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USE OF CARBON HEAT SINK BRAKES ON AIRCRAFT

1. **PURPOSE:** The purpose of this document is to relate areas where something other than traditional brake technology may be advisable when designing for or converting to carbon type aircraft brakes. The marked advantages in carbon brake life and weight negate any special treatment required in their application and use; however, some understanding of the peculiar properties of carbon brakes will surely minimize developmental effort.

A questionnaire has been circulated to approximately 18 participants who have expertise in aircraft brake design, application, and maintenance. The questions paraphrased items resulting from Committee comments related to carbon brakes and solicited any additional information to the point. It is intended that the information may guide users to improve the success of the application.

2. **APPROACH:** The approach to this document has been by questionnaire. This necessarily directs, to some degree, the responses while that is not the intent. It is mentioned because responses to questions may be occasionally contradictory. This appears to be reconcilable when the interests of differing contributors are explored. Some speak from the application viewpoint, others from the operation viewpoint, others from that of the brake manufacturer and yet others from the viewpoint of maintenance and logistic managers. An attempt has been made to highlight the concerns of all.
3. **THERMAL COMPATIBILITY:** At the head of the list are comments relating to the extreme heat capacity of the carbon brake stacks. Due to the high energy vs. small volume of brakes on aircraft, temperatures have always been a factor in design. However, carbon brakes appear to have crossed the threshold in this area and new limits on temperatures must be considered. The brakes themselves may continue to work effectively at temperatures well above the temperature of

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steel brakes. Wheel fuses and/or temperature indicators should be selected such that pilots and/or maintenance personnel shall be alerted to excessive tire, axle, fluid or shock strut temperature exposures and degradation of the metallic chassis of the brake unit. The last point being of particular interest, in the event of a rejected take-off, is that the carbon heat sink may survive undamaged but the brake or other structure may be heat damaged.

The designer must consider the above possibilities and thermally isolate the wheel and brake hardware or select high temperature seals, high temperature fluids and consider the effect on plating of structural members and generally the effect on all surrounding materials. It may be advisable, in the application of carbon brakes, to include in the design, heat shield and wheel fans. Heat shields have been added to prevent seal failures due to heat. Brake temperature sensors may be considered with appropriate annunciation. Some users report somewhat less than desired reliability of these devices on carbon brakes, perhaps related to vibration failures. Most airline type aircraft with carbon brakes report use of some sort of brake temperature monitoring system.

Brake cooling fans, usually electrically powered, are frequently used on high performance, large brakes. Their function is to prevent equipment overtemperature and to shorten turnaround time by reducing brake temperatures to acceptable levels in the time that an aircraft can be serviced and loaded and ready for takeoff. The higher temperatures of carbon brakes have prompted some to observe that wheel fans, if they cause concentrated oxygen streams, may hasten oxidation of the carbon mentioned, particularly if used at over 1300°F (some users specify an 800°F limit). To minimize this consideration the air should be distributed as well as possible and design should attempt to eliminate concentrated streams of air on particularly hot spots that may be unacceptable areas for accelerated oxidation.

It seems noteworthy that one airline contributor expressed desire for heat shielding to prevent fuse plug failure, inclusion of cooling fans and brake temperature sensors of the thermocouple type. All these with emphasis on reliability and freedom from unscheduled maintenance.

Another contributor urges that fans be avoided with carbon brakes due to the history of high maintenance expense and unreliability.

This concern has proponents and opponents in that, it would also seem advisable to cool brakes as soon as possible to reduce the effect of oxidation exposure time. There is insufficient data at this writing to support a firm position on cooling fans on carbon brakes. The reader is cautioned to obtain current information in designing for operating fans on carbon brakes. It could be said that the Concorde operators have experience which is supportive of brake cooling fans and obtain very satisfactory brake life.

Thermal analysis is advisable in the airframe design as well as in the wheel brake and tire design. Particular attention appears to be necessary if an airframe which has been fitted with steel brakes is being converted to carbon. Generally carbon brakes require more space and hence could expose surrounding structure to higher temperatures, both due to the higher operating temperature of the stack and due to reduced clearance with airframe structure.

