Composite Structures – The First 100 Years

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Added content from John Quinlivan, Joe Sutter, Damon Roberts, (Insensys,) GE, and Boeing 787 Program for Composite Design Tutorial, Stanford University 28 Sept 2009

Building the Dream

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Composites Then and Now

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- **Two or more materials combined to perform some useful purpose**
- **Exhibits the best properties of the individual materials plus additional qualities that the individual materials do not exhibit alone**
- **Examples**
  - **Mud and straw**
  - **Steel-reinforced concrete**
  - **Fibers embedded in a plastic resin matrix**
  - **Oriented Strand Board (OSB)**

1943 Popular Mechanics Prediction

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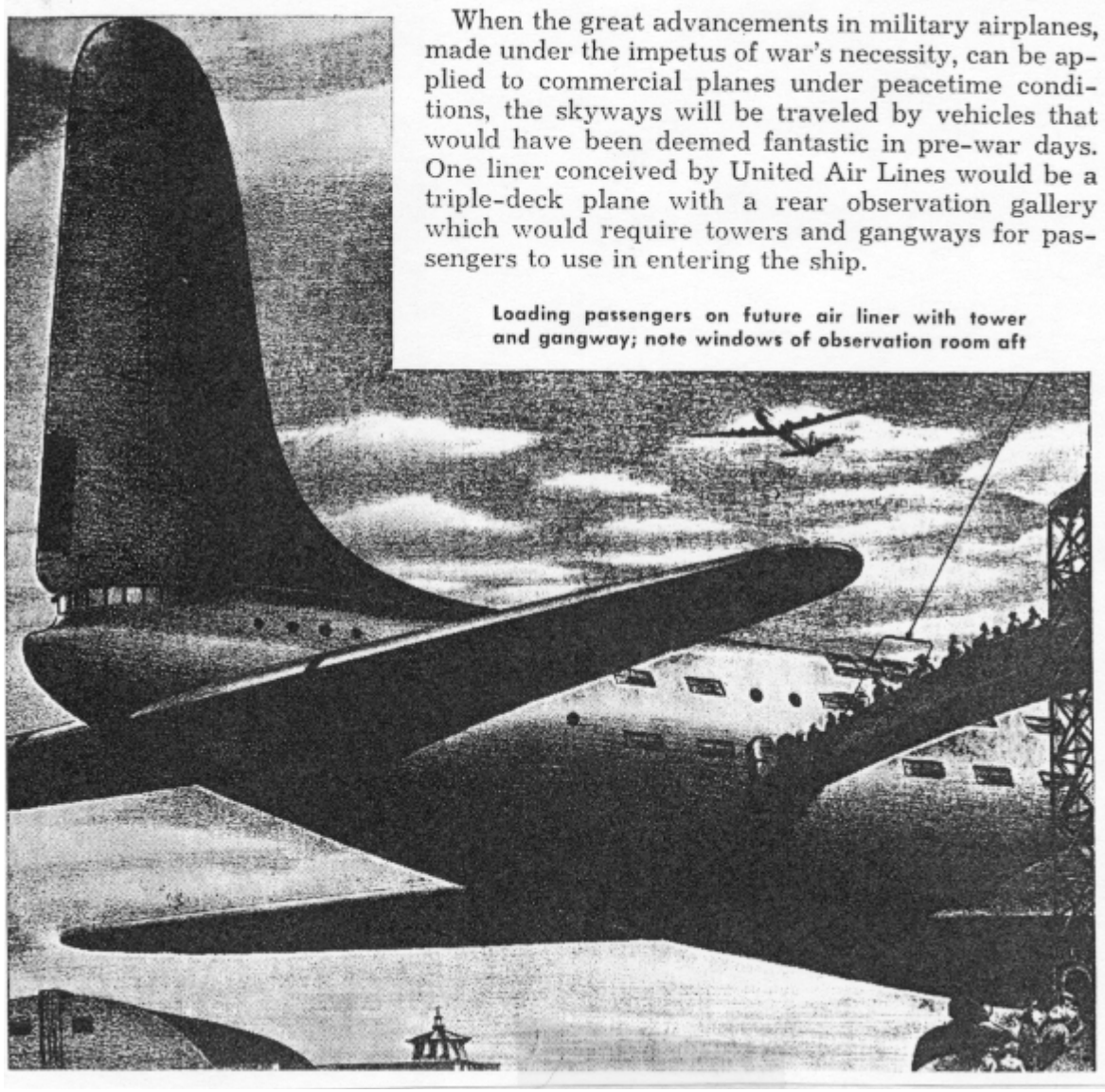
Triple-Deck Plane to Have Observation Room

When the great advancements in military airplanes, made under the impetus of war's necessity, can be applied to commercial planes under peacetime conditions, the skyways will be traveled by vehicles that would have been deemed fantastic in pre-war days. One liner conceived by United Air Lines would be a triple-deck plane with a rear observation gallery which would require towers and gangways for passengers to use in entering the ship.



Loading passengers on future air liner with tower and gangway; note windows of observation room aft

Composites Provide Higher Strength and Stiffness

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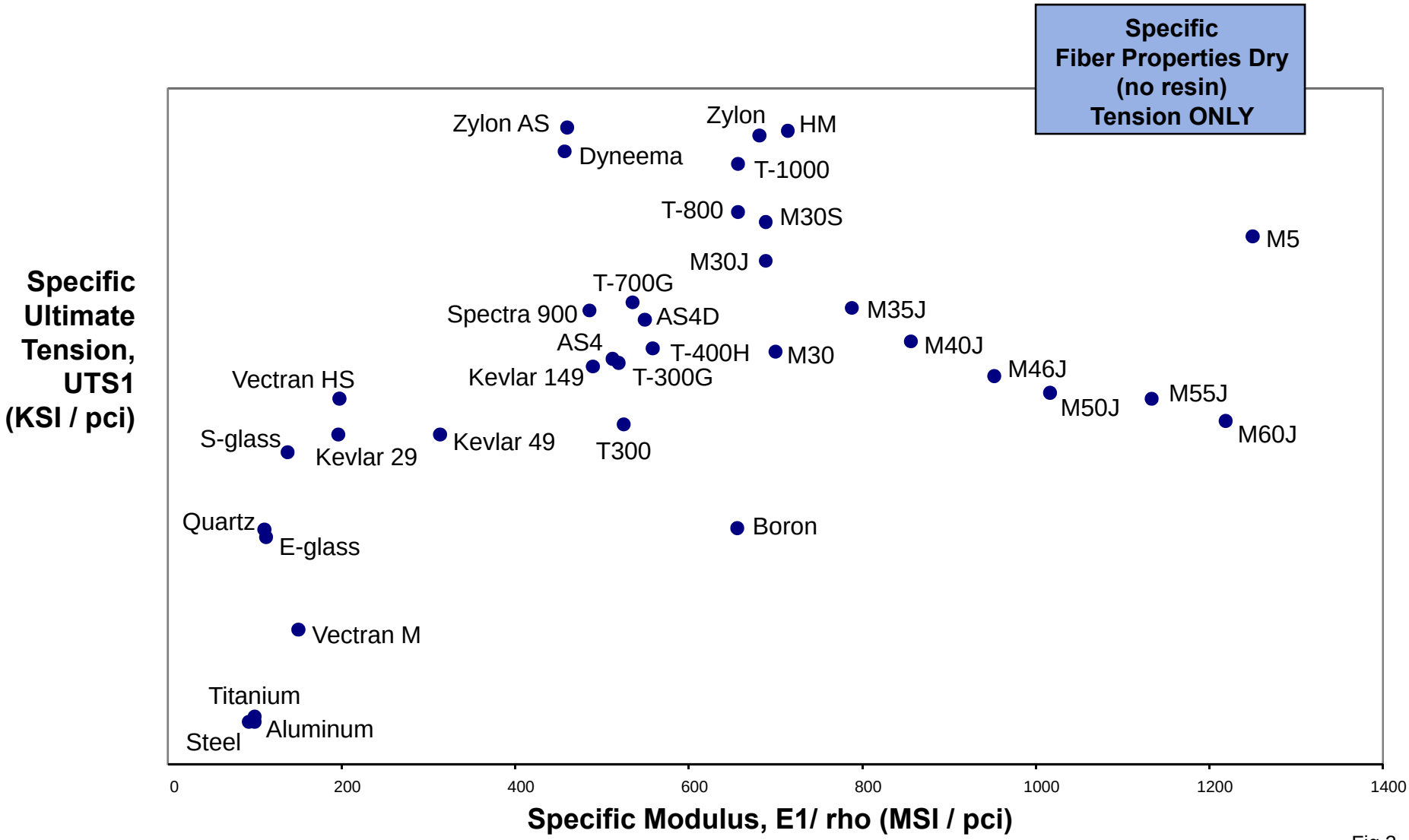

Fig 2

Fiberglass Primary Structures - Rotor Blades (1964 flight test)

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MASS Governor Volpe inspects Autocopter 1966

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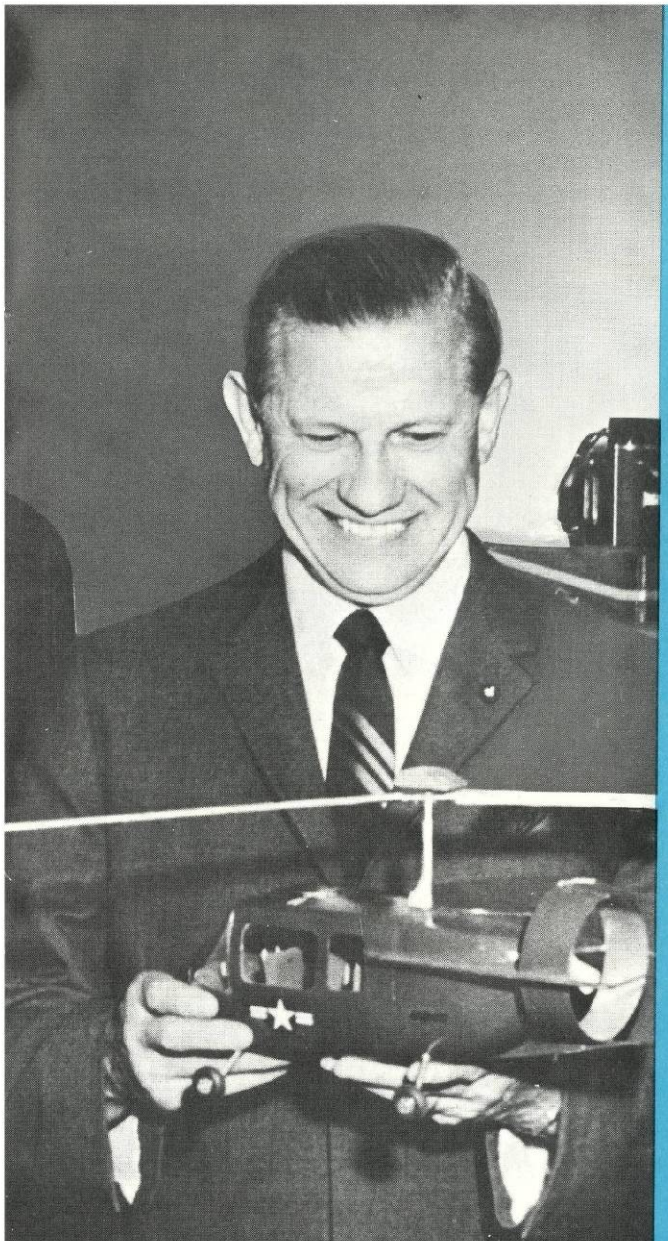

