FINAL INVESTIGATION REPORT ON ACCIDENT TO NATIONAL AEROSPACE LABORATORIES, BANGALORE SARAS PT2 AIRCRAFT VT–XRM AT SESHAGIRIHALLI NEAR BIDADI (KARNATAKA) ON 6TH MARCH 2009

1.	**Aircraft**	**Type & model**	**: Saras Prototype PT 2**
		Nationality	**: Indian**
		Registration	**: VT-XRM**
		Engine	**: P&W,PT6A-67A**

2. Owner & Operator : **National Aerospace Laboratories**
P.B.No:1779, Kodihalli
Bangalore-560017

3. a) Pilot-in command : **Wg Cdr (22917-S),F(P)**
b) co-pilot : **Wg Cdr (23165-H),F(P)**
c) Flight test engineer : **Sqn Ldr (24746-M),AE(M)**

b) Extent of injuries : **Fatal**

4. a) Number of passengers : **Nil**
b) Extent of injuries : **N/A**

5. Place of Accident : **Seshagirihalli , near Bidadi about 37 Km Southwest of HAL airport, Bangalore**
Latitude: N 12º 50' 56"
Longitude: E 077º 23' 46"

6. Date and time of Accident : **6th March 2009, appr 1004 UTC**

(All Timings in this report are in UTC)

S Y N O P S I S

Saras Prototype PT2 aircraft VT-XRM manufactured and owned by National Aerospace Laboratories, Bangalore was scheduled for carrying out its test flight no 49. On 06.3.2009 which also include inflight engine shut down and relight procedure at 10000'AMSL . Chief test pilot was on commander seat , test pilot was on co -pilot seat and Flight test engineer was also on board. Aircraft took-off at 0925 UTC and thereafter changed over to radar. There was no events. Aircraft was then cleared to flight level 100, operate up -to 10miles. After completing general handling checks at 9000'AMSL without any events, Single engine simulated approach was carried out on r/w 09. At about 0941 UTC aircraft was cleared for overshoot, wind 090/06 kts. Aircraft made overshoot at 300'AGL. Aircraft was then changed over to radar again. At 0942 UTC Aircraft was cleared to climb FL100 and pr oceed sector Southwest 2 for carrying out engine relight test procedure. After climbing to about 9000'AMSL in sector Southwest aircraft reported 15 miles and FL 90 at about 0948 UTC and reported turning around. But HAL radar as well BIAL radar was showing level 72 for which aircraft replied that it has descended and climbing back to 9000'AMSL. At about 0956 UTC aircraft reported "OPS NORMAL" at 20Nm in sector Southwest 2. **This was the last contact of aircraft with radar but was in contact with FTD telemetry desk of ASTE, Bangalore.** After successful left engine shut down and its securing procedure, at about 1001 UTC **left engine relight procedure was initiated at about 9200'AMSL. During the relighting of left engine, FTD desk also lost contact with aircraft about 37 secs prior to crash. Aircraft crashed at about 1004 UTC.**

There was no response from pilots even after repeated calls made by the Radar controller as well as FTD desk. Radar contact with the aircraft was also completely lost. All possibl e communication means including through en -route traffic to contact the aircraft went in vain. After extensive search efforts, at about 1100 UTC it was finally established that the aircraft crashed at a village called Sehsagirihalli (close to wonderland amusement park) near Bidadi, 37km by road (1km off Mysore road) southwest of HAL airport, Bangalore.

All the three persons on board were charred to death. There was post impact fire. Aircraft was completely destroyed due impact and fire.

1. **Factual Information :**

1.1 History of the flight

On 06.3.2009 Saras Prototype PT2 aircraft VT -XRM manufactured and owned by National Aerospace Laboratories, Bangalore was scheduled for carrying out its test flight no 49 . Test flight programme includes general a ir tests/handling checks to ascertain the aircraft flying characteristics after the 50 hrs Scheduled servicing, dummy approach in simulated single engine configuration at 5000'AMSL, go around at 300'AGL in a simulated one engine inoperative condition, land ing in a simulated one engine inoperative condition and to carry out in-flight engine shut down and relight procedure at 10000'AMSL within 130 -150 kts speed. Tests are to be carried out as per existing SOP and test procedures and limitations and pre flight test briefing meeting. Aircraft was cleared by approved inspectors of NAL after carrying out daily inspection on 6.3.2009 for test flight No:49 and was duly accepted by the Chief test pilot. Preflight briefing was taken by the **Wg Cdr (22917-S), F(P)**, chief test pilot was on commander seat , **Wg Cdr (23165-H), F(P)** - test pilot was on co-pilot seat and **Sqn Ldr (24746-M), AE(M)** was on Flight test engineer on board. The test team also accepted flight test schedule of flight No:49. Total duration of the tests was estimated to about 45 minutes.

Engines were started at 0913 UTC at ASTE, dispersal area . All engine parameters were reported normal. After carrying out post start up and pre taxy checks, aircraft taxied out for Runway 09 at HAL airport. As pe r departure instructions after departure R/W 09 aircraft to climb on R/W heading 5000', turn right set course to southwest -2 and in coordination with approach radar to operate upto 10 miles and level 100. Aircraft was cleared for take -off from R/W 09 with surface wind 090°/06kts. Aircraft took-off at 0925 UTC and changed over to radar at 0926 UTC. There was no event. Aircraft was then cleared to level 100, operating upto 10miles. After completing general handling checks at 9000'AMSL without any events, Aircraft was stabilized with simulated single engine approach to the landing r/w 09. Single engine simulated approach was carried out. At about 0941 UTC aircraft was cleared for overshoot, wind 090/06 kts. Aircraft made overshoot at 300'AGL. Aircraft was t hen changed over to radar again. At 0942 UTC aircraft was cleared to climb level 100 and proceed sector southwest 2. Aircraft right engine was throttled up to match left engine and aircraft climbed out to 9000'AMSL in sector southwest. At about 0948 UTC aircraft reported 15 miles and FL 90 and reported turning around. But HAL radar as well as BIAL radar showing level was 72 for which aircraft replied that it has descended and climbing back to 9000'AMSL. At about 0955 UTC aircraft reported "OPS NORMAL" at 20 Nm in sector southwest 2. **This was the last contact by aircraft with radar.** After 0955 UTC Radar contact with the aircraft was completely lost.

As per ASTE Telemetry, after turned round to point towards HAL airfield aircraft was observed about 20 miles at 9000'AMSL with 140 kts speed. Telemetry link was good at this position Left engine was then shut down and secured following the test procedure at about 10:00:40 UTC. Pilot was in touch with Flight test director on R/T at telemetry desk. After about 47 secs, **left engine relight procedure was initiated at around 9200'AMSL.** Pilot also reported to Telemetry the start of relight of the engine. Telemetry indications also showed the rise in Ng and ITT. At about 100 secs prior to crash airc raft went into sudden dive from 9200' to 7300' for about 13 secs. Meanwhile **During the relighting of left engine, FTD desk also lost RT contact with aircraft about 37 secs prior to crash and telemetry link with the aircraft was also intermittent. At 37 secs prior to crash when Telemetry called aircraft " can you call up. What is going on", aircraft replied "Standby" this was the last contact of Telemetry with aircraft. After that there was no contact from the pilot.**

Just before 7 secs of crash when the telemetry data signal was restored aircraft already lost to the height of 4260'AMSL(1900'AGL) and in continuous loss of height and Ng was about 31%. There was no response from pilots even after repeated calls from FTD desk. **.** Aircraft was rapidly loosing the height without any control. **Cockpit voice recording clearly showed that on last moments just 10 secs prior to crash ,commander called out " Aircraft has departed" indicating aircraft completely gone out of control. During the last moment of crash telemetry recorded Ng : about 54%(63% as per FDR), Engine oil pressure 88, fuel flow 94%,ITT 647 deg C, indicating engine relight was successful. But by the time aircraft was almost on ground. Aircraft crashed at about 1004 UTC.(10:03:44)**

All possible communication means including through en-route traffic to contact the aircraft went in vain. Search operation by ALH helicopter (A67) ,Chetak(T45) and T55 was effected. At about 1033 UTC police control room reported that an aircraft had crashed near Bid adi. After extensive search efforts, at about 1100 UTC, A67 found out the crash site having bearing 251° and 17Nm from HAL airport. Later it was affirmed that the aircraft crashed at a village called Sehsagirihalli (close to wonderland amusement park) ne ar Bidadi and 37km by road(off Mysore road) Southwest of HAL airport, Bangalore. The crash site was a wide -open residential plot area of uneven hard terrain surrounded by poles and wild plants. It was on a radial of 251° /17 NM from HAL, Bangalore airpo rt having coordinates LAT : N12° 50'56" , LONG: E077° 23'46")

All the three persons on board were charred to death and were on their seats. There was post impact fire. Aircraft fuselage was broken from rear of the main plane and found in an inverted position. The vertical fin leading edge was facing the ground and the respective tail mounted engines by the side of it. The nose portion of the aircraft was facing East direction. Aircraft was completely destroyed due impact and fire.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Others
Fatal	**Three**	Nil	Nil
Serious	Nil	Nil	Nil
Minor/none	Nil	Nil	

1.3 Damage to Aircraft

Aircraft was completely destroyed due impact and post impact fire.

1.4 Other Damage

Nil

1.5 Personnel information

The test flight No:49 of Saras PT2 aircraft VT-XRM was operated by flight test team nominated by ASTE, IAF, Bangalore. The flight test team includes two Indian Air Force Test Pilots and a Test Engineer. The details of the crew members of the flight test team are as follows:

i. Wg Cdr (22917-S), F(P) Chief test pilot was the commander of the aircraft,
ii. Wg Cdr (23165-H), F(P), test pilot was Co-Pilot and
iii. Sqn Ldr (24746-N), AE(M) was Flight Test Engineer.

Both the cockpit crew have become test pilots after completion of the Experimental Test Pilot's course in May 2006.

a) Wg Cdr (22917-S), F(P),aged 35, is a DGCA approved Chief test pilot for Saras PT2 with effect from 5th Aug' 2008. He is also flight test incharge and responsible for deploying DGCA approved test pilots and flight test engineers to carry out flight tests of Saras PT2 aircraft. He had a total flying experience of 2414:00 hrs with about 310:00 hrs on turbo-props including Saras Aircraft.

b) Wg Cdr (23165-H), F(P),aged 36, is a DGCA approved prototype test pilot for Saras PT2 aircraft with effect from 14.11.2007. He had a total flying experience of 2080:00 hrs with about 315:00 hrs on turbo props including Saras Aircraft.

c) Sqn Ldr (24746-M), AE(M) , aged 33, is a DGCA accepted flight test engineer and approved by chief test pilot of Saras PT2 team with effect from 1.12.2006.

1.6 Aircraft Information

a) The SARAS PT-2 aircraft is an experimental aircraft under development by M/s National Aerospace Laboratories, Bangalore and is intended for passenger and cargo transportation on domestic routes. It is designed, manufactured and operated by NAL, Bangalore as Saras Prototype-II aircraft. This aircraft has been duly entered in the register of India with effect from 5.12.2006 and was given the

Registration marking as VT-XRM. The Certificate of Registration issued bears Cert. No. 3460, under category A. The aircraft serial number is SP002 and the year of manufacture is 2006.

b) The aircraft is light transport aircraft configured as a low wing monoplane with T-tail powered by two Pratt & Whitney, Canada ,PT6A-67A Turboprop engine in the pusher configuration. Each engine is fitted with a 5 bladed MT propeller made of Aluminum alloy incorporating a variable pitch, constant speed unit and a propeller over speed governor. The engines are installed on the stub wings on either side of the rear fuselage.

c) The flight compartment is equipped to allow operation of aircraft by a two-man flight crew. The standard design configuration is provided with seating for 14 passengers, seated 2 abreast. Front and rear baggage compartments are provided for the purpose of accommodating the baggage.

d) The fuselage is of semi monocoque construction and is made up of front, center and rear sections. It has all-metal , fully cantilevered dihedral wing.

e) There is a swept back, fully cantilevered vertical stabilizer attached to the top of rear fuselage. A horizontal stabilizer is mounted on top of the vertical stabilizer. Both the stabilizers are removable and are of twin spar construction. Elevators are hinge mounted to the rear spar of the horizontal stabilizer and similarly rudder is mounted to the vertical stabilizer. Balance tab for all the control surfaces with gear ratios are provided.

f) Aircraft is fitted with wing integral tank having fuel capacity of 840 litres on each wing. Fuel used is any of the following: JP1, Jet A, Jet A-1, AVTUR. Oil used is of type II conforming to P&WC SB 14001 or synthetic Oil MIL-L-23699C

g) In a standard design configuration it features a pressurized cabin and is capable of cruising at altitudes upto 30,000 ft. It is designed for all weather operations. SARAS PT2 is designed to meet the airworthiness standards of FAR-25 and operational requirements of FAR-121

h) The aircraft was still under the development stage. Hence the weight schedule was not yet finalized. However the restriction was fixed for the 49th i.e the accident test flight the details of which are given below:

   i. Maximum take off weight of the aircraft: 6400Kg.
   ii. C.G at 30.02% MAC(U/C RETRACTED)
   iii. Fuel status-752 Kg
   iv. Ballast – 99 Kg
   v. Persons on board – Three.
   vi. Max Speed – 200 knots IAS

The aircraft was prepared as per Standard of Preparation SARAS PT-2, Vol 33; Report SOP – 2 dated Nov-2006, Issue B with modifications as indicated in document Ref. vol 33, MOD-SOP-2 Issue A June 2008. There was 793 kg of fuel on the aircraft on clearing the aircraft for 49th test flight on 6.3.2009. Aircraft was also carrying three serviceable parachute unit for emergency purpose.

Aircraft is also maintained by NAL, Bangalore and completed 48 test flights prior to the accident test flight. Aircraft propeller had logged 50:20 hrs on completion of 48th test flight. On 6.3.2009 aircraft was inspected by the airframe, engine, avionics, instruments, electrical system inspectors approved by DGCA as per daily inspection/preflight/engine ground run schedule. Also telemetry serviceability was reported signed by separate person as per DI. Aircraft was certified airworthy for test flight 49 in the form "daily inspection and clearance for Test flight-Saras aircraft" by concerned DGCA approved inspectors. Aircraft was also accepted by the pilots in the form IAFF(T) 700D. **However pilots also signed the "daily inspection and clearance for Test flight". DI inspection record indicating various approved personnel/engineers checked the aircraft prior to departure of 49th flight was not available.**

The following aircraft documents were checked.

1. 50 Hrs. inspection Schedule
2. SARAS PT2 Systems documents.
3. Taxiing & Development test Flights
4. 25 Hrs. Inspection Schedule
5. Snags (Deficiency / Deviation) lists
6. System integration documents.

No significant findings / observations are noticed except reported high control forces.

Further, the following documents were scrutinized:

1. SARAS PT-2 Compendium of mass properties- No major findings observed

2. Pilot Defect Register (PDR) – Flaps struck at 18°, 10°, 2°, 2° and 4° during flight nos. 18,22,24,25 and 34 respectively. Subsequently, flap was set at 10°. Otherwise no major snags observed
3. Electrical, Battery capacitance records verified and found both Main & auxiliary batteries were periodically Capacity tested and recharged and was valid on the day of accident.

From the aircraft flight test records and post flight pilot reports some of the observations are:

- Rudder Force feel inadequate, rudder response sluggish
- During Asymmetric Torque handling, Rudder Force reported heavy
- Poor Aircraft controllability during approach, flare out & touchdown. Exceedance of ITT & Ng reported high at high Torque settings at high altitude

In general, there are Controllability issues and high control forces exist.

It is also observed from the post flight pilot reports(PFPR) that no PFPR was submitted by ASTE for the flight no 38 and 39. Also for flight 40 to 46 PFPR were not submitted by ASTE as the aircraft was used for flying demonstration in Aero India 2009 show at Bangalore. But no DGCA permission was taken by NAL for the purpose.

1.7 Meteorological Information

As per the existing procedure the met report is obtained on telephone. Accident took place at about 1004 UTC under broad day light conditions. The MET report received on 06.03.2009 at 1000UTC is as follows :

METAR VOBG 061000Z 08008KT 8000 NSC 34/07 Q1012

Weather was fine and is not a contributory factor to the Accident.

1.8 Aids to Navigation

SARAS PT2 aircraft is fitted VHF-NAV, ADF, DME, ATC transponder, weather radar, compasses, altimeters and their appropriate indicators to obtain navigational information.

Navigation factor is not having any bearing in the accident.

1.9 Communications

SARAS PT2 had following communication systems installed:

- 2 VHF radio systems
- 1 HF system
- Passenger address / briefing system
- Audio management system (AMS)
- Cockpit voice recorder
- 2 Radio tuning units (RTU).

The real time performance of the aircraft is communicated to the ground station by a system known as Telemetry. This is an effective tool for online monitoring of prototype test flying wherein test crew could be warned by the Test Director in case of any exceedances in flight parameters or a potential hazardous situation leading to an unsafe flight . Some of the Telemetry /data analysis sheet for the previous test flights (eg., flight test no.40) had been checked and did not reveal any telemetry link problems. However during the face to face to discussions, **the reliability of the telemetry system has been reported poor in general throughout the sortie and the auto tracking system was not available on the day of accident.** All various monitoring groups at telemetry station have expressed the same. Moreover **telemetry radio conversation between FTD desk and the aircraft is not a recorded channel.** However CVR conversation reveals telemetry was intermittent. But FTD is in general in contact with the aircraft till 37 secs prior to the aircraft crash. This also includes starting of engine relighting procedure.

At about 0955 UTC aircraft reported “OPERATIONS NORMAL” at 20Nm in sector southwest 2. This was the last contact by aircraft with the radar. HAL radar did not check the position of the aircraft almost for 10 mins after the last reporting at 0956 UTC. **After that radar tried to call the aircraft only at 1006 UTC. Radar also did**

not contact immediately the Telemetry. Its contact with telemetry was also about 15 minutes after the last contact with aircraft.

However the two way communication between HAL Airport and the aircraft was satisfactory and is not a contributory factor to the accident.

1.10 Aerodrome information

Aircraft had crashed near Bidadi on a radial of 251° /17 NM from HAL, Bangalore airport (coordinates N12°50'56" E077°23'46"') and subsequently caught fire resulting into the fatal injuries to the three flight crew and loss of the aircraft. The aircraft crashed at a village called Sehsagirihalli (close to wonderland amusement park) near Bidadi and 37km by road(1 km off Mysore road) southwest of HAL airport, Bangalore. The crash site was a wide open residential plot area of uneven hard terrain surrounded by poles and wild plants. It was on a radial of 251° /17 NM from HAL, Bangalore airport.

1.11 Flight Recorders

SARAS aircraft, VT–XRM is installed with M/s Penny & Giles, UK manufactured a combi version recorder for data and voice recording. It is a combined Solid State Flight Data Recorder and Cockpit Voice Recorder. This is crash and fire protected and is installed in the rear i.e. dorsal fin area. Consequent to accident, the recorder was damaged in post crash fire, the unit was sent to manufacturer's facility at UK for retrieval of the data. From the UK facility, the data has been obtained separately for the Voice and Flight data. The details of the extract of the CVR and DFDR recording are as follows:

<u>Cockpit Voice Recorder:</u>

The voice data has been played, in the Flight Recorder laboratory of DGCA HQ, using different support equipments. Transcript has been prepared after complete and combined hearing of all the channels.

CVR data transcript for last 38 minutes along with elapsed time from the crash event analysed**.** In addition, 06 more minutes of data has also been added to the transcript to give proper continuity for the events.

In the CVR transcript there has been many occasions where the conversation between crew indicates concern. Such locations have been given in bold letters and have been land marked under remarks column with alphabets A to Z. Detailed analysis was carried out at these sites, to evaluate the circumstances in which the crew remained to make such statements. The findings on these sites have been given in the subsequent paragraphs of this report.

<u>Flight Data Recorder:</u>

FDR data has been obtained in raw format from M/s P&G, UK. The data has been converted in to engineering units by using NAL, FOQA, a software tool meant specifically for SARAS aircraft. Though the data length is for last 24 hours, only the test flight number 49 has been decoded and examined. Subsequently different sets of graph have been generated with judiciously chosen various combinations of aircraft and flight parameters. These sets of graphs have been generated for different time lengths. These time lengths vary from 15 seconds to 30 minutes. Inferences have been derived from these graphs and it has been given in the subsequent paragraphs.

Synchronization procedure of CVR and FDR Data and Telemetry data:

As this being a combi version recorder, it is believed that both the components of data would have stopped at the same instant during the final and last event of the crash process. Hence the last coordinate of data appearance in both Voice and Flight Data has been taken as the crash point and has been designated with time mark of 00:00 (minute: sec). The data has been subsequently allowed to grow in the reverse direction with negative timing marked in graphs as well as in CVR text. With this, at any time of required reference, both CVR and FDR can be viewed together for any analysis work. This is one of the adopted procedures for combi version recorders.

The subject flight being a test flight, it remained on complete telemetry monitoring. The telemetry data has also been compared with FDR data and also been used to prepare this data analysis report. Particularly there are some essential parameters like engine oil pressure,ITT,fuel flow etc. are only available with telemetry data. The following analysis includes use of data from FDR and data of flight test Instrumentation with cockpit conversation.

FDR data presentation:

FDR data for the entire test flight no 49 has been converted into engineering units. Of the large volume of data, relevant parameters have been chosen and graphs have been made against time. Graphs in the form of six sets, with each set containing six parameters. The time duration for these data graph have been kept for the last two and five minutes. The time axis grows in negative direction with 00:00 designated as crash point. At any time of required reference CVR and FDR data can be read together as they have been converted to a common time scale.

FDR data inferences:

GO-AROUND in simulated one engine inoperative was done at 100 feet AGL. against the test schedule clearance of 300'AGL. Subsequently, with full power on both engines a normal climb was made up to 9000 feet height.

During left engine shutting down:

Before the left engine shutting down the flying remained steady with speed of 140 kts, altitude of 9400 feet and heading remaining at 60 – 70 deg. The engine oil pressure remained at 122 psi for both L&R engines. The PLA of left engine was brought to zero at the time of -04:53. With this the fuel flow reduced to 80 kg/h, Ng reduced to 73%, torque reducing to 3% with no appreciable change in Np. At the time of -04:00, the prop lever was moved to feathered, as indicated by the Np reducing to 15% from 100%. Torque has increased from 0% to 30% and Ng now is steady at 73%. There has been no change in right engine parameters.

