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A PROMISING LOW SPEED AIR DATA SYSTEM FOR HELICOPTERS

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Abstract :

Derived from a previously realized system called VIMI, a new set of algorithms, CLASS, has been developed, the performance of which is presented.

CLASS can be integrated in various systems, and especially in a Helicopter Air Data Computer, a modern and affordable new product.

INTRODUCTION

Whereas in their early beginnings air data systems were little more than pneumatic indicators, they have now become an increasingly important part of helicopter avionics.

Most measurement techniques come from the airplane : they use pitot pressure and static pressure to elaborate airspeed. Pitot and static probes still exist on all helicopters. It is well known that such systems malfunction at low airspeed - typically below 40 to 50 Knots - this phenomenum is due to the large deflection angles caused by the rotor wake and to the limited accuracy of the pressure sensors.

In order to overcome this problem, a great variety of more or less exotic probes has been invented and flight tested. Just a few have been mass-produced (as their installation is quite complicated) : either above the rotor mast with a fix-pole through it or at the end of a long mast. Installation is either complex or vulnerable for a combat helicopter ; it is always expensive.

A French flight-test engineer has patented an affordable and purely internal air data system, VIMI ; a lot of improvement has been performed, and the improved system is now named CLASS. This system has obtained good results and is presented in this document.

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EVOLUTION OF REQUIREMENTS

The requirements concerning air data systems have changed since the beginnings of helicopter history, but less dramatically than those of aeroplanes (see reference 1). The basic requirement comes from the fact that the helicopter flies in the air : the pilot needs to know at what airspeed and altitude (or height) he is flying for safety reasons. In addition to this, airspeed combined with wind estimates leads to simple dead-reckoning navigation.

This can be done with simple pneumatic systems and indicators.

Another fact is that the helicopter is now used in quite serious weather conditions, essentially for Search and Rescue (SAR) or ambulance tasks ; hovering in strong winds in a city or mountain environment at night is not an easy task ! Bidirectionnal airspeed information during hover, take-off or landing can be very helpful.

This need is emphasized during sea operations such as carrier landing, sonar dipping, etc, when the sea is rough.

Moreover, military helicopters now carry more and more weaponry. Fire control systems have become sophisticated and unguided weapons (i.e. rockets and guns) require a very stringent accuracy. These systems are designed for operation at very low airspeeds (even while hovering) and demand very precise air data parameters.

The avionic integration problem is becoming critical for these combat helicopters : equipment must be light and compact ; probes must be invulnerable to shocks during ground handling and landings.

The only known answer to these challenging requirements is the CLASS which stands for CROUZET Low Air-Speed System.

THE CLASS PRINCIPLE

The objective of this explanation is to make the very simple principle be understood : it is not to show the long list of calculations necessary to demonstrate the final equation. It would be a boring exercise which would convince only a few people. Pragmatism in this domain leads to the only valid demonstration which is flight tests.

The basic idea comes from the observation that the orientation of the rotor tip path plane is correlated to the true airspeed vector. The faster a helicopter flies forward, the more its rotor disc is inclined in this direction. And the faster it flies laterally, the more inclined its rotor disc is in this direction. Strictly speaking, this description is only valid in straight level flight ; nevertheless the flight tests have demonstrated that the function has correct results in transient maneuvers.

The orientation of the tip-path plane in the atmosphere cannot be assessed easily. But it is possible to evaluate this orientation relative to the aircraft fuselage. And the attitude of the helicopter (i.e. yaw and roll) is easily measured either by an Attitude and Heading Reference System (AHRS) or by an Inertial Reference System (IRS).

A careful flight dynamics analysis can be made with a few assumptions in order to simplify the calculation, such as small angle assumption, and discarding small terms with a power greater than two. This leads to two simple equations :

$$V_x = k_1 \theta + k_2 B_1$$

The forward true airspeed is the algebraic sum of a term proportional to the pitch angle and a term proportional to the longitudinal cyclic pitch.

and

$$V_y = k_3 \varphi + k_4 A_1$$

the lateral true airspeed is the algebraic sum of a term proportional to the roll angle and a term proportional to the lateral cyclic pitch.

In fact, it is somewhat difficult to get strictly proportional attitude and pitch sensors, so the correct equations are :

$$V_x = a_1 \theta + a_2 B_1 + a_3 \quad (1)$$

$$V_y = b_1 \varphi + b_2 A_1 + b_3 \quad (2)$$

These two very simple equations are the fundamentals of the VIMI concept. They have been flight tested successfully on helicopters of the French Flight Test Center in this form for more than ten years. A simple analog system was the support for this simple equation.

In fact, the coefficients of equations (1) and (2) are not strictly constant : they depend on second order parameters such as weight, density of the air, and collective pitch. When these parameters are taken into account, the algorithms become CLASS. They are more complicated and they require a careful calibration but give more precise results.

THE CALIBRATION QUESTION

A calibration is necessary for any air data system (except perhaps laser anemometer).

The choice of the air data reference is crucial : a poor reference leads to a poor system, a good reference to a good one.

But the reference choice is not easy. No method seems perfect (ref 2).

The airspeed is the vectorial difference of groundspeed and windspeed. The groundspeed can be accurately assessed through an Inertial Reference System (IRS) or by radar tracking or laser tracking. But windspeed depends on time and place. In other words, the windspeed must be measured in the place where the aircraft is and at the moment when it is there. The only foreseeable solution would be a laser anemometer. But this solution is not yet operational : it will be only in a few months. The conventional method of track following gives poor results at these low airspeeds. The car following method gives no more than a ground speed. It was decided with the Flight Test Center to experiment a new method, described in detail in reference 2. It consists of a mobile truck with an anemometer which samples the windspeed a hundred feet in front of the flying helicopter. The helicopter follows the truck pole, but the pilot does not have to maintain a rigid distance as in the car following technique. The wind velocity is calculated from the vector difference of the truck air velocity and ground velocity, and taking into account the truck heading. This windspeed is vectorially added to the groundspeed of the helicopter measured by an IRS to give the airspeed reference of the helicopter. A time delay can be added depending on the mean value of the windspeed ; it can be adjusted because the reference is not elaborated during the flight test itself, but during postflight analysis.

