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A DETECTION SYSTEM FOR USE
IN AN AIRCRAFT

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6 The present invention relates to a detection system for
7 use in an aircraft and, more specifically, to a detection
8 system of an aircraft which is able to detect the presence
9 of a volcanic ash cloud.

10

11 Volcanic ash clouds constitute a serious hazard to
12 aircraft even after the clouds have moved from the site of a
13 volcanic eruption. Apart from containing ash particles, the
14 clouds include gases such as SO_2 , which after a few days
15 oxidises and hydrolises to form sulphuric acid droplets,
16 either as an ash-acid mixture or as a coating over ash
17 particles. Both the ash particles and the sulphuric acid
18 droplets of volcanic ash clouds are capable of causing
19 significant damage to and possible loss of an aircraft which
20 encounters an ash cloud.

21

22 A number of aircraft encounters with volcanic ash
23 clouds have been recorded in the past where significant
24 damage has occurred. Between April and July 1982
25 Galunggung, a volcano in Central Java, Indonesia, underwent
26 a series of eruptions. The dispersing ash clouds, in moving
27 across commercial flight paths, constituted a major hazard
28 because the radar systems of aircraft were, and still are,
29 unable to discriminate between ash clouds and ice/water
30 clouds. Also a volcanic ash cloud normally can not be
31 distinguished visually from a grey ice/water cloud. Two
32 major incidents resulted from aircraft flying directly into
33 the ash clouds. On 24 June 1982, a British Airways Boeing
34 747, flying from Kuala Lumpur in Malaysia to Perth, entered
35 an ash cloud. All four engines stalled and the aircraft
36 descended 6000 m without power before attempts to restart
37 the engines succeeded. An emergency landing was made at

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1 Jakarta, Indonesia. A second incident occurred on 13 July
2 1982 when a Singapore Airlines Boeing 747 suffered similar
3 inflight problems and again an emergency landing was made at
4 Jakarta. More recently, on 15 December 1989, a KLM Boeing
5 747 encountered an ash cloud produced by an eruption of the
6 Mount Redoubt Volcano in Alaska, U S A. The engines of the
7 aircraft stalled and the jet descended 3600 m without power.
8 Furthermore, the cockpit of the aircraft was reported to
9 have filled with sulphur smelling gases. The descriptions
10 of the encounter were remarkably similar to the Galunggung
11 ash cloud encounters and the effects on the aircraft were
12 also similar.

13

14 The above serves to illustrate the requirement for a
15 detection system which could provide a pilot with early
16 warning of the presence of an ash cloud so the cloud can be
17 avoided. A system relying on data collected from
18 satellites could be implemented, however, satellite data for
19 a particular area of the earth's atmosphere is only updated
20 periodically. For example, data from satellites in a polar
21 orbit is only provided four times a day for most regions of
22 the earth. Therefore a detection system which can be
23 installed in an aircraft to monitor conditions ahead of the
24 aircraft is desired. Furthermore, it would be advantageous
25 if the system could also detect other adverse atmospheric
26 conditions, such as a clear air turbulence, which can not be
27 detected visually or by known aircraft detection systems,
28 and should be avoided by aircraft.

29

30 In accordance with the present invention there is
31 provided a detection system for use in an aircraft,
32 comprising means for monitoring atmospheric conditions ahead
33 of said aircraft, generating an alarm signal if adverse
34 atmospheric conditions exist ahead of said aircraft, and
35 generating information which indicates the position of said
36 adverse conditions so the adverse conditions can be avoided.

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The adverse conditions may comprise a volcanic ash cloud, a high density of sulphur dioxide gas and/or clear air turbulence.

The present invention further provides a detection system for an aircraft,
5 comprising means for detecting the presence of a volcanic ash cloud ahead of said aircraft, and means for alerting a pilot of said aircraft to the presence of said cloud.

Preferably said detection system includes means, responsive to detection of said ash cloud, for generating information representative of the position of said ash
10 cloud relative to said aircraft. Preferably said alerting means system includes means for generating display signals for producing a display of said information.

Preferably said detecting means is also able to detect the presence of sulphur dioxide and/or clear air turbulence.
15

Preferably said detecting means and alerting means include means for monitoring infrared radiation received by said aircraft, filter means for generating intensity signals representative of the intensity of predetermined wavelengths of said radiation, and processing means for comparing the intensity signals of two of
20 said predetermined wavelengths and generating a volcanic ash cloud warning signal if the results of the comparison indicate an ash cloud is present.

Preferably said warning signal is generated if said intensity signals indicate radiation received of the longer wavelength is less than radiation received of the
25 shorter wavelength.

