Kindly switch off or silent phones

AIRCRAFT INCIDENT AND ACCIDENT INVESTIGATION

WORKSHOP – SYSTEMS INVESTIGATION

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Objective

- Systems Investigation
- Investigation Issues and Examples or Cases
- Systems Investigation Techniques
- Questions and Discussions

Systems Investigations

To provide an overview of why and how aircraft systems are investigated to provide the basis from which to build on for your investigations.

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Discussion Areas

- Overview
- Hydraulics
- Pneumatics
- Electrical Systems
- Instruments
- Fuel Systems
- Flight Controls

<u>Cases</u>

- Swiss Air Flight 111
- Helios Flight 522
- USAir Flight 427

Crash Lab Prep

ICAO

ICAO provides guidance for standards and practices for operating aircraft and performing investigations.

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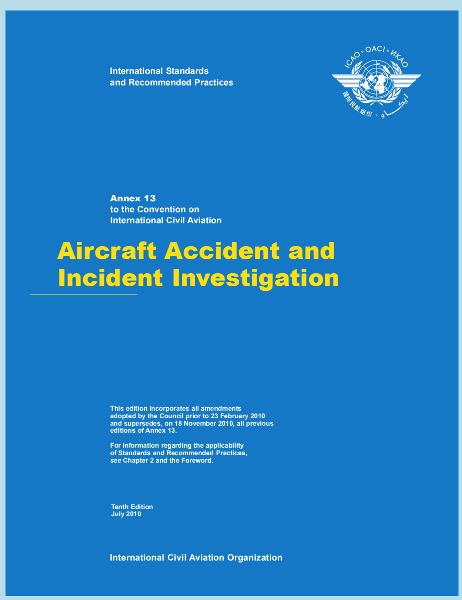
International Standards
and Recommended Practices

Annex 13
to the Convention on
International Civil Aviation

Aircraft Accident and Incident Investigation

This edition incorporates all amendments adopted by the Council prior to 23 February 2010 and supersedes, on 18 November 2010, all previous editions of Annex 13.

For information regarding the applicability of Standards and Recommended Practices, *see* Chapter 2 and the Foreword.

Tenth Edition
July 2010

International Civil Aviation Organization

ICAO Annex 13
Guidance for Investigations

Manual of Aircraft Accident and Incident Investigation Part III -Investigation Doc 9756-AN/965

ICAO-Accident Investigation

A systematic process whereby all of the possible causes of an adverse event are evaluated and eliminated until the remaining causes are identified as applicable to that investigation.

Investigation Process

- Investigators must keep an open mind.
- Don't let the focus on one aspect cause you to overlook anything else.
- Identify all deficiencies possible
- Although an accident may appear similar to another-this can be misleading

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Discussion

What Are Systems?

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NTSB Web Site

SYSTEMS

Study of components of the plane's hydraulic, electrical, pneumatic and associated systems, together with instruments and elements of the flight control system.

ICAO Investigation Manual Chapter 13

The systems investigation covers investigating and reporting on those systems of the aircraft which are not included under other headings.

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Systems

- Hydraulics
- Electrics And Electronic
- Pneumatics/Vacuum
- Pressurization
- Air Conditioning
- Ice And Rain Protection
- Instruments
- Flight Controls
- Stall Warning And Recovery
- Radio Communication And Navigation Systems
- Autopilot
- Fire Detection And Extinguishing System
- Oxygen System

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Investigation Issues

Systems-General

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Systems

- Name an accident where the Systems investigation was a significant part of the investigation and/or causal findings
- Name an accident where it was not involved.

Investigation Technique

Systems-General

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Systems Investigation Basics
Understand How the System Works

- Understand the system’s function
- Understand the system’s influence on aircraft and on accident cause

ICAO

The aircraft systems investigation presents a somewhat difficult task owing to the diversity and complexity of modern equipment.

It is imperative that the investigator have a good working knowledge of hydraulics, electricity/electronics, and pneumatics

ICAO

The investigator should avail himself of appropriate detailed schematic diagrams or working drawings to determine what components are included in each system then make every effort to account for all of these components.

First Actions on Arrival

One of the first items to be documented should be the positions of switches and controls in the cockpit wreckage.

Remember that position of switches may have been altered during search and rescue activities and/or fire fighting.

Aircraft Accident Investigation
Systems Investigation

First Actions on Arrival

Readings on all other available equipment, instruments, and controls should also be documented. Such documentation, should be supplemented by photographs

Basics

Examine for condition, continuity, and integrity

Condition

The state of something, esp. with regard to its appearance, quality, or working order.

"the wiring was not burnt"

Continuity

- The state or quality of being continuous
- An uninterrupted succession or flow
- A coherent whole

Integrity

- An unimpaired condition
- Soundness
- The quality or state of being complete

Examination Methods

- Describe/record
- Photograph
- X-Ray
- Test
- Disassemble

Examination Methods

- Testing of individual components of a system
- Functional testing of a complete system
- Re-installation of equipment in an aircraft for flight tests.

Documentation

- Create a detailed description of the appearance and condition of the components as well as the position of any movable parts.
- Documentation of systems and components should not merely consist of listing what is at the scene.

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Discussion

Hydraulic Systems

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Hydraulic Systems

- Normally essential for large aircraft and most have at least two independent hydraulic systems.
- Usually have separate pumps and reservoirs
- Supply either redundant flight control actuators or dual actuators.

System Operation

If it can be established that the system was operating at a normal pressure, concentrate on individual components rather than the system as a whole

Hydraulic Systems

- Flight Controls
- Flaps
- Landing Gear
- Brakes

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Hydraulic System Elements

- Fluid
- Pumps
- Filters
- Tubes (lines)
- Hoses
- Components
  - selectors
  - valves
  - actuators
  - reservoirs
  - accumulators

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Boeing 737

Cockpit Hydraulic System Control Panel

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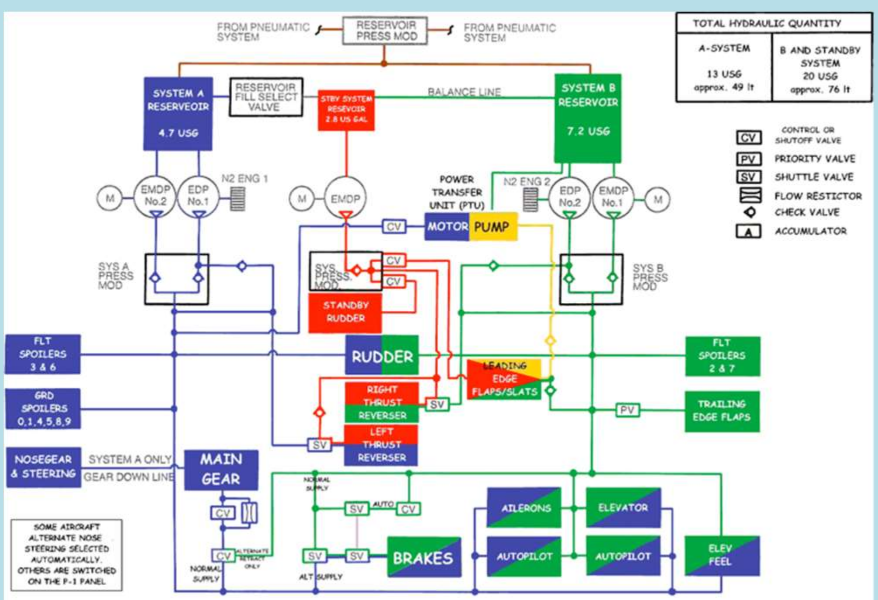

Figure 3 Hydraulic System Power Distribution

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Hydraulic Fluids

- MIL-H-5606
  –Mineral-based found in GA and older a/c
- MIL-H-83282/MIL-H-87257
  –Synthetic hydrocarbon-based
- MIL-H-8446
- Phosphate-Ester or Synthetic Fluids
  –Skydrol, Exxon Hyjet

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Hydraulic Pumps

- The main hydraulic pumps may be engine driven or electric driven
- Auxiliary pumps will generally be electric driven

