A review of aircraft antiskid system and hydraulics application for brake system

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Agenda

• Aircraft brake systems
• Hydraulics for brake system operation
• Review of antiskid systems
• Main antiskid system requirements
• Hydraulic dynamics-related issues
• Modeling and simulation
• Conclusions
• References
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Aircraft Brake Systems

- Aircraft brake system functions:
  - Stop the aircraft during landing or rejected take-off runs;
  - Allow aircraft ground maneuvers during taxiing;
  - Park the aircraft;
  - Halt the wheels rotation during landing gear retraction.

- Brake system types:
  - Drum-and-Shoe Brakes:
    - Early brakes, similar to automobile ones.
    - Drum-and-shoe types:
      - Metal shoe with a riveted lining of asbestos composition.
      - Cast iron drum.
  - Brake actuation:
    - Mechanical actuation (cables, coil springs).
    - Hydrostatic pressure (master cylinders).
  - A/C Examples: Piper Cub, Boeing B-29, etc.
Aircraft Brake Systems

• Brake system types:
  – **Disk-Types Brakes**
    • Higher thermal energy dissipation capacity.
    • Single-disk brakes:
      – Small aircraft.
      – A/C Examples: EMB-312, etc.
  • Multiple-disk brakes
    – Large aircraft.
    – A/C Examples: EMB-170, Boeing 747, etc.
  • Disk materials
    – Steel, berilium, carbon composite.
  • Brake actuation:
    – Hydraulic system pressure.
    – Pilot input by means of brake pedals.
    – Pressure modulation through proportional valves (hydraulically or electrically operated).
Aircraft Brake Systems

- Brake system types:
  - Disk-Type Brakes
    - Boeing 737 brake assembly.

Source: [UNITED STATES, 2012b]
Aircraft Brake Systems

• Brake system types:
  – Electric Brakes
    • Current studies and innovative applications.
    • Brake actuation and control:
      – Digital electronics.
      – Electromechanical actuators.
    • Claimed advantages:
      – Absence of hydraulic leakages (maintenance gains).
      – Good reliability.
      – Data record and monitoring facilities.
  • A/C Examples: RQ-4B Global Hawk, Boeing 787 Dreamliner, etc.
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Hydraulics for Brake System Operation

• Characteristics:
  – Introduction on aircraft in the early 1930s.
  – Most currently applied throughout the world.

• Hydraulic power advantages:
  – High power-to-weight ratio;
  – Relatively low initial costs;
  – Acceptable maintenance costs;
  – Flexibility of installation;
  – Good reliability;
  – Self-lubrication.

• Main components found:
  – Tubing, hoses, fittings.
  – Hydraulic accumulators.
  – Several types of valves: proportional, check, shuttle, restrictor, shutoff, etc.
  – Master cylinders.
Hydraulics for Brake System Operation

Boeing 737 brake system

Source: [UNITED STATES, 2012b]
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Review of Antiskid Systems

• Antiskid system schematics:

Source: [SOCIETY OF AUTOMOTIVE ENGINEERS, 2012]
Review of Antiskid Systems

• Early systems:
  – Remote actuation
    • Electrical or electroinertial controller.
    • Hydro-Aire Mark I (1948): mechanical device or relay-operated solenoid valve.
  – Direct actuation
    • Sensor and valve: unique component on brake assembly.
    • Dunlop Maxaret.

Source: [ZVEREV; KOKONIN, 1975]  
Source: [MOIR; SEABRIDGE, 2001]
Review of Antiskid Systems

• Eletronics development (20th century):
  – Segregation between controller and sensors:
    • Electronic controller: input circuit and power amplifier.
    • Tachogenerators: DC or AC generator (AC/DC converter).
  – More complex control algorithm:
    • Hydro-Aire Mark II (1958).
    • Hydro-Aire Mark III (1967).
    • Goodyear Adaptive Brake Control System.

