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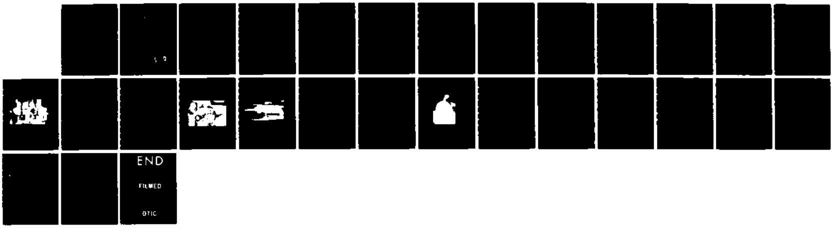

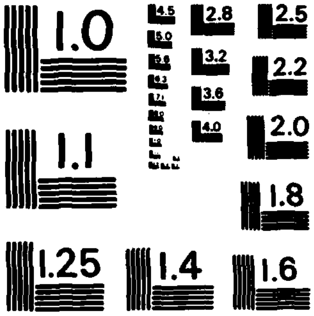

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AIRSPEED AND WIND SHEAR MEASUREMENTS WITH AN AIRBORNE CO$_2$ CONTINUOUS WAVE LASER

by

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SUMMARY

The Laser True Airspeed System (LATAS) developed by the RAE and RSRE and installed on the RAE HS 125 research aircraft is described. It has proved exceptionally reliable and rugged. Examples of results are presented including a climb to 43000 ft; flight through a severe thunderstorm wind shear (microburst); pressure error measurements; and signals observed in cloud, heavy rain and from solid objects such as the ground. The paper concludes with some thoughts on other potential applications such as using the sensor for an intelligent autothrottle; for measuring cross-flow velocities; for measuring tyre and ground speeds to save tyre wear; and as a combined air data and ground velocity system for helicopters (including a facility to maintain a steady hover).

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1 INTRODUCTION

Since about 1970 the RAE have been collaborating with RSRE in the design and testing of CO_2 Continuous Wave (CW) laser Doppler systems (sometimes known as laser radars or LIDARS) for wind measurements. The main aim initially was to establish the feasibility of using these systems to make remote measurements of the wind so that very large changes (wind shear) can be identified. The first system tested was ground based (Fig 1) and housed in a lorry with an accompanying caravan to hold the data processing equipment. The system used telescopes with a primary reflector of 30 cm diameter and worked out to ranges of about 1 km. However, in common with many similar systems, it required frequent attention to maintain the optical system aligned and the laser tuned to the P(20) line without any interference from nearby off-axis modes. Despite these problems the system could be kept aligned and stable for a day or two without adjustment, and its effectiveness in detecting wind shear was very good. This led to the development of a compact and reliable system for flight tests in the RAE HS 125 aircraft. This Laser True Airspeed System (LATAS)[1-3] has now been flying in the RAE HS 125 for 2.5 years and this paper will describe the system and some experiences with it. The system has proved to be both rugged and reliable. The goal of a CO_2 heterodyne system that can be switched on like a light bulb and requires no adjustments has at last been achieved.

The test results have shown that systems of this type could be used for many different tasks in aviation and this paper concludes with the authors thoughts on some of these possible applications.

2 THE LATAS SYSTEM

The various components of the LATAS system are shown in Fig 2. All of these items are of UK manufacture and, although they are for an experimental system, they have been put through many of the vibration and temperature tests required for production equipments. Most of the items were very advanced when specified back in 1978 but are now readily available. The three most important items are the Optics Head, Surface Acoustic Wave (SAW) Spectrum Analyser and the Video Integrator.

The Optics Head was designed and built at RSRE. Its general layout is shown in Fig 3. The main beam from the 3 watt Ferranti Wave Guide Laser is transmitted through a germanium plate set at the Brewster angle and then focussed at a given distance using a remotely adjustable expanding lens. The returning signal is received through the same lenses and after a change of polarisation it is reflected off the germanium plate. This signal is then mixed with a small proportion of the main beam and focussed onto the Mullard CMT detector. The detector has a frequency response better than 100 MHz and is cooled to -196 K using high pressure pure air or 'white spot' nitrogen.

The coaxial monostatic system, with the same optics for transmitter and receiver, is particularly convenient and also tends to minimise effects of beam distortion when propagating through an inhomogeneous atmosphere. Detailed studies have been made of the optimum choice of system parameters, and also of theoretical and experimental signal to noise ratio with calibrated standard targets[4]. These show that within experimental error the equipment performs at the ideal quantum limited level with no unaccountable losses.

The beam waist, from which the strongest return signals are received can be set at distances up to nearly 300 m ahead of the output lens, which is only 15 cm in diameter. The dc current level from the detector is directly related to the power in the local oscillator beam and provides a convenient measure of the main laser power. The dc current is also used in an electronic locking loop to maintain the laser automatically on the P(20) transition by inserting a very narrow band optical filter, which transmits the P(20) line, in the local oscillator path.

The Optics Head (Fig 4), is shown here installed in the nose of the HS 125, where the infra-red beam is transmitted through a 20 cm diameter germanium window (Fig 5) with a special diamond-like surface coating to withstand abrasion and insect and raindrop impact (manufactured by Barr and Stroud). The Optics Head also includes the HT power supplies for the laser and the complete unit is only 68 × 32 × 29 cm. Cooling is from a simple radiator and fan assembly and is used, together with a 100 watt heater mat, to maintain the laser between about 25°C and 45°C. This has proved adequate for ambient temperatures from -60°C to 35°C.

The output from the detector travels about 12 m back to the MESL (Racal-Decca) SAW Spectrum Analyser in the cabin of the HS 125. A sample of 25 ms is taken by the SAW and transformed within a further 35 ms into the frequency plane and transmitted to the Video Integrator. The SAW has a total bandwidth of 25 MHz and with four switchable frequency offsets can cover the frequency range up to 62.5 MHz. 1 MHz is equivalent to just over 10 kn so this gives a true airspeed range of up to 635 kn, with an ample 50% overlap between each of the four bands.

In the Video Integrator, which was made by Cambridge Consultants Ltd (CCL), the transformed signal from the SAW is converted into a frequency spectrum with 834 channels that are each 30 kHz wide. To improve the signal to noise ratio for low signals the Integrator will then accumulate a succession of SAW samples. The number of integrations may be set between 1 and 16000 on the airborne system. With 100 integrations for a single sample the overall sample rate can be about 160 per second.

In the aircraft system, the spectrum from the Integrator is then processed in another CCL unit to measure the main features of the velocity signature. This summary of the total spectrum and many other items describing the configuration of the laser system are then transferred to displays and the recording system. The form of the signal obtained from the system at various stages is shown in Fig 6. The strongest signal comes from the region where the illumination is greatest and thus the velocity of the peak of the frequency spectrum is usually that of the air at the beam waist. The maximum and minimum frequencies of the spectrum correspond to the highest and lowest velocities within the range where signals are detectable. In the LATAS system these are measured by the spectrum width and average ('centroid') velocity at an adjustable level below the peak. All these measurements together with the height of the spectrum are made in real time on the aircraft. These numbers and the complete spectrum are displayed in the cabin and recorded on the Plessey PV 1513 digital recording system for further analysis. Fig 7 shows a typical velocity spectrum recorded in calm air at a height of 13310 ft. The spectrum is clear and unambiguous. This remains true even for small signal levels and makes the identification of the loss of signal very straightforward.

3 FLIGHT TEST RESULTS

Two aspects of the flight test results are described in this section:

(i) system reliability, and

(ii) results from a variety of different measurements.

3.1 Reliability

A principle aim of the RAE/RSRE research has been to demonstrate that the LATAS system is both effective and reliable as a means for measuring air velocities. Normally one would anticipate that a 'one off' experimental system such as this would be less reliable and require more frequent adjustment than an eventual production version. It was therefore a very pleasant surprise to find that:

(a) The system has never needed any adjustment except after changing the laser. (The system has currently been operating for 12 months without any adjustment.)

(b) The 20 cm germanium window in the nose of the aircraft, Fig 8, shows no sign of any damage to its diamond-like coating after over 2 years of flying, which included flights through soft hail.

After a few months of initial teething troubles the system has only suffered four failures in 2.5 years. Two of these were minor laser related faults and two were failures of power supplies to the signal processing equipment.

One subjective measure of the reliability of the system is that it has been demonstrated in flight on 15 occasions to outside parties and has never had a failure. The authors believe that a reliable production version of the LATAS system can be made now using current technology and available UK equipment.

3.2 LATAS measurements

Four different types of measurements have been chosen to illustrate the capability of the system. These are:

(i) A climb to 43000 ft to show the sensitivity in very clear visibility conditions.

(ii) A severe thunderstorm wind shear measured during the Joint Airport Weather Studies (JAWS) at Denver, USA in July 1982.

(iii) Aircraft pressure error measurements.

(iv) Return signals in clouds, rain and from the ground.