At the time of -03:35, the left engine Ng reduced to 60% indicating possible condition lever moving to ground IDLE. Fuel flow (FF) now reduced to 55 kg/h. all the attitude parameters remains unchanged. At the time of -03:24, the FF indicates to zero implying that the condition lever has been selected to CUT OFF. This has resulted in ITT, Engine OIL Pressure, EOP reducing to minimum level. Heading now is seen steady at 70 degree. To balance the asymmetry, the rudder remained at -12 degree, elevator and aileron remained respectively at 5 deg and 3 deg. Side slip was seen to 2 deg with bank angle remaining 10 deg to right.

During the period while left engine remained shut down:

From time -03:20 to -01:56 the left engine (LE) remains shut down, Np remained nearly 5% with prop in feathered stage. ITT remained at 115deg, while the EOP remained 06 psi. The heading remained constant at 65 deg with a steady rudder of 12 deg and pedal force of 20 Kg. The bank angle varied between -6 to 12 degrees.

Left Engine relight:

At the time of -01:44, Np is seen rising through 55% with EOP having remained low at 5 psi. A small rise in Ng could be seen to the level of 7%, which is lower than the minimum 13% required for beginning of relight exercise. FF is seen increasing to 25 - 30 kg/h indicating the condition lever having moved forward from CUT OFF.

Attitude parameters like side slip and bank angle position has started showing changes. Side slip increases up to 28 deg and bank angle changing from 8 deg R to 70 deg L. also the pitch attitude is seen reaching -42 deg.

The rise in prop rpm could be attributed to prop blade pitch having reached FINE from feathered statues. However, with EOP having remained at 5 psi, the blade normally not expected to change the pitch from feathered status. At the time of -01:41, Np is seen to reaching 91% with no change in EOP, pitch angle, roll and side slip kept increasing respectively to -42, 70 and 28 deg. Rudder deflection has changed now from 12 deg R to 4 deg L with pedal force nearly 70 Kg. elevator remained at 8 deg down and aileron wheel deflection to 40 deg. The aircraft speed has reduced from 150 to 130 kt with altitude steady at 9200 feet.

Right engine power reduction:

At the time of -01:40, PLA of R engine was brought down from 26 deg to 0 deg. This has resulted in reduction of torque to 2 % and EOP to 32 psi. This attempt could possibly be explained as an attempt to reduce the thrust asymmetr y and the large side slip faced. During the time of -01:31, both L & R PLAs are seen increasing in steps. In response to this, R torque is seen to increasing and during the same time the course has reduced from 70 deg to 0 deg within a time period of 12 se conds.

Between the times of -01:36 to -01:24, the speed is seen to increase from 125 KTS to 181 KTS with altitude reducing from 9200 feet to 7300 feet. Rate of descend for 12 secs is very high can be attributed to diving of aircraft and speed of aircraft also increasing. The seen ROD, rate of descend is about 10,000 feet per minute, which is very high for this class of aircraft. During this phase, the NpL remained at 100 % and NgL is seen at 12%. Subsequently the aircraft was brought under control with all attitude parameters tending to change towards the normal levels.

During the time of -01:18 the speed has reduced to 160 Kts, altitude at 7200 feet, NpL remained 100%, Ng L at 15 % and the torque L remained 0%. At the time of -00:59 NpL is seen reducing to 80% with Ng L increasing to 22%. Other battery related electrical parameters indicate that the relight process has not been fully successful, or possibly it has been aborted. At the time of -00:28, the aircraft has been observed to be on left turn. The side slip remained at 22 deg with pitch attitude about -15 deg. The speed remained at 130 kt and altitude reducing from 7000 feet to 5200 feet. The R engine torque that has been reduced close to 0, is showing a sharp rise to 85%. Both PLAs were seen to be moving together. All the controls forces have been increasing excessively.

Second relighting attempt:

During time of -00:30, a rise in PLA_ L could be seen with proportional rise in Ng. The raise in Ng, goes up to 60 % with Np having rem ained at the level of 80%. The FF increased to 98 kg/h. Further the ITT – L increasing to 635 deg C and EOP_L increasing to 95 psi together indicates the possible success in relight operation of Left engine. During the period of last 15 seconds there has been large input of pilot controls in all 3 axis resulting in large and proportional variations in aircraft attitude in all axis.

<u>CVR data inferences</u>

Over the 38 minutes of transcript prepared, about 26 different landmarks have been identified, as containing conversations requiring detailed analysis. Such landmarks have been marked with letter A to Z. With reference to the transcript material the following write-ups, details the possible interpretation of the remarks at these identified sites.

(A) Probably referring to the Elevator trim run out (-15 deg, nose down limit reached, as expected at speed ~ 160 KTS).

(B) No comments

(C) No comments

(D) Descending for OEI simulated approach, Torque_L 21%, Torque_R 3%. The crew needs to have some little p ower ON to live engine.

(E) Still Descending for OEI simulated approach (telemetry t=1884s, ALT 3900ft). To maintain the speed of 125 KTS, at level flight, the crew discusses about the need for more power.

(F) CVR Time of - 22:48 (telemetry t=1963.6s, 15:10:45)
Rudder 2 deg, Boom_SS -10 deg, AIL_L -13, Ail_R 8 deg, bank 8 deg left
Torq_L increased from 44% to 64%
Under these conditions, large Left aileron input required to maintain about 10 deg bank to left.(running out of rudder and aileron limit)

(G) CVR Time -22:26, telemetry t= 1986s, 15:11:07

Probably referring to NG_R (E2Ng), which is now close to 102.5% , while the flight test limit is 103% (actual limit is 104% from OEM manual).

(H) CVR Time -21:37, telemetry t=, 2035s, 15:11:56

Here it is symmetric power, controls at normal levels. Discussion seems to pertain to the requirement in general regarding desirability of procedure to bring all trims to neutral before landing.

(I) CVR Time -20:50, 46:33:45, telemetry t=2082s, 15:12:43

Erroneous speed indication on the masked side of speed sensors which is in the wake of Nose Landing gear door when sideslip is > 5 deg. Pilots are probably discussing here the sideslip effect on IAS on two different EFIS.

"Saturation of what?" - Is not understood -. Air show flights being spoken may be referring to NAOA behavior, which used to go to 100% (spurious indication). However, at this instant, in the current flight, NAOA is 30% -40% and no saturation is observed on this.

(J) CVR time -15.47, 46:38:48, telemetry t =2384.6 s, 15:17:46

Seems to be general talk, specific reasons/parameters could not be identified.

(K) CVR Time -15:03

Seems to have descended but not registered in their mind. While communicating to ATC, altitude reported is 9000' in place of 7200 feet. Hence, this reference was to just from P1 to P2.

(L) CVR Time -13:12, 46:41:23
Telemetry t= 2539.6 s, 15:20:21

Torq_L zero, Torq_R 89%, Rud -8 deg (right rudder), Rud tm full +13, side slip 12 deg, wheel 15 deg. The crew may be mea ning the insufficient force here. At this instant the rudder force is 15 kg.

(M) CVR Time -12:56, 46:41:39
Telemetry t= 2555 s , 15:20:37

Rudder is -12 deg (to the right), though Rudder Trim has continued to be full. This comment may be in reference to Rudder trim rather than rudder surface. Pedal force ~ 25 kg

(N) CVR time -12:36, Relative Time 46:41:59
Telemetry t = 2560 s, IST 15:20:39

Sideslip 3-5 deg, speed is 130 Kts. As Torq_L is ~zero, this propeller would be creating negative thrust (disking), so aircraft would appear to encountering more drag, even in clean configuration. Hence, the comment on inability to maintain speed is understandable. Aircraft was descending

(O) Comment is in continuation of that at (N). Reasons at (N) apply here also. Aircraft continued descending and level flight could not be maintained.

(P) CVR Time -11:54, 46:42:41

Comment is in continuation of that at (N). Reasons at (N) apply here also. Subsequently Torq_L increased moderately to remove asymmetric.

(Q) CVR Time -10:56, 46:43:39
Telemetry t = 2675.6 s, IST 15:22:37

Symmetric engine power here. Comment does not seem to relate to parameters at this time. Probably, related to fuel imbalance condition that could have existed.

(R) CVR Time -9:56, 46:44:39

Left Torque is higher (60%) than Torque R, So understandably the ITT_L would be more (750) than ITT_R (710).

He speaks later to explain his doubt expressed at (R). Later, may be it has been realized by crew that, with the left torque remaining higher than right torque, a difference need to exist in ITT also.

(S) CVR Time -07:14, 46:47:21
Telemetry t = 2897.6 s, IST 15:26:19

Torq_L zero, Torq_R 92%, height 9000 feet, bank angle 0 deg, sideslip 6 to 7 deg. ‘Zyada’ seems to refer to more drag on the aircraft. With undercarriage down we will die with this drag.

Probable, reasons could be :
left engine torque is zero (more disking),
sideslip is ~ 6 deg
which also would add to increase in the windmilling drag.

(T) CVR Time -07:02, 46:47:33

Expresses that landing at 10,000 feet airfield elevation, would be difficult with single engine operation ,with the performance seen by the crew in this flight.

(U) CVR Time -05:50, 46:48:45
Telemetry = 3041.6 s, IST 15:28:43
Torq_L 3.5%, Torq_R 92%, sideslip,6 degrees, bank 15 degrees to left

Bank angle is normally used to relieve the rudder requirement from pilot. Here he has been applying pedal force for quite some time. This bank angle would lead to some extra torque requirement to maintain speed/altitude. Additio nally, sideslip also not being at zero (~ 6 deg), could increase the drag. **So overall, more torque would be needed in this configuration.**

(V) CVR Time -05:33, 46:49:02

This is about high Ng at RH engine at high altitudes, which is a known phenomenon. It was explained probably by the ground here, that this problem would not occur at lower altitudes. **When ground opined "low altitude it is better", P1 expressed the dying situation at low altitude.**

At -05:1, 7 FE expressed desire to go back (*and not carry out subsequent tests*). P2 telling not to go back, we will shut down and later shown to PM, - project manager. Co-pilot also hilariously telling commander "road is there for emergency" and advised FTE for the placing readiness of parachute for emergency, without assessing the risk of the situation, which was also expressed by the commander.

(W) CVR Time -01:47, DFDR: 46:52:48

NP_L 38%, ht,9178 feet ,

FE is asking the pilots in suspicion about the actions taken till now. At this instant Rudder, elevator, sideslip are all steady at the values which were maintained till now. There is no change in HDG, also. Immediately within a second heading started changing rapidly and loosing the height

(X) CVR Time -01:18

Battery discharging voice warning is heard for the first time after left engine shut down, indicating that the battery is in use now and probably starter -motor has been engaged. This is the first instant when NG_L has crossed 13%, after the shut down. Speed now is 120 Kts. At this time telemetry link also lost

Battery discharging sound was heard for 13 sec. Then it has stopped. At the instant of Battery discharge sound stopping, NG_L was constant at 25%. For further 5 seconds, NG_L remained at 25% and subsequently started reducing. Fuel flow remained on for 36 sec (could possibly lead to wet start and high ITT).

During this time NP_L was 100% and reduced to 85%. This is an un-natural condition for a engine to start, in the presence of high NP_L. The presence of light-up can't be determined as ITT information is not available for some small length of time.

One more and possible reason for unsuccessful re light could be improper fuel-air mixture.(seen from fuel flow rate)

(Y). CVR time -00:55,

Tor-R-0%, wheel- full, IAS-132 Kts, h-6620 feet, Bank-2 degrees,.
Pitch- -12 degrees ,. Rudder-9 degrees right.

Concern is developing between the crew about, the intentional reduction of power by P1 on the live engine.

(Z) CVR time –00:22, Height : 5000 feet.

P2 instructing P1 to do the action which ever it is, which has brought the aircraft to some stable attitude when it was done earlier).

Again anguish is expressed by P2 to P1on the action of cutting off of the live engine. Stressing to keep the live engine in LIVE condition only.

In addition to the above mentioned, and identified land mark remarks, the most important is last 3 minutes 20 secs and the correlation of CVR with DFDR and available telemetry data is analyzed below.

(a) CVR Time: -03:22

Securing left engine off after shut down procedure.

(b) CVR time: -03:03 to -01: 50

Preparing for relight procedure

(c) CVR time: -1:47

FE is asking the pilots in suspicion about the actions taken till now. At this instant Rudder, elevator, sideslip are all steady at the values which were maintained till now. There is no change in HDG, also. Immediately within a second heading started changing rapidly and loosing the height

(d) CVR Time : -01:41

Np –L- 90%, Ng- L- 10 %, Side slip- 28 degrees, Rudder moved from

–12 to +4 degrees. Heading 44 degrees, Rudder force – 65 Kg,. Roll –23 degrees and further building, reaching 32 degrees within 2 sec, Pitch –24 degrees, nose down and increases to 40 degrees, Bank going up t o 70 degrees. Both pitch rate and roll rate remained at high level.

It is hypothesized here that the flare up of NP_L was possibly due to blade pitch angle reducing below Primary blade angle(PBA).

With disc effect in full force in left propeller, the up wash wind force raising out of the disc, could have caused HT and aileron of the left side, to, induce, an upward force and consequent nose down attitude. As the right side not having similar upward force, a case of asymmetric tail vertical load could have caused the seen roll also.

(e) CVR Time -01:41 to -01:31

speed increased from 140 to 158
Aircraft loosing height from 9200’to 8200’.

Ng_L: 10%, Np_L reaching 99%, Engine oil pressure down to 4.6, fuel flow increased to 38 but still torque is zero on left side, ITT : 102 .

at the same time on right side: Ng down to 73 from 101, Np maintaining 101, oil pressure 119, fuel flow gone down to 72 from 261, torque to zero . this indicates right side engine was brought down

(f) CVR time---01:27,

Altitude: 7311 ft , Bank angle recovers to 8 degrees, pitch recovers to – 9 degrees, side slip recovers to + 2 degrees .

These conditions imply that the **aircraft is momentarily returning to normal attitude. (pilots laughing)**

The possible reasons behind this seen recovery could be:

1. Reduced disc effect due to side slip reduced airflow, over the disc.
2. Pilot added control inputs to correct body attitude.
   But altitude loss continued.

From time -1:41 to -1: 22 aircraft lost height from 9223' to7266' i.e. almost 2000' in 20secs.

At -1:22, CVR revealed the hurried voice of FE telling the pilots to start the engine quickly.

From -1:09 to 0:57 telemetry link was not there.

(g) CVR Time---01:02,

Speed losing to 116 KTS, Altitude to 7280 feet, pitch –9 degrees, bank 0 degree, Live engine Torque was coming up to 16% which was reduced to zero earlier.

Large drop in speed seen, and hence is the comment. P2 is demanding from P1 the same action (which ever recovered the aircraft from bad attitude felt few seconds before).

(h) CVR Time - 00: 55,

PLA-right brought down from 16 to Zero again. Right Torque -0%,right fuel flow reduced to 70, Speed 132 KTS, Bank 2 degrees, pitch – 12 degrees, Rudder – 9 degrees, ht-- 6620 feet , engine oil pressure-left increased to 56 and subsequently started reducing to 38, ITT still 68 deg, Fuel flow remained 36, torq ue zero., Ng raised to 22 and started dropping to 15,Np to 83.

This indicates the Left engine relighting not successful and height continuously dropping. Right engine also brought to idle.

P2 Expressing anguish on reducing power of the live engi ne by P1 .

(i) CVR Time-- -00:44, altitude 6150'

Side slip is 20 degrees to right. Idle Kar do—could be referring to power, possibly referring to right engine. With disc effect prevailing on the left side, the power on the right engine, is the one, causing the noted side slip. (as possibly understood by the crew).

Immediate follow up words of—Ruk, jao.--, indicates, rapidly changing mind set of Pilots while coping up with rapidly changing attitude of the aircraft, as well as the f ast fall in forward speed. Increase of right engine parameters noted.

On left side engine: oil pressure to 26, fuel flow remained 36, Ng 13, Np 85, ITT still 68, almost no torque.

(j) CVR Time –00:33,

Speed reduced to 112 KTS, Height reduced to 5400 feet, E1 Ng-10 % , E2 N g-86 %,

The calculated rate of descent is as high as 12000 feet per min, with fast descend taking place, the crew believes here that they have to have left engine live to cop up the emergency.

P2 and P1 raising alarm voice of drastic reduction of speed. P2 asking P1 to relight immediately.

(k) CVR Time—00:27,

Height 5000 feet,

excess rate of descend ,panics the crew with sayings seen here. The battery discharging warning indicates the action of Second relight attempt on left engine.

(I) CVR Time-- -00:26,

Height- 4800 feet . Side slip to 20 degrees, pitch at –15 degrees, Right engine torque reduced to zero and rapidly and immediately increased to 85 %.

Left engine relight process is on. Np L-77%, Ng –L- 16 %. Rudder pedal force increases as high as 90 kg. Aileron forces too ,seen to raise to 40 kg.

No telemetry link between -0:25 to-0:08

(m) from -0:22 to -0:15

P2 instructing P1 to do the action, which ever it is , which has brought the aircraft to some stable attitude when it was done earlier.

Again anguish is expressed by P2 to P1on the action of cutting off of the live engine. Stressing to keep the live engine in LIVE conditi on only.

(n) CVR Time - -00: 14,

Ng L increasing to 23 %, Np L 80%-- , ITT increased to 96

indication of left engine responding to relight action . Ng R- 102 %.

During 1st un-successful attempt, NP_L reduced from 100% t o 83-85% (An increase in EngOilP_L was noticed from telemetry data which showed that EngOilP_L reached the required minimum of 60 psi.) But in this attempt, NG_L rise was not sustained, so EngOilP_L probably started reducing, thereby preventing further mod ulation of blade pitch angle. It could be conjectured that blade pitch is still below PBA.

During 2nd re-light attempt, EngOilP_L increased beyond 60psi as NG_L was sustained and so probably, now prop blade pitch angle might have come to PBA and matching NP_L for ground idle setting. During this, as expected, NP_L reduced from 82% to 61%.

(o) CVR time: last 10 secs

P1 calling aircraft departed repeatedly indicating aircraft fully gone out control. The word used by the pilots " F (unre adable)." repeatedly at last moment indicating, "No control on aircraft and their life is ending"

(p) CVR Time-- - 5 Secs to 1 sec prior to crash

1 sec prior to crash:

Rapid loss of height from 4300' to 3040', speed started increas ing from 60 to 120 . Ng_L increased to 54,Np to 56, oil pressure to 79, ITT increased to 647, fuel flow to 95,but torque started to come out of zero ,
indicating Left engine successfully relighted.

Whereas on right side:

Ng R- 81%,Np: 86,Oil pressure 118, ITT 773, fuel flow 78(came down from
336 which was increased in the 5 secs prior to crash), torque came down to
11 from 81, PLA from 31 to almost zero. Indicating last moment try by the crew on right engine

At the last second of their life P2 calling " F.......,F......" indicating he is seeing last spell of the life. At the same time Battery discharge Warning coming in the background also stopped, indicating engine relighted successfully. But the aircraft almost on ground, P1 calling " Going to ground"

1.12 Wreckage and Impact information

Aircraft crashed at a village called Sehsagirihalli which is close to wonderland amusement park near Bidadi (about 1 Km off Mysore road) and about 37km by road southwest from HAL airport, Bangalore. **It was on a radial of 251° /17 NM from HAL, Bangalore airport having coordinates LAT : N12° 50'56" , LONG: E077°**

23’46”). Aircraft nose was facing east direction. The salient observations recorded during in-situ inspection of the accident/wreckage site are as follows:

1. The aircraft got destroyed due impact and post impact fire.

2. Crash site was wide open residential plot layout area and was a hard terrain with varying slopes surrounded by poles and wild tress/bushes.

3. All three crew were found burnt and dead on their seats. They were found bent forward with head down and not touching their laps.

4. At the time of site inspection, the fuselage was found broken from rear of the main plane and was in the inverted position. The vertical fin leading edge facing the ground and the respective tail mounted engines by the side of it.

5. The extreme tail portion was un-burnt and there was no smoke shoot mark on the vertical and the horizontal tail plane. **This indicates no pre impact fire.**

6. Entire wreckage was found confined to an area covering radius of 20 meter from the main wreckage. All extreme ends of the aircraft were within the main wreckage with fire damage. **This indicates there is no fire or structural failure prior to impact on ground.**

7. Test boom attached on the nose was broken and lying forward away from the main wreckage and un-burnt**.** Parts of nose radome structures were found lying away from wreckage on its forward right side about 40-45 deg. **This indicates aircraft did not crash on its nose.**

8. **Wreckage inspection ground marks also reveals that there was no forward moment of the aircraft after main plane impacted on the hard ground.**

9. The intensity of the fire was observed diminishing from root to tip on both the wings. **Whereas the effect of fire on the extreme nose and tail was observed to be minimum.**

10. A portion of port wing (measuring approx. 3feet long from the tip) semi burnt found lying adjacent to the cockpit portion at an angle (5-10º) to the longitudinal axis of the aircraft. Rest of the wing at the same angle as mentioned above but fully burnt leaving only the trail of its presence.

11. The Starboard wing found in two pieces sheared off from fuselage semi burnt condition. The root portion is approx. 6 ft and the tip portion approx. 3 ft. The trailing edge of the tip portion is found facing forward (East).

12. The nose section ahead the instrument panel location found in multiple pieces but with out much burn damage. The avionic equipments like VOR, ADC etc libe rated from its location but with severe impact damage. However one of the ADC found with no evidence of any damage. The entire section from cockpit to empennage was completely burnt into ash and lot of molten materials were lying on the ground.

13. Control column found in place with operating cables attached to it. However they were found burnt without deformation in shape. The entire control cable run with respect to aileron, rudder, elevator are found attached either to its control surface brackets or to the operating belcranks / fittings. The cable run (burnt) found running from cockpit to tail almost straight along the axis of longitudinal direction and no discontinuity was observed

14. Engine controls found attached to the control quadrant in cockpit and the operating mechanism. However, few of the operating levers at operating end found sheared off.