Carbon brake heat sink materials have greater heat capacity per unit of weight than steel (at least double) but these same materials have less heat capacity per unit of volume. (Normally carbon brakes are designed to work hotter than steel.) This could result in higher wheel and axle operating temperatures if compensating features such as heat shields are not included in the wheel and brake design. Carbon brakes offer reduced weight at operating temperature equal to steel or if conditions permit even greater weight saving can be obtained at the price of higher operating temperature.

4. REFURBISHING CARBON BRAKES: Carbon material cannot be welded, straightened or hot-worked like metal. Therefore, refurbishing techniques are different than for metal brakes.

At time of writing, there are various efforts to salvage worn carbon discs by machining off the friction surfaces of two discs to new predefined dimensions and clipping, fastening or bonding these together. Some special equipment may be required; i.e., sanding or machining equipment capable of close tolerance thicknessing, carbon dust collection system, and special fixture equipment to remove and replace the various clips and rivets.

One user reports some problems with oxidation in the drive lug area. Such oxidation, if significant, reduces the advisability of refurbishing the disc sections. Relocation of the anchor clips can be performed on the rotor sections. Oxidation in the non-friction areas may be treatable by methods other than machining away the oxidized material.

Definition of repair of nicks, chips, scratch damage, and contamination of discs is continually evolving with manufacturers. Maintenance personnel are cautioned to observe wear limit indicators since reduction of heat sink beyond recommended limits can increase overhaul cost and could reduce brake effectiveness in a high energy stop.

Compared to steel brakes, the feature of long brake life, usually found with carbon brakes, may justify retirement and replacement rather than overhaul. This will not appeal to all users, however, and maintenance and overhaul will continue to be paced by economics.

Manufacturers should be asked to consider the effects of contamination with hydraulic and cleaning fluids and abrasives. It may be desirable to instruct maintenance personnel and operators to avoid contamination, although special handling requirements are generally not appealing to users. It may be

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advisable to cover the brakes while wheel or other maintenance is performed. While there are many advantages to carbon brakes in weight, energy capacity and life, discs are more costly. These costs may be recovered in operation provided they are not inflated by improper exposure to contaminants and/or handling abuses.

Carbon materials generally are more porous and susceptible to absorption of fluids, which can cause smoke, flame and visual effect on first application after service.

Contaminants usually can be burned off in "Burns-in" runs. This practice is common with some operators and acceptable if done in compliance with manufacturer's recommended methods. Brake torque can be affected by fluids in the stack. These should be removed prior to return to normal service where maximum braking could be a possibility.

It should be noted that some users, especially heavy use aircraft will expect no special favors to be paid to carbon brakes and that they should be expected to see exposure to normal aircraft cleaning fluids without special maintenance techniques and/or handling. This fact should be borne in mind in brake design.

If space is available to add extra material in the stack, this can significantly reduce wear and operating temperature; as well as reduce oxidation due to high thermal exposure, which will enhance capability to refurbish the brake.

Some thought is being given to interim replacement of seals and other piston housing components since stack lives of 3,000 landings per overhaul are expected, and present seal technology may not be a match for this long exposure. Seal replacement should be tailored to the application, not necessarily the same as lining overhaul. Heat tolerating seals are strongly advised.

The Concorde reports very satisfactory seal life. Seals outlast stack changes with current life in excess of 2500 landings. It appears that satisfactory heat tolerating seals may be state of the art, but low temperature requirements must also be considered when evaluating high temperature elastomers.

5. DYNAMIC COMPATIBILITY: The operating characteristics differ in several aspects between carbon and steel brakes. One of these is average torque under various conditions. Carbon will exhibit overall a wider range of friction coefficients than its steel counterpart. Carbon materials are sensitive to pressure inputs and produce torque quickly. This feature has

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necessitated a change in pressure/travel curves to provide smooth stops at all speeds. Anti-skid systems which have been mated to a steel brake may require retuning for compatibility with carbon. Concorde employs a torque limiting closed loop control system via a strain gauged tie rod to ensure that the structural integrity of the carbon discs is not impaired.

