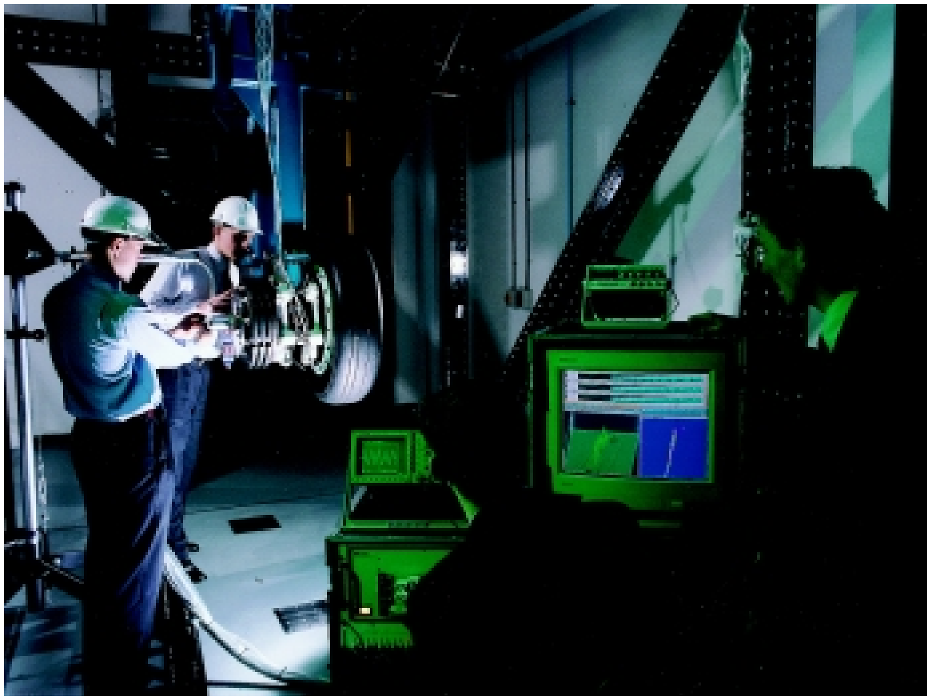
Stopping at all costs

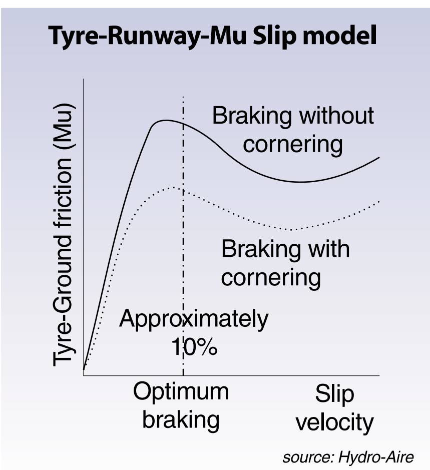
For many airlines, the cost of brake overhaul is second only to the cost of engine overhaul. *Aircraft Technology* takes a look at developments in the world of aircraft braking and the commercial arrangements which are finding preference.



Perhaps the first and most important concept to come to terms with when entering the world of aircraft braking is that braking systems and brakes are usually to be considered separately from each other. At first this may seem rather a strange concept, but the braking system consists of the hydro-mechanical and electronic components associated with the application of braking whereas the brakes themselves consist of hard-wearing, consumable parts which absorb an aircraft's kinetic energy during the process of stopping, the issues start to become clearer.

The worst situation that brakes have to deal with is an aborted takeoff close to V1, where the aircraft is very close to its maximum takeoff weight. Brakes, which could be in their most worn condition, have to transfer all the kinetic energy of the aircraft into heat. From the point of view of the aircraft braking system, the worst case scenario is a very light weight aircraft coming in to land at a high altitude airport on a very wet or icy short runway. Under such circumstances, runway to tyre friction (called Mu, in the trade) is lowest, resulting in very low brake operating pressures, placing increased demands on an aircraft's antiskid system.

In spite of this demarcation between brake and braking systems, there is no general rule as to which company will actually manufacture which component and some companies will be partners on certain projects and competitors on others. For aircraft in what is called the "large category", there are five major manufacturers. These are ABSC, BFGoodrich, Dunlop Aviation, Honeywell (formerly AlliedSignal), Hydro-Aire and Messier Bugatti. Traditionally, but not in all cases, Hydro-Aire has manufactured braking systems for Boeing, Honeywell and BF Goodrich have manufactured wheels and brakes for Boeing, Dunlop Aviation has supplied to BAe, Messier Bugatti has supplied to Airbus Industrie and ABSC supplied to the former McDonnell Douglas, military and many regional aircraft manufacturers. Noteworthy exceptions to these rules do exist such as Dunlop's role as an alternative supplier of wheels and brakes for the B757 and ABSC's supply of wheels and brakes for the A321. This supply situation is sometimes further complicated by the selection of one



manufacturer for the nose wheel and another for main wheels and associated systems.