15. Pilot / co-Pilot and flight test engineer's seats were found fully burnt and deformed. Seats structure could not be traced except one of the arm rest.

16. All the three undercarriage were in retracted position and found burnt but retained its solidity. One of the nose tyres was found half burnt and another tyre was having only burnt steel braiding wires.

17. One of the crew parachutes was found deployed and found un-burnt lying away from the wreckage. Rest two parachutes were found burnt one of which was 2 meter away from the wreckage and the another one is within the wreckage in cockpit rear section.

18. Five propeller blades were found liberated from their attachments and found lying at different places away to the left of the main wreckage(viewing from rear)

19. Main door and Port Emergency door Handle was found in Open position and Stbd. emergency door handle was in closed position, affected by fire. Main door was slightly damaged due impact. All the three doors were lying away from the main wreckage and hence not affected with the fire except slight burn marks to port emergency door. Stbd emergency door was not having any impact/fire damage.

20. LH engine (on RH side of the fin in site) found in two pieces. PWR section and Gas generator / RGB separated from each other. The RGB is found to have two of its blade attached to it. Rest of the blades (Qty.3) found located north side of the wreckage. All the blades are found deformed.

21. RH engine (on LH side of the fin in site) found in three pieces. PWR section and Gas generator section separated from each other. The blade attachment hub with three blades attached to it found lying approx. 12 m aft of the fin on west side. Rest of the blades (Qty.2) found located north side of the wreckage. All the blades are found deformed

22. The digital CVFDR was located inside the wreckage in the tail portion from its mounted location covered with burnt / half melted frames. The CVFDR container was found burnt externally and no trace of its connectors. The ULB found installed with CVFDR also burnt externally.

23. Solid State Recorder(SSR) which forms part of the Flight Test Instrumentation system was located near cockpit was fully burnt as it was not fireproof.

24. The ELT could not be recovered however six ELT cells were recovered in burnt condition.

The wreckage was reconstructed and **All parts were mostly identified .** But the ELT could not be traced. Most probably it could have burnt in fire as its housing was not fireproof. The ELT was not fitted on load bearing members/frames and is fitted separately on platform.

1.13 Medical and Pathological information

Test flight No:49 of Saras PT-2 aircraft VT-XRM was commanded by WgCdr,22917S,F(P), who is also chief test pilot. Wg Cdr, 23165H,F(P),test pilot was co-pilot. Sqn Ldr, 24746N,FTE AE(M), was flight test engineer on board. There was no other persons on the test flight. All three were charred to death on their seats in the post impact fire after the accident.

Immediately after the accident all three bodies of the deceased were shifted to the CHAF hospital, Bangalore. The bodies were duly identified by Wg Cdr A.C.Mathews (22893T) Admn of ASTE,IAF, Bangalore and were medically declared dead at 1730 hrs IST on 6.3.2009. Later the bodies were subjected to Postmortem medical examination. The post mortem report of the all three deceased crew concluded that the crew were dead due to multiple soft tissue and bony injuries in an aircraft crash at ground impact.

1.14 Fire

The evidences at accident site proved that there was post impact fire. The intensity of the fire was very high and complete aircraft structure was found burnt. The aircraft was destroyed due to post impact fire. There was no evidence of pre-impact fire.

1.15 Survival Aspects

The accident proved non survival and all the three occupants of the aircraft were succumbed to their poly-traumatic injuries in the crash.

After the radar contact was lost around 1005 UTC, radar controller tried to contact him directly and also through PW461(Chennai - Coimbatore) and further on 122.7 and 243 Mhz also. Meanwhile tower received a call from Saras telemetry to check if Saras is in RT contact. Since aircraft was not in RT contact as well with radar, Tower was advised to activate SAR through ASTE. ALH A-67 was requested for SAR and it departed at 1014 UTC.followed by T45(Chetak) from ASTE at 1020 UTC. After some time T55(Chetak)also departed at 1058 UTC from ASTE. Based on the telemetry last observation A67 after extensive search located the crash site to be B251/17NM from HAL. Earlier HAL tried through police control room also to find out the exact location of the crash site and police force informed that they had just information of an aircraft accident near “wonderland amusement park” in a village “Seshagirihalli” near Bidadi. Later police Sub-inspector –Bidadi informed the landmark details of the site which were conveyed to the A67 and T45 to locate the crash site of the Saras aircraft. At about 1100 UTC A67 confirmed the crash of the Saras aircraft in Seshagirihalli village.

1.16 Tests and Research

1.16.1 Failure analysis of main door and emergency doors

After the accident, National Aerospace Laboratories was asked to provide a report on the possible failure of the main door and the emergency doors which were found near the main wreckage of the aircraft. Following this, a committee was constituted by Head, C-CADD comprising various experts members to look in to as to how the doors came off the fuselage structure and whether or not there was any failure of locking pins/mechanisms.

The committee examined the doors and the corresponding structures of the fuselage and other evidences. The findings of the committee are summarized as follows.

(a) The main door was in "CLOSE" position during the impact of the aircraft on to the ground. The movement of the handle and the pins to "OPEN" position was caused during the impact by the force created due to breaking of the linkages concurrently with the bending/buckling of the door.

(b) The emergency door (LH) was in "CLOSE" position during the impact of the aircraft on to the ground. The reason(s) for movement of the handle and the locking latches/pins to "OPEN" position appears to be the same as that mentioned in the case of the main door.

(c) The emergency door (RH) was in "CLOSE" position during the impact of the aircraft on to the ground. During impact, the locking latches/pins have come out by damaging the fuselage structure. However, in this case, the handle remained in the "CLOSE" position since there was no bending on the linkages or in the door frames as a whole.

(d) the integrity of the locking mechanisms of the main and the emergency doors were intact at the time of impact of the aircraft on to the ground.

1.17 Organizational and Management information

The ill-fated aircraft was designed and developed and operated for experimental test flight by National Aerospace Laboratories (NAL), Bangalore. National Aerospace Laboratories (NAL), Bangalore is an approved Design Organisation by DGCA, India under CAR-21, subpart JA and its approval is valid till 31.12.2009 vide DGCA certification 5-25/97-RD dated 16th march 2009. It was valid on the day of accident. The design organisation approval provides the scope to NAL to design and develop light transport aircraft "SARAS" and also NAL to classify changes to type design and repairs as major or minor as per the procedures agreed with DGCA. NAL also to evaluate and propose the conditions under which a "permit to fly" operation can be carried out in accordance with procedures agreed with DGCA. DGCA also approved list of designers of NAL as authorized signatories ie., Showing Compliance Engineers and Compliance certification Engineers(SCEs and CVEs) for SARAS project, on 13.8.2008, apart from the approval of head of design organisation and other managers as per design organisation manual(DOM). DOM was approved by DGCA only on 1st Dec 2008 under CAR 21, subpart JA, issue-II, revision 0.

There was an MoU between NAL and IAF on 14th may 2003 for implementing Saras project. MoU provides the role and responsibilities of NAL and IAF and they also agreed to establish appropriate project management and monitoring structure. As a part of agreement NAL and IAF set up the Management Committee(MC) which will be the apex body, responsible for flight testing of SARAS prototype aircraft upto the completion of the certification . This MC will deliberate and decide on all major issues relating to flight test planning, sequencing and supervision of the actual flight tests, flight safety aspects, expansion flight envelope and interaction with the certification agencies.

A joint ASTE(IAF)/NAL Directive has been made effective with effect from 28 th May 2004, which clearly lays down the role, duties and responsibilities of key personnel involved in the Saras flight test programme for efficient and safe conduct of developmental flight tests on Saras prototypes.

However from the records made available to the investigation group revealed some of the salient observations:

1) Management committee did not play its role as envisaged in the MoU. After Aug 2006 there was no periodical review by MC. Only the joint meeting between NAL and ASTE,IAF was held on 28 th Aug 2008. After this meeting there were 27 test flights (including ACCIDENT FLIGHT)done. There was nothing reviewed. Similarly In 2009 also there was no review of the project by MC or NAL.
2) Similarly there is no evidence made available to show that Local Mod committee is established and functioning properly for its purpose said in the joint directive .
3) Continuous evaluation of procedures/design modification for safe conduct of test flight is not at satisfactory level.
4) Co-ordination with OEMs of engine and MT propellers is not there after vetting the relight procedure by ASTE for their comments and guidance.
5) There is no proper interaction between NAL and MT propeller regarding the formulation of the relight procedures.
6) There is no contingency plan in detail available in case of missing aircraft/exigencies/loss of communication and accidents etc.
7) No chase aircraft and film shooting facilities were made available to monitor all critical \test flights especially the test flight involving relight procedure.
8) Failure of regular monitoring and improvement on telemetry monitoring systems and their documentation procedures.
9) Failure of monitoring of CVR and FDR in co-ordination with solid state recorder(SSR) and telemetry data for evaluation of better cockpit procedures and design modification
10) Non-inclusion of critical engine parameters like ITT, engine oil pressure etc., essential for monitoring test procedures, in the vacant slots of FDR
11) **Aircraft was used for flying demonstration in Aero India 2009 show at Bangalore. But no DGCA permission was taken by NAL for the purpose.**
12) **There is no effective and continuous monitoring of test programme by MC and no records of monitoring available.**

NAL also subcontracted a private agency named Aircraft Design and Engineering Services Pvt Ltd (ADES), Bangalore for supporting Saras project. Aircraft Design and Engineering services pvt Ltd (ADES), Bangalore was approved as a design organisation under CAR21, subpart JB and it is valid till 31.12.2009. The scope of it includes design and engineering support to NAL in Civil Aircraft projects 14 seater Saras aircraft to the parts and appliances complying FAR 25 standard. NAL entered into an agreement with this private contractor company-ADES on 1.5.2008. The following peculiarity was observed while scrutinizing the agreement and its attachments:

1) Even though agreement was made on 1.5.2008 it was made effective from 1 st April 2008.

   Contractor will engage experienced aircraft designers, engineers and other technical staff required for task as required during diffe rent phase of the project. The work schedule of the project also indicates almost complete work of the design and development of SARAS project is being done by the contractor.

2) This is not in line with DGCA approval given to the contractor that of only giv ing design and engineering support to the parts and appliances.
3) Since this is the national project, utmost vigil and care shall be taken by CSIR, India while implementing project and also the concept of employing the private contractor involving in each and every stage of the design and development of Saras project requires to be discontinued immediately and only the support for the parts and appliances shall be obtained from them.
4) As per agreement Even though NAL shall retain the absolute right on any pa tent that may be taken from the result of the work, Confidentiality clause of the agreement did not point out the penalty/ punishment action on the contractor under law in case of the pilferage or theft of any technical information such as design, drawings , wind tunnel testing, flight tests results or any software etc.,

   Apart from the above NAL also subcontracted several agencies for getting support facilities and parts for the Saras project.

1.18 Additional Information

1.18.1 **Selection of test pilots:**

It is learnt that ASTE,IAF is the only establishment in India and one of its kind in the world to undertake test flying both for upgrades of existing aircraft and for prototype aircraft. Presently the only prototype testing being undertaken is for LCA by NFTC, IJT by HAL Flight test centre and Saras by ASTE. All the test pilots and FTE are Alumni of ASTE test pilot school. The test pilots and test engineers are trained to undertake test flying on fighters and transport aircraft. The pilots and FTEs have experience in test flying of other turboprop previously like Dorniers, Avros and AN - 32 of IAF. The aptitude for test flying is evaluated by IAF test pilot school. As there have no remarks against the pilots of accident flight NAL accepted the pilots nominated by the Commandant ASTE, IAF as per the “Memorandum of Understanding for SARAS Programme, dated 14.05.2003 .The deceased Test pilots and FTE were given training on various systems of SARAS aircraft by respective designer and Test Director at NAL. On co mpletion of the training, a request was made to DGCA by NAL for approval of test pilots and Chief of Trial Team. Similarly acceptance of FTE was obtained from the DGCA. Previous experience of test pilots/FTE are examined as per advisory circular 01/2001 is sued by DGCA(AED).

Apart from the above, NAL has neither used its own expertise nor outsourced the expertise from other aviation industries to test the Saras test pilots/flight test engineer for their suitability in the civilian test flight wherein exp erimental aircraft under development is used . Moreover, as per MOU of SARAS program it is understood that SARAS is the first civil turboprop prototype test flying undertaken by ASTE,IAF for which assessment of crew for human factor is important . Human factor/CRM of the flight crew were not assessed by NAL for the civilian cockpit and flight operation environment as the test pilots are basically from the Air force environment. Similarly test pilots/test engineer also did not undergo any human factors tr aining before operating the test flights on VT-XRM. No documents were provided to the investigation team on the subject matter.

1.18.2 **Preflight and post flight requirements**:

NAL reported that the following arrangement are available for the purpose of Briefing / debriefing:

For each test flight, the team consisting of Flight crew, Flight Test Engineer (FTE), Design group, Flight planning group along with Flight Test Director will discuss the programme and conditions. FTE will convert this programme and conditio ns to test card and test schedule. The test card is approved by Test crew and FTE. During pre - flight briefing any change in test schedule or test points are discussed and incorporated. Also contingency action for specific emergency/precautionary procedures are discussed during pre-flight briefing, attended by Officer in Command - Proto type test squadron (OC/PTS), Flight Test Director (FTD), Test crew, FTE, Chief of Design, APD/FTG, Telemetry monitoring team, Flight operations in -charge, aircraft maintenance in-charge and crash/chase vehicle coordinator. Flight test schedule is signed by Test crew, FTE and Chief of Design. The program and condition for each flight is transmitted to DGCA R&D prior to pre -flight briefing and conduct of test flight. Block of 10 or 20 test flights are normally approved by DGCA -ADE based on test plan submitted by NAL. Individual test flight “Condition and Programme “ is submitted just a day prior to actual test flight no 49.

After completion of flight, a hot-debrief is given by the flight crew at the telemetry of ASTE and the same is attended by those who were present in the flight briefing. Once the data has been analyzed by the NAL Flight Test team, a detailed data debrief is conducted at ASTE/NAL where all the observations ar e discussed and the results of test points are accepted or repetition of some of the test points are discussed. Prior to conducting the next test flight aircraft readiness is authorized by individual monitoring and analysis team for the following discipli nes: Aerodynamics, Engine/power-plant, Systems, Electrical/Avionics, Telemetry and Maintenance / Operation and FTD.

As a defined procedure, pre-flight briefing is always carried out by the Flight Test Engineer who is part of the flight crew. For the ac cident flight ,the same was done on 6th March 2009 afternoon. The briefing covered aircraft SOP for this flight, work done on the aircraft prior to this flight, configuration limits, test points & test sequence according to the issued test programme and safety considerations. Details are as per flight test schedule dated 6.3. 2009. Flight crew, including the pilots and the flight test engineers, were present. From NAL side the following were present: flight test director, APD (flight testing), PD (Saras aircraft project), members of real-time monitoring team, inspectors from various trades, ground crew, design representatives from relevant disciplines. At the end of the briefing, the pilots were specifically told by the Flight Test Director that in case of any problem during the relight attempt, the engine should be switched off, propeller feathered and single engine landing executed.

No effort should be made to try the relight a second time. These detailed discussions were nowhere documented/minuted.

It has also been reported that the preflight briefing meeting were done before the accident flight. Scrutiny of documents/records revealed that preflight and post flight debriefing of the test flight /to the test pilots were not effectively documented at each and every flight. Moreover the available documents did not include contingencies plan/procedures for unexpected exigencies/missing/loss of communication/ accidents etc.,

Similarly there is no documents made available to indicate the existence of ef fective prefight and post flight medical requirements and its compliance for the test crew. Also there is no proper system exist to monitor the fatigue level of the test pilots prior to the test flight.

It has been reported by NAL that at any stage of d iscussion including critical flight test like "engine shut down and relight" no DGCA official took part. Only the documents are transmitted to DGCA for approval/acceptance/acknowledgement. As the Saras project is national project and involving country's dignity It is felt necessary that either local DGCA Officers or DGCA HQ officer should have participated for effective guidance and timely implementation of each phase of the project. DGCA being the approving authority of the NAL, design organisation and the Saras experimental aircraft as well production aircraft and Since huge public money is involved in the project, DGCA's serious involvement is a must for effective control on the project.

1.18.3 Effective oversight functioning of DGCA,R&D(AED)

When the prototype is completed, NAL submits test plan for block of 10/20/25 flights along with aircraft definition document/SOP. After scrutiny by DGCA(R&D) Head Quarters / Bangalore office will grant permission for conducting test flights. On completion of approved block of test flights, a summary of the test report together with test plan for next block of flights is submitted to DGCA and clearance obtained for continuing the test flights. Further the test program and conditions are prepared for each individual flight in consultation with test crew and submitted to DGCA local office a day prior to execution of flight. During the scrutiny of various programs and records of Saras project it is revealed that there is no continuous monitoring and effective control over the project by DGCA(R&D). Saras being the national project by NAL, a Govt. of India organisation, and approved by DGCA under aircraft rules, much more participation and effective control by DGCA on the project is essential and important.

Some of the serious lapses noted are:

1. NAL without DGCA's permission took part in Aero India show - 2009 from 11.2.2009 to 15.2.2009 covering test flight no: 40 to 46 using Saras PT2 VT - XRM at Bangalore and demonstrated the flight to public upto low alti tude of 300'AGL over Yelahanka airfield.(actual test area: Bangalore LFA), for which no test report were submitted by the test pilots. Participation in the AERO India show

-2009 was planned in the month of Aug 2008 itself. NAL reported that the information of their participation was however, submitted on 9.2.2009 to DGCA. But there is no documentary evidence provided during the investigation for the approval from DGCA. No action was taken by DGCA(R&D) also to restrict their participation. Saras PT- 2 being the experimental prototype aircraft under test and C of A is not yet given to the aircraft, participation in the public demonstrative flight show and that too at low level of 300' AGL is dangerous to the life of the public and their properties. It is also not understood that how the Show Owners/Conveners accepted the uncertified aircraft for flying demonstration in the public show.

2. While giving flight clearance including engine shut down and relight flight tests there is no restriction made on minimum altitude by DGCA.

3. Uncertified propeller is tested on locally fabricated engine test rig, which does not have DGCA approval. No inspection by the DGCA on these facilities for approval even though papers were submitted to them.

4. There is no periodic monitoring of CVR and FDR by NAL

5. No contingency plan for communication failure, accident, missing aircraft etc.

6. Non-participation and strong guidance in critical flight tests procedure like engine shut down and relight test programme.

1.18.4 Periodical monitoring of review of CVR and DFDR:

From the records made available to the investigation team it is clear that CVR and DFDR data was not monitored for each and every flight of Saras PT2 aircraft. There shall be a dedicated experts to do these continuous monitoring for improving the cockpit procedures and discipline apart from evaluating the design modification requirements using DFDR data in collaboration with telemetry data and SSR data.

According to FAR Part 121, paragraph 121.344, no person may operate a turbine powered transport category airplane unless it is equipped with one or more approved flight recorders that use a digital method of recording and storing data and a method of readily retrieving that data from the storage medium. The operational parameters being recorded on the SARAS aircraft by the digital flight recorder as per Vol 10, DR - 36 noted above. All parameters mentioned are being recorded with the ranges, accuracy and resolutions as specified in Appendix M of FAR 121.344. This is also in accordance with the latest NTSB recommendations **.(also AS per note 3 of flight recorder – CAR Sec 2 ser I, Part V)**

However it is understood that DFDR **does not have engine parameters like engine oil pressure, ITT and fuel flow etc to monitor these in relight procedures and the engine performance.** It is also revealed that the SSCVFDR installed in SARAS aircraft has a capacity to record at the rate of 128 words / second. That means 128 parameters of 12 bit resolution can be recorded in one second. At present 100 slots of 12-bit are full and 28 slots of 12-bits are vacant. It means that **SSCVFDR still has**

room for accommodating another 28 parameters of 12-bit each. The above mentioned critical engine parameters like ITT, Oil pressure, fuel flow etc are hence to be included in the FDR.

It is therefore felt that NAL should have prudently included the above mentioned parameters as the slots are still vacant. There is a need to re-look at the parameters being recorded in FDR by a expert team in the field to include additional 28 parameters (could be engine or airframe parameters) .

Similarly it has been reported by the investigation team that the elevator position reading throughout the test flight was noisy probably due to intermittent signal loss in the data**. Hence Elevator position indication needs to be rectified**.

DGCA(AED) office at Bangalore and At HQ also should not exercise the proper control on the matter

1.18.5 **Test flights acceptance by AED, DGCA** :

There was a request from NAL in Oct 2008 for 15000 feet flight clearance. DGCA(AED),Bangalore Granted flight clearance of 15 flights to SARAS PT1 and PT2 aircraft for higher altitude flight upto **15000'** vide AED letter no.BLR/AED/SARAS/2008-08 dated 21.01.2008 to carryout

a) low speed handling checks including approach to stall and stall test
b) Engine re-light checks(one engine at a time)

subject to certain conditions. In one of the conditions (para c)of the said DGCA letter, it is stated that a copy of the emergency procedure and the flight test schedule/order may be submitted to this office prior to commencement of test flights for acceptance.

But, as per records, it is learnt that NAL did not obtain necessary acceptance from DGCA even upto the last fatal flight no.49 and no information/correspondence received from NAL about carrying out the flight test.

However it is not understood till 49th flight test how DGCA-AED,Bangalore was just sitting as a spectator while all the flight tests were being conducted with their awareness. At no stage of previous test flights and their correspondence also the above lapses were not pointed out to NAL, Bangalore. DGCA-AED failed to ensure the conditions given in their flight clearance in spirit.

1.18.6 **Review of SSR –flight instrumentation system:**

It is given to the knowledge that the aircraft is also fitted with Solid State Recorder(SSR) for the purpose of assessing the complete flight performance of the aircraft. It records quite large no. of parameters even better than FDR. It is also understood that it was not housed in a fireproof and crash proof unit. In the accident aircraft it was completely burnt and no data could be recovered from that unit.

NAL should explore all the possibilities of having more safer SSR housing unit from the point of fire proof and crash proof till the Saras aircraft is released for production flight.