Hydraulic Pumps

- Engine or electric driven
- Continuous flow
- Variable displacement
- On-demand
- Suction pumps

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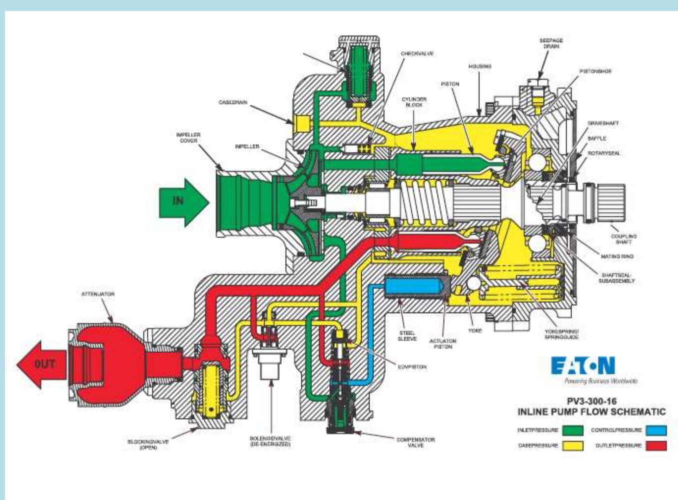
Boeing 747-8, 777
Hydraulic Pump

Engine/air driven
Vickers

Schematic



eBay Pump

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A380 Trimmable Horizontal Stabilizer Actuator (THSA)

- The THSA is powered from its hydraulic motors or an electric motor backup channel.
- The A380 THSA, the largest ever built, is more than 9.5 feet long and provides up to 128,000 lbs. maximum operating force.
- The airplane's horizontal stabilizer is equivalent to a pair of A310 wings.

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Reservoirs and Accumulators

- Reservoirs store fluid
- Accumulators store fluid with energy
  - Gaseous charge with fluid helps add more flow when demanded

Reservoirs

- The reservoir contains the system's extra supply of fluid.
- An important task of the hydraulic reservoir is to maintain a positive head pressure to the hydraulic pump suction port at all altitudes and for the full aircraft maneuvering range

Accumulators

- The hydraulic pumps or regulators cannot always react fast enough to satisfy large hydraulic flow demands.
- This can result in a diminished system pressure which is undesirable even if it occurs for only a very short period.

Accumulators

Accumulators provide hydraulic energy during the initial moments of the increased system flow demand until the pump's variable flow mechanism can respond.

Accumulators

When the system is operating normally, the pressure of the hydraulic fluid balances the nitrogen pressure, and the accumulator is in the state of equilibrium.

Selector Valves

Some selector valves are operated directly from the cockpit by cables or pushrods. The position of such valves should be regarded with caution because aircraft break up can pull the cables or break them thus rendering valve positions questionable.

Hydraulic Actuators

- Actuators provide power to move surfaces
- Proper connection of the actuator input rod and of the actuator to the control surface is critical

Hydraulic Actuators

- Impact forces generally inflict damage indicating the position at the time of impact.
- Actuator rod and linkage positions should be measured externally prior to disassembly.

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Hydraulic Actuators

- The aircraft manufacturer should have charts correlating the dimensions (external and internal) to surface displacement.
- Disassembly and internal examination should be accomplished if conditions warrant.

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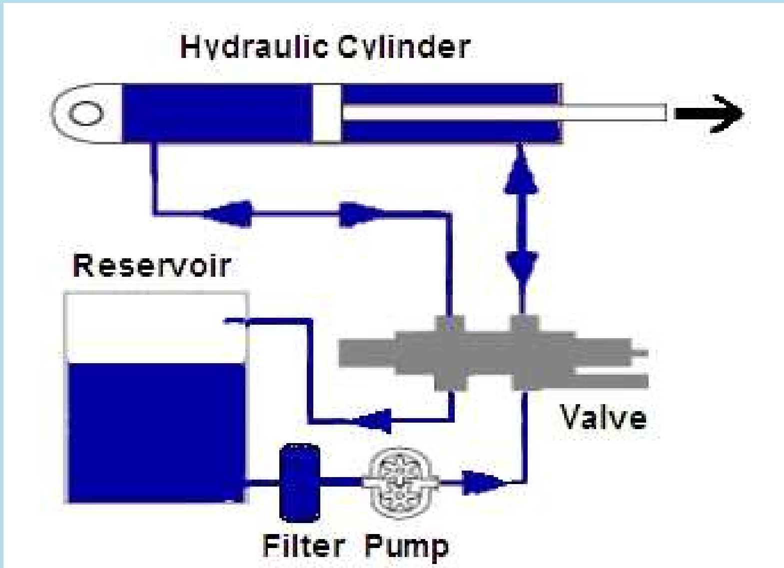
Hydraulic Actuator System



Hydraulic Servo Valve

A Hydraulic Servo Valve is a device that meters the flow of oil in response to an electrical input signal or command to control position, velocity, pressure or force in some type of machine or device (usually through a piston or cylinder).

Hydraulic Line Materials

Depending on function and application, hydraulic lines can be made from:

– aluminum
– corrosion resistant steel
– Titanium

Hydraulic Line Materials

Aluminum lines are usually used for return pressure lines, unless the lines are installed in high-temperature areas.

In this case, return lines are made of steel.

Investigation Issues

Hydraulic Systems

Hydraulic Systems

United 232 Sioux City

On Demand Pump Failure

- Catastrophic failure may release hydraulic fluid, under pressure in the proximity of electrical connections where a fire may be initiated.
- Examine the on-demand pump as a source of a fire if evidence indicates fire evidence in its proximity

On Demand Pump Failure

- Failure of hydraulic systems to operate when demanded requires that the selector switch position and functionality be determined.
- The failure of the crew to engage the pump prior to demand would eliminate the normal operation of the system.
- This may be reported as a in a “hydraulic failure.”

Hydraulic Lines

- The integrity of the aircraft hydraulic tubing is generally lost in a major ground impact.
- Hydraulic plumbing maintenance and repairs have been factors in aircraft incidents and accidents.

Hydraulic Lines

Tube manufacture problems, incorrect metal substitutions, inaccurate tube bending requiring forcing the tube into alignment, failure to replace original installation clamps, over or under tightening connections, or installation errors resulting in a line chaffing against an adjacent structure or object, can result in a high-pressure atomized hydraulic spray.

Hydraulic Lines

Aircraft hydraulic tubing is routed, secured, and protected against chaffing but occasionally, because of maintenance actions, chaffing of hydraulic tubing against aircraft and engine components or adjacent objects occurs.

Hydraulic Lines

This creates very small holes in the tubing, resulting in a very small but extremely high-velocity stream of escaping hydraulic fluid.

Hydraulic Lines

Escaping hydraulic fluid is very flammable under these conditions, and should it contact a hot component such as those of the engine, a fire usually results.

Hydraulic Hoses

- Hoses are used through-out the hydraulic system to connect the various components to the tubing network.
- Hoses are required to provide flexibility so that components can move, and also to isolate the components from vibration which preclude the use of fixed tubing.

Hydraulic Hoses

- Hoses typically have a teflon interior tube coated with a reinforced fabric rubberized surface which is covered with a steel braid.
- Hoses may be factory assembled or may be locally assembled by the hydraulic shops of a maintenance provider.

Hydraulic Hoses

- Most hoses are connected to the aircraft tubing and components with permanent fittings.
- Some components are connected using quick-disconnect fittings.
- Quick-disconnect fittings are almost always used to connect the engine-driven hydraulic pumps to the aircraft system.

Investigation Technique

Hydraulic Systems

Hydraulic Fluid Loss

The most frequent cause of hydraulic failure due to fluid loss the assembly of hydraulic fittings using the jam nut and "O" ring seal.

Finding Loose 'B' Nuts

- It is not uncommon to find fitting tube "B" nuts loose, raising suspicion that the "B" nuts were not properly torqued.
- During a break up, if a tube is subjected to a sizable tension load, the tube stretches at the flare and relieves the nut tension displayed as a finger loose nut or a backed off condition.
- This condition is usually accepted as "normal" when a large number of loose nuts are discovered.

