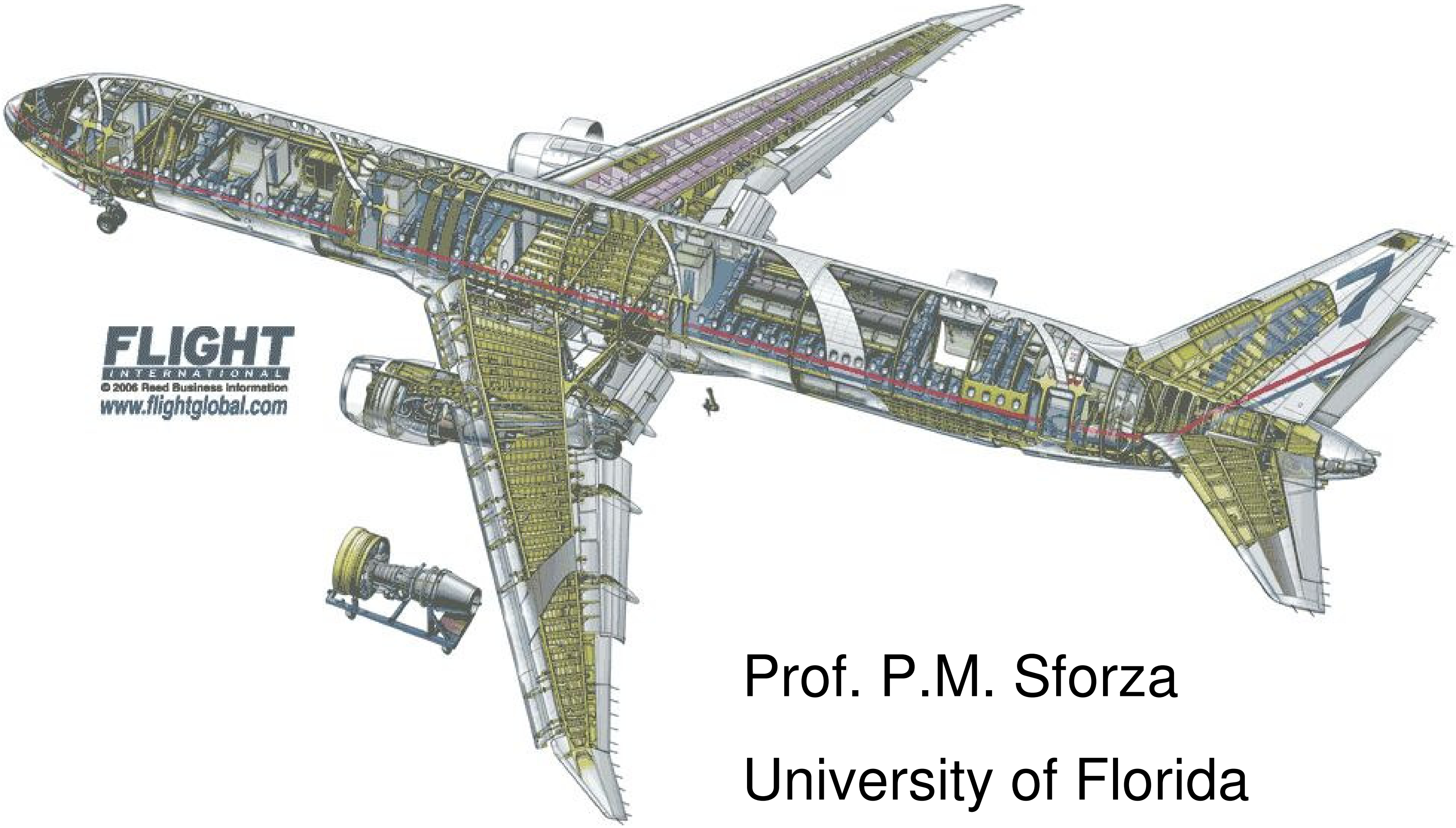
# EAS 4700 Aerospace Design 1

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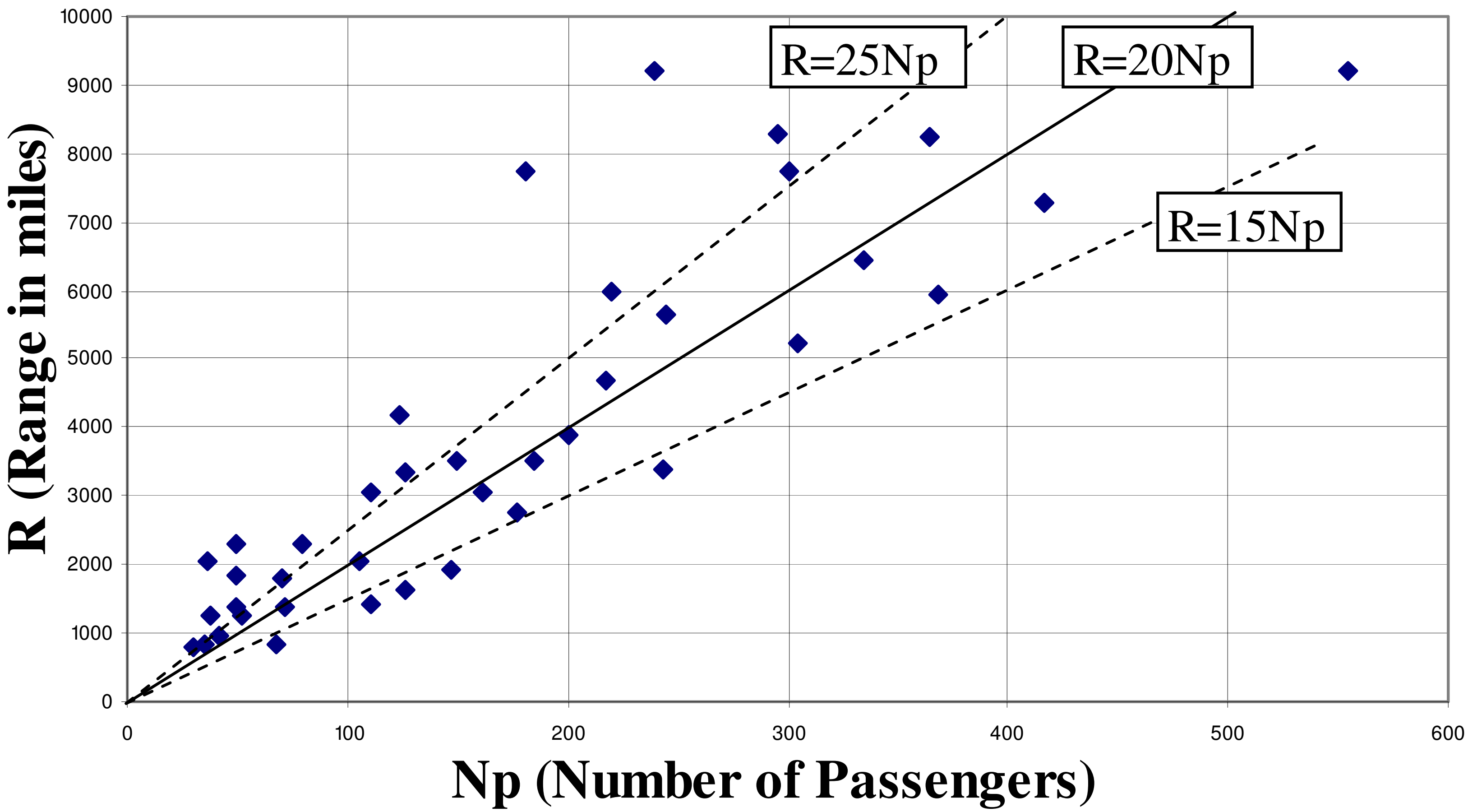
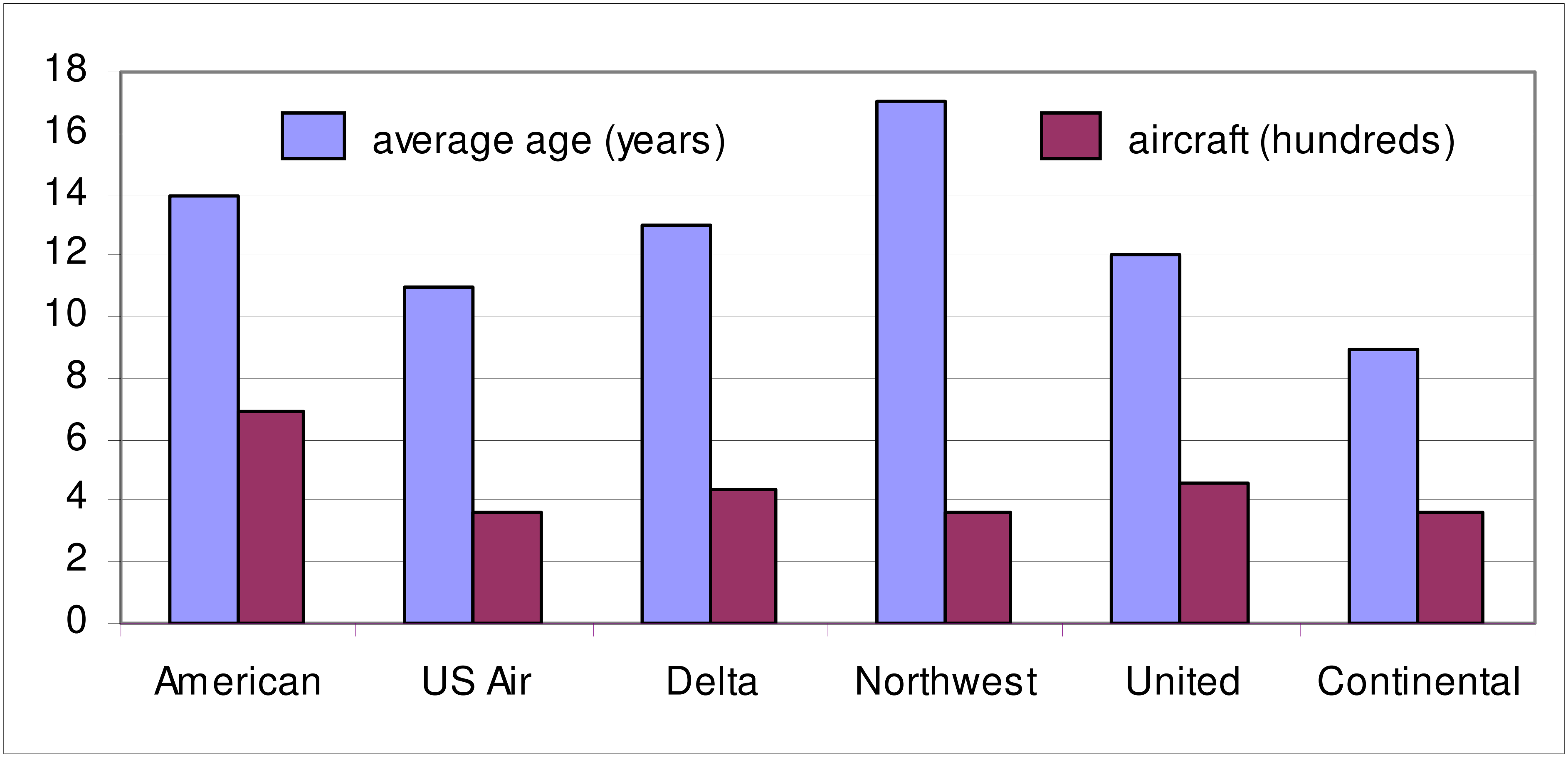
# 1.Mission specification and market survey

