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ABSTRACT

This curriculum guide accompanies another publication in the Aerospace Education II series entitled "Propulsion Systems for Aircraft." The guide includes specific guidelines for teachers on each chapter in the textbook. Suggestions are included for objectives (traditional and behavioral), suggested outline, orientation, suggested key points, suggestions for teaching, instructional aids, projects, and further reading. Major concepts discussed in the textbook are briefly explained with additional background material. Page references corresponding to the textbook are given. A blank sheet is provided after each chapter for teachers to record ideas. (PS)

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AE-II

INSTRUCTIONAL UNIT II

PROPULSION SYSTEMS FOR AIRCRAFT

PREPARED UNDER
THE DIRECTION OF

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SE 017 459

SEPTEMBER 1973

INSTRUCTIONAL UNIT II

PROPULSION SYSTEMS FOR AIRCRAFT

INSTRUCTIONAL UNIT OBJECTIVES - When the book is completed each student should:

a. Be familiar with the historical development of aircraft engines.

b. Know the operating principles of aircraft power plants.

c. Know the major components and relationships for aircraft engines and accessory systems.

d. Be familiar with the current state of propulsion technology.

INSTRUCTIONAL UNIT II CHAPTERS

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CHAPTER I - POWER IN FLIGHT

This chapter is primarily a review of information covered previously in Aerospace Education booklets concerning the historic development of the airplane. The accent is on the development of aircraft powerplants. It also includes brief reviews of historic developments in aerodynamic theory~~, of~~ advances in ballooning ~~and gliding,~~ and more thorough coverage of engine development, starting with the steam engine. Coverage of the reciprocating engine development extends to the Wright brothers' "Flyer." A brief history of the development of jet propulsion for aircraft use is included. The final part of the chapter deals with the power rating terms of horsepower and thrust.

I. OBJECTIVES:

a. Traditional Objectives - Each student should:

(1) Know the significant developments that contributed to the reservoir of knowledge necessary for the first successful powered flight.

(2) Know the importance of the development of the internal combustion engine to the first successful heavier-than-air machine flight.

(3) Know how to determine the power output of reciprocating and jet propulsion engines.

b. Behavioral Objectives - Each student should be able to:

(1) Discuss at least three significant developments that contributed to the reservoir of knowledge needed for the first successful powered flight.

(2) Discuss at least two reasons why the development of the internal combustion engine was important to the first successful heavier-than-air machine flight.

(3) Solve simple power output problems when the necessary data and formulas are given for reciprocating and jet engines.

2. SUGGESTED OUTLINE:

   a. Development of the engine took place over a period of years with many setbacks

      (1) Experimentation with kites, gliders, and sailing ships

      (2) The steam engine (external combustion) had many disadvantages

      (3) Development of the internal engine came as a result of improvement on the external combustion engine

      (4) The Wright brothers collected the recorded progress in all fields of aviation and then added their knowledge

   b. Air theory

      (1) The wind was first power used to sail ships

      (2) Wind was believed to be a sustaining force

      (3) Air supported the flight of birds

         (a) Leonardo da Vinci believed birds swim in air. He believed that air hinders flight

            1. He studied streamlining to reduce resistance

            2. He drew plans for a parachute, for a helicopter, and for an ornithopter--a device with bird-like wings that man could flap

         (b) Borelli, in 1680, published that man would never be able to fly because of poor ratio of power to weight

         (c) No man was able to fly by flapping things like wings. Photography shows that the outer primary feathers of a birds' wings function as propellers

         (d) The major problem with balloons is how to control their direction of flight

   c. Engines

      (1) Steam engine was developed for aircraft (balloons) in 1851 by Henri Giffard of France

(2) Internal combustion engine

(a) First gasoline engine was produced by W. Cecil, an Englishman, in 1820

(b) William Barnett, Englishman, suggested that compressed gasoline would produce more power

(c) J.J.E. Lenoir, a Frenchman, designed the first practical internal combustion engine in 1860

(d) Alphonse Beau de Rochas came out with a theory for a four cycle engine

(e) Nikolaus Otto applied the theory to real engines in 1876

(f) Gottlieb Daimler devised a high speed internal combustion engine in 1883

d. Powered flight

(1) Paul Haenlein, a German, was first to use a four cylinder internal combustion engine on an airship (balloon) in 1872

(2) In 1881, Albert and Gaston Tissandier of France used an electrically driven 1.5 HP engine on an airship

(3) David Schwartz was first to use a gasoline burning internal combustion engine on an airship in 1897

(4) A Brazilian, Santos-Dumont, and a German, Ferdinand von Zeppelin, worked on dirigibles powered by internal combustion engines in 1898. In 1901, Zeppelin's dirigible flew seven miles in 29 minutes and 31 seconds

(5) Balloons supplied information on engine design

(6) Gliders supplied information on aircraft design

(a) Sir George Caley
(b) Otto Lilienthal
(c) Percy Pilcher
(d) Octave Chanute

(7) Adding a source of power

(a) Samuel Langley produced the first successful heavier-than-air model aircraft. His full-sized aircraft, the "Aerodrome," had a good engine built by Charles Manly but never carried a man successfully.

(b) The Wright brothers had to experiment and develop their own ideas

1. Developed a 12 HP engine, 170 lbs, 4 cylinders, with the help of Charles Taylor

2. Constructed their own wooden propellers

(c) December 17, 1903, Orville Wright flew the "Flyer" while his brother Wilbur watched

e. Jets

(1) Isaac Newton's theory on motion, 1687

(2) Sanford Moss, an American, did research on the gas turbine engine

(3) Frank Whittle combined the gas turbine and air compressor to make a jet in 1930

(4) Germany flew the first jet aircraft in August 1939. The engine was designed by Pabst von Ohain

(5) The English successfully flew a jet aircraft in May 1941

(6) The US flew the P-80 in 1944

f. Power terms

(1) Thrust

(2) Work; W=FxD

(3) James Watt developed the concept of horsepower

$$hp = \frac{\text{number of ft lb/sec}}{550}$$

(a) Newton's second and third laws of motion

(b) Acceleration, an increase in velocity per unit of time

(c) Formula for determining thrust is force (in lbs) = mass (in slugs) times acceleration (in feet per sec per sec) or F = MA

(d) Thrust horsepower = $\frac{\text{thrust x airspeed}}{375}$

7

3. ORIENTATION:

a. The historical development of engines used to power aircraft is traced in this chapter. A review of the history of lighter-than-air craft flight and powered flight is included. Successful flight incorporated advances in all of these areas.

b. As instructors, you should be able to have the students explain the following:

(1) The main difference between internal and external combustion engines and the reasons external combustion engines proved impractical for powering aircraft.

(2) Why the internal combustion engine was so long developing and why it was the key to powered flight.

(3) Terms such as thrust and horsepower, and their relationship.

(4) The student should understand the functions necessary to compare a piston engine's power with that of a jet.

4. SUGGESTED KEY POINTS:

** V-9014, pp 80-84 ** V-9002, p 10 ** V-9156, p 58.	a. One of the first engines to be developed was the steam engine (an external combustion type). It had many shortcomings that prevented it from being a powerplant for aircraft. Some of these shortcomings were: it was too bulky; it was too heavy; and it could not change its power output quickly enough to be responsive to the pilot's control.
* V-9013, pp 118-119 ** V-9014, pp 84-87 ** V-9131, p 1 ** V-9147, pp 17-19	b. The internal combustion engine was a great advancement because it did not have the shortcomings of the steam engine (see Key Point a). Its development came only when there was a sufficient accumulation of knowledge in mechanical skills, thermodynamics (the study of heat and energy), the use of new metals which were strong but light, etc. Without this type of engine, it probably would have taken many years before a suitable power source could have been invented.

(Note: Many page references cited in this handbook may not coincide with the exact page of your reference book. Due to purchases over extended periods, some books have been revised several times.)

c. Even though the principles involved in the operation of a jet engine were known for 200 years, an engine of this type was not constructed. The main reason for this was that an internal combustion jet engine had to be developed because the external type was too bulky and produced little power. The development of metals strong enough to withstand a large amount of heat and pressure opened the doorway to producing a jet engine. Sanford Moss' research on turbines helped lead to the development of a practical engine when Frank Whittle coupled the turbine with an air compressor. For about 25 years the jet engine's use as a powerplant was insignificant but with the ending of World War II, there was a tremendous expansion of jet engine usage until today its role in our daily life is taken for granted.

