# Manufacturing and Certification of Composite Primary Structures for Civil and Military Aircrafts

CSIR-NAL
1959-2009

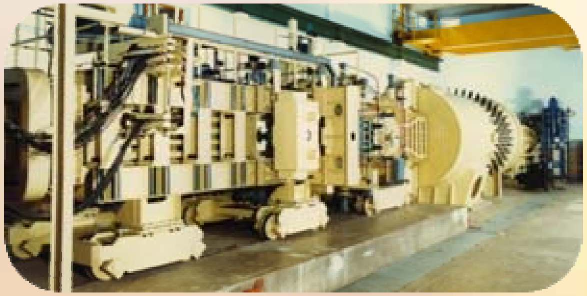
**A R Upadhya**
Director
Council of Scientific and Industrial Research
National Aerospace Laboratories, Bangalore, India

ICAS Biennial Workshop on "Advanced Materials & Manufacturing – Certification & Operational Challenges"

Stockholm, Sweden,
5th September 2011

# CSIR- NAL's Mission

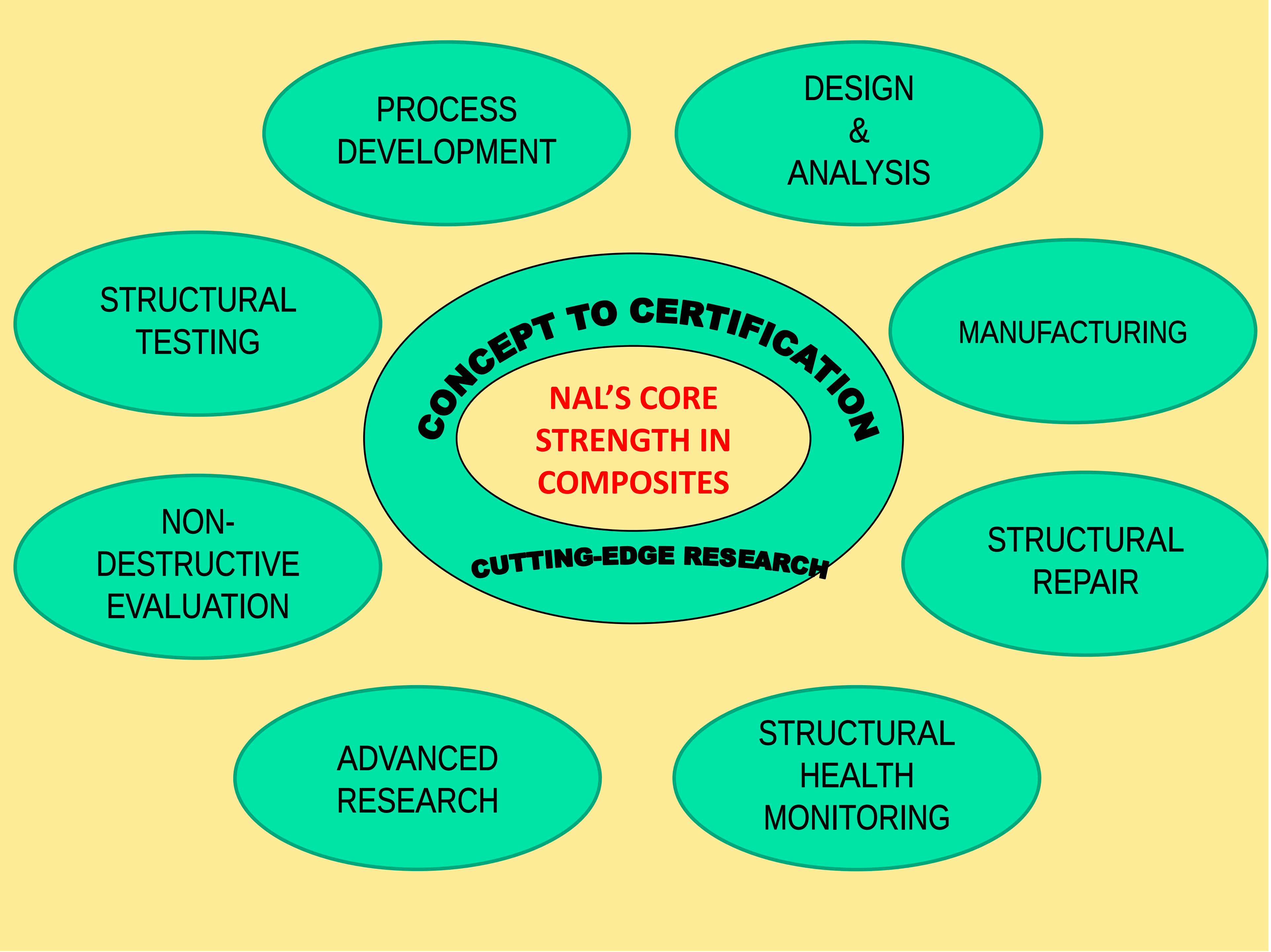
- Development of national strengths in aerospace sciences and technologies
  *Infrastructure, facilities and expertise*
  In-house, Grant-in-aid, Sponsored projects



- Advanced technology solutions to national aerospace programmes
  *Fighter aircraft, gas turbine engines, defense systems, defense services, launch vehicles and satellites, space systems*
  Sponsored projects

- Civil aeronautics development (since 1990s)
  *Design and development of small and medium-sized civil aircraft - Promote a vibrant Indian civil aviation industry*
  Government funding, Industry partnership

Core competence at NAL spans practically the whole aerospace sector



NAL'S CORE STRENGTH IN COMPOSITES

CONCEPT TO CERTIFICATION

CUTTING-EDGE RESEARCH

PROCESS DEVELOPMENT

DESIGN & ANALYSIS

STRUCTURAL TESTING

MANUFACTURING

NON-DESTRUCTIVE EVALUATION

STRUCTURAL REPAIR

ADVANCED RESEARCH

STRUCTURAL HEALTH MONITORING

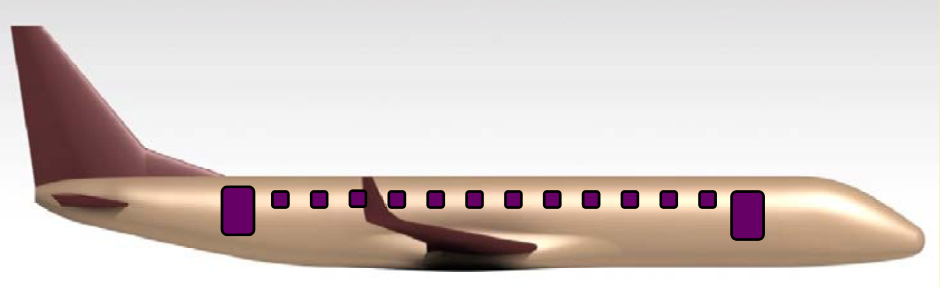
# Evolution of Composites at NAL

**Initial Development:**
**Bridge Deck Plates,**
**Radome Development,**
**DO-228 Rudder with**
**DLR Germany**

**2 Seater HANSA**

**LCA- Tejas**

**14 Seater SARAS**



**90-110 Seater NCA**

**1980-90 1993 2001 2004 2017**

# NAL's HANSA, A Light All-Composite Trainer Aircraft

Two-bladed constant speed Hoffmann propeller of diameter 1730mm.

- Length overall : 25 ft (7.6m)
- Wing span : 34.35 ft (10.47m)
- Empty weight : 550 Kg
- All-up weight : 750 kg
- Usable fuel capacity : 85 litres

Rotax 914F3 (turbo charged engine with 100 BHP max. continuous power @ 5500 rpm)

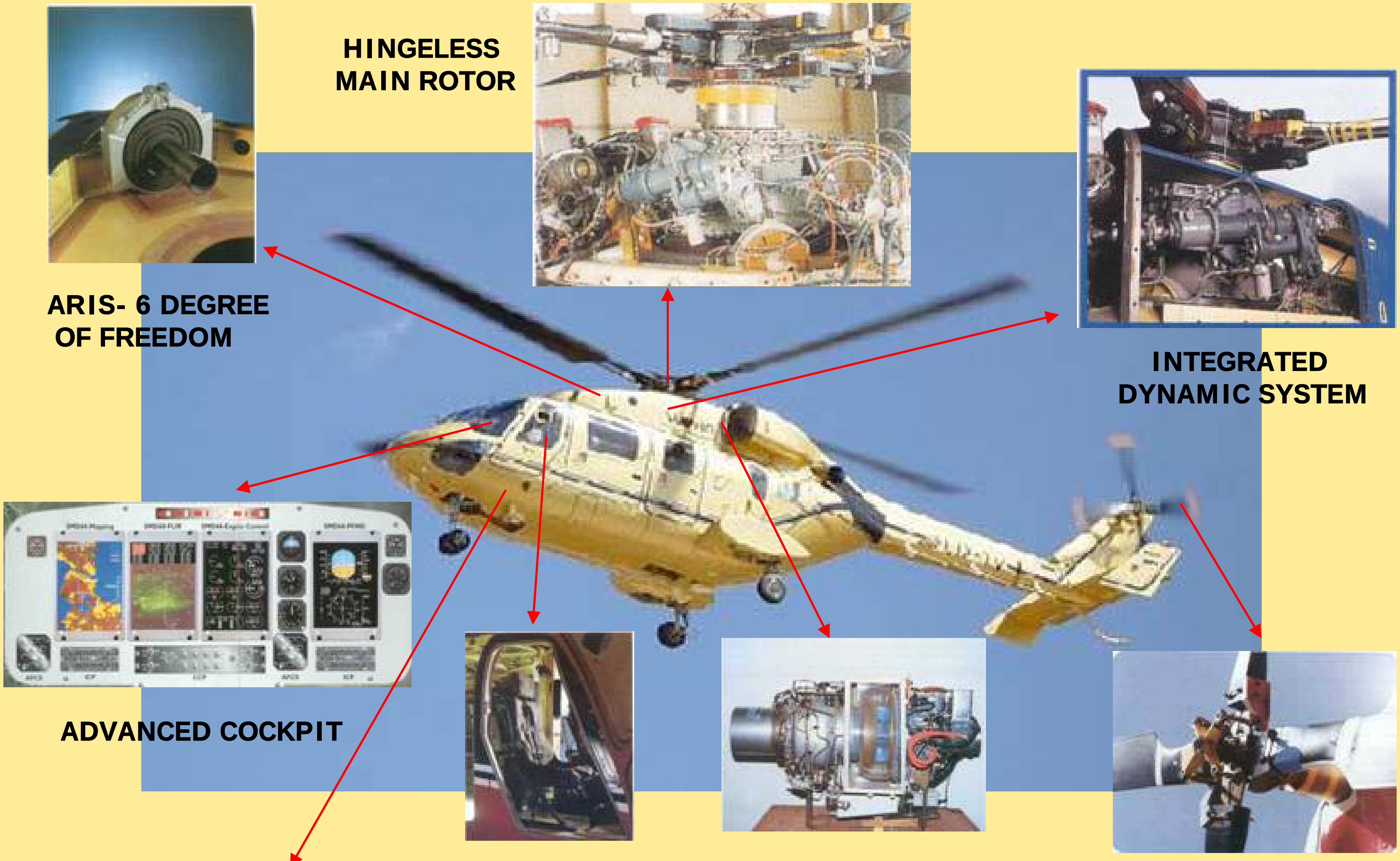
## Performance

- Stall speed with 20° flaps : 43 KIAS
- Max. cruise speed : 96 KIAS
- Max. rate of climb : 650 ft/min
- Endurance : 4 hours
- Landing distance : 1770 ft (540 m)
- Take-off distance : 1355 ft (415 m)

Certified under JAR-VLA in 2000

HAL

# Advanced Technology Features



ARIS- 6 DEGREE
OF FREEDOM

HINGELESS
MAIN ROTOR

INTEGRATED
DYNAMIC SYSTEM

ADVANCED COCKPIT

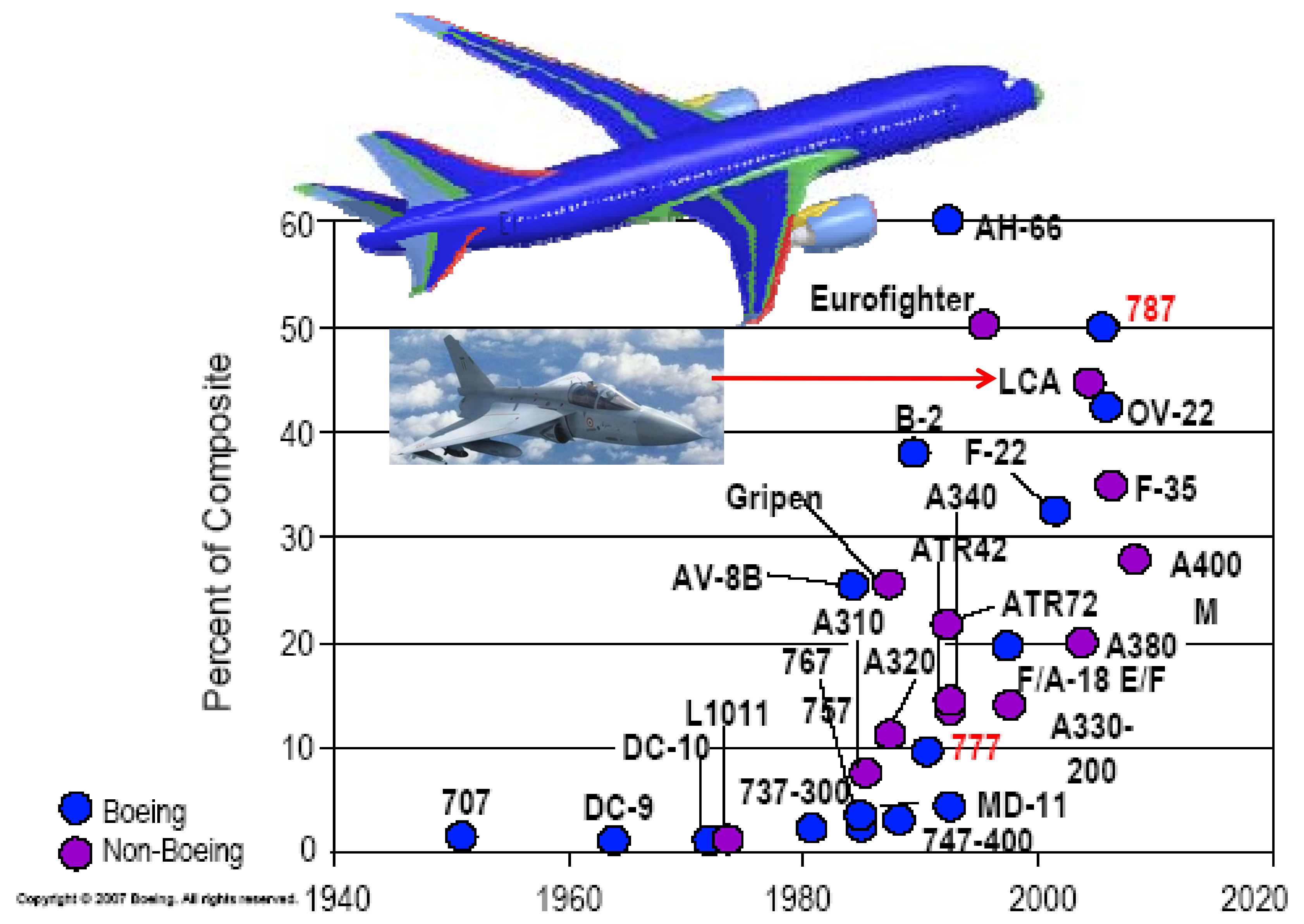
EXTENSIVE USE
OF COMPOSITES

CRASHWORTHY
CREW SEATS

MODERN ENGINE
WITH FADEC

BEARINGLESS
TAIL ROTOR

# India makes it to Global Composites Scene with LCA- Tejas Program



**Courtesy: Boeing**

# LCA - ROLES & SALIENT FEATURES

**Air Defence Roles**

- Point Intercept
- Escort
- Air Superiority

**Offensive Air Support**

- Close Air Support
- Interdiction

**Maritime Reconnaissance and Strike**

**Operational Mass : 9000 Kgs**
**Max. Mach No. : 1.8**
**Max. War Load : 4500 Kgs**
**Max. Altitude : 15 Kms**

# TECHNOLOGIES

**Unstable Configuration**
- High Agility & Maneuverability
- Control laws
- Advanced Carefree Maneuverability

**Advanced Materials (Composite Wing, Fin, Elevons, Fuselage, Rudder, Doors & Hatches)**
- Reduced Weight
- Increased Life
- Reduced Signature