Advantages in using carbon brakes with anti-skid are often found in the fact that running clearances can be reduced and rotating discs will not weld during maximum energy stops. These features provide better and more predictable anti-skid dynamic responses.

Dynamometer tests may be helpful in development of anti-skid with new carbon brakes. Anti-skid optimization on the dynamometer may not result in final tuning, although some report such success. Some contributors recommend dynamometer testing utilizing all possible landing gear parts in testing. Dynamometer wheel curvature, structural spring rates of the gear, axle-brake combination, and the interface (friction coefficients) between tire and dynamometer may not be sufficiently representative for final results. Airframe geometry and handling qualities will also pose variables that cannot easily be simulated. The effect of moisture on the runway is difficult to simulate. Fluid displacement values will probably vary from comparable energy metal brakes since sizing of brake pistons may change to accommodate differences in brake torque for static vs dynamic operation, as discussed below. Anti-skid generally is sensitive to fluid volume and flow rates.

6. UNUSUAL SENSITIVITY: Carbon brakes may have been described as "grabby" compared to metal brakes. This may be due to improper piston sizing based on steel brake displacements which are being retrofitted. The static coefficient of carbon is much less than that of steel (approx 50%). A high static torque requirement could cause a choice of larger pistons than necessary for dynamic conditions. If the piston sizing were made without consideration for both static and dynamic conditions, a grabby brake could result. Some users report occasional sensitivity due to a wide variance in brake friction coefficient.

Generally, the torque response of carbon brakes is smoother than for steel brake friction mixes.

Some attention has been given to anti-skid characteristics which will "initialize" brake contact to offset what otherwise might require pilot technique variations in handling brakes at low versus high speeds. Anti-skid gain variations with speed may be an asset in preventing brake sensitivity problems if piston sizing cannot completely eliminate the problem.

A pulsing brake control system has been incorporated in the F-15 and F-16 aircraft to ease the pilot responsibility when braking under the condition of failed anti-skid system. This has been done on steel brakes as well.

Static braking requirements should be kept realistically low to offset the demand for large pistons resulting from the lower static friction coefficients of carbon. This area seems to be the cause for concern that carbon brakes are "grabby". Static and dynamic requirements should include effects of wet brakes. Carbon does show sensitivity to moisture; therefore, the design must ensure that good, safe braking is always available.

7. STRUCTURAL INTEGRITY: The structural strength of unoxidized carbon discs is decreased due to geometric changes caused by wear. It may be advisable to perform structural torque qualification tests with carbon discs machined to worn geometries.

Oxidation of the carbon materials affects its strength. There are oxidation inhibitors which do have significant value towards oxidation protection. Temperature control is important in this respect.

The effect of material removal for overhaul on the structural integrity should be a matter of consideration. Methods described earlier for salvaging worn discs should be carefully evaluated against structural integrity.

NDT methods of evaluation of carbon brake components are still in developmental stage and not generally felt to be necessary. Visual examination is adequate in that the condition of carbon brakes is very evident.

The possibility of torque differences should be considered against the structural integrity of the undercarriage when converting from steel to carbon brakes.

8. ENVELOPE REQUIREMENTS: Generally, carbon brakes require more space than steel brakes. Many factors combine to affect these variables but a word of caution is indicated. If the brake/wheel cavity is severely space limited, problems may result from attempts to introduce carbon brakes. Consideration should be given to this fact as the aircraft structure is laid out. (See Fig. 1)
9. MISCELLANEOUS COMPATIBILITY: Auxiliary braking systems must be compatible with carbon brakes. Conversion of an existing aircraft may overlook this fact. Fluid volumes and pressures could conceivably change such that the auxiliary systems would be incompatible.

Comments relating to carbon brake freezing have been recorded. While the porosity of the carbon may be expected to contribute to freezing in extreme cold weather, not all users find them any more so inclined than steel brakes. Several users, Military and Commercial, report no change in this regard.

Design of carbon brakes generally looks to long life as an important economic parameter. It has been reported that the pad type brake piston design contributes to shortened life. For best wear life, a full circle brake pressure device is suggested because carbon brake discs are generally thicker