variation when the cells landed at Ellington Field airport, was between 17 °C to 18 °C, at that time, the AOD team was unloading our payload inside the hangar. These small temperature variations may have been associated with the fact that the payload had already been unpowered from the aircraft but because payload was inside the hangar, the temperature was relatively constant at about 14 °C to 15 °C inside the hangar. Temperature variations may have contributed to the cellular alterations, although the variation of temperature was relatively small. Although the active thermal system was proved to provide good temperature stability, especially during the cruise, our team will further work on refining the thermal system to increase its reliability to narrow down the temperature stability range within ± 2 °C for the entire flight.

As we embark for long-term human space exploration, it is critical to gain a better understanding of radiation effect on immune cells and other body systems. The results obtained from this study will be valuable for the development of further payloads against the damage of space induced radiation.

Competing interests

The authors declare that they have no competing interests

Consent for publication

Not applicable

Ethics approval and consent to participate

Not applicable

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Availability of data and materials

Not applicable

Author's contributions

PL and SG organized and coordinated the operations and engineering of the project. KA and PL executed and analyzed the biological experiment. PL guided students in this project as part of the CSO 390 Payloads and Integration class. All authors contributed to editing and final approval of the manuscript.

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Abbreviations: ADS-B, Automatic Dependent Surveillance-Broadcast; AOD, Aircraft Operation Division; AR, Airworthiness Review; ECLSS, Environment Control Life Support System; ERAU, Embry-Riddle Aeronautical University; ERHASER, Embry-Riddle High Altitude Science Engineering Rig; FAA, Federal Aviation Administration; LET, Linear Energy Transfer; NanoLab (1U), 10 cm × 10 cm × 10 cm; SCNE, neem tree Azadirachtaindica; SOAR, Student Opportunities in Airborne Research; STEM, Science Technology Engineering and Mathematics; TRR, Test Readiness Review; TUC, Time of Useful Consciousness; IL-2, Interleukin 2; IL-12, Interleukin 12.

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By Sushil Chandra & Hemant Saini

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COMPUTATIONALFLUIDDYNAMICSANALYSISOFNONSLENDERCROPPEDDELTAWINGSUIT

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Sushil Chandra [α] & Hemant Saini [σ]

Abstract- At present, only hand-full of research work on design and development of wingsuit exists in the open domain and "sew and fly" approach is still used. In this study, CAD software Solid works was used to design the wingsuit model, using a Gottingen 228 airfoil of aspect ratio 1.05. Ansys Fluent solver was utilised to solve the Reynolds Averaged Navier-Stokes (RANS) equations with a k-ω turbulence model. In this study the wingsuit is assumed to be flying at a free-stream velocity of 40 m/s. Detailed simulations were recorded at different angles of attack till stall angle to give an insight into the flow dynamics of the wingsuit. Computations showed that the wingsuit had a maximum lift coefficient of 2.4 and reached a stall angle of 40 degrees. The results were compared with the experimental and CFD results of existing literature in the open domain. The non slender delta wingsuit performs extremely well giving a lift coefficient of 2.4 and C_L/C_D of 6.7. The results were validated by comparing them with flat plate results of AR 1.0 and non slender cropped delta wing results of existing literature. A good agreement in terms of trends was obtained for C_L and C_D which indicates that proposed wingsuit should perform well aerodynamically under typical wingsuit flying conditions.

Nomenclature

- C_L Lift Coefficient
- C_D Drag coefficient
- LE Leading Edge
- TE Trailing Edge
- AR Aspect Ratio
- c Chord
- Re Reynolds Number
- LAR Low Aspect Ratio
- C_{Lmax} Maximum Lift Coefficient
- α Angle of attack

I. Introduction

Wingsuit flying is a sport in which a human being dives from a specific height ranging from 10,000 ft to 22,000 ft and with the help of enhanced surface area high lift is generated. It has always been the desire of human being to fly like a bird, an early attempt to achieve the same was made on 4 February 1912 by a 33-year-old tailor, Franz Reichelt, who designed a wingsuit that was a combination of parachute and wing, to test the efficacy of his wingsuit he jumped from the Eiffel Tower. This experiment proved deadly and he died by hitting his head first opening a measurable hole in the frozen ground [1]. Rex G Finney of Los Angeles, California, made an attempt to achieve higher horizontal distance and maneuverability by wearing a wingsuit in early 1930 [1]. Similarly, many attempts were made to fulfill the desires of human being to fly like a bird. Early wingsuits were made up of canvas, wood, silk, steel, and whalebones and few "Birdmen" like Clem Sohn and Leo Valentin, claimed to have glided for miles though proof of their claim was never provided. Till, 1990s very limited progress was made in design and development of wingsuits and were mainly restricted to sports and fun activity with limited horizontal and man oeuvre capabilities. The wingsuit design was revolutionized by modern wingsuit developed by Patrick de Gayardon of France, his wingsuit was tested in a vertical wind tunnel but it did not went into production due to reasons unknown but peculiarity of his design was increased wing area between the legs and arms. Kuosma established Bird-Man International Ltd. the same year. Birdman's "Classic", designed by Pečnik, was the first wingsuit offered to the general skydiving public [1]. Michael Abrams in his book Birdmen, Batmen, and Sky-flyers states that if piloting an aeroplane is considered to be flying than to row a canoe must be like swimming. This statement in itself gives out the desires of human to fly like a bird. Wingsuit flying gives human an opportunity to fly like a bird and is completely different from other propelled gliders be it Jet packs, hang gliders or small aeroplanes [2]. The major difference between presently used hang gliders and wingsuit is the ability of wingsuit to provide glide capability without adding weight of the motor or propeller. The sport of wingsuit provides the Skydivers to use the aerodynamic shape of the wingsuit to develop lift and obtain high glide ratio that is higher C_L/C_D ratio at a given angle of attack [3].The commercial era of wing suit began in 1999, when Jari Kuosma of Finland and Robert Pečnik of Croatia designed and created a wingsuit that was more safe and feasible to all skydivers[4,5]. The development of an effective wingsuit has been a grey area as very limited researchers have worked upon investigating the design of a wingsuit which is quite evident from the fact that very limited research work is available in open domain to estimate the current status of research concluded in this field. With advent of computational fluid dynamics, it has become possible to design and simulate the wingsuits in actual operating conditions but still a lot of work is

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required to be carried out to compare research work with existing literature and draw logical conclusions for increasing the aerodynamic efficiency of future wingsuit. The aim of this study is to carry out an extensive literature review to first establish the existing work carried out by researcher to improve the aerodynamic efficiency of the wingsuit and use these results in designing an aerodynamically efficient wingsuit using the CFD tools and validate the same with existing literature.

II. Wingsuit Flying Conditions

Though, a very limited literature is available to establish concrete operating conditions in which a Skydiver operates but it generally varies fom 30-50 m/sec [3]. In literature also the researchers have used a variety of flow velocities ranging from 20-80 m/sec which means Re is drastically different in each of these research works. Geoffrey Robson et al [6] in their work have used horizontal velocity of 35 m/sec to 45 m/sec. Keeping this in mind in this study the flow velocity was chosen to be 40 m/sec. Also, the altitude was assumed to be 10,000 ft which generally aligns with the flying altitudes of the skydivers.

III. Aerodynamics Theory

a) *Aerofoil Aerodynamics*

Before starting the designing of a Wingsuit which is a 3D wing, it is pertinent to understand the flow physics involved in generation of lift by an aerofoil. An aerofoil is an cross-section of a wing and is used to understand the 2D aerodynamics, in other words aerofoil has an infinite span i.e no wingtips. Figure 1 explains the basics of lift generation by an aerofoil, as shown the incoming air makes an angle with the aerofoil thus creating change in flow velocity due to change in streamlines which in turn creates a pressure difference thus creating upward force called lift. The weight of the aerofoil is taken as the drag, the aerodynamic efficiency of an aerofoil is seen from its ability to produce higher lift with little drag i.e. higher C_L/C_D ratio[7].

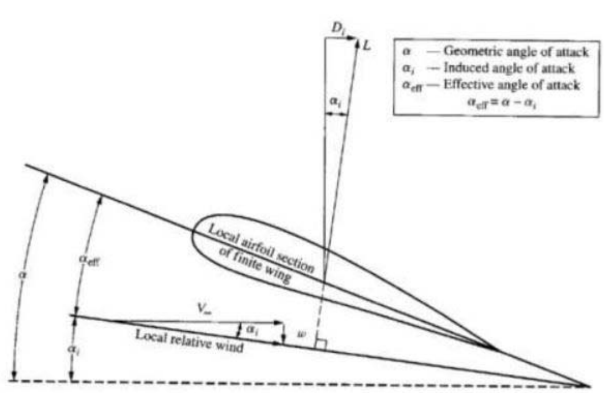


Figure 1: Aerofoil Aerodynamics

Understanding of aerofoil aerodynamics is critical in wingsuit design as it helps in selection of aerofoil for designing wingsuit to meet the requirement of higher glide ratio. Thus, by making use of higher lift generation capability of an aerofoil i.e. higher camber the skydivers can achieve higher range and can even gain altitude by suitable maneuvers.

b) *Wingsuit Aerodynamics*

Though the only difference between aerofoil aerodynamics and wingsuit aerodynamics is that the later is a 3D wing with finite aspect ratio (AR) as shown in Figure 3. In Figure 3, as indicated the space between the skydivers hand and legs is utilized for making the wing segments using a particular shape of a selected aerofoil. The basic wing theory involved in wingsuit aerodynamics, is the skydiver on jumping from the aero-platform or a plataform i.e. aeroplane or cliff etc, dives into the air and the wingsuits makes use of the ram air and takes the shape of the aerofoil, such as Tony Uragallo's Wingsuit that uses the same concept and takes the shape of an aerofoil using ram air and gives a glide ratio of 3.6 to 1[8]. This camber is then used to change the flow of the streamlines which is turns produces pressure difference hence the lift. The wingsuit model designed and tested in this study has been created using GoE 228 aerofoil cross-section. In order to validate the CFD test set up being used for carrying out CFD analysis of the proposed wingsuit in this study, it is desirable to test this setup on 2D GoE aerofoil and then compare these results with the results available for the same aerofoil under similar Re conditions in open domain. As in case of a 2D aerofoil there is no effect of induced angle of attack and the angle of attack of the incoming air is considered to be the angle of attack for the aerofoil. But as wingsuit is 3D in nature it will experience the induced angle effect due to the down-wash thus to obtain an effective angle of attack the same needs to be subtracted from the geometric angle of attack as given below

$$\alpha_{eff} = \alpha - \alpha_i$$

Where α_i is the induced angle of attack and α is geometric angle of attack. Also α_i can be expressed in terms of C_L and aspect ratio (AR) and is given below

$$\alpha_i = \frac{C_L}{\pi e AR}$$

Also the slope of the lift curve is an indication of the aerofoils to generate lift, a higher lift slope indicates that aerfoil can generally produce higher lift at lower angles of attack. The relations between the lift slope and AR is shown below.

$$\frac{dC_L}{d\alpha} = \mathrm{a} = \frac{a_0}{1+\frac{a_0}{\pi AR}(1+\tau)}$$

Where a is the slope for 3D wing and a_0 is the slope for 2D aerofoil cross-section of the wing. τ varies from 0 to 0.25, in the present case its value is taken as 0.

IV. Literature Review

a) Results from existing literature

Wingsuit designed and tested in this study is developed using an exact aerofoil cross section. The wingsuit being a 3D wing behaves differently than an aerofoil because of the obvious reasons. A very limited experimental as well as computational research work on design and development of wingsuit exists in the open domain. Nyberg [9] in his research work studied flow over Apache wingsuit at velocity ranging from 40 m/sec to 83 m/sec, he observed that the stall angle was approached at around 40 degrees with max glide ratio of 4.2. He also, observed that with increase in velocity the performance of the wingsuit reduced due to increased flow separation and higher drag. He in his study found some instability in wingsuit at higher speeds which he contributed to the computational error and not the wingsuit design. Berry et al [10] in their study conducted wind tunnel testing on a novel wingsuit design and compared it with a modified design with a forward wing. They observed that there was a increase in glide ratio with increase in angle of attack in the original wingsuit but addition of forward wing reduced the glide ratio despite having a higher lift coefficient. They contributed this to the increased profile and induced drag generated by the forward wing added to original wingsuit. Also, the max glide ratio achieved was in the range of 2.5. Also, B. Read et al [11] designed and tested Icarus wingsuit which was scanned using laser to capture the entire Icraus wingsuit model. The same was then used to carry out CFD analysis to study the flow field and aerodynamics of the wingsuit. Also, they carried out wind tunnel testing to validate the results so obtained from the CFD analysis. They used the CFD and wind tunnel results to modify the design of the wingsuit to enhance the lift to drag ratio and were able to design "Athena" helmet to improve the gliding performance of the skydiver. Geoffrey Robson et al [6] performed longitudinal stability analysis of a jet powered wingsuit. They were able to obtain real flight data of the wingsuit on which their analysis was based. They contributed phugoid mode as the primary source of instability during the jet powered flight. Based upon their analysis they proposed use of computer aided thrust vectoring methodology to overcome the phugoid instability and improve the performance of the wingsuit. Shields et al [12] studied effect of slideslip on low aspect ratio wings, as the present study also involves wingsuit of lower aspect ratio certain important lessons are drawn from their studies to improve performance of the wingsuit. They observed that sideslip effects the overall performance of a wing, they ascertained this by conducting wind tunnel testing of flat rectangular wing and verified the results using surface tuft flow visualization. Ansari et al [13] conducted a series of wind tunnel experiments on wingsuits and validated that the same using CFD. They observed that the refines wingsuit having inflated surface performed better as compared to plain surface. Though the performance of the wingsuit was below par but they concluded that the surface finish of the wingsuit is an important parameter and has a important role in lift to drag ratio.

b) Comparative Analysis

To better understand the effect of flow velocity and angle of attack on low aspect ratio wingsuit, results from the existing literature [9,13] have been extracted and are plotted as shown in Figure 2. It is observed that with increase in angle of attack the glide ratio tends to decrease and the maximum glide ratio is achieved in the range of $\alpha = 5^0$ to 15^0. The maximum glide ratio is in the range of 4 to 4.2, which is considered to be very good in terms of wingsuit flying.

