Aircraft Electrical Systems

Princeton Airport Flying Tigers

Presented by Ernie Schirmer
Why Study Electrical Systems?

→ To enable a pilot to get a better understanding of how the aircraft’s electrical system operates
✓ which will enable the pilot to maintain and operate the aircraft more safely and
✓ respond more confidently to emergencies.
Learning Objectives

Objectives

✓ To present an overview of basic electrical concepts (e.g. voltage, current and resistance).
✓ To review which aircraft instruments are typically electrically powered.
✓ To understand the electrical system of simple aircraft
✓ To review failure modes and simple troubleshooting techniques.
Preventive Maintenance
What Maintenance Can An Owner or Pilot Perform?

✔ FAR 43.3(g) “The holder of a pilot certificate issued under Part 61 may perform preventive maintenance on any aircraft owned or operated by that pilot which is not used under Part 121, 129, or 135.”

Based on 14 CFR Ch. 1 (1-1-03) Edition
What Maintenance Can An Owner or Pilot Perform?

✔ FAR 43.13(a) “Each person performing maintenance … shall use the methods, techniques, and practices prescribed in the current manufacturer’s maintenance manual or Instruction for Continued Airworthiness prepared by its manufacturer, or other methods, techniques, and practices acceptable to the Administrator except as noted in Section 43.16.”
What Maintenance Can An Owner or Pilot Perform?

✓ FAR 43.13(a) “He **shall** use the tools, equipment, and test apparatus necessary to assure completion of the work in accordance with accepted industry practices. If special equipment or test apparatus is recommended by the manufacturer involved, he must use that equipment or apparatus or its equivalent acceptable to the Administrator.”
What Maintenance Can An Owner or Pilot Perform?

✔ FAR 43.13(b) “Each person ... performing preventive maintenance, **shall** do that work in such a manner and use materials of such a quality, that the condition of the aircraft ... worked on will be at least equal to its original or properly altered condition ... ”
What Maintenance Can An Owner or Pilot Perform?

✔ FAR 43 Appendix A

✔ (c) “Preventive Maintenance is limited to the following work, provided it does not involve complex assembly operations:

✔ (16) Troubleshooting and repairing broken circuits in landing light wiring circuits.

✔ (17) Replacing bulbs, reflectors, and lenses of position and landing lights.

✔ (24) Replacing and servicing batteries.”
What Maintenance Can An Owner or Pilot Perform?

✔ FAR 43 Appendix A

✔ (30) “The inspection and maintenance tasks prescribed and specifically identified as preventive maintenance in a primary category aircraft type certificate or supplemental type certificate holder’s approved special inspection and preventive maintenance program when accomplished on a primary category aircraft … “
The Paperwork

✔ FAR 43.9 (a) “… each person who … performs preventive maintenance … shall make an entry in the maintenance record of that equipment containing the following information:

(1) a description … of work done.
(2) the date of completion of the work
(3) the name of the person performing the work … “
The Panel
Mechanical Instruments

- Attitude Indicator
- Airspeed
- Vertical speed
- Directional Gyro
- Oil pressure
- Tachometer
- Suction gage
- Magnetic compass
- Stall warning
Electrically-powered Instruments

 ✓ Pitot heater
 ✓ Oil temp gage
 ✓ Exhaust gas temperature (EGT)
 ✓ Fuel gages
 ✓ Engine hour meter ("Hobbs")
 ✓ Turn-and-Slip indicator
 ✓ Turn coordinator
 ✓ Clock
The Manual

INFORMATION MANUAL

1980

Cessna

MODEL 172N

SKYHAWK
ELECTRICAL POWER SUPPLY SYSTEM MALFUNCTIONS

Malfunctions in the electrical power supply system can be detected by periodic monitoring of the ammeter and low-voltage warning light; however, the cause of these malfunctions is usually difficult to determine. A broken alternator drive belt or wiring is most likely the cause of alternator failures, although other factors could cause the problem. A damaged or improperly adjusted alternator control unit can also cause malfunctions. Problems of this nature constitute an electrical emergency and should be dealt with immediately. Electrical power malfunctions usually fall into two categories: excessive rate of charge and insufficient rate of charge. The following paragraphs describe the recommended remedy for each situation.
EXCESSIVE RATE OF CHARGE

After engine starting and heavy electrical usage at low engine speeds (such as extended taxiing) the battery condition will be low enough to accept above normal charging during the initial part of a flight. However, after thirty minutes of cruising flight, the ammeter should be indicating less than two needle widths of charging current. If the charging rate were to remain above this value on a long flight, the battery would overheat and evaporate the electrolyte at an excessive rate.

