MINISTRY OF EDUCATION

Aviation and Aerospace Engineering

for Senior High Schools

TEACHER MANUAL

YEAR TWO

NATIONAL COUNCIL FOR CURRICULUM & ASSESSMENT OF MINISTRY OF EDUCATION

MINISTRY OF EDUCATION

REPUBLIC OF GHANA

Aviation and Aerospace Engineering

for Senior High Schools

Teacher Manual

Year Two

NATIONAL COUNCIL FOR CURRICULUM & ASSESSMENT OF MINISTRY OF EDUCATION

AVIATION AND AEROSPACE ENGINEERING TEACHER MANUAL

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Introduction

The National Council for Curriculum and Assessment (NaCCA) has developed a new Senior High School (SHS) curriculum which aims to ensure that all learners achieve their potential by equipping them with 21st Century skills, competencies, character qualities and shared Ghanaian values. This will prepare learners to live a responsible adult life, further their education and enter the world of work.

This is the first time that Ghana has developed an SHS Curriculum which focuses on national values, attempting to educate a generation of Ghanaian youth who are proud of our country and can contribute effectively to its development.

This Teacher Manual for Aviation and Aerospace Engineering is a single reference document which covers all aspects of the content, pedagogy, teaching and learning resources and assessment required to effectively teach Year Two of the new curriculum. It contains information for all 24 weeks of Year Two including the nine key assessments required for the Student Transcript Portal (STP).

Thank you for your continued efforts in teaching our children to become responsible citizens.

It is our belief that, if implemented effectively, this new curriculum will go a long way to transforming our Senior High Schools and developing Ghana so that we become a proud, prosperous and values-driven nation where our people are our greatest national asset.

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SECTION 1: CLIMATOLOGY

Strand: Core Concepts in Aerospace Engineering

Sub-Strand: Aerodynamics and Propulsion

Learning Outcome: *Explain the importance of weather in flight*

Content Standard: Discuss the properties of the International Standard Atmosphere

Hint

- *Assign Group Project Work in Week 2. See Appendix A which has been provided at the end of this section detailing the structure of the group project. The group project will be submitted in Week 8.*
- *Assign learners their Portfolios by Week 3. Refer to Appendix B at the end of the section for further guidance.*

INTRODUCTION AND SECTION SUMMARY

In this section, learners are introduced to weather and its effect on flight, the elements for defining weather, weather measuring instruments and the International Standard Atmosphere. The section focuses on the various layers of the atmosphere and how the elements of weather affect flight operations and safety protocols. This section also contains case studies of certain aviation accidents that occurred due to adverse weather conditions. Learners are expected to become familiar with the impact of weather elements on aviation operations and safety. This section also highlights the role of meteorologists and agencies like the Ghana Meteorological Agency in providing accurate weather forecasts for the Ghana Civil Aviation Authority.

The weeks covered by the section are:

Week 1: Climate, Weather and Weather Elements

Week 2: Weather Measuring Instruments

Week 3: The International Standard Atmosphere

SUMMARY OF PEDAGOGICAL EXEMPLARS

In teaching weather and its impact on air travel, teachers must engage learners in hands-on real-world activities that encourage critical thinking, innovation and problem-solving. By this, teachers are encouraged to make use of innovative pedagogies such as experiential learning approaches (e.g. case studies, research, portfolio building), talk-for-learning approaches and project-based learning that provides adequate experience and exposure to the topic being discussed. In applying the above stated pedagogies, group activities are encouraged. Learners' characteristics, needs and abilities are also to be considered. All in all, after facilitation, the formative and summative assessment must align with the relevant pedagogies used.

ASSESSMENT SUMMARY

Assessing learners' understanding of the effects of weather on flight requires learners to share ideas on the everyday weather conditions that they know and how it affects human life and properties. Based on the foregoing, formative assessment should be emphasised with innovative strategies such as research, case studies, PowerPoint presentations, group project and portfolio building on weather and its impact on air travel. During the assessment, emphasis needs to be placed on learners investigating issues of weather on their own and sharing the ideas with their friends. Diverse characteristics and needs of learners are to be taken into consideration.

A variety of assessment modes should be implemented to evaluate learners' understanding and performance in the concepts covered in this section. It is essential for teachers to conduct these assessments regularly to track students' progress effectively. You are encouraged to administer the recommended assessments each week, carefully record the results, and submit them to the **Student Transcript Portal (STP)** for documentation. The assessments are:

Week 1: *Homework*

Week 2: *Essay*

Week 3: *e-Assessment*

Refer to the "***Hint"*** at the key assessment for each week for additional information on how to effectively administer these assessment modes. Always remember to score learners' work with rubric/marking scheme and provide prompt feedback to learners on their performance.

WEEK 1: CLIMATE, WEATHER AND WEATHER ELEMENTS

Learning Indicator: *Identify and measure the elements of weather using the appropriate instruments.*

FOCAL AREA: WEATHER AND ITS DEFINING ELEMENTS

Introduction to Weather and Climate

The atmosphere refers to the layer of air surrounding the surface of the earth. Due to the certain factors like the heating of the earth's surface by the sun, the rotation and revolution of the earth and Earth's geographical features (like landforms and water bodies), the condition of the atmosphere varies.

Weather refers to the state of the atmosphere over a brief period of time. Climate on the other hand, deals the average atmospheric state observed over a long period of time, usually spanning twenty to thirty years. Weather and climate deal with the same thing with the only major difference being the time frame within which they are observed. Weather conditions in a geographical location can change very quickly. Climate on the other hand changes very slowly and these changes can only be observed by collecting and analysing weather data for two or three decades.

Elements of Weather

The elements of weather refer to the observable or measurable physical features of weather. They are basically used to describe the weather conditions in a geographical area. Below are the major weather elements.

1. **Temperature:** This refers to how hot or cold the ambient atmosphere is. It is the amount of kinetic energy present within the air molecules which we feel on our skin as hotness or coldness. The higher the kinetic energy, the more the air molecules move and the higher the temperature. The instrument used for measuring temperature is called a thermometer.
2. **Precipitation:** Water covers about seventy percent of the Earth's surface. As radiation from the sun enters the Earth's atmosphere, it heats up the Earth's surface, atmosphere and waterbodies. The water vaporises upon being heated. As it rises, it cools and condenses to form clouds. When these clouds become too heavy to remain suspended in air, they fall back down to the earth in the form of rain, snow, hail, drizzle or sleet. These different means through which condensed water falls back to the earth is termed precipitation. The instrument used to measure rainfall is called a rain gauge.
3. **Atmospheric pressure:** Atmospheric pressure is the pressure created by the weight of the air in the atmosphere. The air is composed of nitrogen, oxygen, carbon dioxide, water vapour, argon and other gases. Though not easily perceived, these gases all have weight because they are matter. This weight exerts pressure within the Earth's atmosphere. Atmospheric pressure is measured with an instrument called a barometer.

Figure 1: *An analog barometer*

Figure 2: *A digital instrument showing air pressure, temperature and relative humidity data*

4. **Humidity:** This defines the amount of water vapour present in the atmosphere. Water vapour simply is water in a gaseous state. The instrument for measuring relative humidity is hygrometer.

Figure 3: *A hygrometer.*

5. **Wind:** Wind is the movement of a large mass of air from one place to another. Due to the uneven heating of the Earth by the Sun, there are variations in air pressure across the Earth's surface. This creates regions of high atmospheric pressure and regions of low atmospheric pressure. This pressure gradient (that is, difference in pressure) causes the air to move from the regions of high atmospheric pressure to the regions of low atmospheric pressure. This movement of the air in large volumes is what we experience as wind. Depending on the pressure gradient and the locations of the regions of high and low pressures, the speed and direction of wind may vary. The instrument for measuring wind speed is called an anemometer and the direction of wind is indicated by a wind vane.

Figure 4: *A digital anemometer*

Figure 5: *A wind vane*

6. **Visibility:** This is an indication of how clearly an object can be seen at a distance. It is very important in the aviation industry and has been a cause of many incidents and fatal accidents. It is particularly important when fog, haze, mist and freezing drizzle are present.
7. **Cloud cover:** Clouds are condensed water vapour suspended above the ground. They give an easy indication of weather conditions and also play important roles in forecast. For example, when you observe low dark and heavy clouds, it is logical to conclude that there is a high probability that it would rain.
8. **Sunshine:** Sunshine is the radiation we receive from the sun. It provides visible light and heat to warm up our planet. Sunshine is one of the major drivers of weather and consequently climate. The temperature of a geographical location is usually as a direct result of the intensity and duration of sunshine the region receives.

Figure 6: *Sunshine recorder*

Learning Tasks

1. Step outside to observe and note the weather conditions of your school's vicinity. In class, discuss the state of the various weather elements as observed. Describe how those weather elements may be measured.
2. Using locally available materials, build a wind vane.
3. Using a calibrated beaker, measure its internal diameter and make a rain gauge.

4. Using a thermometer from the physics laboratory, measure the temperature of the atmosphere.

Pedagogical Exemplars

1. **Experiential Learning:** Students pay a visit to a weather station to learn about the elements of weather and how they are measured. Share experiences with the class. Encourage learners to simply and clearly articulate their points and listen to others during the discussions. Make room for non-vocal learners to contribute to the group discussions.
2. **Project-Based Learning:** In small mixed-ability groups, measure temperature, rainfall, wind speed and direction. Thermometers from a physics or chemistry laboratory could be used. Wind vane and rain gauges could be made from locally sourced materials. Offer differentiated instruction sheets with step-by-step guides for wind vanes and rain gauges for approaching proficiency learners, while encouraging proficient and highly proficient learners to explore advanced techniques.

Key Assessment

1. **Assessment Level 1**
   - **a.** Which type of precipitation is common to Ghana and which instrument is used to measure that type of precipitation?
   - **b.** List the instruments used to measure the following weather elements.
     - i. Temperature
     - ii. Sunshine
     - iii. Rainfall
     - iv. Relative humidity
     - v. Wind speed
2. **Assessment Level 2**
   - **a.** Describe how a rain gauge is used to measure rainfall.
   - **b.** Identify a major season in Ghana that is characterised by very low levels of humidity and explain the effects of this low humidity levels on human life during that season.
3. **Assessment Level 3:** Discuss some possible effects of high humidity on plant growth, infrastructure and human comfort.
4. **Assessment Level 4:** Using the Pan American Flight 1736 and KLM Flight 4805 crash incident as a case study, research and present a write-up discussing the causes of the crash and suggest what can be implemented to prevent such an incident from reoccurring.

Hint

*The recommended mode of assessment for Week 1 is **homework.** Do well to use a blend of items of different DOK levels from the key assessment.*

WEEK 2: THE IMPACT OF WEATHER ON FLIGHT

Learning Indicator: *Explain the impact of the weather elements on flight.*

FOCAL AREA: HOW WEATHER AFFECTS AIR TRAVEL

The Impact of Weather on Flight

In the course of flight routing and scheduling, pilots and airlines heavily rely on accurate weather forecasts because weather plays a very important role in the performance and safety of aeroplanes. This section discusses how the various elements of weather affect aviation operations and the hazards they pose.

One major weather element that affects flight is visibility. Poor visibility can be caused by fog, haze, dusty winds and low cloud cover. When the weather is foggy or hazy, visibility becomes very poor and as a result it becomes very difficult to see and identify objects at a distance. This was the case of the Tenerife crash when a Pan American aircraft and a KLM airliner collided on the runway at the Tenerife airport on 27th March 1977. A careful study of the incident revealed that the crash was caused by a series of events. Firstly, both aircraft were not supposed to be at the Tenerife airport on that day. There had been terrorist attack on Gran Canaria airport, where both aircraft were scheduled to arrive. Due to the terrorists' attack, many flights scheduled for the Gran Canaria airport had been diverted to Tenerife airport causing the airport to become overpopulated with aeroplanes. Due to this condition, the usual way to get to the runway was populated with aeroplanes, which meant that aircraft taking off had to go down the runway and turnabout before taking off in the opposite direction. This is called back-taxi. This is an unusual manoeuvre but would not have resulted in such a horrific accident if the runway had not been severely foggy. Due to miscommunication and poor visibility because of the fog, both Boeing 747s found themselves on the runway at the same time, heading towards each other. The Pan American aircraft was taxiing and the KLM aircraft was on its take-off run. Both aircraft collided. Five hundred and eighty-three people died and this accident became the most fatal air crash incident in the history of aviation.

Strong winds and turbulence are other atmospheric conditions that can have severe adverse conditions on an aircraft. As we will learn in the following weeks, the flight of aeroplanes heavily depends on the stream of air flowing around them. It is desirable to have a steady headwind (i.e. the airstream moving opposite to the direction of flight). However, aeroplanes sometimes encounter strong tailwinds and cross winds. Tailwinds and cross winds pose dangers when the aircraft is flying at low speeds, particularly on take-offs and landings. Turbulence is characterised by sudden and violent changes in the airstream through which an aircraft flies. This is felt as a "bumpy ride" by passengers and crew in the cockpit. Turbulence seldom causes fatal accidents but can cause injuries to crew members and passengers who are not strapped into their seats.

Though not a weather element, altitude indirectly plays a role in aviation because atmospheric pressure varies with altitude. Lowland areas have higher atmospheric pressures and densities compared with higher altitudes. As will be seen in the later weeks, air density plays a major role in determining how much lift force a wing may be able to generate. Generally speaking, the higher the density, the higher the lift generated and also the higher the drag force encountered.

Due to this phenomenon, runways at higher altitudes are required to be longer because the aeroplanes land at higher landing speeds and take off at higher speeds. Runways at lower altitudes however may be shorter than those at higher altitudes because the air at lower altitudes is denser and hence aircraft will require shorter take-off run and lower landing speeds.

In Ghana, the precipitation we mostly receive is in the forms of rainfall and drizzle. However, when flying in very cold regions, there can be ice formation on the airframe usually on the leading edges of the wings and nose of the aircraft. As stated earlier, it is desirable to have a smooth steady airflow around the aircraft. The ice formed disrupts this smooth airflow and causes the airflow to become unsteady which hinders the aircraft's performance. This could lead to a stall (i.e. sudden loss of lift) which can result in a crash.

The **Aircraft Accident and Incident Investigation and Prevention Bureau** is responsible for investigating, preventing, regulating and overseeing the management of aircraft accidents and incidents that occur in Ghana. Upon any aircraft incident or accident, this body conducts a thorough investigation to determine the cause of the crash and measures to be put in place to prevent reoccurrence.

Seeing that weather plays a critical role in aviation, it is important to acquire accurate weather forecasts ahead of flight and during flight. The **Ghana Meteorological Agency** provides **Ghana Civil Aviation Authority (GCAA)** and airline companies with weather forecast data. If adverse weather conditions are expected, the flight may be delayed until the conditions are favourable. While safe, delayed flights cost airlines lots of money annually. If in the course of a flight, poor weather conditions are forecast on the aircraft's flight route, the flight may be re-routed or the aircraft may be required to land at the nearest airport until the weather conditions become favourable for flight.

Learning Tasks

1. Research and document findings on the crash incident of Allied Air Boeing 727-221F at Accra on 2nd June 2012.
2. Discuss the role of Ghana Meteorological Agency in fostering safety in air travel.

Pedagogical Exemplars

Talk-for-Learning

1. In small-mixed ability groups, task learners to think-pair-share on the elements of weather that they have experienced within their communities.
2. Assign learners into small mixed-ability groups to brainstorm the impact of weather elements on flight.
3. In small-mixed ability groups, assign learners to research the role of the Ghana Meteorological Agency in enhancing air travel safety in Ghana and give a presentation to the whole class.

Key Assessment

1. **Assessment Level 1:** Identify some industries that could benefit from weather forecast data put out by the Ghana Meteorological Agency.
2. **Assessment Level 2:** Explain how the altitude of airports and runways affect aircraft take-off and landing.
3. **Assessment Level 3:**Using Harmattan as a case study, explain the impact of visibility on air travel.
4. **Assessment Level 4:** Using PowerPoint presentation, provide an analysis of the air crash incident of the Ghana Airways Fokker F27 Friendship aircraft that occurred in Accra on 5th June 2000.

Hint

- *The recommended mode of assessment for Week 2 is* ***essay.***
- *Remember to assign the group project during this week, to be submitted in Week 8. Refer to Appendix A for more information about this task.*

WEEK 3: INTERNATIONAL STANDARD ATMOSPHERE

Learning Indicator: *Explain the impact of altitude on the state of the atmosphere*

FOCAL AREA: INTERNATIONAL STANDARD ATMOSPHERE

The Earth's Atmosphere

The atmosphere can be divided into five different layers, based on temperature. The layer closest to Earth's surface is the troposphere, reaching from about seven and 15 kilometres (five to 10 miles) from the surface. Most of the water vapour in the atmosphere as well as dust and ash particles, are found in the troposphere. The weather phenomena experienced on the earth are all contained in the troposphere. Temperatures in the troposphere decrease with height.

The stratosphere is the next layer up from Earth's surface. It reaches from the top of the troposphere, which is called the tropopause, to an altitude of approximately 50 kilometres (30 miles). Temperatures in the stratosphere increase with altitude. A high concentration of ozone makes up the ozone layer of the stratosphere which protects the surface from ultra-violet radiation from the Sun.

Above the stratosphere is the mesosphere, which reaches as far as about 85 kilometres (53 miles) above Earth's surface. Temperatures decrease in the mesosphere with altitude. In fact, the coldest temperatures in the atmosphere are near the top of the mesosphere—about -90°C (-130°F). The atmosphere is thin here, but still thick enough so that meteors will burn up as they pass through the mesosphere—creating what we see as "shooting stars."

The thermosphere is located above the mesopause and reaches out to around 600 kilometres (372 miles). Solar radiation makes the upper regions of the thermosphere very hot, reaching temperatures as high as 2,000°C (3,600°F).

The uppermost layer, which blends with what is considered to be outer space, is the exosphere. The pull of Earth's gravity is so small here that molecules of gas escape into outer space.

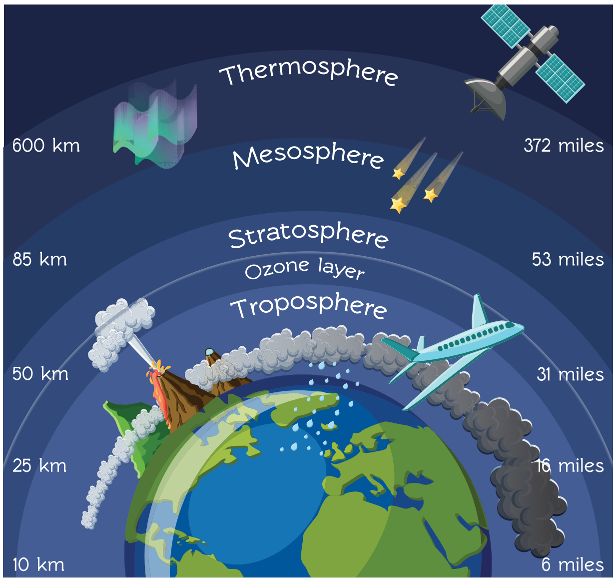

Figure 7: *Structure of the Atmosphere*

International Standard Atmosphere

International Standard Atmosphere (ISA) is a hypothetical model based on temperature and pressure measurements and adapted for the standardisation of aircraft instruments. It was established, with tables of values over a range of altitudes, to provide a common reference for atmosphere based on the thermodynamic equation, as defined by the International Civil Aviation Organisation, devoid of water vapor, wind, and turbulence. It uses a standard reference for pressure, density, viscosity, and temperature at different altitudes throughout the atmosphere. It consists of a table of values and indicates how these values change over a range of altitudes. Temperatures on the model are most often provided in Celsius but can also be given in Fahrenheit or Kelvin. Height is stated in metres, although measurements in feet or inches can also be given.

Lapse Rate

Lapse rate, otherwise known as environmental lapse rate, is the rate of change in temperature with altitude, which can either be positive or negative. As far as ISA is concerned, the lapse rate will always decrease with height at a standard rate. The ISA model uses the standard temperature lapse rate. This lapse rate decreases at the rate of approximately 3.5°F or about 2°C per thousand feet (300 metres) – up to 36,000 feet (11,000 metres). Above this point temperatures are considered constant to approximately 65,600 feet (20,000 metres). Lapse rates will vary if moisture is added. The dry lapse rate is about 5.5°F (3°C) per 1,000 feet (300 metres), and the moist lapse rate ranges (dependent on the amount of moisture) 2-3°F (1-1.5°C) per 1,000 feet (300m). The ISA model uses the standard lapse rate, which falls between these two lapse rates.

Adiabatic Lapse Rate

Each of these parameters decreases when the height from mean sea level reference increases:

- 1 hPa loss each 8 metres or 1 hPa loss each 26.25ft
- 6.5°C loss each kilometre or 1°C loss each 505ft or 154m

From 11 kilometres, or 11,000 metres (approximately 36,000 ft.) up to 20,000 metres (approximately 65,600 ft.), constant temperature is -56.5°C (-69.7°F), and this is also the lowest assumed temperature in respect of ISA.

Impact on Flight Planning

ISA does not change by season or flight region. It is affected when altitude decreases or increases. In the ISA model, the standard sea level pressure/temperature is 29.92 in.Hg (1,013.25mbar) and 59°F (15°C) respectively. As atmospheric pressure decreases with height, the temperature will decrease at a standard lapse rate. Temperature deviation, that is, the difference in temperature from ISA, can either be positive or negative. Standard ISA temperatures within the troposphere are 23.3°F (-4.8°C) at Flight Level (FL) 100, -12.3°F (-24.6°C) at FL200, and -49.9°F (-44.4°C) at FL300. At altitudes above FL360, temperature remains constant. Pressure on average will decrease by nearly half for each 18,000 feet of altitude. The ISA surface pressure is 29.92 in. Hg (1,013.25mbar) or 14.7 pounds per square inch, and at 18,000 feet (5,500 metres) it will decrease by half to about 14.94 in. Hg (500mbar) or 7.35 pounds per square inch. At 36,000 feet (11,000 m) the pressure decreases to half again to about 6.71 in. Hg (225mbar) or about 3.30 pounds per square inch.

Effect on Flight

Each aircraft has different defined ISA performance specifications, and flight crews need to check their take-off, cruise, and climbing performance charts for their particular aircraft. The aircraft may not perform as stipulated in the manufacturers' manual, so average considerations are necessary to ascertain the best aircraft parameters.

Table 1: *ICAO Standard Atmosphere*

Height km & ft	Temperature °C	Pressure hPa	Lapse rate °C/1000ft	Lapse rate °C /1000 m
0 km / MSL	15.0	1013.25	+1.98 (tropo-spheric)	+6.5 (tropo-spheric)
11 km / 36 000ft	-56.5	226.00	0.00 (strato-spheric)	0.00 (strato-spheric)
20 km / 65 000ft	-56.5	54.70	-0.3 (strato-spheric)	-0.1 (strato-spheric)
32 km / 105 000ft	-44.5	8.68		

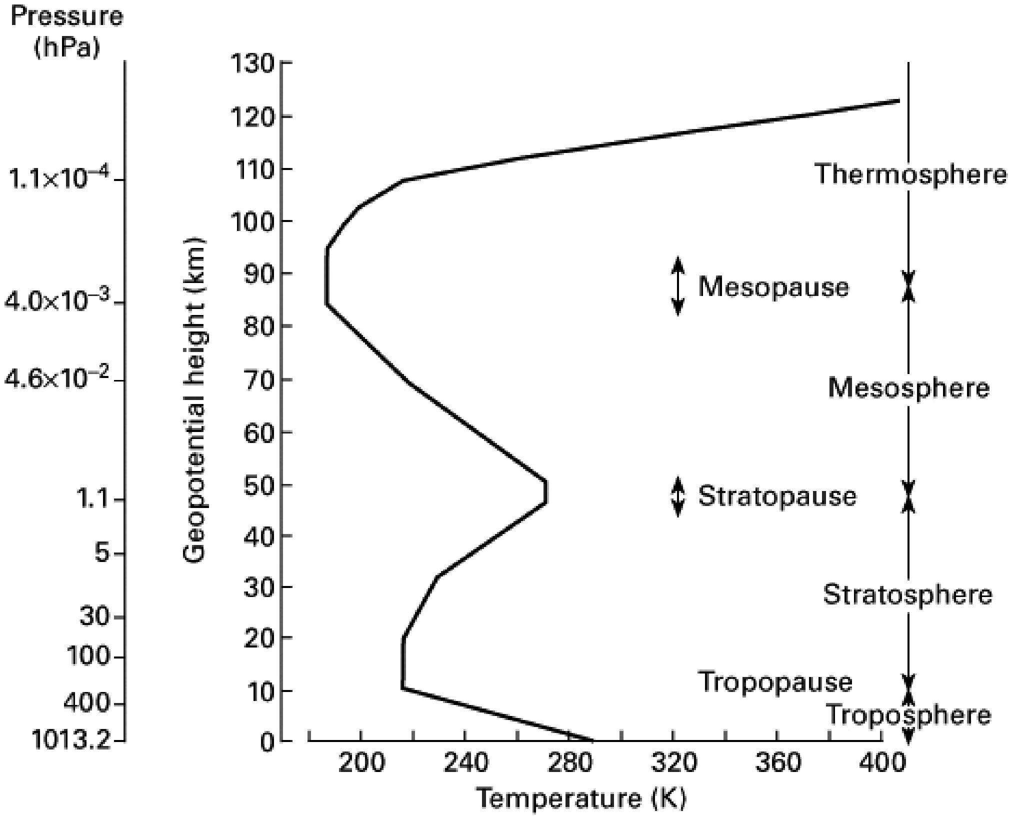

Figure 8: *Vertical temperature profile of the ICAO Standard Atmosphere*

Learning Tasks

1. Demonstrate understanding of the layers of the Earth's atmosphere
2. Demonstrate understanding of the effect of International Standard Atmosphere on flight planning

Pedagogical exemplars

Talk for learning

1. In small-ability groups, learners think-pair-share the structure of the atmosphere, and international standard atmosphere. Learners derive from first principles, the equations that describe the standard atmosphere, building on the popular saying "the higher you go, the cooler it becomes".
2. Put learners into smaller ability groups to brainstorm the implications of international standard atmosphere on flight planning and give a whole-class oral presentation.

Note

In forming the groups, teachers can take into consideration certain characteristics of learners such as gender, ability levels and learning needs. Teachers should encourage learners to accept divergent views from their colleagues as they share ideas. All relevant materials should also be made available to learners for easy class interaction.

Key Assessment

1. **Assessment Level 1**: With reference to the video watched in class, list the layers of the atmosphere in order of increasing altitude.
2. **Assessment Level 2**: From your personal experience, explain why places at high altitudes experience cooler climates.
3. **Assessment Level 3**: In small ability groups, research and present a report on the following scenario: The temperature at sea level is 10 . What will be the surface temperature at an airport situated at 3000ft above sea level?
4. **Assessment Level 4**: In the role of a pilot preparing to transport cargo to a mountain-top village, where the departure airfield in the valley faces high surface temperatures, conduct a comprehensive analysis of two potential threats that could impact the flight. Articulate a detailed strategy outlining how each identified threat can be effectively mitigated to ensure the safe and successful completion of the mission.

Hint

- *The recommended mode of assessment for Week 3 is* ***e-Assessment****.*
- *Portfolio assessment is assigned this week. Refer to* ***Appendix B*** *for further guidance.*
- *Remind learners about their* ***Project Work*** *and offer them the opportunity to seek for clarification and support if they have any difficulties.*

SECTION 1 REVIEW

In this section, we have seen the critical role weather plays in aerospace engineering and aviation safety. Learners have attained first-hand knowledge on incidents and accidents that have resulted as a result of poor weather conditions in aircraft operations. Equally important are the standard values used in aviation and aircraft operations. By this, learners are better positioned to appreciate how aerospace engineers incorporate this knowledge in aircraft design.

APPENDIX A: Guidance for Group Project

1. Example task

Design and build a simple temperature measurement instrument that registers differences in temperature as the brightness of an LED.

Refer to Teacher Manual Section 1, Week 2 and Learner Material Section 1 for more task examples.

2. Marking scheme/Rubrics

Criteria	*Excellent (4 marks)*	*Very good (3 marks)*	*Satisfactory (2 marks)*	*Needs improvement (1 mark)*
Circuit symbols	*Use of the right circuit symbols for more than four components*	*Use of the right circuit symbols for up to four components*	*Use of the right circuit symbols for up to three components*	*Use of the right circuit symbols for up to two components*
Layout of circuit diagram	*Circuit diagram exhibits all three of these: Neatness of design, Groups circuit components by subsystem, Uses appropriate component values*	*Circuit diagram exhibits up to two of these: Neatness of design, Groups circuit components by subsystem, Uses appropriate component values*	*Circuit diagram exhibits one of these: Neatness of design, Groups circuit components by subsystem, Uses appropriate component values*	*Circuit diagram is cluttered and does not use appropriate component values*
Design of physical system	*Circuit exhibits all three of these: Neat solder joints, appropriate use of external cables, Orderly arrangement of components on circuit board*	*Circuit exhibits up to two of these: Neat solder joints, appropriate use of external cables, Orderly arrangement of components on circuit board*	*Circuit exhibits one of these: Neat solder joints, appropriate use of external cables, Orderly arrangement of components on circuit board*	*Circuit has poor soldered joints, excessive use of external cabling and disorderly arrangement of components*
System function	*LED has at least three distinguishable brightness levels in addition to the "off" state that vary with temperature*	*LED has only two distinguishable brightness levels in addition to the "off" state that vary with temperature*	*LED has only two states "on" and "off" that vary with temperature*	*LED brightness/ state does not vary with temperature*

3. Administration

Present project topic to learners and share with them the rubrics for grading the finished product, etc.

Refer to Teacher Assessment Manual and Toolkits pages 34 - 37 for further guidance on conducting project assessments

4. **Feedback**
Praise features of learners' work that highlight their creativity and suggest possible areas for improvement in future tasks.

APPENDIX B: Guidance For Portfolio Assessment

1. Task example

Build a portfolio which includes the following items:

a) Exercises
- i. Homework
- ii. Class exercises
- iii. Peer assessments

b) Project work
- i. Group project
- ii. Individual project

c) Reports on:
- i. Practical assessments
- ii. Research work

d) Results from:
- i. Mid-semester examinations
- ii. End of semester examinations

e) Summary of what is learned during each week, including cutouts from magazines, newspapers, etc. related to the focal area for the week

f) Any awards received

Hint

Learners make a partial submission of the portfolio in Week 10 and the final work is due by Week 22 of the academic year.

2. Organisation of portfolio

The portfolio consists of a file containing the following elements:

a) A cover page which specifies the learner's name, class and academic year

b) A 40- to 50-word introduction that summarizes the contents of the portfolio

c) A table of contents

d) Content items

e) A glossary of new terms picked up during the year

3. Marking scheme/rubrics

The portfolio is graded using the following criteria:

Criterion	Excellent (5 marks)	Very good (4 marks)	Satisfactory (3 marks)	Needs improvement (2 marks)
Completeness of content	Portfolio includes at least seven of the following artefacts: class exercises, homework, peer assessments, group and individual project work reports, reports on practical and research works, examination papers and answer booklets, weekly lesson summary and any awards received	Portfolio includes at least five of the following artefacts: class exercises, homework, peer assessments, group and individual project work reports, reports on practical and research works, examination papers and answer booklets, weekly lesson summary and any awards received	Portfolio includes at least three of the following artefacts: class exercises, homework, peer assessments, group and individual project work reports, reports on practical and research works, examination papers and answer booklets, weekly lesson summary and any awards received	Portfolio has at least two of the following artefacts: class exercises, homework, peer assessments, group and individual project work reports, reports on practical and research works, examination papers and answer booklets, weekly lesson summary and any awards received
Organisation of Portfolio	Portfolio has all these features: a professional cover page, a clear introduction, a well-structured glossary, orderly arrangement of artefacts.	Portfolio is exhibits at least three of these features: a professional cover page, a clear introduction, a well-structured glossary, orderly arrangement of artefacts.	Portfolio exhibits at least two of these features: a professional cover page, a clear introduction, a well-structured glossary, orderly arrangement of artefacts.	Portfolio exhibits less than two of these features: a professional cover page, a clear introduction, a well-structured glossary, orderly arrangement of artefacts.
Introduction	Introduction to portfolio has all these features: summarizes the portfolio, is clear and informative, is brief and concise	Introduction has two of these features: summarizes the portfolio, is clear and informative, is brief and concise	Introduction has one of these features: summarizes the portfolio, is clear and informative, is brief and concise	Introduction is unclear and too wordy

Criterion	Excellent (5 marks)	Very good (4 marks)	Satisfactory (3 marks)	Needs im-provement (2 marks)
Glossary	Glossary includes more than six new words learned in class	Glossary includes up to four new words learned in class	Glossary includes up to three new words learned in class	Glossary includes two or less new words learned in class

a) Learners earn 5 additional marks for submitting the portfolio by the due date.

4. Administration

a) Clear instructions on the purpose of the portfolio and the items to be included are given to learners.

b) The marking scheme/rubric for the assessment is provided to and discussed with learners.

c) Learners are reminded throughout the academic year which exercises should be included in the portfolio.

5. Feedback

Commend individual learners for creativity in the design of their portfolios and suggest areas for improvement in future work.

Additional Reading`

1. Ghana | Bureau of Aircraft Accidents Archives (baaa-acro.com): https://www.baaa-acro.com/country/ghana/

Figure number	Link
Figure 1: Aneroid barometer	**Precision Aneroid Barometer - FCC Precision** https://www.fccprecision.co.uk/product/precision-aneroid-barometer/
Figure 2: Digital weather instrument	**TFA 35115401: Thermo-hygrometer, digital, black - aluminium at reichelt elektronik** https://www.reichelt.nl/nl/nl/thermo-hygrometer-digitaal-zwart-aluminium-tfa-35115401-p269041.html?r=1
Figure 3: Hygrometer	**Hygrometer Gold 90mm - Weather Instruments | Let's Make Time** https://www.letsmaketime.com.au/shop/item/hygrometer-gold---whg-90mm
Figure 4: Anemometer	**Digital Anemometer - Ravi Scientific Industries** https://www.raviscientific.in/product/digital-anemometer-an215/
Figure 5: Wind vane	**Make a Wind Vane to Measure Wind Direction** https://www.amnh.org/explore/ology/earth/make-your-own-weather-station/make-a-wind-vane
Figure 6: Sunshine recorder	**Campbell-Stokes Sunshine Duration Recorder - Earth Sciences** https://www.essearth.com/campbell-stokes-sunshine-duration-recorder/
Figure 7: Layers of the atmosphere	https://www.sciencephoto.com/media/1156402/view/structure-of-earth-s-atmosphere-illustration
Figure 8: International Standard Atmosphere	https://www.researchgate.net/figure/Vertical-temperature-profile-of-the-ICAO-Standard-Atmosphere-79_fig5_285583928

SECTION 2: FORCES ON AN AIRCRAFT

Strand: Core Concepts in Aerospace

Sub-Strand: Aerodynamics and Propulsion

Learning Outcome: *Identify the forces acting on an aerospace vehicle in flight*

Content Standard: Evaluate the balance of forces on an aerospace vehicle in flight

Hint

Mid-Semester Examination *for the first semester is in Week 6. Refer to* ***Appendix D*** *for a Table of Specification to guide you to set the questions. Set questions to cover all the indicators covered for at least weeks 1 to 5.*

INTRODUCTION AND SECTION SUMMARY

In order for an aircraft to get airborne, it should be able to overcome its own weight. Once it is airborne it should be able to manoeuvre itself and perform required tasks. The aircraft designer, based on the aircraft mission requirement, must choose appropriate design parameters. In this section, learners are introduced to the basics of aerodynamics, aerodynamics variables and the forces an aircraft generates to enable it to fly and manoeuvre while airborne. We also look at the weight that the aircraft carries, how it can be optimised and distributed to enhance stability. We conclude the section by looking at the propulsion systems required to power the aircraft. The weeks covered in this section are:

Week 4: *Introduction to Aerodynamics*

Weeks 5 and 6: *Lift*

Week 7: *Drag*

Week 8: *Weight and Weight Distribution*

SUMMARY OF PEDAGOGICAL EXEMPLARS

In order to equip learners with the practical experience of forces that act on aircraft, innovative pedagogical strategies, specifically experiential learning and talk-for-learning approaches are relevant. The approaches will not only deepen learner's understanding of the concept but also enhance their ability to demonstrate how various concepts discussed work. Through group activities, peer interactions and experiments, we aim to foster an environment where learners can hone their skills driven by personal interests and intrinsic motivation. The section prioritises practical skills through experiment and presentations that bridge their classroom experiences with real-world applications.

ASSESSMENT SUMMARY

To unearth what learners know about concepts such as lift, drag, thrust, and weight, innovative alternative formative assessment strategies should be emphasised. In all the assessment tasks that teachers assign to learners, consideration should be given to the four depth of knowledge levels. All resources that would be needed for the completion of every task must be made available to learners. Lastly, considering inclusivity and support, differentiated formative assessment strategies will help to nurture unique talent and career pathways in Aviation.

The assessments outlined for this section are designed to provide a comprehensive evaluation of learners' grasp of key concepts and skills. These assessment methods will help identify strengths, address learning gaps, and guide instructional decisions to enhance student achievement. The recommended assessment modes for each week include:

Week 4: *Research*

Week 5: *Group presentation*

Week 6: *Mid-semester examination*

Week 7: *Practical work*

Week 8: *Discussion*

Refer to the ***"Hint"*** at the key assessment for each week for additional information on how to effectively administer these assessment modes. Always remember to score learners' work with rubric/marking scheme and provide prompt feedback to learners on their performance.

You are encouraged to administer these recommended assessments for each week, carefully record the results, and submit them to the **Student Transcript Portal (STP)** for documentation

WEEK 4: INTRODUCTION TO AERODYNAMICS

Learning Indicator: *Distinguish between the four major forces (lift, drag, thrust and weight) that act on an aerospace vehicle in flight.*

What is Aerodynamics?

Aerodynamics is the study of the air and how it interacts with bodies moving through it.

Basic Aerodynamic Variables

1. **Mass:** This refers to the amount to substance contained in a body. The SI unit for mass is kilogram.
2. **Volume:** Volume is the space occupied by a body. It simply refers to how big an object is. Volume is a derived quantity and its SI unit is cubic metre (m^3).
3. **Density:** Density is the mass per unit volume of an object. It is a derived quantity with SI unit kilogram per cubic metre (kg/m^3). If in a flow, the density of the fluid changes or varies at different points in the flow then the flow is said to be *Compressible*. If the density of the fluid does not change with the flow, then the flow is said to be an *incompressible flow*.
4. **Velocity:** Velocity is the displacement of a body in a unit of time. It has both magnitude and direction. The unit of measurement of velocity is metre per second (m/s). Velocity is mathematically expressed as,
5. **Pressure:** Pressure in air is a measure of how frequently molecules of air collide with each other and the walls of their container. It is measured in Pascal (Pa).