Preferably said monitoring means an infrared detector array and said intensity signals relate to pixels of said array, such that intensity signals of each of said predetermined wavelengths correspond to each one of said pixels and said
30 processing means generates display signals representative of the position of said ash cloud relative to said aircraft on the basis of said intensity signals and position

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signals representative of the position of said aircraft. Preferably said display is generated when said processing means determines said ash cloud is present.

5 The present invention also provides a method of detecting adverse atmospheric conditions, comprising monitoring infrared radiation received by an aircraft, generating signals representative of the intensity of at least one predetermined wavelength of said radiation, processing the intensity signals, and generating a warning signal if said intensity signals indicate said adverse conditions are present.

10

Preferably said warning signal is generated if a value of signals for the longer wavelength is less than a value of signals for the shorter wavelength.

15 Preferably said signals relate to pixels of an infrared detector array, and said method further includes generating a display of the position of said adverse conditions relative to said aircraft on the basis of said signals.

The present invention further provides an aircraft comprising a detection system as described above.

20

Preferably said longer wavelength is approximately 12 μm and the shorter wavelength is approximately 10 μm . Preferably the predetermined wavelengths include two further wavelengths, 6 μm which relates to the detection of clear air turbulence and 9 μm which relates to detection of sulphur dioxide.

25

A preferred embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings, wherein:

Figure 1 is a diagram of a volcanic ash cloud;

Figure 2 is a graph of infrared radiation received from ice/water clouds and volcanic ash clouds vs infrared wavelength;

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Figure 3 is a schematic side view of a preferred embodiment of a detection

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unit of a system according to the present invention;

Figure 4 is a schematic front view of the unit;

Figure 5 is a plan view of a filter wheel of the system;

Figure 6 is a block diagram of the electrical/electronic circuitry of the
5 system;

Figure 7 is a flow diagram of a main operating routine of the system;

Figure 8 is a flow diagram of a warning lamp processor routine of the
system;

Figures 9 and 10 are graphs of infrared radiation received vs infrared
10 wavelength for clear sky and cumulus cloud, respectively;

Figures 11 to 13 are graphs of infrared radiation received vs time for
volcanic ash clouds and different infrared wavelengths; and

Figure 14 is a graph of infrared radiation received vs time for a water cloud
and different infrared wavelengths.

15

Infrared radiometers mounted on satellites have provided a significant
amount of data in relation to infrared radiation emitted from the earth's surface, and
absorbed by clouds, over a range of infrared wavelengths. The satellites include
the TIROS-N/NOAA polar orbiting satellites and the Geostationary Meteorological
20 Satellites (GMS). Analysis of the data has confirmed volcanic ash clouds have a
characteristic infrared signature which enables them to be distinguished from
normal ice/water clouds. A volcanic ash cloud 2, as shown in Figure 1, when
viewed from a satellite, includes a semi-transparent region 4, which in most
instances is disposed around the periphery of the cloud 2 about a more dense
25 centre region 6 which generally absorbs all infrared radiation emitted from the
earth's surface. The infrared semi-transparent region 4, has been shown to exhibit
a "reverse absorption effect", which does not occur in similar regions of ice/water
clouds. The effect causes an increase in the infrared radiation received by the
satellite for the region 4 for longer or increased infrared wavelengths, between 10
30 μm and 13 μm . For similar semi-transparent regions of ice/water clouds the
intensity of radiation received by the satellite decreases

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1 for increasing or longer wavelengths in the 10 to 13 μm
2 range. The radiometers of the satellites include a single
3 detector element which is mounted on a mechanical scanning
4 device so a video display can be produced of the area
5 scanned using the infrared intensity signals generated by
6 the radiometer. For the background 8, which in this case is
7 the earth's surface, and the centre region 6, the absolute
8 value for a brightness temperature corresponding to the
9 radiation received at a selected wavelength can be used to
10 generate the colour displayed. For example, the background
11 8 would appear a shade of blue and the centre region 6 a
12 shade of black. To highlight the existence of the ash cloud
13 2, if the difference between the radiation received for a
14 long wavelength and a short wavelength in the 10 to 13 μm
15 range is positive, the semi-transparent region 4 would be
16 displayed a shade of red, according to the magnitude of the
17 difference. If the difference is negative a different
18 colour can be displayed to indicate the cloud is simply an
19 ice/water cloud. Satellite information, however, as
20 discussed previously for a particular area is only updated
21 intermittently and a volcanic ash cloud may move
22 significantly before the information is updated.

