# Composite Application Challenge
## in
# Primary Aircraft Structures

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# Outline – Composite Application Challenge in Primary Aircraft Structures

◆Composite application on airframe has been increasing.
Typical examples are Boeing 787 & A350XWB.

◆Composite can not be demonstrated prominent advantage
in cost & weight in small commercial airplane, such as MRJ.

◆Summarizing

* Technical challenge against weight reduction

* Recurring cost challenge

◆Need game-changing technology for obtaining prominent advantage

# Scope

**Composite Technology** is one of most important technologies for lowering operation cost on commercial aircraft.

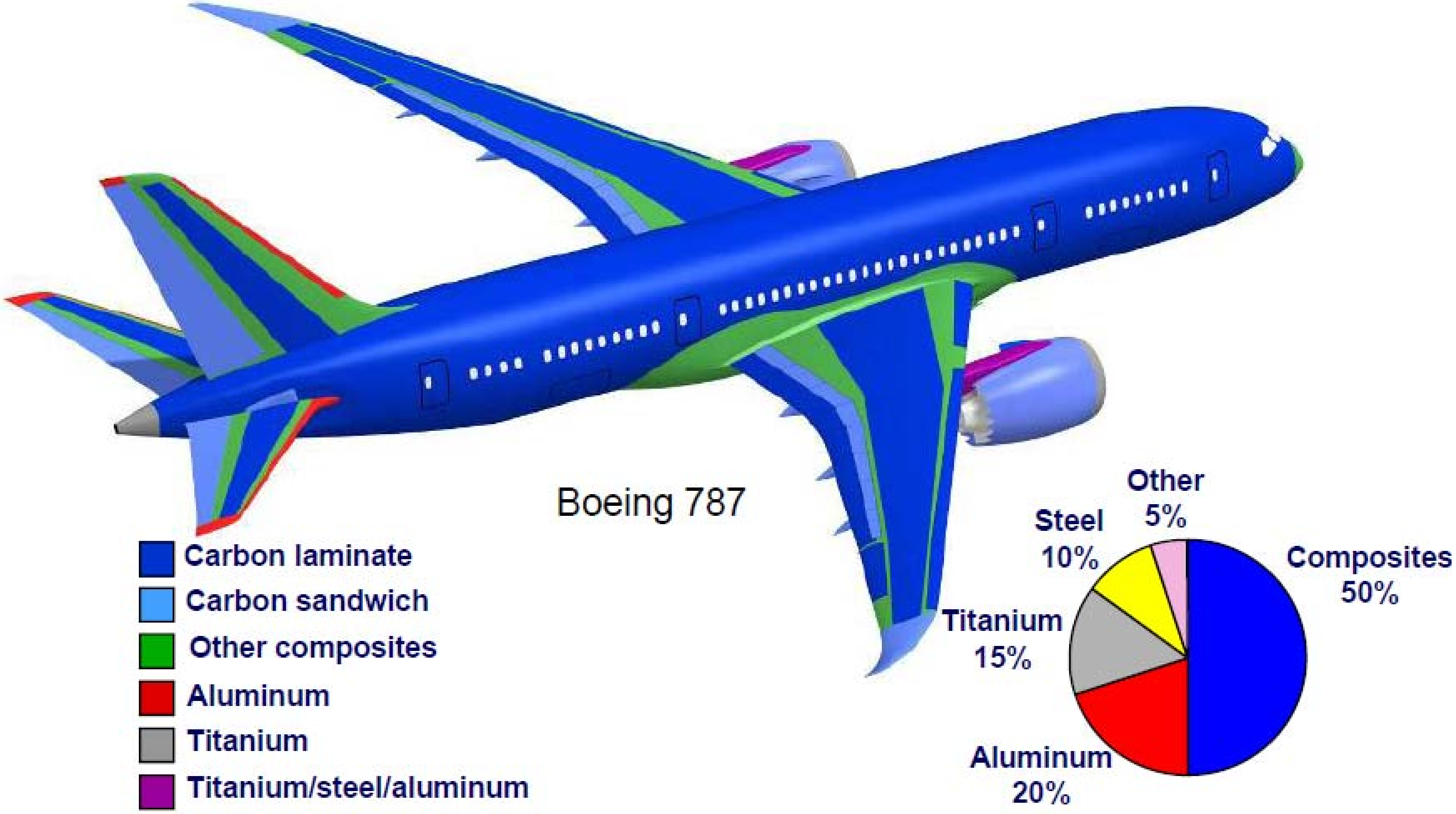
Latest Airplanes are boasting to utilize their owned composite technologies for satisfying the customer needs.

Followings are examples of the new comers.

* Boeing 787
* Airbus A350XWB
* Bombardier CSeries
* Mitsubishi MRJ

All have composite wing except MRJ.
Composite application on MRJ is empennage and control surface, amounting to 10 - 15% of the total airframe weight.

# Composite application on Airframe – Boeing 787 (Example)



Reference from, G.E.Gibson (Boeing), “Fracture Analysis for bondlines and interfaces of composite structures”, 4th International Conference of composite testing & model identification, Oct.20, 2008

# MRJ Aluminum decision on wing structure

- In addition, with the updated design the MRJ will feature an aluminum wing box, which will make it easier to manufacture the optimal wing structure. Easier optimization means enhanced competitiveness across the MRJ family: the MRJ70, the MRJ90 and the MRJ stretch version, a 100-seat jet, which is a recently announced potential addition that we are excited to tell you about in greater detail below.
- The aluminum wing box will allow for a shorter lead-time to make structural changes, and with an aluminum wing box, the wings can be optimized to match the attributes of each member of the MRJ airplane family. This will maximize the performance of all MRJ models, including the possible stretch version.

