

# OF WEAVES, KNITS AND THEIR COMPOSITES

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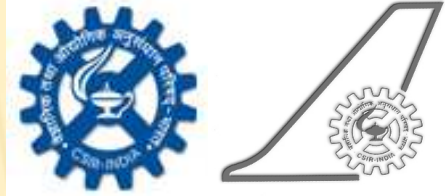
**Senior Scientist**

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**CSIR-NATIONAL AEROSPACE LABORATORIES**

**21 JUNE 2012**

*"Recent trends in textile technology and material science" Technical university of Liberec., 21/06/2012*



*We ought, in every instance, to submit our reasoning to the test of experiment, and never to search for truth but by the natural road of experiment and observation.*

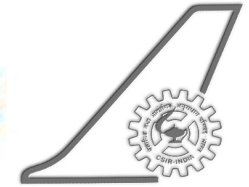
*Antonie Laurent Lavoisier  
Elements of chemistry, Preface*

*Today, just about anything we can figure out on paper can be done in the laboratory & eventually in the factory, our technology has reached a stage where the scientist can safely say : “If we can write it down, we can do it”*

*Zworykin. V K ,  
The American Magazine*

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## ABOUT CSIR ...

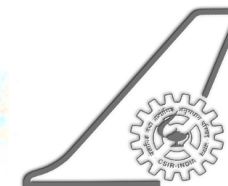


- Council of Scientific and Industrial Research, is one of the premier scientific organisations in the country with about 26 labs in the country.
- The focus is to develop technology base in niche areas “High science” as well as, utilise this base for meeting the needs of the common man in the country.
- Niche areas: Affordable health care, Sustainable energy, Chemistry and environment, smart and functional materials, engineering structure, design and electronics.

[www.csir.res.in](http://www.csir.res.in)

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# CSIR NETWORK OF R & D LABORATORIES...



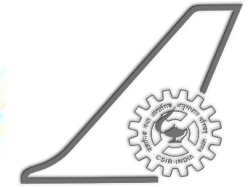
# BANGALORE – THE GARDEN CITY



crown circumference of  
more than 250 metres,





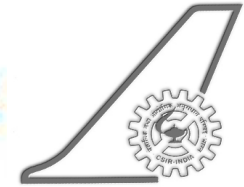


## ABOUT NAL

- NAL's primary interest is in the development of aerospace technologies as part of Civil Aviation programme
- NAL has developed the "All composite 2 seater trainer Aircraft –HANSA" whose All Up Weight is less than 750Kgs
- Currently working on the 14 seater SARAS which is in the process of being certified, other technologies include, MAV programme, Wind turbine system development etc.,

[www.nal.res.in](http://www.nal.res.in)

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## ABOUT NAL CONTD..

- Computational fluid dynamics
- Experimental aerodynamics
- National Trisonic Aerodynamic Facilities
- Flight mechanics and control
- Propulsion
- Composites
- Structural design, analysis and testing
- Structural dynamics and integrity
- Surface modification
- Aerospace materials
- Aerospace electronics and systems
- Civil aviation
- Parallel processing computers
- Meteorological modeling
- Wind energy
- Manufacturing technology
- Information systems

Integrated Facility for Carbon Fibre production

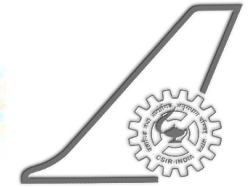


Mark-1 Radome for DWR

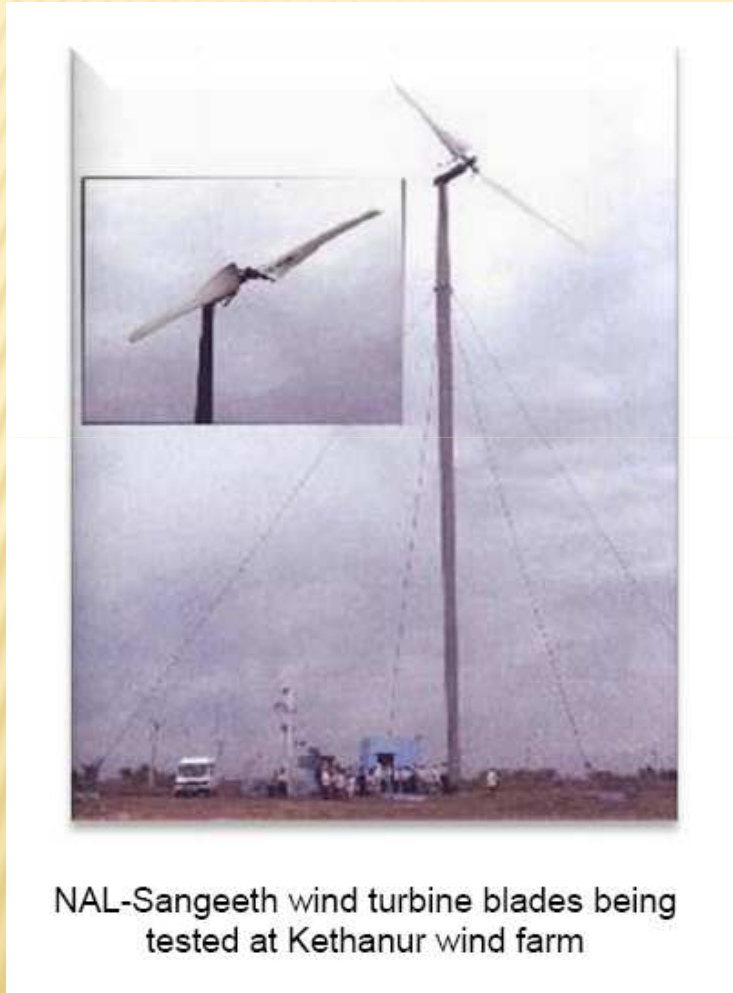


Integrated Facility for Carbon Fibre production



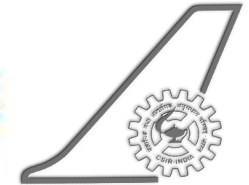


# ABOUT NAL CONTD..



SARAS – PT -1

# MANDATE OF CENTRE FOR SOCIETAL MISSIONS & SPECIAL TECHNOLOGIES



- Utilisation of aerospace related Research & Development activities to meet the societal missions applications the societal missions/applications
- Focus on special technologies to meet the needs of the aerospace sector
  - SMA Technologies for trim tab of aircraft
  - Wind turbine System development
  - MAV , lab-scale autoclave
  - Conductive composites
  - 3D weaving
  - Microwave curing
  - High temperature matrices etc.,

# COMPOSITES

Need arose to address the electronic needs of world war II, protect radar antennas on military vehicles, particularly aircraft fighters and bombers

Radar housings were needed to shield delicate electronic gear from the weather, resist aerodynamic loading and most importantly be transparent to the back and forth passage of electronic information

On March 24, 1944 BT-15 airplane with the plastic fuselage was first flown at Wright-Patterson Air force base.

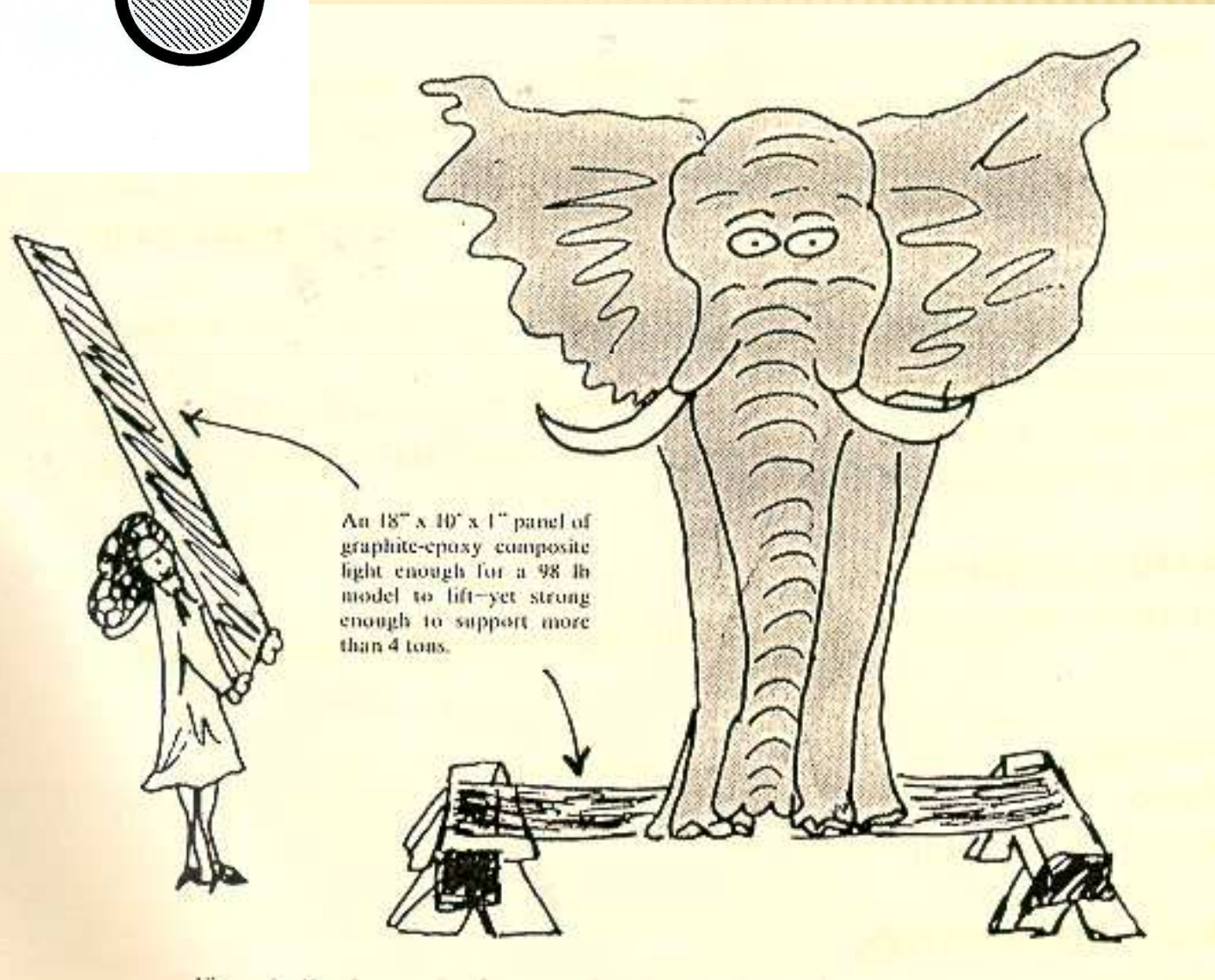
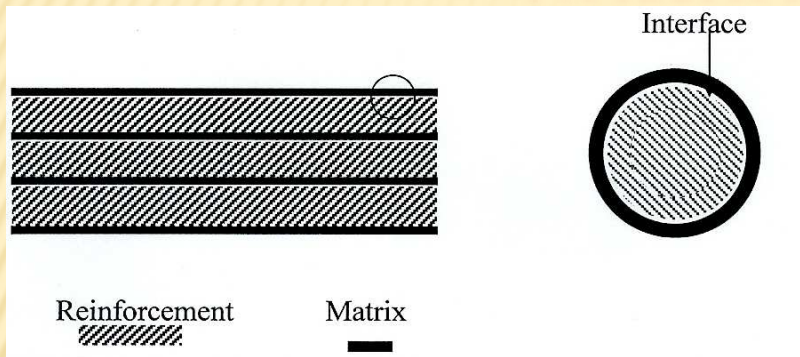
Composites have an interesting combination of properties, of mechanical strength coupled with lightness in weight, resistance to corrosion and both thermal and electrical insulation

If a civilian aircraft were constructed, where possible, from CFRP instead of aluminum alloy, the total weight reduction would be approximately 40%. This creates enormous potential for increased fuel efficiency and increased payload.

A composite is a system that is created by the synergistic mixture of two or more ingredients viz., Reinforcement on one part and matrix (alternatively termed –Resin System) on the other part.

Composites can be classified in a number of different ways viz., fibrous (composed of fibres in a matrix), laminar (composed of layers of materials) and particulate (composed of particles in matrix) within the particulate type are flake and skeletal

# COMPOSITE CONCEPT



# **FUNCTIONAL ROLES OF COMPOSITE CONSTITUENTS**

## **REINFORCEMENT**

- **STRENGTH**
- **STIFFNESS**
- **LIGHTNESS**

## **MATRIX**

- **BINDING / SHAPING**
- **EFFICIENT LOAD TRANSFER**
- **ENVIRONMENTAL PROTECTION**

**The in-service composite performance is governed by the matrix Property (the glass transition temperature  $T_g$ )**

# **3 STEPS INVOLVED IN COMPOSITE MANUFACTURE**

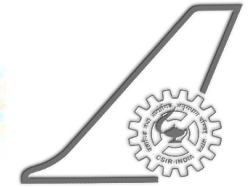
***(Thermoset matrix composites)***

- **IMPREGNATION OF FIBRES IN MATRIX**
- **SHAPING OF WET - FORMULATIONS**  
**By Suitable Moulding Techniques**

**&**

- **SOLIDICATION INTO A FINAL GEOMETRICAL SHAPE**  
**By Chemical Cross Linking (Curing) - *The Chemistry***

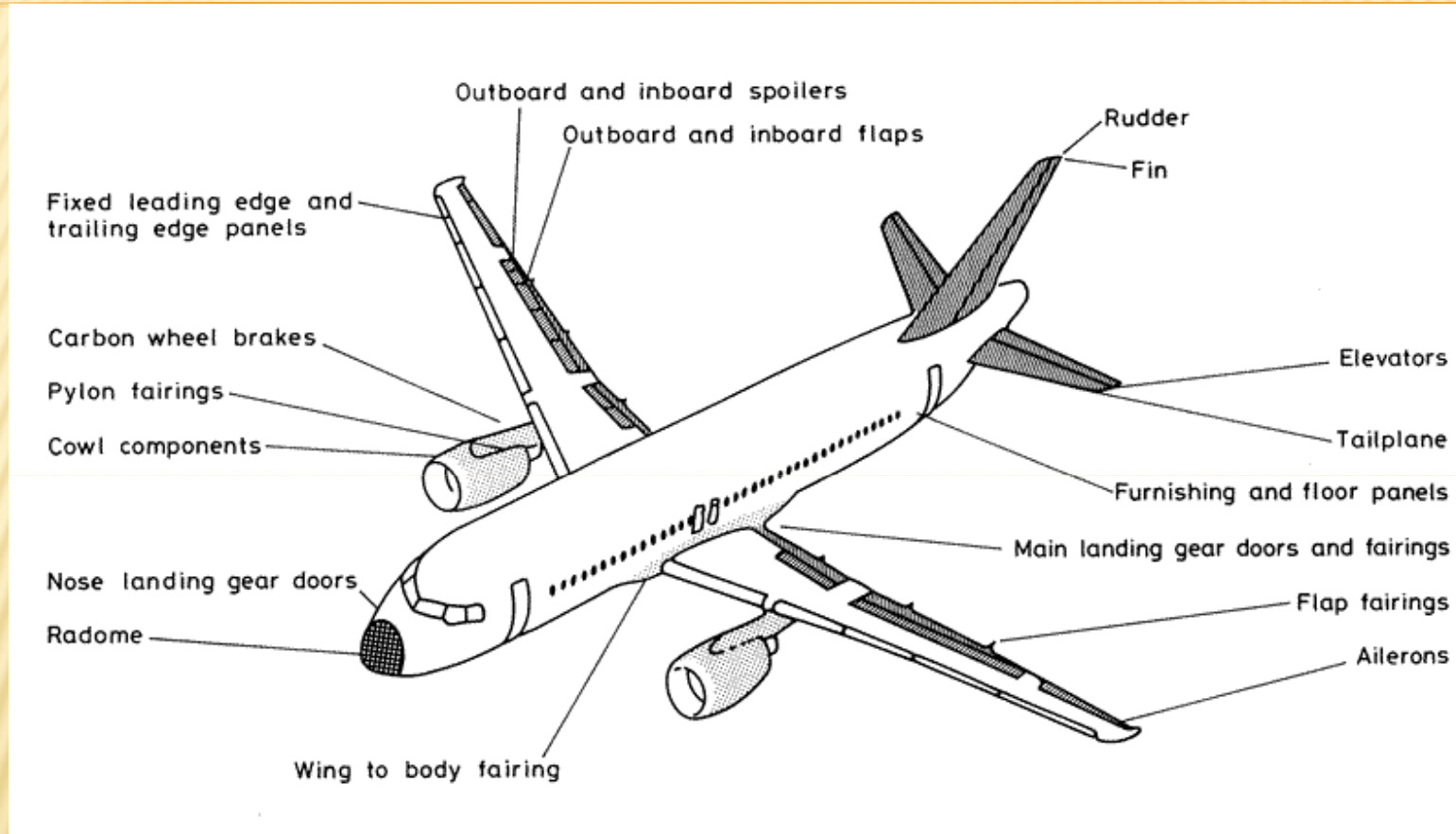




## SOME DEFINITIONS

- × Delamination : Layer separation when composites are subjected to shear / flexural forces
- × Damage tolerance : ability of the structure to contain representative weakening defects under representative mechanical, thermal and environmental loading.
- × Impact behaviour : response of the material to falling mass, bird hits etc.,

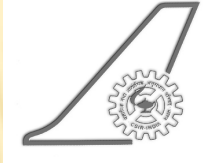
# USE OF 2D WOVEN COMPOSITES IN AIRCRAFT



Composites In A-320, Weight Saving Of 800 Kgs for Equivalent Aluminium Alloy\*

***These laminated composites*** have good in-plane properties but ***poor out-of-plane properties*** due to lack of reinforcement in the third direction.

