The Hong Kong Polytechnic University
香港理工大學

Department of Aeronautical and Aviation Engineering
航空及民航工程學系

Introduction to Aircraft Systems

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Revised schedule

	Date	Content	Assignment	
1)	17-Jan-25	• Overview		
2)	24-Jan-25	• Aircraft Control Systems		
3)	07-Feb-25	• Aircraft Landing Gear Systems	Assignment 1	
4)	14-Feb-25	• Aircraft Engine System		DDL for Assignment 1
5)	21-Feb-25	• Aircraft Fuel Systems		
6)	28-Feb-25	• Aircraft Hydraulic Systems	Assignment 2	DDL for Assignment 2
7)	07-Mar-25	• Aircraft Electric Systems • In-Class Quiz (closed book)		
8)	14-Mar-25	• Atmospheric Conditions	Course Project	
9)	21-Mar-25	• Aircraft Pneumatic Systems	Assignment 3	
10）	28-Mar-25	• Aircraft Environmental Control System		
11）	04-Apr-25	• Public holiday		
12）	11-Apr-25	• Emergency system & course review		DDL for Assignment 3
13）	18-Apr-25	• Public holiday		

April 30: DDL for Course Project

Aircraft pneumatic system/氣壓系統

- Introduction
- Components of pneumatic systems
- Pneumatic system application: bleed air users
  - Anti-ice protection
  - Engine bleed air applications
- Pneumatic system application: Pitot-static systems
- Summary

Fairchild's F-27 is the first American-made plane to use a complete pneumatic system to operate landing gear, wheel brakes, brakes, etc.

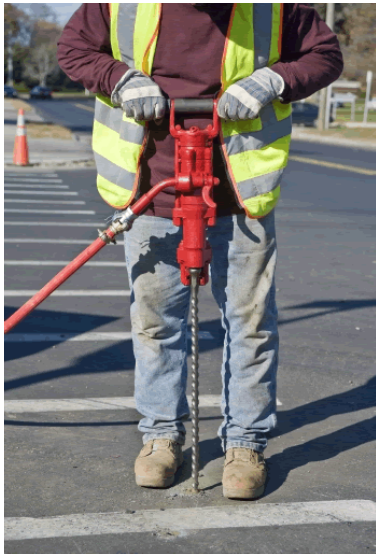
Introduction

Introduction

- In the hydraulic system section, we introduced that incompressible fluid (i.e., oil) is used to transfer power.
- Compressible gas, e.g., air, can also be used to transfer power, and the associate system is called the pneumatic system
- Pneumatic systems in industry are powered by compressed air.
- Sometimes, it is also called the vacuum pressure system

Pneumatics and pneumatic system

- Pneumatics is a branch of physics of using pressurized gas for mechanical purposes
- The gas could be air or nitrogen
- Pneumatic system/device refers to various device or instrument that generates or uses the compressed gas

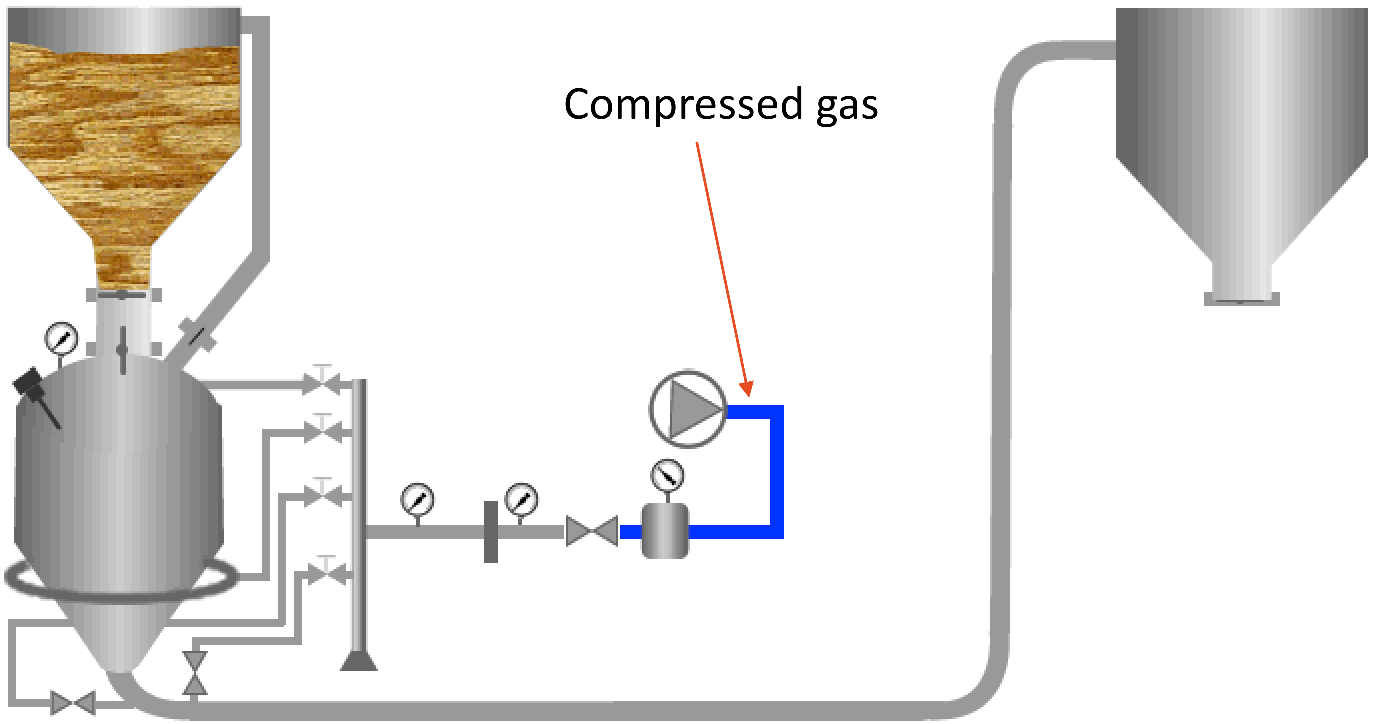


Pneumatic rock drill

Spray gun

Conveyor

Pneumatic conveying



Introduction: historical remarks

- Pneumatics originates from the Greek pneuma ‘wind, breath’

The exact history of pneumatics is unclear. But the Greek physicist and inventor Ctesibius was regarded as “the father of pneumatics” since he built many toys driven by compressed air, though none of his works survived.

Ctesibius of Alexandria (~270 BC)

Introduction: historical remarks

- Human’s ability of building vacuum bump

Otto von Guericke &
the vacuum sphere

Together with the Gay-Lussac's law and Avogadro's law, the ideal gas law was proposed

Introduction: historical remarks

- Development of gas laws

Robert Boyle (1627- 1691)
Irish-born scientist

Boyle's law: $P \propto \frac{1}{V}$

Jacques Charles (1746- 1823)
French scientist

Charles' law: $V \propto T$

Introduction: historical remarks

- 1860s, the compressed-air based rock drill was used for the construction of Hoosac Tunnel

The compound air compressor, which compresses air in a series of cylinders, was first patented in 1829

Introduction: historical remarks

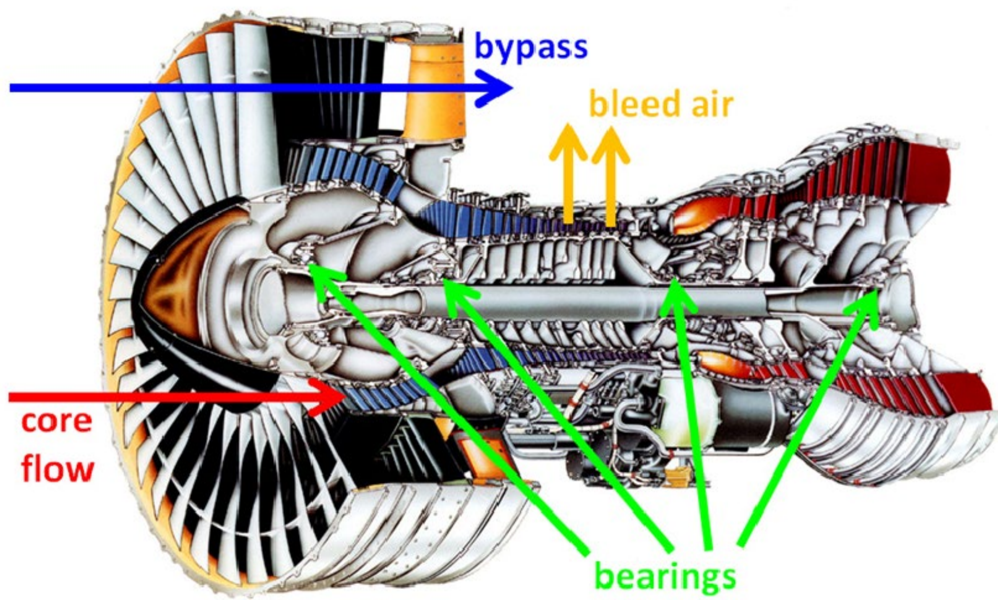
- In 20 century, the introduction of jet engines, which are effective in providing compressed air, stimulated the improvements of air compressors.
- The developments in the automatic control systems led to the use of pneumatics.
- Since 1960s, there has been a significant development of the digital-logic pneumatic-control components, leading to a wide application.

Industrial electro-pneumatics

Aircraft pneumatic system

- In aircraft, compressible gases are also used for different functionalities.
- Particularly, modern turbofan engine is an effective gas generator to provide bleed air

Bleed air refers to the compressed air taken from the compressor of a gas turbine



Aircraft pneumatic system

- In an aircraft, usage of the bleed air can be classified to
  - Provision of motive power:
    - High pressure air: to drive the valves
    - Medium pressure air: to start the engines
  - Acts as heating source: anti-ice or ice protection
  - Pressurize the cabin and air conditioning
  - Pitot-static system
  - Heating/cooling/environmental control

Pneumatic systems and components

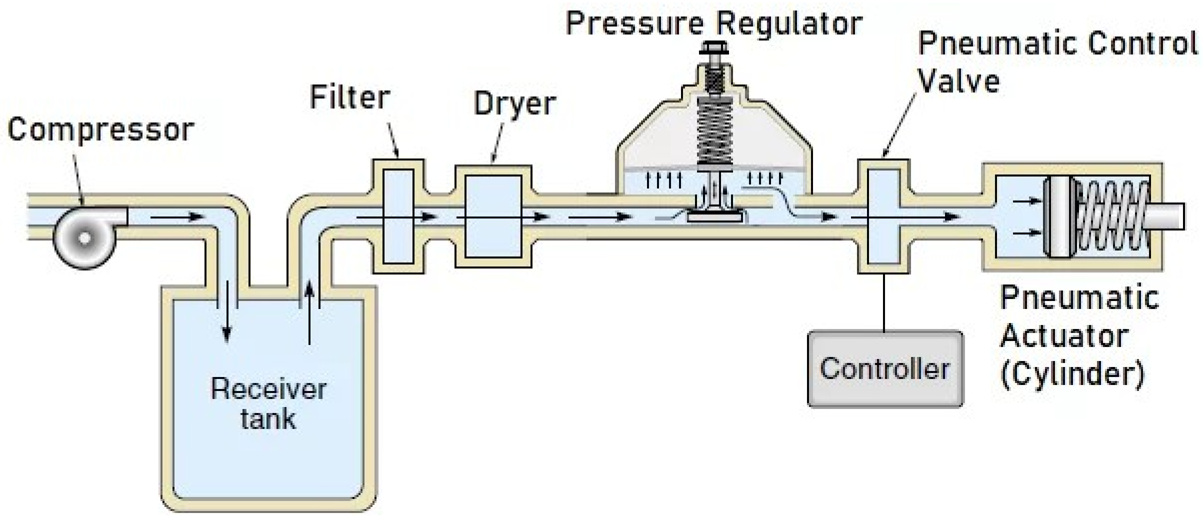
Pneumatic system components

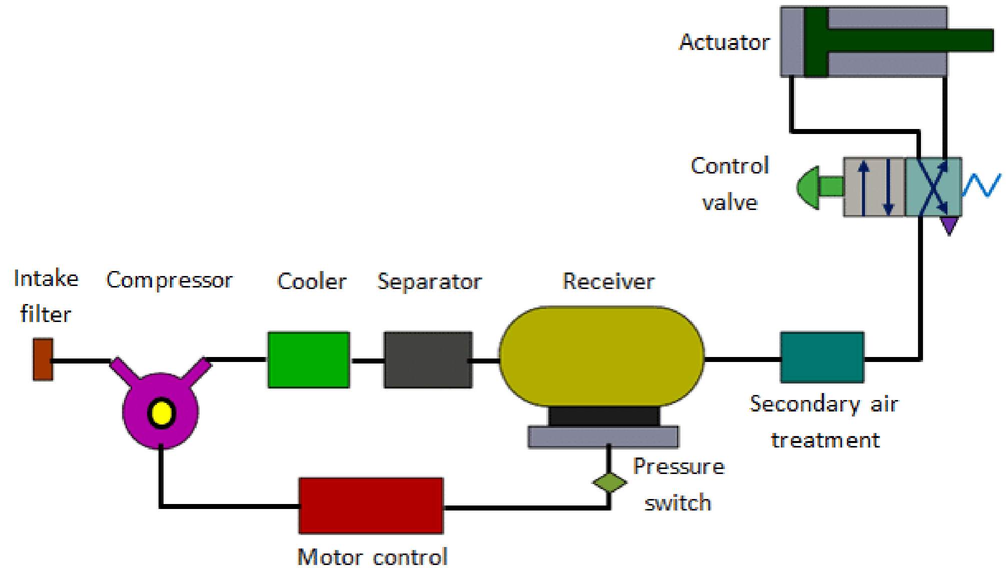
- A wide application fo the pneumatic system suggests the design and working characteristics will be different.
- Many components are connected to realize the target function
- The structure and the sequence of different components of the pneumatic system can be different as well