**Digital Fly By Wire Flight Control System**

**Flat Rated Engine**
- Easy Role Change

**Advanced Avionics**
- Easy Role Change

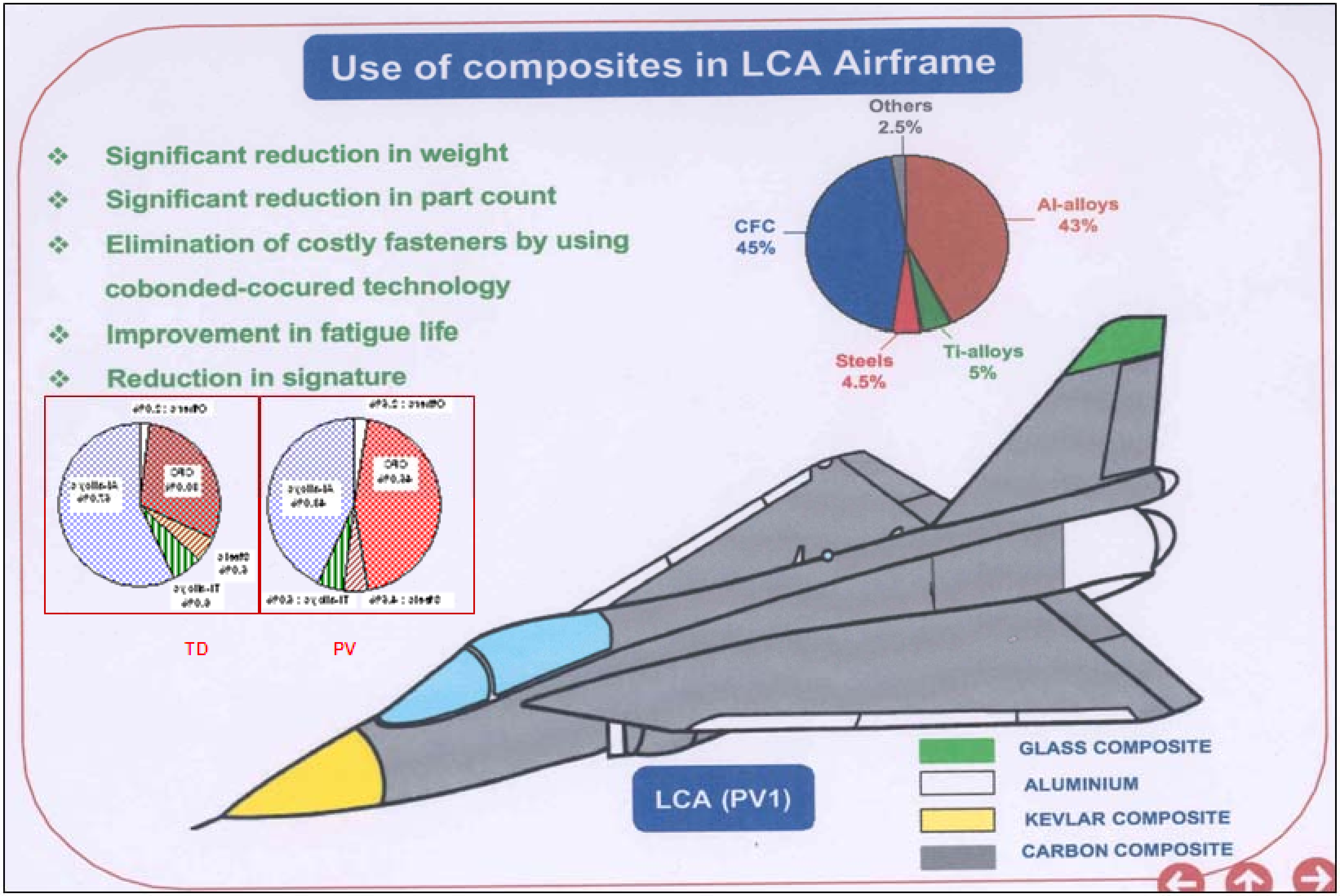
**Stealth**
- RCS
- IR

**Multi Mode Radar**
- Advanced Sensors

**Glass Cockpit**
- Reduced Pilot Load

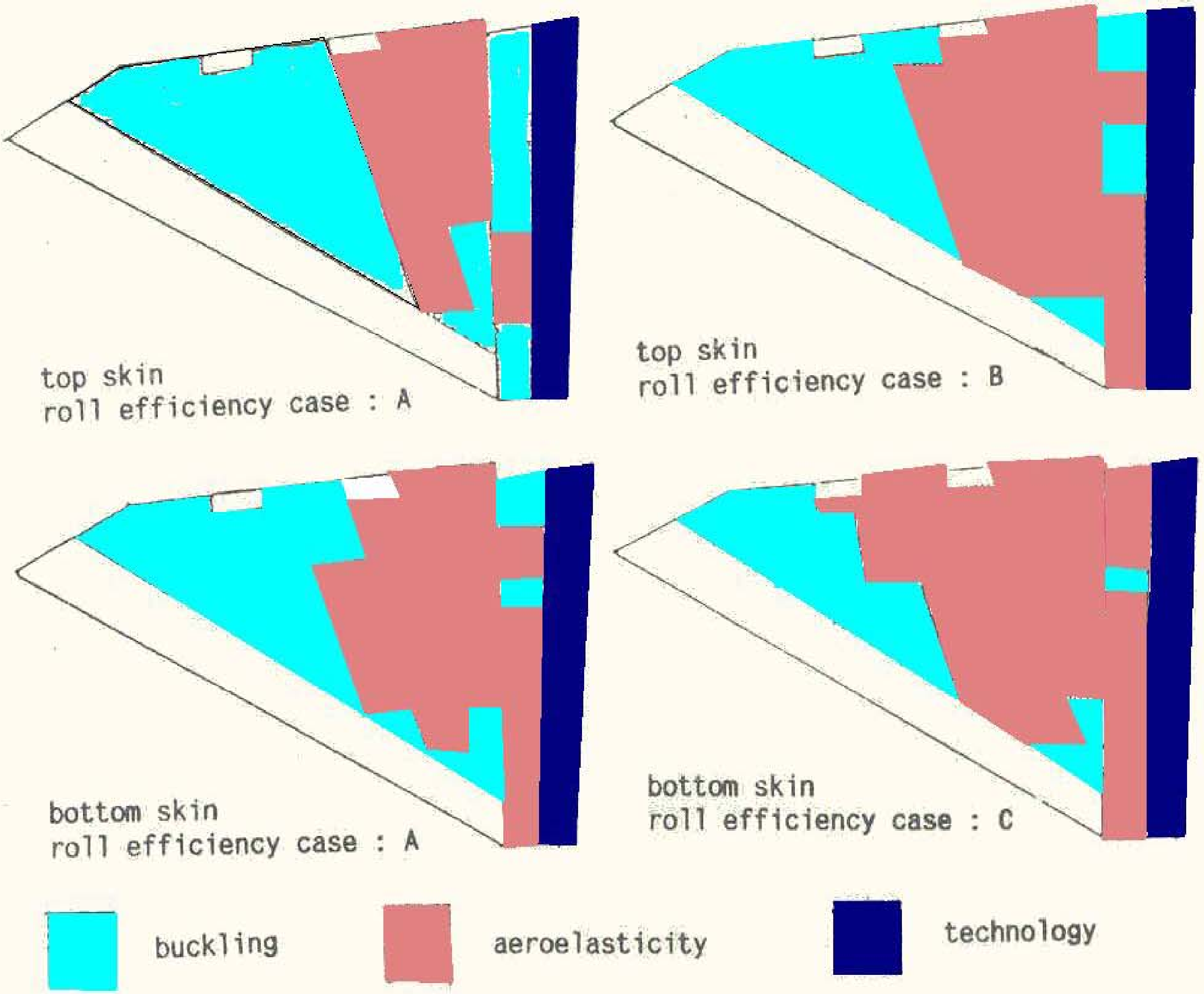
**General Systems**
- Carbon brake disc
- 4000 PSI Hyd System
- ECS for tropical Climate
- Utility systems

# Composites in the LCA Airframe



## Use of composites in LCA Airframe

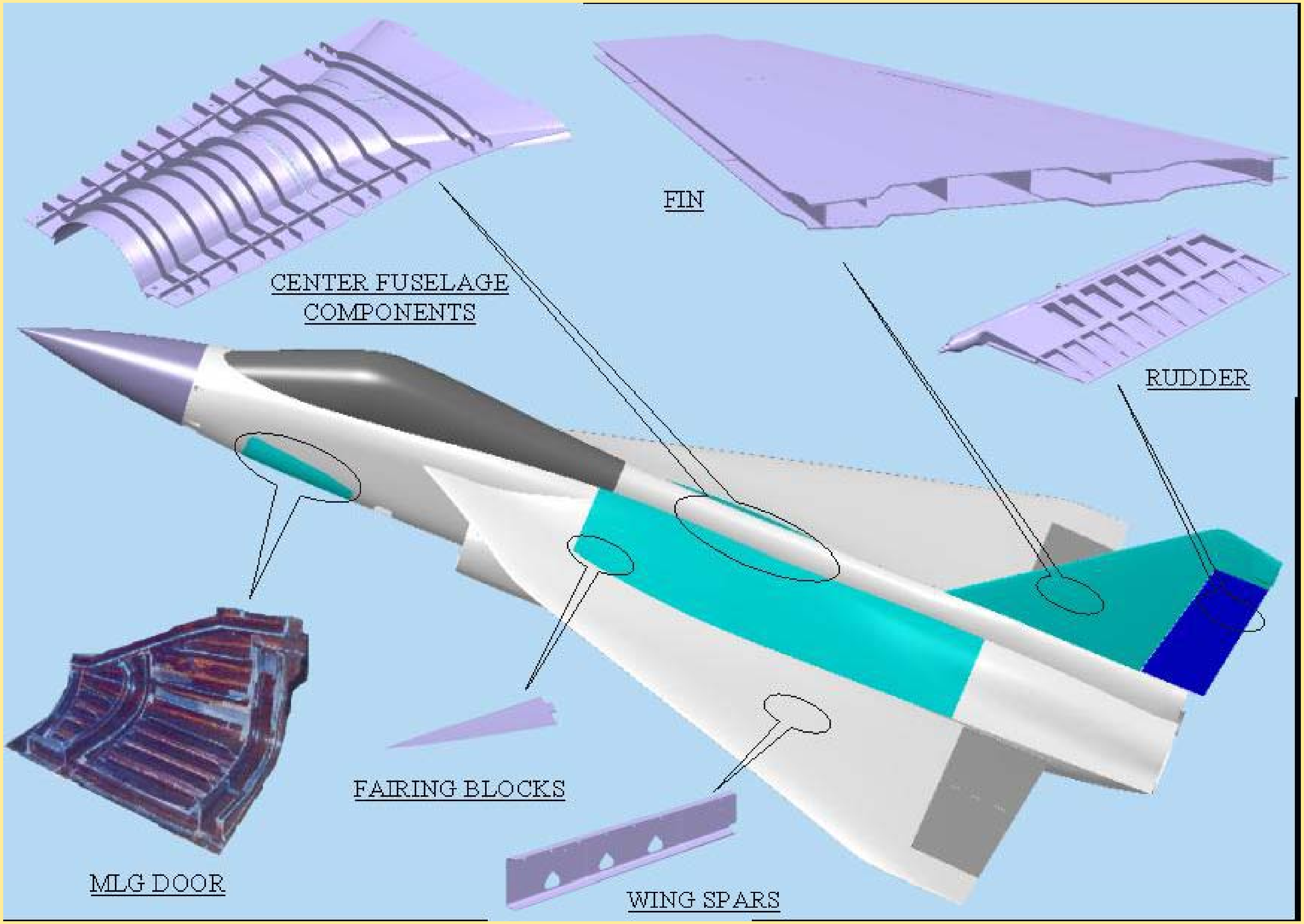
- Significant reduction in weight
- Significant reduction in part count
- Elimination of costly fasteners by using cobonded-cocured technology
- Improvement in fatigue life
- Reduction in signature



Optimisation constraint influence zones.