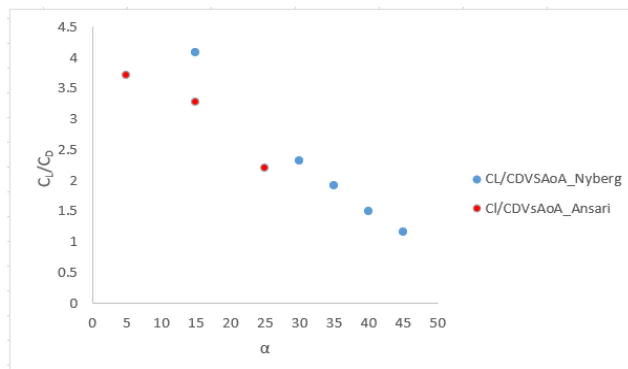


Figure 2: C_L/C_D Vs α Existing Literature

The availability of research work on improving the performance of wingsuit is very limited and still commercially the approach of developing a wingsuit is "Sew and Fly". Though, few researchers have used CFD analysis to design and study the behavior of a wingsuit and used these results to improve the lift to drag ratios but in most cases these designs are not practically feasible and cannot really be used to produce wingsuits e.g. Ferguson et al[16] designed the wingsuit using GoE 228 aerofoil but they ignored the effect of head, arms and feet of the wingsuit flyer thus despite of obtaining a C_L/C_D of 7.7 their wingsuit is not feasible to manufacture and be of use to skydivers. Keeping this in mind the wingsuit in this study was designed to factor in the effect of head, body and feet of the skydiver and at the same time it must give good L/D ratio which is higher than the commercially available wingsuits. Also, as the wingsuit flying velocity ranges is generally from 30 -50 m/sec [5], the flow velocity was kept at 40 m/sec such that the results so obtained can be validated and compared with the existing literature.

V. Wingsuit Design

In order to conduct CFD analysis of a wingsuit, it is pertinent to first design the geometry of the wingsuit. As discussed earlier, the wingsuit takes the shape of an aerofoil using the ram air thus the first step in designing the wingsuit is to select an aerofoil. Since, the aim of this study is to design and develop high range and endurance capable wingsuit it is an inescapable requirement to select a highly cambered aerofoil. Also, in reality wingsuits are flexible in nature but for the purpose of CFD analysis the designed wingsuit is assumed to be of rigid nature. The wingsuit is assumed to be an ideal approximation of the commercially available wingsuits. In this study the typical parachute backpack has been excluded as it is assumed that the flow separates from the head and area behind the head does not really participates in generation of the lift due to the flow seperation from the head.

a) Selection of Aerofoil for Wingsuit Design

To obtain high lift to drag ratio in a wingsuit selection of correct aerofoil is most important. Though a number of highly cambered aerofoil are available which can provide high lift but it is also important to study the associated drag and feasibility of using such aerofoil for wingsuit design. In this study, a well-researched GoE 228 aerofoil has been selected as Ferguson et al[16] found in their study found that the aerofoil produces high L/D ratio. To validate the lift and drag force produced by GoE 228 aerofoil, a CFD analysis of GoE 228 aerofoil was carried out in ANSYS software to obtain the results for lift and drag and the results so obtained were compared with results available in open domain [14] for GoE 228 aerofoil under similar Re conditions. Figure 5 gives out the details of the GoE 228 aerofoil, the aerofoil coordinates were obtained from open source and these were then imported into SOLIDWORKS software to generate the GoE aerofoil.

i. *Mesh Creation for GoE 228*

A mesh or grids are the tools used by the user to define the locations near the body or aerofoil in this case where the flow equations are required to be solve. As, it is not possible to solve the flow equations at each and every point in the computational domain so it is important to have a denser mesh near the body, in the wake region and areas where large gradient exits. To obtain consistent and accurate results, meshing quality needs to be of highest order i.e. a denser mesh is desired especially near the geometry. At the same time, domain far away from the geometry can have a less dense mesh this helps in reducing the computational power required to solve the flow equations and helps in achieving faster results. An all triangles method was used for creation of the mesh at the same time Edge sizing of 12000 divisions was utilized to refine the mesh. Also, refinement factor of 2 was used to create a finer mesh with 2.5 million elements especially near the geometry, in its wake region and around the leading edge where the flow separation is dominant the same is shown in Figure 4.

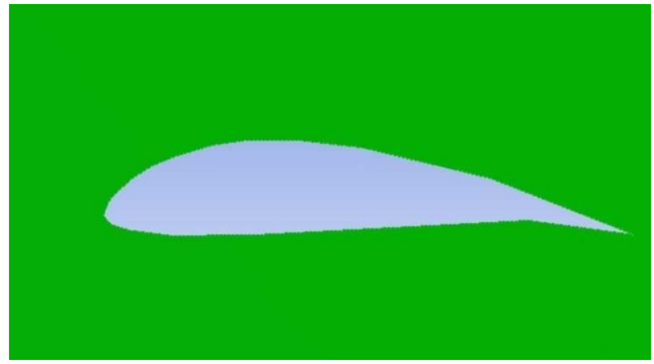


Figure 3: GoE 228 Aerofoil Geometry

b) CFD analysis of GoE 228

GoE 228 as shown in Figure 4 is a highly cambered aerofoil and produces high lift at lower angles of attack. Since, this study aims at designing and development of high glide ratio wingsuit, it is pertinent to study the aerodynamics of the aerofoil selected for designing the wingsuit. Also, CFD analysis of the aerofoil acts as an instrument to validate the CFD model and setup to be used further CFD analysis of the proposed wingsuit. If a good agreement is reached between the results obtained from CFD analysis of the GoE 228 aerofoil and the results available in open domain [14] under similar Re regime then it can be assumed that the CFD model is consistent. The CFD analysis of the GoE 228 aerofoil is carried out using Ansys software. The aerofoil coordinates were imported in SOLIDWORKS software to create the aerofoil and then the same was imported to ANSYS workbench to create the geometry as shown in Figure 4. The 2D enclosure was selected to be of 20m around the aerofoil so as to obtain disturbance free flow and minimum wall effect.

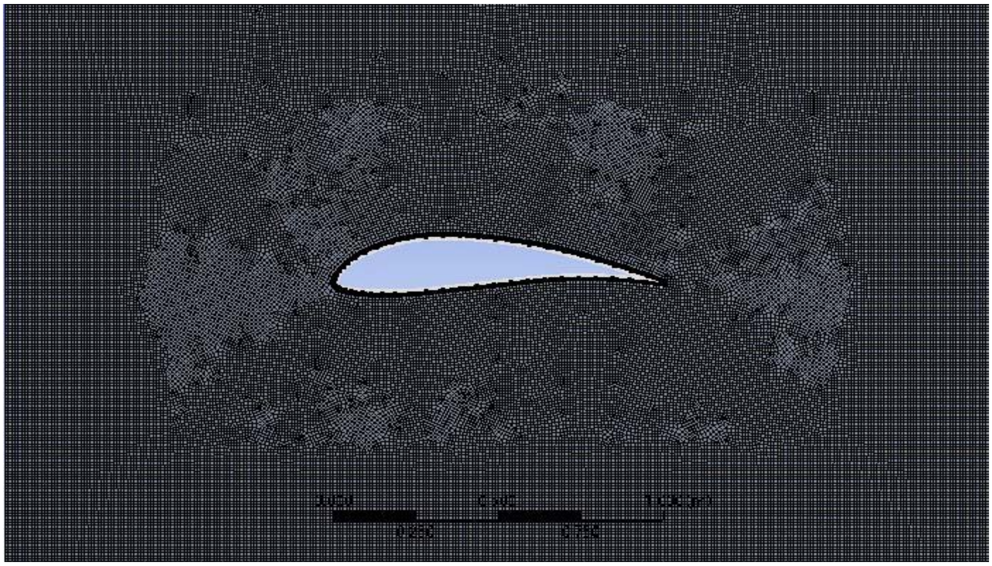


Figure 4: Mesh for GoE 228

k-ω model is a two-equation model and is used for closure of RANS equations. In this model two variables k and ω are used to predict the values of turbulence using PDEs, where k is the turbulence kinetic energy and ω is the specific rate of dissipation by which TKE i.e. turbulence kinetic energy k is converted into internal thermal energy. In the present study k-ω model is used for CFD analysis of GoE 228 aerofoil and later of the wingsuit.

c) GoE 228 Aerofoil results and validation

The Reynolds number for the 2D aerofoil was set to 10^5. k-ω Turbulence Model was used for carrying out the CFD analysis and the results so obtained were compared with the results available in the open domain [14]. It was observed that the lift is obtained at zero angle of attack which is obvious as GoE 228 is a highly cambered aerofoil. As shown in Figure 6 the lift coefficient is observed to increase with increasing angle of attack till 14 degrees and stall is reached at 15 degrees. The results from CFD analysis were then compared with the results available in open source [14] and there seems to be good agreement between the two results with max error of 9 % at 4 degrees was observed which can be attributed to the fact that the data available in the open source is for Re$\sim$ 2.5 x 10^5 but in this study the Re no is of the order of 2 x 10^5 and also to computational error, though a complete agreement in terms of trend for lift coefficient was obtained. Similarly, plot was obtained for coefficient of drag against angle of attack as shown in Figure 7, it was observed that the drag coefficient increases with increase in angle of attack. This increase is gradual till 6 degrees beyond which a rapid increase in drag coefficient can be seen. This rapid increase can be attributed to increase in profile drag as with increase in angle of attack beyond 6 degrees the flow tends to separate from the leading edge.

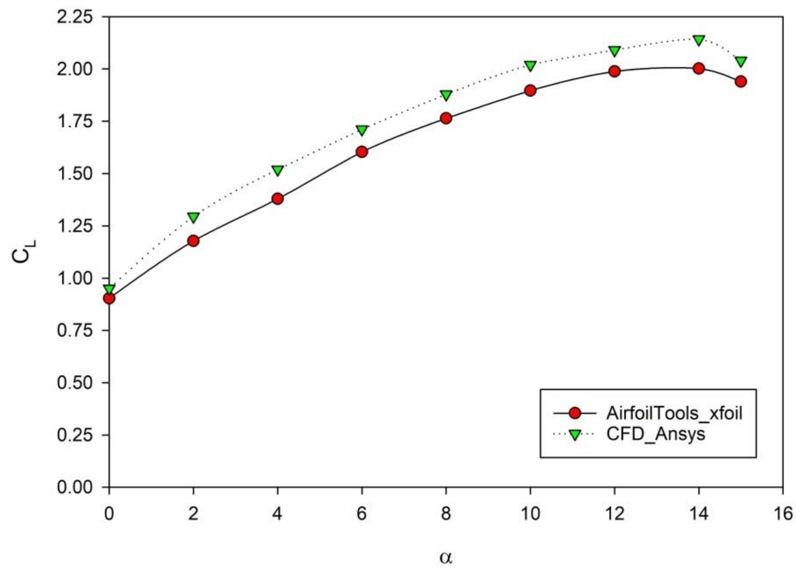


Figure 5: C_L Vs α

This detached flow then reattaches with the airfoil thus creating a leading-edge separation bubble which also contributes to enhaced lift but also drag is increased. A good agreement was achieved between the CFD results and results taken from open source for GoE 228 aerofoil [14]. A max error of 9% was obtained at 2 degrees angle of attack. A good agreement was obtained between the results from open domain and the CFD results also the trends are matching exactly.

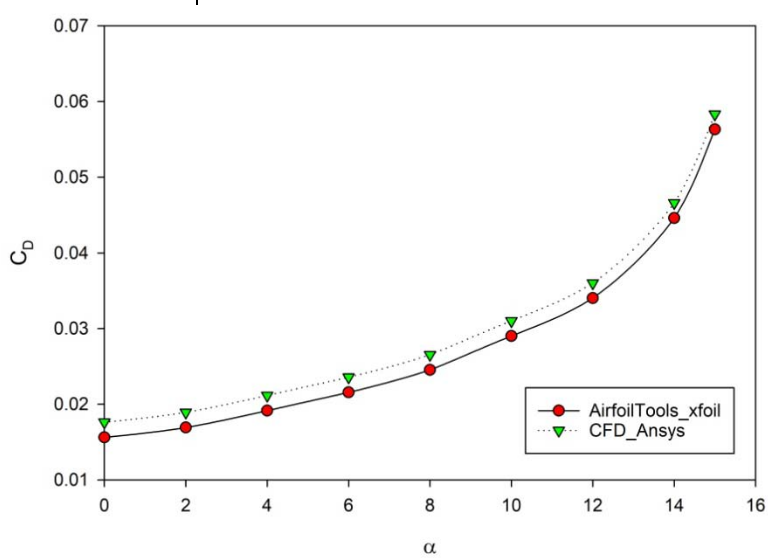


Figure 6: C_D Vs α

d) Mesh Independence Test

Though the effeciveness of the CFD model to be used was validated by comparing the results of the CFD analysis of GoE 228 aerofoil with open domain results but still it is pertinent to establish that the results are independent of mesh size. To ascertain the quality of the results obtained from the CFD analysis of the aerofoil a mesh independence test is carried out. This validates that the results are independent of number of elements, in the present study the results for GoE 228 were obtained for 0.1Million and 0.5Million elements for the given geometry. The results so obtained are appended below.

