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A PERFORMANCE MONITORING SYSTEM FOR HELICOPTERS

G. F. WALKER

MARCONI AVIONICS LTD, ROCHESTER, ENGLAND

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ABSTRACT

A Performance Monitoring System for Helicopters

This paper describes the development over the last two years by Marconi Avionics Limited of a Performance Monitoring System for helicopters. This system, the outlines of which were presented in a paper entitled 'An Integrated Performance and Air Data System for Helicopters' at the 6th European Rotorcraft and Powered Lift Aircraft Forum in 1980, is currently being subjected to flight testing following a period of bench evaluation under contract to the Royal Aircraft Establishment, Farnborough, England. This evaluation has been aimed at establishing a method of predicting helicopter power requirements based on flight profile considerations, and subsequently using such predictions as a basis for detecting degradations in performance such as those experienced during icing encounters. The validity of using this technique as a means of detecting conditions is discussed, and results of the evaluations are presented. Other aspects of performance monitoring, (rotor, engine and airframe) are discussed, and the prototype equipment designed is described in detail. Future possibilities in this field of instrumentation are investigated, for both short and long term programmes.

1.0 Introduction

At the 6th European Rotorcraft and Powered Lift Aircraft Forum in 1980, Marconi Avionics Limited presented a paper entitled 'An Integrated Performance and Air Data System for Helicopters' (Ref 1). The system was designed to meet the identified need for an integrated system capable of providing accurate air data throughout the flight envelope, and also capable of monitoring aircraft performance. The System provides pilots with a continuously updated display of performance capabilities, both under existing atmospheric conditions and also for conditions at a remote site. Air Data is provided by use of the XM-143 Fire and Flight Air Data System.

In December, 1980, Marconi Avionics were asked by the Royal Aircraft Establishment, Farnborough, to adapt the system in order that helicopter performance could be monitored in such a way that performance degradation through flight in adverse environments, particularly icing, could be detected and quantified. A contract was subsequently placed in May 1982, calling for a 6 month program to develop and test a performance model of the Westland Lynx helicopter, and to incorporate the model into the 03-022-01 Lift Margin System, for bench evaluation purposes.

The detection of torque rises has been identified as highly desireable for helicopter operation in icing conditions (Ref 2). Typically, unprotected helicopters are subjected to a maximum torque rise limit. The determination of torque rise, however, imposes an increase of workload upon the pilot, and is frequently subject to error due to the limitations of flight conditions for which power requirements may be determined from aircraft performance data. A system capable of determining the torque rise accurately in all flight conditions would, therefore, be of considerable use in solving pilot workload problems, in addition to enhancing flight safety.

The methods used to develop a performance model, and the result achieved, are described in this paper.

2.0 Theoretical Analysis

The technique adopted for the development of the performance model is an extension of the use of energy concepts for helicopter flight path determination (Ref 3). This technique allows the development of single level flight power production model, with additional flexibility to provide prediction of additional power required for climbing and accelerating flight. The approach is based on the relationship between the power supplied to the rotor system and power required to overcome losses and to change the flight profile. The general relationship is of the form:

$$P_S = P_L + \frac{dE}{dt}$$

Where P_S = Power Supplied
P_L = Power Losses

$\frac{dE}{dt}$ = Rate of change of energy

The energy change in this equation covers the power requirement for climbing, descending and accelerating flight, and also for changes in rotor speed. The major losses considered are those resulting from fuselage drag (Parasite Power), rotor lift (Induced Power) and rotor drag (Profile Power). In addition, losses exist due to the transmission inefficiency, tail rotor losses and power take-off by ancilliary equipment.

A study of helicopter forward flight performance theory showed that analytical expressions could be used to obtain values of the Parasite and Induced Power losses, but revealed that Profile Power required an empirical solution. The typical contribution of the three power losses to the total forward flight power requirement is shown in Figure 2.1.

The change in energy (Kinetic, Potential and Rotational) terms was derived analytically and therefore by developing an expression for Profile Power, and including allowances for other power losses, the total power required at any airspeed and for climbing and accelerating flight could be predicted from the summation of each individual component.

2.1 Equations Used

Potential Energy Rate

$$\overset{o}{PE} = \frac{d}{dt}(mgh)$$

Where m = aircraft mass
g = gravitational acceleration
h = geo-potential altitude