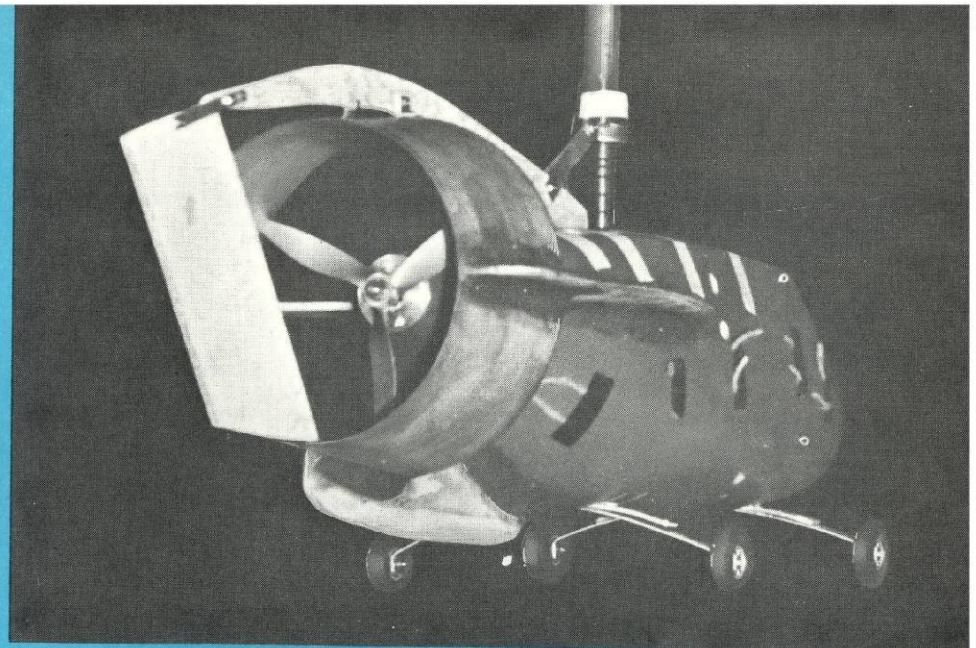

767 and Entry Door Spring 1978

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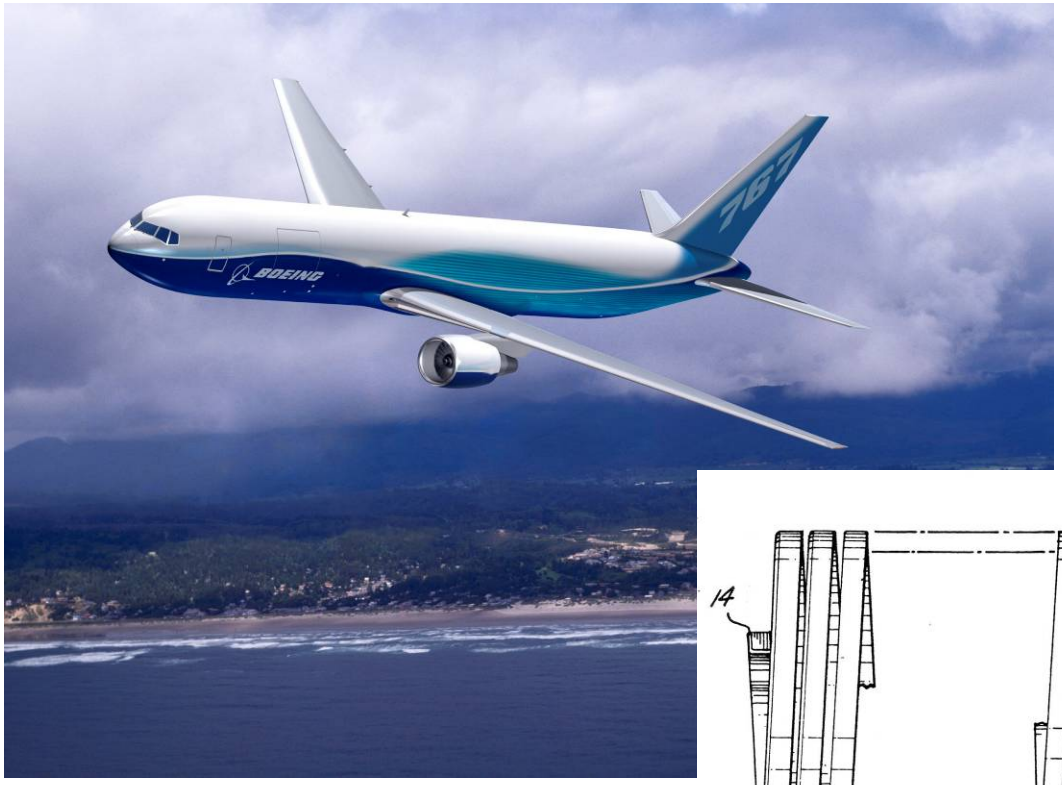


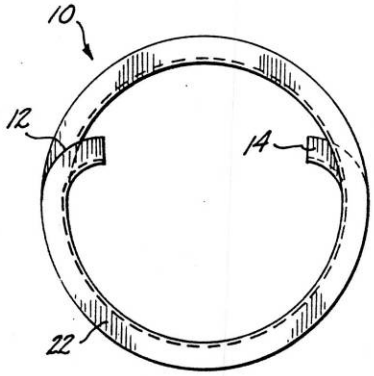
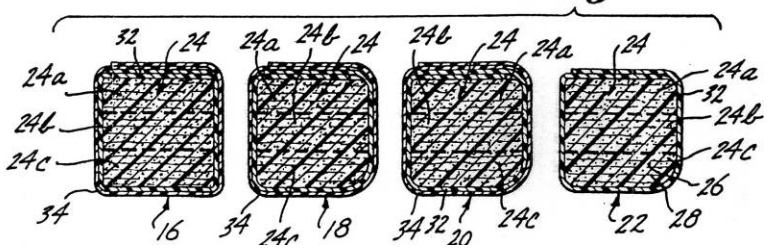
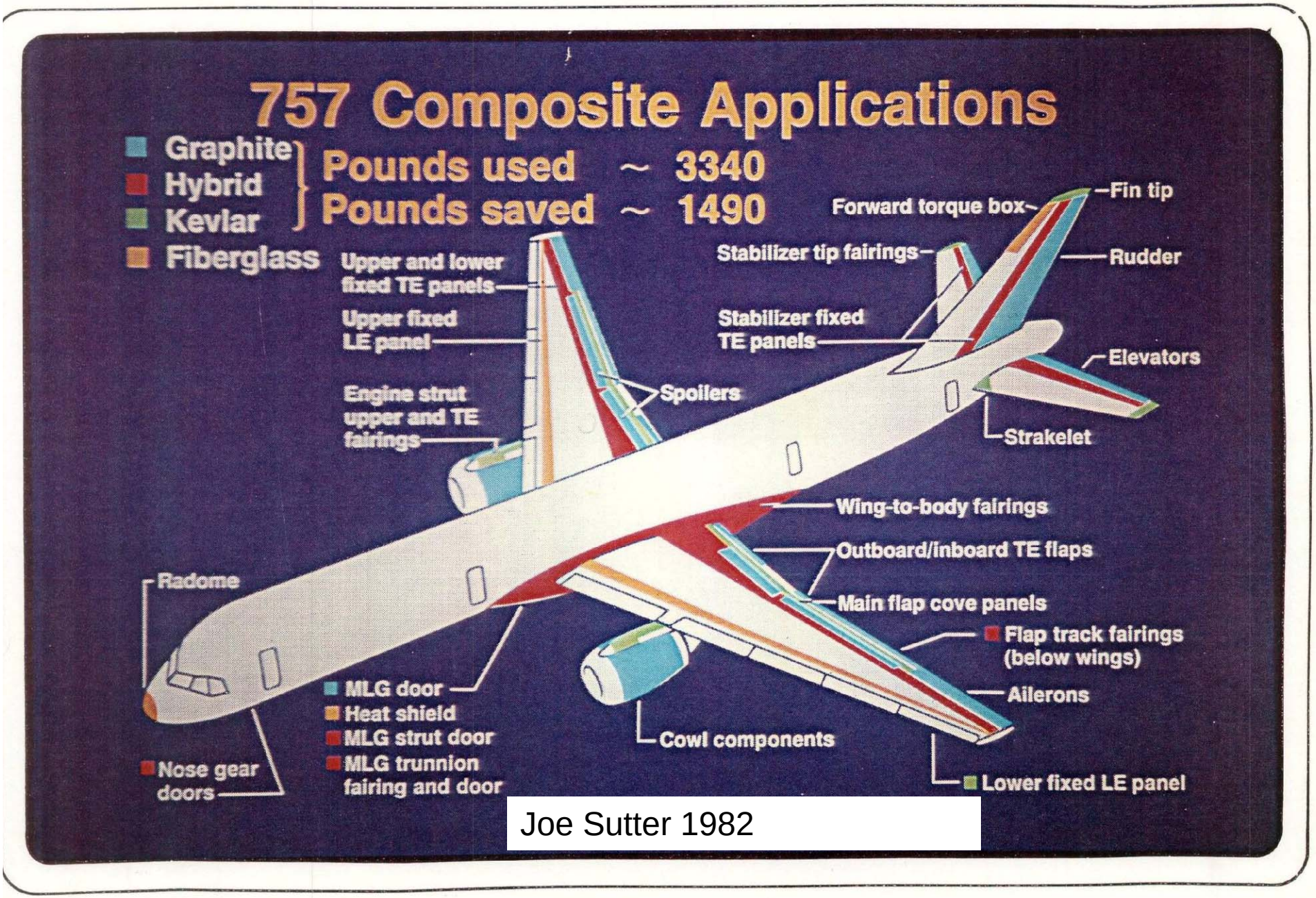


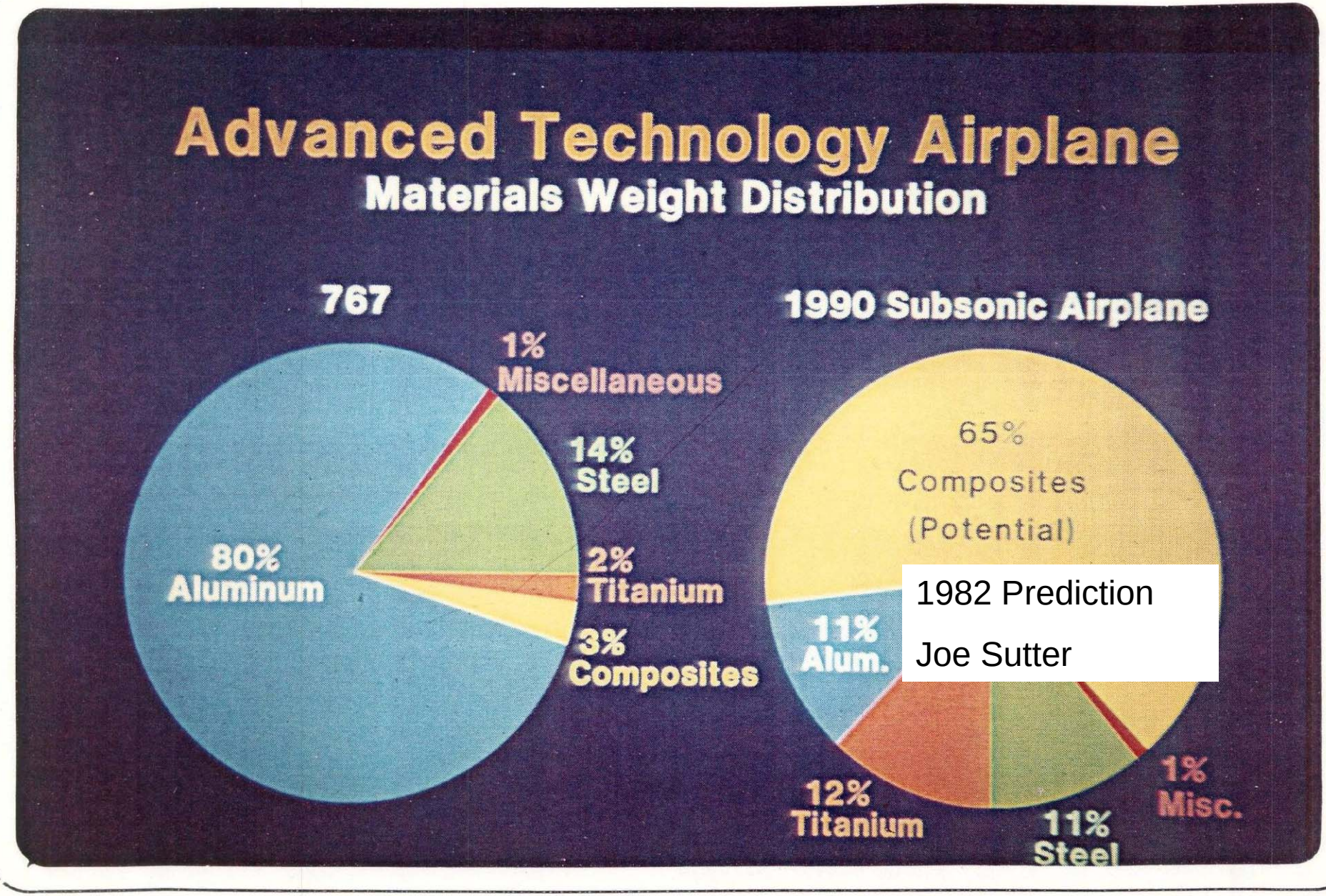
Fig. 3.