# Structural Optimization of Composite Wing Skins for Stress,Buckling, Aeroelasticity and Technological Constraints

# Composite Parts made for LCA-Tejas by NAL



45% by weight in composites

# Benefits of Integration through Cocuring

CSIR-NAL has developed Cocuring technology
within the country for
Light Combat Aircraft (LCA-Tejas) and SARAS aircraft

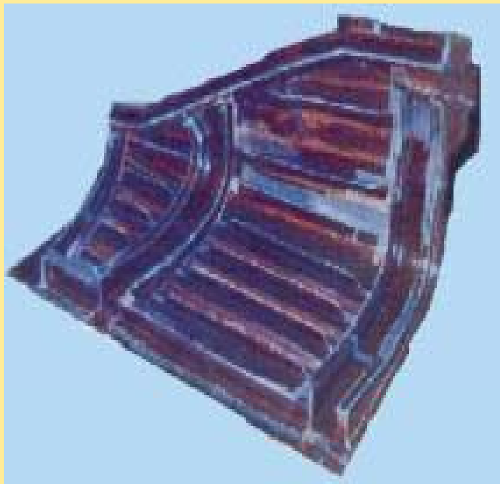
- No holes- No stress concentration
- Increased stiffness of structure
- Better aerodynamic surface
- Reduced assembly time
- Weight saving
- No fuel leakage

# NAL developed composites parts in LCA Tejas

Fin

Fin inner details

- Integral rib-skin cocured construction
- Resulted in weight savings of 35 % and a 20% weight reduction in modified rudder
- Fabrication done using prepregs with a hybridization of tooling technologies like tape winding and dissolvable core technology
- Cost reduced by about 30 %

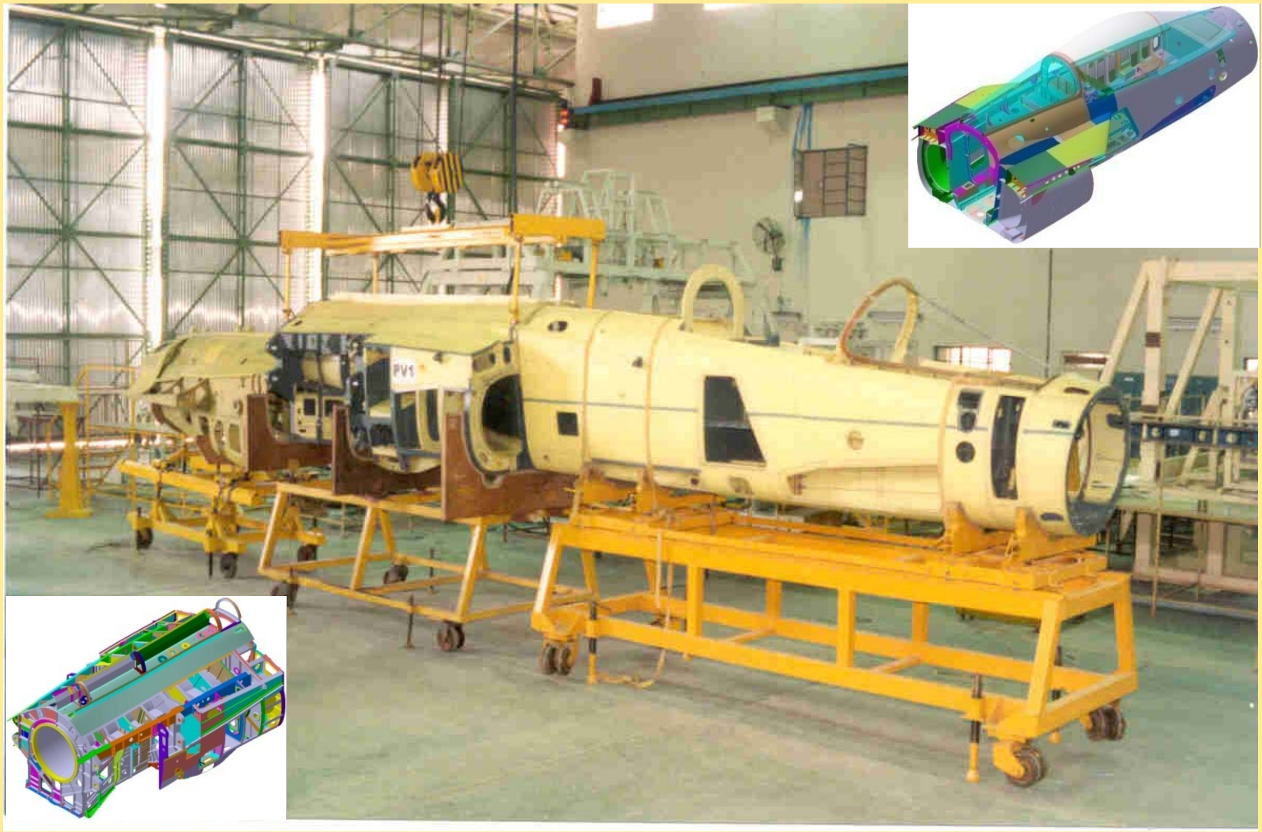


MLG Door

Rudder

Torque shaft

# NAL developed composites parts in LCA Tejas



Fuselage Top Skin

Air Channel Dividing Wall

Co-cured CFC Circular Duct

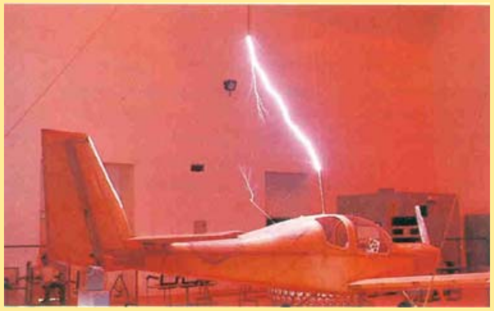
# LCA CFC Wing Assembly

# TEST FACILITIES DEVELOPED FOR LCA


Composite Lay-up Shop


Autoclave


C-Scan


Lightning test rig


Structural Coupling Test

Test Facilities


Main Airframe Static Test

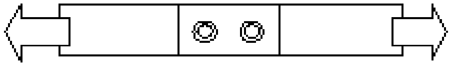

Ground Vibration Test


Half Wing Test

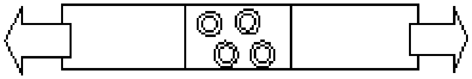

Full Aircraft Test

# Feature Level Testing for LCA

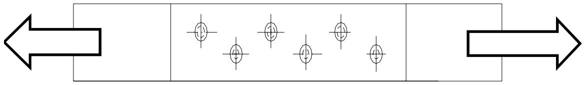
- **Fatigue testing for 5 life cycle**
- **Environmental aging**
- **Static testing under Hot Wet**



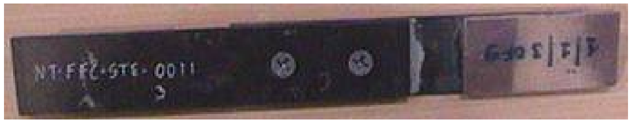
**CFC-CFC joint**

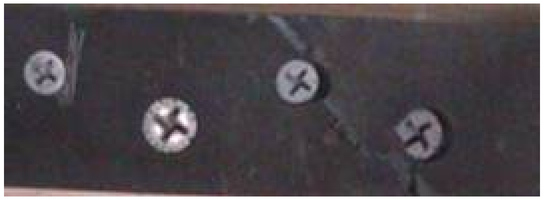


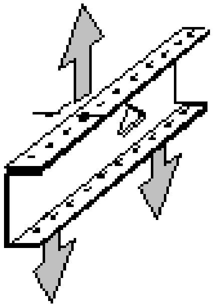
**CFC-Metal joint I**



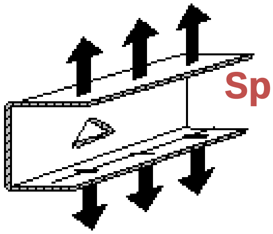
**CFC-Metal joint II**



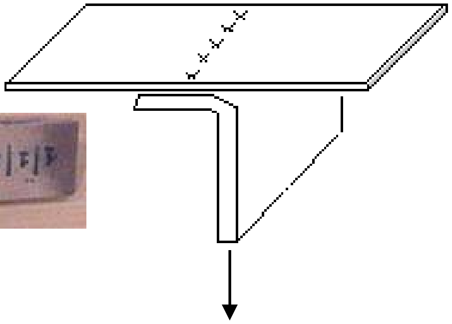




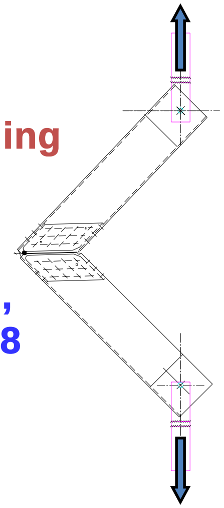
**Spar-3 pt. bending**



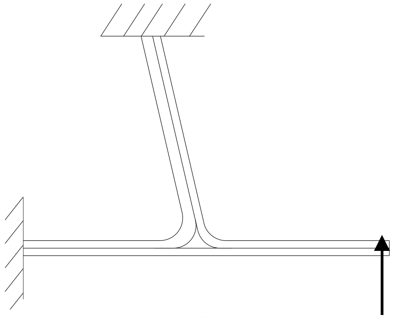
**Spar opening**



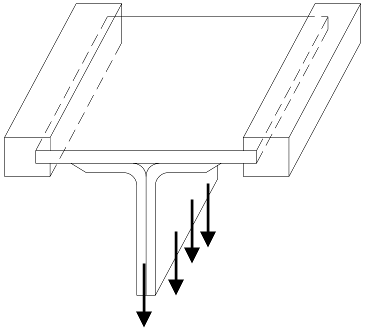
**Skin-Spar Joint**



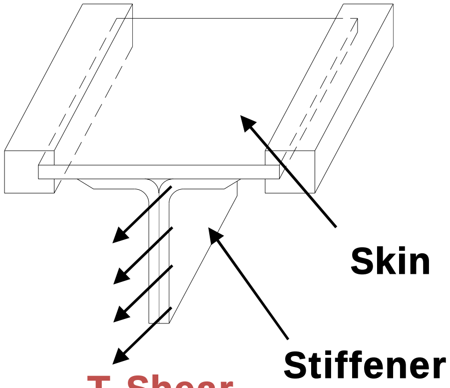
**L-Joint, BLK#18**



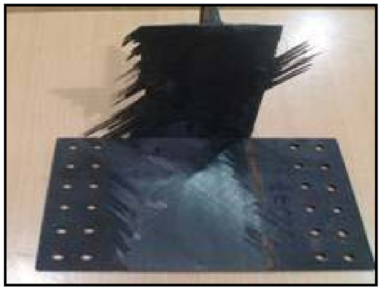
**Y-Joint, Circular Duct**



**T-**

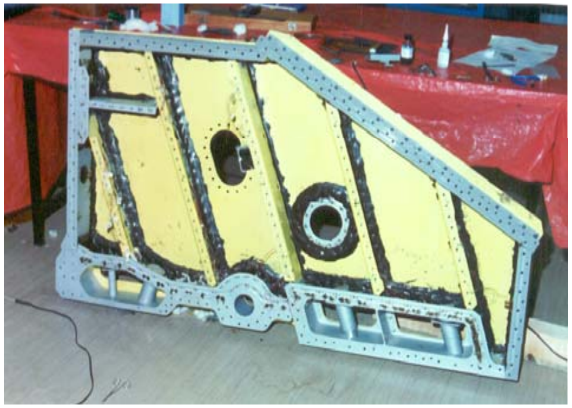


**T-Shear**



WING ROOT FITTING BOX - DRY ASSEMBLY & FINAL ASSEMBLY

WING BUCKLING TEST BOX



WING FUEL TANK
SEALING TEST BOX

O/B Elevon test box

- **Fatigue and burst pressure testing of Drop Tank Nose cone**

# Testing of LCA Wing

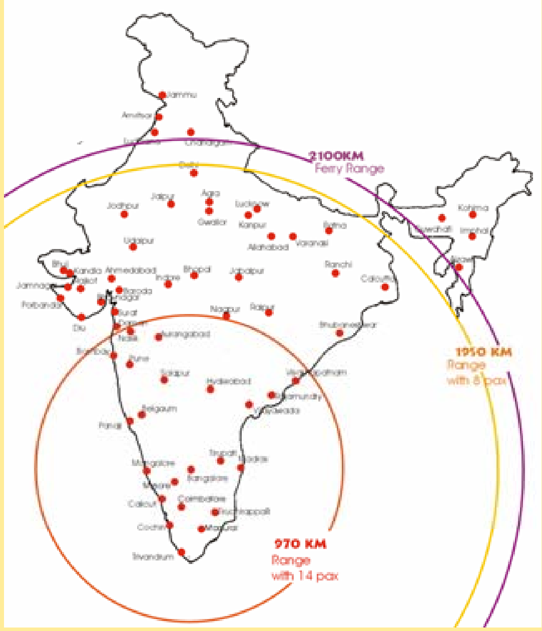
- FLEXIBLE TEST RIG TO SIMULATE STIFFNESS EFFECTS
- ISOSTATIC EQUILIBRIUM SYSTEM
- INSTRUMENTED REACTIONS
  SIMULTANEOUS EXTERNAL & REACTION LOADING

# Development of a Light Transport Aircraft

## 14 seater multi-role LTA - SARAS

- Hybrid (metal + composite) airframe
- CFC flaps, control surfaces, fairings
- P&WC PT6A-67A turbo-prop engine
  - 1200 SHP
- 2.65ϕ (5 bladed) constant speed propeller

- Max. cruise speed : 550 km / h
- Max. cruise altitude : 9 km
- Max. R/C, ISA, SL : 700 m / min.
- Endurance : ~ 5h
- T.O. distance, ISA, SL : 700 m
- Landing distance, ISA, SL : 850 m