This method is probably the most feasible today. We are waiting for the laser anemometer reference available in a few months because it continuously measures the windspeed just ahead of the helicopter. Though it is quite heavy and the results are not available before the post flight analysis, the present method is accurate : its global accuracy has been estimated between 2 and 3 knots.

For transient maneuvers, the airspeed reference used was the vectorial difference of the IRS groundspeed combined with the last measured windspeed from the truck anemometer.

FLIGHT TEST RESULTS

These flight tests were performed during 1984 in the French Flight Test Center at BRETIGNY.

The first conclusions were the feasibility of the reference method : the truck had a 25 ft pole on top with an anemometer and the helicopter PUMA could follow it reasonably well. The pilot was able to track the pole even in pure lateral or reverse flight at a constant speed.

An example of groundspeed comparison is given in Figure 1 : the difference between helicopter and truck speed is below 2 knots. Though the difference is so small, it was decided to use the complete method (i.e. wind is calculated and added to helicopter groundspeed) to have the reference.

STABILIZED FLIGHTS

A great number of stabilized flights have been used for calibration. A single point was the medium value of all the parameters used by CLASS during 3 seconds. Calibration was done and then the algorithms were tested. The results are given in figure 2 for forward airspeed and 3 for lateral airspeed. The results are quite good. The standard deviation is under 3 kts for both sets of information, and some of the points include recovery and turn maneuvers.

If only straight level flights are analysed, the standard deviation lies below 2,4 Kts. The difference between these two figures is explained by the quality difference of the reference used in level flight and in maneuvers : as the standard deviation has the same order of magnitude as the reference system it was chosen not to complicate the CLASS algorithms to a greater extend.

TRANSIENT MANEUVERS

CLASS was tested during different maneuvers and some results are given below.

The first maneuver was a straight level flight at low speed moving in reverse (4 kts) and a strong lateral speed (20 kts). The results are given in figures 4 and 5. The error is quite low, especially for a lateral speed. A little residual noise was still present and it was decided to filter CLASS with a time constant. The second maneuver was a turn to the left. The rate of heading was approximately 10 degrees per second and the bank angle 20 degrees. The results are given in figures 6 and 7. Error was quite low for forward movement. A slight discrepancy appeared for lateral speed. The third maneuver resulted from a level flight acceleration from hover to more than 100 knots with no sideslip ; it is presented in figure 8 : the error between the reference and CLASS is remarkably low under 80 knots.

These results enable an easy hybridization with conventional pneumatic systems between 40 and 60 Knots with good accuracy.

COMPLETE SYSTEM

With CLASS we can propose a whole flight range air data system for helicopters. Two examples are given below. Many others are possible depending on the computer in which CLASS are implemented.

In figure 9, an air data system is presented with a Pitot/static probe and a total temperature probe connected with a CROUZET pressure sensor unit 30 (figure 10), which delivers static pressure Ps, total pressure Pt and total temperature Tt to a Navigation computer. The link between the two is a serial digital line such as defined by ARINC 429. CLASS is implemented in the navigation computer along with conventional air data calculation and the low/high airspeed hybridization. As the attitude of the helicopter is available in the navigation computer, this solution is preferable. But the algorithm can be implemented in any modern computer (fire control, FMS,...).

Another solution is presented in figure 11 using the same probes as above. The Helicopter Air Data Computer is designed especially for the implementation of CLASS together with classical anemometry ; it has a standard ARINC 2 MCU housing and only weights 3.5 Kgs. The HADC can thus provide air data information in the complete flight enveloppe.

CONCLUSION

CROUZET has evaluated a new set of algorithms (CLASS) enabling the calculation of the bidirectional low airspeed of a helicopter.

Accuracy measured during flight tests is better than 3 Knots. Hybridization with conventional pneumatic air data is easy and allows complete air data calculation, during the whole flight range of a helicopter. These algorithms can be implemented in any modern airborne computer, especially in a dedicated Helicopter Air Data Computer, a modern and efficient new product.

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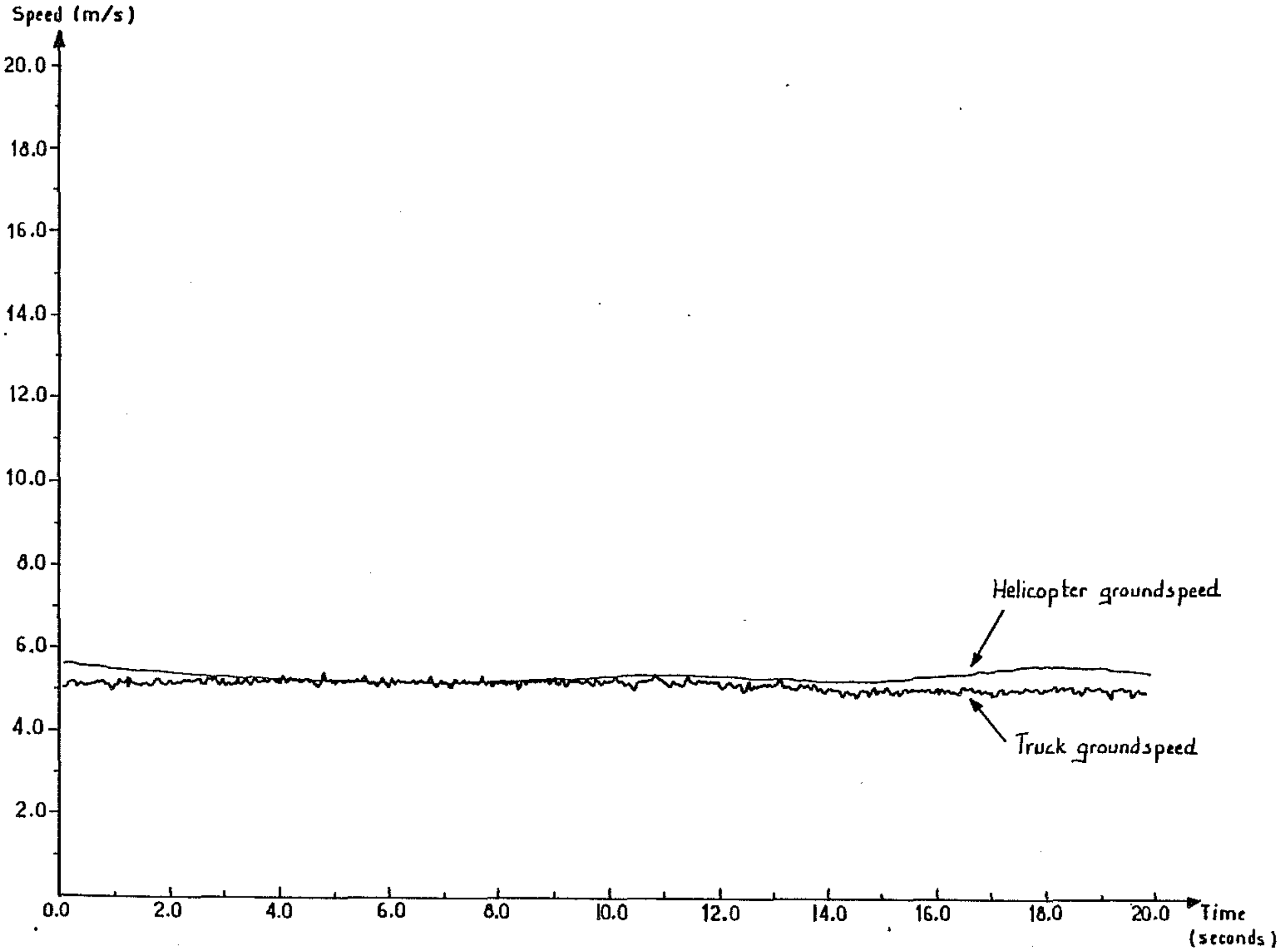

