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A FEW ASPECTS OF FLIGHT DATA ACQUISITION AND ANALYSIS FOR TWIN TURBOPROP SARAS AIRCRAFT

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ABSTRACT: Design and development of civil aircraft for commuter role is a relatively new effort in our country. National Aerospace Laboratories (NAL) are developing a short haul, twin turboprop commuter aircraft, named Saras. We are currently testing two prototypes (PT1 and PT2) of Saras in flight. This paper gives some details about the data acquisition and processing. Subsequently, some aspects of analyzed data are highlighted by using 'classical' techniques wherein steady state aircraft maneuvers are used to generate data. Design expectations of various characteristics are mainly based on wind tunnel test results and were supplemented, wherever required, by panel method computations as well as engineering estimates. The results of flight data analyses are compared with design data. It can be inferred that flight data show reasonably good match with design data for elevator power, power-off drag polar whereas trim tab adequacy is not borne out in flight as per design data. The other two characteristics of engine torque resulting in zero thrust and that of rudder blowback are purely results of flight testing for which no results were available from design data.

Nomenclature

BT	=	Balance tab
CD	=	Coefficient of drag
CL	=	Coefficient of lift
Cm_o	=	Pitching moment coefficient at CL=zero
D	=	Drag
D_P	=	Propeller diameter
dVR	=	Position error in speed
EEPP	=	Estimated engine performance package
GPS	=	Global positioning system
IDPE	=	Indirect power effect
KCAS	=	Calibrated air speed in Knots
q	=	Dynamic pressure
Sref	=	Reference wing area
SSR	=	Solid state recorder
T	=	Thrust
t	=	Time
TAS	=	True air speed
TC'	=	Thrust coefficient
V	=	Aircraft speed
W	=	Weight of aircraft

Subscripts

F	=	Parameter taken from flight data

1. INTRODUCTION

Aircraft flight testing is a multi-faceted activity. What is more amplified for prototype aircraft is a need to evaluate performance on ground as well in the air along with handling characteristics which manifest themselves through inputs of control surfaces/configuration changes and outputs in terms of linear and angular movements of the aircraft as a whole. Of equal importance is the performance of various systems which are installed on the aircraft.

National Aerospace Laboratories (NAL) has designed a short haul aircraft named Saras which is being developed as a commuter aircraft and can also serve executive travel, maritime surveillance and air ambulance roles. Equipped with two turboprop engines, Saras configuration has a low wing and high horizontal tail. Each engine of the first flying prototype (PT-1) is rated at 850 HP and drives aft mounted propellers at a constant speed of 2000 RPM [1]. The second prototype (PT-2) is powered by two turboprop engines, each of 1200HP rating driving the propellers at 1700 RPM. Two prototypes of Saras are being flown currently for testing them in flight.

2. DATA ACQUISITION AND HANDLING

All parameters including several health monitoring signals are acquired through flight test instrumentation by using a multitude of sensors to measure various temperatures, pressures, accelerations, voltages and currents etc. Handling and analyzing large amount of engineering data is an important part of the whole exercise since the results of this activity are submitted to airworthiness certification authorities. Therefore, it is very much desirable that the captured data be largely free from errors and noise signals. For Saras aircraft, onboard data acquisition is done through KAM-500 system. Remote telemetry station is located in ASTE, Bangalore where real-time data is displayed on several monitors. For post-flight analysis, SSR data records are preferred.

A flight data acquisition system with modified modules (schematic diagram is shown in figure 1) has been developed around KAM-500 comprising of two units, each with a capability of accommodating 13 modules to cater to various types of sensors. For certain parameters, special-purpose signal conditioning circuits are developed in-house. KAM-500 units have been inter-connected in a distributed architecture to form a master and slave configuration. The master will receive the signals from the slave unit and generate a PCM stream. Various data acquisition modules also cater to ARINC 429 digital data bus.

One stream of PCM data from the master unit encoder module is recorded on SSR. Another PCM stream is fed to an L-band FM telemetry transmitter. The transmitter, centered at 1500 MHz, feeds two antennas on the aircraft.