- Number of passengers: classes of service
- Range: domestic or international routes
- Cruise speed: turbofans $0.72<M<0.86$
- Cruise altitude: 30,000 to 40,000 ft

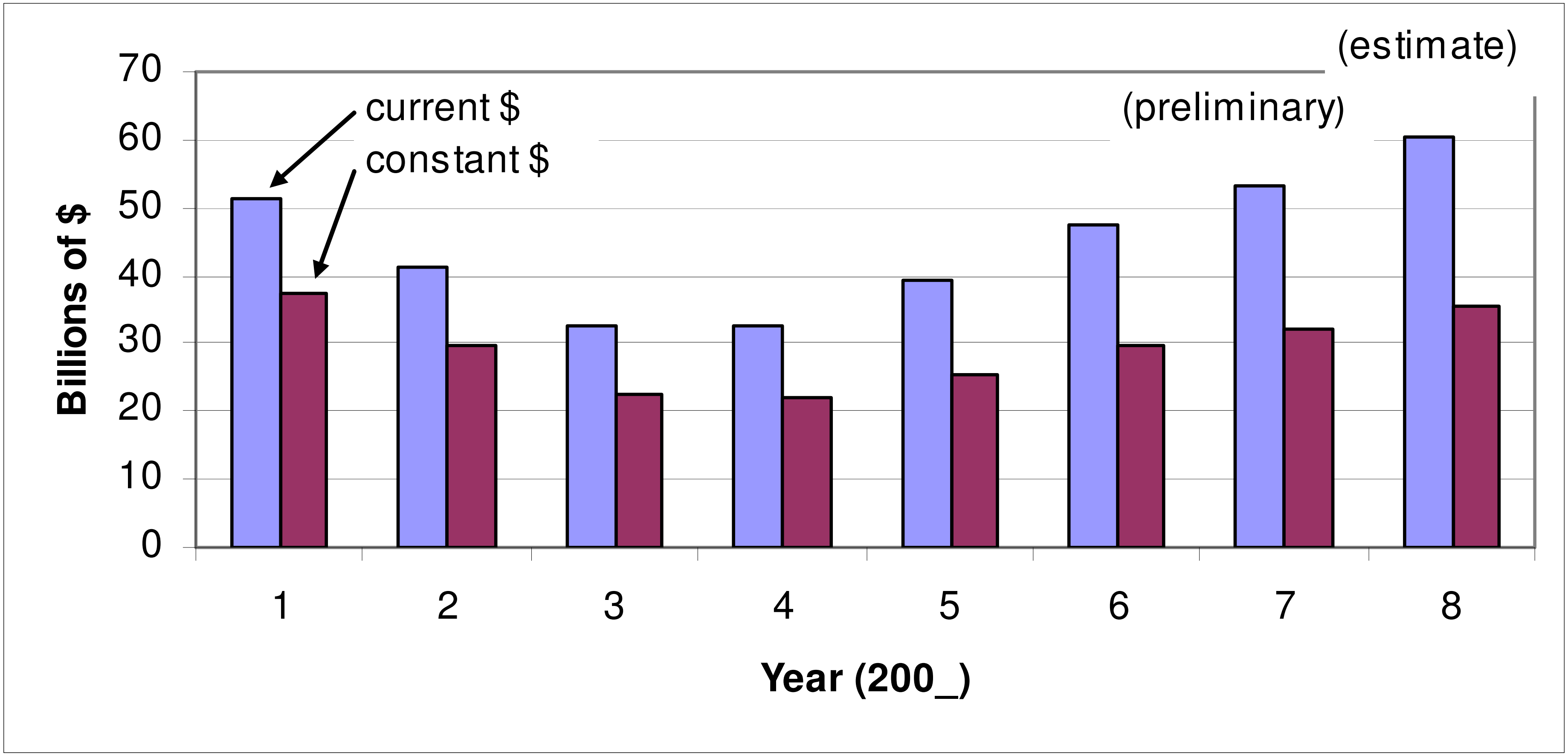
# Range versus number of passenger seats for jet transports



