Flight Research using Radio-controlled Small Airplanes

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The current interest is on Unmanned Air Vehicles (UAV's) as they have considerable potential for economically performing many tasks which are currently in the domain of manned vehicles. For some years now such vehicles have been in use for aerial observation and as communication relays. There is much effort worldwide in developing such vehicles for limited combat duties as well. Quite apart from this line of development, such vehicles have been used for supporting design and development of flight vehicles. Scaled models of aircraft were used in the early seventies in studying the post stall behaviour of F-15 airplane. It is understood that instrumented flights of scaled models of aircraft like the MIG 29 and Su 27 were extensively used during their development. These developments were possible because of extensive developments in computers, sensors, instrumentation, telemetry and other related techniques during the last few decades. These developments have rapidly advanced further in recent times and it is now possible to conduct research using unmanned flight models of relatively small size. Costs involved in such studies are two to three orders of magnitude lower than for studies using manned vehicles. Because of this, academics with very limited resources can now consider using tiny aircraft for research purposes. It is in this context that a program of flight research has been underway at the Indian Institute of Science, Bangalore in the last few years. The emphasis of this program has been on the flight mechanics aspects of combat aircraft configurations while control and guidance aspects are also receiving some attention.

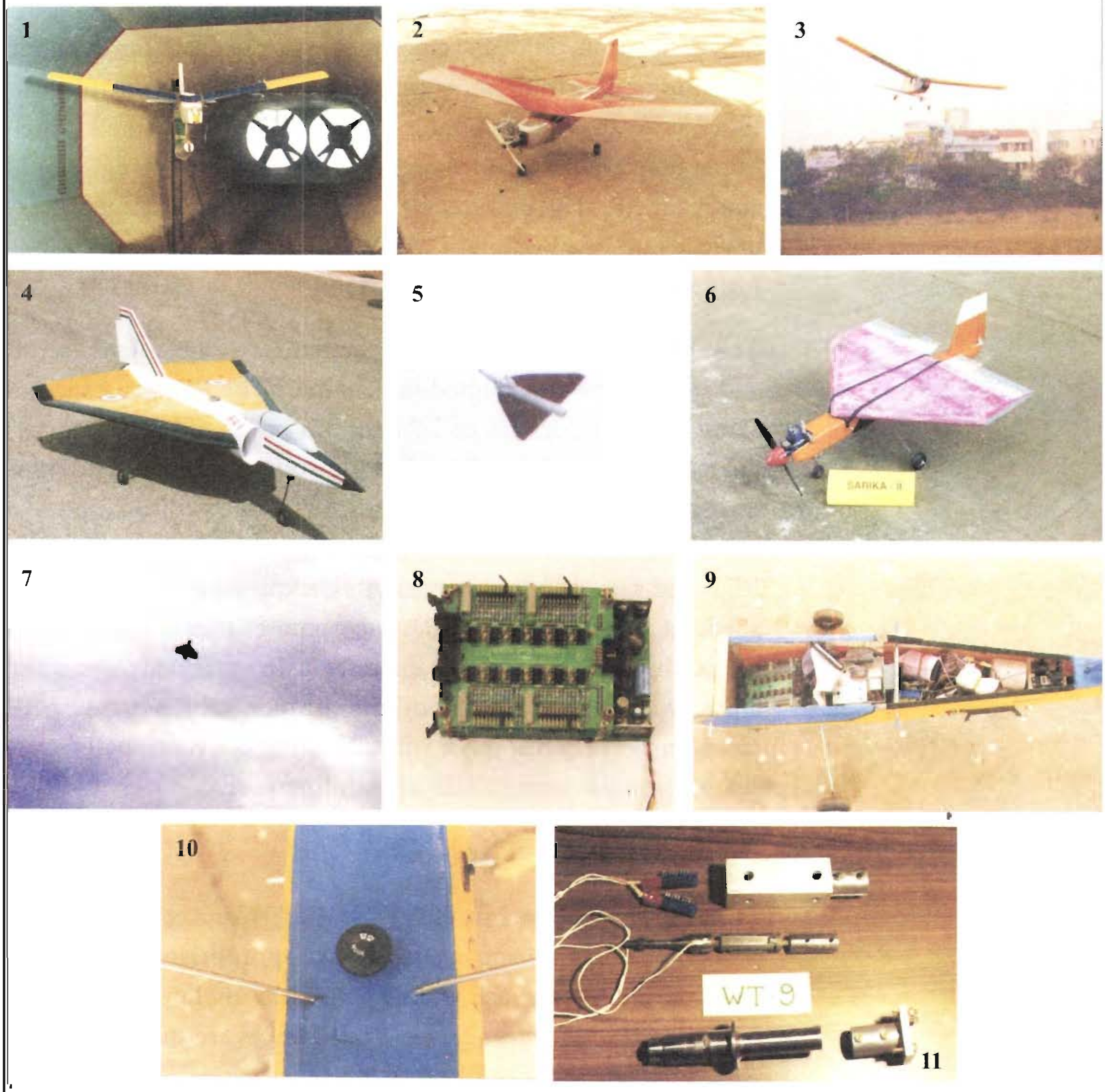
The Airplanes

Keywords
Flight research, UAVs, aircraft testing, flight mechanics.

Two small airplanes, the Flying Test Bed (FTB) and the Research Airplane (RA) have been developed for the studies

(*Figures* 1-11).

The FTB has been thought of as a test bed for development of instrumentation and experimental techniques for flight me-



Figures 1-11. The FTB in the wind, tunnel. 2. The FTB ready for flight. 3. The FTB in flight. 4. The RA ready for flight. 5. The RA in flight. 6. The Sarika II ready for flight. 7. The Sarika II in flight. 8. The flight data recorder. 9. The RDR and sensors installed in the FTB. 10. The PA horizon sensor used for stability augmentation. 11. Miniature wind tunnel balance suitable for UAV tests.

