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FLIGHT TEST SYSTEMS OF UNMANNED AIR VEHICLES - THE INDIAN EXPERIENCE

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INTRODUCTION

The flight test system on an unmanned-air-vehicle (UAV) today holds a unique position. It has progressed from a tool primarily used for post flight analysis and is now the most important data-acquisition and analysis tool used during the entire development phase of the UAV. This includes bench level & hardware-on-line simulation checks on the aircraft flight control system, integration level check out at system level of the entire UAV, pre-flight checks leading to the launch of the UAV, on-line monitoring to provide cues to the controller during the flight of the UAV and finally detailed post flight analysis of the UAV performance.

This paper briefly traces the course of development followed by the flight test telemetry systems on the different UAV programs at the Aeronautical Development Establishment (ADE), Bangalore. It brings out the need for an integrated design of the flight test system with the other UAV systems and illustrates the benefits of such an approach based on the application of this principle to the Remotely Piloted Vehicle reconnaissance UAV program "NISHANT" at ADE.

UNMANNED AIR VEHICLE TELEMETRY SYSTEMS AT ADE

The absence of a pilot on unmanned aircraft to provide feedback on aircraft flying qualities and performance of flight control and other systems makes onboard flight test systems the only alternative for UAV performance evaluation. The availability of extensive flight test data from such systems greatly reduces the number of flight trials to be carried out during the development phase of the UAV and provides for validation of each mission step in-flight before proceeding with the next step. The flight test system derives its inputs from the sensors of the auto-pilot system on the UAV and also from dedicated sensors for vibration, temperature, strain etc. and this data is invariably telemetered to the ground station via a RF link.

Table 1. shows the a comparison between the early flight test telemetry systems used on the ULKA and KAPOTAKA programs at ADE with the later systems used on the LLMT, LAKSHYA and NISHANT programs. The ULKA telemetry system used an IRIG FM/FM format with different voltage-controlled-oscillators for each channel, the channels requiring higher bandwidth were placed on the higher HUG channels. Such FM/FM telemetry systems provided the required bandwidth to accommodate high frequency vibration data but were limited by poor accuracy and limited channel capability. The KAPOTAKA system increased the channel capacity and accuracy by using a Pulse Amplitude Modulator on one of the higher IRIG channels. The first PCM systems characterised by high accuracy was the 8-bit system used on the LLMT program. The LAKSHYA system was an advanced 10-bit PCM system supporting super-commutation and subcommutation of channels. Discrete channels were also accommodated on specific words. The PCM system on NISHANT provides for a 12-bit system with a high bit rate of 125Kbps directly modulating the FM transmitter using a BIFL format. This permits the accommodation of vibration data within the PCM data. Another

unique feature is the addition of Dual-Port-Ram (DPRAM) based interfaces to the different processor systems on the NISHANT for direct access to all intermediate data being processed directly in digital form.

TABLE 1

UAV Program	Brief Description of UAV	Basic Telemetry System	Parameters of Telemetry System
ULKA	Expendable Air Launched target	FM/FM IRIG FM Channels from 2.3 to 70 Khz	Analog Flight Control data and Vibration data.
KAPO TAKA	Low cost aerial target and mini RPV	PAM/FM/FM Mix of IRIG FM Channels and PAM data on one channel	Analog Flight Control data 32 Channel PAM encoder
LLMT	Expendable Air Launched Target with radio altimeter based Low-Level altitude hold	PCM FM/FM NRZL PCM data	8 bit, 32 Channel at 6.25 Kbps
LAKSHYA	Surface/Ship launched high subsonic reusable aerial target with Tele-command	PCM FM/FM NRZL PCM data at 15.625 Kbps	10 bit, 96 word, 4x24 word frame 35 Analog Channels & 30 Discretes
NISHANT	Low speed remotely piloted vehicle for surveillance and reconnaissance	PCM FM BIFL PCM format at 125 Kbps	12 bit, 120 word, 40 x 30 word frame 35 Analog Channels & 40 Direct wired 40 Analog Channels & 45 Discretes DPRAM

THE NISHANT FLIGHT TEST SYSTEM

An integrated approach was taken during the design of the architecture of the avionics system as implemented on the NISHANT. The flight test system was integrated along with the modules which implement the avionics functions of Navigation, Guidance, Autopilot and the Secure data link . The flight test system also directly interfaced to the Payload control system. The following is a brief description of the NISHANT and its system configuration.