3.2.1 Climbs

If a laser is to be used for measuring essential flight data then it must always produce a usable signal and any failures must be easily identified. Part of the research programme at the RAE has been to find the atmospheric conditions under which the laser is unable to provide a signal and to measure the backscatter coefficient of the atmospheric particles. The signal received at the detector comes from scattering off particles (aerosols), which can be as small as a few tenths of a micron and still produce adequate reflections, but if no particles are present then no signal is returned. Visibility at normal optical frequencies is not always a good guide to either the presence of aerosols or the ability of the infra-red beam from the laser to penetrate to the required distance in, say, fog, rain or smoke. Laser signals have been recorded during climbs to the ceiling of the HS 125 (43000 ft) on many flights and Fig 9 shows an example taken on a climb out of Denver in the USA on a very clear summer morning. The visibility at the surface was over 80 miles and there were no clouds. Despite the clear conditions the laser produced a strong signal near the ground and was only briefly lost during the climb. The strong return at 33000 ft later became a visible layer of cirrus cloud. It is noticeable that the signal increased towards the top of the many small temperature inversion layers and then fails suddenly as the aircraft passes up through the top of the layer. Some of the clearest conditions occur just above the strong surface inversion layer which is fairly common in the UK during the winter. As height increases further then the signal usually returns. Comparison of laser signals with meteorological data from Radiosonde ascents shows that the laser signal increases significantly when the relative humidity increases.

During the JAWS programme a flight was made together with a meteorological research aircraft from the University of Wyoming, which is equipped with particle measuring equipment. In a climb to 23000 ft the number of particles greater than 0.5 μm fell to zero although the LATAS was still producing a low but clearly detectable signal.

The measurements using LATAS give unique detailed information on the variation of backscatter in different atmospheric conditions. Such information will assist in the initial specification and interpretation of results from the proposed international 'Windsat' meteorological satellite, which plans to use infra-red lasers to measure winds at different levels in the atmosphere.

To summarise, the LATAS system is very sensitive and has always had strong signals within a few thousand feet of the ground. At greater heights there may be regions where no signal is discernible.

3.2.2 Thunderstorm wind shear

Initial interest in the LATAS system was in its potential to meet the need for a sensor to measure large changes of wind before an aircraft encounters them. Action can then be taken to alleviate the dangers of these wind shears. At present wind shear is responsible for the loss of about two airliners each year. The most recent was in thunderstorm conditions in July 1982 at New Orleans and killed 153 people (all 145 people in the aircraft and 8 on the ground), and seriously injured 9 people on the ground[5]. The aircraft had just taken off and crashed into a residential area ¾ n mile from the airport. At the time of this tragic accident the RAE HS 125 was near Denver, Colorado investigating the nature of the severe wind shears which are associated with thunderstorms. The aircraft with its LATAS system was taking part in the Joint Airport Weather

Studies (JAWS) project which was sponsored by the US National Center for Atmospheric Research (NCAR), the University of Chicago and the US Federal Aviation Agency (FAA). The project has amassed a wide range of data on thunderstorm and other severe weather events from a comprehensive set of ground based sensors, including laser and Doppler radars, and aircraft from the National Oceanic and Atmospheric Agency (NOAA), NCAR, the National Aeronautics and Space Administration (NASA), University of Wyoming and the RAE.

Among the many events recorded by the RAE HS 125 were several severe downbursts such as that shown in Fig 10. This is the type of wind shear that is believed to have caused the New Orleans, and several earlier accidents. The main features are the very large (nearly 40 kn) and rapid changes of headwind and the strong downdraught of about 1200 ft/min. The downdraught is shown in Fig 10 by the 3° increase in the average pitch attitude used to maintain height. If the HS 125 had been flying at the much lower speeds used for landing and take-off then this wind shear would have resulted in a large loss of height. Fig 11 shows a model of the flow in a microburst developed from a vortex ring model suggested by Caracena at a wind shear workshop at the University of Tennessee Space Institute, USA in October 1982. This model is able to explain several features that were observed from the HS 125 during the JAWS flights, such as dust curtains rising to over 1000 ft around the perimeter of several microbursts. This could not be explained by the more usual vertical jet model which would produce dust blowing radially from the centre of the microburst with very little tendency to rise. The vortex ring model also produces intense downflows near the ground and, by keeping the energy of the flow contained, it requires less total energy to produce large velocities than the jet model. It also explains the smaller peaks in horizontal velocity observed (Fig 10) at the beginning and end of the microburst at 36 and 54 seconds. This suggests that the HS 125 penetrated the microburst just below the upper vortex ring. The aircraft was at a safe height of about 1000 ft above the ground. Fig 12 shows the LATAS system measuring the same wind shear just over 2 seconds before it reaches the aircraft, which is equivalent to 250 m distance. The width of the spectrum peak is also interesting as it clearly differentiates between small scale turbulence and significant wind shear. This point is seen more clearly in Fig 13 which shows a sequence of signal spectra from the same time history. By following the sequence it is possible to see each changing wind entering and leaving the tube illuminated by the laser. This tube reaches out to about 700-800 m ahead of the aircraft.

The LATAS sensor has two unique advantages over other airborne sensors:

(i) it can measure wind at a known distance ahead of the aircraft, and

(ii) it can measure the change of wind over distances up to nearly three times its measuring distance.

The range to the beam waist of only 250 m may seem quite short. It corresponds to about 4 seconds lead at typical jet transport landing speeds. However, the aim is to provide a system which will enable safe penetration of wind shear. If the wind is measured too far ahead of the aircraft, then any wind shear can change with time or may move sideways relative to the aircraft. Thus there will be only a limited band of distances which will give adequate lead without giving a significant amount of false data. To help identify a suitable distance a laser sensor was simulated during studies of wind shear effects on aircraft. The results showed, Fig 14, that there was a significant advantage in controlling the aircraft using the airspeed measured by a laser at 300 m ahead, but that increasing that distance to 600 m produced no further improvements. On the basis of these tests the maximum range to the beam waist was specified as 300 m for the LATAS system.

The ability of the laser to identify the maximum difference in wind speed over a distance of about 800 m gives it a unique ability to separate wind shear from turbulence before the disturbance reaches the aircraft. This is a capability that autothrottle designers have been seeking for some time. The main problem is that the only speed signal available on all aircraft is airspeed and control of this is essential for large wind variations. But it is not possible to differentiate between large changes and small changes until after they have happened at the sensor. This means that autothrottle systems may on the one hand be sensitive to all airspeed changes, resulting in the discomfort and wear and tear associated with the throttles chasing the smallest changes, or alternatively the system only responds to large changes, making it sluggish. Some improvement can be obtained by using accelerometers to maintain a ground speed until airspeed changes exceed certain limits. However, these systems still require the airspeed of the aircraft itself to change significantly before they respond. The LATAS system can identify a large shear well ahead of the aircraft and even before it reaches the beam waist. This means that throttle activity can be restricted to the conditions where it is really needed without introducing additional lag. A laser system thus provides the signals for an intelligent autothrottle, which will be responsive without unnecessary engine activity.

The wind shear research programme at RAE Bedford has considered various ways in which the signals from the LATAS (and several more conventional sensors) can be presented to the pilot and automatic control systems and allow safe operations in the presence of severe wind shear.

3.2.3 Pressure error measurements

The LATAS system measures airspeed ahead of the aircraft, where it is not affected by the airflow around the fuselage and wings. With the usual air pressure sensors (pitot and static pressure) it is reasonably easy to measure the freestream pitot (stagnation) pressure, but the static pressure measured at the aircraft is usually different from the freestream static pressure. Static pressure (Fig 15) for a given aircraft configuration is a function of freestream speed, pressure, temperature and direction. By very careful choice the static pressure ports can be located where the difference from freestream pressure is small, particularly at normal cruise and landing configurations. However, all height standards for safe separation from the ground and other aircraft depend on static pressure measurements, which are converted into a pressure height. To ensure that all aircraft display the same height scale, they have to be calibrated to measure the pressure error (pe) of each model of an aircraft throughout its full height and speed range.

The present methods of calibration rely on comparison with a reference pressure measured by a calibrated aircraft which uses photography to establish any height differences (or similar flights past ground based tracking towers), or comparison with measurements from a towed static sensor (trailing static), which is on a long enough tow to be outside the influence of the aircraft. This latter method requires a major installation on the test aircraft.

The tower fly-by at low altitude is satisfactory and convenient, but can only cover a very limited part of the flight envelope. Flights with a calibrated aircraft are costly and difficult (eg the range of speeds of the two aircraft will rarely be the same).

With the LATAS measuring the undisturbed freestream speed and the ability to measure the true stagnation pressure at the aircraft, only a measure of freestream temperature is required to derive the freestream static pressure. Like stagnation pressure the freestream stagnation temperature is also reasonably easy to measure on an aircraft. The freestream static pressure, p_0 , is then given, in subsonic flow, by

$$p_0 = p_t\left(1 - \frac{V_t^2}{7592T_t}\right)^{3.5}$$

where p_t = freestream stagnation pressure

V_t = freestream true airspeed, kn

T_t = freestream stagnation temperature, K.

Thus from the measured static pressure, p , the fundamental pressure coefficient, C_p at the static ports and its variation with flight conditions of flow angles, Mach and Reynolds numbers can be determined for most of the flight envelopes relevant to different aircraft configurations (eg cruise, landing etc).

C_p is defined as

$$C_p = \frac{p - p_0}{0.7p_0M^2}$$

where M = freestream Mach number.

A system such as LATAS could be installed as, say, a temporary replacement for the weather radar and would give complete freedom to establish pressure errors throughout the full range of configurations and flight envelopes.

Tests with the system on the HS 125 are being analysed and some preliminary results at heights from 27000-33000 ft are presented in Fig 16. Data at the different heights show a similar pattern with changing incidence angle α but some of the variations with height seem to relate to individual flights. The variation of Reynolds number does not seem to correlate with these height effects. However, the level of scatter is no greater than that seen with other methods. A C_p change of 0.01 is equivalent to only 0.8 mb at the mean test conditions of 0.6 Mach number and 29000 ft height. Further tests are being analysed to establish the individual contributions from Mach and Reynolds numbers. Results will also be compared with those from calibration flights with the United Kingdom Standard (the calibrated F-4 (Phantom) operated by the Aircraft and Armament Experimental Establishment at Boscombe Down) and with tower fly-by tests.