Electronic components in the electrical system can be adversely affected by higher than normal voltage. The alternator control unit includes an over-voltage sensor which normally will automatically shut down the alternator if the charge voltage reaches approximately 31.5 volts. If the over-voltage sensor malfunctions or is improperly adjusted, as evidenced by an excessive rate of charge shown on the ammeter, the alternator should be turned off, alternator circuit breaker pulled, nonessential electrical equipment turned off and the flight terminated as soon as practical.
If the over-voltage sensor should shut down the alternator, or if the alternator circuit breaker should trip, a discharge rate will be shown on the ammeter followed by illumination of the low-voltage warning light. Since this may be a “nuisance” trip-out, an attempt should be made to reactivate the alternator system. To do this, turn the avionics power switch off, check that the alternator circuit breaker is in, then turn both sides of the master switch off and then on again. If the problem no longer exists, normal alternator charging will resume and the low-voltage light will go off. The avionics power switch may then be turned back on. If the light illuminates again, a malfunction is confirmed. In this event, the flight should be terminated and/or the current drain on the battery minimized because the battery can supply the electrical system for only a limited period of time. If the emergency occurs at night, power must be conserved for later use of the landing lights and flaps during landing.
Electrical Concepts
Electrical Units of Measure

- **Voltage** (pressure)
  - unit of measure is the **Volt**

- **Current** (flow)
  - unit of measure is the **Ampere (amp)**

- **Resistance** (friction)
  - unit of measure is the **Ohm**

- **Power** (force)
  - unit of measure is the **Watt**
Electrical Symbols

✓ Voltage
  – Voltage symbol is traditionally “E” for Electromotive Force (EMF)

✓ Current
  – Current symbol is traditionally “I” for Intensity

✓ Resistance
  – Resistance symbol is “R” in equations and the Greek symbol omega Ω for values

✓ Power
  – Power symbol may be “P”ower or “W”atts
The Equations

\[ E = I \times R \]
\[ \text{Voltage} = \text{Current times Resistance} \]

\[ P = E \times I \]
\[ \text{Watts} = \text{Voltage times Current} \]
Landing Light Problem

Switch

24-volt Battery

Landing Light

What is the resistance (in ohms) of the landing light?

What is the power (wattage) of the landing light?

Actual return path is via aircraft skin

9 Amps
Landing Light Resistance Calculation

\[ E = I \times R \]

\[ 24 = 9 \times R \]

\[ 24/9 = 9 \times R/9 \]

\[ 2.7 \text{ ohms} = R \]

The resistance of the landing light is 2.7 Ω.
Landing Light Power Calculation

\[ P = E \times I \]

\[ P = 24 \times 9 \]

\[ P = 216 \text{ watts} \]
Landing Light Schematic

- Circuit Breaker
- Switch
- 24-volt battery
- Landing Light
- Aircraft Frame (Circuit Return)
Starter Motor Problem

What happens if the resistance of the relay contacts increases from 0.01 ohms to 0.1 ohms?
Starter Motor Voltage Drop Calculation Part 1

\[ E = IR \]

\[ E = 150 \times 0.01 \]

\[ E = 1.5 \text{ volts} \]

\[ 24 - 1.5 = 22.5 \text{ volts} \]

available to

starter motor
Starter Motor Voltage Drop Calculation Part 2

\[ E = IR \]

\[ E = 150 \times 0.1 \]

\[ E = 15 \text{ volts} \]

\[ 24 - 15 = 9 \text{ volts} \]

available to

starter motor
Starter Motor Power Calculation

\[ P = E \times I \]

\[ P = 24 \times 150 \]

\[ P = 3,600 \text{ Watts} \]

746 watts = 1 horsepower
3,600 watts = 4.83 HP at 100% efficiency
What Power Does It Take?

- Nav/Comm
  - ~ 1 amp receive
  - ~ 3 amps transmit
- Transponder
  - ~ 2 amps
- ADF
  - ~ 1 amp
What Takes The Most Power?

✓ Heating loads (typically continuous)
  – Pitot heater (~ 3 amps)
  – Windscreen heater

✓ Motor loads (intermittent)
  – flaps (~ 9 amps)
  – landing gear

✓ Incandescent lamps
  – landing light (~ 9 amps)
  – position lights (~ 2.5 amps)
Aircraft Batteries

FEATURES

• Real aircraft quality terminals, no more lawn and garden tractor type!
• New patented copper alloy internally threaded terminals.
• New brass terminal bolts with conical silicon bronze lock washers.
• Recommended 70-inch pound terminal torque.
• More than 20% higher capacity than the original RG24-11 model.
• Molded carrying or lifting handle.
• Fully aerobatic sealed construction - no spillable electrolyte or flammable gas emissions.
• FAA-PMA

Concorde’s new RG24-15 brings new levels of performance as the most powerful battery available to replace the vented CB24-11 aircraft battery.

