



MINISTRY OF EDUCATION

AVIATION AND AEROSPACE ENGINEERING

For Senior High Schools

TEACHER MANUAL



YEAR THREE



**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 Three



**NATIONAL COUNCIL FOR
CURRICULUM & ASSESSMENT
OF MINISTRY OF EDUCATION**

AVIATION AND AEROSPACE ENGINEERING TEACHER MANUAL

Enquiries and comments on this manual should be addressed to:

The Director-General

National Council for Curriculum and Assessment (NaCCA)

Ministry of Education

P.O. Box CT PMB 77

Cantonments Accra

Telephone: 0302909071, 0302909862

Email: info@nacca.gov.gh

website: www.nacca.gov.gh



©2026 Ministry of Education

This publication is not for sale. All rights reserved. No part of this publication may be reproduced without prior written permission from the Ministry of Education, Ghana.



CONTENTS

INTRODUCTION FOR THE YEAR THREE TEACHER MANUAL	VI
ACKNOWLEDGEMENTS	VIII
SECTION 1: AIRCRAFT STRUCTURES	1
STRAND: CORE CONCEPTS IN AEROSPACE ENGINEERING	1
Sub-Strand: Aircraft Structures and Control	1
WEEKS 1 & 2	2
Focal Area: Aircraft materials (Refer back to Year 1, section 1, week 3: the types of aerospace vehicles and their parts.)	2
WEEKS 3 & 4	10
Focal Area: Airframe Structures (Refer back to Year 1, section 1, week 3: the types of aerospace vehicles and their parts.)	10
MARKING SCHEMES FOR THE KEY ASSESSMENTS	17
SECTION 2: STABILITY AND CONTROL	20
STRAND: CORE CONCEPTS IN AEROSPACE ENGINEERING	20
Sub-Strand: Aircraft Structures and Control	20
WEEKS 5 & 6	22
Focal Area: Aircraft & Spacecraft Flight Controls	22
WEEK 7	42
Focal Area: Aircraft & Spacecraft Stability	42
MARKING SCHEMES FOR THE KEY ASSESSMENTS	52
SECTION 3: AVIONICS	55
STRAND: AVIONICS	55
Sub-Strand: Communication, Navigation and Surveillance Systems	55
WEEK 8	57
Focal Area: Aircraft communication systems	57
WEEK 9	64
Focal Area: Aircraft navigation systems	64
WEEK 10	75
Focal Area: Aircraft surveillance systems	75
MARKING SCHEMES FOR THE KEY ASSESSMENTS	82
SECTION 4: AIRCRAFT MAINTENANCE	85
STRAND: AVIATION INDUSTRY	85
Sub-Strand: Aircraft Maintenance	85

WEEK 11	87
Focal Area: Aircraft Maintenance (Refer back to Year 1, Section 4, Weeks 11 & 12: Introduction to aviation careers, their roles and learning pathways)	87
WEEK 12	100
Focal Area: Aircraft Maintenance	100
MARKING SCHEMES FOR THE KEY ASSESSMENTS	117
SECTION 5: UAV DESIGN	120
STRAND: UNMANNED AERIAL VEHICLES (UAVS)	120
Sub-Strand: Design and Fabrication of UAVs	120
WEEKS 13 & 14	122
Focal Area: Development of UAV concepts	122
WEEKS 15 & 16	130
Focal Area: UAV design estimates	130
MARKING SCHEMES FOR THE KEY ASSESSMENTS	141
SECTION 6: BUILDING UAVS	144
STRAND: UNMANNED AERIAL VEHICLES (UAVS)	144
Sub-Strand: Design and Fabrication of UAVs	144
WEEKS 17 – 20	145
Focal Area: UAV construction	145
MARKING SCHEMES FOR THE KEY ASSESSMENTS	163
SECTION 7: FLYING UAVS	165
STRAND: UNMANNED AERIAL VEHICLES (UAVS)	165
Sub-Strand: Design and Fabrication of UAVs	165
WEEKS 21 & 22	166
Focal Area: UAV simulation flights (Refer back to Year 3, Section 2, Weeks 5 & 6: Aircraft & Spacecraft Flight Controls)	166
WEEKS 23 & 24	169
Focal Area: Real-world UAV flights	169
MARKING SCHEMES FOR THE KEY ASSESSMENTS	174

INTRODUCTION FOR THE YEAR THREE TEACHER MANUAL

The National Council for Curriculum and Assessment (NaCCA) has developed the third and final set of curriculum materials to support the implementation of the new Senior High School curriculum.

This Year Three Teacher Manual for *Aviation and Aerospace Engineering* covers all aspects of the content, pedagogy, teaching and learning resources, and assessment required to effectively support learners in their final year of Senior High School. It contains information for all 24 weeks, including the nine key assessments required for the Student Assessment Portal (SAP). All the necessary information for the SAP has been included in the Year Three Teacher Manual to simplify the development of weekly learning plans, meaning that teachers have a single reference document.

The Year Three Teacher Manual has two main objectives:

- To support learners to consolidate and deepen their understanding of the content, pedagogy, and assessment across all three years of the new Senior High School curriculum in preparation for the West Africa Senior Secondary Certificate Examination (WASSCE).
- To equip teachers with the tools and resources needed to deliver revision-focused, assessment-led lessons that build on the knowledge learners have acquired from Year One to Year Three.

In this third year, teachers will be supporting learners to prepare for the WASSCE. Each section of the Teacher Manual is therefore structured around the highest Depth of Knowledge (DoK) levels, allowing learners to build progressively on knowledge acquired from Year One to Year Three. For each week, learning tasks and pedagogy are built around the assessment, ensuring that classroom activities directly prepare learners for the demands of the examination. Two sets of sample examination papers are also provided — one administered at Week 10 as a first semester practice examination, and one at Week 20 as a mock examination — to gauge learners' competencies and identify areas requiring remediation.

To further support teachers in delivering Year Three, NaCCA, working with the Ghana Education Service, has developed a subject-specific App for each subject using the Playlab AI platform. These Ghanaian-owned Apps — the first of their kind at this scale in Africa — are directly linked to the revised curriculum and will assist teachers in:

- holding their weekly Professional Learning Community (PLC) sessions
- developing weekly learning plans and applying the learner-centred pedagogies and varied modes of assessment required for the new SHS curriculum
- incorporating differentiation, Social and Emotional Learning (SEL), and Gender Equality and Social Inclusion (GESI) into lessons

Information about how to use the Apps, including QR codes, is provided in the Year Three Subject-Specific PLC Handbooks.

The Year Three PLC sessions have been revised in response to findings from the 2025 annual evaluation survey. The survey confirmed that teachers have made strong progress in lesson planning, use of varied instructional methods, ICT integration, and modes of assessment. To address the identified gap in explaining concepts clearly using examples familiar to learners, each PLC session now includes a

dedicated Content Exploration segment. This ten-minute segment brings the subject group together to work through one challenging problem or concept from the week's Teacher Manual content — not to plan how to teach it, but to ensure that every teacher in the group fully understands it. Each PLC session continues to include:

- Planning and Reviewing of Learning Plan (45 minutes) — using the subject-specific App to explore content, plan lessons, and prepare the week's key assessment
- Content Exploration (10 minutes) — collaborative group work on a challenging problem or concept from the week's content
- Enactment (30 minutes) — teaching an activity from the learning plan with structured peer observation and feedback
- Reflection (5 minutes) — sharing views on the session and identifying next steps

The PLC sessions in Year Three also place particular emphasis on connecting the week's content to equivalent topics taught in Years One and Two. Teachers are encouraged to note the recap weeks signposted throughout the Teacher Manual and to use the App to explore how content across all three years links together.

As in previous years, teachers are expected to integrate National Values, Gender Equality and Social Inclusion (GESI), Social and Emotional Learning (SEL), and 21st-century skills into their learning activities, assessment tasks, and rubrics and mark schemes. The subject-specific App will support teachers in doing this throughout the year.

NaCCA acknowledges the dedication of the teachers who have implemented the new curriculum across Years One and Two and recognises that Year Three represents both the culmination of that effort and a critical moment for learners. The Year Three Teacher Manual and its accompanying resources have been developed to ensure that every learner — regardless of background, ability, or school context — is fully prepared to demonstrate what they know and can do in the WASSCE and to progress confidently to further studies, the world of work, and adult life.

ACKNOWLEDGEMENTS

Special thanks to Professor Samuel Ofori Bekoe, Director-General of the National Council for Curriculum and Assessment (NaCCA) and all who contributed to the successful writing of the Teacher Manuals for the new Senior High School (SHS) curriculum.

The writing team was made up of the following members:

National Council for Curriculum and Assessment (NaCCA)	
Name of Staff	Designation
Reginald Quartey	Ag. Director, Curriculum Development Directorate
Anita Cordei Collison	Ag. Director, Standards, Assessment and Quality Assurance Directorate
Dr. Mercy Nyamekye	Ag. Director, Research, Planning, Monitoring, and Evaluation
Joana Adua Vanderpuije	Ag. Director, Instructional Resources Directorate
Rebecca Abu Gariba	Ag. Director, Corporate Affairs
Nii Boye Tagoe	Senior Curriculum Development Officer
Juliet Owusu-Ansah	Principal Curriculum Development Officer
Samuel Owusu Ansah	Principal Curriculum Development Officer
Godwin Mawunyo Kofi Senanu	Assistant Curriculum Development Officer
Stephen Acquah	Principal Curriculum Development Officer
Thomas Kumah Osei	Principal Curriculum Development Officer
Ayuuba Sullivan	Principal Curriculum Development Officer
Dr. Jephthar Adu-Mensah	Principal Standards, Assessment and Quality Assurance Officer (SAQA)
Richard Teye	Principal Standards, Assessment and Quality Assurance Officer (SAQA)
Nancy Asieduwaa Gyapong	Assistant Standards, Assessment and Quality Assurance Officer (SAQA)
Bridget Aku Anku	Principal, Standards, Assessment and Quality Assurance Officer (SAQA)
Francis Agbalenyo	Principal Research, Planning, Monitoring and Evaluation Officer
Joseph Barwuah	Senior Instructional Resource Officer
Samuel Amankwa Ogyampo	Senior Corporate Affairs Officer
Seth Nii Nartey	Corporate Affairs Officer

S/N	Name	Name of Institution	Subject
1	Bernard Adobaw	West African Examinations Council	Accounting
2	Emmanuel Kodwo Arthur	Institute of Chartered Accountants, Ghana	
3	Benedicta Ama Yekua Etuful	Ogyedom SHTS	Additional Mathematics
4	Innocent Nunana Duncan	KNUST SHS	
5	Benedicta Carbilba Foli	Pope Johns SHS & Minor Seminary, Koforidua	Agricultural Science
6	David Esela Zigah	Achimota School	
7	Prof. Jakpasu Victor Kofi Afun	Kwame Nkrumah University of Science and Technology	
8	Eric Morgan Asante	St. Peter's Boys SHS	Agriculture
9	Prof. Frederick Adzitey	University for Development Studies, Tamale	
10	Akuffo Twumhene Frederick	Koforidua SHTS	Applied Technology
11	Emmanuel Korletey	Benso SHTS	
12	Firmin Anewuoh	Presbyterian College of Education, Akropong	
13	Isaac Buckman	Armed Forces SHTS	
14	Kunkyuuri Philip	Kumasi Senior High Technical School	
15	Lavoe Daniel Kwaku	Sokode SHTS	
16	Philip Turkson	St Joseph's SHTS, Bekwai	
17	Dr. Sherry Kwabla Amedorme	Univ. of Skills Training and Entrepreneurial Development	
18	Walter Banuenumah	Univ. of Skills Training and Entrepreneurial Development	
19	Wisdom Dzidzienyo Adzraku	Univ. of Skills Training and Entrepreneurial Development	
20	Abass Umar Mohammed	University of Ghana, Legon	Arabic
21	Mohammed Mahey Ibrahim	Tijjaniya Senior High School, Kumasi	
22	Dr. Ebenezer Acquah	University of Education, Winneba	Art and Design Studio and Foundation
23	Dr. Mantey Jectey-Nyarko	Kwame Nkrumah University of Science and Technology	
24	Kwame Opoku-Bonsu	Kwame Nkrumah University of Science and Technology	
25	Seyram kojo Adipah	GES- Ga East	

26	David Kofi Oppong	Kwame Nkrumah University of Science and Technology	Aviation and Aerospace
27	Obed Frimpong	Zipline International	
28	Jo Ann Naa Dei Neequaye	Nyakrom SHTS	Biology
29	Paul Beeton Damoah	Prempeh College, Kumasi	
30	Dr. Daniel Akwei Addo	Kwame Nkrumah University of Science and Technology	Biomedical Science
31	Dr. Mrs. Dorothy Araba Yakoba Agyapong	Kwame Nkrumah University of Science and Technology	
32	Avole Baba Ansbert	Bolga SHS	Business Management
33	Emmanuel Caesar Ayamba	Bolgatanga Technical University	
34	Faustina Graham	GES HQ	
35	Bismark Kwame Tunu	Opoku Ware School, Kumasi	Chemistry
36	Patrick Nsobila Awumbire	Bolgatanga S.H.S.	
37	Francis Normanyo	Mt Mary College of Education	Christian Religious Studies & Islamic Religious Studies
38	Francis Opoku	Valley View University	
39	Haruna Zagoon-Sayeed	University of Ghana	
40	Kabiru Soumana	GES HQ	
41	Richardson Addai-Mununkum	University of Education, Winneba	
42	Seth Tweneboah	University of Education, Winneba	Clothing and Textiles
43	Jusinta Kwakyewaa (Rev.Sr.)	St Francis SHTS, Akim Oda	
44	Rahimatu Yakubu	Potsin T.I Ahmadiyya SHS	Computing and ICT
45	Dordoe Raphael Senyo	Ziavi SHTS	
46	Gaddafi Abdul-salaam	Kwame Nkrumah University of Science and Technology	
47	Kwasi Abankwa Anokye	Ghana Education Service	Design and Communication Technology
48	Gabriel Bofo	Kwabeng Anglican Senior High Technical School	
49	Mensah Henry Angmor	Anglican Senior High School, Kumasi	
50	Phyllis Mensah	University of Skills Training and Entrepreneurial Development (	Economics
51	Charlotte Kpogli	Ho Technical University	
52	Salitsi Freeman Etonam	Anlo SHS, Anloga	Engineering
53	Daniel Kwesi Agbogbo	Kwabeng Anglican Senior High Tech School	
54	Dr Valentina Osei-Himah	Atebubu College of Education	

55	Benjamin Orrison Akrono	Islamic Girls' SHS	English Language
56	Esther Okaitsoe Armah	Mangoase SHS	
57	Kukua Andoh Robertson	Breman Asikuma SHS	
58	Perfect Quarshie	Mawuko Girls SHS, Ho	
59	Ama Achiaa – Afriyie	St. Louis SHS, Kumasi	Food and Nutrition
60	Lily-Versta Nyarko	Mancell Girls SHTS, Kumasi	
61	Osmanu Ibrahim	Mount Mary College of Education, Somanya	French
62	Mawufemor Kwame Agorgli	Akim Asafo SHS	
63	Comfort Korkor Sam	University for Development Studies, Tamale	General Science
64	Robert Arhin	S.D.A SHS, Akim Sekyere	
65	Ishmael Yaw Dadson	University of Education, Winneba	Geography
66	Prof Ebenezer Owusu –Sekyere	University for Development Studies, Tamale	
67	Raymond Nsiah-Asare	Methodist Girls' SHS, Mamfe	
68	Catherine Ekua Mensah	University of Cape Cape	Ghanaian Language
69	David Sarpei Nunoo	University of Education, Winneba	
70	Prof Kwasi Adomako	University of Education, Winneba	
71	Arko Blay Augustine	University of Education, Winneba	Government
72	Josephine Akosua Gbagbo	Ngleshie Amanfro SHS	
73	Anitha Oforiwah Adu-Boahen	University of Education, Winneba	History
74	Prince Essiaw	Enchi College of Education	
75	Blessington Dzah	Ziavi SHTS	Literature-in-English
76	Juliana Akomea	Mangoase SHS	
77	Dorcas Akosua Opoku	Winneba SHS	Management in Living
78	Grace Annagmeng Mwini	Tumu College of Education	
79	Eric Abban	Mt. Marys College of Education, Somanya	Mathematics
80	Isaac Buabeng	Mamprobi Sempe 2 JHS	
81	Benjamin Ofori	Cocoa Research Institute of Ghana Primary School	Music
82	Cosmas W. K. Mereku	University of Education, Winneba	
83	Davies Obiri Danso	New Juaben SHS	
84	Prof. Joshua Alfred Amuah	University of Ghana, Legon	

85	Evans Kofi Mati	GES HQ	
86	Wilson Klebi	GES HQ	
87	Professor Emmanuel Obed Acquah	University of Education, Winneba	
88	Chris Ampomah Mensah	Bolgatanga S.H.S	Performing Arts
89	Doreen Deedee Quarcoo	University of Education, Winneba	
90	Dr. Latipher Osei Appiah-Agyei	University of Education, Winneba	
91	Albert Sackey	KNUST SHS	Physical Education and Health (Core and Elective)
92	Ebenezer Ewiah-Quarm	Nkroful Agric SHS	
93	Evans Asare Yeboah	Adisadel College	
94	John Benedict Nyarko	Adisadel College	
95	Dr. Mary Aku Ogum	University of Cape Coast	
96	Dr. Linus Kweku Labik	KNUST	Physics
97	Sylvester Affram	Kwabeng Anglican SHTS	
98	Anthony Mensah	Abetifi Presbyterian College of Education	RME
99	Clement Nsorwineh Atigah	Tamale SHS	
100	Eliei Keelson	Kwame Nkrumah University of Science and Technology	Robotics
101	Isaac Nzoley	Wesley Girls High School	
102	Jemima Ayensu	Holy Child Girls SHS, Cape Coast	Social Studies
103	Mohammed Adam, Ph.D.	University of Education, Winneba	
104	Simon Tengan	Wa Senior High Technical School	
105	Franklina Kabio-Danlebo	University of Ghana	Spanish
106	Mishael Annoh-Achampong	University of Media, Art and Communication	
107	Augustina Gloria Henyo	West African Examinations Council	Inclusive Education
108	Dr. Gideon Kwesi Obosu	University of Cape Coast	
109	Dr. Daniel Fobi	University of Education, Winneba	
110	Dr. Martha-Pearl Okai	University of Cape Coast	
111	Francis Kweku Essel	Ashesi University	
112	Richard Doku	Mampong/Akw SHTS For The Deaf	
113	Yao Mati Abotsi	Ghana Blind Union	
114	Seth Kwame Ativor	Okuapemman SHS, Akropong	
115	Bernard Duorinaah	Presbyterian College of Education	

116	Evans Odei	Achimota Senior High School	
-----	------------	-----------------------------	--

S/N	Subject	Name of Reviewer	Institution
1	Accounting	Ms. Ivy Eklemet	Univ. of Professional Studies, Accra
2	Additional Mathematics	Francis Tornyenor	Pope John SHS & Minor Seminary, Koforidua
3	Agricultural Science	Selina Acheampong	Univ. College of Agriculture and Environmental
4	Agriculture	Mr. Godwin B. K. Doli	Municipal Educ. Office, Amasaman
5	Arabic	Abdullah Musah Abdullah	Univ. of Media Arts & Communication, UniMAC
6	Art and Design Studio	Ernest Kwasi Elelakpodia	Hope College, Gomoa Fetteh
7	Art and Design Foundation	Ernest Kwasi Elelakpodia	Hope College, Gomoa Fetteh
8	Automotive & Metal Technology	Okyere Kojo Alex	Ada College of Education
9	Aviation & Aerospace Engineering	Dr. Augustine Akuoko Kwarteng	Univ. of Mines and Technology
10	Biology	Rev. Joseph Kweku Delanyo	formerly of Hope College, Gomoa Fetteh
11	Biomedical Science	Dr. Irene Adzo Agbo	Univ. of Professional Studies, Accra
12	Building Construction & Woodwork Technology	Mr. Alex A. Appah	Christ Calvary Prep. Sch.
13	Business Management	Mr. Emmanuel Boakye	Ghana Employers Association
14	Chemistry	Joyce Okreyewa Odei	Hope College, Gomoa Fetteh
15	Clothing and Textiles	Rosemary Quarcoo	Department of Clothing and Textiles, UEW
16	Design & Communication Technology	Esme Serwaa Boateng	Ghana National College, Cape Coast
17	Economics	Dr. Kofi Kamasa	Department of Management Studies, UMaT
18	Electrical & Electronics Technology	Dr. Emmanuel Ampoma Affum	Telecom Engineering Department, KNUST
19	Engineering	Dr. Albert Kotawoke Awopone	Univ. of Skills Training & Entrepreneurial Development
20	English Language	Prof. Philip Gborsong	University of Cape Coast

21	Food and Nutrition	Sylvia Baaba Yankey	
22	French	Gregory Nana Kobina Nketsia Mensah	Mfantsipim School, Cape Coast
23	General Science	Joyce Okreyewa Odei	Hope College, Gomoa Fetteh
24	Geography	Prof Kofi Adu Boahen	University of Education, Winneba
25	Ghanaian Languages	Prof. Regina Caesar	University of Education, Winneba
26	Government	Clement Adu Acheampong	Prempeh College SHS, Kumasi
27	History	Prof Wilson Yayoh	University of Cape Coast
28	Information Communication Technology	Felicia Archeresuah	Nkoronza Technical Institute
29	Manufacturing Engineering	Dr. Frank Kwabena Nyarko	Kwame Nkrumah Univ. of Science and Technology
30	Mathematics	Ezekiel Osei Bonsu	Bono East Regional Education Office, Nkoranza
31	Management in Living	Ms. Anna Holdbrooke	Swedru Senior High School
32	Music	Prof Mark-Millas Fish	University of Education, Winneba
33	Physical Education and Health Core	Francis Maxwell Ayamba	Atebubu College of Education
34	Physical Education and Health Elective	Sulemana Ahmed Tijani	Atebubu College of Education
35	Performing Arts	Dr. Godfred Asare Yeboah	University of Education, Winneba
36	Physics	Peter Bekoe	Our Lady of Mount Carmel Girls SHS, Techiman
37	Religious and Moral Education	Christian Kwarteng Mensah Oppong	Prempeh College, Kumasi
38	Robotics	Dr. Yaw Okraku-Yirenki	Kofi-Annan Centre of Excellence in ICT
39	Social Studies	Samuel Larbi	St Louis Girls SHS, Kumasi
40	Spanish	Prof. Jonson Asunka	University of Ghana Legon

SECTION 1: AIRCRAFT STRUCTURES

STRAND: CORE CONCEPTS IN AEROSPACE ENGINEERING

Sub-Strand: Aircraft Structures and Control

Learning Outcome: *Identify the structural design of an airframe.*

Content Standard: *Demonstrate knowledge of various types of aircraft construction.*

INTRODUCTION AND SECTION SUMMARY

Hello, and welcome to the first section of the teacher manual for Year 3 of the Aviation and Aerospace Engineering curriculum. In this section, we will be concerned with aircraft structures: the materials used to build them and their properties and use cases, as well as the different approaches to constructing the airframe.

The weeks and the indicators covered by the section are:

- **Weeks 1 & 2:** Identify the right materials for construction of a small UAV.
- **Weeks 3 & 4:** Evaluate the different types of aircraft construction.

Recap weeks

Year 1	Week 3: Differentiate the types of aerospace vehicles.
--------	---

SUMMARY OF PEDAGOGICAL EXEMPLARS

1. Talk for learning
2. Group discussions
3. Collaborative learning
4. Project-based learning

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/or Mode
Identify the right materials for construction of a small UAV.	3	Essay
Evaluate the different types of aircraft construction.	4	1. Poster presentation 2. Group project

WEEKS 1 & 2

Learning Indicator: *Identify the right materials for construction of a small UAV*

Focal Area: Aircraft materials (Refer back to Year 1, section 1, week 3: the types of aerospace vehicles and their parts.)

The focus of this week and the next will be on the different materials available to us for the construction of aircraft parts. These materials include metals such as aluminium, steel and titanium alloys and non-metals such as composites and glass. Let us take them one after the other.

1. Aluminium alloys

Aluminium alloys are among the most widely used materials in aircraft construction, prized for their excellent balance of properties. Their primary advantage is their low weight, which contributes significantly to fuel efficiency and overall aircraft performance. The high strength-to-weight ratio ensures that aircraft structures can withstand substantial loads without excessive structural weight. Various alloying elements, such as copper, magnesium, silicon, and zinc, are added to aluminium to enhance its strength, hardness, and corrosion resistance.

Different aluminium alloys are selected based on the specific requirements of each aircraft component. For instance, alloys like 2024 and 7075 (the alloys are usually assigned an “identification” number or code) are frequently used in wing structures and fuselage skins due to their high strength. These alloys undergo various heat treatments to optimise their mechanical properties, ensuring they meet stringent aerospace standards. The corrosion resistance of aluminium alloys is another critical factor, as aircraft are exposed to diverse environmental conditions that can promote corrosion. To further enhance corrosion protection, aluminium components often receive surface treatments which create a protective oxide layer.

The use of aluminium alloys is particularly beneficial in Ghana due to its humid climate. The enhanced corrosion resistance of these alloys helps to mitigate the impact of moisture and airborne salts, reducing the frequency and cost of maintenance. Additionally, the lightweight properties of aluminium alloys contribute to fuel savings for airlines, making them an economically viable choice. Continuous advancements in aluminium alloy technology are focused on further improving their strength, fatigue resistance, and corrosion performance, ensuring their continued relevance in aircraft manufacturing.

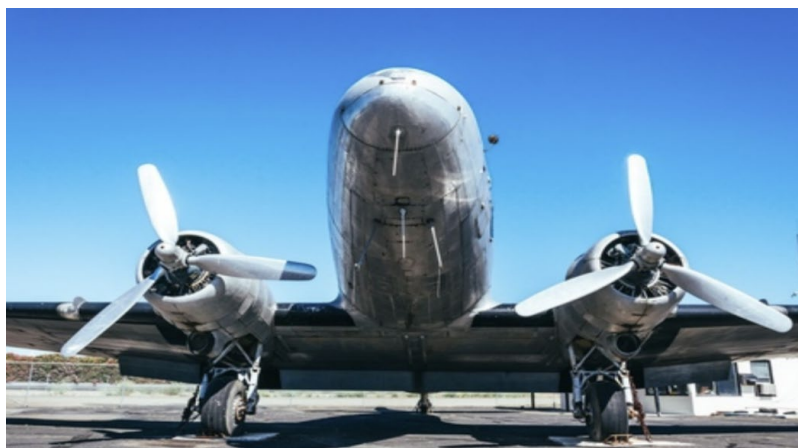


Figure 1.1: *Aluminium skin of an aircraft*

2. Titanium Alloys

Titanium alloys are renowned for their exceptional strength-to-weight ratio, making them indispensable in aerospace applications where performance and durability are paramount. These alloys offer significant weight savings compared with steel while maintaining superior strength and toughness. Their excellent corrosion resistance, even in harsh environments, further enhances their appeal for use in critical aircraft components. Titanium alloys are particularly well-suited for high-temperature applications, retaining their mechanical properties at elevated temperatures where aluminium alloys would fail.

The composition of titanium alloys typically includes elements such as aluminium, vanadium, molybdenum, and iron, each contributing to specific properties. For example, Ti-6Al-4V, the most widely used titanium alloy, combines high strength with good ductility and weldability. These alloys find extensive use in engine components, such as compressor blades, discs, and casings, where they must withstand extreme temperatures and stresses. They are also used in structural components like landing gear and fasteners, where high strength and fatigue resistance are essential.

The benefits of titanium alloys extend to enhanced aircraft performance and safety. Their high strength-to-weight ratio allows for lighter aircraft structures, resulting in improved fuel efficiency and increased payload capacity. Their resistance to corrosion reduces maintenance requirements and extends the lifespan of critical components. While titanium alloys are more expensive than aluminium or steel, their superior performance and durability often justify the higher initial cost, particularly in demanding applications. Ongoing research focuses on developing new titanium alloys with even greater strength, temperature resistance, and cost-effectiveness, ensuring their continued importance in the aerospace industry.



Figure 1.2: *Engine components made with titanium alloys*

3. Steel Alloys

Steel alloys are fundamental materials in aircraft construction, primarily utilised for their high strength, toughness, and ability to withstand significant stress. While steel is denser than aluminium or titanium, its superior strength makes it essential for components subjected to extreme loads and wear. Various types of steel alloys are employed in aircraft, each tailored to specific applications based on their unique properties.

High-strength steel alloys, such as chromium-molybdenum steels, are commonly used in landing gear components, where they must endure the impact of landings and taxiing. These alloys are heat-treated to achieve optimal hardness and fatigue resistance, ensuring reliable performance under demanding conditions. Stainless steels, known for their excellent corrosion resistance, are used in areas exposed to moisture and corrosive substances, such as fasteners, control cables, and hydraulic lines. The addition of chromium and nickel to steel forms a protective oxide layer that prevents rust and degradation.



Figure 1.3: *Landing gear made of steel alloys*

The use of steel alloys in aircraft construction contributes to overall safety and structural integrity. Their high strength ensures that critical components can withstand the stresses encountered during flight, while their toughness prevents brittle failure. Although steel components are heavier than those made from aluminium or titanium, their strength and durability are often essential for meeting the stringent safety requirements of the aerospace industry. Ongoing research aims to develop advanced steel alloys with improved strength-to-weight ratios and enhanced corrosion resistance, expanding their potential applications in aircraft manufacturing.

4. Composite Materials

Composite materials have revolutionised aircraft construction by offering an unmatched combination of strength, low weight properties, and design flexibility. These materials consist of two or more distinct components, typically a reinforcing fibre embedded in a matrix material. The most common types of composite materials used in aircraft include Carbon Fibre Reinforced Polymer (CFRP) and fibreglass, each with its own unique characteristics and applications.

CFRP is valued for its exceptional strength-to-weight ratio, making it ideal for primary structural components such as wings, fuselage sections, and control surfaces. Carbon fibres provide high tensile strength and stiffness, while the polymer matrix, usually epoxy, binds the fibres together and transfers loads. CFRP components can be moulded into complex shapes, allowing for aerodynamic designs and reduced part count. Fibreglass, consisting of glass fibres in a polymer matrix, is less expensive than CFRP and is often used in secondary structures, interior panels, and non-structural components.

The advantages of composite materials extend beyond weight savings. They offer excellent fatigue resistance, reducing the risk of cracking and failure under repeated stress. Some composites require protective coatings, reducing maintenance costs. The design flexibility of composites allows for the creation of streamlined shapes and integrated structures, improving aerodynamic performance and reducing drag. In modern aircraft, composite materials account for an increasing percentage of the total structural weight, contributing to improved fuel efficiency, increased payload capacity, and enhanced overall performance. Continuous advancements in composite technology are focused on developing new materials with even greater strength, temperature resistance, and damage tolerance, further expanding their applications in the aerospace industry.



Figure 1.4: *Composite aircraft*

5. Other Materials

In addition to the primary materials discussed, various other materials play crucial roles in aircraft construction, each selected for its specific properties and contribution to overall performance. These include magnesium alloys, speciality plastics, sealants, and various coatings, each serving a unique purpose in ensuring the safety, efficiency, and comfort of aircraft.

Magnesium alloys are among the lightest structural materials available, making them attractive for use in interior components, such as seat frames, overhead bins, and control panels. While magnesium is highly flammable in its pure form, alloying it with other elements, such as aluminium and zinc, significantly improves its corrosion resistance and reduces its flammability. Speciality plastics, including polycarbonates, acrylics, and polyurethanes, are used in a wide range of applications, from windows and windshields to interior trim and insulation. These plastics offer excellent transparency, impact resistance, and thermal insulation properties. Glass is used for windows and windscreens.

Sealants and adhesives are essential for joining aircraft components and preventing leaks. They are used to seal joints between fuselage panels, around windows and doors, and in fuel tanks. These materials must be able to withstand extreme temperatures, pressures, and exposure to aviation fuels and hydraulic fluids. Various coatings are applied to aircraft surfaces to protect against corrosion, erosion, and ultraviolet radiation. These coatings include primers, paints, and specialised films that enhance the durability and appearance of the aircraft. The selection and application of these other materials are critical to ensuring the long-term performance, safety, and reliability of aircraft. Ongoing research focuses on developing new and improved materials that

offer enhanced properties, reduced weight, and increased sustainability, contributing to the continuous advancement of aircraft technology.

When we build our drones in a later section, we will be using some of these materials. However, for reasons such as cost-effectiveness, ease of use, and availability, materials such as wood and foam may be used as well. These are discussed next.

a. **Wood**

Wood, such as plywood, balsa and ceiba, is an accessible and inexpensive material for constructing drone frames and wings, especially for fixed-wing UAVs. Balsa wood is exceptionally lightweight, making it ideal for creating large wings with minimal weight. Plywood offers greater strength and rigidity compared with balsa, making it suitable for frames and structural components. Wood is also easy to cut, shape, and join using basic tools and adhesives.

However, wood has a lower strength-to-weight ratio compared with other materials like carbon fibre or aluminium. It is also susceptible to environmental conditions, such as moisture, which can cause warping or rot. Wooden drone frames and wings typically require a protective coating or sealant to prevent water damage and prolong their lifespan. Despite these limitations, wood remains a popular choice for drones due to its affordability, availability, and ease of use, particularly for fixed-wing designs.

b. **Foam**

Foam materials, such as Expanded Polystyrene (EPS) and Expanded Polypropylene (EPP), are widely used in the construction of fixed-wing UAVs and protective casings due to their very lightweight and shock-absorbent properties. EPS foam is commonly used for creating the wings and bodies of model aircraft, offering excellent aerodynamic properties and ease of shaping. EPP foam is more flexible and durable than EPS, making it suitable for applications where impact resistance is important.

However, foam materials are relatively fragile and easily damaged compared with other materials. They are also susceptible to degradation from exposure to sunlight and certain chemicals. Foam wings and bodies often require reinforcement with tape, fibreglass, or carbon fibre to improve their strength and durability. Despite these limitations, foam remains a popular choice for creating lightweight and aerodynamic designs, particularly for fixed-wing aircraft intended for recreational or experimental purposes.

c. **Plastics**

Plastics, particularly PLA (Polylactic Acid), ABS (Acrylonitrile Butadiene Styrene), and PETG (Polyethylene Terephthalate Glycol), are commonly used in 3D-printed drone parts. These materials are lightweight, inexpensive, and easy to mould into complex shapes, making them ideal for creating custom housings, mounts, and other components. 3D printing allows us to rapidly prototype and iterate designs, customising our drones to meet specific requirements.

However, 3D-printed plastic parts are generally not as strong or durable as carbon fibre or aluminium. PLA, for example, is biodegradable and has a lower melting point, making it less suitable for high-stress or high-temperature applications. ABS and PETG offer improved strength and heat resistance compared with PLA but may be more challenging to print. Despite these limitations, 3D-printed plastics are invaluable for creating custom parts and enclosures, allowing for personalised designs and seamless integration of various electronic components.

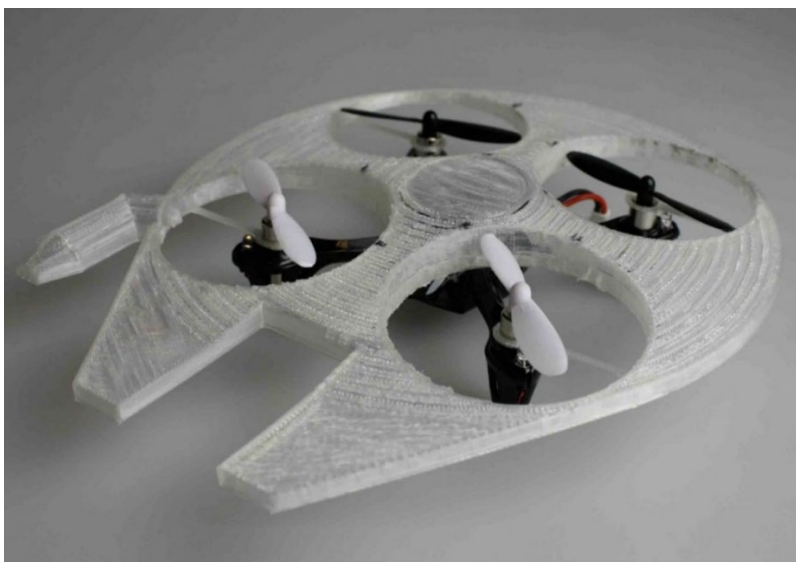


Figure 1.5: 3D-printed UAV

Learning Tasks

1. Participate actively in the question-and-answer session facilitated by your teacher, providing the properties of some materials that you know are used for aircraft construction
2. Discuss with your friends why certain aircraft materials may not be used for manufacturing small UAVs.

Pedagogical Exemplars

Talk for Learning – In a question-and-answer session, discuss with learners, the properties of common materials used for making aircraft components

Group discussions – Supervise learners to discuss, in mixed-ability groups why some of the materials used for traditional aircraft manufacturing may not be used for small UAVs.

Key Assessment Level 3: Individual Class Exercise (Essay)

1. Compare two materials commonly used in aircraft design. Analyse how their properties influence their performance in different parts of an aircraft, and justify which material is more suitable for use in high-stress components. (10 marks) (DOK 3)
2. Some materials used for traditional aircraft construction may not be used for small UAV models. Why is this so? Give examples where you can. (8 marks) (DOK 3)

Refer to Teacher Assessment Manual and Toolkits pages 94 – 97 for further guidance on conducting Essay assessments.

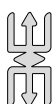
PLC Session 1 & 2

45 minutes

Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to

- a. explain the week's concepts in a practical way that will make it easier for learners to understand
 - b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject-specific app to plan your lesson. Ask the app to
- a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
 - b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
 - c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

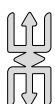
- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
- a. The key assessment for the week is **individual class exercise**. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the exercise (NTS 3k-3q).

10 minutes

Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
- a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
 - b. all teachers in the group work through a similar problem individually for 3–4 minutes
 - c. the group then works through the problem together step by step
 - d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes**Enactment**

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).
 - a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
 - b. After the enactment, ask for structured feedback from the group
 - i. was the concept explained in a way that a learner with no prior knowledge could follow?
 - ii. were the examples grounded in contexts familiar to Ghanaian learners?
 - iii. did any misconceptions surface and if so, how were they addressed?

5 minutes**Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
 - a. transfer your chats into your learning planner template.
 - b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
 - c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEKS 3 & 4

Learning Indicator: Evaluate the different types of aircraft construction

Focal Area: Airframe Structures (Refer back to Year 1, section 1, week 3: the types of aerospace vehicles and their parts.)

For this week and the one ahead, we will study the different types of aircraft construction. These are identified by unique features. Let us begin with the truss structure.

1. Truss Structure

A truss structure is one of the oldest and simplest methods of aircraft construction. It is made up of a framework of beams arranged in triangular shapes. These beams, usually made of wood or metal, are joined together at points called nodes. This arrangement forms a strong and rigid structure that can carry loads effectively. The triangular shape is very important because it helps the structure remain stable and prevents it from bending or changing shape under pressure. In a truss structure, most of the members carry forces through tension (pulling) or compression (pushing), rather than bending.

Some important parts of the truss structure are **longerons, struts, and stringers**. *Longerons* are the main long beams that run from the front to the back of the structure and provide overall strength. *Struts* are members that support the structure by holding different parts together and helping to transfer loads. *Stringers* are smaller, lighter beams that run along the length of the structure and help support the outer covering (skin) while also sharing the load.

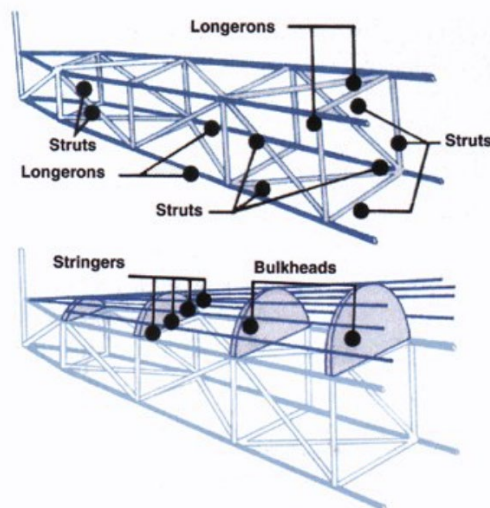


Figure 1.6: Aircraft truss construction

One of the primary advantages of the truss structure is its simplicity in design and construction. It requires relatively basic tools and materials, making it accessible for early aircraft builders and suitable for amateur construction. The open framework also allows for easy inspection and maintenance of the structural components. However, truss structures are generally heavier and less aerodynamic compared with other construction methods. The exposed framework creates significant drag, reducing the aircraft's efficiency.

A classic example of an aircraft employing a truss structure is the Wright 1903 Flyer, the first successful heavier-than-air powered aircraft. Its wings and fuselage were constructed using a

wooden truss framework covered with fabric. Another example is the Piper J-3 Cub, a popular light aircraft that utilised a welded steel tube truss fuselage covered with fabric. While truss structures are less common in modern aircraft, they are still used in some ultralight and experimental aircraft due to their simplicity and ease of construction.

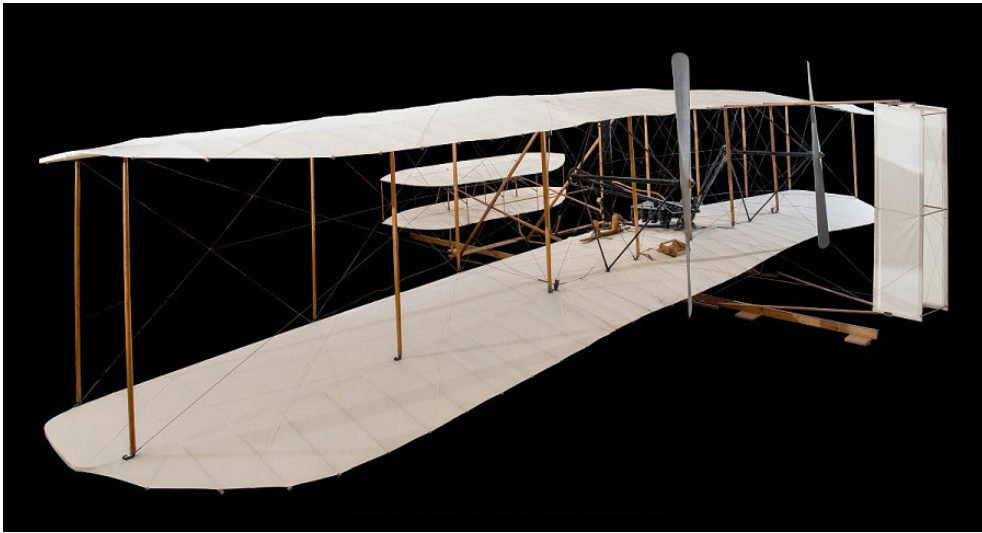


Figure 1.7: *The Wright Flyer*



Figure 1.8: *The Piper J-3 Cub*

2. Monocoque Structure

The monocoque structure represents a significant departure from the truss structure, relying on the outer skin of the aircraft to bear the primary loads. In this design, the skin acts as a stressed member, distributing aerodynamic forces and resisting bending and torsional loads. A true monocoque structure has no internal framework, resulting in a smooth, aerodynamic outer surface and a significant reduction in weight.