The preliminary results with LATAS are very promising. One area where the LATAS system could be particularly useful is in determining true stall speeds and establishing the minimum safe approach speeds for new aircraft. It is essential to maintain a safe speed margin on the approach, but it is very disadvantageous to have approach speeds higher than necessary because of the increased landing distance and tyre wear.

3.2.4 Return signals from clouds, rain and the ground

Any system, such as LATAS, that probes the atmosphere must cope not only with a lack of back scattering particles, but also with conditions with high concentrations of particles. If they are very concentrated then they will obstruct the return signal and attenuate it as a function of distance. However, the signal from close range will be very strong. Rain and cloud (or fog) would produce these effects. Another important feature is any non-uniformity in the distribution of back scattering particles. Strong returns from the ground or other solid objects are obvious examples.

High particle concentration has two main effects. First, the dynamic range of return signals can be very large as the concentration varies from only a single particle in the beam to a dense cloud. Second, the attenuation of the beam and the signal with range will mean that the maximum signal will come from a region closer to the aircraft than the nominal clear air range.

With the LATAS system in its present form, the changes in number of integrations and direct signal attenuation provide a dynamic range of 28 dB (630/1). At any chosen value of integrations and attenuation the signal can be accepted with a dynamic range of 20 dB (100/1). Finally, the signal is treated as an amplitude signal but the return is really a function of powe.. Thus the total dynamic range available is about 96 dB. This has proved adequate for flight through a wide range of conditions.

In a commercial system the input to the SAW could be controlled by an automatic gain control system and it would be straightforward to optimise the number of integrations.

The attenuation caused by high particle concentration affects the range that a laser system can probe. At the infra-red wavelengths (10.6 μm) of the CO_2 laser the beam attenuation is small with sub-micron particles, such as the main constituents of smoke. This means that the laser beam can see further than the human eye. This has led to considerable interest in the use of CO_2 lasers in battlefield conditions. However, in well developed fogs, cloud and rain, the particles are much larger and in these conditions the laser may not see so much further than the human eye.

As the attenuation increases then the signal returned from different distances changes (Fig 17). With very high attenuation the return signal is very strong but its peak is at the transmitting lens. However, the laser can still detect velocity changes out to the visual range limit and it is still measuring air velocity. A typical Doppler spectrum recorded in thick cloud (Fig 18) shows the characteristic saw-tooth return caused by the air in the beam increasing in speed as it approaches the aircraft. (In other locations the air slows down and the saw-tooth would be reversed.) The laser is still providing a usable airspeed signal with an error of only a few knots and the characteristic shape of the spectrum could give a basis for a temporary warning that the laser performance is reduced. It should also be remembered that visibility must be less than about 250 m to have any significant effect and probably less than 50 m to produce the effects seen in Fig 18.

In heavy rain the visibility is very rarely less than 250 m and the airflow over the window prevents any significant layer of water attenuating the laser beam. Fig 19 shows a spectrum taken in heavy thunderstorm rain in Colorado, USA and shows no detectable effects other than a strong signal level.

Ground returns can be obtained easily with the LATAS beam set nose down. In the example in Fig 20, taken during a landing approach in tailwind conditions, the ground signal is stronger than the air signal. The relative strengths depend on the slant range to the ground. At long ranges the beam illumination on the ground will be very weak and the air signal will be stronger despite the much higher reflectivity of the ground. If the ground surface is a concrete runway, as in Fig 20, then the ground return spectrum is very narrow as there is no velocity change in the few milliseconds used to sample the Doppler signal.

4 FUTURE APPLICATIONS

The remarkable reliability and ruggedness of the experimental LATAS system has demonstrated that commercial 'fit and forget' CW Doppler laser systems are a practical proposition with the present state of the art. As mentioned earlier, the LATAS has never needed any adjustment or special treatment during over 2 years of flight trials (except for the rare occasions when the laser was changed).

Three possible applications for such systems have already been discussed, viz:

(i) Wind shear detection at distances of several hundred meters ahead of an aircraft to give time to counterbalance the response lags of the aircraft and its engines.

(ii) Intelligent autothrottle speed sensor using the ability of the laser to differentiate between turbulence and wind shear at the same time as it measures airspeed.

(iii) Pressure error measurement without any external influence on the airflow and including measurements during manoeuvres such as the approach to the stall.

Three other possible applications also spring to mind and there will doubtless be many others.

First, the LATAS system can be used in a conical scan mode to identify the two crossflow air velocities in addition to the axial flow. The frequency response will be lower but still adequate for most applications.

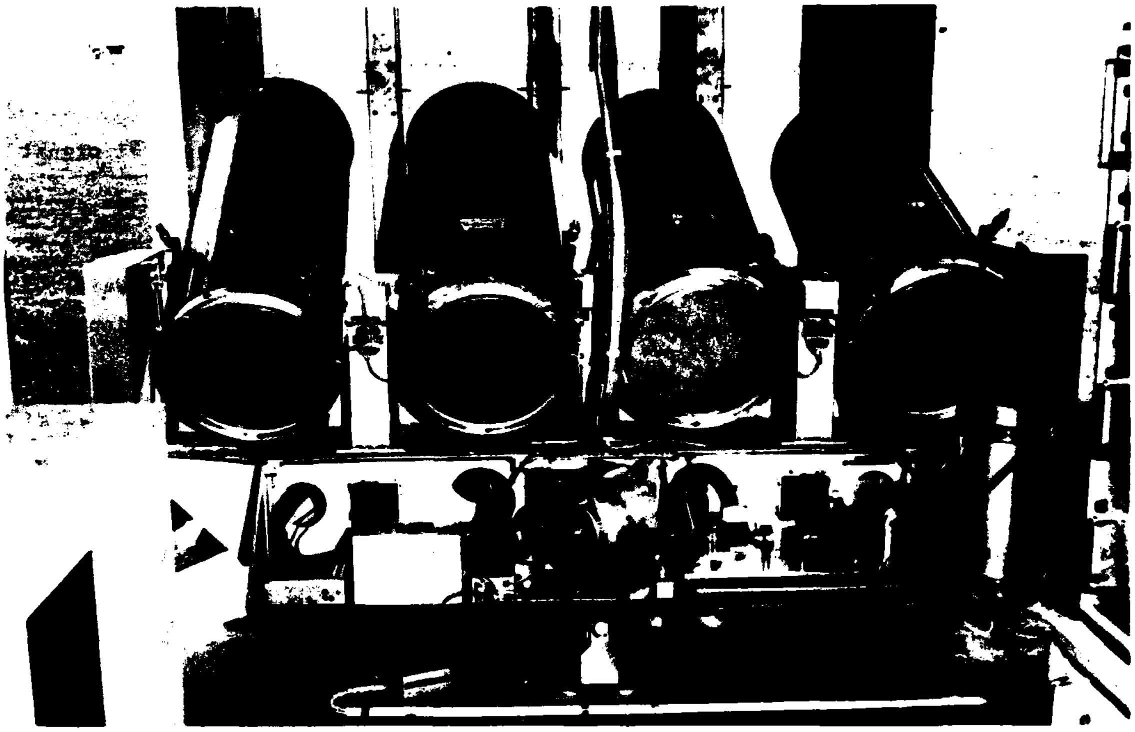

Fig 1 The combined wind and vortex experimental range (CWAVER) equipment. In one mode of operation the outgoing laser beam was switched between the four telescopes in which the range and elevation could be rapidly altered