** V-9131, pp 2, 405-407

d. This chapter is concerned with two different types of propulsion systems, and two different types of power output ratings are needed: horsepower and thrust. Cars and some airplanes have a common type of propulsion unit, the reciprocating engine, so it is not surprising that these aircraft engines can be rated in terms of horsepower. Since jet engines work differently than reciprocating engines, a more appropriate power rating is thrust.

* V-9131, pp 407-408

e. Since power is work done over a period of time, work must first be defined. Work is the exertion of a force over a distance. A formula to compute work is as follows: W = FxD. For example, when a man lifts a box weighing 100 lbs upward from the floor a distance of four feet, he has done 400 ft lb of work. Historically, James Watt was responsible for setting the unit of power, horsepower, at 550 ft lb/sec when he decided to compare the power output of a steam engine with the power output of a horse. Thus, to determine the horsepower rating of an engine, it is necessary to use the formula:

$$hp = \frac{\text{number of ft lb/sec}}{550}$$

For jet and rocket engines the most convenient power rating is thrust. Since thrust is a force, the power rating of a jet can be computed from a formula derived from Newton's Second Law of Motion. This formula (F = MA) shows that the force in pounds (thrust) is equal to the mass in slugs (of air moved through the engine) times the acceleration in feet per second

* V-9002, pp 180-181, 202-203
* V-9005 (1966 ed.), pp.45, 49-50
*** V-9131, pp 8-9, 407-408, 468-470
** V-9171, pp 15-26 545-549

(increase in velocity of the air per unit of time). For example, a jet which has an exhaust velocity of 1700 feet per second and is capable of handling 322 lb of air per second has a thrust of 17,000 lb. This was computed in the following manner: the acceleration (rate of change in velocity) was equal to final velocity minus the initial velocity, divided by the time required for the change:

$$\frac{1700 \text{ ft/sec} - 0 \text{ ft/sec}}{1 \text{ sec}} = 1700 \text{ ft/sec}^2;$$

thus $T = MA$

$$T = \frac{322 \text{ lb}}{32.2 \text{ ft/sec}^2} \times 1700 \text{ ft/sec}^2$$

(Dividing by 32.2 ft/sec^2 effectively removes from our calculation of engine power the normal acceleration caused by gravity.)

$$T = 10 \text{ lb} \times 1700$$

$$T = 17{,}000 \text{ lb}$$

5. SUGGESTIONS FOR TEACHING:

a. Suggested time: 2-3-4 (Translation--if you teach two academic periods per week we recommend you devote two hours to this subject. If you teach three periods per week you could devote three periods. If you teach four academic hours per week you could devote four periods to the subject. These "Suggested times" are just that--recommendations. Adjust the emphasis according to interest and talent--both yours and the students'.)

b. The history of aircraft flight was examined in detail in AE-I. A review of this can be made with the major accent on the development of a suitable powerplant for aircraft. Tracing the history of the development of the steam engine, other external combustion engines, and internal combustion engines such as the reciprocating engine and the jet could be a worthwhile project for the class. This activity could be arranged as a small group activity where each group researches a particular type of engine or as a class project where each student is given a specific assignment. The class could construct a time line on the development of aircraft propulsion systems. Toy engine models and schematics would certainly help the students visualize the powerplants that are being discussed. If enough of these are brought to class, they could be arranged in sequence around the room; each could be labeled and a short description attached. You may want to look ahead to the summary for this book for some interesting historical parallels.

c. If your students do not have the capability to grasp the computations explained in this chapter, do not spend class time developing them. Simple definitions are sufficient for students to understand information presented later in this unit. For those students who have the interest and ability, materials in V-9131 and V-9171 may serve as references for special study or reports. Should you perform horsepower and thrust computations in class, the more advanced students can assist other students. One interesting method might be an individual or group competition in class to see who can compute simple horsepower and thrust computations most quickly.

d. You will want to work very closely with several other departments throughout this unit of instruction. This unit should reinforce and not repeat what is being taught in Driver's Education, Automobile Shop, Vocational Agriculture, History, and Physics. You may want to invite instructors from these departments to serve as guest experts--maybe a teaching interview on how this subject relates to theirs. Also, they might be aware of additional audiovisual materials.

e. Many instructional approaches are effective for this chapter in addition to those already mentioned. An effort should be made to get the students involved as much as possible. A visit to an antique car museum or an antique auto show would be motivating. If your students have a wide variance in ability, contracts can be very effective. Students with an interest in art could make drawings or montages depicting the history of propulsion. Students might be encouraged to compile a glossary for this text. The High School Curriculum Division could duplicate the best one as a supplement to the instructor handbook giving credit to the cadets who compiled it. Projects should be developed based on your students' interests and abilities.

f. A lecture-discussion method might be tried for this material. If you keep the lecture to a minimum but have adequate visual aids for this chapter, your students will be more interested and will learn more. Engines are a particularly popular subject with high school boys. It will take more effort on your part to make this instructional unit interesting to girls. If you can keep their attention and direct them to the sequence of historical steps in the development of modern engines you will have accomplished the major objectives for this chapter.

g. Textbook corrections:

(1) Page 14--In the acceleration formula there should not be an "s" on time.

(2) Page 16--Question 4.--powered is misspelled.

h. Student assignment: read pages 1-17.

6. INSTRUCTIONAL AIDS:

a. Films:

(1) USAF

TF1-3744 Jet Propulsion, 20 min, color, 1946.

(2) US Atomic Energy Commission

Division of Public Information
Washington, D.C. 20545

Power for Propulsion, 15 min, color, 1965. (Traces history of power sources for propulsion.)

The address for your area Office of Information can be found in Educator's Guide to Free Films which your library should have. Borrower pays return postage.

b. Models and charts that might be found in your school, for example, internal combustion engine that the general science or physics teacher has, could be effectively used to illustrate the textbook descriptions.

c. Slides:

Series V-0086 may be somewhat complex for this chapter. However, slides 5, 6, 7, and 10 may prove helpful for classroom explanations.

7. PROJECTS:

a. Art projects depicting the evolution of aircraft propulsion.

b. Build model or cutaway engines for classroom display.

c. Have students role play inventors who failed.

d. Fly a model aircraft using different size propulsion systems and evaluate performance.

8. FURTHER READING:

a. V-9156 Aeroscience, pp 626-647 (Note: Students should be cautioned that the Langley engine discussed on p 644 is actually the Manly engine.)

b. V-9159 Takeoff Into Greatness

c. Current issues of Aerospace Historian

IDEAS FOR IMPROVEMENT OF THE TEXTBOOK AND/OR INSTRUCTOR'S GUIDE
AND TEACHING TECHNIQUES MOST EFFECTIVE FOR THIS CHAPTER.
TO BE COMPILED AT END OF TEXT AND SENT TO JRC

PROPULSION SYSTEMS

CHAPTER II - RECIPROCATING ENGINES

This chapter goes into the essential elements of the mechanical system of the reciprocating engine--the cylinder and its surrounding parts which work together to change fuel into energy and transfer it to the propeller. It also discusses the four-stroke cycle, different engine types, air and liquid cooling systems, and construction materials used to withstand high temperatures.

1. OBJECTIVES:

   a. Traditional Objectives - Each student should:

      (1) Know the essential parts of the reciprocating engine.

      (2) Know that the four-stroke engine produces power by five main steps during each cycle.

      (3) Be familiar with the major types of engine designs in regard to the arrangement of the cylinders.

      (4) Know at least three ways in which excess heat from combustion is carried away from the engine.

   b. Behavioral Objectives - Each student should be able to:

      (1) Identify and list at least four principle parts of the reciprocating engine.

      (2) Describe each of the five steps that occur during one cycle of a four-stroke engine.

      (3) Recognize at least four types of engine designs in regard to the arrangement of the cylinders.

      (4) Discuss at least three ways in which excess heat from combustion is carried away from the engine.