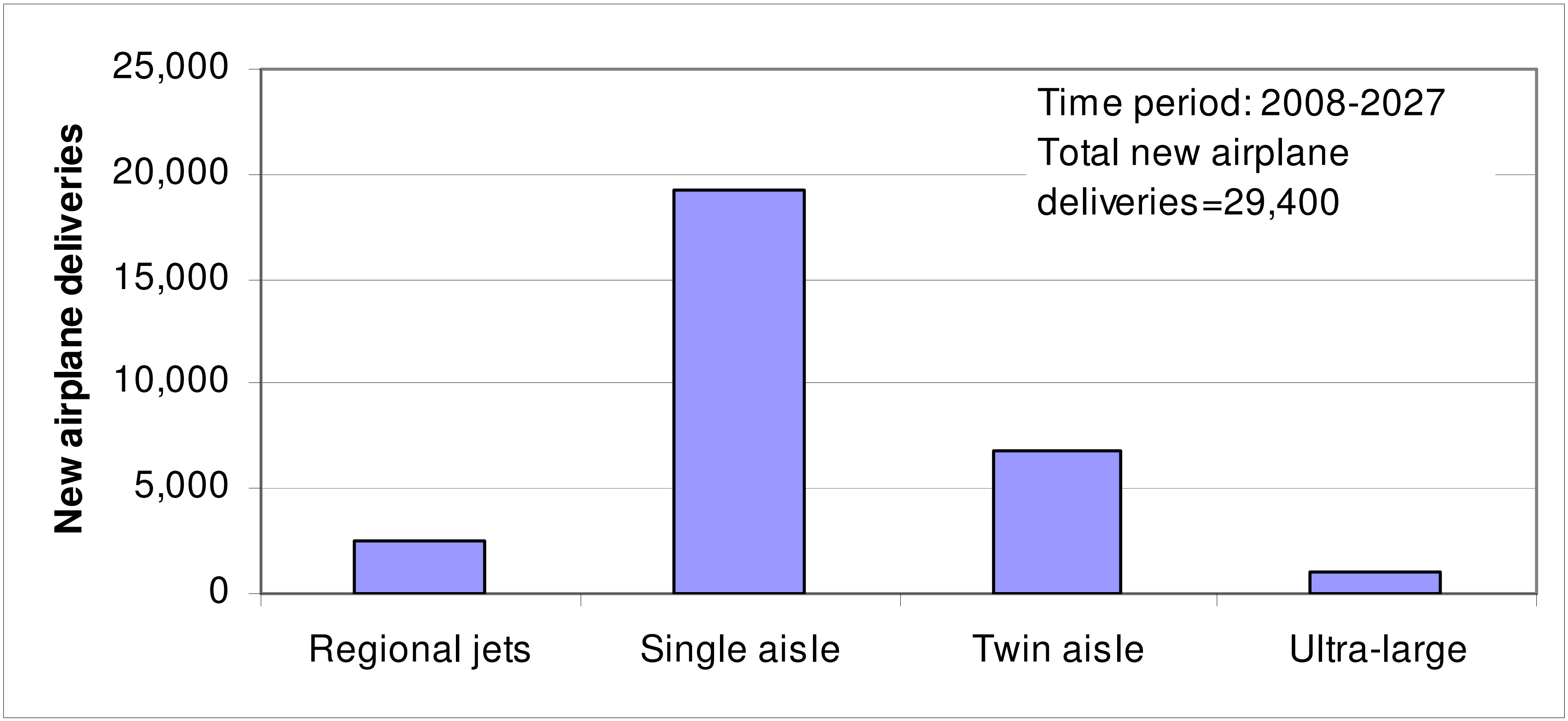
# The market for commercial aircraft



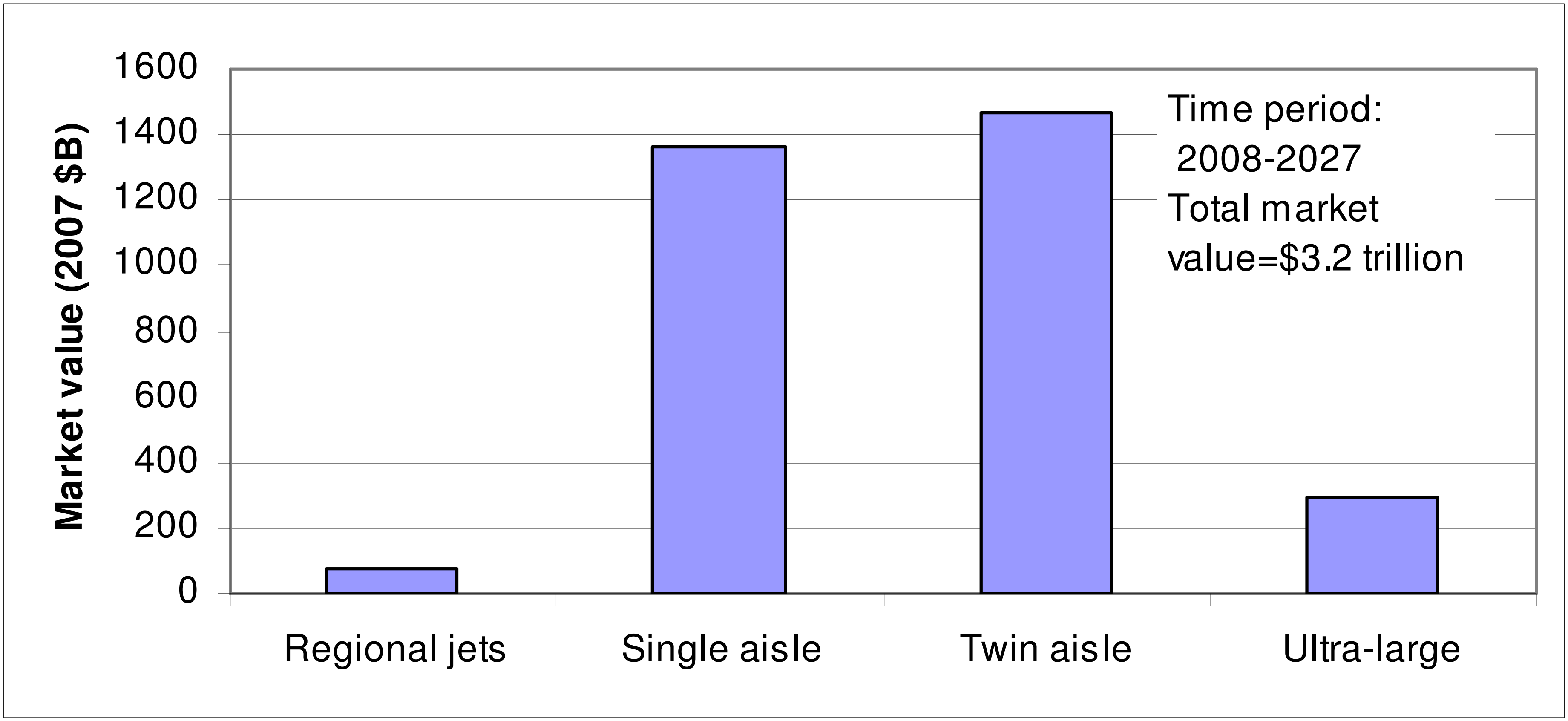
# Annual sales of commercial aircraft: 2001-2008



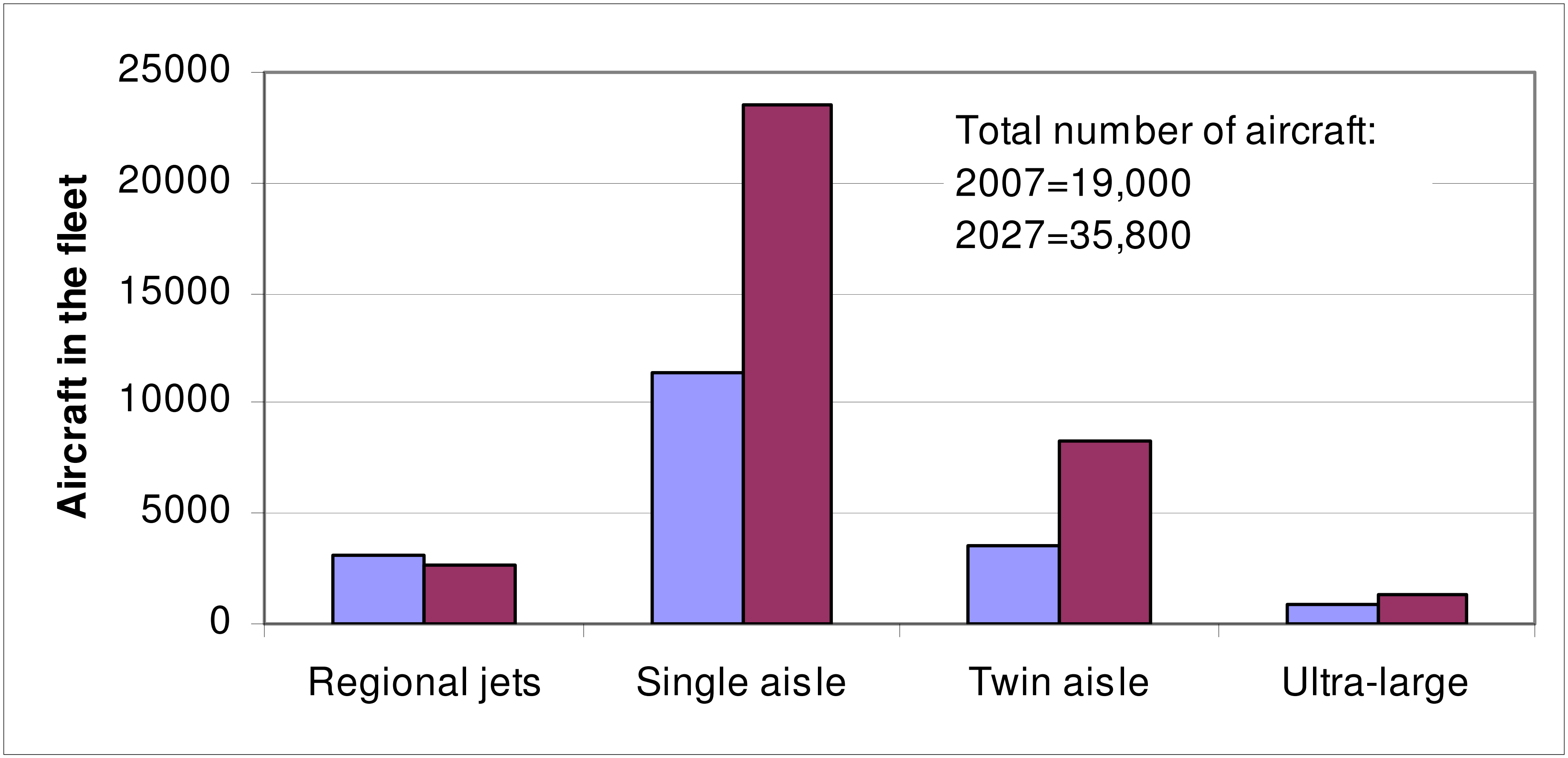
# Forecast of new aircraft deliveries: 2008 – 2027