23

24 A preferred embodiment of a detection system according
25 to the present invention, as described in detail hereinafter
26 with reference to Figures 3 to 7, is mounted on an aircraft
27 and monitors infrared radiation ahead of the aircraft. An
28 aircraft, in flight, is normally directed towards space above
29 the horizon 9 of the earth, as shown in Figure 1. When
30 viewing a cloud 2 and monitoring the infrared radiation
31 received therefrom, the background 8 is space and not the
32 surface of the earth as is the case for satellite
33 radiometers, and it has been found an opposite effect occurs
34 to the reverse absorption effect discussed above

35

36 A graph 12 of infrared radiation received from a cloud
37 2 when viewed horizontally from the aircraft vs wavelength

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1 of the radiation is illustrated in Figure 2. In the graph
2 12 the radiation intensities have been converted to
3 corresponding brightness temperatures. For the 9 to 13 μm
4 range, infrared radiation received is approximately directly
5 proportional to the corresponding brightness temperature.
6 Two curves are illustrated in the graph 11, one curve 13
7 relating to infrared radiation received from the semi-
8 transparent region 4 of a volcanic ash cloud, and the other
9 curve 15 relating to the radiation received from the semi-
10 transparent region 4 of a cloud containing ice particles.
11 The graph 11 illustrates the opposite effect which occurs in
12 that for the semi-transparent region 4, the infrared
13 radiation received decreases with respect to increasing
14 wavelength in the 10 to 13 μm region for ash clouds, whereas
15 radiation received increases with respect to increasing
16 wavelength for ice clouds. A cloud containing water
17 droplets would behave in a similar manner to a cloud
18 containing ice particles. The opposite effect is believed
19 to occur because an aircraft views clouds ahead against a
20 relatively cold background 8, such as space, whereas a
21 satellite radiometer views clouds against a relatively warm
22 background, the earth's surface. According to the graph 11,
23 the difference between radiation received for two
24 wavelengths within the 10 to 13 μm region is greatest for 10
25 μm and 12 μm . By analysing the difference between radiation
26 intensities received at 10 to 12 μm as brightness
27 temperature readings, the detection system is able to
28 distinguish between ice/water clouds and volcanic ash
29 clouds. If the difference between 12 μm brightness
30 temperatures and 10 μm brightness temperatures is negative
31 this indicates the presence of a volcanic ash cloud, whereas
32 if the difference is positive, an ice/water cloud is
33 present. The differences will only occur for radiation
34 received from the semi-transparent region 4 of a cloud 2.
35 Radiation received from the dense centre region 6 of a cloud
36 2 and the background 8 will be substantially the same for 10
37 μm and 12 μm .

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2 The existence of sulphuric acid droplets and particles
3 in a cloud 2 also effects the radiation received in the same
4 manner as for ash clouds. A negative difference between the
5 12 and 10 μm readings therefore indicates the presence of an
6 ash cloud or/and a cloud containing sulphuric acid droplets
7 or particles. Furthermore, the level at which sulphur
8 dioxide absorbs infrared radiation varies with respect to
9 the wavelength of the radiation, and maximum absorption
10 occurs at 8.9 μm . Therefore, by also monitoring infrared
11 radiation received at 8.9 μm , the detection system is able
12 to detect increased levels of sulphur dioxide in the
13 atmosphere, which can be used to confirm the presence of a
14 volcanic ash cloud.

15
16 The detection system is also able to detect the
17 presence of clear air turbulence by measuring infrared
18 emission from water vapour anomalies in the upper
19 troposphere. The anomalies occur due to turbulent motions
20 in the troposphere which transport water vapour rich air
21 upwards into layers which are otherwise dry. The presence
22 of the moist layers can be detected by examining the
23 difference between the 12 μm radiation and 6.3 μm radiation
24 received by an aircraft. If the difference exceeds a
25 predetermined threshold, the existence of clear air
26 turbulence can be inferred.

27
28 The detection system includes a detection unit 10, as
29 shown in Figures 3 and 4, which is housed in an opaque
30 casing 12. The casing 12 has an opening 14, which includes
31 an infrared transmissive window 16. The window 16, which is
32 preferably an ITRAN-2 window or similar, only allows
33 infrared radiation within a predetermined wavelength range
34 to enter the casing 12. The predetermined range includes
35 the wavelengths of interest, 6.3, 8.9, 10 and 12 μm . The
36 window 16 transmits received radiation 18 onto an offset
37 paraboloid reflector 20 mounted on an opposite wall of the

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1 casing 12 from the window 16, as shown in Figure 3. The
2 reflector 20 reflects and focuses the radiation 18 onto a
3 detector array 22. The array 22 includes 256 x 256 HgCdTe
4 infrared detector elements. The detector elements each
5 generate signals which can be used to produce a pixel in a
6 video display. The array 22 eliminates the need for any
7 form of mechanical scanning apparatus.

8

9 The unit 10 is mounted onto an aircraft, preferably in
10 the nose of the aircraft, so the window 16 is directed
11 towards the field of view ahead of the aircraft. The
12 detector array 22 will then receive an infrared image of the
13 field of view ahead of the aircraft of $\pm 5^\circ$ in the
14 horizontal and vertical planes. The image received by the
15 array 22 represents an area of 17.5 km^2 100 km from the
16 aircraft. The detector array 22 is cooled to maximise its
17 sensitivity to infrared radiation.