BOEING

Fiberglass Primary Structure in Service 1984


757 Composite Applications
Graphite
Hybrid
Kevlar
Fiberglass
Pounds used ~ 3340
Pounds saved ~ 1490
Fin tip
Forward torque box
Stabilizer tip fairings
Rudder
Upper and lower fixed TE panels
Upper fixed LE panel
Stabilizer fixed TE panels
Elevators
Engine strut upper and TE fairings
Spoilers
Strakelet
Wing-to-body fairings
Outboard/inboard TE flaps
Radome
Main flap cove panels
Flap track fairings (below wings)
Ailerons
MLG door
Heat shield
MLG strut door
MLG trunnion fairing and door
Cowl components
Nose gear doors
Lower fixed LE panel
Joe Sutter 1982


Advanced Technology Airplane
Materials Weight Distribution
767
1% Miscellaneous
14% Steel
2% Titanium
3% Composites
80% Aluminum
1990 Subsonic Airplane
65% Composites (Potential)
11% Alum.
12% Titanium
11% Steel
1% Misc.
1982 Prediction
Joe Sutter

Rational Growth of Aerospace Usage of Composite Structures

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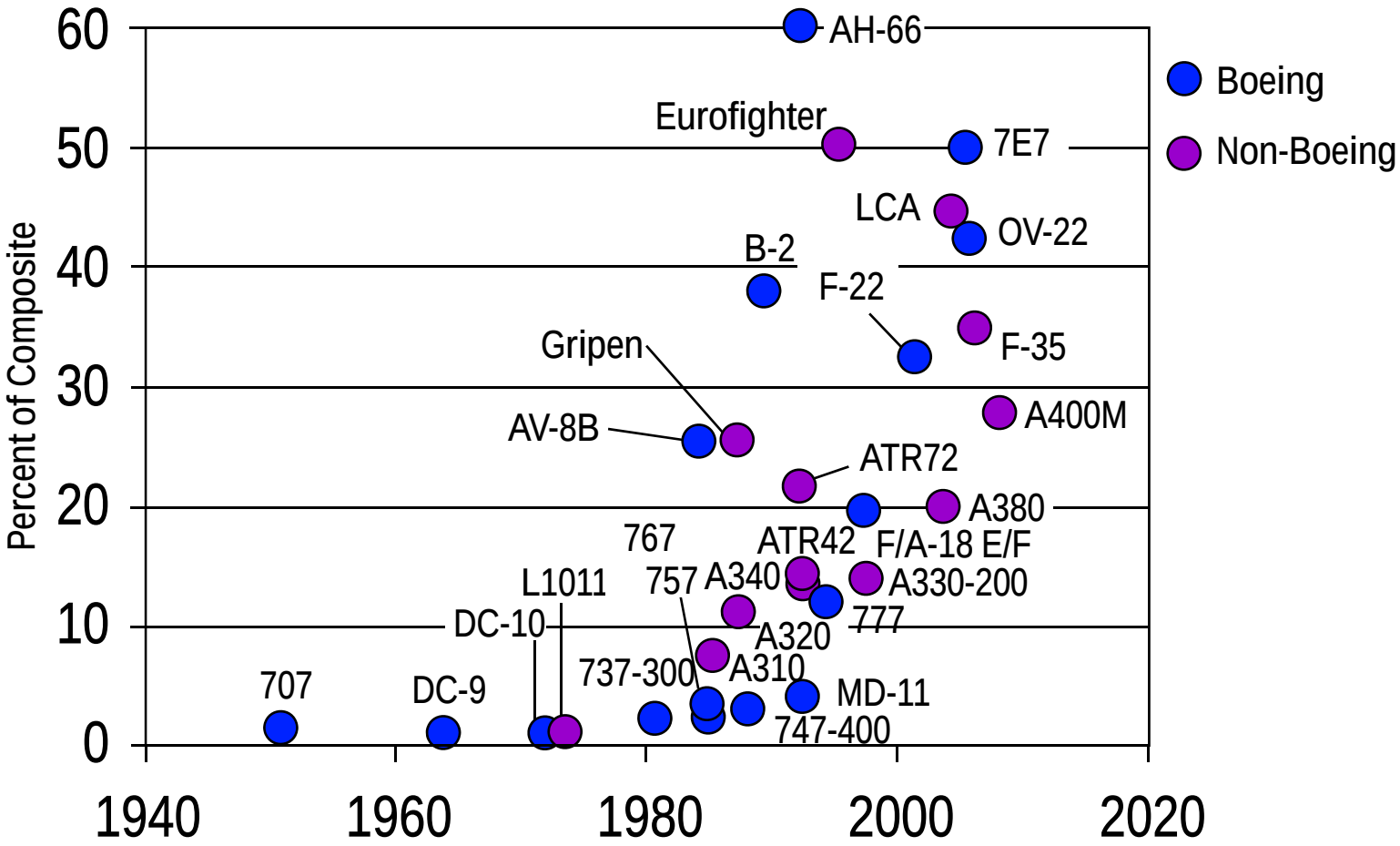
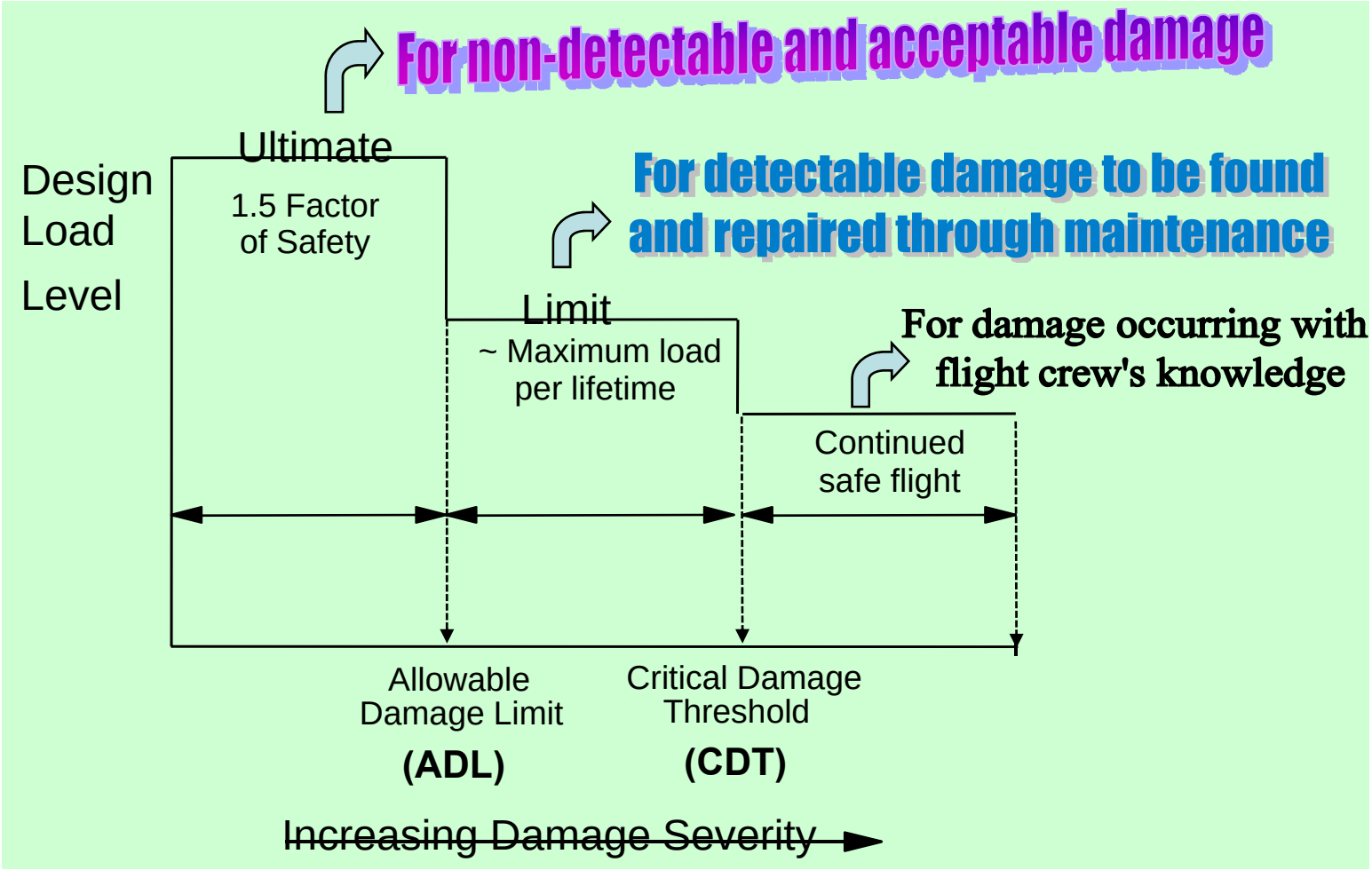


Damage Tolerant Design



LCPAS Compression Panel Test Summary

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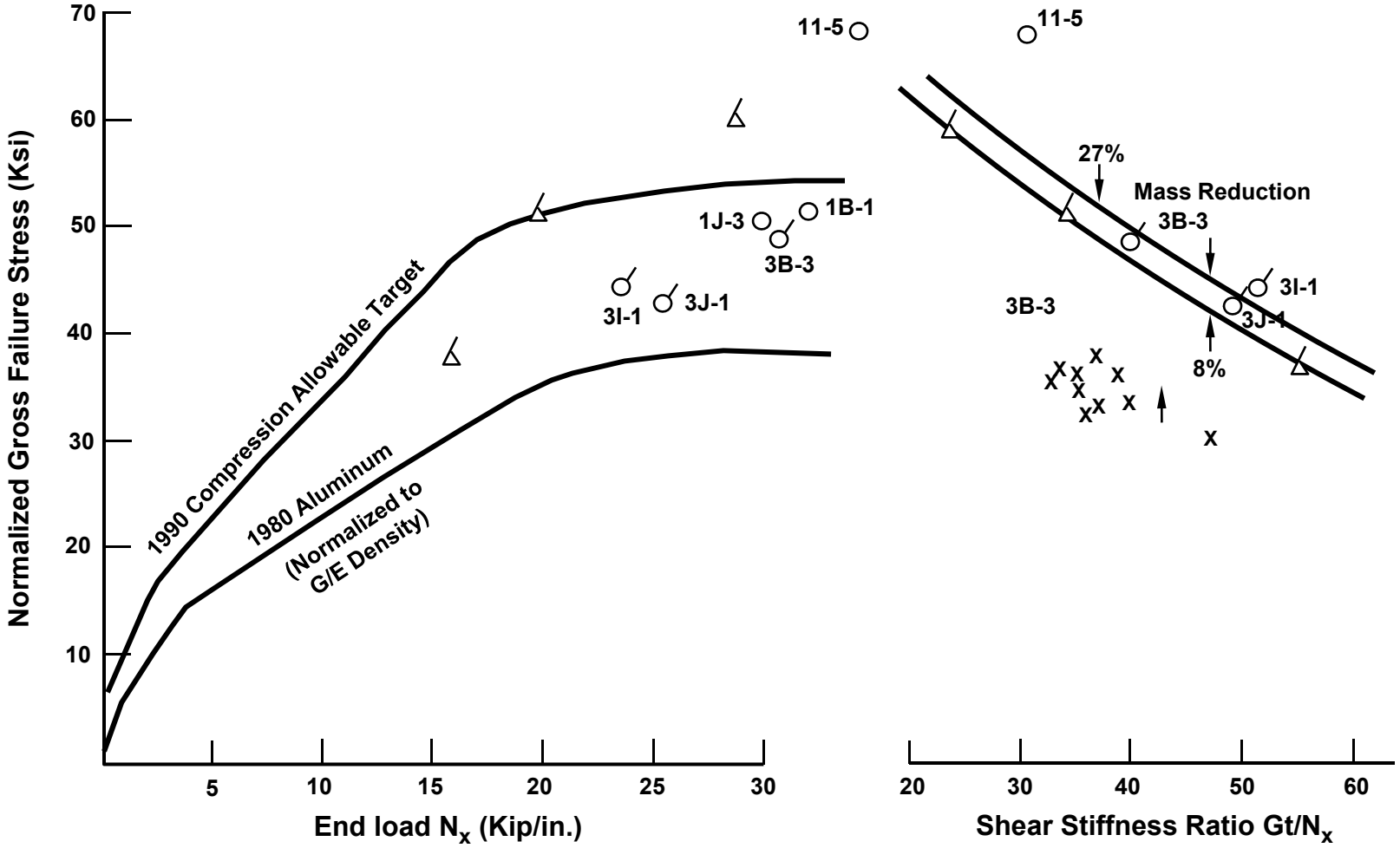