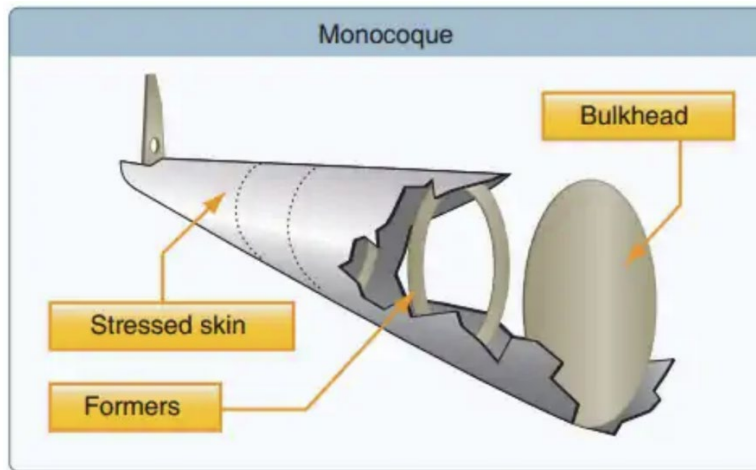


Figure 1.9: Aircraft monocoque construction

The primary advantage of the monocoque structure is its lightweight and aerodynamic efficiency. By eliminating the need for internal bracing, the aircraft's weight is minimised, improving its performance and fuel efficiency. The smooth outer surface reduces drag, further enhancing aerodynamic efficiency. However, monocoque structures are highly vulnerable to buckling and damage if the skin is compromised. Any significant dent or puncture can weaken the entire structure, leading to catastrophic failure.

Due to its vulnerability, the true monocoque structure is rarely used in modern aircraft. It is primarily found in smaller aircraft, such as gliders and some early experimental designs, where the loads are relatively low and the risk of damage is minimal. One example is the de Havilland Mosquito, a British multi-role combat aircraft of World War II, which featured a moulded plywood monocoque fuselage. However, even in this case, the structure was reinforced with internal frames to improve its strength and durability.



Figure 1.10: de Havilland Mosquito aeroplane

3. Semi-Monocoque Structure

The semi-monocoque structure is a hybrid design that combines the advantages of both the truss and monocoque structures while mitigating their weaknesses. It consists of a skin reinforced by internal frame members, such as stringers, bulkheads, and formers. The skin and the internal framework share the load, providing a strong, lightweight, and durable structure. Stringers are longitudinal members that run along the length of the fuselage, providing stiffness and preventing

buckling. Bulkheads are vertical frames that provide support and maintain the shape of the fuselage. Formers are like bulkheads but are typically lighter and spaced more closely together.

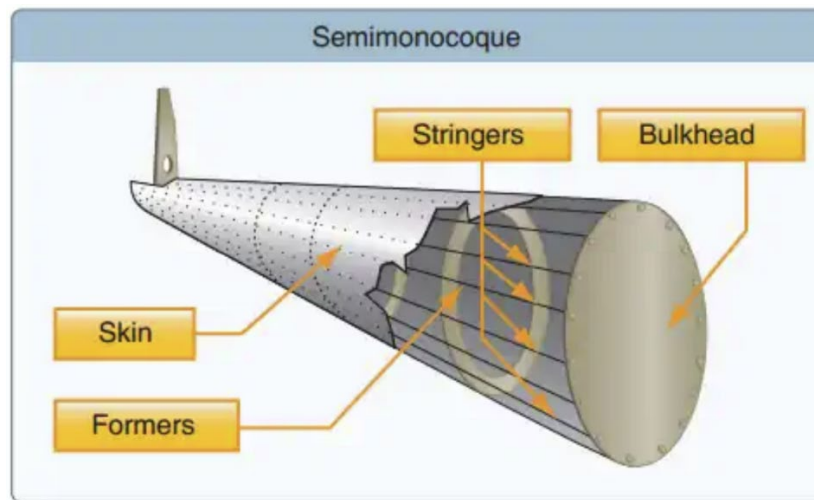


Figure 1.11: Aircraft semi-monocoque construction

The semi-monocoque structure offers an excellent balance between strength, weight, and aerodynamic efficiency. The skin provides a smooth outer surface, reducing drag, while the internal framework provides support and prevents buckling. This design is more resistant to damage than the monocoque structure, as the internal framework can redistribute loads around any localised damage. The semi-monocoque structure is the most common type of construction used in modern aircraft, from small general aviation planes to large commercial airliners.

Examples of aircraft employing semi-monocoque construction include the Boeing 737, a widely used narrow-body airliner, which features a semi-monocoque fuselage made of aluminium alloy. The Airbus A320, another popular narrow-body airliner, also utilises a semi-monocoque structure with extensive use of composite materials in the wings and fuselage. The Cessna 172, a common general aviation aircraft, employs a semi-monocoque design with an aluminium alloy skin and internal framework.



Figure 1.12: A Boeing 737 aircraft

Learning Tasks

1. Create, together with your group members, a poster depicting one type of aircraft construction
2. Build a model of an aircraft fuselage that employs any one of the aircraft construction types

Pedagogical Exemplars

Collaborative learning – Assign learners to create posters depicting the different types of aircraft construction. Pay attention to learners with special needs.

Project-based learning – Put learners in mixed-ability groups and assist them to create models of aircraft fuselages using different construction approaches.

Key Assessment Level 4: Group Project

Presentation

1. Design and deliver a presentation comparing different aircraft construction types. Evaluate how each construction type impacts aircraft performance, cost, and environmental sustainability. Recommend the most suitable construction type for use in future eco-efficient aircraft, justifying your decision with evidence.

(16 marks) (DOK 4)

Refer to Teacher Assessment Manual and Toolkits pages 97 – 99 for further guidance on conducting poster assessments

Group project

2. Research and analyse locally available sustainable materials for their suitability in aircraft fuselage construction. Design an innovative fuselage section (truss, monocoque, or semi-monocoque) using these materials. Construct a scale prototype, documenting the design process and justifying material choices based on performance and sustainability.

(16 marks) (DOK 4)

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

HINT



Assign Group Project to learners and give them reasonable time to complete it. Use the SS App to generate the project as well as the rubric. Learners' projects should be marked immediately and scores entered into the SAP.

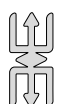
PLC Session 3 & 4

45 minutes

Planning and Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
 - a. explain the week's concepts in a practical way that will make it easier for learners to understand.

- b. identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
 - a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
 - b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).
 - c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

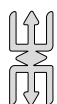
- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Use your app to plan and administer the mode of assessment for the student Assessment Portal (SAP).
 - a. The key assessment for the week is **group project**. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/rubrics for the project (NTS 3k-3q).

10 minutes

Content Exploration

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
 - a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
 - b. all teachers in the group work through the problem individually for 3–4 minutes
 - c. the group then works through the problem together, step by step
 - d. highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- This part is not 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes**Enactment**

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).
 - a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
 - b. After the enactment, ask for structured feedback from the group
 - i. was the concept explained in a way that a learner with no prior knowledge could follow?
 - ii. were the examples grounded in contexts familiar to Ghanaian learners?
 - iii. did any misconceptions surface and if so, how were they addressed?

5 minutes**Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
 - a. transfer your chats into your learning planner template.
 - b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
 - c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 1 Review

In this section, we learned about the materials used to manufacture aircraft parts. These include metals, glass, plastics and composites. We learned about their properties and specific use cases. Then we also looked at the three main approaches to constructing the airframe. These were the truss, monocoque and semi-monocoque structures. The information we have learned here will prove vital when it comes to building our UAV models towards the end of the year.



MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEKS 1 & 2

Question 1

1. Identification and brief description of two relevant aircraft materials 2 marks
2. Accurate comparison of at least two key properties (e.g., strength, weight, durability) 2 marks
3. Analysis of how properties affect performance in aircraft components 2 marks
4. Justification of which material is more suitable for high-stress use 2 marks
5. Logical structure, clarity, and technical accuracy 2 marks

Question 2

1. 2 marks awarded for each of at least two reasons presented 4 marks
2. 1 mark awarded for each specific example to each reason provided 2 marks

WEEKs 3 & 4

Mark scheme

Question 1

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Comparison of Construction Types	Comprehensive and accurate comparison of multiple construction types, including detailed information on manufacturing and structural properties.	Accurate comparison of several construction types with sufficient detail on manufacturing and structural properties.	Basic comparison of a limited number of construction types with some inaccuracies or omissions.	Incomplete or inaccurate comparison of construction types with significant omissions.
Impact on Performance, Cost, & Sustainability	Thorough evaluation of how each construction type affects aircraft performance, cost, and environmental impact, with specific examples and data.	Clear evaluation of the impact on performance, cost, and sustainability, with some supporting examples.	Basic evaluation of the impact but lacking specific examples or data.	Limited or unclear evaluation of the impact on performance, cost, and sustainability.

<i>Recommendation & Justification</i>	<i>Well-reasoned recommendation of the most suitable construction type for future eco-efficient aircraft, supported by strong evidence and a clear understanding of trade-offs.</i>	<i>Clear recommendation with logical justification and supporting evidence.</i>	<i>Recommendation is present, but justification is weak or lacks sufficient evidence.</i>	<i>Recommendation is unclear or unsupported by evidence.</i>
<i>Presentation Quality</i>	<i>Visually appealing and well-organised poster/presentation with clear and concise information, effective use of visuals.</i>	<i>Organised and clear poster/presentation with appropriate visuals.</i>	<i>Poster/presentation is somewhat disorganised or difficult to follow, with limited visuals.</i>	<i>Poster/presentation is poorly organised, unclear, and lacks visuals.</i>

Question 2

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
<i>Research & Analysis of Sustainable Materials</i>	<i>Demonstrates comprehensive and insightful research into a wide range of locally available sustainable materials, with detailed analysis of their properties (strength, weight, durability, availability, cost, environmental impact) and suitability for aircraft fuselage construction.</i>	<i>Demonstrates thorough research into several locally available sustainable materials, with clear analysis of their properties and suitability for fuselage construction.</i>	<i>Demonstrates basic research into a limited number of materials, with some analysis of their properties and suitability.</i>	<i>Research is minimal, with little or no analysis of material properties or suitability.</i>

<i>Innovation & Design</i>	<i>Presents a highly innovative and well-conceived fuselage design that effectively integrates sustainable materials. The design demonstrates a deep understanding of aircraft structural principles and sustainable design practices.</i>	<i>Presents a creative and functional fuselage design that integrates sustainable materials. The design demonstrates a good understanding of aircraft structural principles.</i>	<i>Presents a basic fuselage design that attempts to integrate sustainable materials but may lack innovation. Understanding of structural principles is limited.</i>	<i>Design is incomplete, unrealistic, or demonstrates a lack of understanding of aircraft structures or sustainable design.</i>
<i>Prototype Construction & Documentation</i>	<i>Constructs a high-quality, well-crafted prototype that accurately reflects the design. The design process is thoroughly documented, including material selection, construction techniques, challenges encountered, and modifications made, with clear and logical reasoning.</i>	<i>Constructs a functional prototype that generally reflects the design. The design process is documented with sufficient detail and reasoning.</i>	<i>Constructs a prototype with some flaws or inaccuracies. The design process is documented, but may lack detail or clarity.</i>	<i>Prototype is poorly constructed or incomplete. Documentation of the design process is minimal or missing.</i>
<i>Justification of Material Choices & Sustainability</i>	<i>Provides a compelling and well-supported justification for all material choices, based on performance, sustainability, and cost-effectiveness. Demonstrates a deep understanding of the environmental and social impacts of material selection.</i>	<i>Provides a clear and logical justification for material choices, based on performance, sustainability, and cost.</i>	<i>Provides a basic justification for material choices, but may lack strong evidence or a thorough understanding of sustainability issues.</i>	<i>Justification for material choices is weak, unclear, or missing. Shows little understanding of sustainability.</i>

SECTION 2: STABILITY AND CONTROL

STRAND: CORE CONCEPTS IN AEROSPACE ENGINEERING

Sub-Strand: Aircraft Structures and Control

Weeks 5 & 6

Learning Outcome: *Discuss the flight controls of an aerospace vehicle and its impact on the movement of the vehicle.*

Content Standard: *Demonstrate understanding of how an aerospace vehicle (aircraft, spacecraft) is controlled in flight.*

Week 7

Learning Outcome: *Explain the concepts of static and dynamic stability of aerospace vehicles*

Content Standard: *Demonstrate knowledge and understanding of the factors that account for stability of an aerospace vehicle.*

INTRODUCTION AND SECTION SUMMARY

Having examined the structural designs that give an aircraft its form and strength in Section 1, we now shift focus to how these structures function in motion. Section 2 explores how aerospace vehicles are controlled in flight and how they maintain stability once lift has been generated. Learners will study the primary control surfaces and their effects on movement, as well as the concepts of static and dynamic stability. This progression builds a fuller understanding of how structure and control systems work together to keep an aircraft balanced and responsive in flight.

The weeks and the indicators covered by the section are:

- **Weeks 5 & 6**
 - o Describe the flight controls (and control surfaces) of a fixed-wing aircraft.
 - o Describe the flight controls of a rotary-wing aircraft.
 - o Describe the control mechanisms of spacecraft.
 - o Distinguish between the features of fly-by-wire (automatic) control, mechanical control and hydraulic control of aircraft
- **Week 7**
 - o Apply the understanding of moments in Physics to aircraft movement and stability configurations.
 - o Determine the relationship between the location of the centre of gravity of an aircraft and its stability.

Recap Weeks

Year 1	Week 3: The Types of Aerospace Vehicles and Their Parts
--------	---

SUMMARY OF PEDAGOGICAL EXEMPLARS

1. Talk for learning
2. Collaborative Learning
3. Experiential Learning

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/or Mode
Describe the flight controls (and control surfaces) of a fixed-wing aircraft. Describe the flight controls of a rotary-wing aircraft. Describe the control mechanisms of spacecraft. Distinguish between the features of fly-by-wire (automatic) control, mechanical control and hydraulic control of aircraft	DOK 3	Scenario Analysis / Strategic Thinking
Apply the understanding of moments in Physics to aircraft movement and stability configurations. Determine the relationship between the location of the centre of gravity of an aircraft and its stability.	DOK 3	Visual-based Reasoning / Reflective Writing

WEEKS 5 & 6

Learning Indicators

1. Describe the flight controls (and control surfaces) of a fixed-wing aircraft
2. Describe the flight controls of a rotary-wing aircraft
3. Describe the control mechanisms of spacecraft
4. Distinguish between the features of fly-by-wire (automatic) control, mechanical control and hydraulic control of aircraft

Focal Area: Aircraft & Spacecraft Flight Controls

As discussed in Year 1 (Section 1, Week 3: The Types of Aerospace Vehicles and their parts), the aircraft is a complex machine composed of several interconnected parts. Once airborne, it is essential not only to sustain flight but also to control the aircraft's movement to ensure a safe and efficient flight experience. This is made possible through flight controls—systems and mechanisms that enable a pilot to adjust the aircraft's attitude and direction. These controls are essential to managing the three principal axes of flight: pitch, roll, and yaw. In this section, learners will deepen their understanding of the control surfaces and mechanisms that govern these motions. They will also explore the technologies used to transmit pilot input to these control surfaces, including mechanical linkages, hydraulic systems, and fly-by-wire electronics, laying the groundwork for a comprehensive understanding of how aircraft and spacecraft are manoeuvred in flight.

Control Surfaces of Fixed-Wing Aircraft

Precise control of a fixed-wing aircraft in flight is made possible by strategically designed control surfaces. These surfaces, classified as primary and secondary, work by altering the airflow around the aircraft to produce specific movements. In this lesson, we will begin with the primary control surfaces, which are fundamental to performing basic flight manoeuvres.

1. Primary Control Surfaces

Primary control surfaces are the main components used to control an aircraft's **attitude** (its orientation in space) and **direction** during flight. They include:

- **Ailerons:** These are hinged surfaces located on the trailing edges of each wing, usually near the wingtips. Ailerons control the aircraft's **roll**, which is movement around the **longitudinal axis** (nose to tail). To produce a rolling motion, the ailerons move in opposite directions—when one deflects upward, the other deflects downward—causing one wing to rise and the other to lower, as illustrated in Figure 2.1.

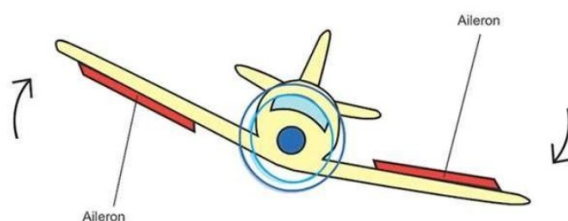


Figure 2.1: Action of ailerons causing roll

- Elevators:** These are movable control surfaces located on the trailing edge of the **horizontal stabiliser** (also known as the tailplane). Elevators control the aircraft's **pitch**—movement around the **lateral axis**, which runs from wingtip to wingtip. When the elevators deflect **upward**, they generate a **downward aerodynamic force** on the tail, causing the nose of the aircraft to pitch **upward**, as illustrated in Figure 2.2. The horizontal stabiliser helps keep the aircraft steady in pitch, while the elevator (attached to it) is the part the pilot moves to control whether the aircraft climbs or descends. On some aircraft, the entire horizontal stabiliser moves as a single unit; this is known as a **stabilator**.

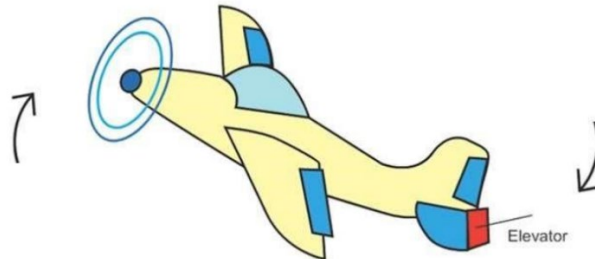


Figure 2.2: *Effect of elevator movement*

- Rudder:** The rudder is a key flight control surface located on the trailing edge of **the vertical stabiliser** at the tail of the aircraft. It is used to control **yaw**, which is the aircraft's movement around its **vertical axis** (running from top to bottom). When the rudder deflects to one side, it creates an aerodynamic force that pushes the tail in the opposite direction, causing the nose of the aircraft to yaw left or right. For example, deflecting the rudder to the right pushes the tail to the left, yawing the nose to the right. This principle is illustrated in Figure 2.3. The rudder is especially important for maintaining coordinated flight during turns and for correcting unwanted yaw due to crosswinds or uneven thrust.

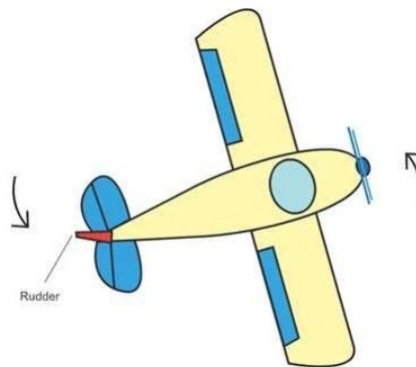


Figure 2.3: *Effect of rudder movement*

2. Secondary Control Surfaces

In addition to the primary control surfaces, aircraft also make use of secondary control surfaces to improve performance, stability, and handling—particularly during critical phases of flight such as take-off, landing, and descent. In Year 2, learners were introduced to some of these as high-lift devices, including flaps and slats. These surfaces enable pilots to adjust the aircraft's lift, drag, and trim more precisely, contributing to safer and more efficient flight operations. In this section, we will examine the most commonly used secondary control surfaces and their functions in various flight conditions.

- **Flaps:** Flaps are movable surfaces located on the trailing edges of the wings, typically positioned closer to the fuselage than the ailerons (shown in Figure 2.8). Their primary function is to increase lift and drag at lower airspeeds, which is especially critical during take-off and landing when the aircraft requires greater lift and slower approach speeds.

As introduced in Year 2, there are several types of flaps, each offering different levels of lift and drag augmentation. These include: plain flaps, split flaps, slotted flaps, and Fowler flaps, among others.

- o **Plain Flaps:** The most basic type, consisting of a simple hinged section at the trailing edge of the wing. When deflected downward, it increases the wing's camber, generating more lift but also increasing drag. Plain flaps are easy to design and operate but are less efficient compared to more advanced types.
- o **Split Flaps:** These involve only the lower surface of the wing, which hinges downward while the upper surface remains fixed. This design creates a significant increase in drag, making them useful for steep approaches during landing. While they increase lift moderately, their high drag limits use in modern designs.
- o **Slotted Flaps:** These flaps feature a narrow gap between the flap and the wing's trailing edge. When deployed, high-energy air from beneath the wing flows through the slot and over the flap, delaying flow separation and allowing for a greater increase in lift with less drag penalty. Slotted flaps are widely used in modern commercial aircraft.
- o **Fowler Flaps:** These flaps slide rearward before hinging downward, increasing both the wing area and camber. This dual action results in a substantial increase in lift, making Fowler flaps highly effective for take-off and landing. They are commonly found on large transport and passenger aircraft due to their high efficiency.

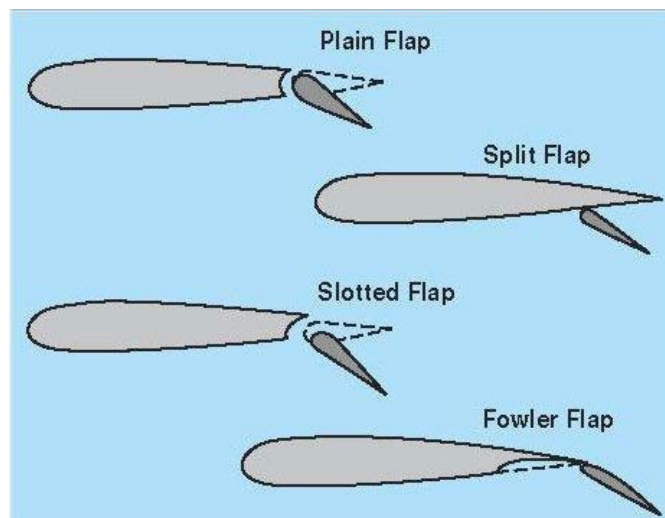


Figure 2.4: *Flaps*

- **Slats:** Slats are movable surfaces located along the **leading edge of the wing**. Their primary function is to **increase lift at high angles of attack**, allowing the aircraft to fly safely at **lower speeds** without stalling. When deployed, slats create a **narrow slot** between themselves and the wing's leading edge. This slot allows **high-energy air** from beneath the wing to flow over the upper surface, helping to **maintain smooth airflow** and **delay the onset of stall**. Slats can be **fixed, manually operated, or automatically extendable**, depending on the aircraft design. In many modern aircraft, they deploy automatically when the angle of attack increases during take-off or landing.

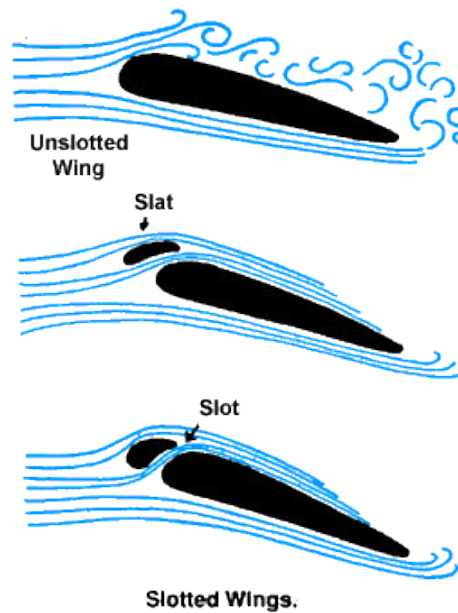


Figure 2.5: Slats

- Spoilers:** These are flat panels located on the **upper surface of the wings** and are used to **reduce lift** and **increase drag**. When deployed, they disrupt the smooth airflow over the wing, causing a decrease in lift. Spoilers can be deployed **symmetrically** on both wings to help **slow the aircraft down**, especially during **descent or after touchdown** (where they act as **lift dumpers** to transfer weight onto the wheels for better braking). They can also be deployed **asymmetrically**—on one wing only—to assist with **roll control**, particularly in combination with or in place of ailerons. Spoilers are commonly found on commercial and high-performance aircraft.

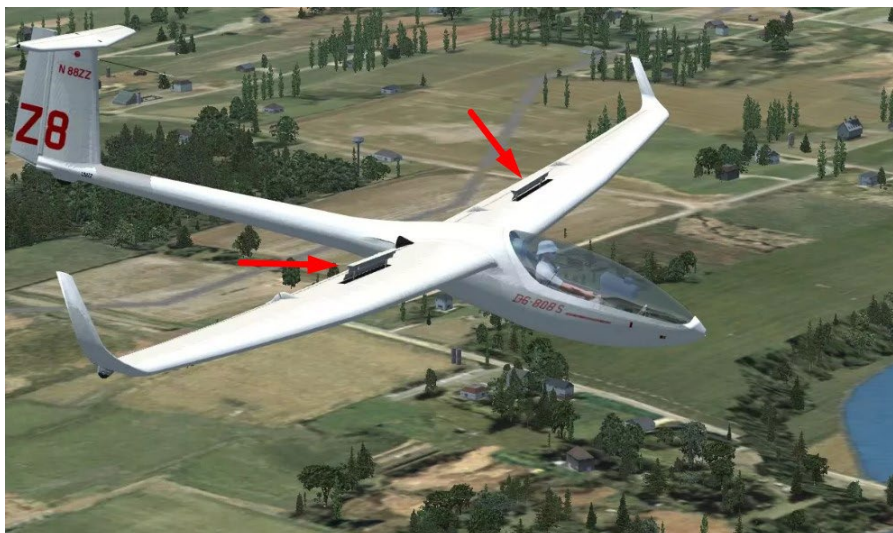


Figure 2.6: Aircraft wing showing deployed spoilers

- Trim Tabs:** They are **small, adjustable surfaces** located on the **trailing edges** of primary control surfaces—typically the **ailerons, elevators, and rudder**. They are used to **reduce the control force** a pilot must apply to maintain a desired aircraft attitude. When adjusted, a trim tab creates an **aerodynamic force** that offsets the pressure on the main control surface, allowing the surface to stay in position without continuous input from the pilot. This helps **to relieve pilot workload and fatigue**, particularly during extended periods of steady flight such as

cruising or climbing. Trim tabs can be manually or automatically adjusted, depending on the aircraft. There are different types of trim tabs, including balance tabs, anti-servo tabs, and ground-adjustable tabs, each designed to serve specific functions depending on the aircraft type and control system configuration.

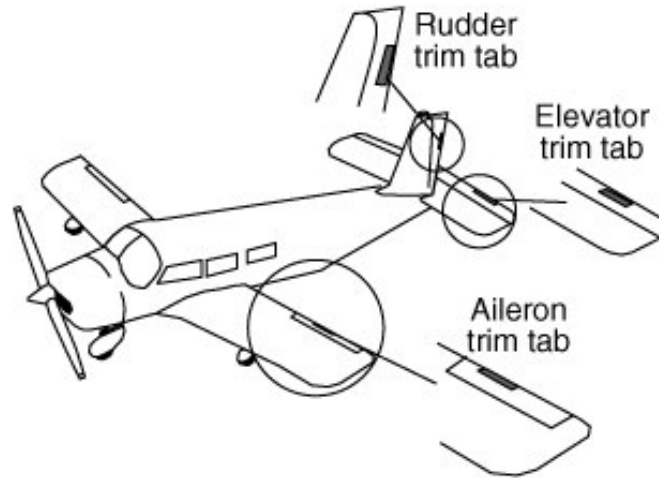


Figure 2.7: *Trim Tabs*

Fixed-wing aircraft rely on a combination of **primary and secondary control surfaces** to maintain stability, control direction, and optimise performance throughout different phases of flight. The **primary control surfaces** manage movement around the aircraft's three axes: roll, pitch, and yaw. **Secondary control surfaces**, such as flaps, slats, spoilers, and trim tabs, enhance lift, drag, and handling characteristics, especially during take-off, landing, and cruise. Together, these components enable precise, balanced, and efficient control of the aircraft in flight. Figures 2.8 and 2.9 below illustrate the primary and secondary control surfaces located on the aircraft's wings and tail assembly.

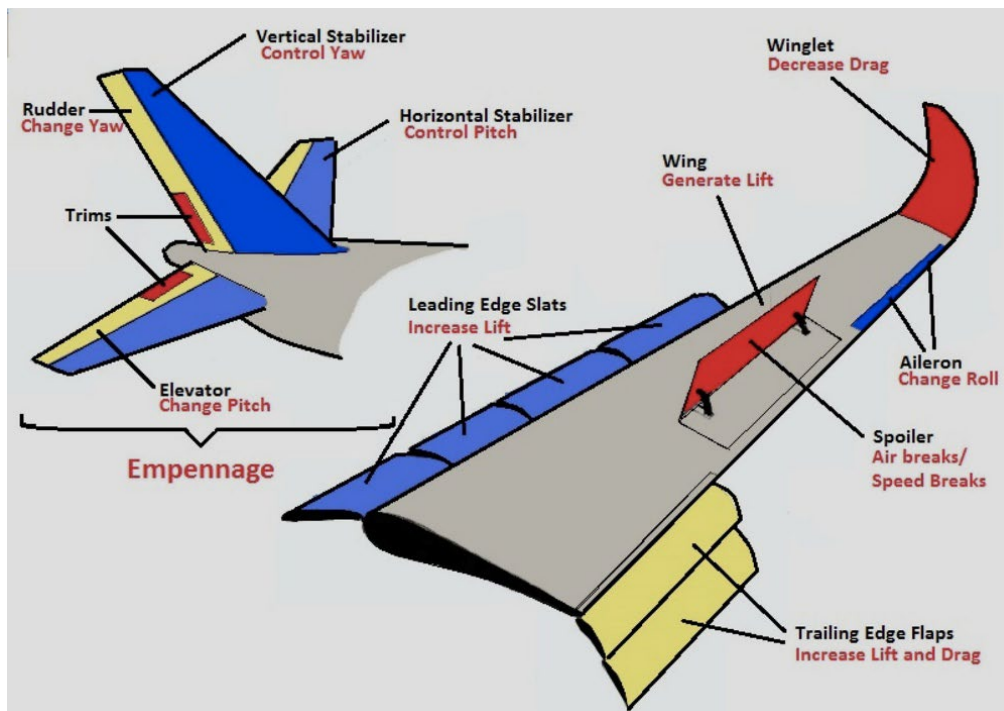


Figure 2.8: *Primary and secondary control surfaces*

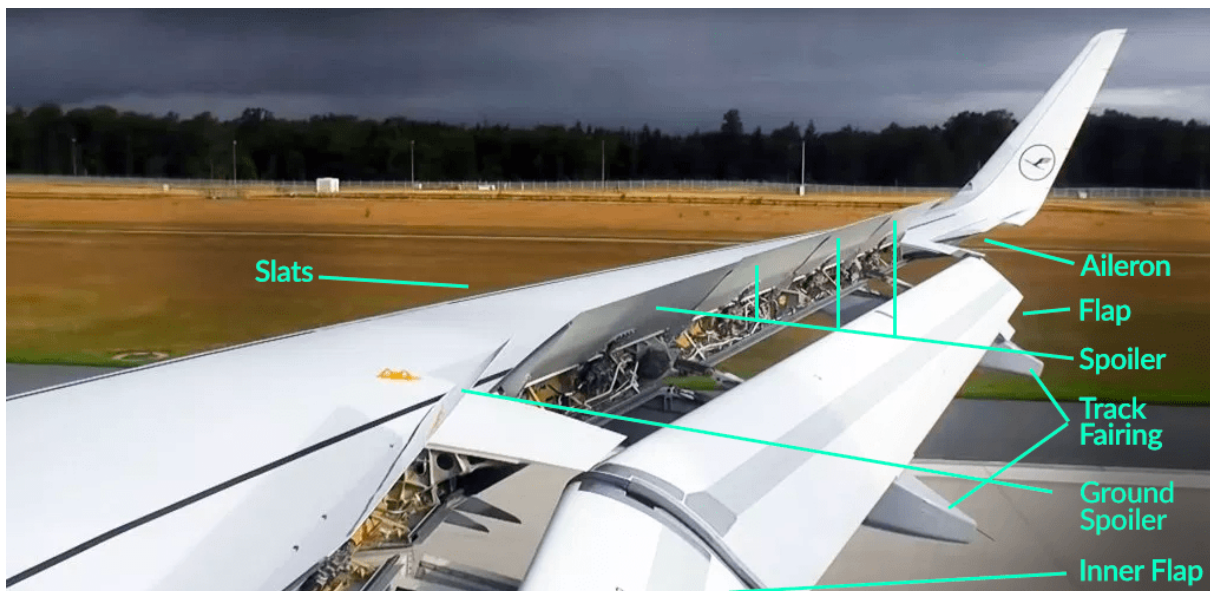


Figure 2.9: *Primary and secondary control surfaces*

Flight Control Systems of Rotary-Wing Aircraft

Unlike fixed-wing aircraft, rotary-wing aircraft (most commonly helicopters) generate lift and control flight through the rotation and precise manipulation of their rotor systems. Although they lack traditional control surfaces such as ailerons and elevators, helicopters use a combination of specialised components to manage motion along the three axes of flight: pitch, roll, and yaw. In this section, we will examine the primary control mechanisms that allow helicopters to hover, manoeuvre in tight spaces, and perform a wide range of complex operations.

1. Main Rotor

The main rotor is the most critical component of a rotary-wing aircraft. It consists of large rotor blades that rotate to generate lift. The rotor also serves as the primary control mechanism, allowing the helicopter to move in any direction.

Control of the main rotor is achieved through two key inputs:

- Collective Pitch Control:** The collective control is used to adjust the total lift produced by the rotor system. It works by changing the pitch angle of all rotor blades simultaneously and equally, regardless of their position in the rotation cycle. Increasing the collective raises the blade pitch, generating more lift and causing the helicopter to climb. Decreasing it reduces lift, allowing the aircraft to descend. The collective is typically a lever positioned to the left of the pilot's seat and is operated with the pilot's left hand.

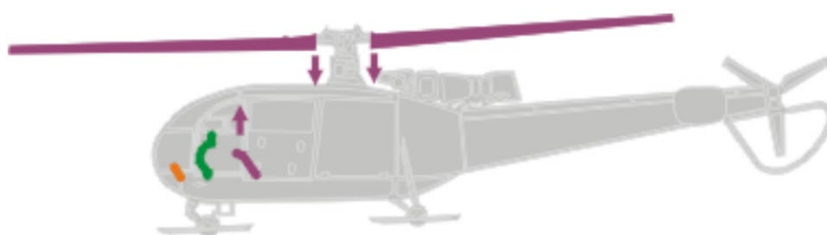


Figure 2.10: *Collective Pitch Control*

- Cyclic Pitch Control:** The cyclic control is the primary means of controlling the helicopter's direction of flight. It varies the pitch of each blade depending on its position in the rotation cycle, tilting the rotor disc in a specific direction. This allows the helicopter to move forward, backward, or sideways. It is typically a stick located in front of the pilot and operated with the pilot's right hand and works much like a joystick.

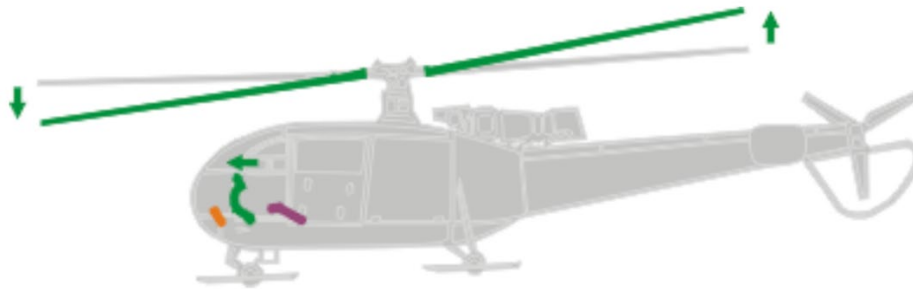


Figure 2.11: *Cyclic Pitch Control*

2. Tail Rotor (or Anti-Torque System)

As the main rotor spins, it creates a torque reaction that would cause the fuselage to spin in the opposite direction. The tail rotor, mounted vertically on the tail boom, counters this effect and provides control over yaw (rotation around the vertical axis). When the pilot presses the right pedal, the pitch of the tail rotor blades increases, producing more thrust and causing the helicopter's nose to yaw to the right. Pressing the left pedal decreases the pitch of the tail rotor blades, reducing thrust and causing the helicopter's nose to yaw to the left. These pedals are crucial for maintaining directional control and stability, especially during hover and low-speed flight.

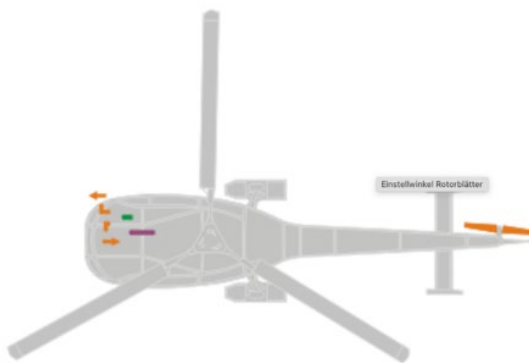


Figure 2.12: *Tail Rotor*

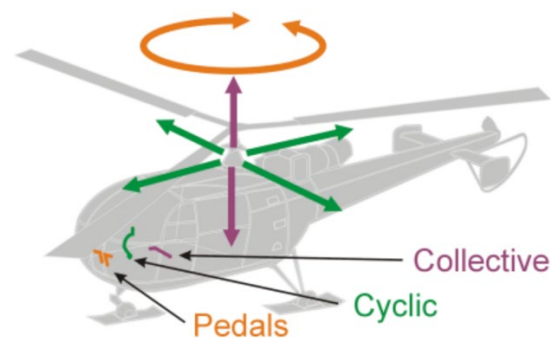


Figure 2.13: *Tail Rotor*

3. Other Control Systems

In addition to the primary flight controls, rotary-wing aircraft rely on other key systems that support precise manoeuvrability and stability.

- Swashplate Assembly:** The swashplate is a vital mechanical system that translates pilot inputs from the cyclic and collective controls to the main rotor blades. It consists of two interconnected parts: a non-rotating (stationary) plate linked to the flight controls, and a rotating plate that turns with the rotor mast. Bearings and control rods allow the assembly to tilt and move vertically, enabling independent pitch changes in each rotor blade during rotation. This precise control is what allows helicopters to climb, descend, and move in any direction.

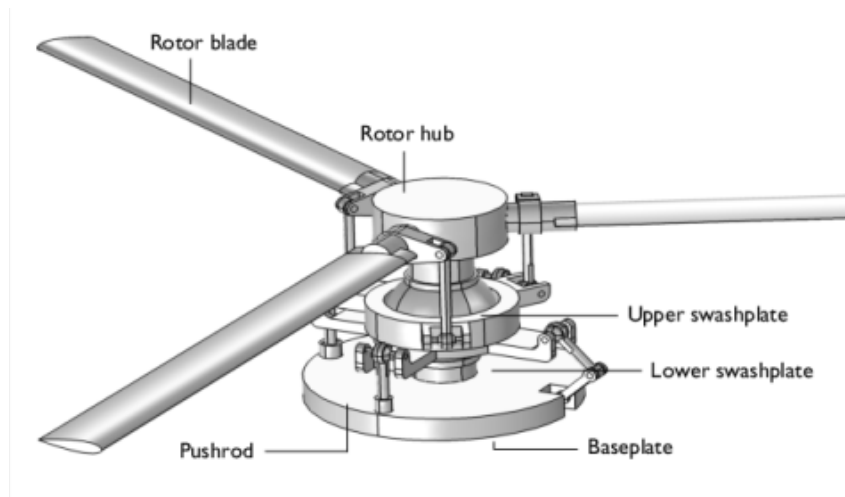


Figure 2.14: *Swashplate Assembly*

- Stabilisation Systems:** Many modern helicopters are equipped with stabilisation systems designed to assist pilots in maintaining control, especially during demanding flight conditions. These include autopilots and Stability Augmentation Systems (SAS), which use sensors, actuators, and onboard computers to detect and correct undesired motion. By automatically adjusting control inputs, these systems help maintain level flight, reduce vibrations, and enhance responsiveness. While they do not replace pilot control, they significantly reduce workload and contribute to safer and more stable flight operations.

Comparing Control Systems in Fixed-Wing and Rotary-Wing Aircraft

Having explored how both fixed-wing and rotary-wing aircraft achieve flight control, it is important to understand how their systems differ in both design and operation.

Fixed-wing aircraft use aerodynamic control surfaces attached to the wings and tail to manage movement around the three axes of flight. These surfaces change the direction of airflow to control pitch, roll, and yaw. Additional devices such as flaps, slats, and trim tabs help enhance lift or reduce drag during specific phases of flight like take-off and landing. Control is achieved by deflecting these surfaces through mechanical, hydraulic, or fly-by-wire systems.

Rotary-wing aircraft, such as helicopters, do not rely on fixed control surfaces. Instead, they control movement by changing the pitch of rotor blades as they rotate. The cyclic control tilts the rotor disc to manage direction, while the collective control adjusts the pitch of all blades equally to increase or decrease lift. Pedals control yaw by altering the thrust of the tail rotor. This setup allows helicopters to hover, take off vertically, and manoeuvre in confined spaces—capabilities not possible with conventional fixed-wing aircraft.

By comparing these systems, learners gain a deeper appreciation of how aircraft type, structure, and flight demands influence control design.

Control Mechanisms in Spacecraft

Controlling a spacecraft in flight presents unique challenges that differ significantly from controlling an aircraft. Unlike aircraft, spacecraft operate in the vacuum of space, where there is no air to generate lift or allow the use of traditional control surfaces like ailerons or rudders. As a result, spacecraft rely on a range of specialised systems to manage both attitude (orientation) and trajectory (movement through space). These control mechanisms are essential for manoeuvring, pointing instruments, maintaining communication with Earth, and safely completing mission objectives.

1. Attitude Control Systems

The primary goal of an attitude control system is to orient the spacecraft correctly in space. This is important for tasks such as keeping antennas pointed at Earth, aligning solar panels toward the Sun, or directing scientific instruments toward targets.