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Fig 2

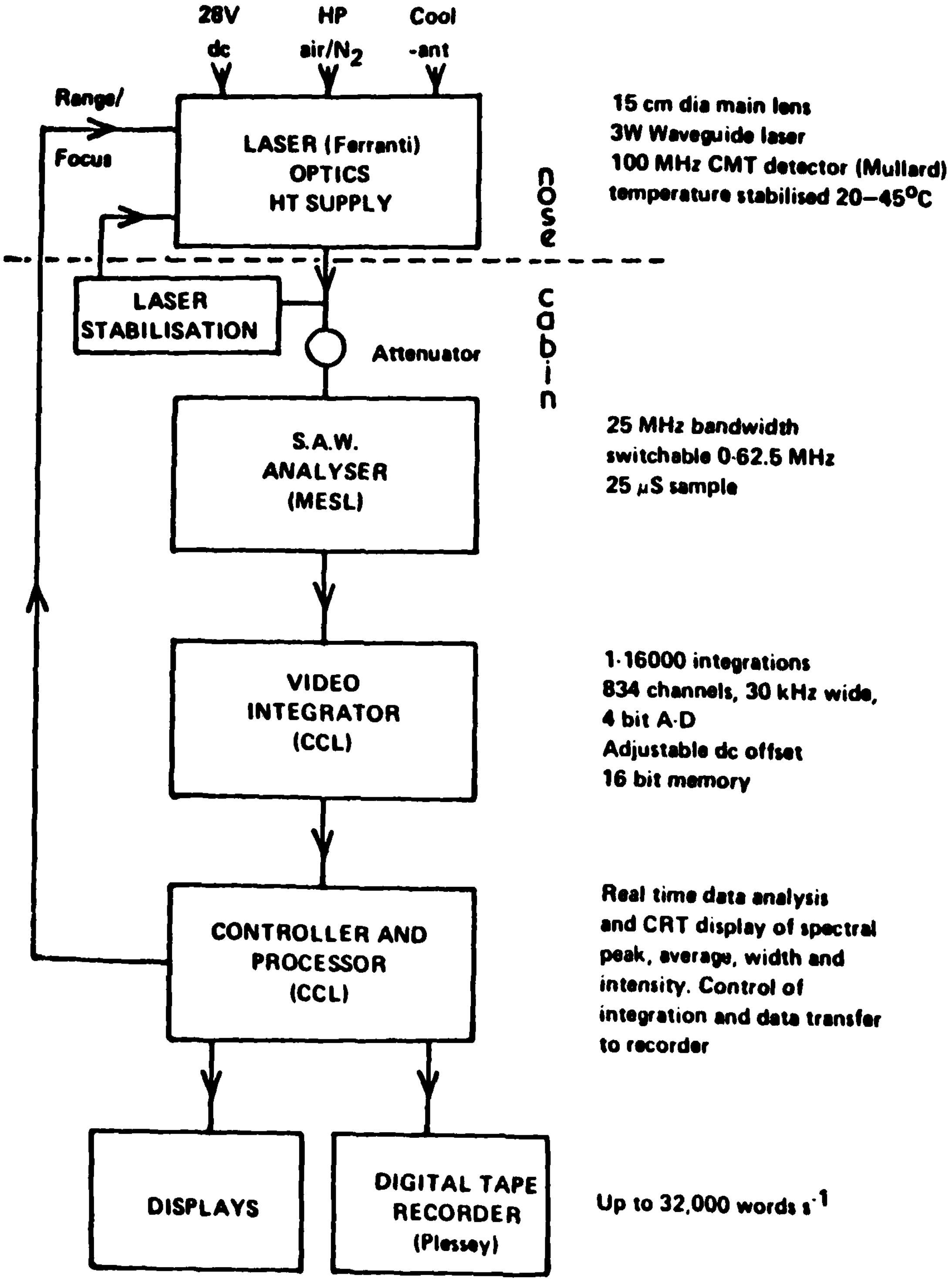

Fig 2 Block diagram of the Laser True Airspeed System (LATAS). The principal equipment parameters are shown and also (in brackets) the manufacturers.

Fig 3

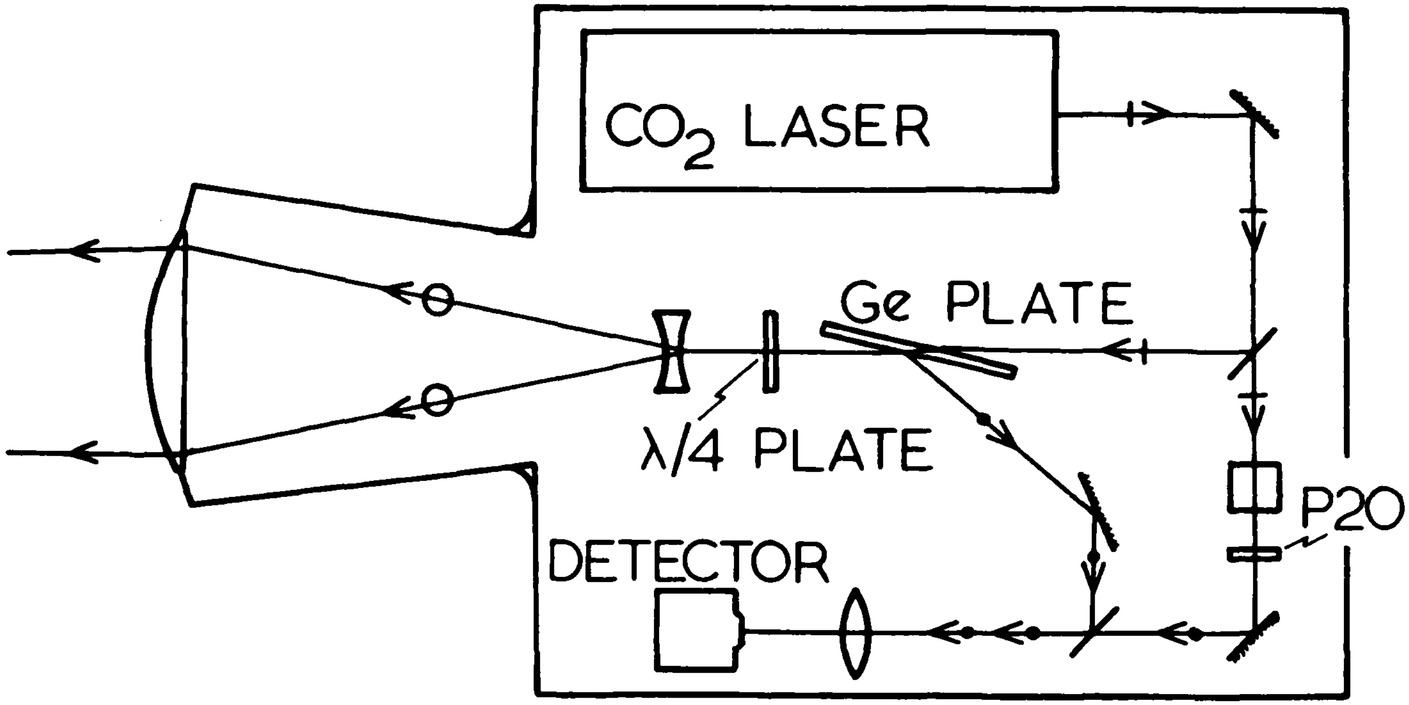

Fig 3 The layout of the Optics Head in the LATAS equipment. Polarisation techniques and germanium and quarter wave plates promote good efficiency

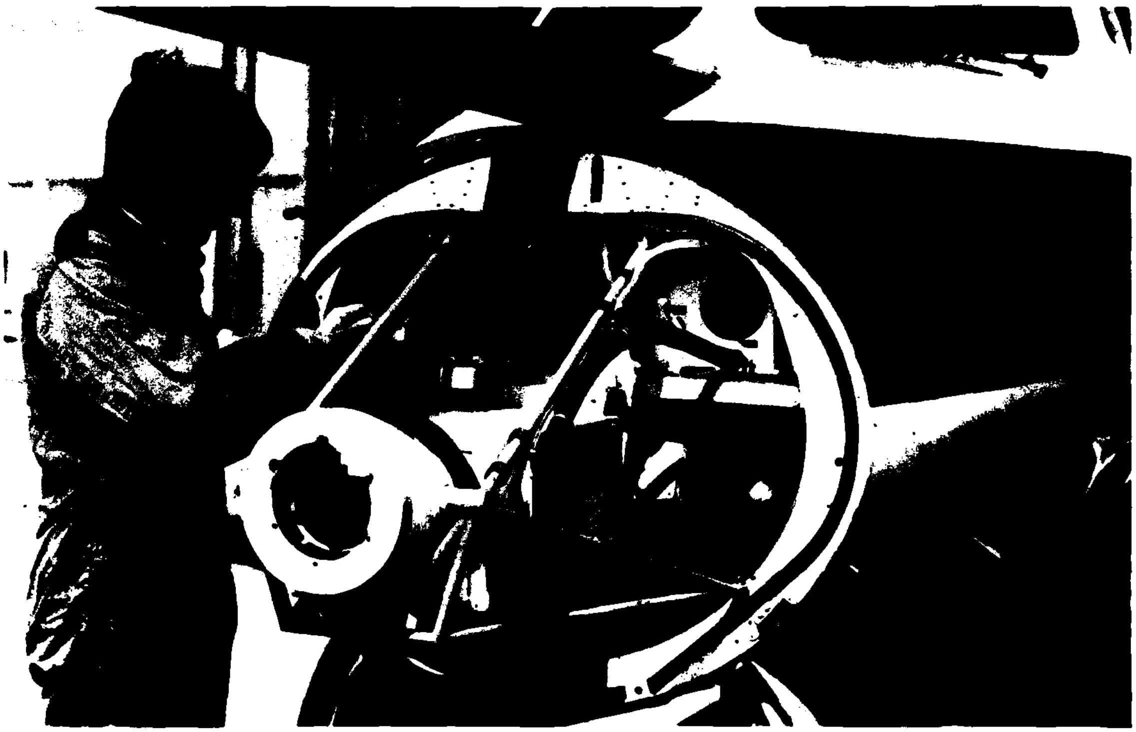

Fig 4 The optics head mounted in the nose of the HS 125 trials aircraft of Flight Systems Department, RAE Bedford

Fig 5 The HS 125 aircraft showing the nose cone and 20 cm diameter germanium window. See also Fig 8