FIG.1 - HELICOPTER AND TRUCK GROUND SPEED COMPARISON

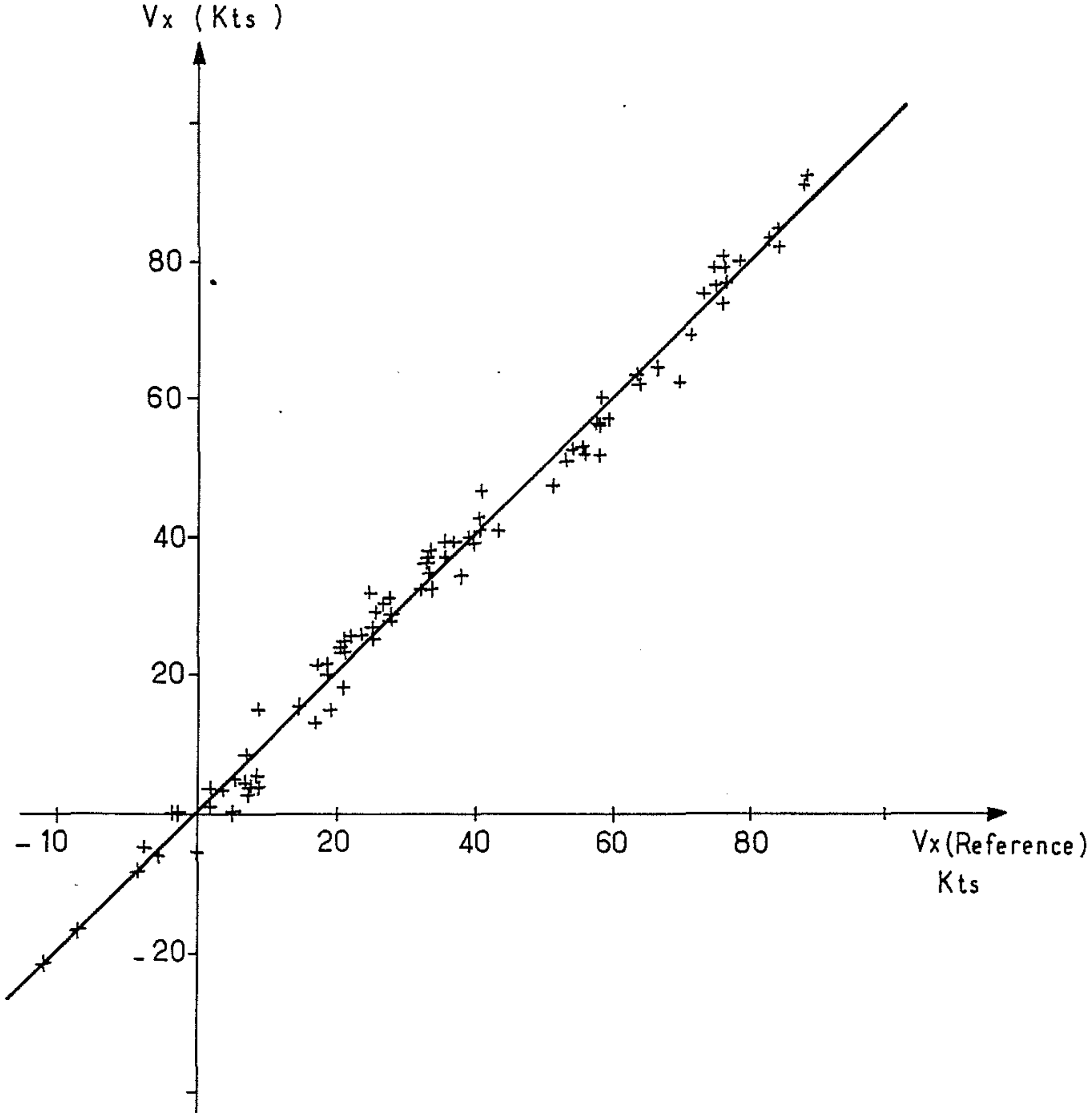

FIG. 2 - ALONG AIRSPEED GIVEN BY CLASS

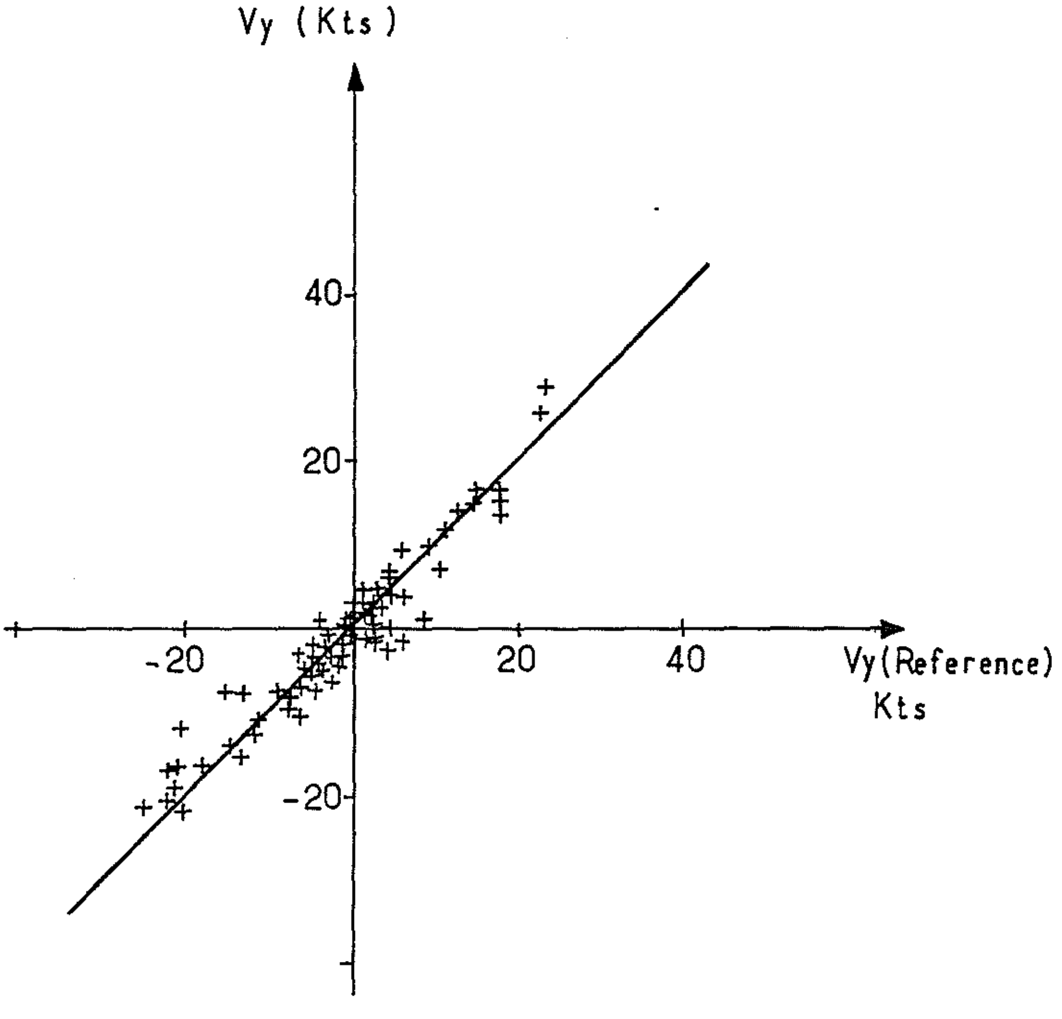