18

19 The unit 10 includes a chopper propeller 24, as shown
20 in Figures 3 and 4, which includes two oppositely disposed
21 blades 26 and 27, and is rotated at a frequency of 50 Hz by
22 a chopper motor 28. The angle between the opposite sides of
23 each blade 26 and 27 is 90° and as the chopper 24 is rotated
24 the blades intermittently prevent radiation from the window
25 16 from being received by the reflector 20, and in turn the
26 array 22. Instead, when a blade 27, as shown in Figure 4,
27 is disposed between the window 16 and the reflector 20, the
28 array 22 only receives the radiation of the chopper 24. The
29 chopper 24 therefore modulates the atmospheric radiation
30 received by the array 22 from the window 16 at a frequency
31 of 100 Hz. Modulation of the atmospheric radiation causes
32 the signals generated by the array 22 to be in the form of
33 amplitude modulated signals having a 100 Hz carrier which is
34 modulated in accordance with the intensity of the
35 atmospheric radiation 18. Signals representative of the
36 received radiation are extracted from the modulated signals
37 using a synchronous detector, as described hereinafter with

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1 reference to Figure 6. Modulation of the received radiation
2 18 by the chopper 24 enables electrical signals to be
3 derived which are only representative of the received
4 infrared radiation and do not include components due to
5 stray light or radiation reflected within the unit 10. Also
6 the high chopping frequency reduces $1/f$ noise which may
7 appear in the radiation signals.

8

9 The size of the unit 10, if desired, can be reduced
10 considerably by excluding the chopper 24. Signal components
11 produced by ambient and stray radiation within the unit 10
12 and $1/f$ noise would then need to be suppressed by
13 appropriate filtering circuitry or other means.

14

15 The detection unit 10 includes a temperature and
16 optical sensor circuit 30, which measures the temperature of
17 the radiation emitted from the chopper 24 so as to provide a
18 reference for converting received atmospheric radiation
19 intensities to corresponding brightness temperatures. The
20 circuit 30 also is responsive to light received from a light
21 source 32 to generate a synchronising signal for use by the
22 synchronous detector. The blades 26 and 27 of the chopper
23 24 pass between the light source 32 and the circuit 30 so as
24 to intermittently prevent the circuit 30 receiving light
25 from the source 32. The synchronising signal enters one
26 state when light from the source is received and another
27 state when a blade 26 or 27 is disposed between the source
28 32 and the circuit 30.

29

30 The received radiation after being reflected by the
31 reflector 20 is filtered by a quadrant 38 of a filter wheel
32 34, as shown in Figures 3 and 5, before the radiation 18 is
33 incident on the array 22. The filter wheel 34 is connected
34 and rotated by a filter wheel motor 36 and the wheel 34
35 completes a revolution every second. The quadrants 38 of
36 the wheel 34 each include a respective infrared filter for
37 one of the four wavelengths of interest. The filters of the

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quadrant 38 only allow the wavelength corresponding thereto to pass through the quadrant 38. The quadrants 38 are rotated from the path of the radiation 18 so as to position the succeeding quadrant 38, every 0.25 seconds. The array 32 therefore generates modulated signals representative of one of the four wavelengths every 5 0.25 seconds and the modulated signals can be considered to belong to one of four wavelength channels. The filter wheel 34 and motor 36 could, of course, be omitted and replaced by appropriate filtering circuitry or other means which would extract the channel signals from signals representative of the broad infrared band received.

10

A signal processing circuit 40 for processing the modulated signals is housed in the casing 12, as shown in Figures 3 and 4, together with the optical and mechanical components of the detection unit 10. The processing circuit 40, as shown in Figure 6, includes a detector sensor circuit 42, a synchronous detector 44, 15 an amplifier converter circuit 46 and a microprocessor 48. The sensor circuit 42 includes the detector array 22 and passes the modulated signals generated by each array element for each wavelength channel, to the synchronous detector 44. The detector 44 extracts the modulation envelope from the signals outputted by the sensor circuit 42, using the synchronising signal received on line 50 from the 20 temperature and optical sensor circuit 30. The extracted envelopes represent the received infrared intensities for each element of the array 22 for the four channels. The amplifier converter circuit 46 amplifies the intensity signals and converts the signals to 256 x 256 digital pixels, each including values of radiation received for the four channels and corresponding to a respective array element. The pixels are 25 then processed by the microprocessor 48 in accordance with a software routine, described hereinafter with reference to Figures 7 and 8, to determine whether the pixels indicate adverse atmospheric conditions are present ahead of the aircraft. If adverse

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1 conditions do exist, a warning lamp 52 and/or an audio
2 warning signal 54 are activated in the cockpit of the
3 aircraft to alert the pilot to the existence of the
4 conditions. The microprocessor 48 then activates a visual
5 display unit 56, also mounted within the cockpit, and
6 supplies RGB signals, derived from the digital pixels, to
7 the unit 56 so as to generate a display for the pilot which
8 indicates the position of the adverse conditions relative to
9 the aircraft.