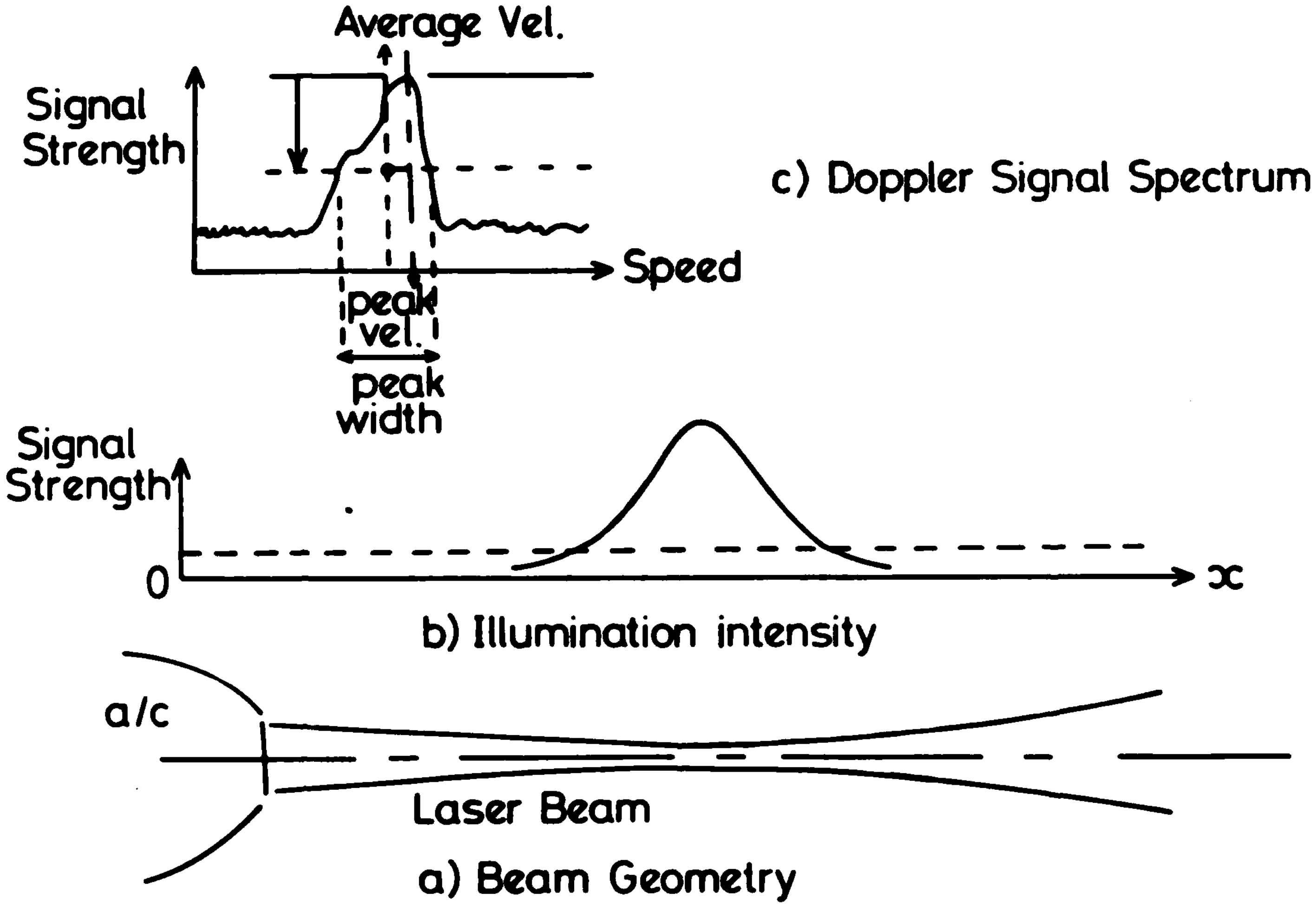

Fig 6 Parameters of a focussed CW laser anemometer showing schematically the laser beam, the illumination, and Doppler spectrum

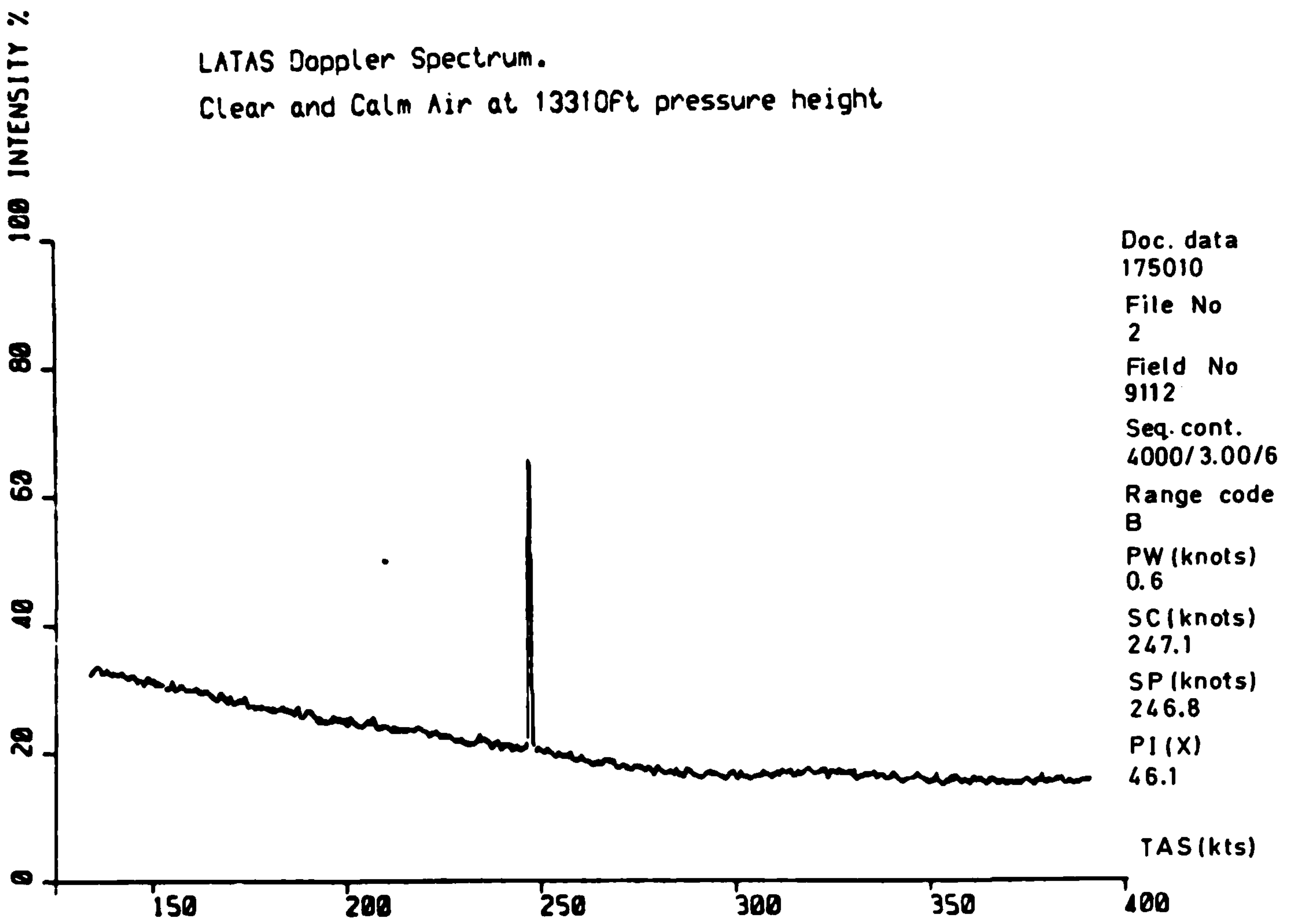

Fig 7 LATAS Doppler spectrum in clear and calm air at 13310 ft pressure height. Note the narrow Doppler signal with peak corresponding to a true airspeed of 246.8 knots

Fig 8 The nose cone of the HS 125 aircraft showing the germanium window and diamond-like hard coating (supplied by Barr and Stroud), after two years of flying. The nose cone shows considerable surface abrasion after about 30 flights since repainting

Figs 9&10

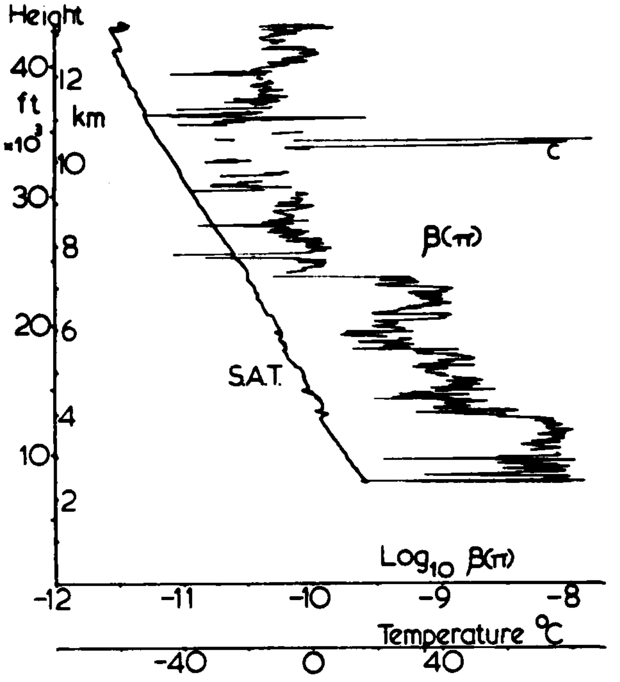

Fig 9 **Atmospheric backscattering coefficient $\beta(\pi)$ sr^{-1} m^{-1} and static air temperature SAT versus indicated height in ft and km (ASL). The strong return at (c) at 33000 ft later in the day became a visible layer of cirrus cloud. [Flt 772, am 1 July 1982, from Jefferson County Airport Colorado, surface visibility >80 miles]**