Aerofoil Nomenclature

The aerofoil is a shape that is used in many aircraft parts. It is used in propellers, aircraft wings and tails, helicopter rotor blades, gas turbine engine blades, car spoilers and wind turbine blades. The reason the aerofoil is preferred in many aerodynamics applications is due to its ability to create a pressure difference between their two sides when it comes into contact with moving air. Below is an image of a typical aerofoil used in aircraft wings.

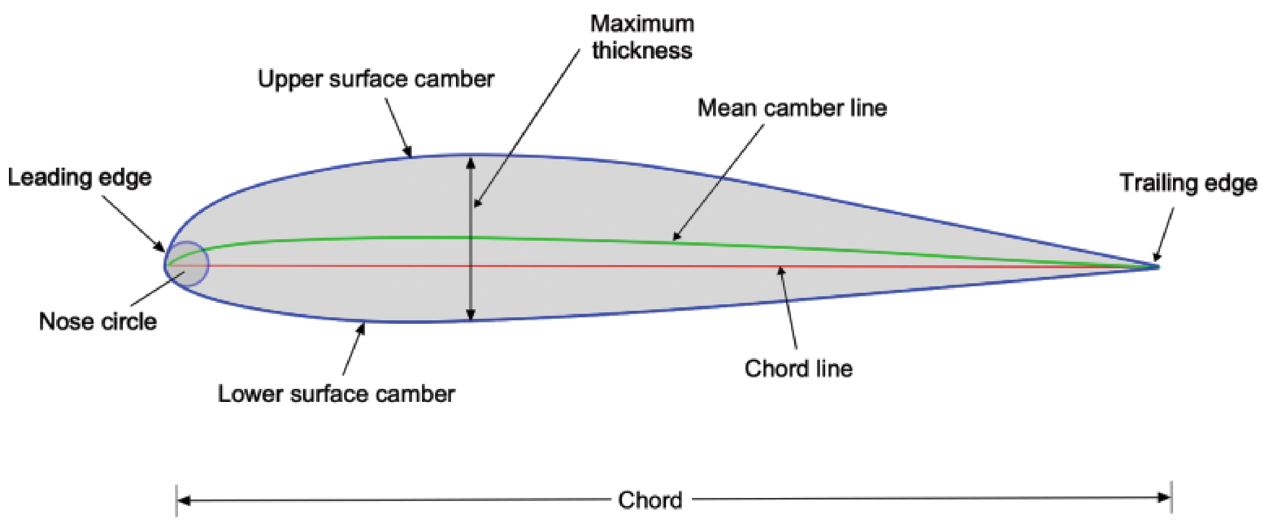

Figure 9: *Aerofoil nomenclature*

1. **Chord line:** This is an imaginary line drawn between the leading edge and trailing edge.
2. **Chord length:** Leading Edge: is the foremost part of the aerofoil that gets into contact with the incoming air before the rest of the aerofoil.
3. **Trailing Edge:** This is the usually sharp part at the rear of the aerofoil.
4. **Nose circle or Leading Edge Radius:** This is the radius of the leading edge of the aerofoil. The bigger the leading edge radius, the blunter the leading edge is.
5. **Maximum thickness:** This describes how thick the aerofoil is. Thicker aerofoils are often desired because of their structural merits and internal space. In many aircraft, the wings are used to store fuel so thicker aerofoils offer more space for fuel storage. On the other hand, thicker aerofoils usually are associated with more drag and hence are not very much desired in high speed applications.
6. **Camber:** This refers to how curved the aerofoil is. The presence of camber in an aerofoil causes a difference in curvature of the upper and lower surfaces of the aerofoil. Aerofoils with this feature are called **cambered aerofoils**. For aerofoils with zero camber, both the upper and lower surfaces have the same curvature. They are called **symmetrical aerofoils**. Cambered aerofoils are mostly featured on wings due to the ability to create more lift. Symmetrical aerofoils, however, are mostly found on the vertical and horizontal tails.
7. **Mean Camber line:** This is an imaginary line drawn midway between the upper and lower surfaces.

Flow Regimes

There are some terms used in aerodynamics to describe the nature of air flow based on certain characteristics of the flow.

1. **Mach number (M)**

   Mach number is the ratio between the speed of an object relative to the air (v) and the speed of sound in air (a). This is a very important parameter used particularly in very high speed flows. Mach number is mathematically expressed as;

   Where **v** is the speed of the object and **a** is the speed of sound, which is about 340 m/s at sea level.

   Aircraft speeds may be classified according to ranges of Mach number.

Subsonic	$M < 1$
Sonic	$M = 1$
Transonic	Mach 0.8 to Mach 1.2
Supersonic	Mach 1 to Mach 5
Hypersonic	$M > 5$

2. **Laminar and Turbulent flow**

   This is a type of fluid flow where the fluid flows steadily in layers, with each layer moving smoothly adjacent to the other. Turbulent flow on the other hand is characterised by irregular erratic fluctuations. (Remember that air is a “fluid”).

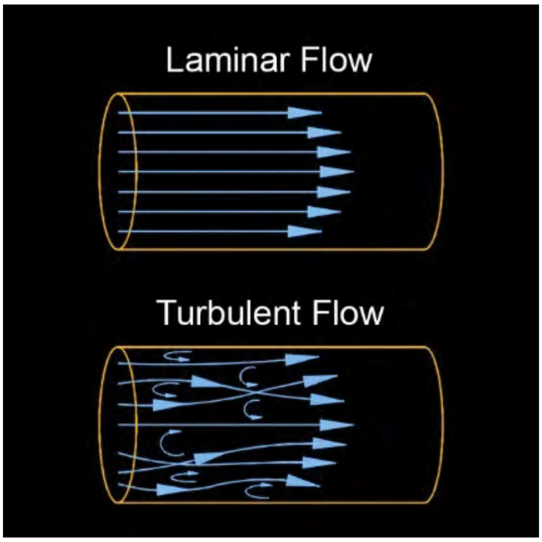

Figure 10: *Laminar and turbulent flow*

3. **Boundary Layer and Flow separation**
When a fluid flows around a solid object, a thin layer of the fluid tends to get attached to the skin of the solid object. This thin layer of fluid is called the boundary layer. The boundary layer creates a friction between the fluid and the solid object as the boundary layer applies a shear stress on the object. Flow within the boundary layer can be laminar or turbulent depending on the shape of the object or speed of the flow.

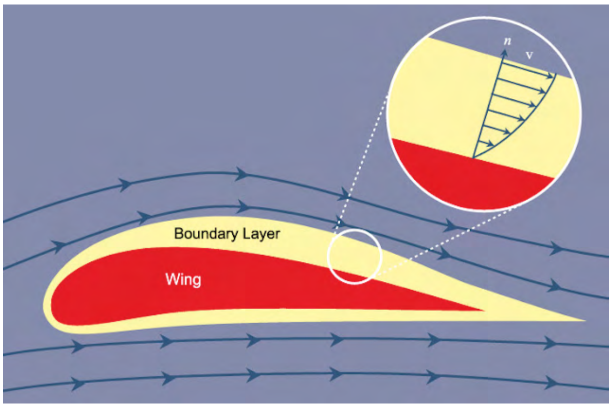

Figure 11: *Boundary Layer*

Conservation of matter and mass flow rate

One principle that is fundamental to the understanding of physics and other science disciplines is the law of conservation of matter. The law of conservation of matter states that in a closed system, matter is conserved. Matter is neither created nor destroyed. This law applies to all scientific processes, except in a nuclear reaction. Take for example water flowing through a tube. If we consider a section of the tube as shown below, the amount of water that enters the section A is the same amount of water that exits at B.

If the water entering at A is more than that exiting at B, then that would mean that matter is being destroyed somewhere along the tube. Also, if the water exiting at B is more than the amount of water entering at A, then it means matter (water in this case) is being created somewhere within the tube. Both of these scenarios are inconsistent with physical observations and do not comply with the law of conservation of matter. What is physically observed is that, the amount of water entering is the same amount that leaves the tube.

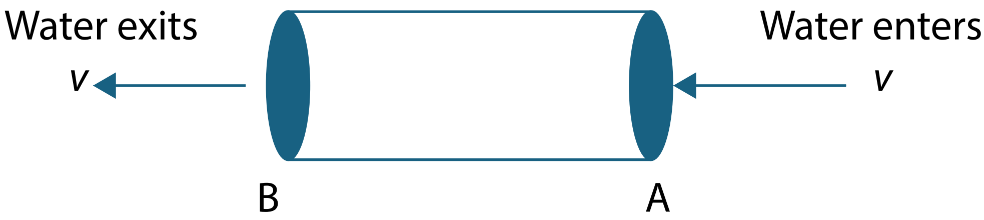

Figure 12: *Flow in a tube*

For the above diagram, the water enters and exits the tube at the same velocity (v) because the cross section of the tube is the same throughout. Now let's take a look at a case where the intake diameter and the exit diameter are not the same. The diameter of the inlet is **D** and the Diameter of the outlet is **d.** Water enters the conical channel at X with a velocity of V_1 and exits at Y with a velocity of V_2. The cross-sectional area of the inlet is A1 and that of the outlet is A2. By the law of conservation of matter, it is expected that the amount of water entering the conical tube should be the same as the amount of water exiting at any point in time. This brings us to the concept of mass flow rate. Mass flow rate is the rate at which the mass of a substance (usually a fluid) flows past a boundary per unit time. Mass flow rate is measured in kilogram per second (kg/s). The formula for mass flow rate is;

$$\text{Mass flow rate} = \text{density} \times \text{cross-sectional area} \times \text{velocity}$$

The mass of water entering should be equal to the mass of water exiting at any instance. This means that the mass flow rate at the inlet should be equal to the mass flow rate at the outlet. Since water is hardly compressible, we will take the flow to be an incompressible flow. For an incompressible flow, the density of the fluid does not change.

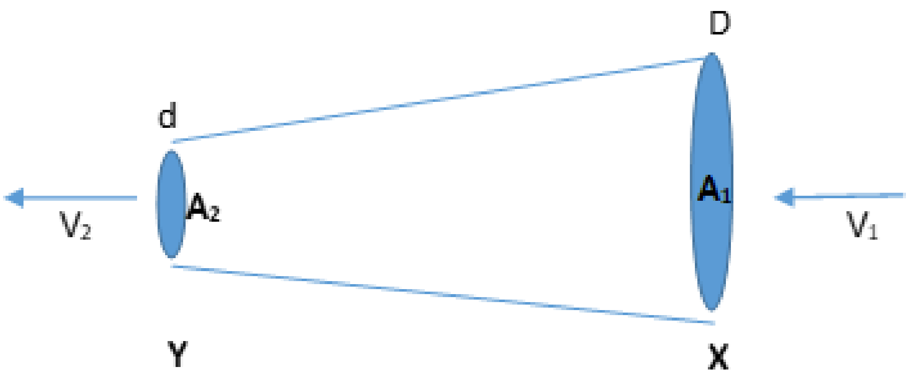

Figure 13: *Flow in a tube*

Therefore, we can write,

The density, ρ on both sides of the equation cancel out to become

This equation is known as the continuity equation for incompressible flow and is derived from the principle of conservation of matter.

Forces of Flight

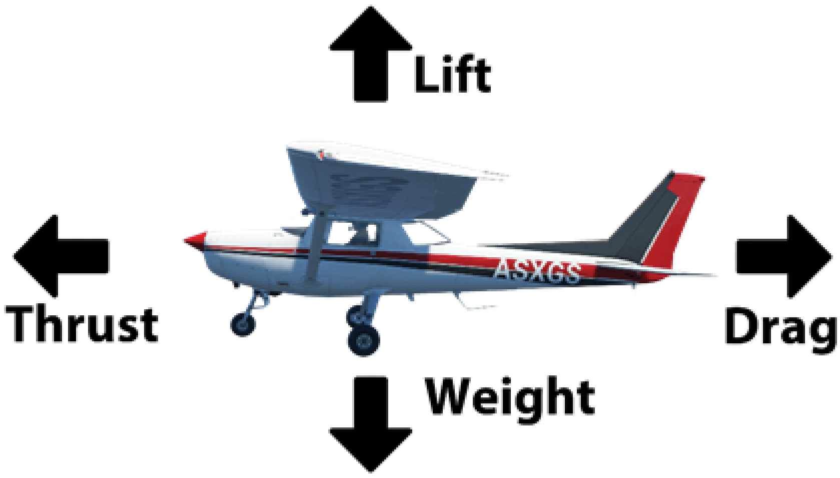

Figure 14: *Forces of flight*

Relationship Between the Forces of Flight

Before any vehicle flies, the first force at play is the weight. It is an inherent property of the materials used to construct the air vehicle. Aerospace engineers always consider how to reduce the weight of the aircraft. This informs the type of material to use as well as the structural design needed to hold the aircraft together. In order to fly, an aircraft must be able to generate a lift force that is equal to or greater than its weight. Lift depends on so many things, notable among them is the selection of aerofoil. This affects the lift coefficient in so many ways. A good aerofoil will produce the most lift with minimum resistance (drag) in the air, enabling good flight performance.

Another notable determinant of lift is the mass flow rate of the air coming toward the wing. The higher the mass flow rate of air toward the wings, the higher the lift generated. This is true for the drag as well.

The thrust provides the force to move the aircraft forward. Almost all aerospace propulsion systems generate thrust by accelerating a mass in one direction to obtain a reaction force in the other direction. A jet engine for example takes in air and accelerates it at high speeds at its outlet nozzle. The faster it can accelerate outward, the higher the thrust. In the analysis of jet propulsion, the conservation of mass plays a crucial role. This conservation law tells us that the total mass entering the engine equals the total mass exiting the engine. This greatly simplifies the analysis because we need not know all the complex processes happening in the engine, we just know by the law of conservation of matter that "what goes in comes out".

Learning Tasks

1. Explain basic aerodynamics terms such as mass, volume, density, pressure, velocity, boundary layer, flow separation, Mach number etc.
2. In pairs, learners run a 100-metre race while being timed with a stopwatch to determine the time it takes them to complete 100-metre sprint. Learners then calculate their own average velocities based on the time it took to complete the sprint.
3. Research on the effect of boundary layers on the skin of a flying aircraft.

Pedagogical Exemplars

Talk-for-learning

a. In small-ability groups, task learners to brainstorm the concept of lift, drag, thrust and weight and share their findings with the whole class.

b. Using mind-mapping, allow learners to independently think about aerodynamics concepts such as mass, volume, density, velocity and so on. Learners are to write their findings in their jotters and share with another person in the class. Teachers are to moderate the discussion in such a way that interaction among learners will be effective. For example provide specific instructions to the groups to guide the discussions and to prevent the possibility of only one learner doing all the talking. Encourage learners to simply and clearly articulate their points and listen to others during the discussions. Make room for non-vocal learners to contribute to the group discussions.

c. In small ability groups, learners research, prepare and give a PowerPoint presentation on boundary layers on the skin of a flying aircraft. Allow for a questions and answer segment in order for learners to reflect on the material presented.

Note

In forming the groups, teachers can take into consideration certain characteristics of learners such as gender, ability levels and learning needs. Teachers should encourage learners to accept divergent views from their colleagues as they share ideas. All relevant materials should also be made available to learners for easy class interaction.

1. **Experiential Learning**
   - **a.** Using a stopwatch, allow learners to run a 100-metre race in pairs. The time used by each pair to complete the race should be recorded. The data during the race should be assigned to the respective pairs to compute their velocity and share with the whole class.
   - **b.** Using a water hose, demonstrate the law of conservation of matter by allowing tap water to flow through the hose at one end and squeezing the hose on the other end. Observe how the velocity of the water increases when the outlet of the hose in squeezed. Using knowledge of the conservation of matter and the continuity equation, explain this observation.

Key Assessment

1. **Assessment Level 1**
   - **a.** Assuming an aircraft flying from Accra to Kumasi along a straight path takes about 35 minutes to complete its journey, calculate the average velocity of the aircraft if the distance between Accra and Kumasi along a straight line is 200km.
   - **b.** A block weighing 5kg has a width of 20cm and breadth of 30cm and length of 50cm. Calculate its density in kg/m^3. (level 2)

2. **Assessment Level 3:** In the diagram below, water flows through a conical tube which has *D* as the diameter of the inlet and d as the diameter of the outlet. Water enters the tube through diameter D at a velocity of V_1 and exits the tube at d at a velocity of V_2. The density of the water is ρ. Derive an expression for V_2 as a function of V_1, D and d.

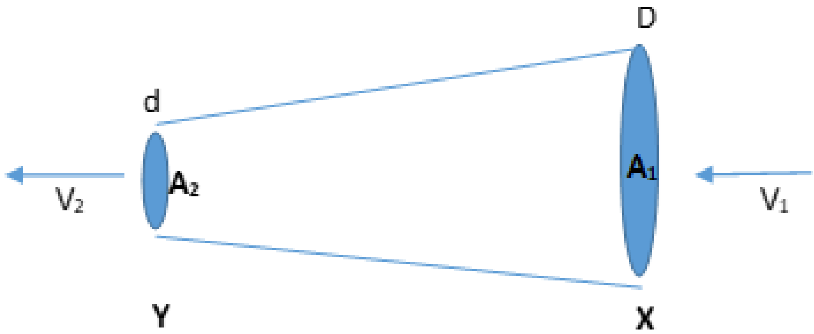

Figure 15

3. **Assessment Level 4:** In a small ability group, research on how the boundary layer contributes to the drag on an aircraft. Present your answer using PowerPoint slides to the whole class.

Hint

- *The Recommended Mode of Assessment for Week 4 is **research.** [You may refer to Assessment Level 4 in the Key Assessment for an example of a research question].*
- *Scores on individual class exercise should be ready for submission to **STP** this week. It should be an average of the various class exercises you have conducted over the past four weeks.*

WEEKS 5 AND 6: LIFT

Learning Indicators

1. *Distinguish between the four major forces (lift, drag, thrust and weight) that act on an aerospace vehicle in flight.*
2. *Calculate the lift, drag and weight of an aircraft.*

FOCAL AREA: INTRODUCTION TO LIFT, HOW IT IS GENERATED AND THE FACTORS THAT AFFECT LIFT

The Theory of Lift

Whenever a fluid (liquid or gas) flows around a body, it exerts a certain amount of force on the body. Whether the fluid is moving around the body, or the body is moving through the fluid, the body experiences a push or pull. If the fluid in question is air, this force is referred to as an aerodynamic force. If the fluid is liquid, mostly water, the force is referred to as a hydrodynamic force.

Lift is the force that acts perpendicular to the flow direction of a fluid around a body. This means that if the fluid moves horizontally around the body, the vertical force that the fluid exerts on the body is the lift force. The horizontal component is called the drag. The drag force opposes the flow of the body through the fluid.

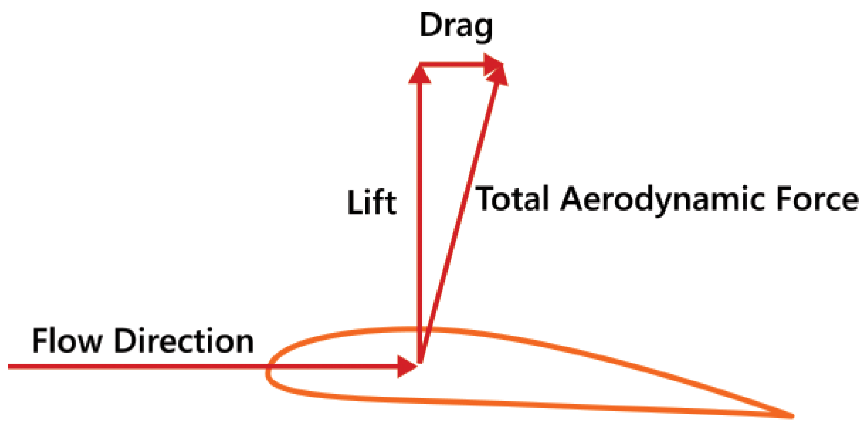

Figure 16: *Aerodynamic forces*

How Lift is Generated

1. **Differences in Air Pressure**

   According to Bernoulli's theory, when a gas is accelerated, its internal pressure drops. An aerofoil takes advantage of this to produce unequal pressure around it. When an aerofoil accelerates through the air, the curved upper surface accelerates the air in the area thus reducing its pressure. At the same time, air beneath the aerofoil has a relatively higher pressure. This pressure difference naturally pushes the whole aerofoil towards the lower pressure zone. This push is the vertical lift force the aerofoil experiences.

   The angle of attack is the angle between the aerofoil chord line and the direction of the incoming air. When the angle of attack increases, the lift increases gradually until it reaches a maximum beyond which it stalls (i.e. loses lift sharply).

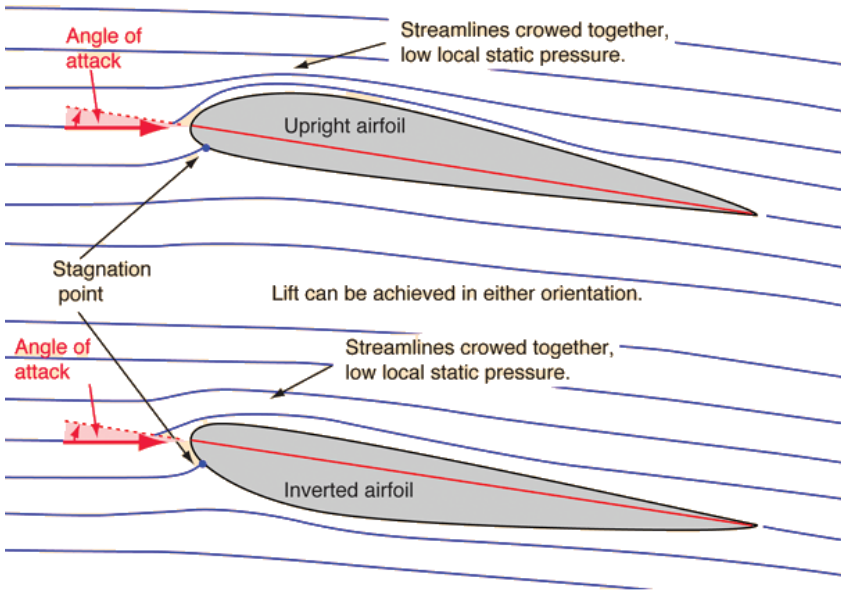

Figure 17: *Lift due to pressure differences*

2. Newton's Third Law of Motion

Newton's 3rd Law of motion states that for every action there is an equal and opposite reaction. When an aerofoil, in this case an aeroplane wing, moves through the air, it exerts an amount of force on the air (action). The air fights back by pushing back on the wing (reaction). The size of the wing, angle of attack, speed of the air and its density affect the amount of lift to be generated.

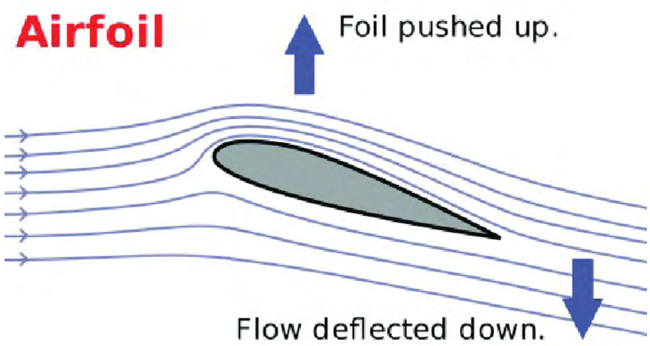

Figure 18: *Newtonian Lift*

How to Calculate Lift

Lift depends mainly on the size of the lifting surface and the curvature or camber of the aerofoil. Environmental factors such as airport altitude and temperature also play a role. The lift equation is given as:

Where

L = Lift

C_{L} = Coefficient of Lift

ρ = density of air

v = velocity or true airspeed

S = planform area of the wing

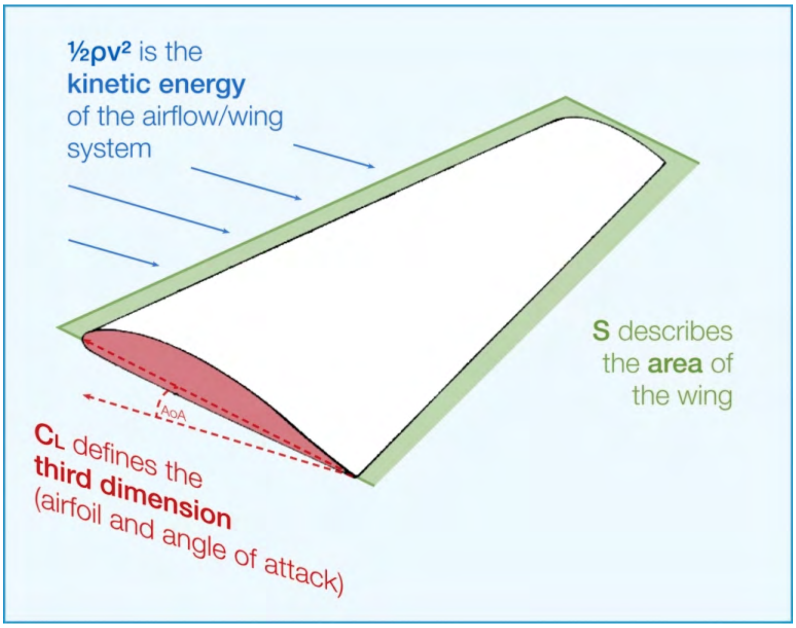

Figure 19: *Factors affecting lift*

Worked Example

1. A light aircraft is flying at 50m/s at an altitude of 200m above sea level where the air density is 1.05kg/m^3. It has a wing area of 16m^2 and a lift coefficient of 1.2. Calculate the lift being generated by the wings.

Solution:

The formula for calculating lift is given by:

$\rho = 1.05 kg/m^3$

$v = 50$ m/s

$S = 16$ m^2

$C_l = 1.2$

High-Lift Devices – How to Increase Lift

During take-off and landing phases of flight, aircraft typically need all the lift they can get. Since the aircraft's size cannot be changed during flight, additional features are usually added to the wings to increase their curvature or wing area. A few are discussed below;

1. **Flaps**
   Flaps are the primary devices used on aerofoils to increase a wing's lift. They are a pair of panels hinged at the trailing edge of the wings. They are slightly deployed for take-off and fully deployed for landing. See the types of flaps in the figure below.

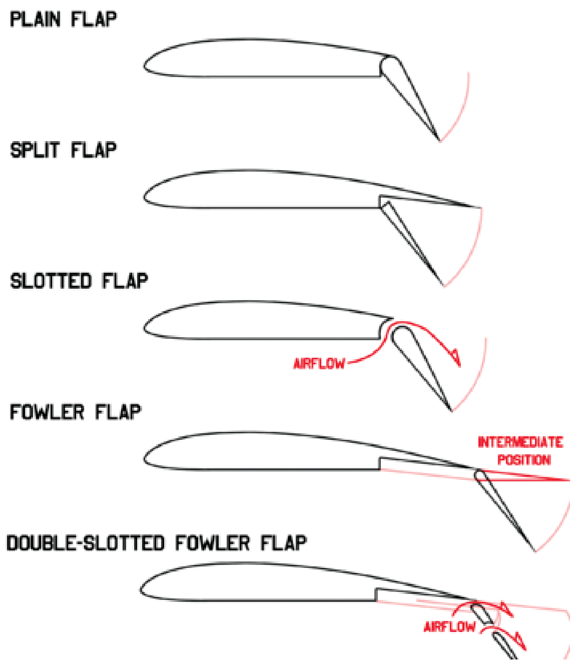

Figure 20: *Types of flaps*

2. **Slats**

   Slats are aerofoil-shaped panels that are attached to the leading edge of wing to increase lift on take-off and landing.

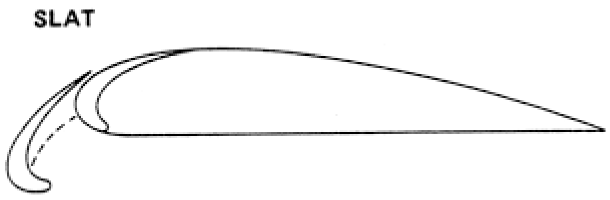

Figure 21: *A leading-edge slat.*

3. **Krueger Flaps**

   Krueger flaps are leading edge slats that are attached to the bottom of the wing. They are also extended during takeoff and landing to increase lift.

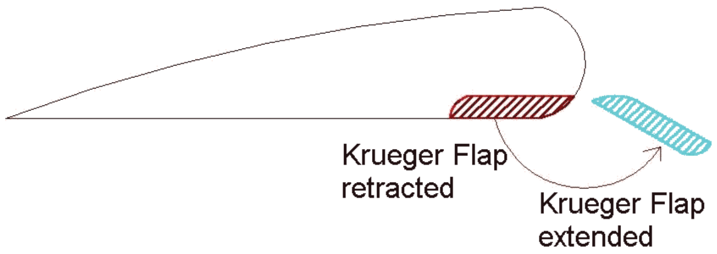

Figure 22: *Krueger flaps*

Basic Wing Geometry

Wings are the main lifting surfaces in an aeroplane. Aeronautical engineers must design wings to achieve the best lift-to-drag ratio during all phases of flight. The wings are also the main structures lifting the entire weight of the aircraft. They also experience a lot of aerodynamic loads during flight and must therefore be designed to withstand all these forces without failing.

The basic geometric features of wings are given below;

1. **Wingspan and semi-span**
   The span, ***b***, is the linear distance from wingtip to wingtip. Semi-span is half this distance and generally used in engineering analysis. If the wing has winglets, they are ignored in determining the wingspan.

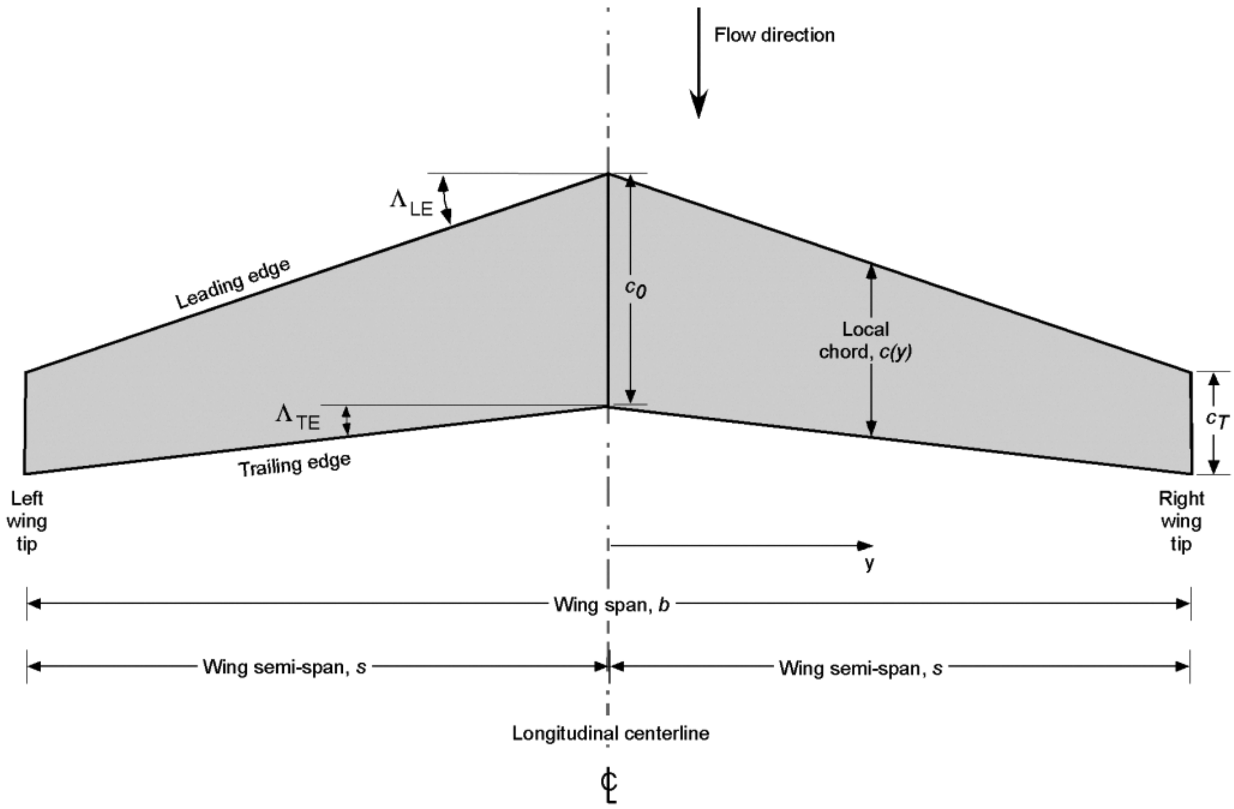

Figure 23: *Wing nomenclature*

2. **Wing planform**
   This is the shape of the wing as viewed from above.

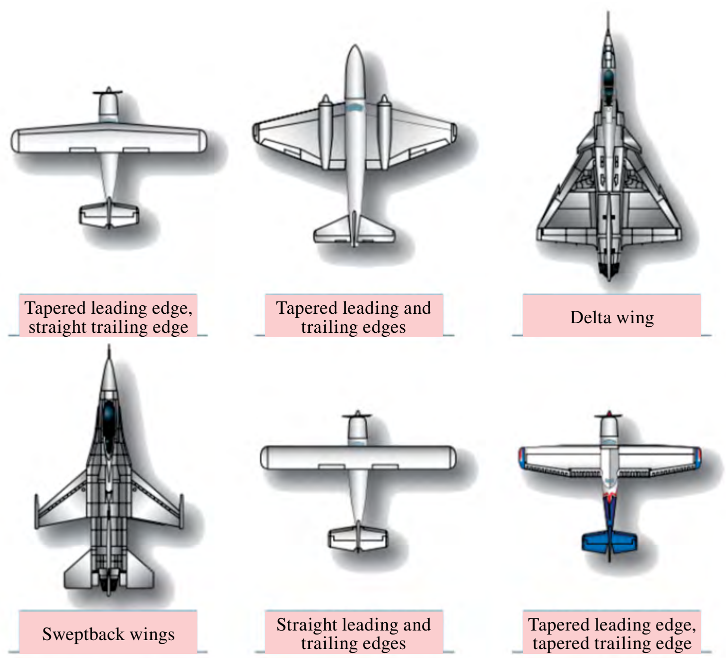

Figure 24: *Some wing planform shapes*

3. Wing chord

The chord is the distance between the leading edge and trailing edge of the wing. It is denoted with the symbol ***c***. Mean aerodynamic chord is used in the analysis of tapered wings. These are wings whose chord lengths vary along their span.

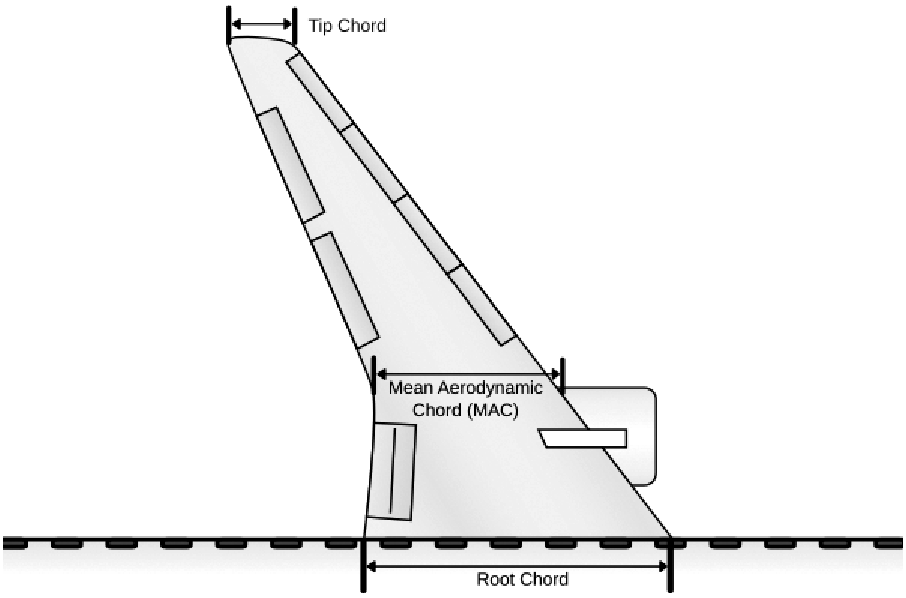

Figure 25: *Wing chords*

4. Sweepback Angle

This is the angle the first quarter-chord points on the wing make with the fuselage. Most aeroplanes have their wings swept back to minimise drag at high speeds. At high speeds the air becomes compressed upon hitting the wings. This would increase drag substantially if the wings were at right angles to the flow.

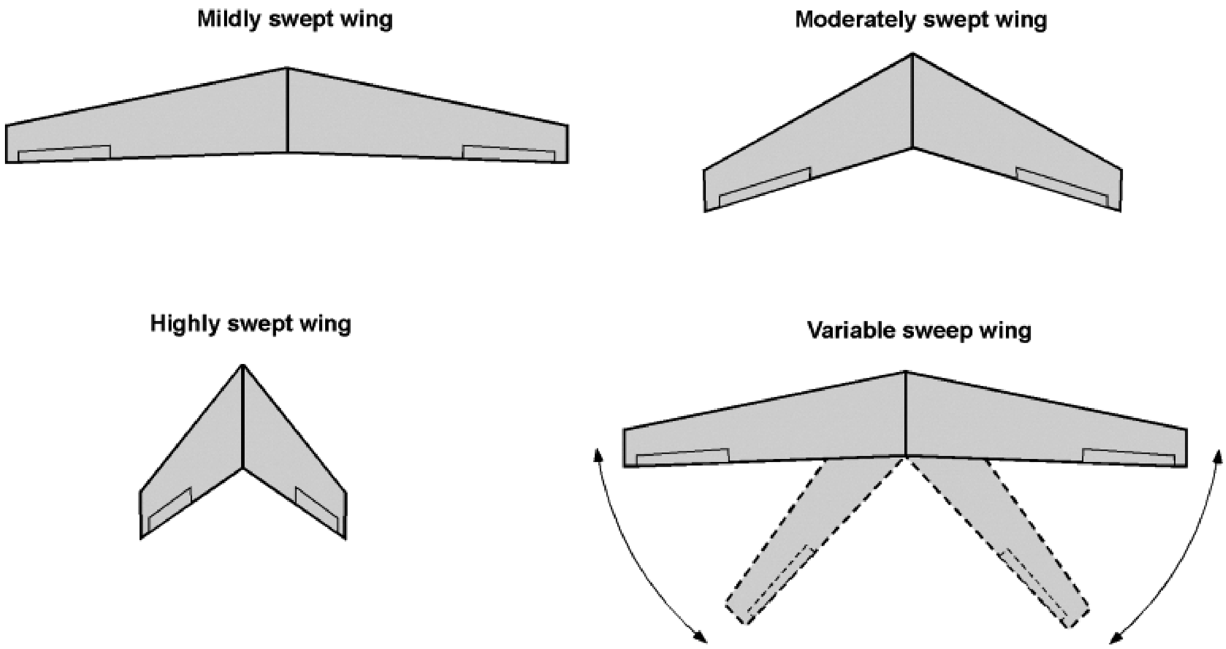

Figure 26: *Different wing sweeps*

5. Wing twist

This is a gradual change in the angle the chord makes with the wing root. Most wings are twisted downwards towards the tip to distribute the aerodynamic forces on the wing fairly.

