NAL'S CIVIL AVIATION PROGRAMME: SOLVED AND UNSOLVED PROBLEMS

K. Yegna Narayan
Head & Programme Director, Civil Aviation Programme,
Centre for Civil Aircraft Design and Development
National Aerospace Laboratories
kynarayan@hotmail.com

Summary
The civil aviation programme, more particularly civil aircraft design and development projects, at NAL has been in progress for more than two decades now. From a modest beginning with the fabrication of a bought-out kit of the Light Canard Research Aircraft (LCRA), to the position now that a two seater ab initio trainer aircraft (HANSA-3) is in 'limited series production'; 14-seater Light Transport Aircraft (SARAS) is in the flight development phase with two prototypes flying and an optimization exercise leading to the production standard aircraft at an advanced stage; design of a 4 / 5 seater multi-role general aviation aircraft (NM5) has just been initiated jointly with a private industry; and a proposal for the development of a 70 seater regional transport aircraft has been submitted to CSIR as a mega project under the 11th and 12th plan periods. For an R&D laboratory to reach this stage is commendable to say the least. It would seem that now is an appropriate time to take stock of where we are, what are the major technical problems that we have encountered and sorted out (or not!). Study of "technical" history is as important as "political" history in order to learn from mistakes and successes. We therefore discuss a few major technical problems that we encountered in our aircraft projects, how they were tackled in a manner appropriate to a mission mode project and what lessons were learnt.

1. Introduction
The civil aircraft programme began in the mid eighties following a strong recommendation form the Research Council that NAL should 'diversify' into development of a product by integrating the technologies that it had developed over the years. The first project that was undertaken was the building, from kits procured from the USA, the Light Canard Research Aircraft (LCRA) and flight testing it. The LCRA is a composite aircraft built with hard foam core and it

was the first experience for NAL to build and fly an aircraft. LCRA has logged about 300 h of snag free flights and gave NAL the confidence of building and flying aircraft. (Lilienthal's famous saying "*that is easy to design and build an aircraft but to fly it is everything*" is as relevant today as it was 120 years ago!). Fig. 1 shows the LCRA in flight.

Fig.1: LCRA in Flight

The successful flights of LCRA gave NAL sufficient confidence that it can design and develop* a composite aircraft. Around the same time, Raj Mahindra[1] presented a report on the requirement of different types of aircraft (from trainers to wide bodied transports) over a long period of time and also recommended how these aircraft should be acquired by the respective operators; Table-1 (reproduced from Raj Mahindra's report) presents a comprehensive picture of this.

---

* *the word "develop" is used in a broad sense and includes manufacture of prototypes, ground and flight testing and certification*

AIRCRAFT TYPE	Twin Seat Trainer/ Mission Oriented Light Aircraft	8/10 Seat Mixed Role Passenger Aircraft	Short to Medium Haul 30/50 Seat Airliner	100 Seat Commuter Aircraft	Wide-bodied 150/300 and 300/500 Seat Airliner
USER AGENCIES	Flying Club, NCC Air Wing	Fourth Level Airline Community Aerial Service	Third Level Airline Vayudoot	Indian Airlines, Vayudoot	Indian Airlines, Air India
MODE OF ACQUISITION	Indigenous Design, Development & Production	Indigenous Design, Development & Production	Joint Development with International Collaboration Coproduction domestic and abroad	Part Development Part Coproduction in Collaboration with International Partner. Final Assembly Domestic and abroad	Mainly import. Small percent of Parts, Components & Assemblies Selectively by Domestic Industrial undertaking for Global Market
WHERE TO DEVELOP & MANUFACTURE	NAL-Private Small Scale Entrepreneur	NAL-Private Large Industrial House	HAL, NAL and Inter national Collaborator Manufacture at HAL/Large Private Industrial House	International Collaborator, HAL & NAL Co-Production HAL & International Collaborator Final Assembly at HAL for Domestic / Export	Production of Selected Components at HAL for Global Market
SALE POTENTIAL	Domestic-200 Export-l00	Domestic 200/250 Export 50/ 75	Domestic-l00 Export-50	Domestic-50 Export-	Air India-50 Indian Airlines-170 Global Market: Components for 500/600 Aircraft

Table-1: Requirement of Different Types of Aircraft

The report also recommended that with the resources available, the design and development of a 2-seater ab initio trainer and a 9 – 14 seat multi-role light transport aircraft should be taken up by NAL.

Initial work on the trainer commenced in 1991 when a non-conventional configuration was proposed; the configuration had a single piston engine pusher propeller and a “bubble” cockpit (Fig. 2). It was ascertained fairly early that this was not a “good” configuration for an ab-initio trainer and thus a conventional layout was defined as HANSA-2. HANSA-2 morphed into HANSA-2RE with a higher power engine. Until then, the certification basis was FAR-23 but on a more detailed study of the requirements, it was concluded that developing the HANSA-2RE to meet FAR-23 would be quite complex, take more effort and cost more. At around this time, the European Joint Aviation Administration published the JAR-VLA valid for very light aircraft (max. TO weight < 750 kg. and stall speed < 45 kts). After long deliberations, it was decided to re-design HANSA-2RE to JAR-VLA standards. This meant that a major weight reduction effort had to be launched. HANSA-3 was thus evolved and this aircraft got DGCA certification in early 2000. (An excellent review of the evolution of HANSA-3 is available in Desai and Shivakumara Swamy[2]). Fig. 3 shows HANSA-3 in flight. The current status is that search for a production partner is still on and in the meantime, NAL is producing the aircraft (in a limited series production mode) using a variety of out-sourcing. Table-2 shows the aircraft deliveries, the operations and the flight time logged by each aircraft.

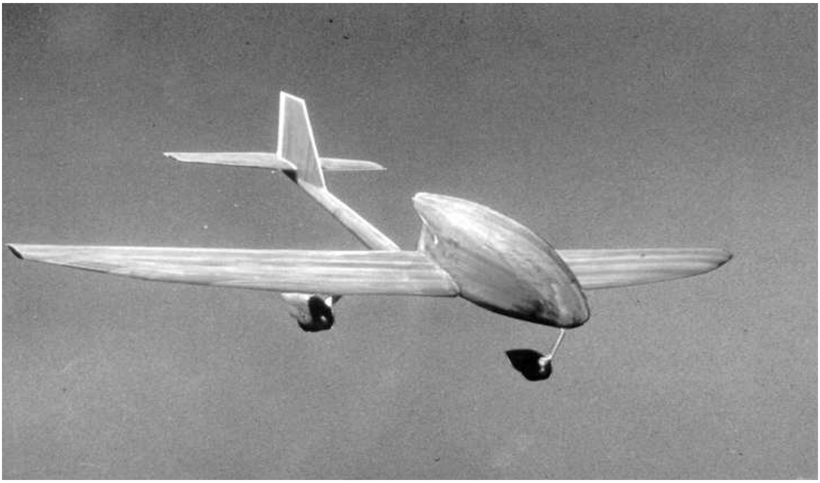


Fig.2: NALLA: Wind Tunnel Test Model

Fig.3: HANSA-3 in Flight

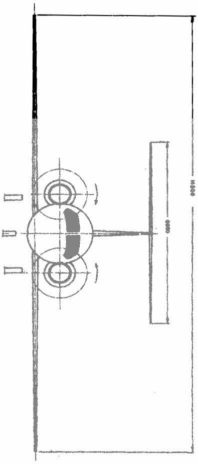
Table-2: TOTAL NUMBER OF HOURS FLOWN AS ON May 2007
HANSA AIRCRAFT