Data are recorded in a columnar format including discrete parameters (primarily for state indication). For Saras PT-1, data acquisition rate is 16 Hz whereas for Saras PT-2, different acquisition rates for different parameters or group of parameters is possible. For this case of non-uniform sampling rate, each column of data has its own accompanying column of time. Software has been developed in-house [2] for handling data acquired with non-uniform sampling rate. Various steps involved in the flow of data from acquired signals to final engineering units are shown in schematic diagram (figure 2).

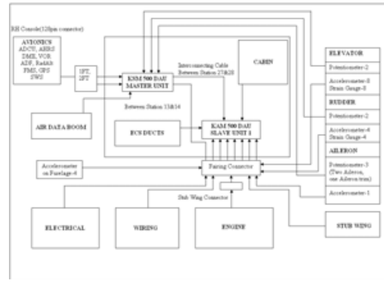


Fig. 1: Schematic of instrumentation

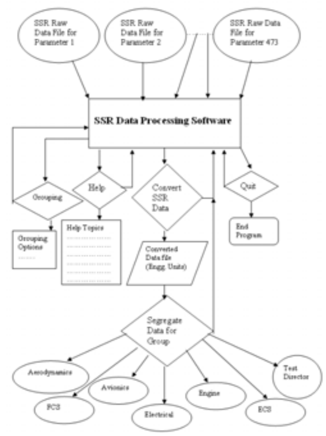


Fig. 2: Data processing flow

3. FLIGHT DATA ANALYSIS

It is very useful to analyze flight test data and compare with data generated through non-flight modes, viz, wind tunnel data, computational fluid dynamics and engineering estimates (put together, these sources can be referred to as ‘design data’). In this section we present comparison of flight test data with design data. In some cases, matching between design data and flight data has been good whereas in some other cases, flight performance did not corroborate design data. This has happened for trim tab performance and climb performance. Climb performance has been improved in PT-2 compared to PT-1 and the issue of trim tab performance is being currently tested on PT-2. Design modifications on PT-2 to this effect have already been made.

Analysis of flight data, as presented in this paper, is primarily based on classical techniques, though a few test points have been carried out to identify aerodynamic parameters by using parametric identification techniques. Even while using classical methods, commonly available literature does not always fulfill the requirements completely. In part this is due to appreciable airframe-propeller interaction on Saras configuration. Therefore, in several instances, methodologies are evolved in-house. All the power-off aerodynamic data referred to in this paper is taken from [3]. All the flight test data presented here have been acquired with a center of gravity location of 30%mac.

3.1. Longitudinal acceleration on ground

Longitudinal acceleration for SARAS PT-1 with flaps 10 deg was determined during take-off ground run and high speed taxi trials. For each high speed taxi trial and flight test considered, acceleration is calculated from speed – time history in the speed range of 30 KCAS to 70 KCAS. Outside air temperature (OAT) was obtained from metrology department at the beginning of each run/ flight test. Engine torque values are average of torque meter measurement during each run. Acceleration values were corrected to a common level of 100% average engine torque. Rolling friction between ground and tyre was assumed to be 0.04. The variation of acceleration with speed is shown in figure 3. The points show acceleration derived from flight test data and in comparison, design data are shown by a line. It can be seen that both data match quite well.

3.2. Elevator required for take-off rotation

Take-off rotation is a critical flight phase to check pitch control adequacy. Since the thrust line of the engines is above the aircraft C.G., nose-down pitching moment is produced by thrust. The propeller slipstream, however, produces an incremental nose-up moment [4] by modifying the flow field around the horizontal tail. Nose rotation of the aircraft is recognized by using the variation of its attitude angle and Radar altitude. Figure 4 shows a plot of elevator deflection vs. speed (as a multiple of stall speed) for flaps 10 deg configuration. Design data is computed with the effect of propeller flow on pitching moment of the aircraft [4] for flight conditions at which nose rotation was exercised. Their comparison shows that the elevator requirement captured from flight tests is fairly close to design estimates. This paraliel shift could be due to several possibilities including in-adequacies in estimation of ground effects on aerodynamic data, wind tunnel results of effect of power on pitching moment and shift in Cm_o relative to the design data. Parallel nature of mean lines of design and flight test results indicates that the elevator power is nearly as per design data.