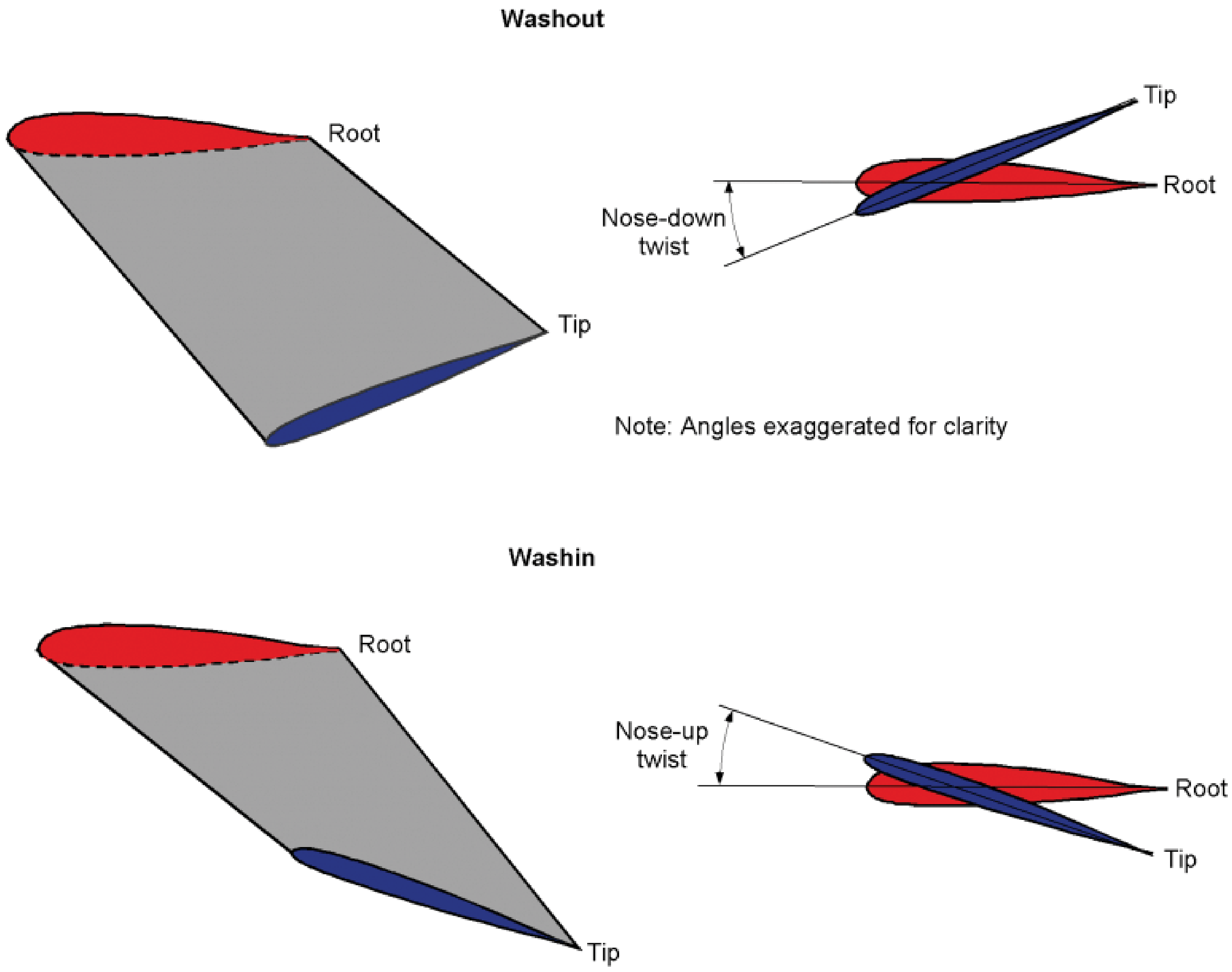

Figure 27: *Wing twist*

6. Wing dihedral and anhedral angle

Wing dihedral angle is the angle the wing makes with aircraft's lateral axis. It is introduced to enhance the aircraft's lateral or roll stability. When the aircraft has a high wing, it makes the aircraft very stable and unable to roll easily. This is because the centre of gravity is below the centre of lift. Engineers therefore bend the wings downwards to bring the centre of lift closer to the centre of gravity. This downward bend is known as the anhedral angle.

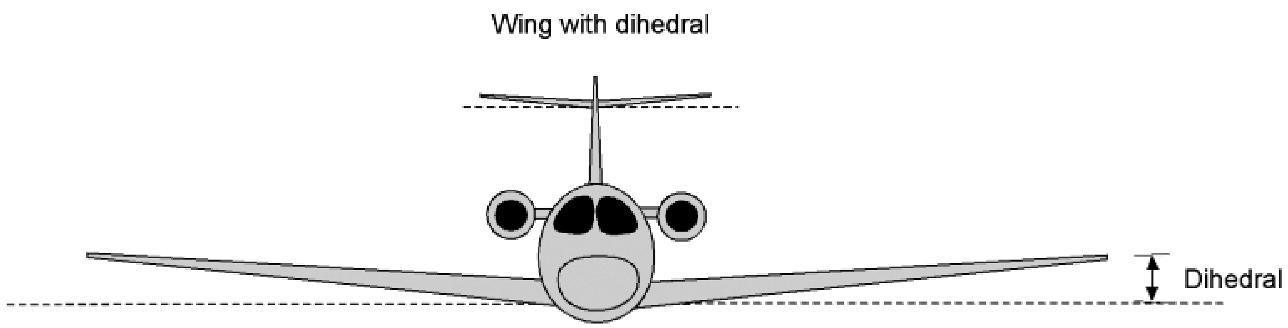

Figure 27: *Wing dihedral angle*

Figure 28: *Aeroplane with dihedral wing*

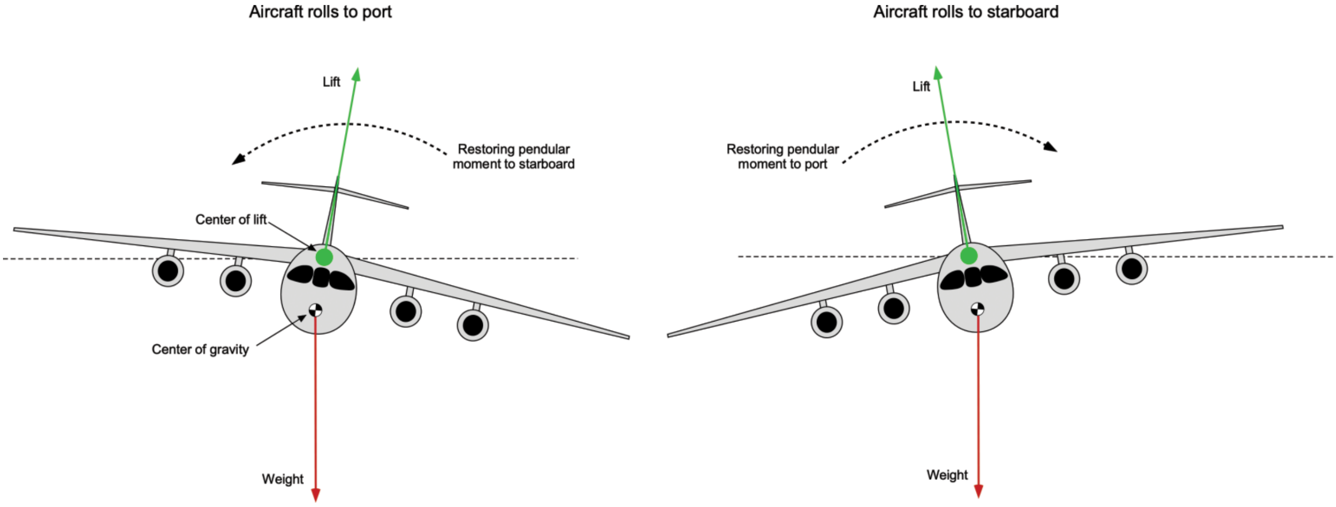

Figure 29: *Wing anhedral angle*

Figure 30: *Military cargo aeroplane with anhedral angle*

How to Calculate Wing Area

To find the area of a wing, use the following formulae:

a. **For a rectangular wing:**
Where S = Area
b = span
c = chord length

Worked Example

1. Find the area of a rectangular wing which spans 3.3m and measures 0.28m in chord length.

Solution

b = 3.3m

Chord = 0.28m

Therefore Area (S) = 3.3m 0.28m

Area=**0.924m²**

b. **For a trapezoidal wing:**
Where S = Area
b = span
c_t = tip chord
c_r = root chord

2. Calculate the area of the wing below:

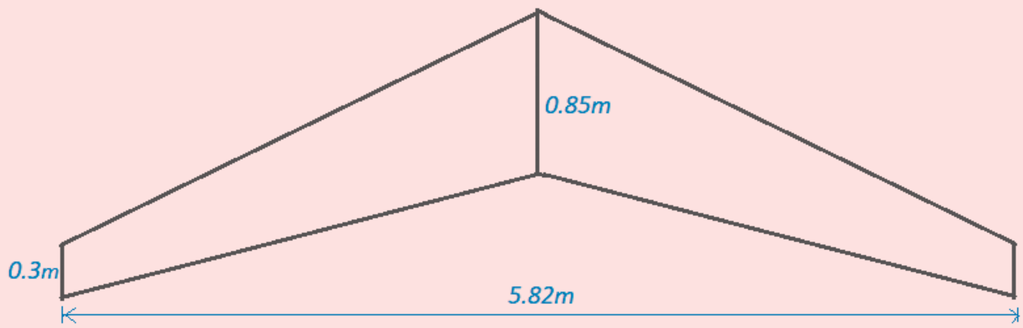

Figure 31: *Wing planform*

Solution

S = 0.5

= 0.5

= 3.3465m²

c. **For a triangular wing:**
Where S = Area

b = span

C_r = root chord

3. Calculate the wing area of the aircraft below:

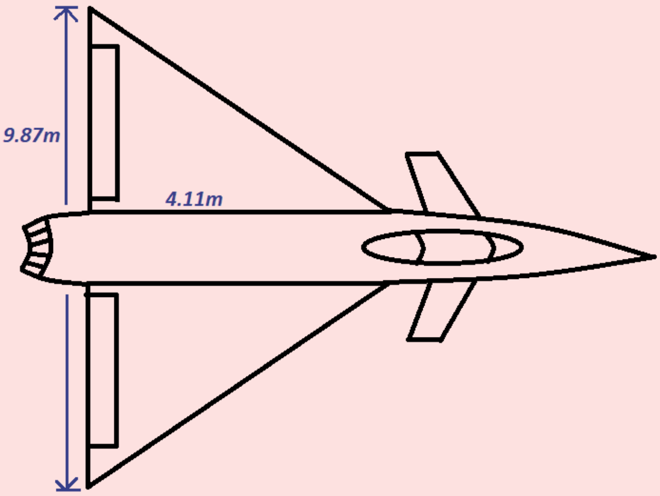

Figure 32: *NaCCA 2024*

Solution

$S = 0.5 \times cr \times b$

$= 0.5 \times 4.11m \times 9.87\ m$

$= 0.5 \times 40.5657\ m^2$

$= 20.283\ m^2$

7. Wing Aspect Ratio

A wing's aspect ratio is the ratio of the span to the mean chord. It can also be derived from the square of the span divided by the area. A high aspect ratio reduces the lift-induced drag on the wings of an aircraft making it more aerodynamically efficient. However, high aspect ratio wings tend to be slender and are subject to large amounts of flexure. So wings with large aspect ratios need more wing reinforcement to help stiffen the wing. It can be observed that gliders and airliners have large aspect ratios. One other effect of having large aspect ratio is that the aircraft's masses tend to be distributed further away from the longitudinal axis, this makes the aircraft more sluggish when rolling. It is for this reason that highly maneuverable aircraft are designed to have low aspect ratios. This is to concentrate all the mass close to the axes of rotation (pitch, roll and yaw axes) and thereby reducing the rotational inertia of the aircraft.

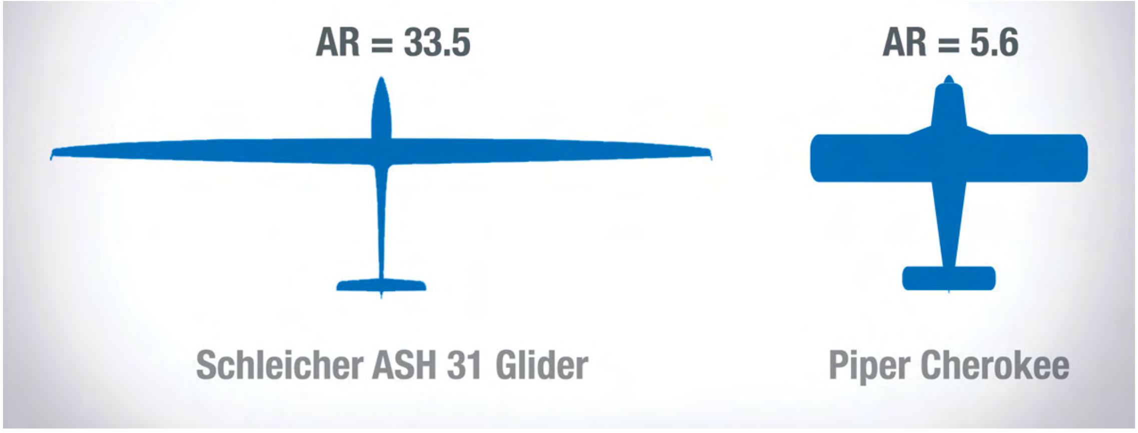

Figure 33: *Aircraft with different aspect ratios*

How to Calculate Aspect Ratio

For a rectangular wing:

Where AR = Aspect ratio

b = span

c = chord

For a composite or tapered wing:

$$AR = \frac{b^2}{S}$$

Where AR = Aspect ratio, b = span, S = wing area

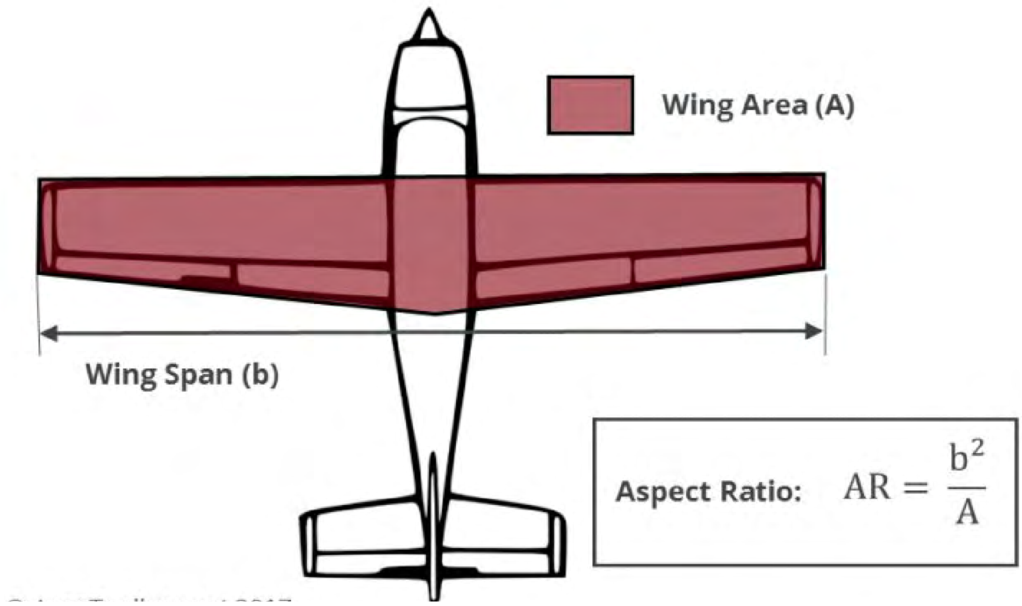

Figure 34: *Wing planform*

Winglets

Winglets are installed at the tips of the wings to prevent high pressure air beneath the wing from leaking onto the upper surface. This would increase drag at the tips and additionally create wind vortices which also contribute to induced drag.

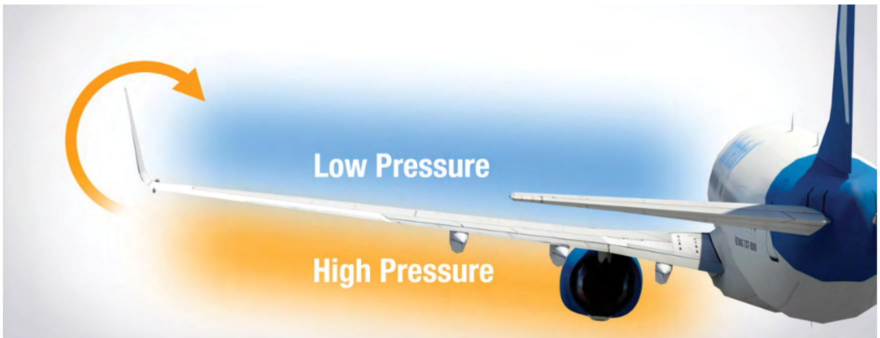

Figure 35: *Winglet preventing wingtip vortex*

Learning Tasks

1. Describe lift as a force of flight
2. Perform simple calculations for lift, wing area and aspect ratio

Pedagogical Exemplars

Talk for learning

1. Put learners into small mixed-ability groups to think-pair-share the concept of lift as a force of flight. Group learners based on their readiness, interests, and learning styles. For example, you could group learners who have a strong interest in aviation together, or group learners who learn best through hands-on activities together.
2. In smaller ability groups, learners brainstorm examples of devices used by aeronautical engineers to increase lift and share with the larger class using PowerPoint presentation.
3. Using the same ability groups, task learners to discuss and perform simple given calculations related to the concept of lift and share with the whole class.
4. In a whole-class plenary discussion moderated by the teacher, learners brainstorm features of birds that support gliding.

Note

To ensure differentiation, the teacher can form groups considering the learners' readiness, interests, and learning styles. The complexity of the task can be varied based on the group's readiness level. For instance, advanced groups can be given additional materials to categorise or asked to explain why certain materials fall into a specific category.

Key Assessments

1. **Assessment Level 1**: List three devices aeronautical engineers use to increase lift on aeroplanes
2. **Assessment Level 2**: An aircraft is flying at a speed of 120m/s. If its speed increases to 240m/s with all other parameters remaining the same, by how many times does the lift increase?
3. **Assessment Level 3**: Using a flashcard containing an image of a bird, explain why certain birds can soar for long periods.

4. **Assessment Level 4**: In small mixed-ability groups, research about high-lift devices used by aeronautical engineers and make a presentation on them.

Hint

- *The recommended mode of assessment for Week 5 is* ***group presentation.*** *Refer to Key Assessment Level 4 in the Key Assessment for an example of such a task. See* ***Appendix C*** *at the end of this section for sample rubric to score the presentation.*
- *The recommended mode of assessment for Week 6 is* ***mid-semester examination.*** *Refer to* ***Appendix D*** *for a Table of Specification to guide you to set the questions. Set questions to cover all the indicators covered for at least weeks 1 to 5.*
- *Take some time off during Week 5 to assist learners to prepare for the mid-semester examination.*

WEEK 7: DRAG

Learning Indicators

1. *Distinguish between the four major forces (lift, drag, thrust and weight) that act on an aerospace vehicle in flight.*
2. *Calculate the lift, drag and weight of an aircraft.*

What is Drag?

Drag is an aerodynamic force caused by the resistance that the air exerts on a solid object passing through it. As a body moves through the air, the air tends to have a "tugging" action on the surface of the body hence slowing it down.

Drag may be desirable or unwanted depending on the application. For example, on aeroplanes, drag is not desired when the aircraft is in flight because high drag requires that more thrust be applied which results in a high power consumption. However, in the event of landing, drag is desirable to help slow down the aircraft quickly.

Factors affecting drag

The drag force acting on a body depends on a couple of factors like the shape and orientation of the object, velocity of the air, air density and the surface area in contact with the air.

When air blows head-on against a billboard. It exerts a force on the surface of the billboard. The higher the wind speed, the higher the force exerted on the billboard. For this reason, billboards sometimes collapse in the presence of storms and strong winds. Since the billboard designers have little to no control over the wind, they employ other techniques to limit the drag force the air exerts on the billboard. One major and notable means to reduce this drag force is to make holes in the billboard. These holes are a means to reduce the surface area of the billboards to decrease the drag force that the air can exert on them.

We also observe in nature that flying and swimming animals usually have sleek and streamlined bodies. This feature of theirs enhances their ability to navigate through the air with ease.

Calculating drag

The drag acting on a body is expressed mathematically as;

$$D = \frac{1}{2}\rho v^2 S C_D$$

Where D is the drag, ρ is the density of the air, S is the surface area of the body and C_D is the drag coefficient of the body. The drag coefficient is a number that is used to factor the shape and orientation of the body into the drag equation. A sleek shape has less drag coefficient while a blunt body has a higher drag coefficient.

Worked Example

A fixed-wing UAV cruising at a speed of 30m/s has a drag coefficient of 0.05 and a rectangular wing of chord 30cm and span of 3.6m. It is flying at an altitude where the air density is 1.18kg/m3. Calculate the thrust that must be supplied by the engine during cruise.

Solution

From the problem statement, we know that the aircraft is in cruise. In cruise, thrust equals drag and lift equals weight.

T = D

Therefore, if we find the drag, then we find the required thrust.

$$D = \frac{1}{2} \rho v^2 S C_D$$

Speed, V = 30m/s

Drag coefficient, $C_D = 0.05$

Density, $\rho = 1.18 kg/m^3$

Surface area, S = span x chord (*for a rectangular wing*)

Therefore, S = (3.6) x (0.3) = $1.08m^2$

$$D = \frac{1}{2} (0.05)(30)^2 (1.08)(1.18)$$

But we know that at cruise, T = D. Therefore,

T = 28.67*N*

Ways to Reduce Drag

In many cases, an aircraft is required to fly nonstop for very long hours. Aircraft for these applications must be highly efficient, with as little energy losses as possible. In designing such aircraft, engineers employ different means to reduce the drag to the barest minimum. This is because an aircraft with high drag force acting on it will need to use more thrust when flying. This usually means more energy consumption which consequently leads to a shorter endurance.

So it is a prime motive to have an aircraft with as little drag as possible. Methods like streamlining, using retractable landing gears, rounding sharp corners and introducing fairings on protruding features like antennas, surveillance cameras and landing gears help reduce the drag force on aeroplanes.

Figure 36: *Landing gear faring*

How angle of attack affects Lift and Drag

Generally, on an aeroplane, the lift and drag vary with the angle of attack. The lift coefficient increases with increasing angle of attack until the angle of attack reaches the critical angle of attack (or stall angle) which is usually about 16 degrees for ordinary aerofoils. (*High lift devices can be used to increase the stall angle*). Beyond the critical angle of attack, the lift coefficient sharply drops. This sudden drop in lift coefficient is due to the separation of the boundary layer on the upper surface of the wing. This condition is called stall and can be very dangerous and difficult to recover from. The type of aerofoil used would determine the stall angle.

Usually, aerofoils with high camber values generate more lift than lower camber and symmetrical aerofoils as shown by the lift coefficient against AoA curve in *figure 37*. Note that for the symmetrical aerofoil, the lift coefficient is zero at 0° AoA. This is because at 0° AoA, a symmetrical aerofoil generates no lift. The pressure distributions on top and below the wing are the same and hence cancel out.

As the angle of attack increases, the drag coefficient also increases. Below are diagrams showing how the lift and drag coefficients vary against angle of attack.

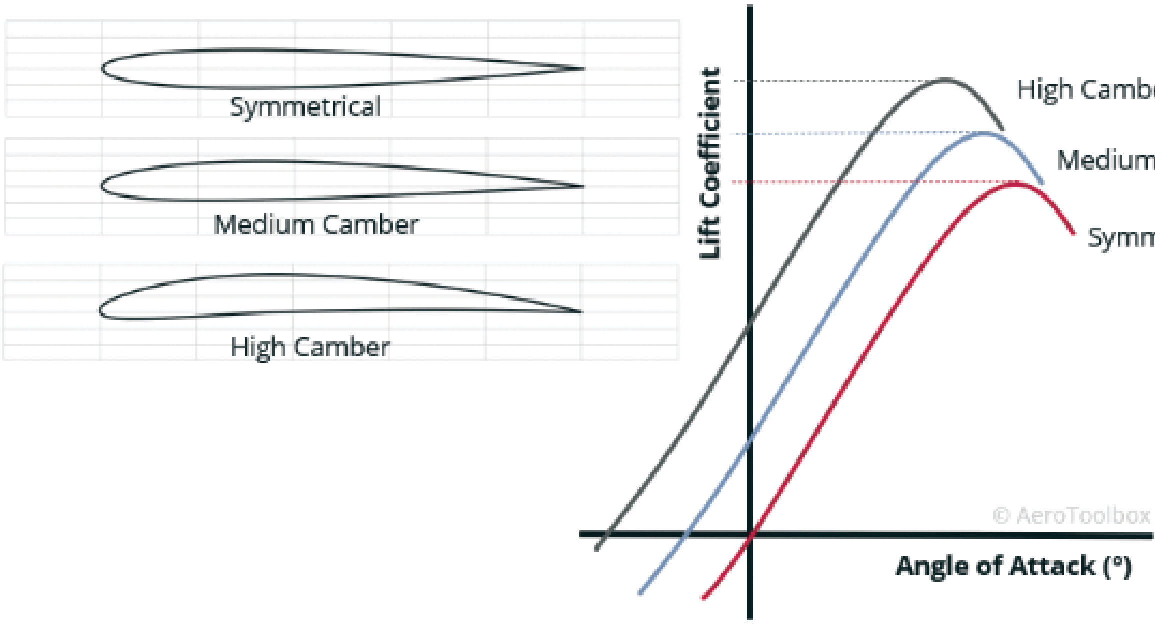

Figure 37: *Variation of angle of attack with lift coefficient*

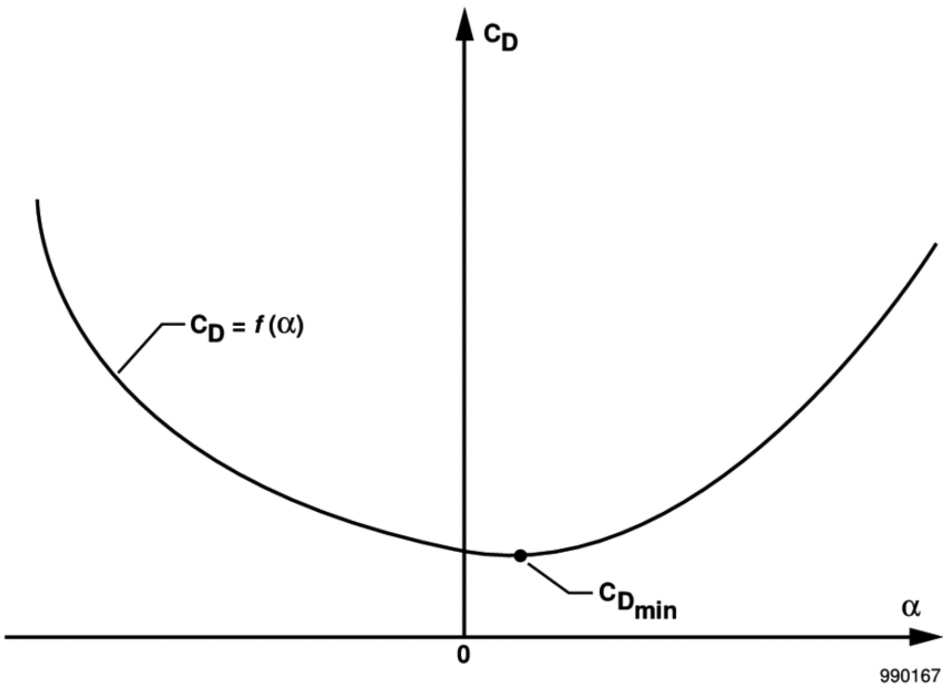

Figure 38: *Variation of drag with angle of attack*

Learning Tasks

1. Explain the concept of drag
2. Using a source of an airstream (electric standing fan or air blower), experiment with a cardboard to experience the force that an airstream exerts on the cardboard. Vary the speed of the air and size (surface area) of the cardboard and document your observation of how the variation of speed and area affects the force on the cardboard. Try this activity on different bodies and shapes.
3. Watch a video on skydivers and share your views on why they spread their arms and legs upon diving.
4. Research on the contribution of the boundary layer to drag.

Pedagogical Exemplars

1. **Talk-for-Learning**
   a. In small ability groups, allow learners to think-pair-share the concept of drag after watching a video on skydiving.
   b. In a whole-class plenary discussion, allow learners to ask questions about the video they watched in order to clarify all misconceptions about drag.

Note

Remember to consider socio-emotional learning by encouraging respectful and open communication among learners. Promote gender equality and social inclusion by ensuring that all learners, regardless of gender or social background, are given equal opportunities to participate in the discussion. Lastly, incorporate national core values in your teaching by relating the discussion to real-life scenarios or issues relevant to Ghana.

2. **Experiential Learning**
   - **a.** Using available resources (e.g. cardboard, A4 sheets, electric fan, electric blower), the teacher demonstrates the resistance of air. Anticipate that some learners may struggle with certain concepts and plan for additional support or resources to help these learners.
   - **b.** In pairs, learners are encouraged to discuss the procedure and outcome of the experiment and ask questions for clarification. Develop a peer mentoring system in the mixed-ability groups to encourage more advanced learners to support their colleagues in understanding and effectively applying these concepts.

Key Assessments

1. **Assessment Level 1:** State three factors that affect the drag generated by an aircraft.
2. **Assessment Level 2**
   - **a.** Using your knowledge of how drag can be reduced, explain why sports cars are designed to have a sleek and streamlined shape.
   - **b.** Explain why boundary layer separation causes a sudden loss of lift.
3. **Assessment Level 4**
   - **a.** On an aircraft, there are sensors installed to warn the pilot of impending stall. Suppose you are a pilot on an aircraft and the stall warning alarm blares, which control inputs will you initiate to get out of the stall?
   - **b.** With the aid of a standing fan/portable air blower and rectangular cards of three sizes, establish the relationship between free-stream velocity, projected area and drag of an object. Summarise your findings in the following table.

S/N	Air speed	Card size	Effect on Drag
1	Slow	Small	E.g. low drag
		Medium	
		Large	
2	Fast	Small	
		Medium	
		Large	

Hint

The recommended mode of assessment for Week 7 is ***practical work****. Refer to* ***Question 3b*** *of Assessment level 4 under the key assessment for an example of such a task.*

WEEK 8: WEIGHT AND WEIGHT DISTRIBUTION

Learning Indicators

1. *Distinguish between the four major forces (lift, drag, thrust and weight) that act on an aerospace vehicle in flight.*
2. *Calculate the lift, drag and weight of an aircraft.*

Weight is the force that the Earth's gravitational field exerts on any mass in that field. Weight is measured in Newtons and is a product of a body's mass and the acceleration due to gravity on Earth. It is algebraically expressed as;

(Where W is the weight of the body, m is the mass and g is the acceleration due to gravity on Earth.)

Every physical object has weight and the weight of any two objects is the sum of their individual weights. For example, in the figure below, the weight of both objects will be equal to the sum of their individual weight. That is;

Total weight,

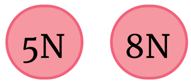

Figure 39: *Summing the weight of two masses*

On an aircraft, the gross weight (total weight) of the aircraft is equal to the sum of the weights of all the individual components. For this reason, aircraft designers resort to using strong, light-weight parts for aircraft construction.

Moment of a Force

It is not only the weight reduction that is important in aircraft design, but also how that weight is distributed. The weight of each component causes a turning effect about a reference point on the aircraft. In physics, this turning effect is called a moment. It is caused when a force is applied to an object at a perpendicular distance.

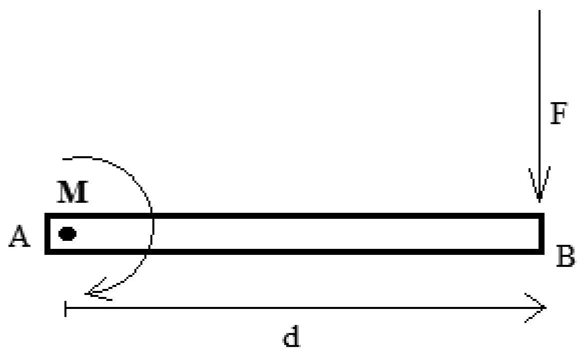

Figure 40: *Force and moment system acting on a beam*

Let's consider the setup in the above figure. A rigid bar of length d is pin-jointed at point A and the other end is free to move. If a vertical force F is applied downward at point B there would be a clockwise turning effect of the bar about point A. This turning effect is what we call a moment in physics. The moment of force F about point A is the product of the force F, and the perpendicular distance d. This is mathematically expressed as;

The SI unit of moment is the Newton-metre (N.m). When multiple forces are exerted on a body, the total moment is equal to the algebraic sum of the moments contributed by the individual forces acting on the body.

Sample Problem 1

A nine-metre rod is subjected to forces as shown below. Calculate the total moment about C.

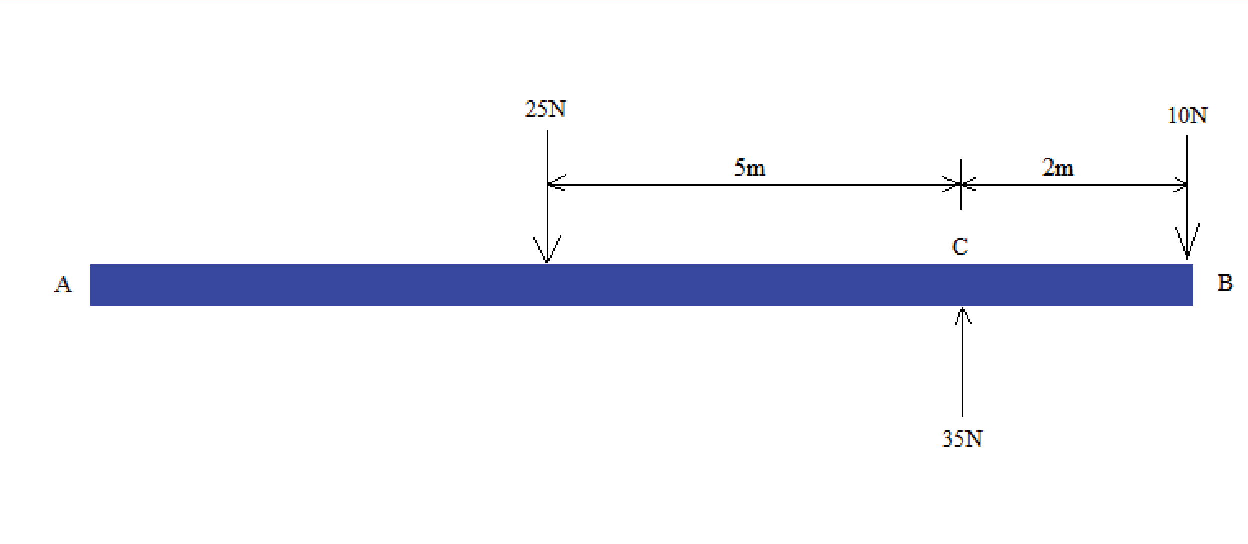

Figure 41: *Diagram for Sample Problem 1*

Solution

There are three forces acting on the bar in the diagram. The point of interest is C. Let the moment about C be denoted by M_c. Let's also pick a sign convention. Let clockwise moments be negative and counterclockwise moments be positive. The 25N force creates a counterclockwise moment about C and the 10N force causes a clockwise moment about C. The 35N force causes no moment about C because it is acting exactly at point C and there is no perpendicular distance between the 35N force and point C. In essence, the perpendicular distance is zero. Therefore,

$M_c = (25)(5) + -(10)(2)$

$M_c = 125 - 20$

$M_c = 105\ N.m$

Therefore, the resultant moment from the system of forces about C is a 105Nm counterclockwise moment about C.

Centre of Gravity

Centre of gravity is the point on a body where the weight of the whole body seems to be concentrated. It is the point on the body where the total moment is zero. Let's take a classic example.