Sl. No.	Aircraft Regn. No.	Aircraft name	No. of hrs. flown	Aircraft location	1st flight	Engine Sl. No.	Propeller Sl. No.	Remarks
1.	**VT-XIU**	LCRA	302:00	ADE, Bangalore	---	----	----	
2.	**VT-XIW**	HANSA-2	128:00	HAL, Museum, Bangalore	23-11-1993	-----	-----	
3.	**VT-XAL**	HANSA-3 PT -1	267:25	Accident on 09-04-2005 Un airworthy	25-11-1996	-----	-----	
4.	**VT-HBL**	HANSA-3 PT -2	380:50	NAL, Bangalore	11-05-1998	4420053	H-802A	
5.	**VT-HNS**	HANSA-3	227:30	IIT- Kanpur	14-05-1999	4420175	H-789A	
6.	**VT-HNT**	HANSA-3	787:35	APAA, Hyderabad Crashed on 29-12-2004	10-03-2001	4420228	H-664A	4420227 @ NAL- Replaced engine- to be overhauled
7.	**VT-HNU**	HANSA-3	684:50	RGAAT, Tiruvananthapuram	15-01-2002	4420274	H-720A	

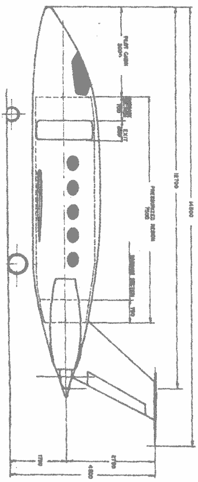
Table-2: TOTAL NUMBER OF HOURS FLOWN AS ON May 2007 HANSA AIRCRAFT (Contd.)

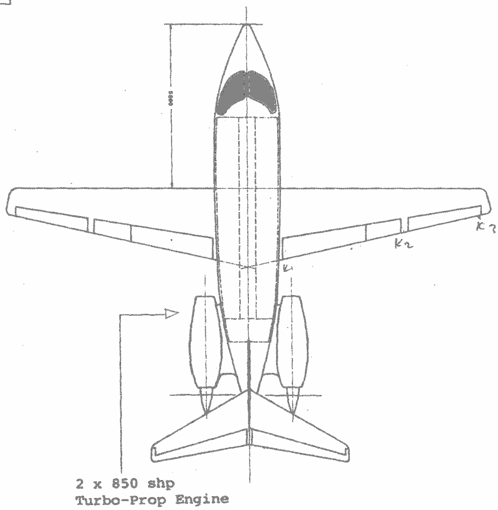
Sl. No.	Aircraft Regn. No.	Aircraft name	No. of hrs. flown	Aircraft location	1st flight	Engine Sl. No.	Propeller Sl. No.	Remarks
8.	**VT-HNV**	HANSA-3	156:45	MPFC, Indore	08-03-2002	4420273	H-665A	
9.	**VT-HNW**	HANSA-3	328:35	RGAAT, Tiruvananthapuram	s	4420275	H-702A	
10.	**VT-HNX**	HANSA-3	36:15	HICA, Karnal	26-04-2004	4420394	H-747A	
11.	**VT-HNY**	HANSA-3	14:55	GFTS, Bangalore	13-07-2005	4420407	H-800A	
12.	**VT-HNZ**	HANSA-3	08:35	NAL, Bangalore Allotted to APAA-Hyderabad	12-08-2005	4420408	H-790A	
13.	**VT-HOA**	HANSA-3	01:25	NAL, Bangalore	03-06-2006	4420419	H-803A	
14.	**VT-HOC**	HANSA-3	02:35	NAL Bangalore Allotted to HICA, Pinjore	19-04-2006	4420420	H-791A	
15.	**VT-HOD**	HANSA-3	10:00	Gippsland Aeronautics, Avolon, for CASA certification	27-01-2007	4420449	H-722A	

The feasibility study for a multi-role light transport aircraft (LTA) was carried out during 1989 – 90. The configuration selected was unconventional: aft mounted turbo-prop engines with pusher propellers. Pusher propellers were preferred from two requirements: to keep the wing flow laminar and to reduce the cabin noise. The first configuration (LTA-1, Fig. 4) also had an unusual front fuselage (again to promote laminar flow) with a "wrap around" windscreen. Design studies continued with the limited resources available; LTA-1 morphed eventually to LTA-10 (Fig. 5). Meanwhile a Russian Design Bureau (Myasishchev Design Bureau-MDB), which was also studying a similar configuration, and NAL, agreed to develop the aircraft on a 50:50 work share basis. This alliance continued till 1995 when the co-operation terminated due to lack of funds from the Russian side. By this time the configuration had undergone further changes and the system definition had been in progress. The Herculean efforts from NAL and CSIR finally paid dividends and the project was approved in 1999 with the first installment of funds being received in September 1999. The first prototype PT1 had its first flight on 29 May 2004 and has so far logged about 109 flights (about 80 h). The second prototype PT2 had its first flight on 18 April, 2007 and has so far logged about 11 flights (about 15 h). Fig. 6 and 7 shows PT1 and PT2 respectively in flight. The flight tests carried out so far have provided a very useful data on performance, stability, controllability, handling and qualitative functioning of the systems.



Overall length	:	48.00 ft (11.5 m)	
Overall height	:	14.76 ft (4.5 m)	
Fuselage length	:	42.00 ft (12.7 m)	
Cabin Width	:	6.00 ft (1.82 m)	
Cabin Height	:	6.00 ft (1.82 m)	
Wing Span	:	48.00 ft (14.5 m)	
Wing Aspect Ratio	:	8.50 ft (2.57 m)	
Wing Area	:	275 ft^2 2.51 m^2	
Wing Taper Ratio	:	0.30 ft	
Horizontal Stabilier Area	:	60 ft^2	5.5 m^2
Horizontal Stabiliser Span	:	20 ft	6.0 m
Horizontal Stabiliser Chord	:	3 ft	0.91 m
Vertical Stabiliser Area	:	55 ft^2	5.05 m^2
Vertical Stabiliser Height	:	8.5 ft	2.75 m
Vertical Stabiliser Chord	:	6.04 ft	1.84 m
Propellors Counter Rotating	:	6 Bladed, 5-6 ft dia Props	
Maximum take-off weight(Approx.)	:	5000-5500 kg (11000-12000 lbs)	
Wing Loading	:	40 lb/ft^2	
Power Loading	:	6.5 lb/SHP	
Take-off and landing distance	:	2000 ft (610 m)	
Landing distance with braking Propellers	:	1200 ft (363 m)	
Cruise Altitudes	:	25000-36000 ft	
Maximum Cruise Speed	:	700 km/hr	





Aircraft concept for Fourth Level Airline and Community Aerial Service.