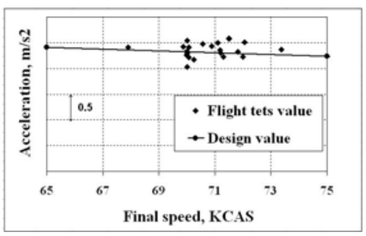


Fig. 3: Longitudinal acceleration

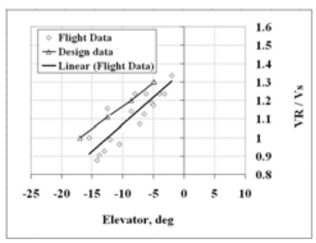


Fig. 4: Elevator at take-off

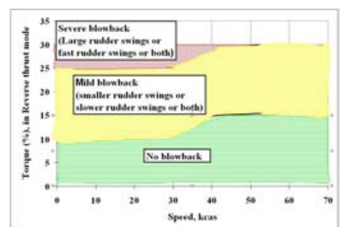


Fig. 5: Boundaries for reverse thrust

3.3. Rudder blow back

During the taxi trials, particularly at low speeds, it was observed that with reverse thrust applied, rudder experienced rapid uncommanded deflection. This phenomenon referred as *Rudder Blowback* occured when high reverse thrust is applied at low speeds. A detailed look at the test data indicated that the extent & rate of un-commanded deflection of rudder depends upon aircraft speed and amount of reverse thrust applied. Based on the test data, an attempt was made to evolve a guideline on the usage of reverse thrust, keeping in view aircraft handling and crew workload. Based on the amount of uncommanded rudder movement, rudder blowback was categorized as severe (rudder going to its deflection limit) and mild (rudder deflection of around 50% of max. value). It is seen that reverse thrust setting with torque below 10% does not cause rudder blowback at any speed. Different speed & reverse torque zones have been marked as shown in figure 5. These guidelines were provided to the flight crew and have been helpful in smooth conduct of flight tests.

3.4. Elevator trim tab requirement

During the initial phase, elevator-to-balance tab deflection ratio was set at 1:0.5. With this gear ratio setting, it was reported by the test flight crew that the elevator stick forces are low. Results of elevator and tab required are shown in figures 6 and 7. A fair amount of scatter is observed in the results of tab deflection with Elev:BT:: 1:0.5. The probable cause is low stick force due to which accurate force trim may not have been achieved. Nevertheless, it was clear that the trim tab would not be able to provide full force trim beyond 150kcas. The maximum tab deflection provided is -15deg to +8 deg.

Subsequently, balance tab gearing ratio was revised to Elev:BT:: 1:0 (balance tab neutral and locked). With this, trim data are of better quality with much reduced scatter (figure 7). The stick feel improved but the trimming ability of the trim tab reduced by about 10 knots in terms of speed holding.

After testing the locked elevator balance tab, a modification was carried out on the aircraft by enlarging the area of trim tab so that the range of trimmable speeds can be enhanced. The area of trim tab was enhanced downstream of the elevator trailing edge so that no re-work on elevator is required. The effect of increased trim tab chord has been partially assessed in flight on PT-2 (results are not shown here).