\* SOURCE - [www.admc.esrtechnology.com](http://www.admc.esrtechnology.com)



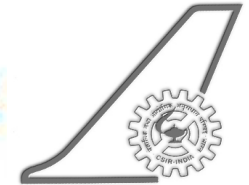
# CURRENT AND FUTURE REQUIREMENTS OF THE COMPOSITES SECTOR

- × Composites that are damage tolerant in-service ( 3D COMPOSITES ??)
- × Increased resistance to crack growth (ANGLE INTERLOCK STRUCTURES ??)
- × Superior impact resistance (KNITS, MULTIAXIAL FABRICS, CARBON – SMA HYBRIDS, 3D COMPOSITES ??)
- × Components with integral tapers, curvatures, bifurcations, holes, stiffeners, flanges etc., (PROFILE WEAVING, ANGLE INTERLOCK WEAVING ??)
- × Load carrying fibre paths through intersecting planes and joints (PROFILE WEAVING ?? )
- × Reduced part count, improved overall process automation, reduced manufacturing steps (3D WOVEN COMPOSITES ??)

# RESEARCH STUDIES TO ADDRESS THE ABOVE ISSUES

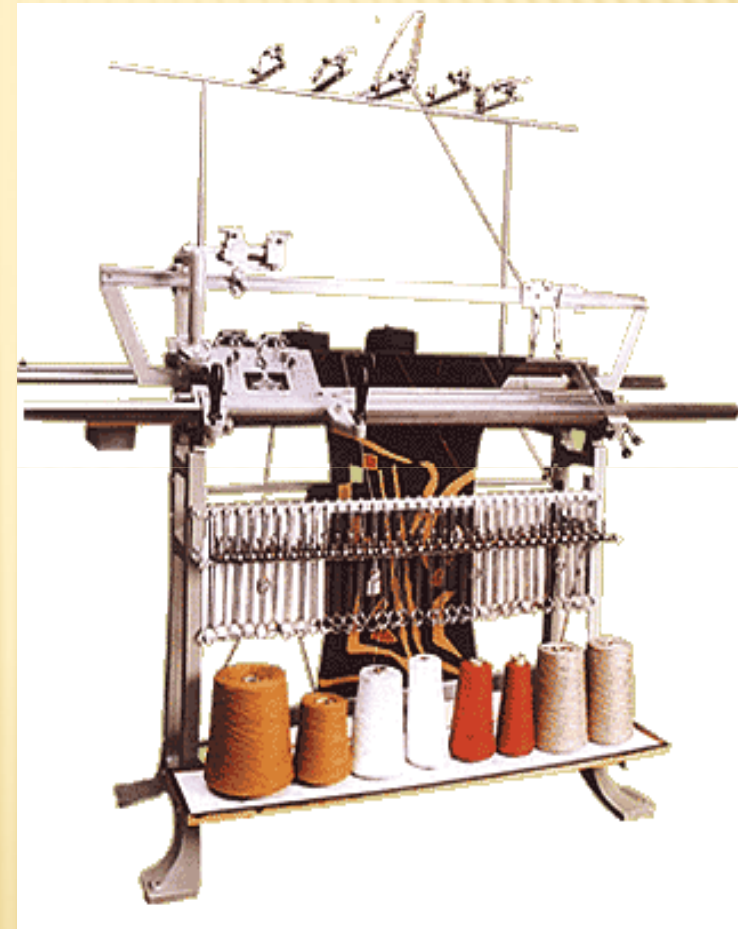
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- ✘ Rib knit preforms with structural modifications
- ✘ Multiaxial preforms and hybrids
- ✘ Carbon-SMA hybrids (ongoing as part of indo-czech collaboration)
- ✘ Three dimensional weaving technologies for composites
  - + Profile weaving
  - + Angle interlock weaving
  - + Three dimensional weaving



## KNIT PREFORMS...

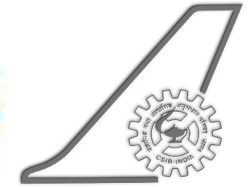
- Single layer Rib knit preforms were developed and the composite properties evaluated
- It was found that these composites had inferior strength properties (Just about 30-40% of equivalent woven fabric composites)
- Structural modifications were made by adding reinforcements in the course direction and strength improvements were observed in the composite properties \*



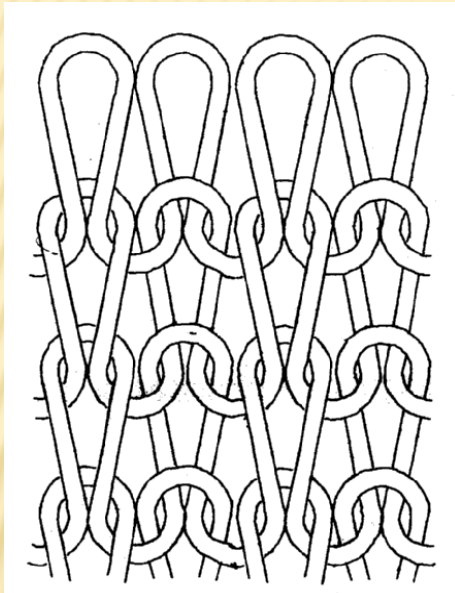
V-BED KNITTING MACHINE

\*JRPC, Vol 19, No 05, 2000, pp.396.,

JRPC, Vol 19, No 06, 2000, pp 492



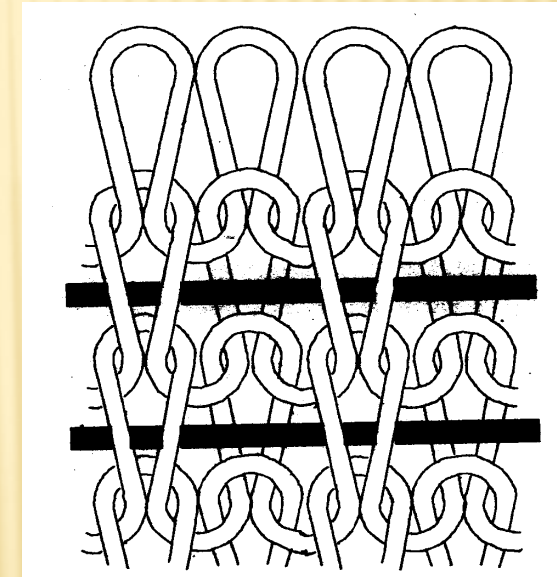
# KNIT PREFORMS CONTD..



Knit architecture  
without reinforcements

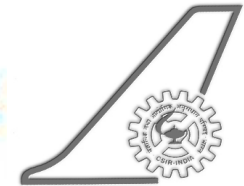


Knit preform



Knit architecture with  
UD reinforcements in the  
Course direction

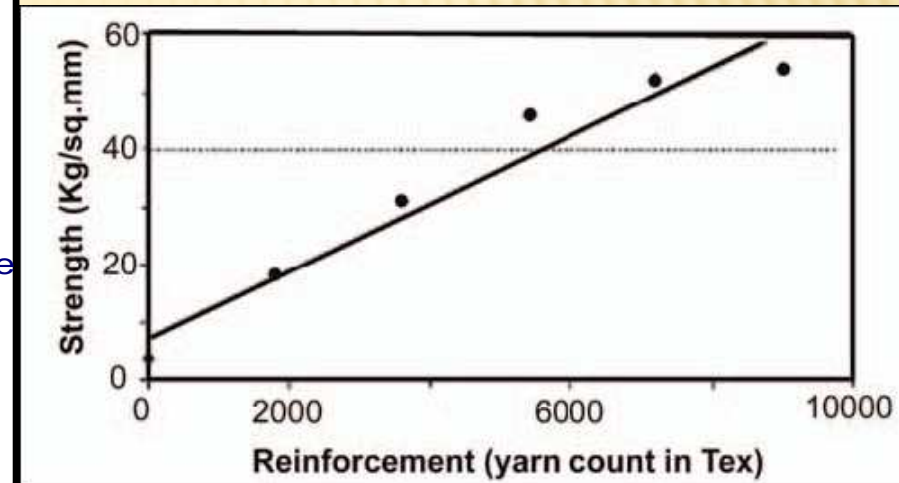
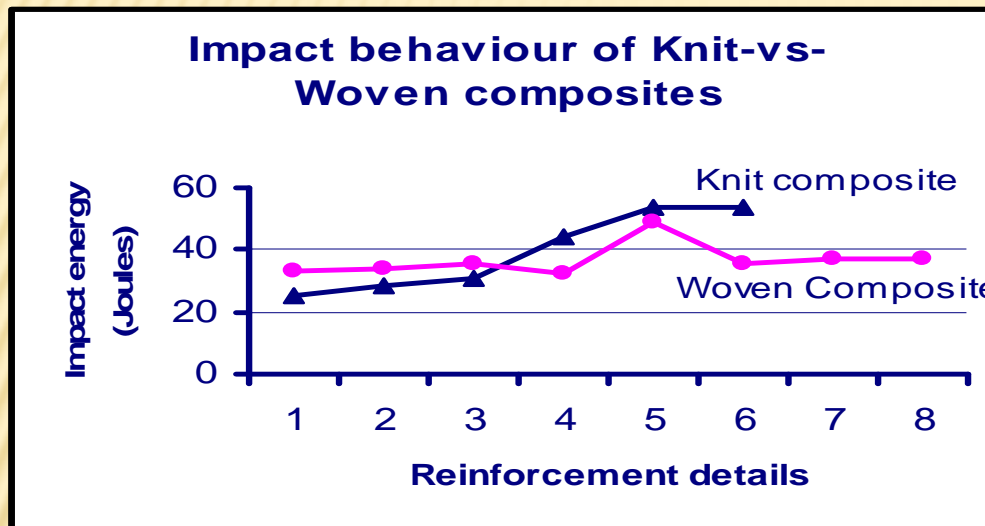
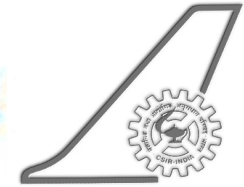
# TEST RESULTS OF KNIT GLASS-EPOXY COMPOSITES



| Reinforcement in course direction | Fabric GSM | Composite $V_f$ | Tensile strength in Kg/Sq. mm | Flexural strength in Kg/Sq.mm |
|-----------------------------------|------------|-----------------|-------------------------------|-------------------------------|
| Plain knit                        | 1700       | 20.5            | 3.728                         | 8.6                           |
| 1800 Tex                          | 2250       | 23.8            | 18.19                         | 15.11                         |
| 3600                              | 2550       | 28.6            | 30.96                         | 24.93                         |
| 5400                              | 3000       | 35.5            | 45.67                         | 33.62                         |
| 7200                              | 3450       | 43.2            | 52.20                         | 37.17                         |
| 9000                              | 4250       | 46.7            | 54.23                         | 40.49                         |

Reference Value -Woven fabric composite BID : Tensile strength 40 Kg/ sq.mm for 0.50 volume fraction

# TEST RESULTS OF KNIT GLASS-EPOXY COMPOSITES CONTD..



Plots of the Total Energy absorbed by the laminates ( incident energy =  $66.6 \pm 0.3$  J.)  
[Above (6a) Plots, Below (6b) Column diagrams]

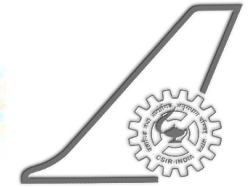
**X-axis :-** For knits 1,2,3,4,5 and 6 represents Plain, 1800, 3600, 5400, 7200 and 9000 Tex Reinforcements respectively in that order.

Woven fabric composites refer to different fibre orientations.

**Y-Axis :-** Energy in Joules

- Woven fabric composite laminates
- ▲ Knit laminates



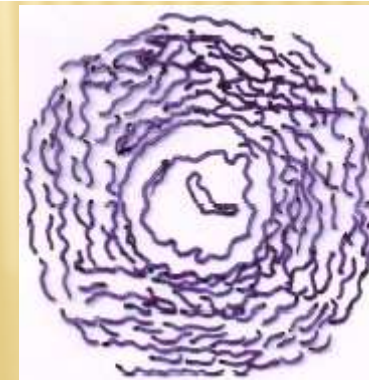


# DAMAGE MODES

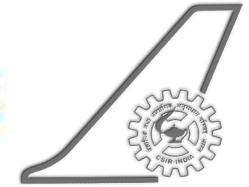
| Woven fabric composite                           | Knit composite  |
|--|---|
| Local delamination in the impact zone            | Rupture of knit configuration is observed in the knit zone and at the tup contact point   |
| Protruding of fibres on the backside             | Projection of the ruptured knit configurations on the backside of the impact surface  |
| Slight propagation of damage beyond the tup zone | Matrix cracking is observed beyond the tup zone with the failure geometry changing over from circular to elliptical form as the reinforcement is increased in the course direction. |



PDA – 141, SDA – 243

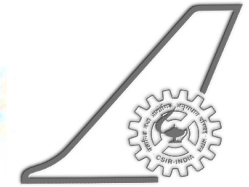


PDA – 207, SDA – 222



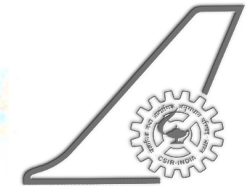
# ADVANTAGES OF KNIT PREFORMS

- Single yarn to fabric stage
- Structural Complexity associated with easy formability
- Adaptable shapes with intricate loops
- Good compressibility properties
- Acceptable mechanical properties
- Minimisation of delamination problem
- Complex loop patterns act as energy absorbing zones

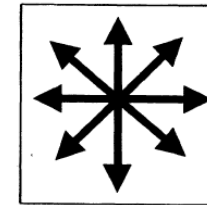
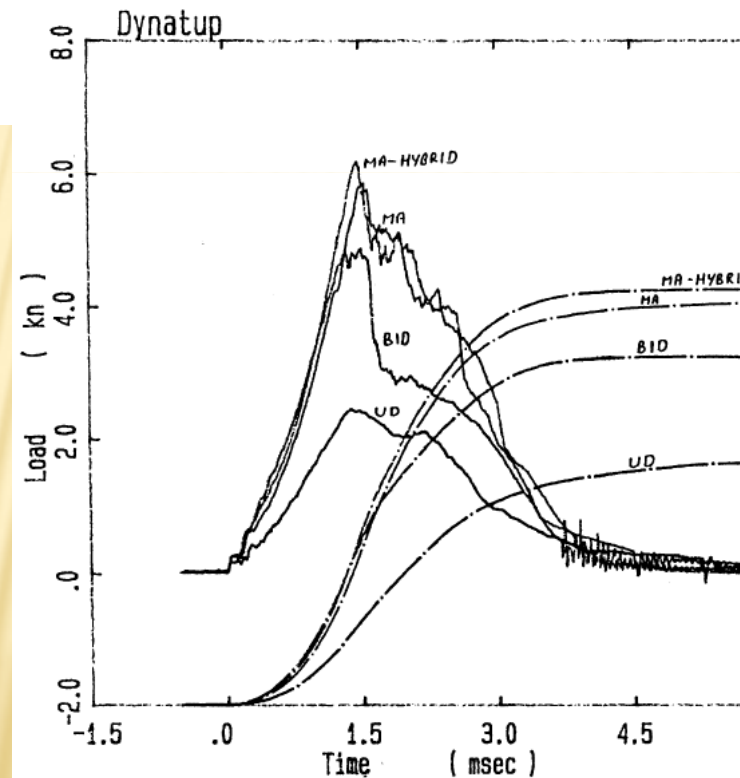
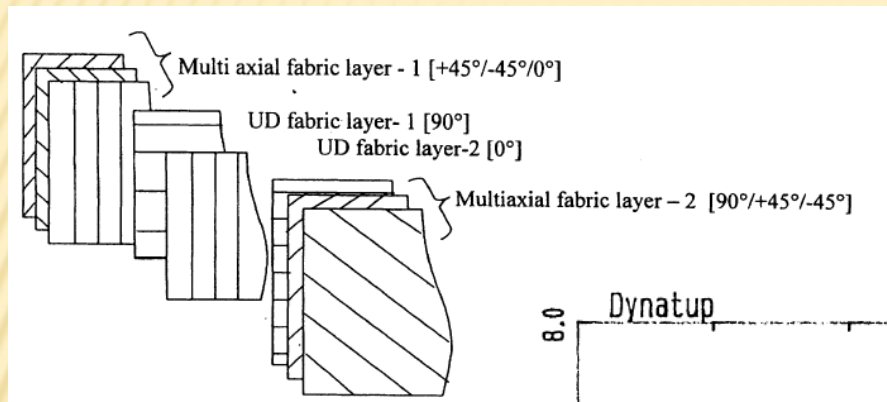


## PROSPECTIVE APPLICATIONS

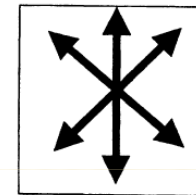
- Improved impact damage resistance – Floor board, Cargo holds
- Enhanced energy absorption – Crash bumpers
- Improved flame resistance of glass knits – Engine cowling region



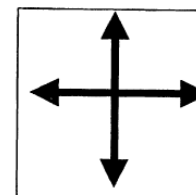
# MULTI-AXIAL WEAVES



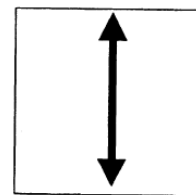
Multi-axial laminate incorporating UD layers (hybridised)



Multi-axial laminate



BID fabric laminate



UD fabric laminate

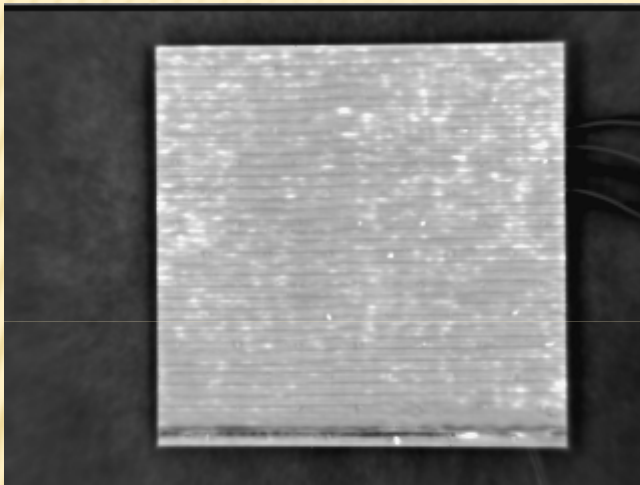
- Reinforcement distribution improves impact response in composites (Ex. Multi-axial, MA – Hybrid)