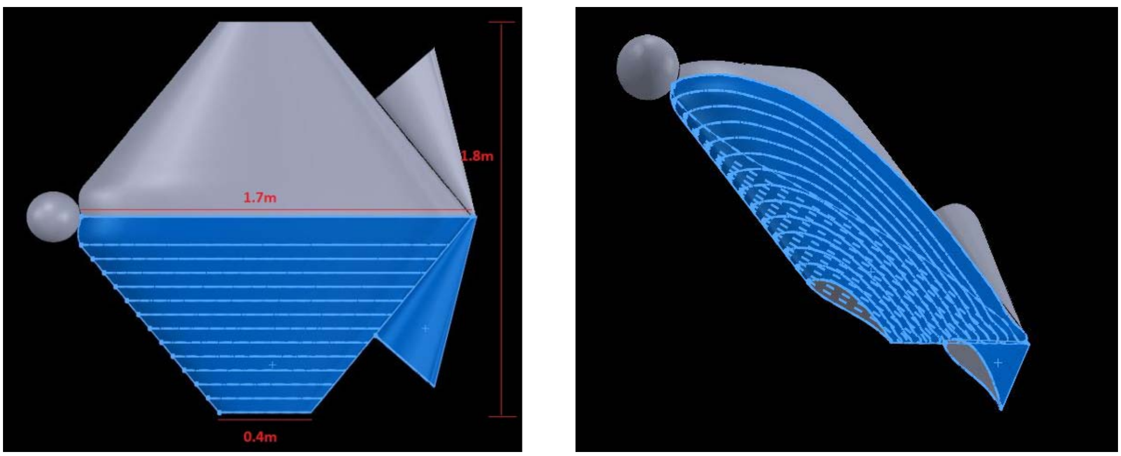
Table 1: Mesh Independence Test

Elements	α	C_L	C_D
0.1Million	6^o	1.71	0.0235
0.1 Million	6^o	1.73	0.0237
0.5 Million	12^o	2.09	0.0360
0.5 Million	12^o	2.11	0.0365

The value of lift and drag coefficient was measured at 6^o and 12^o AoA respectively for both 0.1million and 0.5million element mesh. It was observed that error of less than 1 percent was observed between the two values. This validates that the setup is independent of the size of the mesh and also the setup used can be utilised for CFD analysis of 3D wingsuit which is also designed using GoE 228 aerofoil.

e) 3D Wingsuit Design in SOLIDWORKS

The wingsuit is designed in SOLIDWORKS 2019 software for an average human being having height of 1.7 m and span of 1.8 m thus making the aspect ratio of the wingsuit 1.05, the parachute on the back of the skydiver has been neglected as it is assumed that the flow separation occurs at the head and area behind the head will not participate much in the lift generation. Figure 7 gives out the geometric details of the wingsuit, initially GoE coordinates with 1.7m chord were imported to make the centre aerofoil followed by incremental decrease in chord by 0.05m till the wingtip where chord is 0.4m. A total of 14 aerofoils were used to create one side of the wing. Rear wing to accommodate the feet of the skydiver were created using the same GoE aerofoil with chord of 0.25m as shown in Figure 8. The entire geometry was then lofted to create the other side of the wingsuit.



(a) Top View of the Wingsuit (b) Side View of the Wingsuit

Figure 7: Design details of Wingsuit

VI. Results & Discussion

a) Boundary Conditions

The results were generated using Ansys Fluent CFD software. A finite volume approach has been used to analyze the flow dynamics and aerodynamic behaviour of the wingsuit at different angle of attacks with varying flow speeds. For understanding the behavior of flow field over the wingsuit k-ω turbulence model has been used with low Re correction. For solving the flow field a pressure based coupled algorithm scheme is used. The boundary conditions used are as follow.

Table 2: Boundary Conditions and Solver Setup

Boundaries	Conditions
Inlet	Velocity Inlet
Walls	No Slip
Outlet	Outlet Pressure

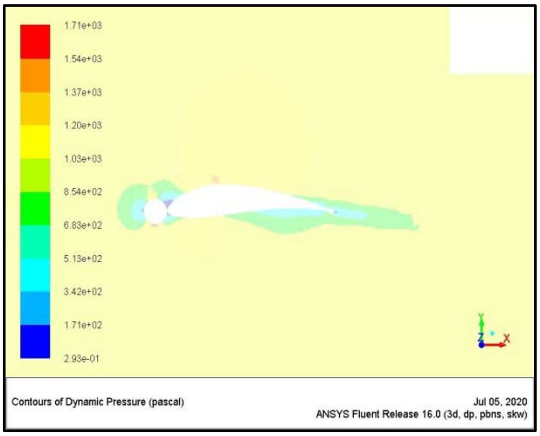
The simulations were carried out at 40m/s with Angle of Attack (AoA) set as 0, 5, 10, 15, 20, 25, 30, 35, 40 and 45 degrees. The pressure-based coupled algorithm obtains a more robust and efficient single phase implementation for steady-state flows. The coupled algorithm solves the momentum and pressure-based continuity equations together. The full implicit coupling is achieved through an implicit discretization of pressure gradient terms in the momentum equations, and an implicit discretization of the face mass flux, including the Rhie-Chow pressure dissipation terms. The k-ω model attempts to predict turbulence by two partial differential equations for two variables, k and ω with the first variable being the turbulence kinetic energy (k) while the second (ω) is the specific rate of dissipation (of the turbulence kinetic energy k into internal thermal energy).The results are discussed case wise at velocity set at 40 m/sec and varying AoA.

b) Computational Fluid Dynamics Simulations of Wingsuit at 40 m/sec

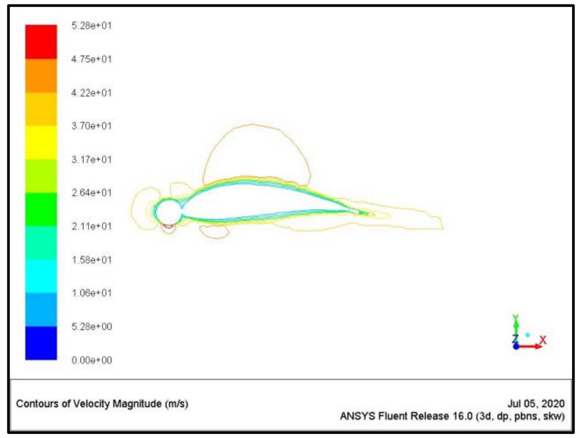
i. *Case 1: 0 degrees AoA*

At 0 degrees angle of attack, the wingsuit is perfectly aligned with the flow as shown in figure 9(a) there exists a very minute variation of pressure that is within 10 units. This indicates that the wingsuit is creating very little disturbance in the flow field and wingsuit behaves as a streamline body. The airfoil section being highly cambered allows flowto remain attached with the wingsuit body as flow passes over.

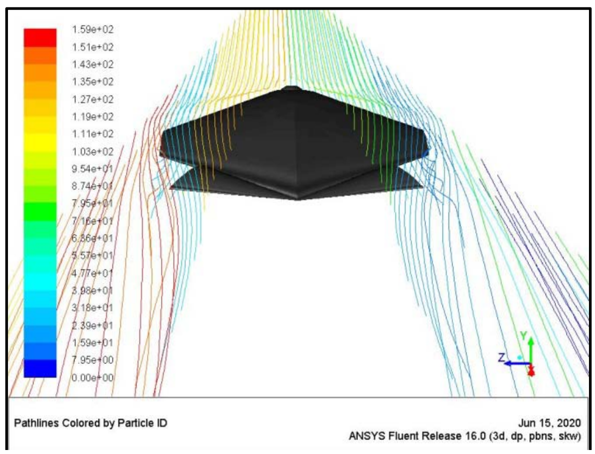
Figure 8(b) gives out the velocity contours, it is observed that there exists a marginal change in the flow velocity thus validating the pressure contours. It can be concluded that wingsuit is behaving like a streamline body with minimum flow seperation at the same time a strong wingtip vortex is created which augments the lift as well as creates induced drag.



(a) Dynamic Pressure



(b) Velocity Contours



(c) Wingtip Vortex

Figure 8: Flow Dynamics at 0 degree AoA

The rear portion of the wingsuit body has extra lift generating surfaces, which not only provides extra lift but also protects the flow from being separated at the trailing edge of the main body by creating vortexes. Sheilds and Mohseni [12], in their study of low AR wing observed creation of the wingtip vortices and attributed the same for additional lift obtained. Flow is observed to be fully attached with the wingsuit also in figure 9(c) it is observed that the strong wingtip vortices are produced which augment the lift produced by the wingsuit. These wingtip vortices are very dense having strong vorticity thus providing additional lift which agrees well with the findings of Sheilds and Mohseni[12].The results are generated for fully converged solution, as shown in figure 9.

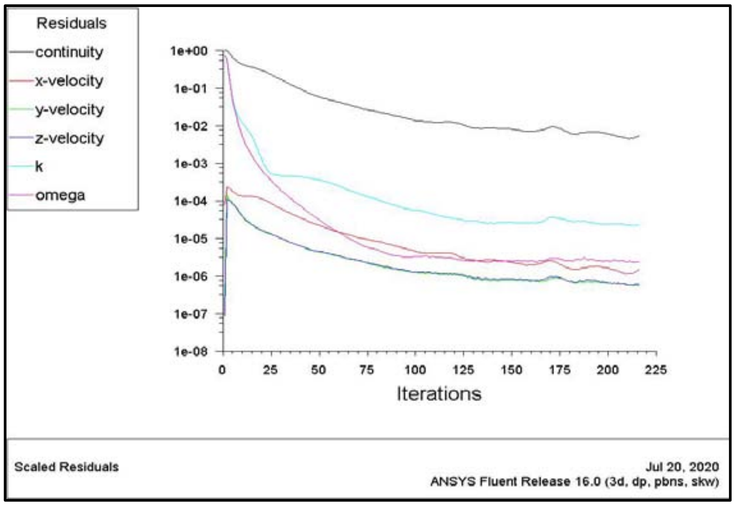
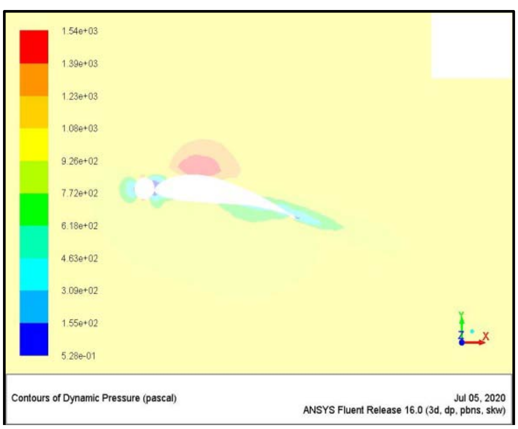


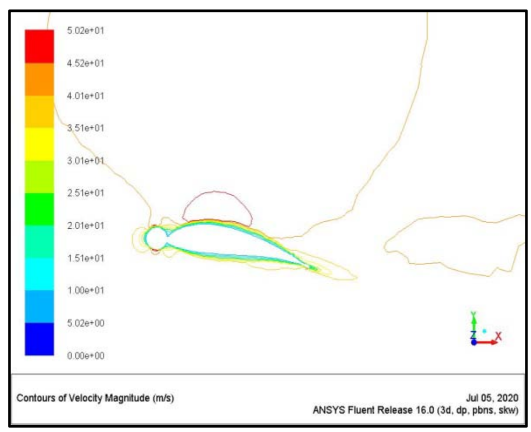
Figure 9: Residuals at 0 Degree AoA

ii. *Case 2 : 10 degrees AoA*

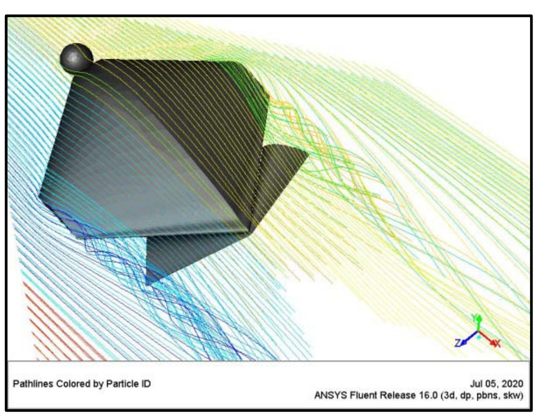
In this case the AoA is increased to 10 degrees keeping the flow velocity same. It is observed that the flow remains attached in this case also, the adverse pressure gradient is the reason for the flowseparation in general, however from the pressure contour plot as shown in figure 10(a) it is observed that pressure variation is minimal. The same is validated from the velocity plot as shown in figure 10(b) as there is minimum change in the velocity contours along the wingsuit indicating that the flow is fully attached even at an AoA of 10 degrees. In figure 10(c), it is seen that with the increase in angle of attack the strength of the wingtip vortices reduce thus the associated lift component reduces but the overall lift is increased due to the lift produced by the wingsuit has increased with increasing angle of attack.



(a) Dynamic Pressure



(b) Velocity Contours



(c) Wingtip Vorex

Figure 10: Flow Dynamics at 10 degree AoA

The results are generated for fully converged solution, which can be seen from the Figure 11.

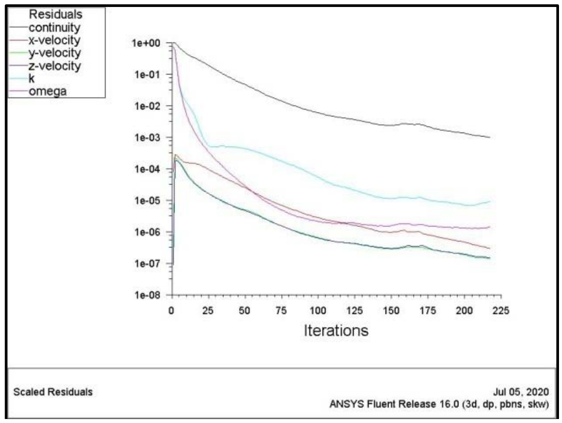
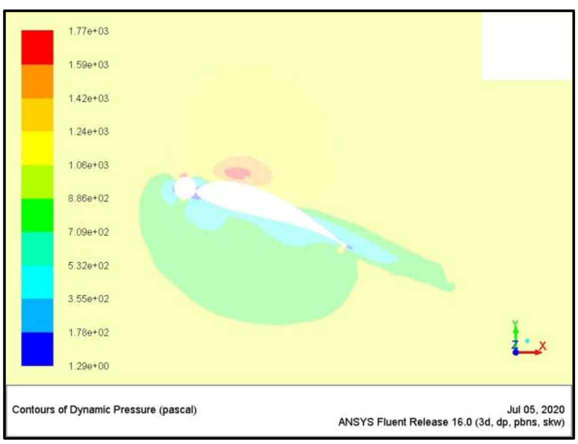


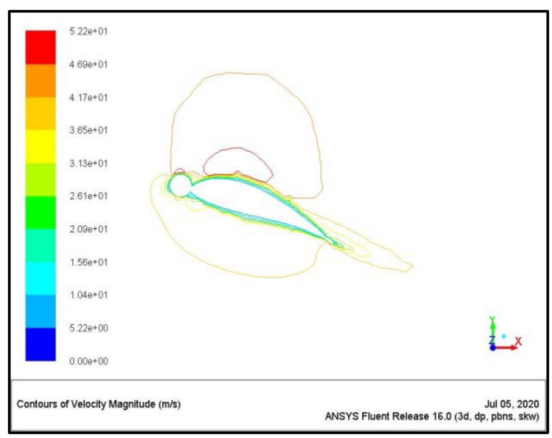
Figure 11: Residuals at 10 Degree AoA

iii. *Case 3: 20 degrees AoA*

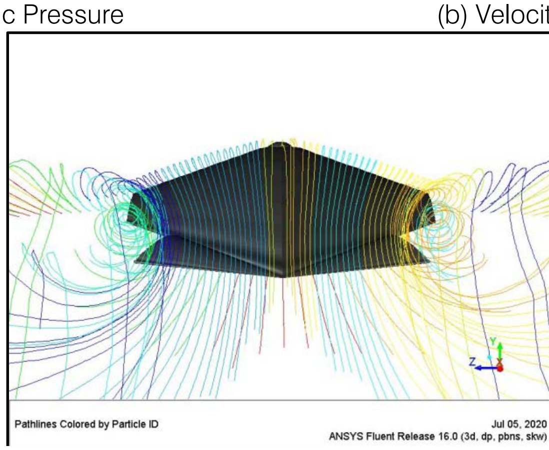
The AoA is set to 20 degrees for this case, with increase in AoA the bluf behaviour of the body has increased. It is observed from figure 12(a) that the variation of pressure over body with respect to surrounding is very low or it can be said that the pressure gradient is favourable. It is also observed that there exists a little increment in pressure gradient near the trailing edge of the body or rise of adverse pressure gradient leading to flow separation from trailing edge. Shields et al[12] in their study found that for low aspect ratio there is an existence of strong wingtip vortices which grow in size with increase in angle of attack. In figure 12(c), it is observed that the size of the wingtip vortex has increased at the same time it is lesser denser in nature i.e. strength of the tip vortex has reduced thus there exists an agreement with findings of Sheild et al [12] and the present study.