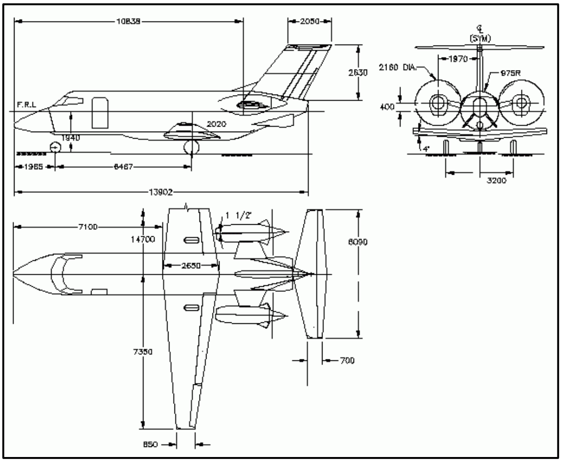


Fig.5: LTA-10 Three view

Fig.6: SARAS PT-1 in Flight

Fig.7: SARAS PT-2 in Flight

As is not unusual in aircraft design, the conservativeness built into the design at various stages essentially due to a lack of legacy database (the "doing-it-for-the-first-time" syndrome) resulted in the prototype weight exceeding target weight. This was a known fact but the manufacture of PT1, PT2 and the structural test airframe (STS) had progressed too far to take any action to reduce the weight. Considering the weight increase, action was taken to procure a higher power engine and suitable propellers for PT2. Thus while PT1 is powered by a 850 SHP engine (P&WC PT6A-66), PT2 has a 1200 SHP engine (P&WC PT6A-67A) with suitable propellers. Structural modifications had to be carried out in PT2 and STS particularly in the nacelle, stub wing and in its attachment to the fuselage. A major weight optimization effort is underway to reduce the empty weight by at least 500 kg.

When PT1 started flying two major problems were encountered: the first was insufficient mass flow through the oil cooler and the second was a shortfall in the measured rate of climb. Both are safety critical issues and were tackled immediately. While the air intake and ducting of the oil cooler system was redesigned, a cap on max. TO weight (about 5950 kg) was imposed and a procedure evolved to handle the one engine failure during take-off and initial climb. While the test flights continued providing valuable data, the design team started working on an improved oil cooler system for the PT2 and understanding the higher drag and propeller installation losses which manifested itself in lesser than estimated performance (e.g. rate of climb). Another problem encountered was with the trailing edge flaps which had unacceptable lateral play between 10^o and 20^o deflection. PT1 was therefore cleared for flight with the flaps operable between 0^o to 10^o only. Certain modifications were carried out on the flap system in PT2, but these resulted in the flaps jamming at around 7^o during one of the flights; thus PT2 is flying with flaps un-deflected.

Of course there were many other issues, which were satisfactorily addressed at various stages of the design and development process. It will be impossible to discuss all of these here and what is presented are the more complex and therefore the more interesting ones. (i) Understanding the mechanism of power effects on drag and efforts to reduce the adverse effects; (ii) Nacelle design (iii) Improvement in the trailing edge flap system and (iv) Weight optimization. Each one of these will be presented in the following chapter.

Following the successful certification of HANSA-3, NAL proposed the development of a 4-seater general aviation aircraft to be carried out during the 10^{th} plan. However the proposal was approved only in May 2005 and thus will spill over into the 11^{th} plan also. This project is now a joint effort between NAL and Mahindra Plexion Technologies (Ltd.), a private company, on a 50:50 partnership basis. Following a series of studies, the requirement specifications of the aircraft have been defined as also a baseline design.

The sectoral committee constituted to advice on the proposals of NAL for the 11^{th} plan period recommended that NAL should prepare a proposal for a supra institutional project which is not restricted to the 11^{th} plan but could spill over. NAL proposed the design and development of a 70-seater regional transport aircraft. The project has been included in CSIR's proposals for the 11^{th} plan submitted to the Planning Commission but final approval may take much more time. The preliminary studies carried out so far are described in detail elsewhere in this proceeding.

In the following chapter, are presented some of the more complex problems encountered in the HANSA-3 and SARAS aircraft and how they were addressed.

HANSA-3: Major problems and solutions

The evolution of HANSA-3 was described briefly in the Introduction. The major issues that the design team had to tackle were to reduce the weight of the aircraft by a significant amount (~190 kg.) in order to meet the requirements of JAR-VLA. The team took advantage of the availability of a recently certified engine from Rotax Bombardier, (Table-3 for details of the engine compared with the original Continental IO 200). The change in the power plant itself offered a weight reduction of about 40kg. The balance of weight reduction essentially came from the aircraft structure. The team went into every single structural element – primary, secondary and tertiary in great detail and was able to realise the weight target. Table 4 shows the original weight and the final weight achieved after the weight reduction exercise.

Sl. No.	Parameters	Continental IO-240B			Rotax 914-F3			
1.	Basic engine (Kg)	93.4			71.9			
2.	Additional fitments (kg)	28.6			10.2			
3.	Dressed engine (Kg)	122.0			82.1			
4.	Propeller (Kg)	9.0			10.0			
5.	Engine + Propeller (Kg)	131.0			92.1			
6.	Power Setting (%)	100	75	65	115	100	75	65
7.	Manifold pressure (in of Hg)	29.5	26.2	24.9	38.4	34.0	30.3	29.1
8.	Engine RPM	2800	2550	2425	5800	5500	5000	4800
9.	BHP	125	94	81	115	100	75	65
10.	Fuel consumption (lt/hr)	43	23	20	33	27	20	18

Table-3: Comparison of Continental IO-240B & Rotax 914 – F3 Engines

Sl. No.	Items	Prototype I VT XAL (Kg)	Production version (Kg)	Weight Reduction (Kg)
1.	Wing	130	105	25
2.	Fuselage	85	80.5	4.5
3.	Control surfaces + other FRP components	85	81.5	3.5
4.	Engine + Propeller	131	92	39
5.	Airframe weight	300	267	33
6.	Systems	327	287	40
7.	Empty weight	627	550	77
8.	All-up weight	827	750	77

Table-4: Weights- Hansa-3 Prototype I (VT-XAL) and the Production version

It may be recalled that the production of HANSA-3 is based on hand lay-up and an innovative vacuum bagging technology. The major advantage of the process is that it does not need an autoclave; the process involves room temperature curing followed by post curing in an oven. As the process is labour intensive, aircraft to aircraft variability has been and probably will be a problem. In particular the structural weight has varied from a minimum of 270 kg; to a maximum of 300 kg. Any increase in structural weight reduces the useful load (payload + fuel) with obvious consequences.

There is a proposal under discussion for re-certifying HANSA-3 under FAR-23 category to improve its marketability. This requires demonstration of compliance to the damage tolerance and fatigue requirements of FAR-23. Design principles, non-destructive inspection methodology, design allowables, inspection intervals and fracture mechanics, all as applicable to composite structure will play a role.

3. SARAS: Major problems and solutions

A project of this magnitude and complexity of SARAS will pose a variety of technical and other issues, which need to be tackled some before certification and some before confirmation of the flight tests as they are safety critical. During the last 3 years since the first flight of PT1, a variety of problems were encountered. A few of the more complex issues are described below. These are: (i) nacelle design; (ii) effects of power on drag and (iii) trailing edge flap system design.

3.1 Nacelle design

The design of the nacelle is quite complex as it determines in some way the losses due to air frame-power plant interaction. Structurally also it is quite complex as a number of system LRU's are housed in none too large a volume and also provide good access to inspection and maintenance. We present one of several major issues here, viz., performance of the engine oil cooler system.