Fluid Samples

- Obtain hydraulic fluid samples from as many sources as possible, e.g., reservoirs, filters, actuators and trapped line sections.
- Ensure contamination does not occur during sampling. The best samples are those taken from components which are capped and sent to a lab.
- Attempt to establish the system pressure at impact by analyzing pressure gauges, annunciator panels, etc.

Testing Hydraulics

Prior to beginning tests of hydraulic components:

- Know the working pressure of the component and ensure that the test equipment can supply adequate pressure and fluid flow rate.
- Analyze fluid for contamination, acid and water content, and type of fluid.

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Mil-H-5606 Test Bench

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Hydraulic Test Stand/Bench

- Test Pressure: 0–5,000 PSI @ 10 gpm; 0–3,000 PSI @ 15 gpm
- Static Test Pressure: 0–25,000 PSI
- Air Pressure: 0–160 PSI
- Pump Drive: 50 hp intermittent (3 minutes); 40 hp up to one hour; 30 hp continuously; Speed 750–5,000 rpm
- Filtration: 5 microns

SAE AS 4059

Cumulative Particle Count/100micro L

	Size	>4 µm (c)	>6 µm (c)	>14 µm (c)	>21 µm (c)	>38 µm (c)	>70 µm (c)
	Size Code	A	B	C	D	E	F
CLASSES	000	195	76	14	3	1	0
	00	390	152	27	5	1	0
	0	780	304	54	10	2	0
	1	1,560	609	109	20	4	1
	2	3,120	1,217	217	39	7	1
	3	6,250	2,432	432	76	13	2
	4	12,500	4,864	864	152	26	4
	5	25,000	9,731	1,731	306	53	8
	6	50,000	19,462	3,462	612	106	16
	7	100,000	38,924	6,924	1,224	212	32
	8	200,000	77,849	13,849	2,449	424	64
	9	400,000	155,698	27,698	4,898	848	128
	10	800,000	311,396	55,396	9,796	1,696	256
	11	1,600,000	622,792	110,792	19,592	3,392	512
	12	3,200,000	1,245,584	221,584	39,184	6,784	1,024

*** The information reproduced on this and the previous page is a brief extract from SAE AS4059 Rev.E, revised in May 2005. For further details and explanations refer to the full Standard.*

Examining Reservoirs

- Examine the position of the piston within an intact reservoir to see if the quantity of fluid remaining can be determined.
- If the reservoir is separated or all fluid has escaped during the break-up, examine the reservoir walls to find witness marks that might indicate the level of fluid remaining at impact.

Selector Valve Examination

Selector valves should be examined for position and integrity of control linkages

Hydraulic Pump Drive Examination

Check drive coupling integrity

Examination of the fracture surfaces of a sheared coupling can provide operational evidence.

Hydraulic Pump Drive Examination

A battered and somewhat polished appearance of the mating fracture surfaces indicates that the coupling failed while the pump was being operated and the driving source continued to operate and the two surfaces were battered together.

Hydraulic Pump Drive Examination

Clean and otherwise undamaged fracture surfaces indicate that the pump and driving source were static at the time of failure.

This failure would most likely be the result of crash forces.

Hydraulic Lines

Hydraulic lines and fittings should be examined for security, evidence of leaking, and other evidence of failure which may have occurred prior to the accident.

Also, check for improper installation, bogus fittings and improper tubing materials.

Hydraulic Hose Failures

Hose failures generally are the result of chaffing or failure at the connector ends, and occasionally are due to the poor quality of locally manufactured replacements.

Hydraulic Hoses

Installation errors, such as failing to control the hose condition when tightening the connection, cause the hose to twist into an abnormal position. This failure is more likely to occur when the hose is connected to a unit that has attachment movement.

Hydraulic Actuators

It is common for impact forces to inflict impact damage or marks depicting the position of the ram or piston at the time of impact

Hydraulic Actuators

- The actuator rod and linkage positions should be measured externally prior to internal examination so that both an outside reference measurement can be compared to any internal impact marks.
- The aircraft manufacturer should have charts correlating the dimensions (external and internal) to surface displacement.

Hydraulic Actuators

The proper connection of the actuator input rod and of the actuator to the control surface is critical, as is the connection of any electrical component.

Hydraulic Actuators

During impact break-up, surfaces may be driven beyond normal ranges or actuator mounts may be broken which might allow extension (or retraction) to move beyond normal. Such impact marks should be supported by other evidence before assuming the actuator was at this position.

Hydraulic Actuators

- There may be a series of impact marks.
- Normally, the first mark in the direction of the final position is the first or position at initial impact.
- Other marks were probably due to the aircraft break-up sequence.

Hydraulic Actuators

Two factors are essential for using actuator positioning in investigative analysis. First, and foremost, the specific actuator must be identified.

Aircraft manufacturers routinely use a common actuator in numerous locations.

Hydraulic Actuators

- The actuators may be working together to move a specific multi-location system or they may be operating different controls.
- When common actuators are present and the actuator is found detached from the surrounding surfaces or structure, it may not be easy to determine which actuator is operating which control.

Hydraulic Actuators

The second factor of importance is the relationship between the impact forces and the mounted position of the actuator.

The impact mark will normally be in the direction of the impact forces. Ideally, the impact force is perpendicular to the actuator allowing a strong impact mark to occur.

Hydraulic Actuators

- Look for corresponding evidence in other actuators or surfaces.

ie. if an aileron actuator is found to have an impact mark indicating the aileron surface was deflected down at impact, an actuator from the other side of the aircraft may exhibit an impact mark indicating its aileron surface was deflected upward.

This type of confirmation adds reliability to the analysis

Hydraulic Actuators

- A control surface that is not being commanded to deflect by the crew (or a subsystem) will normally return to a neutral position.
- No crew intent can be derived from a neutral position unless there is evidence available to indicate otherwise.

Discussion

Pressurization/Environmental
Controls Systems

Air Conditioning/Pressurization Basics

- Bleed Air/APU
- Mechanical and electrical control components
- Pressure/Outflow/Emergency control
- Ducting

A 380 Cooling Capacity

Air Generation System (AGS): The heart of the system is two pneumatically-driven air conditioning packs, or Air Generation Units (AGUs) that produce a total of 752 KBTU/hour cooling, or 62 tons of cooling

Enough to cool more than 67 typical New England homes.

A380 Pressurization System

Cabin Pressurization and Control System (CPCS): The A380 CPCS includes four outflow valves that regulate the cabin altitude to no more than 7,000 feet while flying up to 41,000 feet.

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Bleed Air

Air is bled from the compressor section of the engines in controlled amounts to provide air conditioning and pressurization, and ice and rain protection.

Ducting

Heated air from a leaking or separated duct joint can have an adverse effect on adjacent equipment, electric wiring or fluid carrying plumbing.

Heat effect on wiring can result in erratic operation of electrically operated components

Pressurization

The heart of this system is the mechanical electrical control components, usually found in the cockpit and electrical equipment racks, and the pressure control, outflow and emergency depressurization valves.

APU

Auxiliary power units utilizing turbine engines supply air for engine starting and may also be used to supplement the air conditioning system, particularly for ground operation

Air Conditioning System

Includes flow control valves such as the cabin mixing valve, air delivery valves, pack valves and temperature control valves.

Also included are freon compressors, condensers and evaporators; air cycle machines or cooling turbines; turbo compressors, water separators and heat exchangers.

Air Conditioning System

- Flow control valves are usually of two types; those which are operated by electric motors and those which are electrically controlled but pneumatically actuated.
- The latter-type will, in general, return to the closed position if electric power is removed.

Investigation Technique

Pressurization/Environmental Controls Systems

Bleed Air

- Pneumatic flow control valves, such as shut—off or isolation valves, air delivery valves, pressure reducing or modulating valves, crossfeed valves, temperature control valves and non—return or check valves, should be examined for valve plate positions and associated ducting connection integrity.
- The valve plate positions should be related to cockpit control positions.