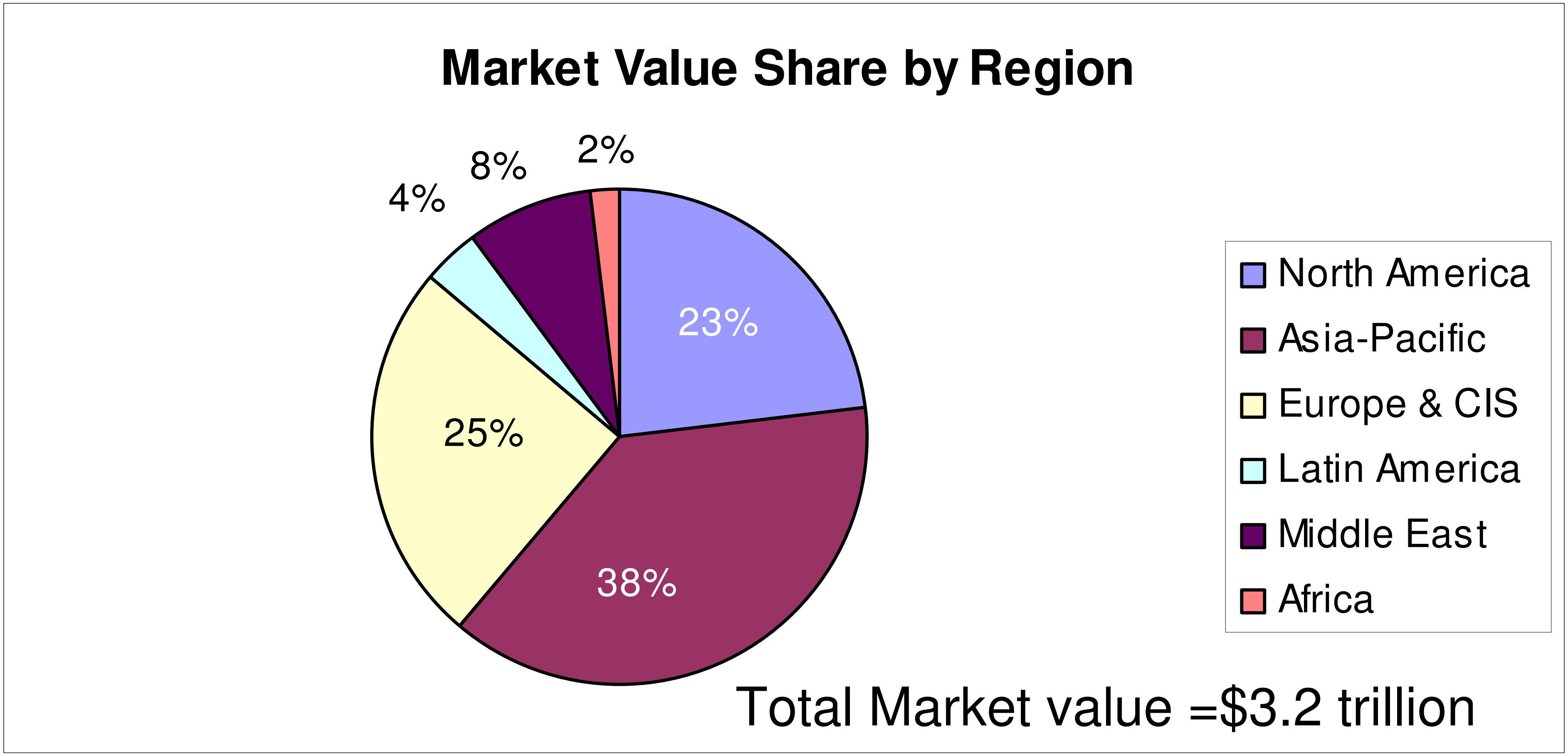
# Forecast of market value of new deliveries by aircraft type: 2008-2027



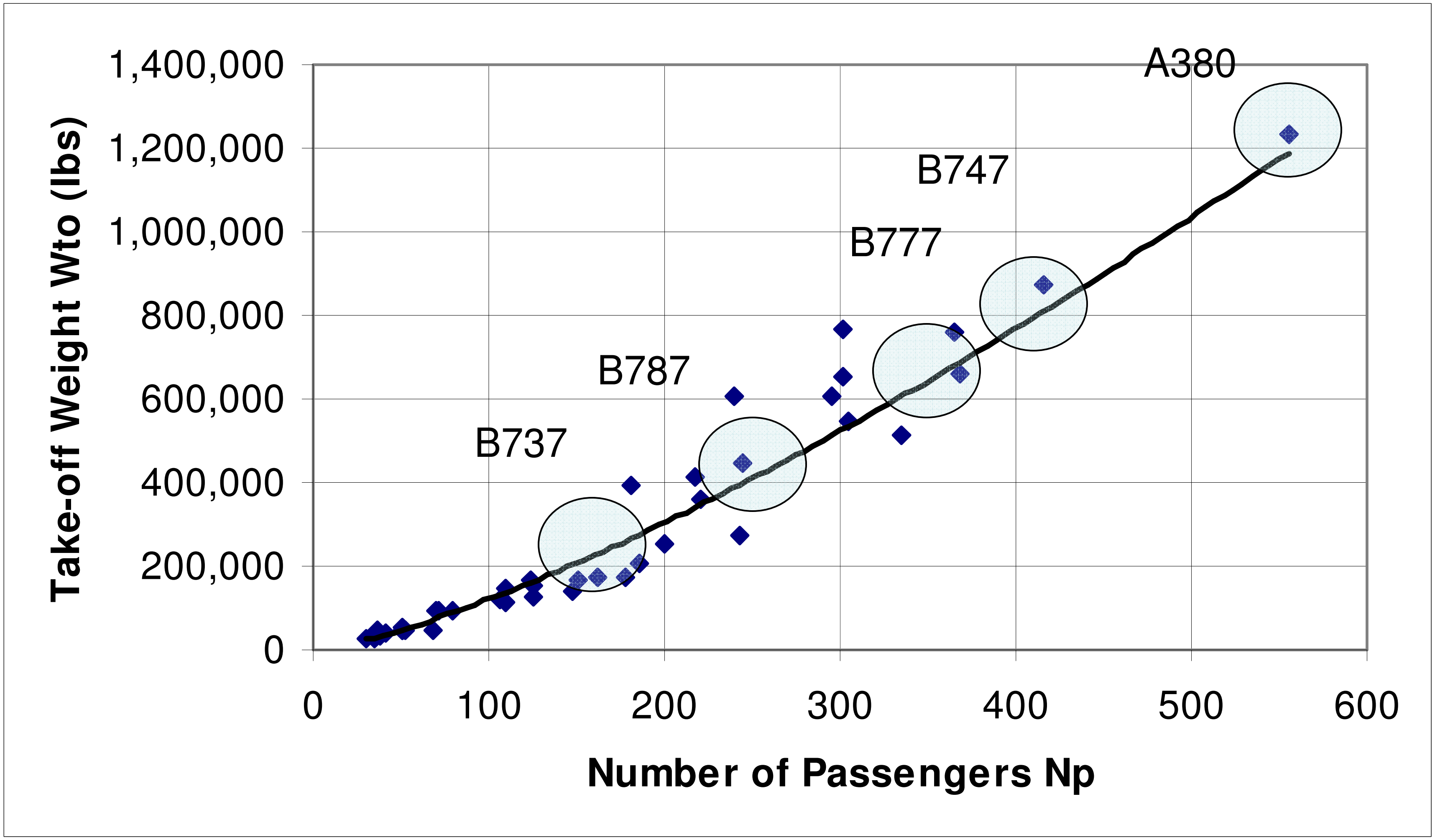
# Forecast for the change the commercial fleet: 2007-2027