# IMPACT STUDIES ON CARBON-SMA HYBRID COMPOSITES

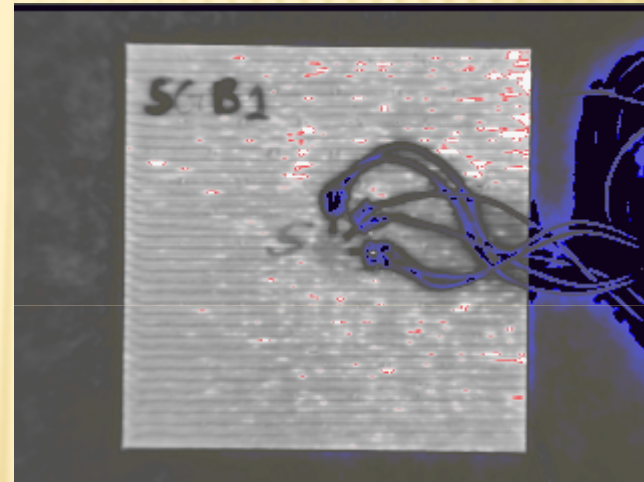
- ✘ Studies carried out as part of continuing Indo Czech collaboration
- ✘ Leno woven SMA mesh was supplied by Institute of Physics
- ✘ Carbon –SMA hybrid composites were developed by incorporating one layer of the mesh in top/bottom and middle layers
- ✘ Epoxy based resin system (5052) was used as matrix material.

| <b>Sl. No.</b> | <b>Ply Orientation</b>                    | <b>Specimen Size (mm)</b> | <b>Remarks</b>                       |
|----------------|---|---------------------------|--------------------------------------|
| 1              | $[0,0,90,+45,-45,0]_s$                    | 90x90x2.16                | Laminate without SMA mesh            |
| 2              | $[0,SMA,0,90,+45,-45,0,0,-45,+45,90,0,0]$ | 90x90x2.16                | Laminate with SMA mesh at top/bottom |
| 3              | $[0,0,90,+45,-45,0,SMA,0,-45,+45,90,0,0]$ | 90x90x2.16                | Laminate with SMA mesh at the centre |

# THERMOGRAPHY RESULTS



SMA TOP



SMA BOTTOM

# IMPACT CONDITIONS

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Specimen dimensions : 90 X 90 X 2mm

Boundary conditions : All round clamped

Tup dia : 15.75mm

Dropping mass : 5.42 Kgs

Drop height : 0.57 mtrs

Incident energy :  $29 \pm 1$  J

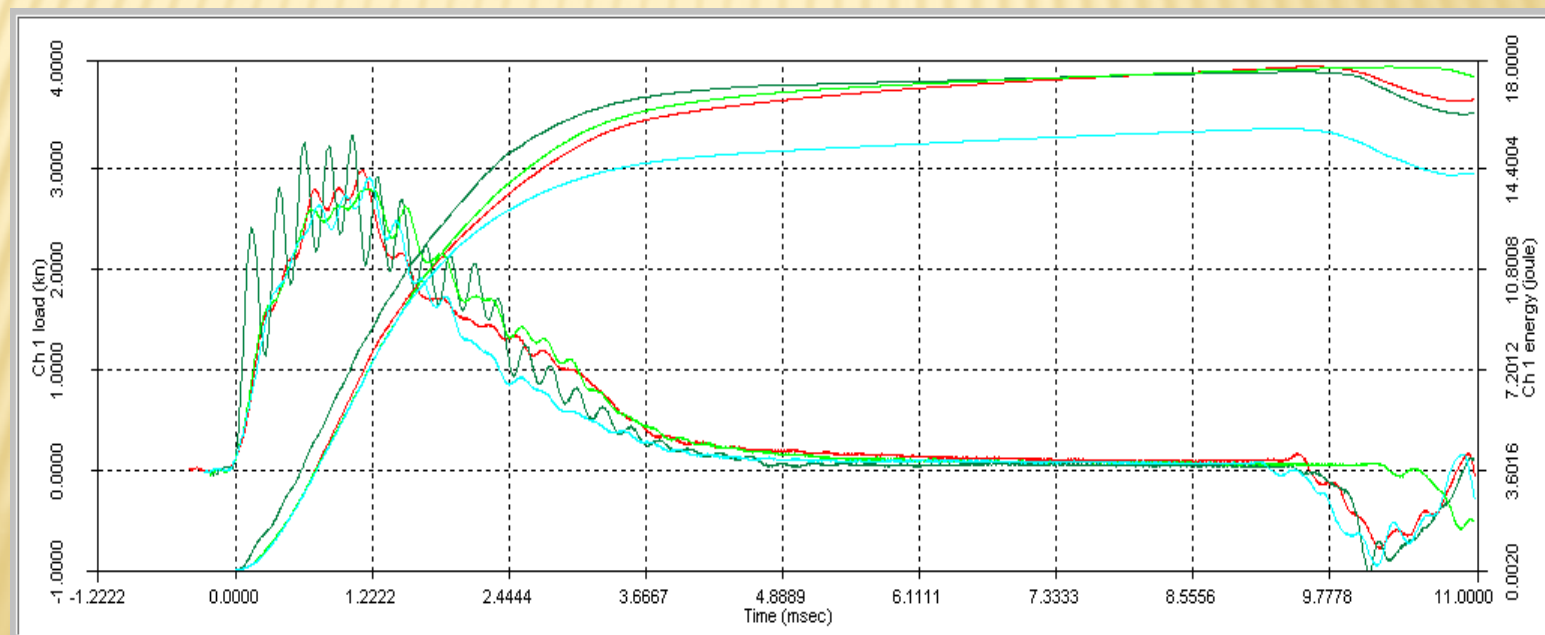
Incident Velocity :  $3.3 \pm 0.1$  m/s

Fall type : gravity assisted free fall

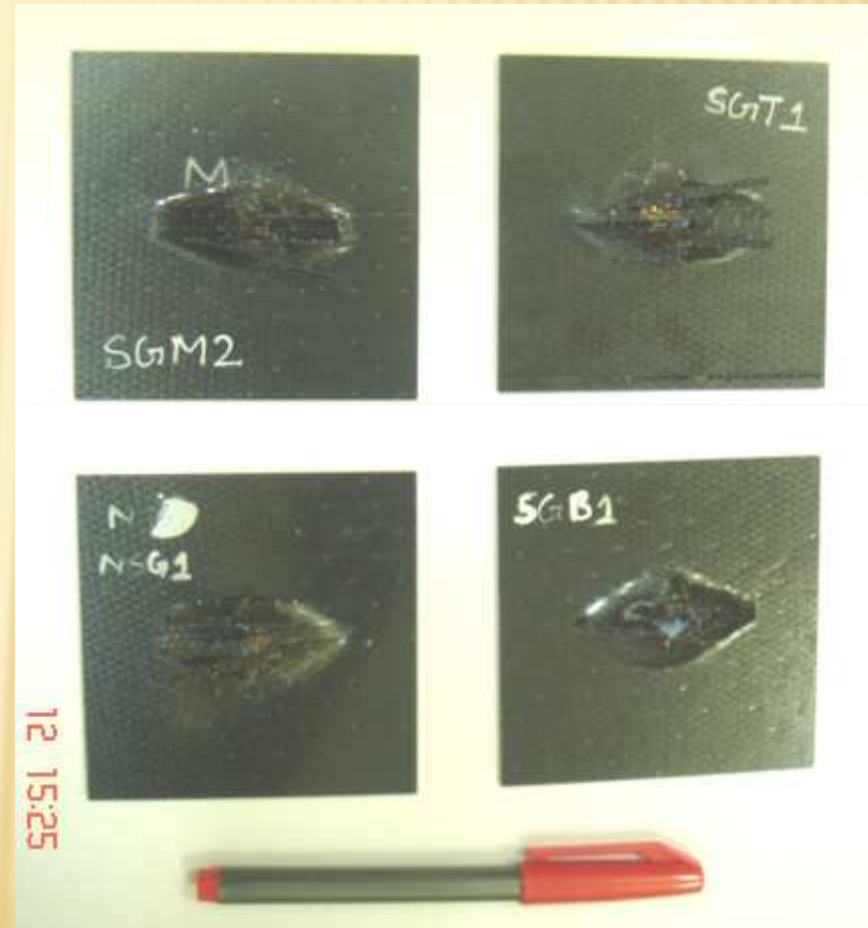
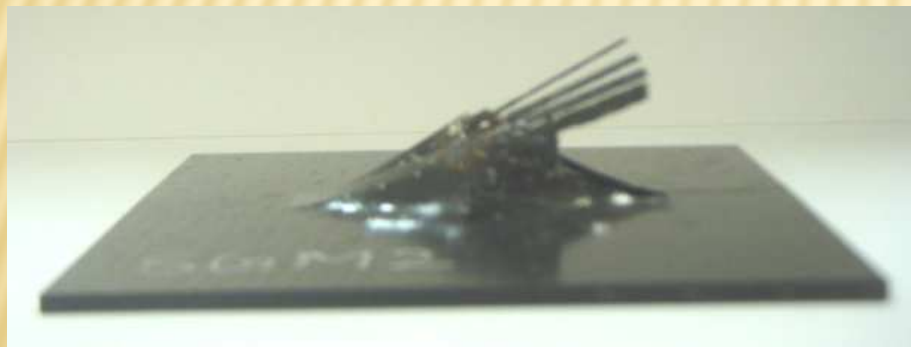
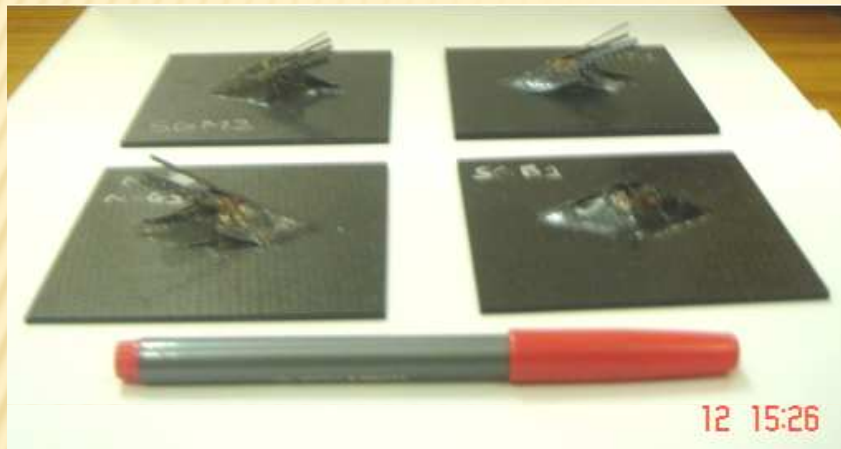


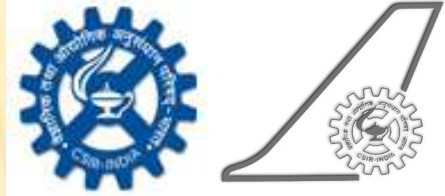
# IMPACT TEST RESULTS

| Batch ID | Test no | Impact energy (1) (joule) | Impact velocity (1) (m/sec) | Maximum load (1) (kn) | Total energy (1) (joule) |
|----------|---------|---------------------------|-----------------------------|-----------------------|--------------------------|
| SGB-1    | 1 -     | 29.9236                   | 3.3229                      | 2.9473                | 17.8413                  |
| SGM-2    | 2 -     | 30.0460                   | 3.3297                      | 3.2792                | 17.6421                  |
| SGT-1    | 3 -     | 28.4460                   | 3.2399                      | 2.7589                | 17.8157                  |
| NSG 1    | 4 -     | 29.0144                   | 3.2721                      | 2.8764                | 15.6255                  |

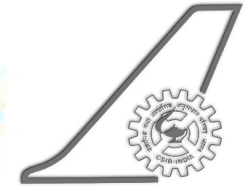


# PHOTOGRAPHS OF IMPACT DAMAGE



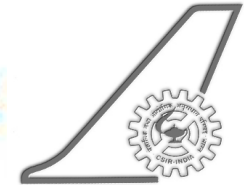


# THREE DIMENSIONAL WEAVING TECHNOLOGIES FOR COMPOSITES

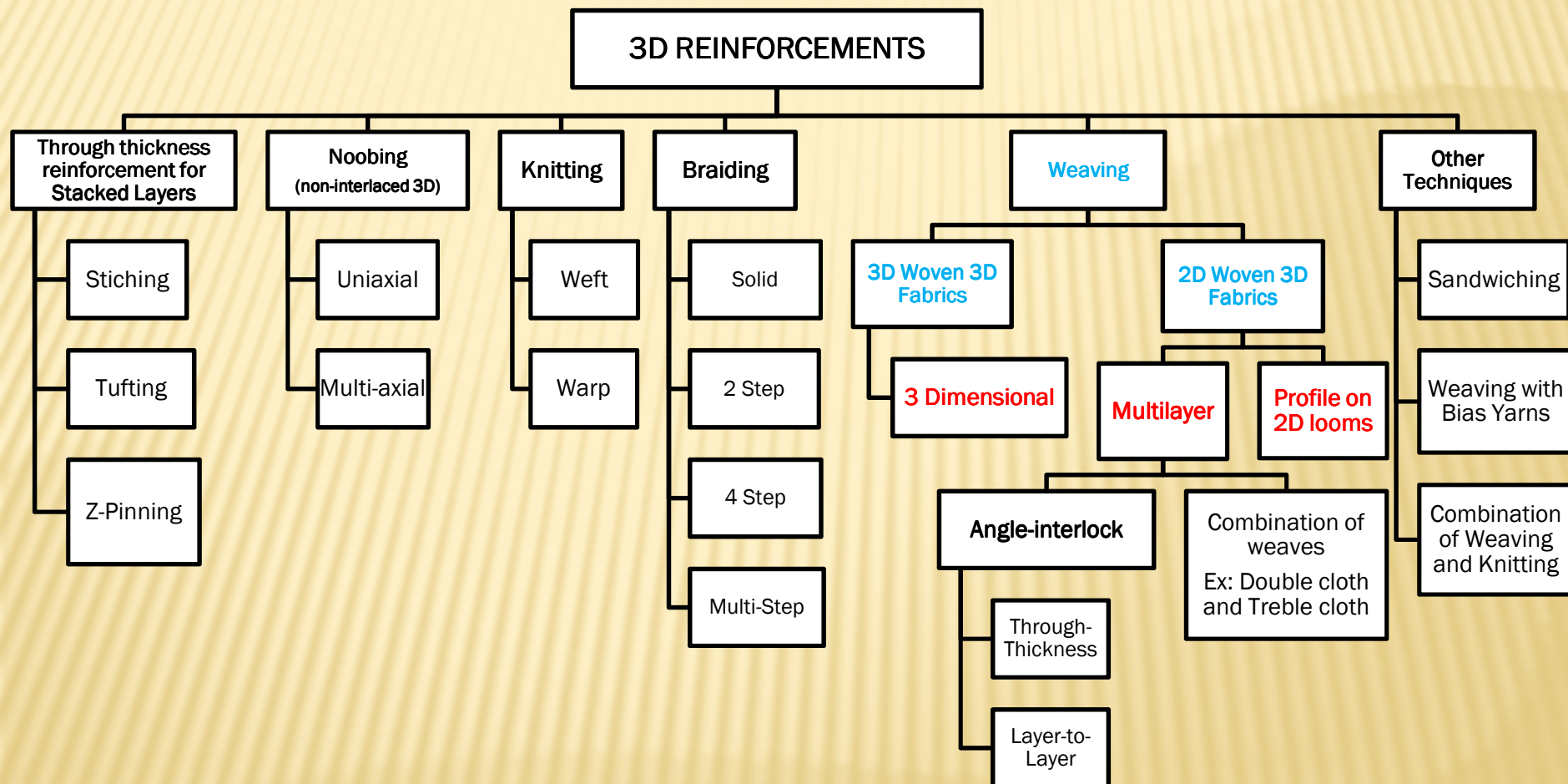


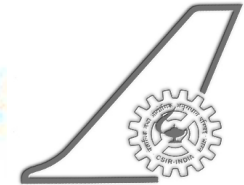
# INTRODUCTION

- Laminated composites have good in-plane properties but poor out-of-plane properties
- This is due to lack of reinforcement in the third direction.
- The emerging 3D reinforcement technologies for composites is expected to finely balance the in-plane with the out-of-plane properties.