Traditionally for a tractor propeller installation, the oil cooler is located as far forward as possible and just downstream of the propeller plane. The oil cooler thus makes use of the higher dynamic pressure of the propeller flow to obtain the required airflow. The oil cooler in a pusher propeller configuration however does not have this advantage; the required flow would have to be generated by other means, for e.g; using an ejector or the engine plenum suction. The critical case for sizing the oil cooler is a hot day with the aircraft stationary.

In PT1, the air intake was common for both the engine and the oil cooler with the branching taking place downstream of the intake (Fig. 8 & 9). Adequate flow through the oil cooler was ensured by connecting the oil duct downstream of the heat exchanger to the engine plenum when a suction pressure induces the required mass flow through the heat exchanger. The duct also has a branch leading to atmosphere. A flip-flop door is provided whereby the downstream duct can be opened either to engine plenum or to atmosphere. In the main engine air duct, there is a door (called the inertial separator door) which is mainly used when the aircraft is flying under icing conditions to ensure that the ice particles do not enter the engine plenum. This is made use of to modulate the air flow through the oil cooler. This schedule for operation of the inertial separator door was finalised through flight tests. Initially on the ground, the oil cooler duct is opened to engine plenum and the inertial separator deployed to half. This configuration provided adequate mass flow through the oil cooler and the engine also did not starve of air. When the aircraft has acquired speed, the oil cooler duct is opened to atmosphere.

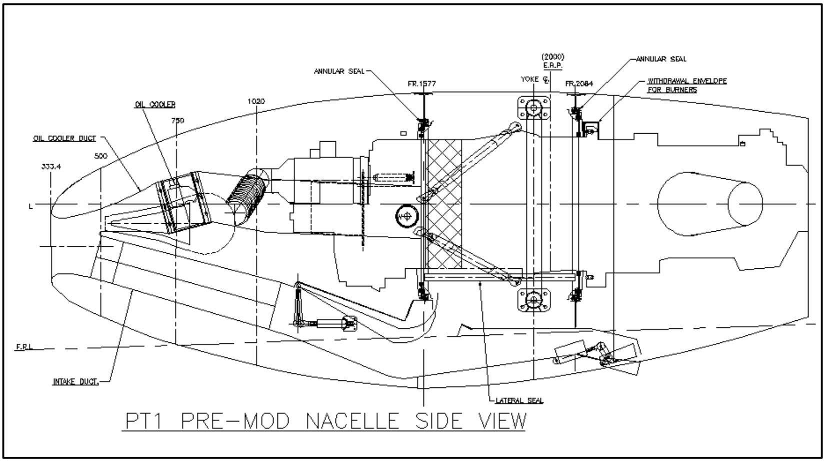


Fig. 8: PT-1 Air Intake, Side View

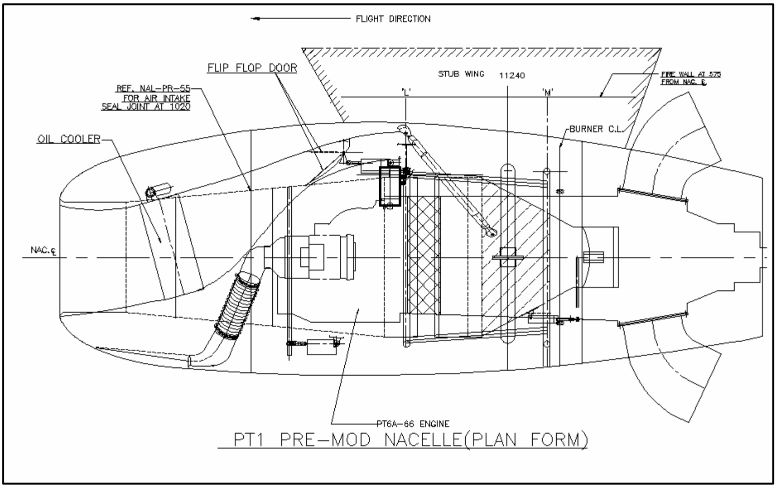


Fig.9: PT-1 Air Intake, Plan View

A full-scale model of the nacelle was built and tested in the Propulsion Division to study its performance under aircraft static conditions. The results from this tests confirmed that the required mass flow through he heat exchanger was in fact available. The model was also tested in the IISc 14' x 9' open circuit tunnel. Hence, the configuration, oil cooler duct open to engine plenum with the inertial separator door deployed to half, was tested. The tests indicated that the required flow was available. However what was not tested was the configuration with the oil cooler duct opened to atmosphere. Not doing this test resulted in a major issue coming to light during the initial taxi and flight tests and the aircraft had to be grounded till the problem was solved. The problem encountered was that with the duct open to atmosphere and inertial separator door deployed to half open, there was insufficient mass flow through the oil cooler and thus the oil temperature could not be stabilized at an acceptable value. The poor performance in spite of the ram pressure available at the intake was determined to be due to the bad shape of the upstream duct forward of the heat exchanger. The shape of the duct was improved along with a few other minor modifications (Fig. 10) and with these modifications, the performance of the oil cooler was satisfactory although the margins available for a hot day operation were not addressed at this stage of the flight tests.

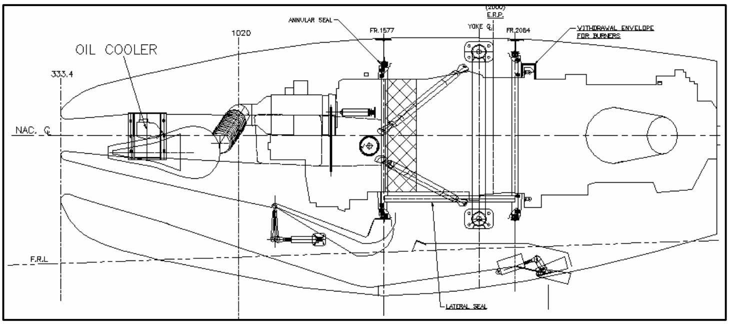


Fig.10: Modified PT-1 Nacelle

As the PT1 flight tests continued, there was a concern that the hot air from the heat exchanger might increase the charge air temperature and more importantly cause a spatial variation of temperature at the compressor face, which might lead to an instability in the engine. It was then decided that the scheme of using engine plenum suction for inducing flow should be changed in PT2. A common method of inducing high mass flow through a duct is to use an ejector driven by high pressure (also high temperature) air bleed from the engine. Before designing the ejector system for the PT2 oil cooler, a few types of ejectors were tested in a ground facility at the Propulsion Division. Fig. 11 shows some of ejector types tested. It was found from these tests that an augmentation by a factor of 8 – 10 was achievable. With this augmentation and the amount of primary flow, which can be bled from the engine, the mass flow requirement of the oil cooler system was met. Fig. 12 shows the overall nacelle arrangement with the heat exchanger, upstream and downstream ducts and the ejector. Through a series of engine ground runs, it was confirmed that the oil cooler system behaved as expected. Oil temperatures measured during the various phases of flights (from take off to landing) with the ejector switched off also showed satisfactory performance; in fact during cruise, the oil temperature is on the lower side. Another aspect to be studied is the possibility higher spillage drag as the oil cooler intake is sized for the static case. Yet another issue which needs study is that with the ejector drawing about 30 lb / min of bleed air, there may not be sufficient bleed air to operate the ECS. The final nacelle design of the production standard aircraft is being optimized from the point of view of weight and airflow. Fig. 13(a) &(b) show two layouts being studied.