(a) Dynamic Pressure



(b) Velocity Contours



(c) Wingtip Vortex

Figure 12: Flow Dynamics at 20 degree AoA

The results are generated for fully converged solution, which can be seen from the Figure 13.

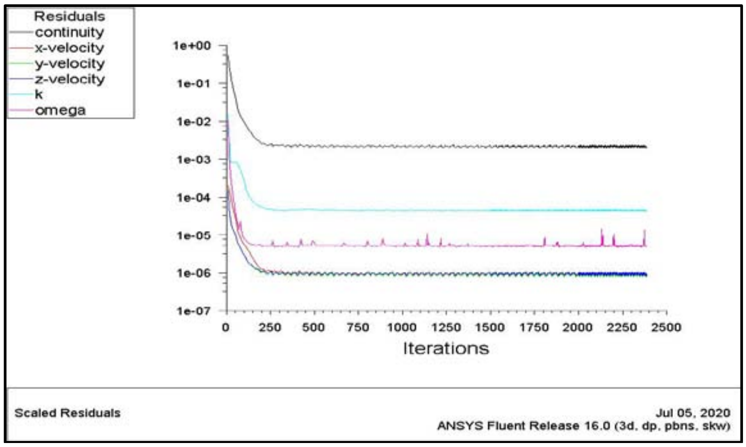
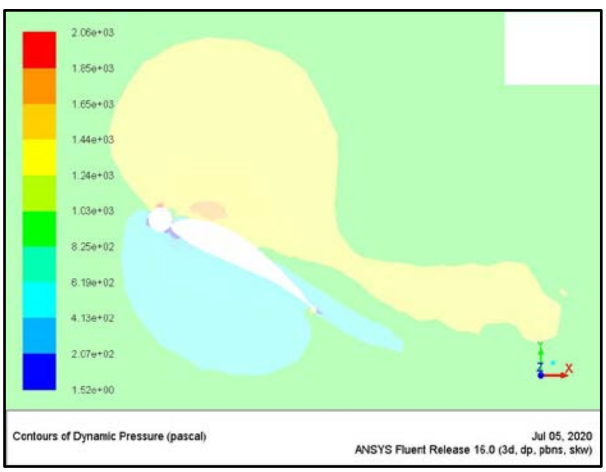


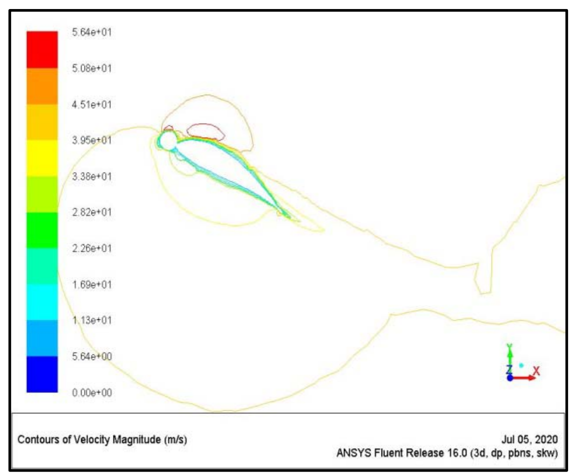
Figure 13: Residuals at 20 Degree AoA

iv. *Case 4: 30 degrees AoA*

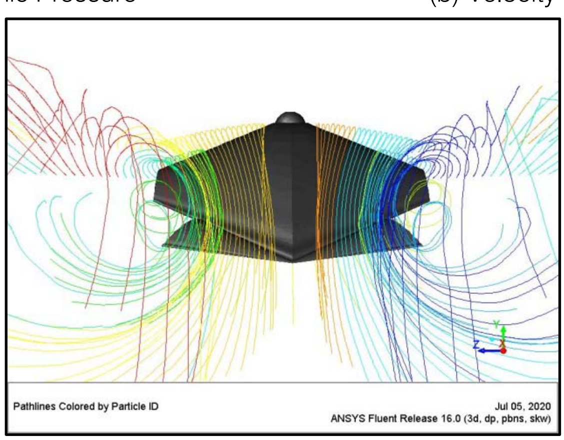
As, AoA is further increased to 30 degrees, the bluf behaviour of the body has increased significantly. It is observed that the variation of pressure over the upper surface of the body with respect to surrounding is higher than the lower surface. But on the lower surface of the body the pressure variation is within the admissible range. In figure 14(a) it is observed that there exists a huge pressure variation creating wake zone near the trailing edge causing the flow to separate from trailing edge. In figure 14 (b), it is observed that there is a creation of wake zone near the trailing edge causing the flow to seperate. In figure 14(c), it is observed that the size of the wingtip vortex has further increased with increase in angle of attack and vorticity has reduced thus making the tip vortex weaker.



(a) Dynamic Pressure



(b) Velocity Contours



(c) Wingsuit during Flying

Figure 14: Flow Dynamics at 30 degree AoA

The results are generated for fully converged solution, which can be seen from the Figure 15.

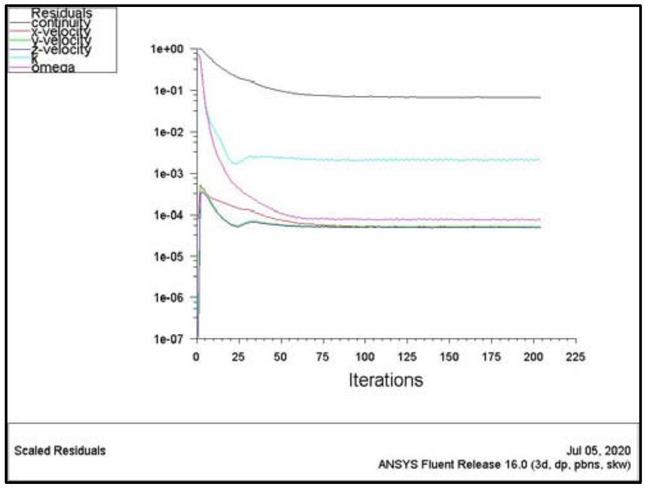
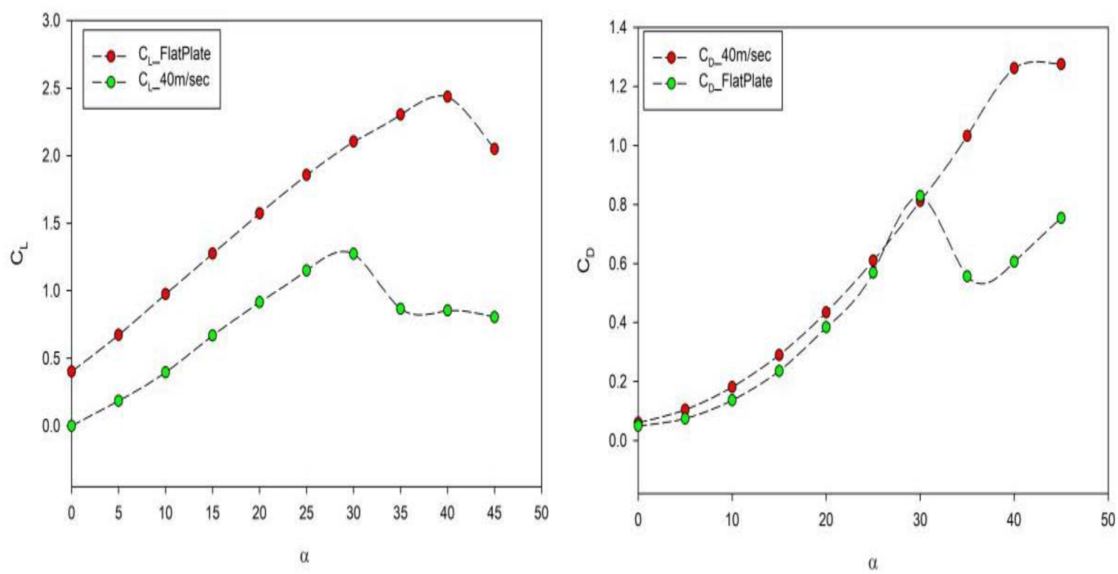


Figure 15: Residuals at 30 Degree AoA

VII. 3D Wingsuit Results and Validations

a) Comparison of C_L and C_D of the Wingsuit with Flat plate results

As discussed above, the results from CFD analysis of the designed wingsuit appeared very promising as the flow remained attached even till 40 degrees AoA. In any study it is pertinent to validate the results from existing literature but as very limited literature is available in the open domain so to validate the trends obtained from CFD study of wingsuit these were compared with results of flat plate having AR~1 [15]. The results obtained for C_L vs α and for C_D vs α for inlet velocity of 40m/s at various AoA and were compared with the flat plate data. As shown in figure 16(a) and 16(b), the trends for both the C_L and C_D matches exactly with flat plate trends, although the difference in values of lift and drag coefficient can be attributed to the difference in Re as flat plate results are obtained at 10 m/s while the proposed wingsuit results are obtained at 40 m/sec. A good agreement in terms of trend is obtained thus validating that the results obtained are not arbitrary and reassures correctness of results.



(a) (b)

Figure 16: A comparison of lift and Drag coefficient vs. angle of attack

b) Comparision of the Results with Existing literature

A comparison of Lift coef$f$icient (C_L vs α) in Fig 17, for velocity at 40 m/s for the proposed wingsuit in this study with the results from existing literature for Wingsuit and flat is carried out. It was observed that the proposed wingsuit body performed much better than commercially available wingsuit and wingsuits from existing literature. The maximum C_L was observed at 40 degrees which is closer to commercially available wingsuit i.e. near to 38 degrees. C_{L_max} was obtained at 0 degrees with C_L value reaching nearly 2.4.

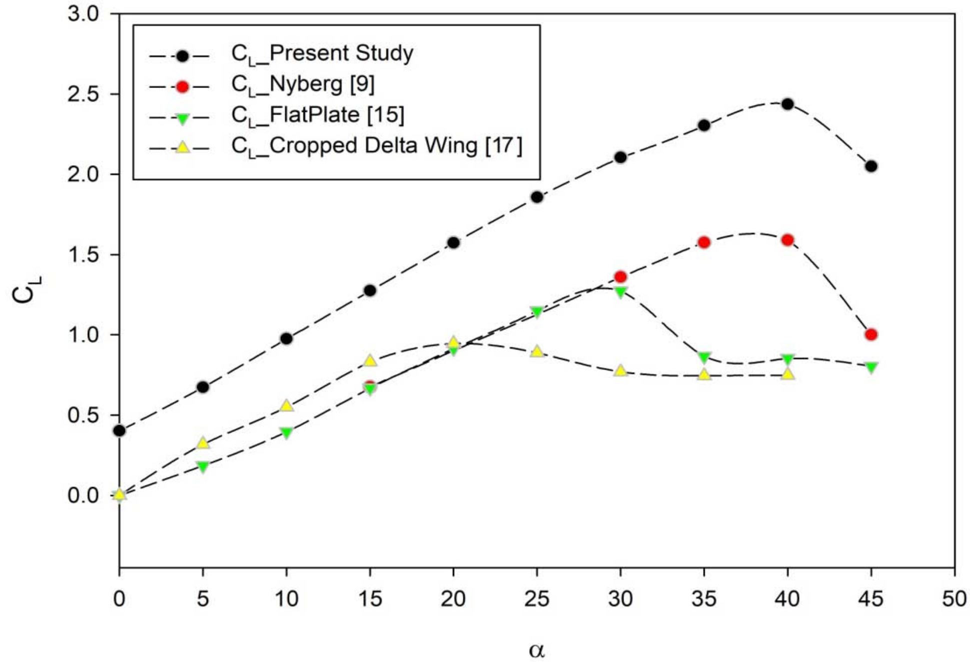


Figure 17: C_L vs α

The C_D vs α curve as shown in figure 18, the drag curve follows the drag curve for the flat plate till 30 degrees AoA. Although at 30 degrees flat plate encounteres stall but for commercially available wingsuit and proposed wingsuit the stall angle is around 40 degrees. It was observed that the drag coefficient of designed wingsuit is a little higher as compared to existing literature, this may be attributed to additional lift generated by the wingsuit due to the camber of the GoE aerofoil i.e. induced drag component has increased due to the additional lift thus increasing the overall drag of the body.