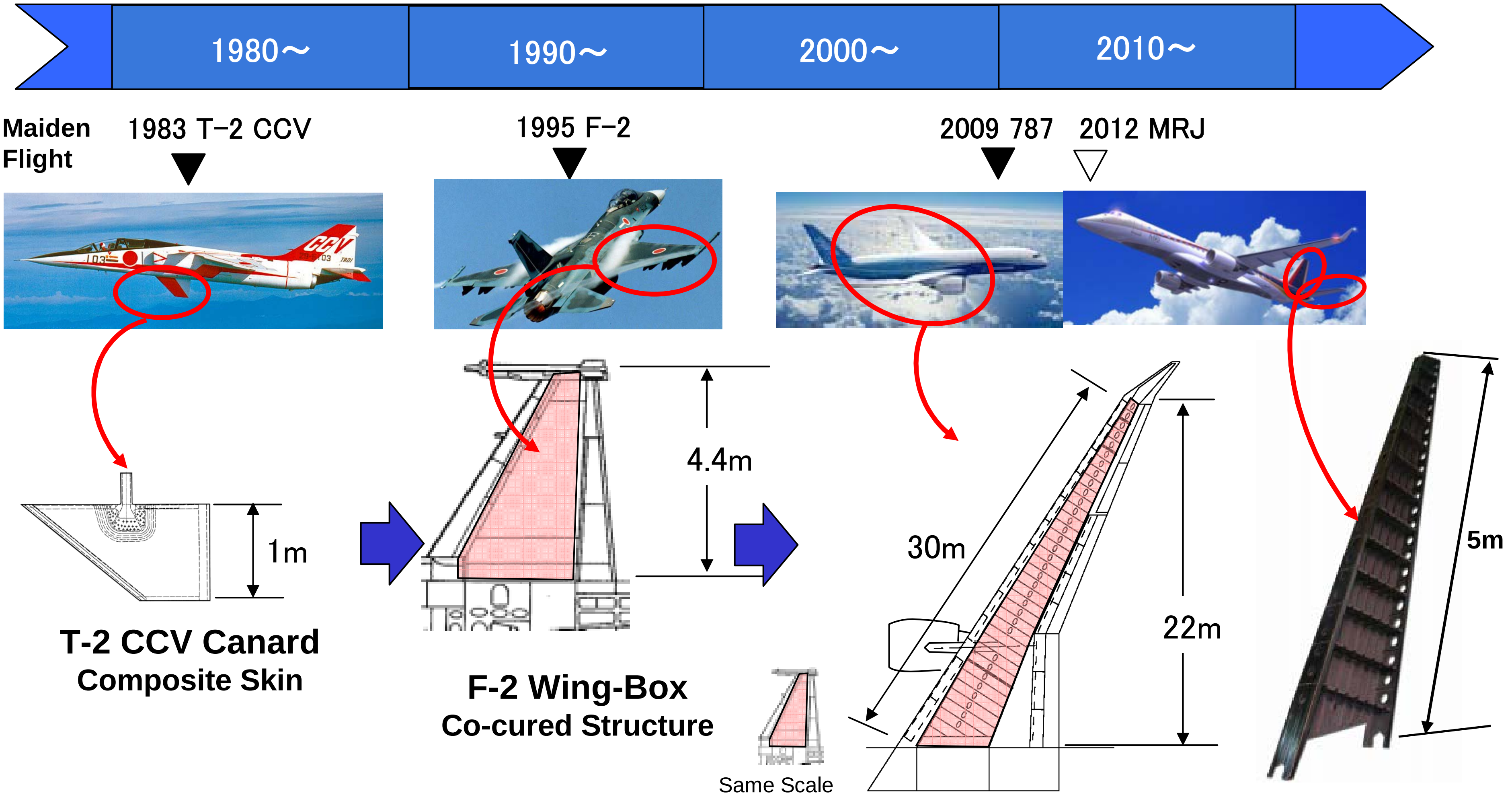
MRJ HP Posted on September 9th , 2009

**Plainly speaking, Composite can not be demonstrated prominent advantage in cost & weight point against conventional Al-alloy structure just in case 90seat-class single aisle regional jet.**

**Today’s Discussion is focusing on :**

**Composite application challenge derived from MHI lesson & learned**

# MHI Composite Application History



**Maiden Flight**

1983 T-2 CCV ▼

1995 F-2 ▼

2009 787 ▼

2012 MRJ ▽

**T-2 CCV Canard**
**Composite Skin**

**F-2 Wing-Box**
**Co-cured Structure**

Same Scale
F-2 Wing

**Boeing 787**
**Wing-Box**
**Co-bond Structure**

**MRJ Empennage**
**A-VaRTM**
**Co-bond Structure**

**Note) T-2CCV and F-2 Photos Ref. from Japan MOD HP**
**Boeing 787 Image Ref. from Boeing HP**
**MRJ Image Ref. from MRJ HP**