- **Reaction Control System (RCS)**

The Reaction Control System consists of small thrusters mounted on different sides of the spacecraft. By firing in short bursts, these thrusters provide precise changes in orientation and small adjustments in position. RCS is commonly used during:

- o Docking operations
- o Attitude adjustments
- o Re-entry orientation
- o Station-keeping for satellites

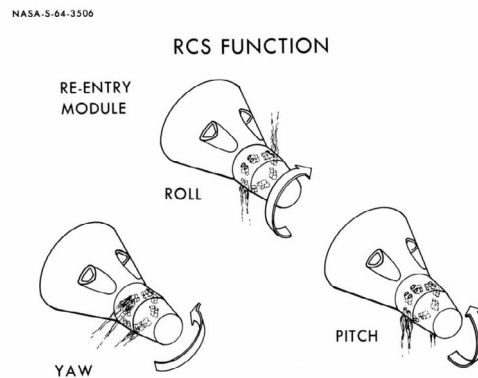


Figure 2.15



Figure 2.16: *Reaction control thrusters*

- **Reaction Wheels**

Reaction wheels, also known as momentum wheels, are **internal spinning discs** mounted along the spacecraft's principal axes. When the speed of a wheel is increased or decreased, the spacecraft rotates in the **opposite direction** due to conservation of angular momentum. Reaction wheels are fuel-free and ideal for **fine, continuous orientation control**. They are widely used in missions such as:

- o **Earth observation satellites**
- o **Space telescopes** (e.g. Hubble)

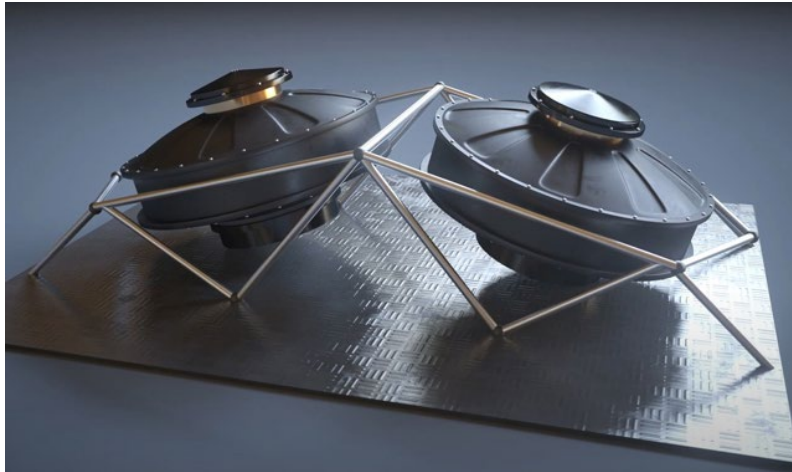


Figure 2.17: Two out of four reaction wheels used in the Hubble Space Telescope

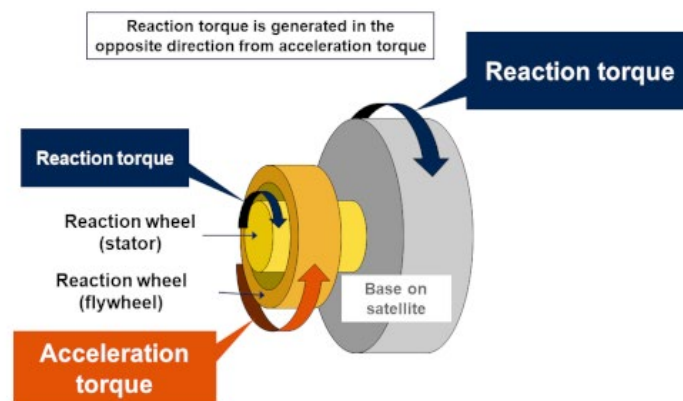


Figure 2.18: Behaviour of reaction wheel

- **Control Moment Gyroscopes (CMGs)**

CMGs operate on a similar principle to reaction wheels but are more powerful. They use spinning wheels mounted on gimbals, which can be tilted to produce torque and rotate the spacecraft. CMGs are particularly useful for larger spacecraft like the International Space Station (ISS), where high torque is needed.

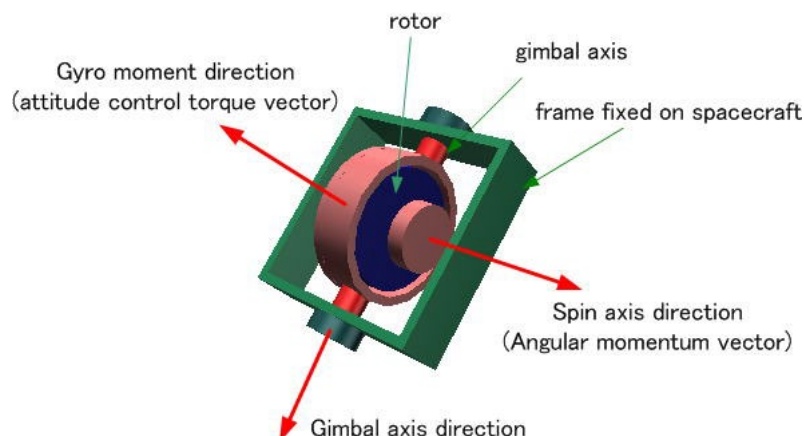


Figure 2.19: Control Moment Gyroscope



Figure 2.20: *Control Moment Gyroscope*

In addition to these main systems, some spacecraft, especially small satellites and those in low-Earth orbit, may use **magnetorquers** (which interact with Earth's magnetic field), **gravity-gradient stabilisation** (which passively aligns the spacecraft using gravitational pull), or miniature **cold gas thrusters** for attitude control. These methods are typically used in specific environments or for simpler spacecraft, and serve as cost-effective alternatives to more complex systems.

2. Thrusters for Orbital Manoeuvres

In addition to adjusting orientation, spacecraft must also change their velocity and trajectory. This is achieved using different types of thrusters:

- **Chemical thrusters** provide **short bursts of high thrust**. These are typically used for major changes like:
 - o Orbit insertion
 - o Course corrections
 - o Deorbit burns
- **Electric propulsion systems** (such as **ion thrusters**) generate much **weaker but highly efficient** thrust over long periods. They are used in:
 - o Deep space missions
 - o Satellite repositioning
 - o Interplanetary travel

These propulsion systems are controlled with high precision to conserve fuel and achieve mission goals accurately.



Figure 2.21: *Thrusters firing to insert the spacecraft into Mars orbit*

3. Guidance, Navigation, and Control (GNC) Systems

Modern spacecraft use onboard computers that work together with sensors and actuators to maintain control. This integrated system is called the Guidance, Navigation, and Control (GNC) system.

- Sensors such as gyroscopes, accelerometers, and star trackers help the spacecraft determine its current orientation and position.
- The navigation system processes this information and sends commands to actuators like thrusters or reaction wheels.
- Guidance systems calculate the optimal path for achieving the mission, whether it is entering orbit, docking, or reorienting for communication.

How Spacecraft Control Differs from Aircraft

Unlike aircraft, which rely on aerodynamic surfaces and airflow to manoeuvre, spacecraft operate in a vacuum and use Newton's Third Law, applying thrust to create motion in the opposite direction. Instead of controlling lift and drag, spacecraft adjust their orientation and trajectory using thrusters, reaction wheels, gyroscopes, and automated systems.

These mechanisms work together to maintain stability, perform precise manoeuvres, and support mission operations without atmospheric assistance. Understanding these control systems helps learners appreciate how spacecraft navigate and function with high accuracy in the challenging environment of space.

Flight Control Transmission: Mechanical, Hydraulic, and Fly-by-Wire

In previous lessons, we learned how aircraft are controlled using control surfaces and systems. This lesson focuses on the technologies that transmit pilot input to those surfaces or components—whether in a fixed-wing aircraft or a helicopter. By comparing mechanical, hydraulic, and electronic (fly-by-wire) systems, learners will see how aircraft type and performance demands influence the choice of control technology.

1. Mechanical Control Systems

Mechanical control systems are the earliest and most straightforward method of transmitting pilot input to an aircraft's control surfaces. They rely on physical linkages, such as cables, pushrods, pulleys, and levers, to connect the pilot's controls directly to the ailerons, elevators, and rudder (or,

in helicopters, to the swashplate and tail rotor). For many years, this was the standard system used in most aircraft. While modern high-performance and large aircraft have moved on to hydraulic or electronic systems, mechanical controls remain common in light aircraft, training planes, and basic helicopters, appreciated for their simplicity, low cost, and direct response to pilot input. This system can be found in aircraft such as the Cessna 172, Piper Cub, and Robinson R22.

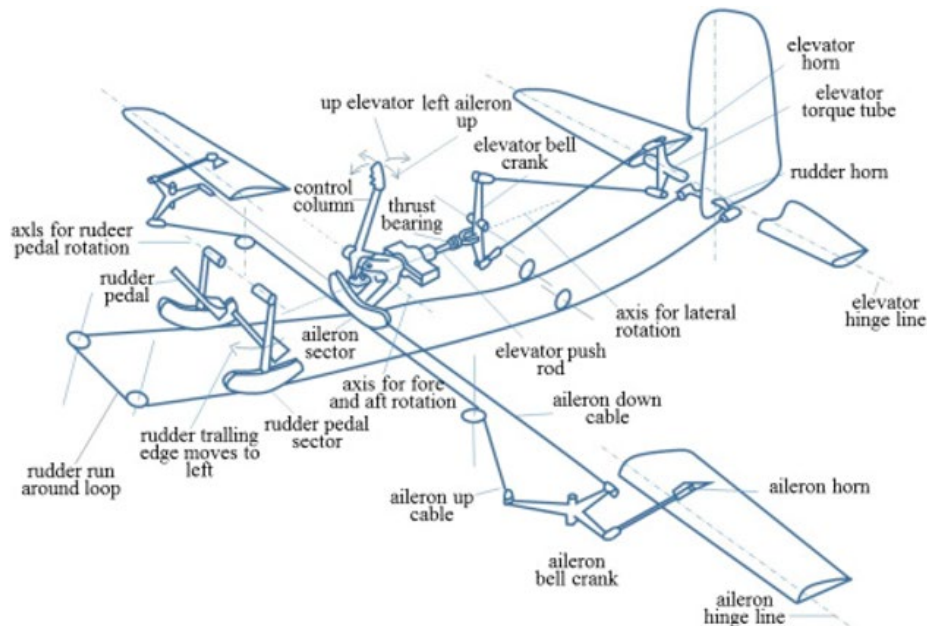


Figure 2.22: Mechanical control system in a light aircraft

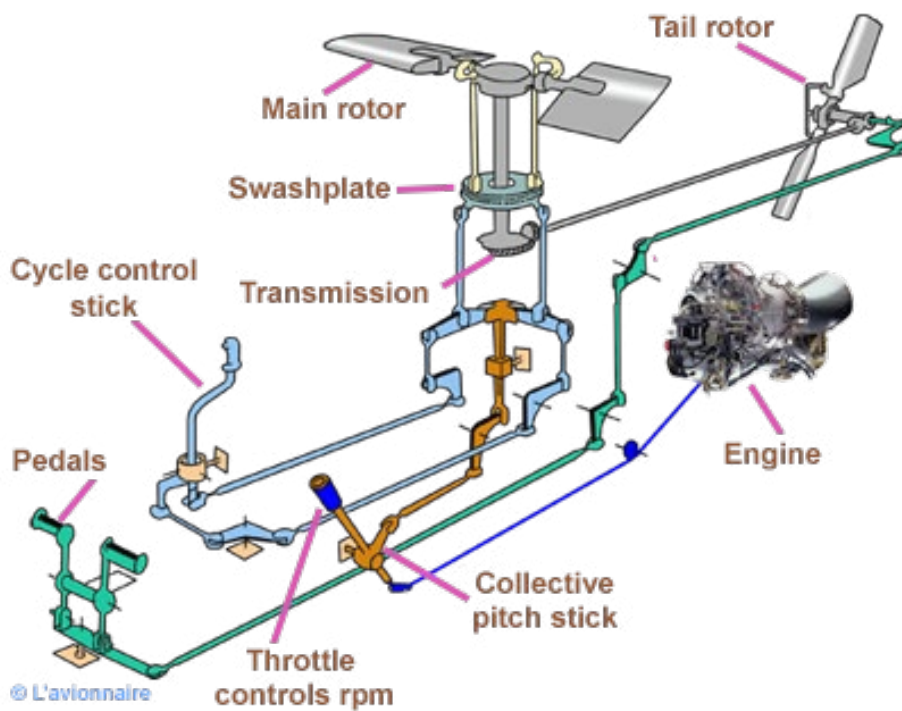


Figure 2.23: Mechanical control system in a helicopter

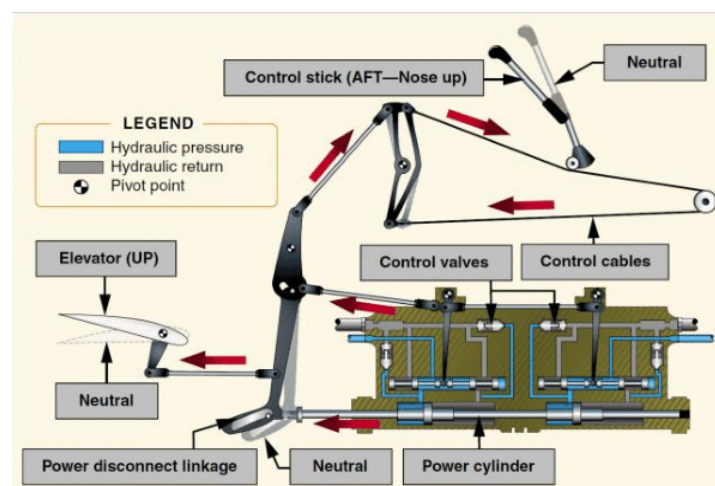
Table 2.1 below summarises the key advantages and limitations of mechanical control systems, highlighting their simplicity and reliability as well as the challenges they present, particularly in larger or more advanced aircraft.

Table 2.1

Aspect	Advantage	Limitation
Design Simplicity	Simple construction makes systems easy to understand, maintain, and repair.	Becomes increasingly complex and harder to manage in larger aircraft.
Reliability	Fewer components; no reliance on electricity or hydraulics.	Subject to friction, wear, and backlash, which can reduce precision and responsiveness.
Pilot Feedback	Provides direct tactile feedback, improving pilot control awareness.	Requires greater physical effort from the pilot; can be fatiguing in prolonged or dynamic flight.
Force Transmission	–	Limited ability to handle high aerodynamic loads, making them unsuitable for large, fast aircraft.
System Weight	–	Can be heavy, especially in large aircraft with long cable runs and structural reinforcements.
Cost	Lower cost in small aircraft; minimal reliance on specialised equipment.	Not scalable or efficient for advanced automation or computerised flight control.

2. Hydraulic Control Systems

Hydraulic control systems use pressurised fluid to transmit forces from the pilot's controls to the aircraft's control surfaces or rotor mechanisms. These systems are essential in larger and heavier aircraft, both fixed-wing and rotary-wing, where the forces required to move flight control surfaces or rotor components exceed what mechanical linkages alone can handle. When the pilot moves the controls in the cockpit, the input is directed to hydraulic control valves, which channel high-pressure fluid to actuators. These actuators convert fluid pressure into mechanical movement, adjusting control surfaces such as ailerons and elevators in fixed-wing aircraft, or operating the swashplate and tail rotor systems in helicopters. Because hydraulic fluid is incompressible, it enables precise, responsive, and powerful control with minimal pilot effort. Hydraulic systems are commonly found in commercial airliners, military jets, and medium to large helicopters, where reliable and forceful control is essential.

**Figure 2.24:** *Hydraulic Control System*

The following table outlines the key advantages and limitations of hydraulic control systems, highlighting their critical role in enabling powerful and responsive control in large or high-performance aircraft, while also noting the complexity and maintenance demands they introduce.

Table 2.2

Aspect	Advantage	Limitation
Design Simplicity	More complex than mechanical systems but allows for powerful, precise control.	Increases system complexity with pumps, actuators, and extensive plumbing.
Reliability	When properly maintained, hydraulic systems are dependable under heavy loads.	Susceptible to fluid leaks, pressure loss, and contamination, which can cause failure.
Pilot Feedback	Reduces the need for direct pilot force, easing physical workload.	Reduced tactile feedback compared to mechanical systems; pilots may rely more on instruments.
Force Transmission	Transmits large forces easily, enabling control of heavy, high-speed aircraft.	Requires powerful pumps and high-pressure systems, adding maintenance demands.
System Weight	More efficient force-wise than mechanical systems for large aircraft.	Heavy components (actuators, reservoirs, tubing) increase overall aircraft weight.
Cost	Justified in large aircraft due to performance and safety benefits.	Higher installation and maintenance costs compared to mechanical systems.
Power & Responsiveness	Provides quick and powerful movement of control surfaces.	Overheating and pressure loss can occur under prolonged high-demand operation.
Redundancy	Can be built with multiple backup circuits for increased safety.	Redundancy adds weight and system complexity.

3. Fly-by-Wire (FBW) Systems

As aircraft technology advanced, engineers began replacing mechanical and hydraulic linkages with electronic systems—leading to the development of fly-by-wire control. These systems are now standard in many modern aircraft due to their precision, safety features, and adaptability.

Fly-by-wire (FBW) systems use electronic signals—instead of mechanical or hydraulic linkages—to transmit pilot inputs to the aircraft’s control surfaces or rotor mechanisms. When the pilot moves the controls, sensors detect the input and send signals to flight control computers, which interpret the commands and transmit them to electronic actuators. These actuators then move the aircraft’s control surfaces (in fixed-wing aircraft) or adjust rotor blade pitch and tail rotor inputs (in rotary-wing aircraft).

Fly-by-wire systems reduce system weight and allow for computer-assisted flight control, including automatic stability correction, envelope protection, and flight mode programming. In fixed-wing aircraft, this enables more efficient aircraft design and improved safety. In rotary-wing aircraft, FBW enhances precision and stability, particularly in advanced military or transport helicopters.

Fly-by-wire is widely used in modern commercial jets (e.g. Airbus A320, Boeing 787), military aircraft (e.g. F-16), and advanced helicopters (e.g. NH90, Sikorsky S-92).

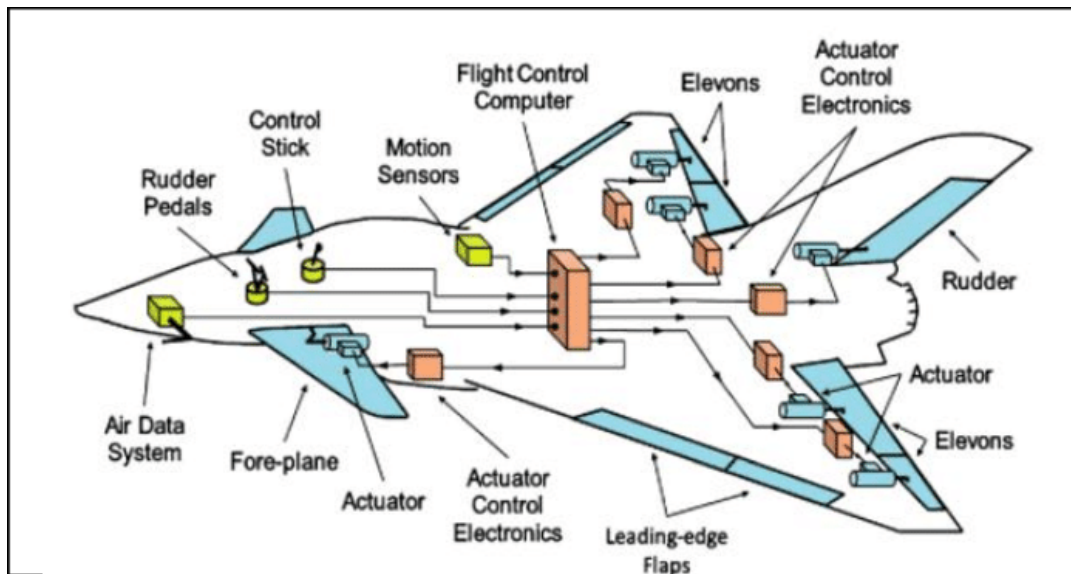


Figure 2.25: *Fly-by-Wire (FBW) Systems*

Table 2.3 below outlines the key advantages and limitations of fly-by-wire systems, highlighting their role in modern aircraft control and the trade-offs involved in relying on electronic and computer-based systems.

Table 2.3

Aspect	Advantage	Limitation
Design Simplicity	Eliminates complex mechanical linkages and hydraulic lines.	Requires complex software and high electrical system reliability.
Reliability	Includes multiple redundant systems to maintain safety.	Vulnerable to software bugs, electrical faults, or cyber threats.
Pilot Feedback	Can simulate feedback through artificial force systems.	Lacks natural tactile feel unless digitally replicated.
Force Transmission	Electronic signals are fast and require no physical effort.	Requires constant electrical power and system monitoring.
System Weight	Lighter than hydraulic or mechanical systems, improving fuel efficiency.	May still require backup systems, slightly increasing weight in some designs.
Cost	Reduces long-term maintenance and supports advanced features.	High initial development and integration cost.
Automation & Control	Supports advanced flight assistance, stability augmentation, and safety features.	Over-reliance on automation can reduce pilot engagement or situational awareness.

Learning Tasks

1. Watch videos demonstrating the mechanisms for control inputs in fixed-wing aircraft, rotary-wing aircraft and spacecraft”. Discuss similarities or differences among their operations.

2. In three groups, with each assigned a specific control system, present arguments on why your assigned system is useful for modern aviation. Respond to challenges raised against your system and submit defence with evidence.

Pedagogical Exemplars

- **Talk for Learning:** With the aid of audio-visuals, learners watch and describe the control mechanisms for fixed-wing aircraft, rotary wing aircraft and spacecraft.
- **Collaborative Learning/Building on What Others Say:** Teacher forms mixed-ability groups and lets learners do brainstorming and presentation on the features of the control systems of aerospace vehicles.

Key Assessment Level 3: Mid-Semester Examination

1. You will be shown a short animation or diagram demonstrating the movement of a specific flight control surface or input on either a fixed-wing or rotary-wing aircraft.

For each scenario:

- i. Analyse how the control input affects the aircraft's motion, considering the interaction of multiple control surfaces (if applicable).
- ii. Compare the aircraft's response in different flight phases (e.g. takeoff, cruise, landing) or conditions (e.g. turbulence, crosswind).
- iii. Evaluate the appropriateness of the control input in achieving the intended manoeuvre, using correct aviation terminology and principles of flight dynamics.

You may complete this task individually or in pairs, depending on your teacher's instructions. Your responses will be assessed on your ability to:

- Interpret the control input shown
- Explain the dynamic aircraft response in context
- Justify your analysis using flight theory and appropriate terminology
(10 marks) (DOK 3)

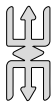
2. Create a three-part Venn diagram to compare the three major aircraft control system technologies:

- Mechanical systems
- Hydraulic systems
- Fly-by-wire systems

Your diagram should be clearly labelled and neatly presented. In each section of the diagram, include:

- The unique features of each system.
- Shared characteristics.
- At least one real-world aircraft example that uses each system.
- A brief summary statement or insight (1–2 sentences) explaining how these systems differ and what type of aircraft they are best suited for.

You may work individually or in pairs, depending on your teacher's instructions. Be sure to use correct aviation terminology and organise your ideas clearly. (10 Marks) (DOK 3).



Note

For PLC Session 5, please use any of the PLC structures without the SAP and select an assessment strategy you would like to implement in Week 5.

HINT



Conduct **Mid-semester Examination**. It should cover contents taught from Week 1 to 6. Refer to the **Table of Specification and Structure of the Paper** to guide you. Learners' papers should be marked immediately and scores entered into the SAP.

Structure

Section A: 25 Multiple choice questions

Section B: 2 Essay questions

Table of specification for item construction for section A and B

Week	Focal area	Types of questions	DoK Levels				Total
			1	2	3	4	
1 & 2	Aircraft materials (Refer back to Year 1, section 1, week 3: the types of aerospace vehicles and their parts.)	MCQs	2	2	2		6
		ESSAY	-	-	1		1
3 & 4	Airframe Structures (Refer back to Year 1, section 1, week 3: the types of aerospace vehicles and their parts.)	MCQs	-	2	1		3
		ESSAY	-	-	-		
5 & 6	Aircraft & Spacecraft Flight Controls	MCQs	1	3	2		6
		ESSAY			1		1
		Total	8	11	8		27

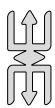
PLC Session 6

45 minutes

Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
 - a. explain the week's concepts in a practical way that will make it easier for learners to understand.
 - b. identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
 - a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

- b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).
- c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

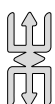
- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Use your app to plan and administer the mode of assessment for the student Assessment Portal (SAP).
 - a. The key assessment for the week is **mid-semester examination**. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/rubrics for the mid-semester examination (NTS 3k-3q).

10 minutes

Content Exploration

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
 - a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
 - b. all teachers in the group work through the problem individually for 3–4 minutes
 - c. the group then works through it together the problem, step by step
 - d. highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- This part is not 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes

Enactment

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).
 - a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
 - b. After the enactment, ask for structured feedback from the group

- i. was the concept explained in a way that a learner with no prior knowledge could follow?
- ii. were the examples grounded in contexts familiar to Ghanaian learners?
- iii. did any misconceptions surface and if so, how were they addressed?

5 minutes**Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
 - a. transfer your chats into your learning planner template.
 - b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
 - c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 7

Learning Indicators

1. Apply the understanding of moments in Physics to aircraft movement and stability configurations
2. Determine the relationship between the location of the centre of gravity of an aircraft and its stability

Focal Area: Aircraft & Spacecraft Stability

In the previous section, we explored how various control systems—mechanical, hydraulic, and fly-by-wire—enable pilots and automated systems to manage the movement of aerospace vehicles in flight. While control inputs are essential for directing an aircraft or spacecraft, their effectiveness depends heavily on the inherent stability of the vehicle itself.

This section focuses on the underlying physical principles that govern stability, particularly the role of moments and the location of the centre of gravity (CG). By linking basic physics concepts with real-world aerospace applications, you will help learners understand how engineers design aircraft and spacecraft to remain balanced and recover from disturbances during flight.

Introduction to Stability

Stability refers to an aircraft or spacecraft's ability to return to its original flight condition after being disturbed by external factors such as wind, turbulence, or thrust imbalance. It measures how the vehicle responds to unintended changes in orientation or motion, and is essential for maintaining safe, predictable, and controlled flight. In aerospace engineering, stability is broadly classified into two types: static stability and dynamic stability, each describing a different aspect of how the vehicle reacts to disturbances over time.

Types of Stability

1. Static Stability

Static stability refers to the initial tendency of an aircraft or spacecraft to respond to a disturbance. If the vehicle begins to return to its original position or flight condition after being disturbed, it is said to have positive static stability. If it remains in the new position without moving further away or returning, it has neutral static stability. If the disturbance causes the vehicle to continue moving further away from its original position, it exhibits negative static stability.

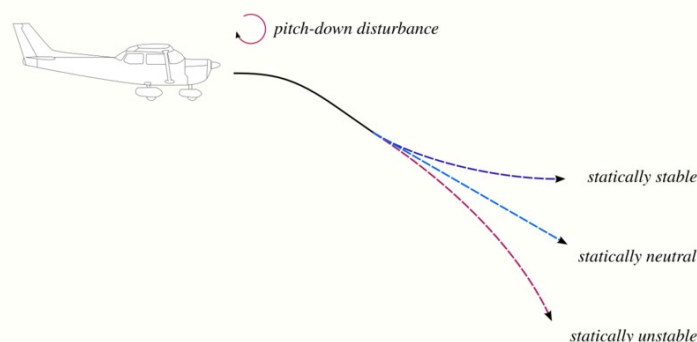


Figure 2.26: Positive, neutral, and negative static stability based on an aircraft's response to a disturbance

2. Dynamic Stability

Dynamic stability refers to how an aircraft or spacecraft behaves over time after experiencing a disturbance. While static stability considers the vehicle's initial tendency to return to its original position, dynamic stability examines whether the resulting motion—often in the form of oscillations—dampens, remains constant, or increases. A vehicle with positive dynamic stability will gradually return to steady flight, with decreasing oscillations. If the oscillations continue at the same amplitude, the vehicle has neutral dynamic stability. If the oscillations grow larger over time, the vehicle is considered to have negative dynamic stability, which can lead to loss of control if not corrected.

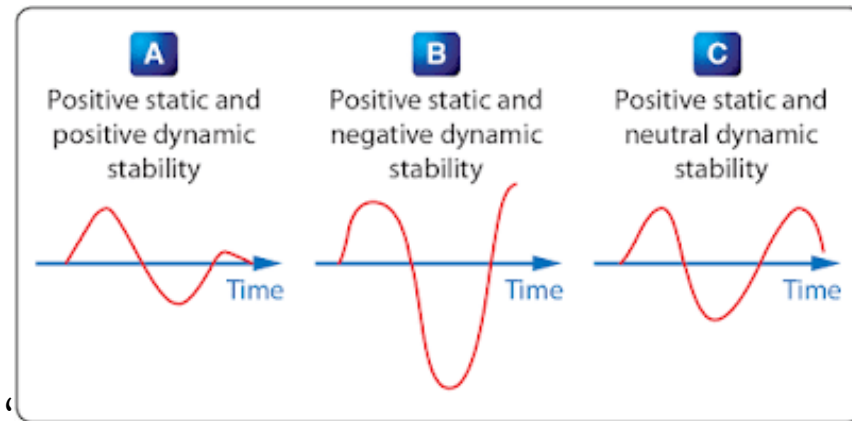


Figure 2.27: *Dynamic stability illustrated through oscillation patterns following a disturbance.*

Axes of Flight

Aircraft move and rotate around three primary axes, each of which passes through the aircraft's centre of gravity (CG). These axes are crucial in understanding how stability works in flight. For an aircraft or spacecraft to remain stable and controllable, it must resist or recover from disturbances around each axis.

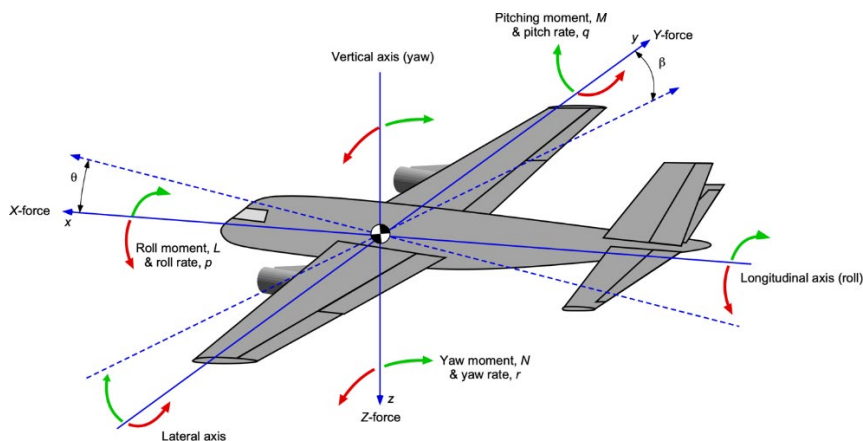


Figure 2.28: *Primary Axes passing through aircraft's centre of gravity*

1. Longitudinal Axis (Roll)

The longitudinal axis runs from the nose to the tail of the aircraft, as illustrated in Figure 2.28 above. Motion around this axis is called roll, where one wing rises while the other lowers. Stability around the longitudinal axis is essential for maintaining balanced turns and resisting side-to-side disturbances, such as those caused by turbulence. In fixed-wing aircraft, the ailerons—located on the trailing edges of the wings—are the primary control surfaces used to initiate and control roll. Additionally, design features like dihedral wings (wings angled slightly upward from the fuselage)

help improve roll stability by creating a natural restoring force after a disturbance. You may recall this concept from the introduction of wing configurations in Year 2.

Teaching Tip: Use a ruler balanced on your finger to demonstrate rolling left and right around its length.

2. **Lateral Axis (Pitch)**

The lateral axis runs from wingtip to wingtip in fixed-wing aircraft. Motion around this axis is known as pitch, which involves raising or lowering the aircraft’s nose. Pitch stability is particularly important during take-off, landing, climbs, and descents, where precise control of the aircraft’s angle is critical. In most aircraft, the elevator—or in some cases, a stabilator—controls pitch by adjusting the angle of the horizontal surface at the tail. The horizontal stabiliser provides a balancing force that helps maintain stability around this axis, ensuring smoother and more controlled flight.

3. **Vertical Axis (Yaw)**

Figure 2.28 shows the vertical axis running straight through the aircraft from its uppermost point to the underside. Yaw refers to the side-to-side rotation of the aircraft’s nose, similar to turning left or right while keeping the wings level. Stability around this axis is essential for maintaining a straight and coordinated flight path, particularly during crosswind conditions or while making heading adjustments. The primary control surface responsible for yaw is the rudder, which is attached to the vertical stabiliser (also called the fin). Effective yaw stability helps prevent unintended directional drift and contributes to smooth, coordinated flight.

Stability Around the Three Axes of Flight

If an aircraft is unstable around any of its three axes, it can significantly affect flight safety and control. Each axis corresponds to a specific type of movement and stability:

- **Instability around the vertical axis** (top to bottom) results in a **loss of directional control**, or yaw.
- **Instability around the lateral axis** (wingtip to wingtip) leads to **difficulty maintaining pitch**, which affects altitude and climb/descent angles.
- **Instability around the longitudinal axis** (nose to tail) results in **uneven or unsafe rolling motions**, impacting the aircraft’s ability to bank or turn safely.

To prevent these issues, aircraft—both **fixed-wing and rotary-wing**—are designed with **aerodynamic and structural features** that help maintain or restore stability around all three axes after minor disturbances. In **fixed-wing aircraft**, stability is supported by features such as the **horizontal stabiliser** (for pitch/longitudinal stability) and **vertical stabiliser** (for yaw/directional stability), along with wing design elements like **dihedral angles** (for roll/lateral stability). In **helicopters**, stability is managed through the **swashplate, tail rotor**, and, in more advanced models, **stability augmentation systems** that assist the pilot in maintaining controlled flight. Table 2.4 below summarises the types of stability and the axes affected, along with the associated motion and the key components responsible for maintaining stability in fixed-wing aircraft.

Table 2.4

Stability Type	Affected Axis	Type of Motion Controlled	Key Components (Fixed-Wing)
Longitudinal Stability	Lateral axis (wingtip to wingtip)	Pitch (nose up/down)	Horizontal stabiliser, elevator
Lateral Stability	Longitudinal axis (nose to tail)	Roll (wing up/down)	Wing configuration, ailerons

Directional Stability	Vertical axis (top to bottom)	Yaw (nose left/right)	Vertical stabiliser, rudder
-----------------------	-------------------------------	-----------------------	-----------------------------

The same principles apply to **spacecraft**, though they operate without the benefit of aerodynamic surfaces. Instead, spacecraft maintain stability using systems such as **thrusters**, **reaction wheels**, and **gyroscopes**, which help control orientation in the vacuum of space.

Moment

A moment is the turning effect of a force about a point or axis. In aircraft, moments are created when aerodynamic forces act at a distance from the aircraft's centre of gravity (CG).

$$\text{Moment} = \text{force} \times \text{Distance from CG (moment arm)}$$

Pitching Moments in Aircraft

During flight, an aircraft must stay balanced in the air, especially in how its nose moves up or down—a motion known as pitch. This balance depends on the relationship between two important points on the aircraft: the centre of gravity (CG) and the centre of pressure. The centre of gravity is the point where the aircraft's weight is concentrated, while the centre of pressure is the point where the total lift force—the upward force that keeps the aircraft flying—is considered to act. This is shown in Figures 2.29 and 2.30 below.

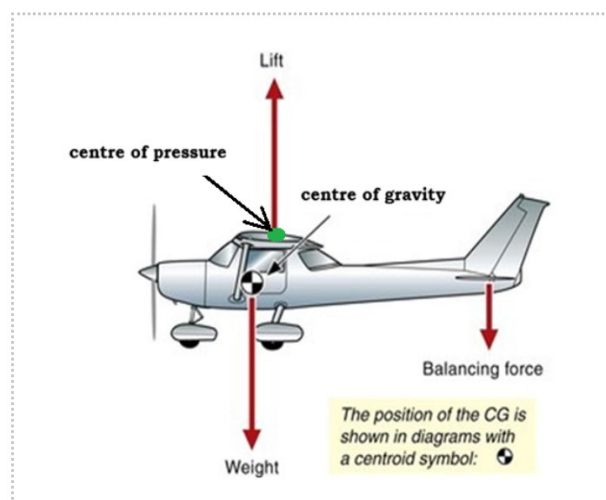


Figure 2.29: *Demonstrating Centre of Gravity and Centre of Pressure*

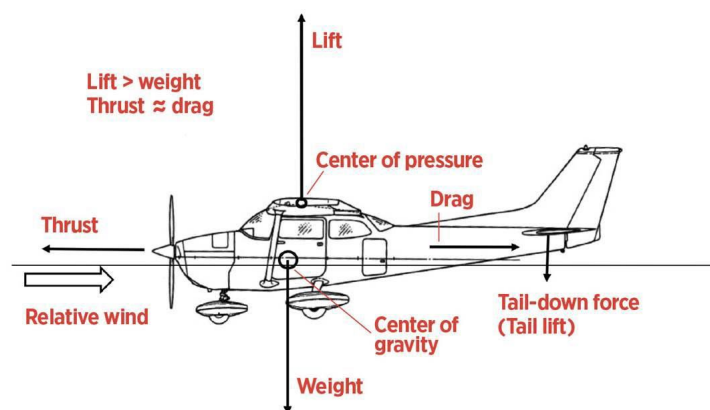


Figure 2.30: *Aircraft weight at centre of gravity; Lift force at the centre of pressure*

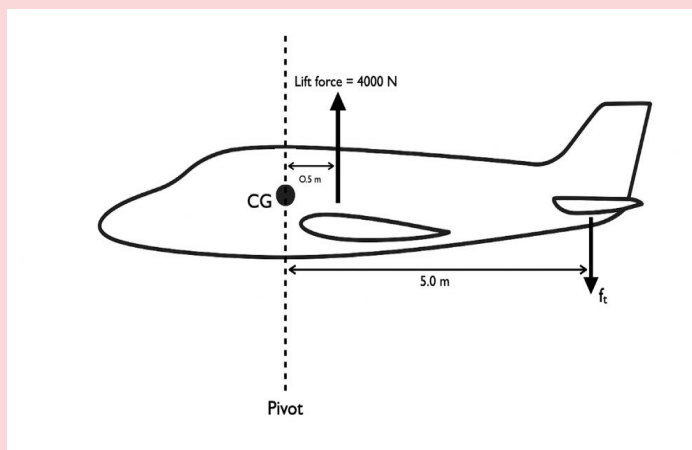
When these two points are not perfectly aligned, the lift force creates a turning effect around the lateral axis (from wingtip to wingtip). This is called a pitching moment. If the centre of pressure is located behind the CG, it causes a nose-down moment, making the aircraft tilt forward. If the centre of pressure is in front of the CG, it results in a nose-up moment, raising the nose. To keep the aircraft flying smoothly and safely, these forces must be kept in balance. Designers use features like the horizontal stabiliser at the tail to help control these pitching moments and maintain stable, level flight.

Worked example:

A small fixed-wing training aircraft is flying level at cruise speed. The **wing's lift force** acts 0.5 metres **behind** the aircraft's **centre of gravity (CG)**, while the **horizontal stabiliser** produces a downward force to balance this effect.

Given:

- Lift force from the wing = **4,000 N**
- Distance from CG to lift (moment arm) = **0.5 m**
- The horizontal stabiliser is located **5.0 m behind the CG**
- Find the **force the horizontal stabiliser must produce, f_t** , to maintain level flight (i.e., balance the pitching moment)



Solution

1. Calculate the moment caused by the wing lift

The lift force acts behind the centre of gravity (CG), creating a nose-down moment around the lateral (pitch) axis.

$$\text{Moment} = \text{force} \times \text{distance}$$

$$\text{Wing Moment} = \text{lift force} \times \text{distance from CG}$$

$$= 4000 \text{ N} \times 0.5 \text{ m}$$

$$= 2000 \text{ Nm}$$

2. Set the stabiliser moment, f_t , to be equal to and opposite the wing moment

To maintain level flight, the horizontal stabiliser must produce a nose-up moment that exactly cancels the nose-down moment caused by the wing. The stabiliser is located 5.0 m behind the CG, and it produces a downward force (f_t)

$$f_t \times 5 \text{ m} = 2000 \text{ Nm}$$

3. Solve for the downward force acting on the stabiliser

$$f_t = \frac{2000}{5} = 400 \text{ N (downward)}$$

The horizontal stabiliser must produce a **400 N downward force** to balance the pitching moment and maintain level flight.

In this example, the weight of the aircraft is not included in the moment calculation because it acts directly through the centre of gravity, which is the pivot point. Since the moment arm is zero, the weight does not create a moment about the CG in this scenario.

The Role of the Horizontal Stabiliser

An important feature that contributes to longitudinal stability in fixed-wing aircraft is the horizontal stabiliser, located at the tail of the aircraft. Its main purpose is to counteract the pitching moment created when the centre of pressure (where lift acts) is located behind the centre of gravity (CG).

In most aircraft designs, the wing's lift force produces a nose-down moment because it acts behind the CG. To keep the aircraft from tipping forward, the horizontal stabiliser generates a downward aerodynamic force at the rear of the aircraft. This downward force creates a balancing moment that holds the aircraft level in flight.

By offsetting the nose-down tendency, the horizontal stabiliser plays a key role in maintaining stable, level flight and preventing unwanted pitching motions. Without it, the aircraft would constantly need manual correction to avoid diving forward. The stabiliser's force is carefully calculated based on the aircraft's size, weight distribution, and flight characteristics, making it a critical component of safe and stable aircraft design.

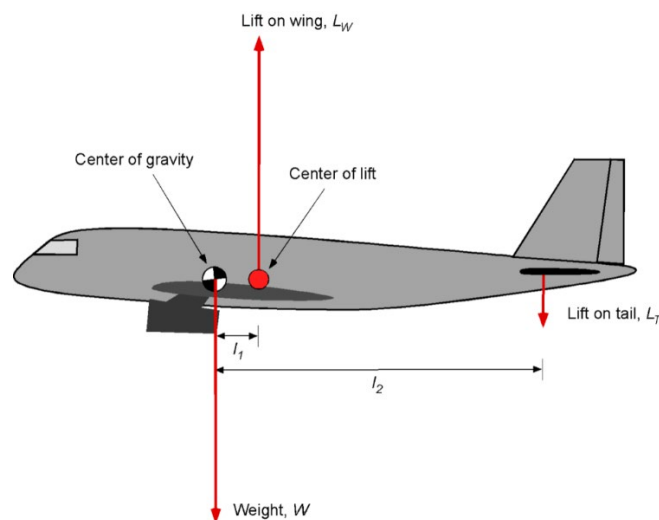


Figure 2.31: Downward force acting on horizontal stabiliser to balance moment caused by Lift at the centre of pressure (or centre of lift)

Stability Configuration

Building on previous discussions of pitching moments and the relationship between the centre of gravity (CG) and the centre of pressure (or lift), it is important to understand how this relationship defines an aircraft's overall stability configuration. This term refers to how the aircraft is aerodynamically balanced in flight, particularly in how it responds to disturbances such as gusts of wind or sudden control inputs. The stability configuration is determined primarily by the relative positions of the CG and the centre of lift. When these two points are appropriately positioned—typically with the CG slightly ahead of the lift—the aircraft tends to return to level flight after a disturbance. If the balance between them is poorly configured, the aircraft may become unstable, requiring constant control input to maintain flight.