Consider the aircraft below. The respective weight of the major components shown in the image are:

1. Engine – 6000N
2. Fuel – 900N
3. Payload – 1500N
4. Battery – 600N
5. Flight Data Recorder (FDR) – 55N

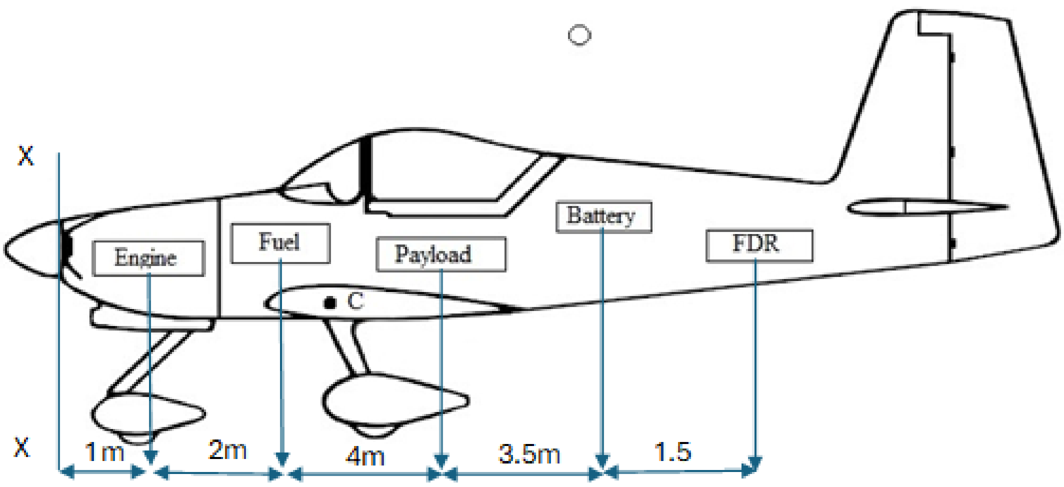

Figure 42: *Weight distribution on an aircraft*

In order to find the CG of the aircraft, we take the moments of all weights of all the individual components and divide by the total weight. Using the line X-X as a reference;

$$M_{x-x} = 6000(1) + 900(1 + 2) + 1500(4 + 2 + 1) + 600(3.5 + 4 + 2 + 1) + 55(1.5 + 3.5 + 4 + 2 + 1)$$

$$M_{x-x} = 6000 + 2700 + 10500 + 6300 + 660$$

$$M_{x-x} = 26160 \text{ N.m}$$

Next, we calculate the total weight by summing up the weights of all the individual components.

$$W = 6000 + 900 + 1500 + 600 + 55$$

$$W = 9055 \text{ N}$$

The centre of gravity position X_{CG} is found by dividing the sum of moments about X-X by the total weight.

$$X_{CG} = \frac{M_{x-x}}{W}$$

$$X_{CG} = \frac{26160}{9055}$$

$$X_{CG} = 2.89m$$

Learning Tasks

1. Using a laboratory scale, measure and record the mass of classroom items like books, a box of markers, etc. Calculate the weight of these items. Take acceleration due to gravity, g, as $9.81 m/s^2$.
2. Using your finger tip, try to find the point on a ruler where it balances.
3. Using a metre rule with masses suspended on them, calculate the point at which the ruler balances (i.e. the point where the total moment is zero).

Pedagogical Exemplar

Experiential Learning: In a laboratory setup, learners should measure the masses of various items (like books, pens, markers) using a digital scale and record their individual masses. Learners should then go on to calculate the weights of the items.

Key Assessment

1. **Assessment Level 1:** A single-seater powered-glider has components with the following weights;
   a. Airframe = 1200N
   b. Fuel = 400N
   c. Engine = 100N
   d. Payload = 800N
   e. Miscellaneous = 100N

   Calculate the weight of the aircraft.
2. **Assessment Level 2:** It has been determined that the CG position of a small UAV is behind the desired point, making the UAV tail-heavy. On the UAV you have the option to move the battery around. As a UAV operator, what action will you take to move the CG forward?
3. **Assessment Level 3:** An electric powered aircraft is to be modified to run on a small jet engine. It has been determined that the jet engine has a similar mass to that of the motor used in the original design. The jet engine is to be run on jet-A1 from a single fuel tank. At what location should the fuel tank be placed to ensure proper balance and why?
4. **Assessment Level 4:** The aircraft below has a total weight of 9055 N. The engine weighs 6000N, the fuel weighs 800N and it carries a payload of 1600N. It uses a 24V battery pack which weighs 550N.
   a. What is the weight of the flight data recorder (FDR)?
   b. Calculate the CG position of the aircraft.
   c. If the quarter-chord of the aircraft is 3.5m away from the reference line X-X and the only option you have is to move the fuel tank. How far from line X-X should the fuel tank be place in order to have the CG at 3.5m away from the line X-X?

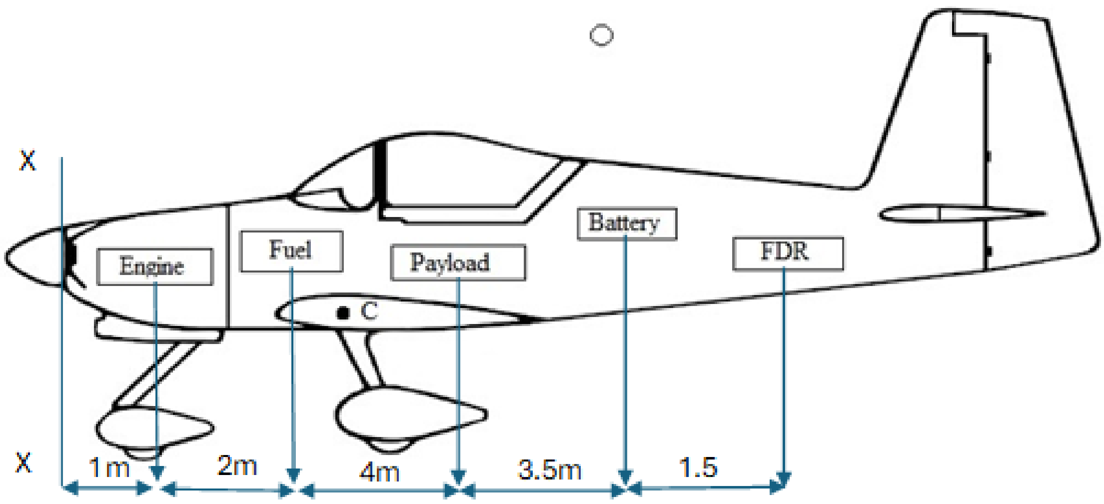

Figure 42

Hint

- *The recommended mode of assessment for Week 8 is **discussion.** Refer to Questions 2 and 3 of the key assessment for sample tasks.*
- *Learners are to submit their **Group Project Work** this week. Please score the group work immediately using the rubric given in **Appendix A** and record the scores for onward submission to the STP.*
- *Mid-semester examination scores should be ready for submission to STP.*

SECTION 2 REVIEW

This has been an exciting journey into the main physical laws governing the behaviour of aerofoils, wings and aircrafts. The four forces of flight, that is lift, drag, thrust and weight, have been discussed as fundamental to the development of air vehicles. This section has broadened learners' horizon on aerodynamic thought, leading up to critical consideration of aerospace design. This basic knowledge will be built upon in subsequent discussions. The learner is now positioned to develop conceptual understanding of aerospace engineering.

Additional Reading

1. Fundamentals of Aerodynamics, 6th Edition – By John Anderson Jnr.

2. Conceptual Aircraft Design: An Industrial Approach – By Ajoy Kumar Kundu, Mark A. Price and David Riordan.

3. General Aviation Aircraft Design – By Snorri Gudmundssonj.

APPENDIX C: Rubric For Scoring The Presentation

Refer to Task from Week 5

Criterion	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs improvement (1 mark)
Communication skills	Presenter exhibits four of the following skills: Audible voice, Keeps eye contact, Pays attention to audience, Interacts with audience, Uses gestures aright	Presenter exhibits three of the following skills: Audible voice, Keeps eye contact, Pays attention to audience, Interacts with audience, Uses gestures aright	Presenter exhibits two of the following skills: Audible voice, Keeps eye contact, Pays attention to audience, Interacts with audience, Uses gestures aright	Presenter exhibits one of the following skills: Audible voice, Keeps eye contact, Pays attention to audience, Interacts with audience, Uses gestures aright
Teamwork	Learners exhibit at least four of these behaviours: Contributing to the group, Respecting the views of others, Tolerating others, Resolving conflicts, Taking responsibility	Learners exhibit three of these behaviours: Contributing to the group, Respecting the views of others, Tolerating others, Resolving conflicts, Taking responsibility	Learners exhibit two of these behaviours: Contributing to the group, Respecting the views of others, Tolerating others, Resolving conflicts, Taking responsibility	Learners exhibit one of these behaviours: Contributing to the group, Respecting the views of others, Tolerating others, Resolving conflicts, Taking responsibility
Knowledge of content	Mention is made in the presentation of four or more high lift devices	Mention is made in the presentation of three high lift devices	Mention is made in the presentation of two high lift devices	Mention is made in the presentation of one high lift devices

Criterion	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs improvement (1 mark)
Design and creativity	The presentation slides show creativity and organisation of all 4 of these: layout that draws attention to key points, Visuals are eye-catching, relevant, and enhance understanding of the content, Text and images are balanced and easy to follow, Slides are not overcrowded with information	The presentation slides show creativity and organisation of three of these: layout that draws attention to key points, Visuals are eye-catching, relevant, and enhance understanding of the content, Text and images are balanced and easy to follow, Slides are not overcrowded with information	The presentation slides show creativity and organisation of two of these: layout that draws attention to key points, Visuals are eye-catching, relevant, and enhance understanding of the content, Text and images are balanced and easy to follow, Slides are not overcrowded with information	The presentation slides show creativity and organisation of one of these: layout that draws attention to key points, Visuals are eye-catching, relevant, and enhance understanding of the content, Text and images are balanced and easy to follow, Slides are not overcrowded with information

APPENDIX D: Table of specification for mid-semester examination (Semester 1)

Week	Focal Area	Type of question	DOK Levels				Total
			1	2	3	4	
1	Climate, weather and weather elements	Multiple choice	4				4
2	The impact of weather on flight	Multiple choice		4			4
3	International standard atmosphere	Multiple choice	2	4			6
		Essay			1		1
4	Introduction to Aerodynamics	Multiple choice	2	4			6
5	Lift	Essay			1		1
	Total	Multiple choice	8	12	-		**20**
		Essay	-	-	2		**2**

4. .

Figure Number	Link	QR Code
Figure 9: Aerofoil nomenclature	Aerofoil Geometries – Introduction to Aerospace Flight Vehicles (erau.edu)	
Figure 10: Laminar and turbulent flow	Laminar Flow (piping-designer.com)	
Figure 11: Boundary layer	Boundary Layer - F1 Technical Terms - SomersF1 - The technical side of Formula One	
Figure 12: Flow in a tube	NACCA 2024	
Figure 13: Flow in a tube	NACCA 2024	
Figure 14: Forces in flight	https://forums.flightsimulator.com/t/guide-the-four-forces-of-flight-how-do-planes-fly/166567	
Figure 15: Flow in a tube	NACCA 2024	

Figure Number	Link	QR Code
Figure 16: Aerodynamic Forces	https://en.wikipedia.org/wiki/Lift_(force)	
Figure 17:	http://230nsc1.phy-astr.gsu.edu/hbase/Fluids/aerofoil.html	
Figure 18: Newtonian lift	https://www.researchgate.net/figure/Lift-generated-on-an-aerofoil-by-a-downward-deflection-of-moving-air_fig1_337298231	
Figure 19	https://airscapemag.com/2015/10/15/lift-equation/	
Figure 20	https://skybrary.aero/articles/flaps	
Figure 21	https://skybrary.aero/articles/slats	
Figure 22	https://skybrary.aero/articles/krue-ger-flaps	
Figure 23	https://eaglepubs.erau.edu/introduc-tiontoaerospaceflightvehicles/chapter/wing-shapes-and-nomenclature/	
Figure 24	https://www.abbottaerospace.com/aa-sb-001/22-aircraft-specific-design-fea-tures-and-design-methods/22-16-57-wings/22-16-1-general/	
Figure 25	https://en.wikipedia.org/wiki/Chord_%28aeronautics%29	

Figure Number	Link	QR Code
Figure 26	https://eaglepubs.erau.edu/introductiontoaerospaceflightvehicles/chapter/wing-shapes-and-nomenclature/	
Figure 27	https://eaglepubs.erau.edu/introductiontoaerospaceflightvehicles/chapter/wing-shapes-and-nomenclature/	
Figure 28	https://eaglepubs.erau.edu/introductiontoaerospaceflightvehicles/chapter/wing-shapes-and-nomenclature/	
Figure 29	https://eaglepubs.erau.edu/introductiontoaerospaceflightvehicles/chapter/wing-shapes-and-nomenclature/	
Figure 30	https://www.rccad2vr.com/aeronautics/dihedral-vs-anhedral-wings	
Figure 31	NaCCA 2024	
Figure 32	NaCCA 2024	
Figure 33	https://www.boldmethod.com/learn-to-fly/aircraft-systems/how-does-aspect-ratio-affect-aircraft-wings/	
Figure 34	https://aerotoolbox.com/intro-wing-design/	
Figure 35	https://www.boldmethod.com/learn-to-fly/aerodynamics/how-winglets-reduce-drag-and-how-wingtip-vortices-form/	
Figure 36	ZODIAC XL Wheel Fairings (zenithair.com)	
Figure 37	Aircraft Flap and Slat Systems | AeroToolbox	

Figure Number	Link	QR Code
Figure 38	Drag coefficient plotted as a function of angle of attack (schematic). | Download Scientific Diagram (researchgate.net)	
Figure 39	NaCCA 2024	
Figure 40	NaCCA 2024	
Figure 41	825-RV7-side-view.jpg (730×323) (vansaircraftbuilders.com)	
Figure 42	825-RV7-side-view.jpg (730×323) (vansaircraftbuilders.com)	

SECTION 3: PROPULSION SYSTEMS

Strand: Core Concepts in Aerospace

Sub-Strand: Aerodynamics and Propulsion

Learning Outcome: *Compute the thrust generated by the propulsion system of an aerospace vehicle*

Content Standard: Determine the force required for propulsion of an aerospace vehicle

Hint

The End of Semester Examination will be conducted in Week 12. Refer to Appendix F for a Table of Specification to guide you to set the questions. Set questions to cover all the indicators covered for at least weeks 1 to 11.

INTRODUCTION AND SECTION SUMMARY

This section introduces learners to the various propulsion systems used on aerospace vehicles and how the thrust force they generate is computed. Emphasis is made on the physics principles that these propulsion systems employ to generate thrust. The section also discusses the unique benefits of each of the types of propulsion system outlined and the performance requirements that they are best suited for. Learners are expected to understand the principles behind the operations of the types of aerospace propulsion systems and be able to perform calculations to estimate the thrust they generate.

The weeks covered by the section are:

Week 9: *Principles and Types of Aerospace Propulsion Systems I*

Week 10: *Principles and Types of Aerospace Propulsion Systems II*

Week 11: *Estimating the thrust of jet engines*

Week 12: *Calculation of Rocket thrust*

SUMMARY OF PEDAGOGICAL EXEMPLARS

Knowledge and competencies around aerospace propulsion systems require teachers to deliberately engage their learners in hands-on activities that incorporate cross-cutting issues such as GESI, SEL, 21st Century Skills and core competencies and national core values. In an attempt to achieve the foregoing, teachers must be intentional in using innovative pedagogical approaches such as problem-based learning, experiential learning and talk-for-learning approaches. Teachers must acknowledge the varied learning styles of learners (i.e., shallow, strategic and deep learners) in order to know the appropriate activities to engage the learners in. Moreover, the varied abilities of learners (i.e. approaching proficiency, proficient and highly proficient) should direct the kind of support services that need to be provided at each teaching learning encounter. To be impactful in using the relevant pedagogies, resources are to be made available for the delivery of the concepts of aerospace propulsion systems. Learner-centred approach should be emphasised throughout the teaching of all the relevant concepts.

ASSESSMENT SUMMARY

The assessment strategies to be used should be based on the characteristics of learners and the resources available. Context and cultural responsive formative assessment should be emphasised. In using the strategies, teachers are supposed to be conscious in the formation of groups and cater for gender, socio-emotional and cultural diversities. For learners to have better understanding and first-hand experience of aerospace propulsion systems, they should embark on field trips to aircraft maintenance facilities or air bases across the country. Online resources like videos and simulators can also be leveraged to supplement learners' experience with aerospace propulsion systems.

The recommended assessment modes for each week include:

Week 9: *Poster presentation*

Week 10: *Debate*

Week 11: *Computational task*

Week 12: *End of Semester Examination*

Refer to the ***"Hint"*** at the key assessment for each week for additional information on how to effectively administer these assessment modes. Always remember to score learners' work with rubric/marking scheme and provide prompt feedback to learners on their performance.

You are encouraged to administer these recommended assessments for each week, carefully record the results, and submit them to the **Student Transcript Portal (STP)** for documentation

WEEK 9: PRINCIPLES AND TYPES OF AEROSPACE PROPULSION SYSTEMS I

Learning Indicator: *Explain the principles of operation of the different propulsion systems (rockets, jet engines, and internal combustion engine)*

FOCAL AREA: PRINCIPLES OF AEROSPACE PROPULSION AND PROPELLER-BASED PROPULSION SYSTEMS (ELECTRICAL AND INTERNAL COMBUSTION)

Introduction to Propulsion

In the discussion on how lift is generated in the previous section, it was emphasised that lift is generated when there is a relative movement of air to the wing. Air vehicles employ various mechanisms to push the aircraft through the air in order to create this relative airstream. These mechanisms are called propulsion systems.

The term propulsion is derived from two Latin words: "pro" which means forward and "pellere" which means to push or to drive. Propulsion simply means to drive a body forward. A propulsion system is a system of components that function together to drive forward a body. The force that propulsion systems generate to move a body forward is called **thrust**.

To better understand the principles behind thrust generation, it is imperative that we first understand Newton's Laws of motion.

Newton's Laws of Motion

1. Newton's first law states that **"a body will be at a state of rest or move with a constant velocity in a straight line, unless acted upon by an unbalanced external force"**. This is known as the law of inertia. It simply means a body at rest will not move unless some unbalanced external force acts on it and also, a body will move at constant speed in a straight line without accelerating, decelerating, changing direction or coming to a stop until an external unbalanced force acts on it.

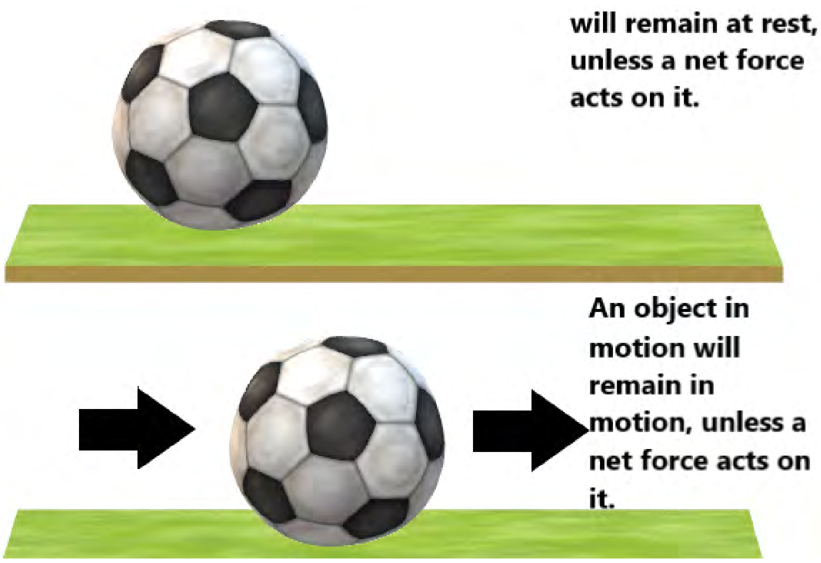

Figure 43: *A ball showing Newton's law of inertia*

Newton's First Law of Motion - Formula, Examples, and Applications

https://www.geeksforgeeks.org/newtons-first-law-of-motion/?ref=lbp

Consider the above diagram. A ball will be at rest if there is no net force acting on it. This is the case observed in nature. An object will be stationary unless moved. The other side of the law of inertia states that, a moving object will not stop unless a net force causes it to. At first, this may seem to be contrary to what we observe in nature because we all know that when a ball is kicked, it rolls, slows down and eventually comes to a stop. This may not seem to conform to the law of inertia because we have ignored a very important force that causes the ball to stop, friction! The friction between the ball and the ground resists the motion of the ball until it brings it to a stop. If there was no friction, the ball would keep moving at constant speed in a straight path.

2. Newton's second law states that "**the rate of change of momentum of a body is proportional to the net force acting on the body and it acts in the direction of the net force**". Momentum is the product of a body's mass and velocity. It is a vector quantity like velocity. It is mathematically expressed as;

   Where P is momentum, m is the mass of the object and v is the velocity.

   Newton's second law simply means a net force acting on a body changes its momentum and the change in momentum acts in the direction of the net force.

   Newton's second law can be expressed as

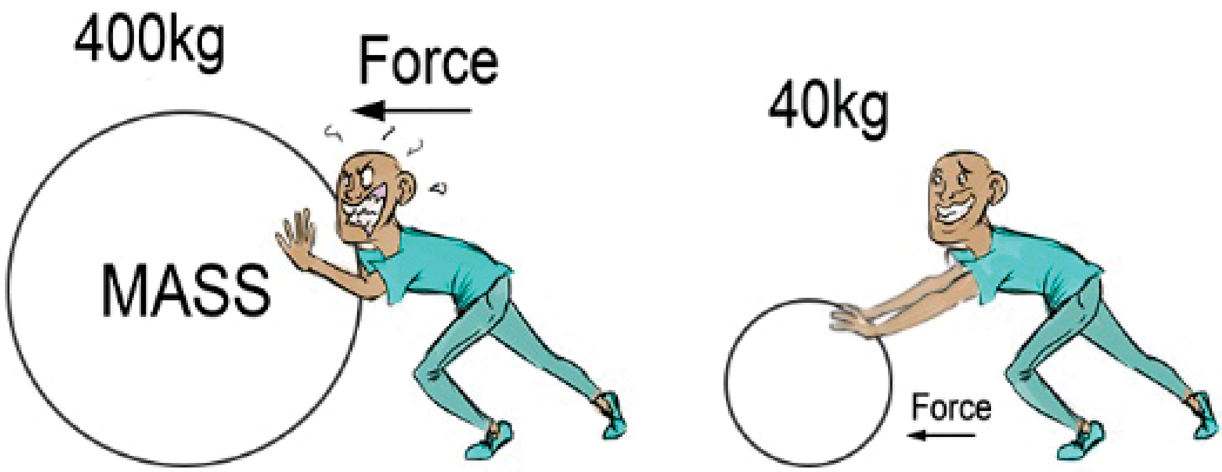

Figure 44: *Demonstrating Newton's second law*

Newton's second law - Examples

https://mammothmemory.net/physics/newtons-laws-of-motion/newtons-second-law--examples/newtons-second-law-examples.html

Consider the image above where in two different instances a man tries to move a mass. In the first instance, the mass is 400kg and in the second, the mass is 40kg. Due to the fact that the first mass is huge, the man needs to apply more force to accelerate it (i.e. change its velocity from zero to some finite value). However, in the second instance less force is required to accelerate the mass since it is less than the mass in the first instance.

3. Newton's third law states that "**to every action, there is an equal and opposite reaction**". This law means that when two bodies come into contact, they exert forces on each other which are equal in magnitude but opposite in direction. Consider for example a brick lying on a table. The brick exerts a downward force on the table due to its weight. The table also exerts an upward force on the brick, equal in magnitude to the weight of the brick to keep the brick in equilibrium. This law is called the law of action and reaction. Let's look at another example. In the diagram below, a balloon inflated with air is released. As air rushes out through the neck of the balloon, it produces a reaction force on the balloon causing it to move in the opposite direction. The action in this case is the air rushing out and the reaction is the balloon moving in the opposite direction.

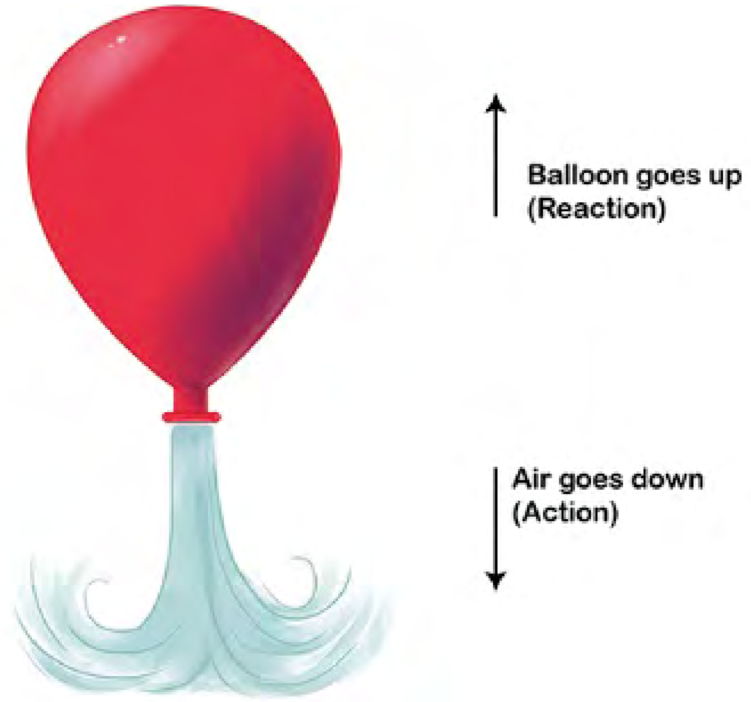

Figure 45: *Inflated balloon showing Newton's third law*

Newton's third law - Examples

https://mammothmemory.net/physics/newtons-laws-of-motion/newtons-third-law--examples/newtons-third-law-examples.html

Almost all aerospace propulsion systems are based on some form of a reaction engine. A reaction engine is an engine that makes use of Newton's third law of motion to generate thrust. Reaction engines achieve this by expelling masses at high speeds in one direction in order to create a reaction force in the opposite direction. This reaction force is the thrust.

Types of Aerospace Propulsion Systems

Aerospace propulsion systems fall into four main categories. They are:

1. Electrical propulsion system
2. Piston engine propulsion system
3. Gas-turbine propulsion systems
4. Rocket propulsion

1. Electrical propulsion system

This type of propulsion system uses a rotating propeller to expel air towards the rear of an aircraft. As the propeller rotates, it scoops air in front of it and shoots it behind. This causes a reaction force to push the aircraft forward. The propeller is driven by an electric motor. The amount of thrust force generated by the propeller typically depends on the rotational speed of the motor as well as the propeller's diameter and pitch. The diameter of the propeller refers to the length of the propeller from tip to tip. It is the diameter of the circle the propeller's tips traverse while rotating. A propeller with a large diameter is able to expel more air and hence generates more thrust. The pitch of the propeller is the distance the propeller moves forward in one complete rotation. Consider a craftsman putting a screw into a piece of wood. For each complete turn the craftsman makes with the screw driver, the screw moves a certain distance into the wood. The more the turns, the further the screw goes into the piece of wood. In a similar way, for each rotation, the propeller moves forward by a certain distance. That distance is the propeller's pitch.

Figure 46: *Elektra Trainer*

Elektra Trainer - Elektra Solar (elektra-solar.com)

https://www.elektra-solar.com/products/elektra-trainer-solar/

Electrical propulsion systems are usually powered by batteries. They are less complex and easier to implement and maintain compared to other types of propulsion systems. They are ideal for light unmanned aerial vehicles. In recent years, they are also being used on light manned aircraft. Two major current drawbacks of electrical propulsion systems are their low power-to-weight ratio and short endurance. However, these drawbacks are set to improve once battery and solar panel technologies improve.

2. Piston Engine Propulsion System

The piston engine (also known as reciprocating engine) is a type of internal combustion engine that uses one or more reciprocating pistons to convert chemical energy from fuel to mechanical energy. These engines are similar to those found in cars with some modifications to make them more suitable for flight. Some of these modifications include the use of two ignition systems for redundancy and safety and air cooling in place of liquid cooling to reduce weight. Piston engines used in aviation are fueled using AVGAS (Aviation Gasoline) or diesel for some light aircraft. The pistons move in and out. Each in or out movement is called a stroke. Piston engines may be two stroke or four stroke engines. A two stroke engine makes one complete power cycle in two strokes while a four stroke engine completes a power cycle in four strokes.

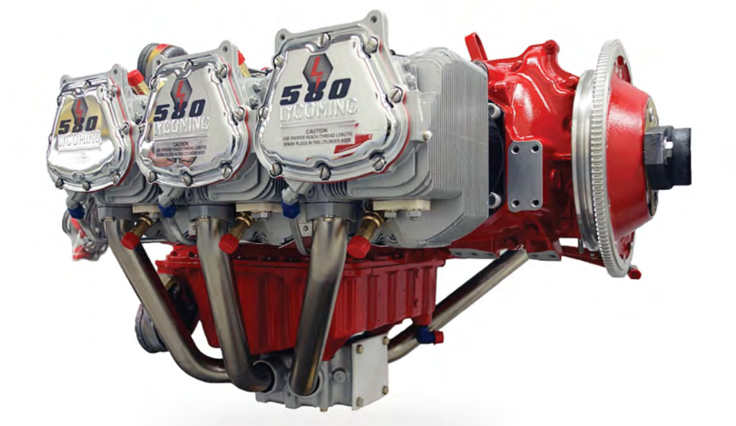

Figure 47: *Internal Combustion Engine*

Thunderbolt Engine | Aerobatic Aircraft | Lycoming

https://www.lycoming.com/engines/thunderbolt

Operation of a 4-stroke piston Engine

The inlet valve opens for air to come into the combustion chamber and the piston moves down. The outlet valve remains closed in this stage.

The inlet and outlet valves close and the piston moves up to compress air in the combustion chamber.

With both valves still closed fuel is injected into the combustion chamber and then ignited. The air-fuel mixture explodes upon ignition and expands rapidly, pushing the piston down. This stroke is where the mechanical energy is derived from the fuel.

The outlet valve opens and the piston moves up to expel the combusted gases from the combustion chamber. The cycle then begins again.

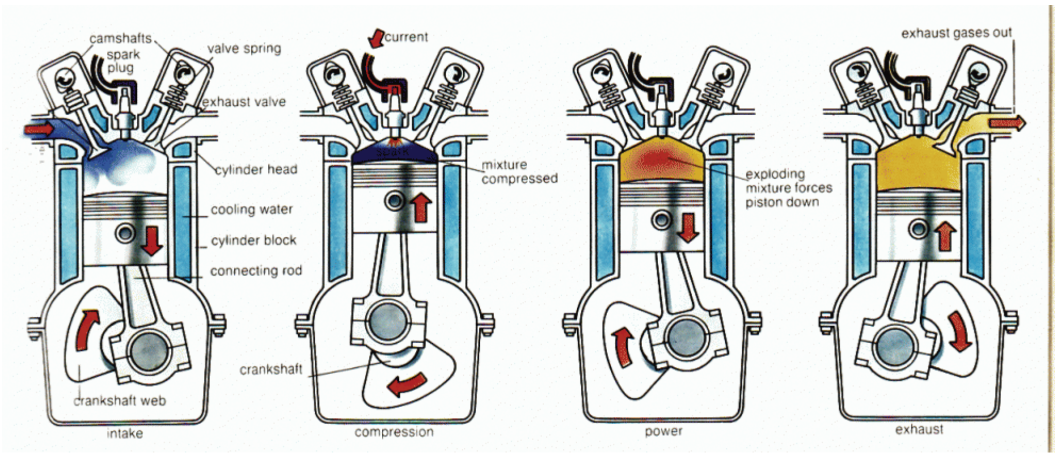

Figure 48: *Operation of a four-stroke IC engine*

How Does a Four-Stroke Engine Work

https://www.bikesrepublic.com/english/archive/four-stroke-engine-work/

Propellers

Electrical propulsion systems and internal combustion engines produce thrust by using a rotating shaft to drive a propeller. A propeller is a type of "fan" driven by a rotating shaft or gears to produce thrust. As it spins through the air, it creates a difference in air pressure between the two faces of the propeller. A propeller may be designed to spin clockwise or counterclockwise. Think of a propeller as a rotating wing. The cross-section a propeller's blade has an aerofoil shape, just like a wing does. The pitch angle is the angle that the propeller's chord makes with its plane of rotation. The pitch of a propeller varies along its length, with a high pitch at its root and a low pitch at its tip. Usually, the higher the pitch angle on a propeller (up to a limit), the more thrust it generates and also the more drag (air resistance) it has.

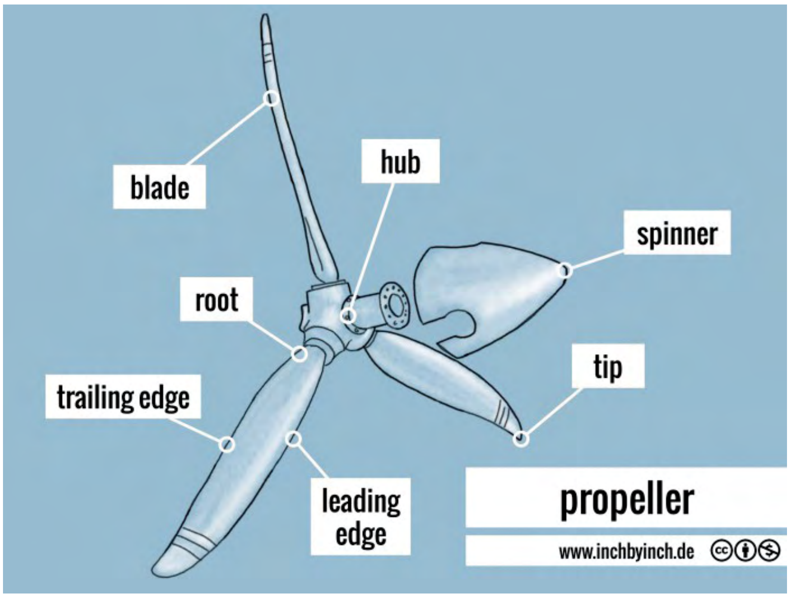

Figure 49: *Parts of a propeller*

INCH - Technical English | pictorial: propeller

https://inchbyinch.de/pictorial/propeller-r/

A propeller is usually defined by its diameter and Pitch. The diameter is the tip-to-tip length of a propeller. It describes the diameter of the circle that the tips navigate while the propeller is spinning. The larger the propeller diameter, the more air it displaces and the higher the thrust generated. The pitch is the forward distance that the propeller would move for each complete rotation it makes if it were spinning through a solid medium. This is sometimes called geometric pitch. In flight however, the actual pitch, which it the forward distance the propeller moves for each complete rotation through the air, is less than the geometric pitch. The difference between the geometric pitch and actual pitch is called propeller slip. Propellers may be made of wood, plastics, metals or composite materials like carbon fibre.

Types of Propellers

There are different types of propellers. Some of them are:

1. **Fixed-Pitch Propellers**
   These are the most widely used type of propellers. They have a set blade angle. They are simple and reliable. They are commonly found on light aircraft and UAVs.

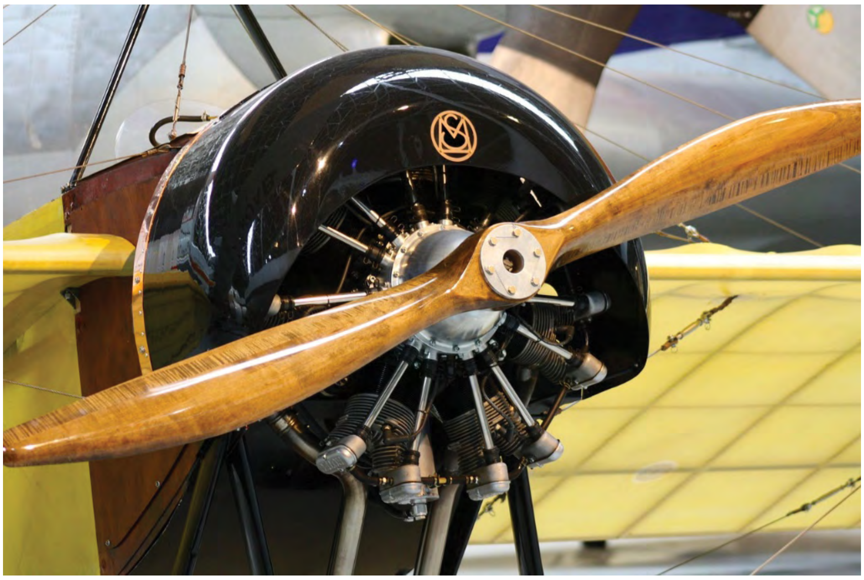

Figure 50: *A fixed-pitch propeller*

Wooden Airplane Propeller Vintage

https://pixabay.com/photos/wooden-airplane-propeller-716734/

2. **Variable Pitch Propellers**
   This type of propeller has an adjustable blade angle. On take-off, the pitch can be increased to help the aircraft quickly gain speed and get airborne. However once airborne, the pitch can be reduced to reduce drag on the propeller. This may be done automatically, or via a switch in the cockpit. The pitch can be adjusted to push air forward to produce **reverse-thrust**. Also in the case of engine failure, the propeller can be feathered parallel to the incoming airstream to reduce drag and thereby decrease the rate at which airspeed is lost.

Figure 51: *Variable pitch propeller*

Effect of Propeller Pitch Angle on an Airplane Thrust. | Science Fair Project Ideas

http://www.sciencefairprojects.in/2013/10/effect-of-propeller-pitch-angle-on.html

Learning Tasks

1. Use an inflated balloon to demonstrate Newton's third law of motion.
2. Explain the operation of four-stroke piston engines.
3. Describe how a propeller spins to generate thrust.
4. Perform a thrust test with a brushless DC motor in the laboratory

Pedagogical Exemplars

1. **Experiential learning**
   a. In a whole class situation, teacher can demonstrate Newton's third law of motion ("To every action there is an equal and opposite reaction") using a balloon. The balloon is inflated and the neck is held shut to prevent air from escaping. The neck is then release and air rushes out through the opening at the neck. The balloon is observed to be propelled in the opposite direction to the opening. Assign specific roles to learners to ensure that all learners participate in the project and are challenged according to their understanding and skills.

   b. Using a video/simulator, put learners in mixed-ability groups and allow them to observe the operation of a four-stroke engine. This link (Animated Engines - Four stroke) may be useful in class. Task learners (either groups or individuals) to make a report of their observations of the video/simulation on the operation of four-stroke engines. Allow learners to submit their work digitally or on paper.

   c. Field trips to aircraft maintenance facilities can be embarked on to give learners a firsthand experience of how aircraft piston engines work.

2. **Project-based learning**
   Task learners in mixed-ability groups perform an engine test on brushless DC motors in the laboratory. Vary the battery voltage and propellers and observe how the electric motor responds. Make observation and write a report on how the electric propulsion system responds to changes in variables like propeller pitch, diameter and battery voltage. Offer differentiated instruction sheets with step-by-step guides, engine tests on brushless DC motors for approaching proficiency learners, while encouraging proficient and highly proficient learners to explore advanced techniques.

Key Assessment

1. **Assessment Level 1**
   a. Describe the operation of a four stroke piston engine.

   b. How does an increase in voltage affect the operation of a brushless DC motor?

2. **Assessment Level 2**
   a. Assuming an engine has a constant rotational speed, what will be the result of an increase in propeller pitch?

b. Write a report on how a rotating propeller (powered by either an electric motor or piston engine) makes use of Newton's third law of motion to generate thrust.

3. **Assessment Level 3:** Make a poster that describes the principle of operation of an aircraft engine.
4. **Assessment Level 4:** Discuss the potential of hybrid-electric propulsion systems in reducing fuel consumption and emissions in aviation.