chanical studies. The FTB has a conventional straight wing configuration, and uses a fuselage of glass reinforced plastic (GRP) in the form of a one-piece moulding. There is sufficient volume inside the fuselage for accommodating various instrumentation packages like the flight data recorder (FDR), sensors for acceleration, angular velocity, pressure sensors for dynamic pressure and altitude measurements, sensors for control positions, etc. It is also possible to carry a payload like a video camera for evaluation purposes. The FTB with a wing span of about 2 metres and powered by 7.5 cc glow plug engine can carry payloads up to 2 kg weight (AUW of 6 kg) and is ideally suited for development of instrumentation.

The RA has been configured to be typical of a combat aircraft and is powered by a ducted fan engine. The RA has a span of about 1.1 m and length of 1.7 m and is powered by a 13 cm dia ducted fan driven by a 15 cc glow plug piston engine. The static thrust of the power plant is about 3 kg and the airplane has a maximum take-off weight of about 6 kg. The RA can carry the FDR and various instruments in its cockpit which is located just ahead of the engine. The RA incorporates thrust vectoring in the pitch plane. The RA is fabricated using primarily wood and fabric with the exception of the airduct, which is an FRP moulding. The RA takes off and lands conventionally on a smooth runway using a tricycle landing gear.

Wind Tunnel Studies

To generate aerodynamic data on small airplane configurations, six-component strain gauge balances of appropriate ratings have been developed for use in the 2.75×4.25 m low speed wind tunnel[1] at IISc (*Figures* 12-14). The balances are suitable for full scale tests of the above research airplanes with the power plant operational. Thus accurate performance, static stability and control data on FTB, RA and other configurations have been generated using the wind tunnel tests of these airplanes. Some dynamic stability parameters (like aerodynamic damping derivatives in various degrees of freedom) have also been mea-

[1] S P Govinda Raju, Role of wind tunnels in aircraft design, *Resonance*, Vol.8, No.1, p.72, 2003.

