# 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

- **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**

# Brakes 101

## Topic Outline

- Need for this presentation
- Pattern of events and how discovered
- Brake basics
- Carbon
- Brake performance
- Anti-skid
- Certification Requirements

# Brakes 101

## Topic Outline

- **Brake testing**
- **Lessons learned in test**
- **Expert review of fleet events**
- **Recommendations**

# 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**

# 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

- **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**

# 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**

# 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**

# Brake Performance

- 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

# Brakes 101 Anti-Skid

- 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**

# Brakes 101

## Carbon

- **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)**

# Carbon

- 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)**

- **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**

# Certification Tests

- **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**

# Test Observations

- **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**

# Test Observations

- 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

# 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**

# Brakes 101 Event Review

- 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

# Brakes 101 Event Review

- #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

# Recommendations

- **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