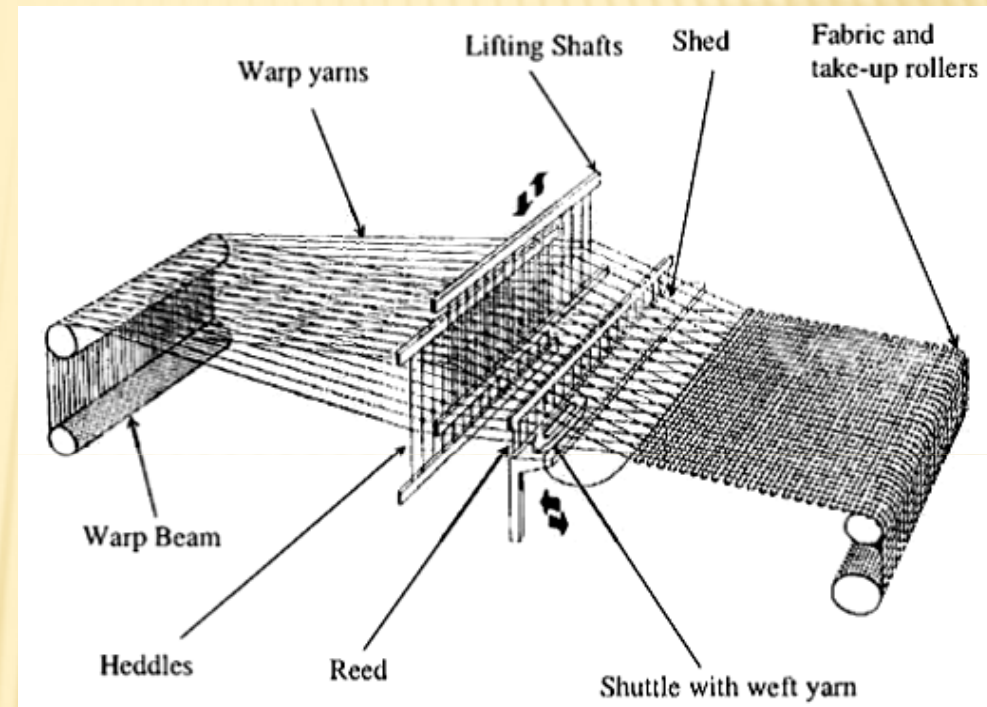
# CLASSIFICATION

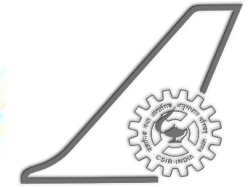




## WEAVING ON 2D LOOMS

- *Let off* – Letting-off of the warp yarns for weaving in incremental steps
- *Shedding* – Process of separation of the warp yarns for weft insertion
- *Picking* – Process of inserting the weft yarns
- *Beat-up* – Process of pushing the last inserted weft to the fell of the fabric
- *Take-up* – Incremental movement of the formed fabric in such a manner, that, the position of fabric fell is unaltered





# SOME 2D WEAVING LOOMS



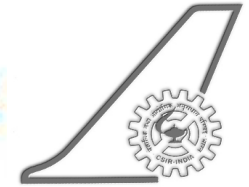
**Plain loom**  
(shirt, sheeting materials)



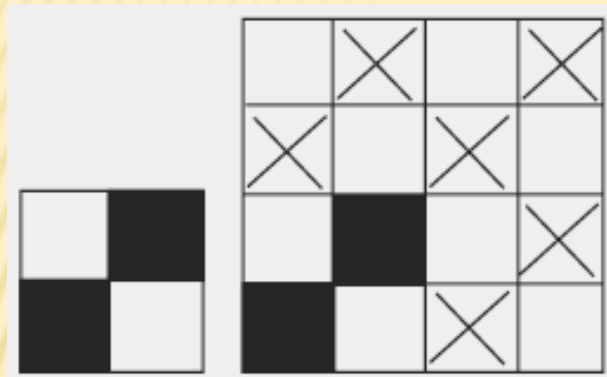
**Dobby loom for small designs**  
(saree weaving, silk dhotis with borders)



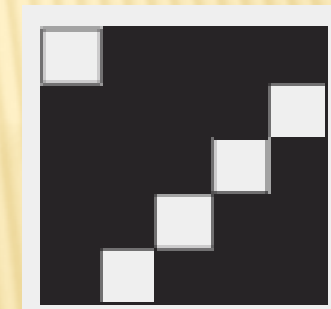
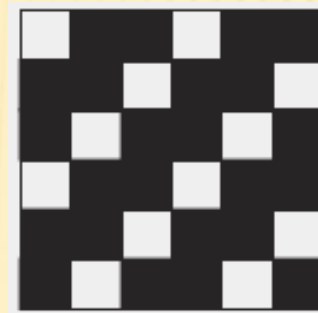
**Jacquard loom for large designs**  
(curtain materials, conical preforms, fabrics with large motifs)



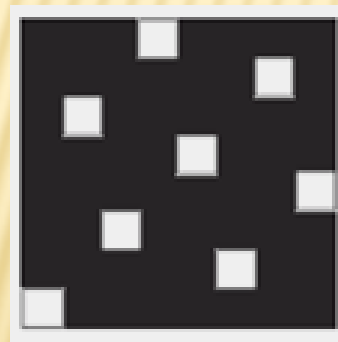
# WEAVE DESIGN DETAILS - GENERAL



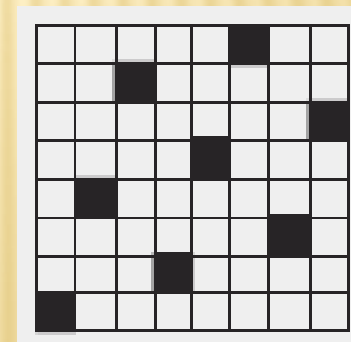
Plain Weave



Twill Weave 2/1 ; 4/1

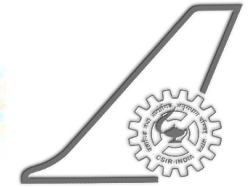


8 End Satin



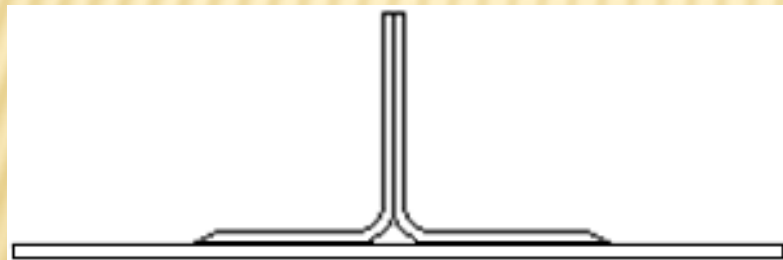
8 End Sateen



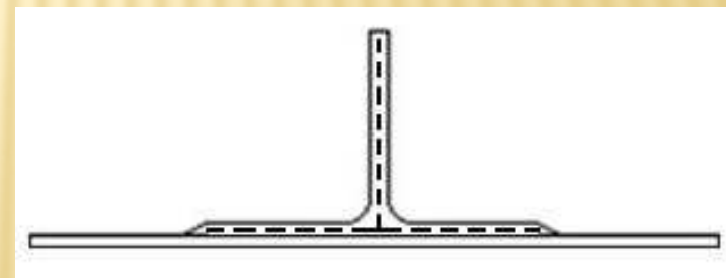


## SINGLE LAYER PROFILE WEAVING

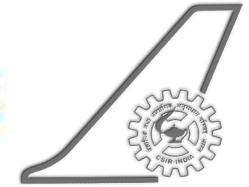
- Single layer profiles can be used as inserts (one continuous layer linking different sections) and partially reinforce the joint and enhance the performance of the composite part in question



Line sketch of 'T' joint without insert



Line sketch of 'T' joint with insert

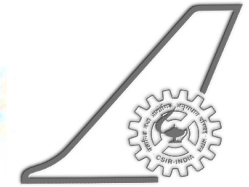


# LITERATURE

- Dale Abildskov (US 4782864, 1988) has patented a “three dimensional woven fabric connector”, which is similar to single layer ‘H’ profile.
- James A Crawford and Keith E (US 5026595, 1991) have patented a “woven gap filler for use in the lay-up of composite plastic structural units”, is a insert of triangular sectional shape.

What is missing?

- Details on how to weave.
- Mechanical data of composites.

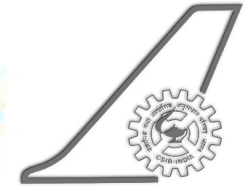


# APPROACH

- Profiles can be woven on Tappet, Dobby or Jacquard looms depending on the structure complexity on similar lines to that of 2D weaving
- Weave Design\* (arrangement, lifting sequence and interlacement pattern of warp and weft) is the starting point for weaving.
- Profiles are woven in folded form on the loom using principles of double cloth / treble cloth.
- Interlacement of the weft with the warp leads to profile generation.

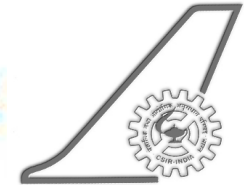
\* A T C Robinson, (1973); R Sen Gupta, (1996)

*"Recent trends in textile technology and material science" Technical university of Liberec., 21/06/2012*

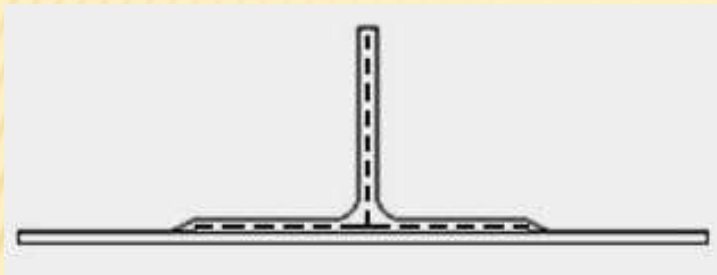


## APPROACH CONTD..

- Unfolding of the preform after weaving (due to flexibility of the textile materials) gives the required profile.
- Depending on the type and dimensions of the profile the number of warp beams get decided ('T' - two beams, 'I' - two or three beams)
- Shedding & beat-up are similar to 2D weaving principle
- Picking is for narrow width, and is by weft path cycle (one pick repeat to generate the profile)
- Take-up - Variable depending on weft path and density and is specific for each profile



# 'T' PROFILE

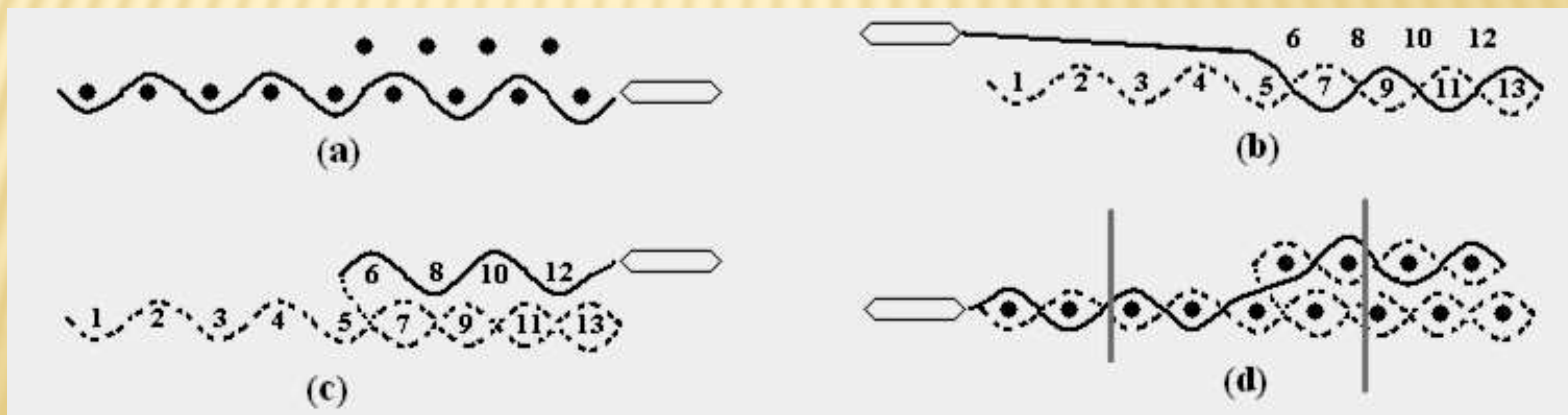


Line sketch of 'T' joint with insert

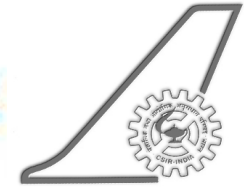


Warp arrangement for 'T' formation in the folded manner

- Warp arrangement will be in folded form
- In the case of 'T' profile, **weft path cycle** constitutes of **4 steps**

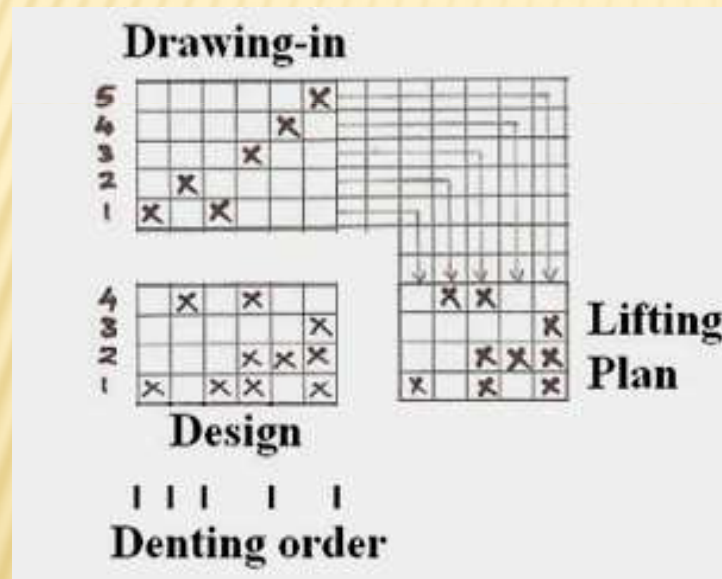


Warp cross-section and Weft path for developing the 'T' profile

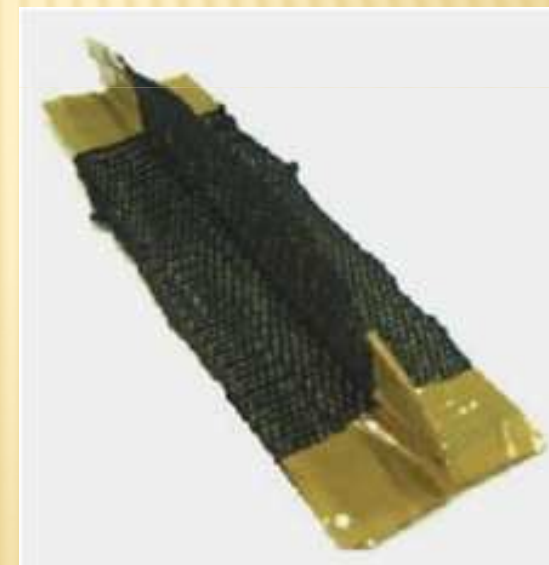


## 'T' PROFILE CONTD..

- ✗ Weave design plan for 'T' developed using warp cross-section
- ✗ It serves as the input for the weaver to develop the profile.

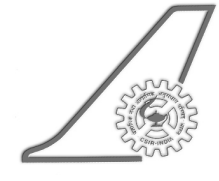


Weave design



Sample woven on handloom

# TEST RESULTS ON COMPOSITES WITH 'T' INSERTS

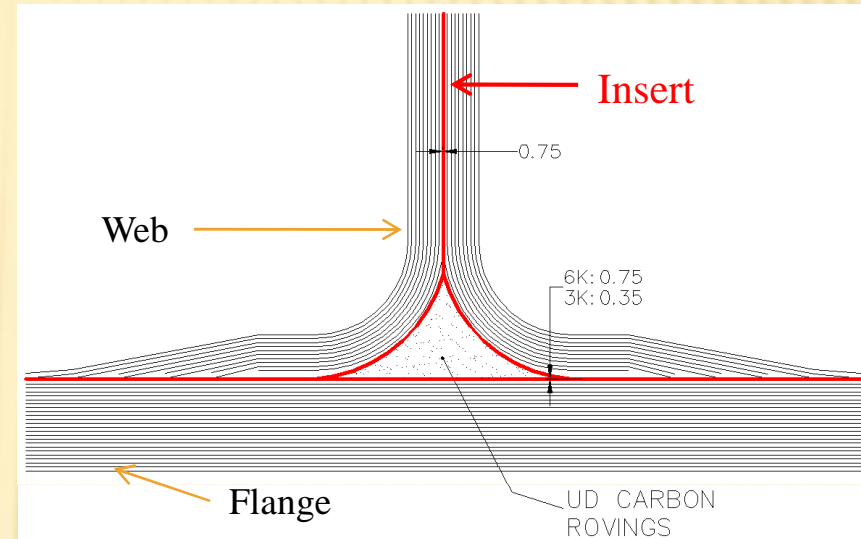


'T' profile woven on Jacquard loom

- ✘ Thickness – Web : 3.06mm Flange : 3.74mm

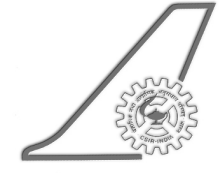
Jacquard Insert – 0.35mm (3K, 200Tex)

Flange length 180mm Web height – 110mm

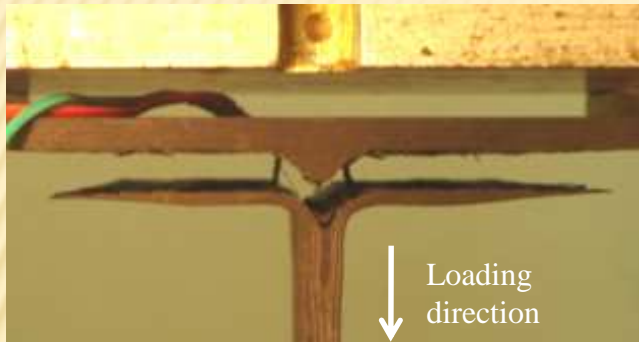


- ✘ Epolam 2063 resin system
- ✘ VERITy process  
(Vacuum Enhanced Resin Infusion Technology)

The authors wish to acknowledge Mr. Kundan & team from Advanced Composites Division, NAL for the above work on the composites fabrication and testing.