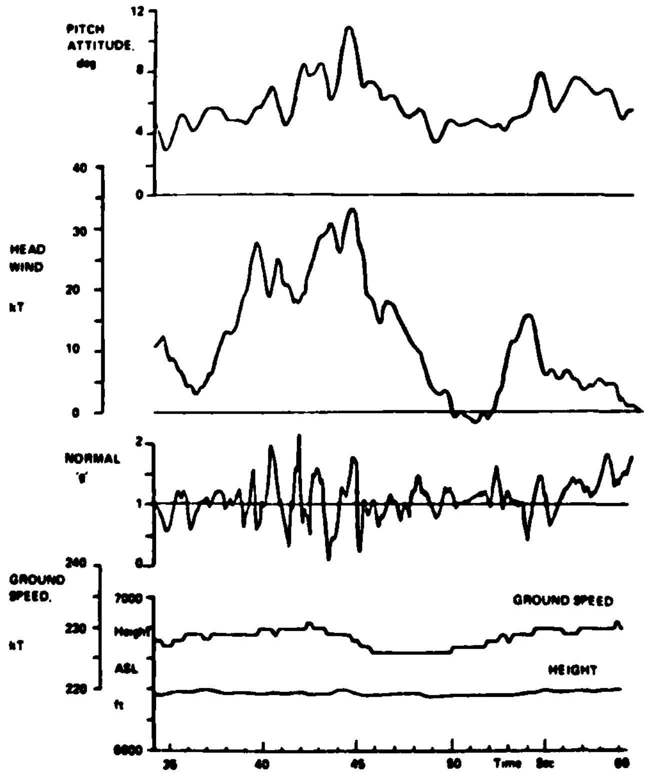

Fig 10 **Passage through a thunderstorm micro-burst recorded at the JAWS project in Colorado [Flt 792, pm 14 July 1982, run 3]**

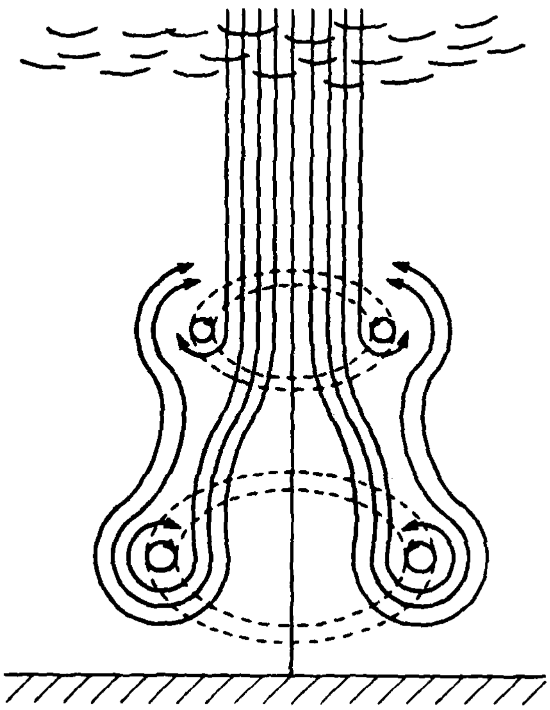

Fig 11 Vortex model of a microburst showing streamlines

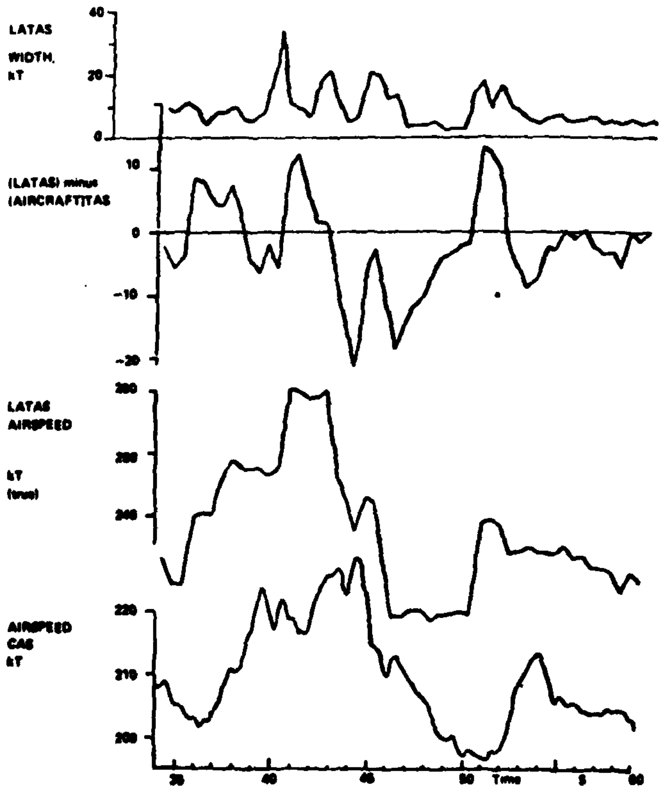

Fig 12 Passage through a thunderstorm microburst showing the response of the RAE/RSRE LATAS system. [Flt 792, pm 14 July 1982, run 3, JAWS project]. *Note the 2 sec lead (corresponding to ~250 m) of the LATAS airspeed*

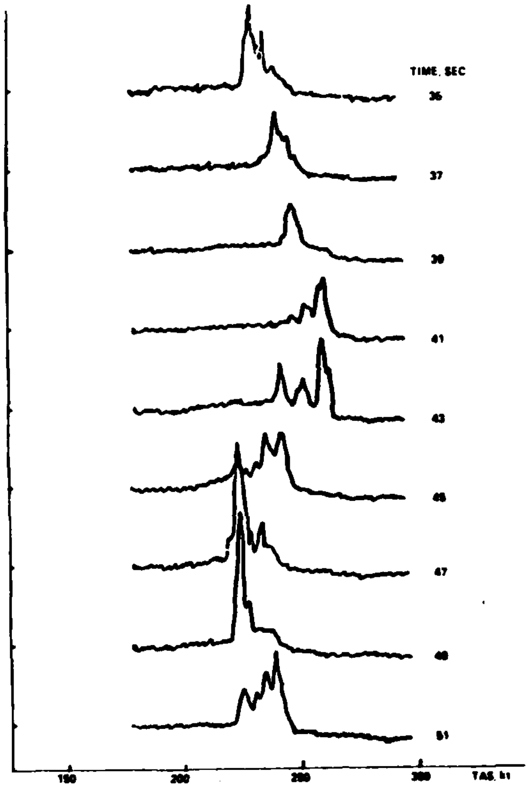

Fig 13 Successive LATAS Doppler spectra on passage through a thunderstorm microburst. The reference times are the same as for figures 10 and 12 [Flt 792, pm 14 July 1982, run 3]

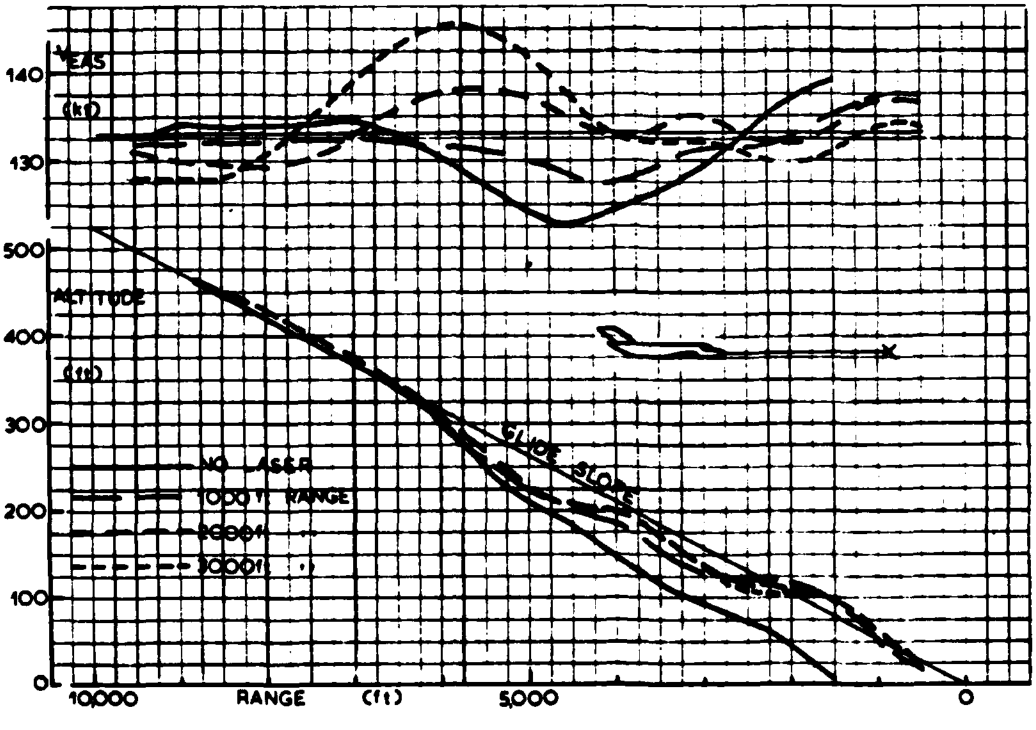

Fig 14 Flight simulations of a coupled approach through thunderstorm wind shear, for a BAC 1-11 medium jet transport, with and without LATAS type advance warning from different ranges. The thunderstorm cell was set at 4,500 ft range, and offset 1500 ft