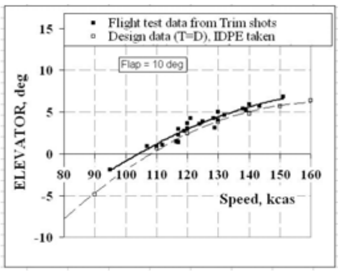


Fig. 6: Elevator to hold a given speed

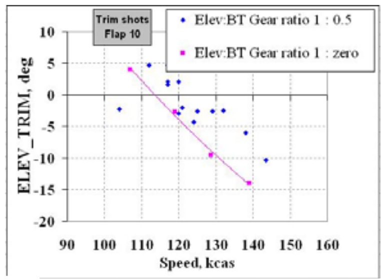


Fig. 7: Effect of BT gear ratio

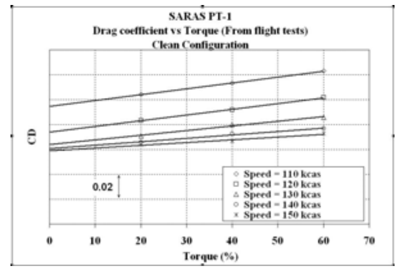


Fig. 8: Derived 'apparent' CD

3.5 Engine torque for zero thrust

Multi-engine aircraft need to demonstrate a minimum level of climb gradient in one engine in-operative (OEI). Saras PT-1 was cleared to fly up to 10,000 ft pressure altitude only. So, to obtain flight test results on OEI climb gradient it required that both engines be kept live and to simulate the failed engine, torque setting should be such that it results in zero thrust from the propeller on one side. Below 20% of engine torque, thrust data can not be obtained from manufacturere's engine model (EEPP) and propeller charts. An iterative methodology was developed to obtain torque setting for zero thrust.

Saras PT-1 was flown through a number of partial climbs and partial descents with different combinations of engine torque and aircraft forward speed. The respective rates of climb (ROC) or descent (ROD) were measured from the change in altitude and the time elapsed. For engine torque greater than 20%, flight test measured ROC or ROD can be converted to an 'apparent' CD by using the relation $(T_{EEPP}\text{-}D)V_F/W_F = ROD_F$ (subscript 'F' refers to flight test values). This results in 'apparent' CD Vs torque relationships where CD = $D/(0.5^* \text{density}^*V_F{}^2{}^*\text{Sref})$. Figure 8 shows these results. The procedure to find engine torque for zero thrust for a given speed is as follows:

Obtain thrust from EEPP at Torque=20% and at flight test ambient conditions. With this thrust and flight test measured value of ROD_F with torque setting of 20%, a value of drag is calculated as below (V_F is true airspeed):

$$D_1 = T_{EEPP\ at\ 20\%\ torque} - (W_F * ROD_F / V_F) - m(V_{F\_final} - V_{F\_intial})/\Delta t \qquad (1)$$

The last term is the inertia force acting on the aircraft due to change in true air speed since all the climbs/descents were carried out at constant calibrated airspeed. Then a new value ROD_2 is calculated by assuming thrust to be zero and using D_1 as drag force:

$$ROD_2 = (-D_1)V_F/W_F \qquad \text{(magnitude of } ROD_2 \text{ is taken to read the graph)} \qquad (2)$$

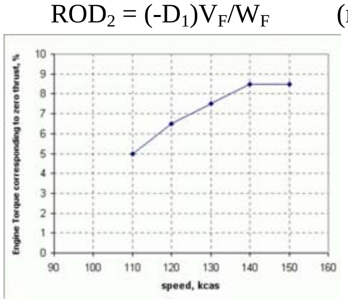
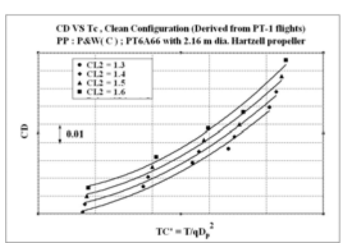


Fig. 9: Engine torque for zero thrust



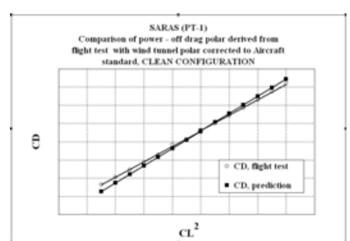


Fig. 11: Power-off drag polar

Plots of ROD vs torque are referred for the speed under consideration and the torque which would results in ROD_2 is read. With this value of torque, a new value of CD is read from figure 8 on the appropriate speed curve. This is repeated till a converged value of engine torque is found. This torque should result in zero thrust from the engine for the speed under consideration.

The above procedure was carried out for 5 different speeds ranging from 110 kcas to 150 kcas. The results are shown in figure 9. These results facilitated the simulation of one engine inoperative condition in flight by keeping both engines live but setting the torque on one engine according to zero thrust level.

3.6. Power-off drag polar

Determination of drag is one of the most difficult tasks undertaken in flight testing. It is, however, a very important aerodynamic parameter. The difficulty for this aircraft arises out of the fact that its drag characteristics are a function of engine power setting.