Pneumatic system components

- Nevertheless, a pneumatic system often contains the following items:
  - A method to generate the compressed air
  - A method to regulate the compressed air
  - A method to control the direction of compressed air
  - An actuator to utilize the air
  - A piping system to connect the necessary components

Pneumatic system components



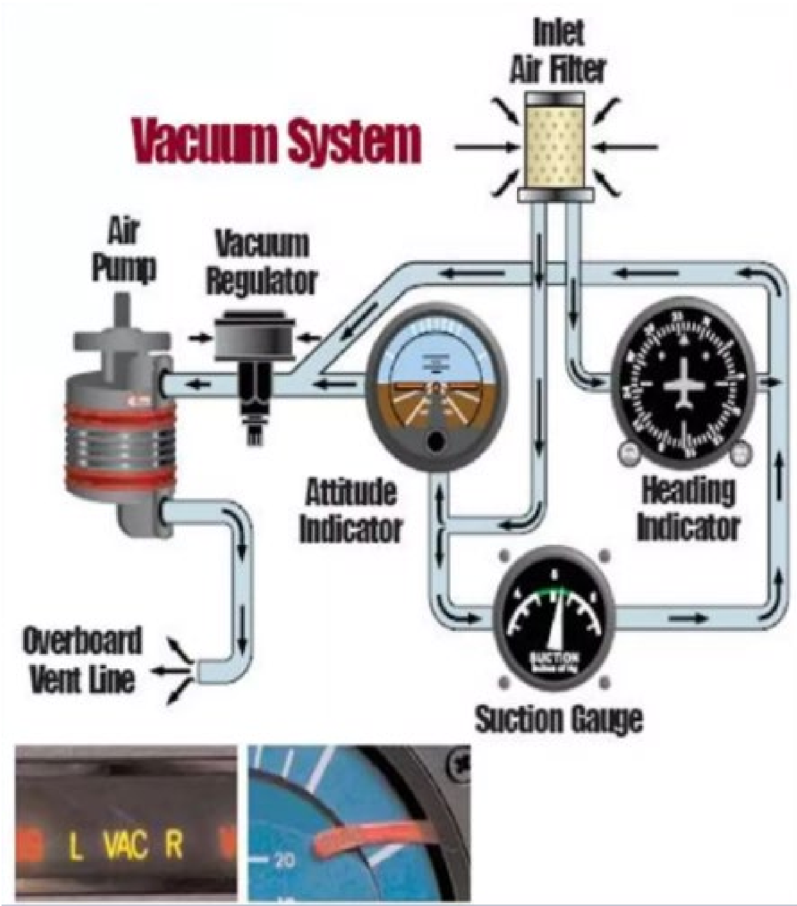


Pneumatic system components

- The principles of many components are similar to that in the hydraulic systems
- In aircraft, the air is supplied by the engine. The pneumatic system could contain:
  - Inlet air filter
  - Air pump/compressor
  - Vacuum regulator/pressure regulator
  - Overboard vent line
  - Attitude, heading and other indicators

Surely, there are difference between hydraulic and pneumatic systems.
This will be summarized later.

Pneumatic system components



The heading indicator (HI) is used to inform the pilot of the aircraft flight direction/heading.

Attitude indicator (AI) is used to inform the pilot the attitude, pitch and roll, of the aircraft.

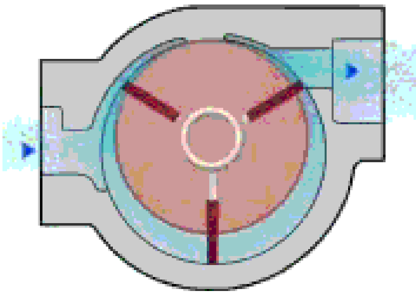
Suction gauge or vacuum gauge is used to measure the pressure

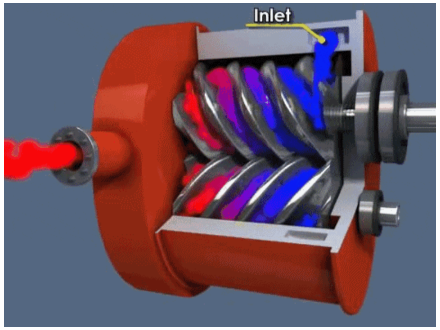
Pneumatic system: compressor

- **Compressors** sometimes are also called **air pumps**
- Air pumps is the heart of the pneumatic system:
  - Pressure air pump / compressor
  - Vacuum air pump

Takes air from an open environment

Takes air from an closed environment





- Positive displacement compressors: to compress the air by forcing air through a chamber with smaller volume.

$$P \propto \frac{1}{V}$$

- Centrifugal compression: the kinetic energy is reduced and converted to the pressure.

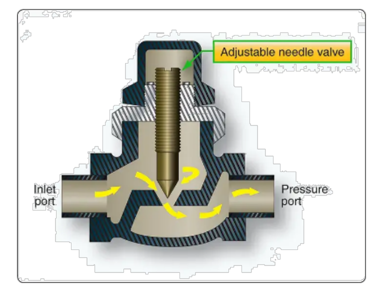
Pneumatic system: air preparation

- All pneumatic motion requires clean and dry air with enough air flow to perform the target work
- This process can contain the processes of:
  - Filtering/过滤: to clean the compressed air
  - Regulating/调制: to control the compressed air pressure
  - Lubricating/润滑: to increase speed, slow wear and reduce leakage

Pneumatic system: air preparation

- Air filter:
  - To prevent the system contamination
  - To remove air particulates
  - To clean air for good operation

- Pressure regulator
  - To prevent the system being over pressurized
  - To insure a proper calibration of the system

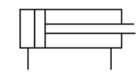


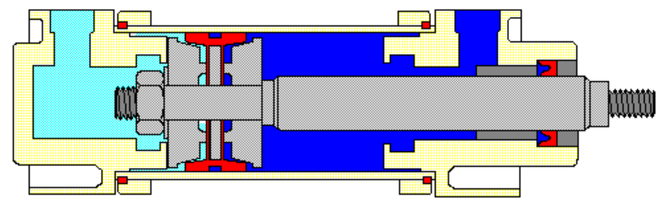
Pneumatic system: actuation

- The pneumatic systems, including those used for non-aircraft applications, can provide linear and rotary motions, depending on the design

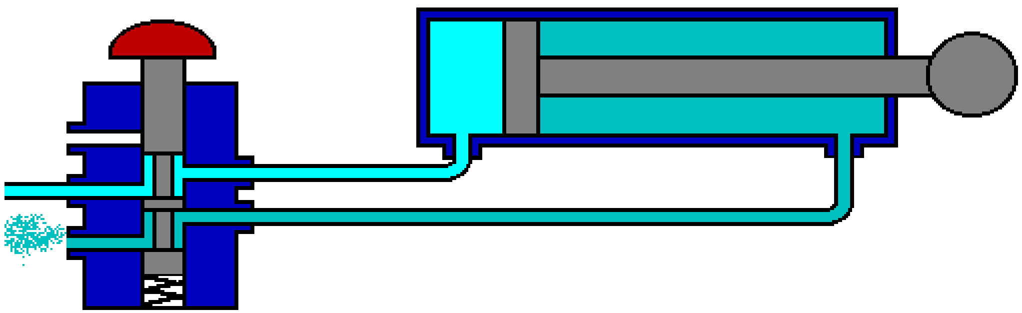
Pneumatic actuators come in a variety of shapes and sizes

Pneumatic system: actuation

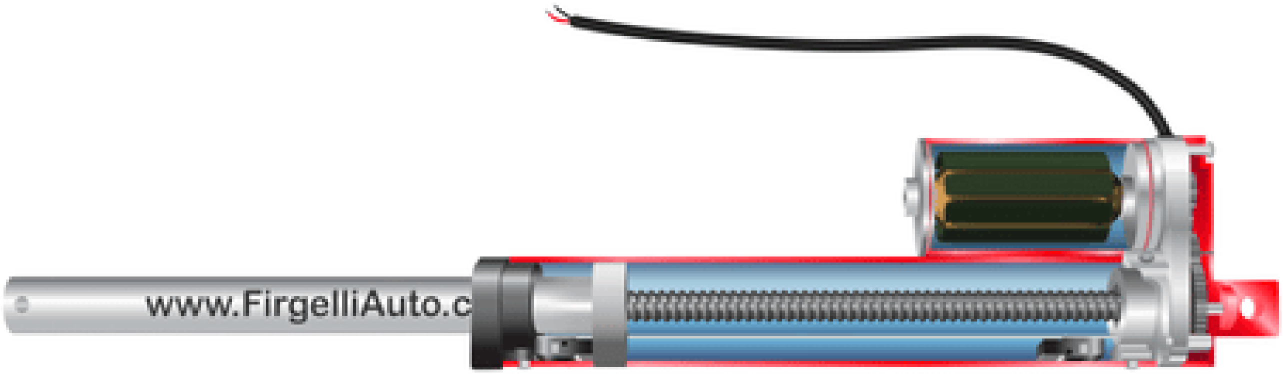




Valve is controlled by solenoids device



Pneumatic system: actuation



Schematic for the pneumatic
rotary motion

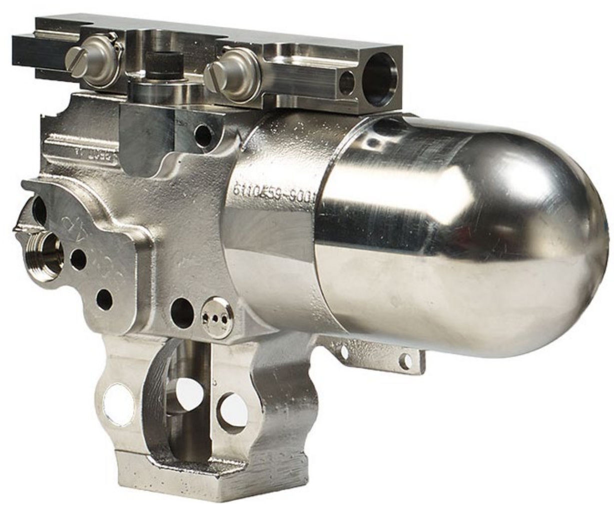
Pneumatic system: piping system

- To guide the compressed air flow, rigid or flexible pipes are needed.
- At the end of the piping system, hoses are often installed to deliver the air to the actuator or other targets

Pneumatic system: valves

- In pneumatic systems, many valves exist to control the air flow rate, direction, etc.
- Manual valves are often operated with a knob
- Solenoid-based valved are often operated under the 24 VDC

Bleed air shutoff valve



Valve for the high-pressure pneumatic system

1 bar = 100,000 Pa

Pneumatic system V.S. hydraulic system

	Hydraulic system	Pneumatic system
fluid	Incompressible liquid	Compressed gas
pressure	Up to 700 bar	Around 5-10 bar
Circuit	Closed	Open
If leakage	Performance reduced	Little impact
Valve control	Difficult	Easy
Weight	Heavier	Lighter
Pressurization	Pumps	Compressors
Safety	Unsafe for fire hazards	Free from fire hazards
Lubrication	Necessary	Special arrangement

Pneumatic system as actuators

Other applications of pneumatic system in aircraft

- In next section, we will introduce the usage of bleed air, which are common application of the aircraft pneumatic system.
- Here, we list some examples of using pneumatic system for providing needed power and other application, including:
  - Tires
  - Oleo
  - Back-up systems for hydraulic failure
  - Flaps
  - Brakes
  - Cargo door actuators
  - Vacuum gauges