1.18.7. **Electrical system and role of Auxiliary battery**

To understand role of auxiliary battery in relight operation electrical system of the aircraft is necessary to be understood

Electrical System Architecture

Electrical System Architecture for SARAS Aircraft is as follows. Two starter / Generators serve as main power supply sources. The same star ter/generators serve as starter motors during starting phase. The capacity of each generator is 400 Amps at 28 Volt; the over load rating of the starter / generator as generator is 600 Amps for 2 minutes and 800 Amps for 5 seconds.

One Main Battery (Ni-Cd) of 44 Ah capacity is used as emergency power source. The same battery serves as internal starting source.

One Auxiliary battery (Ni-Cd) of 16 Ah capacity is used for the following purpose (during starting phase):

To improve voltage supplied to GCPU (Generator Control & Protection Unit), CWP (Central Warning Panel), Fuel flow meters. Also the auxiliary battery serves as additional emergency power source during double generator failure.

Reason for introduction of auxiliary battery.

During starting phase of Saras aircraft development main / emergency bus voltage dips below the operating voltage of Generator Control and protection unit (GCPU), Central Warning Panel (CWP) & fuel flow system due to large motor starting current.

It was found necessary to provide a separate Auxiliary battery and bus bar for these circuits to over come the low voltage problem while starting.

It is to be noted here that Auxiliary battery is not meant to supply starter motor current during starting cycle (on ground and in air).

After starting cycle is completed the auxillary bus bar will be powered by main power source (generator supply) with auxiliary battery under float charge.

The electrical circuit is so arranged that both the emergency bus and auxiliary battery bus are powered by 44 Ah main battery in case of double generator failure (probability is extremely remote) In that case the auxiliary battery bus bar can be isolated and powered by auxiliary battery by selection.

Auxiliary Battery Selection Switch

The Auxiliary Battery is controlled by a three position switch, as follows: The three positions are ‘ON’, ‘OFF’, and ‘CHARGE’.

1. **Position 'OFF'**
The Auxiliary BATTERY is separated from all bus bars. (This battery does not supply even to Auxiliary battery bus bar). However the Auxiliary Battery Bus bar is connected to the emergency bus bar supplied by the main battery.
2. **Position 'ON' (**The Auxiliary bus bar is isolated from main and emergency bus bars)
The Auxiliary battery is connected to Auxiliary battery bus ba r and supplies (discharge) current to all loads connected to Auxiliary battery bus bar only i.e. GCPU, CWP and fuel flow meters. Hence any voltage dip on other bus bars will not affect the Auxiliary battery bus bar (especially during starting cycle).

3. **Position 'CHARGE'**
The Auxiliary Battery is isolated from Auxiliary bus bar and connected to main bus bar for getting charged by generator. Now the Auxiliary battery bus bar is supplied by main power sources (Generator).

Indications and Warning:

a) Main Battery Discharge Warning.
Main Battery Discharge warning will come 'ON' for the following conditions and when the discharge current sensed by the current sensor in DC master box is more than 6 Amps.

1. During internal starting (Main battery)
2. During cross starting (Main BAT + GEN)
3. During double generator failure.

During this condition battery is supplying power to the loads connected to emergency bus bar. Audio warning comes 'ON' along with indication, in CWP.

b) Battery Indications:

Main Battery:
1. Battery disconnect (RED lamp in CWP).
This lamp comes 'ON' when battery is not connected to emergency bus bar.
2. Battery discharge (RED lamp in CWP with Audio warning)
3. Battery 'HOT' (RED lamp in CWP).
This lamp comes 'ON' if the battery temperatures rises above 71 °±2^{0}C.

Auxiliary Battery:
1. Aux. Battery disconnect (RED lamp in over head panel):
This lamp comes 'ON' when battery is not connected to main bus bar.
2. Aux. Battery 'HOT' (RED lamp in over head panel):
This lamp comes on when the battery temperature rises abo ve 71±2^{0}C

1.18.8 Discussion on Synchronization of Propeller Control and Fuel Control

In Saras PT2 VT-XRM aircraft, concept is Three control levers for power, propeller blade pitch and condition are provided on pedestal in cockpit within the reach of both pilots. The mechanical movement from cockpit is transmitted through flexible ball bearing controls to corresponding levers on engine.

Power lever controls the engine power and also selects reverse pitch by blade pitch variation. Propeller lever controls pitch at max. RPM, min. RPM and feather. Positive stops are provided on quadrant so that inadvertent operation to feather regime is prevented.
The required power is selected by means of power lever in direct proportion to torque. It has max. power, idle and max. reverse.

Condition lever has three positions: off, low idle (53% NG) and high idle (70% NG) with positive stops.

Propeller control lever movement provides smooth propeller operation (pitch change) within control range. The propeller lever has a governing range between max. RPM and minimum RPM positions and feather range.

The blade pitch is controlled automatically in flight to maintain the RPM constant to pre-selected value. The chosen relationship of engine power to propeller pitch depends on operating requirements. Based on propeller RPM selected, turbine governor section of propeller governor limits engine power according to ability of the propeller to absorb the power at that speed. When lever is pushed fully forward, pitch changes from course pitch to fine pitch (high RPM).

Whereas in P.180 Avanti II aircraft. There exists two-lever concept.ie., power and condition levers The engines and propellers are operated by two sets of controls mounted in the control pedestal below the centre instrument panel.

The power levers (left side of pedestal) control engine power through the full range from maximum takeoff power down to full reverse. They also select the propeller pitch (beta control) when they are moved back from the detent. A gate provides unrestricted power lever movement from idle to maximum forward but requires the power lever handle to be pulled up before movement can be made from idle to reverse. Each power lever operates the NG speed governor in the fuel control unit in conjunction with the propeller cam linkages. Increasing NG results in an increased engine power.

The condition levers (right side of pedestal) provide the propeller speed commands as well as the fuel cut-off and propeller feathering functions. (ie **combined propeller control and fuel condition lever.)** In flight, the condition levers provide the speed commands to the propeller governor for setting the desired propeller speed. The condition levers are utilized to select high (about 70%) or low (about 54%) idle. Ground idle (low) is the normal condition for ground operations. Flight idle (high) is needed on ground for maintaining low ITTs during periods of high generator loads at high ambient temperatures or when increased bleed air flow is necessary. Moving the condition lever aft from the G.I. position, over the gate, and aft to the FTR(Feather) and CUT OFF results in propeller feathering and fuel cut-off.

The above concept of two lever, single control box operation is easier compare to the three lever operation. NAL should explore the above concepts to adopt in future Saras project for achieving well coordinated cockpit control by the pilot.

1.18.9 **Status of ATR on Inspection by DGCA authorized inspectors** :

As per the instruction of DGCA, Delhi Air India engineering team had visited NAL, Bangalore from 6th Jan to 9th Jan 2009 to review and study the avionics and electrical systems of SARAS aircraft VT-XSD for the purpose of type certification, design, implementation and system architecture. Certain observations were indicated for improvement by NAL.

There were 31 major observations made for implementation. Some of them were pending for implementation. These were regarding provision of spare cables in each loom, flushing of pitot probe and AOA with fuselage, position of pitot probe water drain hole, pitot probe heating, warning for emergency door opening. However these were not contributed to the accident.

1.18.10 Propeller certification

1. ***Selection of engine-propeller combination*:**

Since PT6A-67A engine that was flying in Beech star was selected for SARAS PT-2 , the obvious choice would have been the same propeller driven by this engine on the BEECH aircraft. McCauley, USA supplied the propeller for the Starship power plant. McCauley have stopped the production of this propeller and they have no interest in starting the production line again only for one customer. The other alternatives were also explored and finally discussion held with MT propellers of Germany and a propeller development programme was finalized. Broad details of the 1200 SHP, 1700rpm propeller for PT2 are given for the purpose. MT propeller has been in business of development of propellers for the past nearly 25 yrs for general aviation aircraft. They also have developed larger propellers for various specific applications and have enough experience in design and development of propellers. They also have a facility in Poland(AVIA) to design and develop large metallic propeller(Since last 75 years). The total system weight of Hartzell propeller is 93 kg with Aluminum hub to be qualified with Aluminum material and 108 kg for MT propeller. After the comparison of propulsive efficiency of the MT and Hartzell propeller, MT propeller was chosen as it has higher efficiency. Because of the competitive cost, aggressive development schedules and the rich experience behind, MT propeller was selected for Saras PT2. The test propeller was delivered and 200hrs of endurance test have been completed successfully at NAL facilities, as part of certification tests, along with PT6A-67A engine. The engine-propeller combination has thus been proven for SARAS PT2 aircraft.

2. On the day of accident, MT Propeller fitted on the accident Saras aircraft is not certified propeller by any competent authority ie.,FAR/EASA or Indian DGCA as on date of accident. It was manufactured in the year 2005,September, as per the requirement part 21 by MTP,Germany . Though it is uncertified NAL opted for it due to the above selection process.

3. NAL reported that the MT propeller fitted on the accident aircraft was made as per their specification. it is yet to be certified by competent authority due to other technical/test requirement like actual vibration test in flight. These propellers when received from MT propeller, Germany by NAL in the year 2006 there is no declaration of airworthiness fitness made by NAL for its usage on Saras aircraft. Nor any *provisional clearance was obtained from DGCA for its fitness to fit on the aircraft till the propeller is certified.*

4. The variable-pitch propeller system must be subjected to the applicable functional tests of this section. The same propeller system used in the endurance test must be used in the functional tests and must be driven by a representative engine on a test stand or on an airplane. The propeller must complete these tests without evidence of failure or malfunction. This test may be combined with the endurance test for accumulation of cycles.

5. To comply with the above requirement, the propeller was fitted on PT6 A-67A engine and the tests (functional test and endurance test) were carried out. However No wind tunnel tests have been called for in FAR 35. NAL at their facilities has successfully carried out 200 hours tests (150 hours endurance tests+50 hours function al tests) during the period between 18th January to 26th July 2006 for the purpose of seeking type certification of the new MT propeller for the SARAS -PT2 aircraft. The tests were carried out based on JAR-P-210 (B)(1)(ii) / CS-P 390(b)(2) / FAR 35.39(c)(2), applying JAR-E 740(c)(1), CS-E 740 (c) (1) and FAR 33.87 valid for turbine engines with standard ratings (Maximum Take-off and Continues Power). Functional test was done according to JAR-P210(b)(2) or FAR 35.41 (2 hrs per stage).

Result of the above tests concluded that All the PT6A-67A engine parameters (both installation and engine indicated parameters) were compared with the limits and found to be satisfactory. Dynamic balancing was done for the MT propeller along with PT6A -67A engine was done and the vibration levels were brought down from 0.91 ips to 0.11 ips by addition of balancing weight of specified locations. *However the propeller vibration check on the aircraft is kept pending and this also to simulate actual condition of vibration.*

Moreover the engine test stand/rig used for this purpose is locally fabricated and does not have any approval from DGCA.

6. After the endurance test, MT propeller issued “Statement of Compliance and Inspection” Nr 241106 Issue November 24, 2006. Wherein NAL was given the approval for 100 hr. flight and it has also been mentioned a TBO of 72 calendar months. Since the propeller is not yet formally certified, the reason for accepting the long calendar months by NAL is not understood and no other aviation in dustries was consulted prior to its acceptance.

After the accident, MT propeller clarified that :

(a). The TBO of a propeller is always divided into hours and calendar month, because both may have effect to airworthiness. Because it is not yet fully test ed (vibration flight test not completed) only 100 hours initially allowed , full 72 month is used for TBO, because a reduced calendar time limit was not necessary. This is a normal procedure they use with all propellers.

However it is to bear in mind that it is uncertified components going to be used in prototype aircraft it can not be straight away used for 72 months. NAL Should have consulted other aviation industries before following the TBO of 72 months.(Note: first flight test done on 18.4.2007) propeller was purchased in the year 2005, September.

(b). NAL and MTP have conducted a 150 hours type tests with this propeller at NAL test bench in Bangalore and this bench test included also a functional test as well as a vibration test on ground (non-flying) and a tear-down inspection after the run. This was enough for MTP, to show, the propeller could be safely operated within the desired envelop of the aircraft/engine combination. A second vibration test was intended to be done, once the aircraft was cleared for the entire flight envelope, which was never conducted.

(c). **Because it did not complete the inflight vibration test, the MTV -27-2-N-C-F-R(P)/LD265-417 was never fully certified by the EASA since MTP could not show compliance of this part per CS-P.**

(d). They have to certify the propeller according to CS-P first before they can get FAA Part 35 approval. In order to get the -2 model fully EASA certified, they have to complete the in-flight vibration test and if this does not show any negative results, the TBO will be established for 1500 hours.

It must be noted that there are other tests like Fatigue Characteristics,centrifugal load test , lightning strike tests etc., are yet to be completed for EASA certification purpose.

It is hence concluded that NAL used uncertified propeller either by country of manufacture or by the country of test flying. On receipt of the propeller and prior to use on the aircraft it was not declared "Airworthy" by the NAL .

1.18.11 **Discussion and clarification by MT Propellers :**

After the accident the propeller OEM-MT propeller have been discussed along with investigation team and NAL to provide certain clarifications. As per OEM of the propeller the following are their detailed clarifications/explanations:

1) It was informed by MT propeller that the present feathering angle setting (low: 11 deg, high 79 Deg)communicated by MT Propeller to NAL is based on theoretical calculations only. This would be fine-tuned during flight testing. Minimum engine oil pressure needed to start un-feathering the propeller is any thing above zero and min servo oil pressure needed to overcome the feathering spring piston is 80 psi approx.

2) Drop in Np during both relight attempts would occur only with propeller lever pulled back from fully forward position.

3) Flight clearances were given to NAL for 100 flight hrs based on endurance tests. The factory setting was 11 deg for low pitch and 79 deg for feathering. There is no other aircraft fitted with this engine propeller combination of Saras PT2. Min eng oil pressure required to start un-feathering the propeller is above zero.

4). Propeller control lever should be in "Feather" position for engine relighting and only to move forward after attaining the stabilized Ng at flight idle (ie 50 -55%)as per engine manufacturer

5). MT propeller does not have any data on windmilling drag characteristics of Propeller as no testing was done for that and hence not supplied to NAL

6). MT propeller was in constant touch with NAL till the clearance of 100 flight hours of propeller is completed by Fax and Mail, but not for relight procedures.

7) There was no SOP issued by MT Prop to NAL for re-light procedure

8). As per them there can not be any other failure in the propeller/engine which could have led to the situation experienced in the accident except not moving the propeller to feather for relighting procedure.

9). The propeller was not tested for windmilling conditions during design as it is not covered under requirement

10). For the query of When an engine is cut off in flight and propeller remains feathered and Ng is 7% and Np at 1%, the oil pressure at 6psi --what malfunction in the engine propeller system can cause Np to raise continuously from 1% to 100% in about 14 seconds. (the propeller lever is placed in "fine position" towards preparatory for engine re-light) , it is clarified that If a propeller is feathered, it usually should stand still at Vy. The blade angle to get this must be adjusted during the flight tests, which was not completed, because our chief engineer or me was not present at the first flights, because it was decided to come for the in-flight vibration tests, once the full flight envelope was opened, which was not yet completed. Therefore, we could not adjust the feathering angle for a stopped propeller, in particular important for the engine.

11). If the pilot(s) feather the propeller for a single engine test flight, the propeller levers must remain in feather position. Since the propeller lever was moved forward to max rpm (fine pitch), the propeller behaved normal and because of the existing oil pressure from the engine and the rotating propeller (Np) greater than zero %, the propeller unwinded out of feathering, at the beginning slowly because of the low rpm and hence low servo pressure from the propeller governor, but increased the rpm faster with the windmilling reaction until it reached 100% Np (or close to).

12) For why Ng went never to zero % when the condition lever was pulled into fuel cut off must be answered by PWC. According to one of their test pilots, which has a Beech King Air rating, an air start is also possible with the PT6A - engines and some ram air, which means to us that at 130/20KIAS there was enough ram air blowing into the gas generator and turning it at 7% in this condition. Essential for them as the propeller people is, <u>that the rpm lever should have been left in feathering position for the engine restart and only moved forward, once the Ng is stabilized at flight idle (50 - 55 % or whatever is specified for the engine in question).</u> Since they do not know, what basic AFM was used for train the pilots (they recommended the Beech 1900-D because it uses -67 engine) some mistakes should have been avoided. Again, this is what I do not know and therefore, it is hypothetical.

13). For the query, Can this situation given at above, occur on account of gradual increase of oil pressure by the propeller governor gear pump to a value which overcomes the opposing spring force and thus results in propeller unfeathering process to commence. It is explained that This is absolutely correct. As explained above, there was engine oil pressure supplied to the propeller governor (the governor need always pre-pressure at the pump inlet) and while the propeller was turning with increased rpm, the governor pump increased pressure and flow and pumped the propeller out of feathering, first slow, but with decreased pitch faster and faster until the propeller blades reached hydraulic low pitch stop and consequently 100 % Np in windmilling configuration at 130 KIAS, creating a lot of drag, perhaps too much for controlling the aircraft. Help would have been to feather the propeller again in order to reduce the excessive drag from the windmilling propeller. Whether the airplane could be still controlled in such a configuration must be answered by the designers.

14) ***It was also confirmed that as the system behaves normal as seen from data (prop control full forward), there was no malfunction of the propeller system.***

15) For the query, there have been two attempts to relight the engine in air. The first attempt was unsuccessful and the second attempt, though successful, was too late --just a few seconds before the crash. However, it is noted that on both attempts when Ng started building up (and oil pressure increased), the Np has reduced substantially during the same period. In the first attempt, Np reduced from 100% to 83%, and in the second re-light attempt, the Np reduced from 85% to 61 %. What would be the possible explanation for this?

    It is expressed that the increased Ng needed some engine oil for lubrication and therefore, the pre-pressure dropped and consequently the servo pressure from the governor, which will move the blades towards high pitch (counterweights and springs) and a drop of Np will occur.

16) For the query , Is it possible under the earlier condition mentioned above , the propeller will not respond to feather command, it is clarified th at No, not at this speed of 130KIAS. At higher speeds, it could be possible, if the counterweight mass is not high enough. But since the propeller initially feathered, it can be assumed, the system functioned normal. Measuring the servo pressure would have been part of our tests requirements, especially at high speeds up to Vd, but this was not possible because we had to wait until the flight envelop was fully opened.

17) For the query, Before the engine re-stated, when the propeller lever is placed in fi ne position and Np starts raising due to unfeather action (even at low oil pressure) it is expected that the propeller blade angle will not go below the PBA setting. If the wind milling Np raises to approximately 90% and with propeller at PBA, would the di sking drag be so high as to make the aircraft uncontrollable at the speed of 130 knots.

    MT propeller clarified that assuming that the system functions properly, there is no way to get the blade angles below the hydraulic low pitch stop and as mention ed above, there will be a lot of drag from the windmilling propeller at the given pitch setting on one side and perhaps a lot of high thrust (depending on power setting of the running propeller) on the other side. This asymmetric thrust must have been calc ulated by the aircraft designers and defined. Again, this will be a certification criteria and cannot be commented from our side. However, that there is a problem also with the P - 180 aircraft but no detailed facts are available.

18) It was further clarified that, when the governor starts pumping the propeller out of feathering, the process starts slowly and as the blade pitch decreased, the rpm increases until at a certain pitch, the wind catches the blades and the rpm increase is quite rapid. This is similar on any installation, so nothing special. This is why it was recommended recommend to pilots that they should not move the rpm lever all the way to max. rpm at an air-restart, but only slightly over the feather gate in order to avoid over speeding at this very second, when the wind catches the blades.

19) It is also reported that Since Ng is already turning at 7% (producing the engine oil pressure for the governor), it is unclear , why Ng of about 12% cannot be reached by the starter-generator for relighting the engine. If you have also recorded the position of the condition lever and if this was moved forward out of the fuel cut -off position, there is no real reason for not getting the engine started at or around 10,000 feet. According to MT propeller test pilot, Beech allows engine restart at altitudes up to 20,000 feet.

20) As a propeller manufacturer it was reiterated again, the normal procedure for the engine re-start would be with the propeller in feathering.

21) It was firmly told that Since Np and Ng did not stop in feathered configuration with fuel cut-off, the engine produced still oil pressure, high enough to supply the primary governor with engine oil and hence the propeller behaved as designed and required and pumped the propeller out of feathering into low pitch (full fine), resulting in 100% Np, creating a lot of drag.

The only one action to prevent such a situation would have been to keep the propeller in feathering position, which means the propeller control must stay in feathering position. This was not the case and the consequent result is known.

22) It was also explained that CTM and ATM do not play a factor here, because, there was no attempt from the pilot(s) to feather the propeller again. As the engine is a twin shaft turbo prop, the power turbine run freely from the gas generator and how much influence the reversed airflow from the power turbine (driven by the windmilling propeller) on the gas generator has must be answered by PWC. The same is with the influence of the engine starting procedure with a windmilling propeller, because only the gas generator was started, not the power turbine, must be answered by Engine – OEM. If the beta linkage fails for any reason, the beta valve closes and the propeller is turning towards high pitch (20 feathering) because of the lost servo pressure and the leakage in the oil transfer system at the propeller shaft.

1.18.12 Mismatch of CAS on EFIS.

There has been couple of occasions during the sortie mismatch of CAS on two EFIS. This could be due to the presence of NLG blanking the feed to the pitot head **Suitable modifications on Saras aircraft Pitot system or Nose Landing Gear D-Door mechanism (the D-Doors could be flushed when Nose Landing Gear is extended at certain angle of side slip) to be incorporated by NAL** so that there is no mismatch of CAS between the two EFIS in flight.

1.18.13 Clarification by Engine manufacture on relight SOI:

During the deliberations with engine OEM(P&W), it has been replied by them that "Engine is capable of starting with propeller in any operating position and has nothing to do with the propeller" is not in good spirit as an established engine manufacturer having worked with probably all known propeller industries.

As per OEM engine, as far as propeller concerned , the recommended pre air start check procedure for Normal Air Starts is: ***Propeller Control Lever- anywhere in operating range with Note That: propeller feathering is dependent on circumstances and is at the pilot's discretion.*** Fine pitch selection will provide increased gas generator wind milling speed for emergency starts in the remote event of starter failure. Operating range of the propeller pitch is away from feathered position, during the whole flight profile. The note regarding emergency starts further makes the feeling that the fine pitch is a better choice. NAL and ASTE crew have gone strictly by their documents and answers to their TCM.