Stable vs. Unstable Configurations

A stable configuration occurs when the CG is positioned slightly ahead of the centre of lift. In this setup, if the aircraft is disturbed—by wind gusts or turbulence—it tends to return naturally to level flight without continuous pilot correction. This condition supports positive static and dynamic stability, making the aircraft easier to control and safer to operate. Most training aircraft, commercial airliners, and cargo planes are designed with stable configurations to promote smooth, predictable flight behaviour.

In contrast, an unstable configuration results when the CG is located behind the centre of lift. In this case, even a small disturbance can cause a nose-up moment, moving the aircraft further from its original flight position. Without constant control input or advanced flight computers, the aircraft may become difficult—or even impossible—to fly safely. Despite this, some high-performance military jets (e.g. the F-16 Fighting Falcon) are intentionally designed to be inherently unstable. This allows for greater manoeuvrability, as the aircraft can respond more quickly to control inputs—but such designs rely heavily on fly-by-wire systems to maintain controlled flight.

Understanding the differences between stable and unstable configurations helps learners appreciate how aerodynamic design choices reflect the intended role and performance requirements of an aircraft.

Learning Task

In groups, compare how stability is achieved in spacecraft vs aircraft. Include differences in environment, control systems (e.g., RCS, gyroscopes), and the absence of aerodynamic surfaces. Learners should give one example of a spacecraft and explain how it manages pitch, roll, and yaw.

Pedagogical Exemplars

- **Experiential Learning**
 - o Teacher reviews moments and its applications from Physics.
 - o Through demonstrations, use the motion of a small ball on a plate, a concave surface, and a convex surface to illustrate neutral, stable and unstable static modes, respectively, of aerospace vehicles.
 - o Using the breaking of a twig after being excited by strong wind, teacher explains dynamic stability to learners.

- **Collaborative Learning/Building on What Others Say:** Teacher forms mixed-ability groups and let learners do brainstorming and presentation on the features of the control systems of aerospace vehicles.
- **Experiential Learning:** Through demonstrations, use different movement patterns (crawling baby, upright movement of a grownup and bending over of an elderly person) to explain static stability. With this analogy and emphasising the movement of the centre of gravity from one position to another explain aerospace vehicle stability to learners.

Key Assessment Level 3: Reflective Writing

1. Using what you've learned about **centre of gravity (CG)**, **centre of pressure**, and **pitching moments**, design a simple, balanced layout for a **fixed-wing aircraft**. Your task is to sketch a **side-view diagram** of the aircraft and **clearly label** the following parts:

- Centre of gravity (CG)
- Centre of pressure (or centre of lift)
- Main wing
- Horizontal stabiliser
- Key control surfaces (e.g., elevator)

Next to your diagram, write a **short explanation (4–6 sentences)** that justifies your design. In your explanation, include:

- How the positions of the CG and centre of pressure contribute to **pitch stability**
- Why you chose their locations
- What behaviour you would expect from your aircraft in **normal flight**
- How the **horizontal stabiliser** helps maintain balance

You may draw your design by hand or use a digital tool. The final layout must be **neat, clearly labelled**, and show that you understand the principles of **longitudinal stability**. (10 marks) (DOK 3)

2. Write a short journal entry that reflects on how an aircraft or spacecraft might behave if it were **unstable around each of its three flight axes**:

1. **Longitudinal axis** – affects **roll**
2. **Lateral axis** – affects **pitch**
3. **Vertical axis** – affects **yaw**

For each axis, describe:

- What kind of motion the aircraft would experience if it were unstable in that axis.
- A realistic situation or consequence that could occur during flight
- One possible design feature or control input that could help restore or maintain stability

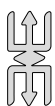
Your journal entry should be between **150–200 words**, written in your own words, and reflect a clear understanding of how **stability around each axis supports safe and predictable flight**. (10 marks) (DOK 3)

PLC Session 7

45 minutes

Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
 - a. explain the week's concepts in a practical way that will make it easier for learners to understand
 - b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
 - a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
 - b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
 - c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

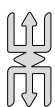
- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app
 - a. The key assessment for the week is **reflective writing**. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the reflective writing (NTS 3k-3q).

10 minutes

Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
 - a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
 - b. all teachers in the group work through a similar problem individually for 3–4 minutes
 - c. the group then works through the problem together step by step
 - d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?

- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes**Enactment**

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).
 - a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
 - b. After the enactment, ask for structured feedback from the group
 - i. was the concept explained in a way that a learner with no prior knowledge could follow?
 - ii. were the examples grounded in contexts familiar to Ghanaian learners?
 - iii. did any misconceptions surface and if so, how were they addressed?

5 minutes**Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
 - a. transfer your chats into your learning planner template.
 - b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
 - c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 2 Review

This section examined how aerospace vehicles achieve control and maintain stability during flight. It covered primary and secondary control surfaces in fixed-wing aircraft, control mechanisms in rotary-wing aircraft, and the use of mechanical, hydraulic, and fly-by-wire systems to transmit input. Motion along the pitch, roll, and yaw axes was linked to specific control functions. The section also introduced static and dynamic stability, highlighting how the relationship between the centre of gravity and centre of lift creates pitching moments. Stable and unstable configurations were analysed, along with the role of the horizontal stabiliser, illustrating how design and physics principles ensure controlled and balanced flight in both aircraft and spacecraft.



MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 5 & 6

Question 1

Criteria	Marks	Guidance for Scoring
<i>Interpretation of control input</i>	3	<i>Correctly identifies the control surface/input and its movement.</i>
<i>Analysis of aircraft motion</i>	3	<i>Explains how the input affects aircraft motion, including interaction with other surfaces if applicable.</i>
<i>Comparison across flight phases/conditions</i>	2	<i>Discusses differences in aircraft response during various flight phases or environmental conditions.</i>
<i>Evaluation and justification</i>	2	<i>Provides a reasoned evaluation of the control input's appropriateness, using correct aviation terminology and flight principles.</i>

Question 2

Criteria	Mark Range	Guidance for Scoring
<i>Unique Features of Each System</i>	0–3 marks	3 marks – Accurately identifies at least two unique features per system. Example: Mechanical – uses cables and pulleys; Hydraulic – uses pressurised fluid; Fly-by-wire – uses electronic signals and computers. 2 marks – Correctly identifies features for two systems, or one feature each for all three. 1 mark – Features are general or unclear but show effort. 0 marks – No relevant features provided or all features incorrect.
<i>Shared Characteristics</i>	0–2 marks	2 marks – At least two accurate, meaningful shared characteristics. Example: “All are used to transmit pilot input to control surfaces” or “All systems aim to achieve control and stability.” 1 mark – One correct shared feature, or two vague/partially correct responses. 0 marks – No shared features or entirely incorrect ones.

<i>Aircraft Examples Provided</i>	<i>0–2 marks</i>	2 marks – At least one correct, relevant aircraft example per system. Example: Cessna 172 (Mechanical), Boeing 747 (Hydraulic), Airbus A320 or F-16 (Fly-by-wire). 1 mark – One or two examples correct, others unclear or generalised. 0 marks – No relevant examples provided.
<i>Summary Insight or Explanation</i>	<i>0–2 marks</i>	2 marks – Clear and thoughtful comparison showing understanding of system differences or usage in context. Example: “Fly-by-wire systems are preferred in modern, high-performance aircraft due to their precision and reduced pilot workload.” 1 mark – Basic or underdeveloped explanation; may show some understanding. 0 marks – No explanation or unrelated content.
<i>Organisation and Use of Terminology</i>	<i>0–1 mark</i>	1 mark – Diagram is well-structured, clearly labelled, and uses appropriate aviation terms like “actuator,” “signal,” “fluid,” or “redundancy.” 0 marks – Poor organisation, missing labels, or no technical vocabulary used.

WEEK 7

Question 1

Criteria	Mark Range	Scoring Guidance
<i>Accuracy and Completeness of Diagram</i>	<i>0–3 marks</i>	3 marks – Diagram includes all required components (CG, centre of pressure, wing, stabiliser, control surfaces), correctly placed and clearly labelled. 2 marks – One or two minor omissions or label errors, but overall correct. 1 mark – Some key elements missing or unclear. 0 marks – Diagram missing, incomplete, or unrelated.
<i>Explanation of CG and Centre of Pressure Placement</i>	<i>0–3 marks</i>	3 marks – Clearly explains placement choices and their impact on stability, showing understanding of pitching moments. 2 marks – General explanation with some correct reasoning. 1 mark – Attempted explanation, but lacks clarity or accuracy. 0 marks – No explanation or inaccurate understanding shown.

<i>Expectation of Design Performance in Flight</i>	<i>0–2 marks</i>	<i>2 marks – Accurately describes expected stable behaviour in flight.</i> <i>1 mark – Partial or vague description of flight performance.</i> <i>0 marks – No description or misunderstanding of aircraft behaviour.</i>
<i>Description of the Horizontal Stabiliser's Role</i>	<i>0–2 marks</i>	<i>2 marks – Correctly explains how the stabiliser contributes to balance by offsetting pitching moments.</i> <i>1 mark – Partial or unclear explanation of the stabiliser's function.</i> <i>0 marks – No explanation or incorrect role described.</i>

Question 2

Criteria	Mark Range	Scoring Guidance
<i>1. Explanation of Instability Around Each Axis</i>	<i>0–3 marks</i>	<i>3 marks – Clearly describes instability effects for all three axes, using correct terminology and examples.</i> <i>2 marks – Describes two axes accurately or all three with minor errors.</i> <i>1 mark – Basic or unclear explanation for one or two axes.</i> <i>0 marks – No relevant explanation.</i>
<i>2. Realistic Consequences of Instability</i>	<i>0–3 marks</i>	<i>3 marks – Provides realistic flight consequences for each axis (e.g. poor roll control causes dangerous banking).</i> <i>2 marks – Provides consequences for two axes or general but relevant consequences.</i> <i>1 mark – Vague or overly simple responses.</i> <i>0 marks – Consequences not discussed.</i>
<i>3. Corrective Features or Inputs Mentioned</i>	<i>0–2 marks</i>	<i>2 marks – Mentions a relevant design feature or control method for each axis (e.g. vertical stabiliser, rudder, dihedral wings).</i> <i>1 mark – Mentions a corrective feature for one or two axes.</i> <i>0 marks – No corrective actions suggested.</i>
<i>4. Structure and Clarity of Writing</i>	<i>0–2 marks</i>	<i>2 marks – Well-structured entry with clear sentences, logical flow, and minimal errors.</i> <i>1 mark – Writing is understandable but lacks clarity or structure.</i> <i>0 marks – Writing is difficult to follow or incomplete.</i>

SECTION 3: AVIONICS

STRAND: AVIONICS

Sub-Strand: Communication, Navigation and Surveillance Systems

Week 8

Learning outcome: *Justify which communication systems are suitable for different communication scenarios in aviation.*

Content standard: *Demonstrate knowledge of the different communication technologies used in aviation.*

Week 9

Learning outcome: *Describe the aircraft and spacecraft navigation systems.*

Content standard: *Demonstrate an understanding of the different navigation systems used in aircraft and spacecraft.*

Week 10

Learning outcome: *Use illustrations to demonstrate knowledge of aerospace surveillance systems.*

Content standard: *Demonstrate knowledge of different aerospace surveillance technologies.*

INTRODUCTION AND SECTION SUMMARY

This is the third section which will take a deeper look at some avionics systems. We will begin with communication systems, touching on the different communications technologies and their use cases. Then we will move on to navigation systems used on aircraft; we will equally look at the different technologies available, their merits and limitations. Finally, we will touch on the technologies that make it possible for us to be aware of the presence of aircraft. This is useful both to us on the ground, and to the aircraft so they avoid collisions between themselves.

The weeks and the indicators covered by the section are:

- **Week 8**
 - *Identify the different communication technologies used in the aviation industry.*
 - *Illustrate the pros and cons of each aviation communication technology.*

- **Week 9**
 - o *Explain the concept of navigation (dead reckoning and position fixing).*
 - o *Identify the advantages and disadvantages of the different navigation technologies.*
- **Week 10**
 - o *Present a summary of on-board surveillance systems.*
 - o *Present a summary of ground-based surveillance systems.*

Recap weeks

Year 1	Weeks 8 – 10: • Explain the functions of avionics communication systems. • Explain the functions of avionics navigation systems. • Explain the functions of surveillance systems.
--------	---

SUMMARY OF PEDAGOGICAL EXEMPLARS

1. Problem-based learning
2. Collaborative learning
3. Building on what others say
4. Talk for learning

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/or Mode
1. Identify the different communication technologies used in the aviation industry. 2. Illustrate the pros and cons of each aviation communication technology.	3	Case study
1. Explain the concept of navigation (dead reckoning and position fixing). 2. Identify the advantages and disadvantages of the different navigation technologies.	3	Computational task
1. Present a summary of on-board surveillance systems. 2. Present a summary of ground-based surveillance systems.	3	Peer assessment

WEEK 8

Learning Indicators

1. Identify the different communication technologies used in the aviation industry
2. Illustrate the pros and cons of each aviation communication technology

Focal Area: Aircraft communication systems

This week, we will delve deeper into the various communications systems onboard aircraft. (Refer back to Year 1, Section 3, Week 8 Introducing communication system in avionics.)

Since it is impossible to attach a cable to the aircraft for communication, most communications take place via radio waves. The radio frequency (RF) spectrum is a range of electromagnetic frequencies used for communication. It spans from extremely low frequencies (ELF) to extremely high frequencies (EHF), and each frequency range, or band, has different properties that make it suitable for various applications. Lower frequencies can travel long distances and penetrate obstacles, while higher frequencies can carry more data but are more susceptible to atmospheric absorption and require line-of-sight transmission. Understanding the characteristics of each band is crucial for designing effective communication systems, including those used in aviation for navigation, communication, and surveillance.

Different frequency bands are allocated for specific uses by international agreements and national regulations to avoid interference. These allocations consider the properties of each band and the needs of various users. In aviation, specific bands are reserved for air traffic control, navigation, weather radar, and communication with aircraft. For example, VHF (Very High Frequency) is commonly used for voice communication between pilots and air traffic controllers, while higher frequencies might be used for radar systems. Table 3.1 lists common frequency bands.

Table 3.1: RF spectrum

Frequency Band	Abbreviation	Frequency Range	Common Uses
Extremely Low Frequency	ELF	3 - 30 Hz	Submarine communication
Voice Frequency	VF	300 - 3000 Hz	Voice communication
Low Frequency	LF	30 - 300 kHz	Navigation, radio beacons
Medium Frequency	MF	300 kHz - 3 MHz	AM radio broadcasting
High Frequency	HF	3 - 30 MHz	Shortwave radio, amateur radio, international broadcasting
Very High Frequency	VHF	30 - 300 MHz	FM radio, television broadcasting, air traffic control
Ultra High Frequency	UHF	300 MHz - 3 GHz	Television broadcasting, mobile phones, radar
Super High Frequency	SHF	3 - 30 GHz	Satellite communication, radar, microwave ovens

Extremely High Frequency	EHF	30 - 300 GHz	Satellite communication, radio astronomy
--------------------------	-----	--------------	--

To carry out radio communications, the aircraft needs to have certain components, including transmitters, receivers and antennas.

Transmitters are essential components in radio communication systems, responsible for generating and broadcasting RF signals. The primary function of a transmitter is to take an input signal, such as voice, data, or video, and convert it into an RF signal suitable for transmission through the air or space. This process involves several stages, including signal modulation, amplification, and filtering. Modulation encodes the input signal onto a carrier wave, enabling it to be transmitted over long distances. Amplification boosts the power of the modulated signal to ensure it can reach the intended receiver with sufficient strength.

Modern transmitters incorporate sophisticated techniques to optimise signal quality, minimise interference, and maximise transmission efficiency. They often employ digital signal processing to enhance signal clarity and reduce noise. Additionally, transmitters must adhere to strict regulatory standards to prevent interference with other communication systems. In aviation, transmitters are critical for air traffic control, allowing pilots to communicate with ground personnel and other aircraft, ensuring safe and coordinated flight operations. In Ghana, the Ghana Civil Aviation Authority (GCAA) regulates the use of radio transmitters to ensure compliance with international standards.

Receivers are designed to capture and process incoming RF signals, extracting the embedded information. The receiver's primary task is to isolate the desired signal from the multitude of other signals and noise present in the environment. This involves several key stages, including signal reception, filtering, amplification, and demodulation. The antenna captures the RF signal, and the receiver then filters out unwanted frequencies and amplifies the weak signal to a level suitable for processing. Demodulation extracts the original information from the carrier wave, converting it back into a usable format, such as audio or data.

Effective receiver design is crucial for reliable communication, particularly in noisy or congested environments. Modern receivers often use advanced techniques like digital signal processing and error correction to improve signal quality and minimise the impact of interference. Sensitivity, selectivity, and dynamic range are key performance metrics for receivers. In aviation, receivers are vital for pilots to receive instructions from air traffic control, navigate using radio-based navigation systems, and monitor weather information, all of which are essential for safe and efficient flight operations.

Antennas serve as the interface between radio communication equipment and the open air, converting electrical signals into electromagnetic waves and vice versa. In transmitting systems, the antenna radiates the RF signal generated by the transmitter, while in receiving systems, it captures incoming electromagnetic waves and converts them into electrical signals that can be processed by the receiver. Antenna design is critical for optimising signal strength, directionality, and efficiency. The physical characteristics of an antenna, such as its size, shape, and material composition, determine its performance characteristics.

Different types of antennas are designed for specific applications, each with its own advantages and disadvantages. Common types include dipole antennas, Yagi-Uda antennas, patch antennas, and horn antennas. Factors such as frequency, bandwidth, gain, and polarisation influence antenna selection. In aviation, antennas are essential for communication, navigation, and surveillance systems. For example, aircraft use VHF antennas for voice communication with air traffic control, GPS antennas for satellite navigation, and radar antennas for weather detection and collision avoidance. The proper installation and maintenance of antennas are crucial for ensuring reliable and effective radio communication.

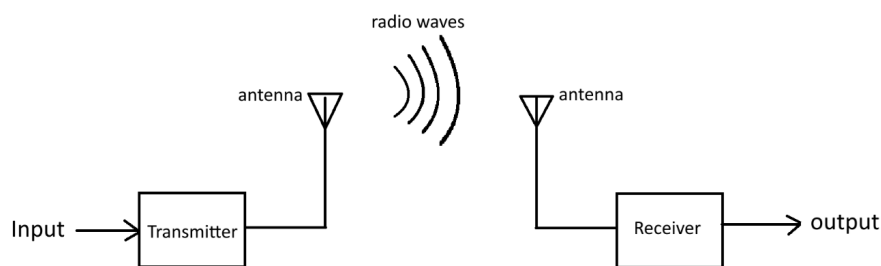


Figure 3.1: *RF communications block diagram*

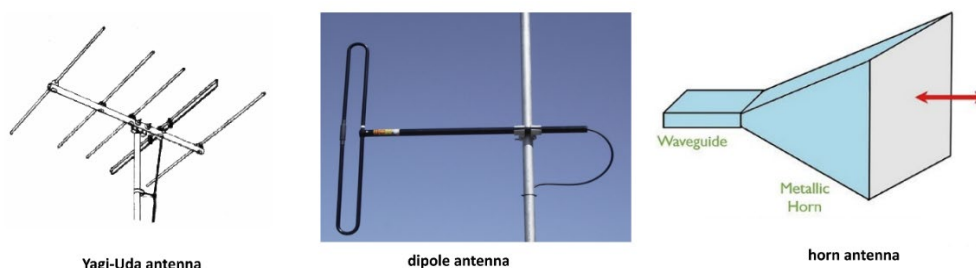


Figure 3.2: *Examples of RF antennas*

Aircraft communication technologies

1. VHF Communication Systems

Very High Frequency (VHF) communication systems are a critical component of aircraft operations, providing essential links for voice and data communication between pilots, air traffic control (ATC), and other aircraft. Operating in the 30 MHz to 300 MHz frequency range, VHF systems offer reliable short-to-medium range communication, making them ideal for use in and around airports and along established air routes. The standardised use of VHF ensures interoperability across different aircraft and ground stations, facilitating seamless communication within the aviation community.

VHF signals primarily propagate via line-of-sight, meaning the transmitting and receiving antennas must be within visual range of each other. The curvature of the Earth and any obstructions (such as mountains) can limit the range of VHF communication. However, VHF signals are less susceptible to atmospheric interference compared with lower frequencies, providing a more stable and clear communication channel. Aircraft antennas are typically mounted on the fuselage or wings to maximise line-of-sight coverage.

VHF systems support both voice and data communication, although voice communication is the most common application. Voice communication allows pilots to receive instructions from ATC, report position and altitude, and exchange critical information with other aircraft. Data communication, using modes like Aircraft Communications Addressing and Reporting System (ACARS), enables the transmission of short messages, weather updates, and flight management system data. Modern VHF radios often incorporate digital capabilities to support enhanced data services.

The range of VHF communication depends on several factors, including the altitude of the aircraft, the power of the transmitter, and the sensitivity of the receiver. In general, an aircraft flying at a high altitude can communicate over a greater distance due to the increased line-of-sight. Typical VHF communication ranges vary from 50 to 200 nautical miles (about 90 – 370 km). VHF communication is most effective for regional and local air traffic control, ensuring pilots have continuous contact with ATC during critical phases of flight, such as take-off, landing, and manoeuvring in controlled airspace.

2. HF Communication Systems

High Frequency (HF) communication systems serve as a vital long-range communication solution for aircraft, particularly on oceanic and remote routes where VHF coverage is limited. Operating in the 3 MHz to 30 MHz frequency range, HF systems enable pilots to maintain contact with air traffic control (ATC), airline operational control centres, and other aircraft over vast distances. While satellite communication is becoming more prevalent, HF remains a reliable and often mandatory backup for long-haul flights.

HF signals utilise skywave propagation, where radio waves are reflected or refracted by the ionosphere, allowing them to travel thousands of kilometres beyond the horizon. The ionosphere's condition varies with time of day, solar activity, and geographic location, affecting the quality and reliability of HF communication. Careful selection of operating frequencies is essential to optimise signal propagation based on these factors. This contrasts with VHF, which relies on line-of-sight propagation.

HF systems support both voice and data communication. Voice communication is used for essential ATC communication, position reporting, and exchanging operational information. Data communication, often in the form of teletype or specialised data protocols, allows for the transmission of weather reports, flight plans, and aircraft maintenance data. Modern HF radios can also support digital voice modes, improving clarity and reducing noise.

HF communication can achieve ranges of thousands of nautical miles, making it suitable for transoceanic and transcontinental flights. The actual range depends on factors such as frequency, atmospheric conditions, and transmitter power. While HF offers extensive range, it is also subject to interference and atmospheric disturbances, which can impact communication quality.

3. Satellite communications

Satellite Communications (SATCOM) have revolutionised aviation, providing reliable, global communication capabilities that overcome the limitations of VHF and HF systems. SATCOM enables voice, data, and broadband connectivity for various applications, enhancing safety, operational efficiency, and passenger experience. From air traffic control communication to real-time weather updates and in-flight entertainment, SATCOM has become an indispensable part of modern aviation.

SATCOM supports a wide range of applications in aviation, including the provision of air traffic control communication voice and data links in oceanic and remote areas where terrestrial infrastructure is unavailable; enabling real-time communication between aircraft and airline operations centres for flight tracking, performance monitoring, and maintenance updates; offering in-flight internet access, voice calls, and entertainment options; supporting emergency communication, distress alerts, and search and rescue operations; and delivering real-time weather information and forecasts to pilots.

Two major providers dominate the aviation SATCOM market; these are Inmarsat and Iridium. Inmarsat offers a range of L-band satellite services, including voice and data communication, as well as broadband connectivity through its Swift Broadband service. Inmarsat is widely used for safety services, ATC communication, and passenger connectivity. Iridium provides global coverage using a constellation of low Earth orbit satellites. Iridium is known for its reliable voice and data services, particularly in polar regions where geostationary satellites have limited coverage.

SATCOM offers several advantages over traditional communication systems. These include:

1. Seamless communication coverage across the globe, including oceanic and remote areas.
2. High-bandwidth connectivity, enabling data-intensive applications such as video streaming and real-time data transfer.
3. SATCOM systems are less susceptible to atmospheric interference compared with HF systems, providing more reliable communication.
4. Supporting a wide range of applications, from critical safety services to passenger entertainment.

As satellite technology continues to advance, SATCOM will play an increasingly important role in shaping the future of aviation communication, enhancing safety, efficiency, and passenger experience.

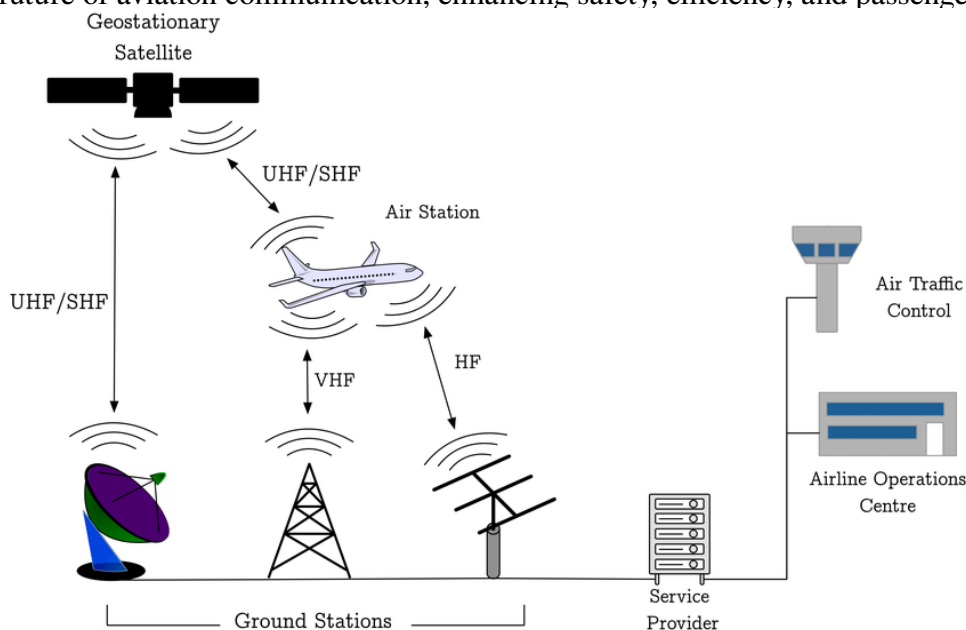


Figure 3.3: Aircraft communications ecosystem

Learning Tasks

1. Imagine that you are a pilot on an international flight. Identify the different communications systems you would employ.
2. Together with your team, write out the modes of propagation of the radio waves used in aircraft communications.

Pedagogical Exemplars

Problem-based learning – Lead learners to brainstorm technologies suitable for aircraft communication in varying scenarios.

Collaborative learning – Put learners in mixed-ability groups to discuss the modes of propagation of the radio waves used for aircraft communication.

Collaborative Learning - By exploring the requirements for aviation communication in different scenarios (short to medium range, long range), learners think, pair and share the merits and limitations of each communications technology.

Key Assessment Level 3: Case study

1. Identify and compare three key communication systems used during different phases of a flight from Accra to New York in the USA, including oceanic crossing. Explain the purpose and limitations of each system, and justify which one is most suitable for long-distance communication over the ocean. (16 marks) (DOK 3)
2. Extreme space activity has interfered with the structure of the ionosphere. Which communication technology would be most affected? And what alternative for long-distance communication exists? (4 marks) (DOK 3)

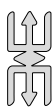
Refer to Teacher Assessment Manual and Toolkits pages 31 – 34 for further guidance on conducting Case study assessments.

PLC Session 8

45 minutes

Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
 - a. explain the week's concepts in a practical way that will make it easier for learners to understand
 - b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
 - a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
 - b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
 - c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

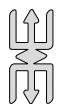
4. Plan the week's key assessment with your app
 - a. The key assessment for the week is **case study**. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the case study (NTS 3k-3q).

10 minutes

Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

- a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
- b. all teachers in the group work through a similar problem individually for 3–4 minutes
- c. the group then works through the problem together step by step
- d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about ‘How do I teach this?’ but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes

Enactment

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).
 - a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
 - b. After the enactment, ask for structured feedback from the group
 - i. was the concept explained in a way that a learner with no prior knowledge could follow?
 - ii. were the examples grounded in contexts familiar to Ghanaian learners?
 - iii. did any misconceptions surface and if so, how were they addressed?

5 minutes

Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
 - a. transfer your chats into your learning planner template.
 - b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
 - c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 9

Learning Indicators

1. Explain the concept of navigation (dead reckoning and position fixing)
2. Identify the advantages and disadvantages of the different navigation technologies

Focal Area: Aircraft navigation systems

This week, we will look in more detail at the navigation systems employed in aircraft applications.

There are generally two methods of navigation: dead-reckoning and position-fixing. (Refer back to Year 1, Section 3, Week 9, Avionics Navigation Systems.)

1. Dead reckoning

Dead reckoning is a fundamental navigation technique that involves estimating the current position of a vehicle or aircraft based on its previously determined position, and advancing that position using estimations of speed, heading, course, and elapsed time. It relies on maintaining an accurate record of these parameters, accounting for factors such as wind, currents, and other environmental conditions that may affect the vehicle's trajectory. Dead reckoning is particularly useful in situations where other navigation aids are unavailable or unreliable, such as during periods of GPS outage or in remote areas with limited infrastructure.

The accuracy of dead reckoning depends heavily on the precision of the initial position, the accuracy of the speed and heading measurements, and the length of time since the last known position fix. Errors tend to accumulate over time, making it essential to periodically update the position using other navigation methods. Despite its limitations, dead reckoning provides a continuous estimate of position, allowing navigators to maintain situational awareness and make informed decisions about course corrections and route planning. It forms the basis for more advanced navigation techniques and serves as a valuable backup in case of system failures.

Worked example

If an aircraft leaves one point and travels on a heading 030° at a speed of 50 knots, after 30 minutes, it would have covered a distance of $50 * (30 / 60)$ or 25 nautical miles. This translates to a displacement of $25 * \cos(30)$ or 21.65 nautical miles north and $25 * \sin(30)$ or 12.5 nautical miles east of the starting point.

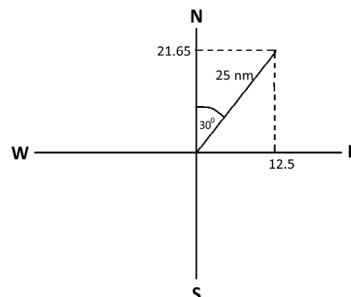


Figure 3.4: Sketch of the solution to the example problem

The inertial and doppler navigation systems are examples of equipment that apply dead reckoning to determine the position of the aircraft.

Inertial navigation system

Inertial Navigation Systems (INS) are self-contained navigation systems that determine an aircraft's position, velocity, and orientation without relying on external references such as GPS or radio beacons. INS uses accelerometers and gyroscopes to measure the aircraft's acceleration and angular rate, respectively. These measurements are then processed by a computer to calculate the aircraft's motion and track its position over time. INS is crucial for navigation in areas where external signals are unavailable or unreliable, such as over oceans, in remote regions, or during GPS jamming.

There are two types of inertial navigation systems: *stable-platform* and *strapdown* INS. Stable-platform INS is an older design that uses a mechanically stabilised platform to isolate the accelerometers and gyroscopes from the aircraft's motion. The platform is kept level and oriented in a fixed direction using a system of gimbals and servo motors. While accurate, stable-platform INS is complex, bulky, and expensive. Strapdown INS is a more modern design that directly mounts the accelerometers and gyroscopes to the aircraft's frame. The system uses sophisticated algorithms to compensate for the aircraft's motion and calculate its position and orientation. Strapdown INS is smaller, lighter, and more reliable than stable-platform INS.

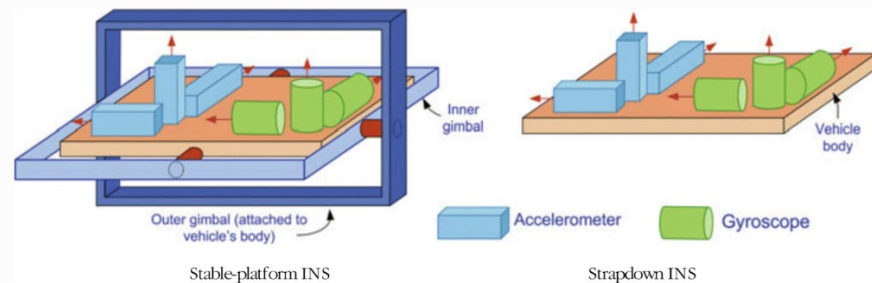


Figure. 3.5: Strapdown and stable-platform INS

Inertial navigation begins with an attitude update, where gyroscope measurements are used to calculate changes in the aircraft's orientation. Next, the specific force frame transformation projects accelerometer measurements (specific force) from the body frame to the inertial frame, accounting for the updated attitude. This transformation is crucial for accurately determining the direction and magnitude of the aircraft's acceleration in a global reference frame. Following this, the velocity update integrates the transformed specific force over time to determine the change in velocity. Finally, the position update integrates the updated velocity over time to calculate the change in position, providing a continuous estimate of the aircraft's location in the inertial frame. These steps are repeated iteratively, providing real-time navigation information.

Inertial navigation systems have several advantages. These include:

1. They are self-contained and do not rely on external signals, making them immune to jamming and interference.
2. They provide continuous position, velocity, and orientation data, even when external signals are unavailable.
3. They can provide highly accurate navigation data, especially over short periods.

Despite these merits, they do have some limitations. These include:

1. INS errors accumulate over time due to sensor drift and computational inaccuracies. The longer the system operates without external updates, the larger the errors become.
2. They require an initial alignment procedure to determine its starting position and orientation accurately.

3. High-performance INS can be expensive, although prices have decreased in recent years.

Doppler navigation system

Doppler navigation systems are based on the Doppler effect, a phenomenon where the frequency of a wave changes relative to an observer moving relative to the source of the wave. In the context of navigation, this effect is used to determine the velocity of an aircraft relative to the ground. The Doppler frequency shift, Δf , can be calculated using the equation:

$$\Delta f = \frac{v \cdot f}{c}$$

where, v is the aircraft velocity, f is the frequency of transmission, and c is the speed of wave (electromagnetic) propagation.

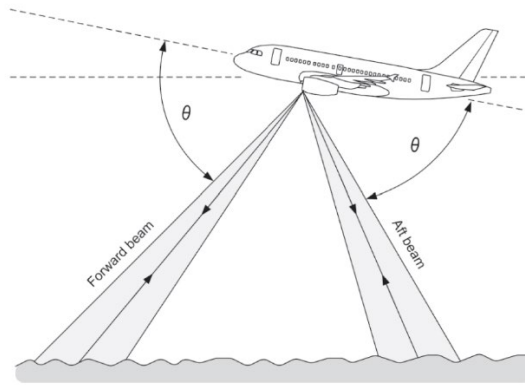


Figure 3.6: *Doppler navigation system beams*

Doppler navigation systems are primarily used in aircraft to provide continuous velocity and position updates. They are particularly valuable in environments where GPS signals are weak or unavailable, such as over oceans or in polar regions. By measuring the Doppler shift of radar signals reflected off the ground, these systems can accurately determine the aircraft's ground speed and drift angle, which are essential for dead reckoning and position fixing.

Some of the advantages of doppler navigation systems include:

1. Doppler systems do not rely on external navigation aids, making them immune to signal jamming and interference.
2. They provide continuous, real-time measurements of ground speed and drift angle.
3. Doppler systems can operate effectively in various weather conditions, providing reliable data regardless of visibility.

Like any other system, however, they do have some limitations. These include:

1. The accuracy of Doppler systems can be affected by the type of terrain over which the aircraft is flying, with rough or uneven surfaces potentially leading to measurement errors.
2. Doppler systems have a limited operational range, typically effective only at relatively low altitudes.
3. The technology can be complex and costly to implement and maintain, especially in comparison to simpler GPS-based systems.

2. Position Fixing

Position fixing is the process of determining the precise location of a vehicle or aircraft at a specific point in time using external references or navigation aids. Unlike dead reckoning, which relies on estimations and calculations, position fixing involves directly measuring or observing the vehicle's relationship to known points or signals. These references can include landmarks, radio beacons, satellite navigation systems, or celestial bodies. By obtaining multiple independent measurements, navigators can triangulate or otherwise calculate their position with a high degree of accuracy.

The methods used for position fixing vary depending on the available technology and the environment. Visual position fixing involves using landmarks or celestial observations to determine position, while electronic position fixing relies on radio signals or satellite data. Modern navigation systems often combine multiple sources of information to improve accuracy and reliability. Position fixing is crucial for verifying the accuracy of dead reckoning calculations, correcting for accumulated errors, and ensuring that the vehicle or aircraft remains on the intended course. It provides a snapshot of the vehicle's location at a specific moment, allowing navigators to update their position and plan their next steps.

Position-fixing systems used on aircraft include VOR, ADF and DME. These systems rely on ground transmitters. Then there is the GNSS system as well which provides position by ranging using satellite information.

VHF Omnidirectional Range (VOR)

VOR is a short-range radio navigation system used by aircraft. A VOR ground station transmits a signal that provides the aircraft with its bearing relative to the station. The VOR system works by transmitting two signals: a reference signal that is transmitted in all directions, and a variable signal that rotates. The receiver in the aircraft compares the phase of these two signals to determine the aircraft's bearing from the station. VOR stations transmit in the VHF band between 108.00 and 117.95 MHz. VOR is subject to line-of-sight restrictions, and its range varies depending on altitude.

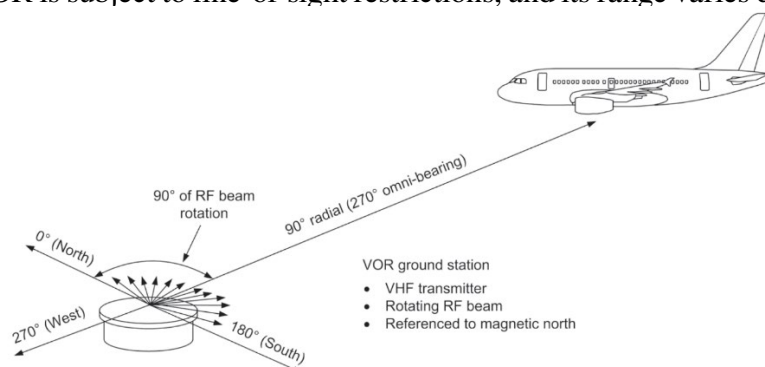


Figure 3.7: VOR navigation system

VOR stations are strategically located along established air routes, providing a network of “highways in the sky.” Pilots use VOR to navigate by selecting a specific VOR frequency on their navigation radio and then using the Course Deviation Indicator (CDI) to centre a needle, which indicates the course to or from the VOR station. By using multiple VOR stations, pilots can determine their position by triangulation. VOR is a fundamental navigation tool, especially useful for enroute navigation and approaches to airports.

Automatic Direction Finder (ADF)

ADF is a radio navigation system that automatically seeks and displays the bearing to a non-directional beacon (NDB). NDBs transmit signals in all directions, and an ADF receiver in the aircraft determines the direction to the NDB station. The ADF system uses two antennas: a directional antenna that receives the signal and a non-directional antenna that is used to resolve ambiguity. The ADF receiver then displays the bearing to the NDB station relative to the aircraft's heading.

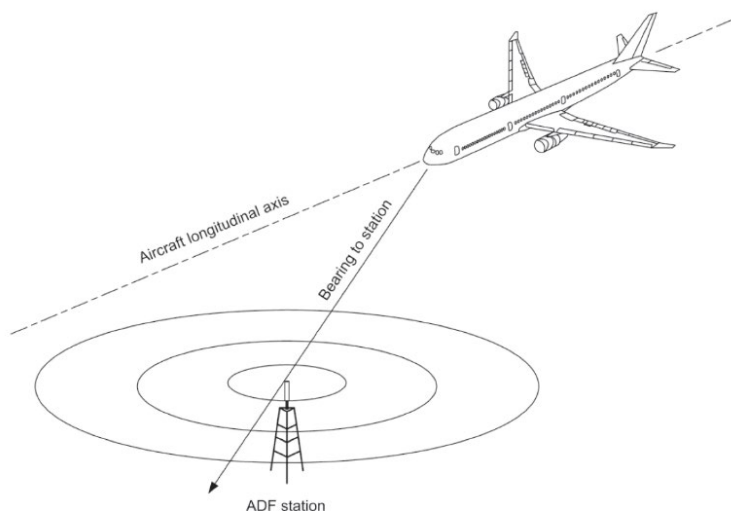


Figure 3.8: *ADF navigation system*

ADF operates in the low to medium frequency band (190-1750 kHz). NDBs are less precise than VOR stations and are susceptible to atmospheric disturbances, such as thunderstorms. However, they can be useful in areas where VOR coverage is limited. Pilots use ADF by tuning to the frequency of an NDB and then using the ADF indicator to determine the bearing to the station.

The Radio Magnetic Indicator (RMI) combines magnetic heading information with radio navigation data. It displays the aircraft's magnetic heading at the top of the instrument, like a standard magnetic compass. Additionally, the RMI incorporates one or two needles that point to the direction of selected VOR or ADF stations. This allows pilots to see both their current heading and the bearing to these navigational aids simultaneously. The RMI simplifies navigation by providing a clear, integrated display of essential information, making it easier for pilots to maintain situational awareness and navigate accurately.

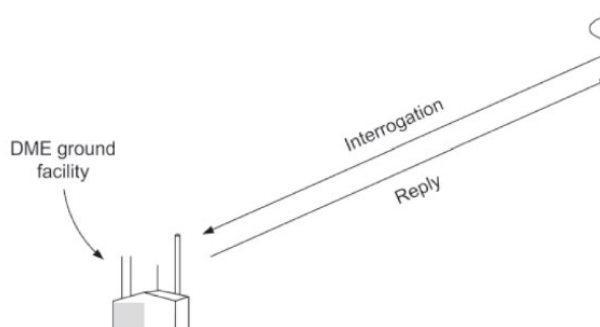


Figure 3.9: *A radio magnetic indicator*

Distance Measuring Equipment (DME)

DME is a navigation system that provides an aircraft with its distance to a ground station. DME operates by transmitting a signal from the aircraft to the ground station, which then replies with another signal. The aircraft's DME receiver measures the time it takes for the signal to travel to the ground station and back and then calculates the distance. DME typically operates in the UHF frequency band (960-1215 MHz).

DME is often paired with VOR stations to provide both bearing and distance information. When combined with VOR, it is referred to as a VOR/DME station. DME is also used in Instrument Landing Systems (ILS) to provide pilots with precise distance information during approaches. For example, Kotoka International Airport in Accra utilises DME as part of its navigation infrastructure. DME is a crucial tool for pilots, enhancing situational awareness and enabling more accurate navigation.