In the first, the oil cooler intake has been sized for cruise and is a NACA submerged intake. An ejector is required for operation when the aircraft is on the ground and on a hot day. In the second, the oil cooler is as close to the (pusher) propeller as possible so that benefit may be taken of the induced flow field of the propeller. If necessary an ejector driven by engine exhaust gas may also be incorporated. In this case, full engine bleed will be available for the ECS.

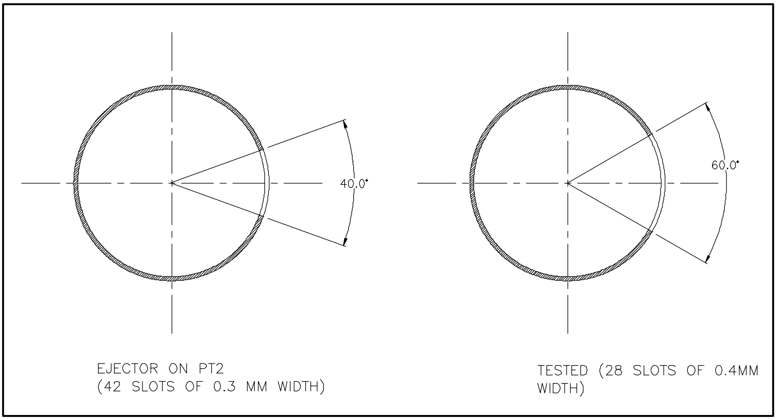


Fig.11: Ejector Configurations Tested

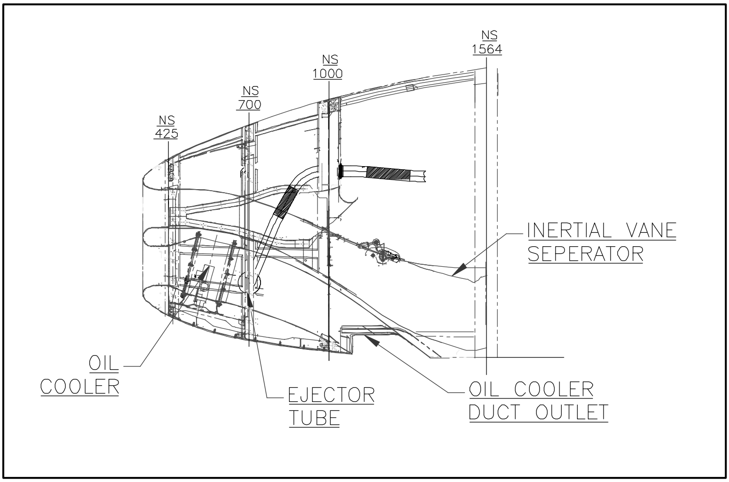


Fig.12: SARAS PT-2 Nacelle Layout

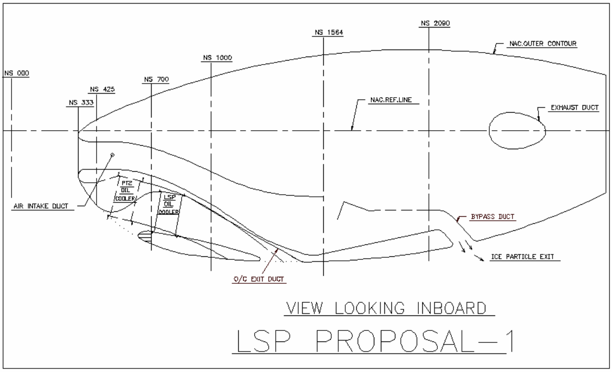


Fig.13 (a): SARAS Nacelle Layout-1 : Production Standard

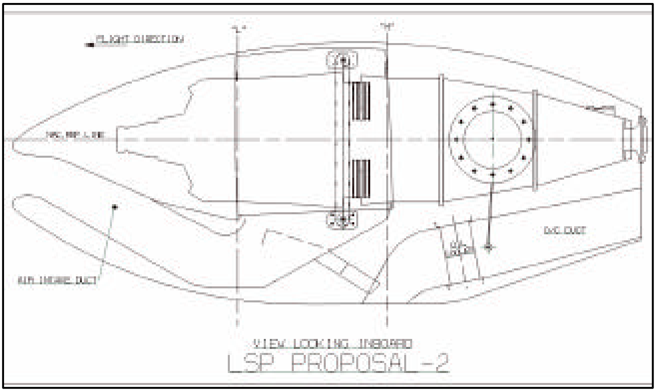


Fig.13 (b): SARAS Nacelle Layout-2: Production Standard

3.2 Power effects on drag

Initial flights of PT1 showed that the Rate of Climb (RoC) was much lower than the estimated numbers. Fig. 14 shows RoC plotted as a function of speed.

$$RoC = \frac{(T - D)}{W} V$$

Where T and D are the thrust and drag respectively and W is the mass and V the true airspeed speed of the aircraft. In order to figure out the reasons for the deficit, the installed thrust and drag characteristics were thoroughly investigated.

W and V are known accurately; thus lower RoC is due to lower (T-D). Thrust and drag are parameters, which are difficult to measure in flight. A series of wind tunnel tests on a powered model of the SARAS was therefore carried out in the 1.5 m low speed tunnel of the Experimental Aerodynamics Division at NAL to understand why (T-D) was much lower than estimated. The tests were specifically planned to provide answers to the following questions:

(i) Is the installation loss of a pusher propeller significantly higher than that of a tractor propeller?

(Here it may be noted that it is common practice to assume a certain amount of installation loss depending on the configuration. The propeller manufacturer suggested that typical losses in a tractor installation are on the order of 2 to 5 percent and higher losses are expected on a pusher installation due to wake effects of the forebody resulting in non-uniform loading of propeller blades)

(ii) What is the effect of power (propeller slipstream) on drag and which part of the aircraft is the major contributor?

(iii) Using the wind tunnel data, can the power–on drag of the aircraft be estimated reasonably accurately?

(iv) Can these data be used to predict the performance of PT2 with its higher power engine, larger diameter propeller running at a lower speed?

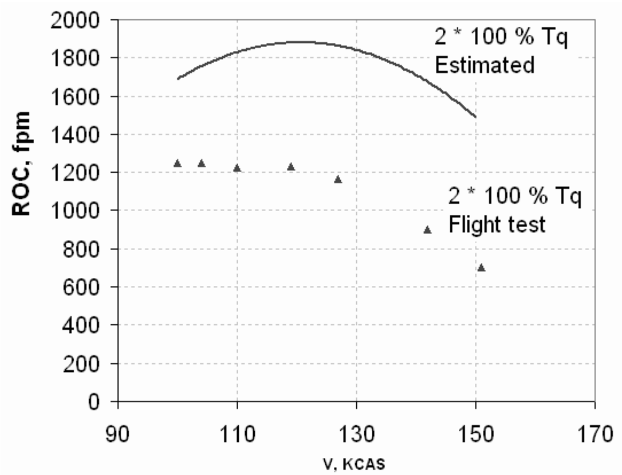


Fig.14: SARAS PT-1: Rate of Climb

The wind tunnel programme was planned in two phases:

I phase tests on an installed propeller both in the tractor and pusher configuration and to determine the effects for the full configuration.

II phase Tests on the same model with the propeller made non-metric to obtain the indirect effects of power.