For the question of "Why only general engine relight SOP procedures were given when it is known that at least some aircraft can have problems with relighting with propeller other-than-feathered position?", P&W replied that the present Specific

Operating Instructions (SOI) has a Note under relight procedure which talks about feathering function which is under pilot's control. **There are installations where start is achieved with propeller out of feather. However, such evaluation is typically done at the end of development testing by design agency to establish the best re-light procedure. It is opined that no relight should take place until aircraft has flown full envelope and aircraft's aerodynamic characteristics fully understood.**

It was ascertained by P&W that ***The present Installation Manual covers 14 engine models which were certified using similar SOI. No issues were reported during relight certification testing***.

However NAL reported that No clue was arrived till the accident day that a turboprop with free turbine configuration, **the propeller lever should be in feathered position to avoid disk Drag and abnormal behavior of the propeller etc., recorded in the accident flight.** Since NAL was concentrating only on relighting of engine in the air, the propeller OEM was not consulted at any stage prior to finalisation of the relight procedure**.**

As an approved Design organisation this should have been the hindmost sight of whole Saras project team and MC. However they failed in this aspect.

For the likely cause(s) of failure of first relight attempt it has been commented by P&W that From the telemetry there is fuel flow indicated before the engine re-Iight is initiated. If this is true then it is possible that the igniters became 'wet' with fuel and did not provide the required ignition source during the first re-light attempt. However, this is not considered as likely as the second re-light attempt was successful with no exceedance or rapid rise of ITT during this relight. It is opined by P&W that a more likely scenario is that the re-light procedure on the first attempt was not completed .The start sequence appears to be completed on the second attempt. This resulted in a normal air re-start with all parameters being as expected.

It is also now clarified by engine OEM- P&W for foot note of SOI "Relight normally should be obtained within 10 secs". It means that it should be obtained within 10 secs of Ignition ON and fuel ON command. Please note that it is not related to the time for an engine to reach idle speed. 50% threshold is recommended min Ng to cut-off starter motor during the start, after that engine Ng will keep accelerating till normal idle is reached and start sequence is completed.

1.18.14 STATUS OF TELEMETRY SYSTEM USED FOR SARAS FLIGHT TRIALS

The telemetry ground station being used for the Saras Program is stationed at ASTE and comprises of RF system (tracking and proximity antenna, receivers and demodulator) provided by ASTE and PCM decommutation system and PC based monitoring stations, video camera, LAN and H/F R/T sets provided by C-CADD. The ranges obtained with the telemetry system are generally in the vicinity of 60 km with the main tracking antenna and 5-10 km with the proximity antenna, which is considered quite poor compared to the ranges close to 250 km provided by the telemetry system at HAL Flight Test Centre being used for LCA and IJT. Factors which affect the telemetry range are the receiver chain on ground, telemetry transmitter being used and the antenna configuration on the a/c as well as on ground.

On the day of accident it was reported that the Autotracking function of the telemetry system was unserviceable and elevation control was not available. The tracking in azimuth was being done manually by monitoring the signal strength and aircraft position. The monitoring group is stationed along with Flight Director in the 2nd floor while tracking group is stationed in 3rd floor (Rx room). When aircraft taxies out the aircraft is tracked closely by the antenna by maximizing Rx signal strength. The control unit has also that AZ / EL display on the panel. Whenever the tracking engineer loses the position of aircraft in flight, he seeks the help of Flight Director to get the aircraft location.

The ground telemetry station has the following weak areas: -

(a) Tracking unit and antenna control unit (ACU) of the RF system do not have any redundancy. The elevation control of ACU was unserviceable. Auto tracking was possible only in azimuth.

(b) Though two telemetry receivers were available, the RF input to the receivers was given independently from tracking antenna and proximity antenna, and automatic source selection was not available.

(c) There was only one demodulator in the telemetry chain and its failure would result in a complete link breakdown.

From the discussions held with the various members of the telemetry group it is inferred that the height and distance for carrying out various critical test points was governed largely by the coverage area of the telemetry system. During the sortie there were frequent link breaks, which increased towards the later part. This probably affected the proper monitoring of the parameters by the telemetry group. Further, due to the absence of any R/T calls from the crew towards the end, there was a total lack of situational awareness among the telemetry group. Availability of a hot mike system in the cockpit would have helped the test director to be in constant communication touch with the test crew. This would especially be helpful in high workload conditions wherein a pilot may not have the time to press the PTT to transmit.

There is a telemetry link break every time during engine start up. This is probably due to the fact that the telemetry transmitter operates in the voltage range of 25 -32 volts and during startup the bus voltage dips below 25 V. As the voltage is restored the transmission restarts. Hence, it is suspected that the two telemetry link breaks of approx 20 sec during relight attempts prior to the accident are due to this reason.

In view of the above, the following is to be considered for the telemetry system: -

(a) The ground telemetry tracking and RF system should be replaced / upgraded with an advanced system with adequate redundancies.

(b) The telemetry transmitter in the a/c should be replaced with a better transmitter, which would be able to give better ranges.

(c) The antenna configuration on the a/c should be optimized in order to give better coverage in all attitudes and directions.

(d) A hot mike system should be introduced in the cockpit in order to give continues hands free transmission of all communication between the crew as well as with the telemetry ground station.

(e) Recording facility should be provided in the telemetry station for the R/T communication between the aircraft and telemetry station.

(f) Necessary modification may be carried out on the aircraft to isolate the telemetry and FTI system from the main bus bar during an engine start up and put it on a standby battery in order to avoid loss of critical data during engine start up.

1.18.15 Emergency Locator Transmitter

ISRO Satellite Centre, Peenya, Bangalore did not receive signal from the ELT fitted on the accident aircraft on 06.03.2009 after the accident. Also during the examination of the wreckage at site the ELT unit was not traceable. Only six batteries of the ELT unit were recovered from the wreckage site in burnt out condition. ELT could have been burnt in post impact fire as its housing is not fire proof. ELT antenna was also found disconnected.

1.18.16 Statements, collection of evidences and investigation:

DGCA, New Delhi vide order No. AV15013/1/2009-AS dated 13-03-2009, apart from appointing inspector of accidents who was also investigator-in-charge, the following investigation groups were also formed to provide input to the inspector of accidents.

1. Operations group
2. Engineering group
3. Wreckage investigation group
4. Recorder group
5. Medical group

NAL provided all the technical assistance to the group members.

The inputs provided by the various investigation group have been taken into consideration and is carefully studied with various other evidences of the inputs.
Also Pratt & Whitney, Canada (Engine OEM), MT Propeller (Propeller OEM) and NAL (Aircraft Designer) had been discussed on face-to-face method and by e.mail/fax etc. All their valid views and comments/clarifications are also taken while finalizing the investigation report.

1.19 Useful or effective investigation techniques :
Nil

2. A N A L Y S I S

2.1 Serviceability of the aircraft

The SARAS PT-2 aircraft VT-XRM is an experimental aircraft under development by M/s National Aerospace Laboratories, Bangalore. The Certificate of Registration issued on 5.12.2006 bears Cert. No. 3460, under category A,. The aircraft serial number is SP002 and the year of manufacture is 2006. The aircraft is fitted with certified two Pratt & Whitney, Canada ,PT6A-67A Turboprop engine . However MT propeller fitted is yet to be certified. The weight schedule was not yet finalized. However the restriction was fixed for the 49th i.e the accident test flight as in test schedule. Aircraft is yet to be issued with C of A. On 6.3.2009 aircraft was inspected by the airframe, engine, avionics, instruments, electrical system inspectors approved by DGCA as per daily inspection/preflight/engine ground run schedule. Also telemetry serviceability was reported signed by separate person as per DI. No snag was reported. Aircraft was certified airworthy for test flight 49 in the form "daily inspection and clearance for Test flight-Saras aircraft" by concerned DGCA approved inspectors. Aircraft was also accepted by the pilots in the form IAFF(T) 700D. Aircraft production and maintenance documents did not reveal any significant findings except reported high control forces, flap operation issues . From the aircraft flight test records and post flight pilot reports the following observations are noted: Rudder Force feel inadequate , rudder response sluggish, During Asymmetric Torque handling, Rudder Force reported heavy, Poor Aircraft controllability during approach, flare out & touchdown and Exceedance of ITT & Ng reported high at high Torque settings at high altitude. In general, there are Controllability issues and high control forces exist. 50 hrs scheduled servicing was carried out after 48th flight and the engine ground run up was given . All the onboard systems were found satisfactory. Auto-feather engine cut-off was also checked on both engines.

Since the aircraft is under developmental stage NAL informed the above design issues of high control forces are being studied continuously for better design evaluation . There is no other known major maintenance defects or structural defects, which were left unattended.

2.2 Inflight procedures , Role of the crew and Cockpit emergency exit provision

NAL clarified that P1 is the Captain of the aircraft. As per ASTE standard operating procedure, FTE reads out the command/ test point/ check list and P1 or P2 as pre-decided by P1 will execute the action. But it was not documented properly anywhere in the relight procedures. Saras PT2 quick reference handbook mention only challenge method, but Standard Aviation practice is "challenge and response" method. Further it does not speak clearly that at each and every stage of flight who challenges and who responses. CVR also revealed that there is no proper crew co-ordination in the cockpit in handling the controls and achieving the action during the accident flight because of lack of cockpit checklist procedures.

The values/ limits of engine oil pressure and ITT that are to be monitored during engine relight exercise is not included in the detailed test points and NAL should include in the future test schedule.

Aircraft records revealed that aircraft was placed with 3 parachutes for emergency evacuation purpose. During wreckage inspection this was also confirmed. Howev er, cockpit checklist procedure does not include checks for parachutes.

At about 5 mins prior to crash , when something abnormal behavior of the aircraft was felt by the pilots Co-pilot was hilariously telling commander "road is there for emergency" and also advised FTE for placing readiness of parachute for emergency. *These parachutes were not used by the pilots/FTE in the accident. It is not known that whether the pilots are trained to operate the parachutes in case of exigencies. Records provided to the investigation is insufficient to show their training on parachutes exercise.*

2.3 Procedural Lapse of project team and Management committee (MC) .

(a) The relight SOP was derived based on a SOI issued by the engine manufacturer P&WC, which did not take the airframe-engine integration aspects into consideration. These SOIs are issued to all P&WC operators (PT6A -67A) worldwide and does not take into account the fact that SARAS was an experimental a/c. The copy of SOI Manual (Part No. 3037028 Revised 11 July 2001) issued from P&WC is attached in attachment folder. The relight document was only vetted and approved by ASTE on 6th Mar 09 even though the trial planner was remarked by CRPO,IAF on 22 nd Jan 2009. ***This document was not sent to the engine and p ropeller OEMs i.e. M/s P&W,C and M/s MT Propellers respectively for getting their comments*** and guidance.

(b) Prior to the conduct of the Relight Tests, NAL had sought certain clarifications from PW&C on 30th Dec 08, on the exact procedure to be follo wed for a relight. The reply was received after a reminder on 26th Feb 09 and it stated that the procedure laid down in the SOI should be followed. The SOI mentions that prop cont rol lever can be in any position in the entire operating range of the lever during a relight. There is also a footnote mentioning that ***"propeller feathering is dependent on circumstances and is at the pilot's discretion.*** **Fine pitch selection will provide increased Gas Generator (Ng) windmilling speeds for emergency starts in the remote event of the starter failure".**

As a well established Aviation engine industry , This lacks the clarity from Engine OEM considering the aircraft being experimental aircraft and NAL was in constant touch with them. P&W should have given clear cut in struction whether to keep the propeller in "feather" or "Fine".

As per OEM of propeller-MTP during the meeting with DGCA investigation team, the **<u>Prop Lever should ideally been kept in FEATHER position</u>** during relight.

In all this time there has been no interaction between NAL and the propeller manufacturer (MT Prop Germany) regarding the formulation of the relight procedure as the NAL and ASTE attention was only on engine relighting ie., presumed propeller having no role to play.

It is hence clear that there is a Lapse of project team and Management Committee (MC) in finalizing the correct procedure for engine relight procedure in flight.

2.4. The confusing instruction and guidance of Engine OEM -Pratt & Whitney, Canada :

Investigation team felt the incorrect position of the Prop lever “FINE” for relighting procedure in a way might have contributed to some extent to the accident. Considering that this was an experimental prototype aircraft with a certified P&WC engine, and uncertified MT propeller, the Engine OEM cannot absolve themselves of the responsibility of giving critical information which could adversely affect the safety of aircraft during the relight. Also, there was no caution provided by the OEM in the SOI in this regard. Considering the very definitive and clear instructions by P&WC to follow the procedure as laid down in the SOI, which specifies the position of the Prop lever to any where in the operating range, the trial team and designers could have been possibly misled by this information and have not realized the repercussions resulting from the placement of the prop lever in the “Fine” position **As a well established Aviation engine industry , This lacks the clarity from Engine OEM considering the aircraft being experimental aircraft and NAL was in constant touch with them. P&W should have given clear cut instruction whether to keep the propeller in “feather” or “Fine”for engine relight in air.** However the P&W still maintains the instructions given in SOI.

It is strongly felt that Indian-Aviation regulatory authority ie DGCA should take up the issue to Pratt & Whitney, Canada through the regulatory body of their country.

2.5 Engine Relight procedures-Revision:

It has been observed from the records and statements that pre-flight briefing meeting was done in the afternoon of 6.3.2009 prior to the test flight 49 in which NAL and ASTE took part of it . This meeting covered SOP for the flight, aircraft serviceability, configuration limits, test points, and test sequence etc as per the test program. Flight crew were also present. It is also understood that at the end of the briefing the pilots were specifically told by FTD that in case of any problem during the relight attempt, the engine should be switched off, propeller feathered and single engine landing executed. No effort should be made to try the relight at second time. This was also repeated to them orally near the aircraft before the crew got into the aircraft.

However the above discussion was nowhere recorded or documented in the relight test procedure.

Saras specific intentional engine shut down and relight procedure has been studied and it revealed some of the following salient points:

1. There is no mentioning of role responsibility of the individual crew, of who will check what and who will act and respond etc.,
2. Relight procedure check list or its note at the bottom does not mention How much should be engine oil pressure to Check. Similarly no mentioning of action on “Engine Start Switch” only mention about Start Mode Switch.
3. Propeller control lever -- fine .(as per engine OEM, any where in the operating range). But not cross checked with MT propeller.
4. Since this is the first relight test procedure nowhere cautioned about prohibition of 2nd relight attempt and that too at low level.
5. No altitude restriction was also highlighted for relighting.

It has been reported by NAL that adequate practice of re -light drill was done by the test crew on ground. Dummy drills in the cockpit were also carried. But it is not clear that whether these drills included the simulation of relighting in air conditions. No records were made available to the investigation group.

In view of the above complete system of test procedure including Engine shutdown and relight procedures is to be revised taking into consideration of all the factors mentioned here or elsewhere in the report.

2.6 Role of Auxiliary Battery in relighting operation:

It has been doubted whether Auxiliary battery in "OFF" position played any role in non-restarting of the engine. From the detailed study of electrical system architecture of Saras PT2 aircraft the following three condition under that Functioning of the engine starting system involved are evaluated and are as follows:

It was reported by NAL that, in view of the above design condition architecture:

- The cross start in air or on ground when the auxiliary battery switch is ON position is always successful.
- On ground, Auxiliary battery must be selected 'ON' as given in the existing procedure (Vol. 28, TB-04, Quick Reference Handbook, page 4–11, dated March 2007).
- The cross start in air when the auxiliary battery switch in OFF or in CHARGE position will also be successful.

In view of the above it is inferred by NAL that

i) Auxiliary battery is not required for relight in air.

ii) Re-light in air will be successful without auxiliary battery.

iii) Three internal/cross starts/ air starts are possible with the main battery.

iv) A time gap of 3 minutes for ground start and 2 minutes for air start to be obse rved between successive attempts to start (on account of limitations of starter contactor unit).

Further Electrical, Battery capacitance records verified and found both Main & auxiliary batteries were periodically Capacity tested and recharged and are val id on the day of accident.

However, it is not understood the above explanation of NAL when Auxiliary battery is not required for engine start in air, why and how it has been included for the ground start when main battery itself is sufficient for grou nd start. It is hence felt that NAL should come out with clear cut procedure for AUX. battery for engine start (internal) or increasing the capacity of Main battery is to be explored and hence removal of Aux.battery from the electrical architecture.

2.7 Review Of Starting And Electrical System Of Saras Aircraft:

1. After the accident a lot of Discussions were held between NAL design team and DGCA investigation committee members regarding the function of aux. battery during cross start on ground and in flight. The following points were discussed. The auxiliary

battery selection switch position and the bus arrangement were explained. With the auxiliary battery switch in any one of the following positions: ON / OFF / CHARGE position. The plausible reasons for engine not starting during the first relight attempt could be;

(a) Aux battery not on line.
(b) Start mode switch selected to motor position.
(c) Fuel mixture rich during relight.

2. Functioning of the electrical and starting system, under the above-mentioned cases is explained as under;

(i). <u>Case (a) Aux. battery switch in 'OFF' position</u>
The aux battery is isolated from the rest of bus bars. Hence no current would be drawn from the Aux. battery. Auxiliary bus (which is supplying power to GC PU during start operation) is connected to the emergency bus and also to the main bus which is being supplied by the live generator. During the cross start in air, a dip in the auxiliary bus bar voltage is expected. In air start, the voltage dip is likely to be less than that during cross start on ground. The air start could be successful because of wind milling effect.

(ii) <u>Case (b) Aux battery switch the 'ON' position</u>

The aux battery is connected to auxiliary busbar and it supplies current (discharge) to all loads connected to that bus bar. In this case, the auxiliary bus is isolated from the main and the emergency bus bars. During the cross start in air / on ground the aux battery voltage is close to 24 volts for all the loads connected to the aux bus bar. However, dip in aux battery voltage due to motoring action would not arise. Hence, relight would be successful in air.

(iii) <u>Case (c) Aux battery switch in 'CHARGE' position</u>

The aux battery is connected to the main bus bar and charged by the generator. Aux bus bar is connected to the emergency bus and also to the main bus which is supplied by the live generator. During cross start in air, a dip in voltage is expected in the aux. bus bar. The dip in voltage during air start would be less than that on ground start and relighting could be successful (for reasons explained in case (a) above).

3**. View of Design Team and Investigation group Members:**

(i) The cross start in air or on ground when the aux battery switch is 'ON' position is always successful. **<u>Hence recommended for all air starts</u>. But it is not required to be done so, as the main battery is sufficient to take the load as already other generator was working during cross start.**

(ii) The cross start in air when the aux battery switch in OFF or in CHARGE position could be successful because of the wind milling effect. However, it is felt that the cross start with aux battery in OFF / CHARGE position needs to be tested on the ground by simulating 13% Ng wind milling effect, to confirm (ii) above **<u>without the effect of dynamics in the air</u>**.

4. While perusing the flight data it was quite apparent that they were two engine relight attempts carried out by the crew on 06th Mar 09 during the course of the sortie. The first attempt was initiated at ~ 7200 ft AMSL and the other at ~ 5100 ft AMSL. It is also evident that the first relight attempt was unsuccessful however during the second attempt while engine parameters were approaching close to idle conditions, the aircraft crashed into the ground. Hence between the two relight attempts possibly some switch selections were made by the crew which resulted in the successful relight in the second attempt. The committee also discussed all the possible reasons for the unsuccessful relight in air during the first attempt at an approx height of 7200 ft AMSL.

(i) It could be possible that the **start mode selector switch was in the 'Motor' position instead of 'Start'. T**his condition would result in dry motoring only (no ignition). This would also increase generator current by about 200 A. This is also corroborated by the data wherein Ng increases to 25% and then drops down gradually. The start switch could have been unintentionally deflected to 'Motor' position by any of the flight crew member during the ensuing dive and unsettling of crew in the cockpit (due to excessive yaw rate, sharp pitch down and effect of negative 'g') caused due to spin up of propeller RPM to ~ 100%..**Moreover there is no mentioning of "Engine Start switch – to Start" in the CVR during this situation. It is quite possible engine was not started at all ie., ignition not started. This is clear from the no minus load current and drop in generator voltage.**

(ii) The aux **battery switch may have been selected to ON position** during the second relight. The short break (about 22 sec) in telemetry data do not permit to check out the discharge current of aux battery which returns to normal state during this break in telemetry link. **However no mentioning of it in CVR . Hence this can be ruled out.**

(iii) The cause of the unsuccessful relight could have been **because of the rich mixture.** The fact is that the fuel condition lever was not moved during the two relight attempts and there has been a constant fuel flow of 30 kg / h. As the conditions with respect to fuel condition remained identical during the two relight attempts, hence, **this factor can be ruled out, as the cause for engine not starting in the first attempt**

5. Inference: The successful second relight confirms that functioning of the starting and ignition system in the aircraft was normal. There is no mention of the selection of aux battery to 'ON' position during the air start in the relight document especially prepared by the NAL Engine team for the sortie, indicating no requirement of the same. Also other designers and ASTE Flight Crew were not very clear on this aspect whether aux battery is required to be put 'ON' for cross start in air except designers from Electrical Group.

Hence, either wrong selection of mode switch or non pressing of Engine start switch to start the engine during the first relight attempt is the most probable cause for engine not relight in the first attempt.

It is also inferred that NAL should increase the capacity of main Battery and removing the auxiliary battery and review the electrical system of the aircraft

2.8 Probable Cause of the First Failed Relight:

After the aircraft had gone into a sudden dive and abnormal attitude, it lost height from 9000 ft to 7000 ft and briefly stabilized. At this point a relight was attempted.