Pneumatic tires

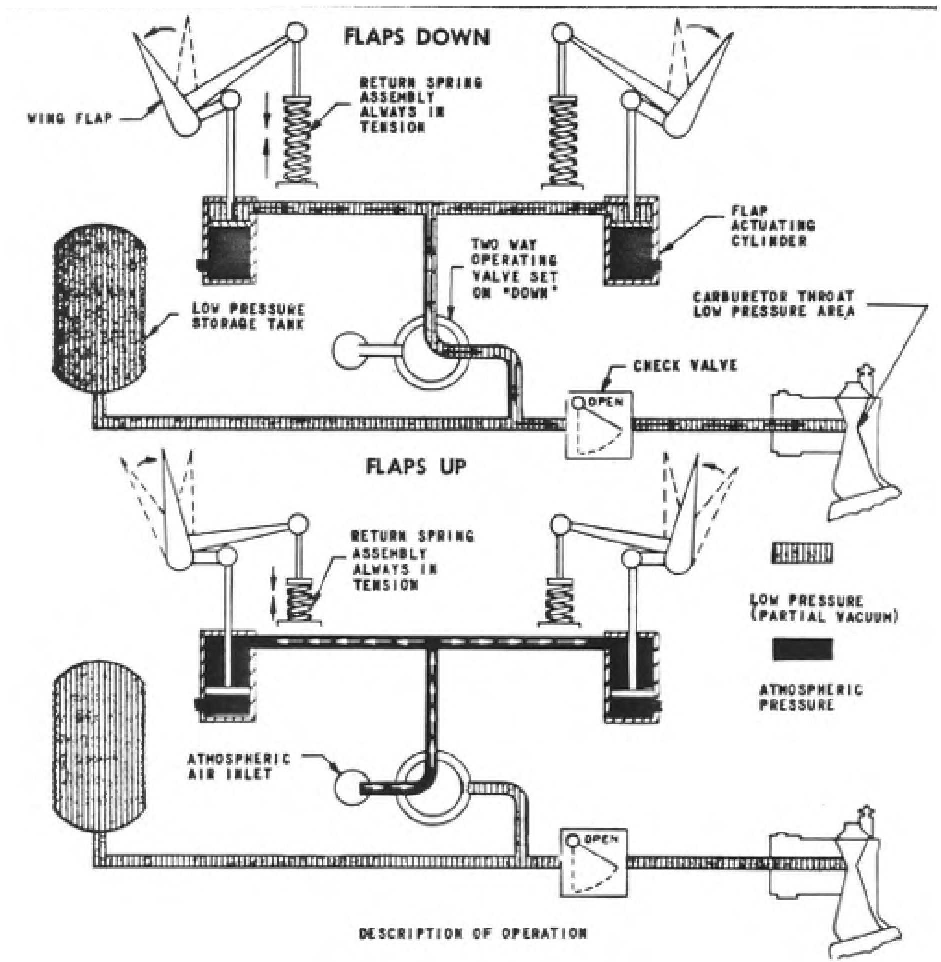
- The rubber tires are filled with air, and the air inside it can be viewed as a pneumatic system.
- The air can act as a shock absorber to ensure the landing gear work safely. It can also help improve the steering performance of the gear.

A heavy landing can often cause the pneumatic tire failure

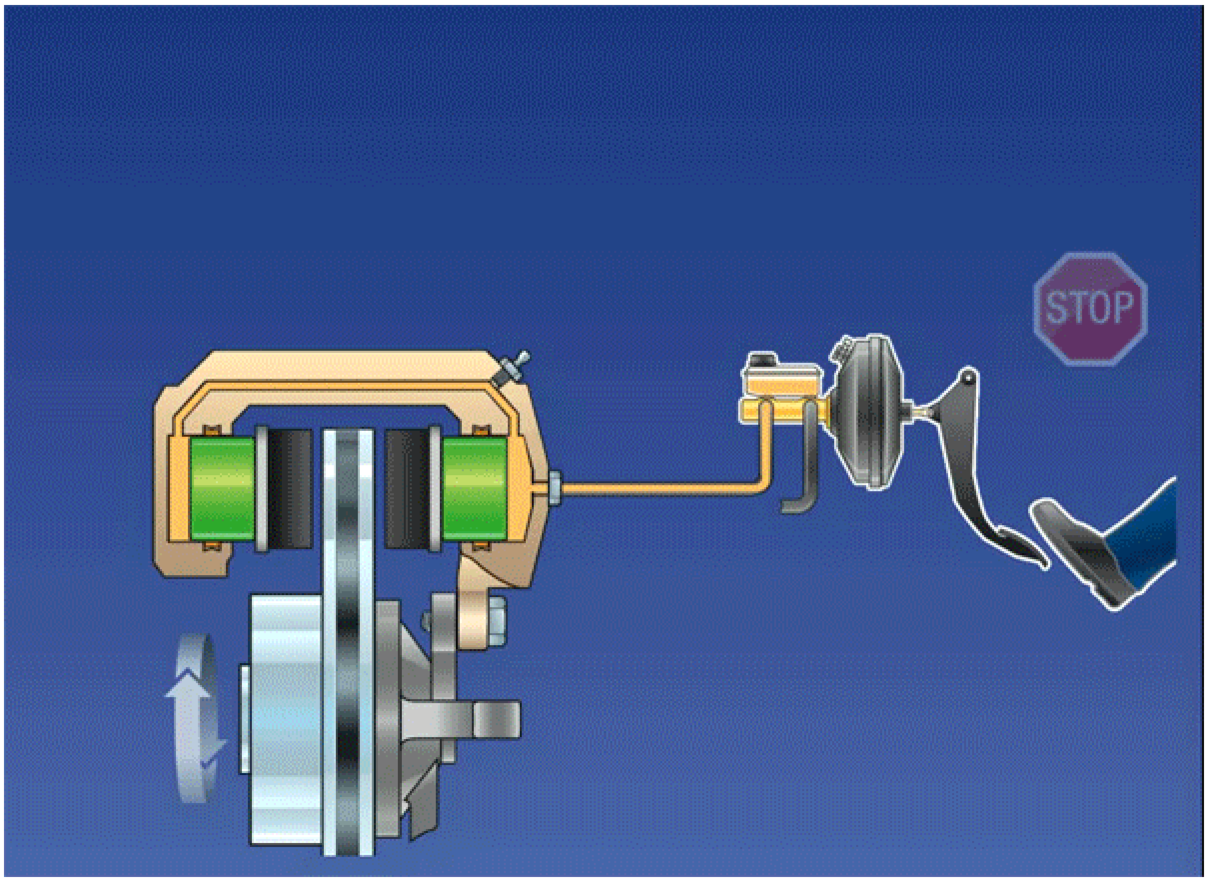
Pneumatic Oleo strut

- For heavy aircraft, the Oleo strut is often driven by the more powerful hydraulic systems
- For light aircraft, the pneumatic Oleo strut is often used.
  - Pressurized nitrogen gas
  - A recharge valve system allows for easy maintenance

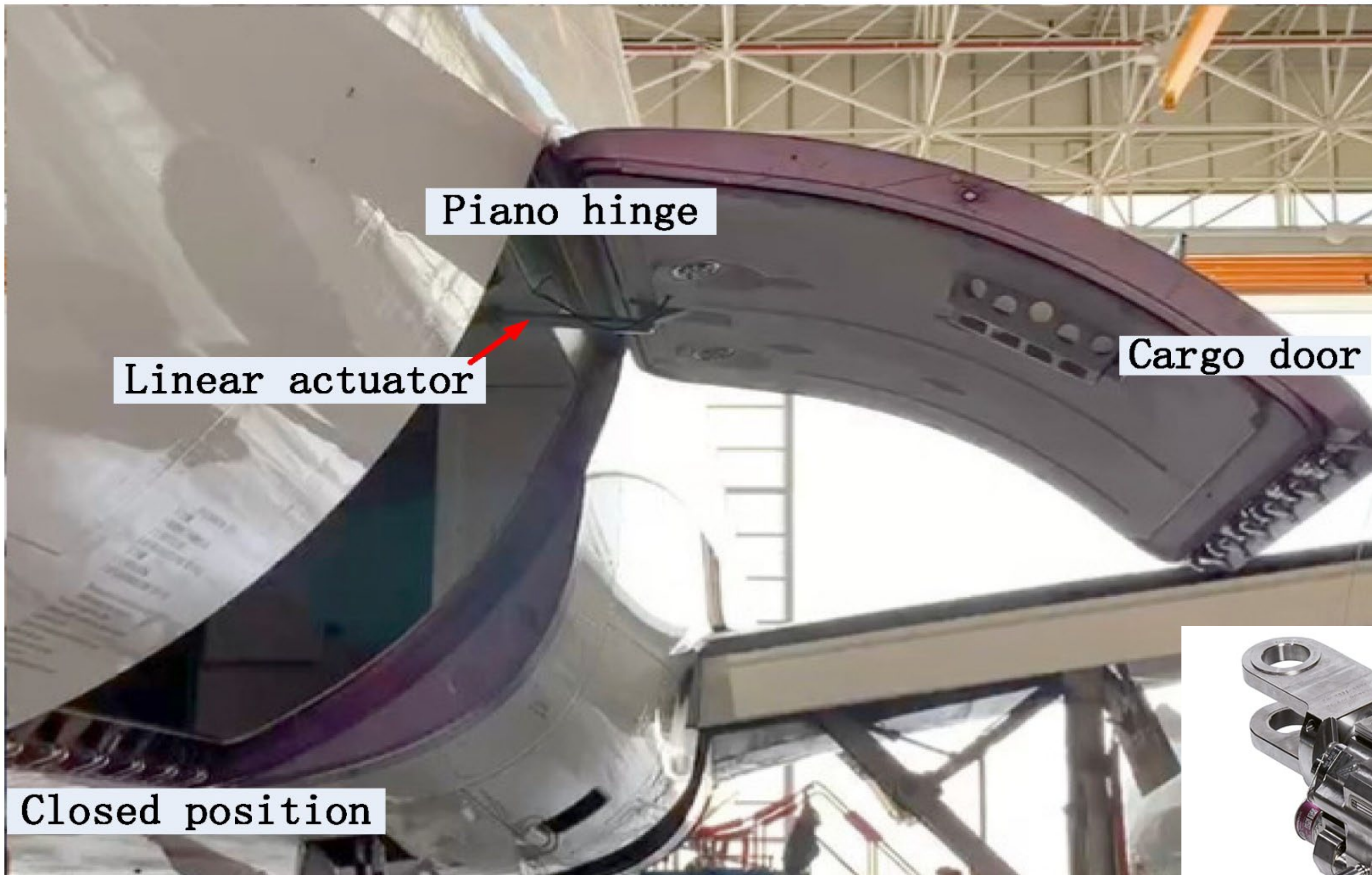
Pneumatic flap system: FM-2 airplane



Pneumatic for braking: air braking



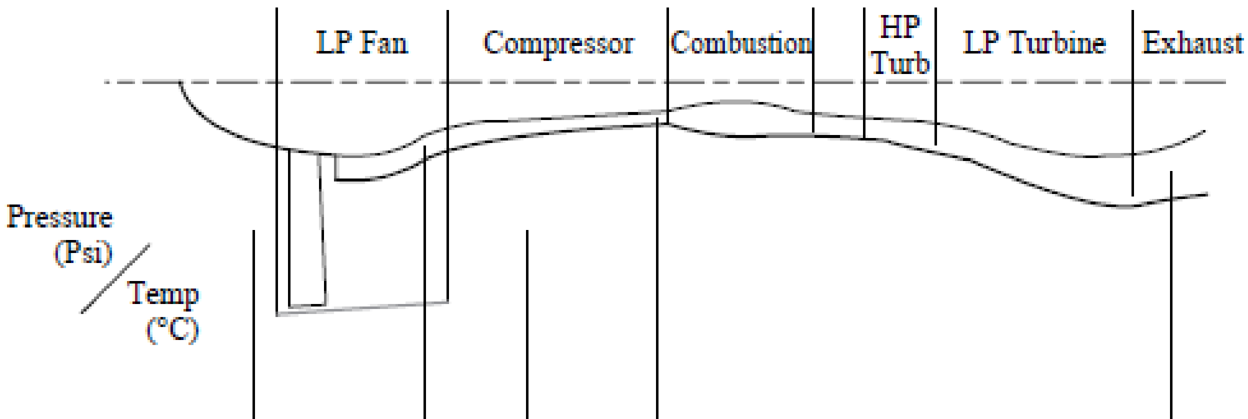
Pneumatic for cargo-door operation



Bleed air system users for aircraft

Air source in aircraft: engines

- The engine provides the high-pressure, high-temperature air.