The phase I tests were carried out on a 1:10 scale model of the propeller and nacelle to determine the installation losses. These tests included propeller in both tractor and pusher configuration. Fig. 15 shows photograph of the model and Fig. 16 shows the arrangement for supporting the model, balance, etc. The thrust coefficients were derived by differencing power on and power off data.

Fig. 15 : Power Model tests: Tractor Configuration

Fig. 16 : Power Model tests: Pusher Configuration

Fig.17 shows the comparison of 'measured' thrust coefficient T_C (=T/qS) and the one read from propeller charts at the same operating condition. The operating condition selected is close to typical climb conditions (propeller blade angle b at 29 deg, advance ratio J=0.83). The T_Cs shown are for two engines. The T_C obtained from propeller charts (0.12x2=0.24) is shown as a solid line.

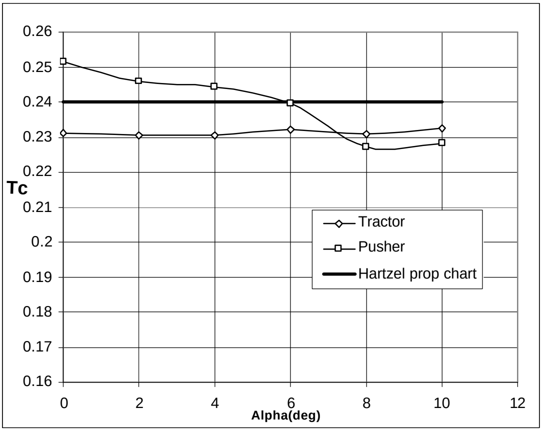


Fig.17: Thrust Coefficients for Tractor and Pusher Configurations

(i) The thrust co-efficient T_C for the tractor configuration (=0.23) is around 4 percent lower than that predicted by the charts (=0.24) throughout the alpha range. This is in conformity with the propeller manufacturer's expectation as well.

(ii) The thrust co-efficient for the pusher configuration is higher than that predicted by charts by about 5 percent at zero alpha

(According to some sources, a pusher propeller can turn out to be more efficient than a tractor due to the flow deceleration caused by the nacelle thereby reducing the effective advance ratio. This seems to be borne out by the experiment, but is seen to be applicable to low AoA only)

(iii) The thrust co-efficient rapidly decreases to a value even below that of the tractor configuration at climb AoA. The decrement is around 5.5 percent. This again seems to be in conformity with the manufacturers experience of fore body wake influencing the efficiency of the blades and is seen to be applicable at relatively higher AoA)

Therefore, it seems logical that the estimation procedure should assume an installation loss of around 5 percent at climb AoA. The slipstream effect on drag is discussed next.

The phase II of the wind tunnel tests was carried out to determine in more detail the effect of power on the aerodynamic characteristics and in particular to determine which component of the aircraft is the major contributor to the drag increase. The propeller alone was made non-metric to determine only the indirect effects of power. Fig. 18 shows the incremental change in drag co-efficient (power on – power off) plotted versus angle of attack for various configurations from fuselage alone to full aircraft. The results show that the incremental drag due to power is negative for the fuselage and fuselage + vertical tail configuration. The maximum incremental drag occurs when the nacelle is added to the fuselage VT + HT configuration. It may be expected that the large contribution on the addition of the nacelle may be due to consequent changes in the aft fuselage flow. It is observed that on the whole the indirect power effect on drag could be as much as 250 counts (dCD=0.025).

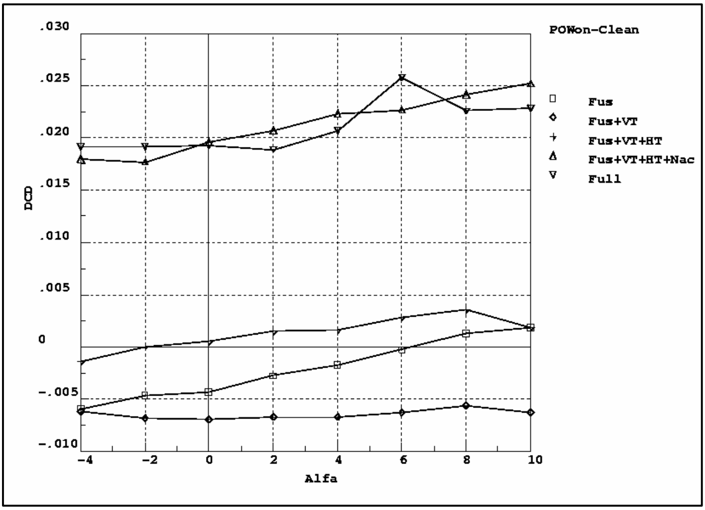


Fig.18: Effect of Power on Component Drag

Tests are being planned to measure the static pressure distribution on the aft fuselage, stub wing and nacelle. The complex flow field induced due to mutual interference between the aft fuselage, nacelle and stub wing with and without power is being calculated using a viscous code abroad, which will also be procured. The CFD results and the wind tunnel test results are expected to lead to a better understanding of the flow field in the aft fuselage region with and without the propeller running.

3.2.1 Estimation of Rate of Climb for PT1

Fig. 19 shows the effect of propeller rpm on the drag coefficient of the full configuration. It is seen that there is a steady increase in the drag coefficient with the increasing rpm. The results are cross-plotted in fig.20 as a function of rpm at various AoA and extrapolated to full-scale rpm (20,000). It is seen that a propeller induced drag increment of around 350 counts (=0.035) might be expected at climb AoA.

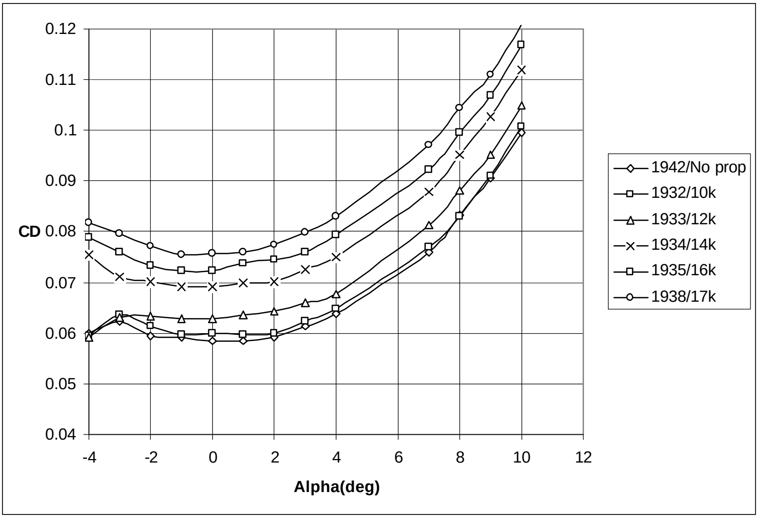


Fig.19: The effect of propeller rpm on drag coefficient

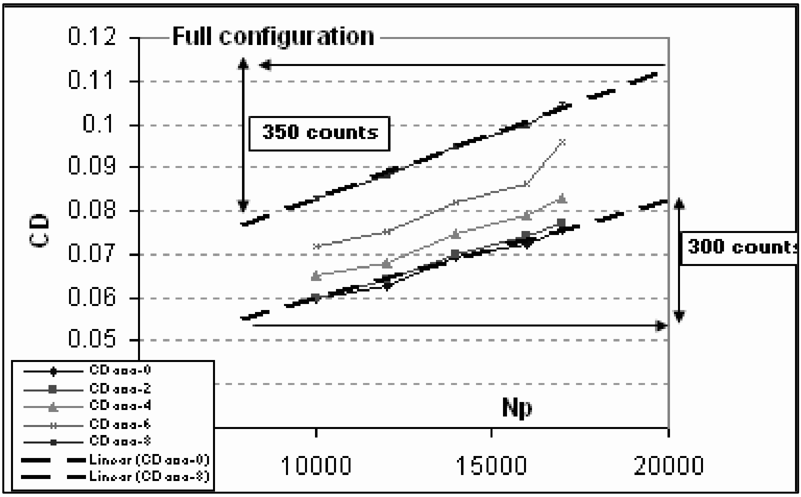


Fig.20: Extrapolation of CD to higher RPM

Using this information, and a 5 percent installation loss, RoC for PT1 is calculated and shown in Fig. 21 along with the flight data. It is seen that there is a much better agreement between the two.