○ LCPAS 1982 (2220-3)
△ Rhodes and Williams 1981 (5208)
X Aluminum (7150)
⁄ Impact damage ½ in. –diameter metal impactor

LCPAS Wing Sizing Based on Test Results

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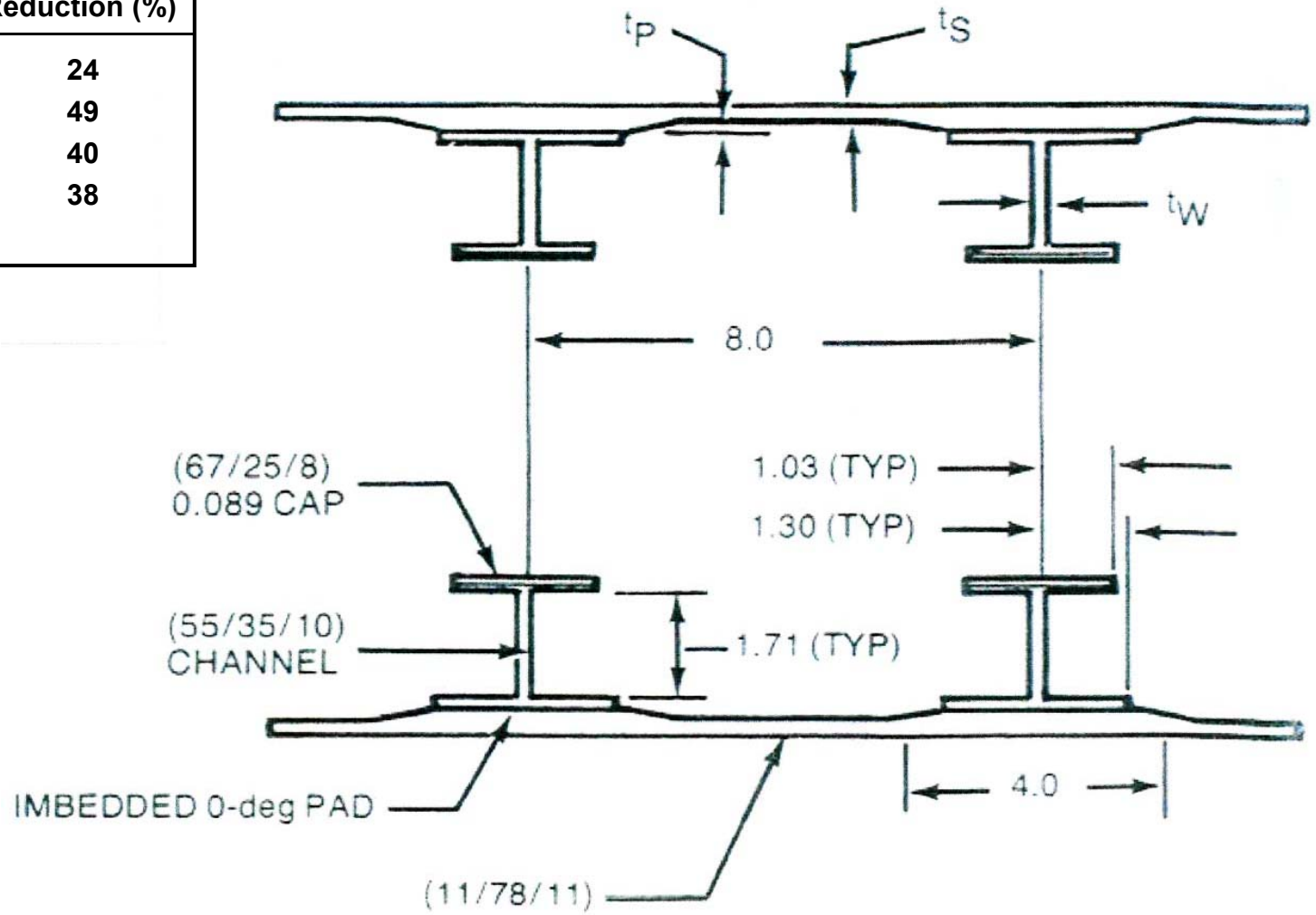
Component	Theoretical Mass Reduction (%)
Upper Surface	24
Lower Surface	49
Spars	40
Total (Panels + Spars)	38



Boeing Structural Aluminum Alloy Improvements

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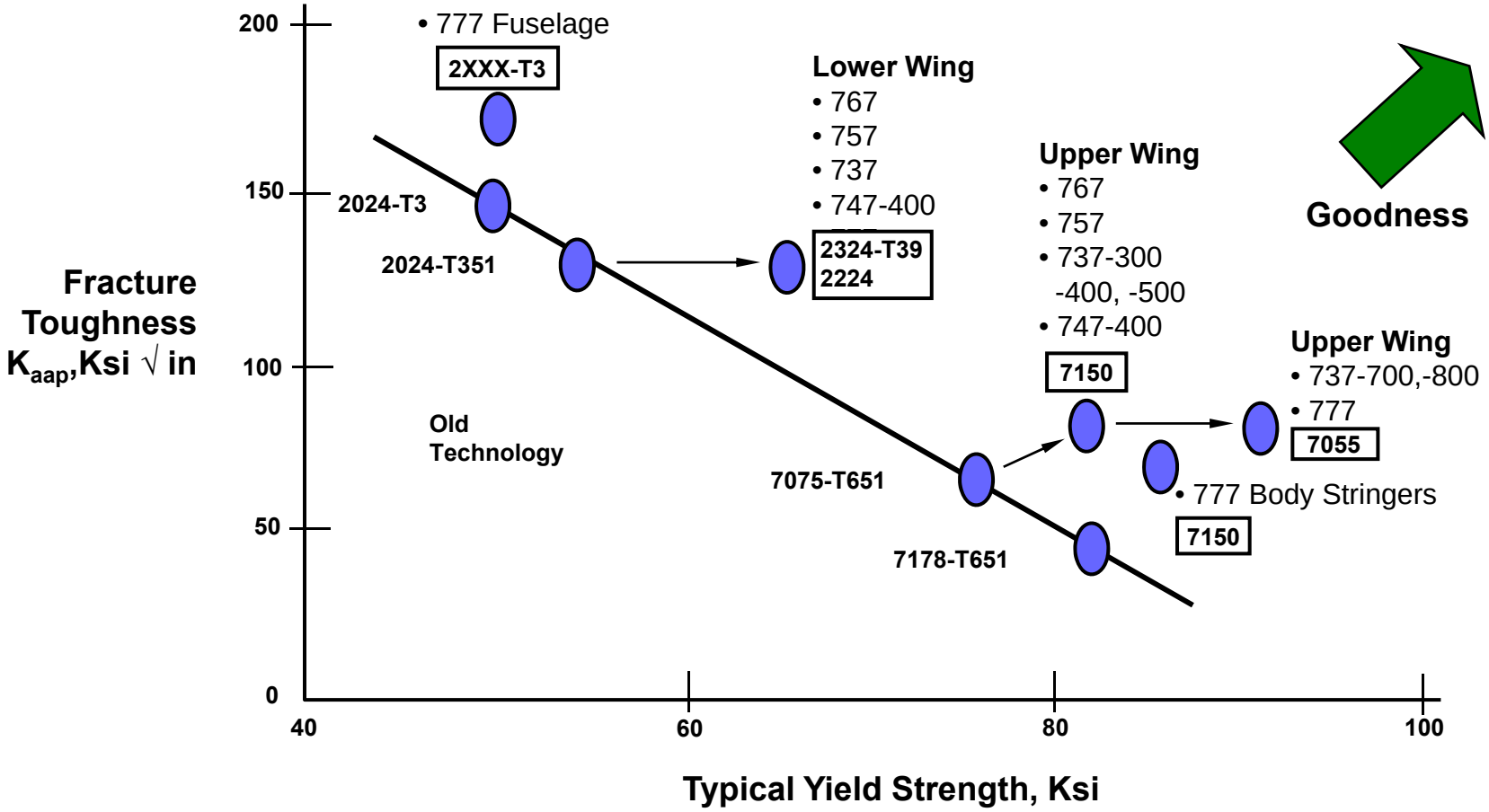
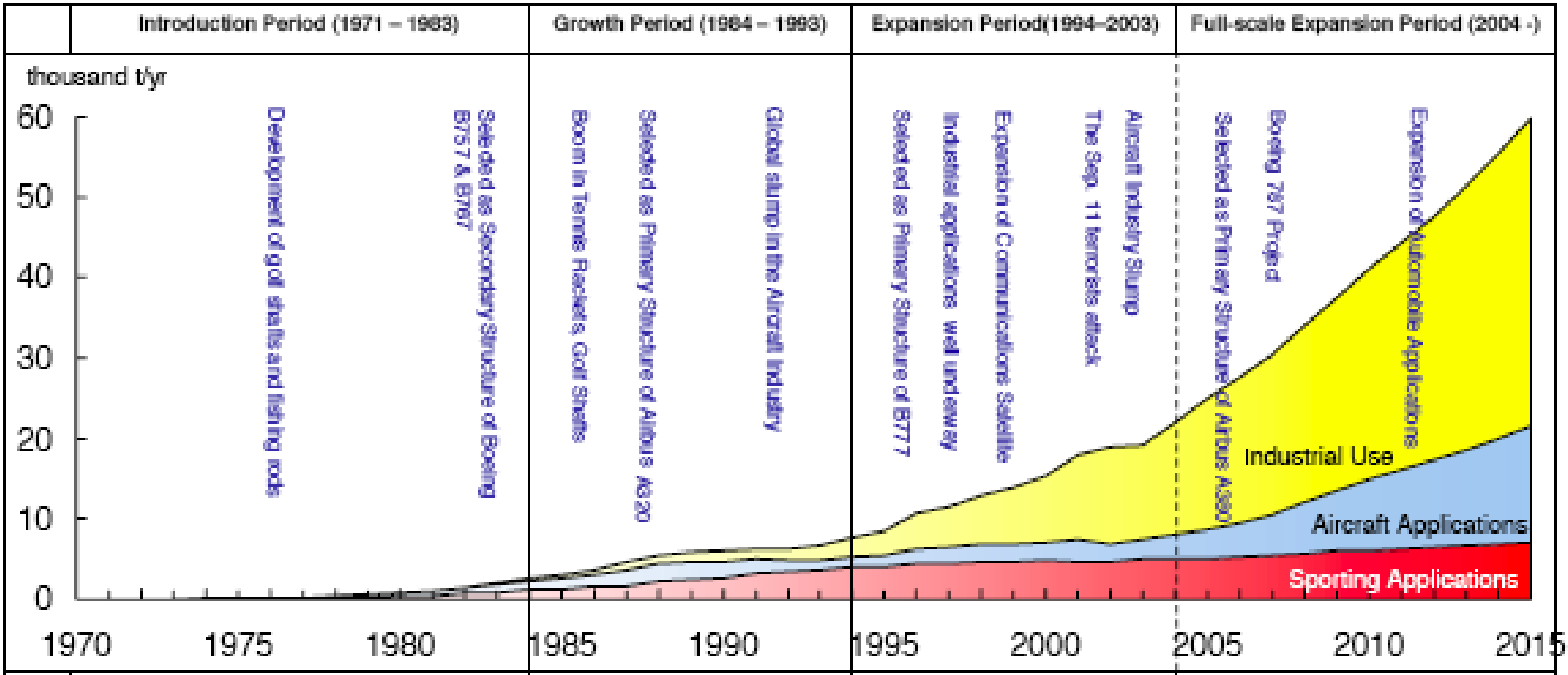