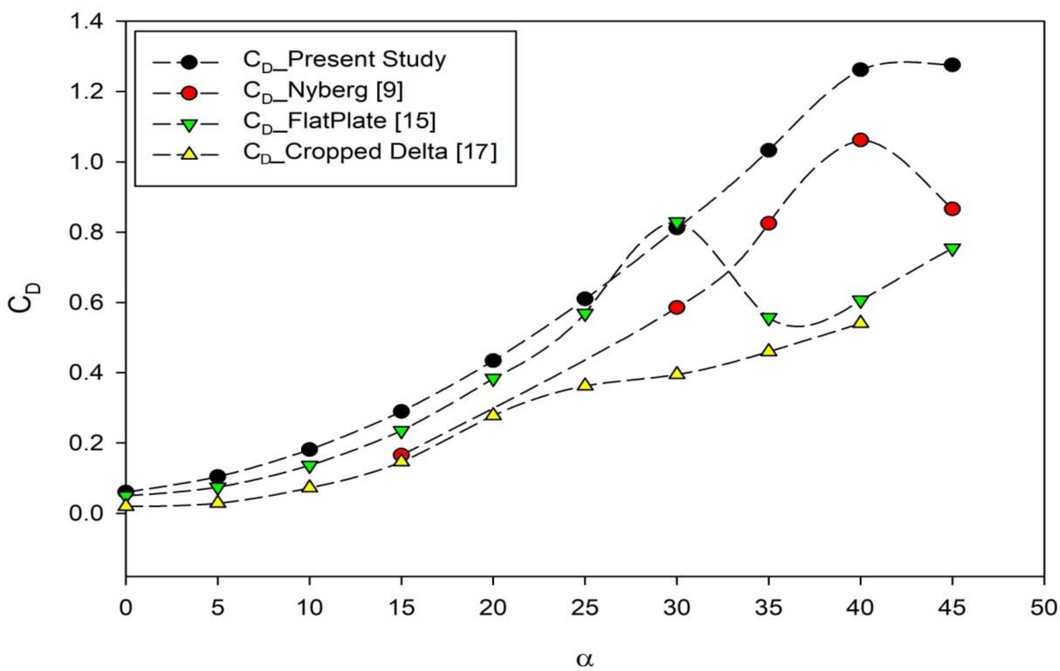


Figure 18: C_D vs α

The results obtained for the lift and drag coefficient looks promising and also agrees well in terms of trend followed by both C_L and C_D when compared with flat plate.

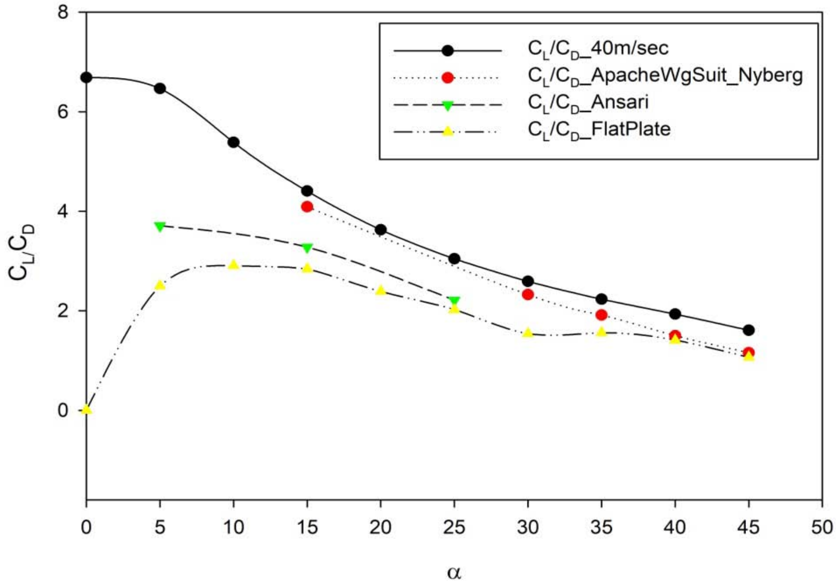


Figure 19: C_L/C_D Vs α

Having obtained the values for lift and drag coefficient the next step is to calculate the aerodynamic efficiency of the wingsuit which is ascertained by calculating C_L/C_D and comparing the same with the results from existing literature for wingsuit and flat plate as shown in Fig 19. It was observed that max C_L/C_D is at AoA of 0 degrees (crusing AoA) which is around 6.7 and much higher than the commercially available wingsuits and flatplate. Thus, it can be concluded that the proposed design of the wingsuit performed extremely well and is likely to give higher range and endurance, which is discussed in next section.

VIII. Range and Endurance for the Wingsuit

As discussed above the designed wingsuit performed extremely well in comparison to commercially available wingsuit and gave a staggering C_L/C_D of 6.7. The obtained values were used to calculate the range and endurance and then compared with the capability of other wingsuits. The range of wingsuit is the distance it travels during the glide descent. It is calculated by the formula mentioned below:

The equations of motion are given by:

$$0 - D - W\sin\gamma = m\dot{V} = 0, L - W\cos\gamma = mV\dot{\gamma} = 0 \quad (1)$$

where γ is the flight path angle (the angle the velocity makes with the horizontal).

If we divide one equation by the other, we get:

$$\tan\gamma = -\frac{D}{L} = -\frac{1}{L/D} \quad (2)$$

It is observed from the above equation that the flight path angle is negative, i.e. the glide angle can be defined as the negative of the flight path angle and written as:

$$\tan\gamma_1 = -\frac{1}{(L/D)} \quad (3)$$

Where (γ_1 is glide angle (and is positive).

From above it is observed that the glide angle depends only on L/D and is independent of the weight of the vehicle also the flattest glide angle occurs at the maximum L/D.

a) Glide Range

$$R = \frac{h_1 - h_2}{\tan\gamma_1} \quad (4)$$

Hence the range for gliding flight depends on the L/D and Δh. This means to acheive maximum range it is important to macimise the L/D ratio.Therefore the maximum range glide is flown at the minimum drag airspeed, V_{md}.

b) Small Glide Angle Assumption

In most cases, the glide angle will be small for an equilibrium glide. Under these circumstances, we can make the following approximations ($\gamma_1 << \pi$):

$$\cos\gamma_1 \approx 1, \sin\gamma_1 \approx \tan\gamma_1 \approx \gamma_1 \approx \frac{1}{(L/D)} \quad (5)$$

The most important result of this assumption is that we can make the approximation that:

$$L = W\cos\gamma = W, V = \sqrt{\frac{W}{1/2\rho S C_L}} \quad (6)$$

Hence we can use the weight in order to compute the airspeed. Without this assumption the calculations can become more difficult.

c) Rate of Climb (Sink)

The rate of climb is given by,

$$\dot{h} = V\sin\gamma \tag{7}$$

We can eliminate $\sin\gamma$ to get,

$$\dot{h} = -V\frac{D}{W} \approx -V\frac{D}{L} = -V\frac{C-D}{C_L} = -\sqrt{\frac{W}{1/2\rho S\, C_L}}\frac{C_D}{C_L} \tag{8}$$

or

$$\dot{h} = -\sqrt{\frac{W}{1/2\rho S}}\frac{C_D}{C_L^{3/2}} \tag{9}$$

We can note the rate of climb is negative (hence a sink rate), and that it is directly related to the quantity, $C_D/C_L^{3/2}$. Therefore, if we want to minimize the sink rate, we must minimize the quantity, $C_D/C_L^{3/2}$ i.e. if we minimize the sink rate, we maximize the time to descend or maximize the time aloft, or endurance.

d) Time to descend

The descent rate depends on the altitude i.e. on ρ. It means, density variations needs to be included to obtain exact solution for the time to descend. If change in density is minimal than density can be assumed to be constant, at the same time if AoA is assumed to be constant throughout the flight then C_L and C_D also become constant. Under these circumstances and assumptions the rate of descent is constant. Thus we have time of flight given by,

$$TOF = -\frac{\Delta h}{\dot{h}} \tag{10}$$

where $\dot{h}$ is assumed constant. Generally the value of $\dot{h}$ used is that calculated for an altitude halfway between the initial and final altitudes.If large altitude changes are involved, the above equation can be used for several smaller increments in altitude and the results obtained using the above formulas are apended below.

Table 3: Range and Endurance for various Wingsuit Design

Wingsuit Design Type	Range (Km)	TOF (min)
Apache Wingsuit Nyberg [9]	12.466	17.63
Ansari [13]	11.27	5.38
Wingsuit Present Design	20.421	22.21

It is observed that the designed wingsuit in this study outperforms the wingsuit results available in the literature by a good margin. The range is increased by 8 km while the endurance has increased by 5 mins.

IX. Conclusion

The desire of human being to fly like a bird has always been an area of interest but a very limited research work exists in the open domain that can be said to be of conclusive nature to draw some lessons that can help researchers in designing high lift generating wingsuits. In the present study GoE 228 aerofoil was selected for designing the wingsuit as the same was found to be aerodynamically very effective in the research work carried out by Ferguson et al[16]. The wingsuit was designed such that it is feasible to manufacture the same and is of practical use to the skydivers. CFD analysis was carried out at velocity of 45 m/sec at various angles of attack till stall. The results so obtained were then compared with the data extracted from the existing literature. It was observed tht the proposed wingsuit performed extremely well and gave a C_L/C_D of 6.7 with range of 20.421 km and endurance of 22.21 minutes. This study paves the path for future researcher's in terms of effective design of the wingsuit and suitability of the design for manufacturing.

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In the New Spectrum of Space Law, Will Biden Favor the Moon Treaty?

By Dennis O'Brien

Introduction- The full spectrum of space law, from nationalist to internationalist, was on display at the Moon Village Association's annual symposium on November 8-9. But the question on everyone's mind was, what will be the effect of Joe Biden's election as the next President of the United States? He has already declared his intent to rejoin the Paris Climate Accords and the World Health Organization. A look at his Senate record gives us a hint concerning his space policy.

In 2007, the Convention on the Law of the Seas (CLOS) came before the United States Senate. The chair of the Foreign Relations Committee was then-Senator Joseph Biden."We should become a party to the convention," said Biden, just before the committee approved the treaty in October by a 17-4 vote."The oil and gas industry is unanimous in its support of the convention . . . I'm unaware of any ocean industry that has expressed opposition to this treaty." [1].

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Introduction

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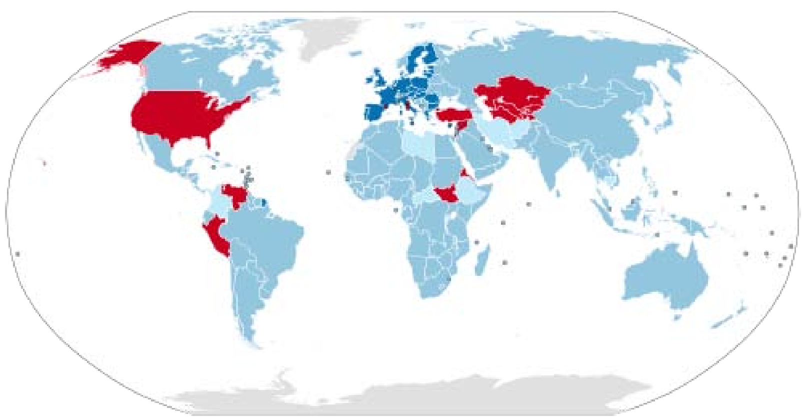
But the treaty was never ratified by the full Senate. Thirty-four Republican senators ultimately signed letters saying that they would never vote to ratify. Their main concern was language that described the seas as the "common heritage of mankind" and thus subject to international jurisdiction.[2] Since a two-thirds vote of approval (67 of 100) is required for ratification of any treaty, it was never brought up for a full vote. Since then, the CLOS has been ratified by 167 states (see map) and has become a pillar of customary international law. [3]



CLOS States Parties in blue, non-parties in red [3]

What can this tell us about how a President Biden will approach space law? A recent article in Time suggested that Biden would likely keep the Artemis Accords in place due to his belief in international agreements:

NASA recently announced the signing of the Artemis Accords, an international partnership to get to the moon, similar to the 15-nation consortium that built and maintains the ISS. In both cases, partner nations would provide hardware like habitation modules and cooperate to launch and maintain them. Biden spent no shortage of campaign-trail oxygen condemning Trump's flouting of international agreements like the Paris climate accord and the Iranian nuclear deal to make one of his first acts in office walking away from even a modest pact like Artemis. [4]

But that same continuity is not as certain when it comes to the Trump Executive Order of April 2020 that preceded the Accords and renounced the 1989 Moon Treaty:

> Sec. 2. The Moon Agreement. The United States is not a party to the Moon Agreement. Further, the United States does not consider the Moon Agreement to be an effective or necessary instrument to guide nation states regarding the promotion of commercial participation in the long-term exploration, scientific discovery, and use of the Moon, Mars, or other celestial bodies. Accordingly, the Secretary of State shall object to any attempt by any other state or international organization to treat the Moon Agreement as reflecting or otherwise expressing customary international law. [5]

It is not necessary to renounce the Moon Treaty in order to support the Artemis Accords, which are

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essentially an interagency agreement. Indeed, the Accords can be viewed as a partial implementation agreement, an evolution of adaptive governance as called for in Article 11 of the Moon Treaty:

> 11.1. The moon and its natural resources are the *common heritage of mankind*, which finds its expression in the provisions of this Agreement, in particular in paragraph 5 of this article. . . .
>
> 5. States Parties to this Agreement hereby undertake to establish an international regime, including appropriate procedures, *to govern the exploitation of the natural resources of the moon as such exploitation is about to become feasible*. This provision shall be implemented in accordance with Article 18 of this Agreement. . .*(emphasis added)*[6]

It is the use of the term "common heritage of mankind" and the perceived threat to national sovereignty that is the target of the Executive Order. It is the Executive Order that may well be the target of President-elect Biden.

The policies underlying the Trump Executive Order, the Artemis Accords, and the Moon Treaty are part of an emerging spectrum of space law agreements and proposals. At one end of the spectrum are the nationalists, such as the United States and Luxembourg, who believe that national law is adequate under a loose interpretation of Article II of the Outer Space Treaty, which prohibits national appropriation via claims of sovereignty or other means. [7] At the other end are the internationalists, like the Outer Space Institute [8] and the 18 countries that have adopted the Moon Treaty, who believe that a binding international agreement is needed. In the middle are those working on non-binding proposals/norms, sometimes called principles, building blocks, or best practices. These proposals are generally more comprehensive than national laws but lack the force of law or means of enforcement of international treaties. The most recent is the Best Practices for Sustainable Lunar Activity (BP's) by the Moon Village Association (MVA).