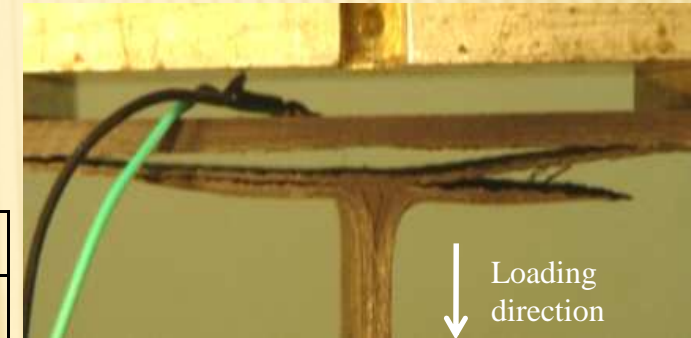


# T-JOINT TEST RESULTS



Normal T-Joint

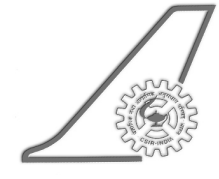
| Failure load (kg/mm) |                                  |
|----------------------|----------------------------------|
| Normal T -Joint      | T-Joint with Insert <sup>#</sup> |
| 6.66                 | 6.59                             |
| -                    | 2.69*                            |



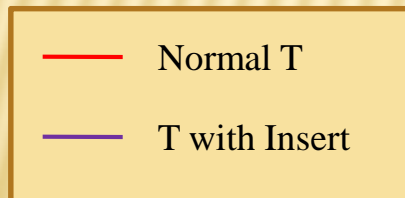
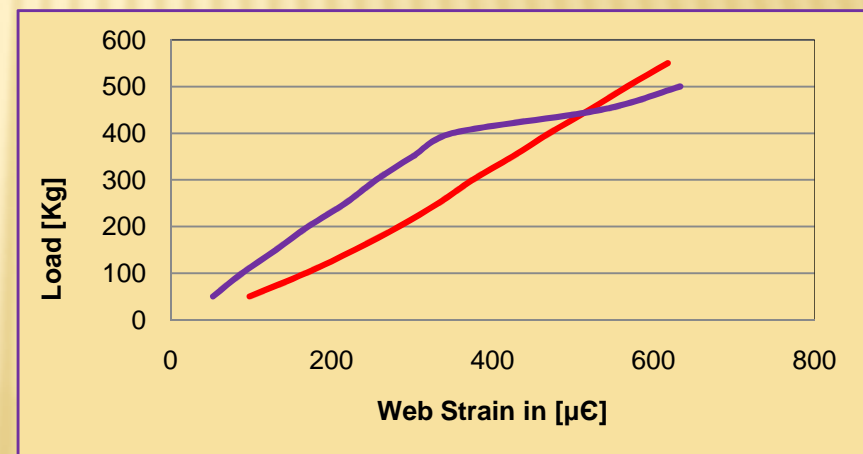
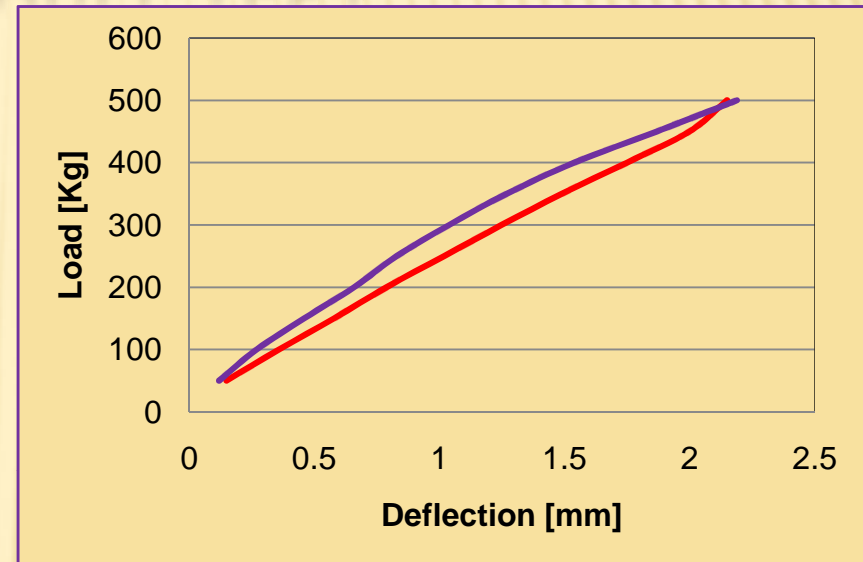
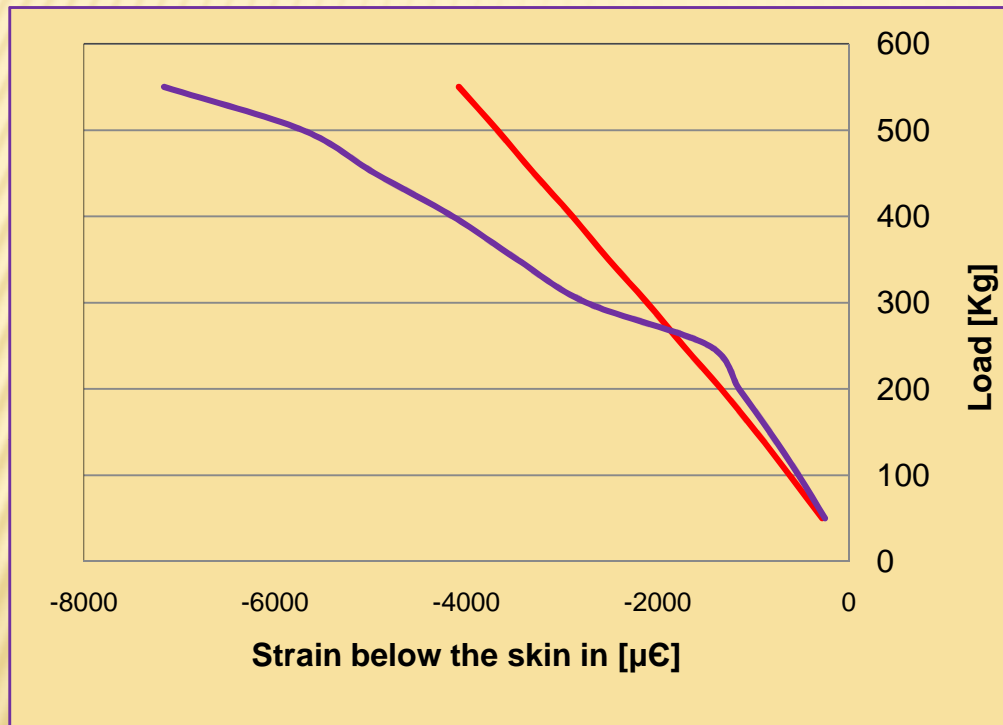
T-Joint with Insert

- ✘ The composite performance with inserts improved in the following aspects
  1. Improved strain capability
  2. improved damage tolerance
  3. Progressive failure mode as against catastrophic
  4. \*Residual Strength (nearly 40% on reloading)

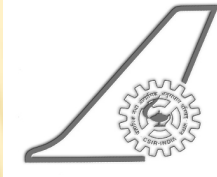




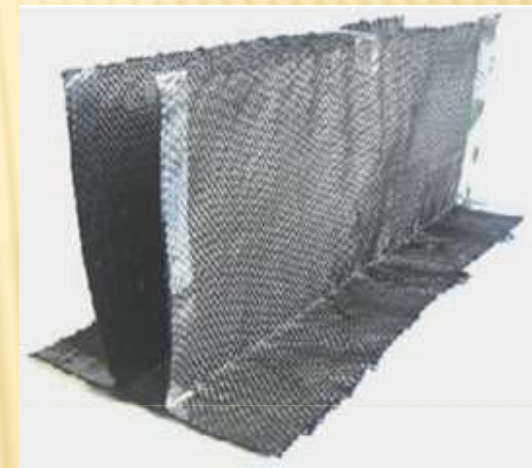
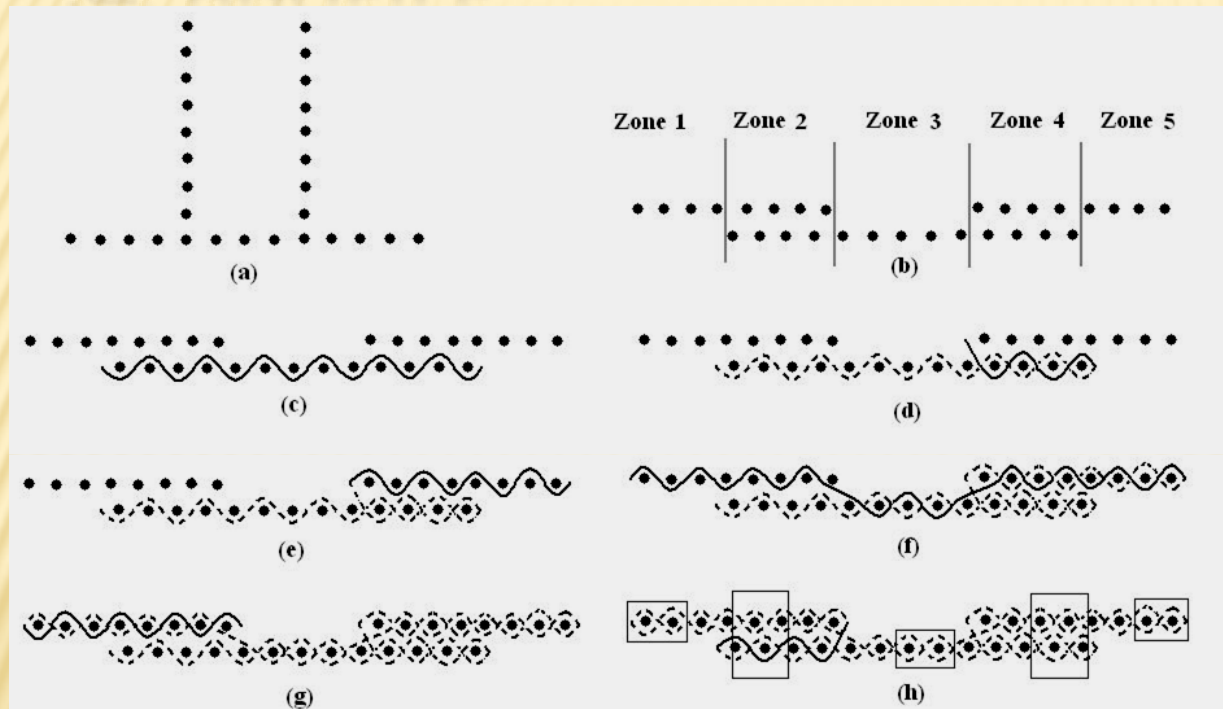
# LOAD - STRAIN DATA OF T-PULL TEST



For equivalent stress levels and deflection, T with insert has been able to sustain more strain, and hence exhibits improved damage tolerance



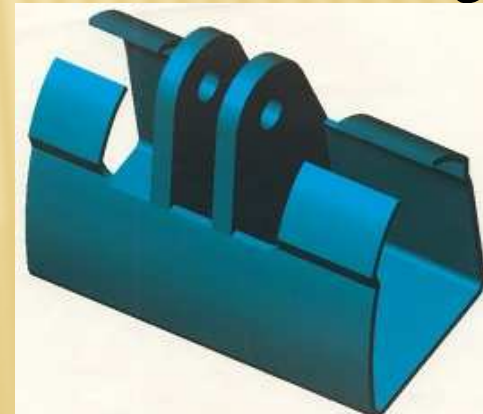
# ' $\pi$ ' PROFILE



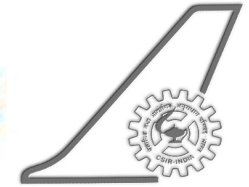
Sample woven on handloom as insert for Aircraft Fitting

## Weave design

- ✘ The ' $\pi$ ' profile was developed on similar lines to that of 'T' with the legs folding outwards.
- ✘ ' $\pi$ ' profile **weft path cycle** constitutes of **6 steps**.
- ✘ Possible application as inserts in aircraft fittings.



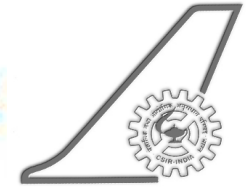
# CONICAL PREFORMS FOR AIR-BORNE RADOMES



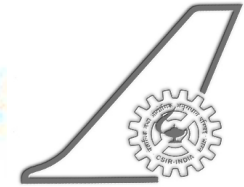
Jacquard woven preforms woven on a 1200 hook Jacquard machine (Double Lift Double Cylinder)

*"Recent trends in textile technology and material science" Technical university of Liberec., 21/06/2012*

# ANGLE-INTERLOCK (MULTILAYER) WEAVING – NEED

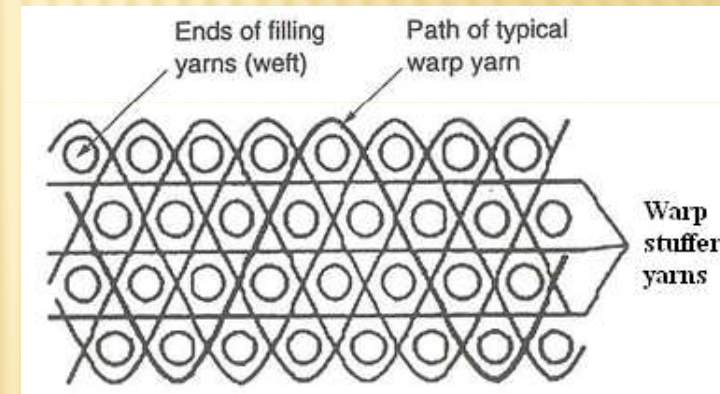
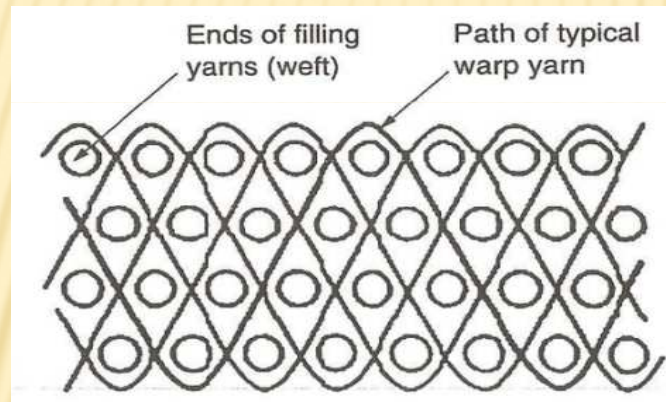


- ✘ Layered reinforcements with matrix material as through thickness bonding are susceptible to delamination.
- ✘ Improved delamination resistance is required in composites which experience thermal loading (exhaust nozzles, brake pads)
- ✘ Angle-interlock structures, due to their interweaves lock several layers together forming one bulk preform and thereby overcoming the issue of delamination.
- ✘ These structures also contribute to improved shear properties.

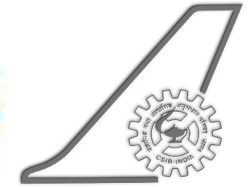


## ABOUT THE TECHNOLOGY

- ✘ Several layers of longitudinal threads (warp) will be arranged one over the other.
- ✘ They will be interwoven with several layers of transverse threads (weft) such that one thick bulk preform will be produced.



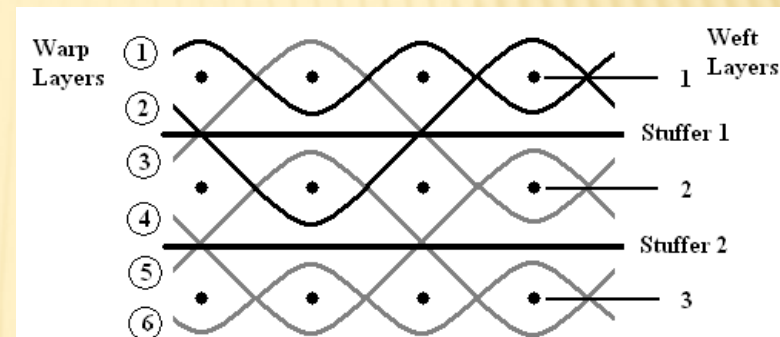
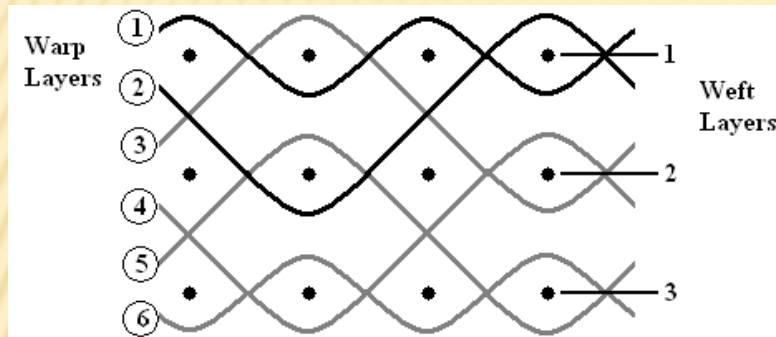
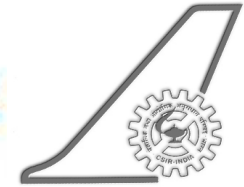
- ✘ The warp yarns criss-cross through the thickness in a pre-defined pattern.
- ✘ There would be possibility of including non-interlacing stuffer yarns to improve strength as well as fibre volume fraction.



## APPROACH

- ✘ Angle-interlock preforms can be woven on Dobby or Jacquard looms depending on the structure complexity.
- ✘ Loom needs minor modifications like multiple warp beam arrangement, linear intermittent take-up system etc.,
- ✘ Weave design is generated from weft cross-section.
- ✘ Weaving is carried out on similar lines to that of 2D weaving
- ✘ Angle-interlock structures can be of the following two types:
  - + Layer-to-Layer
  - + Through-Thickness

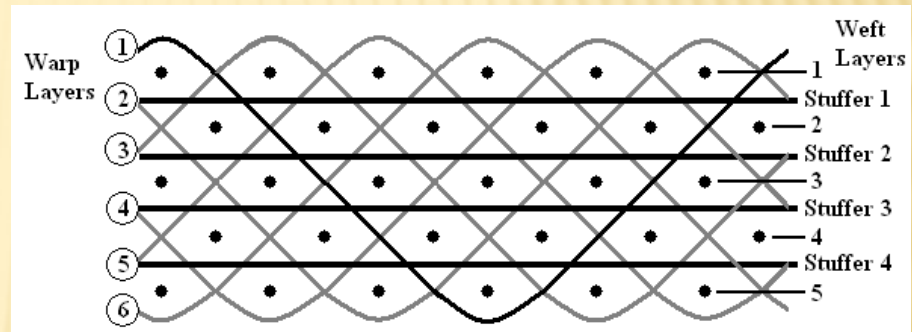
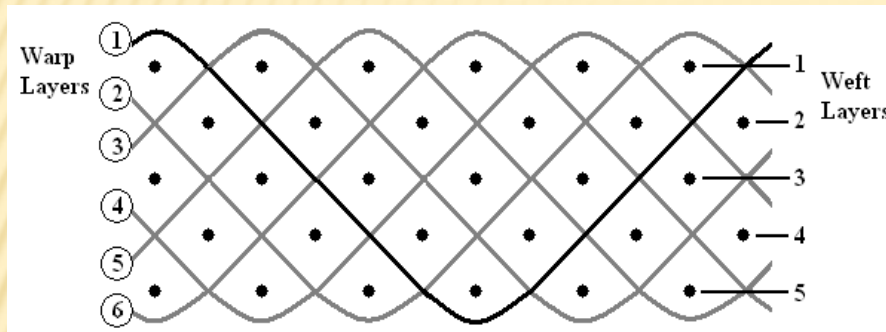
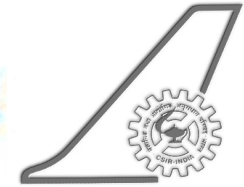
# LAYER-TO-LAYER ANGLE-INTERLOCK STRUCTURE



Note: The dot represents the weft and line represents the warp

- ✘ Each warp thread traverses to some intermediate layer in the architecture.
- ✘ Stuffers yarns (straight threads locked by the weave) can be introduced into the structure in order to improve the strength properties in the warp (loading) direction.