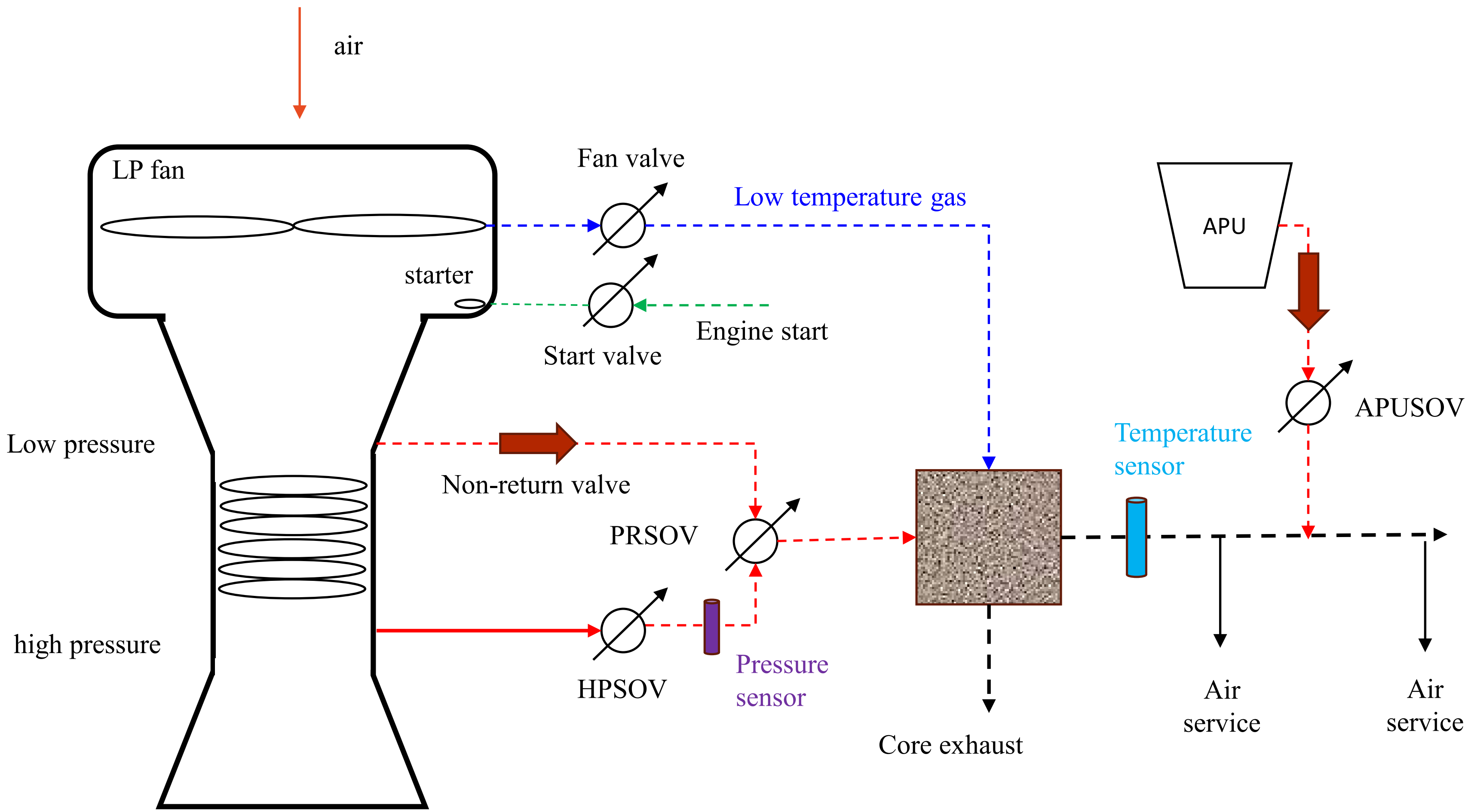
Idle	14.7/15	16/20	15/16	50/180		14.8/340
Take-Off	14.7/15	39/115	25/65	410/540		23.0/510
Cruise	5.3/−25	14/60	8.5/15	150/400		6.8/340

Typical air property in a modern turbofan engine

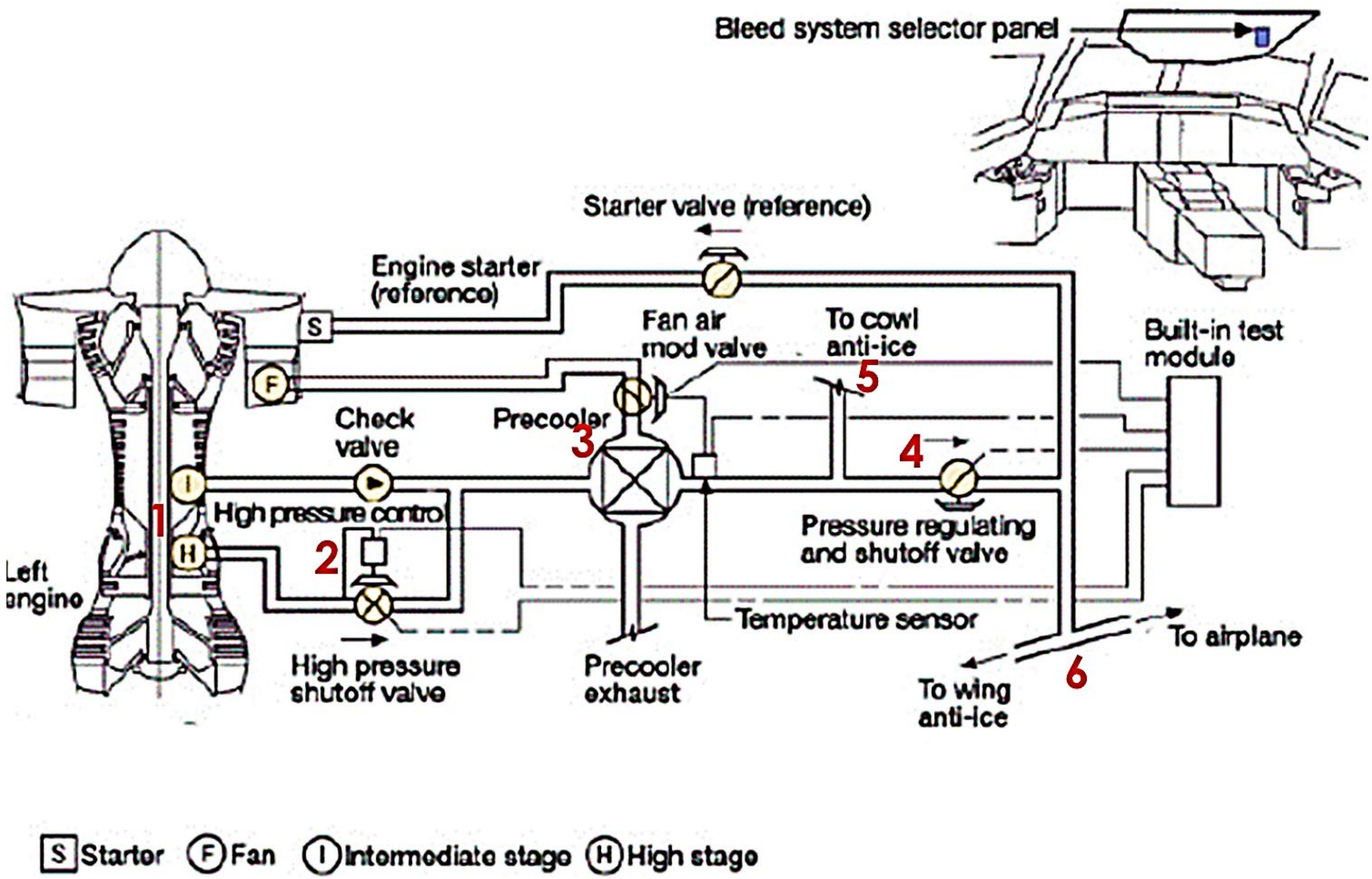
Air source in aircraft: APU

- APU itself can be viewed as a small turbojet engine.
- It is able to provide high-pressure bleed air
- APU is designed to provide:
  - Electrical power: shaft driven generator
  - Pneumatic power: shaft driven compressor

Engine bleed air control: example 1



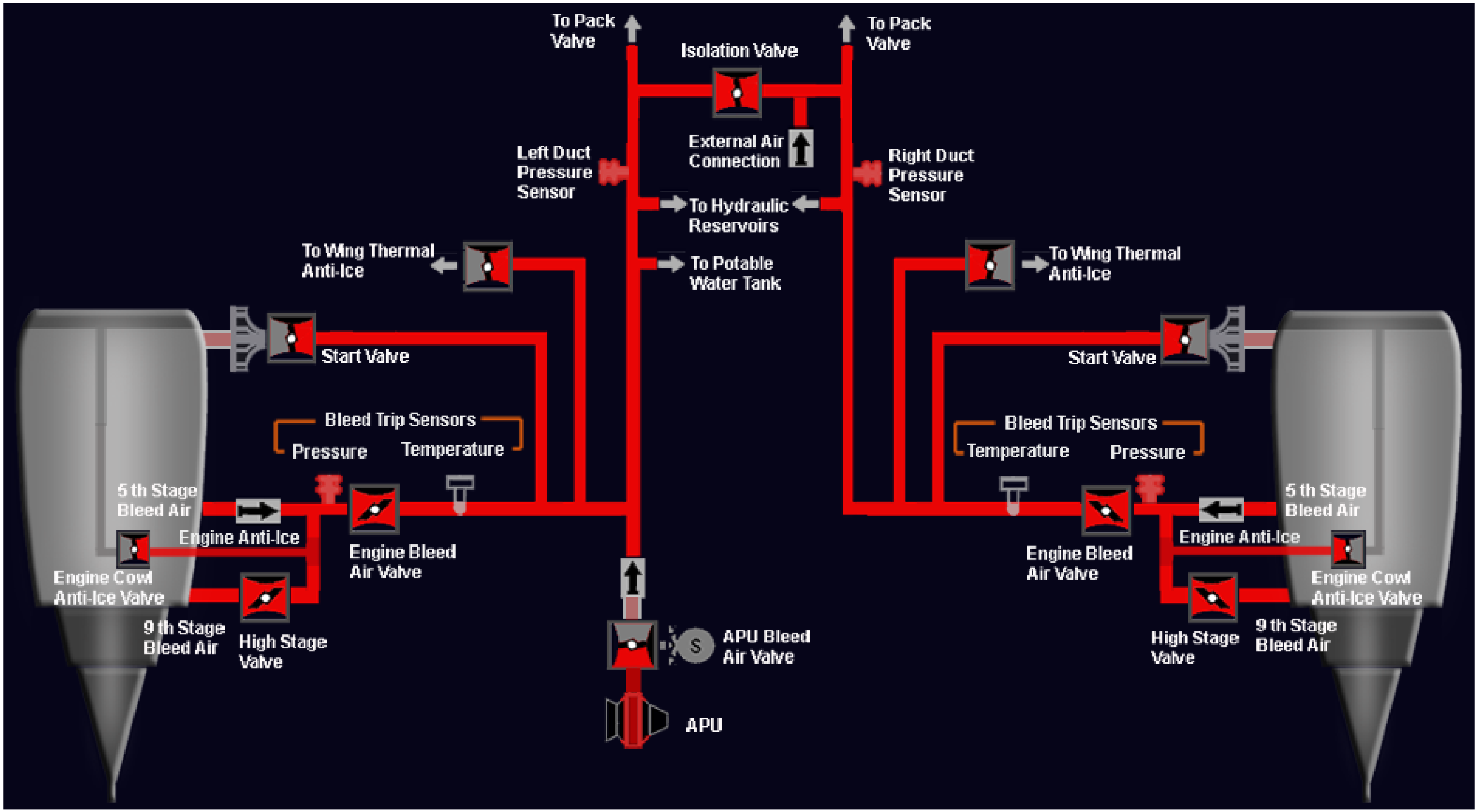
Engine bleed air control: example 2



Engine bleed air control: example 3

1. Air is taken from the engine:
   - an intermediate stage when engine is at high power
   - Or, high pressure stage of the engine compressor at low engine power.
2. High pressure control sensor and HP SOV regulates the pressure of air and controls the supply of bleed air.
3. The air enters the pre-cooler.
   - Flow of cooling air bled from the Low Pressure fan is regulated by the fan valve, which controls the temperature of the bleed air, and temperature is sensed by senor at the exit.
4. A PR SOV controls the pressure and temperature of the bleed air into the aircraft.
5. Bleed air is directed to the cowling for anti-ice function.
6. The bleed air is distributed within the aircraft anti-ice, cabin pressurization, Environmental control functions, and the other engines.