However, the relight was not successful. It was seen from the FDR data that the Ng had risen upto 26% RPM and then wound down. The FDR data did not have the ITT or fuel flow. However, by interpolating the telemetry data du ring the link break, it appears that there was no rise in ITT or fuel flow. The reason for the engine not lighting up in the first attempt could be one of the following: -

(a) Wrong selection of the MODE SWITCH to MOTOR instead of START. From the transcript, at time 00:31:47, it is seen that as there is a call for checking the Start mode switch in Start position, the a/c suddenly yaws and dips viciously (from the pilot's reaction at 00:31:57). If during this time the pilot's hand is on the Mode Switch, there is a possibility that accidentally the switch might have moved to the MOTOR position, thereby resulting in a false start. **From the FDR data, it is seen during this period that the Ng has risen to about 25% rpm, stabilized for about 12 -14 sec and then again wound down, which may be indicative of a motoring action without light up. Moreover there is no mentioning of "Engine Start switch – to Start" in the CVR during this situation. It is quite possible engine was not started at all ie., ignition not started. This is clear from the no minus load current and drop in generator voltage. And also at last moment during second attempt crew was calling for engine start. This indicates LH engine was yet to be started.**

(b) **Aux Battery not changed over to ON from CHAR GE position**. This is a mandatory requirement during ground start. But not for on air start. However , in air the loads are expected to be lower due to wind milling and hence the engine may or may not start with Aux Bat in 'Charge" position. This is a man datory requirement during ground start. But not for on air start. The electrical system architecture however revealed that Auxiliary battery is not required for relight in air. Re -light in air will be successful without auxiliary battery. Three internal/c ross starts/ air starts are possible with the main battery with time difference of 2 minutes in air for second start and 3 minutes in ground. So irrespective of Auxiliary battery position engine should start provided main battery is healthy.

(c) The Fuel Condition lever was not selected ON when the Ng had crossed 13% rpm.

From the CVR transcript, it emerges that the crew was in preparation for the relight and about to set the Start Mode switch to START position when the a/c went out of control. Subsequently, after stabilizing at about 7000 ft altitude, they attempted to start the engine by selecting Start mode Switch to the START . but no conformity of that. From the FDR data, it is seen during this period that the Ng has risen to about 25% rpm, stabilized for about 12-14 sec and then again wound down. The associated parameters of fuel flow and ITT are not available in the FDR and due to a break in telemetry link during the start attempt; the same data is not available from telemetry also during this period. By interpolating the data before and after the link loss, it appears that there has been no change in the ITT and Fuel Flow during this period, indicating a dry crank, which can happen if the Fuel Conditioning Lever is not moved forward. Also, there is no call given by the pilots also in the CVR transcript regarding operation of the fuel lever. However, since the fuel -conditioning lever has not been instrumented, this cannot be corroborated.

(e) From the telemetry data, it is seen that there is an increas e in fuel flow from 6 kg to 35 kg just before the unusual situation took place. On correlating this with the CVR transcript, this point matches with the call of 'BOOSTER PUMP ON' given by the pilot.. Thereafter, the fuel flow has been steady at this value with minor variations till the second relight attempt, after which it has risen due to successful relight just before the crash. However, the reason for this rise in fuel flow could not be established as the fuel flow will start only when Fuel Condition Le ver is moved forward, for which there was no call given by the pilot. It is possible that the FCL was already in slightly forward position which allowed the fuel to flow. This fuel flow could have resulted in a wet start in the first attempt. However, the condition was the same even during the second relight attempt and should have resulted in a wet start again. **This needs to be reviewed in detail by the designer.**

2.9 Control forces and controllability issues:

Saras is being a prototype aircraft wherein the control forces could be marginally higher than the prescribed values of FAR-25. Fine tuning of control forces in a prototype aircraft is a constant evolving phenomenon. In a prototype, optimization of control forces (& controllability aspects) is a process of development through flight testing and progressive design changes are made to meet the FAR requirements. A number of modifications to the control surfaces to meet these requirements are to be continuously assessed and are planned to be flight tested in due course. During development of a prototype, such a process is acceptable, unless perceived as unduly higher or abnormal by the Test Crew. In which case, correction should be made prior to further testing.

FAR 25.143,sub-section (d) stipulates the max control forces permitted for controllability and maneuverability. As per that **permissible limit of the various control forces are given in a tabulated form for conventional wheel type controls during the testing.**

Forces in pounds applied to the control wheel or the rudder pedals	**pitch**	**roll**	**yaw**
For short term application for pitch and roll control-two hands available for control	**75**	**50**	
For short term application for pitch and roll control- one hand available for control	**50**	**25**	
For short term application for yaw control			**150**
For long term application	**10**	**5**	**20**

As it has emerged from the CVR transcript of the 49th flight, the pilots have commented on the excessive control forces experienced during the asymmetric torque conditions in OEI simulation as well as when the left engine was actually switched off. The forces on the rudder were very high and it would have been impossible to fly the aircraft when there is a sudden increase in the control forces both in yaw and roll channel.

Aircraft post flight pilot report records also revealed most of the time ineffectiveness or sluggishness of control forces and high forces were experienced by pilots. Scrutiny of aircraft test records and various reports by Engineering team revealed that Rudder Force feel inadequate in flight no.6. During Asymmetric Torque handling, Rudder

Force reported heavy in flight 36. Poor Aircraft controllability during approach, flare out & touchdown was also reported in flight no.47.

It is hence established that there are unresolved Controllability issues and high control forces are persisting beyond the permissible limit of controllability on the accident flight.

Investigation also established that

1. The rudder pedal and aileron forces during asymmetric torque conditions have been very high and a fair amount of compensation was required to maintain the aircraft in level flight condition. This has been brought out by the crew time and again during the flight as has emerged from the CVR transcript of the 49th flight, wherein the pilots have commented on the lack of control margins during the asymmetric torque conditions in OEI simulation as well as when the left engine was actually switched off.

2. Due to Rudder Stretch, the available full rudder deflection was expected to be ~22 degrees instead of 30 degrees. This aspect needs to be looked into as this could have affected the safe recovery of aircraft. This could have been one of the critical factors which affected the recovery of the aircraft during the critical phase of flight prior to the crash.

3. The control harmony requires aileron to be least control force for piloting. However it can be seen that the aileron forces were also very high after Np >60%The control forces experienced by the pilots during the critical phase, when the Np_L shot up to 100%, were extremely high and reached values as high as 75-90 kgf in rudder pedal and 65-70Kgf in aileron. Under such high sustained forces, it would be almost impossible for the pilot to control the a/c. These forces are also well beyond the permissible limits as prescribed in the above said FAR 25.143,sub-section (d)

4. The control calibration by the pilots with telemetry prior to take off shows that a severe hysterisis existed in the rudder which could result in a reduction in the rudder range of movement in one direction. This data needs further examination

It is hence clear that NAL as a designer failed to design suitable control surfaces to attain the prescribed limit of control forces as prescribed in the FAR 25.143,sub-section (d) even after 48th test flight and prior to formulating the engine relight procedures in air.

Design improvement on control surfaces is hence required to be done such that even for flight testing purpose the magnitude of forces should be such that it is possible by the flight crew to manually fly the aircraft without getting into fatigue level.

Similarly NAL should not look for the Maximum limit provided in the said FAR 25. Rather it should consult other aircraft manufacturing industries to explore the convenient limit of control forces for easy controllability and maneuverability by the pilots. This needs to be ensured by NAL on all prototypes.

2.10 **Propeller Pitch Change Mechanism**.

Initially, it appeared that there was a malfunction of the pitch change mechanism of the propeller, due to which the pitch of the propeller had changed from FEATHER to FINE after the Propeller lever was moved forward to fully Fine position as a preparatory step towards relighting the engine. It was assumed that the pitch change mechanism operated at pressures above 60 psi, which would happen only after the engine had relighted and adequate oil pressure had built up in the engine oil system. However, after discussions with the propeller manufacturer M/s MT Propellers, Germany it emerged that the behaviour of the propeller was **absolutely normal and as expected under the given conditions and selection of propeller control lever**. In case there was any residual oil pressure in the supply line and the propeller was windmilling at that instant, then selection of the Prop lever out of FEATHER position would release this pressure to the inlet of the propeller governor, which would amplify this pressure and supply it to the feathering spring. Once the oil pressure builds up to an extent where it can overcome the spring force, the propeller would unfeather and gradually move towards FINE position till it reached the low pitch stop. At approximately 35-40 deg of blade angle, the wind forces (due to the dynamics of air speed) would start acting on the blades thereby resulting in a rapid movement towards FULLY FINE position and rapid rise in the propeller rpm. ***As inferred from the telemetry and FDR data, this is exactly what had happened and had resulted in excessive drag due to the flat disk effect of the propeller wind milling at 100% rpm***.

Prop OEM further reiterated that as a matter of normal practice, the relight should be done with propeller in feathered condition and the pitch lever should be moved to FINE only after successful relight and engine reaching the flight idle parameters

2.11 Propeller Windmilling drag :

No data has been provided by MT propeller as it is not available with them.

Evaluation of abnormal drag from the propeller in the windmilling condition neither done by NAL nor by MT propeller before cleared for 100 hrs flight operation. There was also no wind tunnel testing done for assessing the normal as well abnormal behavior of propeller under various conditions including wind-milling situations and propeller blade below PBA limit leading to Propeller windmilling drag or abnormal Disk drag.

This drag could be due to spinning propeller at pitch angle well below primary blade angle(PBA ie 11 deg) and lead to the aircraft to behave the way it had in the accident flight where the propeller RPM went to 100% with engine switched off condition.

It was clarified by NAL that till PBA, drag due to propeller is not excessive. They said that it was experienced by them many times PBA was reached in flight, particularly when engine was in flight idle and no adverse conditions were reported by their crew. Therefore it could be possible that most probably the blade pitch has gone below PBA. However there are no recorded documents made available to prove the above claim of NAL.

It was also clarified by NAL that as a part of engine-relight procedure given by P&WC (Specific Operating Instructions, Model PT6A-67A, Part No. 3037028 dated 11.07.2001 and Technical Coordination Memo No. PWC065 dated 02.05.2008), propeller lever was moved to fine pitch setting. The propeller RPM has reached more than 90% before an attempt was made at relight. This wind milling condition of the propeller resulted in significantly higher drag, resulting in increased yaw and side slip. Sideslip always leads to pitch down moment, which can be substantiated by existing wind tunnel results on SARAS. In the usual range of sideslip encountered in flight, the resulting pitch down moment can be controlled with ease using normal elevator action . The rapid increase of sideslip to excessively high value (~30 deg) in 3 seconds could have led to severe initial nose down pitching.

The above aspects must be studied in detail with wind tunnel tests or shop tests or both and other relevant procedures whichever is most appropriate, including trial assessment test prior to the next flight of Saras project.

2.12 CONDITION UNDER WHICH PROPELLER EXCEED 100% RPM

Distinction is made between Engine oil pressure and servo oil pressure. Engine oil pressure is measured at oil sump whereas servo pressure exists at Servo pump (positive pressure pump: in Saras installation it is a gear pump which will keep boosting pressure that is being fed to it.). Servo pump is directly connected to propeller shaft through gearing. Therefore, if propeller shaft is rotating, servo pump gears will be rotating.

Propeller reaching High RPM from feathering:

Situation 1: Initial state taken is when aircraft was flying in controlled level flight condition with LH engine shutdown, propeller in feathered condition (residual RPM ~ 2% implying approximately 35 RPM), Engine oil pressure ~6 psi. This implies that oil will be flowing to propeller system and on the way, it will go through the servo pump. The servo pump pressure is rotating because propeller shaft is rotating but its pressure boost has no effect, since the oil flow path is open to sump. Hence, no pressure build - up takes place.

Situation 2: Now the situation is taken when aircraft was flying in controlled level flight condition with LH engine shutdown, propeller in feathered condition (residual RPM ~ 2% implying approximately 35 RPM), Engine oil pressure ~6 psi and the propeller lever is shifted to FINE condition (flight FINE pitch, this was in accordance with procedure published by engine OEM). Non-zero engine oil pressure (~6 psi) means that there is small but positive pressure being applied to input side of servo pressure pump. Propeller lever in FINE condition is a condition that enables the propeller to come to/remain in FINE pitch condition. In this setting, servo pump is rotating slowly and increasing the pressure of oil going to propeller housing with each rotation. This pressure rise per rotation is very low in the beginning. The oil with this increased pressure is now going to propeller housing and not being dumped to oil sump (which was happening in situation (1). Therefore, propeller feathering spring will feel increased oil pressure and start compressing. Consequently, propeller blade pitch will tend to reduce and its RPM will tend to increase. (This is based on information provided by propeller manufacturer during accident investigation). If this process continues, propeller RPM increase will take place monotonically. At certain stage of blade pitch angle, the 'wind catches the blade' (OEM's phrase; within this time engine should be started-up) and takes it quickly to higher RPM. Beyond the stage of 'wind catching the blades', propeller will be in truly wind milling condition and start producing increasing drag (due to low blade pitch angle).

If the engine does not start-up, propeller is likely to go on increasing RPM till some other mechanism controls it. Gradual RPM increase would be controlled by the propeller governor at 100% RPM. But if RPM increases faster than response time of propeller governor, over-speed governor (OSG) would come into play for RPM>106%. In case of Saras, OSG did function as expected and contained propeller RPM to 109% and brought it to lower value also.

Evaluation of fail-safe engine relights procedure in air – Saras aircraft

After the unfortunate accident on 'SARAS' PT2 prototype aircraft, extensive studies were done on what could be a fail safe engine relight procedure in air for 'SARAS' aircraft which employs a free turbine engine. Detailed discussions were also held with both Pratt and Whitney, Canada (P&W), the engine manufacturer, as well as with MT Propeller, Germany, the propeller manufacturer. The following paragraph outlines such a procedure .

Single Shaft Turbo-Prop Vs Free Turbine Engine

There is a subtle difference between single shaft turboprops (used in aircraft like Avro HS-748, Dornier-228. etc.,) and free turbine engine configuration (SARAS). In the case of former, the gas generator and propeller turbines are mechanically coupled to a single shaft. Therefore, whether engine relight is starter assisted or wind milling started, it is a recommended practice to put the propeller in 'un -feather' position. This has two advantages as below

a)In case of starter assist, it prevents a very high rotational drag on the starter. If on the other hand, the propellers are kept feathered, it may lead to starter/generator burn of the two engines.
b)In case of wind milling start, it improves the wind milling efficiency (higher RPM) due to finer pitch of the propeller.

Also, since all rotating masses are on single shaft, inertia is high and when fine pitch is selected, the propeller does not go to high disking drag position immediately, allowing sufficient time for the pilot to relight. For this reason, there is a separate unfeathering pump in single shaft engine configurations.

However, in the free turbine configuration (which is the case with 'SARAS'), the propeller turbine and gas generator turbine are only aerodynamically coupled and as a result, the inertia of the propeller- turbine combination is relatively low. Therefore, if the fine pitch or 'unfeather' mode is selected, there is a tendency to go very easily to high disking drag situation. To avoid this and also due to the fact that the propeller is not directly driven by the starter, it is recommended that engine relight in flight be done with propeller in 'feathering' mode only. Also, starter assist is mandatory for almost the whole of flight envelope except in a very small region at the high speed end of the flight envelop where it is optional.

Propeller Feathering Operation

Following points may be noted before the operation is studied in detail:

- The oil which operates the propeller system is the same that lubricates and cools the main engine
- In the engine oil system, there is an engine driven oil gear pump
- The propeller shaft has a separate gear pump which takes in oil from the engine gear pump
- Both the gear pumps are of positive displacement type
- As long as pressure at inlet to propeller gear pump is above zero and wind milling is taking place, it is possible that oil pressure at the outlet from this pump builds up over a period of time even at very low RPM of the propeller, when selected to fine position. This result in a closed system scenario (because the oil dumping ceases), a condition that happens when we select `fine' or "unfeather", position, the resulting oil pressure goes to a very high value sufficient to unfeather the propeller.

In a normal operation, the propeller servo pressure acts on one side of the servo piston against the mechanical spring force. This adjusts the pitch of the propeller for various engine demands, by keeping the propeller speed constant.

The feathering of propeller is done through operation of the feathering valve, <u>which is a pilot action</u>, when he moves the propeller lever to feathering position. The dump valve opens the hydraulic system to dump and pressure on the servo piston falls to dump pressure value and consequently no oil pressure build up takes place in the propeller system.

The spring force (when feathered position is selected by the pilot) drives the propeller to feathering mode and it remains there until the feathering valve is operated again.

The following points may be noted which can ensure fail safe engine relight operation in air, once the propeller is in 'feathering' mode.

a) The feathering valve is a purely mechanical valve with a plunger and a spring; it is pilot operated and even if its spring fails, it will remain in the dump position, which is safe.
b) As long as the gas generator keeps running (due to wind milling) even with Ng at low RPM of 6 to 8 percent, there will be some positive pressure at inlet to the propeller pump; but when propeller is selected to feathering mode, oil pressure will reach the value of dump pressure and hence can never reach a value sufficient to un -feather the propeller
c) The spring mechanism in the SARAS propeller servo system comprises of two co - axial springs. This feature has been incorporated to ensure safe operation even if one of the springs fails. Discussions with MT propeller have revealed that the reliability level of spring mechanism is very high; they have not noticed any such failure in service.

To summaries, it is stated that engine inflight re-start is safest when it is starter assisted and the propeller is in 'feathering' mode. This must be a mandatory procedure for all engine re-starts in future.

2.13 Monitoring of Telemetry facilities and FTD role :

Telemetry is an effective tool for online monitoring of prototype test flying wherein test crew could be warned by the Test Director in case of any exceedences in flight parameters or a potential hazardous situation leading to an unsafe flight condition. The reliability of the telemetry system has been poor in general throughout the sortie and the auto tracking system has been unserviceable. The same has been expressed by all designers of various monitoring groups at telemetry station.

The tracking antenna of ASTE works in azimuthal direction only and in elevation it is to be operated manually. Also the software used currently needs to be enhanced for additional functionality. These points to be addressed prior to next Saras operation. Even if the telemetry station were to be working totally in auto tracking mode, when the aircraft makes rapid maneuvers, a mechanical tracking antenna system can never react so fast and link break is likely to occur. This will lead to short term fluctuations in monitoring screen display during the test flight. This is a known phenomenon in the telemetry system. As long as fluctuation frequency is not too high , the parameters can be read and test can be continued. This hence emphasizes the importance of reliable and strong RF communication between aircraft and telemetry station, FTD desk. But as of now RT communication is also limited and telemetry station do not have recording of communication. The existing present system of communication between the monitoring desks to FTD by PTT switch is not valid recording system. Moreover there is no proper logbooks/records maintained for each desk of monitoring. Hence there is no accountability of the desk person.

Suitable advance system should be developed to resolve the telemetry issue.

The regular link breaks at the crucial juncture when the relight was being attempted; probably lead to a lack of situational awareness at the telemetry station. Better awareness at that point might have enabled the telemetry team to give the required inputs to recover from the situation safely. Regular changes in the telemetry monitoring team may result in the team not being familiar with the intricacies and finer nuances of the test plan. Continuity, close inter-action and well-versed communication between the trial team (test crew) and the monitoring team is essential for the optimal conduct of prototype test flying. The aircraft OEM (NAL) needs to set up a system in place wherein the people in the monitoring team should be formally trained to a certain basic level on aircraft systems as well as certain aspects of prototype flight testing, prior to being cleared to sit in the monitoring team.

Informal training was reportedly conducted by a Sq.Ldr. of ASTE,IAF prior to 1st flight of PT1 for initial telemetry team members, including back up team. The present team has undergone on-the-job training along with the trained team members and the same personnel have been accepted by FTD and flight crew. *But no training records were made available.* ***Telemetry system, its facilities and their personnel are required to be brought under DGCA approval system so that the efficiency of the system is under monitoring.***

A formal training syllabus should be formulated for training of new incumbent under supervision for a minimum set criteria before clearing them for independent operations. Similarly some sort of refresher training is also required to be imparted to these personnel.

Probably frequent breaks and disturbances in the telemetry data has resulted in all the ground telemetry monitoring group as well as Test Director missing the rise in Np_L prior to the relight attempt. The trigger for the sequence of all the events on the fateful day has been <u>"this unexpected increase in Np_L"</u> which was not monitored by concerned. **Therefore, necessary up gradation or revamping is required in the telemetry system to make it more purposeful.**

Since during relight operation, the most important parameters like ITT, Oil pressure and Ng were given full attention it was never expected that propeller will unfeather even before engine has started and oil pressure build up.

May be due to telemetry link loss and fluctuations of parameters, the individuals monitoring various system parameters could not appreciate the situation, including the Flight Test Director when there was unexplainable increase in Np-L reaching 100% when Ng was around10% and oil pressure was 6-7 psi.

However from telemetry data it is understood apart from frequent telemetry link failure there were following abnormal situations under his close monitoring when telemetry link was available immediately after starting of relight procedure , for which FTD could have called off the flight test:

1. The Torque required on right engine to maintain the aircraft in stabilised level flight condition with left engine switched off was about 90% and required about 12 – 13^{o} of rudder control input (up to 60% of total travel). This was higher than the predicted value of 50-60% Torque. There was high asymmetric Torque value or excessive rudder input could have been taken.

Aircraft crashed at 3330 secs telemetry time, Altitude: 3016'.

2. Telemetry time: 3234 secs to 3246: aircraft went into dive and loss the height from 9200' to 7300',speed gone from 125 to 181 kts, ROD : 10,000FPM(emergency ROD 3000FPM) – **about 100 secs prior to crash.**

3.TELE time:3273 to 3302 secs, Aux Battery current charging remained nearly Zero., Ng-L reducing and engine parameter showed relight attempt failed. Altitude loss from 7050' to 5300' with speed 130 kts. Pedal force above 60 kg reached 90. The aileron forces were 30-40 kg.--- **about 60 secs prior to crash**

4. Tele time 3321-3329: telemetry link restored after 17 secs from 3302. Aircraft speed 120 kts, height 4600' and continuously reducing.

FTD has the authority to advise the aircrew to abandon any particular test, if he considers it necessary to do so in the interests of safety. As per Annexure-1 to appendix- C of joint Directive between NAL and ASTE,IAF , based on NO GO Items, he could have called off or aborted the flight for the above said situations involving telemetry link problems, abnormal aircraft behavior or doubted towards that, safe conduct of Test not feasible. But FTD failed to do so.