Kinetic Energy Rate

$$\overset{o}{KE} = \frac{d}{dt}\left(\frac{1}{2} mv^2\right)$$

Where v = aircraft velocity
m = aircraft mass

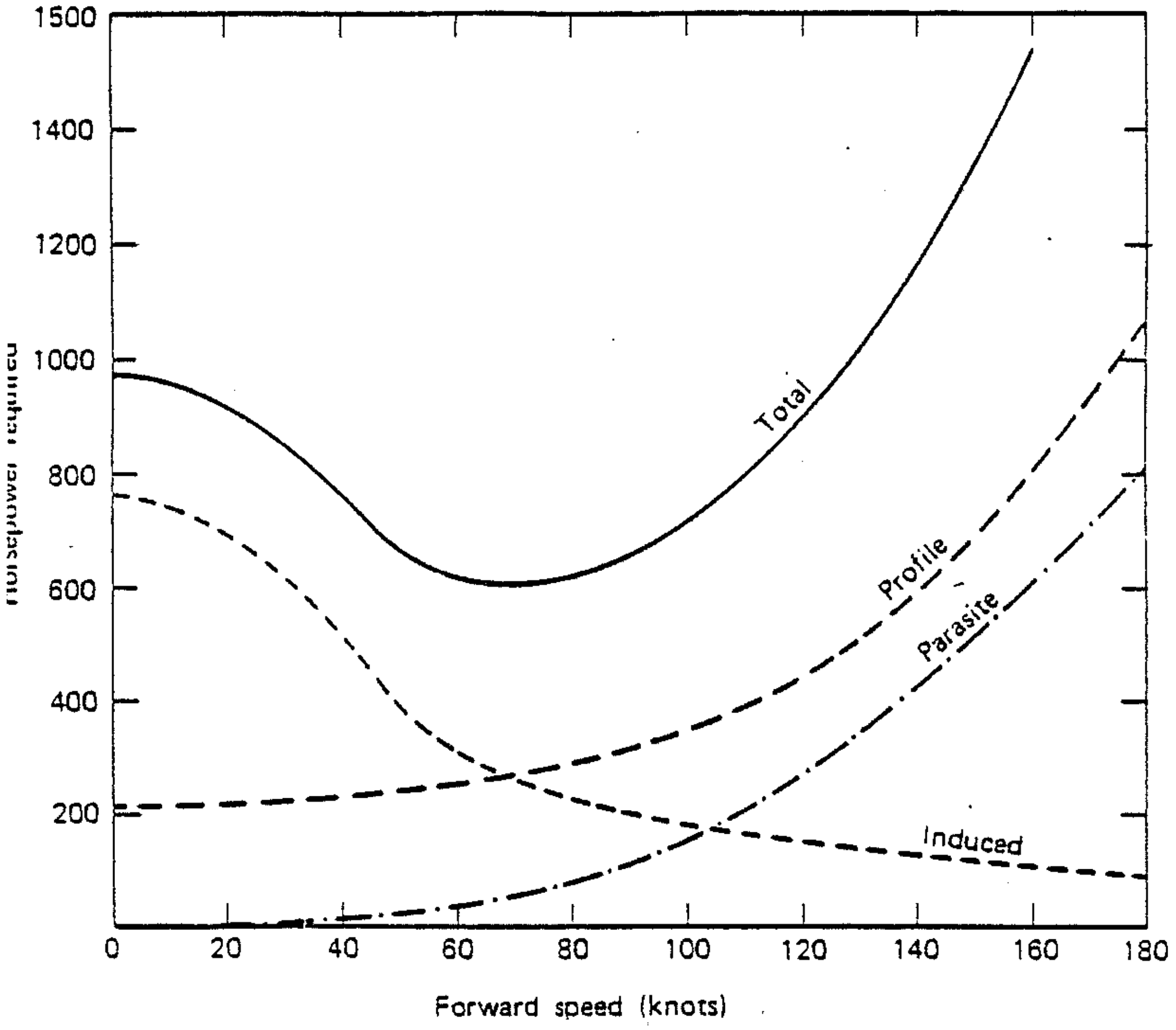

Figure 2.1 Typical Forward Flight Power Requirement

Rotation Energy Rate

$$\overset{o}{RE} = \frac{d}{dt}\left(\frac{1}{2} I \omega^2\right)$$ Where I = Rotor Inertia
ω = Rotor Angular velocity

Parasite Power

$$Pd = \frac{1}{2} \rho V^3 f$$ Where ρ = air density
V = airspeed
f = equivalent flat plate drag area

Induced Power

$$Pi = \frac{m^2 g^2}{2\rho\pi e V R^2}$$ Where m = aircraft mass
e = span efficiency factor
R = rotor radius
g = gravitational acceleration
ρ = air density
V = airspeed

In order to determine the empirical relationship for profile power, flight test data for the Lynx helicopter was subjected to computer analysis, using the following total power equation.

$$P_{PR} = P_s - (P_i + P_a) - \frac{d}{dt}(PE + KE + RE), \qquad \text{Equation 1}$$

All terms on the right hand side of the equation were calculated using the analytical expressions given above. From the results of the analysis, a corrolation between Profile Power, airspeed and atmospheric condition was obtained.

2.2 Results

Using the expression for P_{PR}, equation 1 was re-arranged, in order that an equation to predict Torque demand was obtained. A comparison between the clear air predicted torque and actual torque is shown in Figure 2.2.

Several examples of different flight conditions from clear air flights are shown in Figures 2.3, 2.4 and 2.5.

These flight conditions may be summarised as:

Figure 2.3 Level Flight, 3300 ft

Figure 2.4 Climbing, Descending Flight

Figure 2.5 Climb at 1000 ft/min

The predictive equation was also applied to data from a flight in icing conditions, and a section of this flight indicating a torque rise from 5% to 30% over 5 minutes is shown in Figure 2.6.