FIG. 3 - ACROSS AIRSPEED GIVEN BY CLASS

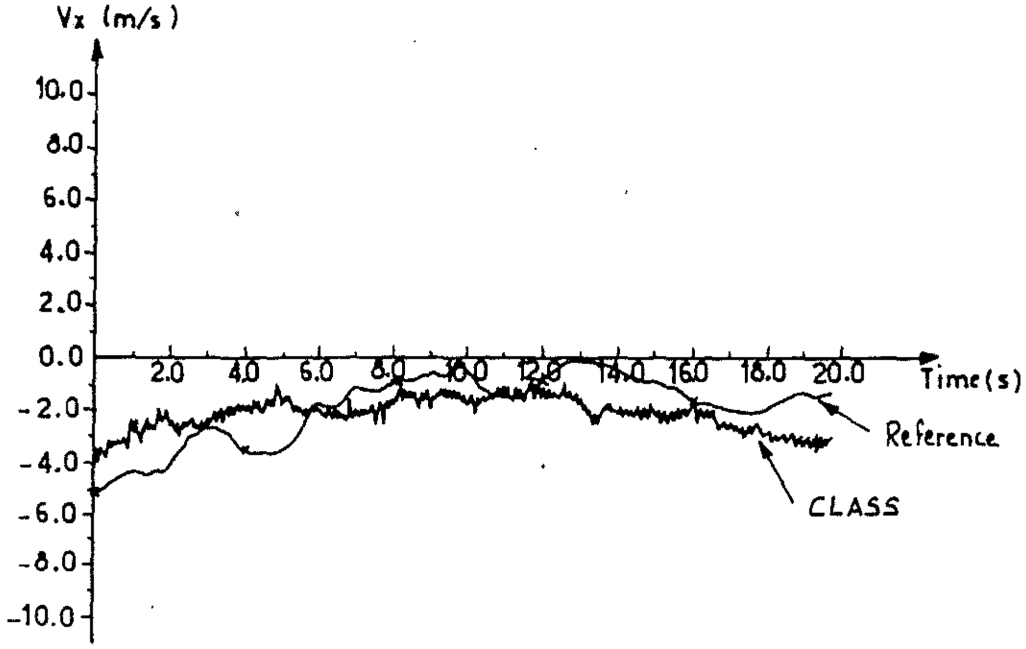

FIG.4 - ALONG SPEED VERSUS TIME FOR A LEVEL FLIGHT