2. SUGGESTED OUTLINE:

   a. Influence and importance of the reciprocating engine. Ninety percent of all aircraft in general aviation have reciprocating engines

b. Components of the mechanical system that should be identified are (Fig 7, p 21):

(1) Cylinder--(combustion chamber)

(2) Piston--(sliding plug on the cylinder that captures the heat energy and starts the conversion of heat to mechanical energy)

(3) Connecting rod--(between piston and crankshaft)

(4) Crankshaft--(changes up and down motion of the piston into circular motion to turn the propeller)

(5) Valves--(control the flow of gases into and out of the cylinder)

c. The five-step, four-stroke cycle (Fig 8, p 22)

(1) Step 1, intake stroke cycle--(pulls fuel mixture into the cylinder)

(2) Step 2, compression stroke cycle--(compresses fuel mixture)

(3) Step 3, ignition--(piston is near the top of the compression stroke when a spark from the spark plug ignites the compressed fuel mixture)

(4) Step 4, power stroke compressed--(piston is pushed down in the cylinder by the explosion of the fuel mixture)

(5) Step 5, exhaust stroke compressed--(the piston moves up in the cylinder to push the burned gases out through the exhaust valve opening)

d. Diesel engines--advantages and disadvantages

(1) More power per cylinder

(2) Less power per pound of weight

(3) More expensive--initial cost

(4) Diesel fuel less expensive

(5) Diesel fuel will not explode under normal crash circumstances

(6) A diesel engine is less responsive to pilot's power demands

e. Types of reciprocating engines (Fig 11, p 27)

(1) Non-radial--air or liquid cooled

(a) Upright (cylinder above crankcase)

(b) Inverted (cylinder below crankcase)

(c) Horizontal opposed

(d) V-shaped block

(e) X-shaped block

(2) Radial--air-cooled cylinders with a one-throw crankshaft

f. Performance of reciprocating engines

(1) Air-cooled radial engine preferred for power requirements of over 300 horsepower

(2) The reciprocating engine can carry more weight farther, on less fuel than other aircraft in the under-400-mph class

(3) Efficient operation

(4) Very versatile--many uses

(5) Relatively short takeoff and landing rolls

(6) Fast acceleration

g. Heat and cooling

(1) Heat from the fuel mixture burning is the source of power

(a) One-third of the heat produced in the cylinder pushes the piston down for power to turn the propeller

(b) About one-third of the heat produced goes out through the exhaust system

(c) The remaining one-third of the heat goes into the wall and lubricating oil and must be removed very rapidly or it will destroy the engine

1. Heat is removed from the cylinder wall by the following means:

a. Air cooled (Fig 13, p 31)

b. Liquid cooled (Fig 14, p 32)

h. Construction materials for reciprocating engines

(1) Cylinder head--aluminum (forged or cast)

(2) Cylinder--steel (high-grade alloy)

(3) Piston--aluminum (forged or cast)

(4) Connecting rod--steel

(5) Crankshaft--chromium steel

(C) Valves

(a) Intake--solid tungsten or chromium steel

(b) Exhaust--hollow tungsten or chromium steel. The hollow part is filled with a salt solution of metallic sodium.

3. ORIENTATION:

We have completed an overview of the history of powered flight. The rest of this unit we are concerned with the aircraft powerplants in use today and what is being developed for tomorrow. In this chapter we will study the basic principles of the reciprocating engine which represents the vast majority of the aircraft powerplants for general aviation and is still a strong backbone for the military and some commercial airlines. The principle of converting heat energy into mechanical energy, that we cover in this chapter, applies to most of our aircraft engines for the foreseeable future.

4. SUGGESTED KEY POINTS:

a. The influence and importance of the reciprocating engine cannot be minimized when we realize that more than ninety percent of all general aviation aircraft use it. A broad understanding of the principles and mechanics of this type of engine is necessary.

*** V-9002, pp 169-179
** V-9005 (1966 ed.), pp 38-45
*** V-9131, pp 3-15
* V-9140, pp 254-255

b. Basic components of the mechanical system of reciprocating engines are similar regardless of their design. The components and their function should be combined for class presentation. The cylinder or combustion chamber is where the action is. It contains the piston which is a sliding plug, in the cylinder, that captures the energy of the rapidly expanding gases and starts the conversion of heat to mechanical energy. The steps necessary to make this conversion are:

*** V-9156, pp 58-67
** V-9187, EO-pp 1-3

(1) The intake stroke consists of the piston being pulled down while the intake valve is open to draw the air-fuel mixture into the cylinder

(2) The intake and exhaust valves are closed by the camshaft-controlled rocker arms as the piston moves up in the cylinder to compress the air-fuel mixture

(3) As the piston approaches the top of the cylinder, the spark plug "sparks," igniting the fuel mixture which expands many times to push the piston down to make the power stroke

(4) The piston moves up the cylinder with the exhaust valve open to force the by-products-of combustion out of the combustion chamber and prepare it for the next cycle. The connecting rod and the crankshaft combine with the piston to change the up and down motion to circular motion which turns the propeller.

* V-9131, p 8

c. The diesel engine is discussed briefly in relation to its utilization as an aircraft engine. Up to now the diesel engine's disadvantages outweigh its advantages. Some of the diesel's problems are its initial cost, the weight to power ratio and the lag in response to the pilot's demand for more power. Some of the advantages of the diesel are more power per cylinder, it is a more durable engine, and the fuel is less expensive. A major plus factor would be that the fuel will not explode under normal crash circumstances.

* V-9002, pp 169-171
** V-9131, pp 16-20
** V-9161, Chap 2, pp 26-28
*** V-9171, pp 36-39

d. The types of reciprocating engines and their advantages and limitations should be explained. Reciprocating engines are identified by the arrangement of the cylinders and how the cylinders are cooled. Smaller engines (less than 300 horsepower) are usually air cooled and in some form of row-type arrangement of cylinders. The names describe the engine's shape or appearance. The upright has the cylinders above the crankcase. The inverted has the cylinders below the crankcase. The horizontal opposed has two rows of cylinders laying on their sides using a common crankshaft in between. The V and X shaped blocks have the cylinders in rows in the shape of a V or X using a single crankshaft common to all the banks of cylinders. The non-radial engines may be either air or liquid cooled. The air cooled are usually preferred because they are less expensive in their initial cost and are less complicated to service. The radial engine is always air-cooled and has its cylinders arranged in a circle around a one crank crankshaft. For more power the radial engines may be lined up in banks all connected to the same crankshaft. The radial engine is preferred for aircraft with power requirements of more than 300 horsepower.

e. Performance features of reciprocating engines include economy of initial cost of aircraft and economy of operation. The reciprocating engine is very efficient and versatile. It does not need as long a runway for takeoffs and landings. The acceleration response is very fast.

f. Heat from the fuel mixture burning is the source of power. However, only about one third of the heat produced pushes the piston down for power to turn the propeller. About one-third of the heat produced goes out through the exhaust system. The remaining one-third of the heat goes into the cylinder wall and lubricating oil and must be removed very rapidly or it will destroy the engine. Heat is removed from the cylinder wall by two means, liquid and air. Some larger (over 300 horsepower) in-line engines are designed for liquid cooling. The outside cylinder wall forms the inner wall of the waterjacket that holds the liquid (usually ethylene glycol) that takes the heat out of the cylinder and transports it to a radiator. Air moving through the radiator dissipates the heat from the liquid. The liquid cooled engine is not popular with aircraft builders, because it is more costly to build, more complicated to maintain, heavier for the same power output and in combat it is more easily disabled. The air cooled engine is the most popular of the reciprocating engines for aircraft because it is lighter than comparable powered liquid cooled engines. It is less expensive to build and maintain. The cooling system is composed of baffles, fins, and flanges attached so that air may be directed around the cylinders to dissipate the heat. Larger engines require a cowling so that the pilot can control the rate of cooling for the cylinder head to obtain the ideal operating temperature. The cowling encloses the engine. The cowl flaps are opened and closed to control the air flow around the cylinders.

* V-9002, pp 184-186
*** V-9013, pp 145-148
*** V-9131, pp 20-22
** V-9166, p 89
** V-9171, pp 164-184

** V-9002, pp 171-176
** V-9171, pp 47-71

g. Several construction materials are used in reciprocating engines. Aluminum (forged or cast) forms the cylinder head and piston. The cylinder wall is usually a high grade steel alloy. The connecting rod is made of steel while the crankshaft, because of the stresses it must be able to stand, is made of chrome steel. The valves may be made of either tungsten or chrome steel. The intake valve is solid while the exhaust valve is hollow. The hollow part of the exhaust valve is filled with a salt solution of metallic sodium.