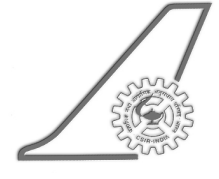
# THROUGH-THICKNESS ANGLE-INTERLOCK STRUCTURE



Note: The dot represents the weft and line represents the warp

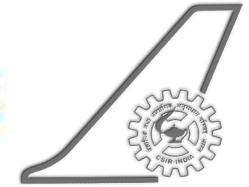
- ✘ Each warp thread traverses from the top to the bottom and back to the top of the structure.
- ✘ Here also provision exists for introducing stuffer yarns.
- ✘ Stuffer yarns also aids in improving fibre content.





# LITERATURE

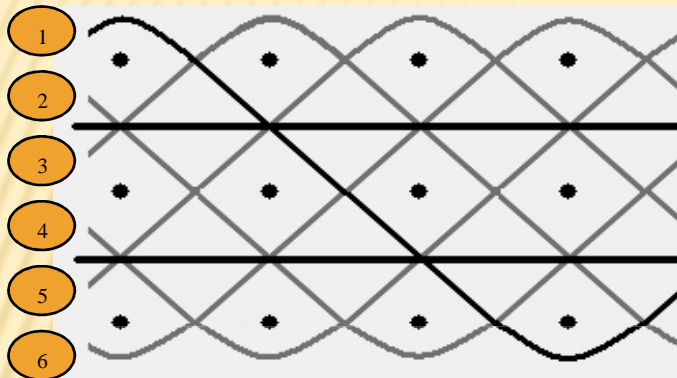
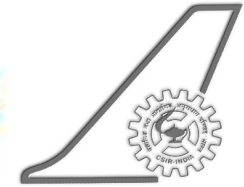
- ✘ M Bannister et al., (*Composites Part A*, 29(A), 1998) – fibre distribution and resin-rich regions in the 3D composite are strongly influenced by the yarn arrangement and compaction pressure during RTM process.
- ✘ X Chen et al., (*Journal of Textile Institute*, 1999) – studies on the 3D woven multi-layer preforms with different weave combinations
- ✘ J A Soden et al., (*Composites: Part A*, 30, 1999) - superior in-plane strength for 3D multilayer woven T-section
- ✘ Ronald P Schmidt and David A Kalser (*US 0056847 A1*, 2003) - Thick multilayer woven 'T' section for structural joint
- ✘ P Potluri et al., (*ICCM 17, Edinburgh, UK. 2009*) – evaluation of 3D interlock woven (Highest ILSS value), stitched and tufted composites.
- ✘ V Herb et al., (*Composites: Part A*, 43, 2012) – low velocity impact damage studies on 3D woven Sic/Sic composites and found them to be highly localised.



## SAMPLES PRODUCED ON HANDLOOM

- ✘ Layer-to-Layer (LL)
  - + 4 warp & 2 weft layers – 1.3mm thick
- ✘ Through-Thickness(TT)
  - + 4 warp & 2 weft layers – 1.3mm thick
- ✘ Layer-to-Layer With Stuffer (LLWS)
  - + 6 warp, 2 stuffer & 3 weft layers – 2mm thick
- ✘ Through-Thickness With Stuffer (TTWS)
  - + 6 warp, 2 stuffer & 3 weft layers – 2mm thick

# WEAVE DESIGN DETAILS OF ANGLE-INTERLOCK WEAVE



(6 warp, 2 stuffer & 3 weft layers)

Note: The dot represents the weft and line represents the warp

The authors wish to acknowledge Shwetha Singh N & Ashwathi, students from Govt S K S J T Institute, Bangalore for weaving the above preforms.

**DRAFT**

|   |   |   |   |   |   |  |   |
|---|---|---|---|---|---|--|---|
| 8 |   |   |   |   |   |  | X |
| 7 |   |   |   |   |   |  | X |
| 6 |   |   |   |   | X |  |   |
| 5 |   |   |   | X |   |  |   |
| 4 |   |   | X |   |   |  |   |
| 3 |   | X |   |   |   |  |   |
| 2 | X |   |   |   |   |  |   |
| 1 | X |   |   |   |   |  |   |

**DESIGN**

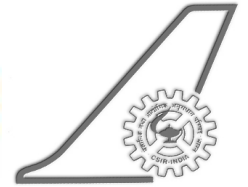
|    |   |   |   |   |   |   |   |   |
|----|---|---|---|---|---|---|---|---|
| 18 | X | X | X | X | X |   |   | X |
| 17 | X | X | X |   | X | X |   |   |
| 16 |   | X |   |   |   |   |   |   |
| 15 | X | X | X |   | X | X | X | X |
| 14 |   | X | X | X |   |   | X |   |
| 13 |   |   |   | X |   |   |   |   |
| 12 |   | X | X | X | X | X | X | X |
| 11 |   |   | X |   | X |   | X | X |
| 10 |   |   |   |   |   |   |   | X |
| 9  | X |   | X | X | X | X | X | X |
| 8  |   |   | X | X |   |   | X | X |
| 7  |   |   |   |   |   |   | X |   |
| 6  | X | X | X | X |   | X | X | X |
| 5  | X |   | X | X |   |   | X |   |
| 4  |   |   |   | X |   |   |   |   |
| 3  | X | X | X | X | X | X | X |   |
| 2  | X | X | X | X |   |   |   |   |
| 1  | X |   |   |   |   |   |   |   |

**LIFTING PLAN**

|    |   |   |   |   |   |   |   |   |
|----|---|---|---|---|---|---|---|---|
| 18 | X | X | X | X | X |   |   | X |
| 17 | X | X | X |   | X | X |   |   |
| 16 |   | X |   |   |   |   |   |   |
| 15 | X | X | X |   | X | X | X | X |
| 14 |   | X | X | X |   |   | X |   |
| 13 |   |   |   | X |   |   |   |   |
| 12 |   | X | X | X | X | X | X | X |
| 11 |   |   | X |   | X |   | X | X |
| 10 |   |   |   |   |   |   |   | X |
| 9  | X |   | X | X | X | X | X | X |
| 8  |   |   | X | X |   |   | X | X |
| 7  |   |   |   |   |   |   | X |   |
| 6  | X | X | X | X |   | X | X | X |
| 5  | X |   | X | X |   |   | X |   |
| 4  |   |   |   | X |   |   |   |   |
| 3  | X | X | X | X | X | X | X |   |
| 2  | X | X | X | X |   |   |   |   |
| 1  | X |   |   |   |   |   |   |   |

**DENTING PLAN**

|   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|---|
| 1 | X | X | X | X | X | X | X | X |
|---|---|---|---|---|---|---|---|---|



# STAGES OF WEAVING



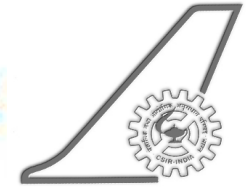
Multiple beam preparation



Warp passing over back rest



Warp passing through heald wires



## STAGES OF WEAVING CONTD..



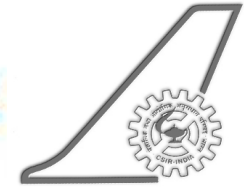
Warp passing through reed to the cloth fell and forming shed



Weft Insertion through the shed

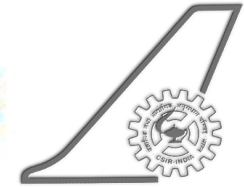


Pushing the inserted weft to the cloth fell



# PREFORM SPECIFICATIONS

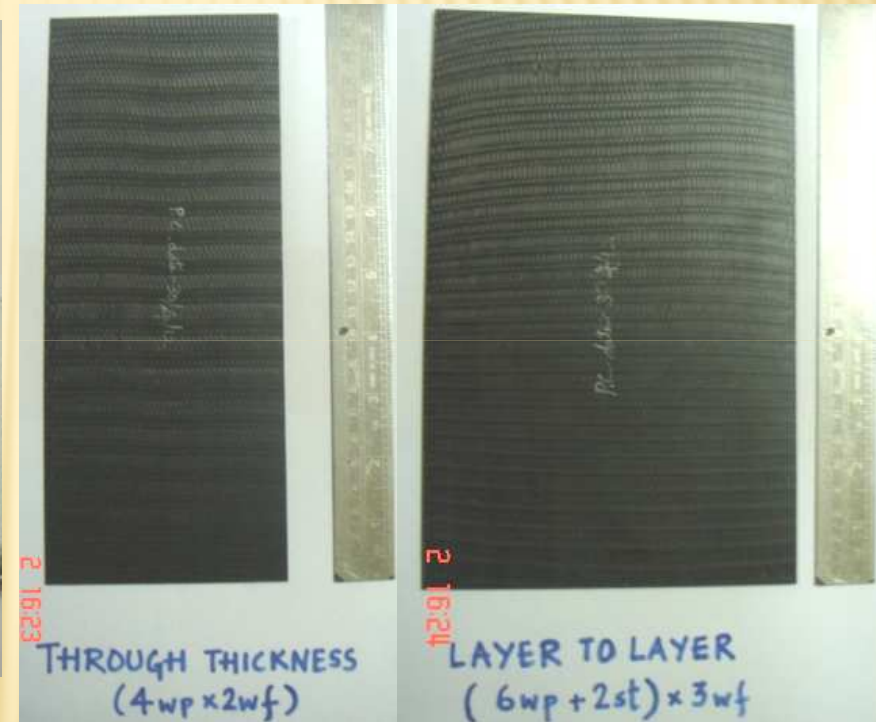
| Particulars                  | 6 Warp Layer<br>(with 2 stuffer)<br>Layer-to-Layer | 6 Warp Layer<br>(with 2 stuffer)<br>Through -Thickness |
|------------------------------|--|--|
| Dimensions L X W             | 250mm X 160mm                                      | 350mm X 160mm  |
| Thickness                    | 2.20mm   | 2.00mm   |
| Specimen Weight              | 76g  | 102g   |
| GSM                          | 1831.4   | 1875   |
| Carbon Fibre Density         | 1.7g/cc  | 1.7g/cc  |
| Carbon Fibre Volume Fraction | 0.50   | 0.49   |



# SOME PHOTOGRAPHS

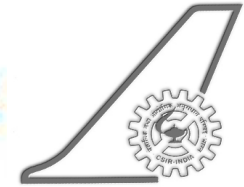


Preforms



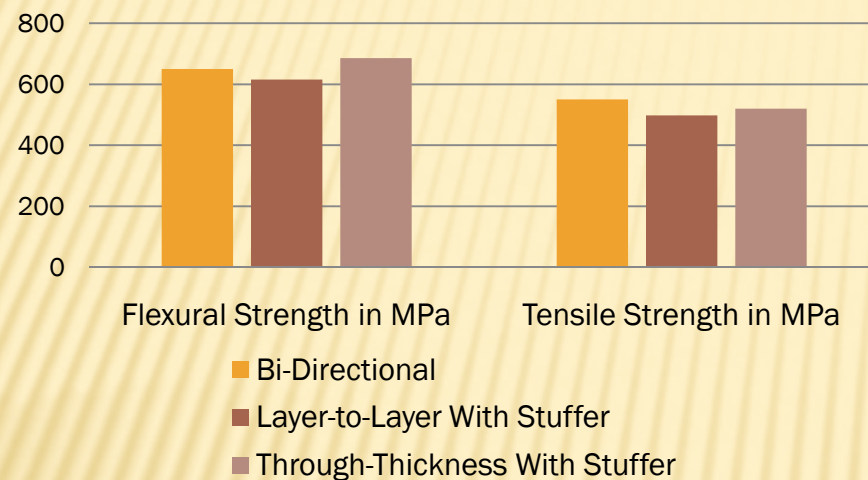
Composites

EPOLAM 2063 resin system

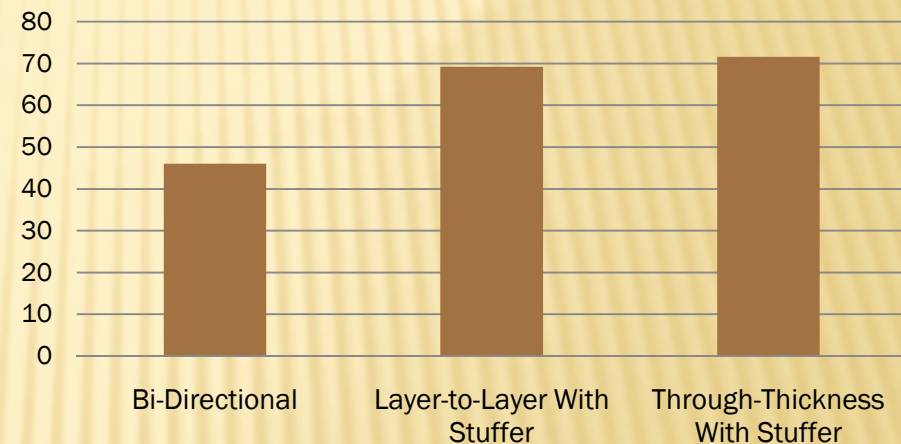


# COMPOSITE TEST RESULT

## Composite Mechanical Properties



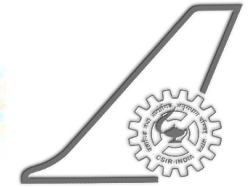
## Inter Laminar Shear Strength in MPa



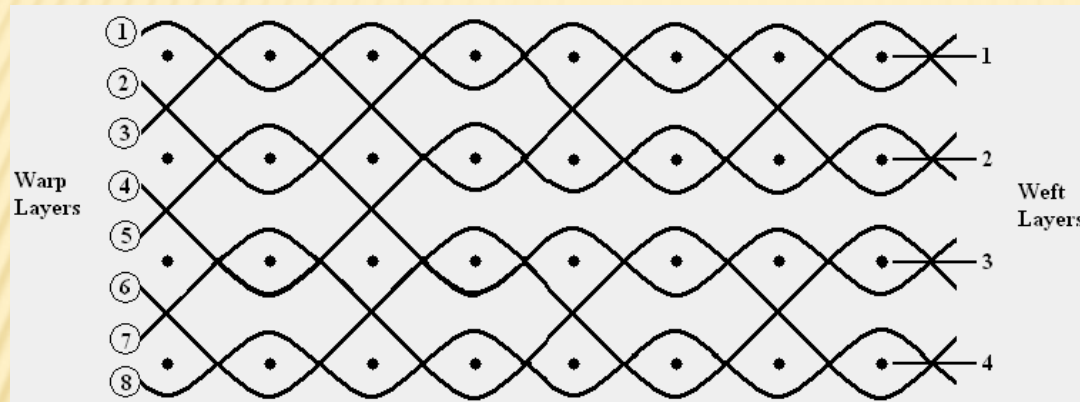
- ✘ ILSS has improved by 45-50%
- ✘ Equivalent tensile and flexural strength - Can be tailored by varying the stuffer yarn content

The authors wish to acknowledge Mr. Kundan & team from Advanced Composites Division, NAL for the above work on the composites fabrication and testing.





# 'T' PROFILE WEAVING

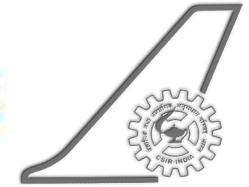


Cross-section of multilayer 'T' profile



Photograph of multilayer 'T' profile

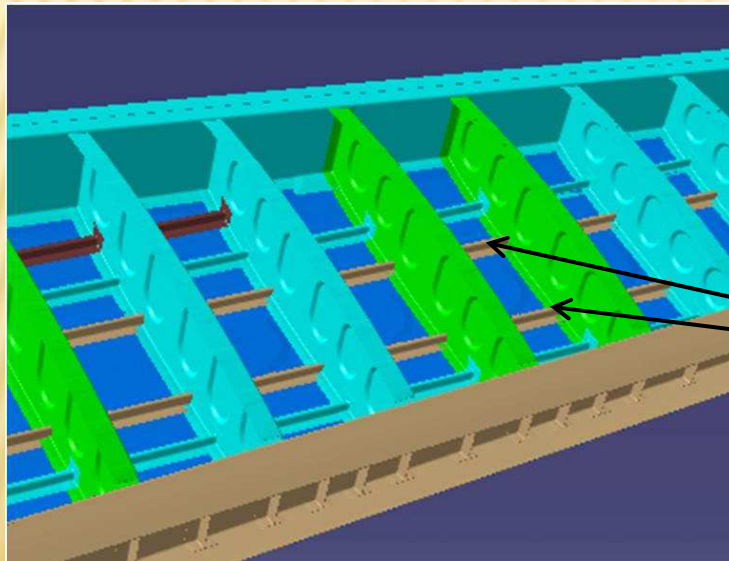
- ✘ Layer-to-Layer type of structure was used.
- ✘ Profile was formed in warp direction.
- ✘ The cross-section was so devised that at an intermediate point, the single planar preform would split into two planar preforms.
- ✘ On taking out of the loom, the two planar preforms would spread out and form the base of the 'T' profile.



