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SEQUENTIAL SELECTIVE OPERATION OF AIRCRAFT BRAKES

The present invention relates to an aircraft brake control system for the control of a plurality of carbon brakes and to an aircraft braking system comprising a plurality of carbon brakes operatively associated with said brake control system.

The ability to stop an aircraft both quickly and economically is of great importance and enormous amounts of kinetic energy have to be dissipated in order to bring a moving aircraft to rest, particularly in an RTO (refused or rejected take-off) situation. The aircraft velocity may be decreased and the kinetic energy thereby dissipated by drag forces, by application of the engine thrust reversers, and by application of the aircraft wheel brakes. The drag forces can be increased by deploying of airbrakes or speed brakes on the aircraft wings.

However, very high energy brake applications in a RTO situation are fortunately rare events and therefore play little, if any, part in determining overall brake operating economics.

It is now recognised that the rate of wear of carbon brake discs is not proportional to the energy dissipated after the brakes are applied, brake wear being disproportionately high when the energy input to the brake is low. Consequently, it is beneficial to apply only a restricted number of the available brakes when the required braking action is relatively low.

The concept of applying only limited numbers of brakes during taxiing operations but all the available brakes in a landing run has already been disclosed in GB 2216209B and US 4986610. The concept has been described variously as brake disabling, selective operation or as taxi-brake select.

In accordance with one of its aspects the present invention provides an aircraft braking system comprising a plurality of carbon brakes, brake actuating means for actuating the brakes in response to an applied control signal and control means whereby operation of a pre-selected number of the brakes is inhibited if at least one control signal applied to the brake actuating means lies beyond a predetermined control signal threshold, the



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control means being operable to inhibit at least one of a plurality of brakes in relation to the braking level requirement of the aircraft, said control means being operable to limit the number and/or proportion of brakes that may be disabled at each stage of a flight spectrum including taxi-out, take-off, landing and taxiing-in and being operable also such that the number and/or proportion of disabled brakes is a function of monitored conditions applicable to the aircraft status at any given time thereby to ensure that the overall safety of the aircraft is not hazarded.

In accordance with another of its aspects the invention provides that operation of an aircraft brake control system is controlled at least in part by an on-board brake control implementation means actuated by a remote land-based signalling means.

Said system may be used to activate the selective brake operating means in response to signalling means located at the junction between an aircraft runway and its ancillary taxi-ways. It is envisaged to "ring-fence" or likewise define the boundary of part of the runway and arrange that the manner of operation of the selective braking means is a function of whether the aircraft is operating within the designated runway area.

At an airport having more than one runway, a further, auxiliary control system may be provided to select from a limited number of a plurality of remote signalling means. Said selection (or inhibition) may be a function of whether (or not) a given runway is designated as being in operational use.

Said remote signalling means may be used in combination with other selective brake operation means.

The control system may comprise an on-board data bank which stores information concerning the conditions relating to those airports to which the aircraft flies frequently and the selective braking control system may receive input from such a data bank. Thus, in use, before an aircraft lands the minimum proportion of the brakes to be operated may be preset to take account of fixed parameters, e g runway length, airport altitude, and variable parameters such as ambient temperature, runway status

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(dry/wet/icy).

The invention further provides a method of operating the brakes of a multi-wheel aircraft during taxiing thereof where the aircraft has a total of N brakes and wherein each of the brakes $n_1, n_2, \dots, n_x$ may be selectively operated in the case of $N > n_x > n_2 > n_1$, said method comprising:-

- operating the aircraft with n_1 brakes during taxiing,
- detecting a condition which at least potentially requires additional force,
- applying additional braking force progressively or incrementally to increase from n_1 to n_2 ,
- detecting whether a condition requiring additional braking force continues to exist, and
- increasing the braking force progressively or incrementally from n_2 to n_x whilst said condition requiring additional braking force continues to exist.