# Forecast of market value share by region: 2008-2027



# General trend of take-off weight vs number of passengers



# Market Survey

- Rigorously examine 3 or 4 existing aircraft which closely satisfy the mission
- Introduce mission specification, the competitor aircraft, and special attributes of your aircraft
- Present detailed quantitative data for the competitor aircraft in tabular form, along with 3-views, in an Appendix.
- Photos of the competitor aircraft appear in Chapter 1 along with airplane descriptions

# Aircraft data resources

- Jane's All the World's Aircraft
- Aviation Week & Space Technology Aerospace Source Book
- Manufacturer's websites

www.boeing.com

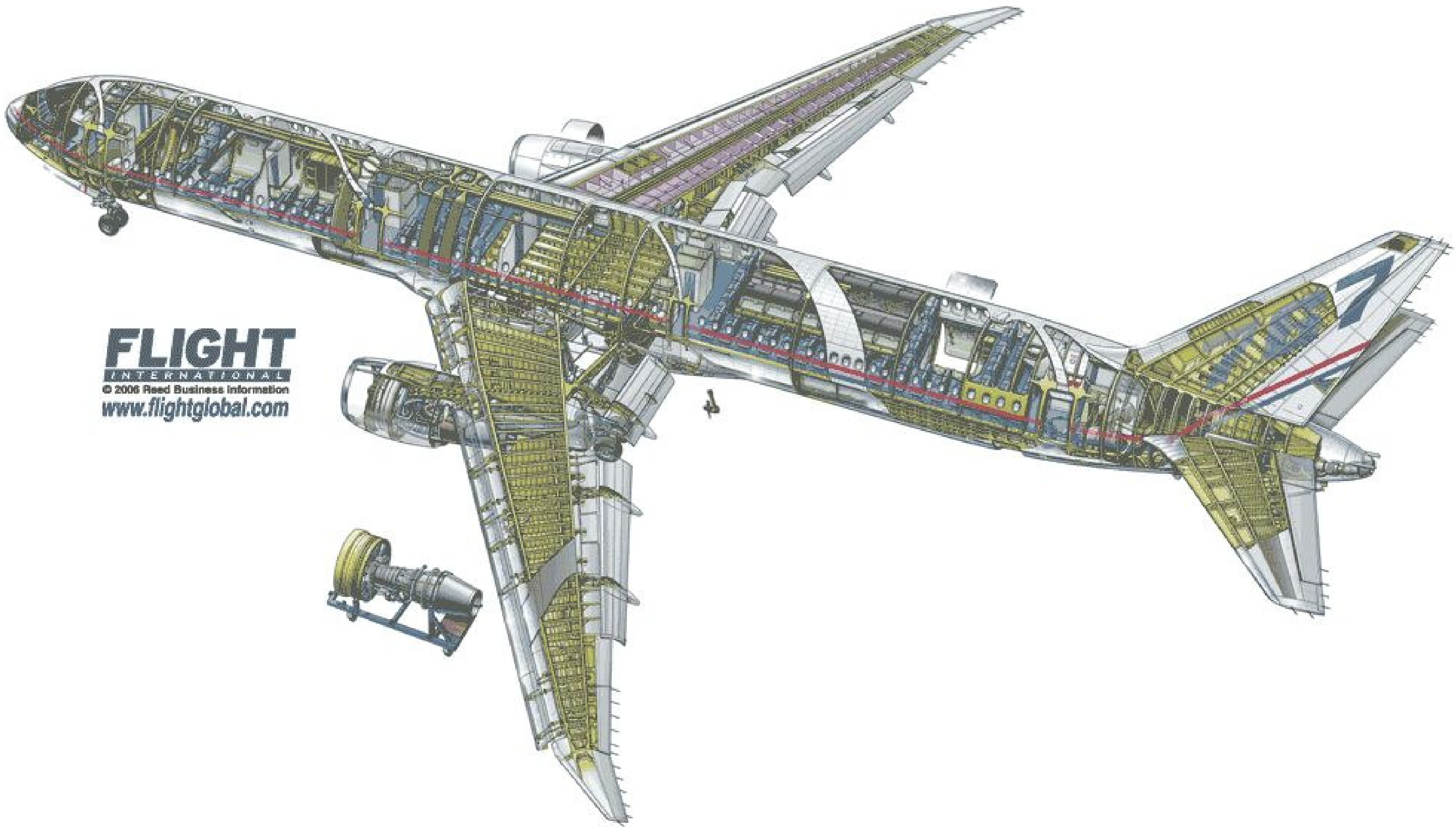
www.airbus.com

http://www.flightglobal.com/StaticPages/cutaways.html

# Federal Air Regulations

- the Federal Aviation Agency (FAA), establishes airworthiness requirements to ensure public safety in aviation.
- It  issues Federal Aviation Regulations (FAR) and FAA Advisory Notes laying down rules for aircraft and their operation.
- The FAR is Title 14 of the Code of Federal Regulations and is available on-line (Ref. 1-4). Subchapter C, Parts 1-59, deal with aircraft.