5. SUGGESTIONS FOR TEACHING:

a. Suggested time: 3-5-7

b. With a subject as technical as reciprocating engines, the instructor will need extensive audio-visual aids. The class could be introduced to this chapter by showing the film "ABC of Automobile Engines." The film could be followed with a discussion stimulated by asking about the engines in the cars the students drive or ride in. Compare the requirements to make their cars go with the requirements to make an aircraft go. Wall charts and transparencies should be available to illustrate the key points that are discussed. Models of engines or actual gasoline engines from model planes or lawn mowers could be used for demonstration. Many of these materials to show how an engine operates could be obtained from an automotive shop instructor, a physics instructor or a driver education instructor.

c. Other instructional approaches include (1) have the more advanced students help instruct the slower students; (2) student reports from students who have repaired their own automobiles; (3) book reports on the two books listed at the end of this section; (4) brainstorm how reciprocating engines influence our lives; and (5) written or oral reports on how races such as the Indianapolis 500 have benefitted propulsion research. The films listed below can be used for Chapter 3, especially if they arrive late.

d. Textbook corrections:

(1) Page 25, paragraph 4--Rudolph Diesel should have been bold faced.

(2) Page 32, Fig 14, line 3--cylinders misspelled.

e. Student assignment: read pages 19-35.

6. INSTRUCTIONAL AIDS:

a. Films:

General Motors Corp., Public Relations Film Library, 3044 W. Grand Blvd., Detroit, Michigan 48202 (borrower pays return postage)

(1) ABC of Automobile Engines, 21 min, color.

(2) Where Mileage Begins, 19 min, color, 1961.

(3) ABC of the Diesel Engine, 20 min, color, 1950.

b. Transparencies:

V-1020 Four Stroke Cycle Engine Operation

c. Slides:

V-0086 Power for Aircraft, slides 8, 9, 24-28.

7. PROJECTS:

a. Obtain a discarded lawn mower or motor bike engine and allow or encourage some students to take the engine apart (clean it) so that all of the class can handle the parts; identify what the parts are and what they do.

b. Arrange with the automotives instructor for a display of different types of auto engines, such as an air cooled VW engine, four cylinder, six cylinder in-line, and a V-8 engine. Perhaps a student could bring in an automobile with a Wankel engine.

c. Arrange for a field trip to a nearby Air Force Base maintenance shop, or to an airport maintenance shop.

d. Organize a tune-up workshop for your school.

e. Make a propulsion systems poster showing Snoopy with his Sopwith Camel.

8. FURTHER READING:

a. V-9138, Rickenbacker.

b. Dickey, Philip ~~S., III~~. The Liberty Engine, 1918-1942. Smithsonian Annals of Flight, Vol. I, No. 3, Washington, D.C.: Smithsonian Institute Press, 1968.

IDEAS FOR IMPROVEMENT OF THE TEXTBOOK AND/OR INSTRUCTOR'S GUIDE
AND TEACHING TECHNIQUES MOST EFFECTIVE FOR THIS CHAPTER.
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PROPULSION SYSTEMS

CHAPTER III - OTHER ENGINE SYSTEMS

This chapter includes systems other than the mechanical and cooling systems which make up the complete reciprocating engine. Included is a study of fuel, ignition, and lubricating systems and a brief consideration of magnetism and electricity in engine ignition. There is a section on propellers and carburetors, and how these components work together to produce power to operate an aircraft. This chapter will lay the groundwork for a comparison of reciprocating engines with various reaction engines discussed in later chapters.

1. OBJECTIVES:

   a. Traditional Objectives - Each student should:

      (1) Know the basic operation of the fuel (carburetor), electrical, and lubricating systems that complement the mechanical system of the reciprocating engine.

      (2) Know at least three main parts of a propeller.

      (3) Know at least two ways that the forces acting on a propeller in flight can be changed by the pilot.

   b. Behavioral Objectives - Each student should be able to:

      (1) Outline the basic operation of the fuel (carburetion), electrical, and lubricating systems that complement the mechanical system of the reciprocating engine.

      (2) Describe at least three main parts of a propeller.

      (3) Discuss at least two ways in which the forces acting on a propeller can be changed by the pilot.

2. SUGGESTED OUTLINE:

   a. The system within a reciprocating engine

   b. The advantages of petroleum-based fuel in aviation

   c The carburetor and its function

      (1) Method of measuring fuel and air

      (2) Accessories for the system

      (3) Downdraft carburetors

      (4) Pressure injection carburetors

d. The supercharger

e. Fuel injection systems

   (1) Mass airflow type

   (2) Intake metering type

f. Electrical system

   (1) Magnetism and electricity

   (2) Ignition system

      (a) Magneto

      (b) Condenser

      (c) Distributor

      (d) Sparkplug

   (3) Operation of starting system

      (a) Indirect starting

      (b) Direct starting

g. The lubricating system and its function

   (1) The wet sump

   (2) The dry sump

h. The propeller provides lift and thrust for the aircraft

   (1) Parts of the propeller

   (2) Propeller motion

   (3) Forces that act on a propeller in flight

   (4) Types of propellers

   (5) Reversing and feathering

   (6) Limitations on propeller use

3. ORIENTATION:

The previous chapter explained the operation of the mechanical system of the reciprocating engine. This is but one part of the whole engine. The other systems necessary to allow the aircraft engine to perform its mission of moving the aircraft will now be examined. Even though the jet propulsion system is extremely popular, there are many planes that still use the older, but useful, reciprocating engine. As we discussed earlier, general aviation aircraft use mainly the reciprocating engine. It is necessary to learn the function of the fuel system, lubrication system, ignition, carburetor and propeller in order to understand the part they play in the operation of a reciprocating engine. Future chapters will show that some of these systems are part of jet engines as well.

4. SUGGESTED KEY POINTS:

** V-9005, pp 42-47
** V-9156, pp 67-79

a. The last chapter completed the study of the structural or mechanical system of the engine. This system alone cannot furnish power to keep the aircraft flying. Systems such as the fuel system (including carburetor), lubrication system, ignition system, and propeller system must work together in order to furnish the power necessary to move an airplane and keep it flying.

** V-9131, pp 136-144
*** V-9171, pp 142-146

b. The engine without fuel cannot work. What properties should a fuel have? It should burn easily at low temperature but not too easily. It should have a high heat or energy content and be easy to store. The fuel should not freeze at low temperatures or boil at high temperatures. There must be ease of storage, purity and a reasonable price. Aviation gasoline fulfills these requirements.

*** V-9002, pp 187-190
* V-9005, p 43
** V-9013, pp 148-151
*** V-9131, pp 63, 71-73, 76, 80, 87, 144
*** V-9161, Chap 2, pp 40-48
*** V-9171, pp 188-190
** V-9187, EO-pp 4-10

c. The fuel system consisting of tanks, lines and pumps along with gauges exists for the purpose of delivering gasoline to the carburetor. The carburetor is a device to provide a combustible mixture of fuel and air necessary for the operation of the engine.

(1) Gasloine will burn in a cylinder if mixed with air in a ratio between 8 parts of air to 1 part of fuel and 18 parts of air to 1 part of fuel. In fuel-air mixtures, the proportions are expressed on the basis of weight because a ratio based on volumes would be inaccurate due to variations in temperature and pressure.

*** V-9171, pp 186-188

(2) The carburetor also has accessories. An economizer supplies and regulates the fuel for all speeds above cruising speed. The accelerating system prevents a lag in the flow of fuel as the result of sudden acceleration. The mixture control system provides for changing the fuel-air ratio during flight. The carburetor heater warms the gas at high altitudes and prevents icing in the carburetor.

*** V-9131, pp 71-76
*** V-9171, pp 199-210

(3) The updraft carburetor is the least desirable of the various types and is being replaced by the downdraft of which there are many types. The downdraft float is similar to the updraft float carburetor in operation except the flow of air is down rather than up, and it is considered to be safer. The pressure injection carburetor is a radical departure from float type designs. It meters the fuel through fixed orifices according to air venturi suction combined with the new function of atomizing the fuel spray under positive fuel pressure.