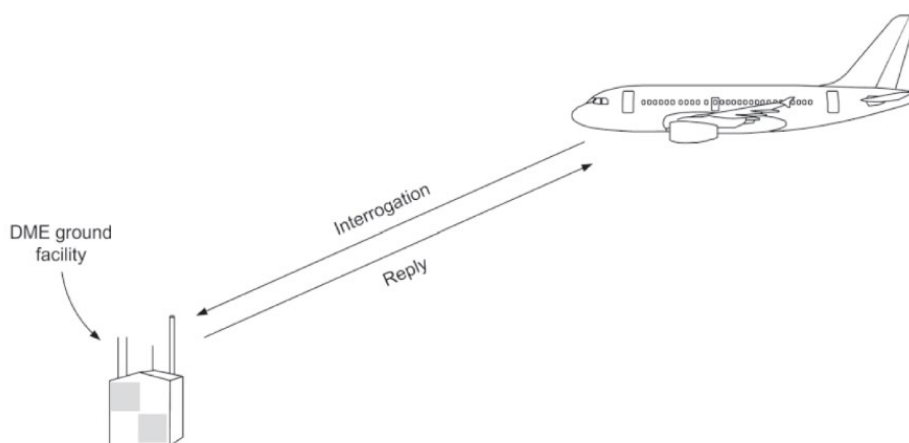


Figure 3.10: *DME navigation system*

Global navigation satellite systems

Global Navigation Satellite Systems (GNSS) provide precise positioning, navigation, and timing services worldwide. By utilising a constellation of satellites orbiting the Earth, GNSS enables users to determine their location accurately, regardless of weather conditions or time of day. The most well-known GNSS is the United States' Global Positioning System (GPS), but other systems include Russia's GLONASS, Europe's Galileo, and China's BeiDou.

GNSS positioning relies on a technique called trilateration. A GNSS receiver on the ground (or in an aircraft) measures the distance to at least four satellites. The receiver calculates this distance by measuring the time it takes for a signal to travel from the satellite to the receiver. Knowing the precise location of each satellite and the distance to it, the receiver can determine its own position in three dimensions (latitude, longitude, and altitude). The GNSS receiver solves a set of simultaneous equations to determine its precise location.

GNSS consists of three primary segments that work together to provide navigation services. The space segment comprises the constellation of satellites orbiting the Earth. Each satellite transmits signals containing its position and the precise time the signal was sent. The control segment consists of a network of ground stations that monitor the satellites, ensuring their proper functioning and maintaining their precise orbital parameters. These ground stations track the satellites, upload corrections, and perform maintenance as needed. The user segment includes the GNSS receivers used by individuals and organisations to determine their position. On the aircraft, this segment is referred to as the aircraft earth station.

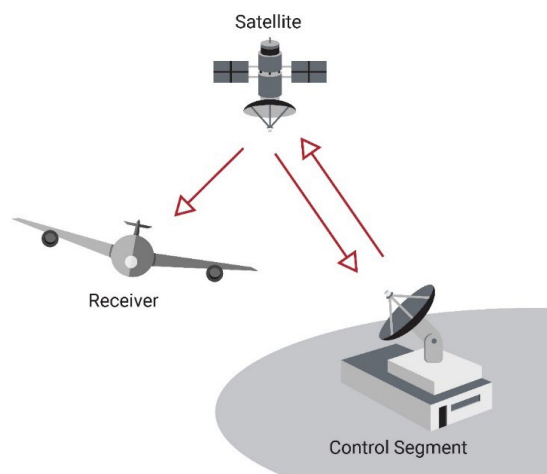


Figure 3.11: *GNSS segments*

GNSS augmentation systems can enhance the accuracy, integrity, availability, and continuity of GNSS signals. These systems use additional infrastructure and techniques to improve the performance of GNSS. Satellite-Based Augmentation Systems (SBAS) use geostationary satellites to broadcast corrections to GNSS signals. Examples include the Wide Area Augmentation System (WAAS) in the United States and the European Geostationary Navigation Overlay Service (EGNOS) in Europe. Ground-Based Augmentation Systems (GBAS) use ground-based stations to transmit corrections to GNSS signals within a limited area, typically around an airport. GBAS is often used for precision approaches to runways.

GNSS navigation has several advantages. These include:

1. GNSS provides positioning information anywhere on Earth, making it ideal for aviation, maritime, and land-based navigation.
2. With augmentation systems, GNSS can achieve accuracies down to a few centimetres.
3. GNSS works in all weather conditions, unlike some other navigation systems that can be affected by rain or fog.
4. GNSS provides real-time positioning information, allowing for continuous tracking and navigation.

It does have a few limitations, though. These include:

1. GNSS signals can be blocked or degraded by buildings, terrain, and other obstructions.
2. GNSS signals are susceptible to interference from electronic devices or intentional jamming.
3. The ionosphere and troposphere can introduce errors in GNSS signals, affecting accuracy.
4. GNSS relies on the proper functioning of satellites, and any failure or disruption can impact availability.

While not a traditional navigation system in a sense, the instrument landing system (ILS) deserves some mention here. It is a precision approach system that provides pilots with guidance to the runway during landing in low visibility conditions. It uses a combination of radio signals and visual aids to guide an aircraft to a safe landing. The ILS is designed to provide accurate alignment and descent guidance, allowing pilots to make precise approaches even when they cannot see the runway until very late in the approach.

The ILS has four major components. The localiser provides lateral guidance to the runway centreline. It transmits a signal that creates a radio beam aligned with the runway. The aircraft's ILS receiver detects this signal and indicates whether the aircraft is to the left or right of the

centreline. The localiser typically operates on one of 40 VHF frequencies between 108.10 MHz and 111.95 MHz.

The glide slope provides vertical guidance, indicating the correct descent angle to the runway. It transmits a signal that creates a sloping radio beam, typically at an angle of 3 degrees. The aircraft's ILS receiver detects this signal and indicates whether the aircraft is above or below the glide path. The glide slope operates on a UHF frequency that is paired with the localiser frequency.

Marker beacons provide distance information along the approach path. They transmit a vertical fan-shaped signal that is detected by the aircraft as it flies over them. There are typically three marker beacons: the Outer Marker, located about 4 – 7 nautical miles from the runway, indicates the initial approach fix; the Middle Marker, located about 0.5 – 0.8 nautical miles from the runway, indicates the point where the pilot should be able to see the runway if the decision height is reached; and the inner marker located 1000 – 1500 ft from the runway threshold.

The approach lighting system provides visual guidance during the final stages of the approach. It consists of a series of lights that extend outward from the runway, helping the pilot align the aircraft with the runway and judge the distance to touchdown.



Figure 3.12: *Instrument Landing System*

Integrated Navigation Solutions

Integrated navigation combines data from multiple navigation sensors and systems to provide a more accurate, reliable, and robust navigation solution than any single system could offer on its own. This approach is particularly useful in aviation, where accuracy and reliability are critical for safety and efficiency. By fusing data from various sources, integrated navigation systems can compensate for the limitations and weaknesses of individual sensors, resulting in a superior overall performance. A simple example of such data fusion is the calculation of the average of several values. We multiply each value by its certainty (which we usually take as 1), sum them up and divide by the sum of certainties.

The outputs of the navigation systems mentioned previously (GNSS, INS, etc.), together with information from the air data system (such as the airspeed, angle of attack, etc.) are combined using a fusion algorithm to produce a unified navigation solution. One of the most widely used data fusion techniques is the Kalman filter. This is a recursive algorithm that estimates the state of a dynamic system from a series of incomplete and noisy measurements. It uses a mathematical model of the system's dynamics and measurement errors to predict the system's state and then update the prediction based on new measurements. The Kalman filter optimally weights the contributions of different sensors based on their estimated accuracy and reliability, providing a statistically optimal estimate of the system's state.

Learning Tasks

1. Solve sample calculations related to aircraft navigation.
2. Engage in conversations with your peers about the different navigation technologies available to aircraft.
3. Discuss the merits and limitations of each navigation technology through exploring the requirements for aircraft navigation in different scenarios.

Pedagogical Exemplars

Collaborative learning – Let learners work together to carry out sample navigation calculations.

Building on what others say – Encourage learners to share ideas about the different navigation technologies used in aircraft.

Collaborative Learning - By exploring the requirements for aircraft navigation in different scenarios, learners discuss the merits and limitations of each navigation technology.

Key Assessment Level 3: Computational Task

1. An aircraft departs Kotoka International Airport in Accra at 9:00 am, intending to fly northeast on a heading of 045° . The airspeed is 45 knots, and a steady wind is blowing from the west (eastward) at 10 knots.
 - a. Using vector analysis or diagrams, estimate the aircraft's ground speed and actual flight path.
 - b. Explain how the wind affects the aircraft's actual direction of travel compared to its intended heading.
 - c. Based on your analysis, suggest how the pilot might adjust the heading to maintain the intended course. Justify your recommendation. (18 marks) (DOK 3)
2. If the one-dimensional position of an aircraft relative to a point, in metres, is given by three onboard systems as 300, 304 and 302, and the equipment have certainties of 0.7, 0.8 and 0.9, respectively, estimate the current position of the aircraft. (7 marks) (DOK 3)

Refer to Teacher Assessment Manual and Toolkits pages 49 – 51 for further guidance on conducting computational assessments.

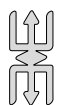
PLC Session 9

45 minutes

Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
 - a. explain the week's concepts in a practical way that will make it easier for learners to understand
 - b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
 - a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

- b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
- c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

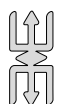
- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
 - a. The key assessment for the week is **computational task**. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the task (NTS 3k-3q).

10 minutes

Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
 - a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
 - b. all teachers in the group work through a similar problem individually for 3–4 minutes
 - c. the group then works through the problem together step by step
 - d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes

Enactment

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).
 - a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
 - b. After the enactment, ask for structured feedback from the group
 - i. was the concept explained in a way that a learner with no prior knowledge could follow?
 - ii. were the examples grounded in contexts familiar to Ghanaian learners?
 - iii. did any misconceptions surface and if so, how were they addressed?

5 minutes**Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
 - a. transfer your chats into your learning planner template.
 - b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
 - c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 10

Learning Indicators

1. *Present a summary of on-board surveillance systems*
2. *Present a summary of ground-based surveillance systems*

Focal Area: **Aircraft surveillance systems**

This week, we will be building on the knowledge we acquired in the first year about aircraft surveillance systems. (Refer back to Year 1, Section 3, Week 10, Introduction to the various aerospace surveillance systems.) We begin with primary surveillance radar.

Primary surveillance radar

Primary Surveillance Radar (PSR) is a radar system used to detect and determine the aircraft's position by transmitting a radio signal and analysing the reflected signal (echo) from the aircraft's surface. The radar antenna rotates, emitting pulses of radio waves in a specific direction. When these radio waves encounter an object, such as an aircraft, a portion of the energy is reflected back to the radar antenna. The radar system then processes this reflected signal to determine the range (distance) and bearing (direction) of the aircraft. By continuously scanning the airspace, PSR provides air traffic controllers with a real-time display of aircraft positions within its coverage area, without requiring the aircraft to carry any special equipment. To calculate the range of the aircraft from the radar station, we multiply the speed of the radar signal (speed of light) by half the time between the transmission of the signal and the reception of the echo.

The information gathered by PSR is crucial for air traffic control (ATC). It allows controllers to monitor the position of aircraft, manage traffic flow, and ensure separation between aircraft. The range is determined by the time it takes for the signal to travel to the aircraft and return, while the bearing is determined by the direction in which the antenna is pointing when the echo is received. This information is then displayed on a radar screen, providing controllers with a visual representation of the airspace. PSR is a fundamental tool for maintaining safety and efficiency in air traffic management, especially in areas with high traffic density or where other surveillance systems may be limited.

Primary Surveillance Radar offers the distinct advantage of detecting aircraft without requiring them to carry any special transponders or equipment, making it an independent surveillance system. This is particularly useful for monitoring non-cooperative aircraft or those that may have transponders that are malfunctioning. PSR provides air traffic controllers with a fundamental means of detecting and tracking aircraft based solely on the reflection of radio waves, enhancing overall air traffic situational awareness and safety, especially in busy airspaces or regions where not all aircraft are equipped with secondary surveillance technology.

However, PSR has several limitations. It relies on the reflection of radio waves from the aircraft, which can be affected by the aircraft's size, shape, and composition, as well as weather conditions. Heavy rain, snow, or dense clouds can attenuate the radar signal, reducing its range and accuracy. Additionally, PSR cannot determine the altitude of the aircraft directly; this information must be obtained from other sources, such as the aircraft's transponder or pilot reports. Finally, PSR can suffer from ground clutter and other forms of interference, which can make it difficult to distinguish aircraft from background noise, potentially leading to inaccurate or missed detections.

Secondary surveillance radar

Secondary Surveillance Radar (SSR) is an advanced radar system used in air traffic control that relies on a transponder aboard the aircraft to provide more detailed information than primary radar alone. Unlike primary radar, which detects aircraft by bouncing a signal off their surfaces, SSR actively interrogates the aircraft's transponder, which then sends back a coded response. This response provides vital data such as the aircraft's identity, altitude, and other relevant information, significantly enhancing air traffic management capabilities.

SSR consists of two main components: the interrogator (ground station) and the transponder (onboard the aircraft). The interrogator transmits a specific radio signal, or "interrogation," to which the transponder is designed to respond. When the transponder receives this signal, it automatically transmits a coded reply containing information about the aircraft. The ground station then decodes this reply and displays the information to air traffic controllers. SSR operates in conjunction with primary radar, providing a more complete picture of air traffic. Interrogation signals are transmitted on a 1030 MHz carrier wave while replies are transmitted on a 1090 MHz carrier wave.

ATC Transponders operate in different modes, each providing specific types of information:

1. Mode A: Provides a four-digit identification code assigned to the aircraft. This code is set by the pilot and is unique to each flight, allowing controllers to identify the aircraft.
2. Mode C: Provides the aircraft's pressure altitude. The transponder automatically reports the altitude based on the aircraft's altimeter, enabling controllers to monitor the aircraft's vertical position.
3. Mode S: A more advanced mode that allows for selective interrogation of individual aircraft. It provides a unique 24-bit address for each aircraft and supports data link capabilities, enabling the exchange of more detailed information between the aircraft and the ground station. Mode S is designed to reduce congestion on the radio frequencies and improve the accuracy and reliability of surveillance data.

SSR offers several advantages, including:

1. Positive identification of aircraft through the Mode A code, reducing the risk of misidentification.
2. Mode C provides automatic altitude reporting, allowing controllers to monitor aircraft altitude without relying on pilot reports.
3. SSR typically has a greater range and is less susceptible to ground clutter and weather interference compared with primary radar.
4. Mode S supports data link capabilities, enabling the exchange of additional information such as flight plans, weather updates, and traffic advisories.
5. Mode S reduces congestion on radio frequencies by allowing for selective interrogation of individual aircraft.

It does have a few limitations, however. These include:

1. SSR relies on aircraft being equipped with functioning transponders. Aircraft without transponders or with malfunctioning transponders cannot be detected by SSR.
2. SSR can suffer from garbling (overlapping replies from multiple aircraft) and FRUIT (False Replies Unsynchronised In Time), which can cause errors in the displayed information. Mode S helps to mitigate these issues.
3. SSR systems are more complex and expensive to install and maintain compared with primary radar systems.
4. SSR signals can be jammed, disrupting the system's operation and potentially compromising air traffic safety.

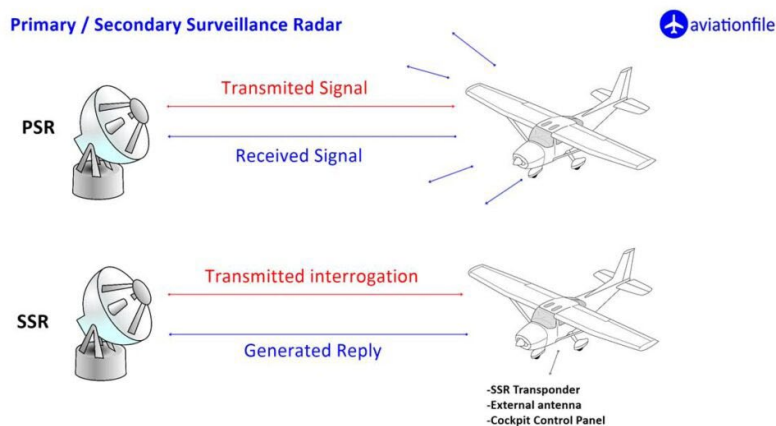


Figure 3.13: *Primary and secondary surveillance radar*

Combined PSR/SSR systems

Combined PSR and SSR systems integrate the capabilities of both technologies to provide a comprehensive and robust air traffic surveillance solution. PSR detects aircraft by analysing reflected radio signals, offering an independent means of surveillance that doesn't rely on aircraft transponders. SSR, on the other hand, actively interrogates aircraft transponders to obtain detailed information such as identity, altitude, and other relevant data. By combining these two systems, air traffic controllers gain a more complete and more reliable picture of the airspace, enhancing their ability to manage traffic flow and ensure safety.

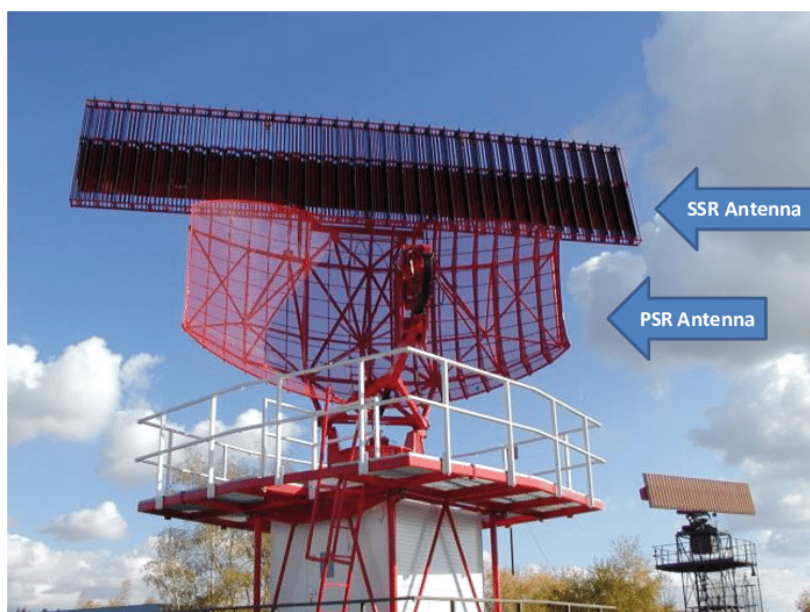


Figure 3.14: *Combined PSR/SSR antenna system*

Automatic Dependent Surveillance-Broadcast

Automatic Dependent Surveillance-Broadcast (ADS-B) is a surveillance technology that enables aircraft to broadcast their identity, position, altitude, velocity, and other information derived from onboard systems, such as GPS, to air traffic control and other aircraft. Unlike radar systems that actively scan the airspace, ADS-B is a “dependent” system because it relies on the aircraft’s navigation system to determine its position, and it is “automatic” because it broadcasts this information without requiring any input from the pilot or ATC. ADS-B enhances situational awareness for both pilots and controllers, improving safety and efficiency in air traffic management.

Aircraft with ADS-B Out transmit data to ground stations and other aircraft equipped with ADS-B In on a frequency of 1090 MHz. Ground stations relay the information to ATC centres, where it is displayed on controller screens. Aircraft with ADS-B In can also receive information directly from other aircraft, providing a more complete picture of the surrounding airspace.

ADS-B is being implemented worldwide to modernise air traffic management systems. Countries such as The United States and European countries already have ADS-B mandates in effect. Australia has implemented ADS-B in much of its airspace, enhancing surveillance capabilities over vast, remote areas. Ghana continues to explore ADS-B to improve air traffic surveillance and safety. The transition to ADS-B is a significant step towards a more efficient and safer global air transportation system.

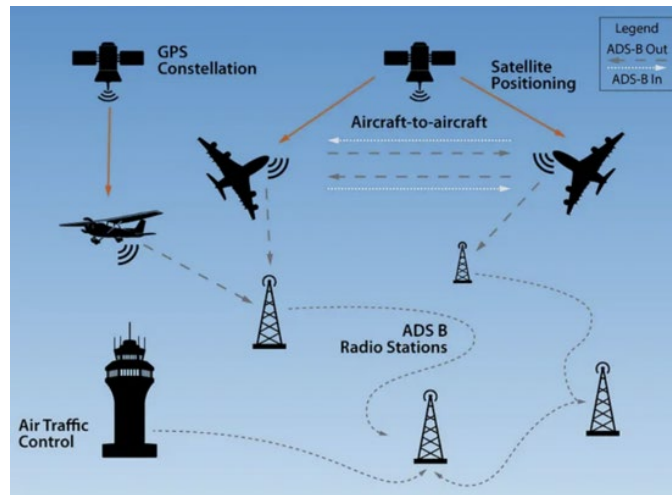


Figure 3.15: *ADS-B architecture*

Traffic Collision Avoidance System

Traffic Collision Avoidance System (TCAS) is an airborne system designed to reduce the risk of mid-air collisions between aircraft. It operates independently of ground-based air traffic control systems, providing pilots with visual and aural alerts to potential conflicts and, in some cases, suggesting evasive manoeuvres. TCAS enhances aviation safety by serving as a last line of defence against collisions, particularly in situations where ATC surveillance or communication may be limited.

TCAS operates by interrogating the transponders of nearby aircraft. It transmits radio signals and listens for replies from other aircraft equipped with transponders. Based on these replies, TCAS calculates the range, bearing, altitude, and relative velocity of surrounding aircraft. It then uses this information to predict potential collision threats. Based on this information, a traffic Advisory (TA) or resolution advisory (RA) may be generated. When TCAS detects a potential conflict, it issues a TA to alert the pilot to the presence of nearby traffic. The TA provides information about the position and altitude of the conflicting aircraft, allowing the pilot to visually acquire the traffic and take appropriate action. If the conflict becomes more imminent, TCAS issues an RA, which provides specific instructions to the pilot on how to avoid a collision. The RA may instruct the pilot to climb, descend, or maintain their current altitude. TCAS coordinates RAs between conflicting aircraft to ensure that the evasive manoeuvres are complementary.

TCAS system components include a computer, the central processing unit of the system, which performs the calculations and generates the alerts; multiple antennas to transmit and receive signals from other aircraft; a transceiver that transmits interrogation signals and receives replies from other aircraft transponders; a display unit that presents traffic information and alerts to the pilot, typically on a

cockpit display and an audio generator that produces aural alerts, such as “Traffic, Traffic” for a TA and “Climb, Climb” or “Descend, Descend” for an RA.

TCAS II is the most advanced version of TCAS, and it is required on most commercial aircraft. It provides both TAs and RAs, enabling pilots to take coordinated evasive manoeuvres to avoid collisions. TCAS I is a simpler version that provides only TAs.

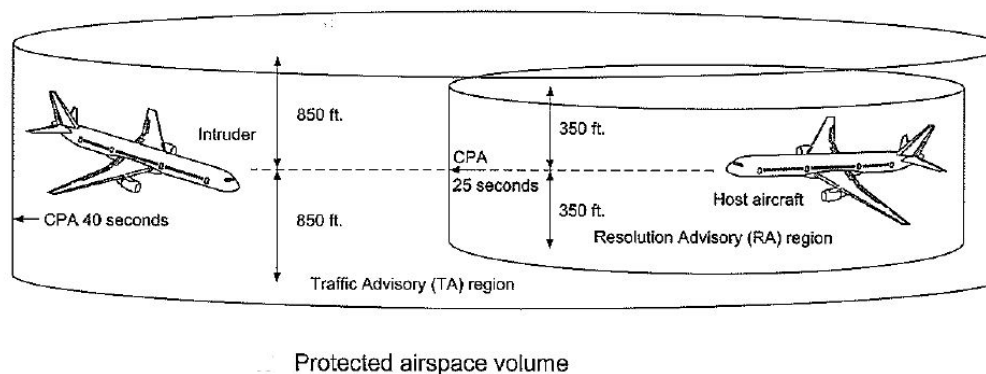


Fig. 3.16: *TCAS protected volume*

Learning Tasks

1. Work with your friends to identify the different aircraft surveillance technologies.
2. In a small group create a presentation about on-board aerospace vehicle surveillance systems.
3. Together with a friend, work through simple range calculation problems for PSR systems.

Pedagogical Exemplars

Talk for learning – Lead an interactive session with learners where the different surveillance technologies are discussed.

Talk for Learning: Through a question-and-answer session, learners share views on ground-based aerospace vehicle surveillance systems.

Collaborative learning – Ask learners to assist each other to perform simple range calculations for PSR systems.

Key Assessment Level 3: Peer Assessment

1. Identify and analyse four key surveillance technologies used by transport aircraft in busy airspace. For each technology, explain how it works and outline its limitations. Based on your analysis, justify which one you consider the most critical for safe navigation, using evidence related to accuracy, coverage, and system integration. (16 marks) (DOK 3)
2. Calculate the distance of an aeroplane from a radar tower, given a signal return time of 3 milliseconds and the speed of light equal to 3×10^8 m/s. What real-world factors, like weather or equipment issues or aircraft size/shape, could affect the accuracy of this distance measurement? Compare your calculation and error factors with a classmate, resolving any differences to reach a consensus. (18 marks) (DOK 3)

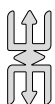
Refer to the *Teacher Assessment Manual and Toolkits* pages 91 – 94 on how to administer *Peer Assessments*.

PLC Session 10

45 minutes

Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
 - a. explain the week's concepts in a practical way that will make it easier for learners to understand
 - b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
 - a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
 - b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
 - c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

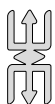
- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the *Values Learning Community Handbook* and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app
 - a. The key assessment for the week is **peer assessment**. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the assessment (NTS 3k-3q).

10 minutes

Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
 - a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
 - b. all teachers in the group work through a similar problem individually for 3–4 minutes
 - c. the group then works through the problem together step by step
 - d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?

- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes**Enactment**

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).
 - a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
 - b. After the enactment, ask for structured feedback from the group
 - i. was the concept explained in a way that a learner with no prior knowledge could follow?
 - ii. were the examples grounded in contexts familiar to Ghanaian learners?
 - iii. did any misconceptions surface and if so, how were they addressed?

5 minutes**Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
 - a. transfer your chats into your learning planner template.
 - b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
 - c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 3 Review

In this section, we learned about aircraft communications, navigation and surveillance systems. We learned that there were different technologies employed, depending on the scenario. Each technology offers unique advantages that supplement those of the other technologies. This enables all-weather operation and maximises the operational capabilities of the aircraft.



MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 8

Question 1

Identification of 3 Communication Systems	3 marks	1 mark each for correctly identifying relevant systems (e.g., VHF, HF, SATCOM).
Explanation of Purpose for Each System	3 marks	1 mark per system – clear explanation of what the system is used for in flight phases.
Explanation of Limitations for Each System	3 marks	1 mark per system – basic but accurate limitation given (e.g., limited range for VHF).
Comparison of the Three Systems	3 marks	Logical comparison based on range, reliability, and suitability for different phases, especially oceanic crossing.
Justification of the Most Suitable System for Oceanic Use	4 marks	Clear reasoning (e.g., coverage area, reliability, data type); reference to safety and operational needs. Stronger answers include redundancy factor.

Question 2

1. Correctly identifying that disruptions in the ionosphere are likely to affect HF communication – 2 marks
2. Suggesting satellite communications as an alternative communication technology – 2 marks

WEEK 9

Question 1

- a. Vector analysis to estimate ground speed and actual flight path (8 marks)
 - Correct vector diagram or description of method used – 2 marks
 - Calculation of wind vector effect on aircraft motion – 2 marks
 - Correct estimation or reasonable approximation of ground speed – 2 marks
 - Correct estimation or logical explanation of actual flight path direction (track) – 2 marks
- b. Explanation of wind impact on direction of travel (5 marks)
 - Correct concept: wind drift causes deviation from intended heading – 2 marks
 - Explanation of how wind from the west pushes aircraft eastward – 1 mark
 - Connection between airspeed, wind speed, and resulting ground track – 2 marks
- c. Heading adjustment and justification (5 marks)
 - Appropriate heading adjustment suggested (e.g., correction into wind) – 2 marks
 - Justification based on counteracting drift to maintain intended heading – 2 marks
 - Clarity and coherence in recommendation – 1 mark

Question 2

1. 3 marks awarded for correctly applying the certainties to the position outputs.
2. 2 marks for summing the certainties

2 marks awarded for arriving at the correct answer

WEEK 10

Question 1

Identification of four surveillance technologies	4 (1 mark each)	Clearly names 4 relevant technologies (e.g., ADS-B, primary radar, secondary radar, MLAT, TCAS).
Explanation of how each technology works	4 (1 mark each)	Provides a clear and correct explanation for each selected technology.
Outline of limitations	4 (1 mark each)	Identifies at least one meaningful limitation for each technology.
Justification of most critical technology	4	Presents a reasoned argument based on factors such as accuracy, coverage, and system integration. Justification must reference comparison to others and include evidence.

Question 2

Criteria	Points Possible	Excellent (Full Points)	Very good (Mostly Correct)	Satisfactory (Partially Correct)	Needs Improvement (Incorrect/ Missing)
1. Distance Calculation	8	Correctly calculates the distance using the formula ($\text{distance} = \text{speed} \times \text{time} / 2$), shows all steps clearly, uses correct units (metres), and arrives at the correct answer (450 km). (8 marks)	Calculates the distance with minor errors in the formula, units, or calculations, but shows understanding of the process. (6 marks)	Attempts to calculate the distance, but with significant errors in the formula or calculations. May miss the division by 2 (to account for the round trip). (4 marks)	Does not attempt to calculate the distance or demonstrates a fundamental misunderstanding of the relationship between speed, time, and distance. (2 marks)
2. Identification of Error Factors	6	Identifies at least three relevant real-world factors that could affect the accuracy of the distance measurement	Identifies two relevant error factors and provides reasonable explanations. 4 marks)	Identifies one relevant error factor or provides weak or unclear explanations. (2 marks)	Fails to identify any relevant error factors or provides explanations that are illogical or unsupported. (1 mark)

		<i>(e.g., atmospheric conditions, radar system limitations, aircraft characteristics) and provides clear and reasonable explanations of how each factor could introduce error. (6 marks)</i>			
3. <i>Collaboration & Consensus</i>	4	<i>Actively participates in the comparison and discussion with their classmate, effectively communicating their own ideas and listening to and considering their classmate's perspective. Successfully resolves any discrepancies in their calculations or analyses and arrives at a consensus solution. (4 marks)</i>	<i>Participates in the comparison and discussion but may have some difficulty communicating their ideas or considering their classmate's perspective. Resolves most discrepancies and arrives at a reasonable consensus. (3 marks)</i>	<i>Participates minimally in the comparison and discussion or struggles to communicate their ideas or consider their classmate's perspective. May fail to resolve discrepancies or reach a consensus. (2 marks)</i>	<i>Does not participate in the comparison and discussion or is unable to resolve discrepancies or reach a consensus. (1 mark)</i>

SECTION 4: AIRCRAFT MAINTENANCE

STRAND: AVIATION INDUSTRY

Sub-Strand: Aircraft Maintenance

Week 11

Learning Outcome: *Expatiate (Explain in detail) the types of aircraft maintenance (routine, periodic, etc.) and the equipment required.*

Content standard: *Demonstrate knowledge of aircraft maintenance activities.*

Week 12

Learning outcome: *Apply standard practices in the performance of simple maintenance tasks.*

Content Standard: *Demonstrate knowledge of aircraft maintenance standards and certification.*

INTRODUCTION AND SECTION SUMMARY

Aircraft maintenance is a critical part of aviation safety, reliability, and performance. This section introduces the fundamental concepts, practices, and systems that ensure an aircraft remains airworthy throughout its operational life. From routine inspections to fault detection and repairs, maintenance activities are essential for preventing mechanical failures, complying with regulatory standards, and supporting efficient flight operations. Whether working with fixed-wing or rotary-wing aircraft, understanding the role of maintenance helps learners appreciate the technical precision and discipline required to keep aerospace vehicles safe and mission-ready.

The weeks and the indicators covered by the section are:

- **Week 11**
 - o Classify various maintenance tasks as routine, periodic, etc.
 - o Identify aircraft maintenance equipment.
- **Week 12**
 - o Carry out simple maintenance tasks, according to established standards.
 - o Make log entries of maintenance activities performed.

Recap Weeks

Year 1	Weeks 11 & 12: Identify the roles of professionals in the aviation industry.
--------	---

SUMMARY OF PEDAGOGICAL EXEMPLARS

1. Talk for learning
2. Experiential Learning
3. Project-based Learning

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/or Mode
1. Classify various maintenance tasks as routine, periodic, etc. 2. Identify aircraft maintenance equipment.	DOK 4	Scenario / Poster presentation
1. Carry out simple maintenance tasks, according to established standards. 2. Make log entries of maintenance activities performed.	DOK 4	Project

WEEK 11

Learning Indicators

1. *Classify various maintenance tasks as routine, periodic, etc.*
2. *Identify aircraft maintenance equipment*

Focal Area: Aircraft Maintenance (Refer back to Year 1, Section 4, Weeks 11 & 12: Introduction to aviation careers, their roles and learning pathways)

This week introduces learners to the essential role of maintenance in ensuring the safety, reliability, and continued airworthiness of aircraft. Learners will explore the different categories of maintenance tasks—from routine daily checks to scheduled inspections and unscheduled repairs—and understand how each contributes to the overall operation of aerospace vehicles. The week also focuses on familiarising learners with common aircraft maintenance tools and equipment, highlighting their functions and safe handling. By the end of the week, learners should be able to classify maintenance tasks appropriately and identify key tools used in aircraft servicing and inspection.

Introduction to Aircraft Maintenance

Aircraft, like all complex machines, require regular maintenance to ensure safety, performance, and regulatory compliance. This lesson introduces learners to the **purpose of aircraft maintenance** and guides them in identifying and **classifying maintenance tasks** based on their frequency, scope, and urgency. Understanding how maintenance is organised prepares learners for further study in aviation operations, safety, and engineering

The Role of Aircraft Maintenance

Aircraft maintenance plays a critical role in ensuring **airworthiness**, **flight safety**, and **regulatory compliance**. According to the International Civil Aviation Organisation (ICAO), *airworthy* means “the status of an aircraft, engine, propeller, or part when it conforms to its approved design and is in a condition for safe operation.” In simple terms, **airworthiness** refers to an aircraft’s ability to operate safely—both in the air and on the ground—while meeting all design and performance standards.

To maintain this status, aircraft must undergo **regular inspections, servicing, and repairs**. These activities help prevent mechanical failures, extend the life of the aircraft, and ensure that the aircraft continues to function within the limits of its original design. Maintenance also ensures that the aircraft complies with **aviation regulations**, which are established by a country’s civil aviation authority. In Ghana, this responsibility lies with the **Ghana Civil Aviation Authority (GCAA)**, which oversees all aspects of aviation safety, including maintenance standards and certification.

In addition to improving safety, effective aircraft maintenance **reduces long-term operational costs** by identifying and addressing wear or potential failures before they become serious problems. It also supports efficient flight operations by minimising unexpected delays due to equipment malfunctions.

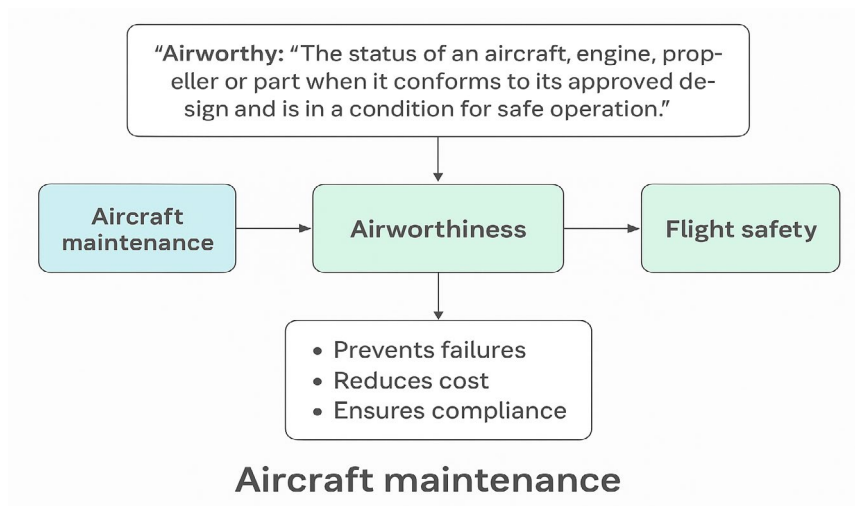


Figure 4.1: Role of aircraft maintenance in ensuring airworthiness and flight safety

Types of Aircraft Maintenance Tasks

Aircraft maintenance can be divided into several categories based on the timing, purpose, and urgency of the work performed. Understanding these types helps clarify how maintenance teams prioritise tasks and plan inspections to keep aircraft safe, airworthy, and operational. The main types of maintenance are outlined below, ranging from routine checks before every flight to emergency repairs after unexpected system failures.

1. Routine or Line Maintenance

Routine or line maintenance refers to scheduled maintenance tasks performed at regular and short intervals, typically daily, between flights, or overnight. These tasks are designed to detect early signs of wear, prevent faults, and ensure the aircraft remains airworthy and ready for service. They are usually conducted at the gate, on the ramp, or at maintenance stands and are often required by aviation authorities as part of regulatory compliance.

Common types of routine maintenance include:

- **Pre-flight inspections:** Conducted before departure to confirm the aircraft is safe and ready for flight.
- **Post-flight inspections:** Performed after landing to identify any issues that occurred during the flight.
- **Service or transit checks:** Brief checks carried out during stopovers to ensure systems are functioning correctly.
- **Overnight inspections:** Slightly more in-depth checks carried out when the aircraft is parked overnight.

Routine maintenance actions may involve:

- **Visual inspections** of the aircraft structure and components
- Checking and replenishing **oil, hydraulic, and brake fluids**
- **Tyre pressure checks** and brake inspections
- **Lubricating moving parts**
- Cleaning and securing panels or access points

These tasks are often carried out by **certified line maintenance technicians**, who work according to checklists approved by the airline's maintenance organisation and the national aviation regulator (such as **GCAA in Ghana**).



Figure 4.2: *Pre-flight inspection on aircraft*

2. Planned Maintenance

Planned maintenance refers to any maintenance activity that is **organised, documented, and scheduled in advance**, typically before a failure occurs or before the aircraft becomes unfit for operation. It is a **proactive maintenance strategy** that supports **airworthiness, operational efficiency**, and **regulatory compliance** by helping to prevent unexpected breakdowns and ensuring critical systems remain functional.

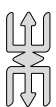
Planned maintenance includes a range of maintenance types:

- **Scheduled or Periodic Maintenance**

Scheduled maintenance involves tasks performed at **regular intervals**, based on time, usage (e.g., flight hours), or manufacturer and regulatory guidelines. It includes inspections, servicing, part replacements, and system diagnostics. These tasks may be required by the **aviation authority** (e.g., the Ghana Civil Aviation Authority) or set by the **aircraft manufacturer**. They help prevent system failure, reduce long-term maintenance costs, and support efficient resource planning.

Scheduled maintenance is usually conducted in a **hangar** and may involve specialised tools and trained personnel. Examples include:

- o 100-hour engine inspections
- o Annual airframe checks
- o Avionics calibration
- o 500-cycle component overhauls



Note

Scheduled maintenance helps minimise reactive maintenance and aircraft downtime by allowing operators to plan tasks during non-operational periods.

- **Preventive Maintenance**

Preventive maintenance consists of planned, repetitive tasks aimed at preventing mechanical failure before it occurs. It focuses on routine upkeep of aircraft systems and components to maintain functionality and reliability over time. While some preventive tasks may also occur during routine maintenance, the purpose of preventive maintenance is long-term preservation rather than immediate readiness.

Tasks may include:

- Lubricating moving components
- Replacing air and oil filters
- Tightening fasteners
- Cleaning electrical or mechanical systems

Preventive maintenance reduces the risk of unscheduled maintenance, extends component life, and helps maintain consistent operational performance. Preventive maintenance should not be confused with routine maintenance, which is tied to immediate flight readiness (e.g., pre-flight checks). Preventive tasks focus on avoiding future faults and may be carried out during periodic inspections or dedicated maintenance cycles.

- **Predictive or Condition-based Maintenance**

Predictive maintenance—also known as condition-based maintenance—uses real-time monitoring tools, historical performance data, and analytical systems to predict component failure before it happens. This modern approach is increasingly used in commercial aviation, particularly for high-value systems or aircraft with integrated digital health monitoring.

Predictive maintenance relies on:

- **Sensors** (e.g., vibration, temperature, fluid condition)
- **Maintenance tracking software**
- **Data analytics**, including AI and machine learning
- **Trend analysis of wear indicators**

Maintenance actions are triggered when certain thresholds are crossed or irregular conditions are detected, allowing technicians **to replace or repair parts just before failure**.



Figure 4.3: *Planned Maintenance*

3. **Unscheduled or Emergency Maintenance**

Unscheduled maintenance—sometimes referred to as corrective or emergency maintenance—refers to maintenance tasks that arise unexpectedly due to faults, system failures, or abnormal behaviour detected during operation or inspection. Unlike planned maintenance, these tasks are not pre-scheduled but must be addressed immediately to ensure flight safety and compliance.

Unscheduled maintenance may be triggered by:

- In-flight system alerts or abnormal readings
- Faults discovered during pre-flight or post-flight inspections
- Pilot reports of unusual aircraft performance

These tasks may involve urgent repairs, replacement of defective components, or temporary grounding of the aircraft until airworthiness is restored. The maintenance team must act quickly to diagnose the issue, repair the fault, and confirm that the aircraft meets all operational safety requirements before returning it to service.

Aircraft Maintenance Equipment and Tools

This lesson introduces learners to the basic tools and equipment used in aircraft maintenance tasks. Building on the previous lesson, which focused on maintenance types and classification, this lesson helps learners connect real-world tools with the tasks they are designed to support. Whether in routine checks, scheduled inspections, or emergency repairs, proper tools ensure that maintenance activities are efficient, accurate, and safe. The lesson also introduces ground support equipment (GSE) and personal protective equipment (PPE), highlighting their role in creating a safe and functional work environment for technicians.

Basic Aircraft Maintenance Tools

Aircraft maintenance requires the use of a wide range of tools, each designed for specific tasks—from simple inspections to precision adjustments. Understanding the function and safe use of these tools is essential for anyone involved in aviation maintenance. The following tools are commonly used in routine, scheduled, and preventive maintenance tasks across fixed-wing and rotary-wing aircraft.

1. **Torque Wrench:** A torque wrench is used to apply a precise amount of rotational force (torque) to nuts and bolts. It ensures that fasteners are neither under-tightened (which could lead to loosening during flight) nor over-tightened (which may damage threads or components). It is typically used for the following:
 - Securing landing gear bolts
 - Attaching engine components
 - Ensuring consistent torque settings during inspections



Figure 4.4: Example of digital torque wrench



Figure 4.5: *Example of adjustable or analogue torque wrench*

2. **Multimeter:** A multimeter is an electrical test instrument used to measure voltage, current, and resistance in aircraft electrical systems. It is essential for diagnosing electrical faults and verifying power supply integrity. It is typically used to:

- Check battery voltage
- Test alternator output
- Diagnose electrical faults in avionics or lighting systems.