The Best Practices were presented November 9 at MVA's Annual Workshop &Symposium, hosted online this year by the Cyprus Space Exploration Organization.[9] Unlike the Artemis Accords, the BP's apply to all lunar actors, not just the contractors working for the Artemis-partnered space agencies. And, also unlike the Accords, the BP's support all private activities, including science and settlements, not just the extraction of materials (space mining). The Best Practices are currently undergoing international consultation and will be presented at the April 2021 meeting of the United Nations' Committee on the Peaceful Uses of Outer Space in Vienna; MVA is an official observer of COPUOS.

Mike Gold, the acting Assistant Administrator at NASA, spoke glowingly of MVA's efforts to develop broad Best Practices for lunar activity. He described the Artemis Accords as part of that process, an "implementation" of the responsibilities of the United States and its partners under the OST and the Registration Convention. He called for "peace and prosperity for all of humanity in outer space"; noted that "national and international institutions have not always been crafted with the private sector in mind, and need to evolve"; and concluded that "the world needs the hope, inspiration, and optimism that lunar exploration can deliver."Other plenary speakers noted the twin goals of "peace and sustainability" and asserted that "international cooperation in outer space will foster peace on Earth." [10]

A broader defense of the Artemis Accords was the focus of a video presentation by Michelle Hanlon, president of For All Moon kind. [11] The video, recorded before the U.S. election, started by noting a gap in the current framework space law - the lack of support for private activity, even as advances in technology make space resources attractive to private actors. The Artemis Accords, she explained, are an affirmation by eight countries that Article II of the Outer Space Treaty (the prohibition against appropriation/sovereignty) does not apply to the extraction of materials (space mining) by private actors, that such activity can proceed under national law. Like the Trump Executive Order, Professor Hanlon dismissed the Moon Treaty as "flawed". But even this full-throated defense of the nationalist model ended on an international note: If countries can agree on preserving cultural heritage sites on the Moon (which the Accords promote), it will open the door for agreement/cooperation in other areas.

At the other end of the spectrum was a video from The Space Treaty Project which argued that the Moon Treaty, with the proper implementation agreement, would provide hard-law international support all private activity (including science and settlements, not just the extraction of materials) while protecting essential public policies. [12] It does this by defining the "utilization of natural resources" in Article 11 of the Moon Treaty to include the use of land on the Moon for any private purpose, including science and settlements. In short, if a country adopts all five outer space treaties and requires its nationals to abide by their terms, then any private activity authorized and supervised by that country will be given priority rights for their lunar activity. There are also provisions for dispute resolution, choice of law, and cultural/historic preservation, a basic framework to allow humanity to begin using the Moon while leaving details for further evolution of "adaptive governance".

Most of the symposium was about returning to the Moon in general, focusing on technical and human/social topics. But two other presentations had legal implications. One applied antitrust law to lunar activity, asking if anticompetitive behavior is a form of "harmful interference". It also questioned the "safety zones" of the Artemis "club" and instead called for regulation of lunar activity via international agreement, including the monetary sharing of the benefits of outer space. [13] The other presentation asserted that the Artemis Accords were lacking in environmental stewardship for the Moon and beyond, that we might "destroy a Martian aquifer" if commercial activities were allowed to proceed without regulation. [14]

All of the videotaped presentations were produced prior to the U.S. election, so none reflected the new political reality or the apparent swing of the pendulum away from the nationalist model and toward the internationalist model. President-elect Joe Biden's support of the Convention on the Law of the Seas, with its use of the "common heritage of mankind", suggests that he will also support the Moon Treaty and its call for an international legal framework to support and regulate private activity on the Moon and beyond. It should be no surprise if he cancels the Trump Executive Order renouncing the Moon Treaty on his first day in office. Indeed, he might even sign the Moon Treaty itself and elevate its status in customary international law, even if 34 senators choose to block its formal ratification.

There is a new world for space law, both literally and figuratively. The Moon Village Association's annual symposium showcased many paths toward the future, from nationalist to internationalist, with their own Best Practices trying to move the effort forward. Humanity has reached a most pivotal moment as we prepare to become an interplanetary species.

(Dennis O'Brien is a space lawyer and president of The Space Treaty Project. The Project is an institutional member of the Moon Village Association; Mr. O'Brien is part of their Coordination & Cooperation working group, which produced the Best Practices for Sustainable Lunar Activities.)

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Airfoil Analysis and Effect of Wing Shape Optimization on Aerodynamic Parameters in a Steady Flight

By Vishu K. Oza & Hardik R. Vala
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Keywords: *airfoil, boundary layer, CFD, wing, optimization, (L/D).*

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AIRFOILANALYSISANDEFFECTOFWINGSHAPEOPTIMIZATIONONAERODYNAMICPARAMETERSINASTEADYFLIGHT

Strictly as per the compliance and regulations of:

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Vishu K. Oza [α] & Hardik R. Vala [σ]

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I. Introduction

The aerodynamic performance of an aerial vehicle is governed by ample factors, including the main components of aircraft; however, the wing is a primary unit for driving performance in a favorable direction. The wing design should be such that it should be preferable for desired lift production at a given altitude. 'Drag' is a key aerodynamic parameter to be considered, and so it should be as minimum as possible to retain the flight condition and to keep the flow environment undisturbed. The Lift to Drag (L/D) ratio of an aircraft signifies how efficient the design of an aircraft is and which will tend to deliver lift at low drag with better performance.

The intention here is to elevate the (L/D) ratio of an aircraft at the expense of the wing's makeover and thereby re-framing the module's geometry. For this purpose, a UCAV model of General Atomics MQ-1B Predator is chosen [1].

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Table 1: MQ-1B Predator specifications

W	1020 kg (10006.2 N)
b	16.84 m
c_r	1.0972 m
c_t	0.396 m
λ (c_t/c_r)	0.360 m
MAC	0.801 m
S_{ref}	11.75 m^2
AR	23.63
Λ_{LE}	2 degrees
h	7620 m

The root section of the wing has Drela GW 19 airfoil, and the tip section has GW 27 airfoil developed by Professor Mark Drela from MIT. Airfoil GW 19 [2] and GW 27 [2] have a highly cambered upper surface for lift generation at high velocities in the subsonic regions.

The wing's performance is examined at an altitude of 3000m under the International Standard atmosphere (I.S.A.) [3], where temperature, pressure, and density are T = 268.7 K, p = 70.1 kPa, and ρ = 0.909 kg/m^3, respectively. With kinematic viscosity of *v* = 1.95x10^{-5} m^2/s, and assuming cruise velocity of 45 m/s and by MAC of 0.801 m, gives Reynolds Number of 1671678 (means turbulent flow nature). With speed of sound at 3000 m, *a* = 328.6 m/s, Mach number is M = 0.136.

a) 2-D Airfoil analysis

The aerodynamic behavior of all airfoils is analyzed in XFLR5 software, which uses preinstalled codes of XFOIL. Ibrahim Halil Guzelbey et al.[4], their paper of 2018 deals with comparing experimental wind tunnel data with XFLR5's generated one for airfoils. The work of Popelka Lukas et al [5]. shows behavior of various airfoils for a sailplane studied in XFLR5 software. Additionally, the flow transition prediction on a 3D wing was also made using the same software. In the present paper, 2-D airfoil analysis has been performed to determine the nature of GW 19, GW 27, and NACA 2315 (it is modified from the conventional NACA 2412 airfoil, by changing the position of its maximum camber and maximum thickness [6]) airfoils from -10 to 30-degree angle of attack (α) at proposed flight condition. From Figure 1. of generated polar, it is clear that the lift coefficient of NACA 2315 is quite less in a low range of angles while drag coefficient is moderately lesser than both GW airfoils. From graph polar for GW19, Cl_{max} is 1.762 at 20 degrees. While a sharp stall after 16 degrees is seen for the new NACA 2315 airfoil, giving out Cl_{max} of 1.563. So, the estimated stall velocity is 34.26 m/s.

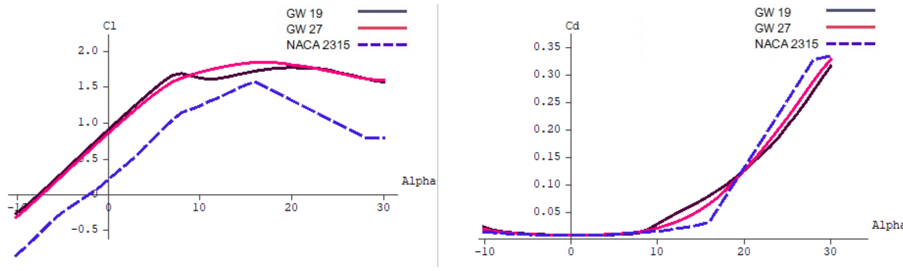

Figure 1: Comparison of Lift and Drag coefficients for airfoils

Furthermore, 2D steady flow analysis has been done in StarCCM+ software, which sets Reynolds Averaged Navier Stokes (RANS) equations, which are used to define turbulent flow by giving approximate solutions. Manuel J. Garcia, Pierre Boulanger, and Santiago Giraldo [7] have worked on aerodynamic profiles optimized with gradient methods. Additionally, the k-epsilon model of turbulence, with Navier Stokes equations, is used for CFD simulations. Jörg Schminder [8], in his thesis, imposed RANS for the computational study of hornet aircraft. To note that, for the shear stress model, k-epsilon was used as k-omega is more sensible to streamlined flow. From the work of Junling Hu, Xingguo Xiong, and Linfeng Zhang, it was seen that the Spalart Allmaras model was not used because of the airfoil's highly cambered surface [9]. Lucas Popelka et al. [10], suitability of the k-epsilon model is well underlined as the flow involves rotation and adverse pressure gradients in a boundary layer. To acknowledge the flow fields, which are shown in Figure 2. And Figure 3, 11131 cells were created by defining the wake refinement length of 3.5 m.

Table 2: Physical model assignation for CFD analysis

Fluid type	Gas
Flow type	Segregated flow
Viscous regime	Turbulent
Shear Stress Transport model	k - epsilon turbulence
Reference pressure	70.10 kPa
Reference velocity	45 m/s
Reference density	0.909 kg/m^3
Domain inlet	Velocity inlet
Domain outlet	Pressure outlet

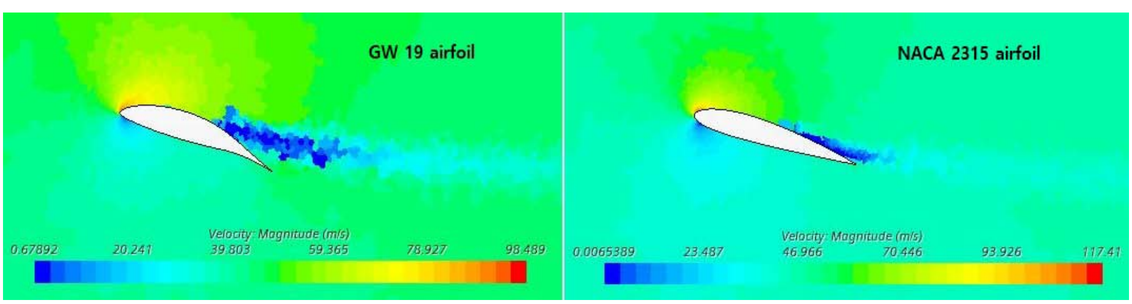

Figure 2: Velocity field at stall angles

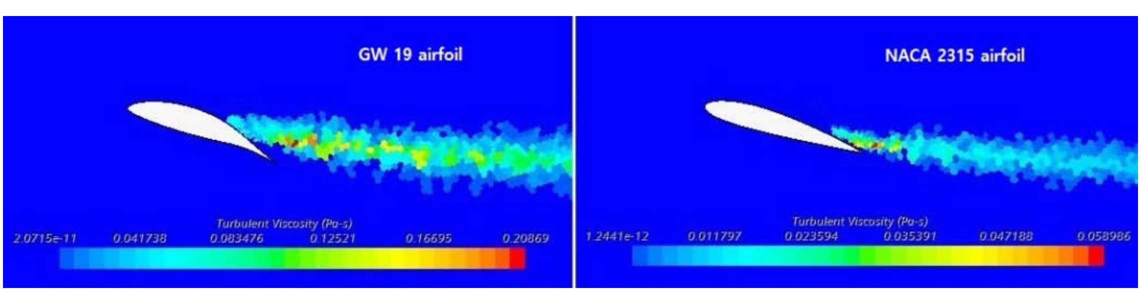

Figure 3: Turbulent viscosity at stall angles

Figure 2 and Figure 3 depict the flow separation phenomena over the airfoils at their respective stall angles. At some point, when flow separates (making velocity negative) on an airfoil, inside a formed bubble, the flow goes turbulent, progressing further, flow again reattaches, making velocity positive and leaving the trailing edge wakes.

Consider a small elemental strip of thickness 'dy' at y distance from the surface of a plate, and at a thickness δ, where fluid velocity 'u' (which is a function of x and y direction at any section) is 99 percent of free stream velocity 'u_∞', where δ is Boundary layer thickness.

In a boundary layer problem, the velocity field is used as an input, which does not converge, as boundary layer disturbs the inviscid flow, and airfoil acts as it has an additional thickness δ^*, called "Displacement thickness" [11], which is represented as,

$$\delta^* = \int_0^\delta \left(1 - \frac{u}{u_\infty}\right) dy \qquad (1)$$

Additionally, a flow layer, for which the momentum flux is equal to the deficit for the same thru boundary layer, is called Momentum thickness θ [11],

$$\theta = \int_0^\delta \frac{u}{u_\infty}\left(1 - \frac{u}{u_\infty}\right) dy \qquad (2)$$

The software uses the Interactive boundary layer solver, having an integral turbulence model created by Professor T. Cebeci [12].

Assumptions for boundary layer analysis are,

1. Sharp velocity gradients are smoothed at trailing edge from inviscid analysis before boundary layer analysis as fluid nature at trailing edge is not reliably predicted by inviscid analysis due to Kutta condition [11].
2. Turbulence is forced at separation, as the transition is always induced by it.

The variation of $\delta^*$and θ with chord length (X) of 1 m is shown in Figure 4. for GW19 and NACA 2315, at planned condition.