Another point is that in recent years there has been a tendency for prime "landing gear system" contractors to be appointed by the airframers. This results in companies such as Messier Dowty and BFGoodrich which design and manufacture landing gears, teaming up with a wheel and brake manufacturer so that a fully dressed landing gear system can be supplied to the airframer. There is a degree of irony in this since the activities of the brake manufacturer are key to systems integration, particularly when considering its pivotal role in the application of structural dynamics which it uses to analyse the vibration characteristics of any particular landing gear, wheel and brake combination.

Brake design

Originally, aircraft braking systems were pneumatically powered. Early designs featured friction pads which were forced against drums by pneumatic bags. Subsequently, calliper disc brakes were introduced, similar to those used on modern cars, although these too were pneumatically powered in the early days. At the beginning of the second world war, the aviation industry tended towards high-pressure hydraulic systems combined with disc brakes and high pressure pneumatic tyres, suitable for runway use, and this became the winning formula for the future.

Initially, landing gears were not stowed and wheel size on pre-world war two aircraft was very large indeed, but as higher aircraft speeds were specified, it became necessary to stow landing gears, which meant that wheels had to become smaller. This, in turn, meant that there was less space available for brakes and, instead of having one brake rotor disc, it became necessary to place several brake rotor discs side-by-side along the same axis, with stators between them. This basic brake design has not changed significantly over the years, although there have been enormous steps forward in brake materials and braking system design.

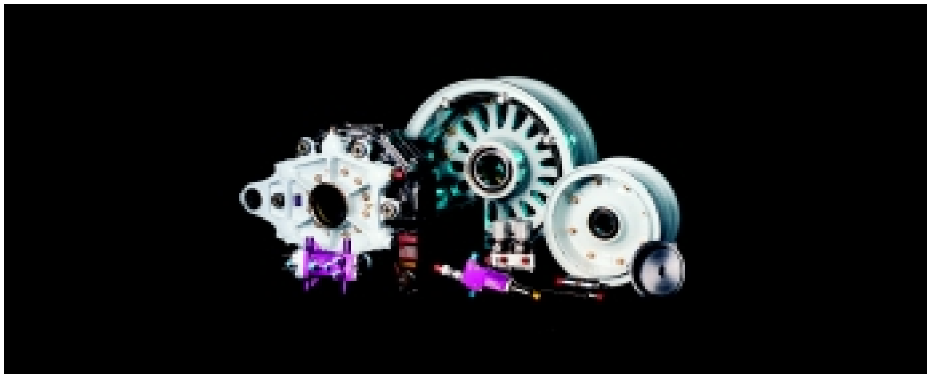
Early brake heat sinks were manufactured from phenolic-based materials but later they were manufactured from copper and then steel. Steel remained in favour until carbon brakes arrived on the scene, initially on military aircraft and subsequently on commercial aircraft, starting with Concorde in 1972. The primary advantages of carbon brakes is that they are substantially lighter than steel brakes and they have higher energy absorption characteristics which do not fade at higher temperatures. Indeed, in the specific case of Concorde, without the use of carbon brakes takeoff weight would have been affected to the point where the aircraft would have been unable to fly LHR-JFK with a full payload.

On the negative side, carbon brakes require more volume within the wheel hub than the equivalent steel brakes and they are also more expensive to manufacture (steel brakes cost about two thirds the price of carbon brakes). Whilst carbon brakes continue to come down in price relative to steel brakes, there is still a case to be made for steel brakes, particularly in shorthaul operations. Frank Crampton, vice president of marketing at ABSC, reckons that "Generally, steel brakes are candidates for commercial transport if the average stage length of the aircraft is 2.5 hours or less."

Advances in steel brake design have been significant. They can effectively be made larger within the envelope available to a carbon brake and this combined with technological improvements has meant that steel brakes, which may formerly have been designed to achieve 1,000 landings between overhauls can now be designed to achieve as much as 2,000 landings – the same sort of figure originally specified for carbon brakes.