** V-9005 (1971 ed.), pp 45-46
*** V-9131, pp 64-71, 76, 87-88

d. The supercharger is a blower or set of blowers which increase the quantity of air (or fuel/air mixture) entering the engine cylinders. Originally the supercharger was developed for the sole purpose of increasing the density of the air taken into the engine cylinders at high altitudes to obtain the maximum power output. However it is now possible to operate a supercharger at low altitudes to increase the charge density above the normal atmospheric pressure and therefore increase the power output of the engine.

** V-9002, pp 183-184
** V-9131, p 97

e. Fuel injection is the introduction of fuel or fuel/air mixture into the induction system of an engine or into the combustion chamber of each cylinder by means of a pressure source. The usual pressure source is an injection pump which may be any one of several types. The mass airflow injection system, used on large aircraft, responds to the engine's demands, at any given time, for

** V-9171, pp 230-238

fuel to match the air intake. The intake metering system, used on smaller aircraft, features a mechanical fuel control that responds to the pilot's manipulation of the throttle control. With fuel injection there is more freedom from icing, more uniform delivery of fuel/air mixture to each cylinder, an increased efficiency of the engine and a reduction in maintenance problems.

f. The electrical system of the aircraft engine provides the spark that ignites the fuel/air mixture in the cylinder for the operation of the engine. This process involves the production of electricity by the magneto.

*** V-9131, pp 200-202, 206-209
** V-9171, pp 242-243, 255-265, 272

(1) Magnetism and electricity are forces with both similarities and differences. Although we do not understand these forces completely, we know how to use them for our purposes. Electricity involves the movement of electrons through a conductor, brought about by ionization of the conductor's atoms. The electromotive force causing this ionization and movement may be applied chemically or by electromagnetic induction. Magnetic attraction or repulsion acts in lines of magnetic flux, which occur in the space around the magnet (the magnetic field). Each line of flux forms a complete circuit through the magnet. Electromagnetism is the induction of electricity through the use of magnetism. For the phenomenon of electromagnetic induction to occur, a conductor must cut through the magnet's lines of flux.

** V-9002, pp 190-191
** V-9131, pp 232-237
** V-9171, pp 307-310

(2) The ignition system includes the magneto, condenser, distributor, and spark plugs. A magneto, basically a rotating four pole magnet, is aided in the buildup of current in the primary coil through the use of a condenser which temporarily stores electricity. The ratio between the distributor gear and the magneto gear is such that the distributor finger (rotor) is driven at one-half engine-crankshaft speed. This ratio insures the proper and timely distribution of high tension current to the spark plugs at the right time. The spark plug is a device that converts the high-voltage pulses from the magneto into heat energy which ignites the air-fuel mixture in the engine cylinders.

** V-9131, p 273

(3) The starting system applies mechanical energy to rotate the crankshaft and magneto. The magneto then generates the spark necessary to ignite the fuel-air which has been compressed by the action of the crankshaft and piston. Basically, there are two types of starters in the reciprocating engine. The first is the inertial starter which may be handcranked or electrically operated. Whether operated by an electric motor or by hand-turning, energy is stored in a flywheel. When this flywheel is engaged, the mechanical energy then rotates the crankshaft and starts the engine. The second type is the direct starter which is hand or electrically operated. A series of gears increase ~~the~~ rotary motion produced by hand-cranking ~~so~~ that the engine can start. In the electric type, the hand crank is replaced with an electric motor which supplies the necessary rotary motion to start the engine.

** V-9002, pp 193-197
* V-9005, p 42
*** V-9131, pp 186-187, 193-195

g. The aircraft engine has many parts which move back and forth (reciprocate) or rotate. To reduce friction and insure the ease of movement of the various parts against each other, a lubrication system is necessary. The lubrication system must supply the proper amount of oil to the engine at the correct pressure in order to provide adequate lubrication and cooling for all moving parts of the engine. This lubrication is distributed to the various parts of the engine by either pressure, splash or a combination of pressure and splash methods. Pressure lubrication is the principle method of lubrication in most aircraft engine systems.

(1) The wet sump system in the airplane is very similar to the lubrication system in your automobile. It has an oil pan or wet sump pan on the bottom of the engine where the oil is stored. A pressure pump forces the oil through openings in the engine to all parts and the unused oil is collected in the sump. Through the splash method the main bearings and rod bearings are oiled. Gravity brings the oil back to the sump.

(2) The dry sump is similar except the oil is stored in a separate tank outside of the engine. The oil not used in operation of the engine is picked up by a scavenger pump and returned to the oil storage tank.

** V-9002, pp 193-197
** V-9131, pp 348, 353-354
*** V-9156, pp 88-93
*** V-9171, pp 485-490

h. The purpose of the propeller is to move the airplane through the air. It does this by means of the thrust obtained by the action of the rotating blades on the air. The thrust developed by the propeller is in accordance with Newton's Third Law of Motion: for every action, there is an equal and opposite reaction and the two are directed along the same straight line. The propeller pushes air to the rear, and reaction to that push causes the plane to move forward.

(1) The propeller consists of the leading edge, trailing edge, back, face, hub, butt, shank, and tip.

(2) The propeller turns in an arc perpendicular to the crankshaft, in an area called its plane of rotation. The propeller's effective pitch is the actual distance the airplane moves forward during one revolution (360 degrees) of the propeller in flight.

*** V-9131, pp 354-355

(3) The three forces acting on the propeller are: the bending stresses induced by the thrust forces as a result by the forward motion of the airplane; tensile stresses caused by centrifugal force tending to throw the blade out from the hub; and, torsional stresses which are twisting effects produced in rotating propeller blades by air-reaction on the blades and by centrifugal force.

(4) Propellers come in four types:

(a) Fixed pitch propellers have unmovable blades.

(b) Adjustable pitch propellers have blades whose angles may be varied--while the engine is stopped--to fit the job, from speed to power.

(c) Controllable pitch propellers are so built that the pilot can change the pitch of their blades while in flight.

(d) Constant speed propellers adjust their own pitch automatically according to engine power.

(5) The propellers on most big planes have a capability for feathering and for reversing pitch.

Feathering is the ability to rotate the edge of the propeller into the wind, thereby streamlining it, and stop its rotation. Reversible pitch propellers allow the pilot to reverse the position of the blades so that a negative thrust is produced which tends to pull the airplane in a reverse direction.

(6) No propeller is 100 percent efficient since all of the power of the engine cannot be transmitted to the propeller. The most efficient propellers use something under 90 percent of the available energy. Also, efficiency declines rapidly after the speed of the tip end of the propeller reaches the speed of sound. This tip speed limitation is the major reason that propeller-driven aircraft cannot move at supersonic speed.

5. SUGGESTIONS FOR TEACHING:

a. Suggested time: 4-6-8

b. A highly technical subject such as this is not too conducive to the lecture method. Better approaches would be the guided discussion or seminar method in which ~~many~~ instructional aids are used. The more the student is exposed to the various facets of the topics in this chapter, the more he will learn. If possible additional aids, besides the ones already provided, such as mock ups, etc., should be obtained. At any rate, adjust the level of instruction to the capabilities and interests of your students.

c. It is possible in many instances to correlate the engine of the family's car with the reciprocating engine of the airplane. Because they basically contain the same major systems and operate in a similar manner, this approach should enhance the class material.

d. You may find that you are unable to cover this material in the recommended time. There is sufficient flexibility in the curriculum so that you can adjust up or down as necessary. The broad range of subjects in this chapter can prove to be a real challenge. One method might be to divide the class into small groups with each group researching one system such as carburetors, ignition, propellers, etc., and then reporting back to the class. Special reports might be for such areas as fuels, octane ratings, the effect of emission controls, dieseling, the importance of tune-ups, the effect of speed on efficiency, etc. The automotive and physics instructors may have some excellent ideas on simplified ways to explain the various engine systems.

e. Textbook corrections:

(1) Page 48, paragraph 5--idling jet should have been bold faced.

(2) Page 60, paragraph 3, line 7--change to lines of flux.

(3) Page 62, paragraph 3, line 5--remove comma after magnets.

(4) Page 65, Figure 35--in the figure itself change breaking to breaker.

(5) Page 77, Figure 43, line 1--change trust to thrust.

f. Student assignment: read pages 37-83.

6. INSTRUCTIONAL AIDS:

   a. Films:

      (1) TF1-0136 Aircraft Engines, Elements of Electricity as Applied to Ignition Systems, 28 min, B&W, 1941.