Hint

*The recommended mode of assessment for Week 9 is **poster presentation.** An example of assessment task is Question 3 of key assessment level 3. Refer to **Appendix E** for a rubric to score learners' performance.*

WEEK 10: GAS TURBINE ENGINES AND ROCKET PROPULSION

Learning Indicator: *Explain the principles of operation of the different propulsion systems (rockets, jet engine, and internal combustion engine).*

FOCAL AREA: PRINCIPLES AND TYPES OF PROPULSION

Gas Turbine Propulsion systems

A gas turbine engine is a type of internal combustion engine that uses gas as the working fluid to turn a turbine. This working fluid used is mostly air. The air enters the gas turbine engine and goes through stages of compression depending on the type and purpose of the gas turbine engine. Fuel is then added to the compressed gas and ignited. The gas, upon ignition expands rapidly. The energy from the expanding gas is then used to turn a turbine that runs the compressor. The gas exits the engine at a rear nozzle.

Useful work or propulsive power can be generated by a gas-turbine engine. It may be used to drive a generator to produce electricity or in the case of a pure jet aircraft engine, develop thrust by accelerating the exhaust flow through a nozzle. High amounts of power can be obtained by such an engine that, for the same output, is much smaller and lighter than a piston engine. Piston engines depend on the up-and-down motion of a piston, which must then be converted to rotary motion by a crankshaft arrangement, whereas a gas turbine delivers rotary shaft power directly. Although conceptually the gas-turbine engine is a simple device, the components for such an efficient engine must be carefully designed and manufactured from expensive materials because of the high temperatures and stresses encountered during operation. When used to power aircraft, gas turbines are capable of propelling air vehicles to very high speeds.

There are different types of gas turbine engines. Notable among them are

1. **Turbojet**: This is the basic and simplest form of the gas turbine engine. Air enters the inlet through a guide vane, passes through the compressor stages, where the gas is compressed. As the air goes through the compressor stages, its pressure and temperature rise. The compressor could be axial or radial. After going through the compressor stages, the air enters the combustion chamber. In the combustion chamber, fuel is added to the compressed air and ignited. The gases expand rapidly, turning the turbine and exiting the propelling nozzle at high speed to create thrust. The turbine runs the compressor stages to keep compressing the incoming air.

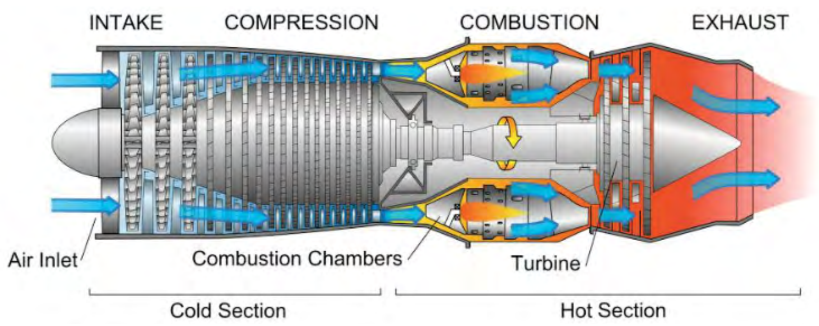

Figure 52: Turbojet engine

How does a jet engine work?

https://innovationdiscoveries.space/how-does-a-jet-engine-work/

2. **Turbofan**: This engine is similar to the turbojet. However, in this type of gas turbine engine, a large fan is mounted at the inlet of the engine. The large fan draws air into the core of the engine however most of the air drawn by the fan flows around the engine rather than through the compressor stages and turbine. The ratio of the mass of air bypassing the engine core versus the mass of the air going through the core is referred to as the bypass ratio.

   The incoming air is drawn in and slightly accelerated by the fan. Most of the air goes around the engine and does not flow through the core of the engine. Inside the core of the engine, the air goes through compressor stages, combustion chamber (where fuel is added and burnt) and turbines just like a turbojet engine and accelerated through the outlet nozzle. However in this case, the turbine does not only drive the compressor stages, it also drives the fan. Hence this engine generates thrust from the fan slightly accelerating large masses of air and the core accelerating smaller masses of air to high speeds.

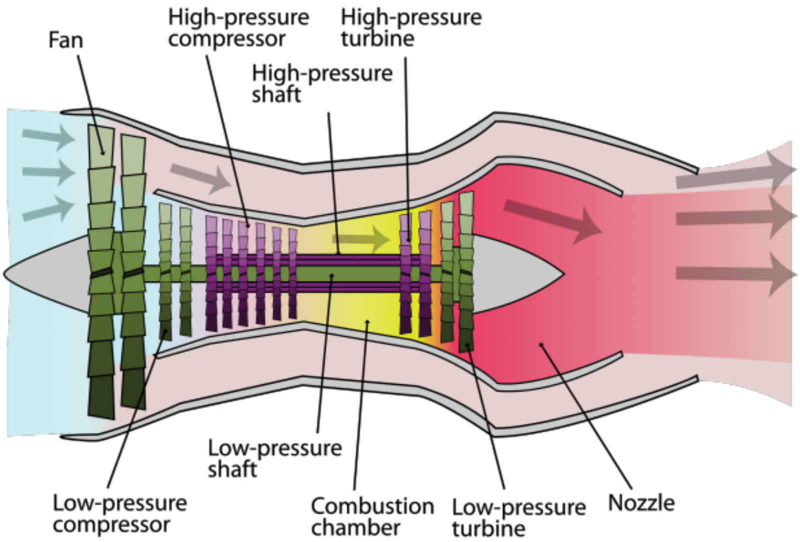

Figure 53: *Turbofan engine with bypass*

How does a jet engine work?

https://innovationdiscoveries.space/how-does-a-jet-engine-work/

3. **Turboprop**: A turboprop engine is a type of gas turbine engine that drives a propeller. It combines the jet engine's efficiency at high speeds with the propeller's efficiency at low to medium speeds, making it ideal for regional and military aircraft.

   Air is drawn in via the intake. The air goes through a set of compressor stages where it is compressed, increasing its temperature and pressure. The compressed air is sent to the combustion chamber where it is mixed with fuel and ignited. Upon ignition, the gas expands rapidly, passing through a set of turbines. The first set of turbines (gas generator turbines) drives the compressor, while the second set (power turbines) drives the propeller through a reduction gearbox. This gear box reduces the rotational speed (and increases torque) of the power turbines before transmitting it to the propeller. The propeller converts the mechanical power into thrust, propelling the aircraft forward. The remaining gases are expelled through the exhaust, providing a small amount of additional thrust.

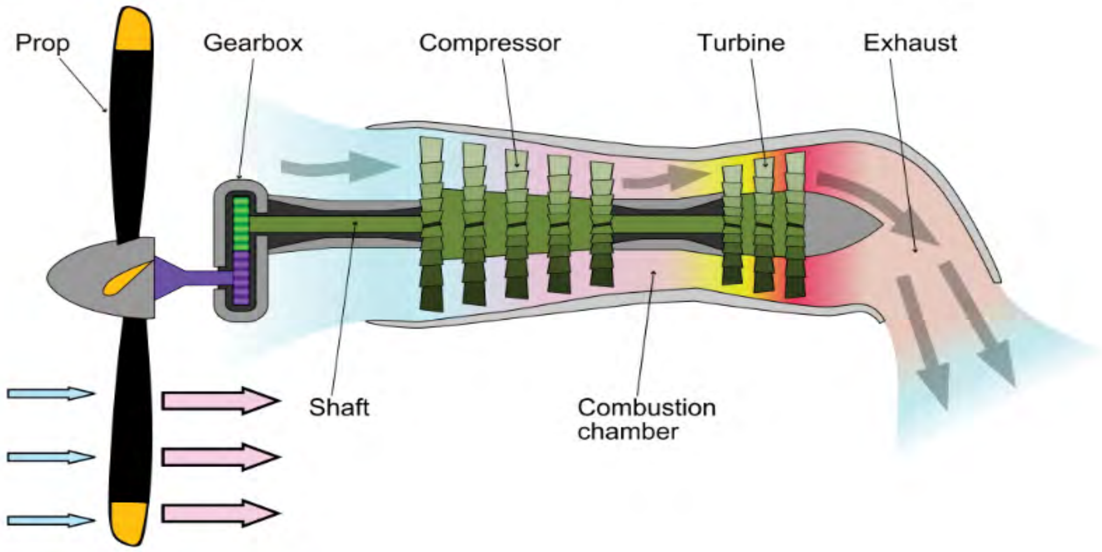

Figure 54: *Turboprop engine*

How does a jet engine work?

https://innovationdiscoveries.space/how-does-a-jet-engine-work/

4. Turboshaft: A turboshaft engine is a type of gas turbine engine that is optimised to produce shaft power rather than jet thrust. The shaft power generated may be used to drive machinery, such as marine vessels, and stationary applications like generators. In aviation, turboshaft engines are most commonly found on helicopters.

Air is drawn into the engine through the intake. The compressor compresses the incoming air, increasing its pressure and temperature. The compressed air is mixed with fuel in the combustion chamber and ignited, resulting in a high-energy airflow. The high-energy airflow passes through the turbines. The first set of turbines (gas generator turbines) drives the compressor, while the second set (power turbines) drives the output shaft. The shaft connected to the power turbine delivers mechanical power to drive rotors, propellers, or generators. The remaining gases are expelled through the exhaust.

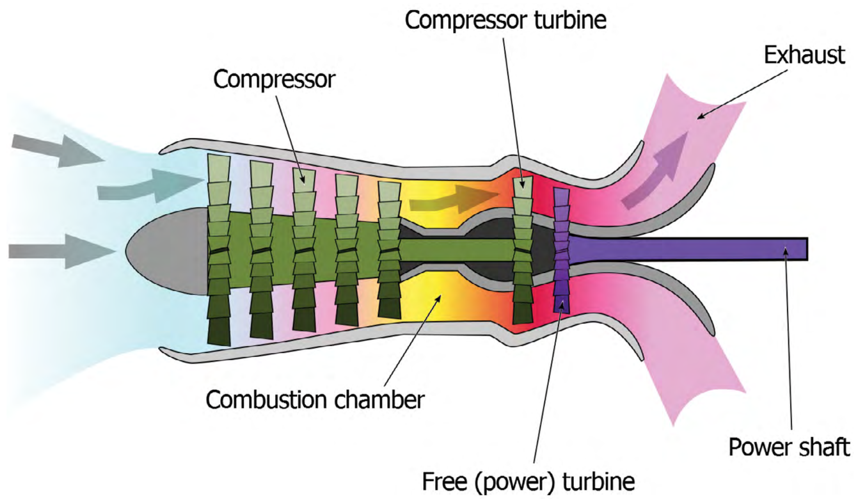

Figure 55: *Turboshaft engine*

How does a jet engine work?

https://innovationdiscoveries.space/how-does-a-jet-engine-work/

Rocket Propulsion

Rocket propulsion is the method by which a rocket moves forward by expelling mass at high velocity from its rear. This action follows Newton's Third Law of Motion: for every action, there is an equal and opposite reaction.

The propellant burns in the combustion chamber, creating high-pressure and high-temperature gases. The gases expand through the nozzle, accelerating to supersonic speeds and creating thrust. The rocket moves in the opposite direction of the expelled gases, generating thrust.

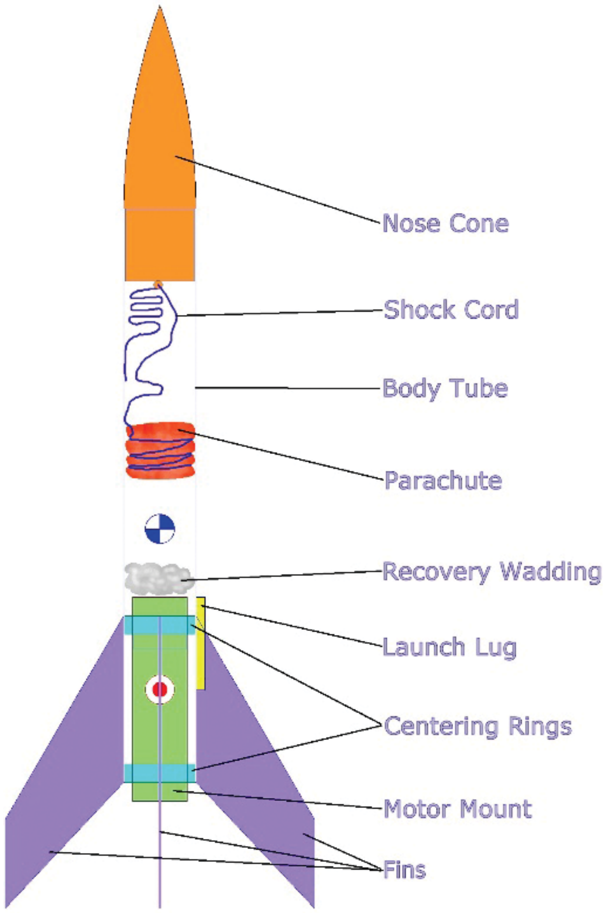

Figure 56: *A rocket Engine*

Eclipse Rocketry Ltd

https://www.eclipserocketry.com/basics.html

Components of a Rocket Engine

1. **Propellant:** The chemical substances (fuel and oxidiser) burned to produce thrust.
2. **Fuel:** The substance that burns (e.g., liquid hydrogen, kerosene).
3. **Oxidiser:** The substance that provides oxygen for combustion (e.g., liquid oxygen, nitric acid).

4. **Combustion Chamber:** Where the propellant is burned to produce high-pressure, high-temperature gases.
5. **Nozzle:** Accelerates the exhaust gases to high velocities, converting thermal energy into kinetic energy.
6. **Turbopumps:** Used in liquid rocket engines to pump fuel and oxidiser into the combustion chamber at high pressures.
7. **Ignition System:** Initiates the combustion of the propellant.

Types of Rocket Propulsion

1. **Chemical Propulsion**
   - **a.** Solid Rocket Motors: Use solid propellant, which is a mixture of fuel and oxidiser. Example: Space Shuttle Solid Rocket Boosters (SRBs).
   - **b.** Liquid Rocket Engines: Use liquid fuel and oxidiser stored in separate tanks. Example: SpaceX Merlin engines.
   - **c.** Hybrid Rockets: Use a combination of solid and liquid or gaseous propellants. Example: Virgin Galactic's SpaceShipTwo.
2. **Electric Propulsion**
   - **a.** Ion Thrusters: Accelerate ions using electric fields. Example: NASA's Dawn spacecraft.
   - **b.** Hall Effect Thrusters: Use magnetic fields to accelerate ions. Example: Satellites for station-keeping.
3. **Nuclear Propulsion**
   - **a.** Nuclear Thermal Rockets: Use nuclear reactions to heat a propellant, which is then expelled. Example: Conceptual designs for Mars missions.
   - **b.** Nuclear Electric Propulsion: Use nuclear reactors to generate electricity for electric thrusters.

Learning Tasks

1. Watch a video or simulation of gas turbine engines and rockets in operation. Identify and discuss the functions of the various parts.
2. Visit an aircraft maintenance facility to learn and experience the operations of gas turbine engines and give a class presentation.
3. Using locally available materials, build a water rocket to demonstrate how rockets use Newton's third law to generate thrust.
4. Discuss the reason(s) for the dominance of rocket engines in spacecraft propulsion systems.

Pedagogical Exemplars

1. **Experiential learning**
   - **a.** In mixed-ability groups, allow learners to watch videos and simulations of rockets and gas turbine engines in operations. Learners after watching the video should brainstorm the functions of the various parts of rockets and gas turbine engines. Encourage learners to simply and clearly articulate their points and listen to others during the

discussions. Make room for non-vocal learners to contribute to the group discussions through writing.

b. With the aid of audio-visuals, the teacher demonstrates the operation of aerospace propulsion systems.

c. Learners embark on a field trip to an aircraft maintenance facility or an air base in the country to have hands-on experience with gas turbine engines. Learners engage maintenance technicians to learn about how these engines operate.

2. Project-based learning

a. Teacher puts learners in groups to use locally available materials (e.g. plastic bottle, water, bicycle pump) to build a water rocket. Groups should have members with different abilities so as to complement each other. Allow learners to choose their own materials to build the water rocket and fly. Learners should document their observations and present for whole-class discussions. Group learners based on their readiness, interests, and learning styles. For example, you could group learners who have a strong interest in aviation science together, or group learners who learn best through hands-on activities together. Anticipate that some learners may struggle with certain concepts and plan for additional support or resources to help these learners.

b. Task learners in mixed-ability groups to do a detailed research on the types of rocket engines used in astronautics. Learners then make a PowerPoint presentation on the types of rocket engines and why they are predominantly used in spacecraft propulsion.

Key Assessment

1. Assessment Level 1

a. Label a sketch of a turbofan engine.

b. Write down the functions of parts of a turbofan engine.

2. Assessment Level 2

a. In groups, learners should produce a brief write-up describing the stages of operation of a jet engine and further explain why the jet engine is said to be a reaction engine.

b. From a short video on rocket and gas turbine engines watched in class, explain an advantage of jet engines over rockets for air vehicle propulsion.

c. Explain why a rocket engine is predominantly used in space vehicle propulsion and a gas turbine engine is not.

3. Assessment Level 3: "It is better to use gas turbine engines rather than piston engines to power aircraft." Argue for or against the motion.

4. Assessment Level 4: What are hybrid rocket engines, and how do they differ from traditional solid and liquid rocket engines?

Hint

- *The recommended mode of assessment for Week 10 is **debate**. Refer to Question 3 of Key Assessment Level 3 for an example task.*
- *Initial (partial) portfolio is to be submitted by learners this week.*

WEEK 11: ESTIMATING THRUST OF JET ENGINES

Learning Indicator: *Calculate the thrust generated from different power sources, e.g., battery and internal combustion engines (rocket, jet engine, internal piston engine)*

FOCAL AREA: CALCULATING THE THRUST OF JET ENGINES

It is the goal of every propulsion system to be capable of generating the required thrust for propelling the aircraft in different flight regimes. The basic conservation laws of mass and momentum are used in deriving expressions for the thrust force. A jet engine is a reaction engine. It takes in air at a lower speed and accelerates it backward at a higher speed. The reaction is the thrust force propelling it forwards.

Consider the diagram of a jet engine in operation below

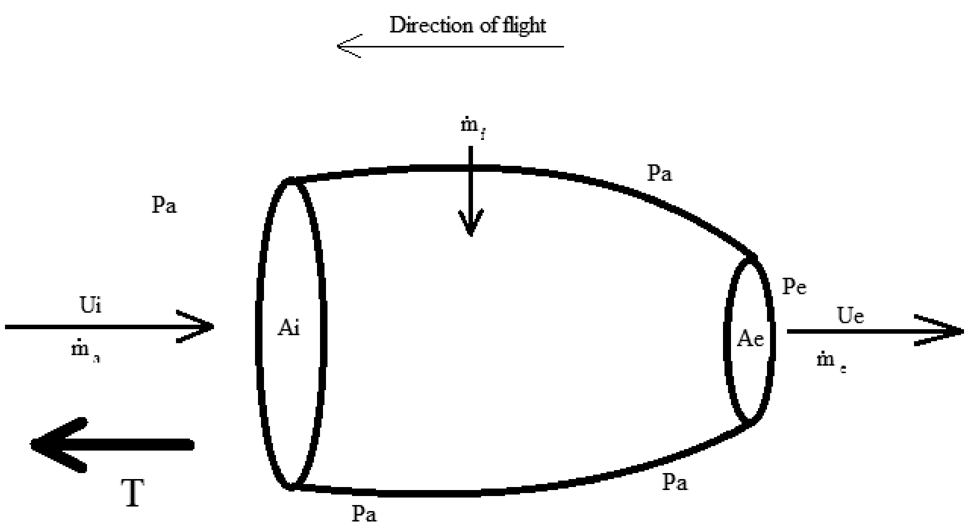

Figure 57: *Jet engine analysis*

P_a is the pressure of the atmosphere

P_e is the pressure at the exhaust

A_i is the area of the inlet

A_e is the area of the exhaust

ρ is the air density

$\dot{m}_a$ is the mass flow rate of air entering into the engine

$\dot{m}_e$ is the mass flow rate of gases out of the exhaust

$\dot{m}_f$ is the mass flow rate of fuel into the combustion chamber

U_i is the inflow velocity

U_e is the exhaust velocity

By the law of conservation of matter, which states that "matter can neither be created nor destroyed" (except in a chemical reaction), the total mass entering the engine must equal the total mass exiting the engine. We can then write that

That is the mass flow rate of the exhaust gases exiting the engine at the outlet nozzle should be equal to the sum of the mass flow rates of air and fuel entering the engine.

Usually, the exit velocity $U_{e,}$ is much higher than the inlet velocity, U_i.

By Newton's second and third law, we know that the rate of change of momentum out of the engine will cause a reaction force pushing the engine forwards. This is known as the **absolute thrust.** It is the product of the mass flow rate of the exhaust gases and the exhaust velocity. So the higher the exhaust velocity, the more the thrust generated. It is expressed as;

However, the air rushing into the engine will cause a **ram drag** on the engine, trying to push the engine backwards. The ram drag acts in an opposite direction to the thrust. Its magnitude is the product of the mass flow rate of the incoming air and its velocity. Mathematically expressed as;

The vector sum of the absolute thrust and the ram drag, when using the desired direction of T as the positive sign convention, is

Although little, the difference between the ambient pressure and the exhaust pressure contribute some amount of thrust force. This is called the pressure thrust. When taken into consideration, the thrust equation becomes

Worked Example

A jet engine has a circular inlet diameter of 1m and exhaust diameter of 0.4m. The mass flow rate of the ram air is 40kg/s. Fuel is being injected into the combustion chamber at 4kg/s. The ambient pressure is 101.3kPa and the pressure at the exhaust is 120.0kPa. If the air intake is 150m/s and the exhaust velocity is 400m/s,

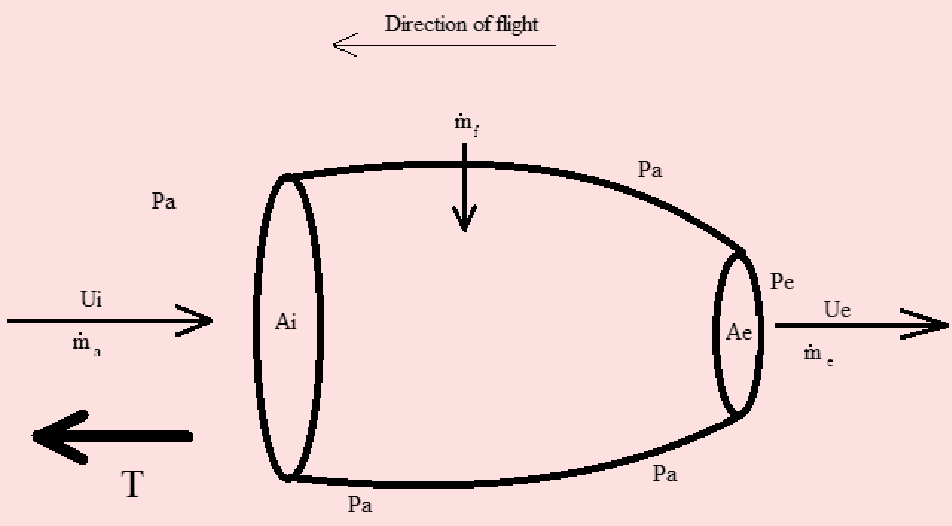

Figure 58: *Jet engine analysis*

i. Calculate the exhaust mass flow rate.

ii. Calculate the ram drag.

iii. Calculate the thrust force.

Solution

i. Using the law of conservation of matter, we can say that the mass entering the engine must be equal to the mass exiting the engine at any point in time. This means that the mass flow rate of the exhaust velocity is equal to the sum of the mass flow rate of the intake air and the mass flow rate of the injected fuel.

$$\dot{m}_e = \dot{m}_a + \dot{m}_f$$

Where $\dot{m}_a$ is the mass flow rate of air, $\dot{m}_e$ is the mass flow rate of the exhaust gases and $\dot{m}_f$ is the mass flow rate of the fuel.

$$\dot{m}_e = (40 + 4)\ kg/s$$

$$\dot{m}_e = 44\ kg/s$$

ii. The ram drag is caused by the incoming air ramming into the engine. It is the product of the incoming air's mass flow rate and its velocity.

$$D_{ram} = \dot{m}_a U_i$$

$$D_{ram} = (40)(150)$$

$$D_{ram} = 6000\ N$$

iii. Using the thrust formula;

$$T = \dot{m}_e U_e - \dot{m}_a U_i + (P_e - P_a)A_e$$

Where $\dot{m}_e = 44\ kg/s$

$\dot{m}_a = 40\ kg/s$

$U_i = 150\ m/s$

$U_e = 400\ m/s$

$P_a = 101.3\ kPa$

$P_e = 120.0\ kPa$

The cross-sectional area of the exhaust is not explicitly stated in the question, however, it can be determined using the diameter of the exhaust which is mentioned in the question.

$$A_e = \pi \frac{d^2}{4}$$

$$A_e = \pi \frac{0.4^2}{4}$$

$$A_e = 0.126\ m^2$$

Substituting into the thrust equation,

$$T = (44)(400) - (40)(150) + (120000 - 101300)(0.126)$$

Learning Tasks

1. Discuss the terms (i.e. absolute thrust, the ram drag and pressure difference) in the thrust equation and explain how they were derived.
2. Perform calculations of the thrust from a jet engine.

Pedagogical Exemplars

1. **Talk-for-Learning**
   The teacher makes use of videos to demonstrate the principles of operation of the different aerospace propulsion systems. Then in small mixed-ability groups, task learners to brainstorm the factors that contribute to the thrust produced by a gas turbine engine. Using the jigsaw approach, learners share what they discussed in their groups with members of other groups.

   In a plenary discussion, the teacher invites ideas from learners on what they discussed in their respective groups. With reference to the relevant physical laws (e.g., Newton's laws, Ohm's law in Physics), the teacher builds on these ideas to explain the process of determining the thrust of an aerospace propulsion system. Also explaining the factors that contribute to thrust generation in a jet engine and how they fit into the thrust equation.

2. **Problem-based Learning**
   The teacher leads the class in solving sample problems on thrust of jet engines. The teacher may vary the approach to arriving at problem solutions to cater for the varied needs of learners. The teacher should be mindful of the various proficiency levels of learners. That is, more attention should be given to learners approaching proficiency, as more challenging tasks are given to learners at high levels of proficiency.

   In the sample problems, learners may be asked to calculate for thrust or may be given the required thrust and be asked to calculate for other parameters such as exhaust velocity, mass flow rate or pressure.

Key Assessment

1. **Assessment Level 1**: Write down the mathematical expression for the ram air drag of a jet engine.
2. **Assessment Level 3**: A jet engine has a circular inlet radius of 0.66m and exhaust radius of 0.25m. The mass flow rate of the ram air is 60kg/s. Fuel is being injected into the combustion chamber at 8kg/s. Assume the difference between the exhaust pressure and the atmospheric pressure is negligible. If the air intake is 100m/s and the exhaust velocity is 400m/s,

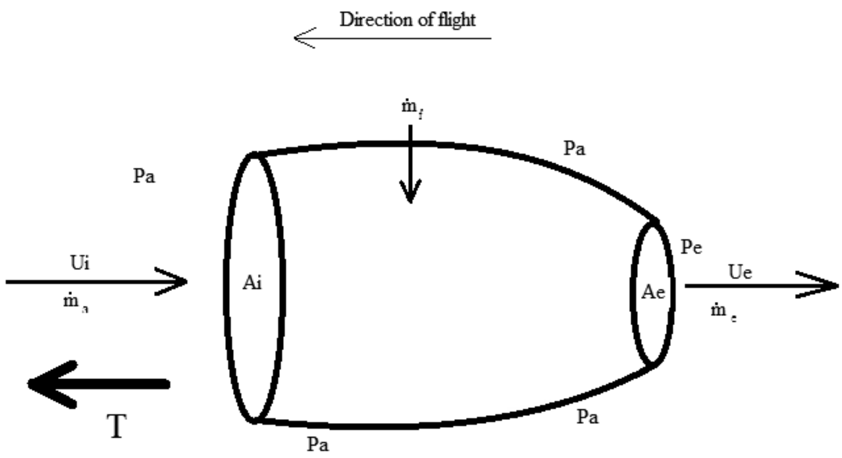

Figure 59: *Jet engine analysis*

i. Calculate the exhaust mass flow rate.

ii. Calculate the ram drag.

iii. Calculate the thrust force.

Hint

- *The recommended mode of assessment for Week 11 is* ***computational task****. Refer to Question 2 of Key Assessment Level 3 for an example task.*
- *Take some time off during this week to assist learners to prepare for the end-of-semester examination.*

WEEK 12: CALCULATION OF ROCKET THRUST

Learning Indicator: *Calculate the thrust generated from different power sources, e.g., battery and internal combustion engines (rocket, jet engine, internal piston engine).*

FOCAL AREA: CALCULATING THE THRUST OF ROCKET ENGINES

Rockets are the most important type of propulsion systems used in spacecraft mainly because they are not air-breathing engines. The level of oxygen in outer space is very low. Rocket engines carry their own oxidiser and do not require atmospheric oxygen for their operation. They are capable of producing very high amounts of thrust. They are mostly used on space vehicles. Rockets may also be used on aircraft for assisted short take-offs. As reaction engines, they operate by expelling mass at very high speeds to generate thrust just like the jet engines. However, since the rocket is not an air-breathing engine, there is no ram drag.

Consider the diagram of the rocket below

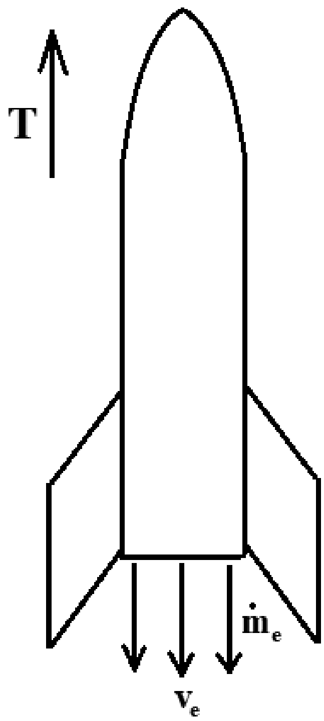

Figure 60: *Rocket engine analysis*

Thrust is the force produced by a rocket engine to propel the rocket. It is a result of the expulsion of exhaust gases at high speed from the rocket's engine nozzle.

Basic Concepts

Newton's Third Law of Motion: For every action, there is an equal and opposite reaction. In rocketry, the action is the expulsion of exhaust gases, and the reaction is the thrust that propels the rocket forward.

Key Equations

1. Thrust Equation (General Form)

The basic thrust equation for a rocket is:
Where:

T is the thrust force in Newtons (N),

$\dot{m}_e$ is the mass flow rate of the exhaust gases in kg/s,

v_e is the velocity of the exhaust gases in m/s.

This is the force generated by the momentum of the exhaust gases being expelled from the nozzle of the rocket. The more of the exhaust gases being expelled per unit time, the higher the thrust force generated.

Like the jet engine, the difference between the ambient pressure and the exhaust pressure contribute to the net thrust that acts on a rocket. The pressure at the exhaust exerts an upward force (in the direction of the thrust) of magnitude:

The ambient pressure is distributed all around the rocket. Most of the forces created by the ambient pressure acting around the rocket cancel out except those acting directly over the area of the exhaust nozzle. This creates a downward force of magnitude:

The negative sign signifies that the force acts in a direction opposite to the selected positive sign convention, which is upwards.

Where:

P_e is the pressure of the exhaust gases in Pa,

P_a is the ambient pressure in Pa,

A_e is the area of the exhaust nozzle in m^2

Combining these forces, the pressure thrust can be expressed as;

Therefore, if the thrust contributed by the pressure differences and the thrust contributed by the expulsion of exhaust gases at high speeds, we get the general thrust equation.

Worked Example

1. A rocket has a mass flow rate of 150 kg/s and an exhaust velocity of 2500 m/s. Calculate the thrust produced by the rocket.

Solution:

Note: In this question, the basic thrust is calculated, ignoring the pressure thrust. This is a quick and easy method to estimate the thrust generated by a rocket engine.

The mass flow rate of the exhaust is $\dot{m}_e = 150$ kg/s

The exhaust velocity is, $v_e = 2500$ m/s

The thrust generated can be written as:

2. For the above rocket, if the exhaust pressure at the nozzle exit is 90 kPa, the ambient pressure is 95 kPa, and the nozzle exit area is 0.5 m², calculate the total thrust

Solution:

We have already calculated the thrust generated by the rate of change of momentum at the exhaust, now we need to calculate the pressure thrust and sum up.

We now add the pressure thrust to the basic thrust we calculated earlier

3. A rocket engine expels gases at a rate of 200 kg/s with an exhaust velocity of 2800 m/s. If the ambient pressure is 101.3 kPa and the nozzle exit area is 0.8 m^2 with an exhaust pressure of 120 kPa, what is the total thrust produced?

Solution:

The general thrust equation for rockets is given by:

Exhaust mass flow rate, $\dot{m}_e = 200$ kg/s

Exhaust velocity, $v_e = 2800$ m/s

Ambient pressure, $P_a = 101.3$ kPa

Exhaust nozzle area, $A_e = 0.8$ m^2

Exhaust pressure, $P_e = 120$ kPa

Substituting into the thrust equation,

Learning Tasks

1. Build a water rocket. Vary the amount of water and the pressure pumped. Observe how high the bottle rises and relate that to the rate of change in momentum at the nozzle of a rocket.
2. Identify the similarities and differences between a rocket engine and a jet engine.
3. Solve questions involving the calculation of rocket engine thrust.

Pedagogical Exemplars

1. Problem-based Learning

The teacher leads the class in solving sample problems on thrust of rockets. The teacher may vary the approach to arriving at problem solutions to cater for the varied needs of learners. The teacher should be mindful of the various proficiency levels of learners. That is, more attention should be given to learners approaching proficiency, as more challenging tasks are given to learners at high levels of proficiency.

In the sample problems, learners may be asked to calculate for thrust or may be given the required thrust and be asked to calculate for other parameters such as exhaust velocity, mass flow rate or pressure.

Key assessment

1. Assessment Level 1

a. Write down the term for the absolute of the rocket engine.

b. A rocket engine has a mass flow rate of 180 kg/s and an exhaust velocity of 3200 m/s. Calculate the thrust produced by the engine.

2. Assessment Level 2

a. A rocket engine expels gases at a rate of 200 kg/s with an exhaust velocity of 2700 m/s. The exhaust pressure at the nozzle exit is 85 kPa, the ambient pressure is 100 kPa, and the nozzle exit area is 0.6 m². Calculate the total thrust produced by the engine.

b. A rocket operates in a vacuum, where the ambient pressure is effectively zero. If the rocket engine has a mass flow rate of 200 kg/s, an exhaust velocity of 3300 m/s, an exhaust pressure at the nozzle exit of 95 kPa, and a nozzle exit area of 0.5 m², calculate the total thrust produced.

Hint

*The Recommended Mode of Assessment for Week 12 is **End of Semester Examination.** Refer to **Appendix F** for a Table of Specification to guide you to set the questions. Set questions to cover all the indicators covered for at least Weeks 1 to 11.*

SECTION 3 REVIEW

This section highlights the various types of propulsion systems used on aerospace vehicles. It emphasises the principles of physics that govern the operation of these propulsion systems. We also discuss the mechanisms by which these propulsion systems generate thrust and how the thrust force from some of these systems may be analytically estimated using the scientific laws discussed in this session and earlier ones.

APPENDIX E: Rubric for scoring the poster presentation task from Week 9

Criterion	*Excellent (4 marks)*	*Very good (3 marks)*	*Satisfactory (2 marks)*	*Needs improvement (1 mark)*
Knowledge of the principle of operation of an aircraft engine	*Poster mentions all the four main stages in the operation of the engine: intake, compression, combustion, exhaust*	*Poster mentions three of the four main stages in the operation of the engine: intake, compression, combustion, exhaust*	*Poster mentions two of the four main stages in the operation of the engine: intake, compression, combustion, exhaust*	*Poster mentions one of the four main stages in the operation of the engine: intake, compression, combustion, exhaust*
Communication Skills	*Learner shows 4 of the skills e.g. Audible voice, Keeping eye contact Pay attention to audience Engaging the audience with interaction Use of gesture*	*Learner shows 3 of the skills e.g. Audible voice, Keeping eye contact Pay attention to audience Engaging the audience with interaction Use of gesture*	*Learner shows 2 of the skills e.g. Audible voice, Keeping eye contact Pay attention to audience Engaging the audience with interaction Use of gesture*	*Learner shows 1 of the skills e.g. Audible voice, Keeping eye contact Pay attention to audience Engaging the audience with interaction Use of gesture*
Teamwork	*Learner exhibits 4 of these: Contributing to the group, Respecting the views of others, Tolerating others, Resolving conflicts, Taking responsibility*	*Learner exhibits 3 of these: Contributing to the group, Respecting the views of others, Tolerating others, Resolving conflicts, Taking responsibility*	*Learner exhibits 2 of these: Contributing to the group, Respecting the views of others, Tolerating others, Resolving conflicts, Taking responsibility*	*Learner exhibits 1 of these: Contributing to the group, Respecting the views of others, Tolerating others, Resolving conflicts, Taking responsibility*

Criterion	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs improvement (1 mark)
Design & Creativity	*Poster shows creativity and organisation of any 4 of these: layout that draws attention to key points. Visuals are eye-catching, relevant, and enhance understanding of the content. Text and images are balanced and easy to follow.*	*Poster shows creativity and organisation of any 3 of these: layout that draws attention to key points. Visuals are eye-catching, relevant, and enhance understanding of the content. Text and images are balanced and easy to follow.*	*Poster shows creativity and organisation of any 2 of these: layout that draws attention to key points. Visuals are eye-catching, relevant, and enhance understanding of the content. Text and images are balanced and easy to follow.*	*Poster shows creativity and organisation of any 1 of these: layout that draws attention to key points. Visuals are eye-catching, relevant, and enhance understanding of the content. Text and images are balanced and easy to follow.*

APPENDIX F: End of first semester examination

Nature of the paper

A two-hour paper consisting of 40 multiple choice questions (Section A) and 2 essay-type questions (Section B), on concepts that have been covered for Weeks 1 to 12.