The Mini RPV "NISHANT" The NISHANT (Fig. 1) is a low speed pusher propeller driven air vehicle launched from a hydro-pneumatic rail launcher with an endurance of over 4 hours and a 45 Kg payload carrying capability. Its airframe is primarily built of carbon/glass fiber reinforced plastic to achieve low weight and radar signatures. The NISHANT is being developed as a battlefield surveillance and reconnaissance remotely piloted vehicle for

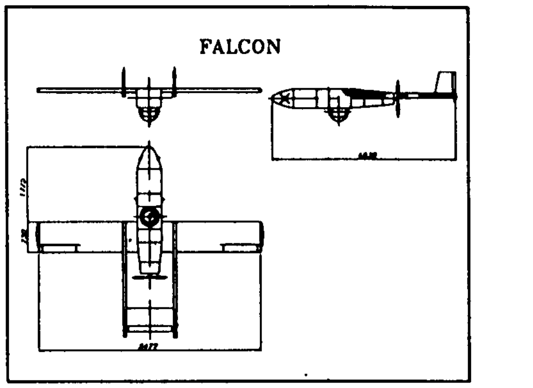

Fig 1. The NISHANTH RPV

the Indian Army. The NISHANT forms a host for a Gimbaled payload assembly which accommodates electro-optic payloads for surveillance, target acquisition and target tracking.

The Task of the Avionics System The task of the Avionics system (Fig. 2) is to position the NISHANT accurately at the intended location so that it can carry out its operational functions. The primary functions of the avionics system are Navigation, Guidance, the Autopilot and the Secure data link.

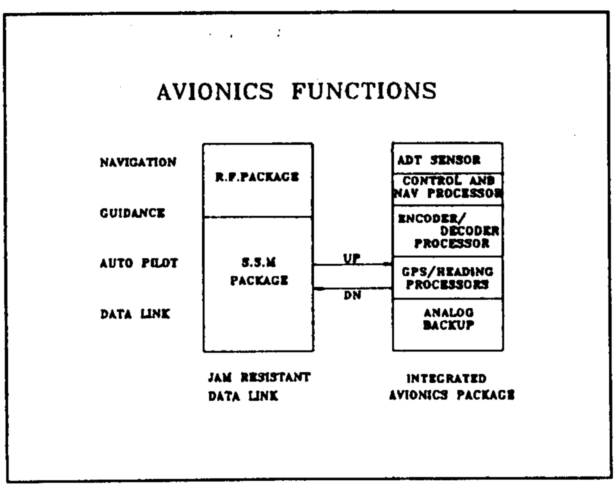

Fig 2. The Avionics System for NISHANT.

The Secure data link is implemented by an RF package operating in C-Band and a SSM package which provides jam resistance to the Uplink and Downlink data using spread spectrum coding. No remainder of die avionics functions are combined in a single LRU called the Integrated Avionics Package (IAP). The Flight test system obtains most of its data via a digital interface to the LAP.

The LAP contains the air data sensors, a control and navigation processor based on the Zilog 8002 processor , an encoder/decoder for the Uplink and Downlink data based on an Intel 80186 processor , a built in GPS kernel, an Intel 8051 based interface processor for handling the GPS data and RS232 data from an external wing mounted magnetic heading sensor. It also provides an analog back-up for the basic flight control functions in case of failure of the control and navigation processor.

System Architecture Fig 3. illustrates the avionics system architecture on the NISHANT. The IAP is interfaced to the SSM package via a two way RS 422 link , it is hard-wired to the basic flight control sensors , the Vertical Gyro and Yaw rate gyro which provide the inertial reference for Roll and Pitch and a damping signal for Dutch roll. The magnetometer is connected to the IAP by a RS232 link.