Bleed Air

- Bleed air pressure relief valves or panels should be located and examined for integrity.
- Control components such as over temperature and over pressure switches and thermostats should be located and preserved for further study if required.

Bleed Air

If cabin fumes or carbon monoxide contamination are suspected in the accident, the air ducting, particularly that closest to the engine bleed, should be examined for smoke or oil deposits.

Pressurization

The pressurization control valves should be examined for condition and position, integrity of mechanical linkage, electrical connectors, and pressure sensing line fittings.

Look for any evidence of malfunction such as sticking valves or failures in diaphragms.

Ducting

All ducting should be recovered and examined for being ruptured from overpressure or material defects and duct joint clamps should be checked for integrity.

Ducting

- Ducting interiors should be examined for evidence of smoke or other deposits.
- Duct insulation should be examined for discoloration which might indicate overheating, and for the presence of fuel or hydraulic fluid saturation resulting from leaks in plumbing adjacent to the ducting.

Pressurization

Some pressure control valves can be tripped closed during emergency conditions such as fighting an under floor compartment fire.

The position of its linkage may indicate an occurrence.

Air Conditioning System

Identify each of flow control valves in order to relate their positions to cockpit controls. The various electrical components of the control and warning circuits, such as thermocouples and pressure switches should be recovered, identified, labeled and preserved for testing or detailed examination if required.

Air Conditioning System

All valve positions and their condition should be documented and related to cockpit control positions.

Air cycle machines and turbo—compressors should be examined for evidence of operation or malfunction.

Investigation Issues

Pressurization/Environmental Controls Systems

Pressurization Systems

Helios Accident, Greece, August 2005

Helios

When the aircraft arrived earlier that morning, the previous flight crew had reported a frozen door seal and abnormal noises coming from the right aft service door, and requested an inspection of the door.

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Helios

- The inspection was carried out by a ground engineer who then performed a pressurization leak check.
- In order to carry out this check without requiring the aircraft's engines, the pressurization system was set to "manual".
- The engineer failed to reset it to "auto" on completion of the test.

Helios

After the aircraft was returned into service, the flight crew overlooked the pressurization system state on three separate occasions: during the pre-flight procedure, the after-start check, and the after take-off check.

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Helios

During none of these checks did the flight crew notice the incorrect setting. The aircraft took off at 9:07 with the pressurization system still set to "manual", and the aft outflow valve partially open.

Helios

As the aircraft climbed, the pressure inside the cabin gradually decreased. As it passed through an altitude of 12,040 feet, the cabin altitude warning horn sounded. The warning should have prompted the crew to stop climbing, but it was misidentified by the crew as a take-off configuration warning, which signals that the aircraft is not ready for take-off, and can only sound on the ground.

Helios

Shortly after the cabin altitude warning sounded, the captain radioed the Helios operations centre and reported "the take-off configuration warning on" and "cooling equipment normal and alternate off line". He then spoke to the ground engineer and repeatedly stated that the "cooling ventilation fan lights were off". The engineer (the one who had conducted the pressurization leak check) asked "Can you confirm that the pressurization panel is set to AUTO?" The captain, however, disregarded the question and instead asked in reply, "Where are my equipment cooling circuit breakers?".This was the last communication with the aircraft.

Helios

In the next few minutes, several warning lights on the overhead panel in the cockpit illuminated. One or both of the equipment cooling warning lights came on to indicate low airflow through the cooling fans (a result of the decreased air density), accompanied by the master caution light. The passenger oxygen light illuminated, at an altitude of approximately 18,000 feet when the oxygen masks in the passenger cabin automatically deployed.

Helios

The aircraft continued to climb until it leveled off at FL340, approximately 34,000 feet (10,000 m). Between 09:30 and 09:40, Nicosia ATC repeatedly attempted to contact the aircraft, without success. At 09:37, the aircraft passed into Athens FIR, without making contact with Athens ATC. Nineteen attempts to contact the aircraft between 10:12 and 10:50 also met with no response, and at 10:40 the aircraft entered the holding pattern for Athens Airport, at the KEA VOR, still at FL340 It remained in the holding pattern, under control of the auto-pilot, for the next seventy minutes.

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Helios

Two fighter aircraft were scrambled to establish visual contact. They intercepted the passenger jet at 11:24 and observed that the first officer was slumped motionless at the controls and the captain's seat was empty. They also reported that oxygen masks were dangling in the passenger cabin.

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Helios

At 11:49, a flight attendant entered the cockpit and sat down in the captain's seat the FA held a UK Commercial Pilot License but was not qualified to fly the Boeing 737. The FA’s experience was insufficient for him to gain control of the aircraft under the circumstances.

Helios

The FA did not have time to save the stricken aircraft. Almost as soon as he entered the cockpit, the left engine flamed out due to fuel exhaustion, the plane left the holding pattern and started to descend. Ten minutes after the loss of power from the left engine, the right engine also flamed out, and just before 12:04 the aircraft crashed into hills near Grammatiko.

There were no survivors.

Investigation Findings

October 2006

The Air Accident Investigation and Aviation Safety Board (AAIASB) of the Hellenic Ministry of Transport & Communications investigated the accident following ICAO practices and determined that the accident resulted from direct and latent causes.

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Helios Accident

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Direct Causes

Non-recognition that the cabin pressurization mode selector was in the MAN (manual) position during the performance of the Preflight procedure, the Before Start checklist and the After Takeoff checklist.

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Direct Causes

Non-identification of the warnings and the reasons for the activation of the warnings (Cabin Altitude Warning Horn, Passenger Oxygen Masks Deployment indication, Master Caution).

Direct Causes

Incapacitation of the flight crew due to hypoxia, resulting in the continuation of the flight via the flight management computer and the autopilot, depletion of the fuel and engine flameout, and the impact of the aircraft with the ground.

Latent Causes

- Operator’s deficiencies in the organization, quality management, and safety culture.
- Regulatory Authority’s diachronic inadequate execution of its safety oversight responsibilities.
- Inadequate application of Crew Resource Management principles.

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Latent Causes

Ineffectiveness of measures taken by the manufacturer in response to previous pressurization incidents in the particular type of aircraft.

Discussion

Electrical Systems

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Electrical Systems Basics

- Power Generation
- Power Control/Protection
- Wiring
- Components

Ram Air Turbine (RAT)

- The RAT provides emergency power in the unlikely event of a complete loss of engine power.
- The A380 RAT is the largest ever built and features a 64 inch diameter propeller that is deployed into the air stream from the wing fairing to power its 70 kVA air-cooled generator.

Auxiliary Power Unit (APU)

- The primary function of the APU is to provide air to power the AGS on the ground and to start the engines.
- The APU also provides auxiliary electric power to the aircraft via two 120 kVA electric generators.
- The A380 APU is the world's most powerful APU, providing 1,800 horsepower.

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Electrical System Protection

Circuit breakers:

- prone to deterioration with time and their ratings may change.
- have been found with internal corrosion and would not work correctly.

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Electrical System Wiring

- Field examination is limited to what the investigator can see or measure with little analytical assistance.
- A magnifying glass and multi-meter will be the best tools for this work.