• Digital systems:
  – Microprocessor-based system:
    • Control over a broader range of aircraft performance.
  – Improved control algorithm:
    • Hydro-Aire Mark IV and V.
Review of Antiskid Systems

- Antiskid system types:
  - ON-OFF (Open-closed) Systems:
    - Incipient locked-wheel condition: brake pressure release.
    - Spin-up to synchronous speed: brake pressure reapplication.
    - Significant brake pressure oscillation and slow time response.
    - A/C example: B-52.

Source: [UNITED STATES, 2012a]
Review of Antiskid Systems

• Antiskid system types:
  – Modulating (Quasi-Modulating) Systems:
    • Pre-programmed sequence.
    • Incipient locked-wheel condition: brake pressure release.
    • Brake pressure held off according to skid depth.
    • Brake pressure reapplied to a lower level and ramped up until a new skid starts: Pressure Bias Modulation (PBM).
    • Efficient on dry runways.
    • A/C example: Convair 990.

Source: [UNITED STATES, 2012a]
Review of Antiskid Systems

- Antiskid system types:
  - Adaptive (Fully-Modulating) Systems:
    - Advanced control logic: high frequency wheel speed transducers, multiple data control functions and nonlinear computing elements.
    - Based on wheel-speed time history.
    - Control over the optimum braking: slip ratio.
    - Efficient on dry and wet runways.
    - A/C examples: DC9-30, Boeing 747, B757 and B767.

Source: [UNITED STATES, 2012a]
Review of Antiskid Systems

• Antiskid system functionalities:
  – Basic function:
    • Prevent a locked-wheel condition and optimize braking performance ("ABS").
    • Control criterion:
      – Deceleration rate / Slip velocity / Slip ratio.
  – Additional functions:
    • Touchdown Protection:
      – Prevent brake application during touchdown at wheels spin-up;
      – Tires subjected to a high load / acceleration condition.
    • Locked-Wheel Protection:
      – Compare the deceleration of paired-wheels or combination of wheels;
      – Avoid inadvertent yaw moments due to assymetrical braking.
    • Hydroplaning Protection:
      – Hydroplaning condition;
      – Release brake pressure in the wheel whose speed is inferior to a percentage of aircraft speed.
    • Drop-out Function:
      – System becomes inative below a threshold value (10 kt to 20 kt);
      – Allow ground taxiing maneuvers.
    • BIT (Built-in Test) Function:
      – System monitoring circuit;
      – Identify electrical failures.
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Main Antiskid System Requirements

• System performance:
  – Stop the aircraft within the required runway length;
  – Operation on dry and wet runways;
  – Good efficiency for all hydraulic system operational conditions.

• Comfort:
  – Smooth braking.

Source: [Adapted from UNITED STATES, 2012a]
Main Antiskid System Requirements

• Tire wear:
  – Avoid uneven tire wear;
  – Prevent a locked-wheel condition and tire blow-out.

• Safety Assessment:
  – Reliability, adequate installation and robust design.

• Landing gear interaction:
  – Do not result in landing gear instabilities.

Source: [GOODYEAR, 2011]
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Hydraulic Dynamics-Related Issues

- Hydraulic installation layout:
  - High tubing length:
    - Pressure drop, fluid inertance and fluid compliance:
      - Influence on system frequency and time response;
      - Impacts on antiskid efficiency.
  - Water hammer effect:
    - Pressure surge (deep skid);
    - Loss of antiskid efficiency or asymmetric braking;
    - Delta pressure varies with temperature: control algorithm difficulties.

Source: [SOCIETY OF AUTOMOTIVE ENGINEERS, 2012]
Hydraulic Dynamics-Related Issues

• Hydraulic installation components:
  – May reduce antiskid system efficiency:
    • Flexible lines and hoses;
    • Tubing with too small or too large diameter;
    • Components with high pressure drop: valves, swivel fittings, etc.
    • Line entrapped air;
    • Inadequate hydraulic system return line design.