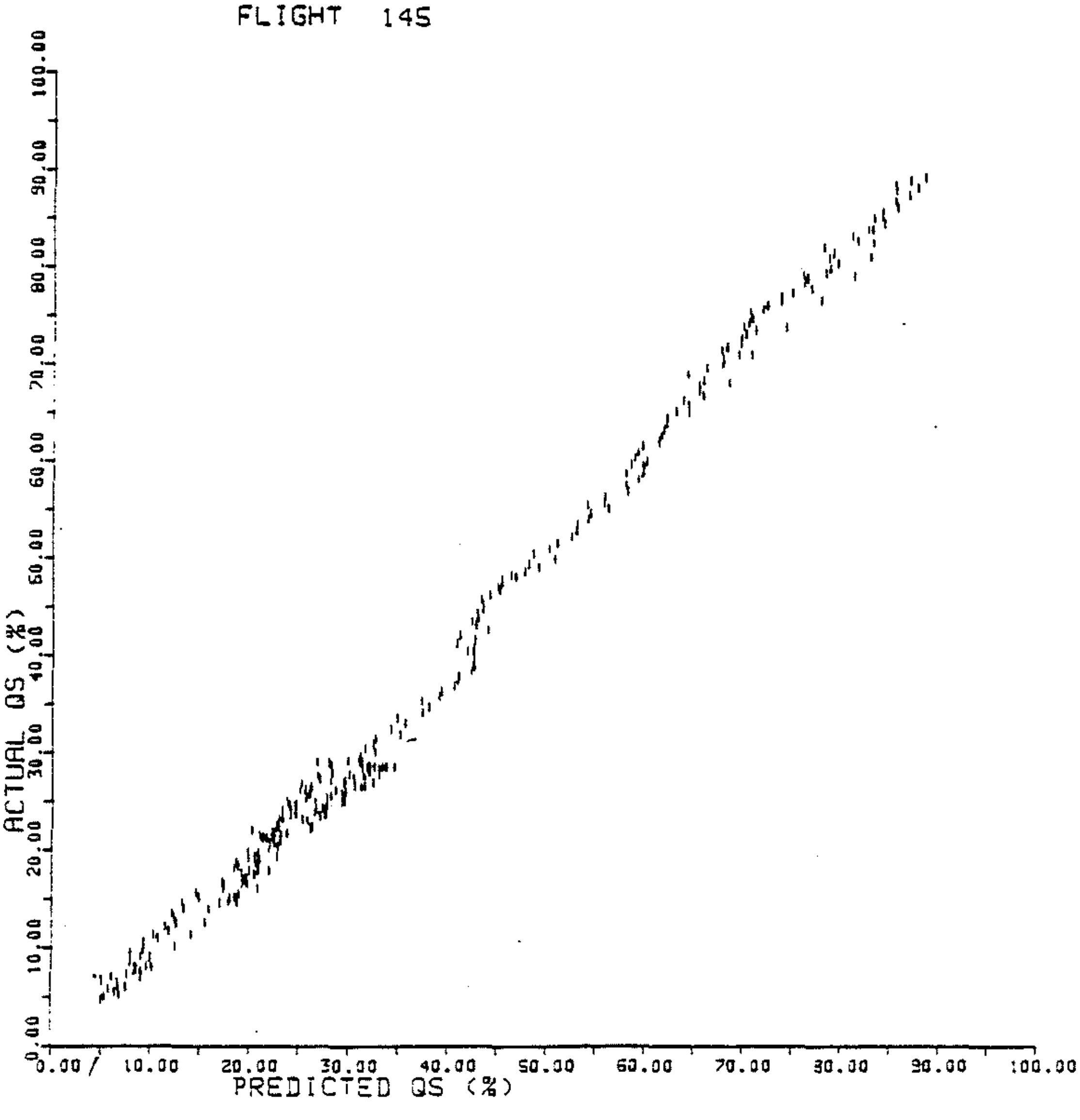

Figure 2.2 Comparison of Actual Torque and Predicted Torques for Clear Air Flight