The RG24-15 model has been completely redesigned with larger positive and negative plates for more capacity and greater starting power even at sub-zero temperatures.

Please visit our Web site @ www.concordebattery.com

CONCORDE BATTERY CORPORATION
2099 San Bernardo Rd., West Covina, CA 91790
Phone 626-812-1234  Fax 1-800-337-4209

RG-2415
Batteries: Failure Mode Analysis

✓ Mechanical
  - Vibration

✓ Thermal
  - Heat

✓ Chemical
  - Normal chemistry of charge/discharge cycles

✓ Electrical
  - Deep cycling
  - Overcharging
Typical Cessna Batteries

Model - G-241

FAA-PMA Installations:
Cessna Aircraft: 152, 172, 182

24 Volts

Rate (AMPS)
1 hr (C1) 8
30 min (2C) 13
60 sec/0 deg F (CCA) 106

Total Weight Filled (lbs.)
24

Electrolyte (gal)
0.52 / 1.285 s.g
Typical Cessna Batteries

Spill-proof Vented Battery Cap
Typical Cessna Battery (Gill)

✓ Unsealed wet lead-acid with non-spill vent caps (not a “maintenance-free” battery).
✓ Consists of multiple 2.1 volt cells connected in series
  – 12 cells for 24-volt batteries
✓ Requires regular maintenance
  – check specific gravity (Gill = 1.285)
  – add distilled water as needed
✓ HEAT and thermal cycling are a battery’s worst enemies.
Where’s The Battery
What’s The Voltage?

“Electrical energy for the aircraft is supplied by a **28-volt**, direct-current, single wire, negative ground electrical system. A **24-volt battery** supplies power for starting and furnishes a reserve source of power in the event of alternator failure. An engine-driven alternator is the normal source of power during flight …”

- 28 volts = nominal system voltage
- 24 volts = nominal battery voltage
Why 24 Volts vs. 12 Volts?

- Power (watts) = voltage * current
- Assume a load of 760 watts.
- 760 watts = 12 volts at 60 amps.
  - Requires #6 AWG copper wire.
- 760 watts = 24 volts at 30 amps.
  - Requires #10 AWG copper wire.
- The smaller wire is cheaper, lighter in weight and easier to handle.
What’s The Capacity?

✔ The battery should be sized* to supply the essential load (current) for 30 minutes**
✔ At the end of 30 minutes a 12-volt battery will discharge to 10.5 volts.
✔ At then end of 30 minutes a 24-battery will discharge to 21 volts.

* Capacity is a function of surface area.
** Batteries ratings are based on 25° C (77° F)
How Long Will It Last?

A battery’s discharge curve is **not** linear.

A battery rated at 36 ampere-hours (7.2 amps for 5 hours) will not deliver 36 amps for 1 hour or 1 amp for 36 hours.

The amount of useful remaining charge in the battery increases at a rate higher than the proportion of load reduction. For example, if the load is cut in half, the battery should last more than twice as long.
Should You Jump A *Dead* Battery?

✓ A battery that is discharged to the point where it can not crank the engine should not be jumped for two major reasons.

1. A *badly* discharged battery is not airworthy because it will not have the reserve capacity to operate electrical equipment that exceeds the capacity of the aircraft alternator.

2. High charging currents will damage the battery and cause premature failure.
Charging A Battery

The main points of consideration during a battery charge are excessive battery temperature and violent outgassing. Under a reasonable rate of charge, the battery temperature should not rise over 115-125°F, nor should gassing be so violent that acid is blown from the vents.
Battery Protection:  

*Flyable Aircraft Storage*

- Defined as a maximum of **30** days of non-operation and/or the first 25 hours of intermittent engine operation.
- No special precautions required to protect battery unless it will be subjected to excessive heat or cold.
Battery Protection:  

**Temporary Aircraft Storage**

- Defined as a maximum of 90 days of non-operation.
- Remove battery from aircraft and store in a cool, dry place.
- Cessna Service Manual note:
  
  “The aircraft battery serial number is recorded in the aircraft equipment list. To assure accurate warranty records, the battery should be reinstalled in the same aircraft … “
Battery Protection:

**Indefinite Aircraft Storage**

- Defined as non-operational status for an indefinite period of time.
- Based on definition of “temporary storage”, “indefinite storage” would appear to mean more than 90 days of non-operation.
- Remove battery from aircraft and store in a cool, dry place.
Charging Circuits
Charging Circuit:
Failure Mode Analysis

- ✔ Generator/Alternator Failure
  - Broken Drive Belt
  - Generator: Brushes
  - Alternator: Diodes
- ✔ Voltage Regulator
Where’s The Alternator?