The invention provides also a method of controlling an aircraft braking system comprising a plurality of carbon disc brakes, said method comprising providing brake actuating means for actuating the brakes in response to an applied control signal, providing control means for inhibiting any one of a plurality of different numbers of brakes and arranging the control means to be responsive to the braking level requirement of the aircraft to inhibit a number of brakes selected as a function of said braking level requirement.

A brake control system of the invention may be programmed to determine the minimum number n_1 of brakes that are required to control the aircraft in a safe manner at a particular airport. If n_1 brakes operate initially out of a total N brakes fitted to the aircraft, then after receipt of an input signal for example denoting anti-skid activity of one or more of said n_1 brakes the number of brakes which are selectively operated may be increased to n_2 where $N > n_2 > n_1$ provided that the aircraft can continue to operate in a completely safe manner. Similarly, if anti-skid activity then continues to occur in one or more of the n_1 brakes, or is initiated in the additional $n_2 - n_1$ brakes which are further selectively operated, then the



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number of selectively operated brakes may be increased to n_3 where $N > n_3 > n_2 > n_1$. In more general terms, the number of selectively operated brakes may be increased incrementally from n_1 to n_x where $N > n_x > n_1$.

Consideration is now given, by way of example, to the case of an aircraft with 16 brakes where initially 4 brakes are sufficient to provide the necessary braking during a taxi-snub, but anti-skid activity then initiates. If the selective operation of 8 brakes would still enable the aircraft to be safely controlled, then it may be arranged advantageously that only the 8 brakes rather than the full 16 brakes are applied, as selective operation of the said 8 brakes would effectively reduce the overall brake wear on the aircraft and give a substantial life saving when the aforescribed type of cascade operating system is used, rather than the conventional arrangement in which the selective operation sequence is "cancelled" and all sixteen brakes are immediately applied upon onset of anti-skid or some other occurrence.

In a further embodiment when external input signals indicative of pilot demand, anti skid control activity, or the proximity of other vehicles or objects lie outside a range of acceptable instantaneous value it may be provided that it is still not always necessary to apply all brakes simultaneously.

The present invention seeks to optimise the benefits of the selective operation/brake disabling procedure whilst ensuring that the airworthiness status and the overall safety of the aircraft are not hazarded. For that purpose the invention provides that limitations are placed on the number and/or proportion of brakes that may be disabled not only at each stage of the complete flight spectrum (i.e. taxiing-out, take-off, in flight, landing, taxiing-in or stationary on the ground) but also that said number and/or proportion applicable during each stage shall be further adjusted in response to the specific conditions applicable to the aircraft status at any given time.

The brake control system which provides a selective operation facility may utilise closed-loop feedback systems to regulate the brake actuation procedures.

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The brake control system may be interlinked with an airbrake deployment system control and an engine thrust reverse control so that full braking action is provided at all times when such other features are operational.

In setting the specification for an aircraft a constructor must design for a worst case scenario.

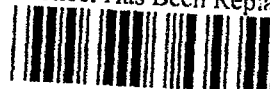
The instructor must consider the likely increase in maximum aircraft take-off (TO) weight that may occur during his programme as he introduces new variants within his model range. For a maximum TO weight increase of 10%, which is typical, the brake energy requirement will increase by 20% as a higher TO velocity will be required in order to produce the increased lift required for take-off.

The constructor needs also to specify brakes capable of use under extreme conditions e g corresponding to those appertaining to airports at high altitude in hot locations e g Mexico City or Denver.

The constructor needs to ensure also that the aircraft has the capability to land and take off at airports with relatively short runways.

Consequently there will be many instances where the actual landing conditions are far less onerous than the specification requirement. Furthermore the landing requirement is always far less onerous than the rejected take off requirement as by the end of the flight the bulk of the aircraft fuel will have been consumed.