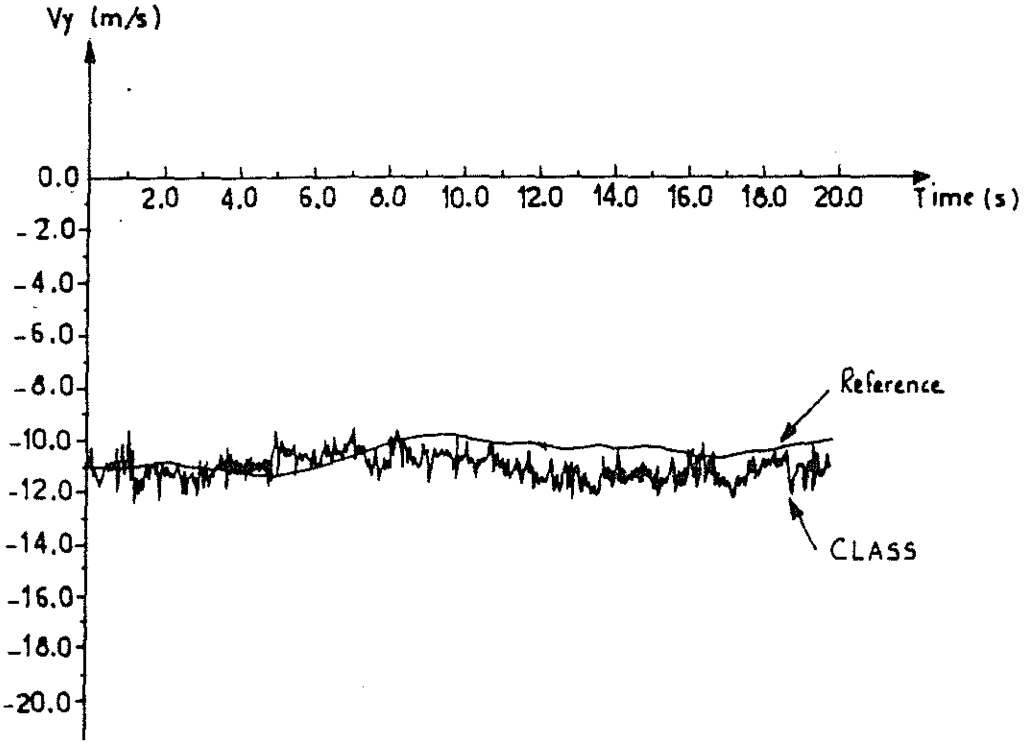

FIG. 5 - ACROSS SPEED VERSUS TIME FOR A LEVEL FLIGHT

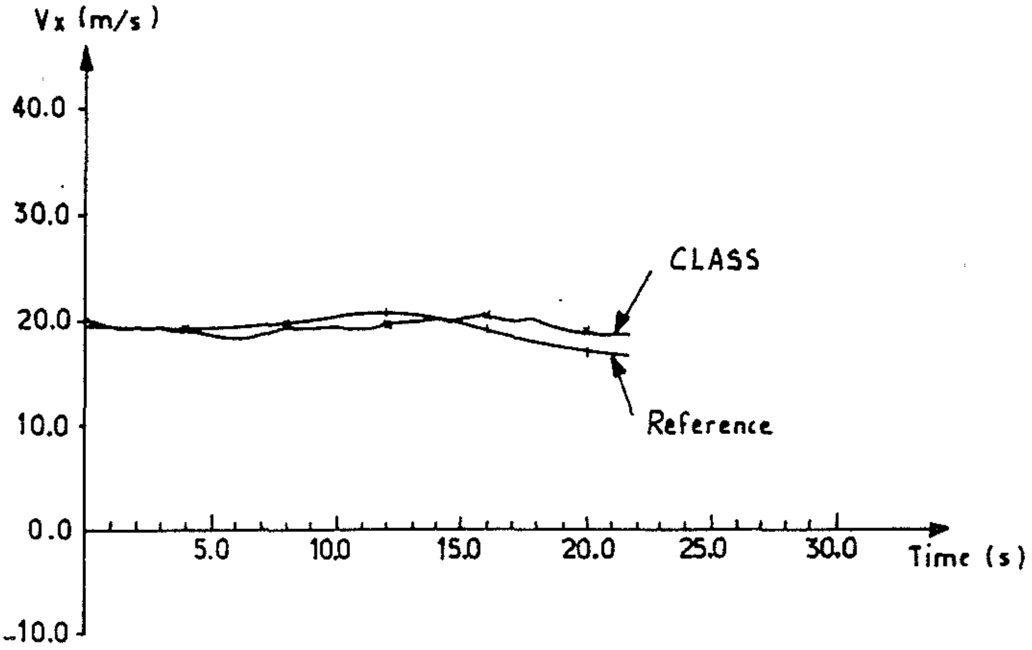

FIG. 6 - ALONG SPEED VERSUS TIME FOR A TURN