From CVR recordings it is also clear that at no time during the engine relight exercise did the crew inform the Test Director regarding controllability problem. All communication during that period was on intercom between the crew and not transmitted to the Test Director. He was not consulted on the requirement to call off the flight. **Crew were also not responding to the doubts raised by FTD on three occasions even at one stage after the initiation of first relighting at about 37 secs prior to crash. FTD also failed to call for the aborting off flight after the abnormal telemetry link as well as abnormal flight situation including rapid loss of predetermined height and not getting response from the pilot at critical stages.**

Similarly ASTE supervisor also failed in his responsibilities for flight safety in co - ordination with FTD as the situation warranted.

It is also informed that alongwith FTD Wg Cdr Jaiswal,Test pilot -Saras,Wg Cdr G.D.singh, FTE_Saras were also monitoring the flight at Telemetry. They also failed to advise FTD for calling off the flight seeing the abnormal situation in the monitor.

The role and responsibility of telemetry monitoring team and Test Director and ASTE supervisor in the Saras test programme needs to be reviewed .

2.14 CVR, DFDR and TELEMETRY Data analysis:

As the crew died in the accident and no other eye witnesses were available to ascertain the facts of the accident the only available effective tool for investigation is CVFDR(CVR& FDR) of the aircraft. Though the aircraft was gutted in fire the flight recorder could be safely recovered and the data were also retrieved. The other effective means of data available for the accident is that Telemetry data recorded by ASTE,IAF. Even though Telemetry link was intermittent especially at critical phases of the flight, the available data was effectively corroborated with flight recorder data/voice recordings and analysed to bring out certain salient facts of the accident.

The following are the salient annotations/ findings derived from the above data/cockpit voice /CVFDR analysis:

1. There were mainly the crew concern about control surfaces in-effectiveness and the felt excessive drag and hence the requirement of more power.

2. Till 1:41min prior to crash, there have been no alarming situation in the cockpit. With preparation for restart of left engine done up, as per procedure, the final command of the MODE SWITCH to START has been called at the Time of 5 secs before, But after that there is no call for “ENGINE START SWITCH to START.” At 1:22min prior to crash there was an excited voice of FTE “ Start..Start..Start Engine..” At this stage ***aircraft lost height from 9223’ to7266’ ie almost 2000’ in 20secs. Subsequently there was a momentary control of the aircraft that was indicated by the pilot laughing. But the height lost continued thereafter .***

3. Alarm has been raised by P2 at 01: 41 min prior to crash, with the aircraft getting in to unexpected attitude changes. There has been a large bank , side slip , pitch and roll. The rates of these motions also remained at high level.

4. There has been no growth in Ng-L, indicating that the engine has not yet started. In addition, the battery discharge call appears only about 25 secs later. Battery discharge call has been designed to rise along with starter motor engaging and large current drawn.

5. There has been a steep raise in Np-L, producing excessive drag. The blades cannot be expected to go to un-feathered state with oil pressure remaining only about 5 psi. However the propeller RPM can increase only if blade pitch angle reduces and the blades un-feathers.

6. The presence of high drag effect on the left side due to disc effect, probably caused an upward force and consequent nose down attitude. As the right side not having similar upward force, a case of asymmetric tail vertical load could have caused the recorded excess roll also.

7. To counter the largely building up sideslip and course change, the crew took to the action of throttle down the right live engine. This happened, after one or two secs , after the first sign of emergency at the time of 1:41 prior to crash.

8. With reduction of thrust asymmetry, and with possibly corrective control in puts given by the crew, the aircraft was probably momentarily brought under control, at the time of about 01 : 24min prior to crash

9. The status of battery current EOP-L, Ng-L, and LC-R, together indicates that the relight probably has not been succeeded, or could have been aborted.

10. With Np –L continuing in range of above 90%, during a large part of remaining flight time, there has been, a repetitive attempt / wrong handling by crew, with control inputs and throttle of both the engine. There has been continuous drop of altitude and speed.

11. The possible second relight attempt seems to have taken place at the time of – 26secs prior to crash. And the growth in Ng –L, the drop in Np-L, the growth in EOP-L and the drop in side slip, all together indicates the probable success in this attempt.

12. However the fast induced variation in power on live engine, and not having enough height, to recover, the aircraft, has departed from the controls and balance.

13. There is no planned and proper crew co-ordination between the pilots and as well FTE. Some times commander was on control and other times the copilot on control. Especially after the initiation of relighting procedure copilot was cautioning the commander for his wrong handling of live right engine at least twice at about 55 secs prior to crash when aircraft was loosing speed . Similarly at critical stage of last moment at about 20 secs prior to crash again **P2 was cautioning the P1 " do not cut live engine" as the aircraft was loosing height rapidly and viciously.**

14. For each and every stage of test procedure, role and responsibility and their action for the situation is not proper and situational awareness and seriousness of the action were missing. Moreover cockpit sterility is not satisfactory.

15. About 6 mins prior to crash commander was commenting "something get drastically wrong-something is not OK". Pilots had not given seriousness to higher drag than expected at that situation. **About 30 secs after this doubting**

performance of the aircraft, when FTE suggested for going back to base, it is blindly rejected by the copilot. Commander also commented "we will switch off and later show to the Ground". Co -pilot also hilariously telling commander "road is there for emergency" and advised FTE for the placing readiness of parachute for emergency, without assessing the risk of the situation.

16. **Crew exceeded their limits and limitations of the test flight and its test poin ts in tackling the risk. Aircraft being under experimental stage they must not have crossed the predetermined limits and limitations . As soon as the first relight attempt at appr. 7100' failed and aircraft started loosing the height viciously pilot should have shut down the involved engine and aborted the flight to come for single engine inoperative landing which they have successfully simulated in the starting of the test flight. Aircraft was continuously loosing height. But crew went ahead with 2 nd relight attempt at about 5000' which was successful just 2 secs prior to crash by the time aircraft almost near the ground. Relight procedure was not done at safe altitude as prefixed at 10000'AMSL**

17. **Crew were not responding to the doubts raised by FTD on three occasions even at one stage after the initiation of first relighting at about 37 secs prior to crash .. FTD also failed to call for the aborting off flight test due to the abnormal telemetry link as well abnormal flight situation including rapid loss of predetermined height and not getting response from the pilot at critical stages.**

18. ***Crew were not using the internationally accepted aviation language and terminology. Most of the time using Hindi and that too broken and unaccepted level creating lot of misunderstanding of the flight deck environment.***

19. **Crew never attained the flight level of 100 as cleared by radar. Maximum reached by the aircraft was 9528'AMSL at 3min 40 secs prior to crash. Similarly at time 09:48(about 15:25 mins prior to cr ash) UTC when radar asked for the level confirmation crew gave wrong level 90 even though they were on level 70. ATC instruction at 0942 UTC for level clearance to 100 from 5000' was not adhered. They reached about 9236' and then descend to 7200' at 0948 UTC.**

20. **DFDR recording also revealed that Radio Altimeter registered erroneous recording most of the time especially below altitude 5200' and also constantly recorded as 2600' as Radio altitude for 3670' to 3150' during the accident flight.**

2.15 Non- functioning of ELT:

It has been observed during the investigation ELT signal was not recorded by ISRO satellite. Causes for the Emergency Locator Transmitter not Operating after the Accident of SARAS PT2 Aircraft VT-XRM on 06.03.2009 has been probed.

The Emergency Locator Transmitter (ELT) used in SARAS PT2 aircraft was procured from *M/s.* AmeriKing Corporation, USA (Model No. AK-450). The set is designed to transmit at two radio frequencies, VHF (121.5 MHz) and UHF (243.0 MHz). The ELT is activated on impact .As per the installation procedures suggested by OEM and guidelines in TSO C91a, all the components of ELT were installed in PT2 in the rear fuselage (forward of rear pressure bulkhead).

The unit has a built-in G switch and the same is automatically activated upon sensing a change of velocity of 3.5 +/- 0.5 FPS (2 +/- O.3G), along its longitudinal axis. The unit can be removed from the aircraft and used as a personal locating device when it is necessary to leave the scene of the accident.

To ensure reliable operation, the equipment was inspected periodically and the internal batteries in the main unit were replaced on 21.01.2009. Periodic maintenance was carried out as per the guidelines of FAR 91.52 and 91.169. The co -axial connection between main unit and antenna was checked during maintenance and found to be good. The switch on the main unit was selected at "ARM" position. This is the switch position to be selected at all times in normal operation. In this position, ON and RESET functions of remote control unit located on MIP was checked and observed the ON/OFF of LED. This is a part of daily inspection and was carried out on 6.3.2009 as per the laid down procedures before clearing the aircraft for flying. ELT was fully functional at that point of time as confirmed by the approved inspector.

As stated above, the ELT unit has a built -in G switch and it is designed to automatically activate upon sensing a change of velocity of 3.5 +/ - 0.5 FPS (2 +/- O.3G), along its longitudinal axis. During the investigation It was confirmed from FDR investigation group that the maximum normal acceleration recorded was 2.12 G in flight (88 seconds prior to crash) and - 6.07 G at impact. The longitudinal and lateral accelerations were - 3.04 G at impact. With these G levels the ELT would have transmitted signal at 121.5 MHz.

All ELTs installed on the aircraft are required to comply with current DGCA, CAR, SEC 2, SER I, PART II. Details of capability are mentioned in CAR SEC2 , SER 'O', Part II,III,IV,V with regard to type of operations. ICAO Annex 10, part 3, referred in CARs also clearly stipulate that after year 2005, all ELTs should be capable of operating on both frequency 121.5 MHz AND 406 MHz. However this fact has been overlooked by NAL and ELT fitted on accident Saras PT-2 aircraft was capable of operating only on frequency 121.5 MHz.

On enquiring at the ISRO Satellite Centre, Peenya, Bangalore it is learnt that, from 01.01.2009 the distress frequency for reception by both SARSA -T and INSAT has been shifted from 121.5 MHz to 406 MHz and thus no signal has been recorded by ISRO on 06.03.2009.

Also during the examination of the wreckage at site the ELT unit was not traceable. It could have been burnt in post impact fire as its housing is not fire proof. However, only six batteries of the ELT unit were recovered from the wreckage site. The disconnection of antenna due to impact in the crash might also be a reason for the unit not emitting the distress signal at 121.5 MHz, in addition to the fire that broke out after the crash.

It is also understood from NAL that ELT was not installed on load bearing primary structure as per standard aeronautical practice but installed separately on a suspended platform attached with fuselage.

It is hence concluded that an inappropriate selection of ELT which is not capable of operating on 406 MHz compatible with satellite tracking system is the cause for ISRO satellite not picking up the ELT signal.

2.16 Operation of doors by crew in emergency

During the wreckage inspection and analysis it was observed that Main door and Port Emergency door Handle was found in Open position and stbd emergency door handle was in closed position, affected by fire. Main door was slightly damaged due impact. All the three doors were lying away from the main wreckage and hence not affected with the fire except slight burn marks to port emergency door. Stbd emergency door was not having any impact/fire damage. This has created the doubts whether the crew operated doors in emergency or came out due to structural failure on impact.

National Aerospace Laboratories was hence asked to provide a report on the possible failure of the main door and the emergency doors, which were found near the main wreckage of the aircraft. Following this, a committee was constituted by Head, C-CADD comprising various experts members to look into the subject as to how the doors came off the fuselage structure and whether or not there was any failure of locking pins/mechanisms.

The committee examined in details the doors and the corresponding structures of the fuselage with available other evidences. The expert committee concluded that the integrity of the locking mechanisms of the main and the emergency doors were intact at the time of impact of the aircraft on to the ground.

It is therefore inferred that handle positions and breakage/distortion of linkages and doors are post impact. Moreover wreckage evidences showed that the charred bodies of the flight test crew were on their respective seats. Cockpit voice recorder also revealed that there is no sufficient time for the crew to attempt opening the doors. **It is hence evident that flight crew did not open the doors in emergency and came out due impact.**

Since there was no much impact damage to the doors it is highly questionable why the doors including emergency doors came out of the fuselage without crew operation. It could be possibly due to the weak locking mechanism of these doors. NAL should hence improve upon the locking mechanism of these doors including emergency doors.

2.17. Structural integrity of Saras aircraft :

During the investigation and analysis of CVR recordings pilot called "aircraft departed" several times prior to the crash indicating the aircraft lost complete control. NAL was asked to assess whether any structural failure of the aircraft led to the cause of the above complete loss of aircraft control.

Based on the nature of impact damage in the accident, HAL structure specialist along with NAL designers studied detailed drawings and stress analysis of the following areas of Saras aircraft structure :

Engine mounts and engine pylon attachment to fuselage
Rear pressure bulkhead

All door attachments and lockings
Fin attachment to fuselage
General cross section in fuselage area

It was found by the structural specialist that normal structural detail design practices have been followed and load diffusion paths are found to be in order. Stress analysis reports showed adequate safety margin. In view of the above findings, It is infer red by them that the specific structural areas are safe from structural integrity point of view for design flight envelope.

It is hence inferred that there is no in-flight structural failure of the aircraft involved in the accident.

2.18 The rationale behind selection of 10,000 feet for the relight exercise:

NAL has clarified that how the altitude selection was done for relighting procedure. It was clarified by them that Relight boundary given by P&WC was upto a maximum of 25,000 ft. and max. speed of 200 kts. Also as the fuselage was not yet pressure tested for PT2, DGCA has cleared operation only up to 15000ft. Since this was the first test for relight in the air, we chose both altitude and speed near the mid band of the engine re-light envelope given by P&WC. This was to give best chance for a successful relight, due to higher pressure and temperature.

Trial planner documents of the in-flight shutdown and relight test programme revealed that even though the engine OEM gave flight envelope for relight operation as maximum of 25000' and speed(EAS) 200 kts, NAL restricted this to 15000' and 200kts due to the reason that Saras PT2 is yet to be commissioned with CPCS and ECS system. DGCA, Bangalore also cleared provisionally to operate the a ircraft upto 15000' while according the approval for the block of next 25 flights. DGCA, Bangalore also did not fix the altitude restriction for engine shut down and relight procedure.

DGCA had extended the flight envelope of Saras aircraft to 15,000 ft A MSL The height of commencement of relight test point ie 9400 ft AMSL (6400 ft AGL) as recommended by designer's (vide relight document) and executed by flight test crew (vide test programme of 49th flight) did not provide the crew with sufficient height to take safe recovery actions, incase of some unforeseen circumstances. Pratt & Whitney, Canada as well as MT Propeller have also indicated that height selected for the trial sortie was inadequate in case of any emergency. This height is considered very low for conducting a critical exercise like engine relight for the first time.

The same documents also mentioned under the heading "Flight Safety Consideration" that minimum altitude in sector for engine shut down and relight trials is 13000'indicated(10000' AGL) as the max. limit is 15000' indicated.

However after the deliberation on the Trial Planner CRPO,ASTE,IAF has made remarks on 22 Jan 2009 that capability of engine on both positions for relight in air at different altitudes above 10000'AGL(13000'AMSL) may be progressed/established. Most of the test documents simply mention 10000' only but never mentioned whether AMSL or AGL. Flight test schedule on 6.3.2009 of 49th test flight also mentioned under "objective" only 10000' altitude for the inflight eng ine shutdown and relight procedure. It might be possible that Saras test team presumed wrongly this as 10000'AMSL and fixed finally as such for the 49th test flight on 6.3.2009.

CTP,IAF also commented that clear procedures for windmilling start in flight (not Starter assisted) and all limits for the same need to be laid down by NAL in consultation with P & W. Nowhere MT propeller was considered for discussion on the relight procedure.

Normally all civilian transport aircraft operate safely upto 14000' wit hout any pressurization requirement and no discomfort to its occupants. This was also not taken into consideration while finalizing relight altitude requirements. Management Committee(MC) of the Saras project also failed to act suitably on the issue.

Taking all the factors into account, the reason for selecting 9400 ft AMSL altitude for the relight test profile was appeared to be inadequate for the flight crew to take suitable recovery actions.

From the above it is inferred that the selection of 10000'AMSL for engine shut down and relight procedure is not prudent. It requires immediate attention and is to be revised prior to the next flight.

2.19. Circumstances leading to the Accident:

At about 0956 UTC aircraft reported "OPS NORMAL" at 20Nm in sector Southwest 2. **This was the last contact of aircraft with radar but was in contact with FTD telemetry desk of ASTE,IAF.** After successful left engine shut down and its securing procedure, at about 1001 UTC **left engine relight procedure was initiate d at about 9200'AMSL. During the relighting of left engine, FTD desk also lost contact with aircraft for about 37 secs. prior to crash.**

CVR revealed that after shutdown of LH engine securing of engine was called for. As per the procedure, propeller con trol lever was kept in "feather", fuel condition lever—OFF. After that, from 2:37 mins prior to crash aircraft was prepared for engine restarting. As a pre -relight check procedure, pilots carried out: auto feather: Off, propeller control lever: Fine, Po wer control lever : Idle, fuel condition lever: OFF, Fuel shut off valve: Open, Booster pump: ON, ECS; Already kept Off, fuel low pressure warning on CWP : Off . This was carried at about 9200'AMSL at about 1:47 mins prior to crash. At that stage FTE asked the pilots in suspicion "**what is happening"** At this instant Rudder, elevator, sideslip are all steady at the values which were maintained till then. There was no change in Heading also. Followed this, as an engine relight procedure check, FE called for "Engine Start Mode switch to Start". But for this there was no action from the pilots as heard in the CVR. At 1:41 mins prior to crash ie., 5 secs after the above Start mode switch call by FE, P2 shouting in alarming tone, "………," . This Alarm has been raised by P2 with the aircraft getting into unexpected attitude changes. There has been a large bank , side slip , pitch and roll. The rates of these motions also remained at high level. At this stage ***aircraft lost height from 9223' to7266' ie almost 2000 ' in 20secs. Subsequently there was a momentary control of the aircraft , which was indicated by the pilot laughing. But the height lost continued thereafter.*** But at no time the call was given for action "ENGINE START SWITCH to START." At 1:22mins prior to crash (ie 24 secs after mode switch selection call)there was an excited voice of FTE " Start.. Start. .Start Engine.." to start the engine. However CVR as well flight recorder and telemetry data did not show engine started. There has been no growth in Ng-L, indicating that the engine has not yet started. Telemetry data did not show minus Load current(Lc) of left engine(negative implies current received for starting the left engine) and drop in Generator voltage (from 28.4 to at least 22.4 volt) at any duration of first relight attempt.

There has been a steep raise in Np-L, producing excessive drag. The blades cannot be expected to go to un-feathered state with oil pressure remaining only about 5 psi. However the propeller RPM can increase only if blade pitch angle reduces and the blades un-feathers. **The presence of high drag effect on the left side due to propeller disc effect, probably caused an upward force and consequent nose down attitude. As the right side not having similar upward force, a c ase of asymmetric tail vertical load could have caused the recorded excess roll also.** To counter the largely building up sideslip and course change, the crew took to the action of throttle down the right live engine. This happened, after one or two secs , after the first sign of emergency at the time of 1:41 prior to crash. With reduction of thrust asymmetry, and with possibly corrective control in puts given by the crew, the aircraft was probably momentarily brought under control, at the time of about 01 : 24min prior to crash.

55 secs prior to crash engine oil pressure-left increased to 56 and subsequently started reducing to 38, ITT still 68 deg, Fuel flow remained 36, torque zero, Ng raised to 22 and started dropping to 15,Np to 83. This indicates the Left engine relighting not successful and height continuously dropping. Right engine also brought to idle. **P2 Expressing anguish on reducing power of the live engine by P1 .The status of battery current EOP-L, Ng-L, and LC-R, together indicates that the relight probably has not been succeeded.** With Np –L continuing in range of above 90%, during a large part of remaining flight time, there has been, a repetitive attempt/ wrong handling by crew, with control inputs and throttle of both the engine. There ha s been continuous drop of altitude and speed. Aircraft lost to 5200’ and speed 110kts. 33 secs prior to crash , Speed reduced to 112 Kts, Height reduced to 5400 feet, E1 Ng -10 % , E2 N g-86 %, the calculated rate of descent is as high as 12000 feet per min,. With fast descend taking place, the crew believes here that they have to have left engine live to cope up the emergency.P2 and P1 raising alarm voice of drastic reduction of speed. “ speed ………..speed…….speed……speed….” and P2 asking P1 “ Oye .. yaar.. do light up…, relight…” to relight immediately. This indicates that earlier first relight attempt was not done successfully. 27 secs prior to crash, aircraft losing to Height 5000 feet, excess rate of descend ,panics the crew with sayings “ going down” in exhausted voice of P2 seen here.

15 to 22 secs prior to crash P2 instructing P1 to do the action which ever is , which has brought the aircraft to some stable attitude when it was done earlier. Again anguish is expressed by P2 to P1on the action of cutting off of the live engine and stressing to keep the live engine in LIVE condition only. The second relight attempt seems to have taken place at the time of just 8 secs prior to crash which was indicated by Minus Lc and drop in Generator voltage . The growth in Ng –L, the drop in Np-L, the growth in EOP-L, increase of fuel flow and the drop in sideslip, all together indicates the probable success of relighting of engine at second attempt. However the fast induced variation in power on live engine, and not having enough height, to recover, the aircraft has completely lost its controls and hence the pilots comments in fully exhausted voice P1-“ aircraft has departed…aircraft going to ground”.

During last 10 secs of the crash **P1 calling aircraft departed repeatedly indicating aircraft fully gone out of control.** At the last second of their life P2 calling in exhausted voice“ F..…, F,., F.., F....”” indicating aircraft is crashing. At the same time Battery discharge Warning coming in the background also stopped, indicating engine relighted successfully. But the aircraft almost on ground, P1 calling “ Going to ground”. Last 5 secs prior to crash Rapid loss of height from 4300’ to 3040’, speed started increasing from 60 to 120 . Ng_L increased to 54,Np to 56, oil pressure to 79, ITT increased to 647, fuel flow to 95, but torque started to come out of zero , indicating Left engine successfully relighted. Whereas on right side Ng R - 81%,Np: 86,Oil pressure 118, ITT 773, fuel flow 78(came down from 336 which was increased in the 5 secs prior to crash), torque came down to 11 from 81, PLA from 31 to almost zero. Indicating last moment try on right engine.

There is no planned and proper crew co-ordination between the pilots and as well FTE. Some times commander was on control and other times the copilot on control. Especially after the initiation of relighting procedure copilot was cautioning the commander for his wrong handling of live right engine at least twice. Crew exceeded their limits and limitations of the test flight and its test points in tackling the risk. Aircraft being under experimental stage they must not have crossed the predetermined limits and limitations for engine relight procedures .