Operation of the selective brake control system may be conditional on other, e g flight, parameters being normal. Thus the system may be inhibited at least in part if for example the approach rate of aircraft or point of landing is not within prescribed boundaries. There may be one boundary outside which there is complete inhibition, i e inhibition of the brake inhibition means thereby to result in full braking. There may be another boundary which results in only partial inhibition, i e a greater number of brakes are brought into operation than would normally be the case, but not all of the brakes are brought into operation. The system may be operable to detect parameters prior to touch down and preselect or pre-establish



whether or not flight and related parameters lie within one or more prescribed boundaries.

A further object of the invention is to reduce the overall wear during the landing run by operating at least one less than all the available brakes during the landing run provided that this is consistent with maintaining operational safety and such means will be considered further.

Previously it has been taught either (1) that above an upper velocity threshold representing the maximum taxiing velocity all brakes shall be operative in order to ensure operational safety or (2) that selective braking can continue above the operational threshold without the benefit of additional safety features as in EP 0443213 A2 or (3) the only additional safety feature being provided by a second manual override system as in US 5172960.

The invention provides in another of its aspects automatic means for activating additional brakes in a selective braking operation in response to transducer signals indicative (1) of at least one of the following parameters of the aircraft external environment:

- a) proximity of the other vehicles
- b) relative velocity of other vehicles or objects in relation to the subject aircraft
- c) the tyre-ground friction coefficient
- d) the location of the aircraft within the airport confines
- e) any other significant operating considerations
- f) external signalling means

(2) the interaction between at least one said signal indicative of the external environment and a transducer signal indicative of at least one characteristic of the aircraft such as

- a) aircraft velocity
- b) wheel velocity
- c) aircraft all up weight
- d) degree of wear of brake disc assembly

These selections provide a sophisticated override system which may





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ensure that a cascade operating system only operates in a manner which is compatible with maintaining the overall safety of the aircraft at all times.

Thus a variable number of brakes may be selected and proportional or incremental actuation of such brakes may be adopted when an aircraft braking operation is needed. The number of brakes to be used is not pre-selected but may be determined by the aircraft operation parameters at the particular time that the braking application is required. The number of selected brakes may be adjusted sequentially in accordance with one or more of the various parameters detailed above.

A suitable proximity means may rotate to ensure that all necessary directions are scanned.

Suitable brake control systems for the above comprise electronic control boxes, microprocessors or dedicated landing gear computers, it being envisaged that in use of the cascade operating procedure on an aircraft, the operation of brakes may be controlled in relation to, and may be used in relation to the control or operation of, other aircraft systems and devices.

Because of the airworthiness implications of a systems failure i.e. that only some of the brakes operate during a landing operation, it may be preferred to provide multiple discrimination means so that a measure of redundancy is built into the selective braking system.

The discrimination between landing and taxiing operations may be accomplished by means either contained within, or fitted externally to, the aircraft and which differentiate between the aircraft being airborne and having landed.

Said discrimination process may comprise means to identify that the aircraft is about to land or has already landed. Said means may be triggered for example by operation of the flying or flight surface controls in a sequence which is indicative of an imminent landing, by the deployment of air brakes or by the operation of the engine controls. Alternative means may respond to the results of operation of the said controls i.e. be triggered when the rate of descent falls below a threshold value, i.e. indicative of the

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aircraft touching down; this means may be triggered by one or more wheel speed sensors when said speed rises above a threshold level indicative of wheel spin-up on touch down. Landing or imminent landing of the aircraft may be detected by a ground proximity warning/signalling device.

One or more of the triggering means recited in the preceding paragraph may be used in combination with a timing delay means of sufficient length to inhibit operation of the selective braking system during the delay period and thereby ensure that the aircraft has completed its landing run before the selective brake system is implemented.

In an alternative arrangement the triggering means could activate an aircraft speed sensing means which inhibits the operation of the selective brake operation means until the aircraft speed falls below a threshold value. In this case the selective braking function will commence operation at a fixed speed. The aircraft speed could be determined by measuring the aircraft wheel speed as is a standard practice in the industry.

Operation of the selective brake operation means may be inhibited if the anti-skid control system is active (i.e. dumping pressure to limit the brake actuation pressure) at any aircraft speed.