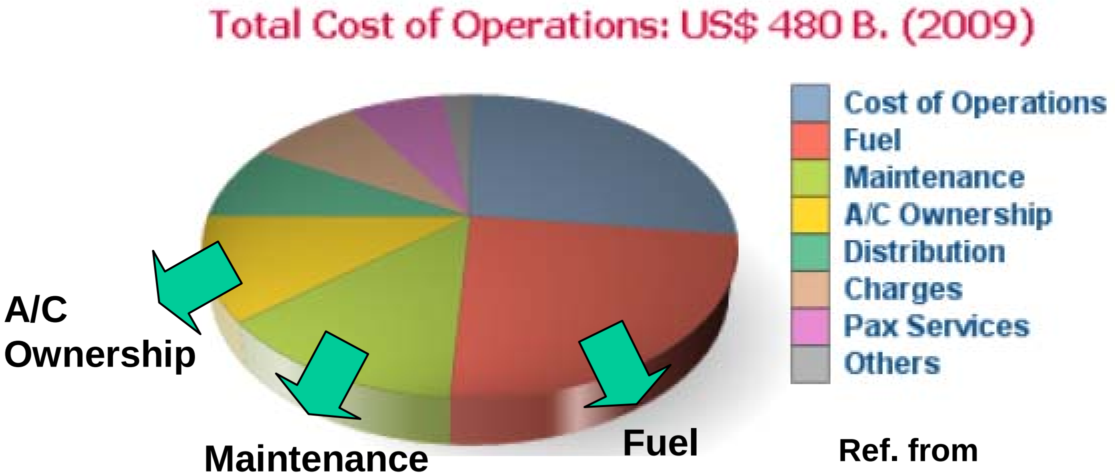
**▨ :Fuel Tank Area**

# Why Composites ?

◆**Reduces Weight**
◆**Reduces maintenance costs**
◆**Reduces / Eliminates corrosion**
◆**Better fatigue characteristics**

**Al-alloy have been improving mechanical characteristics and still holds advantage on material / manufacturing cost.**

**Reducing total operational cost is critically important for the customer.**

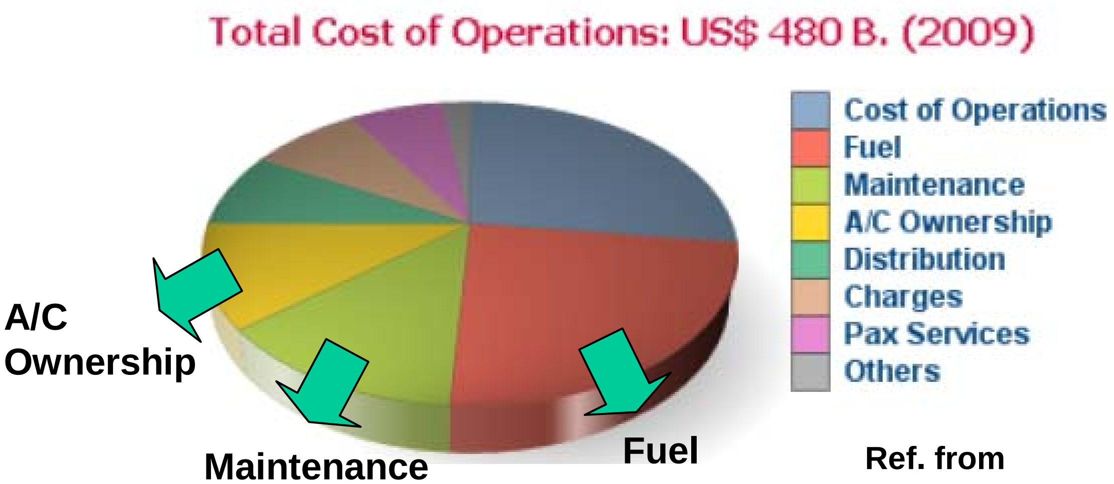


**Ref. from**
**IATA OCRI(=Operational Cost Reduction Initiative) bulletin**

# Composite Contribution

**Composite application contributes following factors on total operating costs.**

- **Fuel** - **Light weight structure contributes low fuel consumption**
  ⇒ **"Fuel" interpreted as "Light Weight" in this presentation**
- **Maintenance** - **Better fatigue characteristics / Less susceptibility on corrosion contributes less maintenance cost and guarantees longer inspection interval**
- **A/C Ownership** - **< Disadvantage for composite structure ? >**
  ⇒ **"A/C Ownership" interpreted as "Competitive Price Product" in this presentation**