Table of specifications for end of first semester examination

Week	Focal Area	Type of question	DOK Levels				Total
			1	2	3	4	
1	Climate, weather and weather elements	Multiple choice	2	3			4
2	The impact of weather on flight	Multiple choice	2	2			4
3	International standard atmosphere	Multiple choice	2	2			4
4	Introduction to Aerodynamics	Multiple choice	2	2			4
5 & 6	Lift	Multiple choice	2	4			8
7	Drag	Multiple choice	2	2			4
8	Weight and weight distribution	Essay			1		1
9	Principles and types of aerospace propulsion systems I	Multiple choice	2	2			4
10	Principles and types of aerospace propulsion systems II	Multiple choice	2	4			6
11	Estimating thrust of jet engines	Multiple choice	1	2			2
12	Calculation of rocket thrust	Essay			1		1
	Total	Multiple choice	17	23			**40**
		Essay			2		**2**

Resources needed

a) *Venue for the examination*

b) *Printed examination question paper*

c) *Answer booklet*

d) *Scannable paper*

e) *Wall clock*

f) *Bell, etc.*

Guidelines for setting test items

a) *Multiple choice*

- **i.** *The stem should be clearly written,*
- **ii.** *The options should be plausible and homogenous in content*
- **iii.** *Vary the placement of the correct answer*
- **iv.** *Repetition of words in the options should be avoided, etc.*

b) *Essay type*

- **i.** *Make the instructions clear*
- **ii.** *Do not ask ambiguous questions*
- **iii.** *Do not ask questions beyond what you have taught, etc.*

Sample multiple choice question (Section A):

An engine that generates thrust by ejecting high velocity gases is likely to be a

A. *Gas turbine engine*

B. *Piston engine*

C. *Steam engine*

D. *Water engine*

Sample Essay question (Section B):

Write down four parts of a gas turbine engine, providing the function of each part.

Mark scheme

Section A: Correct answer is D (1 mark)

Section B:

Engine part	***Function***
Compressor (2 marks)	*Increases the pressure of ingested air before it enters the combustor (2 marks)*
Combustion chamber (2 marks)	*Fuel mixes with high pressure air and is burned in the combustion chamber to release energy (2 marks)*
Turbine (2 marks)	*Extracts some energy out of the hot exhaust to power other parts of the engine (2 marks)*
Diffuser (2 marks)	*Produces thrust (2 marks)*

Figure number	Link	QR Code
Figure 43: Ball showing Newton's law of inertia	**Newton's First Law of Motion - Formula, Examples, and Applications** https://www.geeksforgeeks.org/newtons-first-law-of-motion/?ref=lbp	
Figure 44: Demonstrating Newton's second law	**Newton's second law - Examples** https://mammothmemory.net/physics/newtons-laws-of-motion/newtons-second-law--examples/newtons-second-law-examples.html	
Figure 45: Inflated balloon showing Newton's third law	**Newton's third law - Examples** https://mammothmemory.net/physics/newtons-laws-of-motion/newtons-third-law--examples/newtons-third-law-examples.html	
Figure 46: Elektra Trainer	**Elektra Trainer - Elektra Solar (elektra-solar.com)** https://www.elektra-solar.com/products/elektra-trainer-solar/	
Figure 47: Internal Combustion Engine	**Thunderbolt Engine | Aerobatic Aircraft | Lycoming** https://www.lycoming.com/engines/thunderbolt	
Figure 48: Operation of a four-stroke IC engine	**How Does a Four-Stroke Engine Work** https://www.bikesrepublic.com/english/archive/four-stroke-engine-work/	
Figure 49: Parts of a propeller	**INCH - Technical English | pictorial: propeller** https://inchbyinch.de/pictorial/propeller-r/	
Figure 50: A fixed-pitch propeller	**Wooden Airplane Propeller Vintage** https://pixabay.com/photos/wooden-airplane-propeller-716734/	
Figure 51: Variable pitch propeller	**Effect of Propeller Pitch Angle on an Airplane Thrust. | Science Fair Project Ideas** http://www.sciencefairprojects.in/2013/10/effect-of-propeller-pitch-angle-on.html	
Figure 52: Turbojet engine	**How does a jet engine work?** https://innovationdiscoveries.space/how-does-a-jet-engine-work/	

Figure number	Link	QR Code
Figure 53: Turbofan engine with bypass	**How does a jet engine work?** https://innovationdiscoveries.space/how-does-a-jet-engine-work/	
Figure 54: Turboprop engine	**How does a jet engine work?** https://innovationdiscoveries.space/how-does-a-jet-engine-work/	
Figure 55: Turboshaft engine	**How does a jet engine work?** https://innovationdiscoveries.space/how-does-a-jet-engine-work/	
Figure 56: A rocket Engine	**Eclipse Rocketry Ltd** https://www.eclipserocketry.com/basics.html	
Figure 57: Jet engine analysis	NaCCA 2024	
Figure 58: Jet engine analysis	NaCCA 2024	
Figure 59: Jet engine analysis	NaCCA 2024	
Figure 60: Rocket engine analysis	NaCCA 2024	

SECTION 4: AIRCRAFT INSTRUMENTS

Strand: Avionics

Sub-Strand: Aircraft Instrumentation

Learning Outcomes

1. *Explain the various airborne and ground operation instruments used to ensure safe and secure flight.*
2. *Specify the nature of flight data storage equipment (black box).*

Content Standard

1. Describe the instruments used for airborne and ground operations.
2. Demonstrate an understanding of flight data storage in aircraft.

Hint

Individual Project Work should be assigned to learners by the end of Week 13. Ensure that the project covers several learning indicators and spans over several weeks. Also, develop a detailed rubric and share with learners.

INTRODUCTION AND SECTION SUMMARY

In this Section, we go further to look at aircraft instruments in detail. The various on-board and ground equipment used in measuring aircraft parameters are discussed. The section also explains the principles of operation of these instruments and how they are used in conjunction with other systems to ensure safe flight. Of particular importance is the use of these instruments in analysing air incidents and accidents, and in improving future design of aircraft and related systems.

The weeks covered in this section are:

Week 13 and 14: *Flight Instruments I – Basic Aircraft Instruments*

Week 15: *Flight Instruments II – Secondary Aircraft Instruments*

Week 16 and 17: *Flight Instruments III – Flight Data Recording Instruments*

SUMMARY OF PEDAGOGICAL EXEMPLARS

In teaching aircraft flight instruments, teachers must engage learners in practical activities that encourage critical thinking, innovation and problem solving. In achieving the foregoing, teachers are encouraged to make use of innovative pedagogical strategies such as experiential learning approaches (e.g. case studies, research, field trips, simulations etc.). Talk-for-learning approaches such as think-pair-share, jigsaw method, Socratic questioning, debates and so on that provide adequate exposure to the topic being discussed should be emphasised. In applying the above stated pedagogies, group activities are to be utilised for maximum impact. Learners' characteristics, needs and abilities are also to be considered. All relevant resources are to be provided to make class interaction real and effective. All in all, after facilitation, the formative and summative assessment must align with the relevant pedagogies used.

ASSESSMENT SUMMARY

Assessing learners' understanding of the flight data instruments requires learners to share ideas on aircraft incidents they know and how they affect human life and properties. Based on the above, formative assessment should be emphasised. During the assessment, emphasis needs to be laid on learners investigating aircraft incidents and accidents on their own and sharing the ideas with their friends. Diverse characteristics and needs of learners are to be taken into consideration. Learner needs-based resources should be provided throughout the assessment activities.

A variety of assessment modes should be carried for the five weeks under this section to ascertain learners' levels of performance in the concepts to be covered. It is essential for teachers to conduct these assessments promptly to track learners' progress effectively. You are encouraged to administer these recommended assessments for each week, carefully record the results, and submit them to the **Student Transcript Portal (STP)** *for documentation.*

The assessments are:

Week 13: *Individual project work*

Week 14: *Gamification*

Week 15: *Questioning*

Week 16: *Class exercise*

Week 17: *Case study*

*Refer to the "**Hints**" for additional information on how to effectively administer the assessment modes for the STP.*

WEEK 13 AND 14: AIRCRAFT INSTRUMENTS I

Learning Indicators

1. *Relate the physical variables that are measured in aircraft applications with the instruments used to measure them.*
2. *Explain the principles of operation of the aircraft instruments.*

FOCAL AREA: FLIGHT INSTRUMENTS

What is Instrumentation?

Instrumentation is a term used to describe measuring instruments used for indicating and recording the physical parameters of a system. Aircraft instrumentation refers to a coordination of instruments that provide the crew with information concerning the aircraft and its subsystems. They provide data on aircraft altitude, attitude, speed, engine performance and others.

Basic Aircraft Instruments

These are the fundamental instruments that a pilot needs to ensure safety. These are also known as the 'Six Pack' instruments. They provide the pilot with basic critical information about the aircraft. They include airspeed indicator, attitude indicator, altimeter, turn coordinator, heading indicator, and vertical speed indicator. All these instruments can be traditionally put into two main groups namely gyroscopic and barometric instruments.

Barometric Aircraft Instruments

Barometric instruments basically function by measuring air pressure. The barometric instrumentation system measures two kinds of pressure which are the static and dynamic pressures. The static pressure port is positioned on the side of the aircraft in such a manner that it measures only the static pressure without the pressure induced by the movement of the aircraft through the air. Due to this, the static pressure port only measures the atmospheric pressure.

The pressure reading is then calibrated to display various important flight parameters like altitude and airspeed. Barometric instruments on aircraft include:

1. Airspeed Indicator
2. Altimeter
3. Vertical Speed Indicator

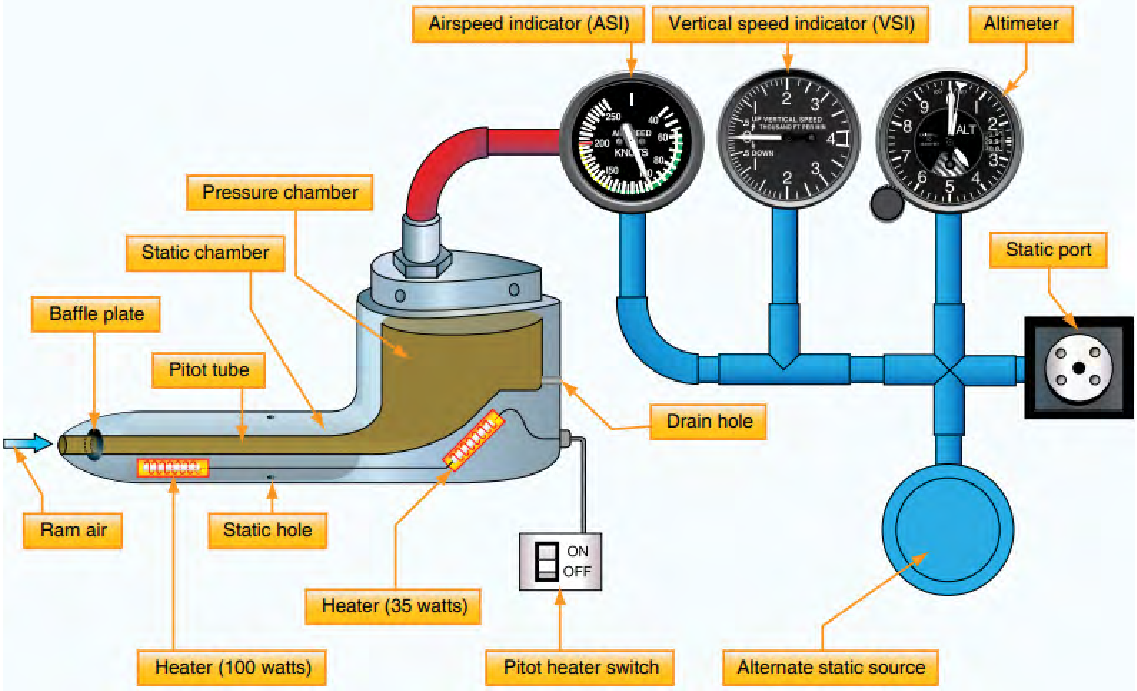

Figure 61: *Pitot-Static system*

Pitot Static Errors Explained - Aeroclass.org

https://www.aeroclass.org/pitot-static-errors/

1. Airspeed Indicator (ASI)

This shows the speed of the aircraft relative to air upstream. This instrument makes use of both the static and dynamic pressure ports on a pitot tube. The speed is usually shown in knots but may be indicated in kilometres per hour or miles per hour. Accurate measurement of airspeed is extremely important to the pilot. This is because if the airspeed should fall below the stall speed, as given by the aircraft manufacturer, the wings will suddenly lose lift and cause the aircraft to fall out of the sky. Stalls are very dangerous and may be very difficult to recover from. It is also important that the aircraft's maximum speed (as rated by the manufacturer) is not exceeded. Exceeding the maximum speed may result in excessive vibrations that could cause structural damage to the aircraft.

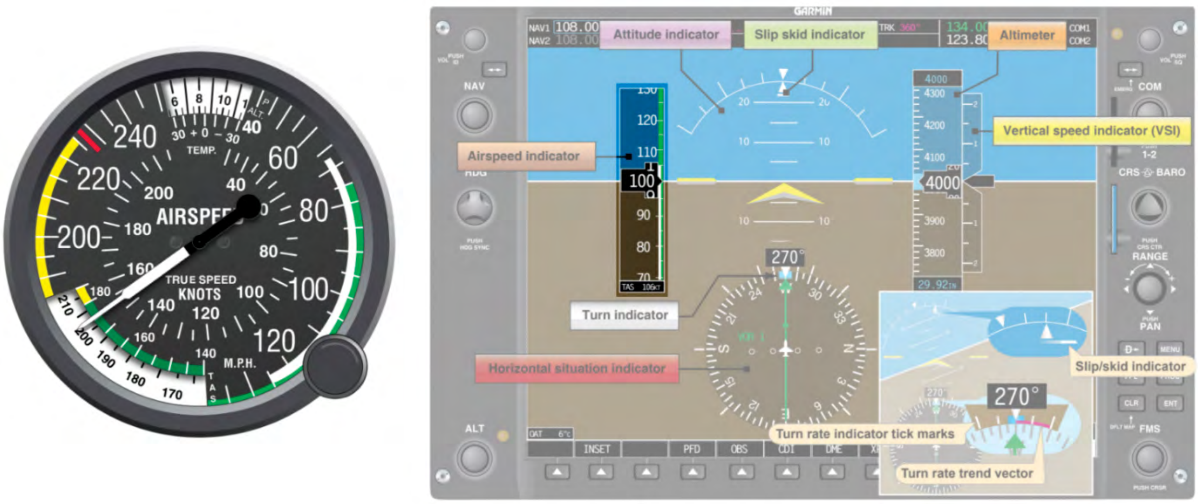

Figure 62: *Airspeed Indicator*

https://pilotinstitute.com/wp-content/uploads/2023/05/Airspeed-Indicator-ASI-1536x703.png

2. Altimeter

This shows the altitude of the aircraft above mean sea level (MSL). The height or altitude is usually given in feet, and in metres for some countries. This information is crucial during take-offs and landings and especially when flying in high mountain areas. From our study of the atmosphere in earlier weeks, we know that pressure varies with altitude. The higher the altitude, the lower the pressure. Aircraft instrumentation engineers take advantage of this physical phenomenon to create devices that measure pressure, called barometers. The barometer, whether mechanical or electronic, is then calibrated to indicate altitude from its pressure reading (from the static pressure port). This is a very common way to measure altitude. This altitude reading is indicated with respect to mean sea level. Altimeters that use this technique are called **pressure altimeters**.

Another interesting way to measure altitude is the use of radio waves. This type of altimeter makes use of radio waves to measure the altitude of the aircraft above the terrain below. Early radio altimeters functioned by sending radio waves directly downwards and measuring the time it takes to bounce on the terrain below and reflect back to the aircraft. Knowing the speed of radio waves (which is the same as the speed of light) and the time it took to bounce back from the terrain below, the distance to the terrain can be calculated. Modern radio altimeters use more complex methods to calculate the altitude above the terrain.

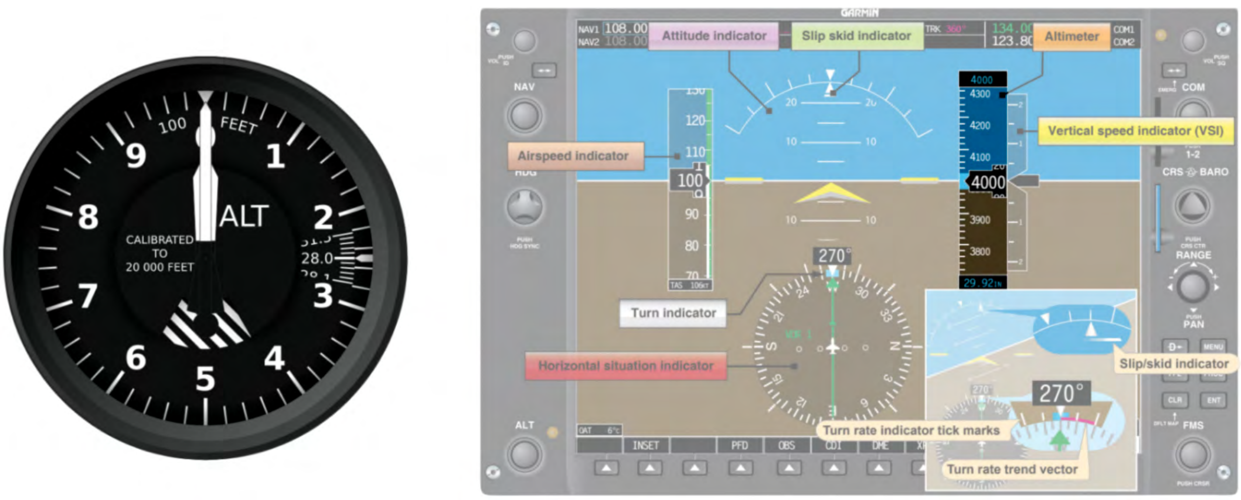

Figure 63: *Altimeter*

https://pilotinstitute.com/wp-content/uploads/2023/05/Altimeter-1536x720.png

3. Vertical Speed Indicator (VSI)

This instrument displays how quickly the aircraft's altitude is changing with respect to time.

In a simple vertical speed indicator, a pressure capsule is contained in a sealed case. The capsule is fed with static pressure, while the case is also connected to that system through a calibrated nozzle. The nozzle restricts the passage of air so that there is a time delay between a change in static pressure and that pressure being experienced within the case. Thus, if the aircraft climbs (or descends), the pressure within the capsule will decrease (increase) while that within the case will decrease (increase) at a lower rate due to the presence of the nozzle. Movement of the capsule is translated into movement of a needle by a mechanical system.

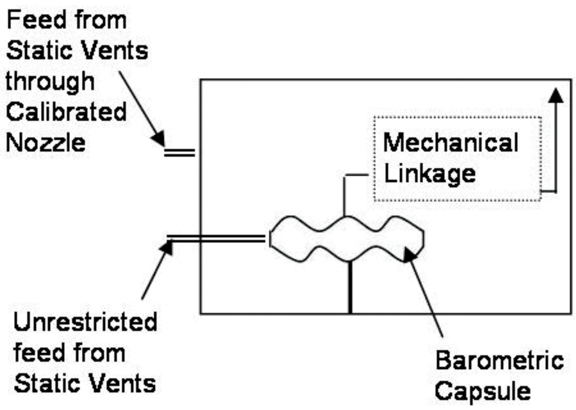

Figure 64: *Mechanism of a vertical speed indicator*

Vertical Speed Indicator | SKYbrary Aviation Safety

https://skybrary.aero/articles/vertical-speed-indicator

It is important to know how quickly the aircraft is gaining height or losing height especially during take-offs, landings, climbs or descents. The display is usually shown in hundreds of feet per minute.

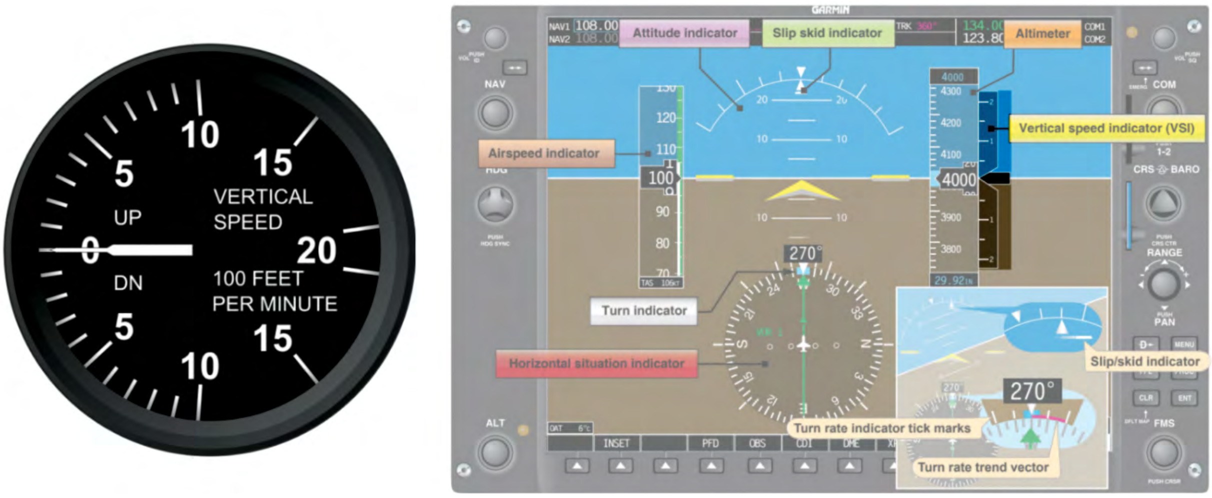

Figure 65: *Vertical Speed Indicator*

https://pilotinstitute.com/wp-content/uploads/2023/05/Vertical-Speed-Indicator-VSI-1536x720.png

Gyroscopic Aircraft Instruments

These instruments make use of a gyroscope to function. A gyroscope is a mechanical device. It consists of a spinning wheel rotating around an axis. The inertia of the spinning wheel gives the gyroscope a property called **rigidity**. This property makes the gyroscope tend to maintain its plane of rotation. This property is very useful in the design of inertial measurement systems in air and ground vehicles. It helps the aircraft to be aware of its orientation in space. This video link (Gyroscope (youtube.com)) provides a visual demonstration of a gyroscope and its use in aircraft.

The aircraft instruments (among the "six pack") that rely on gyroscopes to function are;

1. Attitude Indicator
2. Heading Indicator
3. Turn Coordinator

1. Attitude Indicator (AI) / Artificial Horizon (AH)

This shows the aircraft's angle of pitch and bank. Generally functioning off the gyroscope and operating on the principle of rigidity provides a quick indication of the aircraft's pitch and roll angles. It gives the pilot information on the aircraft's orientation relative to the Earth's horizon. The pilot can then know whether the wings are level and whether the nose is below or above the horizon.

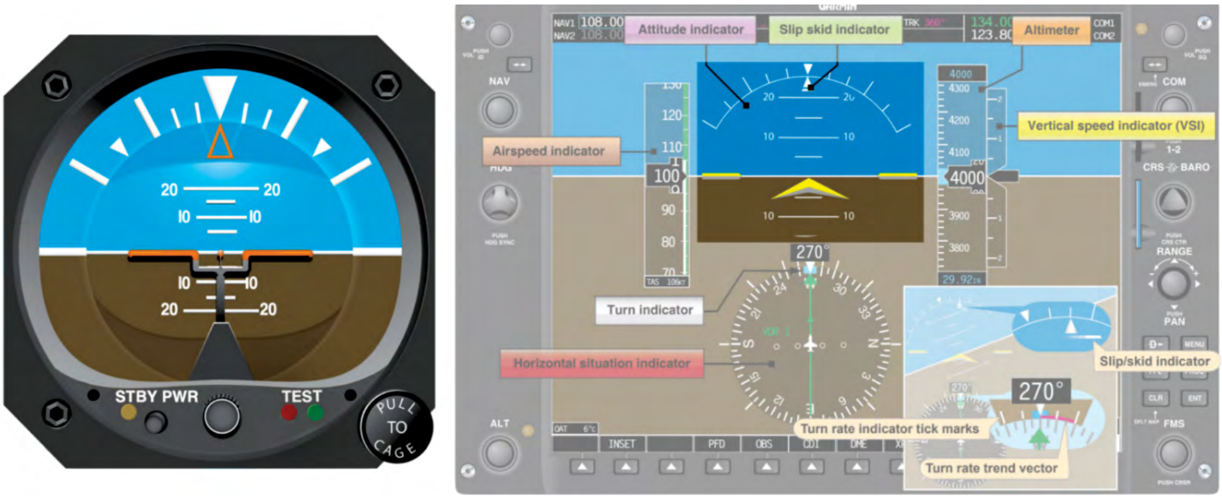

Figure 66: *Attitude indicator / Artificial Horizon*

https://pilotinstitute.com/wp-content/uploads/2023/05/Attitude-Indicator-AI-Artificial-Horizon-AH-1536x680.png

2. Heading Indicator (HI) / Direction Indicator (DI)

A key factor to consider when navigating in an aircraft is to ensure you are headed in the right direction. The instrument that gives an indication of the aircraft's flight direction is the heading indicator. It is a gyroscopic instrument and it indicates the direction of the aircraft (in degrees) relative to Magnetic North.

It is vital to maintain a steady flight especially when one is travelling over a long distance. If the pilot deviates from a heading by even a single degree, the aircraft may be off the destination by several kilometres. This poses air crash hazards, particularly in busy airspaces.

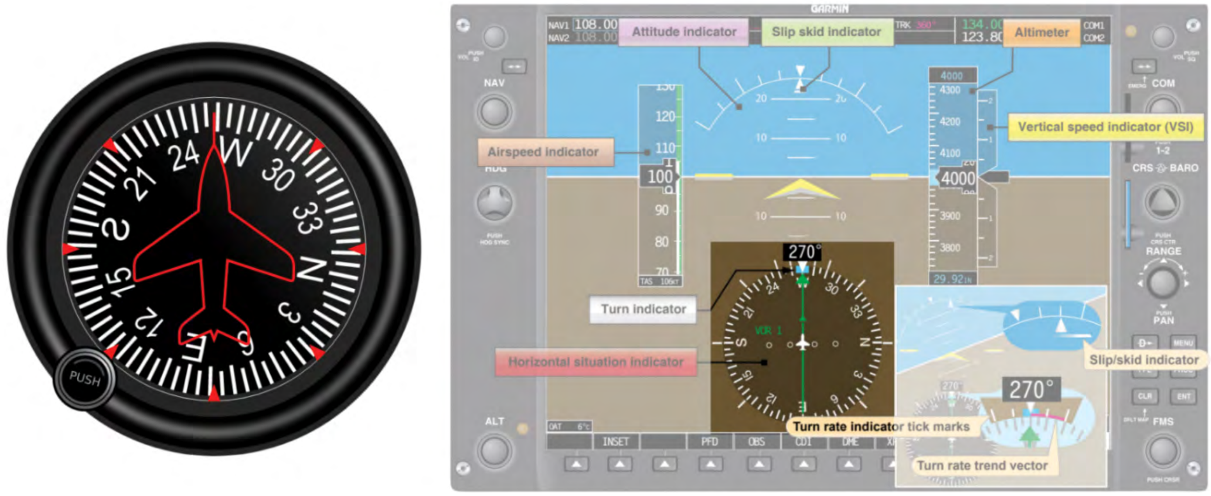

Figure 67: *Heading Indicator / Direction Indicator*

https://pilotinstitute.com/wp-content/uploads/2023/05/Heading-Indicator-HI-Direction-Indicator-DI-1536x720.png

3. Turn Coordinator

The turn coordinator is an essential instrument in an aircraft's cockpit, providing vital information about the rate of turn and the coordination of the turn. The turn coordinator operates on the principle of gyroscopic precession, where a force applied to a spinning gyroscope results in a reaction 90 degrees from the point of force application in the direction of rotation. By understanding and properly using the turn coordinator, pilots can ensure safe and controlled flight, especially in conditions where visual cues are limited. Its combination of gyroscopic and inclinometer functions make it a versatile and reliable tool for maintaining proper flight attitude and coordination.

Figure 68: *Turn Coordinator*

https://pilotinstitute.com/wp-content/uploads/2023/05/Turn-Coordinator-1-1536x720.png

Engine Indicating and Crew Alerting System (EICAS)

The Engine Indicating and Crew Alerting System (EICAS) is an advanced, integrated system used in modern aircraft to monitor, display, and manage engine parameters and other critical aircraft systems. It provides the flight crew with real-time information and alerts about the status and performance of the engines and other essential systems, enhancing situational awareness and safety. It consists of a system of displays, sensors and data acquisition units, processing units and a control interface.

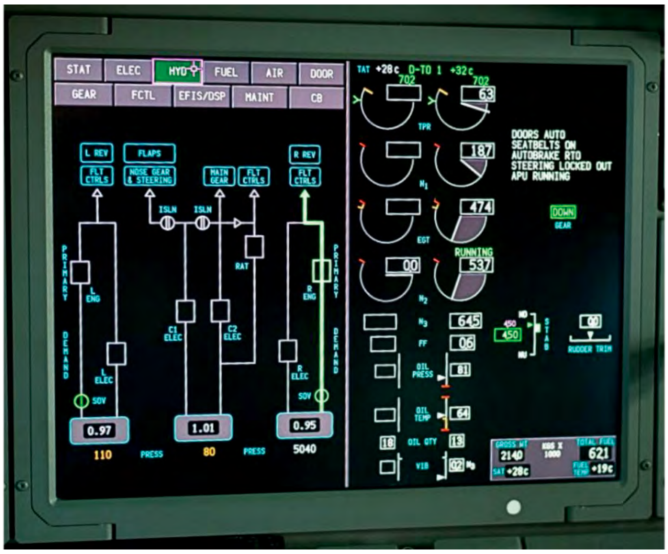

Figure 69: *Engine Indicating and Crew Alerting System display*

https://pilotinstitute.com/wp-content/uploads/2023/05/Engine-Indicating-and-Crew-Alerting-System-EICAS-1536x720.png

Synthetic Vision System (SVS)

This system uses advanced computer graphics to generate a 3D view of the terrain, obstacles and landmarks to pilots. This gives the pilots an enhanced awareness of the environment around them and makes flying much easier especially in inclement weather. The image is projected onto the Primary Flight Display screen for the pilot.

Figure 70: *Synthetic Vision System display*

https://pilotinstitute.com/wp-content/uploads/2023/05/Synthetic-Vision-System-SVS-1-1536x720.png

Magnetic Compass

This provides the magnetic heading of the aircraft during steady flight. However, during a turn, climb, descent or acceleration the magnetic compass may give a wrong heading because of the orientation with the Earth's magnetic field.

Figure 71: *Magnetic Compass for aircraft*

https://pilotshop.rs/airpath-instrument-c-2200-l4b-magnetic-compass-12vdc.html

Horizontal Situation Indicator (HSI)

This is used for navigation. It displays the aircraft's current heading as compared with a desired heading or path. It can be used during instrument take-offs and landings and to intersect a certain course.

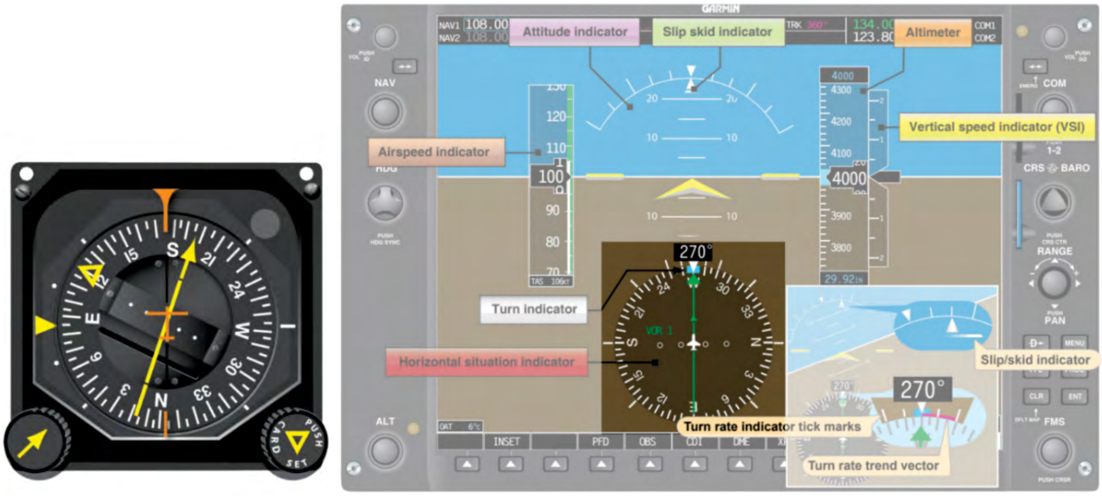

Figure 72: *Horizontal Situation Indicator*

Source: https://pilotinstitute.com/wp-content/uploads/2023/05/Horizontal-Situation-Indicator-HSI-1536x720.png

Learning Tasks

1. Identify critical environmental variables (i.e., including aircraft data) that pilots need ensure safe flight.
2. Identify the corresponding basic instruments used to measure and record aircraft data.

Pedagogical exemplars

1. **Talk-for-Learning:** In small ability groups, use fishbowl discussion approach, where the inner group discusses the outside environment of aircraft whilst the outer group also discusses the inner environment of the aircraft. In a plenary discussion, both groups share their knowledge with the larger class.

   Using the same groups, learners debate about the relevance of paying attention to the environment around the aircraft.

2. **Experiential Learning:** Using simulations/videos/field trips, allow learners to interact with the relevant basic instruments (e.g., airspeed indicator, heading indicator etc.) that are used for displaying and recording flight data. Guide learners to write a report on the basic instruments they observed during the activity and the quantities they measure. Identify for each instrument whether it is airborne or on the ground.

Note

In forming the groups, teachers should be mindful of gender and socio-emotional issues. Again, since the pedagogy is learner-oriented, the background characteristics of the learners should be taken into consideration in all classroom interactions. For example, attention should be given to learners who are approaching proficiency, as we give challenging tasks to proficient learners. Learners with special educational needs should also be served with the relevant atmosphere and resources to be able to learn.

Key Assessment

1. **Assessment Level 2:** Using gamification, learners on an individual basis identify relevant basic aircraft instruments and explain the context within which they are used.
2. **Assessment Level 3:** In groups, research on the critical environmental variables (i.e., aircraft data) and orally share with the larger class.
3. **Assessment Level 4:** In a group project, learners research and write a detailed report on the principles of operation of basic aircraft instruments.

Hint

- *Assign* ***individual project*** *to learners in Week 13. The project work is due in Week 20 of the academic year.*
- *The recommended mode of assessment for Week 14 is* ***gamification.*** *Refer to Question 1 of Key Assessment Level 2 for an example task.*

WEEK 15: AIRCRAFT INSTRUMENTS II

Learning Indicators

1. *Relate the physical variables that are measured in aircraft applications with the instruments used to measure them.*
2. *Explain the principles of operation of the aircraft instruments.*

FOCAL AREA: ENGINE INDICATING INSTRUMENTS

Aircraft engine indicating instruments provide pilots with essential information regarding the performance and health of the engine. These instruments allow for real-time monitoring of critical parameters such as temperature, pressure, fuel flow, and RPM (revolutions per minute). Accurate and timely readings from these instruments are vital for ensuring the safe and efficient operation of the engine during flight.

1. **Tachometer (RPM Indicator)**
   The Tachometer measures the speed at which the engine's output shaft or turbines are rotating. It displays revolutions per minute (RPM), providing a direct indication of engine power output. For piston engines, it reflects the rotation of the crankshaft, while in turboprop or jet engines, it indicates the speed of the gas turbine or propeller. Monitoring the RPM helps the pilot ensure that the engine is operating within safe limits and at the desired power setting. Excessive or insufficient RPM can lead to engine stress or insufficient thrust.

Figure 73: *Tachometer*

2. **Manifold Pressure Gauge**

   This instrument measures the absolute pressure within the engine's intake manifold and is primarily used in piston-engine aircraft, especially those with superchargers or turbochargers. The manifold pressure gauge provides information about the amount of air being delivered to the engine's cylinders, which directly influences the power output. Proper management of manifold pressure is crucial for engine efficiency and longevity, particularly during changes in altitude or throttle settings.

Figure 74: *Manifold Pressure*

3. **Oil Pressure Gauge**
   The oil pressure gauge indicates the pressure of the lubricating oil circulating through the engine. It helps ensure that the engine is receiving adequate oil for lubrication and cooling of internal components. Low oil pressure can be an early warning of oil leakage, pump failure, or excessive engine wear. If the oil pressure drops below a critical threshold, it could lead to catastrophic engine failure.

Figure 75: *Oil Pressure*

4. **Oil Temperature Gauge**
   The oil temperature gauge monitors the temperature of the oil as it circulates through the engine. The temperature of the oil reflects how well the engine is cooling, as oil absorbs heat from the engine components. High oil temperatures can indicate that the engine is overheating, which may result from insufficient oil, cooling system malfunctions, or excessive power settings. Maintaining oil within optimal temperature ranges prevents engine damage.

Figure 76: *Oil Temperature Gauge*

5. **Exhaust Gas Temperature (EGT) Gauge**
   The EGT gauge measures the temperature of the exhaust gases leaving the engine's combustion chambers. This reading provides insight into the engine's combustion efficiency and mixture settings (the balance of fuel and air entering the engine).

   An excessively high EGT can indicate that the fuel-air mixture is too lean, leading to engine damage, while a low EGT may suggest an overly rich mixture, reducing efficiency. Pilots adjust the fuel mixture using EGT readings to optimize engine performance, especially during altitude changes.

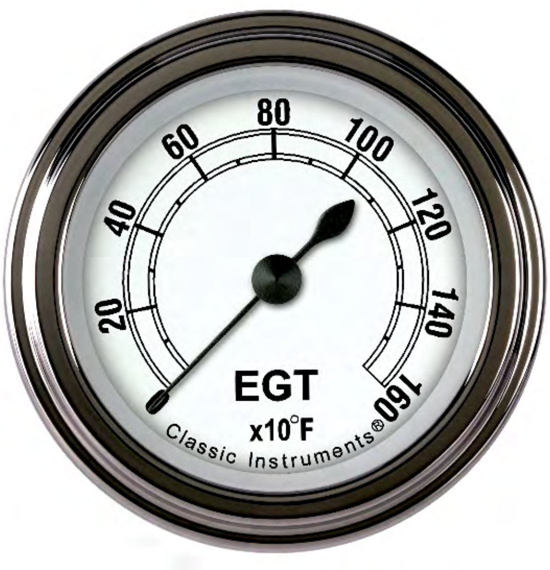

Figure 77: *Exhaust Temperature Gauge*

6. **Cylinder Head Temperature (CHT) Gauge**
   The CHT gauge measures the temperature of the cylinder head in piston engines. This gauge monitors the heat generated in the combustion process and helps indicate whether the engine is cooling properly. Overheating of the cylinder heads can lead to detonation or engine damage, particularly during high power settings, climbs, or in hot weather. Monitoring CHT ensures that the engine is operating within safe temperature limits.