Triggering means as described above may operate independently or in combination (thereby increasing overall reliability) and may additionally be used in combination with means of landing/taxi mode differentiation and selective brake operation inhibiting means of type known per se.

The operational status of the aircraft may be monitored by a pressure gauge mounted in or on the aircraft which measures the atmospheric pressure outside the aircraft. It may be provided that selective braking is only possible if the atmospheric pressure exceeds a threshold value; thus selective braking may be prevented whilst the aircraft is operating at airports/airfields at high altitude. This may be a particularly desirable additional safety feature.

Similarly the operational status of the aircraft may be monitored by a temperature measuring device which measures a temperature outside the aircraft and selective braking may be permitted only when the temperature

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is above a threshold level, e g 0°C .

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CLAIMS:

1. An aircraft braking system comprising a plurality of carbon brakes, brake actuating means for actuating the brakes in response to an applied control signal and control means whereby operation of a pre-selected number of the brakes is inhibited if at least one control signal applied to the brake actuating means lies beyond a predetermined control signal threshold, the control means being operable to inhibit at least one of a plurality of brakes in relation to the braking level requirement of the aircraft, said control means being operable to limit the number and/or proportion of brakes that may be disabled at each stage of a flight spectrum including taxi-out, take-off, landing and taxiing-in and being operable also such that the number and/or proportion of disabled brakes is a function of monitored conditions applicable to the aircraft status at any given time thereby to ensure that the overall safety of the aircraft is not hazarded.
2. An aircraft braking system according to claim 1 wherein the control means is adapted to inhibit none of the brakes if the control signal applied to the brake actuating means is indicative of a requirement for maximum available braking.
3. An aircraft braking system according to claim 2 wherein said control means is adapted to inhibit none of the brakes only if the control signal applied to the brake actuating means is indicative of a requirement for maximum available braking during a landing phase of the flight spectrum.
4. An aircraft braking system according to claim 2 or claim 3 wherein the control means is adapted to inhibit some but no more than a specified proportion of the brakes if the control signal applied to the brake actuating means is indicative of a requirement for maximum available braking at least during a taxiing-in phase of the flight spectrum.
5. An aircraft braking system according to claim 1 or claim 2 wherein the control means is adapted to operate incrementally whereby, as the control signal applied to brake actuating means changes, the number of brakes inhibited changes incrementally one brake at a time.
6. An aircraft braking system according to claim 1 or claim 2 wherein

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the control system is adapted to operate incrementally whereby as the control signal applied to the brake actuating means changes, the number of brakes inhibited changes incrementally two brakes at a time.

7. An aircraft braking system according to claim 6 wherein said two brakes lie respectively at right and left-hand sides of a longitudinal, fore-and-aft centre line of the aircraft.

8. An aircraft braking system in accordance with any one of the preceding claims wherein different brake actuation pressures are applied to different brakes.

9. An aircraft braking system in accordance with claim 8 and arranged such that as different brakes are brought into operation sequentially, different brake actuation pressures are applied to different brakes in a manner selected to tend to equalise as quickly as practical the temperature of all operating brakes.

10. An aircraft braking system according to any one of the preceding claims wherein the braking level requirement is a function of at least one parameter of the aircraft external environment.

11. An aircraft braking system according to claim 10 wherein said at least one parameter is a parameter from the group comprising proximity of other vehicles, relative velocity of other vehicles or objects in relation to the subject aircraft, the tyre-ground friction coefficient, the location of the aircraft relative to predetermined zones or positions of an airport, external signalling means.

12. An aircraft braking system in accordance with any one of the preceding claims wherein the braking level requirement is a function of at least one parameter characteristic of the aircraft or its operation.

13. An aircraft braking system according to claim 12 wherein said parameter is a parameter from the group comprising aircraft velocity, wheel velocity, aircraft all up weight, degree of wear of brake disc assembly.