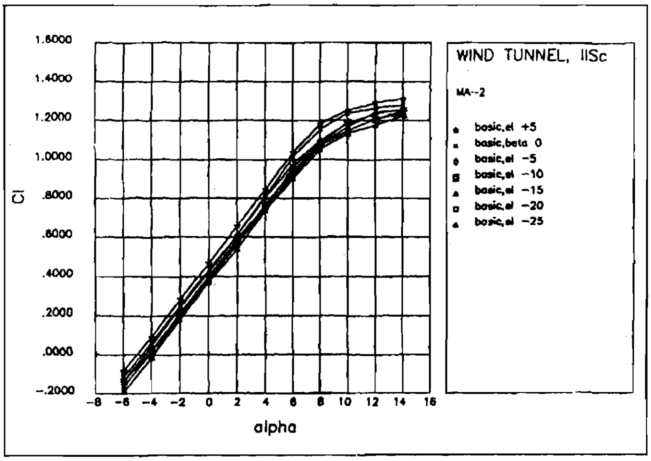


Figure 12. Lift coefficient (Cl) variations with angle of attack (a).

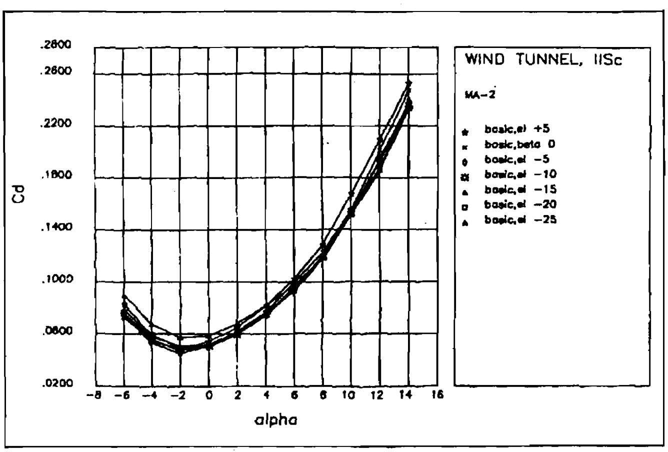


Figure 13. Typical wind tunnel data C_D vs α.

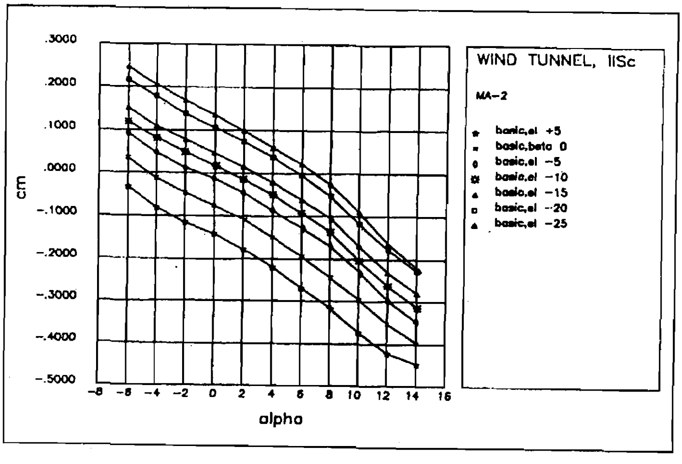


Figure 14. Typical wind tunnel data C_m vs α.

Box 1. Forces on an Airplane

A body in flight experiences in general three forces and three moments generated by the air flowing around it. The three most important quantities are: lift (L), drag (D) and pitching moment (M). (See *figure*). Drag is the force in the direction of the wind and lift is perpendicular to the wind direction.