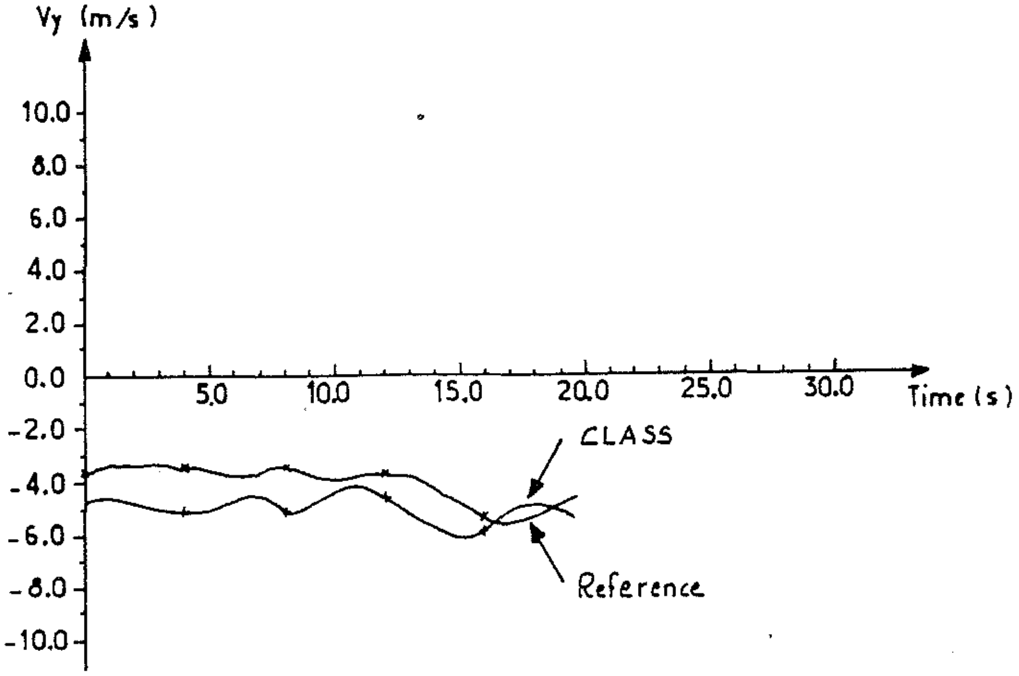

FIG. 7 - ACROSS SPEED VERSUS TIME FOR A TURN

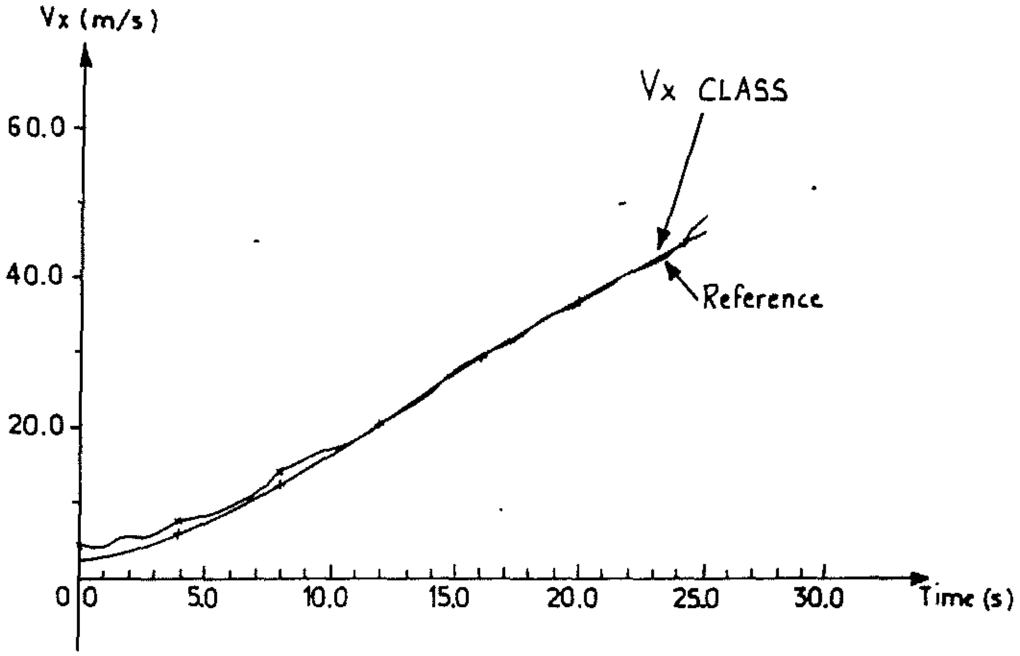

FIG. 8 - ALONG SPEED VERSUS TIME FOR AN ACCELERATION