10

11 The main operating routine 60, as illustrated in Figure
12 7 begins at step 62 where the digital pixels are received by
13 the microprocessor 48. The four channels can be designated
14 channel 1 for the 6.3 μm wavelength channel, channel 2 for
15 the 8.9 μm wavelength channel, channel 3 for the 10.0 μm
16 wavelength channel, and channel 4 for the 12.0 μm wavelength
17 channel. The microprocessor 48 also receives a signal
18 representative of the chopper temperature, TC, via the line
19 50, detector 44 and converter circuit 46. Next, at a
20 calibration step 64, the intensity values of the pixels are
21 converted to corresponding brightness temperature values
22 using predetermined calibration values, the chopper
23 temperature TC and the chopper radiation intensity received
24 as a reference. The calibration step 64 produces respective
25 brightness temperature values T1, T2, T3, T4 for the four
26 channels for each pixel. The routine 60 then proceeds to
27 step 66 where differences between channel temperatures are
28 calculated, as required, and then at step 68, the array of
29 pixels are rearranged so they can be used to produce a
30 display for the pilot which is orientated to correspond with
31 the view that the pilot has from the aircraft. For
32 instance, the infrared image received by the detector array
33 22 may be inverted with respect to the view the pilot has
34 from the cockpit and the arrangement of the pixels
35 representative of the image would need to be inverted before
36 being used to display the image.

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1 After the pixels have been mapped to a desired
2 orientation at step 68, information concerning position of
3 the horizon line is inserted in the pixel array at step 70.
4 The position of the horizon line is determined at step 70 on
5 the basis of altitude, pitch and bearing signals received by
6 the microprocessor 48 from the cockpit. The pixels are then
7 analysed in a warning lamp processor routine 72 and used in
8 a video signal production step 74. The warning lamp
9 processor routine 72 analyses pixel arrays to determine
10 whether an ash cloud, sulphur dioxide or clear air
11 turbulence is present ahead of the aircraft and activates
12 respective warning lamps 77, 79 and 81, accordingly. At the
13 video signal production step 74, selected values of the
14 pixels are used to generate Red, Green and Blue (RGB)
15 signals which are supplied to the video display unit 56.
16 How the temperature values are used to generate the RGB
17 signals depends on the result of the analysis by the warning
18 lamp processor routine 72. For example, if the difference
19 between the temperature of the fourth channel and that of
20 the third channel is negative the value of the difference is
21 used to generate a Red signal at step 74 of the routine 60,
22 whereas if the difference is positive the value of the
23 difference is used to produce a Green signal. If, however,
24 there is no difference between channels three and four for
25 the pixel, and the value of channel four indicates a cloud
26 is not present, the value of channel four is used to
27 generate a Blue signal, whereas if the value indicates a
28 cloud is present, the value is used to generate a Red Green
29 and Blue signal, together so as to produce a black colour on
30 the display 56. The display unit 56 also may only be
31 activated when an alarm condition occurs. After steps 72
32 and 74, the routine 60 proceeds back to step 62.

33

34 The pixels of the array are analysed consecutively by
35 the warning lamp processor routine 72, as shown in Figure 8.
36 The routine 72 begins at step 76 where the brightness
37 temperatures are extracted from the current pixel and a

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1 previously stored brightness temperature TB for the
2 background 8 is retrieved, together with threshold values
3 for the detection of an ash cloud, sulphur dioxide gas, and
4 clear air turbulence, TA, TS, TC, respectively. The
5 threshold values in a number of instances would be
6 approximately 0. The temperature TB and the threshold
7 values TA, TS and TC are determined by the microprocessor 48
8 on the basis of information concerning the position and
9 orientation of the aircraft, such as altitude, pitch and
10 latitude.

11

12 The routine 72 then proceeds to step 78 where a
13 comparison is made between the temperature of the fourth
14 channel and the background temperature. If T4 is less than
15 TB this indicates the pixel corresponds to a cloud and the
16 routine 72 proceeds to step 80 where the difference between
17 the temperatures of the third and fourth channels is
18 compared with the ash threshold TA. If the difference is
19 greater than TA an Ash count is incremented at step 82,
20 otherwise an ice/water count W is incremented at step 84.