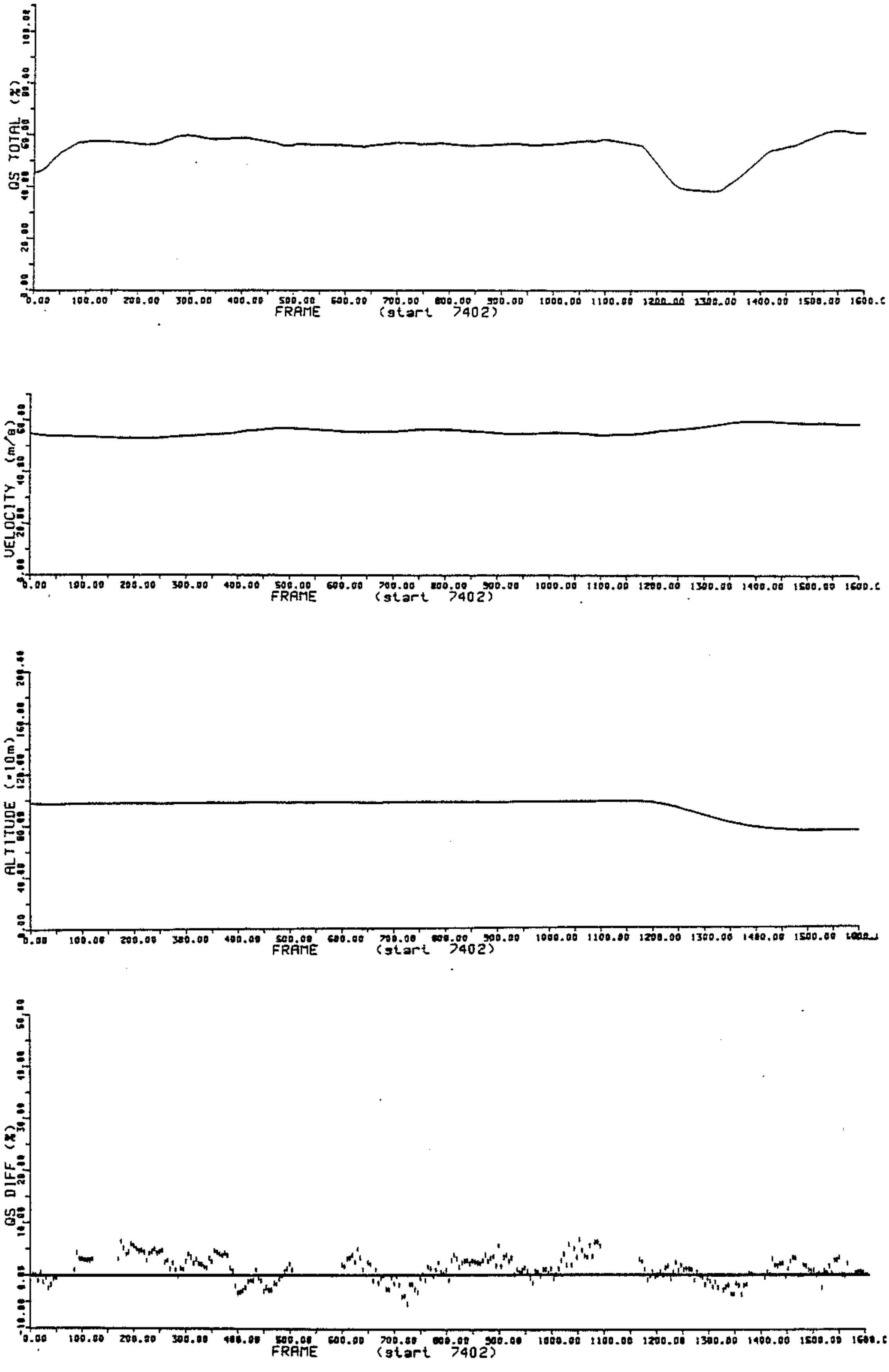

Figure 2.3 Clear Air, Level Flight

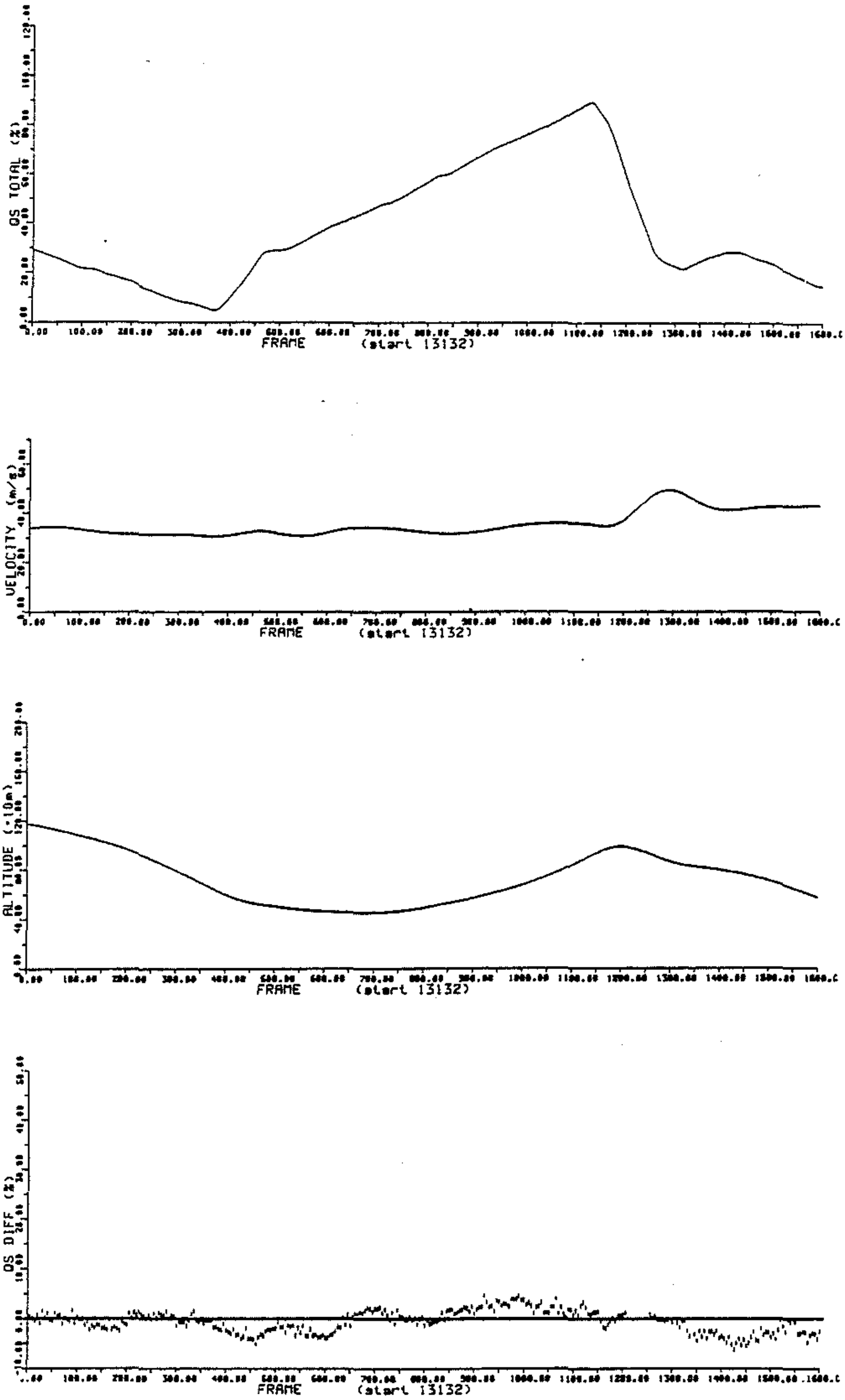

Figure 2.4 Clear Air, Climbing and Descending Flight