Example 4- B373 pneumatic system

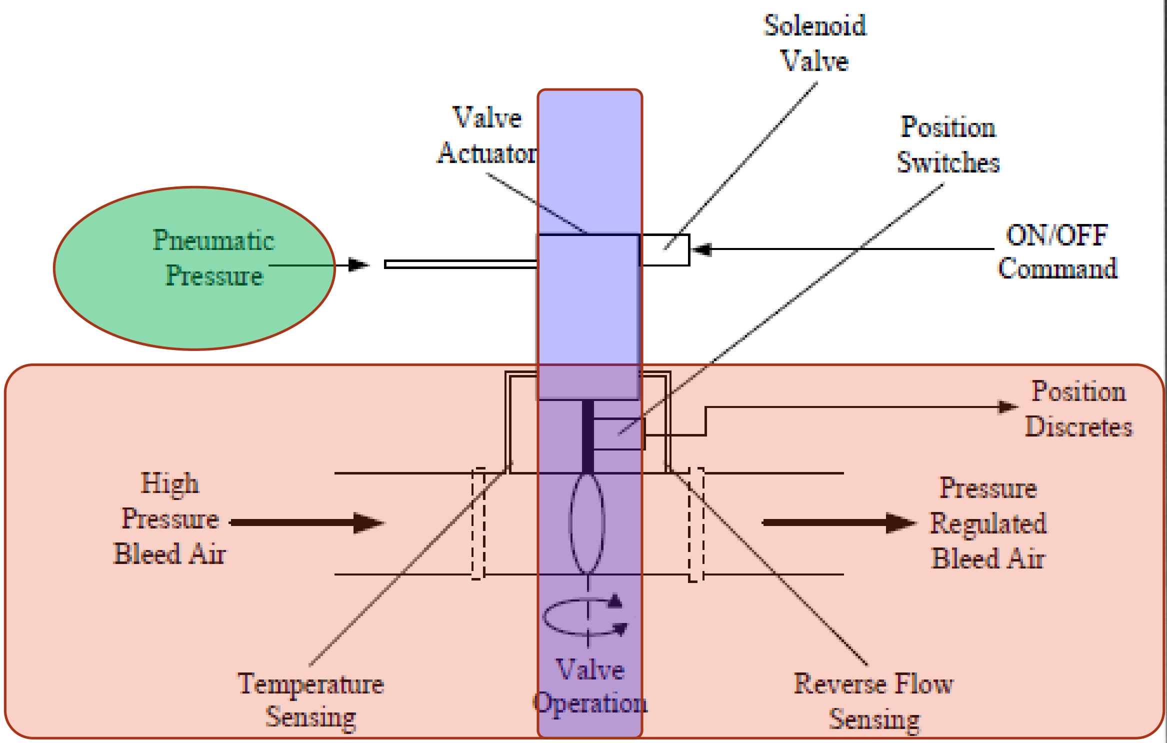


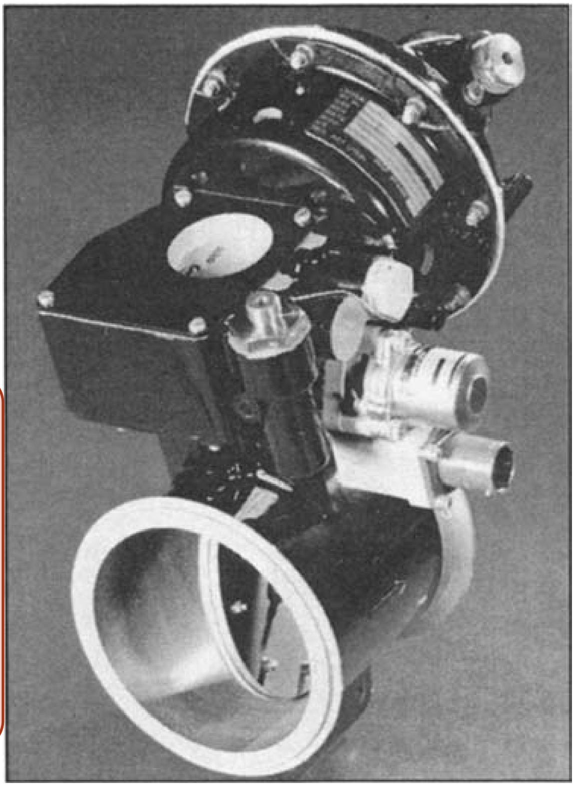
Valves for engine bleed air control

- High-pressure Shut-off Valve (HPSoV)
  - It regulates the pressure of air from the engine to around 100 psi and controls the supply of bleed air from engine
- Pressure-reducing shut-off valve (PRSoV)
  - Regulates the supply of air to around 40 psi before the pre-cooler
  - The temperature of the air is regulated by the fan valves that controls the cooling air
  - Pressure and temperature sensors are needed

Valves for engine bleed air control

- Typical PRSOV





Harrier II pneumatic valve

Bleed air indication

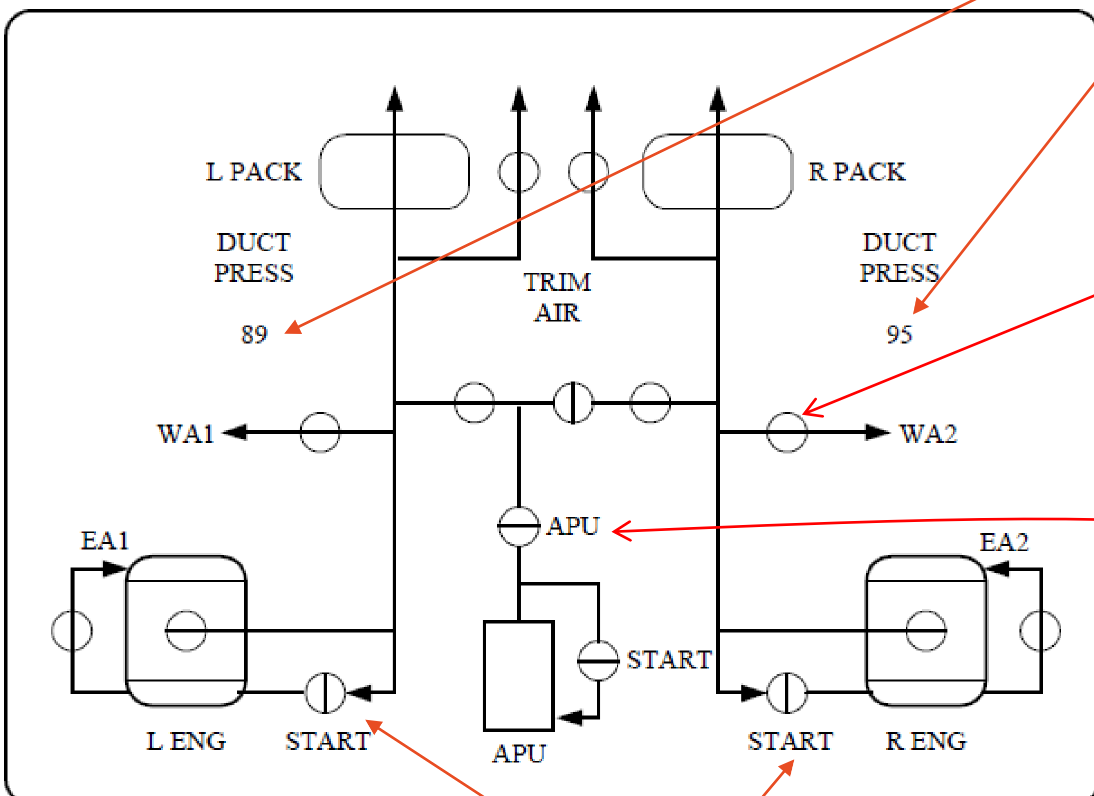
- For civil aircraft bleed air systems, it is common to display system status to the flight crew on the Electronic Flight Instruments System (EFIS)
  - In Boeing aircraft, the status is shown on the Engine Indication and Crew Alerting System (EICAS)
  - In Airbus aircraft, the information is shown on the Electronic Centralized Alerting and Monitoring (ECAM)

Boeing EICAS layout

Airbus ECAM layout

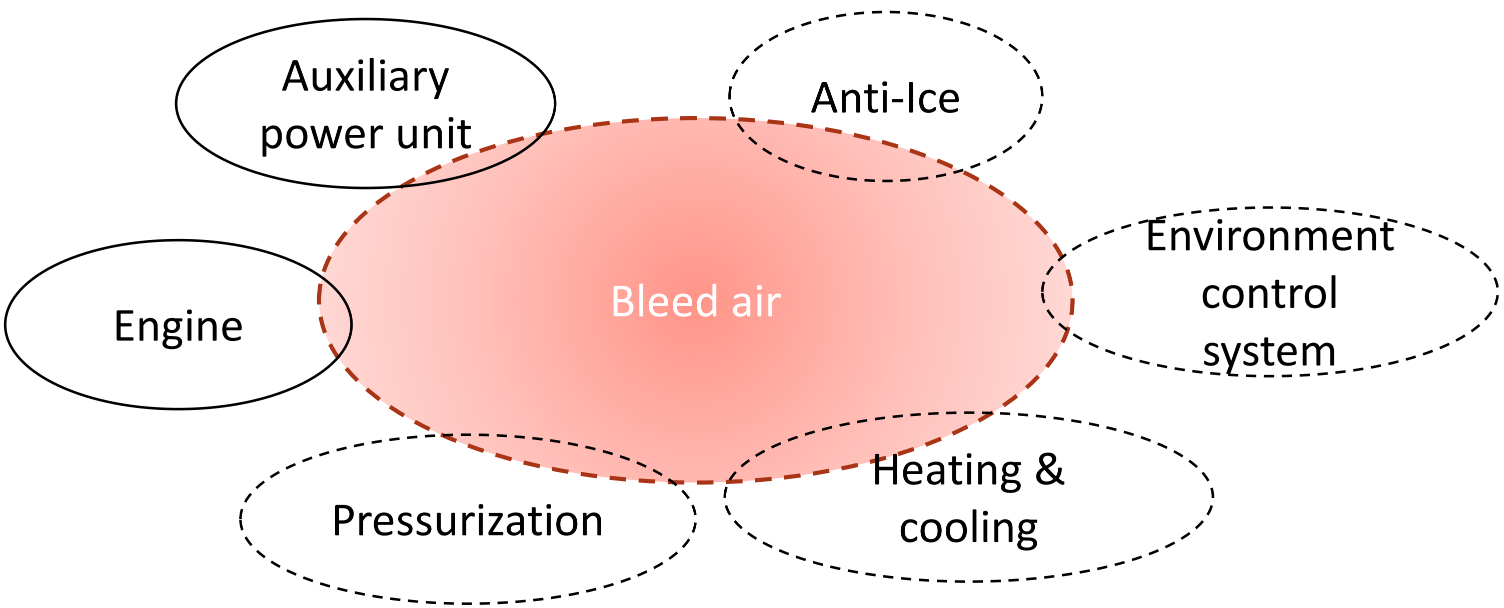
Bleed air indication

- Typical bleed air system synoptic display



Bleed air system users

- The bleed air offered by the pneumatic system is used by the aircraft sub-systems related to air. The functionalities include the cabin environment control, fuel system pressurization, de-icing, and starts the engine, cargo bay heating, etc.



Bleed air applications in aircraft

- For civil aviation, the application of bleed air of the aircraft pneumatic system to different aircraft systems are classified.
- The Aircraft Transportation Association (ATA) has a list to regulate the applications:
  - Air conditioning (ATA Chapter 21)
  - Cargo compartment heating (ATA Chapter 21)
  - Wing and engine anti-icing (ATA Chapter 30)
  - Engine start (ATA Chapter 80)
  - Thrust reverser (ATA Chapter 78)
  - Hydraulic reservoir pressurization (ATA Chapter 29)
  - Rain repellent nozzles – aircraft windscreen (ATA Chapter 30)
  - Water tank pressurization and toilet waste (ATA Chapter 38)
  - Air driven hydraulic pump (ADP) (ATA Chapter 29)

Bleed air system users

- The largest bleed air user is the air system, which is used for:
  - Cabin environmental control
  - Cabin pressurization
  - Cargo bay heating
  - Fuel system pressurization

Will be covered by the ECS section

- Wing and engine-anti icing
- Engine start
- Thrust reverser actuation
- Hydraulic system