A 1:10 scale powered model was tested in 1.5 m low speed wind tunnel at NAL to investigate the incremental effects of pusher propeller operation on propeller-airframe interaction [5]. Propeller thrust from wind tunnel results was shown to be a function of aircraft angle of attack, blade angle and advance ratio [6, 7]. It was also shown that a correlating parameter which has propeller diameter as one of its independent variables would be suitable to describe the effects of propeller-airframe interaction, particularly on drag coefficient.

To generate drag polar, a number of partial climbs and partial descents with clean and 10 deg flap were carried out at different speeds and different engine torque settings. Inputs from engine and propeller data were used in deriving CD and Tc' for each flight test point. Consequently, flight test data can be expressed as CD vs Tc' ($=T/qD_P^2$) for different CL^2 as shown in figure 10. Such data were available up to CL^2 of 0.5. The power-off drag polar for clean as well as flap 10 deg configuration is obtained by a slight extrapolation to Tc' = zero. The result is presented in Figure 11 which shows power-off drag polar for clean configuration.

Comparison of the flight test based power-off drag polar was made against design data which was based on wind tunnel tests on power-off full model [3] supplemented by incorporating effects of Reynolds number as applicable to each flight test point and effect of aircraft protuberances and scoops on drag coefficient [8,9]. The comparison in figure 11 is seen to be fairly good.

3.7. Determination of position error correction on air data probes

Calibrated airspeed and altitude are two important references. Saras PT-1 has total pressure and static pressure probes mounted on both sides of the front fuselage. Wind tunnel tests were conducted and CFD studies were carried out to generate data on the error which these probes might experience [10]. The results were incorporated as correction tables in the Air Data Computing Units (ADCU) installed on Saras PT-1 prior to commencement of flight testing. Subsequently, additional data has been generated from flight testing to determine residual error in speed and altitude through flight testing by using post-processed DGPS technique.

Tests were carried out within a speed range of 95 kcas to 160 kcas. The flight test technique [11] is based on flying 3 legs, each leg at a constant heading and a constant speed. A set of 3 such legs constitute a single test point. The heading of each leg should be nearly 120 deg apart from the other two legs. By solving the equations relating GPS ground speed and ground track to true air speed and wind vector, one can obtain the values for true airspeed and wind velocity. This TAS can be converted to IAS and CAS and then comparison can be made against values of CAS obtained from data based on pressure probes of the aircraft. This leads to the error in speed (dVr) experienced by pressure probes. The next step is to convert this error in speed to an error in static pressure sensed by the static pressure sensor assuming that the total (pitot) pressure is measured without any error. The error in indicated

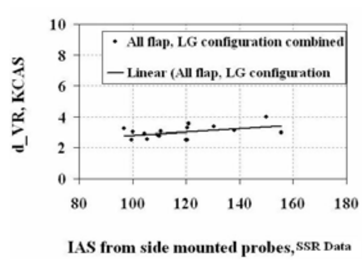


Fig. 12: Airdata probe speed error

altitude was determined by using energy height method [12]. Figure 12 shows the result of speed error which can be seen to increase with aircraft speed though remaining within 3% approximately.

4. CONCLUSIONS

In this paper, a few details on instrumentation scheme, data acquisition and handling have been given. In these days of instrumentation, large amounts of flight test data are generated. These data comprise of aircraft flight parameters, aircraft system parameters and state indication parameters. Aircraft flight parameters are used to derive aerodynamic and performance related details and wherever possible, comparison with design data also have been presented. In general, the quality of flight data captured through the instrumentation has been good and lent itself easily to analysis without much problem of data scatter. Of course, all the aspects presented here belong to steady state conditions. Results of derived aerodynamic phenomena have been good for control surface adequacy, speed error in symmetric flight conditions, longitudinal acceleration on ground and power-off drag polar. Some other aspects like trim tab performance were found to be wanting. Additionally, certain configuration specific topics were covered like rudder blowback and torque for obtaining zero thrust from the installed engine-propeller combination. A lot more needs to be covered in the flight testing of Saras aircraft.

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