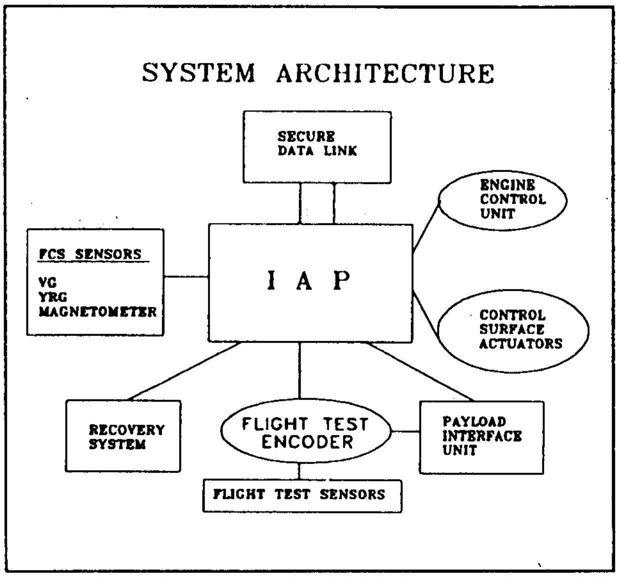

Fig 3. System Architecture on the NISHANT

The Control and navigation processor obtains data from the encoder/decoder, the flight control sensors and the GPS receiver and provides demand outputs to the engine control system and control surface actuators so as to provide basic air vehicle stability and control and implement the navigation modes of flight. The IAP provides data and commands to the Payload Interface unit which controls all the hard mounted and gimbal mounted sensors on the air vehicle. All data transfer between the processors contained in the LAP and between the IAP and the Payload interface unit and Flight test encoder are through dual-port RAMS. The flight test encoder thus has direct access to all within the IAP and Payload interface unit instantaneously in digital form.

The air vehicle is recovered using a two stage recovery system and the ground impact is contained using an air-bag system. The recovery sequence is controlled primarily by the IAP.

The NISHANT Flight Test System The NISHANT Avionics architecture is totally processor based, all parameters are readily available in the digital domain with a few exceptions such as vibration , wing root strain and engine temperatures which are analog signals. Parameters required by the controller for controlling the NISHANT are down linked by via the telecommand link and form the operational telemetry link. The Flight test encoder interfaces directly to the LAP via dual-port RAMS. Separate RAMs are provided for the interface to the control & navigation processor, the command encoder-decoder and the payload interface unit. By its extremely high connectivity to the entire avionics system the flight test encoder forms a unique data acquisition system. This data acquisition system is being used through all phases of the hardware development and flight test of the NISHANT.

PHASES IN DEVELOPMENT & FLIGHT TEST OF THE NISHANT

Phase 1. Ground Based Testing of the IAP (Fig. 4.). During these tests the IAP is interfaced to four major test units. The first is the Digital link test set which replicates the RPV Pilots control panel, the second is a computer on which the full-force six-degree of freedom NISHANT aerodynamic model is implemented in real time, an intermediate interface computer which outputs the Heading and GPS data in serial form to the LAP and finally a Data presentation system connected to the Flight Test interface which is used for display and monitoring of all test data. The ground based tests of the LAP include open-loop and closed loop hardware-on-line tests which are used to perform a detailed V&V of all software and hardware functions of the Avionics system.

Phase 2. Systems Integration of the NISHANT During this phase the IAP is installed in the air vehicle and interfaced to the other sub-systems such as the vertical gyro, yaw rate gyro, control surface actuators, gimbal-payload assembly and propulsion system including the alternator. The flight test encoder data is connected in a direct mode/ or via an RF link to a real time data display