# 2. Preliminary Weight Estimate



# 2. Preliminary weight estimate

$W_{TO} = W_E + W_{TFO} + W_{PLC} + W_{F,USED} + W_{F,RES}$

=Take-off Weight

$W_E$ =Empty Weight

$W_F = W_{F,USED} + W_{F,RES}$

= Weight of Fuel Used+ Weight of Fuel Reserve

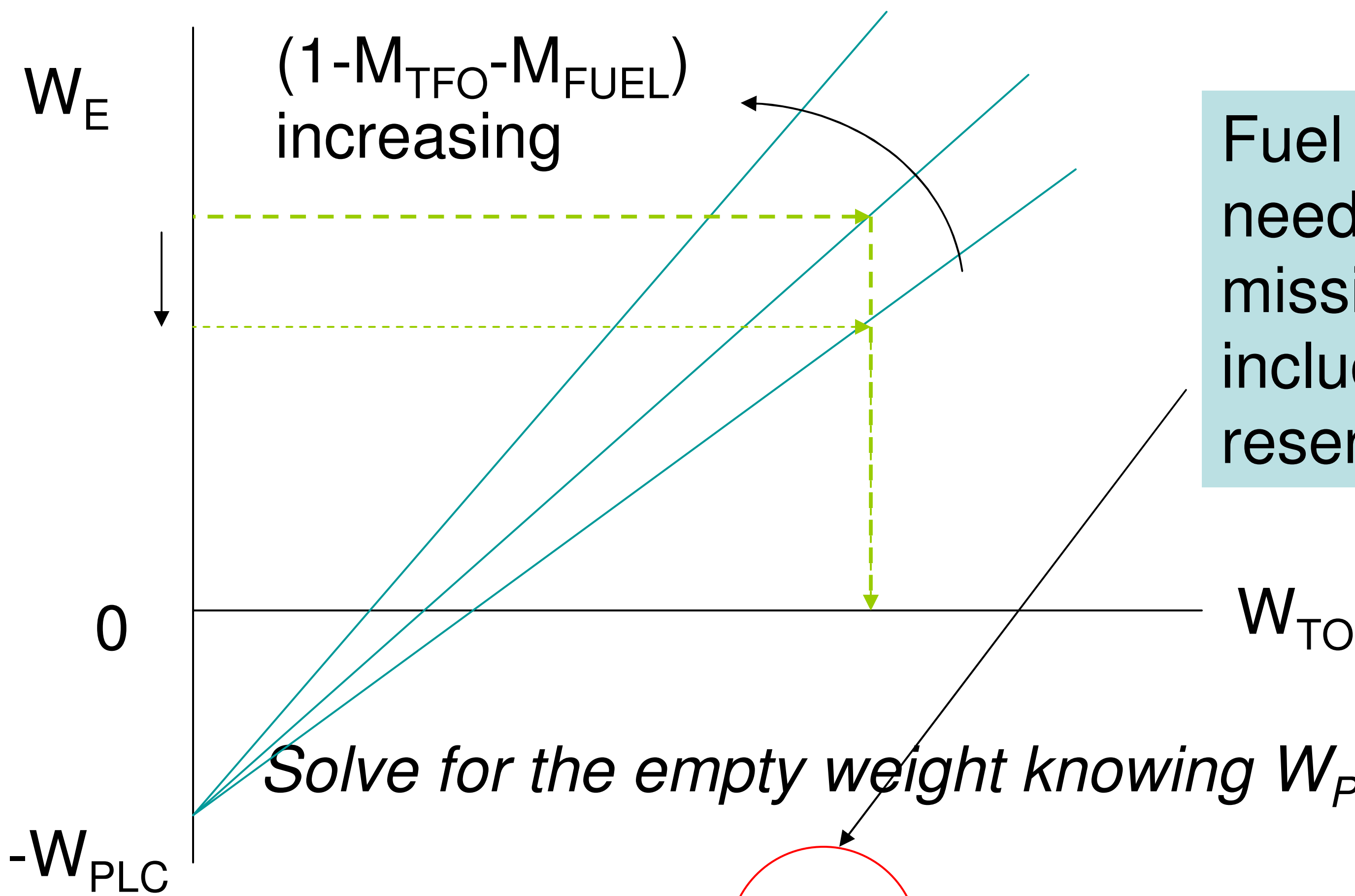
= Total Fuel Weight

$W_{PLC} = W_{PL} + W_{CREW}$ = Weight of Payload +Weight of Crew

$M_{TFO} = W_{TFO} / W_{TO}$=(Trapped Fuel and Oil Weight)/$W_{TO}$

$M_{FUEL} = W_F / W_{TO}$= Fuel Fraction

# Empty weight vs take-off weight




Fuel fraction needed for mission, including reserves

*Solve for the empty weight knowing $W_{PLC}$*

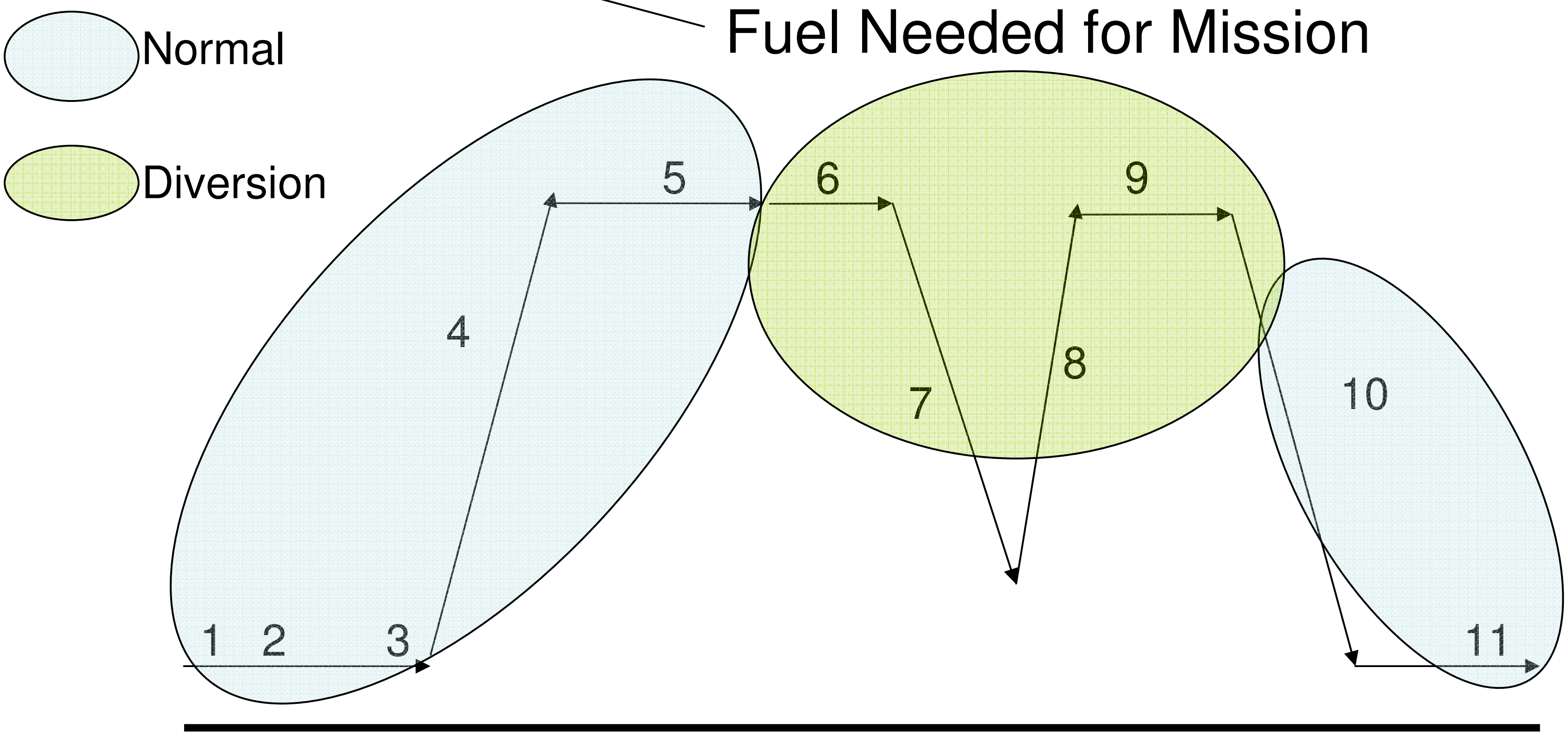
$$W_E = (1 - M_{TFO} - M_{FUEL})W_{TO} - W_{PLC} = aW_{TO} + b$$

# Mission profile

$$W_F = W_{TO} - W_{FINAL} = W_{TO} - (\text{Weight at End of Mission})$$

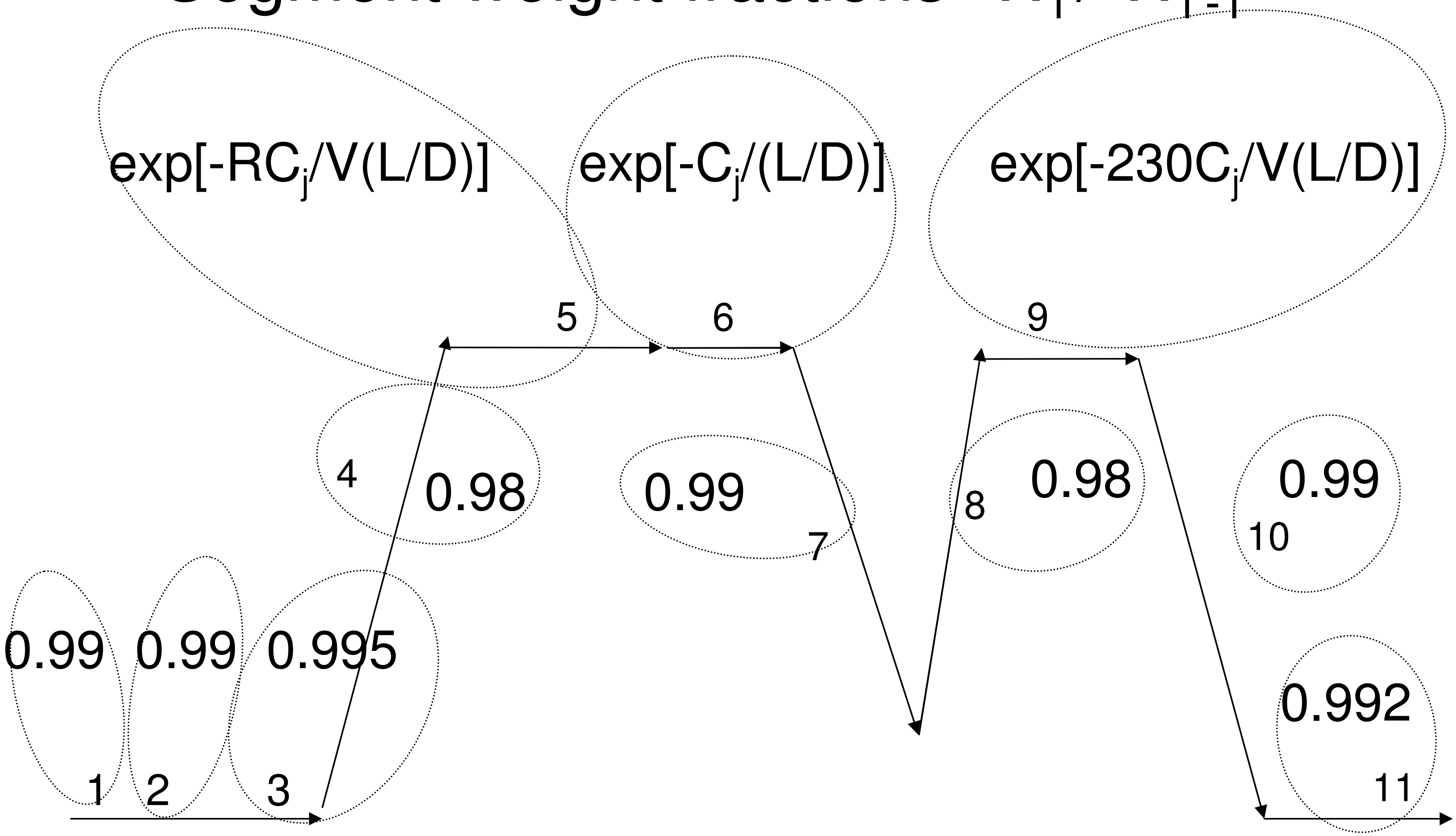
$$W_F/W_{TO} = M_{FUEL} = 1 - W_{FINAL}/W_{TO} = 1 - M_{FINAL}$$