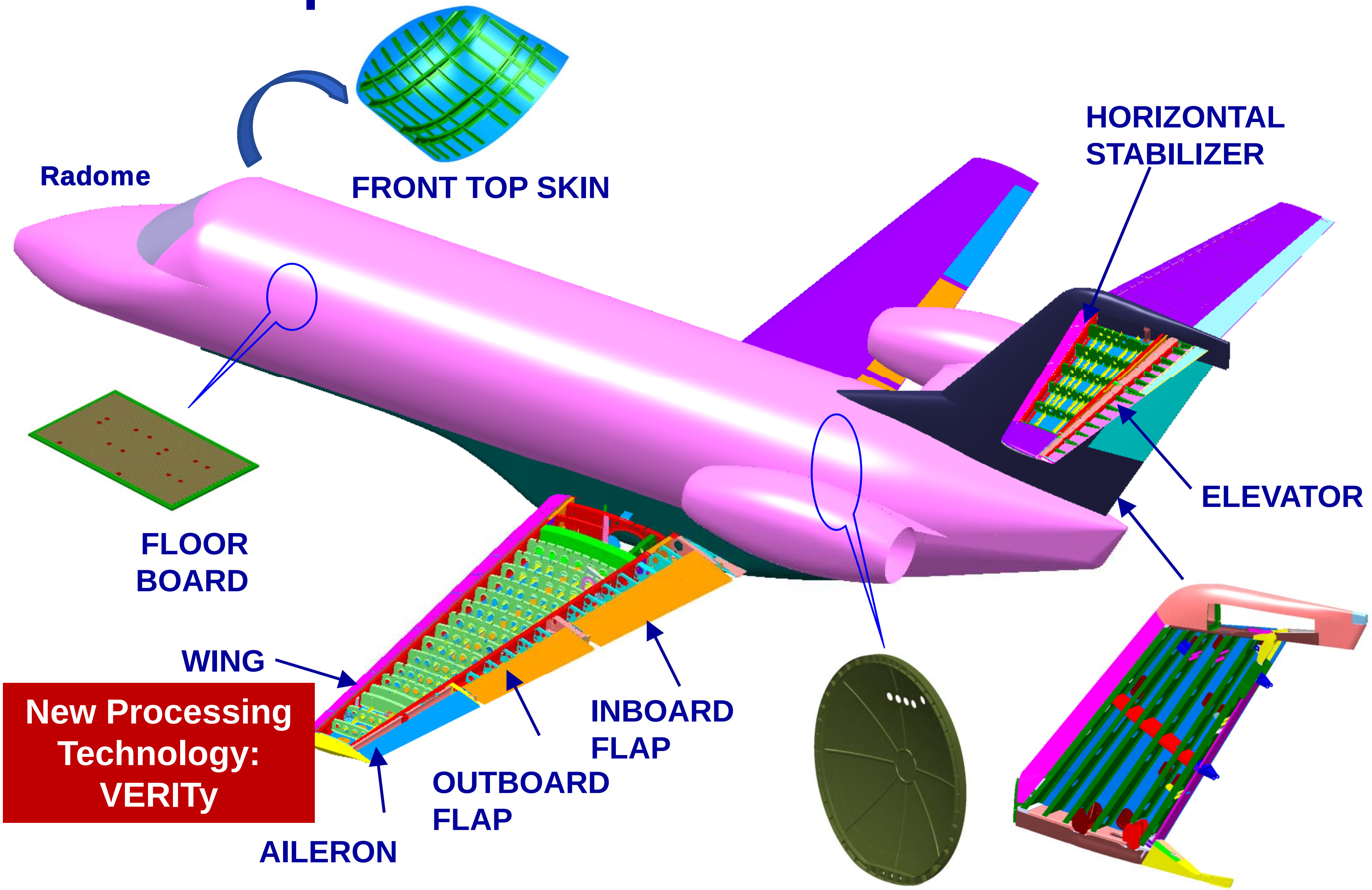
**Design to meet FAR-23 requirements**

# Materials used for LCA and SARAS programmes

1. **AS4/914 Prepreg materials from Hexcel composites Pvt Ltd; 180 deg C curing systems; Dry $T_g$ =175 deg C**
2. **Unidirectional fabric from Hexcel Composites and Resin from Axson France for the VERITy process; 80 deg C cure followed by 180 deg C post cure: Dry $T_g$ of 145 deg C**
3. **Rohacell foam for stringers and access covers**

**VERITy process mechanical properties within 2 % of prepreg properties**

# Composite Parts in SARAS Aircraft



**New Processing Technology: VERITy**

**35% by weight in composites**

# HT Components of SARAS

Cocured Inter Spar Box with Bottom Skin With 2 Spars, 11 Ribs, 7 Stringers

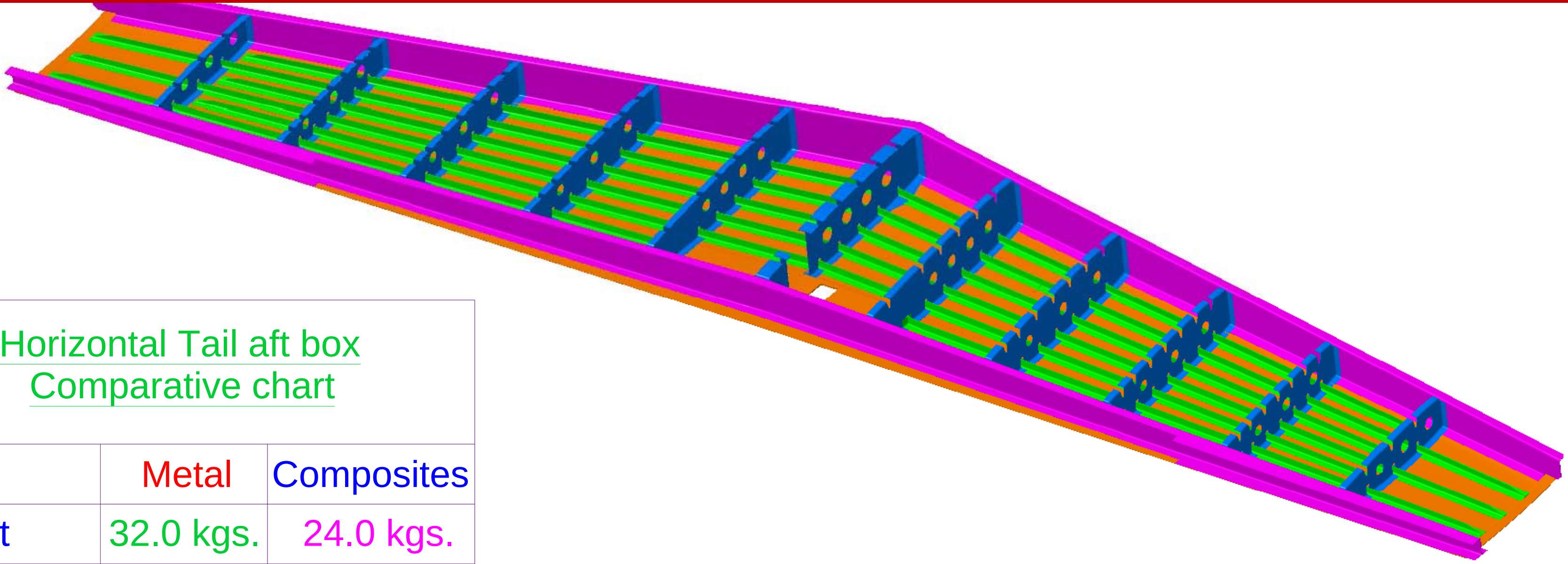
Cocured Top Skin with Stringers

**Size: 5.5mx 1m**

HT Tip Cocured with Stringers

| | Metal | Composite |
|---|---|---|
| Weight | 92 Kg | 70 Kg (24%) |
| No. of parts | 243 | 11 |
| No. of Fasteners | 10,500 | 2900 |

# Horizontal Tail of SARAS: Cocured Bottom Section



| Horizontal Tail aft box<br>Comparative chart | | |
|---|---|---|
| | Metal | Composites |
| Weight | 32.0 kgs. | 24.0 kgs. |
| No. of parts | 75 | 1 |
| No. of fasteners | 5200 | Nil |
| Assembly | 4 weeks | Nil |

**Dimensions: 5.5mx1m. The skin is co-cured with stringers, ribs and spars.**

# Tooling Concepts

**Basic outer CFC Mould**

**Internal Flexible tools**

**Skin stringer Integration**

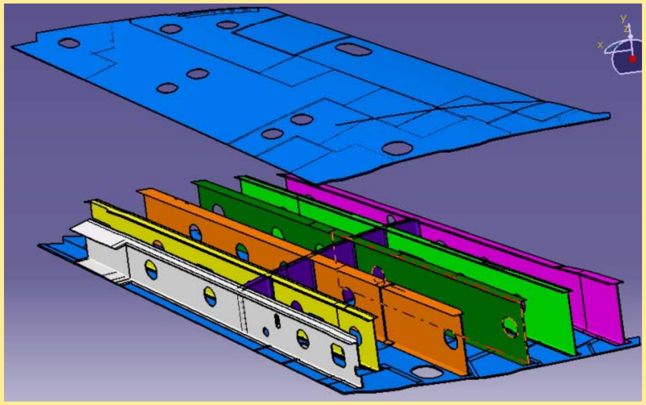
**Skin stringer spar Integration**

**Final bag for curing**

# Vertical Tail of SARAS

Cocured Inter Spar Box with 6 Spars and a Mid Rib

**Size: 2.8mx1.8m**



| | Metal | Composite |
|---|---|---|
| Weight of IS Box | 65 Kg | 50 Kg<br>(23%) |
| No. of parts | 130 | 01 |
| No. of Fasteners | 1100 | 0 |
| Total VT weight | 126 Kg | 101Kg<br>(20%) |

**Master Model For Mould**

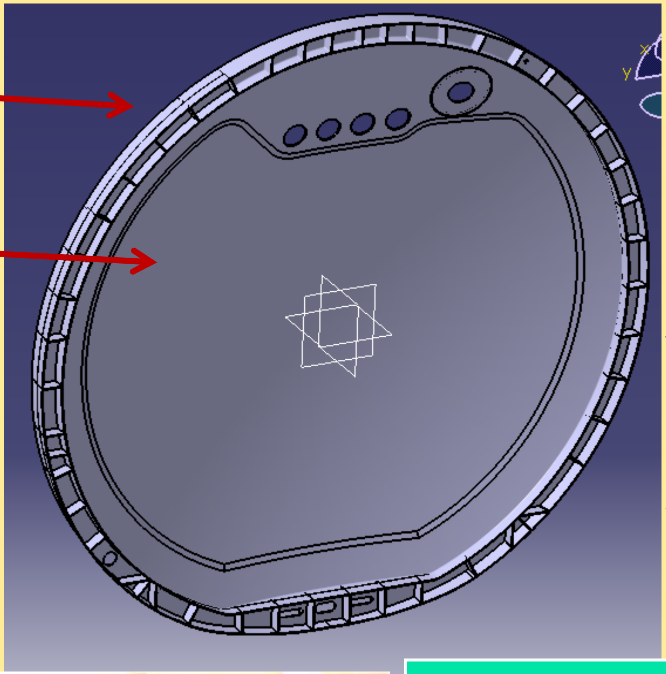
**Rh & LH Mould Assembly**

**Cured Component**

**Skin Bonded With Spars & Mid Ribs**

**Final Bagging for Curing**

# Cocured CFC Pressure Bulkhead of SARAS



**1.8 m diameter dome having a depth of 175 mm, with thickness varying from 1.2 to 3.00 mm**

**Accuracy of outer contour and gusset spacing = + / - 0.5 mm**

| | Metal | Composite |
|---|---|---|
| Weight | 34 Kg | 17 Kg (50%) |
| No. of Fasteners | 700 | 0 |

All the above were fabricated using Prepregs and Autoclave Moulding Technology

Challenge: How to cut costs???

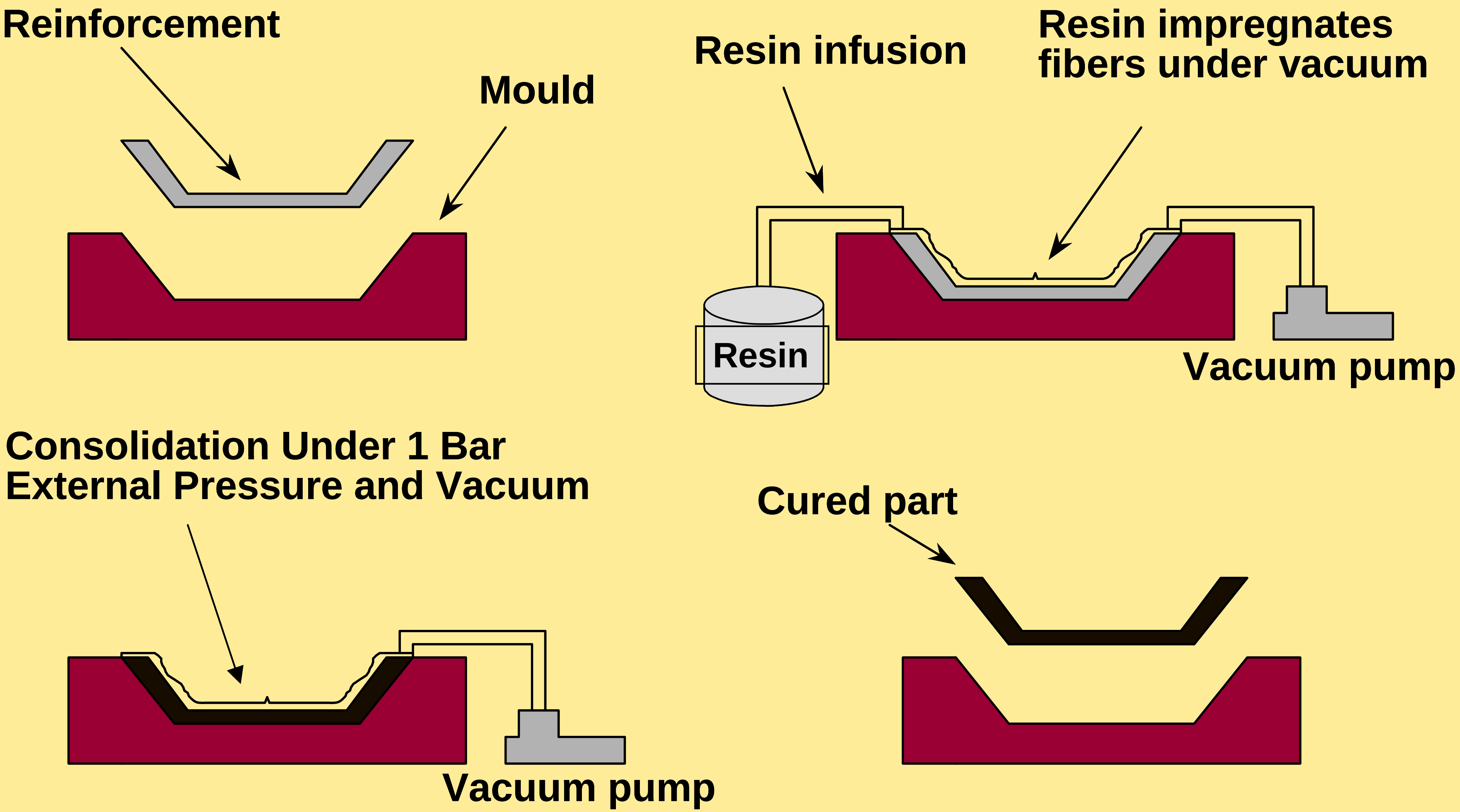
One solution- Liquid Moulding Technology

# LCM and its Variants

- RTM (Resin transfer moulding)
- RIM ( Resin injection moulding)
- VARTM ( vacuum assisted resin transfer moulding)
  - SCRIMP ( Seeman composite resin infusion moulding process)
  - DCVRTM (Double chamber vacuum resin transfer moulding)
  - FASTRAC ( Fast remotely activated channels)
- RFI ( Resin Film Infusion)
- SRIM ( Structural reaction injection moulding)