**Ref. from**
**IATA OCRI(=Operational Cost Reduction Initiative) bulletin**

**Reference – Fuel efficiency on Boeing 787**

**The airplane will use 20 percent less fuel for comparable missions than today's similarly sized airplane.**

**(From Boeing HP)**

**Reference – Fuel efficiency on GEnX**

**The GEnx will deliver 15 percent better specific fuel consumption than the engines it replaces**

**(From geae.com HP)**

# Light Weight Structure

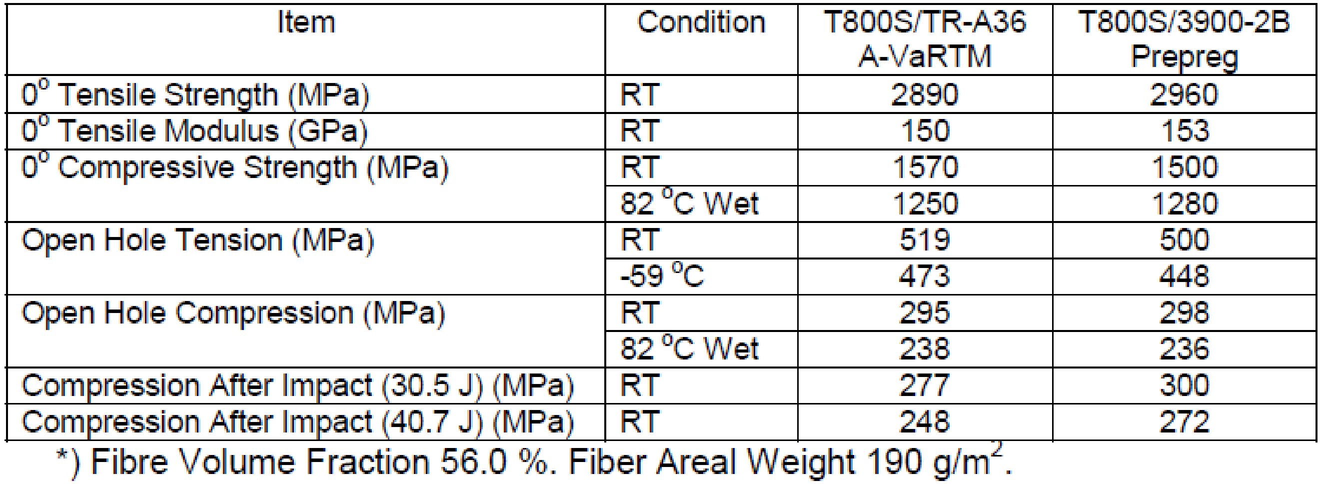
**Key aim of composite application is to realize light weight structure.**

**Properties on today’s typical composite for primary structure is shown below.**

**[ Note: 350MPa is an allowable value for typical Al-alloy considering fatigue knockdown. Composite strength shown below is good enough to realize low weight structure counting on advantage of material density. ]**

**Roughly speaking, 10 through 15% weight reduction is realized for almost modern developed airplane.**
**This weight reduction capability is questioned for small, single-aisle airplane due to several technical challenges.**

**Table Typical mechanical properties of composite material**



| Item | Condition | T800S/TR-A36 A-VaRTM | T800S/3900-2B Prepreg |
|---|---|---|---|
| $0^{o}$ Tensile Strength (MPa) | RT | 2890 | 2960 |
| $0^{o}$ Tensile Modulus (GPa) | RT | 150 | 153 |
| $0^{o}$ Compressive Strength (MPa) | RT | 1570 | 1500 |
| | 82 °C Wet | 1250 | 1280 |
| Open Hole Tension (MPa) | RT | 519 | 500 |
| | -59 °C | 473 | 448 |
| Open Hole Compression (MPa) | RT | 295 | 298 |
| | 82 °C Wet | 238 | 236 |
| Compression After Impact (30.5 J) (MPa) | RT | 277 | 300 |
| Compression After Impact (40.7 J) (MPa) | RT | 248 | 272 |

*) Fibre Volume Fraction 56.0 %. Fiber Areal Weight 190 $g/m^2$.

**Note) A-VaRTM is material & process for MRJ empennage structure.**
**Prepreg(T800S/3900-2B) is an identical material of application on Boeing 787 structure.**
**Ref. from, T.Abe, et al, “A-VaRTM for primary aircraft structures”, Proc.27th Int. Conf. SAMPE Europe, Paris, 2006**

# Technical Challenges – Light Weight Structure

**【Technical Challenges based on today's composite technology】**

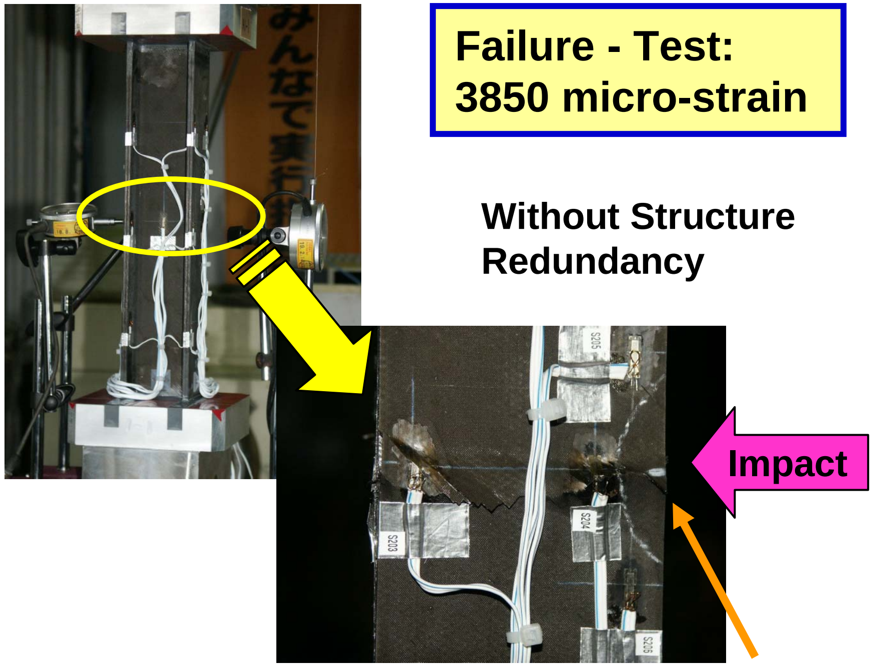
**Due to following technical challenges, weight reduction opportunity can not be fully utilized.**