Figure 4.6: *Multimeter testing power supply*

3. **Safety Wire Pliers:** These pliers are used to twist locking wire through bolts or fasteners to prevent loosening due to vibration. This is a standard safety practice in aviation maintenance, particularly in high-vibration areas. They are used for:

- Locking engine fasteners
- Securing access panels
- Safety-wiring oil caps and filters



Figure 4.7: *Safety Wire Pliers*

4. **Borescope:** this is a small, flexible inspection camera used to view internal or hard-to-reach parts of an aircraft without disassembly. It allows for detailed internal inspections of engines, ducts, or structural components. They are commonly used in the visual inspection of aircraft engines, wind turbines, industrial gas turbines, steam turbines, and automotive engines.



Figure 4.8: *Borescope being used for an internal inspection*

5. **Spanners and Screwdrivers:** These are essential hand tools used for tightening and loosening various fasteners during routine tasks. Aviation-grade tools are designed to be durable and precise, with some insulated for electrical safety. They are commonly used in removing and securing access panels, servicing battery compartments or avionics systems, as well as adjusting mechanical linkages and fittings, among several others.



Figure 4.9: *Toolkit showing assorted spanners and screwdrivers*

The tools outlined in this section represent some of the most commonly used equipment in routine and scheduled aircraft maintenance. Each plays a vital role in ensuring safety, accuracy, and efficiency during inspection, servicing, and repair tasks. While these tools provide a strong foundation for understanding maintenance operations, It is important to note that there are many other specialised tools used in aviation.

Ground Support Equipment (GSE)

Ground Support Equipment (GSE) refers to the specialised tools and machinery used to support aircraft operations while they are on the ground. GSE enables technicians and ground crews to service, inspect, maintain, and move aircraft safely and efficiently. These tools are essential for tasks such as starting engines, accessing elevated components, refuelling, towing, and stabilising the aircraft during inspections or repairs.

1. **Aircraft Handling Equipment:** This category includes equipment used to move, position, or support the aircraft while on the ground. It includes equipment such as tow bar and tug, wheel chocks, aircraft jacks, and tripod stands, among others.



Figure 4.10: *An aircraft towed by a tug*

2. **Servicing and Power Equipment:** This equipment supports essential systems like electrical power, air pressure, or engine start-up while the aircraft is not running. They may include Ground Power Unit (GPU), Air Start Unit (ASU), Hydraulic test stand and Air Conditioning Unit, among others.



Figure 4.11: *Aircraft connected to Ground Power Unit (GPU)*

3. **Maintenance Access and Safety Equipment:** These are used to support technicians access high or confined areas of aircraft to ensure safety during maintenance. Equipment that falls under this category include maintenance platform/steps, service ladders, among others

GSE are essential to aviation maintenance operations. Whether towing an aircraft into position, supplying power for onboard systems, or enabling access to elevated components, GSE help ensure that aircraft are maintained safely and efficiently while on the ground.

Personal Protective Equipment (PPE)

Personal Protective Equipment (PPE) refers to the clothing and equipment worn by aircraft maintenance personnel to reduce the risk of injury or health hazards while working. In aviation maintenance, technicians are regularly exposed to noise, moving machinery, sharp tools, pressurised systems, chemical substances, and elevated surfaces. PPE is essential for ensuring that individuals can perform maintenance activities safely, efficiently, and in compliance with occupational safety standards.

PPE is not optional and must be worn whenever hazards are present. The type of PPE required is determined by the specific maintenance task being performed. It is a regulatory requirement in all maintenance environments and must always be worn correctly to ensure the safety of personnel.

Purpose of PPE in Aircraft Maintenance

PPE serves several significant purposes during maintenance. The following highlights some of these:

- Protects technicians from injury during inspections, repairs, or servicing tasks
- Complies with national and international safety standards, such as those set by aviation authorities and occupational safety agencies
- Promotes a culture of safety and accountability in maintenance hangars, airside areas, and workshops

Common Types of PPE and Their Uses

The table below summarises some common types of PPE and their uses

	PPE Item	Purpose
	Safety goggles or face shields	Protect the eyes from dust, debris, hydraulic fluid, or sparks
	Protective gloves	Prevent cuts, burns, chemical exposure, or hand fatigue
	Safety boots (steel-toe)	Protect the feet from falling tools or heavy equipment
	Ear protection (earplugs or earmuffs)	Reduce exposure to high noise levels from engines or tools
	High-visibility (hi-vis) vest	Ensure visibility near active aircraft or vehicles
	Coveralls or flame-resistant clothing	Protect against dirt, grease, or sparks
	Respirators or masks	Filter harmful particles or fumes
	Hard hat	Protects head from overhead risks or falling objects



Figure 4.12: *Technician working in full PPE.*

Technicians typically practise safe guidelines in the selection of their PPE. Some of these are as follows:

- Always inspect PPE before use for signs of wear, damage, or contamination.
- Replace disposable items (like gloves or masks) after use or when soiled.
- Never use PPE that is torn, expired, or missing certification labels.
- Ensure PPE **fits properly**. Ill-fitting equipment can create additional hazards.

PPE is an essential for safe and professional aircraft maintenance practice. Whether preventing chemical exposure, hearing damage, or mechanical injuries, the correct use of PPE protects technicians and ensures maintenance work can proceed without unnecessary risk. A strong understanding and respect for PPE requirements not only helps learners develop safe habits but also prepares them for real-world maintenance environments governed by strict safety regulations.

Learning Tasks

1. As a class, discuss why maintenance matters in Aviation. Highlight what could go wrong if maintenance is not properly performed.
2. Draw or list four PPE items used in aircraft maintenance. For each one, write when or why it should be worn. Keep your answers simple but clear.

Pedagogical Exemplars

- **Experiential Learning:** Learners visit an aircraft maintenance facility or watch videos/pictures to learn about maintenance activities. Learners take notes and share with the class. Others add to the presentation. Organise views using a flowchart.
- **Experiential Learning:** Learners visit an aircraft maintenance facility or watch video/pictures to learn about aircraft maintenance equipment. Organise views using a flowchart or webbing.
- **Talk for Learning**
 - o Teacher discusses with learners the regulations that govern aircraft maintenance, including personnel certification.
 - o Teacher presents to learners a case study of aviation incidents due to improper maintenance practices for discussion.

Key Assessment Level 4: Poster Presentation

- You will be given **four maintenance scenarios**, each describing a real-world aircraft maintenance situation. For **each scenario**, complete the following:
 - Classify the type of maintenance** being performed
 - Identify at least three tools or pieces of equipment** that would be required to perform the task safely and effectively.
 - Justify your choices** by explaining:
 - Why the maintenance fits into the category you selected
 - How each tool or piece of equipment contributes to completing the task
 - Any **safety precautions or PPE** that should be used during the procedure

Be thorough in your responses and refer to what you've learned about maintenance procedures, equipment, and task classifications. Your explanations should show a deep understanding of how different elements of aircraft maintenance work together to ensure safety, compliance, and airworthiness. (10 marks) (DOK 4)

- As a group, you will create a **visual poster or chart** that shows your understanding of aircraft maintenance tasks, the tools used, and associated safety requirements. Your task must:
 - Include at least **three types of maintenance tasks** (e.g., routine, scheduled, preventive, or unscheduled), each with a **real-world aviation example** (e.g., “Tyre pressure check before flight” or “100-hour engine inspection”).
 - Identify **specific tools or equipment** commonly used to perform each task (minimum of two per task).
 - List the **personal protective equipment (PPE)** required for at least one of the tasks.
 - Present your chart to the class, and choose **one maintenance category** to explain in detail—describing the tools, steps involved, and safety considerations.

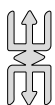
You are expected to demonstrate your ability to **combine what you have learned from different lessons**, show how tools, procedures, and safety work together, and **communicate your reasoning clearly** during your group presentation. (10 marks)

PLC Session 11

45 minutes
Planning & Reviewing the Learning Plan

- Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
- Use your subject specific app to explore the content before planning. Ask the app to
 - explain the week's concepts in a practical way that will make it easier for learners to understand
 - identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
- Use your subject specific app to plan your lesson. Ask the app to
 - suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

- b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
- c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

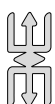
- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
 - a. The key assessment for the week is **poster presentation**. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the poster presentation (NTS 3k-3q).

10 minutes

Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
 - a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
 - b. all teachers in the group work through a similar problem individually for 3–4 minutes
 - c. the group then works through the problem together step by step
 - d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes

Enactment

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).
 - a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
 - b. After the enactment, ask for structured feedback from the group
 - i. was the concept explained in a way that a learner with no prior knowledge could follow?
 - ii. were the examples grounded in contexts familiar to Ghanaian learners?

iii. did any misconceptions surface and if so, how were they addressed?

5 minutes

Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
 - a. transfer your chats into your learning planner template.
 - b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
 - c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 12

Learning Indicators

1. Carry out simple maintenance tasks, according to established standards
2. Make log entries of maintenance activities performed

Focal Area: Aircraft Maintenance

Building on the foundational knowledge of maintenance types, tools, and safety practices covered in the previous week, this week introduces learners to the practical application of aircraft maintenance procedures. The focus is on helping learners understand how to carry out simple maintenance tasks in accordance with established standards, and how to accurately document the work performed. Learners will also be introduced to the role of Maintenance, Repair, and Overhaul (MRO) organisations and the importance of following approved procedures and regulatory guidelines. By the end of the week, learners will have developed both practical insight and the discipline required for safe, standard-compliant maintenance operations.

Introduction to Aircraft Maintenance Standards

Before any maintenance task is performed, it must comply with approved procedures defined by regulatory authorities, aircraft manufacturers, and international industry guidelines. These procedures are collectively referred to as maintenance standards. They include technical specifications, service intervals, inspection criteria, and documentation requirements that guide how maintenance should be carried out to maintain airworthiness and safety.

Maintenance standards are important because they:

- Ensure consistency, safety, and compliance across all maintenance activities
- Prevent shortcuts, errors, or guesswork in aircraft servicing
- Clearly define who is authorised to carry out certain tasks, when they must be done, and how they should be recorded

These standards are set and maintained by a range of organisations at national, regional, and international levels to promote global consistency in aviation maintenance practices.

Entity	Role
National Civil Aviation Authorities (e.g., GCAA – Ghana Civil Aviation Authority)	Enforce national aviation safety and maintenance standards. Approve local MROs and certify personnel.
ICAO (International Civil Aviation Organisation)	Provides global frameworks and recommended practices for aviation safety, including maintenance guidance.
EASA / FAA (European Union Aviation Safety Agency / U.S. Federal Aviation Administration)	Develop technical standards and airworthiness regulations in Europe and the U.S. Their publications are widely referenced worldwide.
Aircraft Manufacturers (OEMs)	Publish Aircraft Maintenance Manuals (AMMs) and Service Bulletins (SBs) that specify maintenance procedures for each aircraft model. These are mandatory references during maintenance.

Maintenance Procedures and Documentation

All aircraft maintenance tasks must be performed in strict accordance with both the **Aircraft Maintenance Manual (AMM)** and the organisation's **Standard Operating Procedures (SOPs)**. These two resources serve different but complementary roles in ensuring that maintenance is performed safely, correctly, and in compliance with regulatory requirements.

The **Aircraft Maintenance Manual (AMM)** is issued by the aircraft manufacturer and provides **aircraft-specific technical instructions** on how to carry out inspections, servicing, and repairs. It contains detailed procedures, specifications, approved materials, torque values, and diagrams. Technicians must **always follow the AMM** to ensure tasks are done to the exact technical requirements of that aircraft model.

In contrast, **Standard Operating Procedures (SOPs)** are developed by the airline or Approved Maintenance Organisation. SOPs guide how maintenance is carried out **within the organisation**, detailing **internal workflows, safety protocols, and documentation procedures**. They support the practical implementation of the AMM and ensure consistency across the maintenance team.

Together, the AMM and SOPs ensure that:

- All maintenance work is **technically correct** (AMM)
- All processes are **consistently applied and recorded** (SOPs)

In addition to following approved procedures, **documentation is a critical part of maintenance**. Every maintenance action must be properly recorded in a logbook or maintenance tracking system. In many cases, the work must also be **certified by a licensed engineer** to confirm that the task was performed correctly and the aircraft remains airworthy.

Only **certified personnel** are authorised to perform and sign off specific tasks listed in the approved **maintenance programme**, which itself is based on manufacturer guidance and approved by the national aviation authority (e.g., the Ghana Civil Aviation Authority).

Approved Maintenance Organisations (AMO) or Maintenance, Repair and Overhaul (MRO) Organisations

An Approved Maintenance Organisation (AMO) is a company or facility that is formally authorised by a national civil aviation authority to perform aircraft maintenance in accordance with approved standards and procedures. In Ghana, AMOs are certified and regulated by the Ghana Civil Aviation Authority (GCAA), which ensures that the organisation meets all safety, personnel, equipment, and facility requirements.

AMOs play a critical role in ensuring that aircraft are properly maintained, airworthy, and compliant with both national and international regulations. They are responsible for carrying out various types of maintenance, including routine checks, scheduled inspections, repairs, and overhauls.

The term MRO (Maintenance, Repair, and Overhaul) is often used in the aviation industry to refer to these organisations as well, especially in commercial and international contexts. However, AMO is the formal regulatory term used by authorities/organisations such as GCAA, ICAO, and EASA.

AMOs or MROs often handle the following types of maintenance:

- **Line Maintenance:** Performed at the airport gate or ramp, includes pre-flight checks, minor repairs, and servicing between flights
- **Base Maintenance:** Conducted in a hangar and includes more in-depth work such as heavy checks, component replacements, and structural inspections.

Performing a Basic Maintenance Task According to Procedure

This lesson builds on learners' understanding of aircraft maintenance standards and the role of AMOs or MROs. The focus is to give learners a practical introduction to carrying out a simple maintenance task, such as a tyre pressure check, fluid level inspection, or pre-flight visual inspection, while applying the correct procedure. Emphasis should be placed on following safety protocols, using checklists, and referring to manuals or SOPs as applicable. Where practical tools or aircraft are unavailable, simulated tasks using models or checklists should be used.

Preparing for the Task

Before learners begin any maintenance activity, it is essential to introduce them to the proper steps for preparation, which mirrors the discipline and procedures followed by licensed technicians in real-world aviation environments. Good preparation not only ensures that the task is completed safely and correctly, but also helps instil in learners the importance of following standard operating procedures and checklists.

In this phase, guide learners to carry out the following:

- **Identify and wear the required personal protective equipment (PPE):** Depending on the task, this may include safety gloves, goggles, coveralls, ear protection, or high-visibility vests. Emphasise that PPE is mandatory and is the first step before approaching any aircraft or maintenance area.
- **Gather the appropriate tools for the task:** For example, a tyre pressure gauge for checking landing gear tyres, a dipstick for inspecting oil levels, or an inspection torch and mirror for a visual pre-flight check. Ensure learners know the names of the tools and their purposes.
- **Review the applicable procedure:** Provide learners with a printed checklist, Standard Operating Procedure (SOP), or a page from a simulated Aircraft Maintenance Manual (AMM). Learners should read and understand the steps before beginning the task, noting any safety precautions or sequence of actions.
- **Ensure the aircraft or model is secured and safe to approach:** In a live or simulated environment, learners should be trained to check that the aircraft is stationary, chocked, or correctly stabilised before starting work. This reinforces awareness of environmental safety and ground handling protocols.

***Teaching Tip:** In the absence of an aircraft or aircraft model, teachers can use a **car, motorcycle, or bicycle** to demonstrate basic maintenance procedures—such as fluid checks, tyre inspection, or visual walkarounds. This helps reinforce the **concept of systematic preparation** and allows learners to grasp key principles before applying them in an aviation-specific context.*

Example Maintenance Tasks (Choose One or Simulate)

Option A: Tyre Pressure Check

- Use a tyre pressure gauge on a training model or cut-out
- Read and record the pressure value
- Compare it to the acceptable range from a sample manual or SOP

Option B: Oil Level Inspection

- Use a mock-up dipstick and container
- Demonstrate removing, wiping, reinserting, and reading the oil level
- Discuss what actions to take if the level is too low

Option C: Pre-flight Visual Inspection

- Walk around a training model or aircraft image
- Inspect key areas: tyres, lights, control surfaces, fuel cap, pitot tube
- Use a printed checklist to tick off each step

Maintenance Log Entry and Reflection

In aviation maintenance, performing a task correctly is only part of the job. **Documenting what was done, when, how, and by whom** is just as critical. Accurate log entries are essential for tracking the airworthiness of an aircraft, confirming regulatory compliance, and ensuring that no step in the maintenance process is missed or repeated unnecessarily. A maintenance record refers to the broader collection of all documentation related to the maintenance history of an aircraft or component.

This lesson teaches learners how to **complete a basic maintenance log entry** following a simple task (real or simulated) and encourages them to **reflect on the maintenance process**, focusing on what they learned, what went well, and what could be improved.

Aviation Maintenance Daily Log Sheet

DATE :		A/C REG :	
MAINTENANCE TYPE	TASK DESCRIPTION		TOOLS USED
ENGINEER SIGNATURE :		INSPECTOR SIGN-OFF :	
NOTES / FINDINGS			

Purpose of Maintenance Logs or Records

Maintenance records or logs serve several purposes in aviation. Some of these are:

- Maintenance records provide a legal and historical record of all work done on an aircraft.
- They improve equipment management by supporting maintenance planning to optimise equipment lifespan.
- They ensure compliance since they are required by aviation authorities and subject to inspection.
- A proper log entry provides documented evidence that the aircraft is airworthy, and that the maintenance was performed in line with approved standards. In commercial aviation, poor or missing records can lead to grounding of aircraft, fines, or safety incidents.

Components of a Basic Maintenance Log Entry

The table below outlines the typical fields found in a basic aircraft maintenance log entry. While these fields are commonly used across the industry, it is important to note that there is no universally fixed format. The specific content and structure of a maintenance log may vary depending on national aviation regulations, airline or AMO (MRO) policies, and aircraft type. However, all entries must be clear, traceable, and accurate, especially for tasks that affect the airworthiness of the aircraft.

Field	Purpose
Date & Time	Indicates when the maintenance task was performed
Aircraft/Component ID	Identifies the aircraft or specific component involved (e.g., aircraft registration or part number)
Task Performed	A concise description of the maintenance action (e.g., “tyre pressure check”, “engine oil replenished”)
Tools/Materials Used	Lists tools, equipment, or materials involved in the task
Outcome	States the result of the maintenance task (e.g., “Serviceable”, “Adjusted”, “Replaced”)
Signature/Initials	Identifies the technician or engineer who completed or supervised the task
Remarks/Notes (Optional)	Provides additional information, observations, or follow-up actions if necessary

In completing a log entry technician must ensure they:

- use clear, concise, and accurate language
- avoid slang, vague wording or guesswork
- use only approved abbreviations (if taught)
- double-check entries for errors before submission
- note reasons for not completing maintenance tasks.

Learning Task

With a partner, act out the steps in a maintenance checklist provided (e.g., tyre check or visual inspection). Take turns reading the steps and demonstrating how they would be done. Follow the checklist exactly.

Pedagogical Exemplars

Talk for Learning

1. Teacher discusses with learners the regulations that govern aircraft maintenance, including personnel certification.
2. The teacher presents to learners a case study of aviation incidents due to improper maintenance practices for discussion.

Experiential Learning: Visit a workshop to undertake maintenance duties under the supervision of resource persons.

Talk for Learning: Through a question-and-answer session, learners brainstorm what a logbook is. Show learners what a logbook is using videos or pictures.

Project-Based Learning: In pairs/ small groups, learners develop a logbook and make entries of maintenance activities. Using manila cards and display in class for comments. Encourage learners to respect and tolerate others' comments.

Key Assessment: Practice Paper 1

1.
 - (i) Create your own **Standard Operating Procedure (SOP)** for a **basic maintenance task of your choice**. Your task must include the following:
 - Create a brief SOP for your selected task that includes:
 - A **clear title** and purpose of the procedure
 - **Step-by-step instructions** for how to safely carry out the task
 - A list of **required tools and materials**
 - The **personal protective equipment (PPE)** needed
 - Any **safety checks or precautions** to follow before, during, or after the task
 - (ii) Design a simple maintenance log template that could be used to record this task. Your log must include:
 - Fields for **date, time, task performed, tools used, outcome, and signature**
 - Space for **remarks or additional notes**
 - A **clean, organised layout** that mirrors real logbooks
 - (iii) Fill out your log template with a **sample log entry** as if you performed the task according to your SOP. Ensure your language is clear, professional, and uses appropriate aviation terminology.
 - (iv) Write a short explanation (5–7 sentences) that explains:
 - How your SOP reflects **approved maintenance standards** (e.g., use of checklists, PPE, sequencing)
 - How your log format ensures **accurate documentation, traceability, and safety compliance**
 - Why standardisation and good documentation practices matter in aviation maintenance

HINT



Conduct **Practice Paper 1**. It should cover contents taught from Year 1 to 3. Refer to the **Table of Specification and Structure of the Paper** at the end of this section to guide you. Learners' papers should be marked immediately and scores entered into the SAP.

ITEM SPECIFICATION FOR PRACTICE EXAMINATION 1

1. PAPER 1 (Objective test)

S/N	Strand	Sub-strand	Content standard	Learning indicator	Number of items				Total
					DOK 1	DOK 2	DOK 3	DOK 4	
1	Core concepts in Aerospace Engineering	Fundamentals of flight	Demonstrate knowledge and understanding of the evolution of flight	Describe the stages that led to the attainment of powered, controlled flight	2				2
			Demonstrate understanding of flight vehicle nomenclature	Differentiate the types of aerospace vehicles	1				1
				Make freehand sketches of current and future aerospace vehicles, labelling their major parts				1	1
			Show understanding of safety regulations in the aerospace laboratory	Discuss the advantages of adhering to safety precautions in the laboratory (Aerospace, Physics, Electrical/Electronics)	1				1
		Aerodynamics and Propulsion	Demonstrate knowledge of the properties of the international standard atmosphere	Identify and measure the elements of weather using the appropriate instruments		1			
				Explain the impact of altitude on the state of the atmosphere.			2		2
			Demonstrate knowledge and understanding of the balance of forces acting on an aerospace vehicle in flight	Calculate the lift, drag and weight of an aircraft			1		1

						1		1	2
		Demonstrate understanding of the force required for propulsion of an aerospace vehicle	Explain the principles of operation of the different propulsion systems: rockets, jet engines, internal combustion (spark) engines			1		1	2
	Aircraft Structures and Control	Demonstrate knowledge of various types of aircraft construction	Identify the right material for construction of a small UAV.				1		1
		Demonstrate understanding of how an aerospace vehicle (aircraft, spacecraft) is controlled in flight	Describe the flight controls (and control surfaces) of a fixed-wing aircraft				2		2
		Demonstrate knowledge and understanding of the factors that account for the stability of an aerospace vehicle	Apply the understanding of moments in Physics to aircraft movement to explain stability configurations.			2			2
2	Avionics	Demonstrate knowledge of the various classes of avionics systems	Illustrate avionics systems in relation to the monitoring abilities of dogs or other animals in security for surveillance			1			1
		Demonstrate knowledge of the vast functions of avionics systems.	Explain the functions of avionics navigation systems			1			1
	Aircraft instrumentation	Demonstrate knowledge of the instruments used for airborne and ground operations and their principles of operations.	Relate the physical variables that are measured in aircraft applications with the instruments used to measure them			1			1
			Explain the principles of operation of the aircraft instruments			1			1

3	Aviation industry		Demonstrate an understanding of flight data storage in aircraft	Identify the salient features of flight data storage equipment, how data was previously stored and the importance of flight data storage.	1					1
			Communication, navigation and surveillance systems	Identify the different communications technologies used in the aviation industry	1					1
				Illustrate the pros and cons of each aviation communication technology			1			1
				Explain the concept of navigation (dead reckoning and position fixing)	1					1
			Demonstrate an understanding of the different navigation systems used in aircraft and spacecraft	Identify the advantages and disadvantages of the different navigation technologies			1			1
			Demonstrate knowledge of the different aerospace surveillance technologies	Present a summary of ground-based surveillance systems	1		1			2
			Demonstrate knowledge of various career paths in the aviation industry	Describe the various career paths in the aviation industry		1				1
		Aviation organisations	Demonstrate knowledge of the various operations in the aviation industry.	Identify the roles of professionals in the aviation industry.		1				1
			Aviation organisations	Identify the major aviation agency in Ghana and its key operations	1					1
				Identify global aviation agencies	1					1

			Demonstrate understanding of the roles of the aviation agencies in ensuring the safety of air transport	Explain the functions of ICAO, IATA, FAA, EASA etc.	1				1
	Aircraft maintenance		Demonstrate knowledge of aircraft maintenance activities	Classify various maintenance tasks as routine, periodic, etc.	1				1
			Demonstrate knowledge of aircraft maintenance standards and certification	Carry out simple maintenance tasks according to established standards	1				1
	UAV applications		Demonstrate knowledge and understanding of the types of UAVs	Explain the principles of operation of UAVs	1				1
			Demonstrate knowledge of the various uses of UAVs	Describe civilian uses of Unmanned Aerial Vehicles	1				1
	UAV safety and regulations		Show understanding of safety regulations for building and operating UAVs.	Evaluate official regulations relating to the possession and operation of UAVs.	1				1
	Design and fabrication of UAVs		Demonstrate knowledge of how to develop and evaluate conceptual designs of UAVs.	Apply evaluation tables to select the best concept from a number of UAV concepts.			1		1
			Demonstrate knowledge of how to undertake basic UAV design calculations.	Perform simple calculations that yield the properties (such as wing area, number of motors, propellant, etc.) for a small UAV.	1				1
			Demonstrate knowledge and understanding of how to fabricate and test a selected design.	Fly the fabricated UAV.	1				1
	Total				12 (30%)	16 (40%)	12 (30%)		40 (100%)

2. PAPER 2 (Written)

S/N	Strand	Sub-strand	Content standard	Learning indicator	Number of items				Total
					DOK 1	DOK 2	DOK 3	DOK 4	
SECTION A									
Q1	Core concepts in Aerospace engineering	Fundamentals of flight	Demonstrate understanding of flight vehicle nomenclature	Make freehand sketches of current and future aerospace vehicles, labelling their major parts	2				2
	Avionics	Fundamentals of Avionics	Demonstrate knowledge of the various classes of avionics systems	Discuss avionics systems in relation to traditional musical instruments and dance for communication.		1			1
	Unmanned aerial vehicles	UAV applications	Demonstrate knowledge of the various uses of UAVs	Examine the military applications of Unmanned Aerial Vehicles (UAVs)	1				1
				Describe civilian uses of Unmanned Aerial Vehicles					

SECTION B									
Q2	Core concepts in Aerospace Engineering	Aerodynamics and Propulsion	Demonstrate knowledge of the properties of the international standard atmosphere	Explain the impact of altitude on the state of the atmosphere.				3	3
Q3		Aircraft Structures and Control	Demonstrate knowledge of various types of aircraft construction	Identify the right material for construction of a small UAV.	2	1			3
			Demonstrate knowledge and understanding of the factors that account for the stability of an aerospace vehicle	Apply the understanding of moments in Physics to aircraft movement to explain stability configurations.	1	1			2
SECTION C									
Q4	Avionics	Aircraft instrumentation	Demonstrate knowledge of the instruments used for airborne and ground operations and their principles of operations.	Explain the principles of operation of the aircraft instruments		1		2	3

						Identify the salient features of flight data storage equipment, how data was previously stored and the importance of flight data storage.				1	1
Q5		Communication, navigation and surveillance systems	Demonstrate an understanding of flight data storage in aircraft		1	Identify the different communications technologies used in the aviation industry	1			1	1
			Demonstrate knowledge of the different communication technologies used in aviation			Illustrate the pros and cons of each aviation communication technology				1	1
			Demonstrate an understanding of the different navigation systems used in aircraft and spacecraft		1	Explain the concept of navigation (dead reckoning and position fixing)	1	1			2

SECTION D									
Q6	Aviation industry	Aviation organisations	Demonstrate understanding of the relationship between aerospace and aviation organisations and how this helps to regulate operations.	Identify the major aviation agency in Ghana and its key operations	2		1		3
				Identify global aviation agencies					
			Demonstrate understanding of the roles of the aviation agencies in ensuring the safety of air transport	Identify the functions of local aviation organisations					
				Explain the functions of ICAO, IATA, FAA, EASA etc.					
Q7		Aircraft maintenance	Demonstrate knowledge of aircraft maintenance activities	Classify various maintenance tasks as routine, periodic, etc.	1				1
				Identify aircraft maintenance equipment.	2		1		3

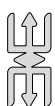
3. PAPER 3 (Practical)

S/N	Strand	Sub-strand	Content standard	Learning indicator	Number of items				Total
					DOK 1	DOK 2	DOK 3	DOK 4	
Q1	Unmanned aerial vehicles (UAVs)	Design and fabrication of UAVs	Demonstrate knowledge of how to develop and evaluate conceptual designs of UAVs.	Generate UAV concepts given a set of mission requirements.			1		1
				Apply evaluation tables to select the best concept from a number of UAV concepts.					
			Demonstrate knowledge of how to undertake basic UAV design calculations.	Perform simple calculations that yield the properties (such as wing area, number of motors, propellant, etc.) for a small UAV.					
				Build a small UAV (aircraft/rocket) using locally available materials					
			Demonstrate knowledge and understanding of how to fabricate and test a selected design.	Fly the fabricated UAV.					

PLC Session 12

45 minutes
Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
 - a. explain the week's concepts in a practical way that will make it easier for learners to understand.
 - b. identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
 - a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
 - b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).
 - c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

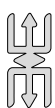

Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Use your app to plan and administer the mode of assessment for the student Assessment Portal (SAP).
 - a. The key assessment for the week is **practice paper 1**. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/rubrics for the practice paper (NTS 3k-3q).

10 minutes
Content Exploration

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
 - a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
 - b. all teachers in the group work through the problem individually for 3–4 minutes
 - c. the group then works through the problem together, step by step
 - d. highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).


Note

- This part is not 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.

- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes**Enactment**

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).
 - a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
 - b. After the enactment, ask for structured feedback from the group
 - i. was the concept explained in a way that a learner with no prior knowledge could follow?
 - ii. were the examples grounded in contexts familiar to Ghanaian learners?
 - iii. did any misconceptions surface and if so, how were they addressed?

5 minutes**Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
 - a. transfer your chats into your learning planner template.
 - b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
 - c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 4 Review

Over the two-week period, learners explored both the theoretical foundations and practical applications of aircraft maintenance. Week 11 introduced key maintenance concepts, including the classification of maintenance tasks—such as routine, scheduled, preventive, and unscheduled—and familiarised learners with essential maintenance tools, ground support equipment, and personal protective equipment (PPE). In Week 12, learners examined the importance of maintenance standards, procedures, and documentation, along with the role of Approved Maintenance Organisations (AMOs). They engaged in guided practice by performing simple maintenance tasks and completing log entries according to established procedures, reinforcing the connection between hands-on work, safety protocols, and regulatory compliance.



MARKING SCHEMES FOR THE KEY ASSESSMENTS

UNIT 11

Question 1

Criteria	Marks	Example of What Earns This Mark
Accurate Classification of Maintenance Type	2	All 4 scenarios correctly classified (e.g., tyre pressure check → Routine, oil change after 100 hours → Scheduled, lubrication → Preventive, replacing failed starter → Unscheduled).
	1	2–3 scenarios correctly classified; others misclassified or unclear (e.g., preventive labelled as routine).
	0	Most or all classifications incorrect or missing.
Identification of Appropriate Tools/Equipment	2	At least 3 relevant tools named per scenario (e.g., tyre pressure gauge, dipstick, torque wrench).
	1	1–2 tools per scenario, some vague or partially correct (e.g., “toolbox”, “spanner” without explanation).
	0	Tools not listed, irrelevant, or completely inaccurate.
Justification of Maintenance Classification	2	Clear reasoning provided (e.g., “This is preventive because it avoids future faults through regular lubrication.”).
	1	Attempted justification but lacks clarity or accuracy (e.g., “It is scheduled because we check it.”).
	0	No explanation or unrelated answer.
Explanation of Tool Use and Relevance	2	Accurate link between tool and task (e.g., “The dipstick is used to check oil level before topping up.”).
	1	General or vague use of tool (e.g., “A wrench is used to fix things.”).
	0	No explanation or incorrect use described.
Integration of Safety and Procedural Knowledge	2	Mentions PPE and task-specific safety (e.g., gloves for fluid handling, checklist used as per SOP).
	1	Safety or procedures mentioned generally (e.g., “Be careful” or “Use checklist”), but lacks task-specific detail.
	0	No mention of safety or procedures.

Question 2

Criteria	Marks	What Earns the Mark
1. Accurate Description of Maintenance Tasks and Examples	0–2	2 – All 3 tasks correctly categorised with clear, aviation-related examples. 1 – 2 tasks completed correctly; 1 unclear or missing. 0 – Fewer than 2 accurate tasks or vague/general examples.

2. Correct Identification of Tools/ Equipment per Task	0–2	2 – At least 2 tools correctly matched per task; total of 6+ tools. 1 – 1 tool per task, or minor mismatches. 0 – Tools mostly incorrect, vague, or missing.
3. Inclusion and Relevance of PPE	0–2	2 – Relevant PPE listed and linked to at least one task (e.g., gloves for fluid checks). 1 – PPE mentioned but vague or not clearly tied to a task. 0 – No mention of PPE.
4. Depth of Presentation and Explanation	0–2	2 – One task explained in detail during presentation, showing understanding of procedures, tools, and safety. 1 – Task explained, but lacks depth or clarity. 0 – Task explanation unclear or missing.
5. Team Collaboration and Visual Clarity	0–2	2 – All members participate; poster/chart is clear, well-organised, and visually supports the content. 1 – Some collaboration or visual issues; mostly clear. 0 – Poor participation or unclear presentation.

UNIT 12

(10 marks) (DOK 4)

Criteria	Marks	What This Looks Like
1. SOP Completeness and Accuracy	0–3	3 – Clear title, steps, tools, PPE, and safety measures; accurate and realistic. 2 – Mostly complete, with minor omissions or unclear steps. 1 – Basic structure present, but vague or missing essential elements. 0 – Incomplete or off-topic.
2. Maintenance Log Template Design	0–2	2 – Well-organised, contains all required fields, professional layout. 1 – Some key fields present, but layout or clarity could be improved. 0 – Poorly structured, missing key fields.
3. Sample Log Entry	0–2	2 – Realistic, clearly written, uses correct aviation terminology. 1 – Attempt made, but lacks detail or accuracy. 0 – Missing or irrelevant entry.

<i>4. Justification and Reasoning</i>	<i>0–3</i>	<i>3 – Clear, thoughtful explanation linking SOP and log to standards, traceability, and safety.</i> <i>2 – Reasonable explanation with some relevant points.</i> <i>1 – Basic justification with weak reasoning.</i> <i>0 – No explanation or unrelated response.</i>
---------------------------------------	------------	---

SECTION 5: UAV DESIGN

STRAND: UNMANNED AERIAL VEHICLES (UAVS)

Sub-Strand: Design and Fabrication of UAVs

Weeks 13 & 14

Learning outcome: *Make sketches of several UAV concepts to satisfy stipulated mission requirements.*

Content standard: *Demonstrate knowledge of how to develop and evaluate conceptual designs of UAVs.*

Weeks 15 & 16

Learning outcome: *Determine by analytical means, the physical properties of a UAV.*

Content standard: *Demonstrate knowledge of how to undertake basic UAV design calculations.*

INTRODUCTION AND SECTION SUMMARY

In this section we will examine the principles of aircraft conceptual design. This will involve an assessment of the problem that requires the design, development of requirements for the aircraft, development of candidate concepts and selection of the “best” concept and conclude with performing design calculations of the size of the aircraft when constructing/building the model in the subsequent section.

The weeks and the indicators covered by the section are:

- **Weeks 13 & 14**
 - o Generate UAV concepts given a set of mission requirements.
 - o Apply evaluation tables to select the best concept from a number of UAV concepts.
- **Weeks 15 & 16**
 - o Perform simple calculations that yield the properties (such as wing area, number of motors, propellant, etc.) for a small UAV.

Recap weeks

Year 1	Week 3: Differentiate the types of aerospace vehicles. Week 4: Make freehand sketches of current and future aerospace vehicles, labelling their major parts. Weeks 19 – 21: • Examine the military applications of Unmanned Aerial Vehicles (UAVs). • Describe civilian uses of Unmanned Aerial Vehicles.
Year 2	Weeks 4 – 8: • Distinguish between the four major forces (lift, drag, thrust and weight) that act on an aerospace vehicle in flight • Calculate the lift, drag and weight of an aircraft Weeks 9 – 12: • Explain the principles of operation of the different propulsion systems: rockets, jet engines and internal combustion (spark) engines. • Calculate the thrust generated from different power sources, e.g., battery and internal combustion engines (rocket, jet engine and internal piston engine).
Year 3	Weeks 1 – 4: • Identify the right materials for construction of a small UAV. • Evaluate the different types of aircraft construction.

SUMMARY OF PEDAGOGICAL EXEMPLARS

1. Experiential learning
2. Group work
3. Project-based learning

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/or Mode
Generate UAV concepts given a set of mission requirements. Apply evaluation tables to select the best concept from a number of UAV concepts.	4	Project work
Perform simple calculations that yield the properties (such as wing area, number of motors, propellant, etc.) for a small UAV.	2	Research work

WEEKS 13 & 14

Learning Indicators

1. *Generate UAV concepts given a set of mission requirements*
2. *Apply evaluation tables to select the best concept from a number of UAV concepts*

Focal Area: **Development of UAV concepts**

The lessons for this week and the next will focus on defining the aircraft/UAV design problem, developing requirements to be met by the design, generating concepts that satisfy the design requirements and how to select the best concept out of the proposed ones. Let us begin with the first item.

Defining the aircraft/UAV design problem

All of engineering is aimed at applying science to solve society's problems. This is the starting point of the design process and is the same for any aircraft design. It sets the foundation for a successful UAV development project. It involves identifying the mission requirements, operational environment, performance objectives, and constraints that will guide the design process. A well-defined problem statement ensures that the final UAV meets the intended purpose and operates effectively within its intended environment.

Mission requirements form the core of the UAV's purpose and functionality. The primary mission must be clearly articulated, specifying whether the UAV is intended for surveillance, reconnaissance, delivery, agricultural applications, or another purpose. Determining the payload is also essential, including its type, size, weight, and power requirements, whether it involves cameras, sensors, communication equipment, or cargo. Furthermore, the required range, indicating the maximum distance the UAV must travel, and the endurance, representing the flight time, need to be defined. The operational altitude should also be specified, considering factors such as terrain, weather, and airspace regulations.

The operational environment significantly impacts the UAV's design and capabilities. This includes considering the weather conditions in which the UAV will operate, such as temperature, wind speed, precipitation, and humidity, which can affect its performance and durability. The terrain over which the UAV will fly, whether it be mountains, forests, urban areas, or open water, influences the design of its navigation and control systems. Additionally, adherence to airspace regulations and restrictions in the operational area, including no-fly zones and altitude limitations, is paramount for safe and legal operation.

Performance objectives dictate how well the UAV must perform its mission. The required cruising speed, maximum speed, and stall speed must be defined to ensure the UAV can effectively navigate its environment.

Constraints place practical limitations on the design and development process. The budget available for the design, development, and production of the UAV must be established to guide material selection and design complexity. Limits on the overall size and weight of the UAV, considering factors such as transportability and launch/recovery requirements, influence the structural design. The available power sources and their limitations, including battery capacity or fuel consumption, affect the UAV's endurance and operational capabilities. The materials selected for the UAV structure should be appropriate, considering factors such as strength, weight, cost, and environmental resistance. Finally, compliance

with all applicable regulations and standards, including those related to safety, airspace, and environmental protection, is essential for responsible UAV design.

By carefully considering these factors and developing a comprehensive problem statement, we can ensure that the UAV design process is focused, efficient, and aligned with the intended goals.

An example problem statement is:

Design a small, lightweight UAV system to be used for monitoring crop health over a 5-acre farm. The UAV must be able to capture high-resolution imagery of the crops, operate for at least 15 minutes on a single battery charge, and withstand typical weather conditions in a farming community. The UAV system must be affordable, easy to operate, and comply with all relevant aviation regulations.

We will use this problem throughout the rest of this section.

Developing requirements

It is always said that “failing to plan is planning to fail”. Before we begin to design the aircraft, it is necessary that we identify our design goals. These are referred to as requirements. Requirements serve as the foundation for the entire project, guiding the design process, informing testing and validation, and ensuring that the final product meets the intended needs and expectations. Well-written requirements minimise ambiguity, reduce the risk of errors, and facilitate effective communication among stakeholders. This requires that our requirements are clear, complete, verifiable, consistent, traceable and feasible.

Clarity in writing requirements is paramount. Requirements should be written in clear, simple, and unambiguous language. It is important to avoid jargon, technical terms, and vague words that can be interpreted in multiple ways. Each requirement should have only one possible meaning to prevent misunderstandings and ensure everyone involved has the same understanding.

Completeness ensures that all aspects of the UAV system are covered. Requirements should encompass performance, functionality, safety, reliability, and regulatory compliance. It is essential to address the needs of all stakeholders and ensure that no essential aspects are overlooked. A comprehensive set of requirements leaves no room for assumptions and ensures all critical areas are considered.

Verifiability is essential to confirm that the requirements have been met. Each requirement should be verifiable through testing, analysis, inspection, or demonstration. Avoid subjective terms that cannot be objectively measured, ensuring that verification can be performed accurately.

Consistency ensures that the requirements do not conflict with each other. Requirements should be consistent, with no contradictions or conflicts. Different requirements should not impose conflicting demands on the system. Ensuring consistency prevents design conflicts and ensures the UAV system can meet all specified requirements simultaneously.

Feasibility ensures that the requirements are realistic and achievable. Requirements should be technically and economically feasible. We must avoid setting requirements that are impossible or impractical to achieve within the available resources and technology. Setting feasible requirements ensures that the project can be completed successfully within the given constraints.

The requirements may be derived by considering the desired functionality, performance, safety features, as well as regulatory demands of the UAV. (Refer back to Year 2, week 9, Principles of Aerospace Propulsion; week 11, Estimating thrust of Jet Engines)

A sample set of requirements from the problem we defined earlier are:

1. The UAV shall capture imagery with a minimum resolution of 12 megapixels.
2. The UAV shall have a minimum flight endurance of 15 minutes on a single battery charge.

3. The UAV shall be capable of operating in wind speeds up to 15 km/h and light rain conditions.
4. The UAV shall be capable of monitoring a 5-acre farm in a single flight.
5. The UAV system shall be operable by a single user with minimal training.
6. The UAV shall comply with all applicable aviation regulations for small, unmanned aircraft systems as specified by the GCAA.
7. The total cost of the UAV system (including the UAV, ground control station, and necessary accessories) shall not exceed GHS 20,000.
8. The UAV shall have a maximum take-off weight of 5 kg to ensure portability and ease of handling.

Developing evaluation criteria

It is often the case that more than one solution to the design problem is possible. However, we often must select one. Developing clear and comprehensive evaluation criteria is therefore essential for assessing the performance and suitability of a UAV design. These criteria provide a structured framework for comparing different design options, identifying strengths and weaknesses, and making informed decisions throughout the development process. Well-defined evaluation criteria ensure that the final UAV meets the intended mission requirements and operates effectively within its operational environment. (Refer back to Year 3, weeks 1 & 2: Identify the right materials for construction of a small UAV. And weeks 3 & 4: Evaluate the different types of aircraft construction.)