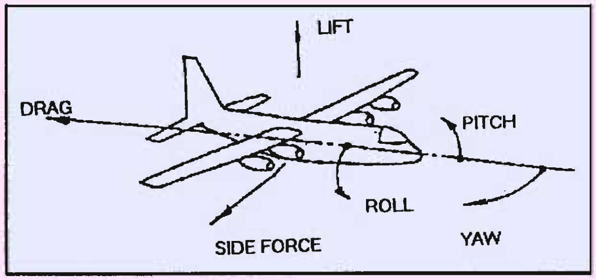
In level flight, engine thrust $T = D$, L = Weight W.

It is useful to define non-dimensional coefficients as follows:

$$C_L = \frac{L}{\frac{1}{2}\rho\, Uo^2 A}$$

$$C_D = \frac{D}{\frac{1}{2}\rho\, Uo^2 A}$$

$$C_M = \frac{M}{\frac{1}{2}\rho\, Uo^2 A\, C},$$



where ρ is air density, U_0 is relative velocity between the airplane and the ambient air, A is a reference area usually the planform area of the wing and C is wing chord.

sured using forced oscillation rigs in the wind tunnel. Thus accurate computer modeling of the dynamics of the research aircraft is feasible and is an integral part of the flight research. One may specifically mention studies of the effect of thrust vectoring on performance and control of RA in this context.

Flight Instrumentation

For studying the mechanics of any flight vehicle, inflight acquisition of data is an essential first step. Considering the small size and payload capabilities of research aircraft, a flight data acquisition system of low weight, size and power consumption has been developed. The system consists of the FDR, sensors for control positions, air data and motion parameters, and signal injection system (SIS) which injects command signals into the radio control transmitter so that the airplane performs pre-programmed manuevres.

The Flight Data Recorder: The key element of the instrumentation system is the FDR. It is a compact unit of roughly 5 cm × 12 cm × 20 cm size and weighs about 350 gms. The on-board sensors can be interfaced with the FDR through appropriate analogue filters. The FDR includes preamplifiers of adjustable gain so that even low level signals can be effectively recorded. The FDR consists of a 8 channel multiplexer and 12 bit analog to digital converter. The data is stored in a memory of 256 kilo bytes. Sampling rate can be selected in a range of 50 to 2000 samples per second. The data after a flight stored in the FDR can be downloaded to a PC for analysis.

Sensors: Control positions on the aircraft are sensed by tapping the feedback potentiometers of the servo motors actuating the control surfaces. Air data consisting of flight speed, incidence and sideslip are sensed using differential pressure sensors after converting these quantities into pressure differences through pitot-static tube and aerodynamic pitch/yaw sensors. These are precalibrated by wind tunnel tests. The response of the airplane is sensed using motion sensors in the form of miniature rate gyros and accelerometers. Flight altitude is sensed using a differential pressure sensor provided with a reference corresponding to runway surface from which the airplane takes off. Other sensors can be added as required, but are subject to limitations of weights and size. However, the above sensors are entirely adequate for flight mechanical studies of airplanes.

Signal Injection System: For detailed studies of the dynamical aspects of airplane motion and to estimate the stability derivatives, well defined and repeated manoevre have to be performed by the airplane. Manual inputs are unsatisfactory for this purpose and a full computer based control system is complex and expensive. It is in the context that a stimulus injection system (SIS) is being developed based on a micro controller. The system is designed to inject a preselected waveform (like 3-2-1-1 or doublet) input into any chosen channel (s) of a radio control system, thus activating the relevant control surface motion. The radio control system is otherwise used only for remote piloting.