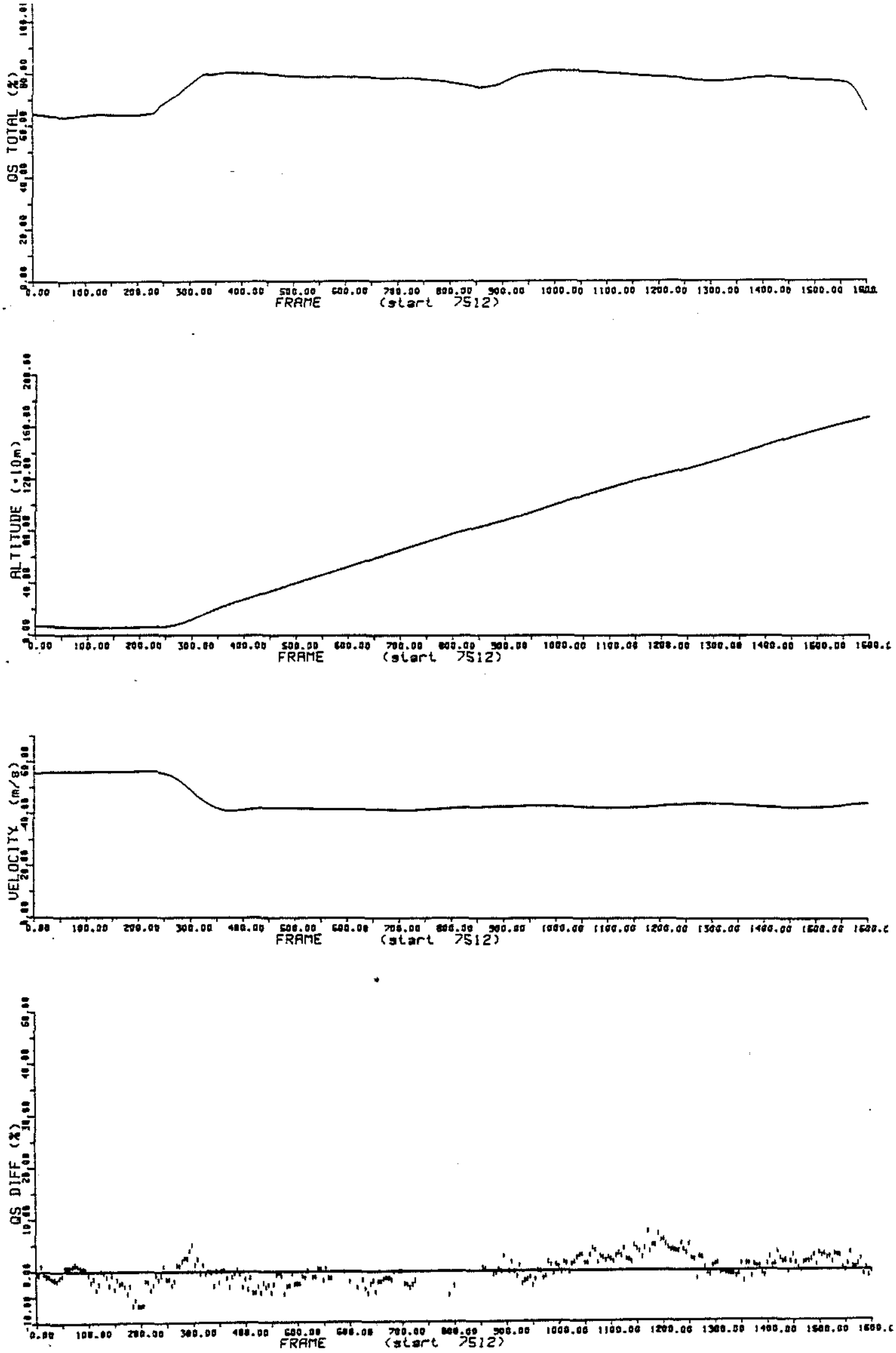

Figure 2.5 Clear Air, Climbing Flight

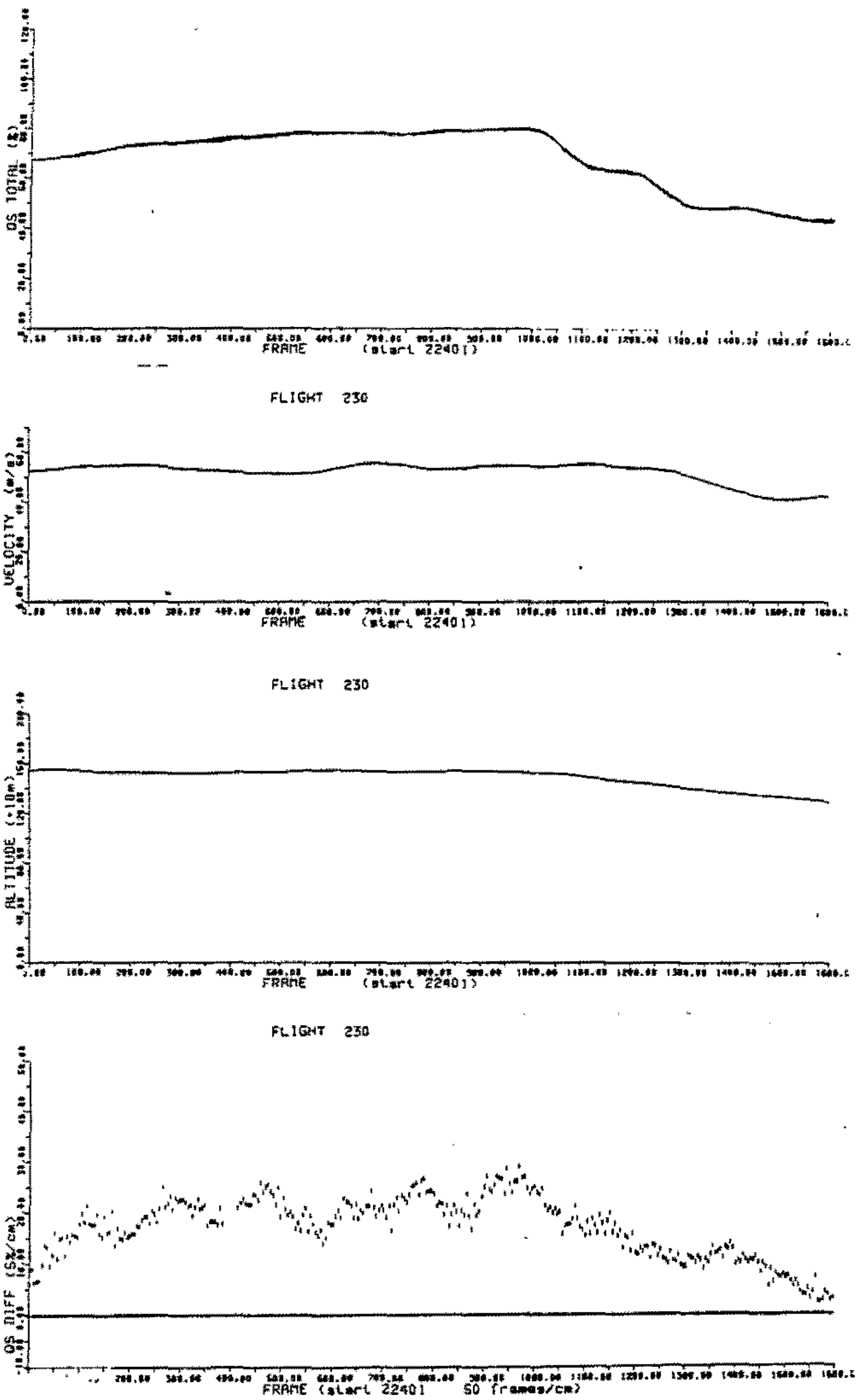

Figure 2.6 Typical Icing Encounter

3.0 System Implementation

In order to demonstrate the capability of the predictive equation, the Helicopter Lift Margin System shown in Figure 3.1 was adapted to perform the appropriate calculations and display functions.

