BRAKES - 101

John Salamankas
• Turned onto taxiway and found both RH brakes on fire

• While parked in front of the hangar, tires started going flat as fuse plugs melted

• Blew left main tires. Tires caught fire and had to be extinguished by the fire department

• After turning off the runway the #1 & #2 tires caught fire

• #4 tire blew, other tires all flat spotted
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Introduction

• Taxied in to FBO ramp with flash fire in left wheel well

• 5 minutes later the left MLG brakes were found on fire

• Came to a complete stop at end of landing roll and all four brakes seized
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Topic Outline

- Need for this presentation
- Pattern of events and how discovered
- Brake basics
- Carbon
- Brake performance
- Anti-skid
- Certification Requirements
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- Brake testing
- Lessons learned in test
- Expert review of fleet events
- Recommendations
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Fleet Status

- Gulfstream actively monitors the in-service fleet
- Daily AOG meeting in Tech Ops
  - Required attendance by SAV departments
    - Conference call with FSR’s and select off-site locations
  - Review and update of Fleet Status Report
  - Review of Tech Ops Conversation Log
  - Review of Field Service Reports
- Safety Review Team
  - Participates in AOG meeting
  - Monitors for potential safety or airworthiness issues
• Wheel and Brake Fires
  – Numerous events throughout past year
  – G-100 thru G-450
  – Some damage extensive/expensive

• Circumstances surprising
  – No problems during takeoff aborts or landings
  – No problems in passenger service
  – All problems while taxiing
    • Troubleshooting brake problems
    • Testing brakes after maintenance
    • High speed taxi “training”
• All taxi tests involved-
  – Higher than normal taxi speed
  – Abnormally high number of brake applications

• All but one aircraft were at light weight

• “Grabby Brakes” were a frequent reason for testing

• BTMS was available in several of the aircraft

• None of the crews realized they were overheating their brakes
• Several events also involved –
  – High speed stops on a runway
  – Braking with anti-skid OFF

• One major event caused by turning anti-skid OFF during braking at high speed
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Cause for Concern

- Fire hazard
- Potential for mishap and injury
- Damage to aircraft
- Cost to Operators
  - Expensive repairs
  - Lost productivity
- Events occurring on a regular basis
  - MOL’s & Breakfast Minutes not effective
  - Root cause not obvious
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• Brake Systems
  – Common to all aircraft with minor differences
  – Reliable
  – Comparatively simple
  – Maximum capability reserved for emergency use
    • Seldom if ever necessary
    • Limitations rarely approached
  – Minimal training required
    • System operation and use are intuitive
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Brake Basics

• Brakes vs. Engines
  – Brakes convert Kinetic Energy to Thermal Energy by Friction
  – Engines convert Thermal Energy to Kinetic energy by Combustion

• Drum and disk types both appeared circa 1900
  – Drum brakes by Louis Renault in France
  – Disk brakes by F. Lanchester in England
    • Poor reliability until
      – Jaguar C-Type 1953
      – Corvette Stingray 1965
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Disk Brakes

• Early acceptance and widespread use in aviation
  – Better stopping performance
  – Resist fading caused by overheating
  – Recover quickly from immersion in water
  – Don’t catch and hold contaminants
  – Braking is proportional – constant response for a given application of force
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- Friction is key
  - Between rotors and stators
  - Between tires and runway

- Force of friction between two surfaces
  - Opposes their relative motion
  - Depends on the strength of the force pushing the two surfaces together

- Friction between tire and runway limits useable brake friction

- Best performance
  - Highest tire and brake friction without skidding
• Static friction is greater than dynamic (sliding) friction

• Skidding results in lost performance

• Skidding tires offer little directional control

• Anti-Skid is designed to –
  – Allow maximum pressure to disks and rotors (develop max friction) without skidding
  – React quickly to changing runway conditions
    • High operating pressure and flow required
    • Brake pistons release and fill quickly
• “Skid Pressure” – The hydraulic pressure required to cause a skid with the available tire friction

• Tire friction varies with –
  – Tire composition and temperature
  – Runway surface
  – Contact force between tires and runway
    • Aircraft weight is greatest contributor
    • Other factors may also apply
• Advantages
  – Light weight
    • Can absorb more energy for a given mass than steel
  – Withstands very high temperatures
    • Low coefficient of expansion
    • Resists thermal shock
  – Friction properties good up to 2000° F
  – Excellent wear characteristics in heavy use

• Disadvantages
  – Affected by debris, brake dust, & oxidation
  – Absorbs liquids (water, hydraulic fluid, de-icing fluid)
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• Manufacture
  – Carbon-carbon composite
    • Woven carbon cloth
    • Solid carbon matrix
  – Chemical Vapor Infiltration method
    • Heated gas forms solid phase carbon with –
      – Ceramic – protects carbon from high heat
      – Silicon – forms friction film

• Wear – Type I
  – Low energy conditions or low applied brake pressure
  – Wear debris forms as particulate powder (sandpaper)
  – Most damaging
• Wear – Type II
  – High energy conditions or high applied brake pressure
  – Plastic deformation of wear particles forms a smooth debris film
  – Smooth film reduces wear
  – Smooth film promotes strong adherent friction (glass on glass)
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Certification