Trends in World's Carbon Fibers Market

'TORAY'



	Introduction Period (1971 – 1983)	Growth Period (1984 – 1993)	Expansion Period(1994–2003)	Full-scale Expansion Period (2004 -)
Applications	**Limited Area** Fishing rods Secondary structure of Aircrafts	**Expand Applications** Tennis rackets Golf shafts Primary structure of Aircrafts	**Industrial Uses under way** Pressure vessels Industrial machinery, Boats & Ships, Civil engineering and Construction, Repair and Reinforcement	Huge Expansion of Aircrafts Automobiles under way Significant Aircraft Program Wind-power Generation Automobile-related, Offshore Oil Field
Remarks	High-quality	Increase of products, Advancement in molding technology	Cost reduction Large structural material	Diversification of manufacturing methods Recyclability

Specific Strength Of Wing Bending Materials

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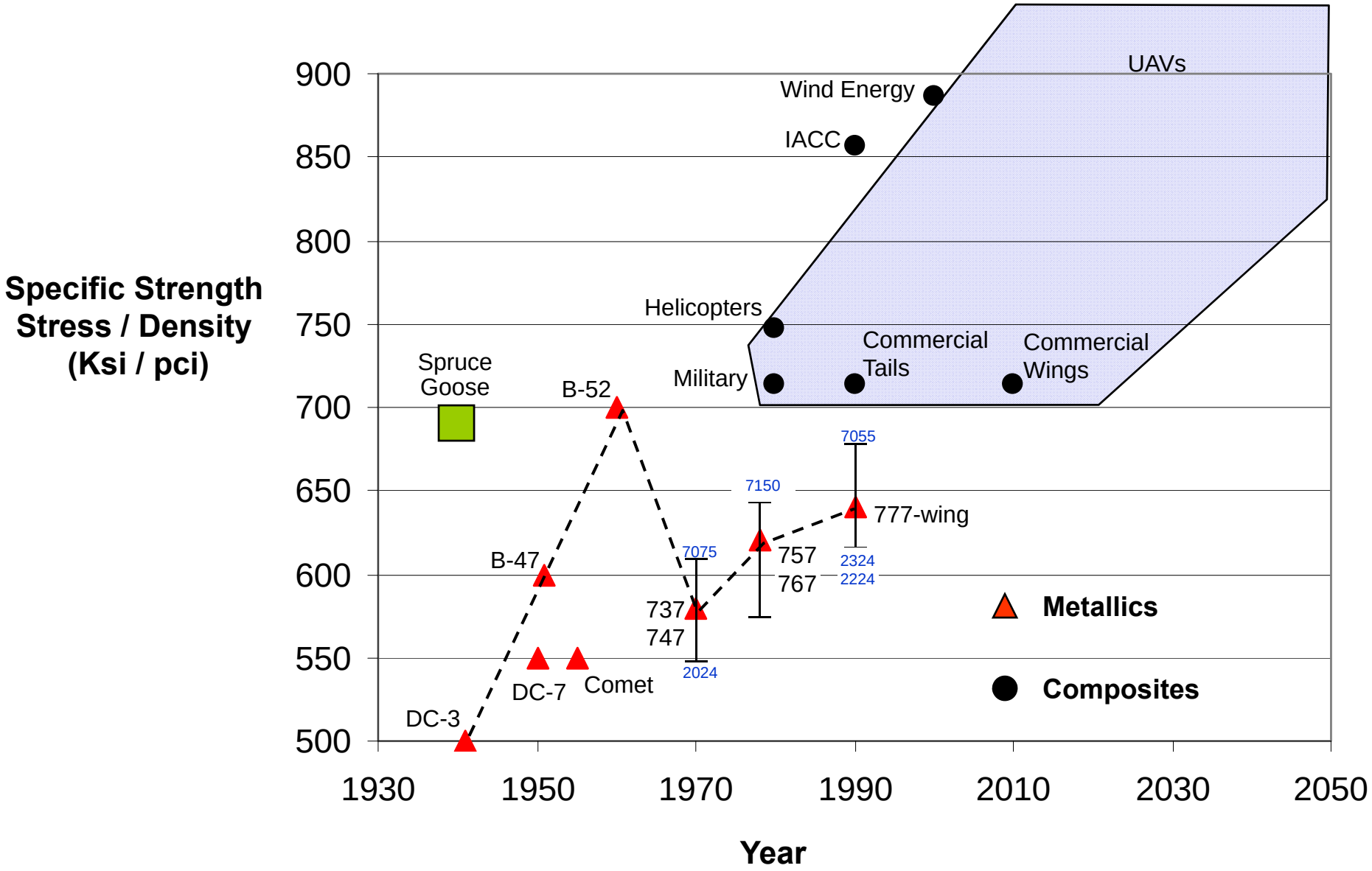

Setting New Levels of Leadership

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- **Less fuel used**
- **Lower emissions**
- **Quieter for communities, crews, and passengers**
- **Fewer hazardous materials**
- **Less waste in production**

Opening a New Era in Fuel Efficiency

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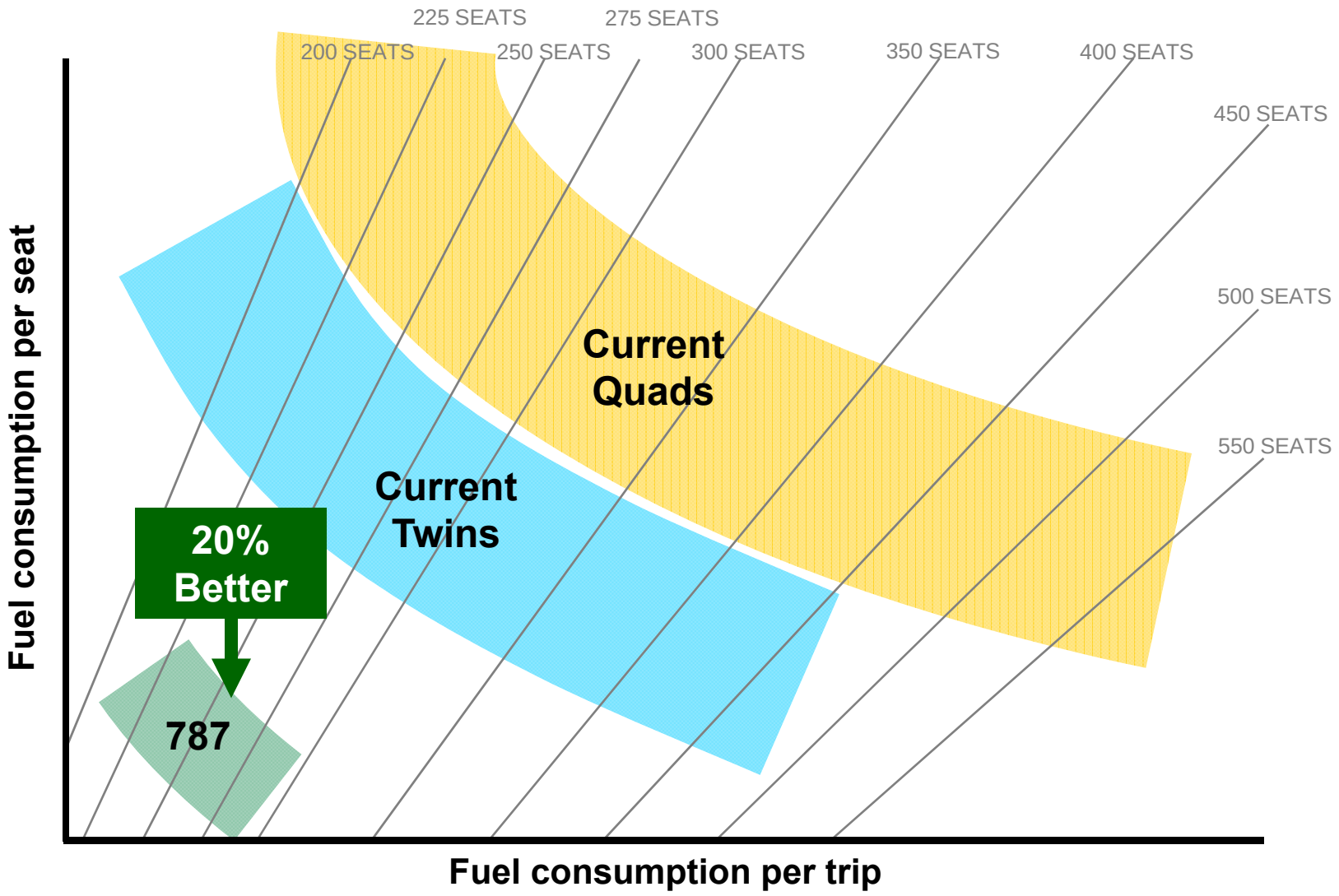

Addressing the Market's Needs *(2006-2025)*

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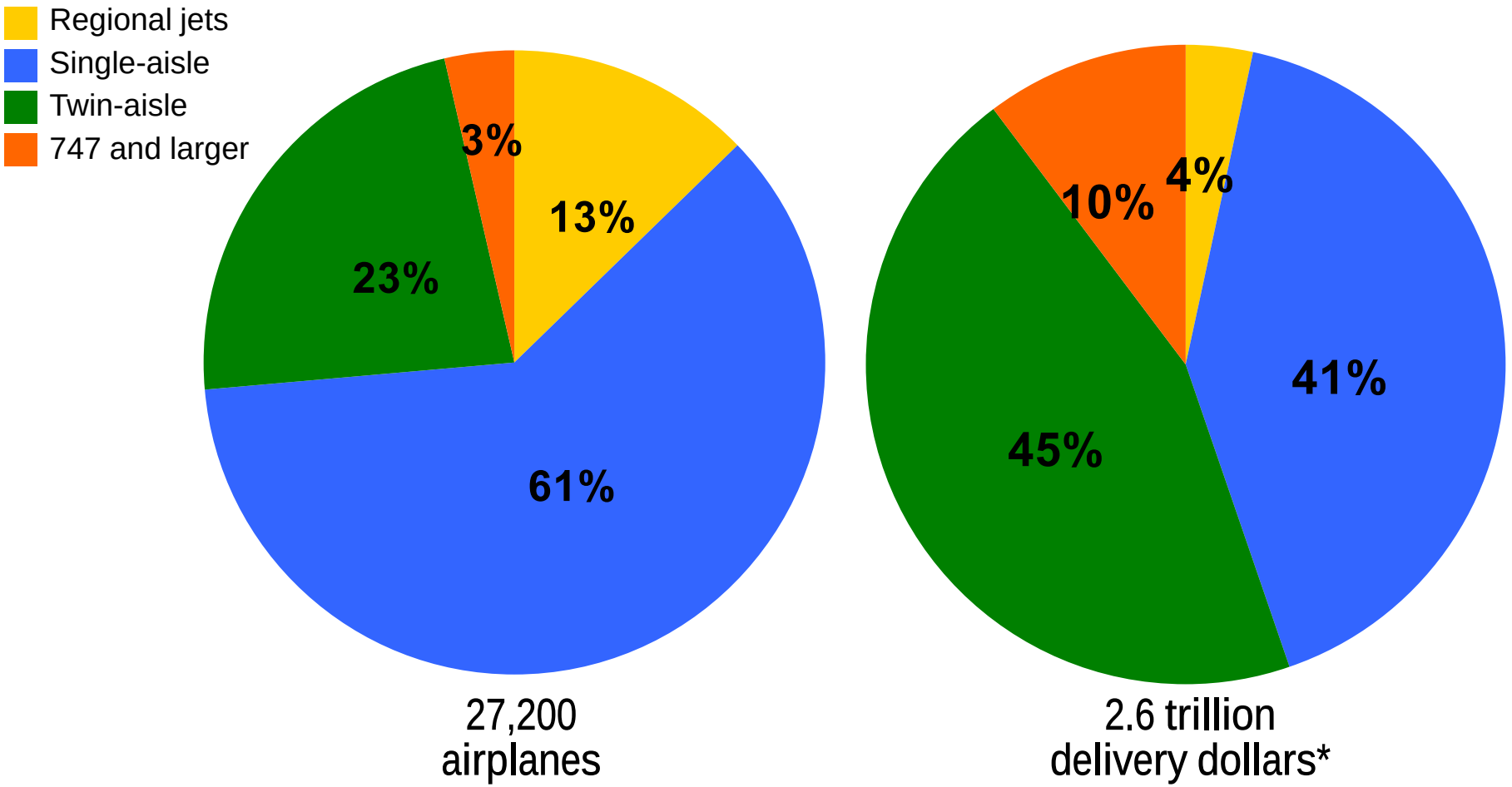