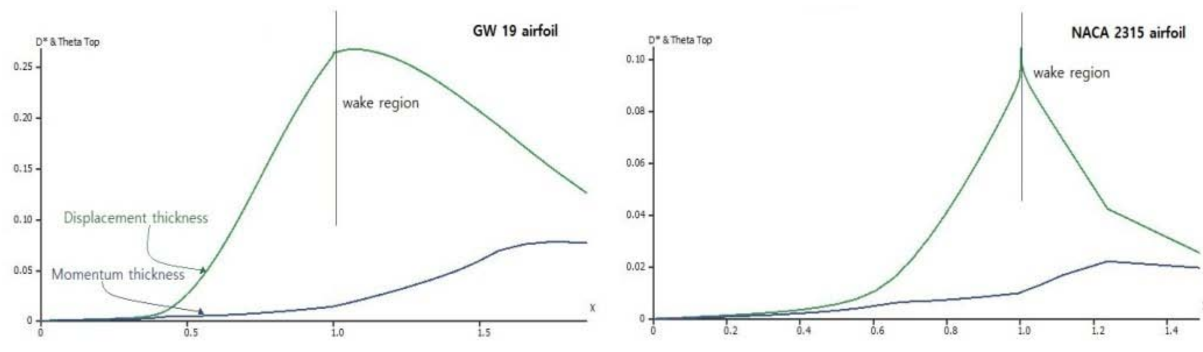

Figure 4: Variation in Displacement and Momentum thickness

From Interactive boundary layer analysis, the top flow transition for GW 19 and NACA 2315 airfoil is predicted as

Table 3: For GW 19 airfoil

Flow nature	chord location(m)
Laminar to turbulent	0.645
Laminar separation	0.645
Turbulent separation	0.656

Table 4: For NACA 2315 airfoil

Flow nature	chord location(m)
Laminar to turbulent	0.487
Laminar separation	0.487
Turbulent separation	1.04

From values in Table 3., and Table 4., it is seen that flow is getting turbulent on GW 19's top surface at 0.64 m of length and wakes are formed at 0.656 after turbulent flow separation. However, the transition is a little ahead in NACA 2315's top surface, and turbulent flow is separated at 1.04 m of the chord length, which means the boundary layer is maintained on the top surface.

The software uses the e^N method for boundary layer transition prediction, which is a free transition method, where the N_{crit} value has to be defined for flow's changeover. The e^N, with an amplification factor (N), operates as growing Tollmien-Schlichting waves, J.L van Ingen [13]. For an average experimental wind tunnel, the default N_{crit} is 9, which is pre-setted in XFLR5 from 2-D boundary layer analysis. Again, as seen in the airfoil's coefficient of pressure (C_p) plot and plot of edge velocity against chord length, the laminar separation for GW 19 is before the NACA 2315 airfoil, as seen in Figure 5. and Figure 6. respectively.

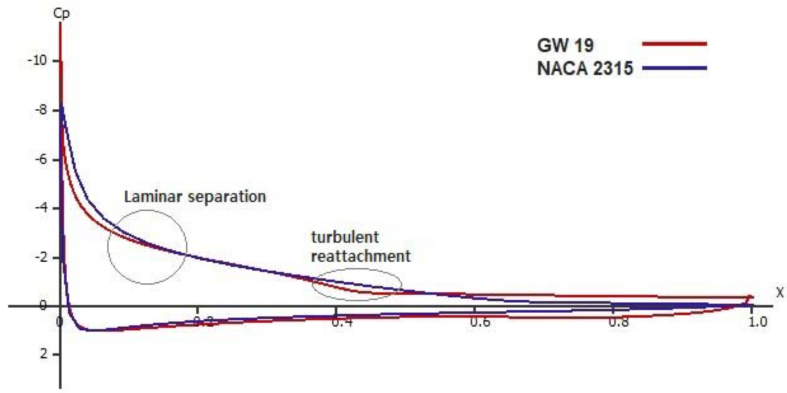

Figure 5: Variation in pressure coefficients at stall angle

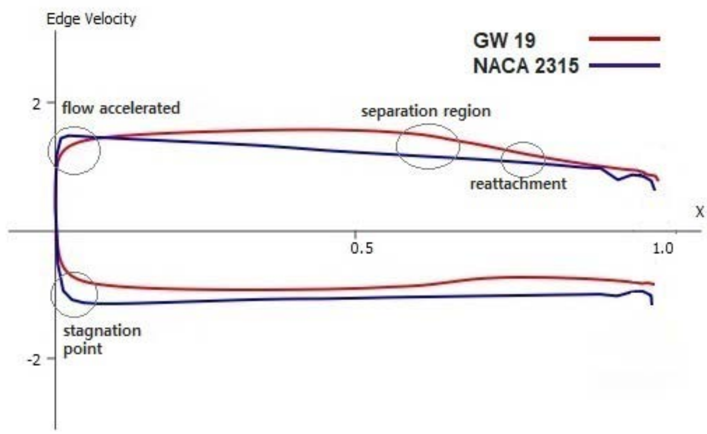

Figure 6: Variation in edge velocity at stall angles

II. Wing Design and Analysis

For new construction with load distribution sectionally, the wing is divided into four sections. For the lower bending moments, the load should concentrate at the root. The configuration has been kept the same as mid-wing. Wing sweep is generally provided in transonic aircraft for delaying the wave drag, it also improves static lateral stability and moderately reduces dynamic pressure, and so is given, M. Sadraey [14].

From the work of Boitumelo Makgantai et al. [15], winglets can be implemented for reducing induced drag and increasing (L/D) ratio.

The wing is not twisted in any of the four sections. For directional stability, dihedral is provided in section three as well as section two. Detailed dimensions of the wing are provided below, having NACA 2315 airfoil at all four sections.

Table 5: Detailed dimensions of the new wing

Wing section	Span position(m)	Chord (m)	Sweepback (degree)	Dihedral (degree)
1	0.385	0.865	3.5	0
2	5.80	0.64	8	7
3	8.50	0.401	35	40
4	10	0.120	0	0

a) 3-D analysis approach

Starting with Navier Stokes equation, for solving the greater part of the complexity, by assumption of time-dependent incompressible flow, gives out Laplace equation ($\nabla^2\phi = 0$). On computation via time-averaged turbulence, which derives the Reynolds equation, is comprised in RANS solver.

For analysis in XFLR5, the Laplace equation is solved, satisfying the given boundary condition. Boundary conditions taken into account are of Dirichlet or Neumann type. Of mathematical type, the Dirichlet boundary condition specifies the value of a potential function at a specific location. While Neumann boundary condition specifies the value of the gradient of potential function on surface, $\nabla\phi = \overrightarrow{V_0}$ (which is a velocity vector). XFLR5 interpolates viscous results from XFOIL and reintroduces them in the 3-D inviscid solution.

Vortex Lattice Method (VLM), having many vortices in panels, is fitted with Neumann boundary condition. The approach to this method comprises of one ring vortex present on each meshed region on a point. VLM models the disturbance formed on a wing, by summation of vortices, and the strength of a single vortex is examined by an imposed boundary condition. VLM is selected for current analysis because the flow is considered inviscid and potential, Chethan R. Patil et al. [16], and additionally only induced drag can be measured, A. Septiyana et al. [17]. Oliviu Sugar Gabor et al. [18] preferred XFLR5 to compare the aerodynamic characteristics of a wing with the non-linear VLM method and experimental's. Even it can be used for stall prediction, Hasier Goitia, Raúl Llamas [19].

Cian Conlan-Smith et al. [20] have implemented panel methods for wing's analytical study and it is stated that the use of quad panels is not preferable because just three points are taken for plane definition as the quad panel may not cover a 3-D curved surface completely. In the Triangular panel method, each quad panel is replaced by two triangles of uniform density. Then, the wing surface can be treated as a thin sheet, and this method involves solving meshed triangular surface integrals on it, along with the defined boundary condition.

Before the wing's analysis in XFLR5, Parasite Drag acting on the wetted area is taken into account, using OpenVSP software. The flow solver in OpenVSP is based on VLM, Ilias Lappas, and Akira Ikenaga [21]. The usage of OpenVSP software for computing aircraft Cessna's model is noted in work by Marine Segui and Ruxandra Mihaela Botez [22]. Andrew S. Hahn [23] had depicted the suitability of the OpenVSP software for complex parameterized geometries like fuselage and fairings. Additionally, any kind of complex wing geometry, having multi-sections with different airfoils, can be easily modeled in OpenVSP, William J. Fredericks [24].

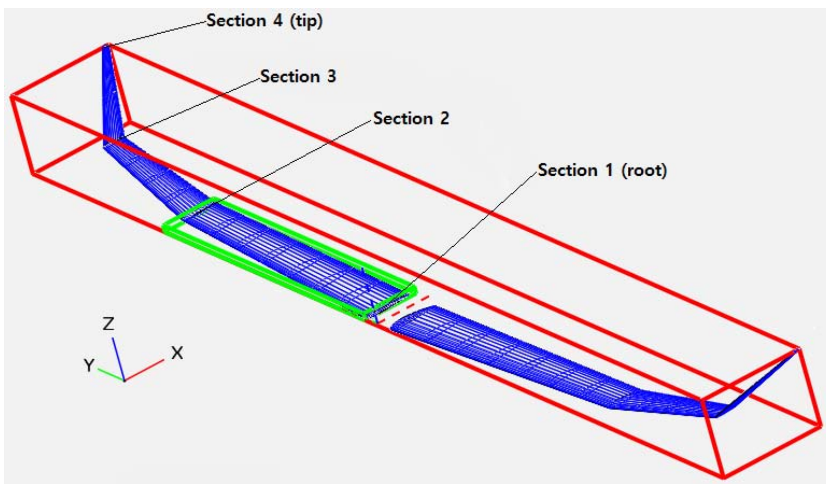

Figure 7: CAD model of new wing created in OpenVSP

The viscous drag coefficient is difficult to predict by numerical methods and is based on experimental data and is generally taken 0.005 for vehicles flying at Reynolds number more than 200000. Here, the surface roughness of the upper surface of the wing is assumed to be uniform.

For calculating, net viscous drag coefficient on net wetted area, equations selected for skin friction coefficients [25] are,

1. Laminar skin friction coefficient: Blasius equation

$$C_f = \frac{1.32824}{\sqrt{Re}} = 0.00102 \qquad (3)$$

2. Turbulent skin friction coefficient: Power Law High Reynolds Number

$$C_f = \frac{0.0725}{Re^{(1/5)}} = 0.00412 \qquad (4)$$

Ohad Gur et al.[26], for estimating skin friction drag, Torenbeek's and Hoerner's equation for Form Factor (FF) have been taken into consideration, as both are the function of airfoil's thickness to chord (t/c) ratio.

Form Factor (FF) equation: Average (t/c) for NACA 2315 is 0.14009, so with the Hoerner equation,

$$FF = 1 + 2\left(\frac{t}{c}\right) + 60\left(\frac{t}{c}\right)^4 = 1.33 \qquad (5)$$

The reference area for the new wing is $S_{ref} = 11.75\ m^2$, wetted area $S_{wet} = 24.24\ m^2$ and $C_{Do} = 0.01118$, Equivalent viscous drag coefficient can be calculated following equation [26],

$$C_{fe} = FF \times C_{Do} \times \left(\frac{S_{ref}}{S_{wet}}\right) = 0.0071 \qquad (6)$$

The value of C_{fe}, if FF is not taken into consideration, is near to one of the single-engine light aircraft (0.0055), as seen in the work by Abderrahmane Badis[27]. With $\mathrm{AR} = 34$, XFLR5's (by VLM) generated $C_L = 0.54$, induced drag coefficient $C_{Di} = 0.0054$, and assuming the span efficiency e = 0.5, the total drag coefficient is given as [28],

$$C_D = C_{Do} + \left(\frac{C_L^{\,2}}{\pi\ \mathrm{AR}\ e}\right) = 0.0165 \tag{7}$$

So, Lift to Drag ratio (L/D) = (C_L/C_D) = 32.7.

III. Wing Optimization

Optimization is either minimizing or maximizing the objective function. Here Covariance Matrix Adaptation Evolution Strategy (CMA-ES) is implemented for the intended purpose. It involves generating the finite solutions, then evaluating them and selecting accurate one of them, and reproducing the next set of finite solutions until iterations are terminated. The solution which is generated optimum from both sets of iterations is considered as an optimum solution. In the thesis work of Matthieu Parenteau [29], the design variables are manipulated for better performance requirements, by using the CMA-ES algorithm.

Wing shape optimization

Objective function = Maximize: (L/D)

Maximize: $f = L/D(x)\ ;\ i = 1 \text{ to } 100$

Total design variables = 12

Table 6: Selected design variables

Sr. No	Design Variable	Base value	Lower bound	Upper bound	Units
1	Span position (1st section)	0.385	0.32	0.42	m
2	Span position (2nd section)	5.8	5.4	6	m
3	Span position (3rd section)	8.5	8.3	8.7	m
4	Span position (4th section)	10	9.7	10.3	m
5	Chord (1st section)	0.860	0.8	0.9	m
6	Chord (2nd section)	0.64	0.5	0.7	m
7	Chord (3rd section)	0.401	0.3	0.5	m
8	Chord (4th section)	0.12	0.1	0.4	m
9	Sweepback (1st section)	3.5	2	4	degree
10	Sweepback (2nd section)	8	6	10	degree
11	Dihedral (2nd section)	7	6.8	9	degree
12	Dihedral (3rd section)	40	39	41	degree

Table 7: Optimum dimensions after 100 iterations

Wing section	Span position(m)	Chord (m)	Sweepback (degree)	Dihedral (degree)
1	0.355	0.8	4	0
2	5.903	0.546	8.366	6.8
3	8.602	0.388	35	40.757
4	10.202	0.1	0	0

The optimized NACA 2315 wing is analyzed at the same flight condition at α = 2.5 degrees, with wingspan $b = 20.4\ \mathrm{m}$, $S_{ref} = 10.77\ \mathrm{m}^2$, and $\mathrm{AR} = 38.64$. Higher the AR, lower will be the induced drag (coefficient). Again, the parasite drag coefficient is calculated in OpenVSP by following the same steps. With wetted area $S_{wet} = 22.21\ \mathrm{m}^2$, the parasite drag coefficient acting is $C_{Do} = 0.01143$.

Following is the detailed analysis for an initial wing and optimized wing, done by both VLM and Panel methods.