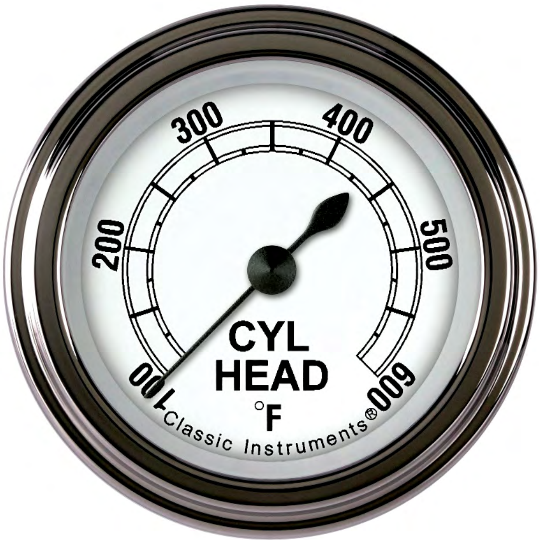

Figure 78: *Cylinder Head Temperature Gauge*

7. **Fuel Flow Indicator**

The fuel flow indicator show the rate at which fuel is being consumed by the engine, typically measured in gallons or litres per hour. It provides the pilot with real-time information on fuel consumption, allowing for better fuel management and planning during flight. Monitoring fuel flow is critical for long flights or in cases where fuel consumption rates fluctuate due to changes in engine power settings or altitude. It helps the pilot calculate fuel endurance and avoid running out of fuel mid-flight.

Figure 79: *Fuel Flow Indicator*

8. **Fuel Pressure Gauge**

This gauge measures the pressure of the fuel being delivered to the engine's injectors or carburettor. Proper fuel pressure ensures that the engine receives an adequate supply of fuel to maintain combustion. A drop in fuel pressure can indicate issues with the fuel pump, fuel line blockage, or fuel tank levels, potentially leading to engine failure if unaddressed.

Figure 80: *Fuel Pressure Gauge*

9. **Turbine Inlet Temperature (TIT) Gauge**

   The TIT gauge is used in turbine engines to measure the temperature of the gases entering the turbine. It helps monitor the thermal stress on the turbine components and reflects the efficiency of the combustion process. Monitoring TIT is critical in preventing thermal damage to the turbine blades, as excessive temperatures can cause them to overheat and fail.

Figure 81: *Turbine Inlet Temperature Gauge*

10. **Vibration Indicators**

    Vibration indicators detect abnormal levels of vibration within the engine. These instruments provide early warning of potential mechanical failures, such as imbalanced rotors, loose components, or damaged engine parts. High vibration levels can indicate engine wear or damage, leading to performance degradation or mechanical failure if not addressed.

Learning Tasks

1. Discuss some engine indicating instruments found in automobiles.
2. Visit an aircraft maintenance facility to observe some engine indicating instruments and how they work. In the absence of a close maintenance facility, videos on engine instruments can be used to supplement class discussions.

Pedagogical Exemplars

1. **Talk-for-learning:** Using Socratic questioning for specific smaller ability groups, allow learners to brainstorm the engine indicating instruments and share with the larger class. Allow learners to demonstrate their understanding in different ways. For example, some learners could present their findings to the class, while others could create a report or a mind map.

   In smaller ability groups, allow learners to think-pair-share the principles of operation of engine indicating instruments citing relevant examples on their own.

2. **Experiential Learning:** Watch a video in class, and in smaller ability groups, discuss the circumstances or situations in which specific engine indicating instruments would be used to ensure safe flight. All relevant resources needed for all categories of learners to fully participate in the lesson should be provided.

Note

In forming the groups, teachers should be mindful of gender and socio-emotional issues. Again, since the pedagogy is learner-oriented, the background characteristics of the learners should be taken into consideration in all classroom interactions. For example, attention should be given to learners who are approaching proficiency, as we give challenging tasks to proficient learners. Learners with special educational needs should also be served with the relevant atmosphere and resources to be able to learn.

Key Assessment

1. **Assessment Level 1:** Learners make a list of engine indicating instruments
2. **Assessment Level 2:** Explain the use of a given number of engine indicating instruments.
3. **Assessment Level 3:** Watch a video documentary of an aircraft that experienced an engine failure. From the video, write a report discussing the engine indicating instruments that alerted the flight crew to the incident.

Hint

*The recommended mode of assessment for Week 15 is **questioning**. Refer to Question 2 of Key Assessment Level 2 for an example task.*

WEEK 16 AND 17

Learning Indicators

1. *Identify the salient features of flight data storage equipment, explain how data was previously stored and summarise the importance of flight data storage.*
2. *Indicate the various aircraft parameters that are recorded.*

FOCAL AREA: FLIGHT DATA STORAGE EQUIPMENT

Flight Data Recorder

This is a device used to record specific aircraft flight data to aid air crash investigations. The data recorded can include time, altitude, attitude, airspeed, heading, flap position, autopilot mode, etc. The data recorded is primarily used to determine whether an air crash was caused by mechanical failures, environmental factors or human error. The analysis of this data is also used by aircraft manufacturers to improve future aircraft design and related systems. Flight data recorders are installed mostly in the tail sections of aircraft where they are likely to survive air crashes. They are colloquially referred to as 'Black Boxes'.

The data recorders are designed to survive the following conditions (features):

1. Fire (High Intensity) - 1100°C flame covering 100% of recorder for 30 minutes.
2. Fire (Low Intensity) - 260°C Oven test for 10 hours
3. Impact Shock - 3,400 Gs for 6.5 ms
4. Static Crush - 5,000 pounds for 5 minutes on each axis
5. Fluid Immersion - Immersion in aircraft fluids (fuel, oil etc.) for 24 hours
6. Water Immersion - Immersion in sea water for 30 days
7. Penetration Resistance - 500 lb. Dropped from 10 ft. with a ¼-inch-diameter contact point
8. Hydrostatic Pressure - Pressure equivalent to depth of 20,000 ft.

https://imgk.timesnownews.com/story/Flight_Data_Recorder_iStock_image_Black_Box.jpg

Figure 82: *A Flight Data Recorder / Black Box*

Cockpit Voice Recorder

This is the 'cockpit area microphone'. It records all important sounds in the cockpit notably, pilot conversations, air traffic control conversations, engine noise, gear extension and retraction sounds, stall warnings, airspeed call-outs, automated weather briefings, ground and cabin crew conversations.

After an aircraft incident, a committee from the various aviation units is formed to listen to the recording. From this, an audio transcript is created to highlight the points of interests within the sequence of events. The final transcript may then be released to the public.

The cockpit voice recorder is designed to survive the following conditions:

1. Time recorded- 30 min continuous, 2 hours for solid state digital units
2. Number of channels- 4
3. Impact tolerance- 3400Gs / 6.5 ms
4. Fire resistance- 1100 degC / 30 min
5. Water pressure resistance- submerged 20,000 ft
6. Underwater locator beacon- 37.5 KHz; battery has shelf life of 6 years or more, with 30-day operation capability upon activation.

https://tailstrike.com/description/

Figure 83: *A Cockpit Voice Recorder*

ACCIDENT CASE STUDY

The following examples are air crashes whose causes were later determined from the transcript of the flight data recorders and cockpit voice recorders.

Air France Flight 447

On 1 June 2009, Air France Flight 447 (AF447) was scheduled to fly international passengers from Rio de Janeiro, Brazil, to Paris, France. The aircraft departed from Rio de Janeiro–Galeão International Airport on 31 May 2009 at 19:29 Brazilian Standard Time (22:29 UTC)with a scheduled arrival at Paris-Charles de Gaulle Airport at 11:03 Central European Summer Time (09:03 UTC) the following day.

Three and half hours into the flight over the Inter-Tropical Convergent Zone, ice started to build up in the airspeed sensors. The airspeed indications in the cockpit showed inconsistent readings.

This caused the autopilot to disengage and remove the protections inherent in the system. The surprised pilots had to fly the aircraft manually.

The pilots mistakenly over-controlled the aircraft when it started to roll from side to side. This caused the aircraft to roll left and descend sharply. In an attempt to restore the pitch angle, the pilots again overcorrected and pulled back on the controls until the aircraft stalled.

The aircraft then entered a free-fall towards the ground. The pilots misinterpreted this as an overspeed. The pilots moved to reduce the engine thrust and apply the speed brakes, the exact opposite of what they needed to do to recover from the stall. The pilots made contradictory inputs on the controls in an attempt to fly the plane without realising.

By the time the crew realised the situation, the aircraft was too close to the surface to recover from the stall. The aircraft crashed into the sea and broke apart killing all passengers and crew onboard. A total 228 people lost their lives that day.

After two years of searching underwater, the flight data recorder and cockpit voice recorder were recovered. Aviation units used the transcripts to piece together the sequence of the incident.

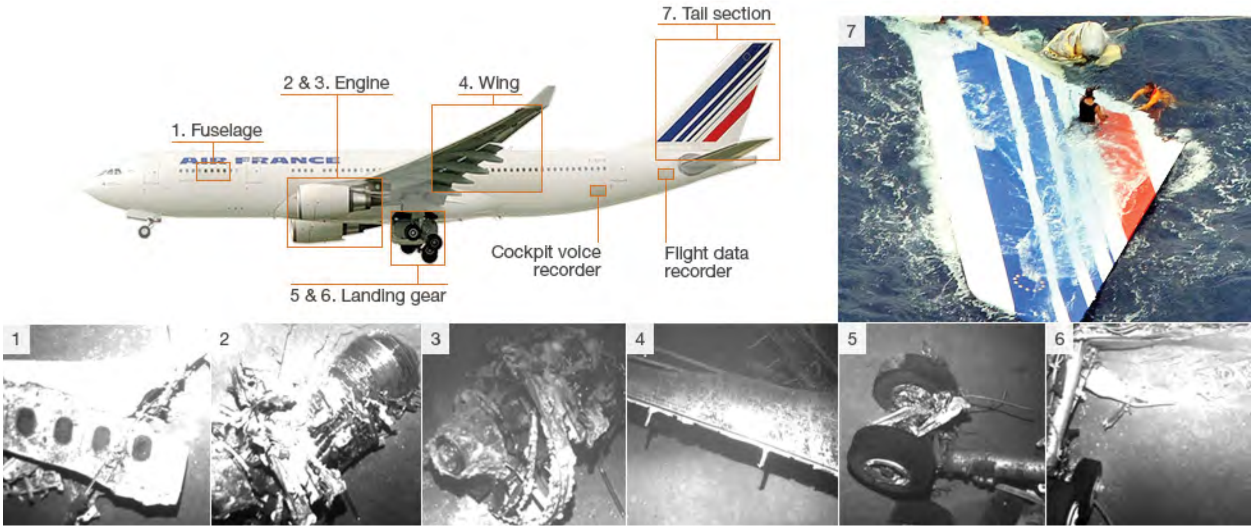

Figure 84: *Recovered debris from Air France Flight 447*

https://www.bbc.co.uk/news/world-europe-13145313

Gol Transportes Aéreos Flight 1907

On 29th September 2006, a passenger Boeing 737-800 carrying 154 people on board took off from Manaus heading to Rio de Janeiro, Brazil. Another Embraer 135 RJ was doing a ferry flight from São José dos Campos (São Paulo State) to Fort Lauderdale, Florida, USA, with a technical stop programmed for Manaus International Airport carrying 7 people on board.

The private jet was instructed by Air Traffic Control to level off at 37,000ft whereas the passenger jet was also instructed to level off at the same 37,000ft. Strangely, both pilots and ATC did not contact each other for some 25 minutes when ATC tried to contact. The transponder on board the private jet was not turned on, which meant that the Traffic Collision Avoidance System (TCAS) was not working. As such, neither aircraft could identify each other.

At 16:56:54 BRT, the winglet of the Embraer jet sliced through the left wing of the Boeing jet. The passenger jet lost a third of its left wing leading to a hard left spin towards the ground. The speed of the spin caused the structure of the jet to fail and break apart in the air. The debris fell into the dense Amazon jungle. The Embraer jet could however maintain flight and declared an emergency to a military air base about 160 kilometres from the collision point.

Following the incident, the Brazilian Air Force set up a search and rescue team to the crash site. On October 2009, the flight data recorder and cockpit voice recorder were both recovered and used to determine the sequence of events leading to the crash.

Figure 85: *Artist rendering of mid-air collision between Gol Transportes Aéreos Flight 1907 and Embraer Legacy Jet.*

Learning Tasks

1. Discuss the design features of flight data recorders
2. Explain the importance of flight data recorders.
3. Watch videos on aircraft accidents cases in which flight data recorders were used to detect possible causes of the accidents

Pedagogical Exemplars

1. Talk-for-Learning

With the aid of audio-visuals, the teacher makes a presentation to students about flight data storage.

Using the jigsaw method, divide learners into small ability groups to discuss the design features of flight data recorders. Members of each group should identify a person from a different group and share what they learned with that person. Encourage learners to simply and clearly articulate their points and listen to others during the discussions. Make room for non-vocal learners to contribute to the group discussions through writing.

2. Experiential Learning

Students visit the laboratory to observe a flight data recorder, or the teacher should allow learners to watch a video in class on the use of flight data recorders. Learners should be allowed to individually present a report on the importance of flight data recorders they watched in the video. All resources needed to make this lesson possible should be provided.

The teacher explains how the entire data in aircraft is stored, e.g., Airborne data from the pilots, Air Traffic Controller (ATC) data, meteorological data, check-in data, Airport Fire Service and then makes a demonstration on saving data on a flash drive, Google drive, iCloud; and explains how it is protected from hacking.

Note

In forming the groups, teachers should be mindful of gender and socio-emotional issues. Again, since the pedagogy is learner-oriented, the background characteristics of the learners should be taken into consideration in all classroom interactions. For example, attention should be given to learners who are approaching proficiency, as we give challenging tasks to proficient learners. Learners with special educational needs should also be served with the relevant atmosphere and resources to be able to learn.

Key Assessment

1. **Assessment Level 1:** List the design features of flight data recorders.
2. **Assessment Level 3**
   - **a.** Using practical scenarios, explain the conditions under which flight data recorder features help safe data keeping.

     Note: This task should be given on individual and on group basis.
   - **b.** Read about the Air France Flight 447 crash in 2009 and answer the following questions.
     - i. What occurrences led up to the accident?
     - ii. What was identified as the cause of the accident?
     - iii. What parameters of the aircraft were stored by the flight data recorder and how did it assist the accident investigators?
3. **Assessment Level 4:** Research on the importance of flight data recorders and give a PowerPoint presentation of your findings.

Hint

- *The recommended mode of assessment for Week 16 is **class exercise.***
- *The recommended mode of assessment for Week 17 is **case study.** Refer to Question 3 of Key Assessment Level 3 for an example task.*
- *Learners' scores on individual class exercise should be ready for submission into the STP. This could be an average of the number of exercises conducted from Week 13.*

SECTION REVIEW

In this Section, we have closely looked at flight instruments and the critical role they play in ensuring flight safety. Extremely important is the role they play in aircraft incident analysis and improving the design of aircraft and associated systems. Knowledge gained from this section is crucial in informing the learner about safe aircraft operation.

Additional Reading

1. Cockpit Voice Recorder Handbook for Aviation Accident Investigations, NTSB, December 2019

   https://skybrary.aero/bookshelf/books/5945.pdf

2. ICAO Annex 6, Operation of Aircraft, Vol I, Attachment D and Vol III

Figure	Link	QRCode
Figure 61: Pitot-Static system	https://www.aeroclass.org/pitot-static-errors/	
Figure 62: Airspeed Indicator	https://pilotinstitute.com/wp-content/uploads/2023/05/Airspeed-Indicator-ASI-1536x703.png	
Figure 63: Altimeter	https://pilotinstitute.com/wp-content/uploads/2023/05/Altimeter-1536x720.png	
Figure 64: Mechanism of a vertical speed indicator	https://skybrary.aero/articles/vertical-speed-indicator	
Figure 65: Vertical Speed Indicator	https://pilotinstitute.com/wp-content/uploads/2023/05/Vertical-Speed-Indicator-VSI-1536x720.png	
Figure 66: Attitude indicator / Artificial Horizon	https://pilotinstitute.com/wp-content/uploads/2023/05/Attitude-Indicator-AI-Artificial-Horizon-AH-1536x680.png	
Figure 67: Heading Indicator / Direction Indicator	https://pilotinstitute.com/wp-content/uploads/2023/05/Heading-Indicator-HI-Direction-Indicator-DI-1536x720.png	
Figure 68: Turn Coordinator	https://pilotinstitute.com/wp-content/uploads/2023/05/Turn-Coordinator-1-1536x720.png	

Figure	Link	QRCode
Figure 69: Engine Indicating and Crew Alerting System display	https://pilotinstitute.com/wp-content/uploads/2023/05/Engine-Indicating-and-Crew-Alerting-System-EICAS-1536x720.png	
Figure 70: Synthetic Vision System display	https://pilotinstitute.com/wp-content/uploads/2023/05/Synthetic-Vision-System-SVS-1-1536x720.png	
Figure 71: Magnetic Compass for aircraft	https://pilotshop.rs/airpath-instrument-c-2200-l4b-magnetic-compass-12vdc.html	
Figure 72: Horizontal Situation Indicator	https://pilotinstitute.com/wp-content/uploads/2023/05/Horizontal-Situation-Indicator-HSI-1536x720.png	
Figure 73: Tachometer	https://www.aircraftspruce.com/catalog/inpages/tso_tachometer.php	
Figure 74: Manifold Pressure Gauge	https://www.aircraftspruce.com/catalog/inpages/midcontinent10-05452-57.php	
Figure 75: Oil Pressure Gauge	https://www.aircraftspruce.com/catalog/inpages/vdooiltempgauge1.php	
Figure 76: Oil Temperature Gauge	https://www.autobox.com.au/saas-oil-temperature-gauge-black-face	
Figure 77: Exhaust Gas Temperature Gauge	https://www.carid.com/classic-instruments/classic-instruments-classic-white-series-exhaust-gas-temperature-gauge-1649053736.html)	
Figure 78: Cylinder Head Temperature Gauge	https://www.truckid.com/classic-instruments/classic-instruments-classic-white-series-cylinder-head-temperature-gauge-1649050669.html	

Figure	Link	QRCode
Figure 79: Fuel flow indicator	https://www.aircraftspruce.eu/uma-2-1-4--fuel-flow-indicator-0-8-gph-non-tso.htm	
Figure 80: Fuel Pressure Gauge	https://www.aircraftspruce.com/catalog/inpages/umaelecfuelpresstso.php	
Figure 81: Turbine Inlet Temperature Indicator	https://innovative-ss.com/products/indicators/turbine-inlet-temperature-indicator-titi/	
Figure 82: A Flight Data Recorder / Black Box	https://imgk.timesnownews.com/story/Flight_Data_Recorder_iStock_image_Black_Box.jpg	
Figure 83: A Cockpit Voice Recorder	https://tailstrike.com/description/	
Figure 84: Recovered debris from Air France Flight 447	https://www.bbc.co.uk/news/world-europe-13145313	
Figure 85: Artist rendering of mid-air collision between Gol Transportes Aéreos Flight 1907 and Embraer Legacy Jet.	https://static.wikia.nocookie.net/planecrash/images/3/38/Gol_%26_Legacy.jpg/	

SECTION 5: LOCAL AND INTERNATIONAL CIVIL AVIATION BODIES

Strand: Aviation Industry

Sub-strand: Aviation Organisations

Learning Outcomes

1. *Understand the ICAO and IATA regulations governing the operations of both the aerospace and aviation agencies*
2. *Itemise the functions of both local and international aviation organisations*

Content Standards

1. Understand the relationship between aerospace and aviation organisations and its regulations of operation.
2. Recount the roles of the aviation agencies in ensuring the safety of air transport

Hint

*The **mid-semester examination** will be conducted in Week 18. Refer to **Appendix G** at the end of this section for a Table of Specification to guide you to set the questions. Set questions to cover all the indicators covered for at least weeks 13 to 17.*

INTRODUCTION AND SECTION SUMMARY

In this Section, we consider the local and international aviation bodies that regulate the operations of air operators to ensure smooth air travel. Air travel is recognised in the world as the safest and reliable form of transport partly because it is heavily regulated and monitored by such aviation bodies. The learner will appreciate the numerous functions these bodies play in ensuring safe skies. The weeks covered in this Section are:

Week 18 and 19: *Local and International Aviation Organisations*

SUMMARY OF PEDAGOGICAL EXEMPLARS

Innovative learner-centred procedures are to be employed to facilitate a comprehensive understanding of local and international aviation organisations and their functions among mixed-ability groups. Techniques such as think-pair-share, pyramid discussions, and whole-class plenary discussions encourage active participation, critical thinking, and collaboration, allowing learners to engage deeply with the subject matter and share their perspectives. These approaches enable learners to clarify doubts, build on each other's ideas, and construct knowledge collectively.

Experiential learning approaches, including watching documentaries on aviation organisation functions and field trips to local organisations, further enhance learners' understanding and skills. Documentaries provide a visual representation of aviation organisations' roles and responsibilities, while field trips offer a firsthand experience of their functions, enabling learners to connect theoretical concepts with practical applications. By leveraging these innovative methods, learners develop critical thinking skills, innovation, and collaboration, essential for success in the aviation industry. The approaches foster a dynamic and inclusive learning environment, accommodating diverse learning styles and abilities, and empowering learners to take ownership of their learning.

ASSESSMENT SUMMARY

A comprehensive assessment approach is employed to measure learners' knowledge and thinking skills, including recall, application, strategic, and extended thinking, with a focus on cultivating critical thinking, collaboration, and innovation skills. This approach recognises that learners possess diverse learning styles, strengths, and needs, and seeks to accommodate these differences through a range of assessment strategies. The assessment environment is to be designed to be inclusive and equitable, with all necessary resources and accommodations made available to support learners with special education needs, such as extra time to complete assessments, or the provision of assessments in alternative formats. By taking a multi-faceted approach to assessment, the process aims to provide a complete and nuanced picture of learners' knowledge, skills, and thinking abilities, empowering teachers to tailor their instruction to meet the diverse needs of their students and provide learners with a range of opportunities to demonstrate their learning.

The modes assessments outlined for this section are designed to provide a comprehensive evaluation of learners' grasp of key concepts and skills. The recommended assessment modes for each week are:

Week 18: *Mid-semester examination*

Week 19: *Dramatisation*

*Refer to the "**Hint**" at the key assessment for additional information on how to effectively administer these assessment modes.*

WEEK 18-19: LOCAL AND INTERNATIONAL AVIATION ORGANISATIONS

Learning Indicators

1. *Identify the major aviation agency in Ghana (Ghana Civil Aviation Authority [GCAA])*
2. *Identify global aviation agencies*
3. *Identify the functions of the local aviation organisations*
4. *Explain the functions of ICAO, IATA, FAA, EASA, etc.*

FOCAL AREA: CIVIL AVIATION ORGANISATIONS

Local Civil Aviation Organisations

1. Ghana Civil Aviation Authority

Figure 86: *GCAA logo*

The Ghana Civil Aviation Authority (GCAA) is a regulatory body charged with ensuring safety within Ghana's airspace. The Ghana Civil Aviation Authority was established under PNDC Law 151 in May 1986. Prior to that, it was a unit under Public Works Department in 1930 and granted Departmental status in 1953. In 2004, the Ghana Civil Aviation Act 678 officially established the agency as Ghana Civil Aviation Authority.

It was further restructured into these two bodies;

a. Ghana Civil Aviation Authority (GCAA)

b. Ghana Airports Company Limited (GACL)

Functions of Ghana Civil Aviation Authority

a. Licensing of aviation personnel

GCAA has the sole mandate in Ghana to license individuals who seek to work in the aviation industry within the country's airspace. This includes applications for licensing of pilots, air traffic controllers, cabin crew, maintenance engineers, flight instructors, etc. They also make sure that flight crew are medically fit to work in various capacities. Periodically, GCAA review and upgrade or revoke the licenses of aviation personnel.

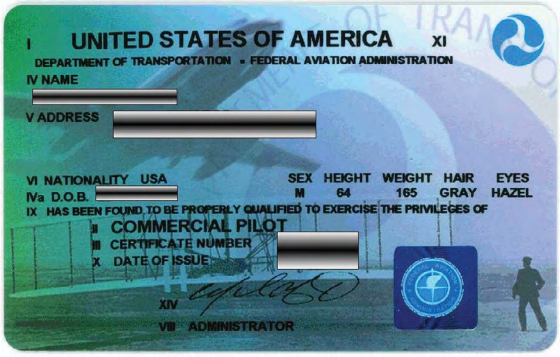

Figure 87. A sample pilot license card

b. Licensing of aviation training schools

GCAA has the mandate to approve and register aviation schools in the country which train aviation personnel. Their activities also include inspection of trained personnel, facilities, equipment and aircraft in line with the required standards.

c. Registration and marking of aircraft

The Authority has the sole responsibility of registering any civil aircraft whatever the use of the aircraft. The Authority also determines the designation to be inscribed on the aircraft for identification.

Figure 88. An Africa World Airlines aircraft registered in Ghana as 9G-AEU

d. Airworthiness Certification

The Ghana Civil Aviation Authority certifies aircraft and its components to make sure it meets international safety standards. It issues airworthiness certificates to both local and international operators. These certificates are subject to renewal by the authority after it meets quality assurance checks.

e. Registration of Maintenance and Repair Organisations (MROs)

The authority licenses and operationalises all maintenance and repair organisations that seek to offer services to aviation in the country. Periodically, the authority monitors the activities of these MROs to either renew or revoke their operational certificates.

f. Inspection of instruments and equipment

The authority determines the minimum equipment list any aircraft or air crew should have. These include equipment and devices such as airborne and ground instruments, safety harnesses, ground equipment, emergency and warning systems, automatic landing systems, enhanced vision systems and so on. These equipment are critical for various operations and aircrafts and therefore ensured that these equipment are present and in good condition.

g. Alignment of operations

The GCAA also plays an enforcement role by ensuring compliance with directives regarding the day-to-day operations of the aircraft. These include cargo and passenger handling, terminal and airside operations, handling of equipment, flight planning and performance, environmental safety and others.

h. Certification of Air Operators

The authority certifies local and international airline operators according to safety standards. This certification covers all aspects of the airline's operations including equipment, facilities, personnel, airside and terminal operations. As of July 2024, some of the operators that were certified in Ghana included the following; Africa World Airlines, Passion Air, Air Burkina, Arik Air, Asky Airlines, British Airways, Delta Airlines, Egypt Air, Emirates, Ethiopian Airlines, Kenya Airways, KLM, Brussels Airlines, Royal Air Maroc, South African Airways, TAP Air Portugal, Turkish Airlines, Air Peace, RwandAir, Air Cote D'ivoire, Middle East Airlines, Qatar Airways, United Airlines, Ibom Airlines, Air France, ITA Airways, DHL, Turkish Cargo, Emirates Cargo, Ethiopian Cargo, Cargolux, and Air Ghana.

i. Environmental protection

The authority is legitimised to set rules that guide the emission of noise and pollutants by aircraft and the protection of the environment around aerodromes.

j. Safe transport of dangerous goods

Dangerous goods such as weapons and ammunition, radioactive materials, infected live animals, poisonous gases, explosives and infectious substances are regulated by the GCAA to protect the public against any threats.

k. Registration of aerodromes

The GCAA registers all aerodromes intended for use in the country for commercial operations. Aerodromes must be inspected and approved by the GCAA before any flight operations are begun. In addition to aerodrome site conditions, inspectors will also check the availability of required facilities, personnel and equipment before certifying the aerodrome for operations.

l. Regulation of Remotely Piloted Aircraft Systems (RPAS)

GCAA also has the mandate to regulate the use of unmanned aerial systems such as drones, air balloons, rockets and so on within the country's airspace. They offer licenses to RPAS personnel and institutions, aerodromes and drones that require license.

m. Provision of air navigation services

The GCAA is the main establishment that provides aerial navigation services for flights within the Accra Flight Information Region (FIR).

2. Ghana Airports Company Limited

Figure 89: *GACL logo*

The company was registered in January 2006 with specific responsibility for planning, developing, managing and maintaining all airports and aerodromes in Ghana. The company currently holds charge of the following airports; Kotoka International Airport, Prempeh I International Airport, Tamale International Airport, Sunyani Airport, Ho Airport and Wa Airport.

Figure 90: *Kotoka International Airport*

International Civil Aviation Organisations

1. International Civil Aviation Organisation (ICAO)

Figure 91. ICAO logo

The international civil aviation organisation is an agency of the United Nations Organisation tasked with ensuring aerial safety through legislation and navigation. It is headquartered in

Montreal, Canada. The ICAO council periodically reviews and sends bulletins across the world on the recommended practices in the aviation industry.

Functions of the International Civil Aviation Organisation (ICAO)

1. **Safety oversight**: ICAO is the main body tasked with ensuring aviation safety around the globe. They do this by developing very comprehensive safety standards and regulations that seeks to minimise or prevent accidents and reduce risks that may affect aviation safety.
2. **Air Navigation Standards:** ICAO develops a framework of standards and recommended practices in areas such aircraft design, maintenance procedures, aerodrome infrastructure, air traffic handling, flight operations and air navigation. These are strictly adhered to by all member states and help to standardise global aviation practices.
3. **Facilitates air transport:** As an oversight body, ICAO ensures that all member states keep the same procedures and protocols for practices such as immigration, customs and quarantine operations at airports. This standardisation ensures that all countries maintain similar levels of safety and smooth international operations.
4. **International cooperation:** ICAO serves as a central body that coordinates the activities of all member states through forums, working groups and technical committees to build consensus and exchange ideas on best practices across the world.
5. **Capacity building:** ICAO provides technical assistance to all member states to enhance their regulatory capabilities, infrastructure development and human resource capacity. This fosters transfer of knowledge for the development of civil aviation across the world.
6. **Environmental Sustainability:** ICAO actively addresses environmental challenges such as climate change and noise pollution with its member states. Through programs such as the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), the body seeks to minimise the emission of greenhouse gases by international civil aviation.

The International Civil Aviation Organisation Annexes

These are documents that contain international aviation standards and recommended practices across the aviation industry. The documents are subject to review when necessary. Each of them deals with a specific subject. The Annexes are:

Annex 1 - Personnel Licensing

Annex 2 - Rules of the Air

Annex 3 - Meteorological Services

Annex 4 - Aeronautical Charts

Annex 5 - Units of Measurement

Annex 6 - Operation of Aircraft

Annex 7 - Aircraft Nationality and Registration Marks

Annex 8 - Airworthiness of Aircraft

Annex 9 - Facilitation

Annex 10 - Aeronautical Telecommunications

Annex 11 - Air Traffic Services

Annex 12 - Search and Rescue

Annex 13 - Aircraft Accident and Incident Investigation

Annex 14 - Aerodromes

Annex 15 - Aeronautical Information Services

Annex 16 - Environmental Protection

Annex 17 - Security

Annex 18 - The Safe Transportation of Dangerous Goods by Air

Annex 19 - Safety Management

2. International Air Transport Association (IATA)

Figure 92: *IATA logo*

This is a trade association of the world's airlines formed to promote their economic and operational interests. It was formed in 1945 in Havana, Cuba and headquartered in Montreal, Canada. As of 2024, 330 airlines from 120 countries were part of IATA.

Objectives of the International Air Transport Association

The main objectives of IATA are:

1. To ensure the safe, regular and economical air transport for the benefit of people worldwide.
2. To provide a means of collaboration.
3. To prevent economic waste caused by unreasonable competition.
4. To encourage the art of aircraft design and operation for peaceful purposes.
5. To promote and develop international tourism.
6. To provide a common platform for travel agencies and tour operators.
7. To provide training and education facilities for members.
8. To cooperate with the International Civil Aviation Organisation and other international and national organisations.

3. The Federal Aviation Administration

Figure 93: *FAA logo*

This is an agency of the United States Department of Transportation responsible for the regulation and oversight of civil aviation within the United States, as well as operation and development of a National Airspace System. Its primary mission is to ensure safety of civil aviation. However, its reach extends to the rest of the world, as various nationalities draw from its established framework.

Major activities of the agency include safety regulation, airspace and air traffic management, air navigation facilities, civil aviation abroad, commercial space transportation, research, engineering and development.

Primary responsibilities of the Federal Aviation Administration

1. Regulating civil aviation to promote safety within the U.S. and abroad;
2. Encouraging and developing civil aeronautics, including new aviation technology;
3. Developing and operating a system of air traffic control and navigation for both civil and military aircraft;
4. Researching and developing the National Airspace System and civil aeronautics;
5. Developing and carrying out programs to control aircraft noise and other environmental effects of civil aviation;
6. Regulating U.S. commercial space transportation. The FAA licenses commercial space launch facilities and private launches of space payloads on expendable launch vehicles.

4. European Union Aviation Safety Agency (EASA)

Figure 94. EASA logo

The European Union Aviation Safety Agency (EASA) is an agency of the European Union established by the European parliament and the Council to ensure safety in civil aviation, by the use of common measures and rules.

Responsibilities of EASA

The agency's responsibilities include:

1. Expert advice to the European Union on the drafting of new legislation;
2. Developing, implementing and monitoring safety rules, including inspections in the Member States;
3. Type-certification of aircraft and components, as well as the approval of organisations involved in the design, manufacture and maintenance of aeronautical products;
4. Certification of personnel and organisations involved in the operation of aircraft;
5. Certification of European organisations providing air services;
6. Certification of organisations located outside the European Union to provide air services to member states.
7. Safety analysis and research, including publication of an Annual Safety Review.

Learning Tasks

1. Explain the functions of local aviation organisations
2. Explain the functions of international aviation organisations

Pedagogical exemplars

Talk-for-learning/Experiential Learning

1. In mixed-ability groups, have learners' think-pair-share examples of local aviation organisations in Ghana. Teacher should guide learners in their groups to identify when those organisations were established. In a pyramid discussion, learners should share their knowledge with different learners in different groups. Individuals add to what others have said respectfully. Learners should be encouraged to tolerate others' views.
2. In a whole-class plenary discussion, brainstorm the functions of local aviation organisations (with particular focus on GCAA). Teacher should guide learners to share their ideas on the functions of local aviation organisations. Encourage all learners to contribute to the discussion while ensuring that a few learners do not dominate the discussion session. Develop communication and discussion skills to facilitate learning.
3. Teacher and learners should embark on a field trip to GCAA to interact with the staff of the organisation and learn from them what they do. In small ability groups, learners should be tasked to produce a report on their observations during the trip.
4. Have the whole class watch a video documentary on the work of various international aviation organisations such as ICAO, IATA, EASA, and FAA. Teacher helps learners to identify the functions of these organisations. In small groups, learners share ideas on the functions of these aviation organisations. Allow learners to choose between creating a mind map, concept diagram, or a written summary of key points.

Key Assessment

1. **Assessment Level 1:** Mention one local and any other two international aviation organisations.
2. **Assessment Level 2:** Summarise the main functions of a local aviation organisation and explain how these functions support aviation operations in your community.
3. **Assessment Level 3:** Analyse the roles of two international aviation organisations and compare how their functions impact global aviation safety and regulation. Prepare a detailed report or presentation highlighting the similarities and differences in their approaches.
4. **Assessment Level 4:** Act out a 30- to 45-minute play illustrating the functions of any of the international aviation organisations.

Hint

- *The Recommended Mode of Assessment for Week 18 is **mid-semester examination.** Refer to **Appendix G** for a Table of Specification to guide you to set the questions. Set questions to cover all the indicators covered for at least weeks 13 to 17.*
- *The Recommended Mode of Assessment for Week 19 is **dramatisation.** Refer to Question 4 of Key Assessment Level 4 for an example task.*

SECTION 5 REVIEW

In this Section, we have closely considered the roles aviation bodies play in ensuring that air travel remains safe and reliable. We began with local aviation bodies in Ghana and ended with international aviation bodies. Both set standards for the aviation industry and enforce them so that lives and property are always protected.

APPENDIX G: Mid-Semester Examination

The mid-semester exam is a 1 - 1½ hour paper consisting of 20 multiple choice questions and two essay-type questions, testing students on various aspects of the subject that have been covered from Weeks 13 to 17.

Table of test specifications for mid-semester examination (Semester 2)

Week	Focal Area	Type of question	DOK Levels				Total
			1	2	3	4	
13 & 14	Aircraft instruments I – Flight instruments	Multiple choice	3	3			6
		Essay			1		1
15	Aircraft instruments II – Engine indicating instruments	Multiple choice	2	4			6
		Essay			1		1
16 & 17	Flight data storage equipment	Multiple choice	4	4			8
	Total	Multiple choice	9	11			**20**
		Essay			2		**2**

Sample multiple choice question

Which of the following is a distinguishing feature of a flight data recorder?

A. ***Bright colour***

B. *Dark colour*

C. *Multicoloured*

D. *No colour*

Sample essay question

What aircraft parameters are stored in a flight data recorder?

Figures Table

Figure	Link	
Figure 86. GCAA logo	https://www.atc-network.com/Upload/Associations/Logo/GCAA%20Ghana_top.png	
Figure 87. A sample pilot license card	https://epicflightacademy.com/types-pilot-licenses/	
Figure 88. An Africa World Airlines aircraft registered in Ghana as 9G-AEU	https://www.airliners.net/photo/Africa-World-Airlines/Embraer-Harbin-ERJ-145LI-EMB-145LI/6036431?	
Figure 89. GACL logo	https://upload.wikimedia.org/wikipedia/en/c/c5/Ghana_Airports_Company_Limited_Logo.png	
Figure 90. Kotoka International Airport	https://www.routesonline.com/airports/8173/ghana-airports-company-limited/news/287114/terminal-3-at-kotoka-international-airport/	
Figure 91. ICAO logo	https://iaf.nu/wp-content/uploads/2020/12/ICAOsquare.png	
Figure 92. IATA logo	https://logowik.com/content/uploads/images/542_iata.jpg	
Figure 93. FAA logo	https://upload.wikimedia.org/wikipedia/commons/thumb/c/c8/Seal_of_the_United_States_Federal_Aviation_Administration.svg/600px-Seal_of_the_United_States_Federal_Aviation_Administration.svg.png	
Figure 94. EASA logo	https://upload.wikimedia.org/wikipedia/commons/thumb/a/a2/EASA_Logo.png/800px-EASA_Logo.png?20140630081343	

SECTION 6: UAV LAWS AND SAFETY PRACTICES

Strand: Unmanned Aerial Vehicles (UAVs)

Sub-Strand: UAV Safety and Regulations

Learning Outcome: *Explain the need for UAV regulations*

Content Standard: Discuss safety regulations for building and operating UAVs

Hint

- *Individual Project Work should be ready for submission by Week 20.*
- *For the **End of Semester Examination** refer to **Appendix H** for a Table of Specification to guide you to set the questions. Set questions to cover all the indicators covered for weeks 13 to 24.*

INTRODUCTION AND SECTION SUMMARY

UAVs have gained a lot of popularity in many industries due to their numerous operational and cost benefits when compared with traditional manned aircraft operations. Due to this, there has been a boom in the UAV sector, instigating the importation and usage of UAVs by organisations and individuals. Due to this fact, it is necessary that the Ghana Civil Aviation Authority lays down certain directives to govern the acquisition and usage of drones in Ghana's airspace. This section discusses some of the general and special case GCAA RPAS directives. This is to give learners an insight into the regulations and legal responsibilities regarding the use of drones. The section also highlights some general safety precautions that operators must observe when working with drones to reduce operational hazards. The section concludes by introducing learners to UAV simulation so as to build up their skill and competences to fly small UAVs.