The first step involves identifying Key Performance Parameters (KPIs). We begin by pinpointing the most critical performance parameters that directly impact the UAV's ability to fulfil its mission. These KPIs should be measurable, relevant, and aligned with the overall project objectives. Examples of KPIs include flight endurance, payload capacity, range, speed, stability, image resolution, and data transmission rate, each serving as a crucial indicator of the UAV's capabilities.

Next, we define metrics and measurement methods for each KPI. Specify the particular metrics that can be used to quantify performance, ensuring they are objective and easily measurable. Examples of metrics include flight time, measured in minutes, payload weight, measured in kilograms, range, measured in kilometres, and image resolution, measured in megapixels.

Establish target values and thresholds for each metric to set performance benchmarks. Set target values for each metric, representing the desired level of performance, ensuring they are realistic and achievable based on the available technology and resources. Define threshold values for each metric, representing the minimum acceptable level of performance; designs failing to meet these thresholds may require significant modifications.

Assign weights to the criteria to reflect their relative importance. Criteria that are more critical to the success of the mission should be assigned higher weights, indicating their greater significance in the overall evaluation. Ensure that the weights sum to 1 (100%) to ensure that all criteria are considered in the overall evaluation and that the weighting is balanced.

Develop a scoring system that assigns numerical scores to each design based on its performance against the evaluation criteria. The scoring system should be objective and transparent, with clear guidelines for assigning scores to minimise bias. A common approach is to use a scale from 1 to 5 or 1 to 10, with higher scores indicating better performance and guiding decision-making.

Finally, consider qualitative factors that may not be easily measurable but are still important to the overall evaluation. Examples of qualitative factors include ease of use, maintainability, safety, and aesthetics, which can significantly impact the practical application of the UAV. Develop a system for assessing and scoring these qualitative factors, using subjective ratings or expert opinions to provide a comprehensive evaluation.

Table 5.1 provides a structured framework for evaluating different UAV designs based on our design problem, based on key criteria, allowing for a more objective and informed decision-making process.

Table 5.1: Evaluation criteria

Criterion	Description	Weight	Metric	Target Value	Threshold Value	Scoring
Image Quality	Ability to capture clear and detailed images of crops for health assessment.	0.2	Image Resolution	12 Megapixels	8 Megapixels	1: <8 MP, Unusable. 2: 8–9 MP, Poor. 3: 10–11 MP, Acceptable. 4: 12–13 MP, Good. 5: >13 MP, Excellent
Flight Endurance	Duration of flight on a single battery charge.	0.2	Flight Time	15 minutes	12 minutes	1: <12 min, Unacceptable. 2: 12–13 min, Poor. 3: 14 min, Acceptable. 4: 15–16 min, Good. 5: >16 min, Excellent
Ease of Use	How easy the system is to operate, deploy, and maintain.	0.3	Training Time, Deployment Time	Training: <4 hours, Deployment: <10 min	Training: <8 hours, Deployment: <15 min	1: Complex, requires extensive training. 2: Difficult, long setup. 3: Moderate, some training. 4: Easy to use, quick setup. 5: Very intuitive, minimal setup
Cost	Total cost of the system.	0.3	Total System Cost	GHS 20,000	GHS 25,000	1: >GHS 30,000, Unaffordable. 2: GHS 25,000–30,000, Expensive. 3: GHS 20,000–25,000, Moderate. 4: GHS 15,000–20,000, Good. 5: <GHS 15,000, Excellent

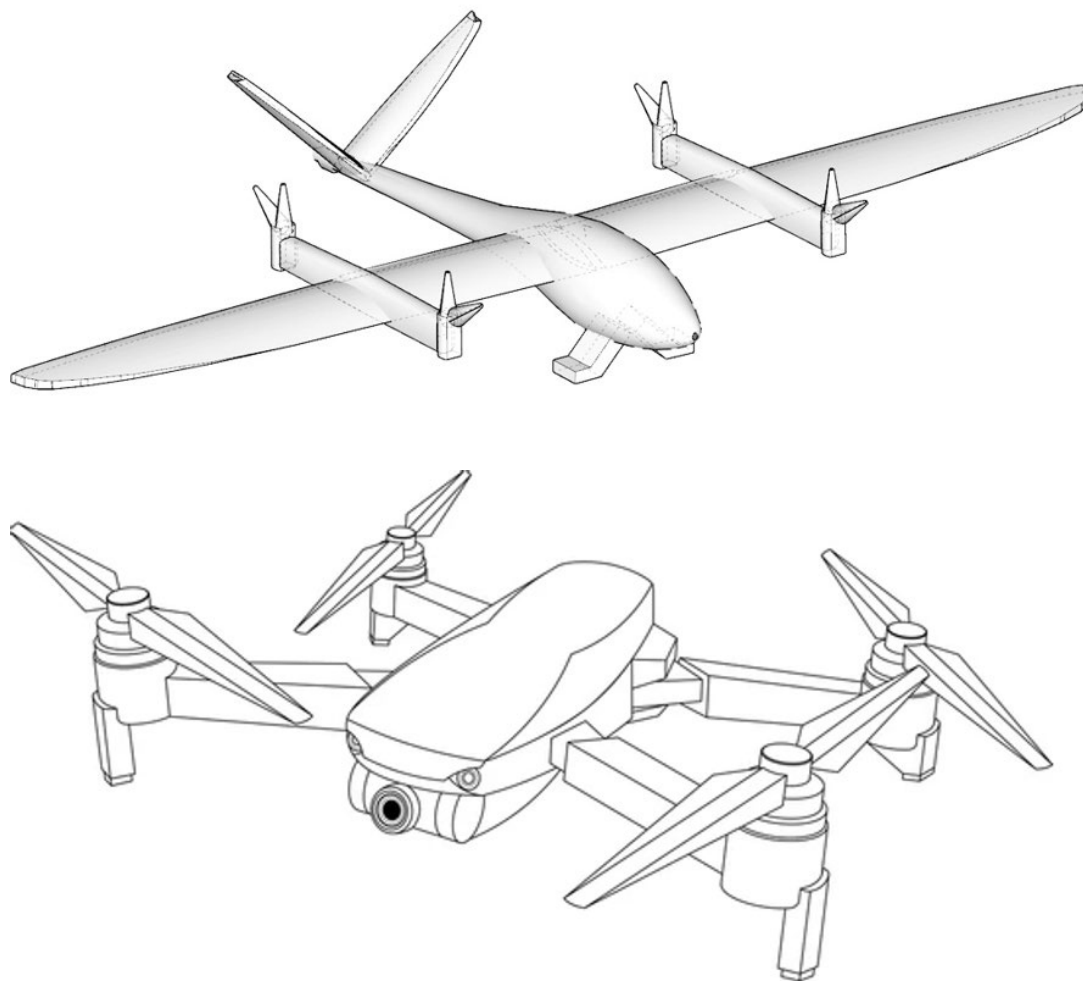
Developing and Evaluating Design Concepts

Here we propose several solutions to the design problem. Generating multiple concepts allows for a broader exploration of potential solutions, encourages innovation, and increases the likelihood of identifying the best design for the specific mission requirements.

Most of the design process is usually carried out by engineering teams. Brainstorming sessions are organised to generate a wide variety of ideas. It is always good to encourage creativity and avoid premature judgment of ideas. Consideration must be given to different UAV configurations, propulsion systems, materials, and control strategies. The brainstormed ideas must be translated into rough sketches and conceptual diagrams. These sketches should illustrate the basic features and functionality of each concept. Computer-aided design (CAD) software or hand-drawn sketches may be used to create visual representations of the concepts.

The generated concepts are organised into logical categories based on their key features and characteristics. A concept matrix or table is then created to compare the different concepts side-by-side, highlighting their strengths and weaknesses. It is necessary to identify common themes and variations among the concepts to facilitate further refinement and combination. Identify any critical technologies or components that may be required for each concept and assess their availability and cost.

For our design problem, Table 5.2 presents candidate concepts.



Conceptual UAV design sketches

Table 5.2: Design concepts

Feature/ Criteria	Concepts		
	Quadcopter with Gimbal-Stabilised Camera	Fixed-Wing UAV with Automated Flight Path	Hybrid VTOL UAV
Image Quality	Resolution: 12 MP – 20 MP	Resolution: 12 MP – 20 MP	Resolution: 12 MP – 20 MP
Flight Endurance	Typically, about 20 minutes	Typically, about 50 minutes	Typically, about 35 minutes
Ease of Use	Training: 2 hours, Setup: 5 minutes	Training: 8 hours, Setup: 15 minutes	Training: 10 hours, Setup: 20 minutes
Cost	GHS 17,000	GHS 22,000	GHS 29,000

Based on this information, we can score each concept, with reference to Table 5.1, to select one as the desired candidate for further development. This is shown in Table 5.3.

Table 5.3: Decision matrix

Feature/ Criteria	Weight	Concept 1 – Quadcopter with Gimbal-Stabilised Camera		Concept 2 – Fixed- Wing UAV with Automated Flight Path		Concept 3 – Hybrid VTOL UAV	
		Score	Weighted score	Score	Weighted score	Score	Weighted score
Image Quality	0.2	5	1	5	1	5	1
Flight Endurance	0.2	5	1	5	1	5	1
Ease of Use	0.3	5	1.5	3	0.9	2	0.6
Cost	0.3	4	1.2	3	0.9	2	0.6
Total			4.7		3.8		3.2

With reference to Table 5.3, we select the first concept: Quadcopter with gimbal-stabilised camera, for further development because it has the highest weighted score.

Learning Task

Identify a problem in your community that can be solved using a UAV. Develop viable concepts and select the best one.

Make a sketch of a conceptual multicopter design suitable for surveillance.

Pedagogical Exemplars

Experiential learning – Using a well-known problem in the community, walk learners through the process of developing and evaluating UAV concepts that solve the problem.

Group work – Put learners in mixed-ability groups and guide them through the process of selecting evaluation criteria and creating decision matrices for evaluating design concept

Key Assessment Level 4: Mini-Project

With reference to what you learned in Year 1 about the applications of UAVs, identify a problem in your community which can be solved using UAVs. For this problem, define at least five requirements for your design. Select three evaluation criteria which you will use to evaluate the concepts you develop. Propose two UAV design solutions (concepts) that can address the problem and select the best of the two. (16 marks) (DOK 4)

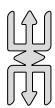
Refer to Teacher Assessment Manual and Toolkits pages 34 - 37 for further guidance on conducting project assessments.

PLC Session 13 & 14

45 minutes

Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
 - a. explain the week's concepts in a practical way that will make it easier for learners to understand
 - b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
 - a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
 - b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
 - c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

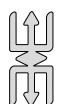
4. Plan the week's key assessment with your app
 - a. The key assessment for the week is **mini-project**. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the project (NTS 3k-3q).

10 minutes

Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

- a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
- b. all teachers in the group work through a similar problem individually for 3–4 minutes
- c. the group then works through the problem together step by step
- d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about ‘How do I teach this?’ but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes

Enactment

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).
 - a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
 - b. After the enactment, ask for structured feedback from the group
 - i. was the concept explained in a way that a learner with no prior knowledge could follow?
 - ii. were the examples grounded in contexts familiar to Ghanaian learners?
 - iii. did any misconceptions surface and if so, how were they addressed?

5 minutes

Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
 - a. transfer your chats into your learning planner template.
 - b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
 - c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEKS 15 & 16

Learning Indicator: Perform simple calculations that yield the properties (such as wing area, number of motors, propellant, etc.) for a small UAV

Focal Area: UAV design estimates

This week and the next focus on carrying out simple calculations that will help size a selected UAV concept. We will consider how to size fixed-wing and multirotor UAVs.

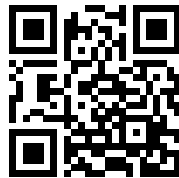
Sizing fixed-wing UAVs

The stall speed is usually given as part of the requirements. Say for this discussion that it is specified as 40 km/h or 11.11 m/s; Let us also say that we decide to use electric motors and propellers for propulsion.

There is a design parameter known as Wing loading. It is the ratio of the aircraft weight to the area of its wing. It helps us to determine the size of the wing. But before we can do this, we need to select a suitable aerofoil for the wing section.

There are numerous aerofoils we can select, as we learned in the Second Year. (Refer back to Year 2, week 4, Introduction to Aerodynamics). Perhaps the most common are the NACA four-digit, five-digit and six-digit aerofoils. Others include the Clark series and Eppler series aerofoils. Some aerofoils are symmetrical while others are cambered. We usually use cambered aerofoils for the wing and symmetrical ones for the horizontal and vertical stabilisers. We also consider the maximum thickness of the aerofoil in the case where we want to store for example, fuel or stow the landing gear in the wing.

Each aerofoil has a maximum coefficient of lift for a given flow condition (Reynolds number) which occurs at the critical angle of attack. Most of the UAVs we will build operate at low speeds (lower Reynolds numbers). The website at <http://airfoiltools.com/> is very useful for finding the maximum coefficient of lift.; it has a catalogue of a great number of aerofoils we can select from.



Say we select the NACA 63-415 aerofoil for our design. It has a maximum lift coefficient of about 1.5 at 15 degrees angle of attack.

Recall that the formula for finding the lift coefficient is,

$$C_L = \frac{L}{\frac{1}{2} \times \rho \times V^2 \times S}$$

where L is the lift, ρ is the density of air, V is the freestream velocity of the aircraft and S is the wing area. Just before stall, the lift generated by the wing equals the aircraft's weight. Replacing L with the weight, W, V with the stall speed, V_{stall} and C_L with $C_{L,max}$ and rearranging the equation, we find that the wing loading,

$$\left(\frac{W}{S}\right) = \frac{1}{2} \times \rho \times V_{stall}^2 \times C_{L,max} \quad (1)$$

GCAA mandates that our aircraft flies below 400 ft (122 m) above ground level. Let us approximate this to 400 ft (122 m) above sea level. The air density at this altitude is approximately 1.2 kg/m^3 (this value can be obtained by interpolating between 100 m and 200 m on the International Standard Atmosphere table).

Substituting the values into Equation 1, we obtain the wing loading for our design,

$$\left(\frac{W}{S}\right) = \frac{1}{2} \times 1.2 \times 11.11^2 \times 1.5 = 111.089 \text{ N/m}^2$$

This is the maximum wing loading that meets our stall speed requirement. Any value smaller than this implies a smaller stall speed, which is preferable.

Knowing our design weight (let's take it to be 5 kg) we can find the wing area now:

$$S = \frac{W}{\left(\frac{W}{S}\right)} = \frac{5 \times 9.81}{111.089} = 0.442 \text{ m}^2$$

Another design parameter that will help us select the propulsion system components is the thrust-to-weight ratio or power-to-weight ratio. Thrust-to-weight ratio is normally used for jet engine designs while the latter for propeller-driven designs.

The following equation can help us estimate the power-to-weight ratio for our design, knowing the wing loading.

$$\left(\frac{W}{P}\right) = \frac{\eta_P}{\frac{aV_{max}^3}{\left(\frac{W}{S}\right)} + \frac{b}{V_{max}} \left(\frac{W}{S}\right)} \quad (2)$$

In Equation 2, η_P is the propeller efficiency, V_{max} is the maximum aircraft velocity, equal to about 1.2 – 1.3 times the cruise speed (which is usually part of the requirements), P is the power at sea level (useful for selecting a gas engine) and a and b are defined as follows:

$$a = \frac{1}{2} \times \rho_0 \times C_{D_0}$$

where ρ_0 is the air density at sea level and C_{D_0} is the aircraft zero-lift drag coefficient.

$$b = \frac{2K}{\rho\sigma}$$

where $K = \frac{1}{\pi \times e \times AR}$, e being the Oswald efficiency factor, usually between 0.7 and 0.95 and AR , the wing aspect ratio, which must be decided (higher aspect ratio wings make for good performance at high altitudes).

ρ is the air density at the altitude where the maximum speed is specified, and $\sigma = \frac{\rho}{\rho_0}$

We will use the following values in our calculation of the power loading:

Parameter	Value
V_{max}	70 km/h or 19.44 m/s
η_P	0.8
C_{D_0}	0.01

ρ_0	1.225 kg/m ³
e	0.9
AR	6
ρ	1.2 kg/m ³

With these values,

$$a = \frac{1}{2} \times 1.225 \times 0.01 = 0.006125$$

$$K = \frac{1}{3.142 \times 0.9 \times 6} = 0.0589$$

$$\sigma = \frac{1.2}{1.225} = 0.9796$$

$$b = \frac{2 \times 0.0589}{1.2 \times 0.9796} = 0.1$$

$$\left(\frac{W}{P}\right) = \frac{0.8}{\frac{0.006125 \times 19.44^3}{111.089} + \frac{0.1 \times 111.089}{19.44}} = 0.82 \text{ N/W}$$

We multiply this value by the maximum velocity to get the thrust loading,

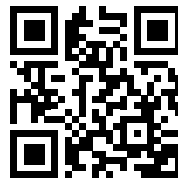
$$\left(\frac{W}{T}\right) = 0.82 \times 19.44 = 15.941$$

With this value, and knowing the design weight, we can select a motor-propeller combination that

$$T = \frac{W}{\left(\frac{W}{T}\right)} = \frac{5 \times 9.81}{15.941} = 3.08 \text{ N}$$

Usually, manufacturers will quote the thrust value in kg; so, our target thrust is $\frac{3.08}{9.81} = 0.314 \text{ kg}$ or 314 grams. If this value is too high, we can use more than one propulsion system, say two motors, etc.

A quick search on <https://hobbyking.com/>, an online shop for drone parts leads us to the *PROPDRIVE*

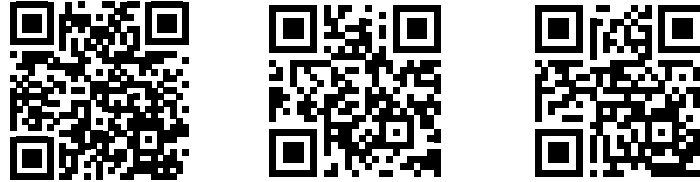


v2 2826 1000KV Brushless Outrunner Motor. This motor provides 670 grams of static thrust when combined with an 8 x 6 (inches) propeller and powered by a 3S Lithium-polymer battery (11.1 V). At full throttle, it consumes a current of 10 A. Since the thrust provided by a propeller generally decreases with forward speed, we decide to use this motor; the extra thrust becomes a plus.

If our aircraft must fly for 15 minutes or 0.25 hours, we need to select a battery pack that has a capacity of about $10 \times 0.25 = 2.5 \text{ Ah}$ or 2500 mAh. Let us add on an extra 500 mAh to cater for start-up, etc. This means we need to find a 3S Lithium polymer battery that has a capacity of at least 3000 mAh. (You can add up the extra in the time. For instance, you could have used 20 minutes instead of 15 for

the calculation.) Another battery parameter you might come across is the C-rating. A higher C-rating means that the battery can charge/discharge faster and is generally preferable.

Looking again on Hobbyking (there are many other places where we might find drone parts including Horizon Hobby – <https://www.horizonhobby.com/>, Banggood – <https://www.banggood.com/> and AliExpress – <https://aliexpress.com/>), we select the *Turnigy 3300mAh 3S 30C Lipo Pack w/XT-60*.



It is of moderate price, and its capacity meets our specifications. It weighs approximately 300 grams and comes with the XT-60 connector.

To complete the power system design, we select an electronic speed controller (ESC) for the motor: the *Turnigy Plush-32 20A (2~4S) Brushless Speed Controller w/BEC* (it is always good to choose an ESC with a higher amperage rating than the motor) and a propeller: the *Duraflly Rare Bear Reno Racer 680mm Replacement 8x5 Propeller*. The propeller available has a smaller pitch and so will produce slightly lower thrust than the 8x6. But this is acceptable, since we do not require all its thrust for our design, anyway.

We selected a value of 6 for aspect ratio. With this value, and knowing the wing area, we can determine the wingspan. This is the length of the wing from tip to tip.

$$b = \sqrt{AR \times S} = \sqrt{6 \times 0.442} = 1.63 \text{ m}$$

If we have decided to use a rectangular wing for our design, we can find the chord length,

$$c = \frac{S}{b} = \frac{0.442}{1.63} = 0.271 \text{ m} \approx 28 \text{ cm}$$

We now turn to sizing the tail of the aircraft. The horizontal/vertical tail volume coefficient relates the tail surfaces to the wing.

$$\bar{V}_H = \frac{l_h}{c} \times \frac{S_H}{S}$$

and

$$\bar{V}_V = \frac{l_v}{b} \times \frac{S_V}{S}$$

where S_H is the area of the horizontal tail and S_V is the area of the vertical tail, and the distances l_h and l_v are as shown in Figure 5.1 and Figure 5.2.

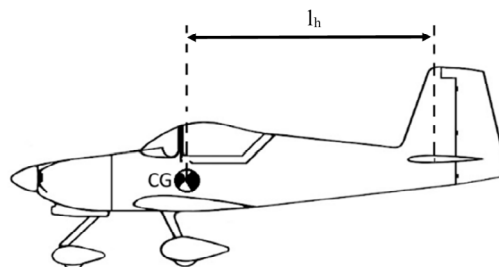


Figure 5.1: Horizontal tail arm

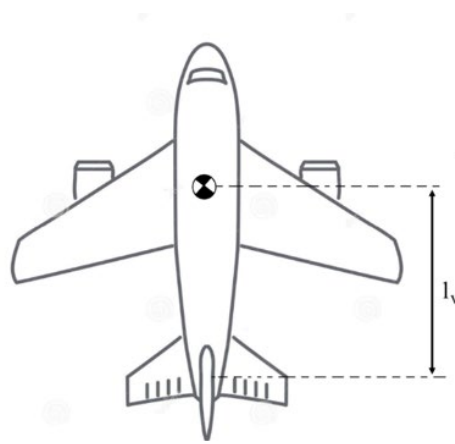


Figure 5.2: Vertical tail arm

The value of l usually depends on the length of the fuselage, and here, we will take $l_v = l_h = l$. We usually design the centre of gravity of the aircraft to be at the position of the wing along the fuselage. Depending on how we plan to distribute the weight of the aircraft components, for example, we might like to mount the motor and propeller at the front and put the payload midway along the fuselage. Our portability requirements might also dictate a maximum fuselage length. Suitable values of the horizontal tail volume coefficient for general aviation aircraft lie somewhat between 0.5 and 0.7, while, for the vertical tail, a range of 0.03 to 0.07 is common. We will adopt these values for our design.

Let us take $l = 0.5 \text{ m}$, $\bar{V}_H = 0.6$ and $\bar{V}_V = 0.04$, then,

$$S_H = 0.6 \times \frac{0.271}{0.5} \times 0.442 = 0.144 \text{ m}^2$$

$$S_V = 0.04 \times \frac{1.63}{0.5} \times 0.442 = 0.058 \text{ m}^2$$

Using $AR = 4$ for the horizontal tail and 5 for the vertical tail, and assuming rectangular surfaces, the chord and span for the same are presented in Table 5.4.

Table 5.4: Tail size

Parameter	Horizontal tail	Vertical tail
Span, b	0.76 m or 76 cm	0.54 m or 54 cm
Chord, c	0.18 m or 18 cm	0.107 m or 10.7 cm

To complete the design, we select the wheels, again from our online stores, picking one whose diameter provides adequate ground clearance for the propeller.

It is worth mentioning here that the design process is iterative, and if at any time we are unsatisfied with any parameter or unable to find a component that meets our specifications on the market, we can adjust the relevant value and perform the calculations again.

Let us now turn to multirotors.

Sizing multirotor UAVs

Recall from our first-year lessons about UAVs that multirotors use several motor-propeller units to provide both lift and thrust. They have the capability to hover as well as transition in all directions.

In selecting the propulsion system components for a multirotor, we must satisfy both hover and forward (backward, sideward) flight requirements. In hover, the total thrust generated by the rotors must equal the weight of the aircraft. In forward flight, the UAV tilts at an angle to the horizontal, and the thrust

generated by the rotors must support the weight and provide the force that propels it forward. We will therefore use the results from the forward flight analysis to select the propulsion system components.

Let us design a quadcopter (multirotor with four motors) as an alternative to the fixed wing we designed earlier. With reference to Figure 5.3, the following equation applies:

$$F_{drag} = W \cdot \tan \theta \quad (3)$$

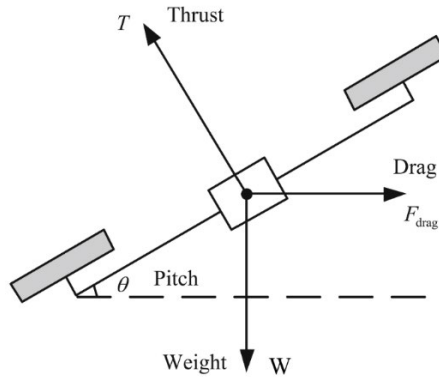


Figure 5.3: Multirotor UAV in forward flight

To move at a constant speed, the forward force must balance the drag. The drag force can be found using the following equation:

$$F_{drag} = \frac{1}{2} \times \rho \times V^2 \times S \times C_D$$

where ρ is the air density, V is the forward velocity of the UAV, C_D is the drag coefficient and S is a reference area, which we will take equal to the area of the drone when viewed from above. The drag coefficient will vary depending on the pitch angle, but for design, we will use the maximum value.

We evaluate the drag equation for flight at 400 ft (122m) where the density is about 1.2 kg/m^3 with a maximum velocity of 70 km/h (19.44 m/s) and take C_D equal to 0.05. We must now estimate the area, S . Say, that due to portability requirements, we are limited to a maximum linear dimension of 0.6 m. Let us take S to be the area of the square with sides equal to this value. Hence, $S = 0.6 \times 0.6 = 0.36 \text{ m}^2$. Substituting these into the drag equation, we get:

$$F_{drag} = \frac{1}{2} \times 1.2 \times 19.44^2 \times 0.36 \times 0.05 = 4.08 \text{ N}$$

Knowing the design weight, 5 kg or 49.05 N, we can find θ , using Equation 3:

$$\theta = \tan^{-1} \left(\frac{4.08}{49.05} \right) = 4.75^\circ$$

The total thrust we need to generate can be determined using, again, with reference to Figure 5.3 as:

$$T = \frac{W}{\cos \theta} = \frac{49.05}{\cos(4.75)} = 49.22 \text{ N}$$

We could have used Pythagoras' theorem to obtain the same result:

$$T = \sqrt{F_{drag}^2 + W^2} = \sqrt{4.08^2 + 49.05^2} = 49.22 \text{ N}$$

Since we have four rotors, each must generate a thrust of $\frac{49.22}{4} = 12.3 \text{ N}$ or $\frac{12.3}{9.81} = 1.25 \text{ kg}$.

We head again to our online store, Hobbyking to find a motor-propeller combination to meet our specification. We find that the *PROPDRIVE v2 2836 2200KV Brushless Outrunner Motor* generates static thrust of 1.428 kg when combined with a 6 x 5.5inch propeller and running on a 3S Lithium polymer battery (11.1 V), drawing 35 A of current.

We can estimate the battery capacity required, just like we did for the fixed wing case. Here there are four motors, each drawing 35 A of current. That makes $35 \times 4 = 140 \text{ A}$. If we want to run for 15 minutes (0.25 hours), we need a battery with a capacity of at least $140 \times 0.25 = 35 \text{ Ah}$ or 35000 mAh.

We found the highest capacity available for a 3S LiPo battery on Hobbyking to be 8000 mAh; It is the *Turnigy Rapid 8000mAh 3S2P 140C Hardcase LiPo Battery Pack w/XT90*. It weighs about 500 grams. If we combine four of these in parallel, we will obtain a capacity of 32000 mAh for a total weight of about 2 kg. 32000 mAh will afford us $\frac{32}{140} \approx 0.23$ hours, close to 14 minutes of flight time.

This is ok for us. You may have realised now, that the power requirements for a multirotor UAV are higher than that required for a fixed-wing UAV with the same performance.

Let us now design the frame of the quadcopter.

We can use either a plus (+) or X-configuration for our quadcopter. Figure 5.4 illustrates this.

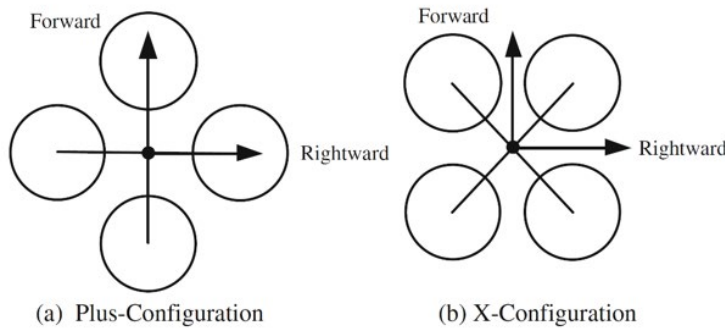


Figure 5.4: Plus and X quadcopter configurations

The geometry of a multicopter is generally defined, with reference to Fig. 5.5 by,

$$R = \frac{r_{max}}{\sin \frac{\theta}{2}} = \frac{r_{max}}{\sin \frac{180^\circ}{n}} \quad (4)$$

where n is the number of arms the multicopter has and θ is the angle between the arms.

where n is the number of arms the multicopter has and θ is the angle between the arms.

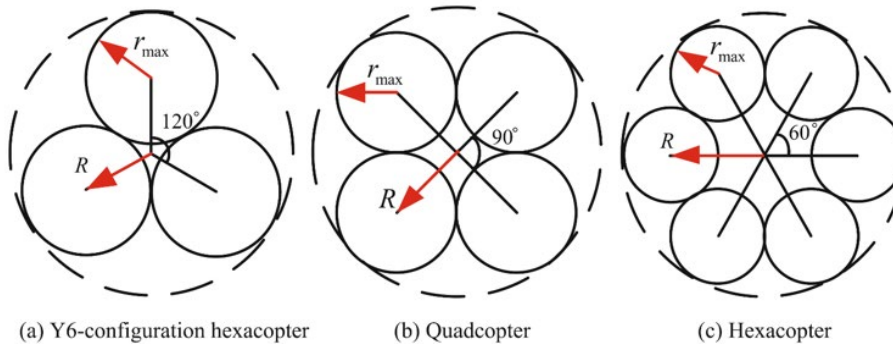


Figure 5.5: Multicopter arm length

So, for our quadcopter which has $r_{max} = \frac{6}{2} = 3 \text{ inches}$ or 0.0762 m and $\theta = 90^\circ$ or $n = 4$, we have

$$R = \frac{0.0762}{\sin\left(\frac{180}{4}\right)} = 0.108 \text{ m or } 10.8 \text{ cm}$$

For a quadcopter, adjacent motors rotate in opposite directions. Hence, we will need two clockwise (CW) and two anticlockwise (CCW) propellers.

Learning Tasks

1. Determine, by performing calculations, the characteristics of a UAV you selected in the previous weeks to solve a problem in your community.
2. Visit the aerospace laboratory to familiarise yourself with available UAV components. Remember to take note of their specifications (dimensions, thrust generated, etc.).

Pedagogical Exemplars

Project-based learning – Continue to develop the final concept selected from the previous weeks' activities, this time walking learners through the process of sizing the UAV.

Experiential learning – Take learners to the laboratory to familiarise learners with UAV components such as, propellers, motors, wheels, batteries, etc. Encourage learners to research more components on their own, taking note of, for instance, their dimensions, the amount of thrust they generate, etc.

Key Assessment Level 2: Research

1. Based on the design requirements for a quad-rotor aircraft used for package delivery (payload: 1 kg; flight time: 15 minutes), complete the table below by calculating or estimating values for the starred parameters. Use appropriate formulas or assumptions and explain each calculation. (10 marks)
2. A fixed-wing UAV is being developed to spray a small experimental farm. Use the following data to **complete the table** for its design. Show calculations for all **starred** parameters and briefly explain your reasoning. (10 marks)

Provided data:

Farm size: 2 m × 2 m

Fertiliser application rate: 80 ml/m²

Fertiliser density: 800 kg/m³

Flight time: 15 minutes

Take-off weight: 2.0 kg

Stall speed: 12 m/s

Aspect ratio: 6

Propeller size: 30 cm

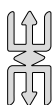
Completion Table:

Parameter	Value	Reasoning/Calculation
Take-off weight		
Stall speed		
Aspect ratio		
Wingspan*		
Mean aerodynamic chord*		
Number of propellers*		
Propeller size		

PLC Session 15 & 16

45 minutes
Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
 - a. explain the week's concepts in a practical way that will make it easier for learners to understand
 - b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
 - a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
 - b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
 - c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

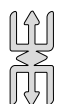

Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app
 - a. The key assessment for the week is **research**. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the research (NTS 3k-3q).

10 minutes**Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
 - a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
 - b. all teachers in the group work through a similar problem individually for 3–4 minutes
 - c. the group then works through the problem together step by step
 - d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

**Note**

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes**Enactment**

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).
 - a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
 - b. After the enactment, ask for structured feedback from the group
 - i. was the concept explained in a way that a learner with no prior knowledge could follow?
 - ii. were the examples grounded in contexts familiar to Ghanaian learners?
 - iii. did any misconceptions surface and if so, how were they addressed?

5 minutes**Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
 - a. transfer your chats into your learning planner template.
 - b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
 - c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 5 Review

This section has covered the principles of conceptual design of UAVs. This begins with an identification of a problem, which leads to the definition of requirements and development of candidate concepts and selection of the “best”. Following this, calculations can be performed to estimate the size and specifications of its components. We learned how to perform these calculations for both fixed-wing and multi-rotor UAVs.

GLOSSARY

Stall Speed

The lowest speed at which an aircraft can fly while still generating enough lift to remain airborne.

Wing Loading

The weight of an aircraft divided by its wing area. It indicates how much weight each square meter of wing must support.

Reynolds Number

A dimensionless number used to describe airflow behavior around an object, helping engineers determine whether the flow is smooth (laminar) or turbulent.

Maximum Coefficient of Lift ($C_{L_{max}}$)

The highest lift coefficient an airfoil or wing can produce before stalling.

Power-to-Weight Ratio

The amount of engine power available compared to the aircraft’s weight. Higher values generally result in better climb and acceleration performance.

Thrust-to-Weight Ratio

The ratio of engine thrust to aircraft weight. It indicates how effectively an aircraft can accelerate and climb.

Propeller Efficiency

A measure of how effectively a propeller converts engine power into useful thrust.

Zero-Lift Drag Coefficient (C_{D_0})

The drag coefficient of an aircraft when it is producing no lift. It represents drag caused by the aircraft’s shape and surface friction.

Oswald Efficiency Factor

A number that indicates how efficiently a wing produces lift while minimizing induced drag. Values closer to 1 represent greater efficiency.

Tail Volume Coefficient

A dimensionless parameter that describes the size and effectiveness of an aircraft’s tail relative to the wing and fuselage, helping ensure stability and control.



MARKING SCHEMES FOR THE KEY ASSESSMENTS

UNIT 13 & 14

Component	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs improvement (1 mark)
1. Problem Definition	Identifies a specific, well-defined, and significant problem in the local community. Provides a compelling justification for why the problem is important and how UAVs offer a unique or advantageous solution, supported by evidence.	Identifies a relevant problem in the local community. Provides a clear justification for the problem's importance and the potential of UAVs as a solution.	Identifies a general problem in the community, but the problem definition is vague or lacks specificity. The justification for using UAVs is weak or unsupported.	Fails to identify a clear problem or provides a justification that is illogical or irrelevant.
2. Design Requirements	Defines at least five clear, complete, verifiable, consistent and feasible requirements for the UAV design.	Defines at least five requirements for the UAV design, most of which are clear, verifiable, consistent and feasible.	Defines fewer than five requirements or the requirements are not well-defined or feasible.	Fails to define a sufficient number of requirements or the requirements are vague and unrealistic.
3. Evaluation Criteria	Selects three distinct and relevant evaluation criteria that can be used to objectively assess and compare different UAV design concepts. Provides a clear and well-reasoned explanation for why each criterion is relevant to the problem and how it will be measured or assessed.	Selects three evaluation criteria that are mostly relevant to the problem. Provides a reasonable explanation for their relevance and assessment methods.	Selects fewer than three evaluation criteria or the criteria are not clearly relevant to the problem. The explanation for their relevance or assessment is weak or unclear.	Fails to select a sufficient number of evaluation criteria or the criteria are irrelevant to the problem. No explanation is provided.

4. Design Concepts	Proposes two detailed and well-developed UAV design solutions (concepts) that could potentially address the identified problem and meet the defined requirements. Clearly describes the key features, functionality, and operation of each design. Systematically compares the two designs against the selected evaluation criteria.	Proposes two UAV design solutions that are generally relevant to the problem. Describes the key features and operation of each design and compares them against the evaluation criteria.	Proposes two basic UAV design solutions, but the designs may be unrealistic or poorly developed. The descriptions and comparison are limited.	Proposes fewer than two design solutions or the designs are irrelevant or lack detail. No comparison is provided.
--------------------	--	--	---	---

UNIT 14 & 16

- Based on the design requirements for a quad-rotor aircraft used for package delivery (payload: 1 kg; flight time: 15 minutes), complete the table below by calculating or estimating values for the starred parameters. Use appropriate formulas or assumptions and explain each calculation. (10 marks)

Parameter	Value	Marks	Explanation
Quad-rotor frame dimensions*	Approx. 450 mm diagonal (e.g., 450 mm x 450 mm)	2	Reasonable for 1 kg payload, ensuring stability and balance.
Propeller size*	25.4 cm	1	Larger props (23–30 cm) improve thrust efficiency and flight time.
Number of CW propellers	2	1	Standard quad configuration: 2 clockwise, 2 anticlockwise.
Number of CCW propellers	2	1	Complements the CW configuration for torque balance.
Motor current	Approx. 15 A per motor under load	1	Based on typical quad-motor systems handling ~1 kg total payload.
Battery capacity*	Approx. 4 motors $\times$ 15 A $\times$ 15 min = 15 Ah (or 15000 mAh)	2	$I = 60 \text{ A total}; t = 0.25 \text{ hr} \rightarrow Q = I \times t = 60 \times 0.25 = 15 \text{ Ah}$
Number of battery packs*	1 or 2 (if using 7.5 Ah each)	2	Total capacity can be met with one high-capacity or two medium packs.

Total: 10 marks

2. A fixed-wing UAV is being developed to spray a small experimental farm. Use the following data to **complete the table** for its design. Show calculations for all **starred** parameters and briefly explain your reasoning. (10 marks)

Parameter	Answer	Marks	Reasoning/Calculation
Wingspan*	2.4 m	3	Use $AR = (\text{span})^2 / \text{Area}$. Area = 2 m × 2 m = 4 m ² sprayed area not wing area. Assume wing area = 1.0 m ² (typical small UAV). $\text{span}^2 = 6 \times 1 = 6 \Rightarrow \text{span} \approx \sqrt{6} \approx 2.4 \text{ m}$
Mean aerodynamic chord*	0.42 m	2	$MAC = \text{Wing area} / \text{Wingspan} = 1.0 / 2.4 \approx 0.42 \text{ m}$
Number of propellers*	1	1	Most fixed-wing UAVs use a single pusher or tractor propeller.
Take-off weight	2.0 kg	1	Provided in data.
Stall speed	12 m/s	1	Provided in data.
Aspect ratio	6	1	Provided in data.
Propeller size	30 cm	1	Provided in data.

Total: 10 marks

SECTION 6: BUILDING UAVS

STRAND: UNMANNED AERIAL VEHICLES (UAVS)

Sub-Strand: Design and Fabrication of UAVs

Learning Outcome: *Construct and fly a small UAV*

Content Standard: *Demonstrate knowledge and understanding of how to fabricate and test a selected design*

INTRODUCTION AND SECTION SUMMARY

This section will cover issues relating to the construction of a designed UAV concept. We will first review safety regulations in the laboratory; we will look at the various materials available to us for the construction of the UAV; we will look at tools and equipment in the lab which will help us with the construction; we will also look at some supplies we will need to construct our models.

The weeks and the indicators covered by the section are:

- **Weeks 17 – 20:** Build a small UAV (aircraft/rocket) using locally available materials

Recap weeks

Year 1	Week 5 • Explain safety precautions in the laboratory (Aerospace, Physics, Electrical/ Electronics). • Discuss the advantages of adhering to safety precautions in the laboratory (Aerospace, Physics, Electrical/Electronics).
Year 3	Weeks 1 – 4 • Identify the right materials for construction of a small UAV. • Evaluate the different types of aircraft construction.

SUMMARY OF PEDAGOGICAL EXEMPLARS

1. Experiential learning/group work
2. Whole-class discussions

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/or Mode
Build a small UAV (aircraft/ rocket) using locally available materials.	4	Discussion

WEEKS 17 – 20

Learning Indicator: *Build a small UAV (aircraft/rocket) using locally available materials*

Focal Area: UAV construction

Throughout this week and the next three, we will be concerned with producing the physical UAV that we have designed in the previous section.

As much of our work will be carried out in the laboratory, we will first briefly review some safety regulations. (Refer back to Year 1, Week 5, Safety In The Laboratory.)

Safety practices while building UAVs

Building UAVs in a lab involves working with various tools, materials, and electrical components, which can pose safety risks if not handled properly. Adhering to strict safety practices is crucial to prevent accidents and injuries.

General lab safety is paramount. This includes maintaining a clean and organised workspace to prevent tripping hazards and ensure easy access to tools and materials. Proper ventilation is essential to avoid the build-up of fumes from soldering, adhesives, or other chemicals. It is also crucial to familiarise yourself with the lab's emergency procedures, including evacuation routes, fire extinguisher locations, and first aid kit locations. Personal Protective Equipment (PPE) should be worn at all times, including safety glasses, gloves, and closed-toe shoes preferably with steel toecaps to protect against potential hazards.

Electrical safety is a key consideration when working with UAVs. Use properly grounded power supplies and avoid overloading circuits to prevent electrical hazards. Ensure all wiring and connections are secure and properly insulated to prevent short circuits and electrical shocks. Handle batteries with care, especially lithium polymer (LiPo) batteries, which can be volatile; avoid puncturing, crushing, or exposing batteries to extreme temperatures, and use appropriate chargers and storage containers. When soldering, use a soldering iron with care, avoid touching the hot tip, and use a fume extractor to remove harmful fumes.

Mechanical safety involves the safe handling of tools and components. Use hand and power tools safely and according to the manufacturer's instructions and always wear safety glasses when using power tools. Secure materials before cutting or drilling to prevent them from moving and use appropriate cutting and drilling tools for the materials being worked on. Ensure all components are securely fastened and properly aligned, using appropriate fasteners and adhesives. Handle propellers with care, as they can be sharp and cause injury, and never test the UAV with propellers installed in a confined space.

Chemical safety is important when working with adhesives and solvents. Use these materials in a well-ventilated area and avoid inhaling fumes. Wear gloves to protect your skin from contact with chemicals. Handle materials safely and dispose of waste properly, following the manufacturer's instructions for handling and disposal of hazardous materials.



Figure 6.1: *Personal protective equipment*

Laboratory tools/equipment/supplies for UAV construction

Most of our work will be carried out on a workbench. A sturdy workbench provides a stable surface for cutting, assembling, and working on the UAV.