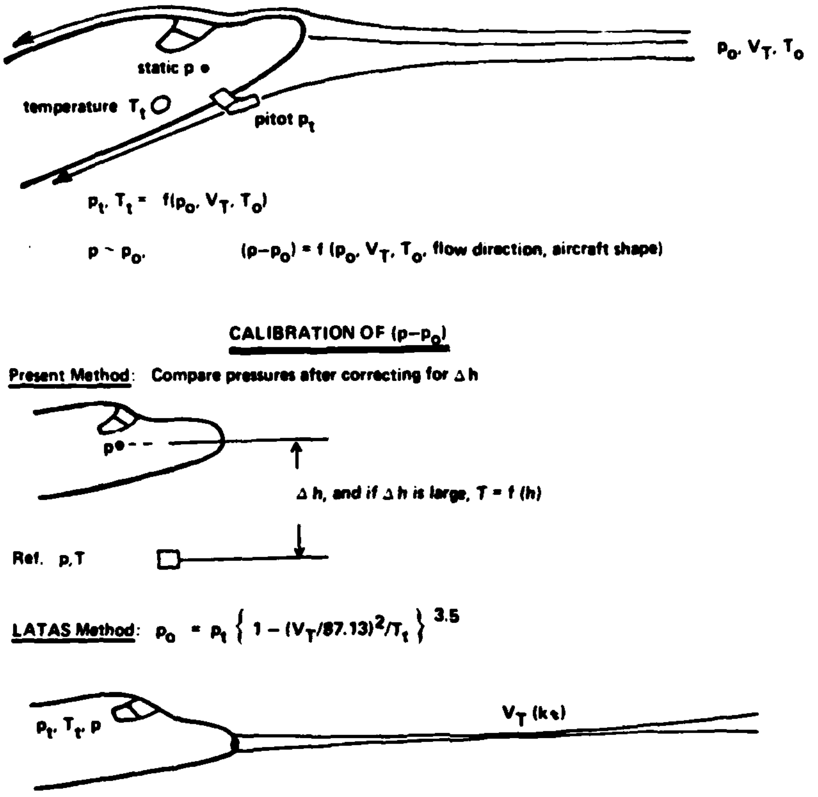

Fig 15 Calibration of pressure error ($p-p_0$); comparison of present methods and LATAS method

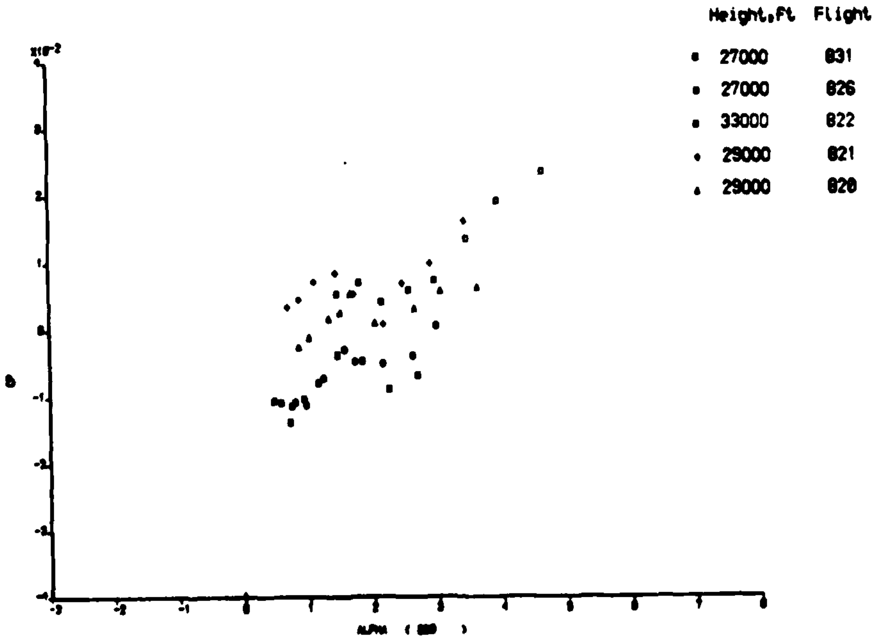

Fig 16 Pressure errors on the HS 125 aircraft measured by LATAS

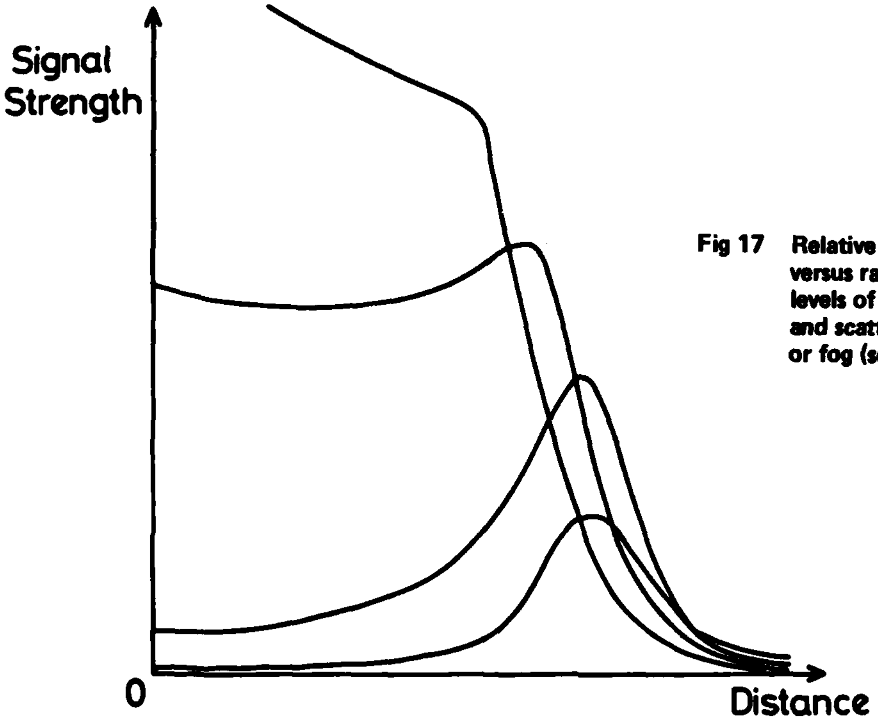

Fig 17 Relative signal strength versus range for high levels of attenuation and scattering in cloud or fog (schematic)