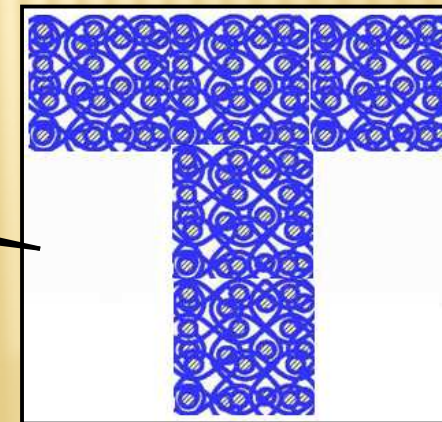
# THREE DIMENSIONAL WEAVING

One unified coherent structure with yarn interlacements in X, Y and Z directions can be developed using this technology

The profile as one single entity to the required dimensions can be developed using this technology.

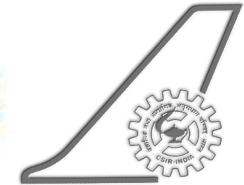


Joint in an aircraft's bottom skin



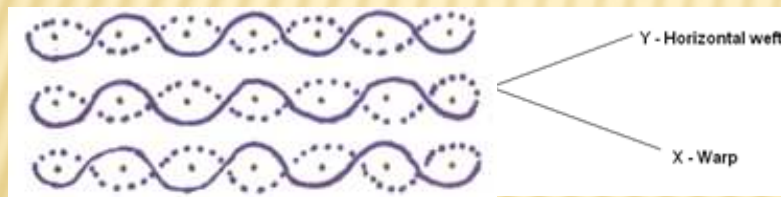
Magnified view of 'T'

# 3D WEAVING .....

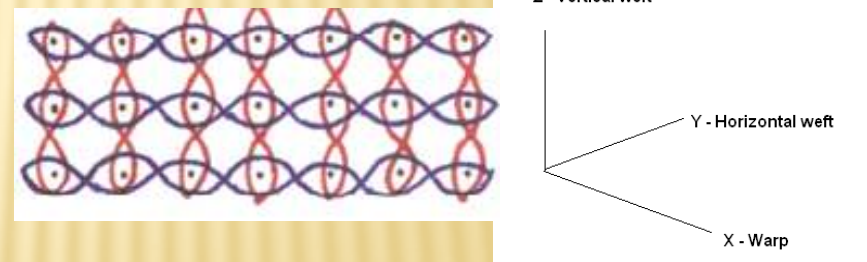


Consists of grid like yarns interwoven both in the horizontal and vertical plane to the required preform dimensions

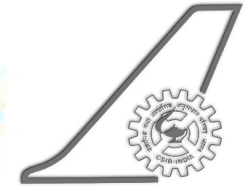
Works on the 2D weaving principle requiring similar motions but the mechanisms required to execute them are entirely different.



3 layers of 2D woven reinforcement  
laid one above the other



3 layered 3D woven preform



# LITERATURE

- ✘ N Khokar (*Journal of the Textile Institute*, 92 : 2, 2001, US 6186185 B1, 2001, US 6338367 B1, 2002,)
  - + technical characterisation of 3D weaving process based on adaptation of dual-directional shedding and development of an experimental set-up.
  - + a conceptual weft insertion method for 3D weaving.
  
- ✘ Fredrik Stig and Stefan Hallström (*Composites Science and Technology*, 69, 2009)
  - + 3D composites possess higher out-of-plane tensile strength and shear strength compared to conventional 2D laminates.
  - + Difficult to evaluate the true out-of-plane properties

[www.biteam.com](http://www.biteam.com)

## 3D WEAVING CAN...

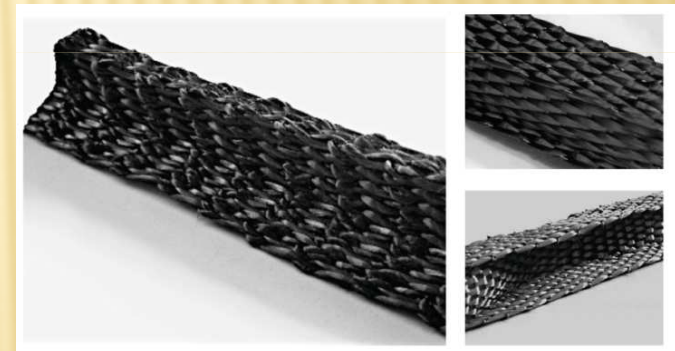
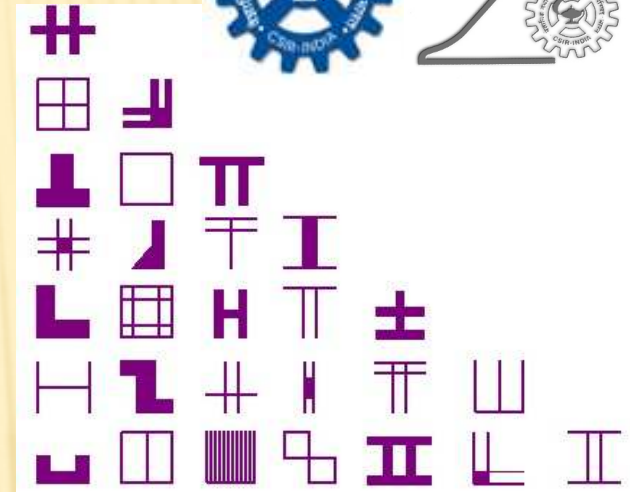
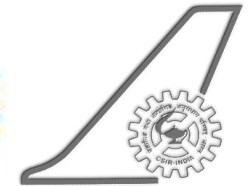
Develop specific profiles and modular joints for special applications in aerospace / space / defence sectors

Finely balance the in-plane and out-of-plane properties

Address the multidirectional, multiplanar loads and stresses and distribute them appropriately

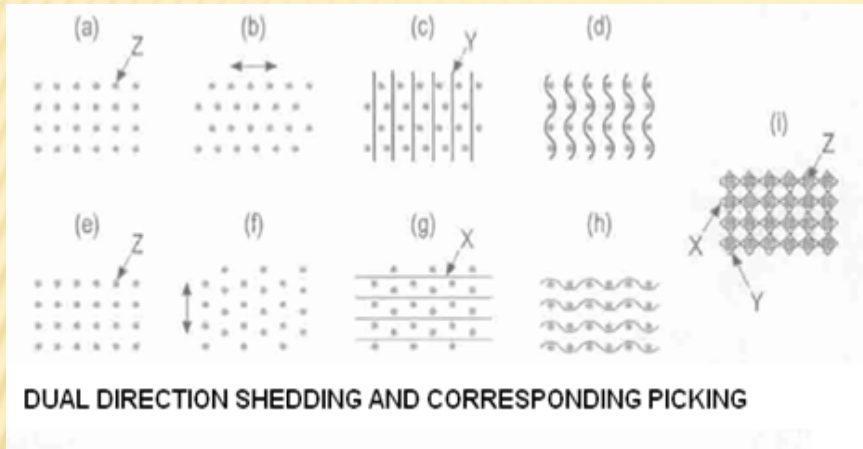
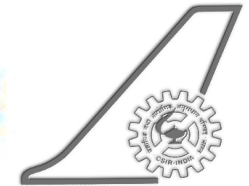
Design an integrated, custom made reinforcement for the end application

*FINALLY, CHANGE THE WAY PROFILED STRUCTURES ARE MADE*

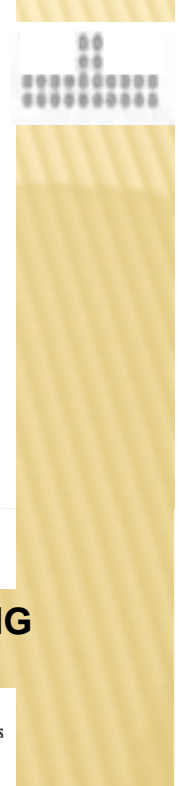
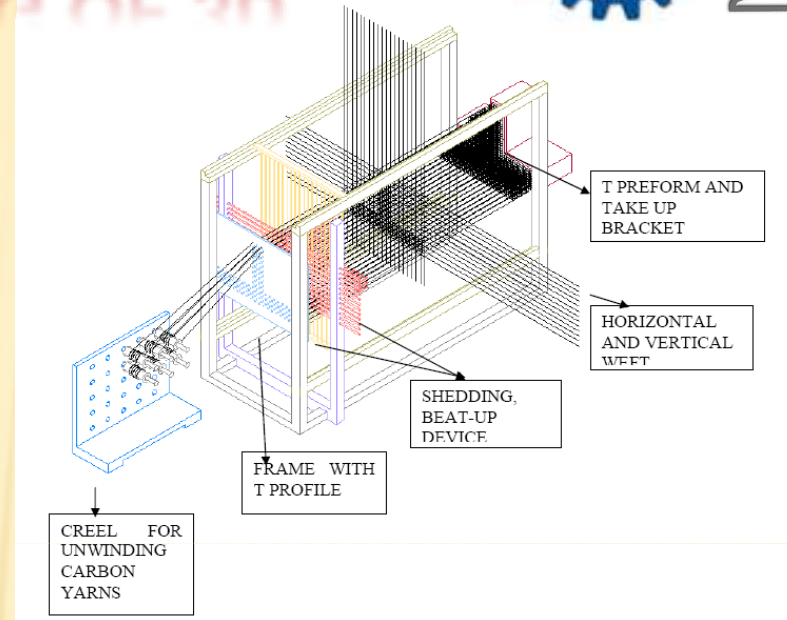


*Possible profiles (top) and samples developed (M/s BITEAM, Sweden)*

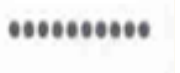
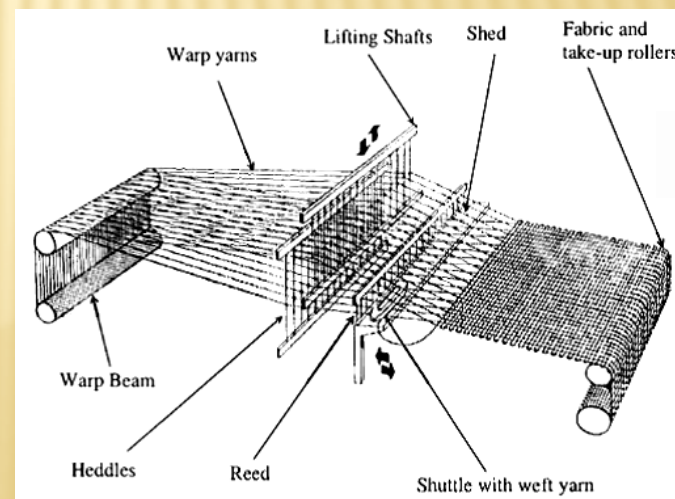
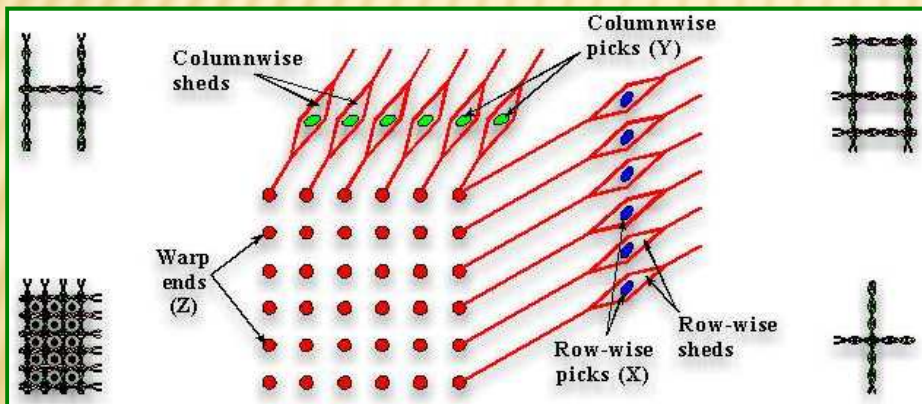
# CONCEPTUAL WORKING OF 3D



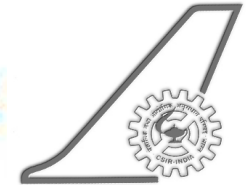
120 mm x 120 mm (Max. Cross-section)



## CONCEPTUALISED 'T'WEAVING

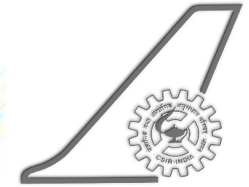


# ADVANTAGES OF 3D WEAVING



- High stability due to network structure
- Warp yarns parallel to the fabric length without traversing from one layer to the other
- Structure remains intact even when cut (Like 2D fabric)
- Increased structural integrity, more effective load transfer, possibility to tailor the material for specific load cases
- Open, closed, solid, thin walled, curved beams, complex shapes can be developed
- Engineering of mechanical properties by changing weaving parameters such as number of warp and weft yarns, yarn tension, tow sizes etc.,
- High impact damage tolerance, superior Interlaminar fracture properties, improved overall composite performance

# LIMITATIONS OF 3D WEAVING



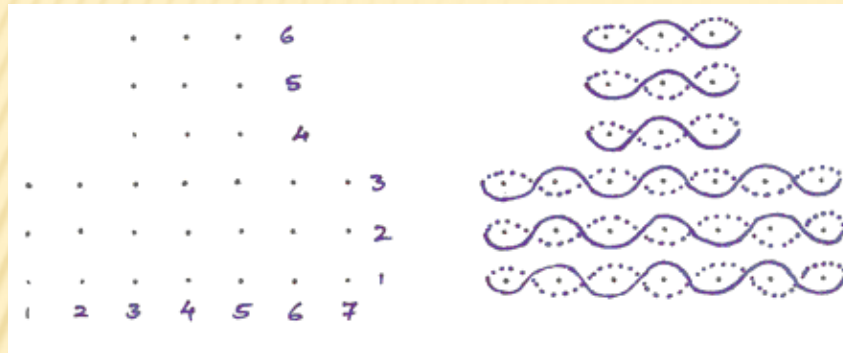
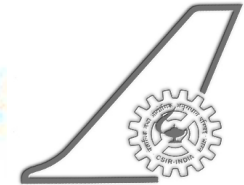
- Slow production rate due to complexity involved in weaving
- Complexity of profile becomes important
- Production greatly affected by the spacings between the horizontal and vertical wefts



# TECHNICAL CHALLENGES FOR DEVELOPMENT

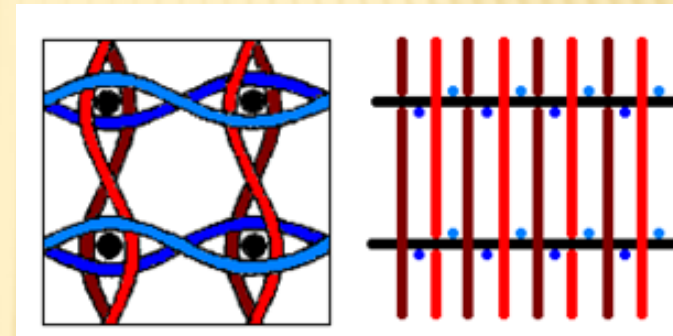
- Speciality creels for grid-like warp arrangement
- Dual direction shedding mechanism for warp separation
- Positive picking mechanism for vertical weft insertion
- Design of slimmer and smaller shuttles for Narrower sheds
- Optional insertion mechanisms as relevant for stuffer yarns
- Special beat-up mechanisms for weft beat-up to preform fell
- Preform shaped take-up required

# APPROACH TO 3D WEAVING OF 'T'

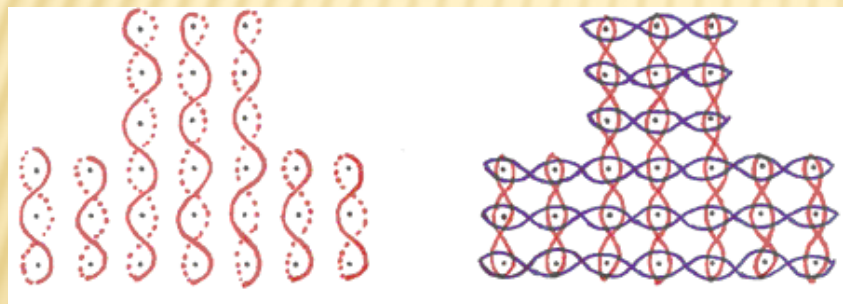


Grid like warp arrangement (X)

Horizontal weft insertion (Y)

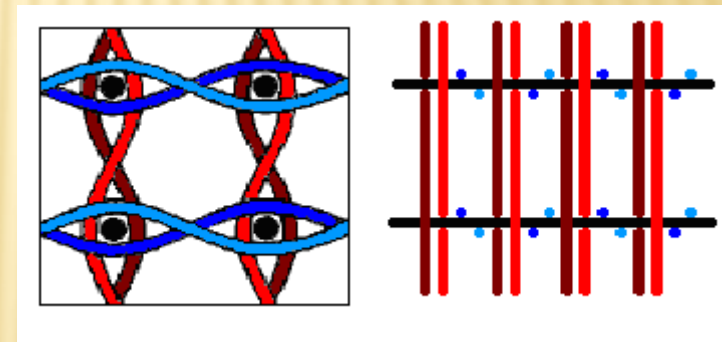


Geometrical structure 1



Vertical weft insertion (Z)