27,200 airplanes

2.6 trillion delivery dollars*

*In year 2005 dollars

Composite Solutions Applied Throughout the 787

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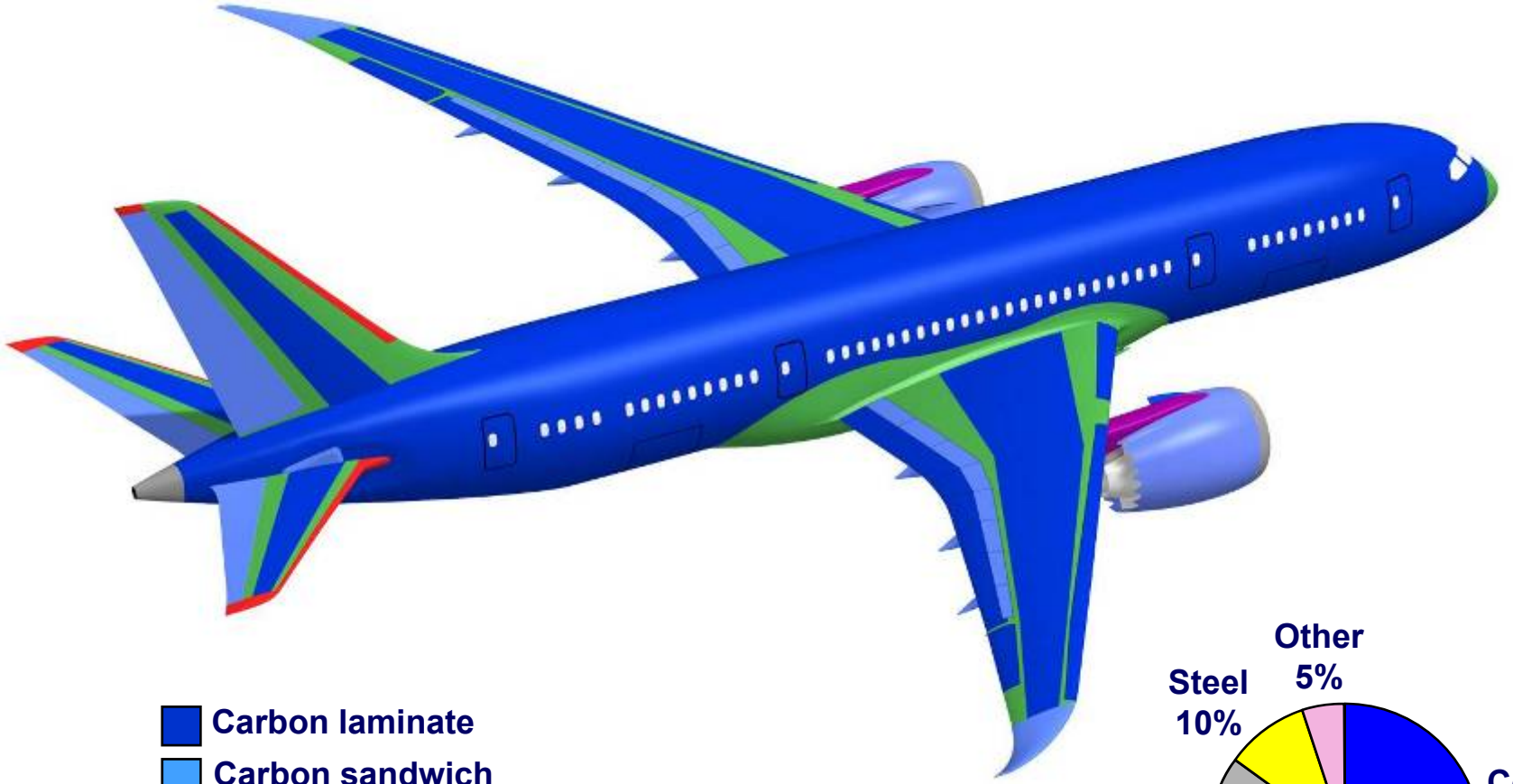
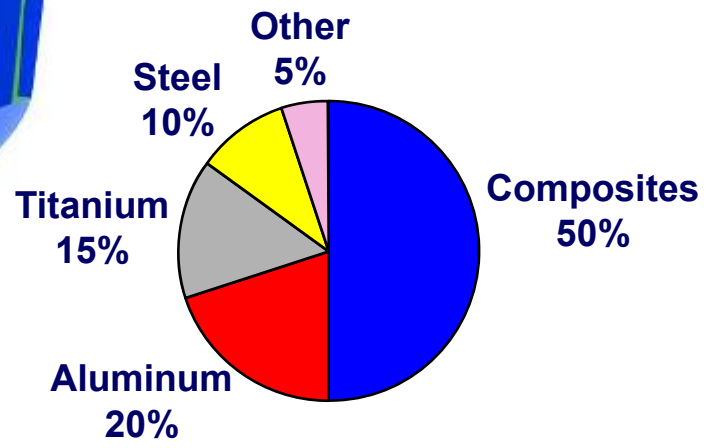


- Carbon laminate
- Carbon sandwich
- Other composites
- Aluminum
- Titanium
- Titanium/steel/aluminum



Partners Across The Globe Are Bringing The 787 Together (2007 data)

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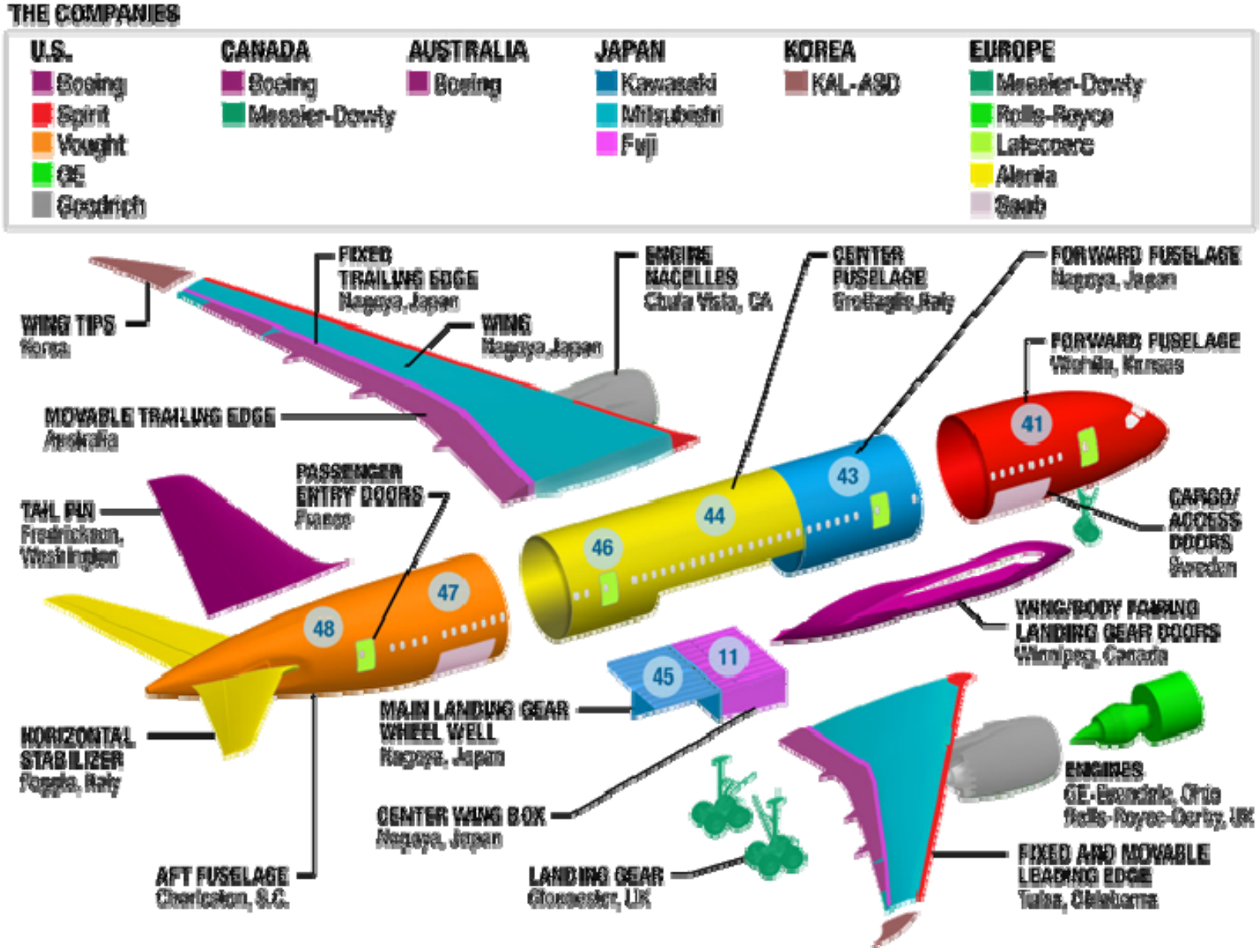

787 Final Assembly Flow Everett, Wash.

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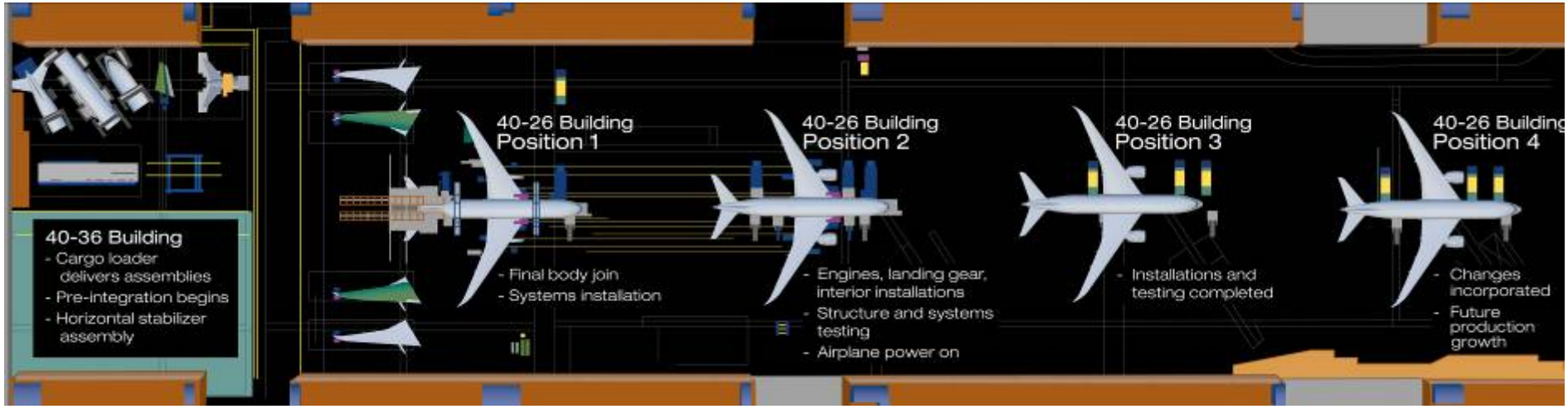