Typical Wire

Wiring Problems

- Considered an "on-condition" component
- Can be damaged during manufacturing
- Maintenance – routed near hot equipment, bundled together with incompatible wire types
- Deteriorates with age – insulation and conductor dry out, become brittle, creating small cracks in thin insulation exposing the conductor

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Wire Damage

Damage is often caused by one of three failure mechanisms:

1. Electrical
2. Mechanical
3. Fire

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Avionics

- Use manufacturer’s help where possible
- Maintenance and quick access recorders may have additional data
- Don’t apply power until you understand the effects

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Investigation Issues

Electrical Systems

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Video
Swiss Air Flight 111

Investigation Technique

Electrical Systems

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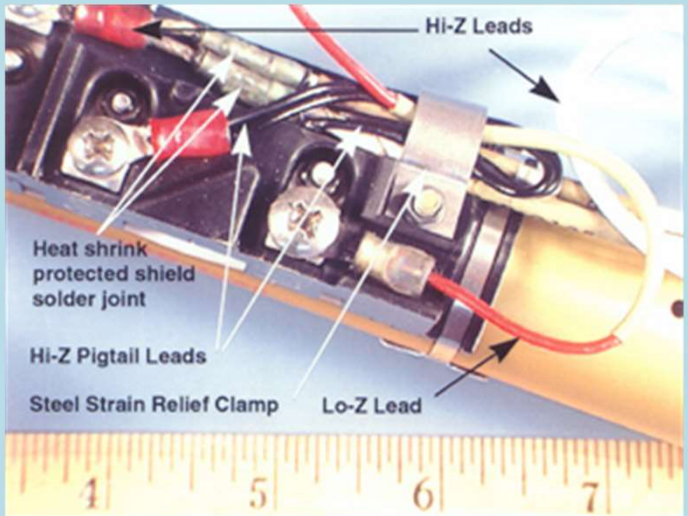
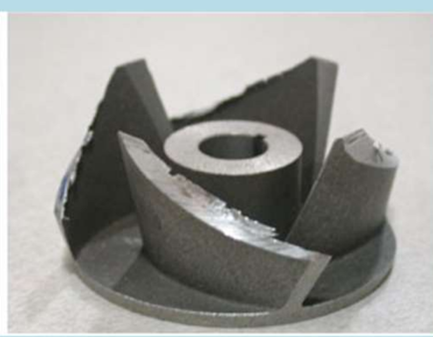
B747 FQIS Wiring in Fuel Tank

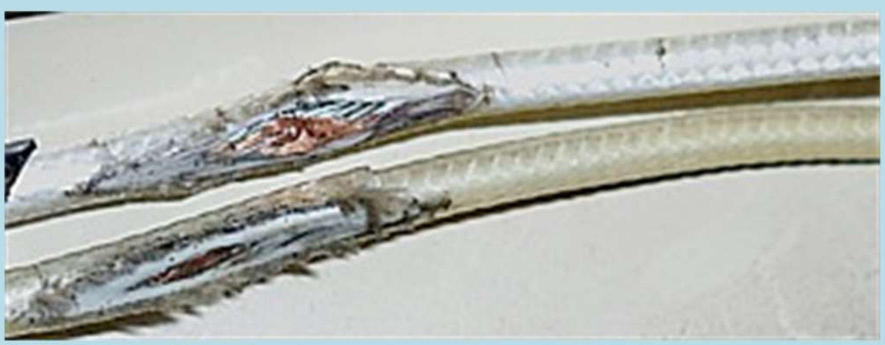


B747 Conduit Arc Thru and Pump Impeller Heat Damage



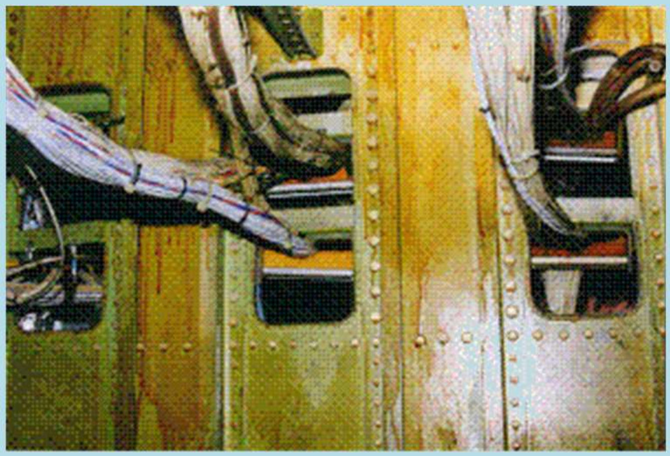
Chafed Wire in Wire Harness

Wire Abrasion

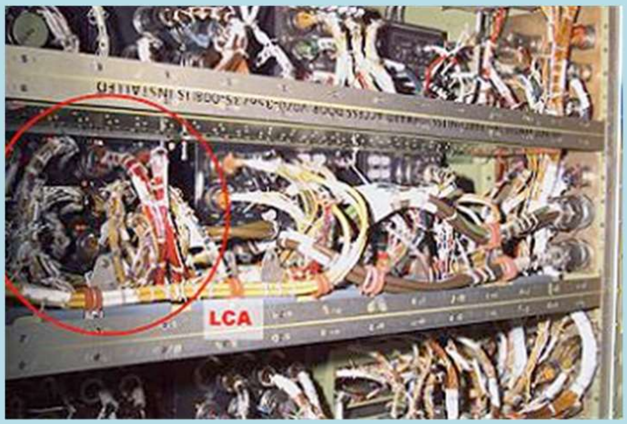


Fuel Pump Wire Found During Inspection Program

Connectors

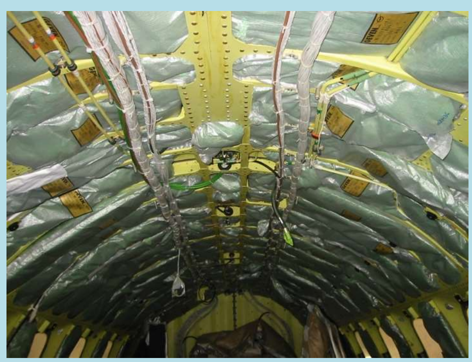


Space Shuttle Endeavor Equipment Rack



Wire Removal

- If wire failure is suspected at point of connection-remove component with wire attached
- If arcing is suspected-remove surrounding wire/structure



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Discussion

Flight Compartment Instruments

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Flight Compartment Instruments

- All instruments should be recovered, their readings and condition documented and their connections examined.
- Usually indicate condition at time of impact not before (the event)
- Fragile with perishable information

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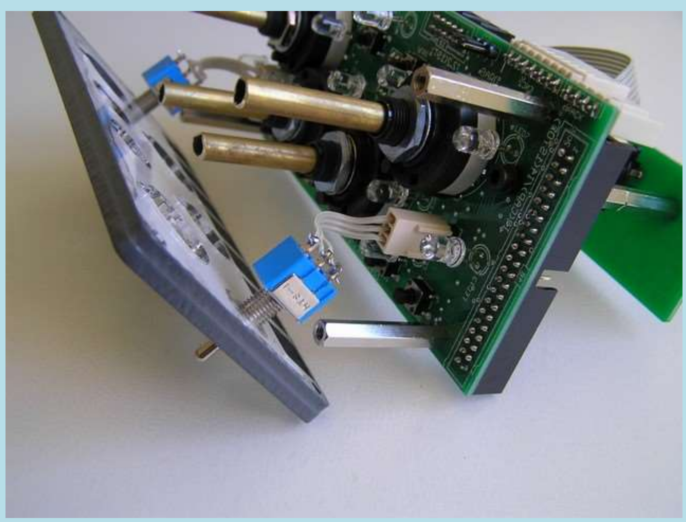

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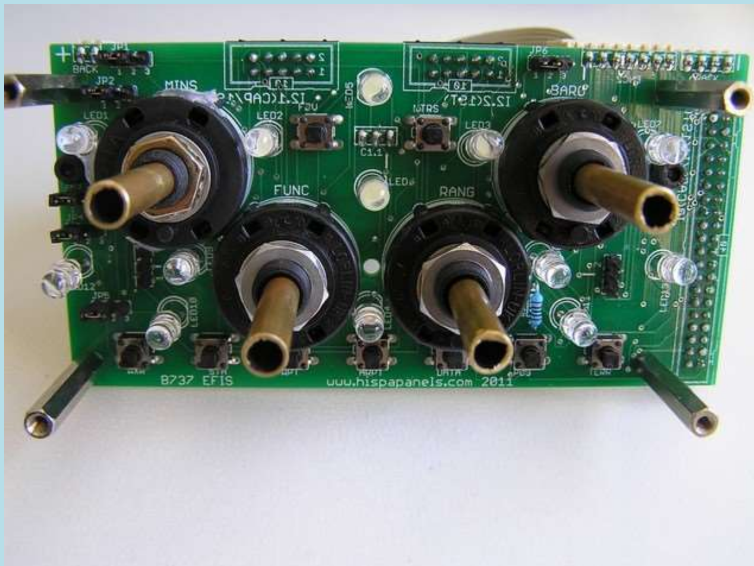

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Investigation Issues

Flight Compartment Instruments

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Investigation Technique

Flight Compartment Instruments

Documenting Switch Positions

Examination Methods

Combine these methods to correlate findings

- What do they read/indicate
- Internal exam
- Microscopic exam
- External readout equipment

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Flight Compartment Instruments

- Electrical connectors should be examined for loose pins or poor soldering of wiring
- Wire bundles behind instrument panels should be examined for shorts, overheating, or chafed insulation.
- Clamped bundles should be examined under the clamps since this is a likely place to find worn insulation.