21

22 If the pixel is determined at step 78 not to relate to
23 a cloud, the routine 72 proceeds to step 86 where the
24 difference between the brightness temperature of the second
25 channel and the fourth channel is compared with the sulphur
26 dioxide threshold TS. If $T2 - T4 > TS$ this indicates the
27 atmosphere corresponding to the pixel contains sulphur
28 dioxide particles and a sulphur dioxide counter S is
29 incremented at step 88. If the comparison at step 86 does
30 not prove positive, a comparison is made at step 88 with
31 respect to the difference between the temperature of the
32 first channel and the temperature of the fourth channel and
33 the clear air turbulence threshold TC. If $T1 - T4 > TC$, this
34 indicates the atmosphere corresponding to the pixel includes
35 clear air turbulence and a clear air turbulence counter C is
36 incremented at step 92.

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After steps 88, 92, 90, 82 and 84, the routine proceeds to a step 94 where the values of the counts are examined to determine if any anomalies exist, such as a count exceeding the total number of pixels for an array and then at step 96, a check is made to see if all of the pixels of an array have been processed. If all of the pixels have not been processed, the routine 72 proceeds to step 76, otherwise the routine executes four decision steps 98, 100, 102 and 104. At step 98, if the ash count A exceeds an ash cloud existence threshold, a volcanic ash cloud exists ahead of the aircraft and a corresponding red warning lamp 77 is illuminated in the cockpit to alert the pilot. Similarly, at steps 100 and 102, if the sulphur dioxide and clear air turbulence counts S and C exceed corresponding existence thresholds, corresponding red warning lamps 79 and 81 are illuminated in the cockpit accordingly.

If one of the decision steps 98, 100 or 102 produces a positive result and a red warning lamp is illuminated, an activation flag is set and the routine 72 passes operation of the processor 48 to the video signal production step 74, and all of the counts A, W, S and C are reset. In response to the activation flag being set, the video display unit 56 is activated and a display generated, which provides the pilot with a visual representation of the location of the adverse condition detected relative to the aircraft. The display viewed by the pilot when a volcanic ash cloud 2 is present is similar to that illustrated in Figure 1, where a horizontal line 9 will be placed across the display, the semi-transparent region 4 would appear in a shade of red and the centre region 6 appears black. The background 8 is coloured a shade of blue. As the pilot moves the aircraft relative to the cloud 2 to avoid the cloud the display is updated accordingly so as to show the pilot's movement away from the cloud 2.

The presence of sulphur dioxide gas, if detected, could also be displayed. However, detection of the gas would normally be used as confirmation that a volcanic ash cloud exists ahead of the aircraft. The clear air turbulence anomalies, when detected, are displayed on the visual display unit 56 as colour encoded

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variations in the intensity of the signals received on the 6.3 μm channel.

For adverse atmospheric conditions at a range of 100 km and with the aircraft travelling at an airspeed of 600 km/hour, the detection system provides
5 approximately ten minutes warning to the pilot.

At step 104 of routine 74, a decision can be made as to whether the state of the ice/water count W indicates a cloud ahead of the aircraft is a water/ice cloud and a display of the cloud can be provided if desired. The cloud would be
10 displayed in a similar manner to a volcanic ash cloud, as described above, except the semi-transparent region 4 would appear green. To indicate the system is functioning correctly a series of green lamps are provided for each adverse condition capable of being detected. The green lamps are illuminated if none of the adverse conditions are present ahead of the aircraft.

15
A detection unit similar to the detection unit 10 described above was placed in an aircraft and tested during 8 to 14 December 1990 over Hobart in the State of Tasmania. The unit was placed in the port wing of the aircraft and mounted so as to receive radiation in front of the aircraft. At an altitude of 12000 feet the aircraft
20 was directed to view horizontally clear sky and then at 10000 feet was directed to view horizontally a cumulus cloud. Readings were obtained by the unit over a 10 to 12 μm wavelength range as illustrated in Figures 9 and 10. The data points represent an average of 5 to 10 seconds of data received and the error bars represent the standard deviations about the means. Figure 9 illustrates the radiation
25 received from the clear sky which was seen to decrease from 10.2 μm to minimum near 10.8 μm and then again increase towards 12.0 μm . The warmer sky at 10.2 μm is due to radiation received from a warm band of ozone centred at 9.6 μm . The radiation received from the cumulus cloud is illustrated in Figure 10 and shows the cloud appears to be warmer at longer wavelengths. The two examples
30 demonstrate that a detection unit 10 directed horizontally towards clear and/or cloudy skies experiences a marked increase in radiation received from the 10.8 μm

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to 11.9 μm wavelengths.