From the preceding analysis, it is certain that engine was not relighted at first attempt at an appropriate altitude of 10000’ AMSL instead done at 7100’ AMSL and correct procedure of completing electrical start cycle and engine start cycle was not done by the pilots by selecting mode switch to “Start” and pressing “Engine Start Switch- to start” at first attempt. Due to which aircraft behaved in abnormal way, speed was reaching very high and losing altitude rapidly out of relight envelope. During the first relight attempt live engine was also handled injudiciously by the pilots. Aircraft viciously came down to about 5000’. **As soon as the first relight attempt at appr. 7100’ AMSL failed and aircraft started loosing the height viciously pilot should have shut down the involved engine and aborted the flight to make single engine inoperative landing, which they have successfully simulated in the starting of the test flight.** Aircraft was continuously loosing height. **But crew went ahead with 2nd relight attempt just 8 secs prior to crash at about 5000’ which was successful just 2 secs prior to crash. Speed was almost washed off Just 2 secs Prior to the crash and then started rising. This was again done outside the relight envelope(speed and altitude). Even though the second relight attempt was successful aircraft almost reached near the ground and crashed.**

Absence of any emergency call from the aircraft was possibly due to pilot remaining occupied in controlling the aircraft till last moment of the critical situation.

3. C O N C L U S I O N S :

3.1 F I N D I N G S :

1. Aircraft was duly registered in India with effect from 5.12.2006 and issued with Certificate of registration under Category A,. Aircraft is yet to be issued with C of A as it is still under developmental stage. 49th flight on 6th march 2009 is the first test flight, which covered the test point of engine, relight procedure.

2. There was no evidence of any defect or malfunction in the aircraft due maintenance, which could have contributed to the accident. There were in general controllability issues and high control forces exist in Saras PT2 accident aircraft. There is no other known major maintenance defects or structural defects.

3. Accident took place in a broad day light and Weather is not a contributory factor to the accident.

4. Crew were appropriately licensed and qualified to undertake the flight. They were also medically fit and taken adequate rest prior to operate the flight.

5. Test crew did not undergo approved human factors/CRM training and the NAL/ASTE also did not ensure CRM training of the pilots/test crew before using them.

6. There was no pre impact fire. All extreme ends of the aircraft were within the main wreckage with fire damage. **This indicates there is no fire or structural failure prior to impact on ground. Aircraft did not crash on nose and there was no forward moment of the aircraft after main plane impacted the hard ground.**

7. The cable run (burnt) found running from cockpit to tail almost straight along the axis of longitudinal direction and no discontinuity was observed. All the three undercarriages were in retracted position and found burnt but retained its solidity.

8. Crew did not use the parachute on board as there was no time for that in the accident situation. The crew did not operate Main doors and emergency doors and it got opened in the crash.

9. Aircraft was used for flying demonstration in Aero India 2009 show from 11.2.2009 to 15.2.2009 at Bangalore. But no DGCA permission was taken by NAL.

10. There is no effective and continuous monitoring of test programme by NAL-ASTE(IAF) Management Committee and no records of monitoring available.

11. NAL also subcontracted a private agency named Aircraft Design and Engineering service Ltd,Bangalore. The work schedule of the project indicates almost complete work of the design and development of SARAS project is being done by the contractor, which includes flight testing analysis also. **This is not in line with DGCA approval given to the contractor that of only giving design and engineering support to the parts and appliances.**

12. As per agreement between NAL and ADES-subcontractors, Even though NAL shall retain the absolute right on any patent that may be taken from the result of the work, Confidentiality clause of the agreement did not point out the penalty/ punishment action on the contractor under law in

case of the pilferage or theft of any technical information such as design, drawings, wind tunnel testing, flight tests results or any software etc.,.

13. There is no effective pre-flight briefing to the crew and no records available to indicate the same on the day of accident. There is no contingency plan for unexpected emergencies like accident, missing aircraft, loss of communication etc.,

14. There is no meaningful and effective supervision and control on the Saras project by DGCA-AED.

15. There is no periodic monitoring of CVR and DFDR by NAL. DFDR does not have critical engine parameters like engine oil pressure, ITT and fuel flow etc to monitor these in relight procedures and the engine performance. The elevator position reading throughout the test flight was noisy probably due to intermittent signal loss in the data**. Hence Elevator position indication is also to be rectified**.

16. Several observations made in the inspection report of Air India engineering team in 2009 are pending action by NAL

17. Aircraft was fitted with certified P&W engine . However the MT propeller fitted is under the process of certification and is yet to be certif ied. **On receipt of the propeller and prior to use on the aircraft it was not declared FIT by NAL .**

18. Propeller manufacturer confirmed that Propeller control lever should be ideally kept in "Feather" position for engine relighting and only to move forward to "Fine" after successful relighting and engine attaining the stabilized Ng at flight idle (ie 50 -55%)as per engine manufacturer. Propeller manufacturer reiterated Again and again that the normal procedure for the engine re-start would be with the propeller in "feathering" which was "Fine" in the accident flight for relight procedure.

19. There has been no interaction between NAL and the propeller manufacturer (MT Prop Germany) regarding the formulation of the relight procedure as the NAL and ASTE attention was only on engine relighting ie., presumed propeller having no role to play. NAL at any stage did not consult MT propeller for instruction and guidance before finalizing the engine relight procedures

20. ***It was also confirmed that as the propeller system behaved normal as seen from data (prop control full forward), there was no malfunction of the propeller system.***

21. **There was no malfunctioning of the engine system.**

22. Facilities, functioning and training of monitoring personnel o f telemetry system requires immediate review as there is no proper documentation of monitoring, frequent link interruption etc.,

23. There is no proper recording system of RF between the FTD and the crew as well telemetry monitoring personnel on ground. Moreover there is no proper logbooks/records maintained for each desk of monitoring. Hence there is no accountability of the desk person.

24. CVR revealed that at no time during the engine relight exercise did the crew inform the Test Director regarding controllability problems. All communication during that period was on intercom between the crew and not transmitted to the Test Director. He was not consulted on the requirement to call off the flight.

25. Crew were not responding to the doubts raised by FTD on three occasions even at one stage after the initiation of first relighting at about 37 secs prior to crash. FTD also failed to call for the aborting off flight testing due to the abnormal telemetry link as well abnormal flight situation including rapid loss of predetermined height and not getting response from the pilot at critical stages.

26. Similarly ASTE supervisor also failed in his responsibilities for flight safety in co-ordination with FTD as the situation warranted.

27. Some Test pilot-Saras,FTE_Saras were also monitoring the flight at Telemetry. They also failed to advise FTD for calling off the flight seeing the abnormal situation during monitoring.

28. There is no "challenge and response" method formulated by NAL and adopted by the crew for carrying out checklist procedures.

29. The relight document was only vetted and approved by ASTE on 06 Mar 09 and ***was not sent to the engine and propeller OEMs i.e. M/s P&W,C and M/s MT Propellers respectively for getting their comments*** and guidance.

30. As a well established Aviation engine industry , There is a lack of clarity from Engine OEM considering the aircraft being experimental aircraft and NAL was in constant touch with them. P&W should have given clear cut instruction whether to keep the propeller in "feather" or "Fine" for relight procedures.

31. There is a Lapse of project team and Management committee(MC) in finalizing the correct procedure for engine relight in flight.

32. Test documents available with NAL did not mention about aborting of flight in case of failure of engine relight at first attempt.

33. "Saras specific intentional engine shut down and relight procedure" was not well planned and prepared and did not include the following:

a) There is no mentioning of role and responsibility of the individual crew, of who will check what and who will act and respond ,etc.,

b) Relight procedure checklist or its note at the bottom does not mention how much should be engine oil pressure. Similarly no mentioning of action on "Engine Start Switch" only mention about Start Mode Switch.

c) Propeller control lever -- fine .(as per engine OEM, any where in the operating range). But not cross checked with MT propeller.

d) Since this is the first relight test procedure nowhe re cautioned about prohibition of 2nd relight attempt and that too at low flight level.

e) No altitude restriction was also highlighted for relighting.

34. It has been reported by NAL that adequate practice of re -light drill was done by the test crew on ground. Dummy drills in the cockpit were also carried. But it is not clear that whether these drills included the simulation of relighting in air, using the internal start method. No sufficient records were made available.

35. **NAL should increase the capacity of main Battery and to remove the auxiliary battery and review then the electrical system of the aircraft to avoid unwanted confusion in the operational procedures.**

36. Control forces for rudder and aileron were very high. The rudder pedal and aileron forces during asymmetric torque conditions have been very high This has been brought out by the crew time and again during the flight as has emerged from the CVR transcript of the 49th flight, wherein the pilots have commented on the lack of contr ol margins during the asymmetric torque conditions in OEI simulation as well as when the left engine was actually switched off. **NAL should not only look at the Maximum limit of FAR 25. Rather it should consult other aircraft manufacturing industries to explore the convenient limit of control forces. This needs to be looked in by NAL on all prototypes.**

37. After moving propeller to "Fine" The propeller RPM has reached more than 90% before an attempt was made at relight. This wind milling conditi on of the propeller resulted in significantly higher drag, resulting in increased yaw and side slip. ***As inferred from the telemetry and FDR data, there was excessive drag due to the flat disk effect of the propeller wind milling at 100% rpm*** .

NAL should study this abnormal behavior of propeller leading to the situation of disk drag effect when it is windmilling.

38. Technical evaluation study by NAL concluded that engine inflight re -start is the safest when it is starter assisted and the propell er is in 'feathering' mode. This must be a mandatory procedure for all engine re-starts in future.

39. The procedure given by P&W <u>**lacked clarity**</u> and did not give any Advice / caution particularly with respect to free turbine configuration. This was not clearly spelt out by Engine OEM(P&W) in their SOI for engine shut down and relight procedure. At any stage of finalization of engine relight procedure in flight, MT propeller had not been consulted by NAL for their instruction and guidance. Now MT pro peller also reiterated that Propeller Should be in "FEATHER" position for relighting of engine in air. However this should have

been finalized by the designer ie., NAL before undertaking such critical exercise.

40. During the first relight attempt, it could be possible that the **start mode selector switch was in the 'Motor' position instead of 'Start'. T** his condition would result in dry motoring only (no ignition). This would also increase generator current by about 200 A. This is also corroborated by the data wherein Ng increases to nearly 25% and then drops down gradually. The Start Mode Switch could have been unintentionally deflected to 'Motor' position by any of the flight crew member during the ensuing dive and unsettling of crew in the cockpit (due to excessive yaw rate, sharp pitch down and effect of negative 'g') caused due to spin up of propeller RPM to $\underset{\sim}{\sim}$ 100%..**Moreover there is no mentioning of "Engine Start switch – to Start" in the CVR during this situation. It is quite possible engine was not started at all ie., ignition not started. This is clear from the no minus load current and drop in generator voltage.**

41 The successful second relight confirms that functioning of the starting and ignition system in the aircraft were normal. There is no mention of the selection of aux battery to 'ON' position during the air start in the relight document especially prepared by the NAL Engine team for the sortie, indicating no requirement of the same. Also other designers and ASTE Flight Crew were not very clear on this aspect whether aux battery is required to be put 'ON' for cross start in air except designers from Electrical Group.

42 Hence, either wrong selection of mode switch or non-pressing of Engine Start switch or non selection of Both to start the engine during the first relight attempt is the most probable cause for engine not relighting in the first attempt.

43 Till 1:41min prior to crash, there have been no alarming situation in the cockpit. With preparation for restart of left engine done up, as per procedure, the final command of the MODE SWITCH to START has been called at the Time of 5 secs before, But after that there is no call for "ENGINE START SWITCH to START." At 1:22 mins prior to crash there was an excited voice of FTE " Start..Start..Start Engine.." At this stage ***aircraft lost height from 9223' to7266' ie almost 2000' in 20secs. Subsequently there was a momentary control of the aircraft which was indicated by the pilot laughing. But the aircraft lost height continued thereafter.***

44 The presence of high drag effect on the left side due to disc effect probably caused an upward force and consequent nose down attitude. As the right side not having similar upward force, a case of asymmetric tail vertical load could have caused the recorded excess roll also.

45. The status of battery current, EOP-L, Ng-L, and LC-L, together indicates that the relight probably has not been succeeded at first attempt.,

46. With Np –L continuing in range of above 90%, during a large part of

remaining flight time, there has been, a repetitive attempt/ wrong handling by crew, with control inputs and throttle of both the engine. There has been continuous drop of altitude and speed.

47. **The possible second relight attempt seems to have taken place at the time of 26secs prior to crash. And the growth in Ng –L, the drop in Np-L, the growth in EOP-L and the drop in side slip, all together indicates the probable success in this attempt. However the fast induced variation in power on live engine, and not having enough height, to recover, the aircraft, has departed from the controls and balance.**

48. There is no planned and proper crew co-ordination between the pilots and as well FTE. Some times commander was on control and other times the copilot on control. Especially after the initiation of relighting procedure copilot was cautioning the commander for his wrong handling of live right engine at least twice at about 55 secs prior to crash when aircraft was loosing speed . Similarly at critical stage of last moment at about 20 secs prior to crash again **p2 was cautioning the P1 " do not cut live engine" as the aircraft was loosing height rapidly and viciously.**

49. **For each and every stage of test procedure, role and responsibility and their action for the situation is not proper and situational awareness and seriousness of the action were missing. Moreover cockpit sterility is not satisfactory.**

50. ***Crew were not using the internationally accepted aviation language and terminology. Most of the time using Hindi and that too broken and unaccepted level creating lot of misunderstanding of the flight deck environment.***

51. **A**t about 6 mins prior to crash commander was commenting "something getting drastically wrong-something is not OK". Pilots had not given seriousness to higher drag than expected at that situation. **About 30 secs after this doubting performance of the aircraft, when FTE suggested for going back to base, it is blindly rejected by the copilot. Commander also commented "we will switch off and later show to the Ground". Co-pilot also hilariously telling commander "road is there for emergency" and advised FTE for the placing readiness of parachute for emergency, without assessing the risk of the situation.**

52. **Crew exceeded their limits and limitations of the test flight and its test points in taking the risk. Aircraft being under experimental stage they must not have crossed the predetermined limits and limitations. As soon as the first relight attempt at appr. 7100' failed and aircraft started loosing the height viciously pilot should have shut down the involved engine and aborted the flight to come for single engine inoperative landing which they have successfully simulated in the starting of the test flight. Aircraft was continuously loosing height. But crew went ahead with 2nd relight attempt at about 5000' which was successful just 2 secs prior to crash by the time aircraft almost near the ground. Relight procedure was not done at safe altitude as prefixed at 10000'AMSL**

53. Crew never attained the flight level of 100 as cleared by radar. Maximum reached by the aircraft was 9528'AMSL at 3min 40 secs prior to crash. Similarly at time 09:48 UTC(about 15:25 mins prior to crash) when radar asked for the level confirmation crew gave wrong level 90 even though they were at level 70. ATC instruction at 0942 UTC for level clearance to 100 from 5000' was not adhered. They reached about 9236' and then descend to 7200' at 0948 UTC.

54. DFDR recording revealed that Radio Altimeter registered erroneous recording most of the time especially below altitude 5200' and also constantly recorded 2600' as Radio altitude for 3670' to 3150' pressure altitude during the accident flight.

55. ELT was not installed on the load bearing primary structure as per standard aeronautical practice but installed separately on a suspended platform attached with fuselage.

56. An inappropriate selection of ELT, which is not capable of operating on 406 MHz compatible with satellite tracking system, is the cause for ISRO satellite not picking up the ELT signal after the accident.

57. Door handle positions and breakage/distortion of linkages and doors are post impact. Moreover wreckage evidences showed that the charred bodies of the flight test crew were on their respective seats. Cockpit voice recorder also revealed that there is no sufficient time for the crew to attempt opening the doors. **It is hence evident that flight crew did not open the doors in emergency and came out due impact.**

58. There is no inflight structural failure of the aircraft involved in the accident

59. Taking all the factors into account, selecting 9400 ft AMSL altitude for the relight test profile is inadequate for the flight crew to take suitable recovery actions. The *selection of 10000'AMSL for engine shut down and relight procedure is not prudent. It requires immediate attention and is to be revised prior to the next flight.*

60. It is certain that engine was not relighted at first attempt at an appropriate altitude of 10000' AMSL instead done at 7100' AMSL and correct procedure of completing electrical start cycle and engine start cycle was not done by the pilots by selecting Start Mode Switch to "START" and pressing "Engine Start Switch- to start" at first attempt. Due to which aircraft behaved in abnormal fashion, speed was reaching very high and losing altitude rapidly out of relight envelope. During this first attempt live engine was also wrongly handled by the pilots without following proper procedures. Aircraft viciously came down to about 5000'AMSL.

61. As soon as the first relight attempt at appr. 7100' AMSL failed and aircraft started loosing the height viciously pilot should have shut down the involved engine and aborted the flight to make single engine

inoperative landing, which they have successfully simulated in the starting of the test flight. Aircraft was continuously loosing height. **But crew went ahead with 2nd relight attempt just 8 secs prior to crash at about 5000' AMSL which was successful just 2 secs prior to crash. Speed was almost washed off Just 2 secs Prior to the crash and then started rising. This was again done outside the relight envelope (speed and altitude). Even though the second relight attempt was successful aircraft reached almost near the ground and crashed.**

3.2. PROBABLE C A U S E (S):

Incorrect relight procedure devised by the designer and adopted by the crew at insufficient height leading to rapid loss of altitude and abnormal behavior of aircraft resulted into accident.

Contributory factors:

a) Lack of crew coordination and cockpit procedures
b) Handling of the controls
c) Non-aborting of flight by the crew in coordination with the flight test Director after failure of first relight attempt.
d) Devising engine relight procedures by NAL without consulting the propeller manufacturer.

4.0 S A F E T Y R E C O M M E N D A T I O N S :

1. Saras Project shall be monitored by the high level group consisting of eminent personnel from aircraft design, safety and operational discipline on regular basis.

2. Any abnormality reported/observed by the crew has to be rectified immediately prior to the subsequent flight.

3. Since Saras is the national project, utmost vigil and care shall be taken by CSIR, India while implementing project and the concept of employing the private contractor involving in each and every stage of the design and development of Saras project requires to be discontinued immediately and only the support for the parts and appliances shall be obtained from them. The contracting system followed by NAL is to be reviewed by competent authority.

4. DGCA should get the project overseen regularly by team of officers from Airworthiness, R & D and Air Safety. IAF representative may be associated.

5. Appropriate action shall be taken on the findings pertaining to NAL, IAF (ASTE) and other agencies.

6. NAL should explore all the possibilities of having more safer SSR housing unit from the point of fire proof and crash proof till the Saras aircraft is released for production flight.

7. Synchronization of propeller control and fuel control in the cockpit should be explored by NAL for better flight management.

8. ELTs capable of operating on 406 MHz frequency be installed for monitoring purpose on the Saras aircraft at suitable location.

9. Suitable modifications on Saras aircraft Pitot system or Nose Landing Gear D-Door mechanism are to be incorporated by NAL so that the re is no mismatch of CAS between the two EFIS in flight.

10. Telemetry system, its facilities and their personnel are required to be brought under DGCA approval system for proper monitoring.

11. Engine shutdown and relight procedures shall be revised taking into consideration of all the relevant factors.

Mumbai **C. P. M. P. R a j u**
6.12.2009 **Inspector of Accident**

GLOSSARY

t :Time : secs

CAS_L :Speed kcas

ALT_L :Altitude ft

Rad_Alt :Radio Altitude ft

VG_L :Nz In term of g

HDG_L :Heading deg

HDG_R :Heading deg

VS :vertical speed ft/min

Stick :control column deg

St_Ail :Wheel deg

RudPed : mm

Elev :surface deg

Ail_L :surface deg

Ail_R :surface deg

Rud_Pos :surface deg

Rud_Tm :rudder trim deg

AIL_TM :Aileron trim deg

P_Tm :pitch trim deg

bank :bank angle deg

PR :Pitch rate deg/s

YR :Yaw rate deg/s

RR :Roll rate deg/s

PA :pitch attitude deg

Boom_AOA :Angle of attack deg

Boom_SS :Side slip deg

Boom_Speed: kcas

FQty_L :Fuel quantity kg

AMSL : above mean sea level

AGL : above ground level

FL : flight level

Kts : Knots

UTC : Universally coordinated time

BIAL : Bangaluru International airport Ltd

FTD : Flight test director

NM : nautical mile

L : left

R : right

FF : fuel flow

EOP : engine oil pressure

CAS : calibrated airspeed

OEI : one engine inoperative

s,secs : seconds

PBA : primary blade angle

ASTE : aircraft and system testing establishment

C-CADD: centre for civil aircraft design and development

DGCA : Director General of Civil Aviation

AZ : azimuth

EL : elevation

OPS : operations

LAT : latitude

LONG : Longitude

PFPR : post flight pilot report

FQty_R :Fuel quantity kg

Gen_L :generator, left volt

Gen_R :generator, right volt

HydPr :Hydraulic pressure bar

FFlow_L :Fuel flow, left kg/hr

FFLOW_R :Fuel flow, Right kg/hr

NG_L :gas generator, left %

NG_R :gas generator, right %

NP_L :propeller rpm, left %

NP_R :propeller rpm, right %

OIL_T_L :oil temperature, left deg

OIL_T_R :oil temperature, right deg

PLA_L :power lever angle, left deg

PLA_R :power lever angle, left deg

EngOilP_L :Engine oil pressure, left, psi

EngOilP_R :Engine oil pressure,right, psi

Torq_L :torque, left %

Torq_R :Torque, right %

ITT_L :inter turbine temperature deg C

ITT_R :inter turbine temperature deg C

CVR : cockpit voice recorder

D/FDR: digital/flight data recorder

LH : Left hand

RH : right hand

ATC : Air traffic control

min/s : minute/s

ELT :emergency locator transmitter

ATR : action taken report

KIAS : knots indicated air speed

OEM : original equipment manufacturer

PTT : press to talk

prop : propeller

SOI : standard operating instruction

SOP : standard operating instruction

ft :feet

RPM : revolution per minute