**VERITy ( Vacuum enhanced resin infusion technology) Developed by NAL**

# VERITy Process



Reinforcement

Mould

Resin infusion

Resin impregnates
fibers under vacuum

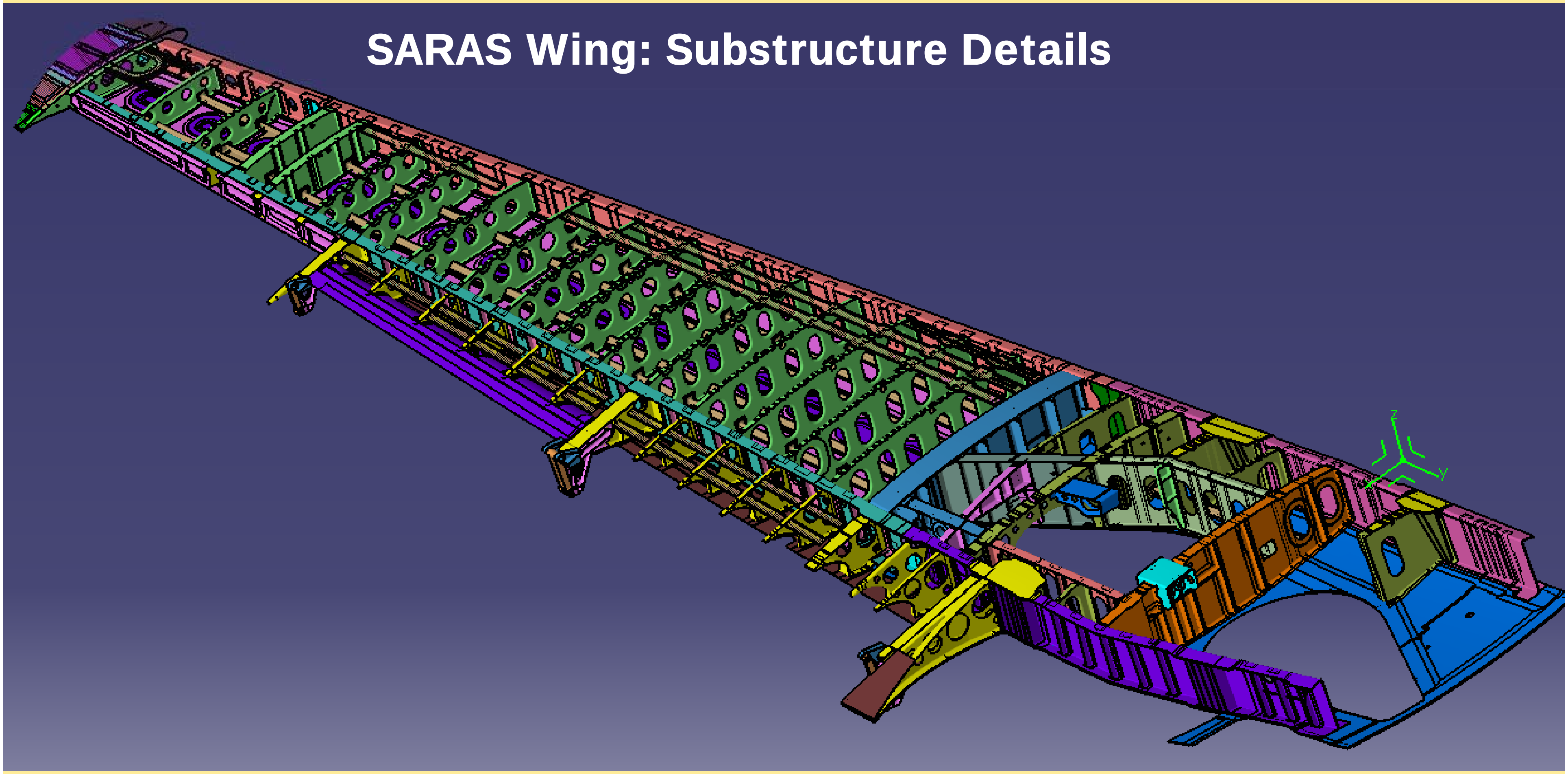
Vacuum pump

Consolidation Under 1 Bar
External Pressure and Vacuum

Vacuum pump

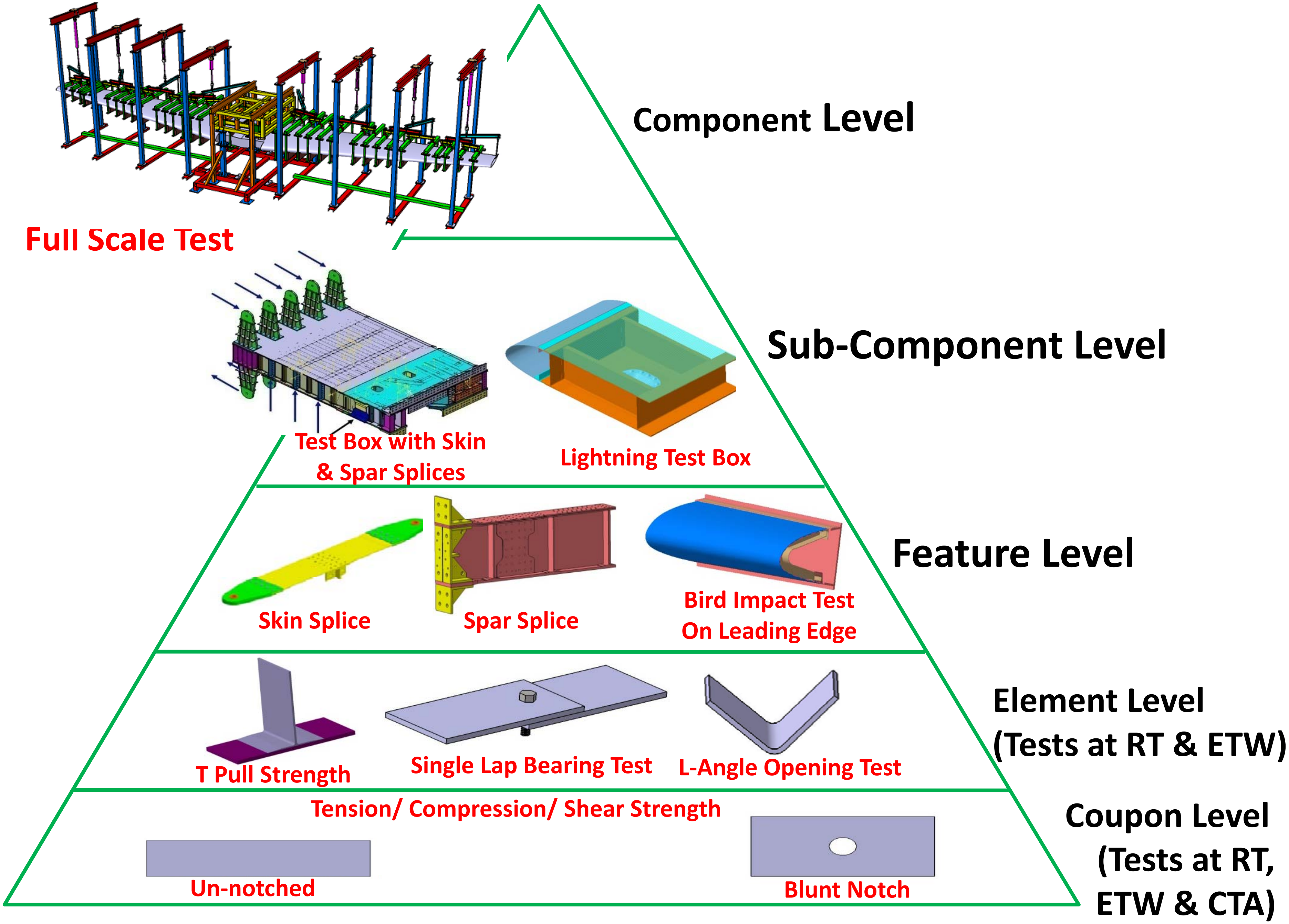
Cured part

# Development of Integrated Wing Structures at NAL using VERITy Process



SARAS Wing: Substructure Details

# Building Block Approach for Composite Wing of SARAS Aircraft



Component Level

Full Scale Test

Sub-Component Level

Test Box with Skin & Spar Splices

Lightning Test Box

Feature Level

Skin Splice

Spar Splice

Bird Impact Test On Leading Edge

Element Level (Tests at RT & ETW)

T Pull Strength

Single Lap Bearing Test

L-Angle Opening Test

Coupon Level (Tests at RT, ETW & CTA)

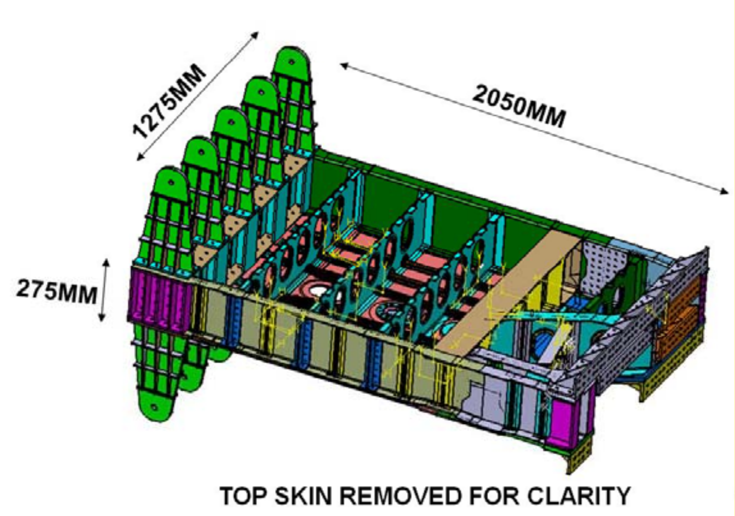
Tension/ Compression/ Shear Strength

Un-notched

Blunt Notch

# Box Level Studies using VERITy : SARAS Wing Test Box

**Structural Details of Wing Test Box**



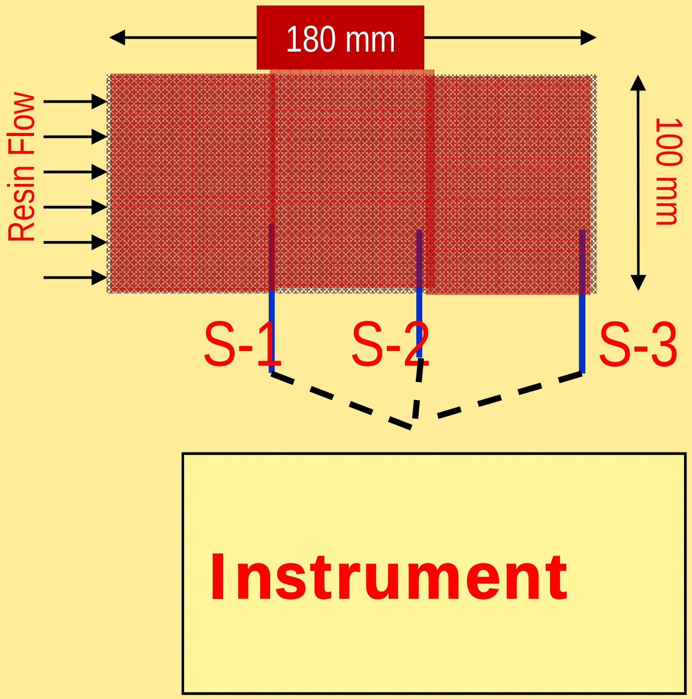
TOP SKIN REMOVED FOR CLARITY

**Cocured bottom box**

**Assembled box undergoing Static Testing**

# Flow Sensor Development

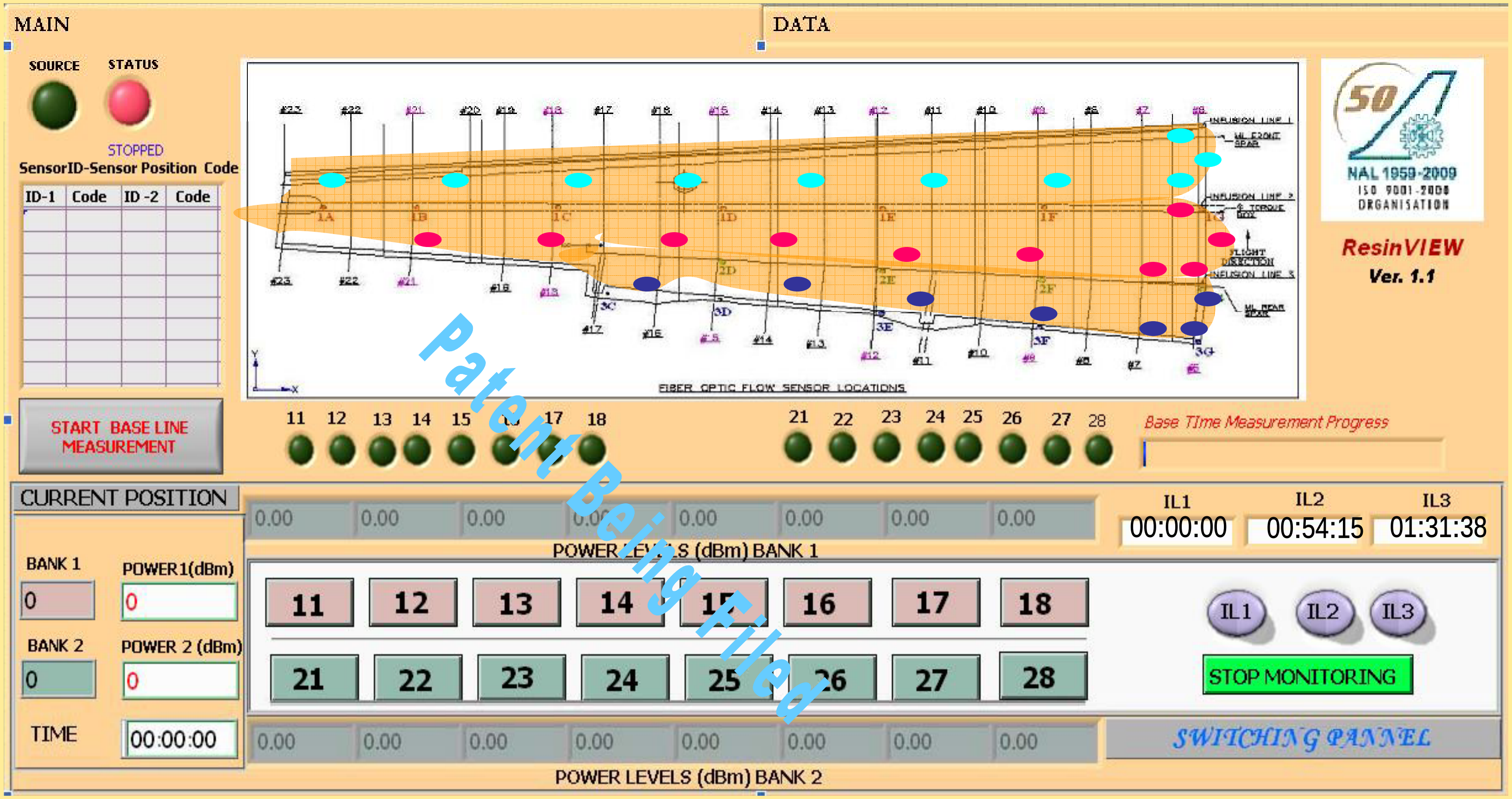
# Fibre Optic Flow Sensor



| Process | Sensor – 1 | Sensor – 2 | Sensor – 3 |
|---|---|---|---|
| After Embedment | a | a | a |
| Before Infusion | b | b | b |
| Resin crossed Sensor – 1 | c | b | b |
| Resin crossed Sensor - 2 | c | c | b |
| Resin crossed Sensor - 3 | c | c | c |