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EFIS

- Most current generation aircraft present flight information to the crew via “flat panel displays” or “multifunction displays” generated on a screen.
- The data for display is generated by the same type components in the more traditional instrument systems, but is artificially generated for display.

EFIS

- Because the displays are dynamic representations of data once electrical power is lost, all displays vanish.
- No mechanism is present to provide clues to conditions at impact.
- The same technology that generates the images for the EFIS has given rise to the use of non-volatile memory in the generating components.

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Engine Instruments

- The majority of engine instruments are repeaters of the instrument transmitters and employ no gear train.
- The instrument readings can change during impact if the electrical signal is lost and capture has not occurred.

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Engine Instruments

- Some indicators will return to mechanical zero or ambient conditions upon loss of electrical power unless capture occurs.
- Instrument transmitters should also be recovered and analyzed for position of various gears and actuating mechanisms at time of impact.

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Discussion

Fuel Systems

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Fuel Systems

- Quantity
- Availability
- Supply
- Filters
- Contaminants

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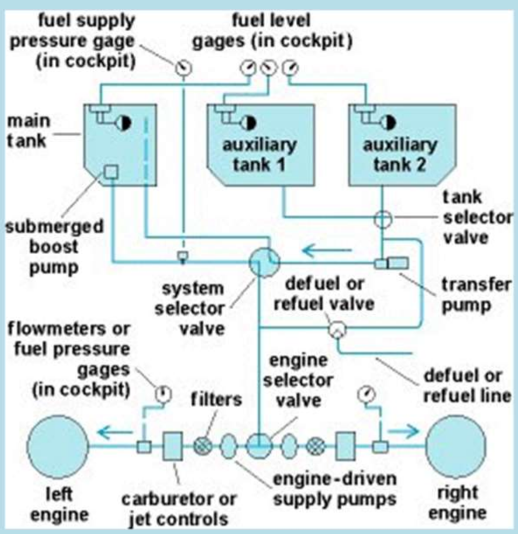
Typical Basic Fuel System



Typical Fuel Tanks

- Integral
- Rigid Removable
- Bladder
- External

Components

- Main Tanks
- Header Tank (separate from main tanks, holds enough fuel for engines to run during complicated maneuvers)
- Gravity Feed (small aircraft only)
- Electric/Engine-driven Fuel Pumps

Fuel Quantity and Availability

- A major consideration in many fuel-related mishaps deals with determining the quantity and location of the fuel within the aircraft.
- Fuel tank selectors, especially manual valves, should be examined carefully to ensure the valve is open to a tank with fuel available.
- Accidents have occurred when the crew member selected an incorrect valve position cutting fuel off to one or all engines.

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Investigation Issues

Fuel Systems

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Fuel Systems

BA 777 at LHR

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Investigation Technique

Fuel Systems

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Fuel and Fire Patterns

- The fire pattern in a partially destroyed aircraft mishap may provide the first clue.
- A fire located in the right wing area with none on the left wing and very little in the fuselage area points to trapped fuel in the right wing.

Fuel Source Integrity

- Examine fuel source/quality
  - Trucks, underground, etc.
  - Contamination/proper grade?

Discussion

Flight Controls

A320 First Commercial FBW

Boeing 777
First Boeing Primary FC FBW

Falcon 7X First FBW Business Jet

Flight Controls

- Accident investigation of aircraft flight control systems is time consuming.

- Since the flight control system is distributed throughout the structure of the aircraft, the task of identifying, recovering, and inspecting all flight control components is a large one.

Flight Controls

- Always consider maintenance history
- Think in 3-axis
  – Lateral
  – Vertical
  – Longitudinal

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Flight Controls

- Mechanical (unpowered)-Cable and pulley
- Hydro-mechanical (powered)-Hydraulic
- Hydroelectric (fly-by-wire)

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Flight Controls

- Before beginning, review the aircraft maintenance history for evidence of flight control problems or recent work accomplished in this area.
- Do not develop preconceived notions based on what is found in the records

Flight Controls

- The flight control system of each type aircraft is significantly different, the detailed investigation of three typical systems are discussed.
- The three systems are a mechanical flight control system, a hydro-mechanical system, and a hydroelectric (fly-by-wire) system

Flight Controls

Stability and control augmentation and autopilot systems are generally considered separately

Flight Controls

- All flight control systems control motion about the longitudinal, lateral, and the vertical axis of the aircraft.
- The flight control surfaces can be divided into two major groups, the primary and secondary (or auxiliary) control surfaces

Flight Controls

The primary and secondary control surfaces are controlled and activated through many components which include actuators, hinges, brackets, bellcranks, push-pull tubes, tie rods, cables, pulleys, balance weights, and bob weights.

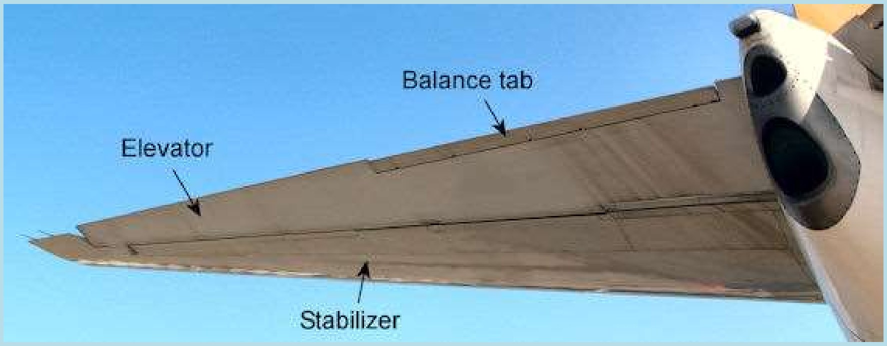
Flight Controls

In helicopters, the collective and cyclic control systems and components, including the main and tail rotors, are an integral part of the flight control system.

Primary Control Surfaces

- The primary control surfaces are ailerons, elevators or stabilators, and rudders.
- Most control surfaces are similar but vary in size, shape, method of attachment, and method of activation.

Boeing 737



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Secondary Flight Control Surfaces

- Secondary control surfaces consist of trim tabs, balance tabs, servo tabs, flaps, spoilers, speedbrakes, and leading edge devices.
- Used to reduce the force required to activate the primary controls, to trim and balance the aircraft in flight, to reduce landing speed or shorten the length of the landing roll, and to change the speed of the aircraft in flight.

Dual Purpose Controls

On some aircraft a control surface may serve a dual purpose.

- Elevons, combine the function of both ailerons and elevators.
- Flaperons are ailerons which can also act as flaps.
- A stabilator is a movable horizontal tail section which serves both as a horizontal stabilizer and an elevator.

Basic Flight Control Components

Cable Assembly

- The conventional cable assembly consists of flexible cable, terminals (end fittings) for attaching to other units, and turnbuckles.