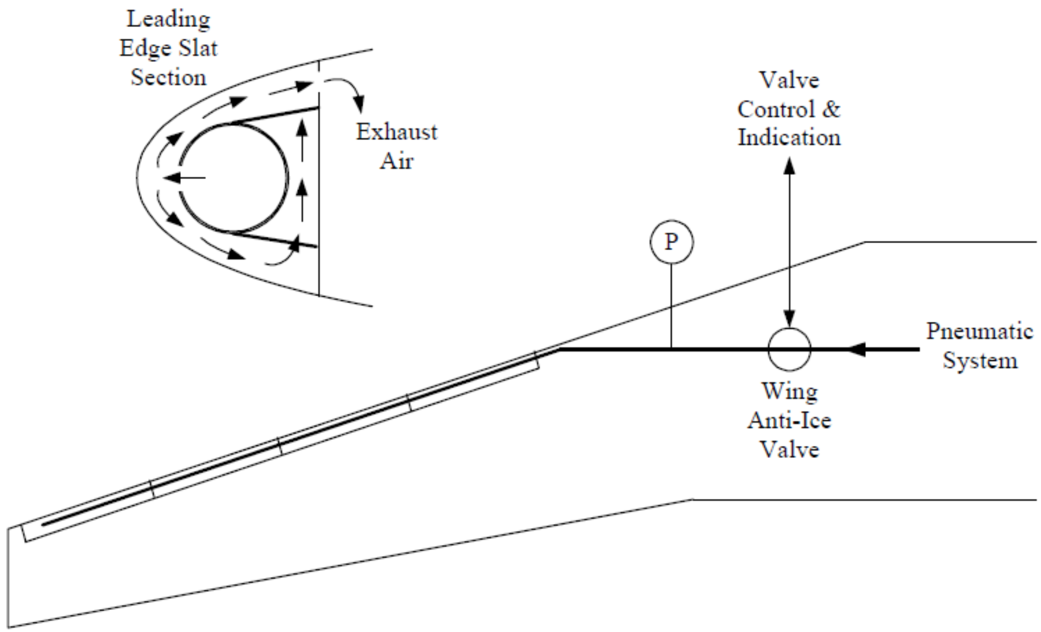
Anti-ice protection

- Anti-ice protection is important to ensure the aerodynamic performance and flight safety.
  - Ice on wing leading edge: cause stall and loss of light control ability
  - Ice on engine intake: affect the free flow entering of the air
  - Ice on window screen: cause visual obstacles to the pilot
  - Ice on sensors: affect the reading and measurement accuracy



Anti-ice protection: wing

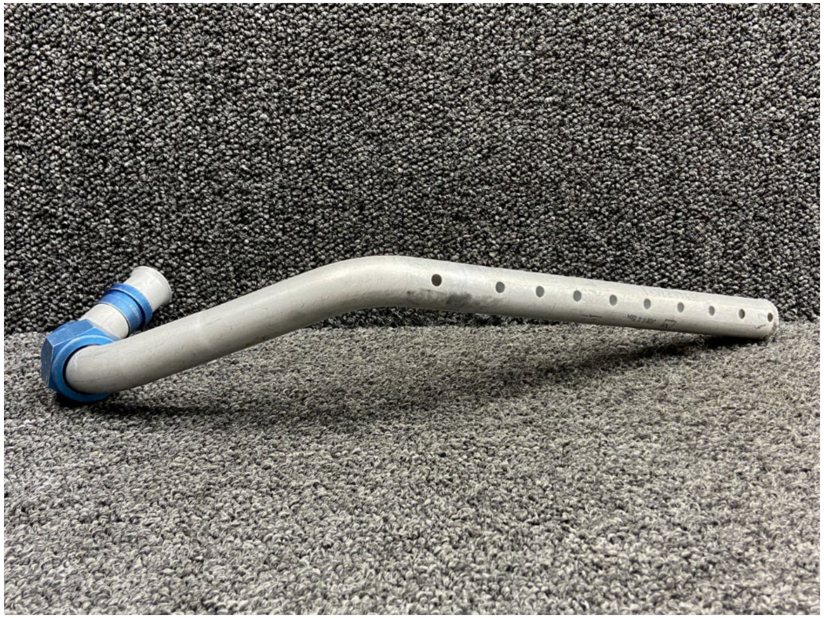
- Principle: hot air to the outer wing leading edges is controlled by the Wing Anti-Ice Valve.
  - Flow is modulated by electric-controllers to allow air pass down to the heating duct: piccolo tube
  - Slat is controlled to move, and the air is bled out into the slat, and heat the structure.

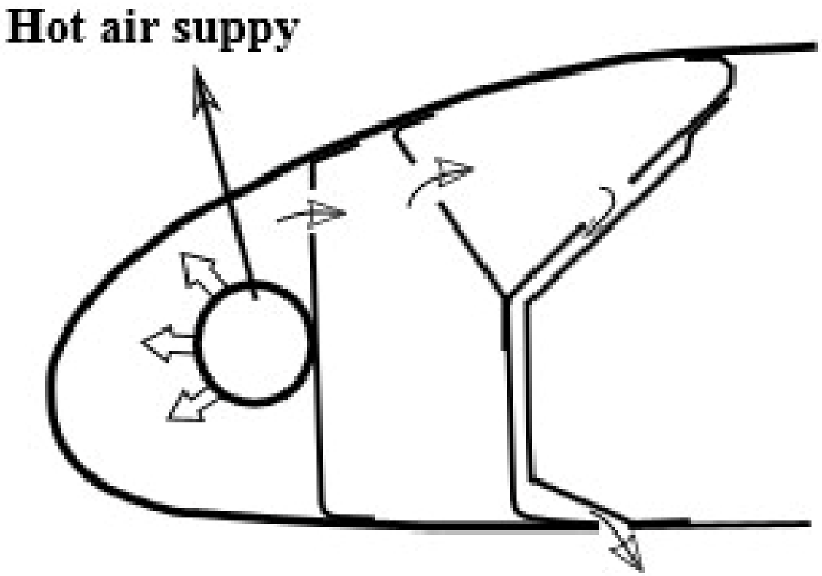


Piccolo/短笛

Anti-ice protection: wing

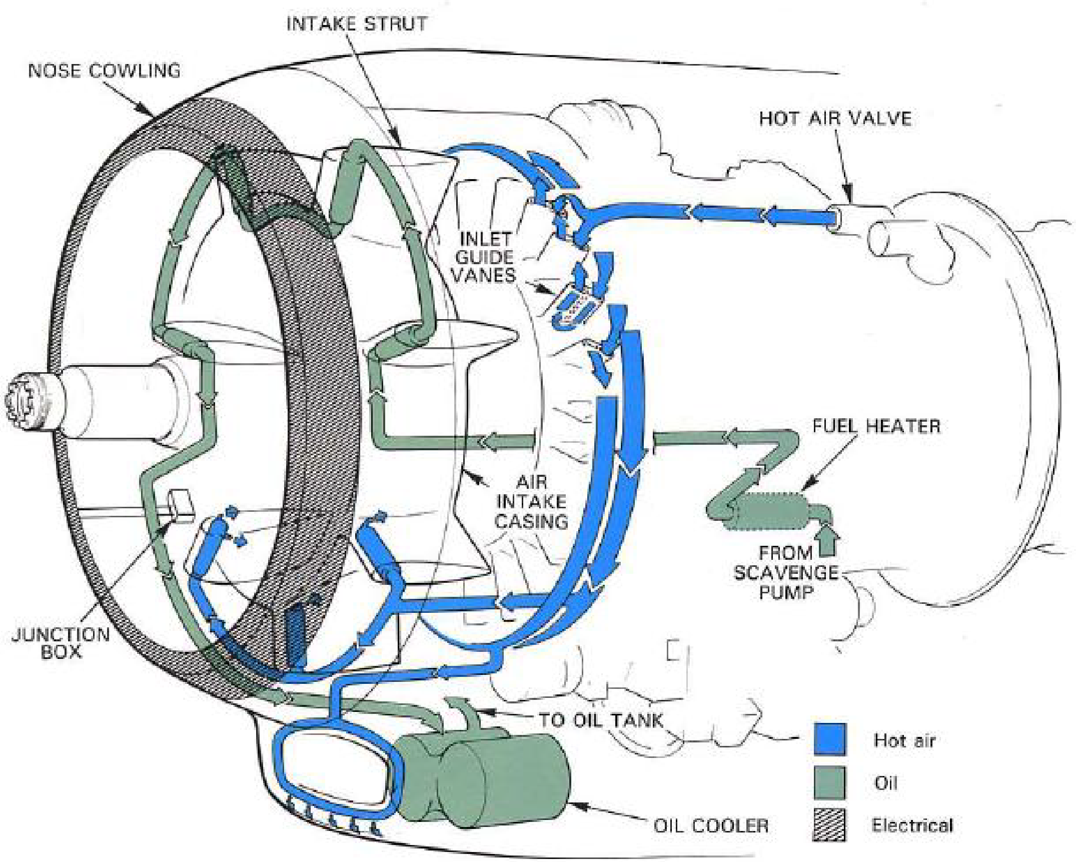
- Piccolo tube: the pipe has holes with approximate size to allow the air go into the leading-edge slat
- The pressure is controlled to around 20-25 psi





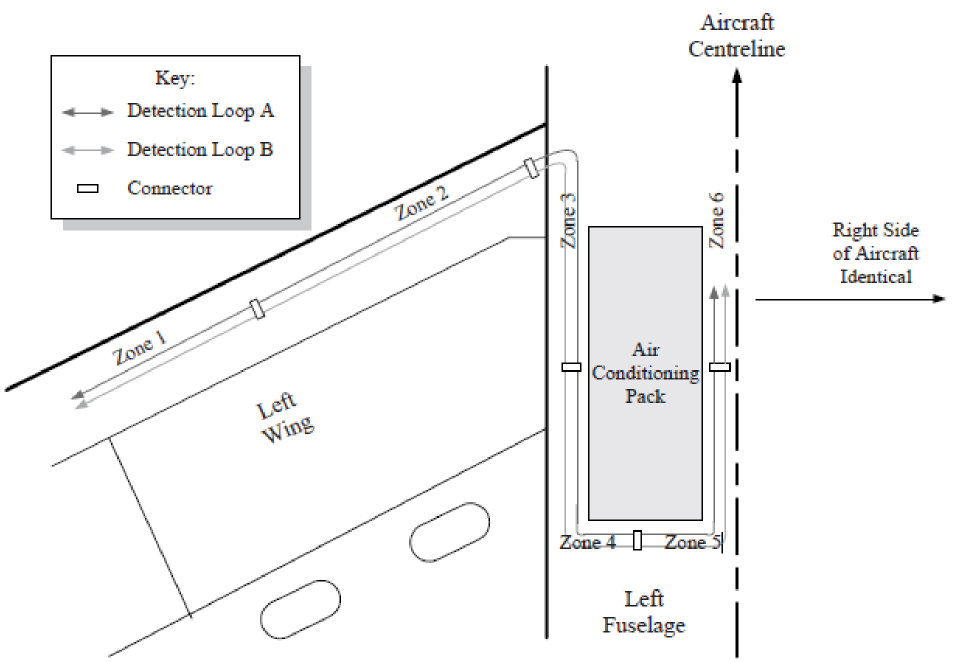
Anti-ice protection: engine

- The process is similar for engine. An engine anti-ice (EAI) valve is located on the engine fan casing to control the hot air.



Anti-ice protection: overheating warning

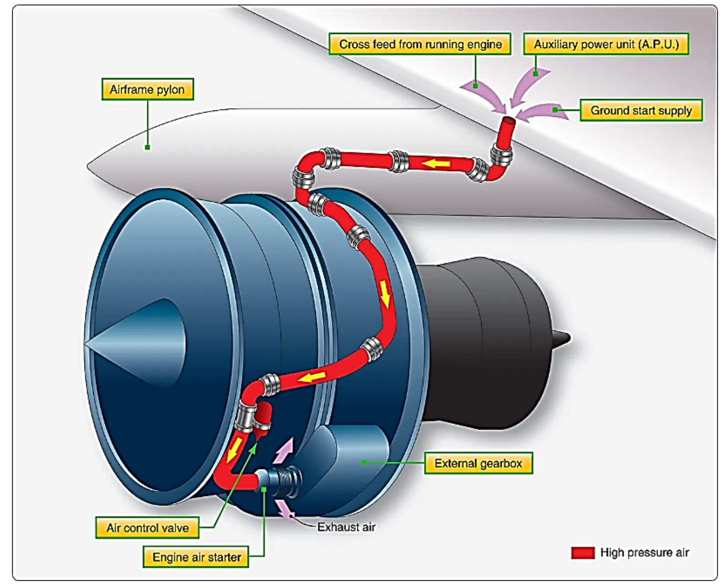
- The presence of hot air throughout the airframe and engine nacelle can cause a problem of overheating
  - The hot air leakage
- Overheating detection and warning systems are needed in sensitive areas including:
  - Air conditioning
  - Wing leading edge
  - Engine nacelle