Increased Use of Composites Over Time

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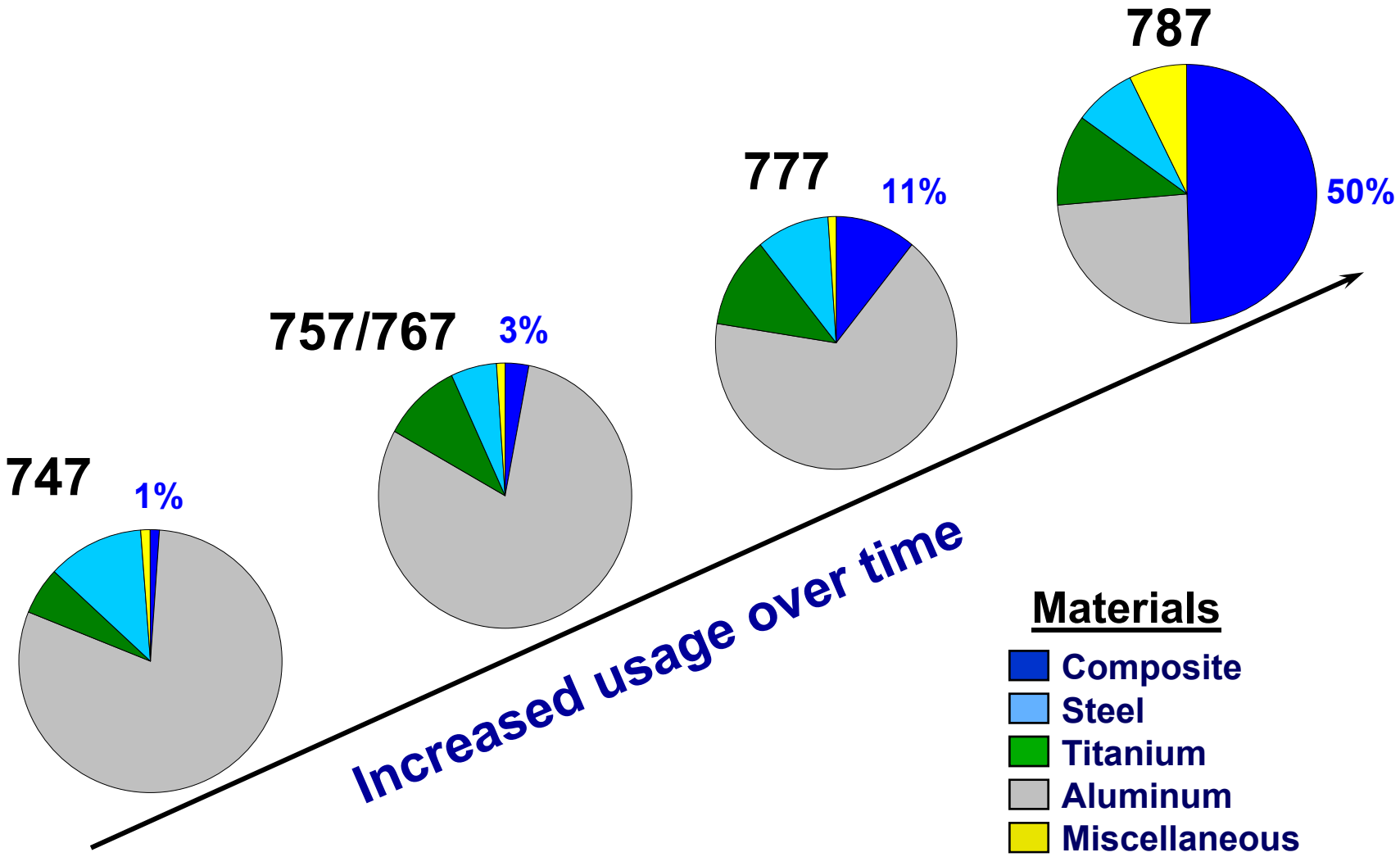

Validation Process Ensures Safety, Reliability

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- **Proven Certification process, validated by positive service experience**
- **Boeing design objectives typically exceed minimum regulatory requirements**

Airplanes

Static Test
Fatigue Test
Ground & Flight Tests

Assemblies

Components

Elements

Material Specimens

Increasing Levels of Complexity

Static Test Airframe Moves To Testing Rig 25 April 2008

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787 Airframe Static Test

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Composites Also On Jet Engines

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GE-90-94B
B777-100

GE-90-115B
B777-300ER

GEnx
B787 & 747-8

Composites at Work with Wind Turbines (Vestas V90)

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BOR 90, Newest Carbon Fiber Flying Machine, Anacortes, WA 2008

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Composites at Sea with the Maltese Falcon

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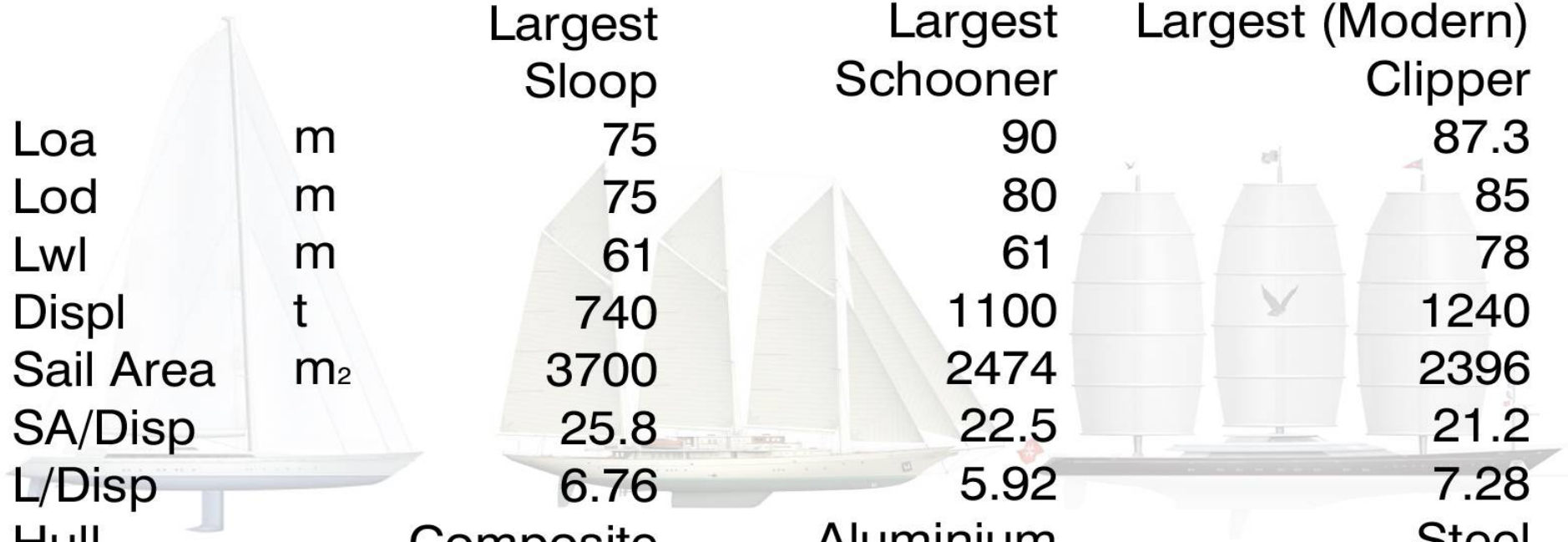
Damon Roberts Insensys, Ltd

The World's Three Largest Yachts

		Mirabella V	**Athena**	**Maltese Falcon**
		Largest Sloop	Largest Schooner	Largest (Modern) Clipper
Loa	m	75	90	87.3
Lod	m	75	80	85
Lwl	m	61	61	78
Displ	t	740	1100	1240
Sail Area	m_2	3700	2474	2396
SA/Disp		25.8	22.5	21.2
L/Disp		6.76	5.92	7.28
Hull		Composite	Aluminium	Steel



Maltese Falcon Rig Engineering and Build
Structural Overview

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Bending moment at deck 17,000,000 Nm

Torque at deck 1,200 kNm

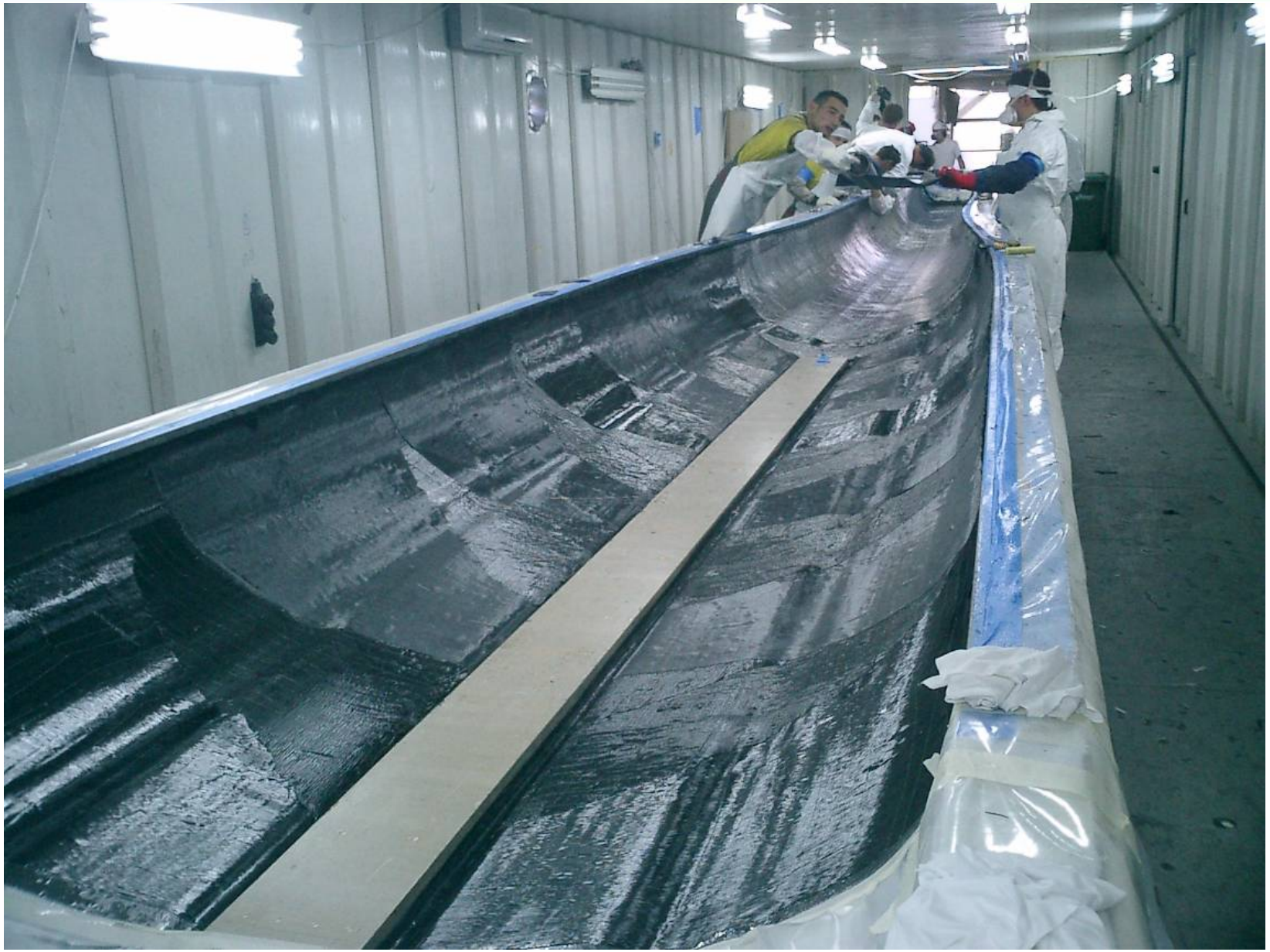
Height 58m

Sail area on each spar 800 sqm

Elliptical spar 1.8m by 1.1m max, tapering to 0.6 by 0.4m at top and reducing to 1.1m diam at deck