Brake systems design

As brake efficiency was improved, it became necessary to consider how best to stop brakes from locking up in wet or icy conditions and this caused companies such as ABSC, Westinghouse, Hydro Aire and Dunlop Aviation Braking Systems to introduce their respective anti-skid systems. The early Dunlop solution was a completely mechanical one called Maxaret which involved the rotation of a small heavy disc in contact with the wheel rim. When the relative motion between the disc and the wheel indicated the onset of wheel lock-up, hydraulic pressure was released from the braking system, thereby preventing wheel skidding. Such systems were designed to prevent tyre blow-out and were frequently referred to as "on-off" systems, as they pulsed brake pressure and did not utilise adaptive control methods.
According to Hydro-Aire, early braking systems resulted in braking efficiencies of about 60 per cent whereas the modulating Mark II systems introduced in the 1960s resulted in braking efficiencies of between 70 and 85 per cent. Mark III systems introduced in 1973 were based on an analogue, closed loop feedback control system and these achieved up to 90 per cent braking efficiency. In 1978 Hydro-Aire introduced its first digital systems onto aircraft such as the B767.
All of these systems were dependent upon a mechanical or hydro-mechanical linkage between the pilot's brake pedal and the brake itself. Upon the introduction of Mark V brake-by-wire system the primary control of braking was managed through electrical means, albeit with a mechanical back-up system, achieving braking efficiencies



as high as 98 per cent, according to Hydro-Aire. Brake-by-wire design techniques have been applied to all Airbus Industrie aircraft and the next generation of A340-500, -600 and A3XX aircraft will feature what Messier Bugatti describes as full brake-by-wire, where there is no hydro-mechanical back-up system. Until recently, full brake-by-wire systems were mostly fitted to the very latest military aircraft.

Latest developments

According to Carl Trustee, head of engineering at Dunlop Aviation: "What we are working towards now is the development of higher density carbon materials capable of absorbing more energy with higher density and better wear characteristics. While working towards these goals we are also continually striving to maintain consistent material properties – referred to as process control in industry." Apart from this, Dunlop Aviation is looking at lighter and stronger materials for structural components and advancing design design methods for optimised brake performance. These advancements are going to be needed given the current industry trend of continually increasing aircraft payloads, more frequent as well as more rapid aircraft turnarounds and more demanding regulatory specifications.

Over the last two years, Dunlop Aviation has dedicated significant time, money and effort to the development of its structural dynamics capabilities. It now has a sophisticated vibration analysis capability supported by the latest analytical modelling facilities and a laboratory which can accommodate a full-scale landing gear assembly, complete with wheels and brakes so that any dynamic instability can be identified early in the design process. Dunlop's stated intention is to produce engineering excellence within an integrated design at a reasonable cost to the customer. Other brake manufacturers are also active in this arena and, no doubt they share these goals.

When considering design criteria for brakes and braking systems, safety, reliability, performance, cost and weight come out on top. Trustee explains that whilst the first three parameters are expected to be designed into any brake and braking system, the customer also expects this to be accomplished at minimum cost and preferably weight, although there may be a trade off between the last two criteria.

When asked what the latest developments might be, Trustee answered: "We are always working on advancing wheel and brake control systems technology. Currently, one of the biggest development areas in the industry is the electric brake." The fundamental idea behind this concept is that existing hydraulic systems, including hydraulic reservoirs, hydraulic motors and hydraulic tubing, are replaced by an electrical system. As things stand, it would appear that the electric brake is heavier than the equivalent hydraulic actuator, but when complete systems are considered, there are potential weight benefits. What is more, there are safety benefits as a result of deleting a potential fire source and electric brakes are considered to offer better control and improved braking efficiency.

However, the introduction of electric brakes would only come about with significant changes to aircraft design. Flight control surface actuators, for example, would probably have to become electrically actuated before weight savings become sufficient to justify the switch to a new system. Trustee reckons that electric brakes could be introduced to military aircraft within the next five years. Crampton, on the other hand, believes the introduction of electric brakes could be further off, with the US Joint Strike Fighter probably retaining hydraulic brakes.