14. An aircraft braking system according to any one of claims 10 to 13 and comprising automatic means for activating additional brakes in a selective braking operation in response to a signal related to at least one of





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said parameters.

15. An aircraft braking system according to any one of the preceding claims wherein the control signal is responsive to remote signalling.

16. An aircraft braking system according to any one of the preceding claims and comprising an electronic database which stores information concerning characteristics of each of a plurality of potential aircraft landing locations, and selector means whereby in response to a setting of the selector means the data store is operable selectively to define specified operating parameters of the control means.

17. An aircraft braking system according to any one of the preceding claims and comprising proximity sensing means whereby operation of the control means is a function of a signal from said proximity means.

18. An aircraft braking system in accordance with claim 1 and substantially as described in the description of this application.

19. An aircraft brake control system the operation of which is controlled at least in part by an on-board brake control implementation means actuatable by a remote land-based signalling means.

20. A brake control system according to claim 19 wherein said system is operable to activate selective brake operating means in response to signalling means located between an aircraft runway and ancillary taxiways.

21. An aircraft brake control system according to claim 19 or claim 20 wherein the manner of operation of the brake control implementation means is a function of whether the aircraft is operating within a designated runway area.

22. An aircraft brake control system according to claim 21 and comprising an auxiliary control system operable to select from a specified number of a plurality of remote signalling means.

23. An aircraft brake control system according to claim 19 and substantially as herein described.

24. Method of operating the brakes of a multi-wheel aircraft during taxiing thereof where the aircraft has a total of N brakes and wherein each of the brakes $n_1, n_2, \dots, n_x$ may be selectively operated in the case of $N > n_x > n_2$

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> n_1 , said method comprising:-

- operating the aircraft with n_1 brakes during taxiing,
- detecting a condition which at least potentially requires additional force,
- applying additional braking force progressively or incrementally to increase from n_1 to n_2 ,
- detecting whether a condition requiring additional braking force continues to exist, and
- increasing the braking force progressively or incrementally from n_2 to n_x whilst said condition requiring additional braking force continues to exist.

25. Method according to claim 24 wherein the control means operates to inhibit the maximum number of brakes consistent with operational safety.

26. Method according to claim 24 or claim 25 wherein control means is operable to limit the number and/or proportion of brakes disabled at a plurality of stages of a flight spectrum and is operable also such that the number and/or proportion operable during said phases may be further adjusted in response to the conditions applicable to the aircraft status at a specified moment in time.

27. Method of controlling an aircraft braking system comprising a plurality of carbon disc brakes, said method comprising providing brake actuating means for actuating the brakes in response to an applied control signal, providing control means for inhibiting any one of a plurality of different numbers of brakes and arranging the control means to be responsive to the braking level requirement of the aircraft to inhibit a number of brakes selected as a function of said braking level requirement.

28. Method according to claim 27 and comprising monitoring for anti-skid activity and increasing the number of operational brakes progressively or incrementally in the event of anti-skid activity until the anti-skid activity ceases or decreases to below a preselected threshold on a designated number n_1 of the active brakes.

29. Method in accordance with claim 27 or claim 28 and comprising





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monitoring parameters on which the onset of a skid condition is known to depend and arranged that when the onset of a skid condition is predicted or whilst the occurrence of a skid condition continues the number of operational brakes progressively or incrementally increases.

30. Method according to claim 27 or claim 28 and comprising monitoring conditions on which a requirement for increased braking force is known to depend and in the event of detecting a potential requirement for increased braking force arranging that said control means brings into operation at least some or all of the brakes the operation of which has been inhibited.

31. Method in accordance with any one of claims 24 to 30 wherein the control means brings into operation all of the brakes in the event of a specified condition occurring.

32. Method in accordance with claim 31 wherein said specified condition is operation of an air brake deployment system control or is operation of engine reversed thrust control.

33. Method of operating the carbon disc brakes of an aircraft braking system according to claim 24 or claim 27 and substantially as hereinbefore described.

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