The weeks covered by the section are:

1. Weeks 20 and 21: GCAA RPAS Regulations and Safety
2. Weeks 22, 23 and 24: UAV Simulation and Piloting to Enhance Safety

SUMMARY OF PEDAGOGICAL EXEMPLARS

A comprehensive and inclusive learning experience is facilitated through the utilisation of innovative student-centred pedagogical approaches in teaching aviation agencies, UAV safety, ethics, and regulations. This approach prioritises experiential learning, collaborative learning, and talk-for-learning strategies to foster critical thinking, innovation, creativity, collaboration, and leadership skills among learners. Experiential learning activities provide hands-on experience and direct application of concepts, while collaborative learning encourages active participation, peer-to-peer learning, and collective knowledge construction through group work and whole-class discussions. Talk-for-learning approaches facilitate meaningful discussions, debates, and presentations, developing communication, critical thinking, and problem-solving skills. Group formation considers gender sensitivity and socio-emotional issues, ensuring equal representation and participation of all genders and promoting a supportive and inclusive learning environment. By leveraging these pedagogical exemplars, students develop a deeper understanding of aviation concepts while cultivating essential skills for success in the field. This innovative approach to teaching and learning enhances student engagement, motivation, and overall academic achievement.

Assessment summary

The assessment process for the UAV operations session is designed to be innovative, practice-based, and formative, with the goal of providing learners with a comprehensive and engaging learning experience. To achieve this, a range of assessment techniques are employed that allow learners to demonstrate their understanding of UAV operations, guidelines, ethics, and principles in a variety of ways, catering for different learning styles and strengths. Throughout the session, learners are actively engaged in hands-on activities and assignments that require them to apply their knowledge and skills in real-world scenarios. This approach enables learners to develop a deeper understanding of the subject matter and to develop practical skills that can be applied in real-world contexts.

To ensure that the assessments are rigorous and effective, they are aligned with the four levels of depth of knowledge.

In addition, accommodations are made for learners with special education needs to ensure inclusivity and differentiated assessment. This includes providing all necessary resources and support to enable learners with special needs to participate fully in the assessments and to demonstrate their knowledge and skills. By taking a comprehensive and inclusive approach to assessment, the session aims to provide a supportive and engaging learning environment that allows all learners to succeed.

The recommended assessment mode for each week is:

Week 20: *Checklist*

Week 21: *Peer assessment*

Week 22: *Simulation*

Week 23: *Dramatic monologue*

Week 24: *End of semester examination*

*Refer to the "**Hint**" at the key assessment for additional information on how to effectively administer these assessment modes.*

WEEKS 20 AND 21: GCAA RPAS REGULATIONS AND SAFETY

Learning Indicators

1. *Explain safety practices with regards to building and operating UAVs.*
2. *Summarise official regulations relating to the possession and operation of UAVs.*
3. *Discuss the need for observing regulations that govern the operation of UAVs*

FOCAL AREA: GCAA UAV REGULATIONS

In today's world where UAVs are gaining popularity in industrial, military and consumer applications, it has become very important that their operations are monitored and regulated. The Ghana Civil Aviation Authority is the body responsible for regulating all vehicles that operate within our airspace, including unmanned aerial vehicles in Ghana.

In order to ensure safety in UAV operations, the GCAA has put forth a directive that addresses the protection of persons and property from accidents, incidents and mid-air collisions (MACs) involving drones. The directive provides UAV operators with the rules required to safely integrate RPAS operations into Ghana's airspace system.

Some components of the GCAA General Directives

1. According to the GCAA, an RPAS must be operated in a manner as to minimise hazards to persons, property and other aircraft in accordance with the GCAA directives.
2. UAV operators are not allowed to control two or more UAVs with an RPS unless authorised by the GCAA.
3. No one is permitted to operate UAVs for commercial purposes unless the person has been granted an RPAS Operating Certificate by the GCAA.
4. No person is permitted to organise training sessions for any aspect of UAV operations unless they have been granted an RTOC by the GCAA.
5. Drone pilots are not permitted to fly in restricted, prohibited, danger areas and Special Use Areas (SUA) unless they seek prior authorisation from GCAA and any other relevant government agencies.
6. No pilot must fly a UAV above four hundred feet (400ft) without prior notification and permission of the GCAA.
7. All private and recreational drone operations must be within the visual line-of-sight of the operator unless permitted by the GCAA.
8. All private and recreational UAV operations must be below 120m (400ft).
9. No drone is permitted to operate within a 10 kilometre radius from an airport or helipad unless approved by the GCAA.
10. Drones may not fly within a 30-metre radius of buildings or vehicles.
11. No UAV is permitted to operate at night without authorisation by the GCAA.

12. No person must import, export, sell or operate RPAS or any parts of an RPAS without the approval of the GCAA.
13. No person must manufacture an RPAS or parts of it without the written approval of the GCAA.
14. All UAV operators must comply with the applicable noise control, emissions and privacy regulations.
15. No permission given to a UAV operator by the GCAA shall relieve that operator of its duty to adhere to any other legislations of other relevant Governmental agencies.
16. No one must perform maintenance for a large RPAS without the approval of the GCAA. All maintenance services must be performed according to the UAV manufacturer's maintenance requirements.
17. Any association, group or club formed for the purpose of the promotion, use or operation of RPAS, shall notify the GCAA in writing of its existence within three months of its formation

These rules and regulations are set by the Ghana Civil Aviation Directives (GCADs) Part 28 which is on remotely-piloted aircraft systems. They apply to all air vehicles as stated in the directive. The RPAS directives (GCAD Part 28) can be fully accessed on the GCAA website linked below.

Remotely Piloted Aircraft Systems / Drones – Ghana Civil Aviation Authority

https://www.gcaa.com.gh/web/?p=894

However, the directives in the GCAD part 28 do not apply to the operation of the following:

1. A manned balloon or a hot air balloon; or
2. A control-line aircraft (that is, a model aircraft that is constrained to fly in a circle, and is controlled in attitude and altitude, by means of inextensible wires attached to a handle held by the person operating the model); or
3. An aircraft indoors; or
4. An unmanned airship indoors; or
5. A small balloon within 100 metres of a structure and not above the top of the structure; or
6. An unmanned tethered balloon that remains below 400 feet AGL (Above Ground Level)

Special Authorisation

The above listed general rules must be adhered to at all times. However, there are special cases in which UAV operations may go against the general rules and regulations. In this case, the operator must seek authorisation from the GCAA and any other relevant bodies before carrying out the operation. Below are the special authorisation regulations put forth by the GCAA;

1. No person shall operate an RPAS in the following operations without special authorisation from the GCAA:
   a. The carriage of goods

b. The carriage of dangerous goods

c. Night operations

d. Banner towing

e. Cross border operations

f. Hazardous operations

g. Dropping and discharging of things

h. Acrobatic, formation and racing flights

i. Operations in the restricted areas of aerodromes

j. Operations in areas of high RF transmission/interference (e.g. radar sites, high tension wires)

2. A request for special authorisation shall be made in a form and manner as prescribed by the Authority.

3. The request for authorisation shall be made not less than thirty days before the date of intended operation.

RPA Registration

It is required by law that any person who wants to operate a drone must register that drone with the GCAA. As part of the registration process, a proof of insurance for the drone must be submitted.

Classification of RPAS

The GCAA classifies remotely-piloted aircraft systems into 3 major categories. The following classifications apply to the operations of RPAS:

a. Small RPAS: Unmanned aircraft with maximum take-off weight up to 1.5 kg, and shall be flown only within the visual line of sight of the pilot.

b. Light RPAS: Unmanned aircraft with maximum take-off weight of more than 1.5 kg but less than or equal to 7 kg, and shall be flown within the visual line of sight (VLOS) of the pilot.

c. Large RPAS: Unmanned aircraft with maximum take-off weight of more than 7 kg which shall be flown either within the VLOS of the pilot or beyond the visual line of sight (BVLOS) of the pilot with prior authorisation of the Authority.

Issuance of permit

In order to fly an RPAS, one must first acquire a permit issued by the GCAA. The permit issued must be renewed yearly. The UAV operations must be conducted within the limitations of the issued permit. This permit may be revoked by the GCAA if the operations do not conform to the directives issued in the permit.

UAV Operation Safety

It is very important for UAV operators to protect themselves from hazards associated with UAV operations. It is therefore vital to take measures that enhance operational safety and minimise possible hazards. Below are some notes and precautions to take when operating UAVs:

1. Ensure the remote pilot station is in a safe and suitable site. Make sure there is an appropriate route for take-off and approach, devoid of buildings and high structures. Acquire approval from the GCAA and any other relevant agencies for the operation. This should be ahead of the flight.
2. Ensure there are no power lines, high-rise buildings or crowds near the take-off point. Observe the weather conditions to ascertain if it is suitable for the operation.
3. Ensure that the batteries of the RPA, RPS and any other relevant gadget are fully charged ahead of time. Losing power on any relevant component of the RPAS while the RPA is airborne is dangerous
4. It is recommended to have a shed or tent to shelter the RPS components from direct exposure to the weather elements (like rain, drizzle or sunshine).
5. Assemble the RPA. Do not connect the batteries yet! Make sure all the parts are in place as specified by the manufacturer. Be mindful of propellers installation. Clockwise propellers must be mounted on clockwise spinning motors. The same is true for counterclockwise propellers. (For maiden flights or experimental drones, it is not advisable to install the propeller at this stage during the assembly. It is recommended that the propellers be mounted once the UAV operator is certain the UAV behaves in a controlled and predictable manner).
6. Power up the remote pilot station (RPS). Ensure that the RPS behaves and responds as expected.
7. Position the UAV at the intended taxi or take-off point. With the throttle stick down (zero throttle or idle), install the battery, power up the UAV and step away from it. Make sure the battery is properly strapped and will move around during the flight. Safely dispose of faulty, swollen or punctured batteries.
8. When installing the battery, ensure the polarity is correct. Allow the UAV's sensors to calibrate. Link the RPA and RPS. Ensure the link is stable.
9. Plan the flight on your RPS. Perform a walk-around inspection before executing the mission.
   Ensure that all electrical connections and mechanical joints are secured. Ensure that there are no exposed wires. During the whole operation, there must be constant communication between the RPAS crew.
10. Maintain a visual line-of-sight of the RPA at all times unless BVLOS approval has been granted by the GCAA for the said operation.
11. Have a fire extinguisher on site (preferably a powder-based extinguisher).
12. Never go close to rotating propellers especially when the UAV is on ground.

Benefits of Adhering to Safety Precautions

Adhering to safety precautions provides numerous benefits, ensuring a productive and secure working environment. Here are some key advantages:

1. **Prevents Accidents and Injuries**: Safety precautions help minimize the risk of accidents, such as liquid spillages, fires, and equipment malfunctions, protecting personnel from harm.

2. **Ensures Compliance with Regulations**: Adhering to safety protocols ensures compliance with local, national, and international safety regulations and standards, avoiding legal issues and potential fines.
3. **Protects Equipment and Facilities**: Proper safety practices help prevent damage to expensive and sensitive equipment and infrastructure, ensuring their longevity and functionality.
4. **Enhances Productivity**: A safe working environment reduces downtime caused by accidents or equipment failures, leading to increased efficiency and productivity.
5. **Fosters a Positive Work Environment**: Prioritizing safety creates a culture of care and responsibility, which can improve morale and satisfaction.
6. **Reduces Risk of Contamination**: Adhering to cleanliness and safety protocols helps prevent contamination data, ensuring the integrity of results.
7. **Facilitates Training and Skill Development**: Safety protocols provide a structured framework for training new personnel, helping them understand best practices and procedures for a safe working environment.
8. **Mitigates Liability**: Proper safety practices reduce the risk of accidents and associated liabilities, protecting the organisation from legal claims and financial losses.
9. **Supports Emergency Preparedness**: Adhering to safety protocols ensures that emergency procedures are in place and understood, enabling a swift and effective response to incidents or accidents.

The Importance of Observing UAV regulations

Unmanned Aerial Vehicles (UAVs), commonly known as drones, have seen widespread adoption in various fields such as agriculture, surveillance, logistics, and recreation. As their usage proliferates, observing civil aviation UAV regulations becomes crucial for several reasons:

1. **Safety**
   a. **Airspace Safety**: Drones share the sky with manned aircraft, including commercial jets, helicopters, and private planes. Regulations ensure that drones operate in designated airspace, preventing collisions and accidents.

   b. **Ground Safety**: UAV regulations often mandate operational limits to minimise risks to people and property on the ground. This includes maintaining safe distances from populated areas, events, and infrastructure.
2. **Privacy and Security**
   a. **Privacy Protection**: Regulations help protect individuals' privacy by restricting UAV operations over private properties and sensitive locations without consent.

   b. **National Security**: UAV regulations play a role in national security by limiting drone activities near critical infrastructure, government facilities, and restricted zones, preventing potential threats.
3. **Legal Compliance**
   a. **Avoiding Legal Consequences:** Compliance with UAV regulations helps operators avoid fines, legal actions, and potential confiscation of their drones. It also ensures that their activities are lawful and transparent.

b. **Insurance and Liability:** Many insurance policies require operators to follow UAV regulations. Non-compliance can result in the voiding of insurance coverage and increased liability in case of accidents or damages.

4. **Operational Progress and Credibility**
   a. **Industry Credibility:** Adhering to regulations enhances the credibility and professionalism of UAV operators, fostering trust and acceptance from the public and stakeholders. A clear regulatory framework supports the sustainable growth of the UAV industry by providing guidelines for safe and responsible use, encouraging innovation within defined boundaries.

Observing civil aviation UAV regulations is essential for ensuring safety, protecting privacy and security, maintaining legal compliance, enhancing operational efficiency, fostering industry growth, protecting the environment, and supporting emergency response efforts. By adhering to these regulations, UAV operators contribute to a safer, more reliable, and sustainable aviation ecosystem, benefiting society as a whole.

Learning Tasks

1. Discuss the general GCAA regulations regarding remotely-pilot aircraft systems.
2. Discuss the classes of UAVs.
3. Brainstorm the reasons behind the recommended safety precautions regarding UAV operations.

Pedagogical Exemplars

1. **Building on What Others Say**

   The teacher leads discussions on the byelaws on building and operating UAVs. Individuals add to what others have said. Organise views using webbing or mind maps. As teachers steer discussions, they are mindful to stay off biases, stereotypes, and prejudices and place efforts to provide well-balanced examples. This will make learners;

   a. aware of their personal biases and stereotypes, embrace diversity, and practising inclusion..

   b. embrace tolerance and empathy among each other.

   c. develop emotional intelligence as others critique their submissions.

   d. learn to listen to others of different genders and abilities, thus developing tolerance and listening skills

2. **Talk for Learning:** Students summarise their understanding from the discussion on byelaws for building and operating UAVs and share with the class.

3. **Experiential learning / Collaborative Learning**

   a. Learners pay a visit to the GCAA RPAS office to interact with resource persons, discussing with them the regulations regarding UAV operations and personnel licensing. Learners take notes of the engagement and share what they learnt later in class.

b. With the aid of online videos and a practical session at the Aerospace Laboratory, guide learners to understand the safety operating procedures of every available UAV component and facility. Invite learners' views on the reasons behind the stipulated safety guidelines. Encourage all learners to participate, respect and tolerate the views of all learners while working in groups or pairs.

Key Assessment

1. **Assessment Level 1:** List two regulations or guidelines for UAV operation.
2. **Assessment Level 2**
   - **a.** Describe two (2) common safety protocols that UAV operators should follow to minimise the risk of accidents or incidents.
   - **b.** Evaluate the ability of learners to mention several components of GCAA's RPAS directive
3. **Assessment Level 3:** Explain three safety precautions one must take when undertaking the following UAV operations;
   - **a.** Working on electronic components
   - **b.** Preparing the UAV for flight
   - **c.** Piloting the UAV
4. **Assessment Level 4:** Evaluate how emerging technologies such as collision avoidance systems and geo-fencing enhance UAV safety and how should ethical concerns regarding surveillance capabilities and data collection be addressed in their implementation.

Hint

- *The recommended mode of assessment for Week 20 is **checklist.** Refer to Question 2b of Key Assessment Level 2 for an example task.*
- *The recommended mode of assessment for Week 21 is **peer assessment**.*
- *Individual Project Work should be ready for submission by Week 20. Ensure to score the scripts promptly and record the scores for onward submission into the STP.*

WEEKS 22, 23 AND 24: UAV SIMULATION AND PILOTING TO ENHANCE SAFETY

Learning Indicators

1. *Explain safety practices with regards to building and operating UAVs*
2. *Summarise official regulations relating to the possession and operation of UAVs*
3. *Discuss the need for observing regulations that govern the operation of UAVs*

FOCAL AREA: INTEGRATING SIMULATORS TO ENHANCE UAV OPERATIONS SAFETY

Introduction to flight simulators

UAV operations can pose a hazard to human beings and property. Mistakes from the pilot, UAV airframe or software could arise due to numerous reasons. It is therefore expedient for the UAV operator to ensure that such dangers are completely eradicated.

Flight simulators come in handy when ensuring UAV operation's safety. A flight simulator is a software program that recreates the flight of an aircraft and the flight conditions it operates in for the purposes of training, design and analysis. This is a computer 'game' that mimics the behaviour of aircraft in different phases of flight, thus allowing the user to understand the dynamics of aircraft before physically handling them. Equipped with a software physics engine, it takes input from a user, usually through a joystick to emulate real world flight physics, and outputs the result on a graphical display in real-time.

Generally, the user or pilot's inputs are run through a couple of simulation modules which are then processed at high speeds using the aircraft's equations of motion. The output is then rendered in the form of vision, sound, movement or instrument display.

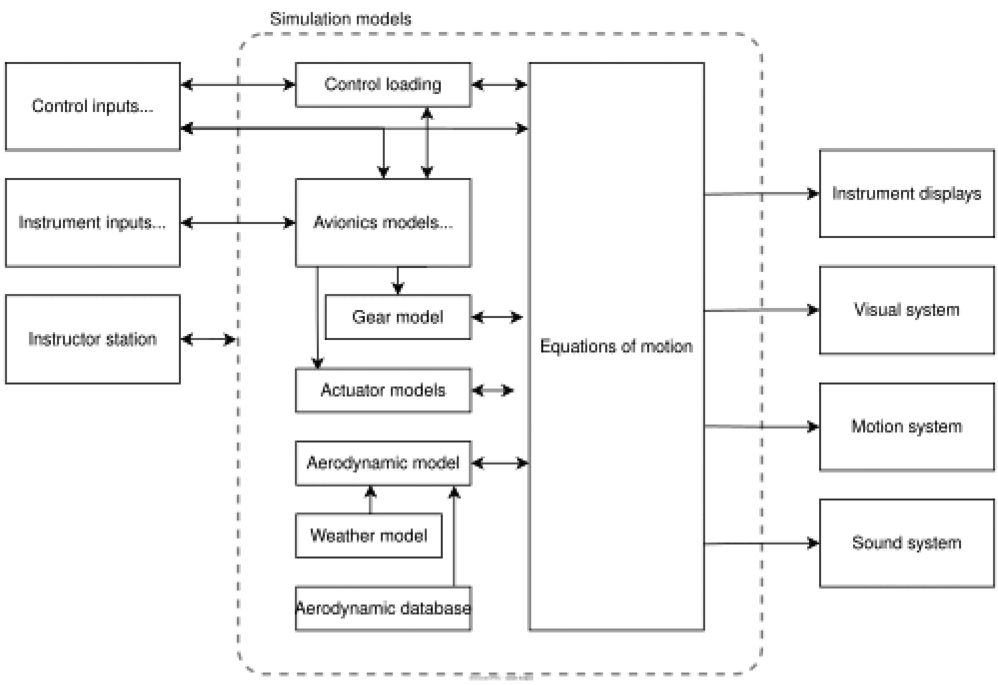

Figure 95: *Flight simulation block diagram*

Control Inputs

Flight controllers take user inputs from a joystick controller. Most modern joystick controllers connect to computers via USB. These controllers come in all shapes and sizes. Controllers are usually classified according to their channels. The channels refer to the number of individual inputs that can be engaged on the controller. For example, on a six channel controller, the user can only control six actuators on the aircraft, e.g. throttle, elevator, rudder, ailerons, flaps and landing gear doors. If the user needs to control any other thing (e.g. payload/cargo door), then the controller will need to be replaced with one that has more than six channels.

Figure 96: *Simulator controller by Interlink*

Figure 97: *Thrustmaster simulator controller*

Control modes

There are four main control modes controllers (for both RC and simulator). No mode is better than the other because it mostly comes down to pilot preference.

Figure 98: *Mode 1*

Figure 99: *Mode 2*

Figure 100: *Mode 3*

Figure 101: *Mode 4:*

Source: [RC Transmitter Modes for Airplanes (rc-airplane-world.com)](https://www.rc-airplane-world.com/rc-transmitter-modes.html)
https://www.rc-airplane-world.com/rc-transmitter-modes.html

Some notable flight simulators are listed below:

1. RealFlight simulator
2. ClearView
3. neXt-RC
4. accuRC
5. Absolute RC
6. Airsim
7. R/C Desk Pilot
8. CRRCsim
9. FlightGear
10. Flying Model Sim
11. FS One
12. Picasim
13. Quadcopter FX Simulator
14. Hover Here
15. Ron's RC Sim

Software-In-The-Loop (SiL)

Generally speaking, software-in-the-loop is a method of testing embedded software algorithms or entire control loops with or without environment model on a PC without the hardware. In the UAV space, some simulators allow the user to perform software-in-the-loop. For example, one can use RealFlight simulator and Mission Planner GCS to simulate the performance of Ardupilot firmware (a firmware for drones) executing an autonomous operation. The actions and performance of the UAV is shown in real-time on the realFlight graphical environment.

This enables the user to test different flight modes and scenarios, execute planned missions, identify errors and challenges and correct them without having to test on an actual UAV which may compromise safety and raise financial concerns. It also helps in the research and development of new and unconventional UAVs. They are tested and fine-tuned on the simulators where they pose no danger to life and property, before being actually manufactured.

Figure 102: *Mission Planner software interface*

Fundamentals of flying

It is important for a UAV pilot to know the basic controls for the type of UAV they operate. We shall first consider the basic controls of multicopter UAVs. For the purpose of conceptual understanding, we will use the quadcopter to explain the basic manoeuvres. Since the mode 2 configuration is the commonest, it would be used here.

Introduction to multirotor piloting

Throttle

In mode 2 controller mode, the throttle is engaged by moving the left stick vertically (up and down). This generally controls the revolutions per minute (RPM) of all four motors on the quadcopter simultaneously. Increasing the throttle increases the RPM of all motors by the same amount. This causes the drone to increase in altitude. Reducing the throttle decreases the RPM of all motors, causing the drone's altitude to drop.

Roll

This is achieved by pushing the right stick to the left or right. With reference to the image of the quadcopter below, moving the right stick to the right will increase the RPM of the motors on the left (3 and 4) causing the drone will tilt to the right. If the right stick of the controller moves left, the RPM of the motors on the right (1 and 2) will increase, causing the drone to tilt and move to the left.

Pitch

Pitch movement is controlled by pushing the right stick forwards or backwards. Moving the right stick upwards causes the RPM of the motors at the rear (2 and 3) to increase, thereby causing the drone to tilt and move forward. Conversely, moving the right stick downward causes the motors at the front (1 and 4) to increase RPM causing the drone to tilt and move backwards

The drone will move forward or move backward.

The pitch is controlled by moving the right stick of the controller vertically (up and down).

Yaw

By convention (generally accepted or common norm), motors 1 and 3 rotate in the counterclockwise direction, while motors 2 and 4 rotate in the clockwise direction. The reason being that if all the motors rotate in one direction (say clockwise), then the drone's frame will tend to spin in the opposite direction (counterclockwise).

The yaw manoeuvre (in mode 2) is done by moving the left stick left and right. Still with reference to the image below, in order for the drone to yaw left, the clockwise motors spin faster than the counterclockwise. This produces a counterclockwise reaction moment on the airframe of the drone causing it to yaw left.

In the same way, if the counterclockwise motors spin faster than the clockwise motors, a clockwise reaction moment is created causing the airframe to yaw right.

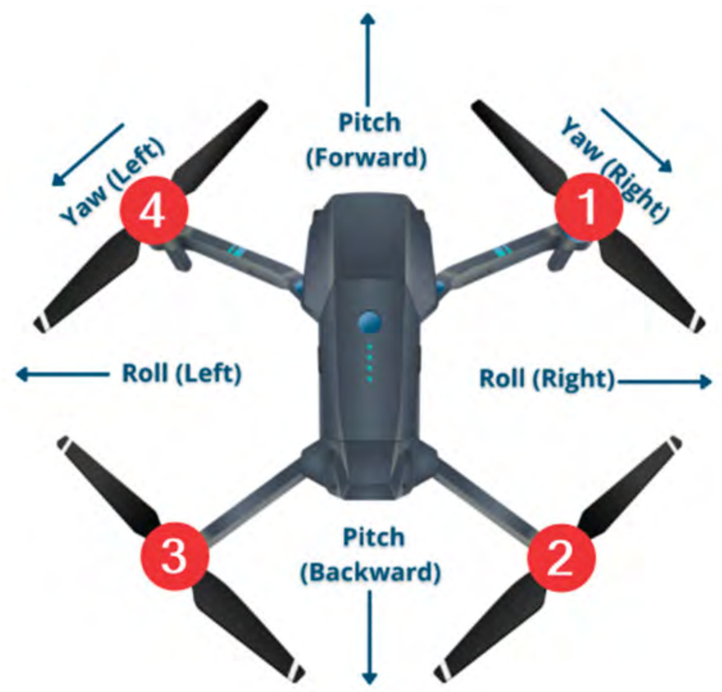

Figure 103: *Quadcopter movements*

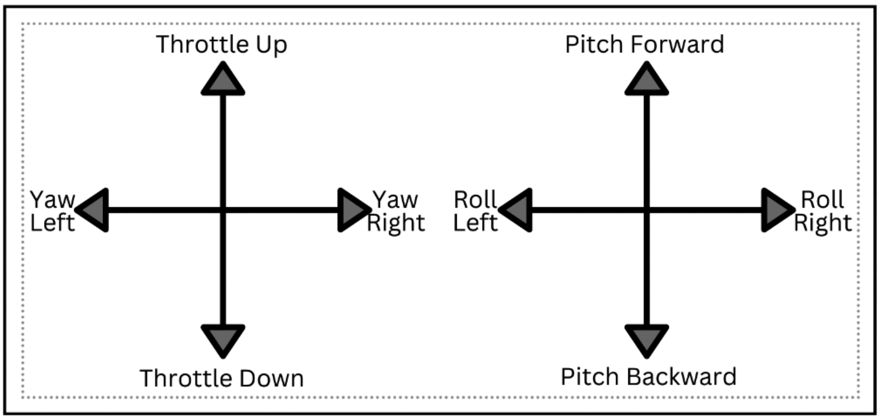

Figure 104: *RC Transmitter stick inputs*

Now practice the following manoeuvres with a quadcopter on your airfield.

a. Take-off
b. Climb
c. Descend
d. Hover
e. Roll left
f. Roll right
g. Yaw left
h. Yaw right
i. Pitch forward
j. Pitch backward
k. Land

Introduction to fixed-wing piloting

Throttle

Push the left stick forwards or backwards. This causes the motor speed to increase or decrease.

Yaw

Push the left stick to the left or right. This causes the rudder to yaw the nose to the left or to the right.

Roll

Push the right stick to the left or right. This causes the ailerons to roll the aircraft to the left or to the right.

Pitch

Push the right stick backwards or forwards. This causes the elevator to pitch the nose upwards or downwards.

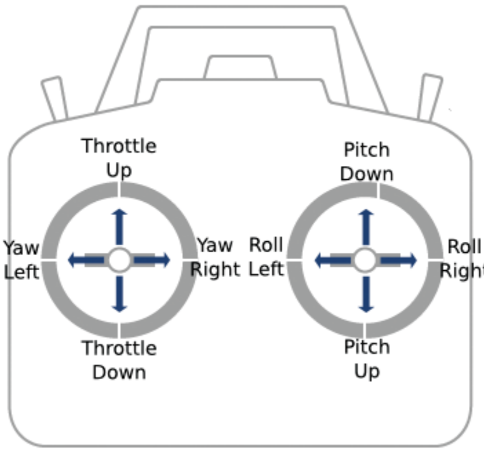

Figure 105: *RC transmitter stick inputs (Mode 2)*

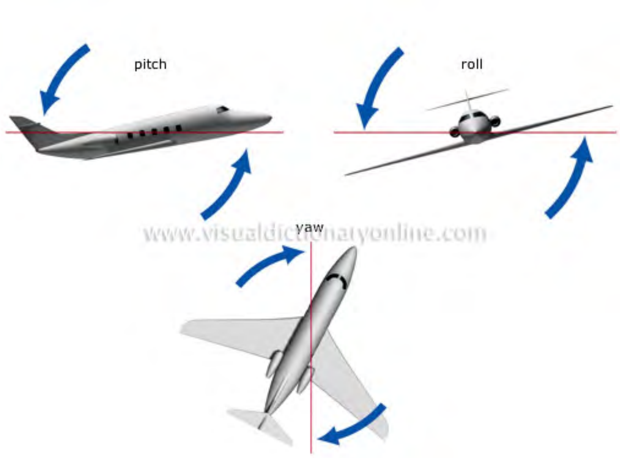

Figure 106: *Fixed-wing aircraft movements*

Now practice the following with a fixed-wing RC plane on your school's airfield.

- **a.** Take-off
- **b.** Pitch up
- **c.** Pitch down
- **d.** Roll left
- **e.** Roll right
- **f.** Roll left + yaw left
- **g.** Roll right + yaw right
- **h.** Straight and level flight
- **i.** Landing

Learning Tasks

1. Demonstrate skill in flying radio-controlled quadcopter
2. Demonstrate skill in flying radio-controlled fixed-wing airplane

Pedagogical Exemplars

Experiential Learning: Learners visit a computer laboratory with model aircraft flight simulators installed to practice basic flight manoeuvres in a simulator environment. The both fixed-wing and multicopter UAVs should be simulated in the lab. The teacher should foremost provide guidance and instructions on how to perform basic maneuvers on a UAV and should demonstrate to learners. The teacher should ensure that all learners have ample time on the simulator to practice. Learners who demonstrate high levels of proficiency on the simulator should be encouraged to guide and assist those approaching proficiency to encourage peer-to-peer interaction and learning.

Key Assessment

1. **Assessment Level 2**
   - **a.** Perform a take-off and landing operation on a UAV (fixed-wing and multirotor) in a simulator.
   - **b.** Keep a UAV (fixed-wing and multirotor) airborne for 3 minutes while demonstrating basic flight manoeuvres (pitch, roll and yaw) in a simulator.

2. **Assessment Level 3**
   - **a.** Perform a take-off and landing operation on an actual UAV.
   - **b.** Keep an actual UAV (fixed-wing and multirotor) airborne for 3 minutes while demonstrating basic flight manoeuvres (pitch, roll and yaw).
   - **c.** As an operator of UAVs in Ghana, explain the need for adhering to safety practices and regulations for building and operating UAVs.

Hint

- *The recommended mode of assessment for Week 22 is **simulation.** Refer to Question 1 of Key Assessment Level 2 for example tasks.*
- *The recommended mode of assessment for Week 23 is **dramatic monologue.** Refer to Question 2c of Key Assessment Level 3 for an example task.*
- *The recommended mode of assessment for Week 24 is **end of semester examination.** Refer to **Appendix H** at the end of the section for Table of Specifications for drafting examination questions. Set questions to cover all the indicators covered for weeks 13 to 24.*
- *Collect learners' portfolios in Week 22 and score them promptly. Remember to document all the scores and submit them as soon as possible into the STP to avoid carry over into the following academic year.*

SECTION 6 REVIEW

This section looks at the regulations put forth by the Ghana Civil Aviation Authority to govern the acquisition and operation of drones in Ghana's airspace. It also explores the safety precautions and recommended practices that one must observe when operating drones. We finally discuss the use of simulators to aid and build learners' confidence in flying UAVs.

APPENDIX H: Guidelines for End of Second Semester Examination

Nature of the paper

The examination is a two-hour paper consisting of 40 multiple choice questions and 2 essay-type questions, on concepts that have been covered from Weeks 13 to 24.

Resources needed

a) Venue for the examination

b) Printed examination question paper

c) Answer booklet

d) Scannable paper

e) Wall clock

f) Bell, etc.

Guidelines for setting test items

a) Multiple choice

- **i.** The options should be plausible and homogenous in content
- **ii.** Vary the placement of the correct answer
- **iii.** Repetition of words in the options should be avoided, etc.

b) Essay type

- **i.** Make the instructions clear
- **ii.** Do not ask ambiguous questions
- **iii.** Do not ask questions beyond what you have taught, etc.

Table of specifications

Week	Focal area	Type of question	DOK Levels				Total
			1	2	3	4	
13 & 14	Aircraft instruments I – Flight instruments	Multiple choice	2	4			6
15	Aircraft instruments II – Engine indicating instruments	Multiple choice	2	4			6
16 & 17	Flight data storage equipment	Multiple choice	2	3			4
		Essay			1		1
18 & 19	Local and international aviation organisations	Multiple choice	3	4			8
		Essay			1		1

Week	Focal area	Type of question	DOK Levels				Total
			1	2	3	4	
20 & 21	GCAA RPAS regulations and safety	Multiple choice	4	4			8
22 – 24	UAV simulation	Multiple choice	4	4			8
	Total	Multiple choice	17	23			**40**
		Essay			2		**2**

Sample multiple-choice question

Which of the following may be used to train pilots before flight?

A. *Horses*

B. *Pickup truck*

C. *Race car*

D. ***Simulator***

Sample essay question

Compare piston and gas turbine engines.

Additional Reading

1. Flying Your RC Plane - Self-teaching Tips
   https://www.rc-airplane-world.com/flying-your-rc-airplane.html

2. Learn to Fly RC Planes: 10 Simple Steps For Learning How to Fly RC Planes - Remote Air Racing
   https://remoteairracing.com/how-to-get-started-flying-rc-planes/

Figure Number	Link	
Figure 95: Flight simulation block diagram	https://upload.wikimedia.org/wikipedia/commons/thumb/9/90/Flight_simulator_block_diagram.svg/500px-Flight_simulator_block_diagram.svg.png	
Figure 96: Simulator controller by Interlink	InterLink DX Simulator Controller with USB Plug | Spektrum (spektrumrc.com)	
Figure 97: Thrustmaster Simulator controller	Manche Joystick Thrustmaster T.flight Hotas X Pc Original | Frete grátis (mercadolivre.com.br)	
Figure 98: Mode 1	RC Transmitter Modes for Airplanes (rc-airplane-world.com) https://www.rc-airplane-world.com/rc-transmitter-modes.html	
Figure 99: Mode 2	RC Transmitter Modes for Airplanes (rc-airplane-world.com) https://www.rc-airplane-world.com/rc-transmitter-modes.html	
Figure 100: Mode 3	RC Transmitter Modes for Airplanes (rc-airplane-world.com) https://www.rc-airplane-world.com/rc-transmitter-modes.html	
Figure 101: Mode 4	RC Transmitter Modes for Airplanes (rc-airplane-world.com) https://www.rc-airplane-world.com/rc-transmitter-modes.html	
Figure 102: Mission Planner	Mission Planner Overview — Mission Planner documentation (ardupilot.org) https://ardupilot.org/planner/docs/mission-planner-overview.html?width=1380&height=620	

Figure Number	Link	
Figure 103: Quadcopter movements	https://www.t-drones.com/imag-es/202404/231713860873887044.jpeg	
Figure 104: RC trans-mitter stick inputs	https://www.droneblog.com/wp-content/up-loads/2023/07/stick-inputs.png	
Figure 105: RC trans-mitter stick inputs, mode 2	https://smaccmpilot.org/images/radio.png	
Figure 106: Fixed-wing aircraft stick move-ments	https://www.visualdictionaryonline.com/images/transport-machinery/air-transport/movements-an-airplane.jpg	

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2. (225) Learning to Fly—Airplane Controls - YouTube

3. Australian Transport Safety Bureau (2014) Black Box Flight Recorders https://skybrary.aero/sites/default/files/bookshelf/3679.pdf

4. Beginner's Guide to Propulsion (nasa.gov)

5. Civil Aviation | Ghana Meteorological Agency

6. Civil Aviation | Ghana Meteorological Agency

7. Fundamentals of Aerodynamics, 6th Edition – By John Anderson Jnr.
8. General Aviation Aircraft Design – By Snorri Gudmundsson

9. Ghana | Bureau of Aircraft Accidents Archives (baaa-acro.com)

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11. Ghana Civil Aviation Authority Policy Directives, Part 1-33.

12. How to fly RC airplane updated (youtube.com)

13. ICAO Annex 6, Operation of Aircraft, Vol I, Attachment D and Vol III
14. International Civil Aviation Organisation Annexes, 1 – 19.

15. Meteorological Aerodrome Report (METAR) | SKYbrary Aviation Safety

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18. Pilot's Handbook of Aeronautical Knowledge (FAA-H-8083-25A) 2008.

19. Rocket Propulsion Elements, Ninth Edition- By George P. Sutton and Oscar Biblarz

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21. Turbofan Engine | SKYbrary Aviation Safety

22. Williamson, G. W. (1937). "Instrument Planning: The New Service Blind-Flying Panel Described". *Flight*. p. 193.

23. www.iata.org/en/programs (accessed 15:38pm, 31/07/24)