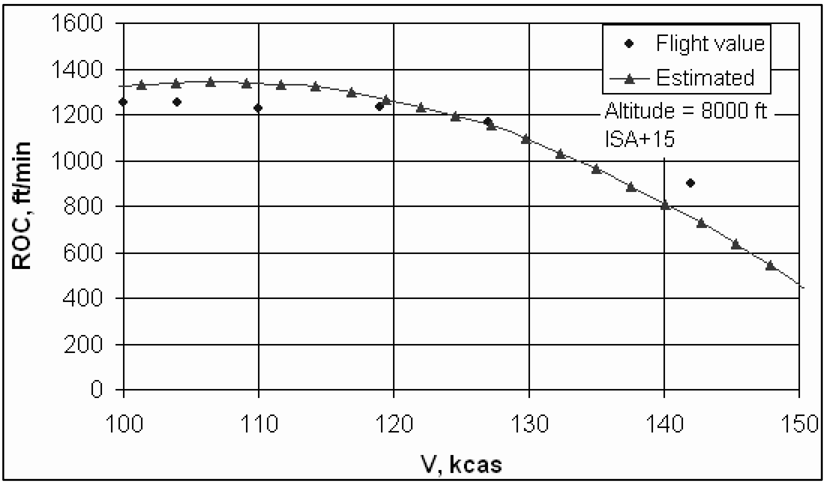


Fig.21: PT1 Rate of Climb

3.2.2 Estimation of Rate of Climb of PT2

In order to estimate the RoC performance of PT-2, PT-1 flight test data was used as the basis. The excess thrust (T-D) was calculated by assuming the thrust given by the engine deck without any installation loss. The drag coefficient was derived from the RoC performance, and was plotted as a function of the propeller disc thrust loading T'_C (=T/qS_p).

The procedure, as can be seen lumps the installation loss, indirect power effect on drag etc. on the derived drag coefficient, which could be called as a pseudo drag coefficient. This is shown in fig.22. The RoC of PT2 has been calculated and shown in Fig. 23 along with flight data. There is good agreement between the two.

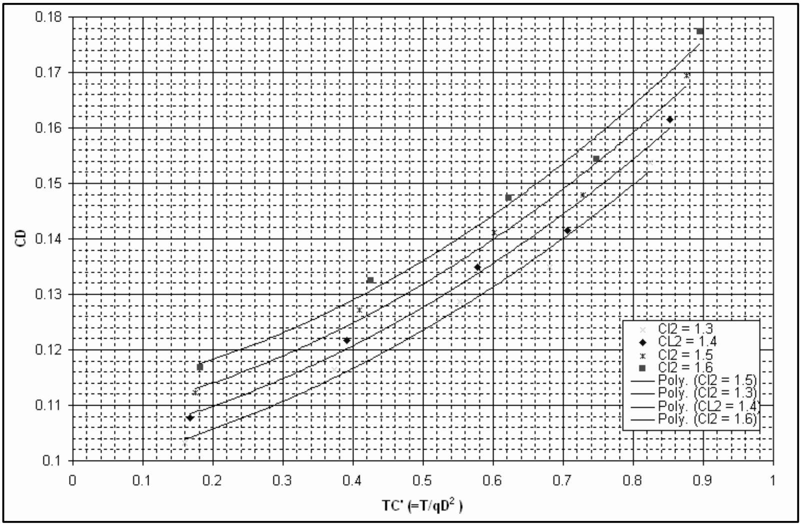


Fig.22: PT-1 Drag Coefficient derived from PT-1 flight tests

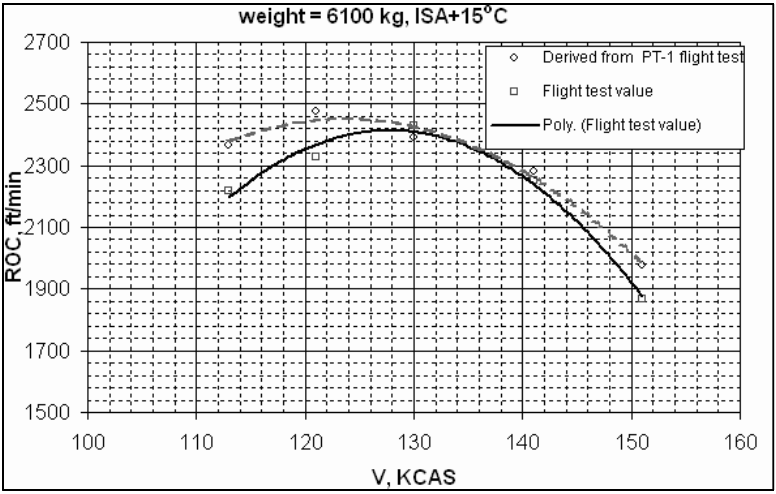


Fig.23: PT2 Rate of Climb

Summarizing, it may be stated that:

- (i) Installation losses cannot be neglected
- (ii) There is significant effect of power on drag
- (iii) The effect is due to the complex aft fuselage – nacelle – stub wing flow filled with the propeller slipstream
- (iv) The calculated RoC shows good agreement with flight data
- (v) Using PT1 flight data and the thrust given by the engine deck, RoC for PT2 can be estimated with reasonable accuracy
- (vi) Much more work involving CFD and wind tunnel tests are required to better understand the fluid mechanics of the interaction and suggest means to reduce the adverse effects.

3.3 Trailing edge flap design

SARAS has a single slotted Fowler flap to meet the field performance requirements. An extensive database is available in literature[3] (Wentz) for two-dimensional GA(W) airfoil with the single slotted Fowler flaps. Based on a series of extensive experiments, Wentz has given iso - $C_{L_{max}}$ contours for a wide range of gap and overlap and for different flap deflections. A typical result is shown in Fig. 24. Tests were also conducted on a 1/6 scale model of SARAS in the IISc 14' x 9' low speed wind tunnel with a view to determine the optimum flap trajectory. Fig. 25 shows a picture of the model used for flap optimization in the IISc tunnel and also the iso-$C_{L_{max}}$ contours for a flap deflection of 40°. These tests were however at a relatively lower Reynolds number (0.46 to 0.93 million) whereas the 2D tests of Wentz were at a much higher Reynolds number. Since it was not possible to extrapolate the IISc results to higher Reynolds numbers, it was decided to use the 2D results of Wentz appropriately corrected for three-dimensional effects. Also, the flaps were tested on a 1:9 scale model at the TsAGI T-106 tunnel at relatively high Reynolds numbers and the results obtained were close the estimates.