Open slot down compression face

Maltese Falcon main spar, note slot for furling sails



Maltese Falcon Rig Cured in 4 pieces, secondary bonded together

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Maltese Falcon Rig Stepping

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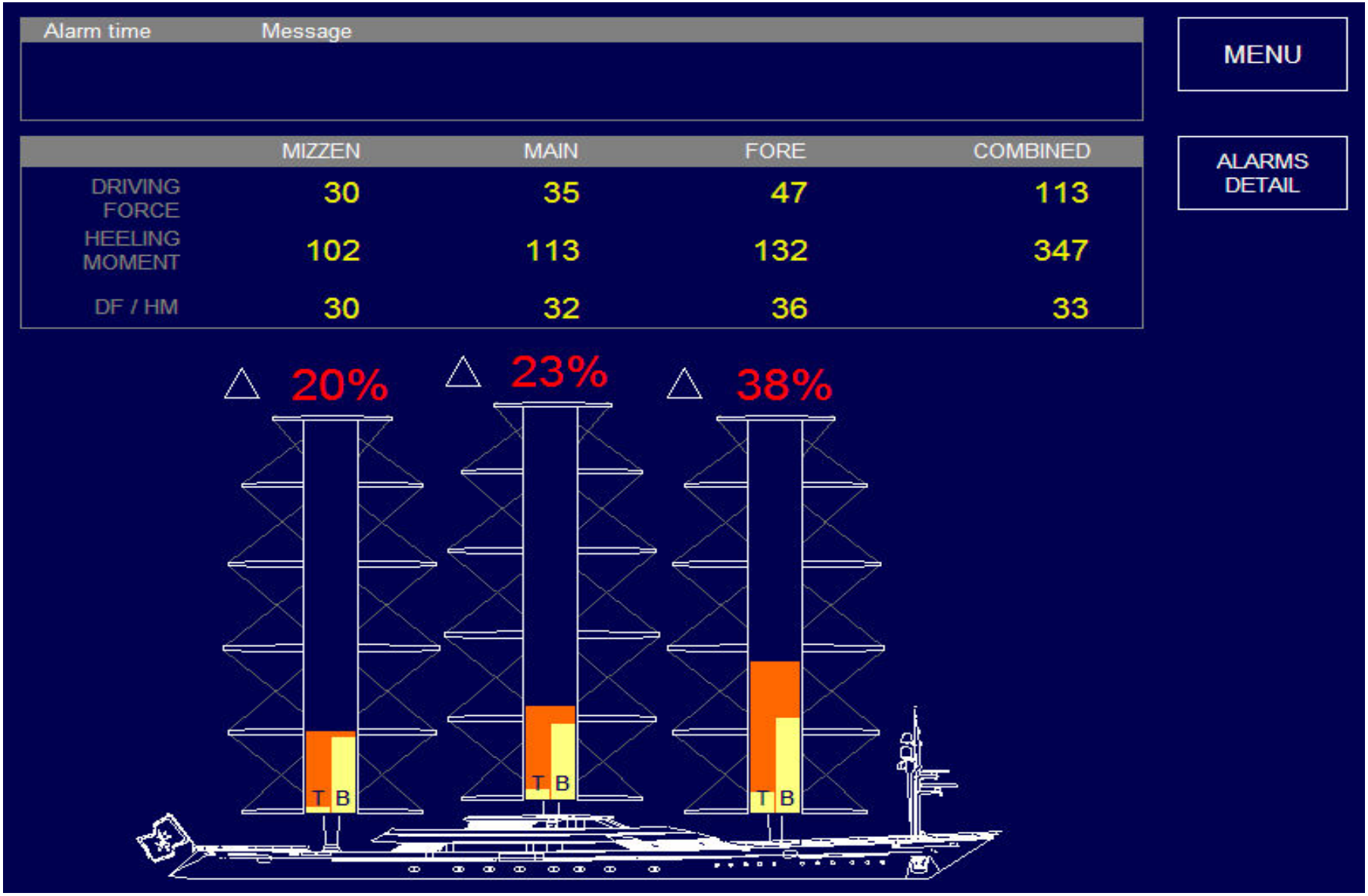
Real Time Display in Wheel House, Maltese Falcon



Improvements in Specific Strength During the First 100 Years of Composites

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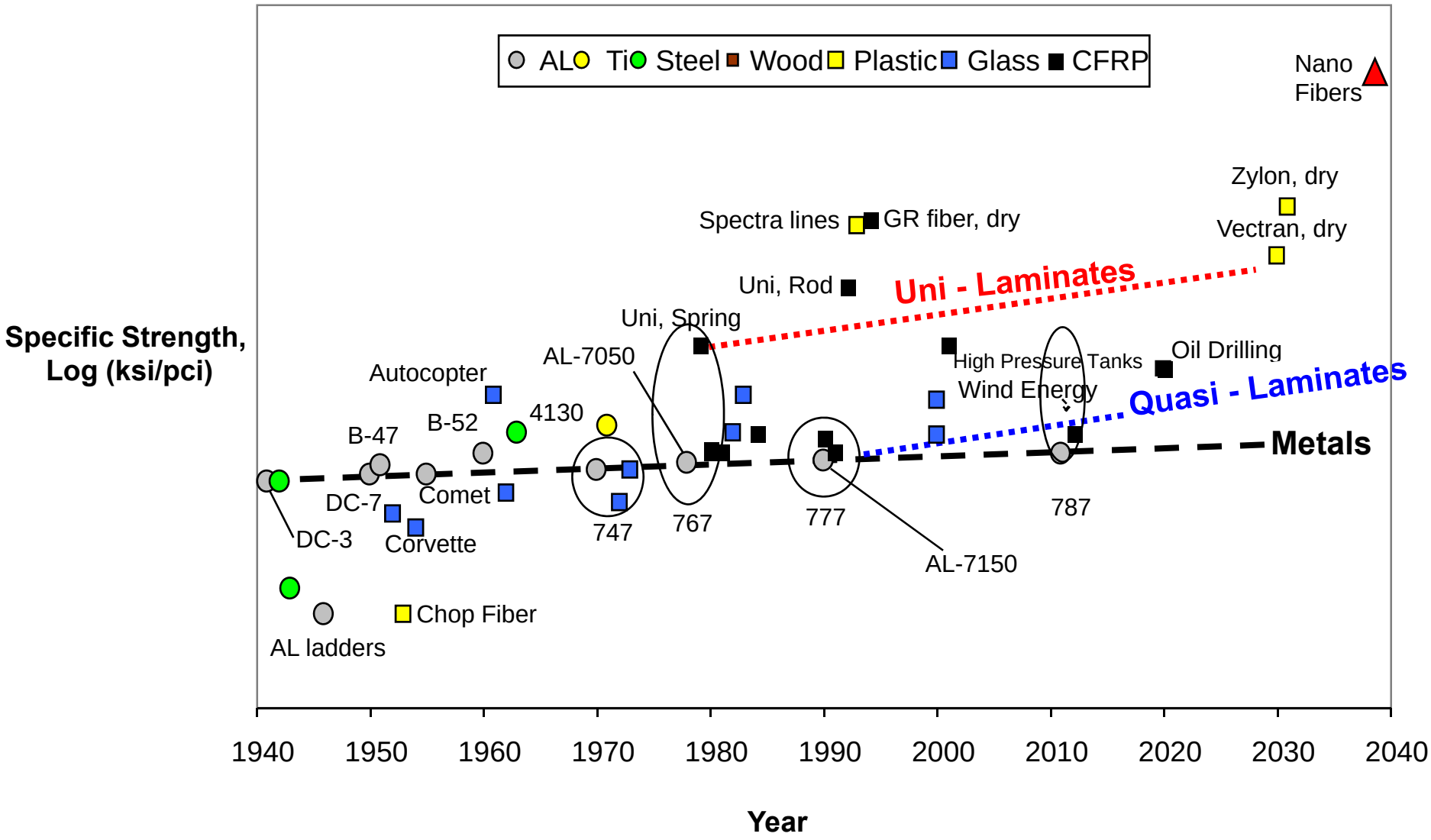
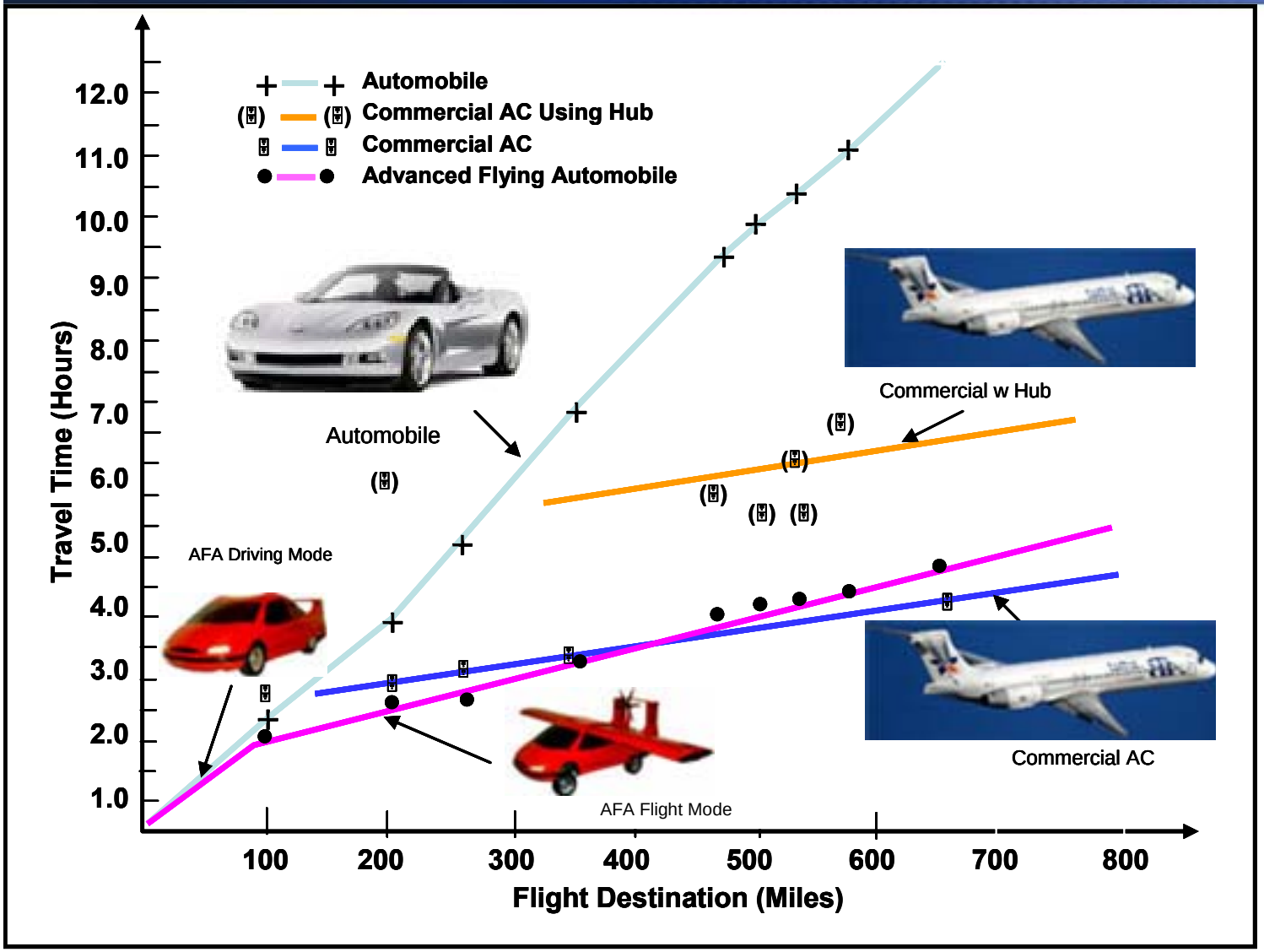


Diverse Modes of Transportation



On the Land, In the Sky, On the Sea: The Best Is Yet to Come

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