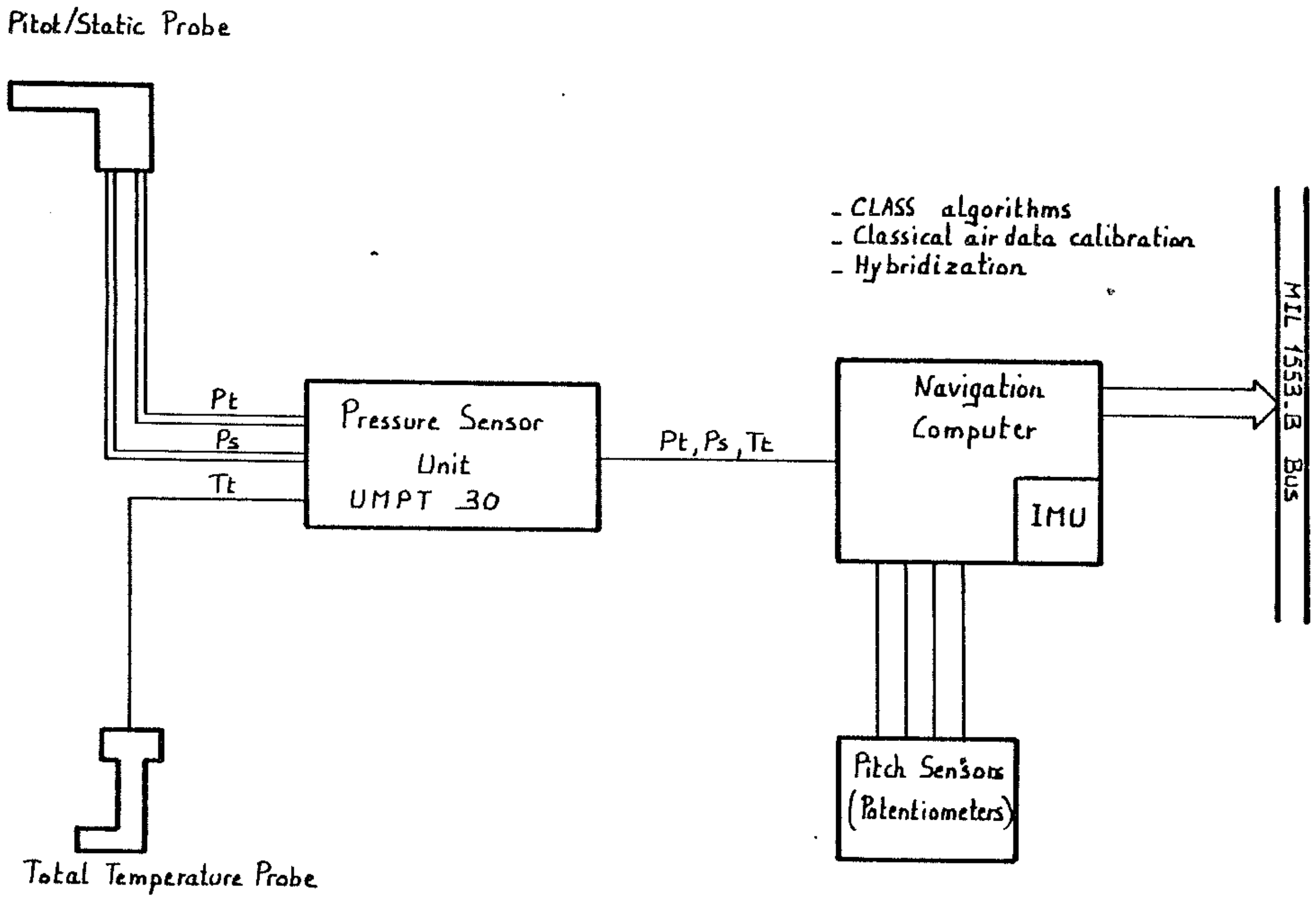

FIG. 9 - AIR DATA DIAGRAM 1

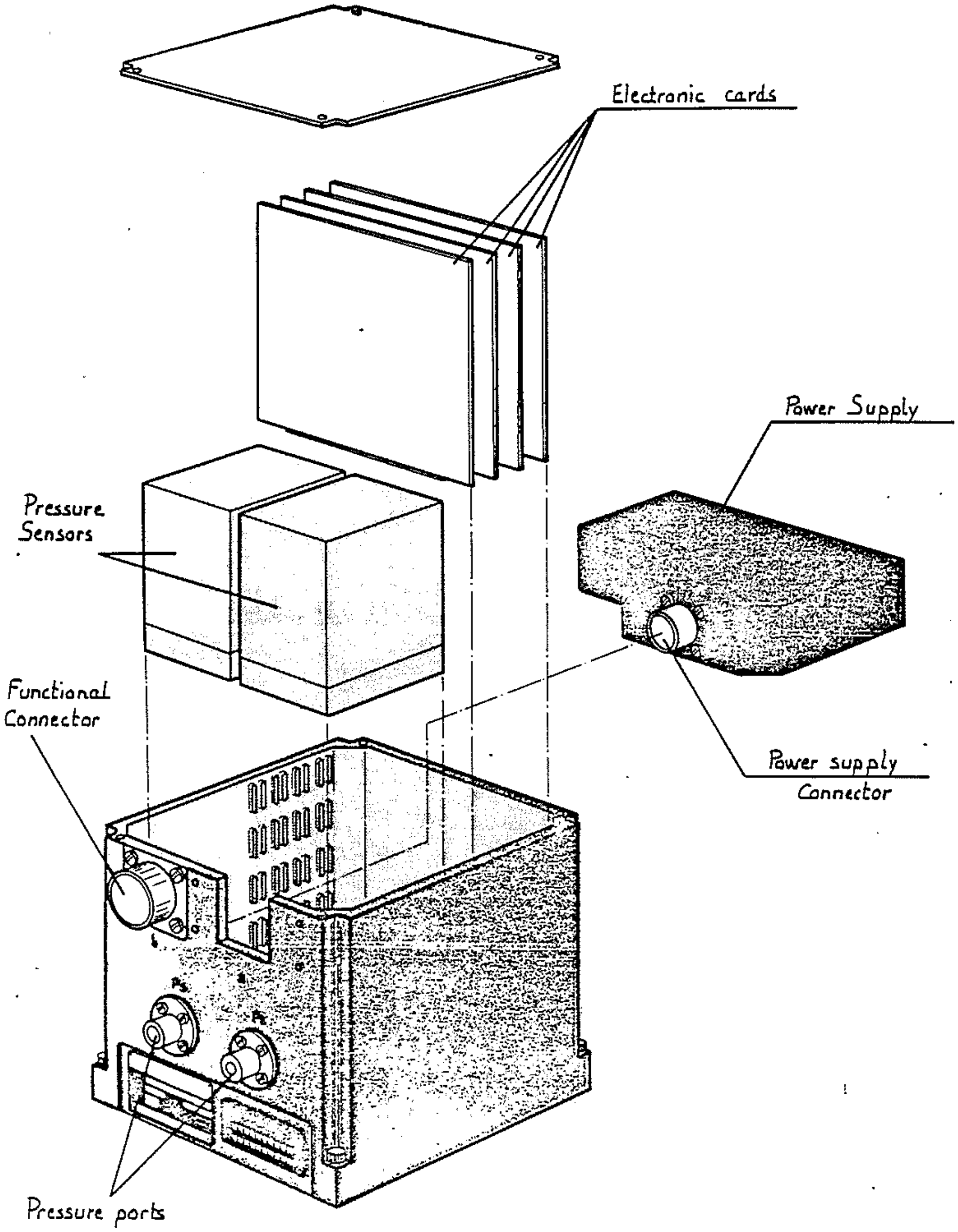

FIG. 10 - DIGITAL AIR DATA TRANSDUCER TYPE 30