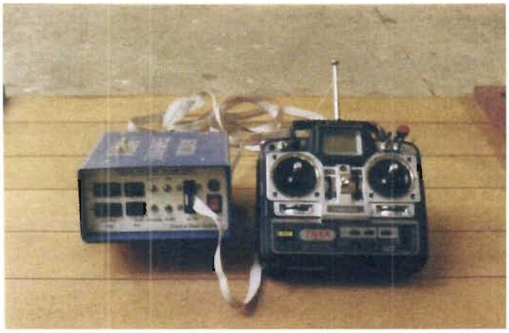
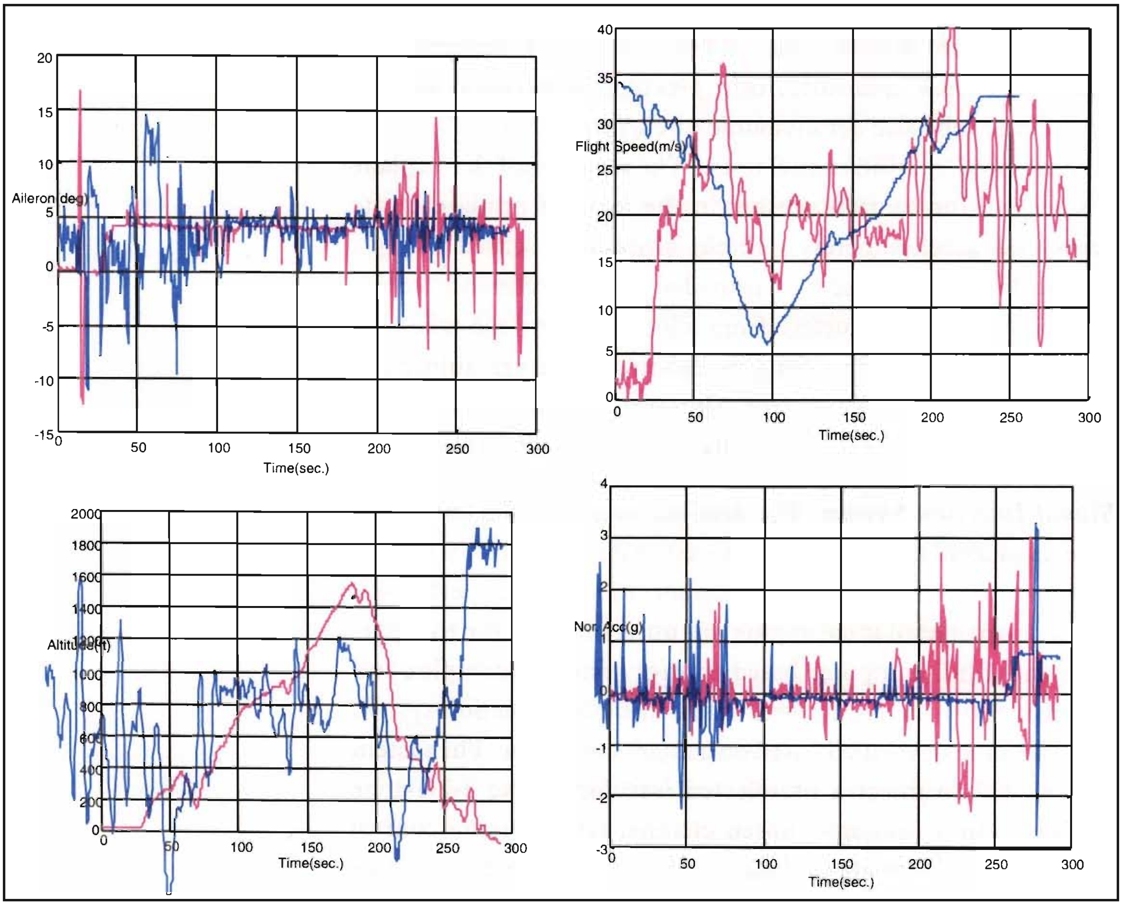


Figure 15. The signal injection system suitable for pre-planned maneuvers.

Thus the airplane will take off and reach steady level flight conditions under the command of the remote pilot before the SIS is activated to inject the signals in upto two channels required for performing a controlled maneuver. The FDR will start recording all relevant parameters slightly prior to the maneuver and continue to record for a suitable time thereafter. The airplane will continue to be under the command of the remote pilot after the maneuver. After landing the flight data can be downloaded for analysis.