      (2) TF1-5274 Carburetor--Principles of Operation, 23 min, B&W, 1957.

   b. Transparencies:

      V-1002 Gravity Type Fuel System

   c. Slides:

      V-0086 Power for Aircraft, slides 2-3, 11-23, 29-31

7. PROJECTS:

   a. Construct a schematic of the various systems.

   b. Find out if any of the students possess models of aircraft with moveable pitch propellers. If so, they may want to explain and demonstrate how a propeller may be feathered, pitch reversed during landing, or controlled in flight. A rubber band model airplane could be used to illustrate the operation of a propeller. Perhaps an actual propeller could be obtained.

   c. Have a student demonstrate how to change points, plugs, condenser, rotor, etc.

   d. Have students demonstrate magnetism using iron filings on a paper.

   e. Take a field trip to an aircraft manufacturing plant, an automobile manufacturing plant, or a company that makes parts for one or more of the systems studied.

   f. Have your students prepare a class briefing on how proper tune-ups and driving/flying techniques save fuel. Give the report before a school assembly.

8. FURTHER READING:

   a. CAP Text, Power for Aircraft.

   b. FAA, "VFR Pilot Exam-O-Gram No. 38."

   c. V-9166, Private Pilots Handbook of Aeronautical Knowledge.

IDEAS FOR IMPROVEMENT OF THE TEXTBOOK AND/OR INSTRUCTOR'S GUIDE
AND TEACHING TECHNIQUES MOST EFFECTIVE FOR THIS CHAPTER.
TO BE COMPILED AT END OF TEXT AND SENT TO JRC

PROPULSION SYSTEMS

CHAPTER IV - GAS TURBINES AND JET PROPULSION

This chapter compares jet and reciprocating engines and includes a discussion of their similarities and relative advantages. The different types of jet engines are examined with particular emphasis on the turbojet. A brief description of helicopter propulsion systems is included, as is a discussion of environmental problems facing engine manufacturers.

1. OBJECTIVES:

a. Traditional Objectives - Each student should:

(1) Know at least two operating principles of the jet engine and of the gas turbine engine.

(2) Know how these principles are similar to and different from those of the reciprocating engine.

(3) Know at least one advantage of each of these engine types: reciprocating, jet, and non-jet turbine.

(4) Know the characteristics of the main types of jet and gas turbine engines.

b. Behavioral Objectives - Each student should be able to:

(1) Discuss at least two operating principles of the jet engine and of the gas turbine engine.

(2) Discuss at least two ways in which the operating principles of the jet engine are different than or similar to those of the reciprocating engine.

(3) Outline at least one advantage of each of these engine types: reciprocating, jet, and non-jet turbine.

(4) Describe at least one characteristic for each of the main types of jet and gas turbine engines.

2. SUGGESTED OUTLINE:

a. Jet engine--a means of power (speed)

(1) No propellers

(2) High speeds

b. Sections of the jet engine

(1) Ram air duct

(2) Compressor

(3) Fuel injection section

(4) Gas turbine section

(5) Exhaust nozzle

c. Compare sections of jet engine with parts of reciprocating engine (four cycle)

d. Principle of operation--Newton's second and third law

(1) Force equals mass times acceleration
$F = MA$ or $A = \frac{F}{M}$

(2) For every action there is an equal and opposite reaction

(3) Both engines gain power from moving air

(a) Jet--air through tube at high acceleration

(b) Reciprocating--unconfined air

e. Present jet engine types

(1) Ramjet

(a) Structure--fuel nozzles with fuel under pressure and ignition by spark (igniter) plugs

(b) Use of flame holder (blocking loss of flame and force)

(c) Used only above approximately 250 mph

(d) No limitations of speed up to mach 5

(e) Ramjet is used in missiles

1. BOMARC surface to air interceptor (now obsolete)

2. Redhead/Roadrunner guided target missile (obsolete)

(f) Scramjet

(2) Pulsejet (more complex than ramjet)

(a) Valves (open) are used to allow air intake

(b) Fuel injected in combustion chambers

(c) Valves (closed) at ignition in combustion chamber

(d) Pulsejets powered German V-1 missiles

(e) Limited speed--not too efficient

(3) Turbojet (uses principles of ramjet and pulsejet)

(a) Combination of gas turbine and air compressor operated by turbine

(b) Sections of turbojet--compressor; combustion chamber; turbine; exhaust; afterburner

(c) Compressor section

1. Rotor--series of moving blades

2. Stator--stationary blades that straighten and direct airflow

3. Multi-stage compressor

4. Split compressors

(d) Combustion section

1. Use of less volatile fuel (kerosene)

2. Many combustion chambers--greater cooling

3. Crossover tubes connecting the combustion chambers

(e) Turbine section

1. Hot gases strike turbine wheel blades

2. Very high temperatures are reached--1500 degrees Fahrenheit

3. High rpm--1200 revolutions per minute

4. Need for metals to withstand stress, pressure, and temperature

(f) Exhaust section

1. Nozzle has an inner cone which straightens out the flow of gases as they leave the tailpipe

2. Velocity of gases; Force = Mass times Velocity

(g) Afterburner--use is similar to a ramjet to provide additional power

(h) Turbojet--with or without afterburner, is the most widely used type of jet engine

(4) Turboprop engine

(a) Increasingly popular for low and intermediate speed (up to 400 mph) aircraft

(b) Sections; propeller; air inlet; reduction gear; compressor; combustor; compressor-drive turbine; propeller-drive turbine; exhaust

(c) Turbine powered propeller for power

(d) Used quite extensively--commercial airlines

(5) Turbofan engine (bypass engine)

(a) Movement of larger volumes of air at lower velocities--four times that of turbojet

(b) Sections: intake, fan; dual compressor; combustion chamber; high and low speed turbine; exhaust

(c) Turbofan is capable of greater thrust for takeoff, climbing and cruising

f. Helicopters

(1) May use either turbine (turboshaft) or reciprocating engines

(2) Large helicopters may have two engines

g. Important systems and devices on jet aircraft

(1) Accessory section houses mechanical controls for operation of systems, including electric starter, generator, oil and fuel pumps, hydraulic pumps, and other accessories

(2) Starter systems

(a) Electrical starters

(b) Air starters

(c) Gas turbine compressor

(3) Fuel system controls in jets are complex

(4) Lubrication systems are simple

(5) Water injection systems

(6) Thrust reversers

(a) Reverse thrust must be different on jets than propeller engines

(b) Parachutes used for braking power

1. Not very satisfactory because no pilot control over amount of braking

2. Must be repacked after each use

(c) Mechanical thrust reversers

1. Reverse the airstream in bypass duct and exhaust nozzle

2. Reverse only exhaust gases

(7) Noise suppressors

(a) Need for reducing the noise of jet-powered aircraft

(b) Exhaust noise is caused by high velocity jet stream moving through relatively quiet, still air

(c) Curbing these noises

1. By exhaust silencers which break up the exhaust stream into smaller streams

2. Through the use of acoustical materials

(8) Pollution control

(a) Main pollutants are unburned hydrocarbons, carbon monoxide, and nitrogen oxides

(b) Hydrocarbons are the most visible but the least dangerous aircraft-produced pollutants

(c) Nitrogen oxides are instrumental in the production of poisonous photochemical smog, through their reactions with sunlight

(d) Current methods of curtailing visible pollution increase the threat of invisible pollution

3. ORIENTATION:

The students will have some knowledge of the various engines that will be discussed in this chapter. Since they have studied about the reciprocating engines in the previous chapter, it will be beneficial to start with a review and bring in some of the limitations of a reciprocating engine. This will bring out some of the needs of developing and building jet engines. In this chapter we will be comparing the advantages of other types of engines, most of which are varying types of jet engines. Also, we will discover that the jet engine is not the best engine for all types of flight.