• Landing gear instabilities:
  – Hydro-Aire Mark I / II: not a concern (f = 3.5 Hz);
  – From Hydro-Aire Mark III on: a significant concern (f > 50 Hz);
  – Brake system hydraulic dynamics influence;
  – Main phenomena: shimmy, gear walk, brake squeal, brake chatter.
Hydraulic Dynamics-Related Issues

- Landing gear instabilities:

Source: [LERNBEISS, 2003 apud KHAPANE, 2008]

Source: [ENRIGHT, 1985 apud KHAPANE, 2008]
Hydraulic Dynamics-Related Issues

- Landing gear instabilities:
  - Case Study (KHAPANE, 2008):
    • Two-mass model of a flexible landing gear;
    • Hydraulic line parameters considered: pipe length and thickness;
    • Effect evaluated: gear walking.

Source: [KHAPANE, 2008]
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Modeling and Simulation

• System Model:

• Industry application:
  – Early systems: cut-and-try methods with extensive test campaign;
  – Modulated systems: introduction of system simulation (system interface).

• Current Practices:
  – System tuning:
    • Use of simulation to adjust system controller gains;
    • Optimize system performance throughout operational envelope.
  – Failure simulation:
    • Simulation of critical conditions and/or component failures.
  – Simulation types:
    • “Pure” simulation;
    • “Hardware in the loop”: rig (mock-up).
Modeling and Simulation

- Complete Block Diagram:

Source: [Adapted from SOCIETY OF AUTOMOTIVE ENGINEERS, 2008]
Modeling and Simulation

• **Example of a simplified brake system:**
  – Impacts of hydraulic system geometry on system response.
    - Software: LMS® Imagine.Lab AMESim
    - Brake assembly: 4 piston multiple-disk type.
    - Pipe model: HLG0020D (hydraulic line CFD 1D Lax-Wendroff):
      - Continuous model;
      - Rigid tube;
      - 1D Navier-Stokes equations;
      - Developed to compute wave effects with a high level of accuracy.
    - Hose model: HH04R (simple wave equation hydraulic pipe/hose: C-IR):
      - Lumped model;
      - Compressibility, friction and fluid inertia are considered;
      - Effective bulk modulus: fluid compressibility and hose wall flexibility.
    - Valve Actuation: Square wave.
      - Frequency: 3.5 Hz;
      - Pulse ratio: 80% (1 cycle: 80% operated, 20% no signal);
      - Simulates an “on-off” antiskid system.
Modeling and Simulation

- Example of a simplified brake system:

3.5 Hz

AMSIm Model

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Modeling and Simulation

- Nominal conditions.

![Graphs showing Valve Output Pressure, Piston Chamber Pressure, and Clamping Force with a 37% increase.](image)

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Modeling and Simulation

- Tubes/Hoses: 100% increased length.

- No piston return: slower response, clamping force cycles.
Modeling and Simulation

- Nominal dimensions, 35 Hz, pulse ratio = 60%.

- Reduction of operational pressure

- Mean force value

- Less amplitude oscillation

- No piston return
Modeling and Simulation

- Tubes/Hoses: 50% reduced length, 35 Hz, 60%.

- No piston return: more amplitude oscillation

- Pressure cycling: higher values

- Valve Output Pressure

- Piston Chamber Pressure

- Piston Displacement

- Clamping Force

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Conclusions

• Hydraulic power for aircraft brake systems:
  – Most currently applied throughout the world;
  – Considerable advantages.

• Antiskid system:
  – Significant development since early systems;
  – Several functionalities;
  – Important requirements: efficiency, safety, comfort, tire wear, landing gear stability.

• Impacts of hydraulic dynamics on antiskid system:
  – May affect system response and its efficiency;
  – May result in landing gear instability problems.

• System modeling and simulation:
  – Powerful tool for antiskid system design, tuning and sensibility analysis;
  – An example of the impacts of hydraulic system geometry on system response has been provided: shows the importance of system optimization.
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References

Thank You!

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