In service

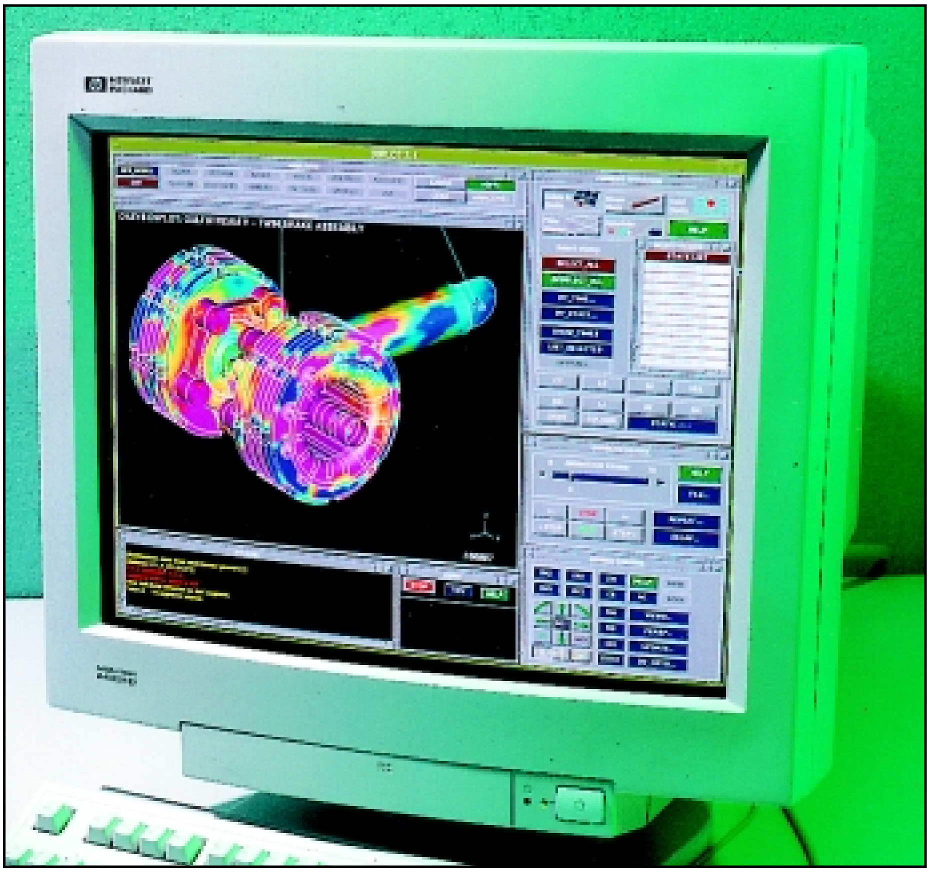
When considering the maintenance costs of aircraft brakes and braking systems, typically 95 per cent of the cost is associated with brake heat sink wear and only about five per cent is consumed by the braking system itself. It is fair to say, however, that there are still very significant variations in these costs between airlines. At busy airports, where there is a significant requirement for start and stop taxiing, brakes can be worn to limits four times as quickly as at quiet airports where there is little traffic at all.

Another factor which can affect brake wear is the idle thrust produced by the engine. Where two or more engines types are specified for a particular aircraft type, it is not unusual to see that the idle thrust produced by one is significantly higher than another, resulting in much higher brake wear. This effect is more pronounced on two-engined aircraft.

With the introduction of health monitoring and self-diagnostics within digital braking systems, additional parameters can be monitored and in certain instances these can advise crews that a degrade has been affected or a back-up system selected. An example of this could be where a wheel speed transducer has become defective as a result of a frayed cable, resulting in a back up system being initiated in the form of paired wheel control, as compared with the normal individual wheel control. This degrade permits the aircraft to continue in service until maintenance personnel have the opportunity to rectify the defect.

Crampton explains that ABSC has become very active in monitoring brake wear in service and this can vary significantly between operators as a result of operational profiles and pilot operating techniques. On one occasion, ABSC worked with US Airways on its MD-80s, in view of the fact that it was achieving less than 900 landings between its steel brake overhauls. In terms of brake costs, this represented one of the worst MD-80 operations, but by the time that ABSC had finished its analysis with the US Airways flight department, improvements to pilot techniques were introduced which caused the average number of landings between brake overhauls to increase to 1,200 cycles, making US Airways one of the best performers.

According to Crampton ABSC has also made significant efforts to work with its customers when the brake comes into the workshop for overhaul. It is frequently possible to minimise overhaul costs by creating operator specific brake stack builds so that, for example, the number of brake rotors rejected from a four rotor stack is reduced from two per brake overhaul to an average of 1.25 per brake overhaul.



There are many different charging mechanisms for brake and brake system maintenance support, ranging from time and material contracts right the way through to cost per landing (CPL) contracts. Furthermore, there are usually several different options for spares support and the associated logistics. These days, there is frequently an incentive clause within CPL contracts, whereby the cost benefits accrued from brake performance exceeding a pre-agreed standard are shared between the OEM and the operator. With total brake costs per landing for the B747 with 16 carbon brakes being around $180 per landing, the B767 with eight carbon brakes being around $95 per landing and the B737 with four steel brakes being around $20 per landing, this tends to make a lot of sense (costs vary significantly depending upon whether brakes are available on a single or double source basis).