We will require some measuring tools including a ruler/tape measure for accurate measurements of materials and components; a digital calliper for precise measurements of small parts and dimensions and a protractor for measuring and marking angles accurately.



Figure 6.2: *Digital calliper*

We will need pencils/markers for marking cutting lines, drilling points, and assembly guides; a centre punch for making precise starting points for drilling in metal and a scribe for marking metal surfaces.



Figure 6.3: *Centre punch*

Clamps, e.g., C-clamps, spring clamps, quick-grip clamps are essential for holding pieces together while gluing, drilling, or fastening.

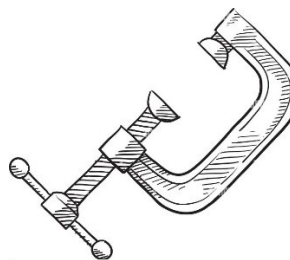


Figure 6.4: *C-clamp*

In order to work with wood, we will need tools such as the hand saw/coping saw for cutting wood to size and creating intricate shapes; a power drill for drilling holes and driving screws; some sandpaper (smooth/rough) for smoothing wood surfaces and edges; a power sander, for faster and more efficient sanding of larger surfaces and wood glue for bonding wood pieces together.



Figure 6.5: *Hand saw*



Figure 6.6: *Coping saw*

When we work with metals, we will use tools such as the hacksaw for cutting them to size; drill bits for drilling holes; files for deburring sharp edges and smoothing metal surfaces; a rivet gun/riveter for joining metal pieces together using rivets; metal adhesive (e.g., Epoxy) for bonding metal pieces together and welding equipment if the design requires welding.

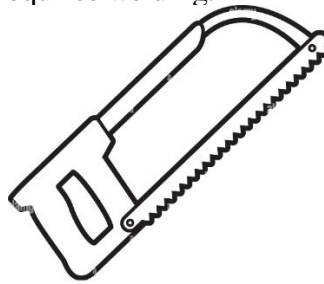


Figure 6.7: *Hacksaw*

For plastic components, we may use a 3D Printer for creating custom plastic parts from digital designs, in which case we will require 3D printing filament; flush cutters for removing supports and rafts from 3D-printed parts; sandpaper (fine grit) for smoothing 3D-printed surfaces and removing imperfections; and plastic adhesive for bonding the pieces together.

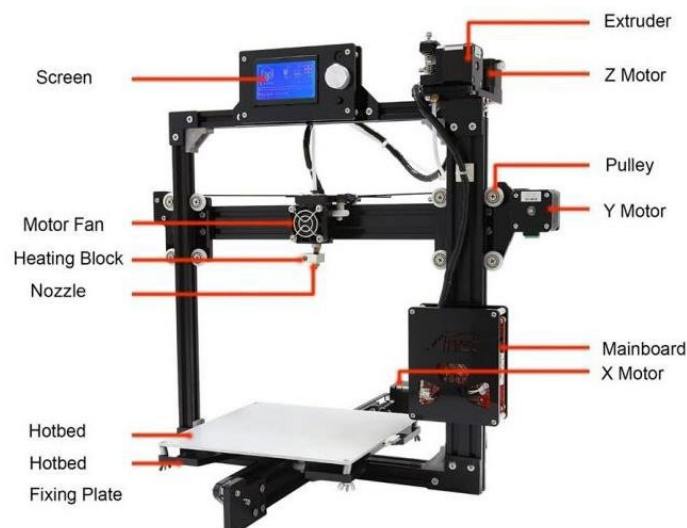


Figure 6.8: *Parts of a 3D printer*

If we use Styrofoam in our design, we will need a sharp knife or blade for cutting and shaping Styrofoam with precision; a hot wire cutter for creating smooth, clean cuts in the material; sandpaper (various grits) for smoothing and shaping Styrofoam surfaces; and Styrofoam-safe glue.

Tools for working with composites include scissors/shears for cutting composite fabrics (e.g., fibreglass, carbon fibre); mixing cups and sticks for accurately mixing epoxy resin and hardener; brushes/rollers for applying epoxy resin to composite fabrics; a vacuum bagging system for applying pressure to composite layups and removing excess resin; and release film/tape for preventing epoxy resin from sticking to moulds or work surfaces.

Some electronics tools that might be essential for integrating electronic components into the UAV include a soldering iron and some solder for connecting electronic components; wire strippers/cutters for preparing wires for soldering; a multimeter for measuring voltage, current, and resistance; and helping hands (a tool with adjustable clips for holding components in place while soldering).



Figure 6.9: *Soldering station*



Figure 6.10: *A multimeter*

Some tips to keep in mind are:

1. Choose a glue appropriate for the type of material and the application; some glues can dissolve or damage the Styrofoam.
2. Use cutting oil to lubricate the drill bit and prevent overheating when drilling metals.
3. Choose a 3D printing filament appropriate for the application (e.g., PLA, ABS, PETG).

We often will have to join two or more components together. We have a variety of options available to us regarding the type of fasteners to use.

Screws are versatile fasteners and are known for their ability to create strong, easily disassembled joints. They come in various types, including machine screws, self-tapping screws, and wood screws, each designed for specific materials and applications. Machine screws, used with nuts or threaded holes, are ideal for joining metal, plastic, and composite parts, offering a robust and reliable connection for structural components and electronic attachments. Self-tapping screws provide a convenient solution

for quick assembly in sheet metal, plastic, and wood, eliminating the need for pre-drilled holes. The ease of installation and removal makes screws a preferred choice for components that require maintenance or replacement. Different head types, such as pan head, flat head, and button head, allow for optimised aesthetics and functionality.

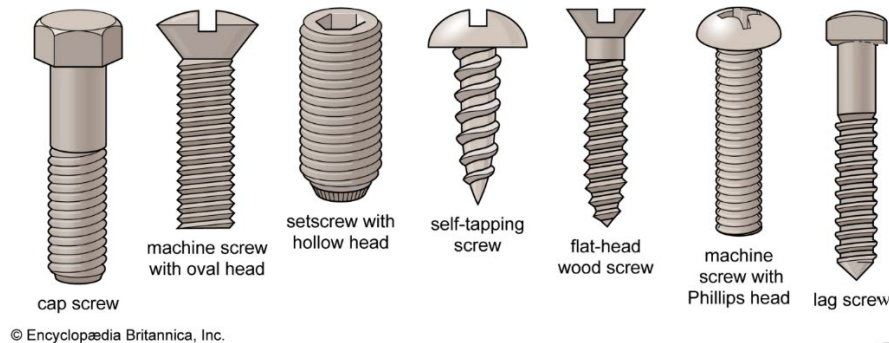


Figure 6.11: *Types of screws*

Nuts are essential companions to screws, providing the clamping force needed to secure joints in UAV structures. Hex nuts, the standard six-sided variety, are commonly used with machine screws for general-purpose fastening of metal and plastic components, offering a reliable and straightforward connection. Lock nuts, or Nylock nuts, feature a nylon insert that creates a friction fit, preventing loosening due to vibration, which is particularly important in UAVs where motors and propellers generate significant movement. The variety of nut types allows for tailored solutions in different applications. Wing nuts, for example, enable easy hand tightening and loosening, making them ideal for components that require frequent adjustments or disassembly, such as battery compartments or adjustable camera mounts. The combination of nuts and screws provides a dependable fastening system that can withstand the rigors of flight, ensuring that critical components remain securely in place.



Figure 6.12: *Examples of nuts*

Rivets are permanent fasteners that create strong, tamper-proof joints, making them suitable for structural components in UAVs that do not require frequent disassembly. Pop rivets, also known as blind rivets, are particularly useful in UAV construction because they can be installed from one side of the material using a rivet gun, simplifying assembly in areas with limited access. These rivets are commonly used to join sheet metal, plastic, and composite parts, providing a secure and lasting connection. The installation process involves inserting the rivet through pre-drilled holes and then using a rivet gun to pull the mandrel, which deforms the rivet and clamps the materials together. This creates a clean, flush finish that is both aesthetically pleasing and structurally sound. While rivets are not easily removed, their strength and reliability make them an excellent choice for permanent joints that need to withstand significant stress and vibration, ensuring the structural integrity of the UAV.



Fig. 6.13:: *Types of rivets*

Zip ties, also known as cable ties, are versatile and inexpensive fasteners used primarily for cable management and securing lightweight components in UAVs. Made from nylon, these straps can quickly bundle and organise wires and cables, preventing them from interfering with moving parts and ensuring a clean, professional finish. Their ease of use and disposability make them a staple in UAV construction for managing wiring harnesses and securing smaller components to the frame. The self-locking mechanism of zip ties allows for quick and secure fastening, and they can be easily trimmed to remove excess length. While not suitable for structural applications, zip ties are invaluable for keeping wires tidy and preventing them from getting tangled or damaged during flight. They are particularly useful in areas where flexibility and ease of access are needed, allowing for quick adjustments and modifications to the wiring layout.



Figure 6.14: *Zip ties*

Velcro straps, with their hook-and-loop fasteners, offer a convenient and adjustable method for securing components in UAVs that require frequent access or removal. These straps are particularly useful for securing batteries, attaching removable panels, and mounting components that may need to be adjusted or replaced. The ease of use and adjustability of Velcro straps make them ideal for applications where quick changes are necessary, such as swapping out batteries or adjusting camera angles. The non-permanent nature of Velcro straps allows for easy access to components for maintenance, repairs, or modifications. They provide a secure hold while still allowing for quick release, making them a practical choice for components that need to be easily accessible. Velcro straps are also lightweight and flexible, minimising added weight and allowing for versatile mounting options within the UAV frame.



Figure 6.15: *Velcro strap*

After construction, we may apply finishing to its surface to increase the aesthetic appeal of our UAV. Some of the options available to us include paints, varnish (for wooden surfaces) and sticker paper.

Paint offers a versatile and customisable finish, allowing for a wide range of colours and designs to be applied to various materials, including wood, metal, and plastic. Proper application involves surface preparation, priming, and multiple coats to achieve a durable and aesthetically pleasing result. While paint provides good protection against moisture and UV damage, it can be prone to chipping and scratching, especially if not applied correctly. It is essential to use primers and paints specifically designed for the material being coated to ensure optimal adhesion and longevity.

Varnish is a traditional wood finish that provides a clear, protective coating, enhancing the natural beauty of the wood while offering resistance against moisture and scratches. Varnish provides good protection, although it can be challenging to apply evenly and may require more coats to achieve adequate coverage. Its ability to showcase the wood's grain while providing a durable finish makes it a suitable choice for UAV components made of wood, balancing aesthetics with practical protection.

Sticker paper provides an easy and cost-effective way to customise the appearance of a UAV with logos, markings, or decorative graphics. Printable on both inkjet and laser printers, sticker paper allows for the creation of custom labels that can be applied to various surfaces. While sticker paper offers great flexibility in design, it is not as durable as other finishes and can be susceptible to peeling, fading, and scratching. To enhance its longevity, we may apply a clear coat over the sticker to protect it from the elements and physical wear.

Learning Tasks

1. Work with your colleagues to complete the construction of a UAV designed in the previous section.
2. Discuss with a friend what materials are preferable for constructing the different parts of a UAV.

Pedagogical Exemplars

Experiential learning/group work – Supervise learners to work in mixed-ability groups to construct selected UAV designs. Encourage the spirit of teamwork.

Whole class discussions – Engage learners in discussions about which materials are preferable for constructing the different parts of a UAV.

Key Assessment Level 4: Practice Paper 2

1. A learner is designing a wing component that requires joining two pieces of wood. Evaluate at least two methods for joining these pieces, considering the impact of each method on the wing's strength, weight, aerodynamic properties, and long-term durability. Provide a detailed recommendation explaining which joining method you think is best for the model wing, including the necessary tools, materials, and safety precautions.

(20 marks, plus 2 optional bonus points) (DOK 4)

2. You are helping to design a fixed-wing UAV that needs to land safely on rough terrain. You have two material options for the landing gear: wood or metal. Discuss with your colleagues which material is better for this purpose. In your discussion, remember to touch on the following:
 - a. A comparison of wood and metal in terms of strength, weight, and durability.
 - b. How each material would affect the UAV's performance, cost, and how often it would need repairs.
 - c. Your final choice and a clear explanation of why you chose it.
 - d. How your choice might change if the UAV had to fly in different weather or land on different surfaces.

(20 marks) (DOK 4)

Refer to Teacher Assessment Manual and Toolkits pages 66 – 69 for further guidance on administering discussion assessments.

HINT



Conduct **Practice Paper 2**. It should cover contents taught from Year 1 to 3. Refer to the **Table of Specification and Structure of the Paper** at the end of this section to guide you. Learners' papers should be marked immediately and scores entered into the SAP.

ITEM SPECIFICATION FOR PRACTICE EXAMINATION 2

1. PAPER 1 (Objective test)

S/N	Strand	Sub-strand	Content standard	Learning indicator	Number of items				Total
					DOK 1	DOK 2	DOK 3	DOK 4	
1	Core concepts in Aerospace Engineering	Fundamentals of flight	Demonstrate knowledge and understanding of the evolution of flight	Trace the evolution of flight prior to powered, controlled flight	2				2
			Demonstrate understanding of flight vehicle nomenclature	Differentiate the types of aerospace vehicles	1				1
				Make freehand sketches of current and future aerospace vehicles, labelling their major parts				1	1
		Show understanding of safety regulations in the aerospace laboratory	Explain safety precautions in the laboratory	1					1
			Aerodynamics and Propulsion	Demonstrate knowledge of the properties of the international standard atmosphere	Explain the impact of the weather elements on flight		1		
				Explain the impact of altitude on the state of the atmosphere.			2		2
			Demonstrate knowledge and understanding of the balance of forces acting on an aerospace vehicle in flight	Distinguish between the four major forces (lift, drag, thrust and weight) that act on an aerospace vehicle in flight.			1		1

						1		1	2
		Demonstrate understanding of the force required for propulsion of an aerospace vehicle	Calculate the thrust generated from different power sources, e.g., battery and internal combustion engines (rocket, jet engine, internal piston engine)			1			
	Aircraft Structures and Control	Demonstrate knowledge of various types of aircraft construction	Evaluate the different types of aircraft construction			1			1
		Demonstrate understanding of how an aerospace vehicle (aircraft, spacecraft) is controlled in flight	Describe the flight controls of a rotary-wing aircraft			1			1
			Distinguish between the features of fly-by-wire (automatic) control, mechanical control and hydraulic control of aircraft.			1			1
		Demonstrate knowledge and understanding of the factors that account for the stability of an aerospace vehicle	Apply the understanding of moments in Physics to aircraft movement to explain stability configurations.			1			1
			Determine the relationship between the location of the centre of gravity of an aircraft and its stability			1			1
	Avionics	Demonstrate knowledge of the various classes of avionics systems	Discuss avionics systems in relation to traditional musical instruments and dance for communication.			1			1
2		Demonstrate knowledge of the vast functions of avionics systems.	Explain the functions of surveillance systems			1			1

	Aviation industry	The Aviation Professions and Operations	Aircraft instrumentation	Demonstrate knowledge of the instruments used for airborne and ground operations and their principles of operations.	Relate the physical variables that are measured in aircraft applications with the instruments used to measure them	1			1
				Demonstrate an understanding of flight data storage in aircraft	Explain the principles of operation of the aircraft instruments	1			1
					Indicate the various aircraft parameters that are recorded	1			1
			Communication, navigation and surveillance systems	Demonstrate knowledge of the different communication technologies used in aviation	Identify the different communications technologies used in the aviation industry	1			1
					Illustrate the pros and cons of each aviation communication technology		1		1
				Demonstrate an understanding of the different navigation systems used in aircraft and spacecraft	Explain the concept of navigation (dead reckoning and position fixing)	1			1
			Demonstrate knowledge of the different aerospace surveillance technologies	Demonstrate knowledge of the different career paths in the aviation industry	Identify the advantages and disadvantages of the different navigation technologies		1		1
					Present a summary of on-board surveillance systems.	1	1		2
			The Aviation Professions and Operations	Demonstrate knowledge of various career paths in the aviation industry	Describe the learning pathways that lead to careers in aviation.	1			1
				Demonstrate knowledge of the various operations in the aviation industry.	Demonstrate how the different aviation operations work together to achieve smooth air travel	1			1

4	Unmanned aerial vehicles	Aviation organisations	Demonstrate understanding of the relationship between aerospace and aviation organisations and how this helps to regulate operations.	Identify the major aviation agency in Ghana and its key operations	1				1
			Demonstrate understanding of the roles of the aviation agencies in ensuring the safety of air transport	Identify global aviation agencies	1				1
			Demonstrate knowledge of aircraft maintenance activities	Identify the functions of local aviation organisations		1			1
		Aircraft maintenance	Demonstrate knowledge of aircraft maintenance standards and certification	Identify aircraft maintenance equipment.		1			1
			Demonstrate knowledge and understanding of the types of UAVs	Make log entries of maintenance activities performed		1			1
		UAV applications	Demonstrate knowledge of the various uses of UAVs	Analyse the features of Unmanned Aerial Vehicles		1			1
			Show understanding of safety regulations for building and operating UAVs.	Examine the military applications of Unmanned Aerial Vehicles (UAVs)		1			1
		UAV safety and regulations	Demonstrate knowledge of how to develop and evaluate conceptual designs of UAVs.	Explain safety practices with regard to building and operating UAVs.	1				1
		Design and fabrication of UAVs		Apply evaluation tables to select the best concept from a number of UAV concepts.			1		1

		Demonstrate knowledge of how to undertake basic UAV design calculations.	Perform simple calculations that yield the properties (such as wing area, number of motors, propellant, etc.) for a small UAV.	1			1		1
		Demonstrate knowledge and understanding of how to fabricate and test a selected design.	Fly the fabricated UAV.	1					1
	Total			12 (30%)	16 (40%)	12 (30%)			40 (100%)

2. PAPER 2 (Written)

S/N	Strand	Sub-strand	Content standard	Learning indicator	Number of items				Total
					DOK 1	DOK 2	DOK 3	DOK 4	
SECTION A									
Q1	Core concepts in Aerospace engineering	Fundamentals of flight	Demonstrate understanding of flight vehicle nomenclature	Differentiate the types of aerospace vehicles	1				1
			Show understanding of safety regulations in the aerospace laboratory	Explain safety precautions in the laboratory (Aerospace, Physics, Electrical/Electronics)	1				1
	Avionics	Fundamentals of Avionics	Demonstrate knowledge of the various classes of avionics systems	Explain avionics systems in relation to the flight of a flock of birds for navigation			1		1

	Unmanned aerial vehicles	UAV Safety and Regulations	Show understanding of safety regulations for building and operating UAVs.	Evaluate official regulations relating to the possession and operation of UAVs.		1			1
SECTION B									
Q2	Core concepts in Aerospace Engineering	Aerodynamics and Propulsion	Demonstrate understanding of the force required for propulsion of an aerospace vehicle	Explain the principles of operation of the different propulsion systems: rockets, jet engines, internal combustion (spark) engines			1		1
				Calculate the thrust generated from different power sources, e.g., battery and internal combustion engines (rocket, jet engine, internal piston engine)			1		1
				Identify the right material for construction of a small UAV.			1		1
Q3		Aircraft Structures and Control	Demonstrate knowledge of various types of aircraft construction	Evaluate the different types of aircraft construction			1		1
				Distinguish between the features of fly-by-wire (automatic) control, mechanical control and hydraulic control of aircraft.			1		1
				Apply the understanding of moments in Physics to aircraft movement to explain stability configurations.			1		1

SECTION C									
Q4	Avionics	Aircraft instrumentation	Demonstrate knowledge of the instruments used for airborne and ground operations and their principles of operations.	Relate the physical variables that are measured in aircraft applications with the instruments used to measure them	1				1
				Explain the principles of operation of the aircraft instruments		1			1
				Indicate the various aircraft parameters that are recorded	1				1
				Demonstrate an understanding of flight data storage in aircraft					
Q5		Communication, navigation and surveillance systems	Demonstrate knowledge of the different aerospace surveillance technologies	Present a summary of on-board surveillance systems		1			1
				Present a summary of ground-based surveillance systems		1			1
				Explain the concept of navigation (dead reckoning and position fixing)	1				1
				Identify the advantages and disadvantages of the different navigation technologies.	1				1
SECTION D									
Q6	Aviation industry	Aviation organisations	Demonstrate understanding of the relationship between aerospace and aviation organisations and how this helps to regulate operations.	Identify the major aviation agency in Ghana and its key operations	2	1			3
				Identify global aviation agencies					

Q7		Aircraft maintenance	Demonstrate understanding of the roles of the aviation agencies in ensuring the safety of air transport	Identify the functions of local aviation organisations						
			Demonstrate knowledge of aircraft maintenance activities	Explain the functions of ICAO, IATA, FAA, EASA etc.						
				Classify various maintenance tasks as routine, periodic, etc.		1	1		2	
				Identify aircraft maintenance equipment.		2				2

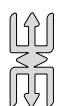
3. PAPER 3 (Practical)

S/N	Strand	Sub-strand	Content standard	Learning indicator	Number of items				Total
					DOK 1	DOK 2	DOK 3	DOK 4	
Q1	Unmanned aerial vehicles (UAVs)	Design and fabrication of UAVs	Demonstrate knowledge of how to develop and evaluate conceptual designs of UAVs.	Generate UAV concepts given a set of mission requirements.			1		1
				Apply evaluation tables to select the best concept from a number of UAV concepts.					
			Demonstrate knowledge of how to undertake basic UAV design calculations.	Perform simple calculations that yield the properties (such as wing area, number of motors, propellant, etc.) for a small UAV.					
				Demonstrate knowledge and understanding of how to fabricate and test a selected design.	Build a small UAV (aircraft/rocket) using locally available materials				
			Fly the fabricated UAV.						

PLC Session 17– 20

45 minutes Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
 - a. explain the week's concepts in a practical way that will make it easier for learners to understand.
 - b. identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
 - a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
 - b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).
 - c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



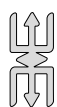
Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Use your app to plan and administer the mode of assessment for the student Assessment Portal (SAP).
 - a. The key assessment for the week is **practice paper 2**. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/rubrics for the practice paper (NTS 3k-3q).

10 minutes Content Exploration

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
 - a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
 - b. all teachers in the group work through the problem individually for 3–4 minutes
 - c. the group then works through it together the problem, step by step
 - d. highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- This part is not 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.

- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes Enactment

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).
 - a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
 - b. After the enactment, ask for structured feedback from the group
 - i. was the concept explained in a way that a learner with no prior knowledge could follow?
 - ii. were the examples grounded in contexts familiar to Ghanaian learners?
 - iii. did any misconceptions surface and if so, how were they addressed?

5 minutes Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
 - a. transfer your chats into your learning planner template.
 - b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
 - c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 6 Review

Congratulations on coming to the end of Section 6! In this section, we were concerned with the business of constructing the UAVs we had designed in Section 5. We looked at the safety measures to observe while working in the laboratory. Then we looked at the different materials available to us for constructing our models. We also looked at tools and equipment we could use, and some laboratory supplies we would need. It is necessary to remember that working together in a group as a team allows us to harness the strengths of each member to produce a more robust UAV.



MARKING SCHEMES FOR THE KEY ASSESSMENTS

1. Question 1

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
<i>Understanding of Joining Methods</i>	<i>Clearly explains at least two appropriate joining methods with accurate technical detail.</i>	<i>Explains two joining methods with mostly accurate detail.</i>	<i>Describes two methods, but with limited or partially incorrect information.</i>	<i>Mentions methods with little or no explanation or relevance.</i>
<i>Evaluation of Engineering Factors (Strength, Weight, Aerodynamics, Durability)</i>	<i>Thoroughly evaluates each method across all four factors with clear reasoning.</i>	<i>Evaluates most factors with reasonable reasoning.</i>	<i>Addresses some factors but lacks depth or clarity.</i>	<i>Minimal or unclear evaluation of factors.</i>
<i>Recommendation and Justification</i>	<i>Provides a well-reasoned recommendation with strong justification based on evaluation.</i>	<i>Gives a recommendation with some justification.</i>	<i>Offers a recommendation with weak or unclear justification.</i>	<i>No clear recommendation or justification.</i>
<i>Tools, Materials, and Safety</i>	<i>Lists all necessary tools and materials; includes relevant safety precautions.</i>	<i>Lists most tools and materials; mentions some safety precautions.</i>	<i>Lists some tools/materials; safety precautions are vague or missing.</i>	<i>Tools, materials, and safety are not addressed.</i>
<i>Organisation and Clarity</i>	<i>Response is well-organised, clear, and free of grammar/spelling errors.</i>	<i>Mostly clear and organised; few minor errors.</i>	<i>Somewhat disorganised or unclear; several errors.</i>	<i>Poorly organised or difficult to understand.</i>
<i>Creativity and Insight (optional bonus +2)</i>	<i>Demonstrates original thinking or innovative approach to the problem.</i>	—	—	—

Question 2

Category	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
<i>Material Comparison</i>	<i>Clearly compares wood and metal using accurate facts (strength, weight, durability).</i>	<i>Compares both materials with mostly correct facts.</i>	<i>Some comparison, but missing or unclear facts.</i>	<i>Little or no comparison of materials.</i>
<i>Impact on UAV Design</i>	<i>Explains how each material affects performance, cost, and maintenance.</i>	<i>Explains most effects clearly.</i>	<i>Mentions some effects but lacks detail.</i>	<i>Effects are unclear or missing.</i>
<i>Final Recommendation</i>	<i>Strong, well-explained choice with clear reasons.</i>	<i>Good choice with some explanation.</i>	<i>Choice is made but not well explained.</i>	<i>No clear choice or explanation.</i>
<i>Adaptability to Conditions</i>	<i>Thoughtfully explains how the choice might change in different environments.</i>	<i>Mentions some changes with basic reasoning.</i>	<i>Mentions changes but lacks explanation.</i>	<i>No mention of different conditions.</i>
<i>Clarity and Effort</i>	<i>Well-organised, easy to read, and shows strong effort.</i>	<i>Mostly clear and organised.</i>	<i>Somewhat hard to follow or rushed.</i>	<i>Disorganised or incomplete.</i>

SECTION 7: FLYING UAVS

STRAND: UNMANNED AERIAL VEHICLES (UAVS)

Sub-Strand: Design and Fabrication of UAVs

Learning Outcome: *Construct and fly a small UAV*

Content Standard: *Demonstrate knowledge and understanding of how to fabricate and test a selected design*

INTRODUCTION AND SECTION SUMMARY

The final section of this teacher manual will focus on flying the models we have built in the previous section. We will look first at flying UAVs in simulation software. This should give us some confidence to fly the actual models in the final weeks.

The weeks and the indicators covered by the section are:

- Weeks 21 – 24: Fly the fabricated UAV.

Recap weeks

Year 2	Weeks 20 & 21: • Explain safety practises with regard to building and operating UAVs. • Evaluate official regulations relating to the possession and operation of UAVs.
Year 3	Weeks 5 & 6: • Describe the flight controls (and control surfaces) of a fixed-wing aircraft. • Describe the flight controls of a rotary-wing aircraft

SUMMARY OF PEDAGOGICAL EXEMPLARS

1. Experiential learning
2. Group discussions

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/or Mode
Fly the fabricated UAV.	3	Simulation
		Practical assessment

WEEKS 21 & 22

Learning Indicator: *Fly the fabricated UAV*

Focal Area: UAV simulation flights (Refer back to Year 3, Section 2, Weeks 5 & 6: Aircraft & Spacecraft Flight Controls)

The lessons for this week will focus on gaining experience flying UAVs in a simulation environment. There are several simulators at our disposal including RealFlight, FlightGear, PicaSim, Reflex XTR² and many others.

We will follow the following procedure to set up the flight simulator.

1. Open the UAV flight simulation software, making sure the controller or transmitter is connected and recognised by the software.
2. Choose an aircraft model (fixed-wing, multicopter, helicopter, etc.) from the simulator's aircraft library. Select one that closely matches the UAV your class has built, looking out for beginner-friendly models at the start.
3. Select a training environment with clear skies, low wind, and a wide-open field or runway. Avoid complex terrain or poor weather conditions for this task.
4. Go to the settings or controller setup menu and calibrate the transmitter. Ensure all control surfaces (elevator, rudder, ailerons, throttle) respond correctly. Test each axis before starting the flight.
5. Check the aircraft's weight, battery level (if simulated), and control sensitivity. Adjust settings to match a realistic training scenario if needed.
6. If the simulator allows, save your setup as a custom scenario or load a pre-made training mission that includes take-off, climb, cruise, turns, and landing.
7. Start the simulation and begin practicing manoeuvres including take-offs, climbs, turns, cruise and landings.
8. Use the simulator's replay or telemetry features to review your performance afterward.

Learning Tasks

1. Set up the available simulation software for flight of a multicopter or fixed-wing aircraft.
2. Fly several manoeuvres in the simulation environment including take-offs, climbs, landings, etc.

Pedagogical Exemplars

Experiential learning – Guide learners to set up the flight simulation environment and fly common manoeuvres.

Key Assessment Level 3: Simulation

Question 1

You are preparing for a real-world UAV flight by using a flight simulator to practise essential flight manoeuvres under controlled conditions. Your goal is to demonstrate your ability to apply flight principles, adjust to simulated conditions, and evaluate your performance.

1. Set up the flight simulation software for a fixed-wing UAV flight in good weather conditions. Adjust the aircraft model, environment, and control settings to match a realistic training scenario. Explain your setup choices and how they reflect real-world flight preparation.
2. Perform a complete flight sequence that includes take-off, climb, level flight, coordinated turns, descent, and landing. During the flight, monitor your altitude, speed, and heading. Make adjustments as needed to maintain control and stability.
3. Analyse your flight performance by reviewing the simulator's flight data or replay. Identify what went well and what could be improved. Reflect on how your simulator experience prepares you for actual UAV operation and what skills you still need to develop.

(20 marks) (DOK 3)

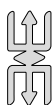
Refer to Teacher Assessment Manual and Toolkits pages 69 – 72 for further guidance on conducting simulation assessments.

PLC Session 21 & 22

45 minutes

Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
 - a. explain the week's concepts in a practical way that will make it easier for learners to understand
 - b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
 - a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
 - b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
 - c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

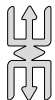
4. Plan the week's key assessment with your app
 - a. The key assessment for the week is **simulation**. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the simulation (NTS 3k-3q).

10 minutes

Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

- a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
- b. all teachers in the group work through a similar problem individually for 3–4 minutes
- c. the group then works through the problem together step by step
- d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about ‘How do I teach this?’ but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes

Enactment

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).
 - a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
 - b. After the enactment, ask for structured feedback from the group
 - i. was the concept explained in a way that a learner with no prior knowledge could follow?
 - ii. were the examples grounded in contexts familiar to Ghanaian learners?
 - iii. did any misconceptions surface and if so, how were they addressed?

5 minutes

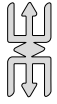
Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
 - a. transfer your chats into your learning planner template.
 - b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
 - c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEKS 23 & 24

Learning Indicator: *Fly the fabricated UAV*

Focal Area: **Real-world UAV flights**



Note

Refer back to Year 2, Section 6, Weeks 20 & 21: GCAA UAV regulations and Year 3, Section 2, Weeks 5 & 6: Aircraft & Spacecraft Flight Controls.

This week and the next, we will be concerned with flying the models we have built. We will begin with a recap of GCAA's rules regarding flying UAVs which we covered in Year 2 Section 6, Weeks 20 & 21: UAV safety and regulations.

GCAA requires that we remain within visual line of sight (VLOS) of the UAV throughout the flight. If we must fly beyond visual line of sight (BVLOS), we need to obtain approval. Most of our flights will be non-commercial in nature, and we will have to stay away from airports and national security zones. We are not allowed to fly over crowds, and we must remember that we will be held responsible for any damage or injury caused by our aircraft. It is necessary that we respect the privacy of others and avoid unauthorised surveillance or data collection. We will always be flying at a maximum altitude of 400 feet above ground level and must adhere to safety procedures and airspace regulations.

Airfield safety

1. Always use the correct batteries and chargers. Damaged or swollen batteries should never be used, and charging should be done in a safe area under supervision.
2. Avoid flying in bad weather such as strong winds or rain. Weather conditions can affect how the UAV flies and how safely it can be controlled.
3. Choose a clear, open space for take-off and landing. Keep people and obstacles away from this area to prevent accidents.
4. Learners should be trained to respond calmly to problems like low battery or signal loss. Practising emergency landings helps prepare for real situations.
5. All learner flights should be supervised by an instructor or trained adult to ensure safety and provide guidance.
6. Safety glasses and keeping a safe distance from spinning propellers are important. Never touch the UAV while it is powered on.

Preflight checks

1. Check the airframe, propellers, landing gear, and all structural components for cracks, loose parts, or signs of wear. Ensure everything is securely attached.
2. Inspect the battery for damage or swelling. Make sure it is fully charged and properly connected. Only use approved chargers and never leave batteries unattended while charging.
3. Test all controls (throttle, yaw, pitch, roll) to ensure they respond correctly. Calibrate the controller if needed. It might be necessary to bind the RC transmitter to the receiver.
4. If your UAV uses GPS, wait for a strong satellite lock. Calibrate the compass in an open area away from metal objects or electronics to avoid interference.

5. Ensure that the flight controller, transmitter, and any onboard software are up to date. This helps prevent bugs or compatibility issues during flight.
6. Check the weather forecast for wind, rain, or extreme temperatures. Confirm that the flight area is legal and safe—away from airports, crowds, and restricted zones.
7. Use a printed or digital checklist to confirm all systems are ready. This includes checking propeller tightness, battery voltage, and control link strength.
8. Review safety rules with learners: maintain line of sight, keep a safe distance, and know emergency procedures. Assign roles if working in teams (e.g., pilot, spotter, recorder).
9. Discuss the flight objective, route, altitude, and duration. Make sure learners understand what they are testing or observing during the flight.
10. Identify a clear, open space nearby where the UAV can safely land in case of a malfunction or loss of control.

Piloting notes

First, the extra switches, knobs or buttons, called accessory channels can be programmed to control special features on the drone, such as turning lights on and off, adjusting a camera angle, or deploying landing gear. Using accessory channels will help us manage more complex tasks without taking our hands off the main controls. It is important for learners to learn how to assign and test these channels safely before flight, so we can make the most of our drone's capabilities.

Also, when flying, it is important to always know which direction the drone is facing, this is called maintaining orientation. It can be easy to get confused, especially when it is far away. A good way to stay oriented is to imagine that we are “inside” the drone, thinking about which way its front is pointing. Some drones have coloured lights or markings to help tell the front from the back. It might be a good idea to practise flying with the drone facing away from them, so the controls feel more natural. As we gain experience, we can learn to fly in different orientations and even use a compass display to help stay in control.

Usually, we will launch our UAVs by hand or conventional take-off. Hand launching gets the UAV into the air by gently throwing it forward while the motor is running. It is useful when there's no runway or flat surface available. In hand-launching, it is necessary to ensure the UAV is stable, the propeller is clear of the hands, and the launch is done into the wind for better lift. Conventional take-off and landing involve using a flat, open surface where the UAV rolls forward to gain speed and liftoff and later returns to land on its wheels. This method is more realistic for fixed-wing aircraft.

Post flight review

The following steps, if taken after flight, will ensure safety and care for the equipment. First, the UAV and transmitter should be powered off safely, then the battery should be removed and inspected, checking for heat or damage before storing it properly. Next, the UAV should be inspected for any signs of wear or damage that may have occurred during the flight. It is also a good practice to record flight details in a logbook, including flight time, battery performance, and any issues encountered. Finally, the UAV should be cleaned if needed and stored in a safe place. Take a moment to review what went well during the flight and what could be improved for future flights. This routine helps build responsibility and reinforces good aviation habits.

Learning Tasks

1. Discuss with your friends some GCAA regulations that govern the flight of UAVs in Ghana
2. Fly a fixed-wing or multi-rotor UAV

Pedagogical Exemplars

Group discussions – Put learners in mixed ability groups and assign them to discuss some safety practices to be observed while flying.

Experiential learning – Assist learners to perform pre-flight checks and fly their UAV models

Key Assessment: Practical Assessment

Question 1

You are part of a learner flight operations team preparing to conduct a test flight of a fixed-wing UAV that your class has built. Your mission is to demonstrate safe and effective UAV operation while applying your knowledge of aviation systems, flight dynamics, and regulatory compliance.

Working with your team, complete the following:

1. Prepare the UAV for flight by conducting a full pre-flight inspection. Identify and explain the function of each component you check (e.g., control surfaces, battery, transmitter, propellers). Document any issues and how you resolved them.
2. Rehearse and apply safety procedures and GCAA RPAS regulations. Lead a short safety briefing that includes key rules (e.g., altitude limits, no-fly zones, line-of-sight operation). Explain how these rules apply to your flight area and mission.
3. Fly the UAV, performing a complete flight sequence: take-off, climb, cruise, turns, descent, and landing. During the flight, demonstrate control and awareness of orientation. After the flight, reflect on your performance: What went well? What challenges did you face? How did you respond? (20 marks) (DOK 3)

Refer to Teacher Assessment Manual and Toolkits pages 46 – 49 for further guidance on conducting practical assessments

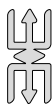
PLC Session 23 & 24

45 minutes

Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
 - a. explain the week's concepts in a practical way that will make it easier for learners to understand
 - b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
 - a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

- b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
- c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



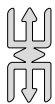
Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
 - a. The key assessment for the week is **practical assessment**. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the assessment (NTS 3k-3q).

10 minutes Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
 - a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
 - b. all teachers in the group work through a similar problem individually for 3–4 minutes
 - c. the group then works through the problem together step by step
 - d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes Enactment

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).
 - a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
 - b. After the enactment, ask for structured feedback from the group
 - i. was the concept explained in a way that a learner with no prior knowledge could follow?
 - ii. were the examples grounded in contexts familiar to Ghanaian learners?
 - iii. did any misconceptions surface and if so, how were they addressed?

5 minutes**Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
 - a. transfer your chats into your learning planner template.
 - b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
 - c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 7 Review

In this section, we were concerned with flying the UAVs we had designed and built. We first conducted simulation flights where we got to practise flying in a controlled environment. We learned how to set up the simulator and fly a few manoeuvres including take-offs, climbs, forward flights and landing. In weeks 23 and 24, we applied the knowledge we had gained with the simulator to the real-world. Hopefully, you can fly a UAV now!



MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEKS 21 & 22

Question 1

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Simulation Setup	Clearly explains setup choices with strong connection to real-world flight conditions.	Explains setup with some connection to real-world relevance.	Basic setup with limited explanation or realism.	Setup is unclear or lacks explanation.
Flight Execution	Performs all maneuvers smoothly with strong control and situational awareness.	Performs most maneuvers with good control; minor issues.	Some maneuvers completed; control or awareness inconsistent.	Flight is incomplete or lacks control.
Use of Flight Data	Effectively uses simulator data or replay to analyse performance.	Uses some data to support analysis.	Limited use of data; analysis is mostly observational.	No meaningful use of data or analysis.
Reflection & Evaluation	Thoughtful reflection with clear insights into strengths, challenges, and learning goals.	Reflects on performance with some insight.	Basic reflection with limited depth.	Reflection is vague or missing.
Communication & Presentation	Work is well-organised, clearly written, and easy to follow.	Mostly clear and organised; minor errors.	Somewhat disorganised or unclear.	Disorganised or difficult to understand.

WEEKS 23 & 24

Question 1

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Pre-Flight Preparation	Thorough inspection with clear explanation of each component's function; issues identified and resolved.	Most components checked and explained; minor issues addressed.	Basic inspection with limited explanation; some steps missing.	Incomplete or unclear inspection; major steps skipped.

<i>Safety & Regulation Briefing</i>	<i>Accurately explains GCAA rules and applies them to the flight area; leads a clear, confident safety briefing.</i>	<i>Covers most key rules and safety points; some application to flight area.</i>	<i>Mentions basic rules but lacks detail or connection to flight.</i>	<i>Safety rules are unclear, incorrect, or missing.</i>
<i>Flight Execution</i>	<i>Performs all maneuvers smoothly with strong control and orientation awareness.</i>	<i>Performs most maneuvers with good control; minor issues.</i>	<i>Some maneuvers completed; control or orientation inconsistent.</i>	<i>Flight is incomplete or lacks control and awareness.</i>
<i>Flight Log & Reflection</i>	<i>Detailed log with thoughtful reflection on performance, challenges, and learning.</i>	<i>Clear log and reflection with some insight.</i>	<i>Basic log and brief reflection; limited analysis.</i>	<i>Log is incomplete or lacks meaningful reflection.</i>
<i>Teamwork & Communication</i>	<i>Team collaborates effectively, shares roles, and communicates clearly.</i>	<i>Good teamwork with some role-sharing and communication.</i>	<i>Some collaboration; roles or communication unclear.</i>	<i>Poor teamwork or lack of communication.</i>

REFERENCES

- Aircraft Communications and Navigation Systems, 2nd Edition by Mike Tooley and David Wyatt
- Aircraft design: A conceptual approach, 6th Edition, by Daniel P. Raymer
- Aircraft design: A Systems Engineering Approach, 1st Edition, by Mohammad H. Sadraey
- Aircraft structures for engineering learners, 6th Edition by T. H. G. Megson
- Airworthiness Definition: <https://skybrary.aero/articles/airworthiness>
- [Beginners Guide to Aeronautics](#) by NASA
- El-Sheimy, N., Youssef, A. Inertial sensors technologies for navigation applications: state of the art and future trends. Satell Navig 1, 2 (2020). <https://doi.org/10.1186/s43020-019-0001-5>
- Ghana Civil Aviation (Remotely Piloted Aircraft Systems) Directives, 2018
- Ghana Civil Aviation (Remotely Piloted Aircraft Systems) Directives, 2018
- [Helicopter Flying Handbook](#) by FAA
- Introduction to multicopter design and control by Quan Quan
- Maintenance Logs: <https://limblecmms.com/learn/equipment-facility-maintenance/equipment-log/#:~:text=A%20basic%20maintenance%20log%20is,performed%20based%20on%20predictive%20data> NASA's Basics of Space Flight (JPL) (Advanced Learning)
- [Pilot's Handbook of Aeronautical Knowledge](#) by FAA
- Pilot's handbook of aeronautical knowledge, FAA
- Routine maintenance: <https://www.naa.edu/types-of-aviation-maintenance-checks/>
- Shigley's Mechanical Engineering Design, 10th Edition, by Richard G. Budynas and J. Keith Nisbett
- Smith, M., Moser, D., Strohmeier, M., Lenders, V., & Martinovic, I. (2018). Undermining privacy in the aircraft communications addressing and reporting system (ACARS). Proceedings on Privacy Enhancing Technologies, 2018(3), 105-122.
- The FlightGear Manual for FlightGear version 2024.1.1, March 2025
- The FlightGear Manual for FlightGear version 2024.1.1, March 2025
- [Video: Aircraft Control Surfaces Explained | Ailerons, flaps, elevator, rudder and more](#)
- [Video: Introduction to Spacecraft Navigation, Guidance and Control](#)(Advanced Learning)
- [Video: Reaction control system Explained](#)
- [Video: Spacecraft Gyroscopes And Reaction Wheels](#)