4. SUGGESTED KEY POINTS:

** V-9002, pp 201, 206
* V-9005, p 45
** V-9131, pp 405-408

a. The jet engine and the reciprocating engine are similar because they have an intake, compression, power and exhaust section. However, the two engines differ quite radically in mechanical operation. The jet has the advantages of higher speed and ability to fly at greater altitudes. The chief advantage of the reciprocating engine is its economy at low speeds and at low altitudes. However, the jet engine differs from the reciprocating engine in that the flow of air is confined to its inner chambers while in the reciprocating engine it is not. Also, jet engines utilize smaller amounts of air with greater velocities.

b. The jet engine depends on Newton's second and third laws of motion for its operation. The second law states that a force is equal to mass times acceleration. Jet thrust is equal to the quantity (mass) of air multiplied by the acceleration. The third law states that for every action there is an equal and opposite reaction. Thus, in a jet engine, there is a force exerted opposite that created by the exhaust as it leaves the tailpipe.

** V-9002, pp 214-215
** V-9005, pp 46-48
** V-9013, pp 180-183
* V-9140, p 257
** V-9156, pp 98-99
*** V-9171, pp 562-564

c. A ramjet is a tube that is fitted with fuel nozzles and spark plugs to start the combustion. A diffuser decreases the velocity of the incoming air, thereby increasing its pressure. The ramjet cannot operate below approximately 250 mph. Theoretically, the speed attainable by the ramjet is unlimited since the faster it travels the greater the thrust. Practically, the speed limit is about mach 5. Ramjet engines were used in missiles such as the Bomarc, a surface to air interceptor, and the Redhead/Roadrunner guided target missile. Both missiles are now obsolete. The pulsejet engine is slightly more complex than the ramjet, in that it has a grill of valves which open during intake and close during combustion. This cycle is repeated as pulses. It was used in the German V-1 missiles, but was not very practical and is not used today.

* V-9002, pp 204-209
** V-9005, pp 47-50
*** V-9013, pp 156-172
** V-9131, pp 408-411
** V-9140, pp 255-257
** V-9171, pp 565-572

d. The turbojet is much more complex than either a ramjet or a pulsejet since it is a combination of a gas turbine and an air compressor. The compressor is composed of a rotor, a stator, and a casing. The rotor blades increase the air velocity which in turn increases its energy. This kinetic energy is converted to pressure energy by the stator. The compressed air then enters the combustion chamber, where it is mixed with the fuel and ignited. About one-fourth of the air is used for combustion while the remainder is used for cooling purposes. The spark plugs serve the combustion system only for the initial ignition and then, since air and fuel are constantly being pumped in, the mixture burns continuously. The hot gases from the combustion section enter the turbine section through a nozzle diaphragm which increases the velocity to about 2000 ft/sec. These gases then impart their energy to the turbine causing it to rotate. The high temperatures in this section create extreme stresses on the turbine, but recent advances in metallurgy have helped to eliminate some of the problems encountered with heat, shock and centrifugal force. From the turbine section, the very hot gases (1200 degrees Fahrenheit) enter the exhaust section. The tail pipe shape is designed to increase the velocity of these gases so that they produce the maximum thrust without causing overheating of the engine. As you may remember, thrust is equal to mass of the gases times their velocity. The afterburner section acts as a small ramjet which increases the velocity of the gases even more, thus providing additional thrust when maximum performance is needed.

* V-9002, pp 212-213 *** V-9013, pp 174-179 ** V-9131, pp 432-440, 442-448 * V-9140, p 255 ** V-9171, pp 572, 578-583	e. Two relatively recent turbine engines that are affecting aviation today are the turboprop and turbofan. The turboprop, or propjet, engine receives most of its thrust from the propeller driven by a gas turbine engine. This engine develops much more horsepower than a reciprocating engine. Since this engine is so powerful, a reduction gear must be used to keep the propeller's tip speed below that of the speed of sound. The turbofan engine was developed to use some of the advantages of the jet as well as the turboprop and still not have the limitation of the propeller speed. It is known by several names: turbofan, fanjet, bypass engine, and ducted fan engine. The turbofan engine moves four times as much air as the turbojet; this enables the engine to operate economically at low speeds and low altitudes. It also can operate at high speeds and high altitudes. Burning fuel in the fan-duct can double the normal thrust of the turbofan engine; this is similar to the afterburner used in turbojets.
* V-9135, pp 23-31 ** V-9156, pp 106-107	f. Helicopters are discussed in this section because of the growing use of turbine engines--called turboshaft engines--to power helicopters. Turboshaft engines operate similarly to turboprop engines, transmitting the turbine's force to the rotor through a set of reduction gears. The gears change the plane of the spinning motion and also serve to control rotor tip speed. Some high-performance helicopters feature short fixed wings in addition to the rotor, or moving wing. The fixed wing allows the helicopter to attain greater speeds than would be possible without it. Rotor torque may be overcome by means of a tail rotor or, if two engines are used, by counter-rotating rotors.
** V-9002, pp 210-211 ** V-9131, pp 424-425	g. There are a number of important systems on jet engines that are not discussed at any great length in this book, but which should be mentioned. Controls for some of these systems are lumped together in the engine's accessory section. Jet engines have starters, but they

*** V-9156, pp 101-106
** V-9171, pp 586-587, 602-611

require so much power to get the engine started that an outside power source normally operates the plane's starter motor. Jet engine fuel systems are complex, being influenced by airflow, pressures within the engine, tailpipe temperatures, and fuel/air mixture ratios. Lubrication of the jet is relatively simple, with oil being directed specifically at stress points. The water injection system increases mass flow through the engine and, by lowering tailpipe temperatures, increases fuel flow. The speed of jet aircraft created a need for longer runways for landing. Parachutes were first used to reduce the required length. Later, thrust reversers in the engine were developed to slow the jet quickly with little use of the brakes. Objectionable noises produced by the high velocity exhaust gases have been reduced by addition of exhaust silencers and the use of acoustical materials in building the engines. Noise suppressors divide the large exhaust streams into smaller ones which have a higher frequency so few people can hear them. Jet engine pollution comes in several forms, most noticeably smoke caused by unburned hydrocarbons. Efforts to solve the smoke problem have been successful, but have tended to increase the more serious but less visible forms of pollution: poisonous gases such as carbon monoxide and nitrogen oxides. Research continues and there has been some progress in controlling visible and invisible air pollution from aircraft engines.

5. SUGGESTIONS FOR TEACHING:

a. Suggested time: 3-5-7

b. The chapter can be introduced by reviewing briefly the main points about the reciprocating engine and listing some of its limitations. This will suggest some of the advantages that jet engines could have over the reciprocating engine. A class discussion could then point out the advantages and disadvantages of each type of engine in relation to a particular mission. Economy, range, carrying capacity, etc., could be discussed to determine if one type would be better than another. A class debate about the relative merits and usefulness of the two kinds of engines might provide a welcome change of pace.

c. It would be helpful to ask the students to bring to class whole or cutaway models of the various engines that they might have. The students could make a chart using columns for the four types of jet engines, the turboprop engine, and the reciprocating engine. With the horizontal rows, use the types of performances that can be obtained by an aircraft having that type of engine.

d. Since there is a large amount of information in this chapter which does not need to be covered in great depth, a lecture with a question and answer period might be appropriate. Be sure to contrast the various types of engines so that the student begins to see that each type can be used for a particular situation. Of course, certain types are more flexible than others and have been used more widely.

e. It would be quite easy to expand this section into rocket propulsion. We recommend you resist this temptation as that part of the curriculum is adequately covered in AE-I and AE-III. While its true that rockets can be used in the atmosphere, they do not require atmospheric oxygen, making this artificial cut-off point a logical approach. The theory of helicopter flight will be covered in Theory of Aircraft Flight, while noise suppression will be discussed again in Civil Aviation and Facilities. The main points here are that students recognize that helicopter flight applies the same principles and laws as those governing aircraft flight and the main ecological objections to aircraft flight stem from the emissions from their powerplants--therefore it is quite appropriate to expand the ecology aspect if you so desire. Be sure your cadets understand that aircraft pollution is relatively insignificant compared to automobile pollution. A student report on this concept might be effective.

f. Textbook corrections:

(1) Page 112, Figure 64--oil line from 3 to 4 should be blue.

(2) Page 115, paragraph 1, line 4--delete "moving".

g. Student assignment: read pages 85-120.

6. INSTRUCTIONAL AIDS:

a. Films:

(1) USAF

(a) TF 1-5364 An Introduction to Jet Engines, 13 min, color, 1960.

(b) TF 5628 The J-57 Afterburner Engine, 25 min, color, 1964.

(c) TF 5750 T-39 Fuel System, 7 min, color, 1966.