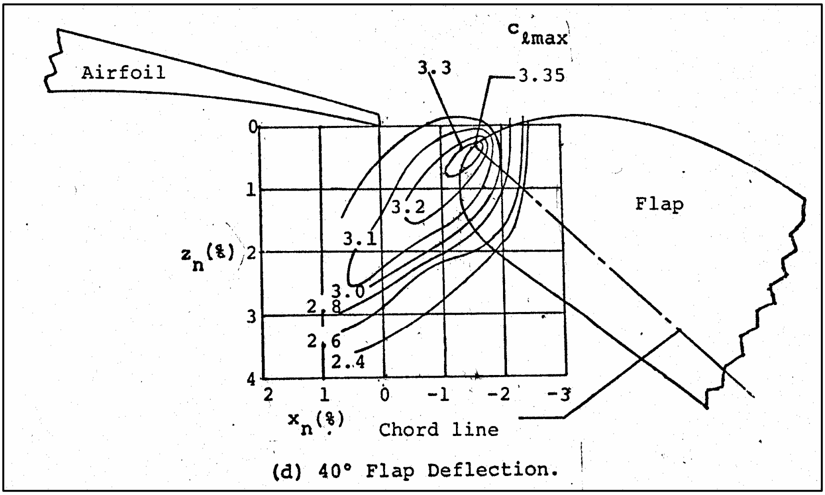


Fig.24: Iso-CL_{max} Contours from Wentz

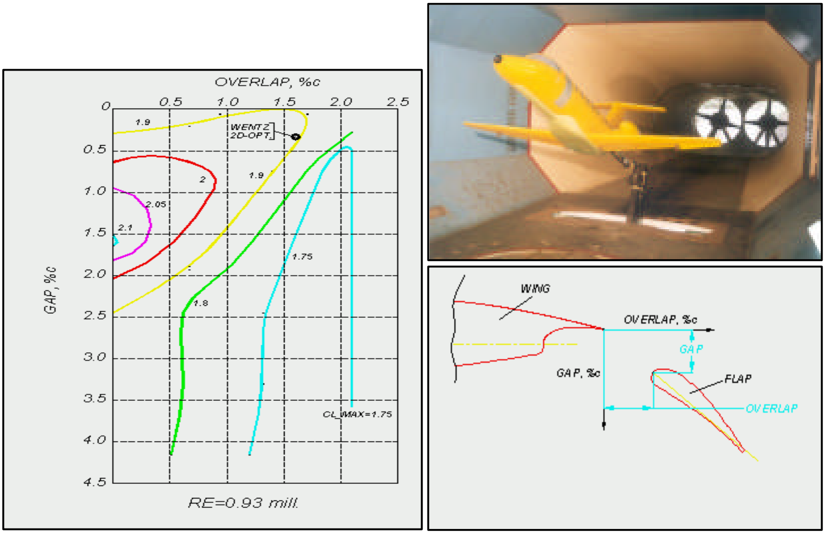


Fig: 25:Flap Optimization Tests at IISc wind tunnel

Fig. 26 shows the trajectory of the flap for different deflections, each location of the flap w.r.t the wing being optimum for the deflection. Table 5 Shows a comparison of 2D $C_{L_{max}}$ from Wentz with the 3D $C_{L_{max}}$ obtained from the TsAGI wind tunnel tests. To design a mechanism to get this flap trajectory proved extremely complex. Fig. 27 shows the track shape finally defined to provide the required motion of the flap.

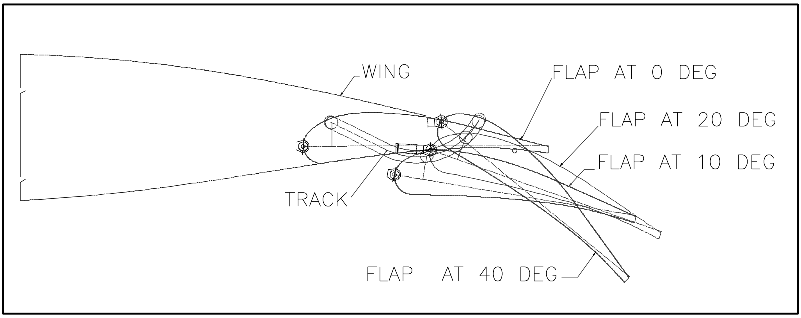


Fig.26: Flap Trajectory with Optimum Locations

Flap deflection (deg)	2D CL_{max}	3D CL_{max}
0	1.7	1.57
10	2.7	2.05
20	3.1	2.25
30	3.28	2.3
40	3.35	2.38

Table-5: 2D CL_{max} (Wentz) and 3D CL_{max} (TsAGI)

After assembly of the flap system in the aircraft, during ground tests, it was found that the flaps had unacceptable lateral play between about 10^{o} and 20^{o}. The flap deflection was therefore limited to 10^{o} during flight tests on PT1. Some modifications were made for the flap system of PT2; although it worked extremely well during ground tests (at no load), during flight the flaps got jammed at around 7^{o}. A number of modifications (suggested by an expert committee constituted for this purpose) are being studied. It has been decided that the modified system will be first tested in a ground rig, preferably under load before integrating it in the aircraft. Yet another option, which is being studied, is to use a single arc of a circle for the flap track (as appears to be the case with other aircraft with similar mechanisms). The disadvantage of this will be that the flap position may not be at the optimum location at any deflection resulting in a lower $C_{L_{max}}$. A decision will be taken after studying the benefits of this simpler track shape with a lower field performance.

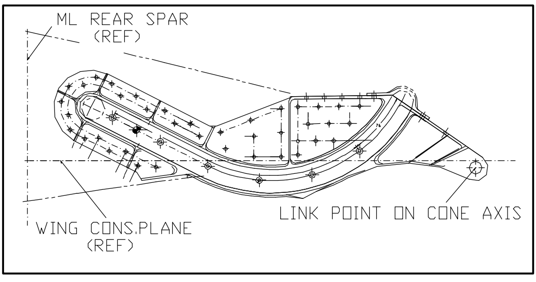


Fig.27: Flap Track Shape

4. Conclusions

A variety of design issues were encountered during the development process of the aircraft projects of NAL. These were both in the nature of issues, which are required to be solved before certification, but more important were those which were safety critical and thus required to be solved before continuation of flight tests. A few examples from the development of HANSA-3 and SARAS have been selected as being both complex and interesting. The steps take to solve these problems are also described.

5. Acknowledgements

A large number of scientists, engineers, test pilots, test engineers and technicians have contributed to NAL's civil aviation programme. The author acknowledges their contribution without which the projects would not have reached the status that they are at today. Mr. G.K. Panda and Mr. Bhaskar Chakravarthy of C-CADD helped me to put the paper together; my sincere thanks to them.

References

1. Raj Mahindra, 'Some Thoughts Towards the Establishment of a Civil Aviation Industry in India' PD DU 8805, October 1988
2. S.S.Desai, M.Shivakumara Swamy, 'HANSA-An Epitome of Team Work and a Product Development at an R&D Laboratory', SP 2001, Feb 2000
3. W.H.Wentz, Jr. 'Wind Tunnel Tests of the GA(W)-2 Airfoil with 20% aileron, 25% Slotted Flap, 30% Fowler Flap, and 10% Slot-Lip Spoiler', NASA Langley Research Center, August 1976