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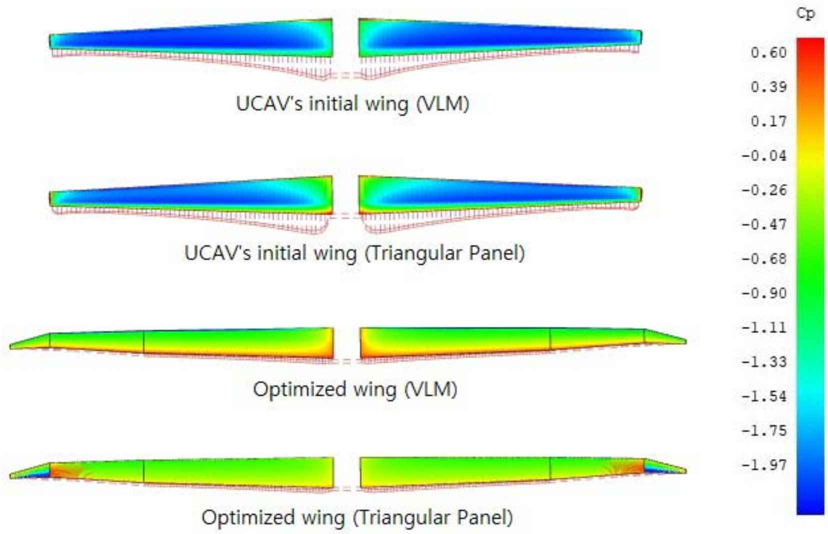

Figure 8: Variation in pressure distribution on the upper surface of the initial wing and optimized wing by both methods

Table 8: Aerodynamic coefficients for initial wing

Method	C_L	C_{Di}	C_{Do}	C_D	C_{fe}	(C_L/C_D)
VLM (Neumann)	0.600	0.0097	0.0119	0.0216	0.0072	27.77
Panel (Dirichlet)	0.612	0.010	0.0119	0.0219	0.0072	27.94

Table 9: Aerodynamic coefficients for optimized wing

Method	C_L	C_{Di}	C_{Do}	C_D	C_{fe}	(C_L/C_D)
VLM (Neumann)	0.55	0.0049	0.0114	0.0163	0.0071	33.74
Panel (Dirichlet)	0.581	0.0055	0.0114	0.0169	0.0071	34.37

IV. Results and Discussion

From Figure 9 It can be seen that the initial wing has elliptical lift distribution, not completely, due to span efficiency is less than 1. The maximum C_L is at the midspan and drastically decreases approaching the tip, as vortices are formed. While, for the optimized wing, the distribution remains near-uniform from mid-span and at tip section, it is maintained as induced drag is minimized. Also, from the results by VLM analysis, C_L is little more than at tip section, like that of the Triangular panel method analysis.

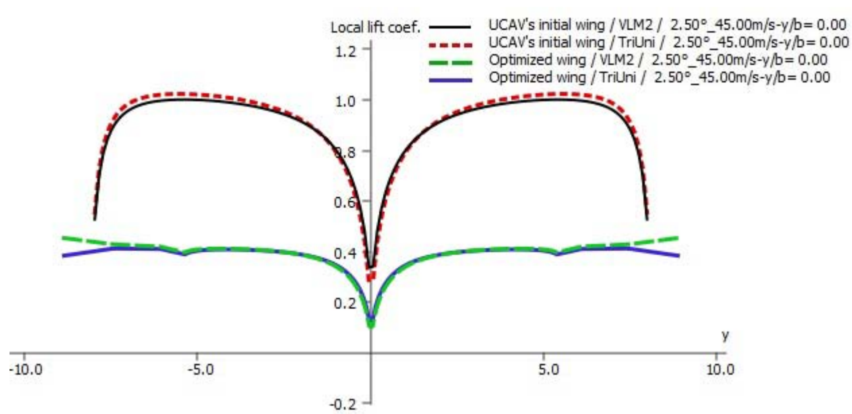

Figure 9: Lift distribution along the wingspan

From Figure 10, the total drag acting at the wing-fuselage section, is substantially decreased for the optimized wing design. By analysis of the VLM method, for the initial wing, the total drag coefficient, comprised of induced drag coefficient, is more at the wing tip section. Induced drag, being a function to total drag, is very much minimized because of near approximate constant elliptical lift distribution in optimized wing design [30] (but indeed not necessary to have provided a twist in airfoil or wing geometry), as seen in Figure 9. However, the total drag coefficient is maintained low over the entire wingspan, and near tip section, by installing winglets, total C_D has highly reduced.

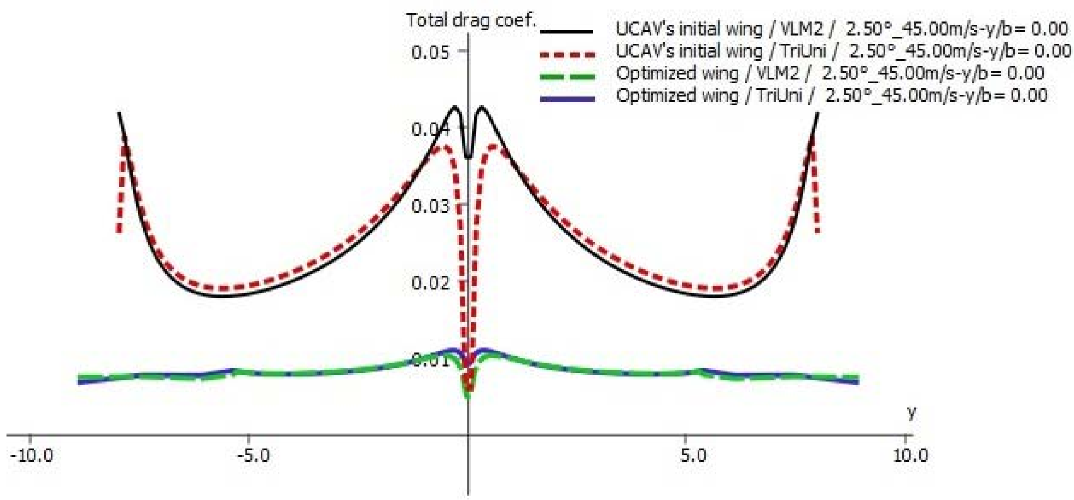

Figure 10: Variation in total drag coefficient along the span

The intention of dividing optimized wing into sections is seen in Figure 11, as the Bending moment of the final wing at the root section, following towards the tip section, is observed as being minimized. Because of the dihedral provided, at sections two as well as three, the Bending moment had gradually decreased from root to tip section as compared to the analysis of the initial wing.

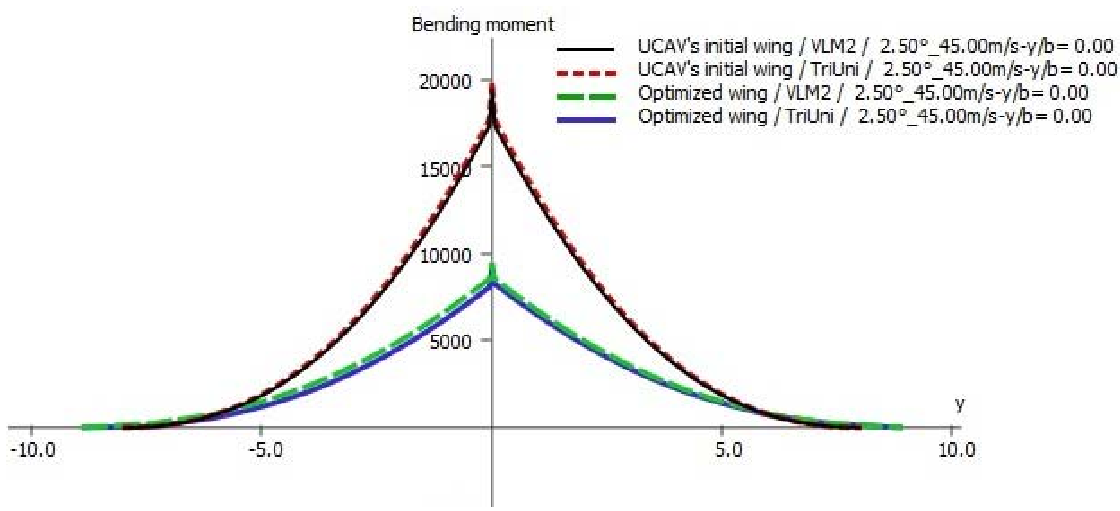

Figure 11: Variation in Bending moment along the wingspan

The airfoil used in the new wing design, for which the boundary layer analysis was done, had delayed the boundary layer separation on the top surface. For 3D wing analysis, the percentage flow transition to turbulent flow for the new wing is less than that of the initial wing. Additionally, moving towards the tip section, as seen in Figure 12, the flow curve is linear as the majority of the vortex shedding had lowered due to the use of winglets.

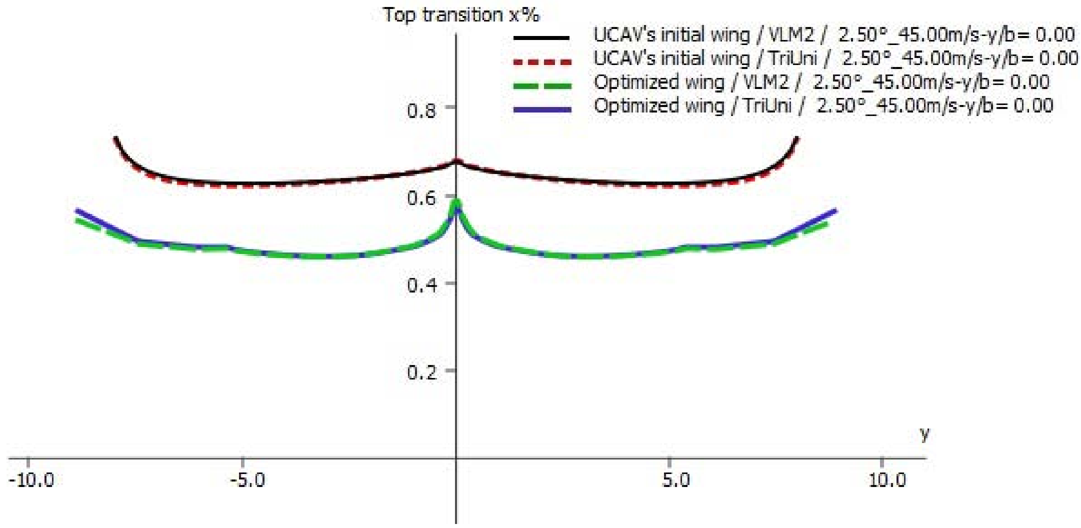

Figure 12: Variation in top flow transition

On the other side, once the C_L and C_D at any particular velocity are obtained, then the product of that velocity and Required Thrust will help in determining the Power required P_{req} as [28],

$$P_{req} = T_{req} \times v = \frac{W}{(\frac{C_L}{C_D})} \times \sqrt{\frac{2W}{\rho \times S_{ref} \times C_L}}$$

$$\text{So}, P_{req} = \sqrt{\frac{2 \times W^3 \times C_D^2}{\rho \times S_{ref} \times C_L^3}} \text{ kW} \tag{8}$$

Considering the UCAV's gross weight constant, at 2.5 degrees, the P_{req} with UCAV's initial wing (by considering the analysis of VLM) comes out to be 19.9 kW, and considering the same method, the optimized wing is 18 kW. So, with an increase in (L/D) ratio, as the total lift and drag coefficients are impacted, about 1.9 kW of power is saved with optimized wing design, and that is economical [31].

V. Conclusion

To elevate the (L/D) ratio of a UCAV, prominent attention has to be given to the design of an airfoil, as its curve is the driving element for desirable flow conditions. In the present work, the airfoil performance of NACA 2315 airfoil, which was designed by modifying the parameters from conventional NACA 2412 airfoil, had proven effective. The Drela GW 19 and GW 27, being high Reynolds Number airfoils, are originally implemented in UCAV MQ-1B Predator's wing design. However, NACA 2315 airfoil can also be used in medium-speed subsonic flight.

For 3-D wing performance, some factors accounted for the steady flight, had proven efficient. Again, the Aspect ratio, which was increased, and the provision of winglets, were two of the weighted governing parameters for reducing the induced and total drag. The optimization results came out to be advantageous, as it did not only reduced total drag but also lowered the wing bending moment and made the wing structurally better.

For future work, how the internal deformation occurs by changing the wing's external topology can be examined so the ribs and spars arrangement can be revised again with a viewpoint of the wing's weight reduction. Furthermore, a complete stability analysis can be performed by introducing the horizontal and vertical stabilizers and their components, making the design of the whole UCAV better statically and dynamically stable.

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Notations

kg = kilogram
N = Newton
kW = kilowatt
m = metre
T = temperature
K = Kelvin
p = pressure
kPa = kilopascal
v = velocity
ρ = density
v = kinematic viscosity
Re = Reynolds Number
a = Speed of sound
M = Mach Number
α = Angle of attack
W = Gross take-off weight
b = Wingspan
S_{ref} = Wing reference area
AR = Aspect ratio
c_r = Root chord
c_t = Tip chord
λ = Taper ratio
MAC = Mean aerodynamic chord
S_{wet} = Wetted area
Λ_{LE} = Leading edge sweep
H = Ceiling height
C_L = Coefficient of lift
Cl_{max} = Maximum coefficient of lift
C_{D0} = Parasite drag coefficient
C_{Di} = Induced drag coefficient
C_D = Total drag coefficient
C_p = Coefficient of pressure
C_f = Skin friction coefficient
C_{fe} = Equivalent skin friction coefficient
δ = Boundary layer thickness
δ^*, d^* = Displacement thickness
θ, theta = Momentum thickness
u = flow velocity
u_∞ = free stream velocity
X = chord length in x-direction
∇ = Laplace operator
ϕ = Potential function
$\overrightarrow{V_0}$ = Velocity vector
e = Span efficiency
FF = Form Factor
T_{req} = Thrust Required
P_{req} = Power Required

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Appealing Decisions

Unless specified in the notification, the Editorial Board's decision on publication of the paper is final and cannot be appealed before making the major change in the manuscript.

Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

Declaration of funding sources

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Preparing your Manuscript

Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.
22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.
23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- o Explain the value (significance) of the study.
- o Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- o Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- o Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- o Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- o In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- o Present a background, such as by describing the question that was addressed by creation of an exacting study.
- o Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- o Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- o Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- o Do not include raw data or intermediate calculations in a research manuscript.
- o Do not present similar data more than once.
- o A manuscript should complement any figures or tables, not duplicate information.
- o Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- o You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- o Give details of all of your remarks as much as possible, focusing on mechanisms.
- o Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- o One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- o Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

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Criterion for Grading a Research Paper (Compilation) by Global Journals

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

Index

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