Aircraft Cable

Identify: 7x9, 1x19, 1x7, 3x7, 7x19

Mechanical Systems

- Cables
- Pulleys
- Bellcranks
- Control rods
- Torque tubes

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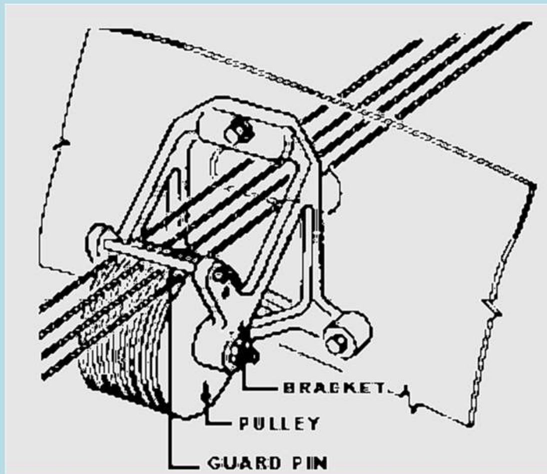
Pulley



Pulleys

- Pulleys are used to guide cables and also to change the direction of cable movement.
- Brackets fastened to the structure of the aircraft support the pulleys.
- Cables passing over pulleys are kept in place by guards. The guards are close-fitting to prevent jamming or to prevent the cables from slipping off when they slacken due to changes in temperature

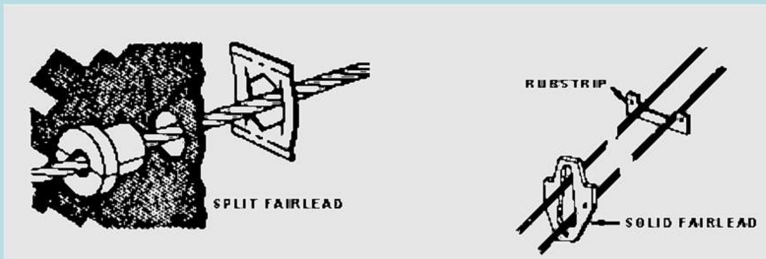
Pulleys

Pulley tunnels are a typical place for foreign objects to become jammed

Fairleads

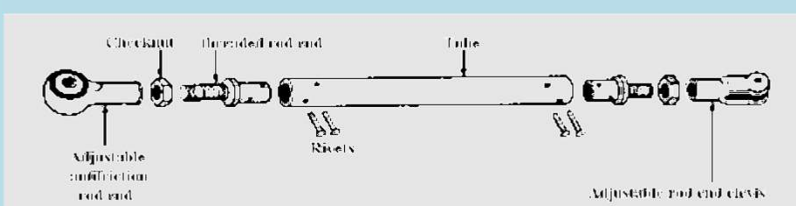
- Another type of cable guide made either from a non-metallic material (phenolic) or a metallic material (soft aluminum).
- The fairlead completely encircles the cable when it passes through holes in bulkheads or other metal parts.
- Fairleads are used as cable guides in a straight line through or between structural members of the aircraft.

Fairlead



Control Rods

Control rods are used as links in the flight control system to give a push-pull motion. Therefore, they are also known as push-pull rods. They may be adjusted at one or both ends. Control rod consists of a tube having threaded rod ends.

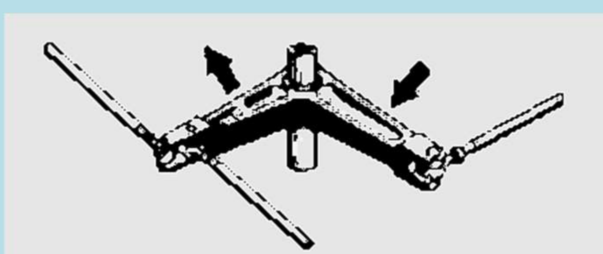


Control Rods

- An adjustable antifriction rod end, or rod end clevis, attaches at each end of the tube. The rod end, or clevis, connects the tube to flight control system parts.
- The check nut, when tightened, prevents the rod end or clevis from loosening

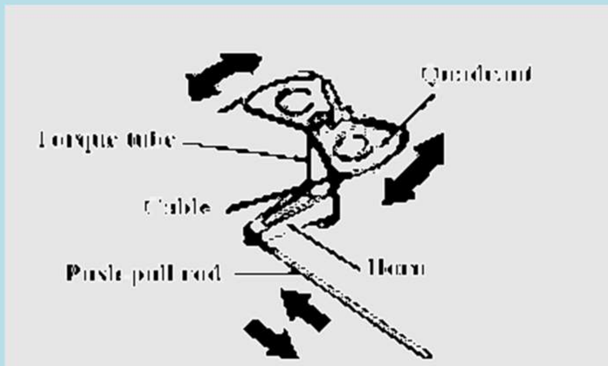
Bellcrank

A bellcrank changes direction of motion and transmits motion to such parts as control rods, cables, and torque tubes.



Torque Tube

A torque tube is installed when an angular or twisting motion is needed in the flight control system.



Turnbuckle

A turnbuckle is used in cable control systems to adjust cable tension. The turnbuckle barrel is threaded with left-hand threads inside one end and right-hand threads inside the other.

Jackscrew

A jackscrew is a mechanism adjusted by threading action to apply pressure on a surface.

Jackscrews are normally actuated by an electric motor, and are used to position flap and trim tab control surfaces

Swiss Air RH Horiz Stab Jackscrew

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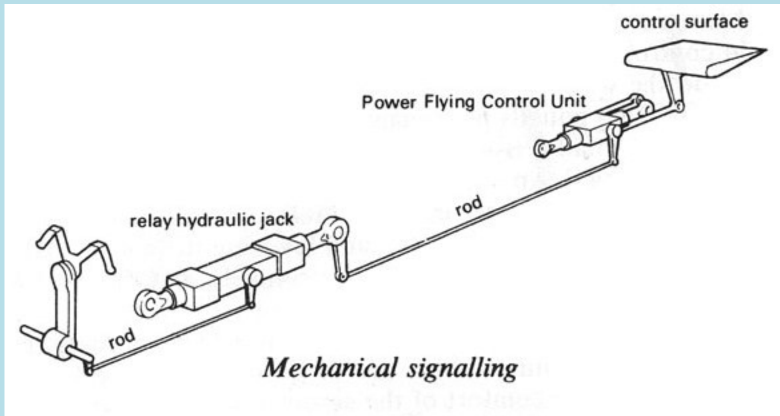
Mechanical Flight Control System

The simplest flight control system is strictly mechanical.

The aileron, elevator, and rudder control surfaces are connected to the pilot's stick or yoke by cable assemblies operating through control rods, bellcranks, and torque tubes.

Tiger Moth Empennage Controls

Mechanical System Control Concorde



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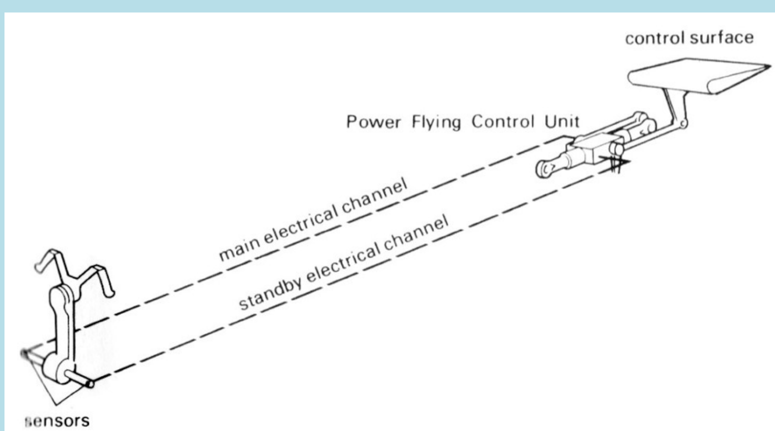
Electrical System Control Concorde



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Hydro-Mechanical Systems

The typical hydro-mechanical system employs aircraft primary flight controls, to include a stabilator or elevator, rudder and ailerons and/or spoilers. The controls are activated by irreversible hydraulic power cylinders

Hydro-Mechanical Systems

Crew actions do not directly position the control surfaces but instead direct hydraulic fluid through control valves to actuators.