- Battery
- Battery Contactors
- Voltage Regulator
- Alternator
- Ground Power Plug
Typical Cessna Alternator

- Rated at 60 amperes at 28 volts
  - 29.4 volts maximum under normal conditions
- Field excitation provided by battery
- Master switch is split
  - BAT half
  - ALT half
- Turning off the ALT half of the master switch takes the alternator off-line.
The Master Switch

The split master switch “... allows the battery to be on-line without the alternator, however, operation of the alternator without the battery on the line is not possible.”
Aircraft Wiring
Wire Sizes
American Wire Gauge (AWG)

The smaller the number, the larger diameter of the wire.
Aircraft Wire and Cable

✓ You can’t get it at Home Depot.
✓ MIL-W-22759/16
  – general signal and power
✓ MIL-W-22759
  – severe wind and moisture problems (SWAMP)
  – wheel wells, flap areas
✓ MIL-W-5088L
  – approved aircraft wire types
Aircraft Wire and Cable

- Stranded cable is used to withstand vibration.
- Wire smaller than #20 AWG (American Wire Gage) must have extra support clamps, be bundled with at least two other wires and have extra support at terminations.
Handyman Crimp Tool
Controlled-Cycle Crimp Tool

Yes
Controlled-Cycle Crimp Tool
Crimp Lug Termination

- Constant contact resistance as a result of precisely repeated crimp connection quality.
- Corrosion free connections as a result of cold weld action.
Basic Starter Circuit
Battery Contactor
Basic Block Diagram
Power Distribution Diagram
Mechanical Bus-Bar Diagram
Circuit Breaker Configuration

BEGINNING WITH 1981 MODELS
Switched Split-Bus Diagram
Polarity-protected Ground Power Circuit

AC = aircraft
Magnetos
Magneto Components

Magneto Coil

P-Lead
Emergency Locator Beacon
Emergency Locator Beacon: Failure Mode Analysis

✔️ Dead Battery
  (1) Because it has passed its expiration date
  (2) Because it is defective (old TSO-C91)

✔️ Failure To Activate
  Defective “G” switch (old TSO-C91)
Emergency Locator Beacon

✓ FAR 91.207

✓ Battery replacement/recharge rules
  – When the transmitter has been used for 1 cumulative hour; or
  – When 50% of their useful life … has expired, as established by the transmitter manufacturer.
  – The new expiration date for replacing (or recharging) the battery must be legibly marked on the outside of the transmitter and entered into the aircraft maintenance record.
Emergency Locator Beacon

- FAR 91.207
- ELT must be inspected every 12 calendar months for:
  - Expired battery
  - Battery corrosion
  - Ability to transmit (since 1995 TSO-C91a)
- AIM 6-2-5
- On-the-air testing should be done only during the first 5 minutes past the hour.
  - No more than 3 audible sweeps.
Emergency Locator Beacon

✓ Newer ELTs use standard “D” cells.
✓ “Best If Used Before” date on batteries help, but you have to calculate when to replace the batteries based on 50% of dated life.
✓ For example, if you buy batteries with a dated life of 2008 in 2002, you must make a note to replace the batteries in 2005. (You can always put the batteries you take out of the ELT into your flashlight.)
Emergency Locator Beacon

✓ Original TSO-C91 1971
  – False alarm rate: 90%

✓ Current is TSO-91a 1985
  – False alarm rate: 5% (primarily due to redesigned “G” switch)

✓ Not required to upgrade to a 91a unit if an exact replacement for a 91 unit can be obtained.

✓ TSO-91/91a to be phased out by Feb. 1, 2009 and replaced by TSO-126.
Emergency Locator Beacon

✓ TSO-91/91a Specifications
  – Amplitude modulation (AM)
  – 50 to 100 milliwatts (0.1 watt)
  – Should be able to transmit continuously for 48 hours (minimum)
  – Transmits on 121.5 MHZ and 243 MHz
  – Accuracy: 12 miles
  – Time to locate: 2 passes (up to 3.5 hours)

TSO-91a panel-mounted control
Emergency Locator Beacon

TSO-126 Specifications

- Digital modulation
- 5 watts
- Should be able to transmit continuously for 48 hours (minimum)
- Transmits on 406 MHz
- Accuracy: 2 miles (100 meters with GPS data)
- Time to locate: 1 pass
- At this time TSO-126 ELTs are not required in any aircraft flying in the United States.
What Can Go Wrong?

- AOPA *Pilot* Magazine, October, 2002
  - “Never Again” (B-25 with water-soaked magneto harness)

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To Learn More

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