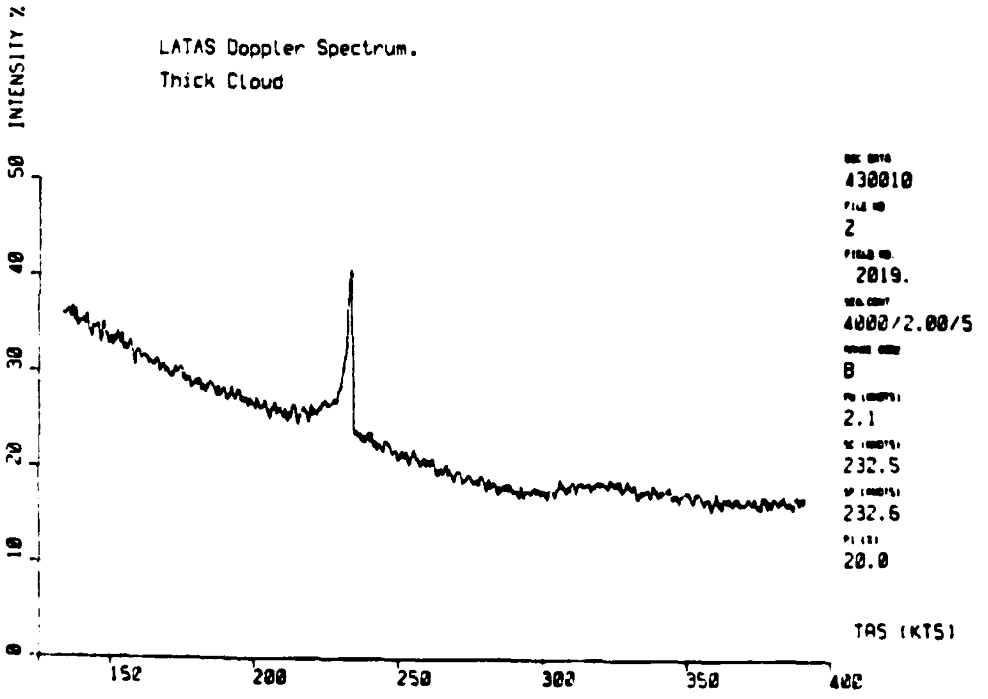

Fig 18 LATAS Doppler spectrum recorded in thick cloud

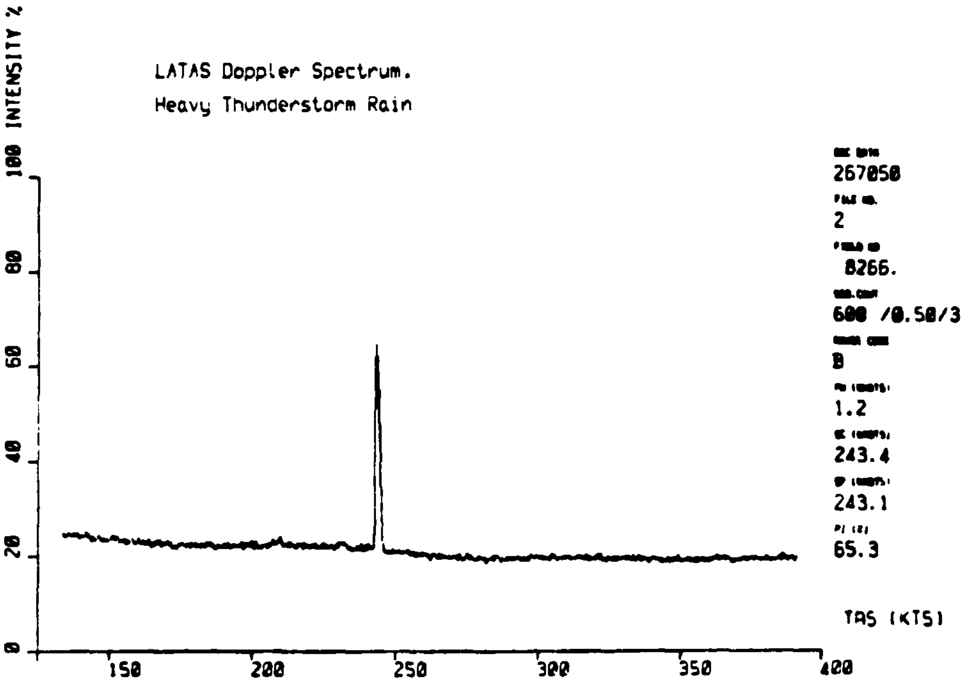

Fig 19 LATAS Doppler spectrum recorded in heavy thunderstorm rain

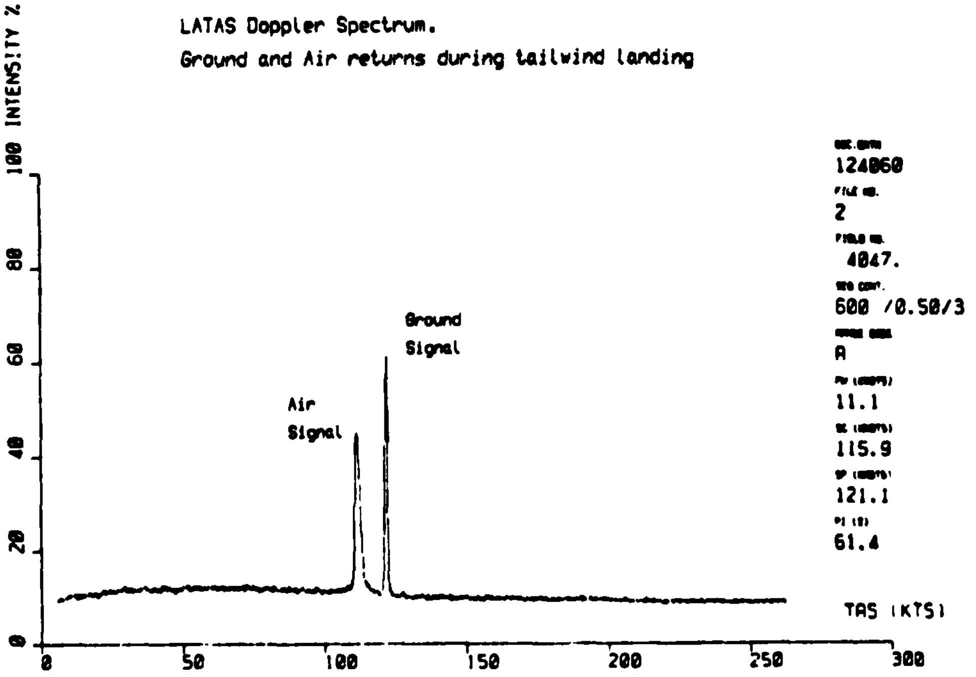

Fig 20 LATAS Doppler spectrum recorded with ground and air returns during a tailwind landing. Note the slightly broadened spectrum from turbulent air

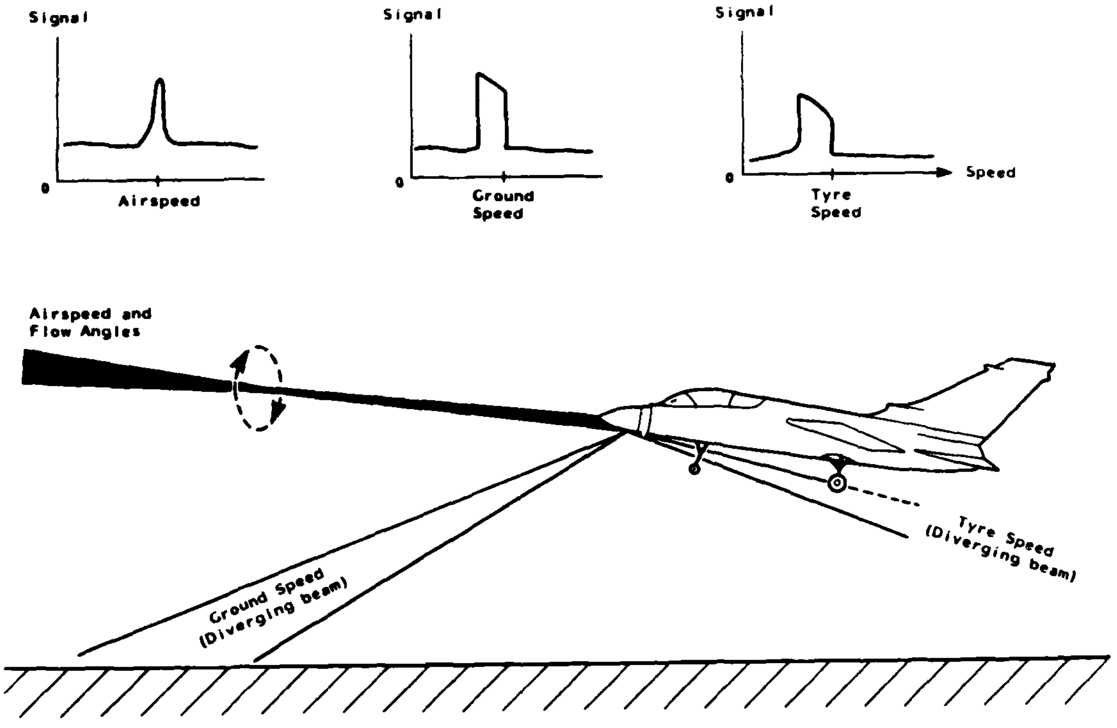

Fig 21 CW Laser Doppler system for airspeed, ground speed and tyre speed

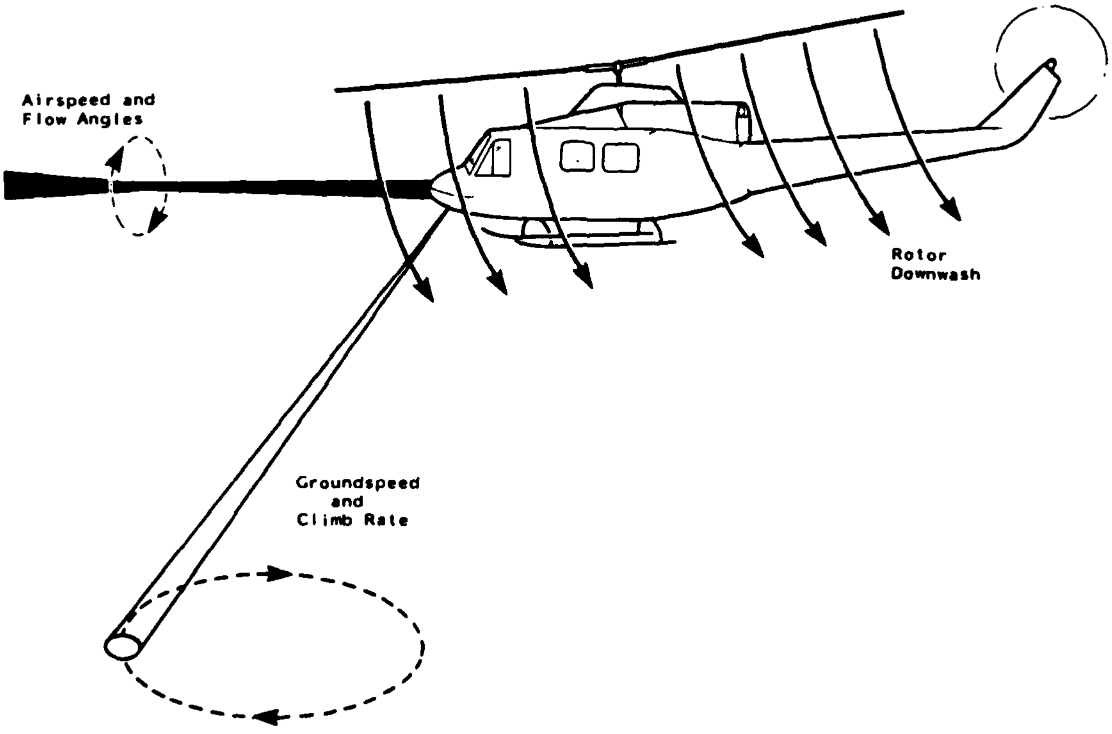

Fig 22 CW Laser Doppler system for air data, ground speed, climb rate and automatic hover on helicopters

REPORT DOCUMENTATION PAGE

Overall security classification of this page

UNCLASSIFIED

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17. Abstract

The Laser True Airspeed System (LATAS) developed by the RAE and RSRE and installed on the RAE HS 125 research aircraft is described. It has proved exceptionally reliable and rugged. Examples of results are presented including a climb to 43000 ft; flight through a severe thunderstorm wind shear (microburst); pressure error measurements; and signals observed in cloud, heavy rain and from solid objects such as the ground. The paper concludes with some thoughts on other potential applications such as using the sensor for an intelligent autothrottle; for measuring crossflow velocities; for measuring tyre and ground speeds to save tyre wear; and as a combined air data and ground velocity system for helicopters (including a facility to maintain a steady hover).