Between 3 and 18 March 1991, another detection unit, similar to the detection unit 10 described previously, was tested at the Sakurajima Volcanological Observatory (SVO), Arimura, Mt Sakurajima on the south Japanese island of Kyushu. The unit was mounted for ground based viewing of volcanic ash clouds produced by eruptions from the Mt Sakurajima volcano. The detection unit was mounted to view the ash clouds substantially horizontally and at various elevations and Azimuth angles, in a similar manner as the clouds would be viewed ahead of an aircraft in flight. The results are illustrated in Figures 11 to 14 and the heading of each Figure indicates the local time at the start of the measurement cycle, the date, the location, the type of cloud being viewed, the elevation angle (El in degrees) and the Azimuth angle (Az in degrees) of the detection unit. Figure 11 shows the brightness temperatures corresponding to infrared radiation received at 10.8 μm and 11.9 μm from a volcanic cloud approximately 3 km away. The brightness temperature at 10.8 μm is clearly greater than that at 11.9 μm . The volcanic cloud was laden with ash. A second example is illustrated in Figure 12 for a dispersed volcanic cloud. Brightness temperatures were obtained for the 10.2 μm and 12.0 μm wavelengths and again the brightness temperatures for the shorter wavelength were distinctly greater than those for the longer wavelength. The detection of sulphur dioxide to confirm the presence of a volcanic ash cloud was also tested and Figure 14 shows brightness temperatures as a function of time for five infrared wavelengths whilst the detection unit was used to view a water cloud. The wavelengths examined included 8.7, 10.2, 12.0, 10.8 and 11.9 μm . For the water cloud, it is clear that the brightness temperature at 8.7 μm is lower than that at 11.9 or 12.0 μm . Whereas when viewing a volcanic ash cloud the brightness temperature at 8.7 μm is greater than the signals for all of the other channels, as indicated by the results illustrated in Figure 13. The enhanced signal at 8.7 μm is due to emission from sulphur dioxide and this was confirmed by measurements taken at the same time from a correlation spectrometer, which indicated that there was large amounts of silicon dioxide in the Mt Sakurajima volcanic clouds.

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The Japanese tests described above clearly demonstrated that a detection unit 10 directed substantially horizontally towards volcanic ash clouds experiences a marked decrease in radiation received from the 10.2 μm to the 12.0 μm wavelengths, and that the 8.7 μm channel can be used to detect the presence of

5 sulphur dioxide.

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CLAIMS:

1. A detection system for use in an aircraft, comprising detecting means (10) for monitoring atmospheric conditions ahead of said aircraft, generating an alarm
5 signal if adverse atmospheric conditions exist ahead of said aircraft, and generating information which indicates the position of said adverse conditions so the adverse conditions can be avoided.
2. A detection system as claimed in claim 1, wherein the adverse conditions
10 include a volcanic ash cloud, a high density of sulphur dioxide gas and/or clear air turbulence.
3. A detection system as claimed in claim 1 or 2, wherein said detecting means (10) is adapted to generate video display signals for producing a video
15 display which indicates the position of said adverse conditions relative to said aircraft.
4. A detection system as claimed in claim 1, 2 or 3 wherein said detecting means (10) includes means (16, 20, 22, 24) for monitoring infrared radiation
20 received by said aircraft, filter means (34, 42, 46) for generating intensity signals representative of at least one predetermined wavelength of said radiation, and processing means (48) for comparing the intensity signals with reference signals or intensity signals of another infrared wavelength and generating an adverse condition warning signal if the results of said comparison indicates said adverse
25 conditions are present.
5. A detection system as claimed in claim 4, wherein said warning signal is generated if said intensity signals indicate radiation received of a longer wavelength is less than radiation received of a shorter wavelength.
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6. A detection system as claimed in claim 5, wherein said wavelengths fall

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with the range of 10 to 12 μm .

7. A detection system as claimed in claim 6, wherein said monitoring means (16, 20, 22, 24) includes an infrared detector array (22) and said intensity signals
5 relate to pixels of said array, such that intensity signals of each of said wavelengths correspond to each one of said pixels, and said processing means (48) generates display signals representative of the position of said adverse conditions relative to said aircraft on the basis of said intensity signals and position signals representative of the position of said aircraft.
- 10 8. A detection system for an aircraft, comprising means (10) for detecting the presence of a volcanic ash cloud ahead of said aircraft, and means (48, 52, 54, 66) for alerting a pilot of said aircraft to the presence of said cloud.
- 15 9. A detection system as claimed in claim 8, including means (48), responsive to detection of said ash cloud, for generating information representative of the position of said ash cloud relative to said aircraft.
- 20 10. A detection system as claimed in claim 9, wherein said alerting means (48, 52, 54, 56) includes means for generating display signals for producing a display of said information.
- 25 11. A detection system as claimed in claim 8, 9 or 10 wherein said detecting means (10) is also able to detect the presence of sulphur dioxide and/or clear air turbulence.
- 30 12. A detection system as claimed in claim 8, 9 or 10, wherein said detecting means (10) and alerting means (48, 52, 54, 56) include means (16, 20, 22, 24) for monitoring infrared radiation received by said aircraft, filter means (34, 42, 46) for generating intensity signals representative of the intensity of predetermined wavelengths of said radiation, and processing means (48) for comparing the



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intensity signals of two of said predetermined wavelengths and generating a volcanic ash cloud warning signal if the results of the comparison indicate an ash cloud is present.