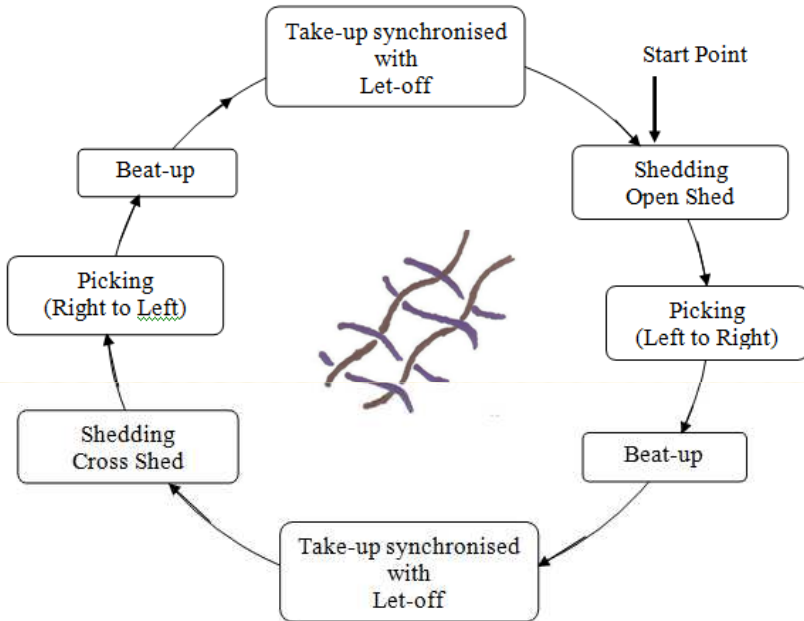
3D woven "T" structure



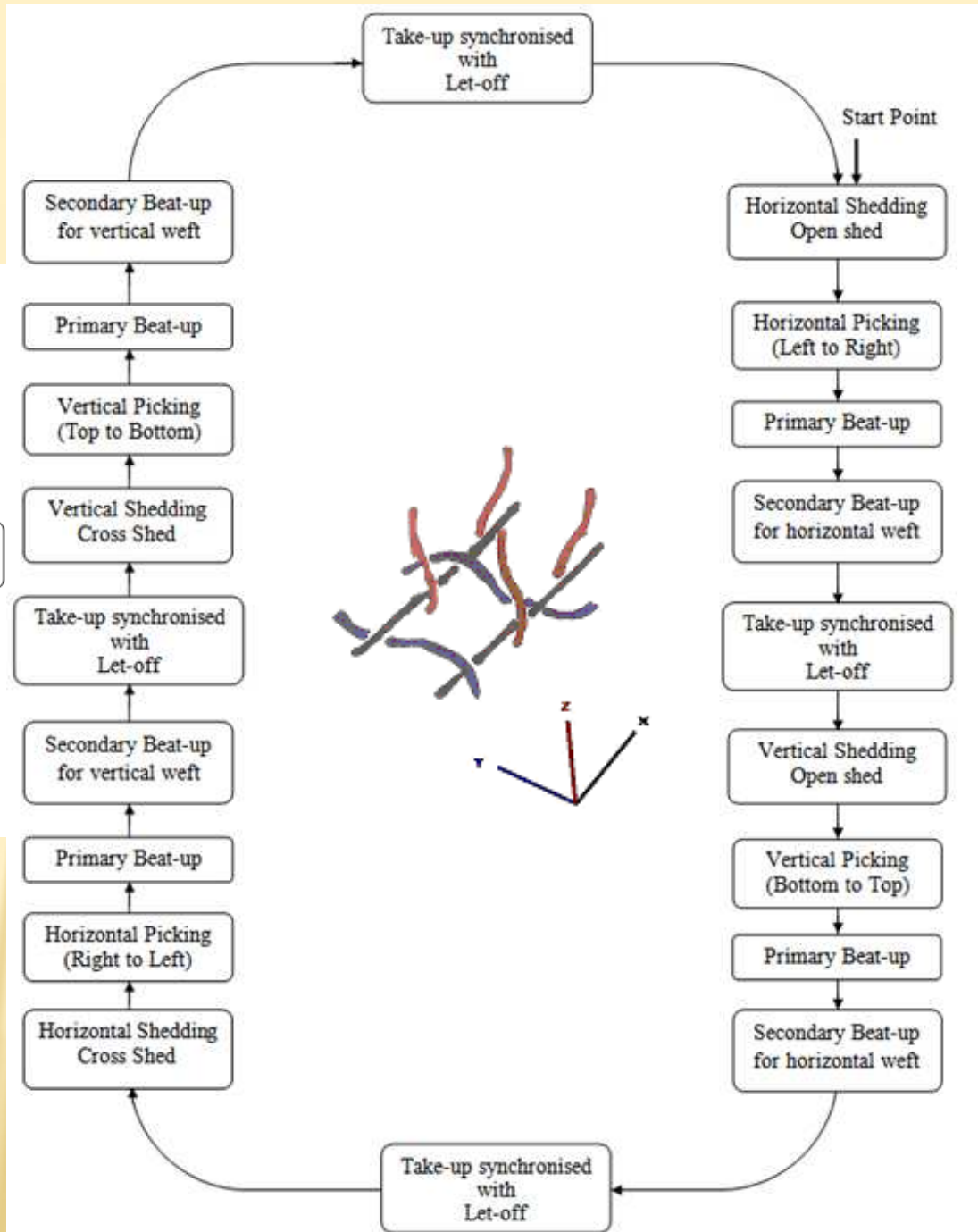
Geometrical Structure 2

## Three layer 'T' construction

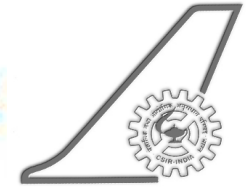
# 2D & 3D WEAVING CYCLE



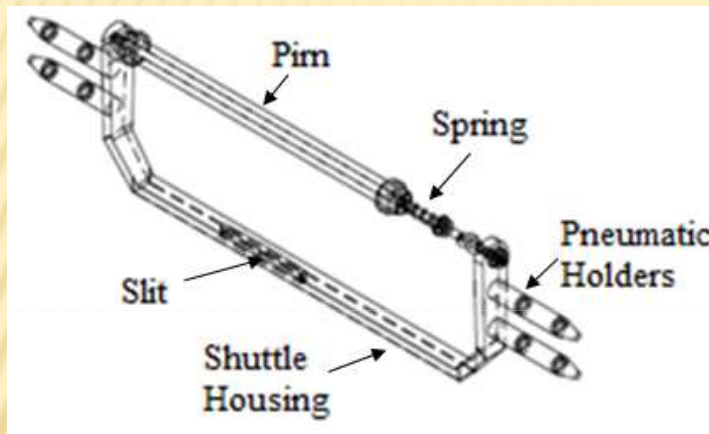
**2D Weaving Cycle**



# PICKING, BEAT-UP AND TAKE-UP



*Positive picking concept – Multiple shuttles need to insert threads in multiple layers*

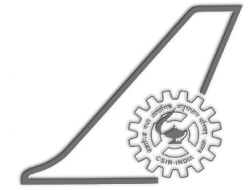


*The mechanisation approach - vacuum holding principle*

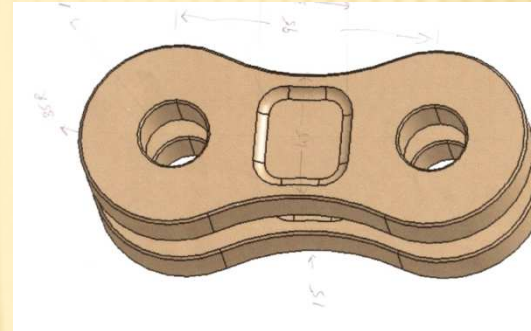
*Use of dual concept beat-up (primary and secondary) to assist preform compaction (as against single beat-up device in 2D weaving)*

*Take-up will be in linear form (as against cloth roller)*

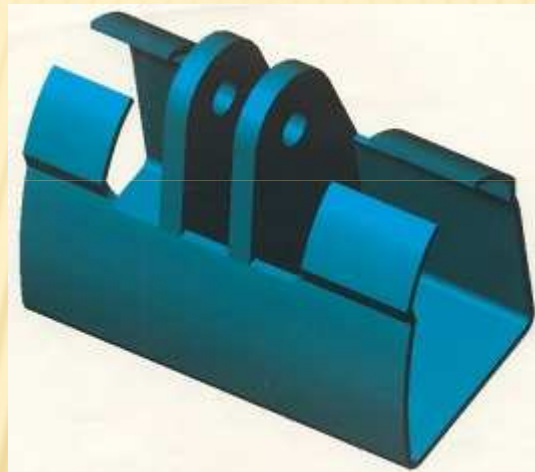
# TARGETED APPLICATIONS IN AIRCRAFT SUB-STRUCTURES



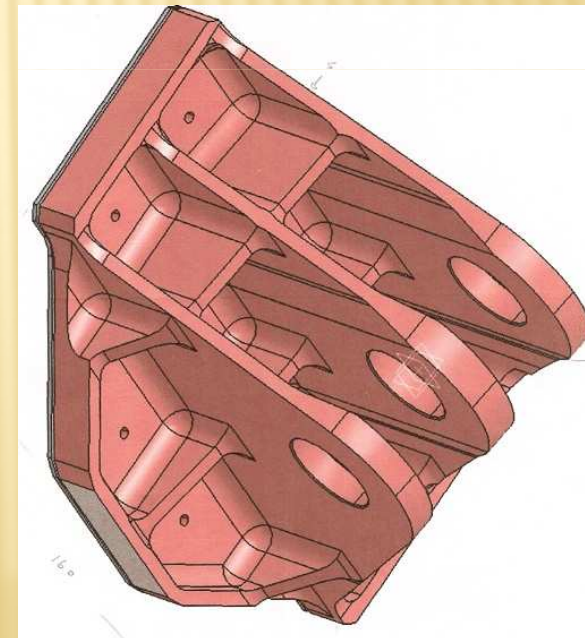
× ***T Stiffeners***



× ***I sections***

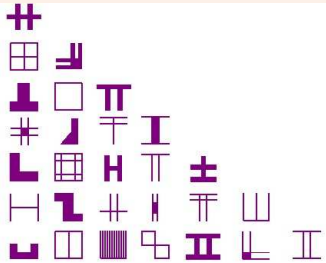


× ***Links***

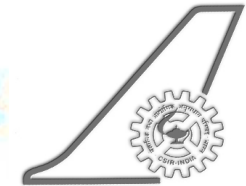


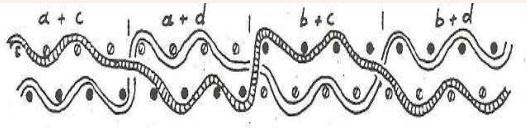
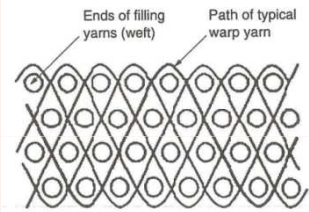
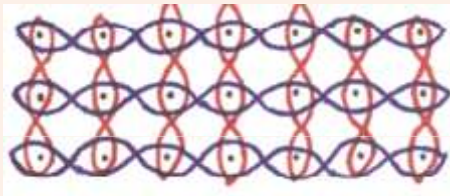
× ***Fittings***

# COMPARISON OF THE 3 TECHNOLOGIES

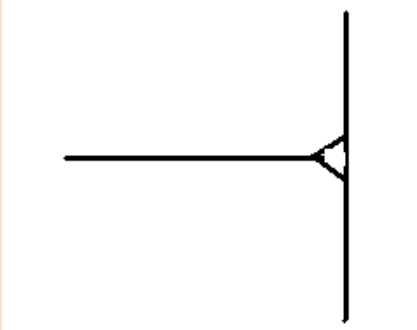
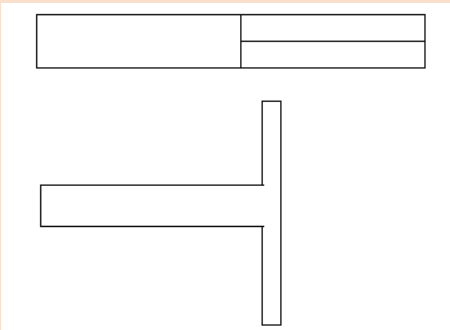

| PROFILE WEAVING   | MULTILAYER WEAVING  | 3 DIMENSIONAL WEAVING   |
|---|---|---|
| <b>POSSIBILITIES</b>  |   |   |
| Single, double or three layered planar structures                                       | Upto 20 layered planar structures interwoven<br>In the thickness plane      | Upto 68 layers both in the horizontal and vertical plane  |
| Width – 1.5 to 2.0 mtrs<br>Length – few hundreds of meters<br>Thickness – upto 1 mm     | Width – upto 0.5 mtr<br>Length – few tens of meters<br>Thickness – 6 to 8mm | Width – 204 mm<br>Length – 4 to 5 meters<br><br>Thickness – upto 204 mm   |
| Profiles restricted to conical, cylindrical , ogival and T, I,J (with some limitations) | Simple profiles such as T, I, H can be developed                            | Profiles as below (T, I, Pi, blocks, +, J, H, etc.) Can be developed<br> |

# COMPARISON OF THE THREE TECHNOLOGIES



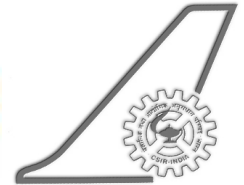
| JACQUARD WEAVING  | MULTILAYER WEAVING   | 3 DIMENSIONAL WEAVING  |
|---|--|--|
| <b>TECHNICALITIES</b>   |  |  |
| Angular thread deposition in the thickness plane<br> | Angular thread deposition in the thickness plane, angle decided by number of layers and spacing<br> | Perfect Perpendicular thread deposition in the vertical plane<br> |
| Single warp sheet   | Multiple warp sheets   | Grid Like warp sheet   |
| weft insertion devices – 1  | weft insertion devices – 1   | Each layer in each plane requires 1 device.<br>(68 + 68 = 136)   |
| Commercial machines available   | Commercial machines can be modified and adapted to some extent but best if the design is from scratch  | Machine has to be custom designed  |

# COMPARISON OF THE THREE TECHNOLOGIES

| JACQUARD WEAVING  | MULTILAYER WEAVING  | 3 DIMENSIONAL WEAVING   |
|---|---|---|
| <b>Limitations and challenges</b>   |   |   |
| Single layer  | Multiple layer (upto max 20)  | Cross section (max 204 X 204 mm) Geometric limitations for design exist               |
| Thread crimp  | Thread waviness   | Thread crimp  |
|   | Reduces fibre volume fraction and in-plane properties by 30%<br>Can be supplemented by inclusion of axial yarns | Reduces fibre volume fraction and in-plane properties (to be quantified)              |
| Fwf – UPTO 0.70   | Fwf – UPTO 0.55   | Fw F – anywhere between 0.35 – 0.50   |
|  |                             |  |



## LOOKING BACK . . .

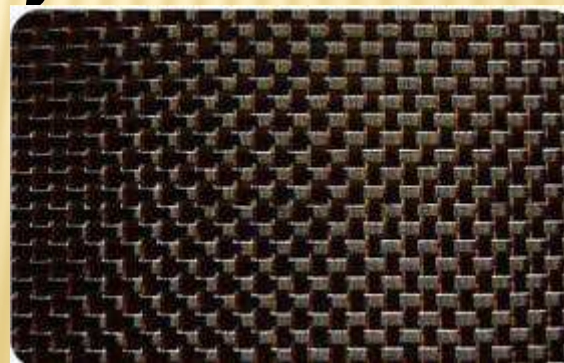


Textile Reinforcements have indeed travelled a long journey into the composites domain and created a niche for themselves

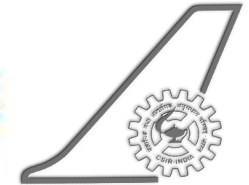
They have indeed performed to the satisfaction of the composites community albeit few glitches

But then the performance requirement just increases as the textile reinforcements of yester-years were

***“simply- made- for the composite”***



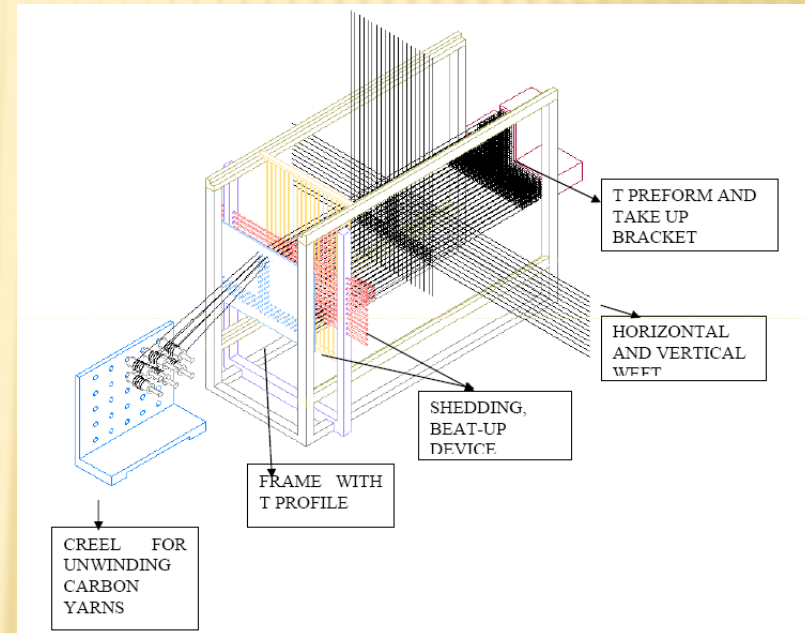
# LOOKING FORWARD...



A COMBINATION OF 2D & 3D TECHNOLOGIES  
WILL BE THE JOURNEY AHEAD FOR TEXTILE  
REINFORCEMENTS

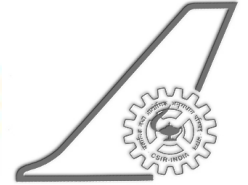


AS



**“THE TEXTILE REINFORCEMENTS WILL BE  
SPECIFICALLY-DESIGNED-INTO  
THE COMPOSITE”**

## ACKNOWLEDGEMENTS...



Dr. Petr Sittner, Head, Department of Functional Materials, Institute of Physics, Prague for providing me the invitation to come here under the Indo-Czech collaboration


Dr. Ludek Heller for his support and total co-ordination for helping me complete the formalities to come here

Prof. Dr. Jiri Militky, EURING, Dr. Ing. Dana Kremenakova, Dr. Rajesh Mishra and Dr. Sayed Ibrahim of Technical University of Liberec for providing me an opportunity to present

Dr. Shyam Chetty, Director NAL for his total support

Dr. Dayananda GN, Head CSMST who has been the driving force for my visit

My other colleagues S. Jayashankar, Senthil Kumar Palanisamy, Kannan GM, Admin staff at NAL who have supported me in this programme.

A white rectangular card with a double-line gold border is placed on a brown textured surface. The words "Thank You" are written in a gold cursive font. A clear pen with a gold-colored tip and a textured grip is positioned diagonally below the card.

Thank You