- ◆ **Impact Damage strength regression**
- ◆ **Bolted Joint**
- ◆ **Stress Concentration**
- ◆ **Inter-laminar Failure / Delamination / Disbond**
- ◆ **Ply Drop-off**

**Note that Post-buckling design is an issue for future composite challenge.**
**Need advance in material / process and design manner / failure criteria for achieving the post-buckled structure.**

# Technical Challenges – Light Weight Structure

## ◆ Impact Damage strength regression



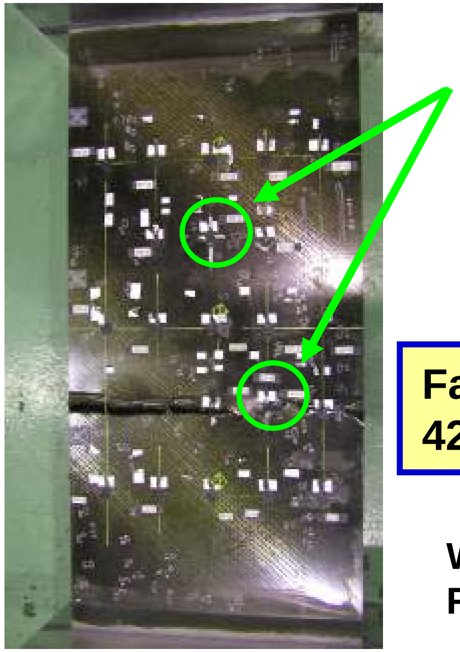
**Failure - Test: 3850 micro-strain**

Without Structure Redundancy

Impact

Damaged Area defined by NDI

### Single Stringer Compression



Impact locations on panel (Energy 136J)

**Failure - Test: 4250 micro-strain**

With Structure Redundancy

### Multi-Stringer Co-bonded Panel Compression

*Edge Impact*

**Strength capability deteriorates dramatically due to impact damage even in using today's toughened resin system composite.**

Ref. from, T.Abe, et al, "A-VaRTM for primary aircraft structures", Proc.28th Int. Conf. SAMPE Europe, Paris, 2007

# Technical Challenges – Light Weight Structure

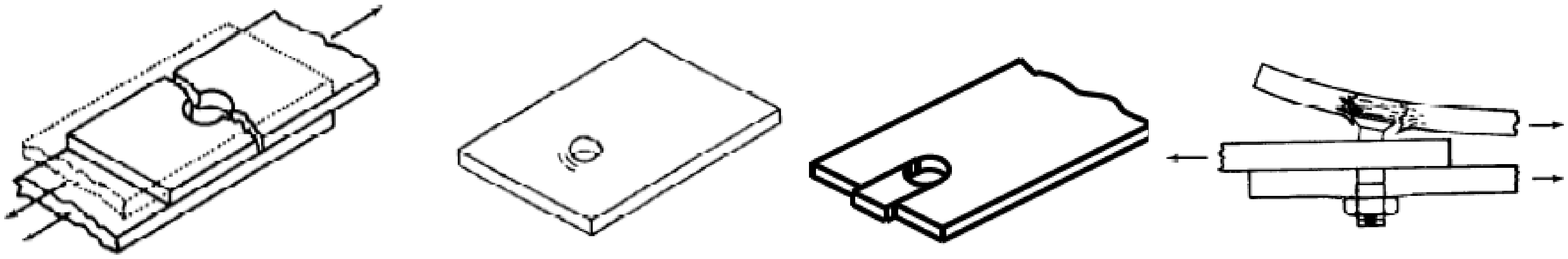
## ◆ Bolted Joint

**Bolted joint is also a weak point on composite structure.
Even in applying the premium priced toughened resin composite,
bearing strength demonstrates 40% lower than conventional Al-Alloy.**

**Bearing strength comparison between typical Al-alloy & composite**

| Al-Alloy<br>7050-T7451 Plate (AMS4050) | Typical toughened resin composite |
|---|---|
| **980MPa**<br>(e/D=2.0, t=1.5～2.0”) | **600MPa**<br>considering environmental knockdown |

**40% lower strength than conventional Al-alloy**



**Net-section failure** **Bearing failure** **Shear-out failure** **Pull-through failure**

**Typical failure modes on fastener joints**

# Technical Challenges – Light Weight Structure

## ◆ Stress concentration

**Stress concentration, such as hole, fillet, also deteriorate strength and needs additional thickness = weight.**
**Compared with metallic structure, composite needs more thickness.**

**【Comparison】**

- **Metal, or Al-alloy ⇒ Ductile ⇒ Significant deformation / load re-distribution prior to final failure**
- **Composite ⇒ Brittle ⇒ Minor permanent deformation prior to failure**