# *ResinVIEW* Software Development

- **LabVIEW & MATLAB based modular code development for real time resin flow.**
- **Enables sequential infusion based on *NetSense* feedback.**
- **Resin arrival time information important for future infusion strategy and modeling.**
- **Low cost reusable sensor & modular open system architecture system.**



BANK 1: 0
POWER1(dBm): 0
BANK 2: 0
POWER 2 (dBm): 0
TIME: 00:00:00

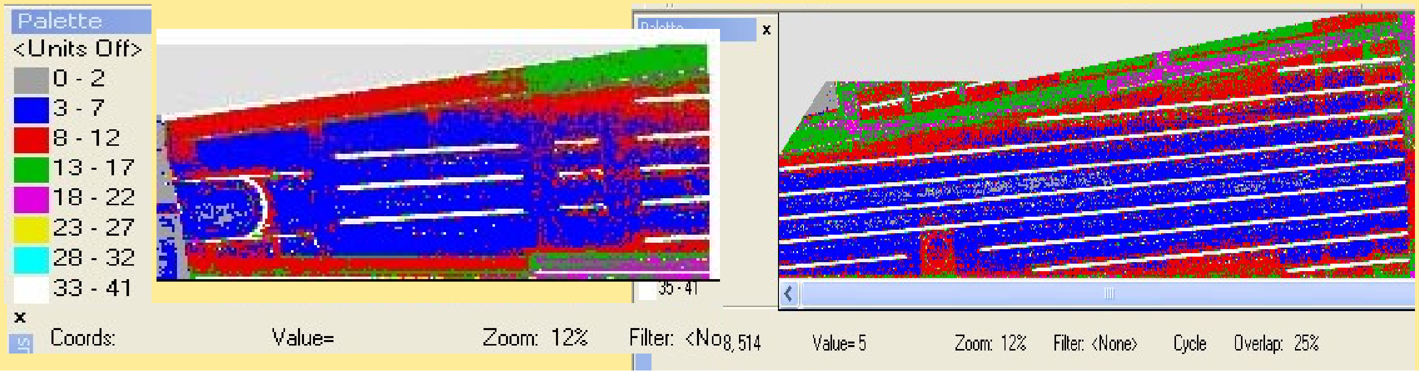
IL1: 00:00:00
IL2: 00:54:15
IL3: 01:31:38

# SARAS Wing Components made using VERITy


Top Skin 6mx2m Inner Side


Top Skin 6mx2m Outer Side

**Thickness varies from 1.7 mm to 8.6 mm**
**Thickness of hat stringer is 1.36 mm**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- 🟥 8 - 12
- 🟩 13 - 17
- 🟪 18 - 22
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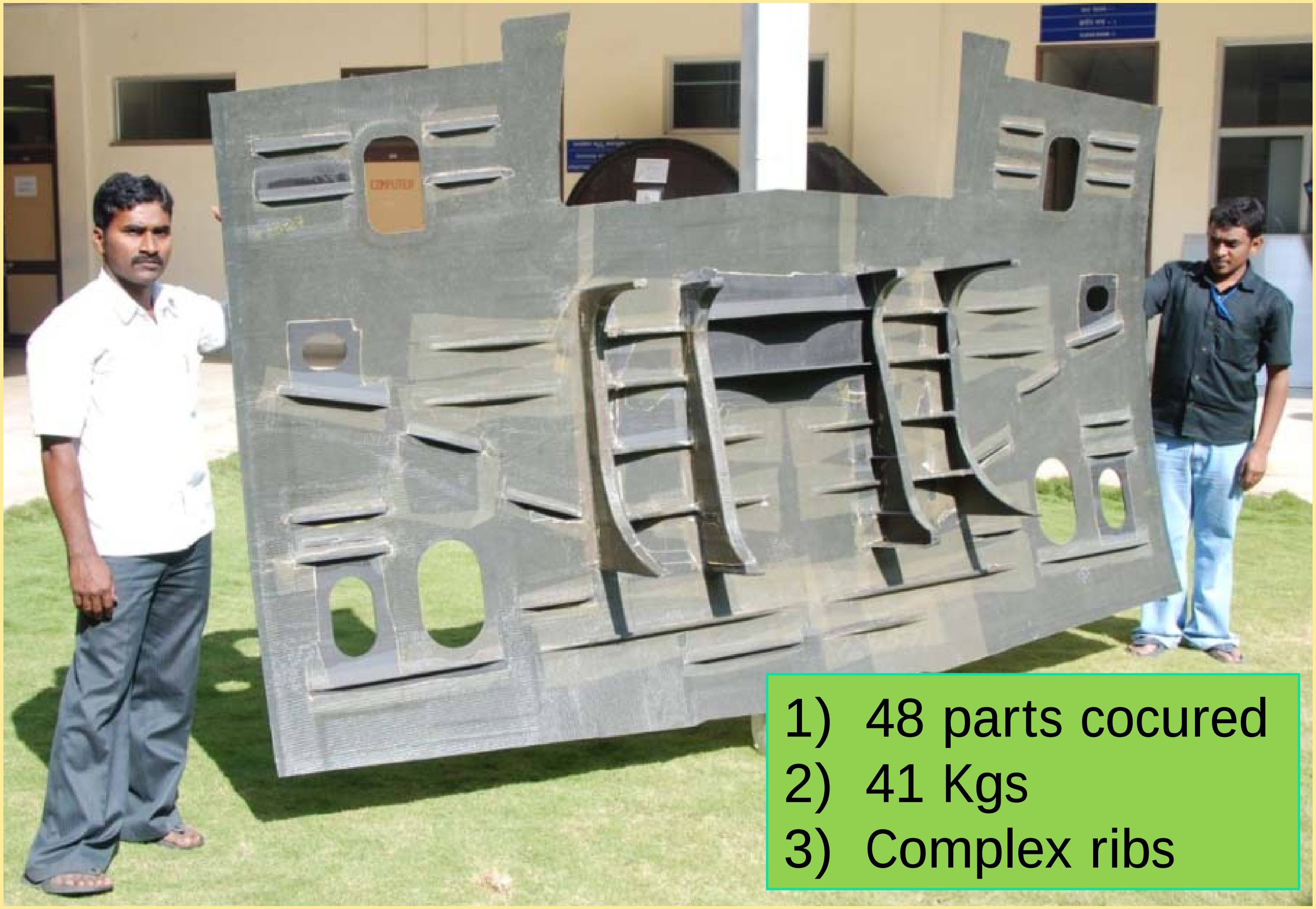
- ⬜ 28 - 32
- ⬜ 33 - 41

Coords: Value= Zoom: 12% Filter: <No

35 - 41

8, 514 Value= 5 Zoom: 12% Filter: <None> Cycle Overlap: 25%

# Centre Top Skin



1) 48 parts cocured
2) 41 Kgs
3) Complex ribs

# SARAS Outboard Wing: Integrated Wing Concepts
## Cocured Coinfused Wing Bottom Skin with Substructure

**@ 300 parts Cocured in one shot**

**Cocured Ribs and Stringers**

**Cocured Rib with Gussets**

**Cocured Spar with Gussets**

# Tool Design

## Infusion Strategy

- Infusion strategy plays a key role, especially in components where the thickness and geometry of a component varies from section to section and a lot of features are to be co-cured.
- In large structures, sequential and/or parallel infusion strategies need to be employed, as there is a limited time available to complete the infusion.

## Vacuum Bagging Technology

- This is yet another aspect that needs to be dealt with in order to get a complex co cured component that meets the required specifications of compaction and dimensions.
- Care has to be taken to avoid any ‘Bridging’ at the radius and proper vacuum communication needs to be maintained throughout the cure of the component to ensure proper consolidation of the part.

# Fabrication Methodology

## Cocured Component

Master Model

**Finished Master Model**

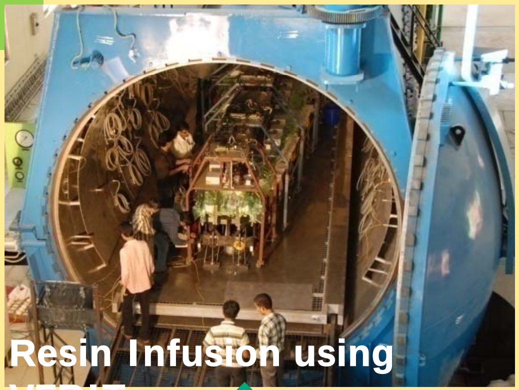
Mould Layup

Finished Mould

Internal Tool Development

Locator Development

Preform Layup & assembly



Resin Infusion using VERITy

5.8 m

1.8m

# Trial Assembly of Wing

# Manufacturing & Assembly Issues

1) **Tool corrections for spring forward behaviour of composites is trail and error method and difficult for complex composite parts.**

2) **Thickness growth -2% to +8% in composites are lead to assembly fitment problems.**

3) **Maintaining the fiber direction during the lay up of complex component is difficult issue.**

4) **Out of plane loads are important when laminate is assembled with mechanical fasteners. If fastener pulling forces are too high, Composites experience delaminate & possible loss of structural integrity.**

5) **Presence of ply drops ,lap joints (BD Composites) and their variability in thickness results in higher thickness shim when mating with machined metallic members during the assembly.**

# Operational Issues with composite Structure

1) **Removal of Panels: As composite have low wear resistance as compared to metal ,holes are elongating as panels are removed frequently. In case of fuel tanks, fuel is leaks due to this elongates.**

   **Remedial: Use metallic sleeves/bushes for these holes**

2) **Delaminations are occurring during drilling & other machining operations even for minor deviation in the process like improper support during drilling and direct drilling of higher diameter holes.**

3) **As composites are brittle , even minor deviations in the contour is difficult during assembly.**

4) **The inspection time required for composite structures is more as compared to metallic structures. It is difficult to inspect the delamination/damages other than through the ultrasonic inspection. Some impact damage are noticed only during schedule maintenance period.**

# Operational Issues with composite Structure *Contd…*

5) More precautions have to taken while walking on composite parts like wing as it leads to delamination/ debonding when there is local hard points.

6) Edge damages are occurs frequently when composites doors/panel are removed from the aircraft & during installation.

7) Fuel leaks are occurring during the service (1-2 years) due to resin starvation zones even though it is cleaned structurally.

8) Modification of composite structures due to operation requirements like installation of new equipments etc, is difficult as compared to metal.

# Damage Tolerance Studies towards certification

# Aspects

- Damage threats & classification
- Aspects of damage tolerant design
- Airworthiness requirements
- Structure substantiation
  - Building block approach
  - Test Sequence/Protocol

# Damage Threats

- **Processing anomalies and in-process handling damages**
- **In-service damages: E.g. Tool drops, ground vehicle impacts, bird strikes, runway debris, uncontained engine rotor failure etc.**
- **Environmental damages: E.g. Hail, Lightning strike, Moisture ingression, UV radiation etc.**
- **IATA survey: Ground handling and moisture intrusion are most common sources of damage**

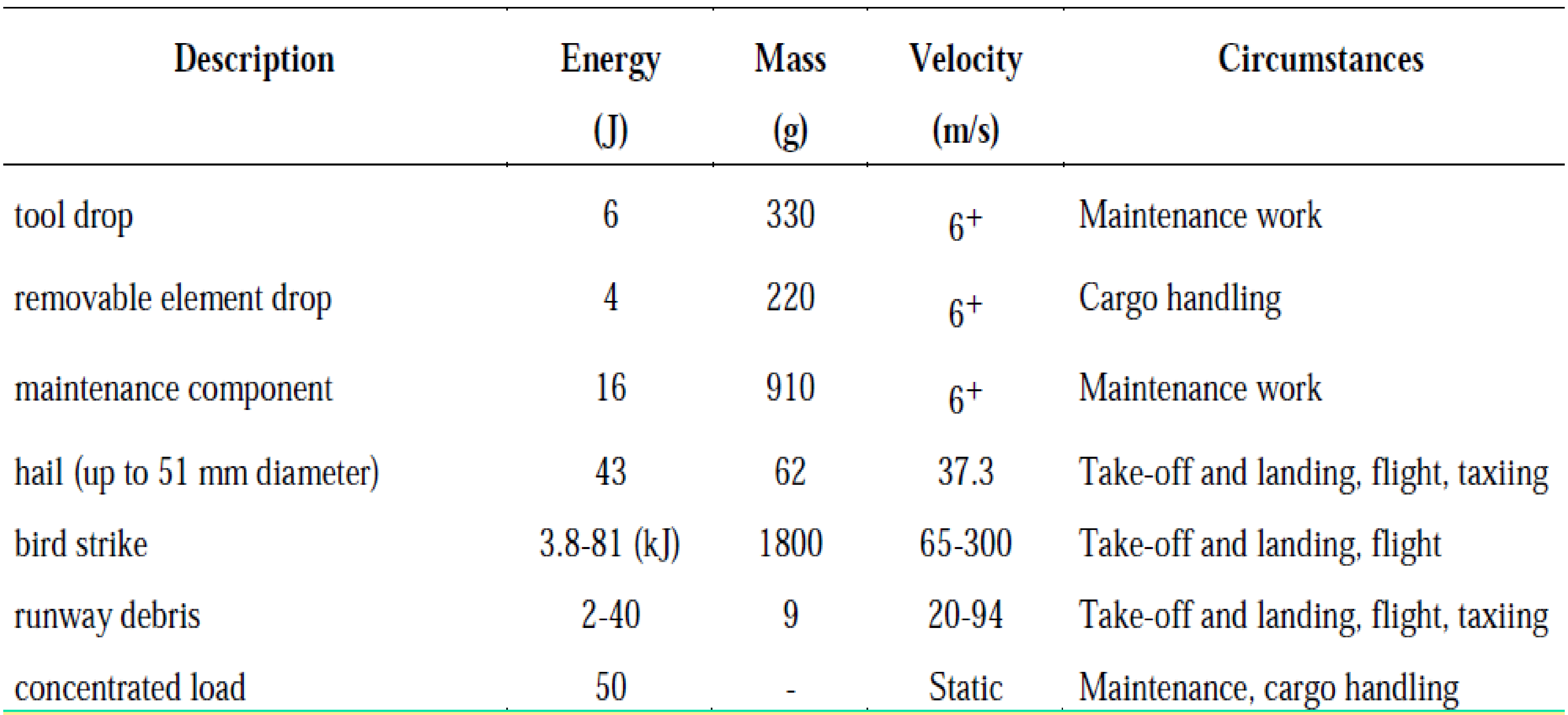
# Damage classification

- **Barely visible impact damage (BVID)**
  - Small damages that may not be found during inspection
  - Typical dent depth 0.5 to 1 mm
- **Visible impact damage (VID) and penetrations**
- **Scratches, gouges, surface and coating inspections**
- **Fluid and moisture ingress**
- **Delamination, debonds etc.**
- **Thermal damage; Chemical damage; Others**