- 5 13. A detection system as claimed in claim 12, wherein said warning signal is generated said intensity signals indicate radiation received of the longer wavelength is less than radiation received of the shorter wavelength.
14. A detection system as claimed in claim 13, wherein said monitoring means
10 (16, 20, 22, 24) includes an infrared detector array (22) and said intensity signals relate to pixels of said array, such that intensity signals of each of said predetermined wavelengths correspond to each one of said pixels and said processing means (48) generates display signals representative of the position of said ash cloud relative to said aircraft on the basis of said intensity signals and
15 position signals representative of the position of said aircraft.
15. A detection system as claimed in claim 7 or 14, wherein said processing means (48) executes said comparison for each of said pixels and a count is adjusted when the difference between the intensity signals, corresponding a
20 respective pixel, of said longer wavelength and said shorter wavelength is negative, and said warning signal is generated when said count exceeds a predetermined threshold.
16. A detection system as claimed in claim 15, wherein said longer wavelength
25 and said shorter wavelength, which relate to the detection of volcanic ash cloud, are approximately 12 μm and 10 μm , respectively.
17. A detection system as claimed in claim 16, wherein said predetermined
30 wavelengths include approximately 9 μm which relates to the detection of sulphur dioxide.

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18. A detection system as claimed in claim 16 or 17, wherein said predetermined wavelengths include approximately 6 μm which relates to the detection of clear air turbulence.

5 19. A detection system as claimed in claim 18, wherein said processor means (48) generates a clear air turbulence warning signal when said intensity signals indicate a cloud is not ahead of said aircraft and said intensity signals indicate radiation received for said 6 μm wavelength is greater than radiation received for said 12 μm wavelength.

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20. A detection system as claimed in any one of claims 14 to 19, wherein said display signals are generated when said processing means (48) determines said ash cloud is present.

15 21. A method of detecting adverse atmospheric conditions in an aircraft, comprising monitoring atmospheric conditions ahead of said aircraft, generating an alarm signal if adverse atmospheric conditions exist ahead of said aircraft, and generating information which indicates the position of said adverse conditions so the adverse conditions can be avoided.

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22. A method as claimed in claim 21, wherein the adverse conditions include a volcanic ash cloud, a high density of sulphur dioxide gas and/or clear air turbulence.

25 23. A method as claimed in claim 21 and 22, including generating a display which indicates the position of said adverse conditions relative to said aircraft.

24. A method as claimed in claim 21, 22 or 23, including monitoring infrared radiation received by said aircraft, generating intensity signals representative of at
30 least one predetermined wavelength of said radiation, comparing the intensity signals with reference signals or intensity signals of another infrared wavelength

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and generating an adverse condition warning signal if the results of said comparison indicates said adverse conditions are present.

25. A method as claimed in claim 24, wherein said warning signal is generated
5 if said intensity signals indicate radiation received of a longer wavelength is less than radiation received of a shorter wavelength.

26. A method as claimed in claim 25, wherein said wavelengths fall with the range of 10 to 12 μm .

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27. A method as claimed in claim 26, wherein said monitoring step involves using an infrared detector array and said intensity signals relate to pixels of said array, such that intensity signals of each of said wavelengths correspond to each one of said pixels, and display signals representative of the position of said adverse
15 conditions relative to said aircraft are generated on the basis of said intensity signals and position signals representative of the position of said aircraft.

28. A method as claimed in claim 27, wherein said comparison is performed for each of said pixels and a count is adjusted when the difference between the
20 intensity signals, corresponding a respective pixel, of said longer wavelength and said shorter wavelength is negative, and said warning signal is generated when said count exceeds a predetermined threshold.

29. A method as claimed in claim 28, wherein said longer wavelength and said
25 shorter wavelength, which relate to the detection of volcanic ash cloud, are approximately 12 μm and 10 μm , respectively.

30. A method as claimed in claim 29, wherein said predetermined wavelengths include approximately 9 μm which relates to the detection of sulphur dioxide.

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31. A method as claimed in claim 29 or 30, wherein said predetermined

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wavelengths include approximately 6 μm which relates to the detection of clear air turbulence.

32. A method as claimed in claim 31, including generating a clear air
5 turbulence warning signal when said intensity signals indicate a cloud is not ahead of said aircraft and said intensity signals indicate radiation received for said 6 μm wavelength is greater than radiation received for said 12 μm wavelength.

33. A method as claimed in any one of claims 27 to 32, wherein said display
10 signals are generated when said ash cloud is present.

34. An aircraft comprising a detection system as claimed in any one of claims 1 to 20.

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