Bunch of Man-holes are placed in lower skin

**Wing-box Structural Test Article**
**(Ref. Bombardier HP)**

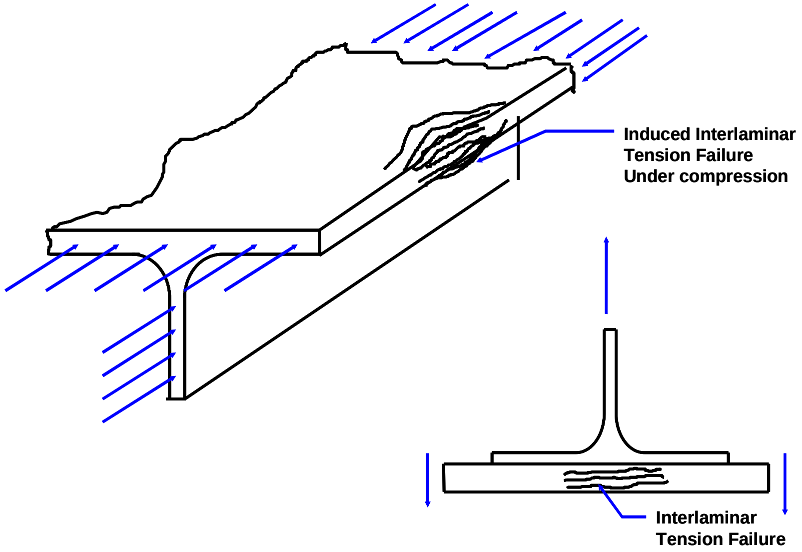
# Technical Challenges – Light Weight Structure

## ◆ Inter-laminar Failure / Delamination / Disbond

**These failure modes are unique for composite structure and have became our Achilles' heel on modern composite structures.**

**Special treatment needed on the area, such as flatwise loading location, co-bond / co-cured interface area.**
**In some case, need reinforcement using heavy metallic fitting / radius block…**

**Various Interlaminar (Flatwise) Tension Failures**



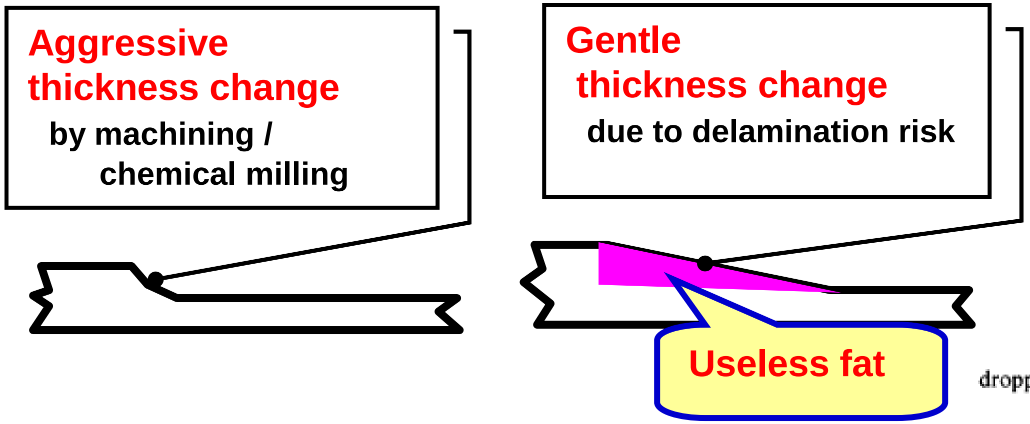
# Technical Challenges – Light Weight Structure

## ◆ Ply Drop-off

**Ply Drop-off introduces stress concentration due to discrete steps of plies.**
**This leads to failure of the parts through delamination and resin failure.**

**⇒ Need gentle ply drop-off for preventing premture failure introduced by out-of-plane (interlaminar) stress.**

**⇒ composite structure inevitably retains weight handicap.**



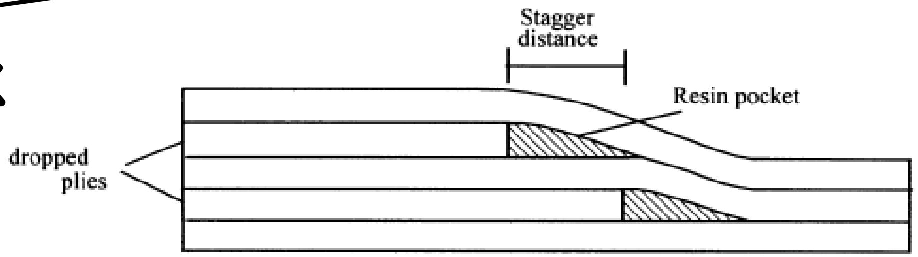
**Aggressive thickness change**
**by machining / chemical milling**

**Gentle thickness change**
**due to delamination risk**

**Metallic Structure**

**Composite Structure**

**Thickness transition area comparison**



**Typical Ply Drop-off geometry**

# Technical Challenges – Light Weight Structure

## Aircraft size dependence

**Weight advantage on composite application might be varied assuming the size of the aircraft.**

| Aircraft size<br>Parameter | Medium / Large aircraft | Small aircraft |
|---|---|---|
| Internal load | High = Need thicker gauge<br>Less susceptible to Impact damage | Low = Need thinner gauge<br>More susceptible to Impact damage |
| Minimum gauge restriction due to bolt counter-sunk / flutter characteristics | Less influence due to thicker gauge | More influence due to thinner gauge |
| Parts geometry / Size | Less susceptible to “fat weight” due to gentle ply drop-off | More susceptible to “fat weight” due to gentle ply drop-off |

**Easy to obtain prominent weight advantage**

**Hard to obtain proper weight advantage using today’s best technology**

# Lower Maintenance Costs Boeing787 (Example)

Lower Maintenance Costs - More Flying

Ref. from
http://www.newairplane.com/787/design_highlights/#/ExceptionalValue/LowerMaintenanceCosts