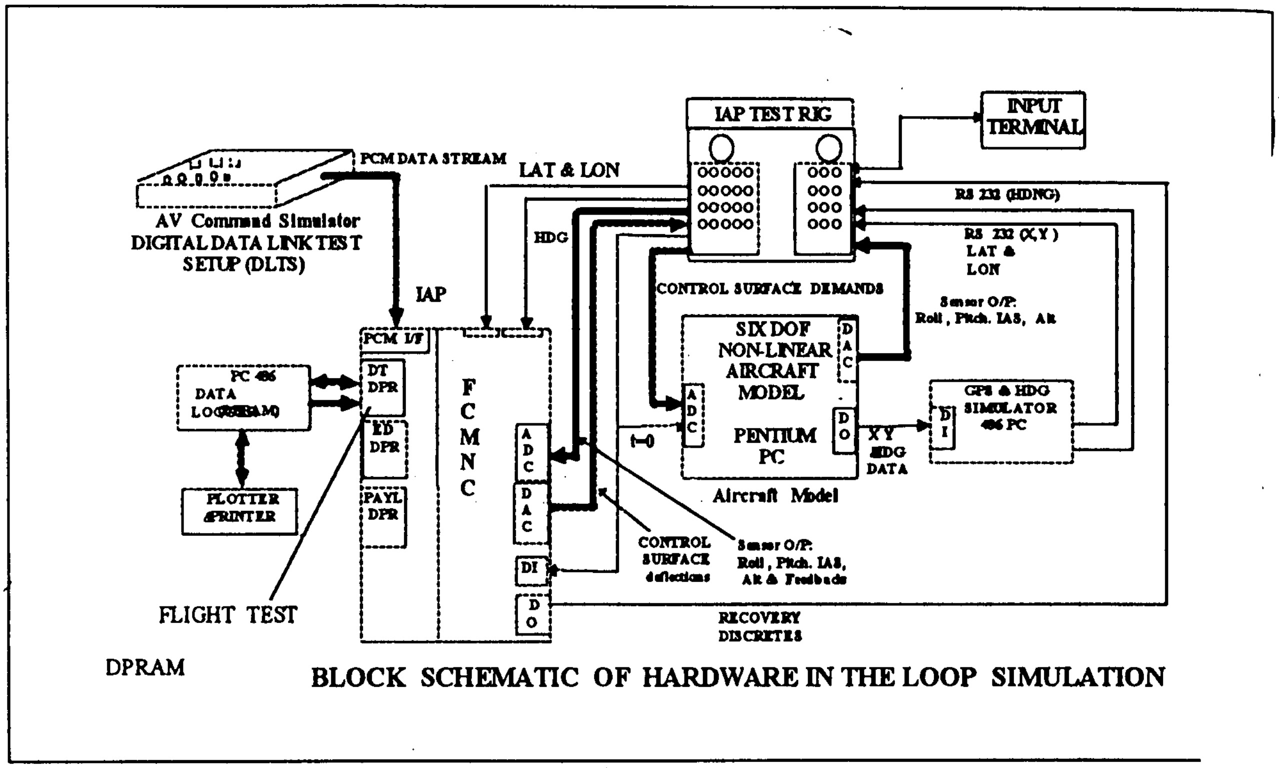

Fig 4. Ground Based Testing of the IAP

system which forms the basis of all test data recording and analysis during the systems integration phase.
System integration tests include:

- Qualitative tests on the Flight control system to determine correct functionality and adherence to correct system logics.
- Quantitative tests on the Flight control system to evaluate all gain and response parameters. These tests are computer aided.
- Detailed functional tests on the Gimbal payload assembly to evaluate performance in the manual, inertial and auto-track modes.
- Detailed tests on the SSM command link and finally
- A ground engine run to access the performance of the integrated NISHANT system including the propulsion system under engine driven alternator power.

During all these tests the primary data acquisition, display and analysis system is based on the Flight test data .

Phase 3. Pre Launch checks & Flight Phase (Fig.5)

During this phase of testing the Air vehicle is placed on the launcher and the Pilot is in command via the Ground

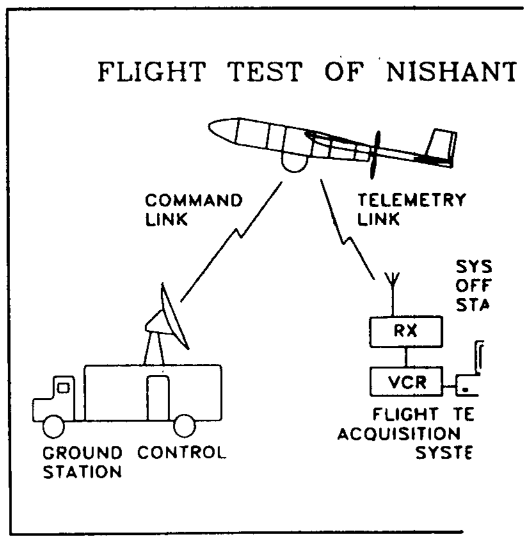

Fig 5. Control & Telemetry Li

Control Station. All data acquired via the tem is presented to the "Systems Officer' the health of the NISHANT during the I and gives the final clearance for the launc

With respect to Fig.5, the pe NISHANT is monitored at the Systerr via the Flight Test Telemetry link. Thi:

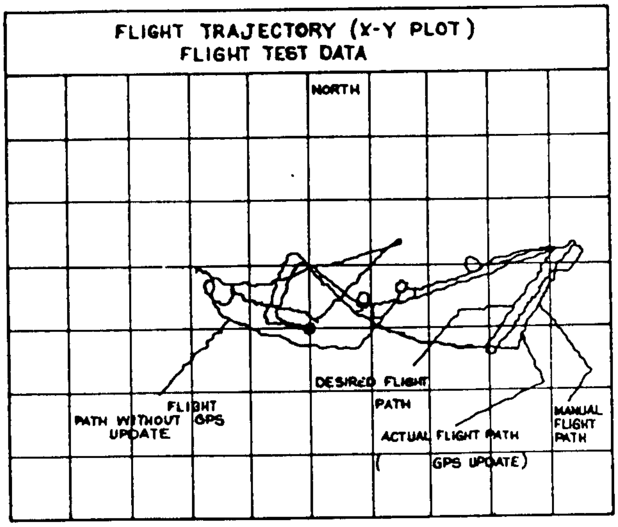

Fig 6. Flight Trajectory NISHANT.

tems officer with data related to the stability of the aircraft, performance of the Flight control system hardware, engine health, RPV position based on GPS and detailed parameters on the payloads. The Systems Officer is in a position to prompt the NISHANT controller on the system performance aspects of the air vehicle throughout the flight. This data is recorded both on magnetic tape using a standard Video Cassette Recorder (VCR) and also on hard-disk and is available immediately after the flight for post-flight analysis.

Fig 6. shows the ground track of a typical NISHANT flight test sortie. The track flown with respect to the desired path during the manual mode of control, air data dead reckoning (ADDR) mode and GPS aided navigation mode can be seen.

<u>The NISHANT Flight Test Parameters</u> Table 2. shows a typical list of telemetry parameters and lists the NISHANT performance parameters derived during the flight test program based on these parameters.

LESSONS LEARNED OUT OF THE NISHANT PROGRAM.

An integrated approach to the avionics and flight test system has been followed on the Mini RPV NISHANT. A major lesson learned has been that with an all digital RPV system the Flight test system provides a powerful tool for the development of the UAV. In the NISHANT Program the data acquisition and display system developed in Phase 1. of the development remains the primary post flight analysis system, and the display system developed as part of Phase 2. is useful for both system integration testing and also for the pre-launch and flight phases of NISHANT. The greatest advantage of these display and analysis systems is that they are fully validated during ground tests as they form the primary data acquisition systems and fit in automatically for on-line data display and post flight analysis.

TABLE 2.

TELEMETERED PARAMETERS	PERFORMANCE PARAMETERS MEASURED/ESTIMATED
IAS, Altitude, GPS X-Y, Low Fuel Warning, Time	Ground Speed, Range, Endurance, Operational Ceiling, Max Speed, Min Speed, Rate of Climb, Rate of Descent, Navigational Accuracy
Pitch, IAS, Altitude	Stall Speed
Roll, Roll Rate, Heading, Time.	Lateral Dynamics in Normal And Heading Hold Modes
Heading, Time, GPS X-Y	Turn Rate, Time to 360 Deg Turn
Yaw Rate	Lateral Stability
Pitch, Pitch Rate, Time	Longitudinal Dynamics Normal and Heading Hold Modes
Control Surface Feedback on Aileron, Elevator, Rudder	Dynamic Performance and Duty Cycle of Control Actuators
IAS, Eng RPM, Throttle Feedback, Engine Temperatures, Time	Engine Performance, IAS Hold Loop Dynamics
Wing Root Strain	Wing Loading During Different Flight Modes, Gust and During Recovery
Accelerometers	Vibration Data at Different Locations on Air Vehicle

CONCLUSION & FUTURE TRENDS

In conclusion it can be stated that the experience gained during the flight testing of unmanned air vehicles at ADE has been the need for an integrated design of the avionics and flight test systems and the use of the Flight Test System as the primary data acquisition and analysis system during all phases of UAV development and Flight Test.

The unmanned air vehicle pilot misses out on the "seat of pants" cues that are available to a manned aircraft pilot, the next step is to use the flight test telemetry data and an Artificial Intelligence system to provide a Pilot Associate to the UAV controller and introduce other cues to the him using Virtual Reality techniques.