# Why should we care about impact damage?

- **Laminated composites have very low shear strength, hence are susceptible to impact damage**
- **Invisible internal delamination and BVID are most detrimental and leads to low allowable load/strain in design**
- **Impact damage is accommodated by limiting the design strain – leading to significant conservativeness**
- **Safety & economical reasons – damage has to be detected and repaired during inspection and maintenance**

# Typical Energy Levels for Projectile Impact



| Description | Energy (J) | Mass (g) | Velocity (m/s) | Circumstances |
|---|---|---|---|---|
| tool drop | 6 | 330 | $6^+$ | Maintenance work |
| removable element drop | 4 | 220 | $6^+$ | Cargo handling |
| maintenance component | 16 | 910 | $6^+$ | Maintenance work |
| hail (up to 51 mm diameter) | 43 | 62 | 37.3 | Take-off and landing, flight, taxiing |
| bird strike | 3.8-81 (kJ) | 1800 | 65-300 | Take-off and landing, flight |
| runway debris | 2-40 | 9 | 20-94 | Take-off and landing, flight, taxiing |
| concentrated load | 50 | - | Static | Maintenance, cargo handling |

**Courtesy: Impact on aircraft, Marcílio Alves et.al.**

# Aspects of Damage Tolerant Design

- **Residual strength capability**
  - Residual strength of several damage scenarios to be demonstrated after application of repeated loading
- **Damage growth characterization**
  - “No initiation – No growth” approach is usually adopted
- **Usual design practices**
  - Multiple/Redundant load paths
  - Materials with slow crack growth rates
  - Design for good inspectability

# Development of Composite Structural Repairs & Validation

- Design, Fabrication, Testing and Validation of Composite Repair Schemes

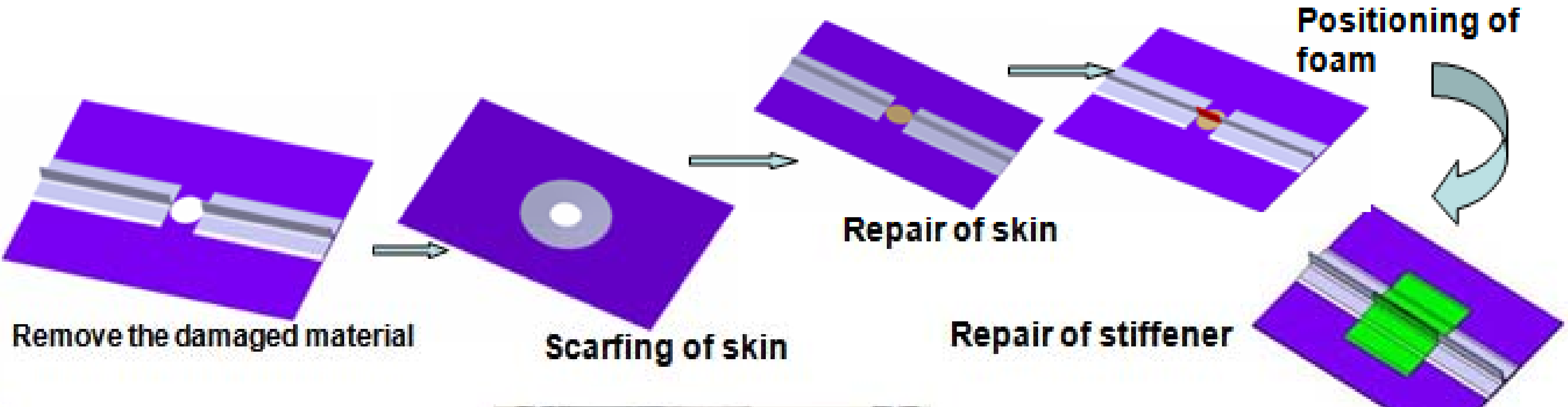
  6 types of composite materials & 4 types of adhesives tested at RT & HTW

  15 Types of repairs on Monolithic, Stiffened and Sandwich structures

**Specimens tested: 400 Nos**

**Panels tested: 55 Nos**

## Repair & Testing of CFC T-Stiffened Panel


Remove the damaged material

Scarfing of skin

Repair of skin

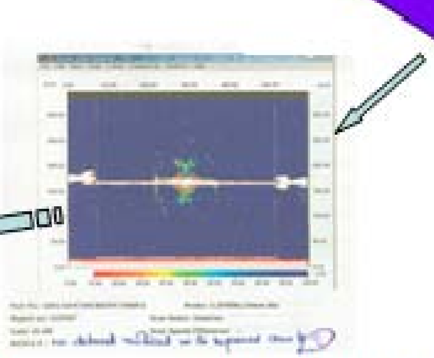
Positioning of foam

Repair of stiffener


Tensile - NAL


Compression - (IITM)


Four Point Bend - NAL


Ultrasonic C scan -HAL

# Civil Aviation Authorities

| Federal Aviation Administration (FAA) | European Aviation Safety Agency (EASA) |
|---|---|
| Federal Aviation Regulations (FAR) | Certification Specifications (CS) |
| Airworthiness Directives (AD) | Airworthiness Directives (AD) |
| | |
| Advisory Circulars (AC) | |

# Compliance to FAR/CS

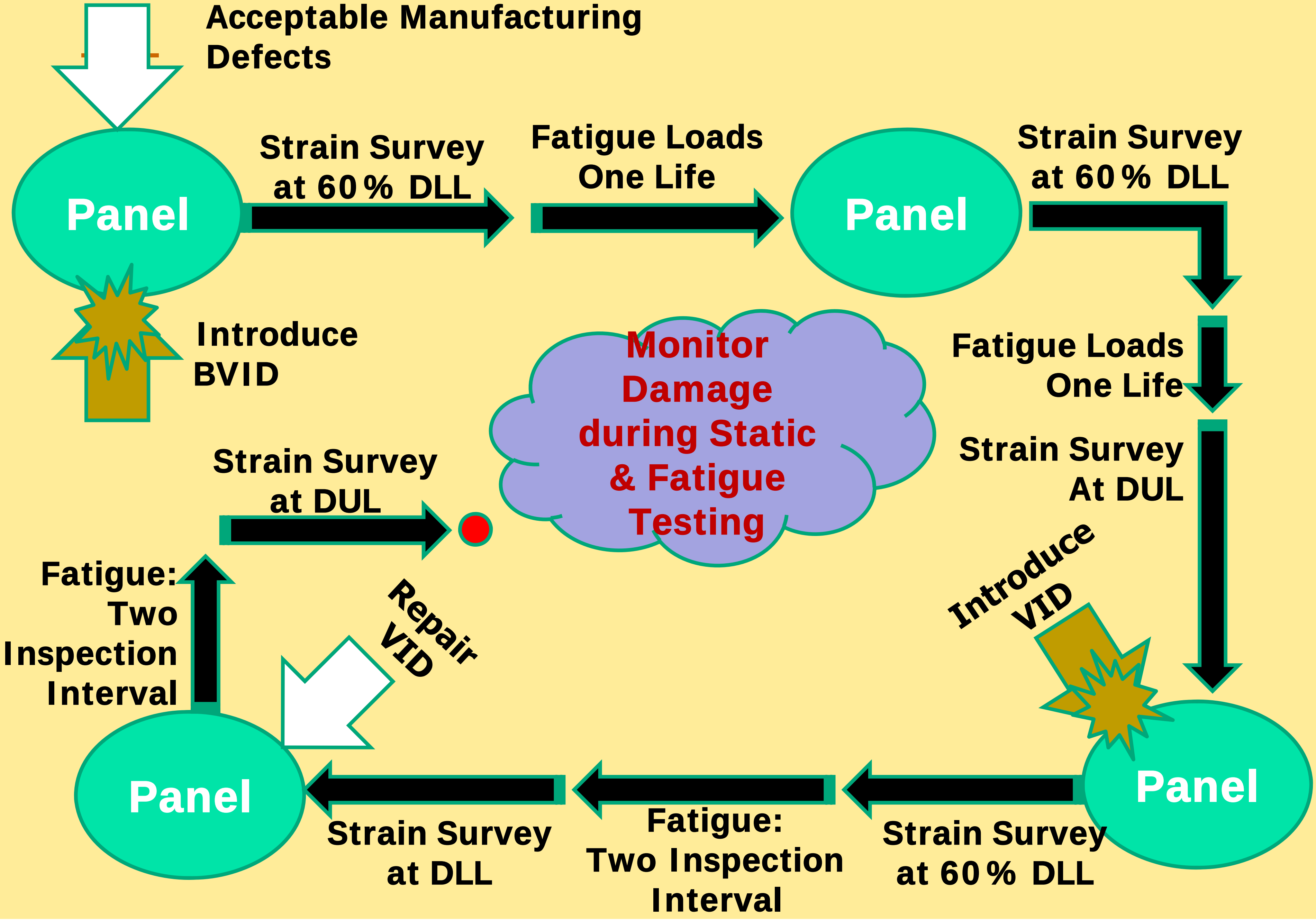
- **Allowable damage that may go undetected**
  - **(DUL residual strength; No growth for minimum of 2 service lives)**
- **Damage detected by field inspection**
  - **(DLL residual strength; No growth until 2 inspection intervals)**

- **Discrete source damage known to pilot**
  - **(Continued safe-flight; “get-home” loads)**

- **All damage that lowers strength below DUL must be repaired when found**

- **Any damage that is repaired must withstand DUL and not impair safe operation of the aircraft for its lifetime**

# Damage Tolerance Test Protocol



Acceptable Manufacturing Defects

Panel

Introduce BVID

Strain Survey at 60 % DLL

Fatigue Loads One Life

Panel

Strain Survey at 60 % DLL

Fatigue Loads One Life

Strain Survey At DUL

Introduce VID

Panel

Strain Survey at 60 % DLL

Fatigue: Two Inspection Interval

Strain Survey at DLL

Panel

Repair VID

Fatigue: Two Inspection Interval

Strain Survey at DUL

Monitor Damage during Static & Fatigue Testing

# The Next Design Philosophy???

- Design Philosophies
  - Safe-life
  - Fail-safe
  - Damage tolerance

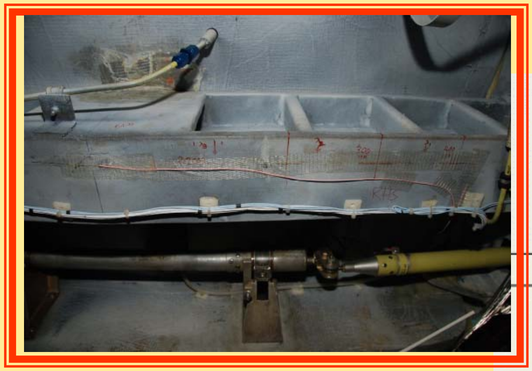
- Structural Health Monitoring (SHM)
  - Sensors can be embedded in the structure
  - Attained certain degree of maturity and field trials started
  - Can we go for a SHM based design?
  - Is it possible to build a light weight and damage tolerant structure using this philosophy?
  - What are the Issues?

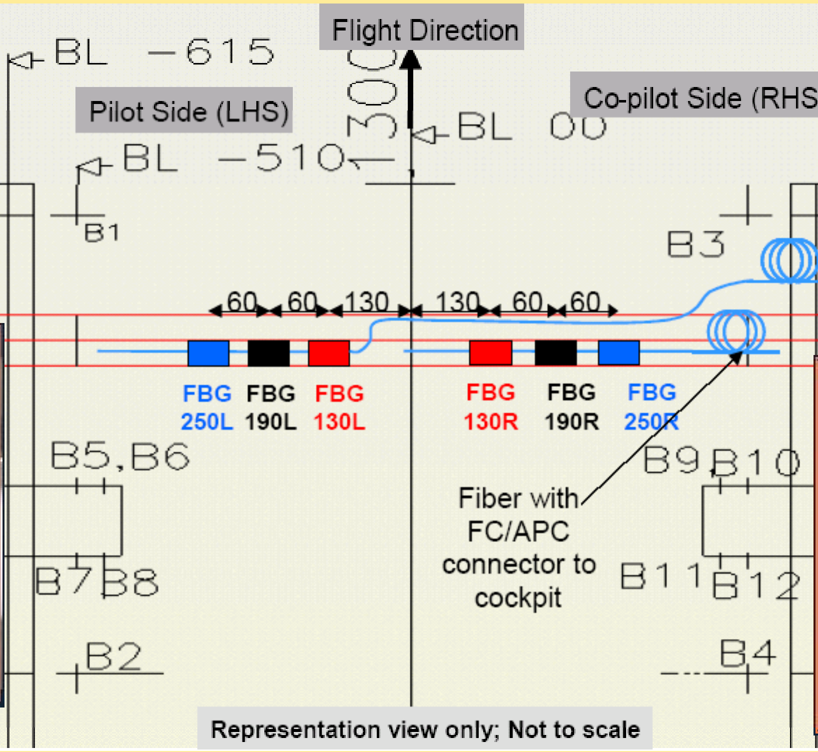
# Benefits of Structural Health Monitoring

- **‘Condition-based maintenance’ or ‘maintenance-on-demand’**
  - Lower maintenance costs
  - Higher availability of aircraft
- **Prognostic capabilities of SHM**
  - Better fleet management leading to better resource utilization
- **SHM-based design**
  - Move away from Damage Tolerance design philosophy
  - Lower weight, lower operating costs