Fuel Needed for Mission



# Mission profile

Segment weight fractions $W_i / W_{i-1}$



$$M_{FINAL} = (W11/W10)(W10/W9)(W9/W8)\ldots.(W2/W1)(W1/W0)$$

$$M_{FINAL} = \frac{W_{FINAL}}{W_{TO}} = \frac{W_{11}}{W_0} = \prod_{i=1}^{n} \frac{W_i}{W_{i-1}}$$

Final Weight Fraction

$$\frac{W_{F,USED}}{W_{TO}} = M_{F,USED} = 1 - M_{FINAL} - M_{F,RES}$$

Fuel Weight Fraction Used

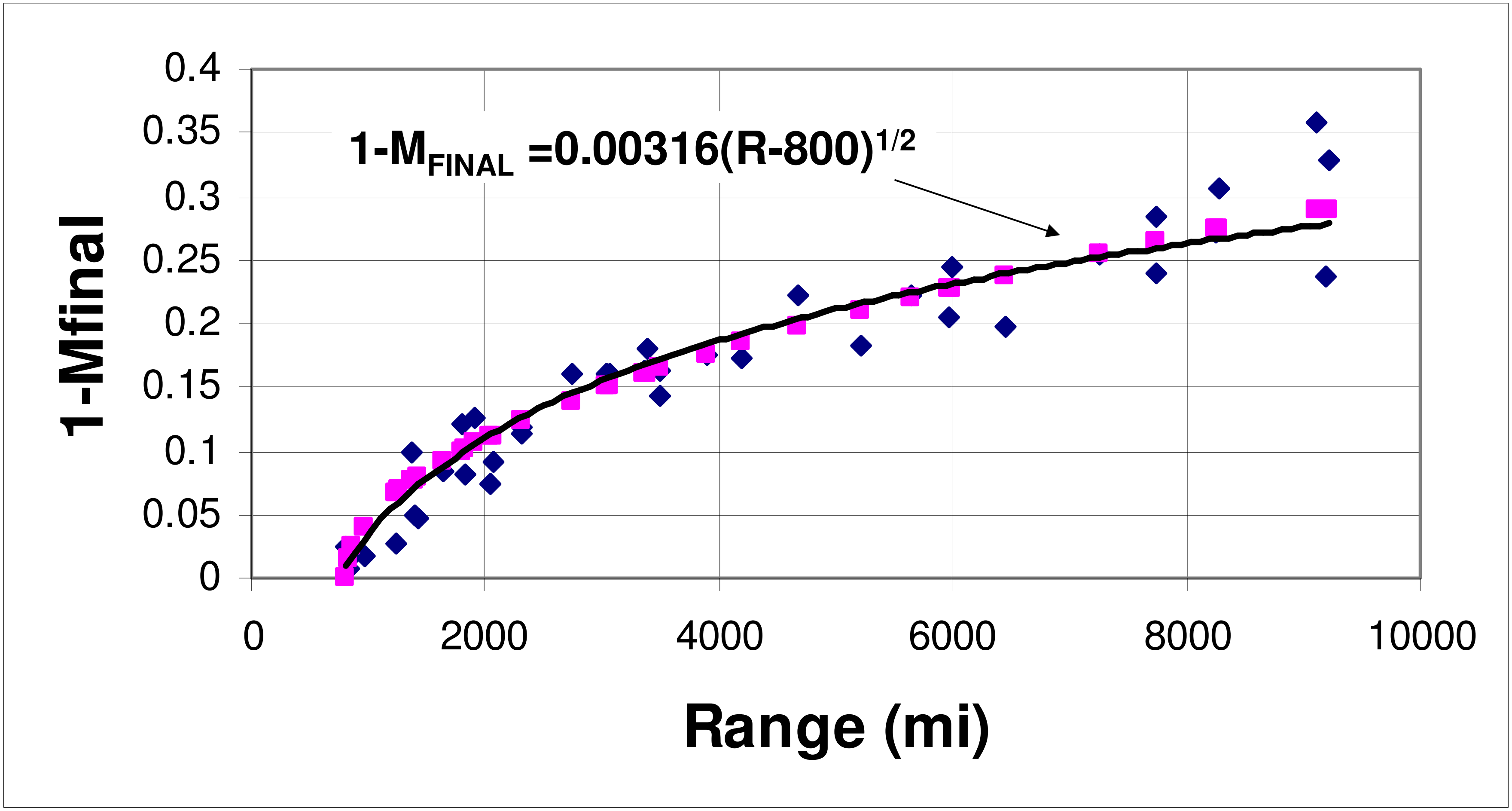
$$\frac{W_{LAND,NOM}}{W_{TO}} = M_{FINAL} + M_{F,RES}$$

Nominal Landing Weight

$$M_{F,RES} = \frac{W_{F,RES}}{W_{TO}} = \left(\prod_{i=1}^{5} \frac{W_i}{W_{i-1}}\right)\left(1 - \prod_{i=6}^{9} \frac{W_i}{W_{i-1}}\right)$$