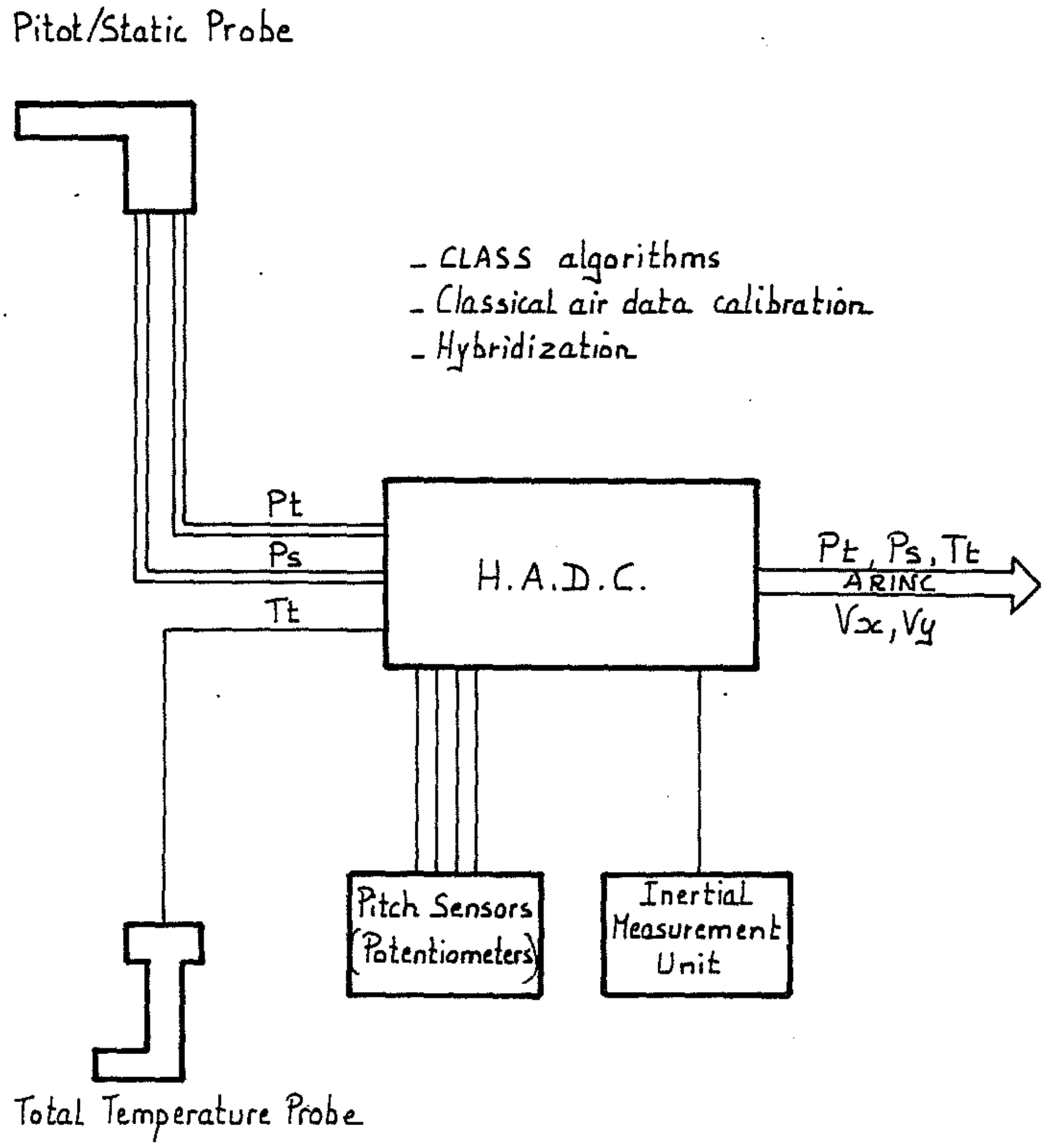

FIG. 11 - AIR DATA DIAGRAM 2

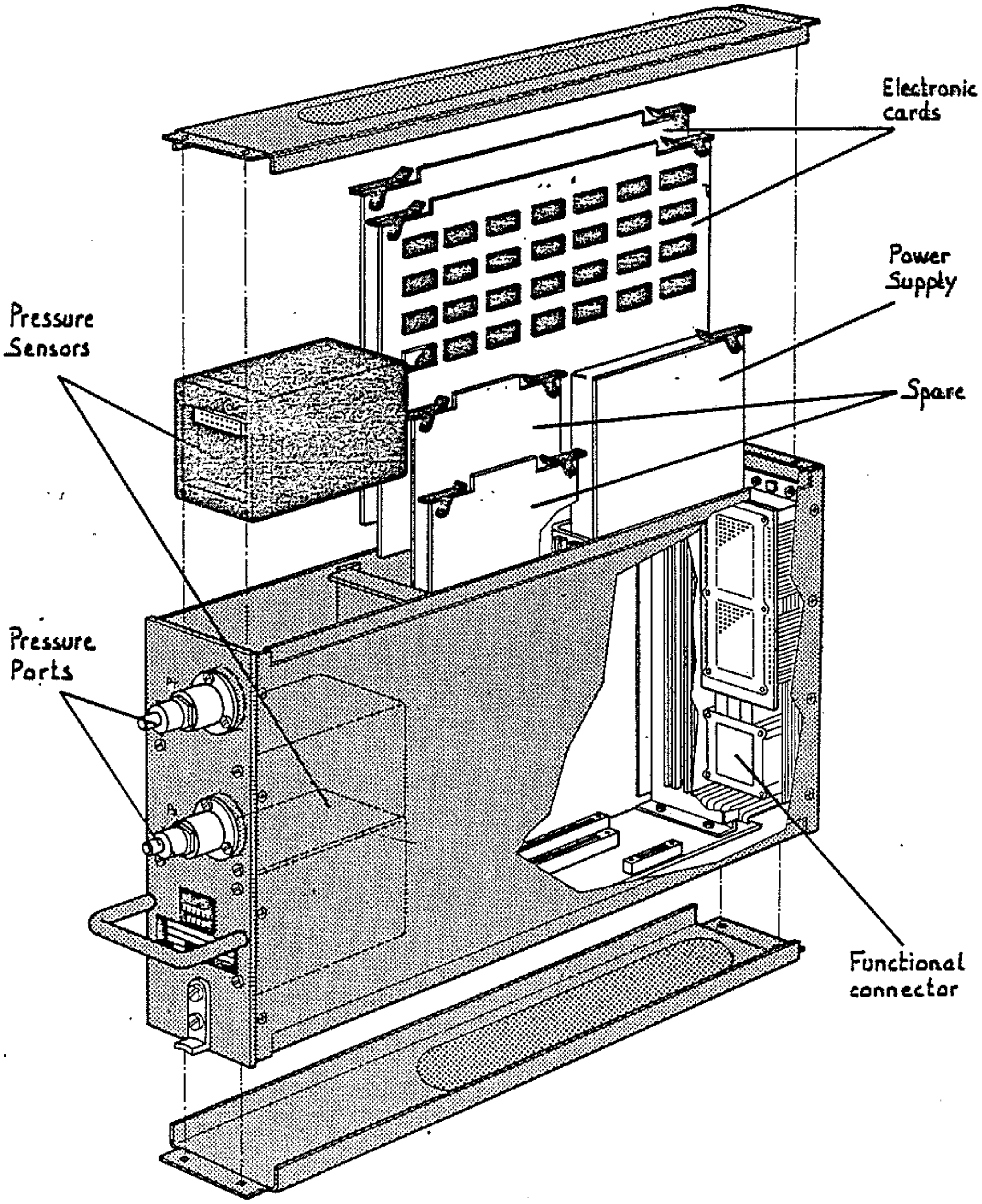

FIG. 12. - HELICOPTER AIR DATA COMPUTER