• TSO C26d, Aircraft Wheel/Brake Assemblies
  – Structural integrity
    • Maximum torque
    • Hydraulic overpressure
  – Endurance. 5cc total leakage and no malfunctions
    • 100,000 cycles at pressure used for max landing weight
    • 5,000 cycles at maximum available system pressure

• FAR 25
  – Functionality and/or maximum performance demonstrations of all brake system components
  – Test requirements are thorough and demanding
Fuse Plug Integrity at maximum landing energy
- Engines set at high idle limit
- Taxi 3 miles with 3 intermediate stops
- Close traffic to high speed landing at max LGW
- Brakes on (Rapid/Full) at target groundspeed and held to full stop
- Taxi 3 miles with 3 intermediate stops
- Park in area minimizing wind effects
- Wait until fuse plug temps peak and assure no releases
• Maximum Kinetic Energy Accelerate-Stop
  – Brakes worn to 10% remaining
  – Must be an RTO
  – Fires on or around landing gear are acceptable if they can be allowed to burn for 5 minutes before extinguishing is required for safety of airplane
  – Fuse plugs may release late in the stop if directional control not compromised

• Takeoff & Landing Performance Data
  – Six rejected takeoffs
  – Six landings on the same wheels, tires, and brakes
• Unreasonable test requirements sometimes aren’t
  – Max KE RTO by left engine fuel cut
    • Verify anti-skid operation during bus power transfer

• Skid pressure varies greatly with gross weight
  – Testing in three weight bands
    • 100 Knots RTO’s in 10,000 lb increments yielded stops within three aircraft lengths
  – Blown tire not noticed at light weight
    • 40-Knot taxi stops
    • 100 Knot Stop & Go
• Brake cooling
  – Light pedal pressure
    • Prolongs stop
    • Absorbs same energy
    • Results in same peak temperatures
  – Brakes cool much faster when not set
  – Cool brakes while pointing into the wind
    • Crosswind doesn’t reach all brakes equally
    • Tailwind blows warm exhaust over brakes
  – 15 minutes airborne will cool any overheat condition
    • Gear extended at Vle
• Pilots all have a strong side/heavy foot
  – Brakes on one side will be hotter
    • Applied at higher speed
    • Held at higher pressure
• Pedal position affects feel
  – Pilot strength greatest near full extension
  – Easier to apply max force to distant pedal
• Crosswind affects brake temperature distribution
  – Pedals not even at brake application
  – Downwind brakes in greater contact with runway
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Test Observations

- Ground spoilers increase skid pressure 200-300 psi
- Worn brakes get hotter
  - Less mass to absorb given energy
- Properly functioning anti-skid does not damage tires
  - Flat spots indicate problems
- Max anti-skid at heavy weight is smooth and comfortable
- Max anti-skid at light weight or on contaminated runways is not comfortable
• Maximum performance braking can involve high risk
  – Mitigated by
    • Fully instrumented systems
    • Data recording equipment
    • Real-time monitoring by on-board engineer or telemetry
    • Orderly build-up of test points
    • Inspection by ground crew after every stop
    • Careful attention to brake temperatures
    • In-flight cooling between test points
  – Risk can be managed but not eliminated
Turned onto taxiway and found both RH brakes on fire
  - Received an anti-skid fail message while conducting high speed taxi/rejected takeoff training. Turned anti-skid OFF and continued training until tower reported smoke from gear.

While parked in front of the hangar, tires started going flat as fuse plugs melted
  - Performed two high speed taxi tests with high energy stops in an effort to alleviate chattering brakes. Desired results achieved and taxied back to hangar.

Blew left main tires. Tires caught fire and had to be extinguished by the fire department.
  - Conducting high speed taxi for ops checks with anti-skid selected OFF.

After turning off the runway the #1 & #2 tires caught fire
  - Troubleshooting “Brake Hot” message. Performed two high energy stops. #4 tire blew, other tires all flat spotted
- #4 tire blew, all other tires flat-spotted.
  - Crew performed high speed taxi with anti-skid OFF as requested by DOM.

- Taxied in to FBO ramp with flash fire in left wheel well
  - Brakes overheated during high speed taxi checks. All four MLG wheels and brakes replaced.

- Came to a complete stop at end of landing roll and all four brakes seized
  - During flight test program collecting landing performance data test pilot held brakes for five seconds at completion of stop. Steel brakes fused.
5 minutes later the left MLG brakes were found on fire
  – After returning to the ramp after two high speed taxi checks, the parking brake was set. Fire lasted 2-3 minutes and TE box sustained heavy damage.

One FDR Analysis
  – Gross weight 65,000 lbs
  – 27 brake applications in 9 minutes
  – Speeds from 20 to 105 knots
  – BTMS available
  – Cumulative energy greater than 90 million ft/lbs
• Preventive Measures
  – General reminders have been unsuccessful
  – Brake energy information in the Aircraft Operating Manuals does not include cautions about testing
  – Develop a model-specific taxi test procedure
    • Define common terms
      – “Grabby”, “Jerky”, “Hot”, etc.
    • Suggest technique for troubleshooting
    • Provide tab data for brake temperature expectations
    • Provide contact info for specialists in Tech Ops/Flight Ops
  – Brake test information on WAYPOINTS
Questions