(2) Lockheed-Georgia Company
Motion Picture Film Library
Zone 30, B-2 Bldg
Marietta, GA 30060

(use letterhead stationery, borrower pays return postage)

Engine Starting Procedure, 19-1/2 min, color, 1959. (C130A propjet)

(3) General Motors (see Chapter 2)

(a) ABC of Jet Propulsion, 17 min, color, 1954.

(b) Air Pollution in Perspective, 25 min, color, 1971.

(c) No Time to Waste, 14 min, color, 1971 (emission control).

(4) Ford Motor Co
Film Library
The American Road
Dearborn, Michigan 48121

(use letterhead stationery, borrower pays return postage)

Eleven Together, 25 min, color (emission control)

b. Transparencies:

V-1038 Turbojet and Ramjet Engines

c. Slides:

V-0086 Power for Aircraft, slides 32-38

d. Film Strips:

Filmstrips No. 3, "How Helicopters Fly," and No. 4, "Jet Power" from the JAM HANDY filmstrip series Aircraft--Their Power and Control. These can be purchased individually ($15.00 each) or as a set, with cassettes (#JH5960FC, $90.00) or records (#JH5960FR, $84.00) from: Scott Education Division, 104 Lower Westfield Road, Holyoke, MA 01040.

7. PROJECTS:

a. For a special project or independent study, a student or group of students can compare the operation of a four-stroke reciprocating engine to a particular type of jet propulsion engine. The final presentation can be presented to the instructor as a research paper or oral report. Other reports of a similar nature are encouraged.

b. Have a student find out how much fuel is burned during takeoff and landing delays and report this to the class.

c. See things to do for Chapter 4.

8. FURTHER READING:

a. V-9110, Helicopters and Autogiros

b. V-9135, Basic Helicopter Handbook

c. Current issues of Aviation Week and Space Technology

IDEAS FOR IMPROVEMENT OF THE TEXTBOOK AND/OR INSTRUCTOR'S GUIDE
AND TEACHING TECHNIQUES MOST EFFECTIVE FOR THIS CHAPTER.
TO BE COMPILED AT END OF TEXT AND SENT TO JRC

PROPULSION SYSTEMS

CHAPTER V - SUMMARY: PROPULSION'S EVOLUTION

This chapter reviews developments in the short history of powered flight, concentrating on the evolution of jet propulsion. Using examples of American events concurrent with European research milestones on the way toward powered flight, some historical perspective is shed on the long search for useful power and its relatively recent success. Speculation is made on the direction of aircraft propulsion development for the near future.

1. OBJECTIVES:

a. Traditional Objectives - Each student should:

(1) Know why American involvement in the search for aircraft propulsion systems was so long in coming.

(2) Understand that progress in aviation propulsion did not stop during the nation's preoccupation with space exploration.

(3) Know that the quest for more powerful engines has been modified to an approach where engines and aircraft are designed for specific jobs.

(4) Know how ecologic, economic, and political factors influence fields of scientific and manufacturing endeavor.

b. Behavioral Objectives - Each student should be able to:

(1) Discuss some of the problems that occupied Americans while Europeans sought to develop workable engines.

(2) Summarize the progress in aircraft propulsion systems in the 1960's and 1970's.

(3) List at least three airplanes now in use that have powerplants specifically designed for them.

(4) Outline how factors other than scientific knowhow can affect aircraft development.

2. SUGGESTED OUTLINE:

a. Historical perspective

(1) Europeans led in aviation research

(2) Americans made no significant contributions until the end of the nineteenth century

(3) American success based on European research

b. Jet development

(1) Europeans flew first jets

(2) Development of jets since 1944

(3) Military and commercial aircraft

c. Political influence on aviation

(1) Ecological considerations

(a) Tradeoffs: speed and power vs need and environmental considerations

(b) The SST

(2) Economic considerations

d. Designing aircraft for specific jobs

3. ORIENTATION:

This summary is designed to give a practical and philosophical outlook on the development of aircraft and aircraft propulsion systems. The development of such an outlook will enable the student to understand how and why aircraft-propulsion research has proceeded as it has and where it is going now. And to understand current events in the area of aircraft research and development, not only from a technical development perspective but from an appreciation of the political considerations involved: why a project was discontinued, why another is favored, what these decisions portend for the short and the long run. The summary traces the evolution of propulsion plants, specifically jet aircraft developments, and points a way for future developments.

4. SUGGESTED KEY POINTS:

a. Europeans led the way in the search for successful aircraft powerplants. Until the end of the nineteenth century, American concentration was on nation building and nation preserving, not on dreams like flying machines. Moreover, Europe had both a tradition of scientific research and--especially in England--the tools of the Industrial Revolution long before these blessings came to America's shores. When Americans could turn their attention to matters less urgent than survival, they did succeed in developing engines and aircraft, but on a base of European research in theory and materials.

b. It is interesting to note that even after Americans succeeded in flying first, aviation progress and interest was located overwhelmingly in Europe, not in America, and stayed there until World War II. German, Italian, and British airmen developed and flew jet airplanes years before Americans did, but the war-built American aircraft industry assumed the lead after the war. Since 1944, the United States has led the way in most aircraft developments, although there are exceptions: the supersonic transport, which we abandoned voluntarily, and vertical takeoff aircraft. This trend has been true both in military and commercial jet aircraft development.

c. Political considerations have always played a large part in American aviation. Government support of research and development projects, for instance, and government contracts for aircraft in numbers have been the spur that has kept many aircraft manufacturing companies moving. Attitude changes on the part of the public is reflected in congressional action, and the last several years have brought somewhat reduced public support for aviation research. Ecological consciousness has been an influence on this change of attitudes. More and more, the questions are being asked, Do we need this or is it designed for the benefit of the industry? What will be the effects of a certain project in terms of air and noise pollution? Is the benefit worth the costs? An example of the effectiveness of these questions is the American abandonment of the SST project, which would have been costly both ecologically and economically. The subsonic cruise armed decoy (SCAD) is another example of a seemingly worthwhile project abandoned because of economics. Planned to extend the service life of the B-52, SCAD was all but killed in the spring of 1973 when the Pentagon decided it would cost more than the anticipated results warranted. The SCAD program, planned at $800 million, was stopped after an expenditure of $67.5 million, although the option to resume development was retained.

5. SUGGESTIONS FOR TEACHING:

a. Suggested time: 1-2-2

b. In teaching this chapter, the instructor will generally be surprised at how much the students know about the recent developments of aircraft. At least they will have scattered and varied information from daily and weekly news media. The main objective of classroom activity would be to determine what the students know and then fill in the information so it would be complete as far ~~as~~ possible. Your experience in life and in the Air Force will be a valuable tool in the teaching of this chapter, because you have seen much of what is described here firsthand, e.g., the post-war development of aircraft. Also, your life has been influenced by the changing attitudes of the nation and of Congress in regards to hardware development. Properly used, your experiences can bring this chapter to life for your class. Keep in mind, however, that your students probably are not as oriented toward continued government support and encouragement of technological research as you may be.

c. A debate is an excellent technique to use for this chapter. The list of topics is quite long, e.g., (1) should the B-1 be funded, (2) should the SST be built, (3) is air transportation more important than ecology? etc. Another variation could be a role playing situation where students act as a congressional committee taking testimony on an aviation related research project. Or certain students may act as a panel of experts with the class acting as Congress trying to deny funds. This approach may demonstrate the political process and its impact on scientific research and aviation progress.

d. Student assignment: read pages 121-126.

6. INSTRUCTIONAL AIDS:

Films:

NASA, HQ 205, Space in the 70's--Aeronautics, 28 min, color, 1971.

7. PROJECTS:

a. This chapter lends itself well to a series of reports on current events in the field of aviation development; for instance, what a given aircraft was designed for, its capabilities, its prospects, its ecological impact, government decisions affecting its development, etc. Reports may be approached from different viewpoints.

b. Have the class brainstorm possible future uses of propulsion systems.

c. Certain students could write articles for the school newspaper or the local newspaper on what they are covering in this unit. The public is currently vitally interested in this subject.

d. If you have collected a large number of models, engines, etc., invite other classes or the faculty in to see them.

8. FURTHER READING:

a. Many of the books used as references for the first chapter will serve as excellent summary material.

b. Current periodicals and newspapers.

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