# HANSA Flight Trials

## Real Time Measurement

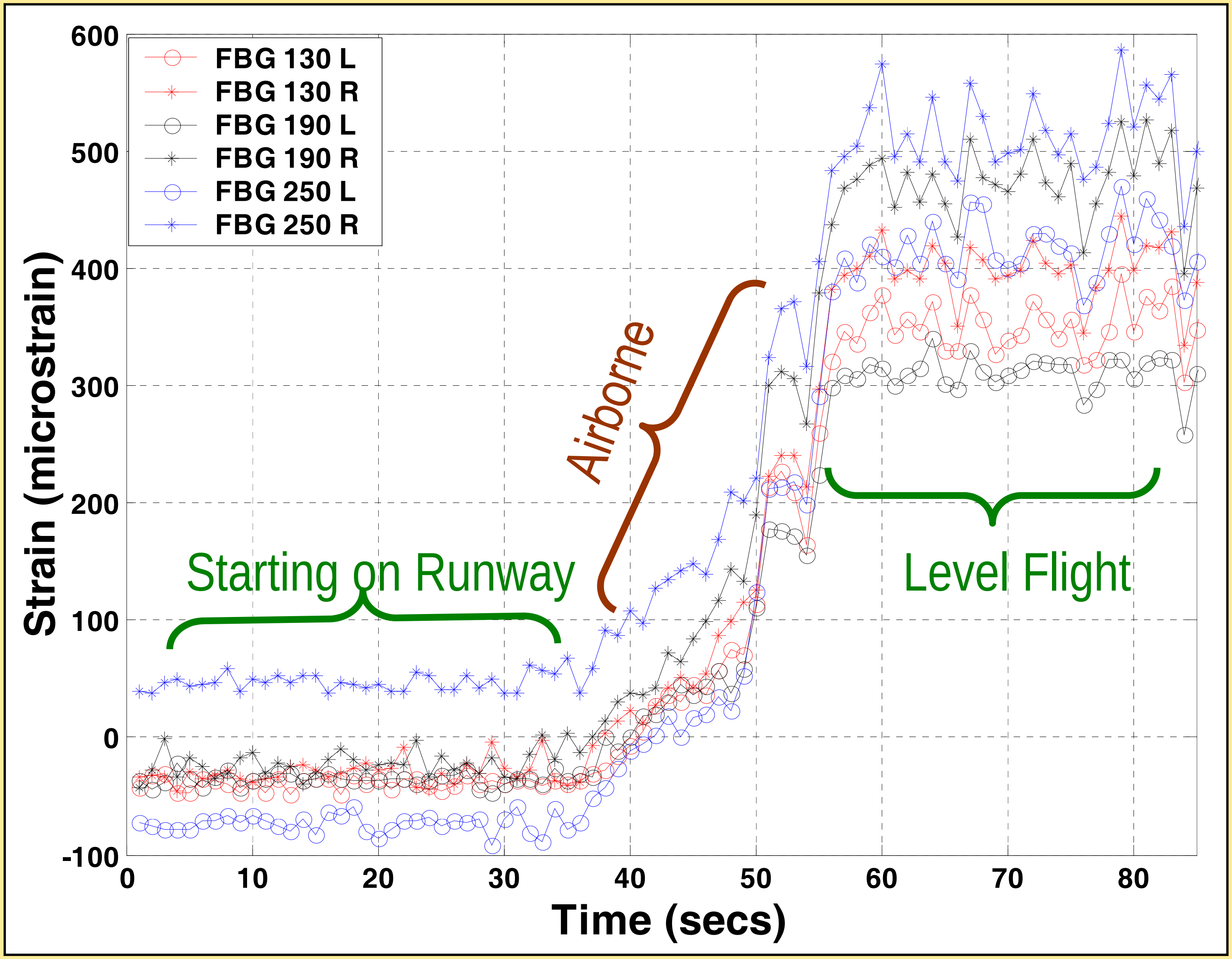




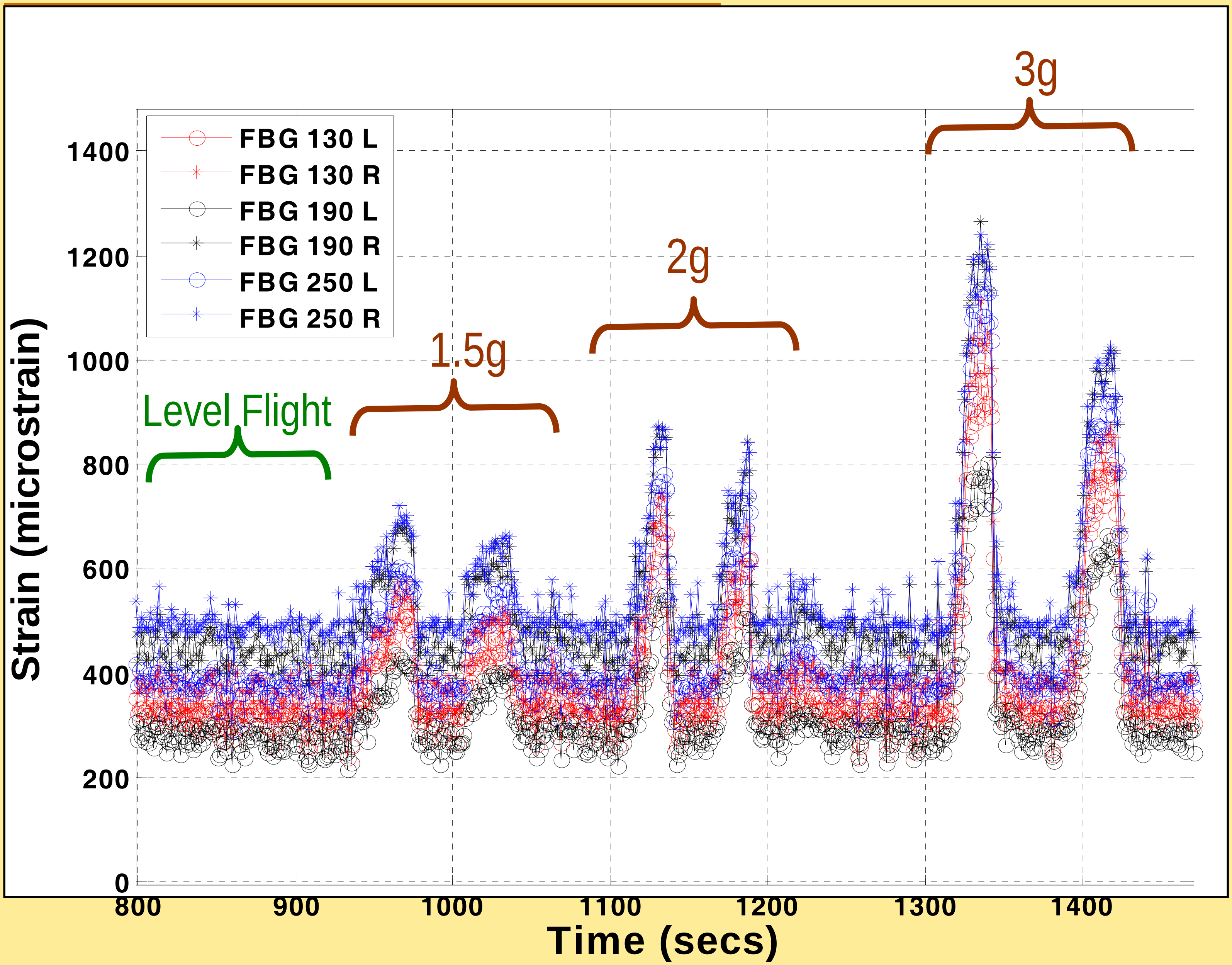
Fiber with FC/APC connector to cockpit

Representation view only; Not to scale

# Strain Variation During Take-off



# Strain Variation During Flight Maneuvers

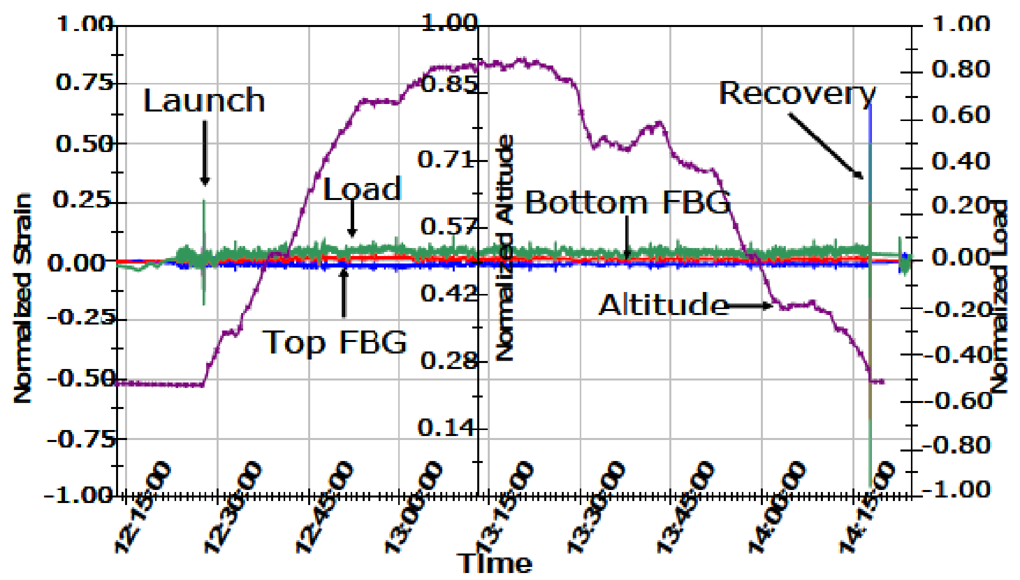


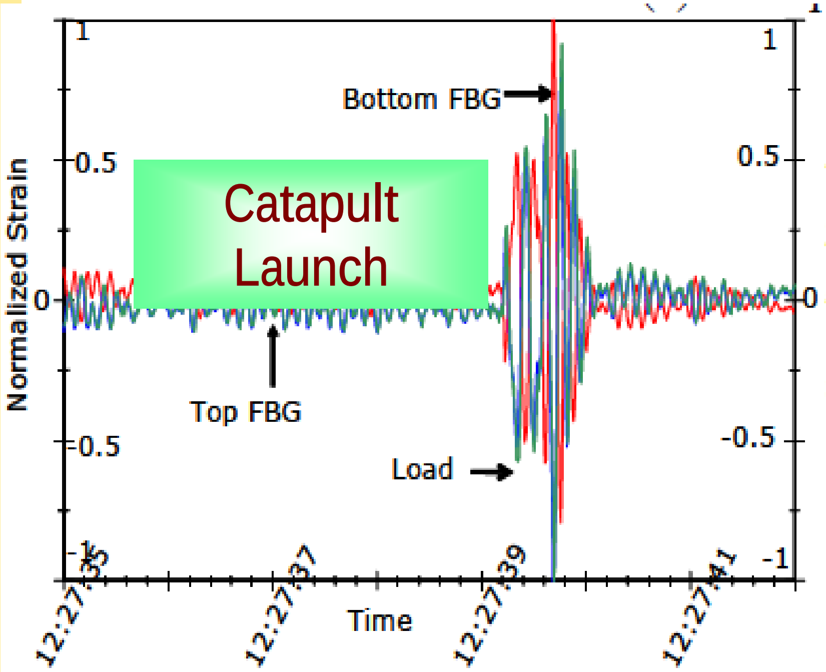
# Flight Trial of SHM system on Nishant UAV

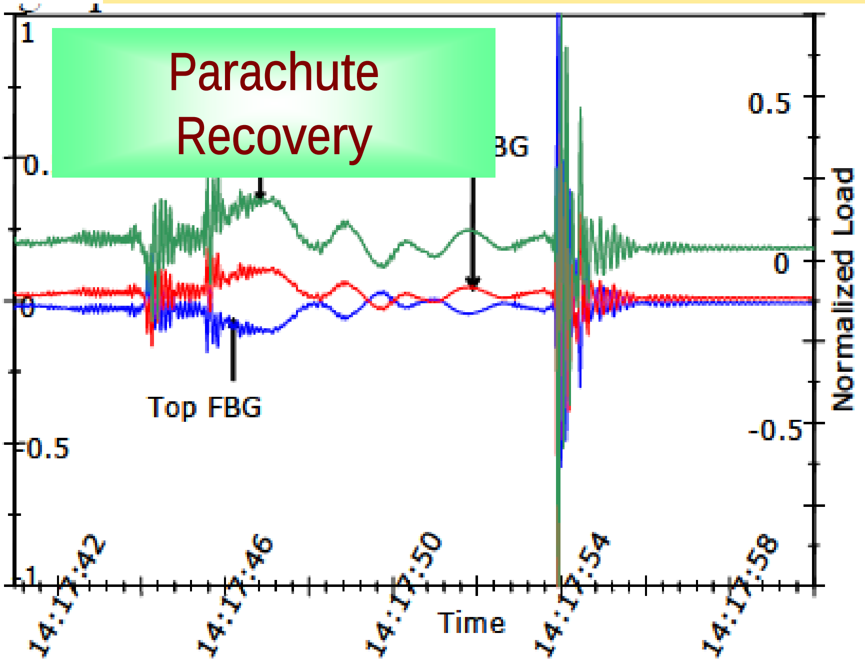
- A successful flight trial of SHM system was conducted on Nishant UAV on October 28, 2010 at 12:15 PM at Kolar.
- The UAV was flown for more than two hours as per the flight plan starting from catapult launch, various flight maneuvers and recovered as per parachute recovery.

- More than 6GB of FBG sensor data throughout the flight was acquired.
- Challenge: Large volume flight data processing and load estimation
- *QuickVIEW* software was developed
  - Temperature compensation with Push-Pull topology
  - Sensor data integration with flight data (pitch, yaw, roll etc.)
  - On-site data view and load estimation using ANN based load estimator.

# Flight Data Analysis Results







Optic Sensors

# Smart Concepts: SMA based HANSA trim tab actuation

## Wind Tunnel Tests

Wind tunnel tests have been carried out at different wind velocities of 25, 35 & 42m/s

SMA actuated trim-tab remained stable in the deflected condition under the wind load.

# Concluding remarks

**Challenge is to reduce cost**

- Aerospace materials & associated design and manufacturing processes must be optimized in an integrated manner to deliver cost efficient products
- Environmental effects and issues of recycling to be addressed
- Advanced striker aircrafts being developed which will fly at higher mach nos: hence need composites to meet higher temperatures.
- Stealth technology is a major area of research → New materials and nano coatings

# Concluding remarks

- Need to reduce maintenance costs and have fully on line SHM systems
- Smart materials/structures for morphing
- FML for energy absorption need to be fully developed
- ‘Mechanic friendly’ repair technology to be established
- Better understanding of damage tolerance : more robust failure theories – will enable faster certification
- All fields of Engineering likely to use more composites – challenge is higher efficiency at a lower cost

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# Thank you