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Hydro-Mechanical Systems

Artificial feel systems provide simulated aerodynamic control stick and rudder pedal forces due to the lack of aerodynamic feedback forces from the power control cylinders. The feel systems have trim actuators which, through the power cylinders, move the entire control surface.

Hydro-Mechanical Systems

Artificial feel is usually provided by springs and bob weights. Most trim systems employ jackscrews or separate trim actuators.

Hydro-Mechanical Systems

The aileron power cylinders receive metered hydraulic fluids from control valves. The control valves, in turn, are controlled by push-pull rods, operating through bellcranks and the control stick. The power cylinder piston rod is joined at one end by a yoke that is attached to the aircraft structure. The cylinder portion of the power cylinder is attached to the aileron

Hydro-Mechanical Systems

Stabilator and elevator system components include the control stick, push-pull rods, cables, bellcranks, control valves, and power cylinders. When the control stick is moved longitudinally, the motion is transmitted by push-pull rods to the bellcrank. It is then transmitted by a cable assembly to another set of push-pull rods. The second set of push-pull rods activates the control valve, which meters hydraulic fluid to the power cylinder

Hydro-Mechanical Systems

The rudder control system consists of the rudder pedals, push-pull rods, cable assemblies, bellcranks, a rudder damper, control valves, and a power cylinder. When the pedals are moved, the motion is transmitted by the push-pull rods, bellcranks, and cable assemblies. This positions the control valve meters and routes hydraulic fluid to the power cylinder, positioning the rudder. It is usually possible to have limited mechanical authority over the rudder in a hydraulic system failure

Hydraulic Actuated Control Surfaces

In a hydraulic actuated system, the pilot's input is used to open valves directing hydraulic fluid to actuators, which are connected to the control surfaces by control rods.

Hydraulic Actuated Control Surfaces

The actuators move the control surface to the desired flight condition. The inputs can be controlled manually through a power transmission quadrant or electrically as in a fly-by-wire system.

Investigation Technique

Flight Controls

On Scene

- Account for all systems
- Look for foreign objects (jams)
- Check for continuity and attachment
- Determine control position at impact
- Determine trim tab positions
- Examine balance weights

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On Scene

- Verify that electrical and hydraulic power are available
- Examine supply tubing/wires
- Take fluid samples for contamination testing
- Look for impact-related markings, bends, deformation in components

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On Scene

- Identify, tag, and photograph as much as possible
- If you must disconnect portions-index by marking each side and document
- Mark position of anything free to move prior to moving
- Layout components in secure area for further examination

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Mechanical Systems

After identifying all control surfaces and as much of the flight control system as possible at the crash site, begin a detailed examination.

Mechanical Systems

Establish:

- That all surfaces, including trim tabs, are accounted for.
- The presence of any foreign objects.
- The continuity of each flight control from the stick or rudder to the control surface
- The position of each flight control surface at the time of impact.
- The position of trim tabs at the time of impact.

Hydro-Mechanical Systems

Jackscrews indicate the control position by counting the number of threads exposed beyond the associated nut or gear box.

Normally are not free to move or change after impact.

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Post Scene

- Test when possible
- Always photo, x-ray, and index actuators before moving

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Investigation Issues

Flight Controls

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Flight Controls Accidents

- United DC 10 Sioux City
- American Airlines DC-10 Detroit
- Japan Airlines 747 Japan
- USAir B737 Pittsburgh
- Air Transat A310 Rudder
- Alaska Airlines MD-83

USAir Flight 427
Sept 1994



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USAir Flight 427

- On September 8, 1994, about 7:03 pm EDT, USAir flight 427, a Boeing 737-300 crashed while maneuvering to land at Pittsburgh International Airport on a flight from Chicago-O'Hare International Airport.
- The flight departed about 6:10 pm, with 2 pilots, 3 flight attendants, and 127 passengers on board.
- The airplane entered an uncontrolled descent and impacted terrain about 6 miles northwest of the airport.

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NTSB Probable Cause (Partial)

A loss of control of the airplane resulting from the movement of the rudder surface to its blowdown limit. The rudder surface most likely deflected in a direction opposite to that commanded by the pilots as a result of a jam of the main rudder power control unit servo valve

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Systems Investigation Concerns

Rudder system anomalies that could cause the rudder to move full left without pilot input:

- Previous history
- Factual evidence
- Test results

Observations

- Single actuator with dual servo valve.
- Most transport airplanes use multiple actuator rudder control design.
- B737 not unsafe but different from others

Key Finding

- With one of the two parts of the servo valve intentionally jammed-movement of some valves could cause a rudder reversal.
- This resulted from port alignment only possible in some valves at random.

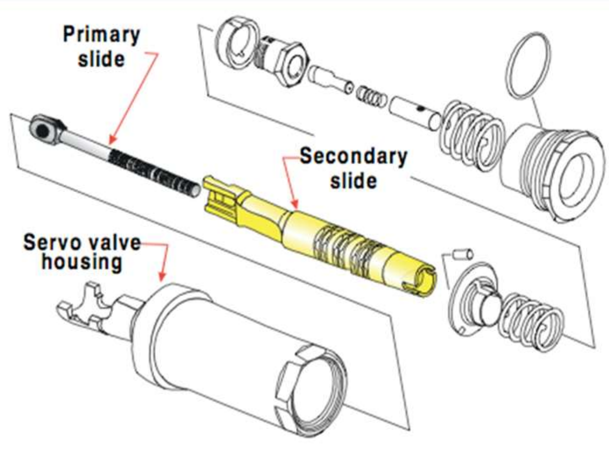

Figure 10. Boeing 737 main rudder PCU servo valve.

No Rudder Movement

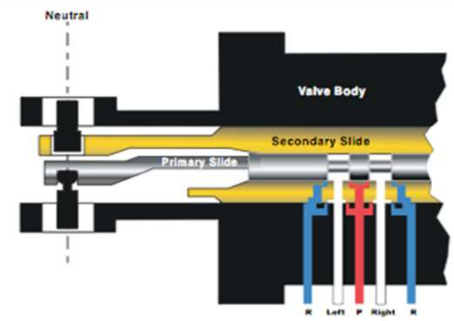

Figure 14. Normal operation of the 737 PCU servo valve with slides in the neutral

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Full Rate Rudder TEL

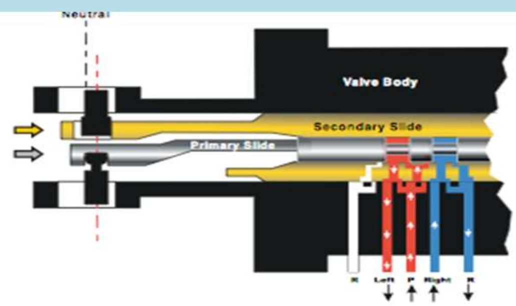

Figure 15. Normal operation of the 737 PCU servo valve with slides in the extend

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Factors

- Tight clearances within the servo valve
- Thermal effects
- Particulate matter in the hydraulic fluid
- Fluid contamination
- Other unknown factors

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Intentional Jam Tests

During tests, a secondary slide was intentionally jammed (pinned) to the servo valve housing and a rapid input was applied in the opposite direction.

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Rudder Reversed with a Jam

These tests showed that the primary slide could over-travel resulting in hydraulic fluid porting in such a way that the rudder moves in the direction opposite to the rudder input.

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Thermal Test Jam

During the most severe post-accident thermal tests, the secondary slide jammed to the servo valve housing, and hydraulic fluid flow data indicated that a momentary reversal of the rudder occurred during this jam.

258

New Valves Do Not Jam

Although the accident servo valve jammed repeatedly during thermal tests, a new servo valve never jammed.

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No Evidence Of A Jam

The thermal tests demonstrated that it was possible for the secondary slide of the servo valve to jam to the valve housing and leave no evidence of physical marks.

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Summary

- Tests were conducted that could duplicate the rudder reversal condition
- Newer parts did not behave as older parts
- There was no physical evidence of a jam
- Conditions tested during the thermal jam test probably did not exist during accident
- Combination of acceptable adverse tolerances could cause over travel of valve

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