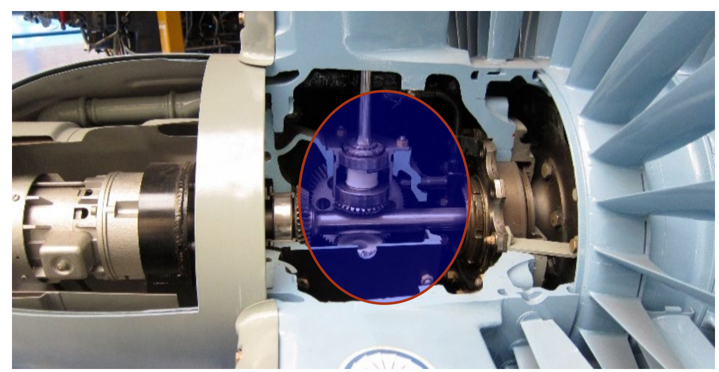


Dual detection looks are used to detect, localize and increase redundancy

Use of engine bleed air: engine start

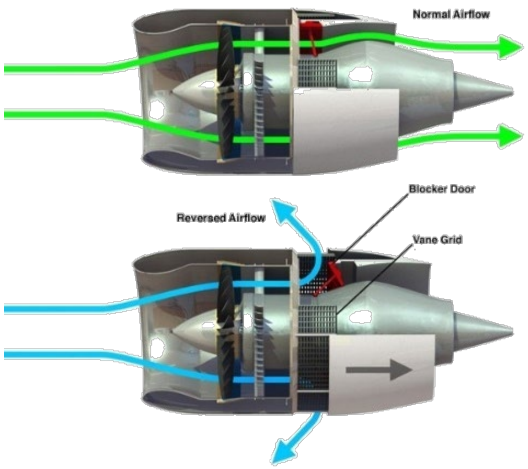
- The availability of high-pressure air throughout the bleed air system lends itself readily to the provision of motive power to crank the engine during the engine start cycle.
- During the engine start, the bleed air is often offered by APU.
- Sometimes it can also be provided by:
  - Ground air supply cart
  - Another engine that has been operated
- A start valve is used to supply bleed air to the engine starter, which is located at an external accessor gearbox





Use of engine bleed air: thrust reversers

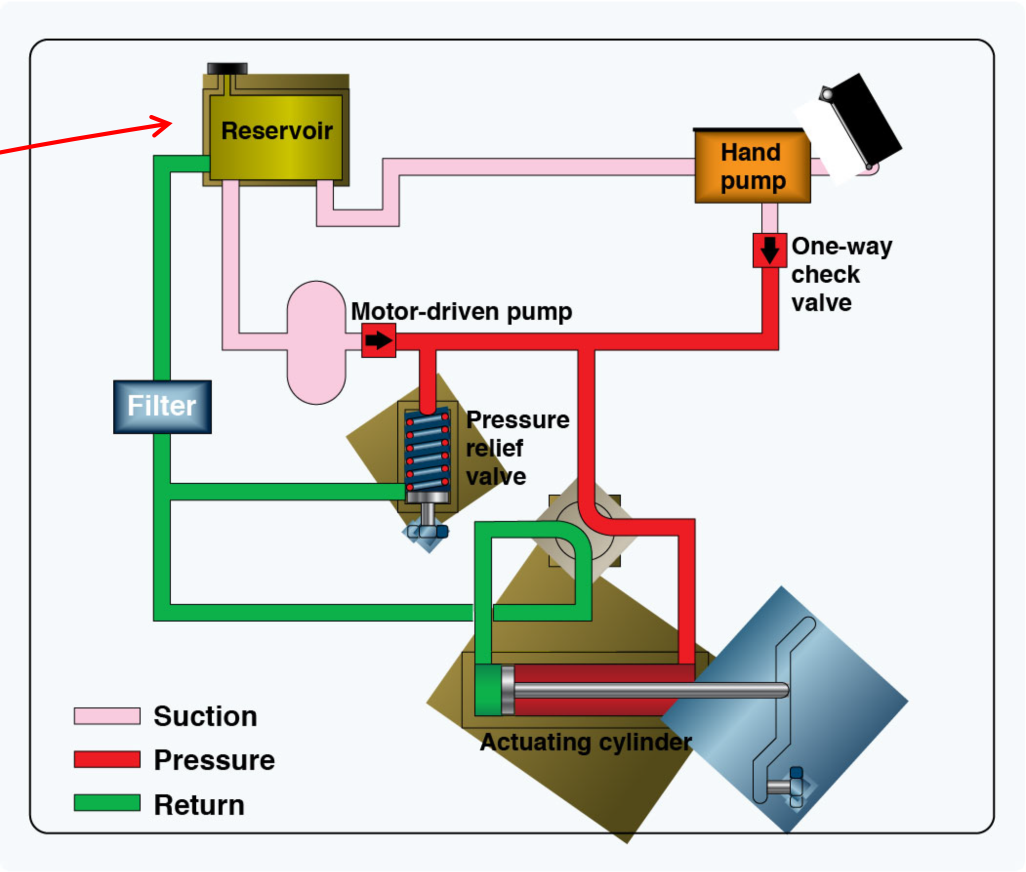
- Engine thrust reversers are commonly used to deflect engine thrust forward during the landing roll-out to slow the aircraft and preserve the brakes
- Thrust reversers include buckets on engine surface.
  - They are pneumatically operated by air turbine motors to deflect the fan flow, yielding the braking effect
- Inter-lock mechanisms are necessary to prevent the thrust reversers during flight.



Use of engine bleed air: hydraulic systems

In hydraulic system, the fluid in the reservoir should be pressurized. This can realized by the pneumatic system.

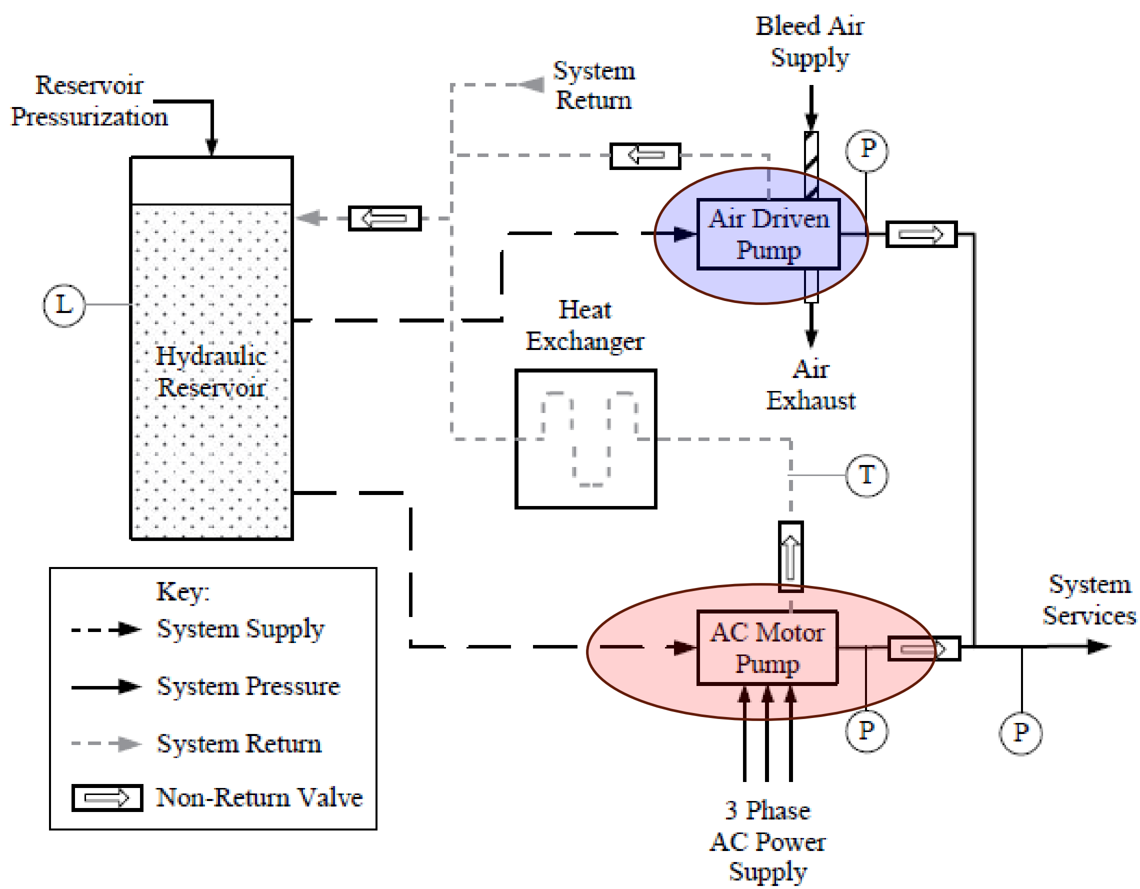
An alternative approach is to use electrical motors .



Use of engine bleed air: hydraulic systems

Usually, the AC motor pump is used as the primary source of power for hydraulic fluid pressurization and the Air Driven Pump is used as the secondary power.

Pressure and temperature sensors are placed in the whole system.



Example of a pneumatic system-hydraulic system integration

Pitot-static systems

Pitot-static systems

- Being different from the use of air bleed to provide the energy or power to move the aircraft components, the pitot-static system is an instrumentation system to measure the flight speed.
  – It is a system with high levels of redundancy

Bernoulli principle

- The Pitot-static system is based on the Bernoulli principle:

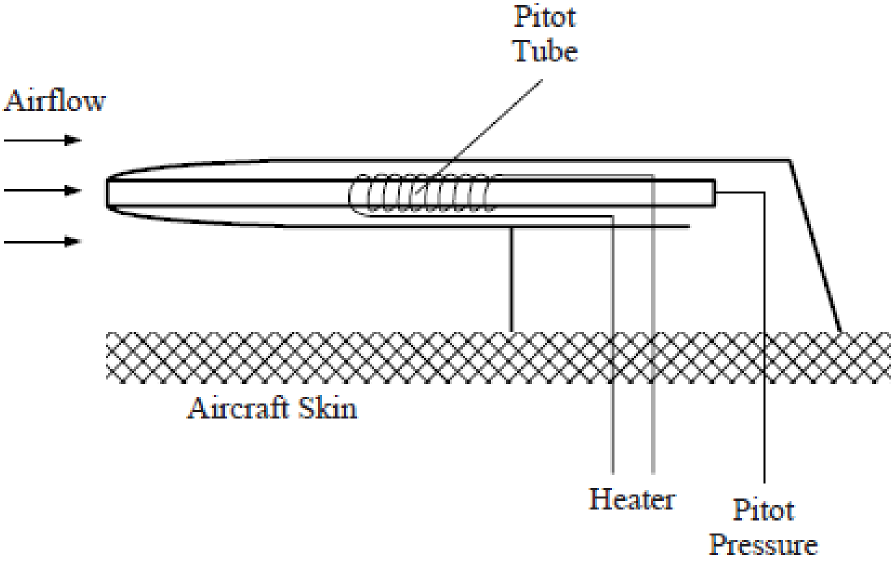
$$P_s + \frac{1}{2}\rho u^2 = P_t$$

- Here:
  - P_s is called the static pressure
  - $\frac{1}{2}\rho u^2$ is called the dynamic pressure, u is the flow speed
  - P_t is called the total pressure
- It is the consequence of the mechanical energy conservation
- Here the gravity potential is omitted.

Daniel Bernoulli

Pitot probe

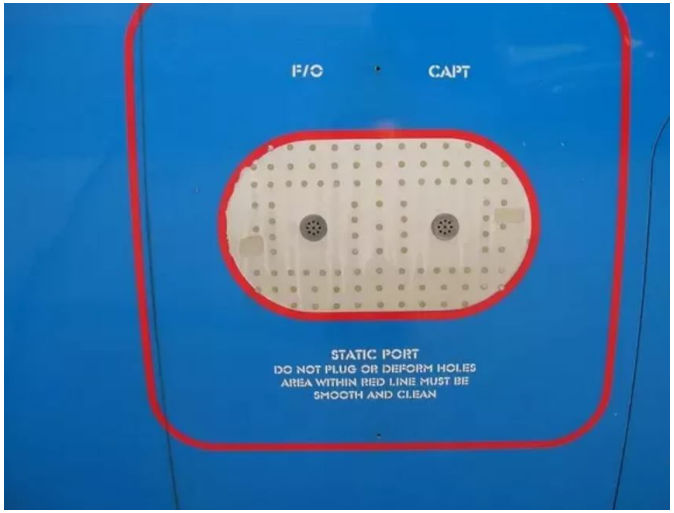
- The Pitot probe is installed facing the flow so that it can sense the variation in the aircraft speed.
- The probe should be installed away from the surface to avoid the effect of boundary
- The heater is used to avoid icing

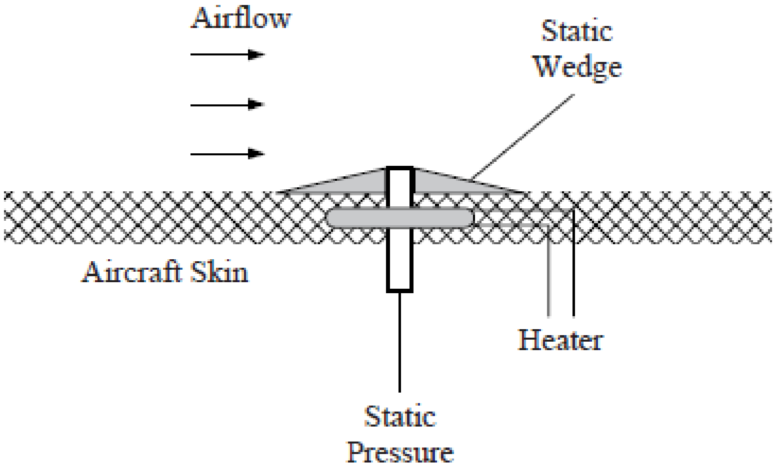


The static pressure can be used to determine the pressure altitude!