The system, shown in block schematic form in Figure 3.2 is configured as three units:

- Performance Processor Unit (PPU)
- Control and Display Unit (CDU)
- Torque Indicator) (TI)

The PPU is a micro-processor based computer, and is used to perform all calculations, interface and system control functions. The CDU, developed for the Lift Margin System as a general-purpose pilot interface, is used in the Torque Monitoring System to allow crew input of take-off weight and configuration constant.

The torque indicator used is a modified version of an instrument originally designed for the Helicopter Energy and Rotor Management System (HERMES) for the Royal Aircraft Establishment Farnborough. This was a dual-engine torque indicator, which displayed torque generated by each engine as a percentage of the maximum available torque under existing atmospheric conditions, taking into account engine degradation. For the Torque Monitoring System, the display has been modified such that the predicted torque is displayed on one pointer, and the second pointer is used to display the average torque being generated. In clear air, assuming no rotor deterioration, the two pointers are superimposed. When a torque increment is detected, the second pointer becomes visible, thus giving an indication of both the magnitude of increment, and the actual torque generated. This display is re-inforced by an alpha-numeric display on the CDU, giving these two quantities to a resolution of 1%.

This equipment is currently being subjected to flight evaluation to verify system performance, and to extend the range of the performance model to cover turning, side-slip and hovering flight.

Following the successful demonstration of the use of energy concepts and rotor dynamics to predict torque requirements, the optimized system architecture is currently being defined. This is viewed as a two-fold excercise. It is clear that the next generation of helicopter will rely heavily on the concepts of data distribution through a multiplexed bus system, which will lead to the extensive use of electronic display media. In this concept, torque monitoring information can be supplied to the crew on an on-demand basis, or as an automatic advisory when the situation warrants such action.

As an interim solution to the problem of icing severity indication in existing helicopters, the prototype hardware designed is of a complex nature, and it has been determined that a single-unit configuration for the Torque Monitoring System will be required. Design studies are in progress to incorporate the required elements into a standard instrument housing, which may be readily incorporated as a retrofit indicator.