# Competitive Price Product

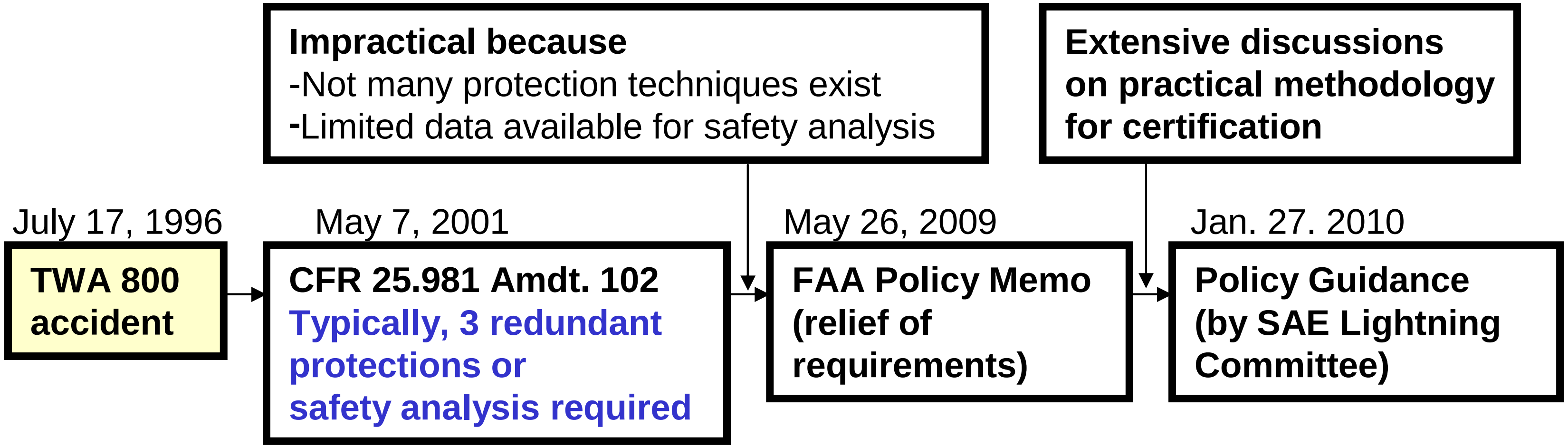
## Composite structure is accused by inherently expensive compared to Al-alloy structure.

| Material usage / Cost contributor | Composite structure | Al-alloy structure |
|---|---|---|
| Material | High<br>◆aerospace grade / toughened resin material<br>◆bagging film … | Low |
| Hardware | High<br>◆composite fastener<br>◆EME compatible hardware | Low |
| Parts fabrication | High<br>◆Need expensive tool / equipment<br>◆Need intensive NDI<br>◆Need fine-tuned process warding off wrinkle/voids… | Low |
| Assembly | High<br>◆Need corrective force/ shimming due to parts geometrical imperfection (spring-in/warpage)<br>◆Need intensive treatment warding off EME risk. | Low |

Note) EME = Electro-magnetic Effect,   NDI = Non Destructive Inspection

# Lightning Protection – Competitive Price Product

## Brief History of the Lightning Protection Regulation



**Impractical because**
-Not many protection techniques exist
-Limited data available for safety analysis

**Extensive discussions on practical methodology for certification**

July 17, 1996
**TWA 800 accident**

May 7, 2001
**CFR 25.981 Amdt. 102**
**Typically, 3 redundant protections or safety analysis required**

May 26, 2009
**FAA Policy Memo (relief of requirements)**

Jan. 27. 2010
**Policy Guidance (by SAE Lightning Committee)**

**Reconstructed TWA flight 800**
**Ref. NTSB accident report for TWA Flight 800**

**Example of improperly installed clamp (pinching wire)**
**Ref. www.caasd.org/atsrac/nbaa/0845-ATSRACandEWIS.pdf**

# Lightning Protection – Competitive Price Product

## 14 CFR 25.981 Regulation Doc. No. 1999-6411, 66 FR 23129, May 7, 2001)

**(a) No ignition source may be present at each point in the fuel tank or fuel tank system where catastrophic failure could occur due to ignition of fuel or vapors. This must be shown by:**

**(1) Determining the highest temperature allowing a safe margin below the lowest expected auto ignition temperature of the fuel in the fuel tanks.**