Static probe

- The static probe is installed on the surface and perpendicular to the flow direction
- It is used to measure the static pressure around the aircraft
- Heater is needed to prevent icing



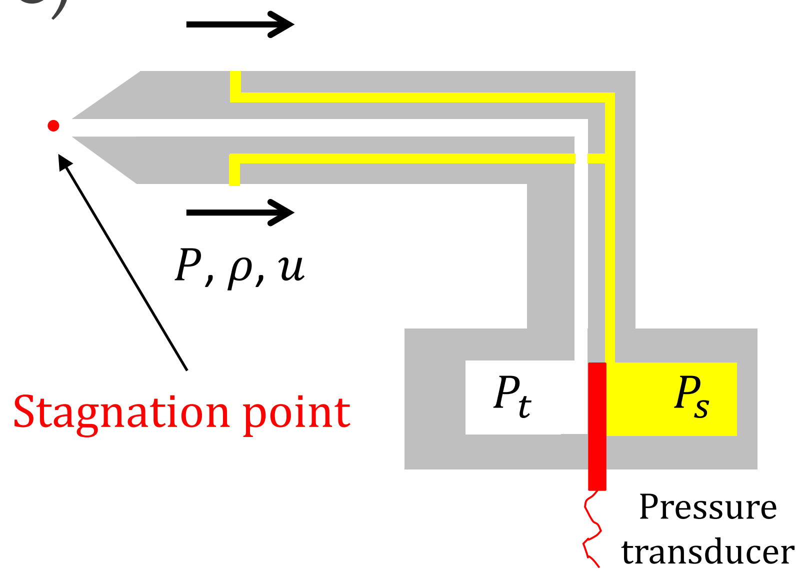


Pitot-static tube (Prandtl tube)

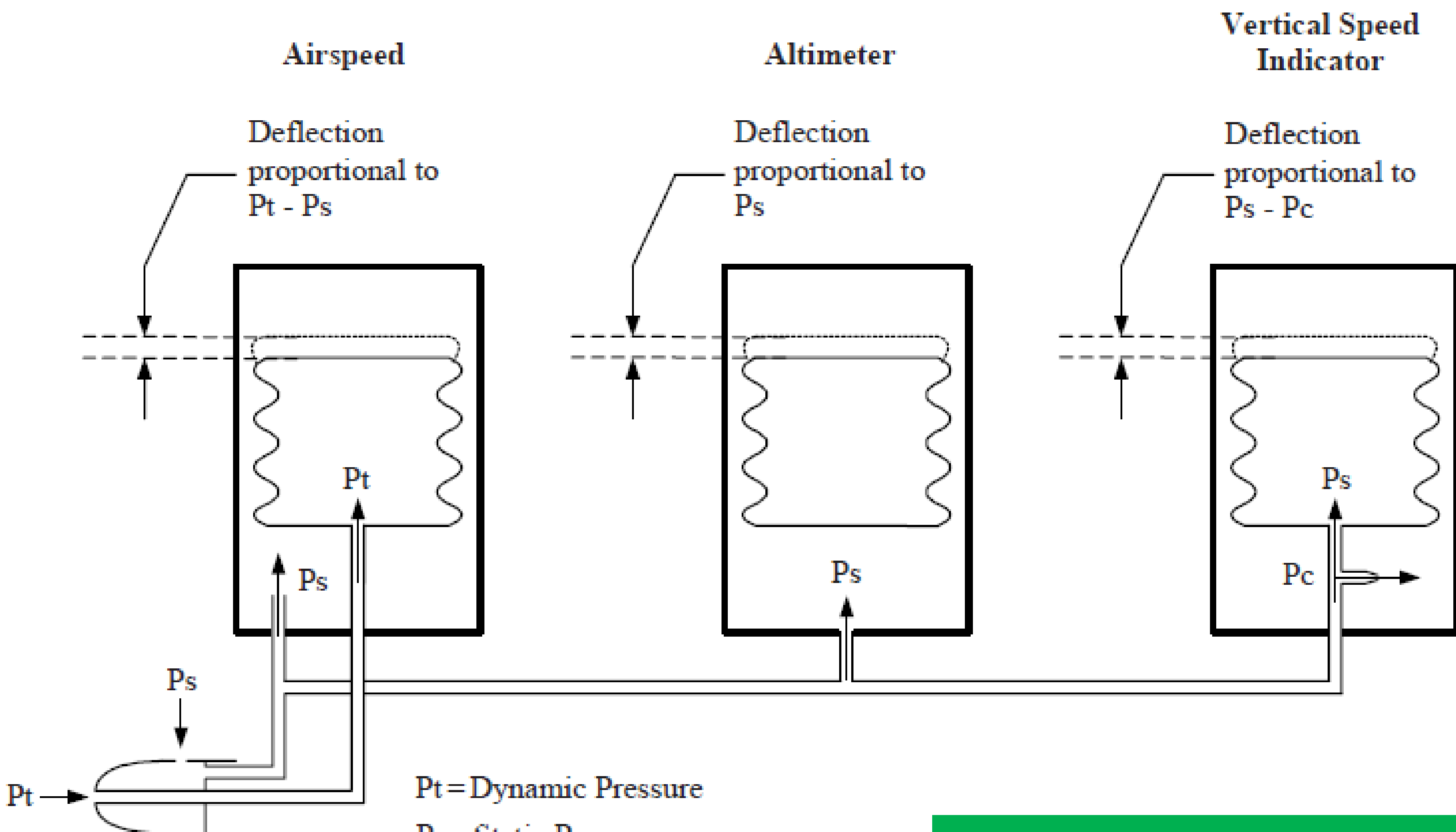
- By using a pressure transducer, we can measure:
  - Total pressure: P_t
  - Static pressure: P_s
- Bernoulli equation

$$P_t = P_s + \frac{1}{2}\rho u^2$$

$$\Rightarrow u = \sqrt{\frac{2(P_t - P_s)}{\rho}}$$



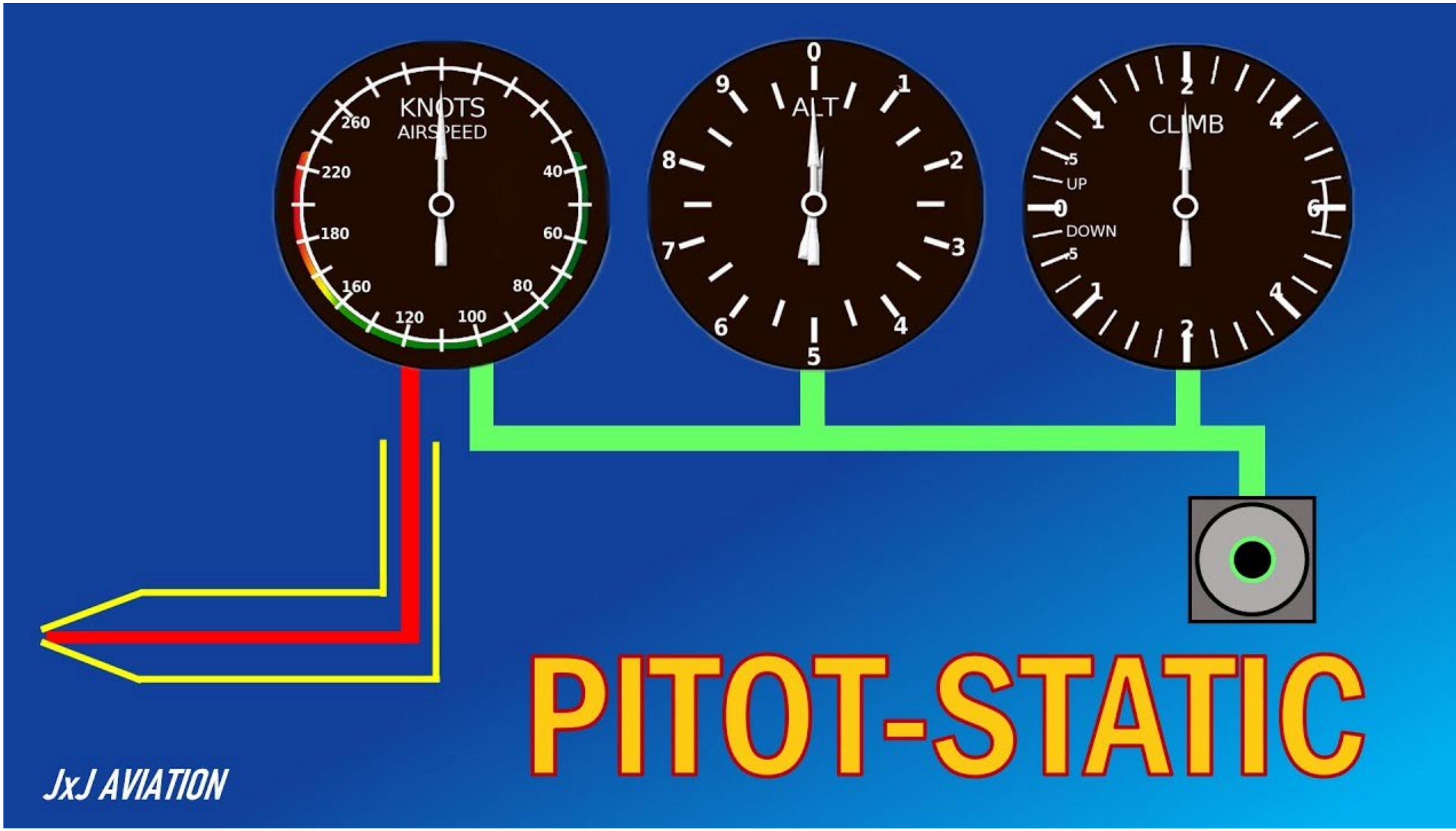
Pitot-static systems on aircraft



Pt = Dynamic Pressure
Ps = Static Pressure

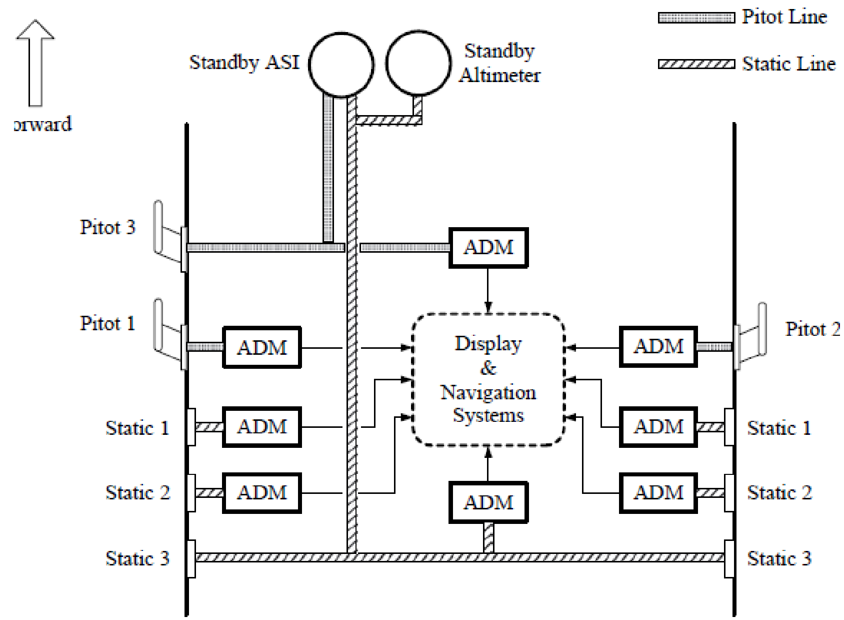
The static pressure corresponds to the pressure altitude

Pitot-static systems on aircraft



Air data system

- In modern aircraft, multiple probes are integrated to form the air data system, which can then be converted to useful aircraft related parameters
- Since 1980s, Air Data Modules (ADMs) are used at different locations to sense the pitot and static information.
  - Save installation and maintenance cost



Summary

Summary

- Background of the aircraft pneumatic system is introduced
- Key components of aircraft pneumatic system is introduced
  - Despite that the actual design can be different from those for the hydraulic fluids, the principles of many devices are similar
- Applications of the pneumatic systems
  - Pitot-static system, anti-icing system, engine bleed air system are introduced
  - The bleed air is also used for the cabin environment control, and details will be given in the “Environmental Control System” lecture