Figure 16. Typical flight results.



Flight Trials

Instrumented flights of the research aircraft have been performed for studying the performance and stability characteristics of the research aircraft and useful results have been obtained on the FTB (*Figures* 15-17). Further flight trials and analysis of data based on parameter estimation techniques is continuing. The studies are being extended to cover some aspects of control and navigation of airplanes. These studies have relevance in the context of autonomous flight of small airplanes for surveillance purposes.

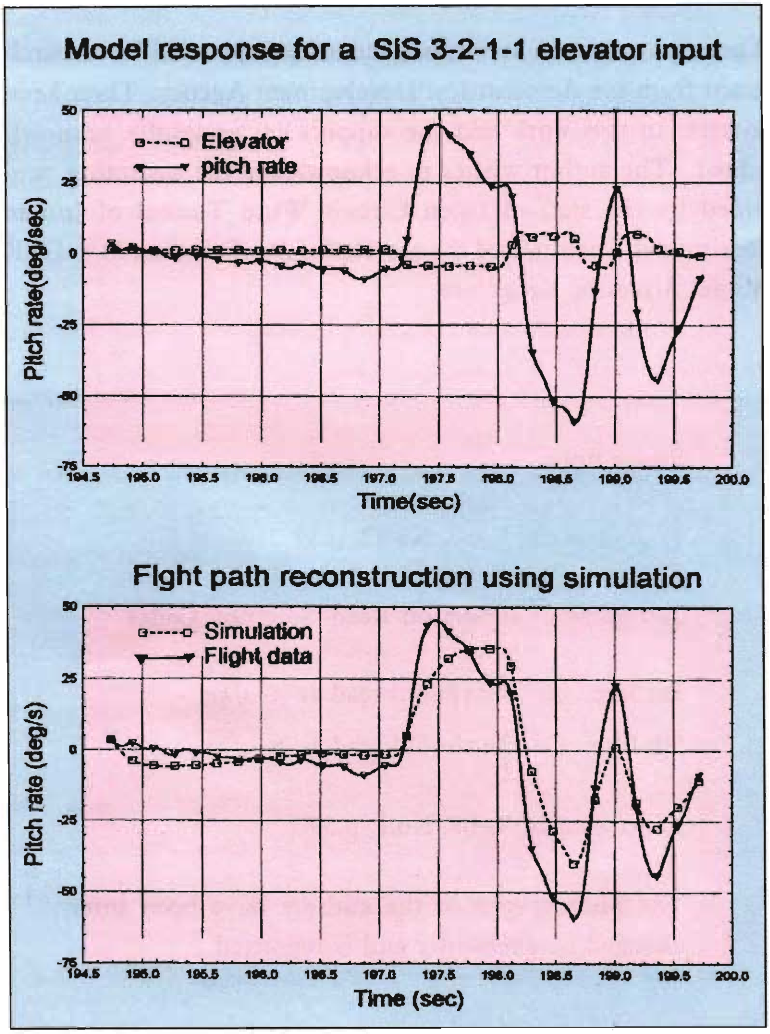


Figure 17. Typical flight results using SIS.

Conclusions

Instrumented small airplanes for research and development of airplanes and other flight vehicles offer a viable method of study which is very cost-effective. The studies could also be extended into control and navigation. Development of small airplanes for various surveillance applications can also be effectively handled by this route. It is expected that the methods and instruments developed in the present context will find wider applications in future.

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Please note:

1) *Resonance*, Vol.7, No.12, p.89

2nd paragraph: Section Reed–Solomon Codes

3rd line: $n = \sqrt{kn}$ should read as $n-\sqrt{kn}$.
5th line: $n = \sqrt{kn}$ should read as $n-\sqrt{2kn}$.

2) *Resonance*, Vol.8, No.1, p.59

The photographs of the authors have been interchanged inadvertently and is regretted.