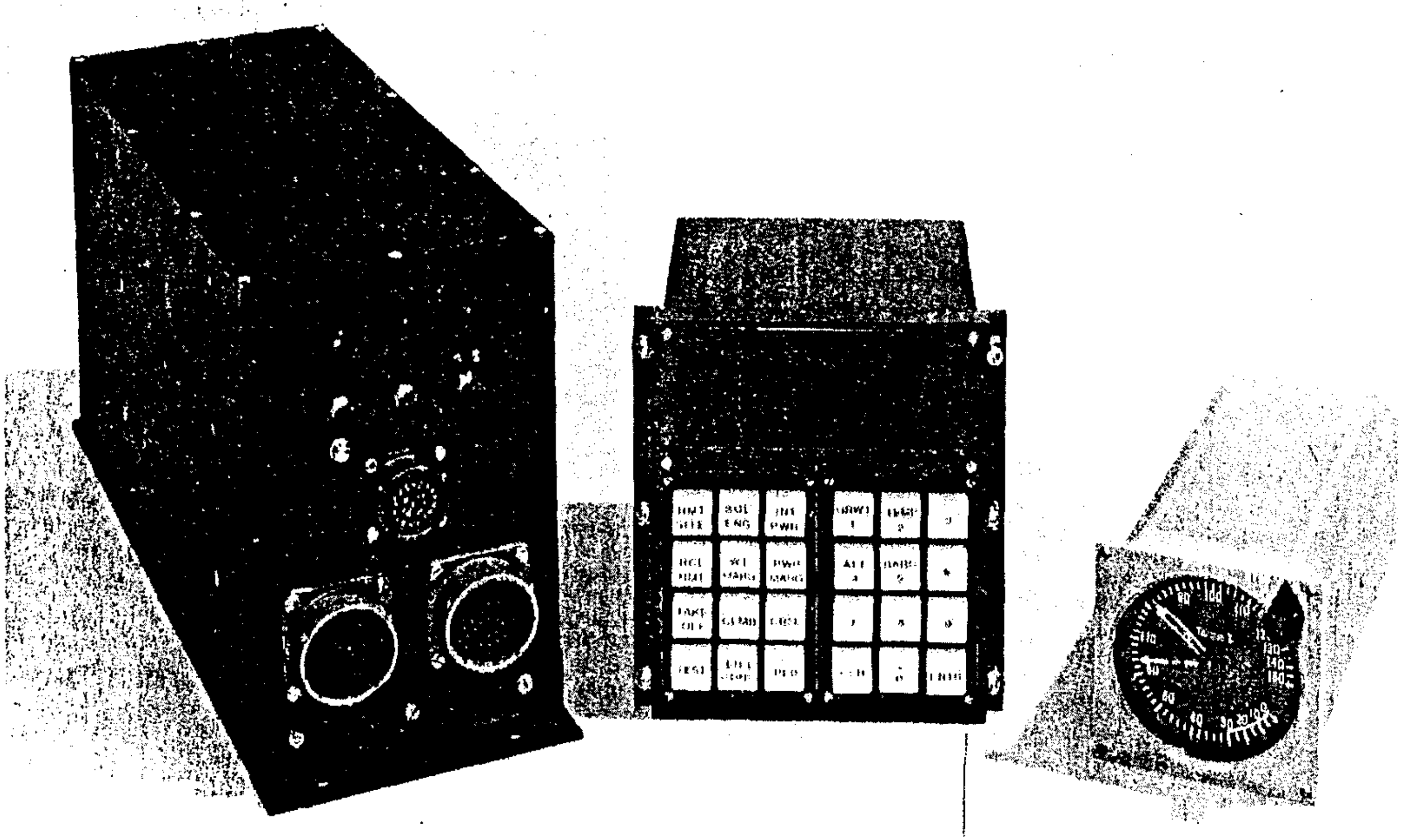

Figure 3.1 Lift Margin System

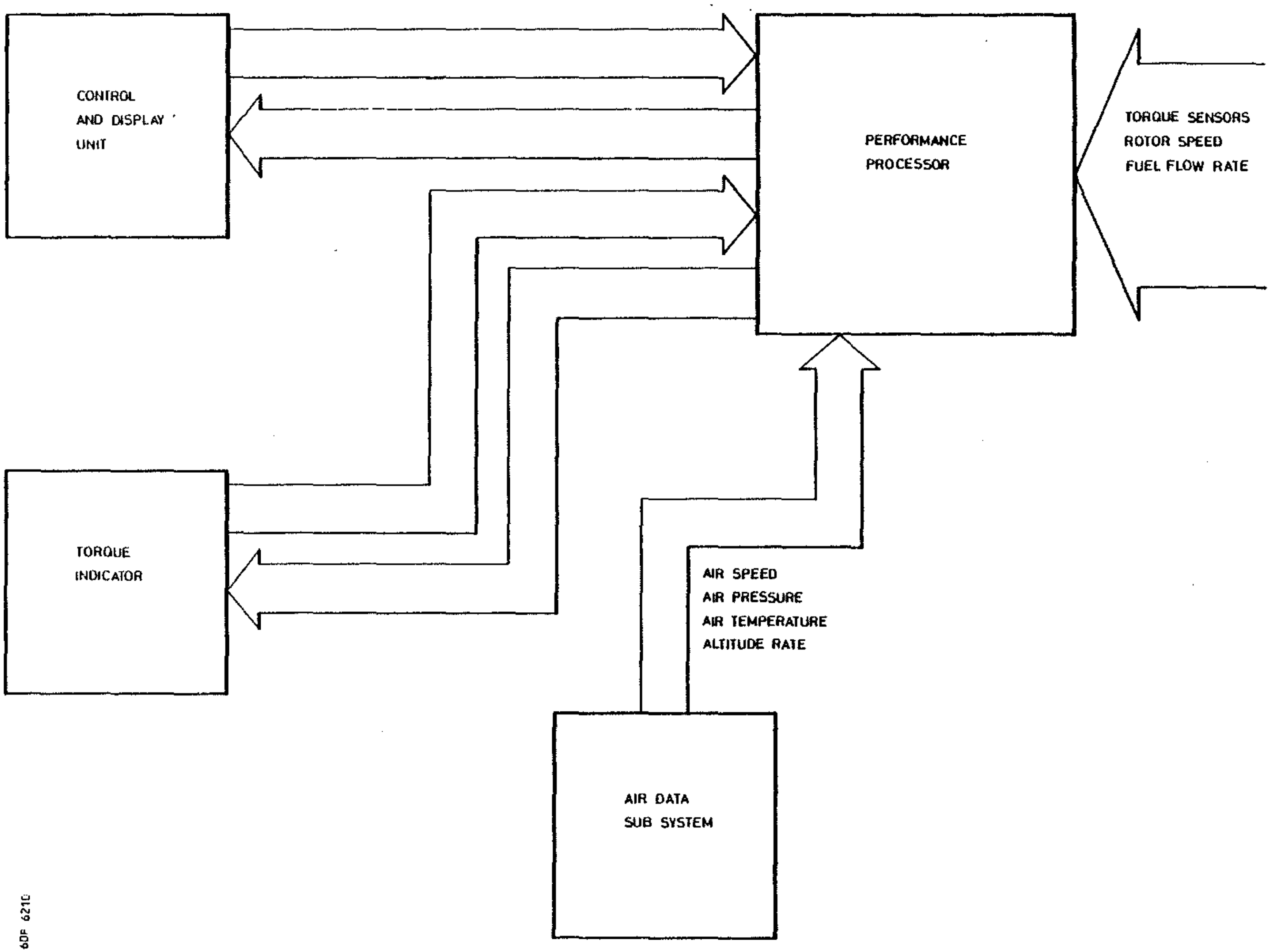

Figure 3.2 System Configuration

4. Summary

The detection of helicopter performance degradation in icing encounters has been identified as a requirement in order to enhance safety of flight. A method to detect such degradation, using the principles of energy conservation and rotor dynamics has been developed and evaluated. The results have indicated that prediction of power requirements to an acceptable accuracy may be achieved, and that potential equipment requirements need not impose significant installation complexity constraints for retro-fit programs.