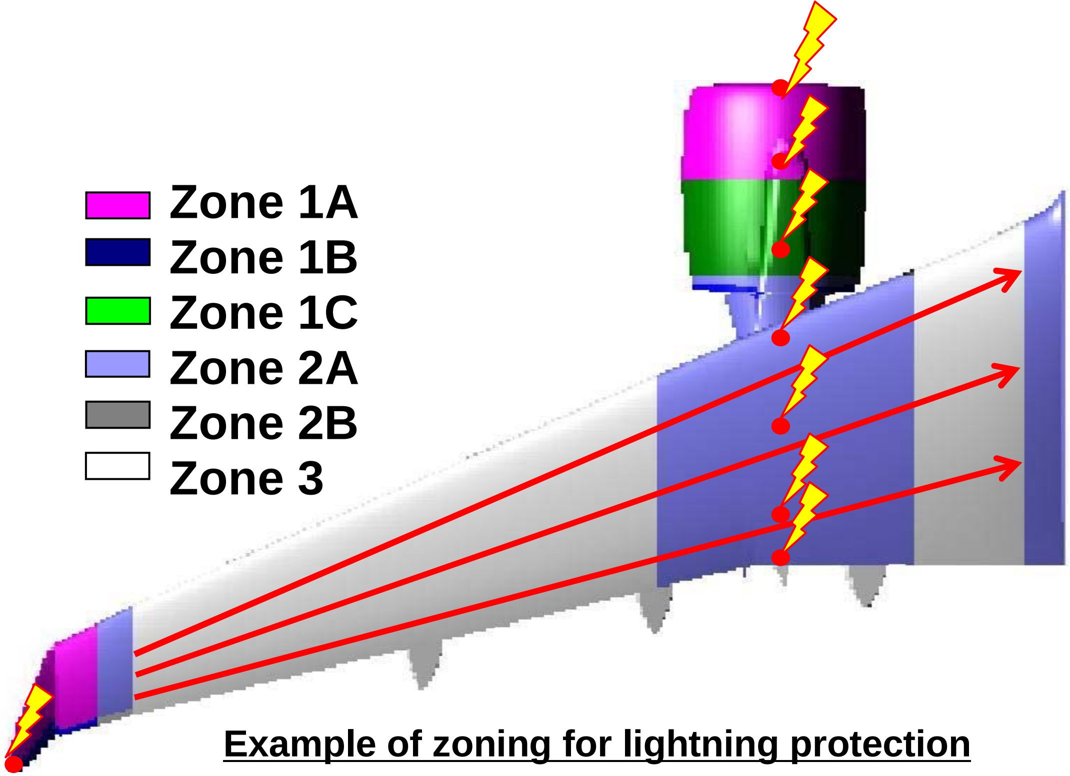
**(2) Demonstrating that no temperature at each place inside each fuel tank where fuel ignition is possible will exceed the temperature determined under paragraph (a)(1) of this section. This must be verified under all probable operating, failure, and malfunction conditions of each component whose operation, failure, or malfunction could increase the temperature inside the tank.**

**(3) Demonstrating that an**
**ignition source could not result from each single failure, from**
**each single failure in combination with each latent failure condition not shown to be extremely remote,**
**and from all combinations of failures not shown to be extremely improbable.**
**The effects of manufacturing variability, aging, wear, corrosion, and likely damage must be considered.**

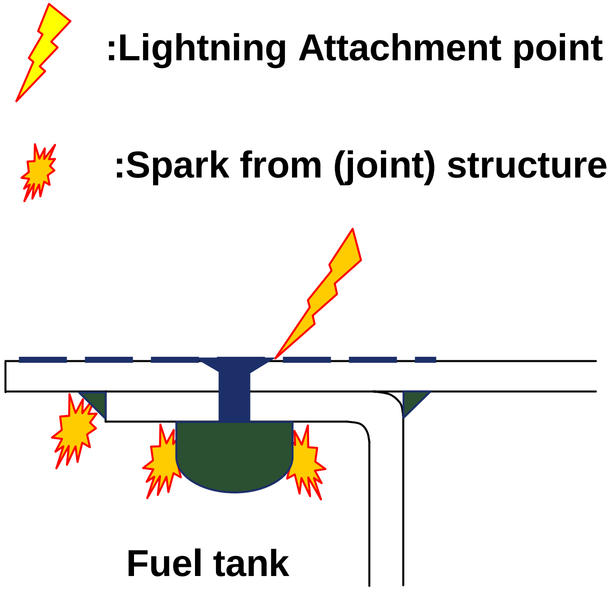
# Lightning Protection – Competitive Price Product

- **Vapor of fuel would be flammable if the temperature is above a certain threshold.**
- **Lightning can provide several MJ of electro-magnetic energy into an airplane.**
- **Lightning protection for integral tank area is required to protect against more than 200 μ J spark.**

**Due to less conductive characteristics, composite requires intensive treatment for suppressing ignition source. ⇒ Cost increase potential**



Example of zoning for lightning protection



# Needed improvement for composite structure

**So far, MHI can not always justify composite application in commercial basis.**

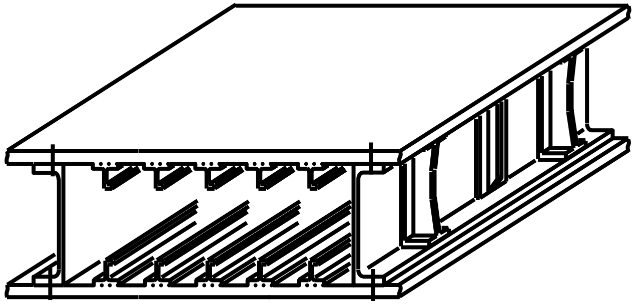
**Need next game-changing technology, which demonstrates prominent advantage on composite structure.**

**Especially, challenge remains in following two important aspects.**

◆ **To realize light weight structure**
◆ **To realize low cost structure**

**<< Needed composite technology >>**

◆ **To realize large one-piece structure**
  ⇒ **Bolt-less, shim-less structure**
◆ **To establish cost-effective EME counter-measure**
◆ **To realize tight tolerant structural parts (for geometry / thickness)**
  ⇒ **To enhance automation for assembly**
◆ **To develop cost-effective and tougher composite material**



**Large One Piece Structure**

# Thank you for your attention!