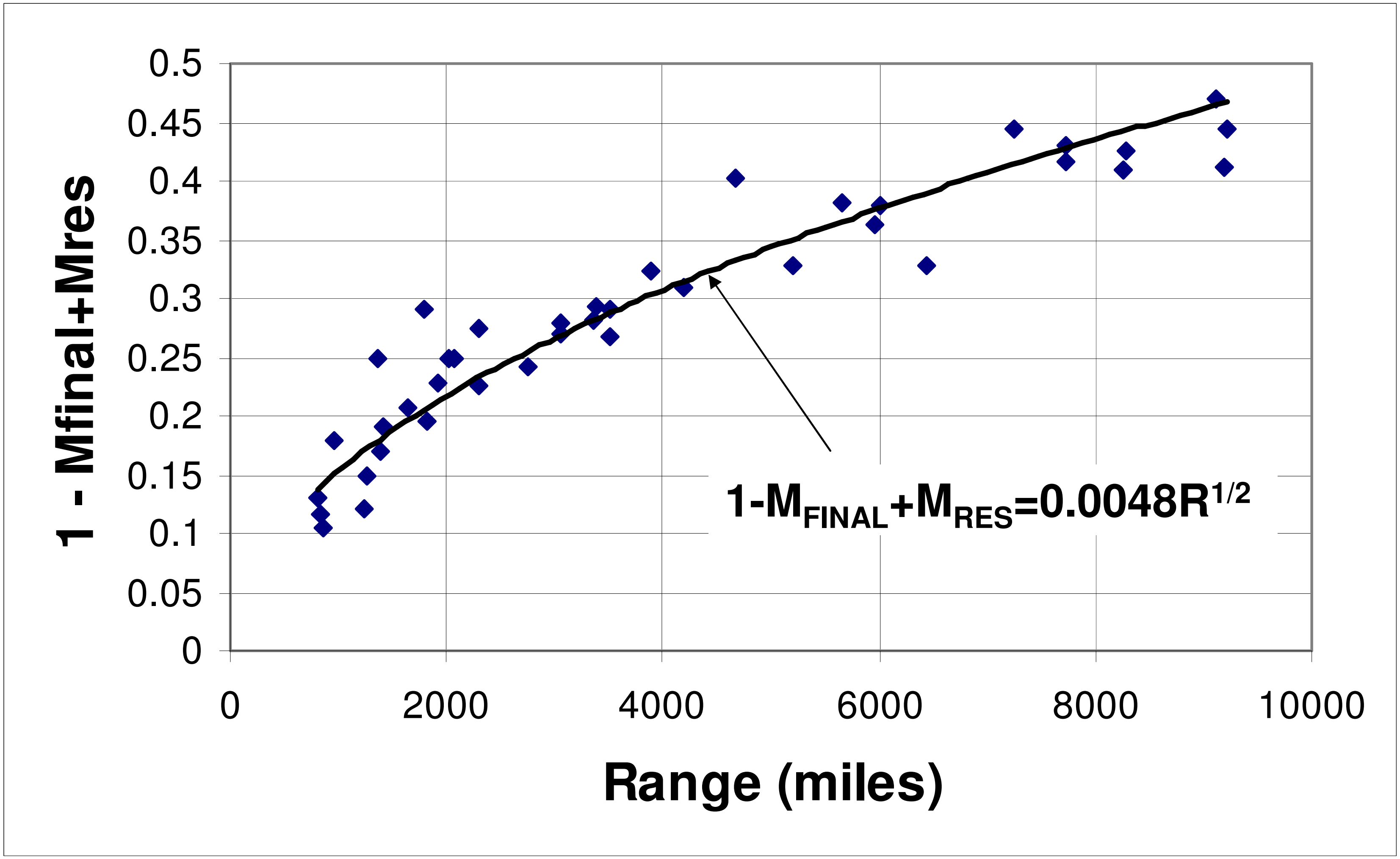
Reserve Fuel Fraction

# Mission fuel fraction vs range



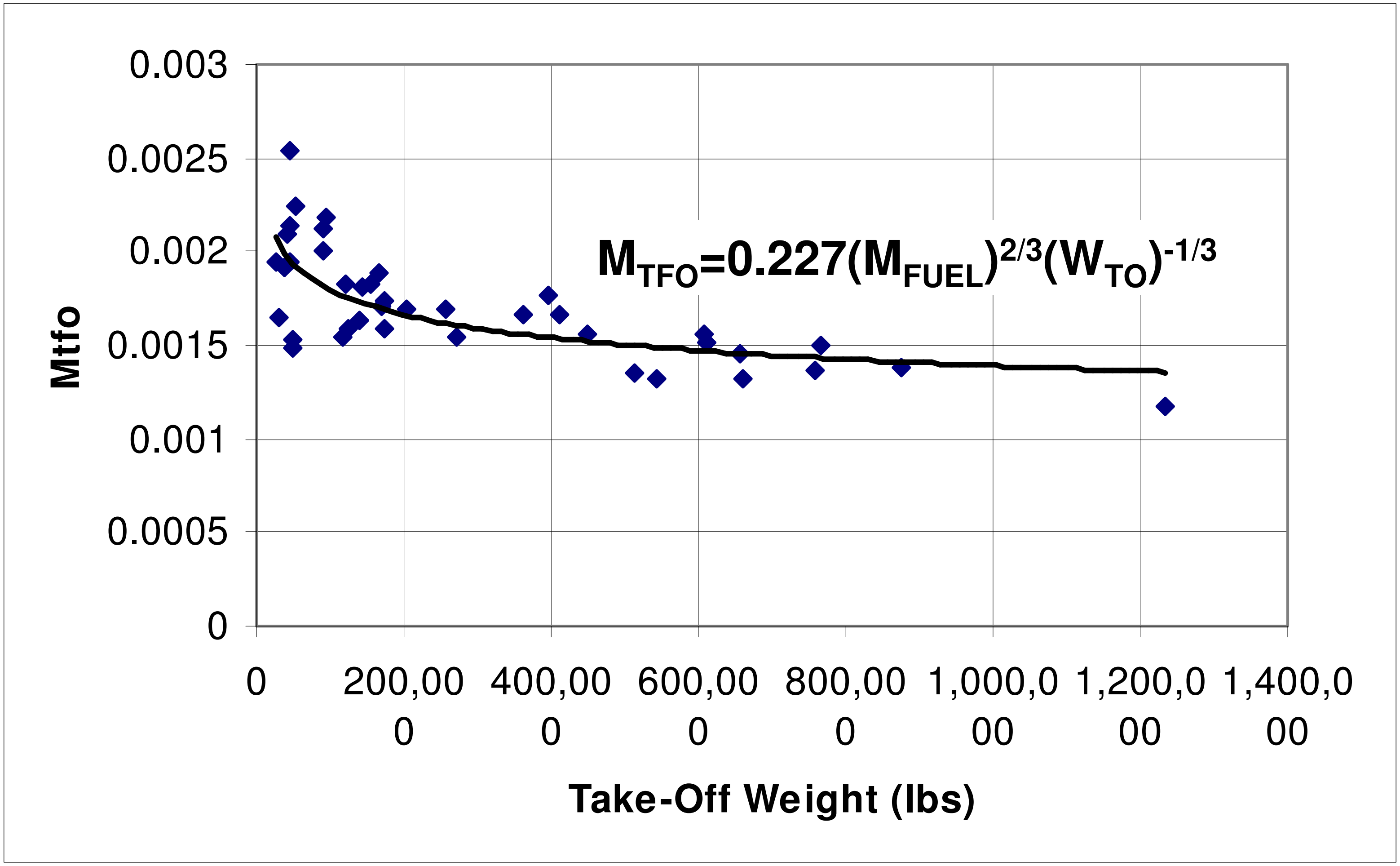

This is the nominal value of the ratio $W_{F,USED}/W_{TO}$

# Total fuel fraction vs range



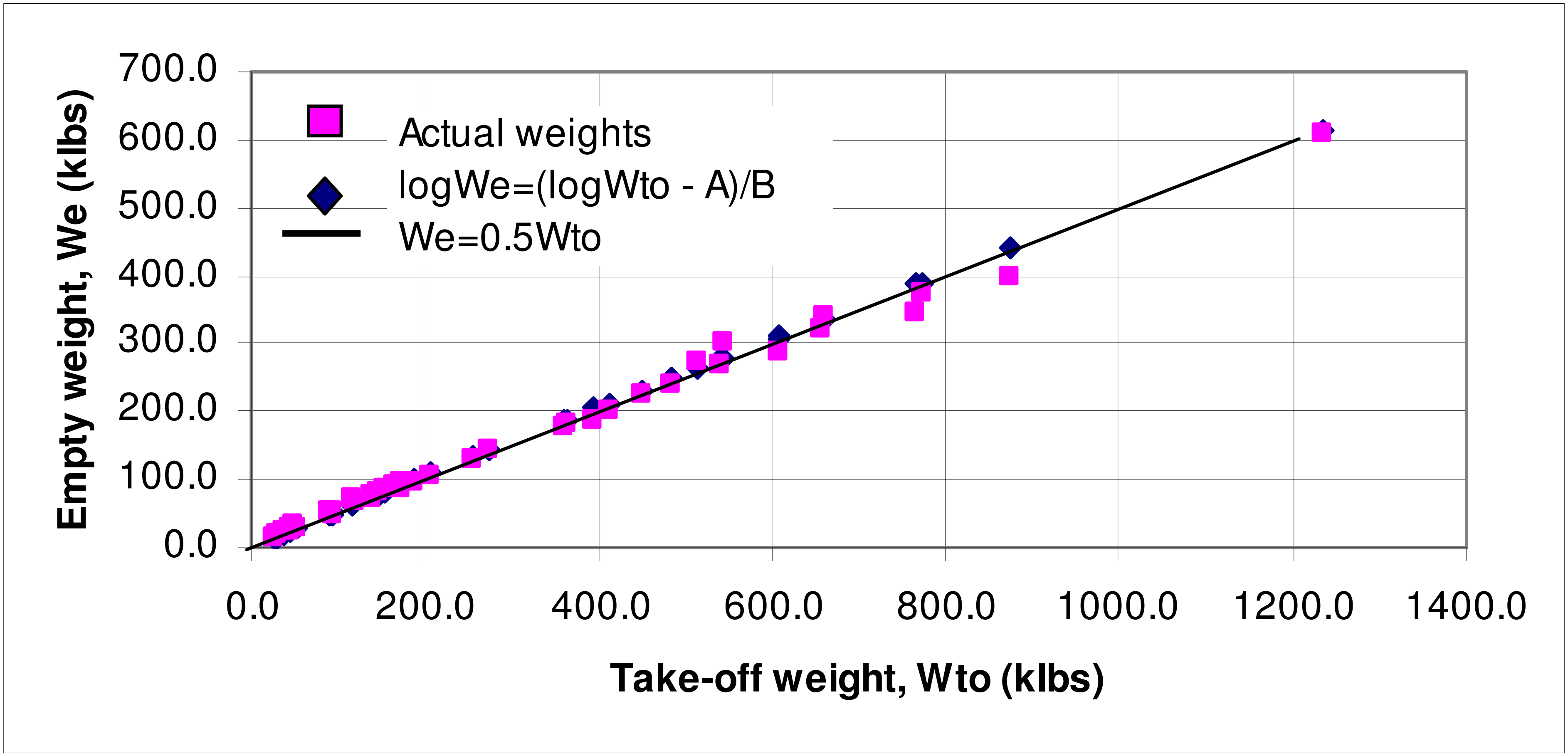

Nominal ratio of total fuel carried to take-off weight, $M_{FUEL}$

# Fraction of trapped fuel and oil

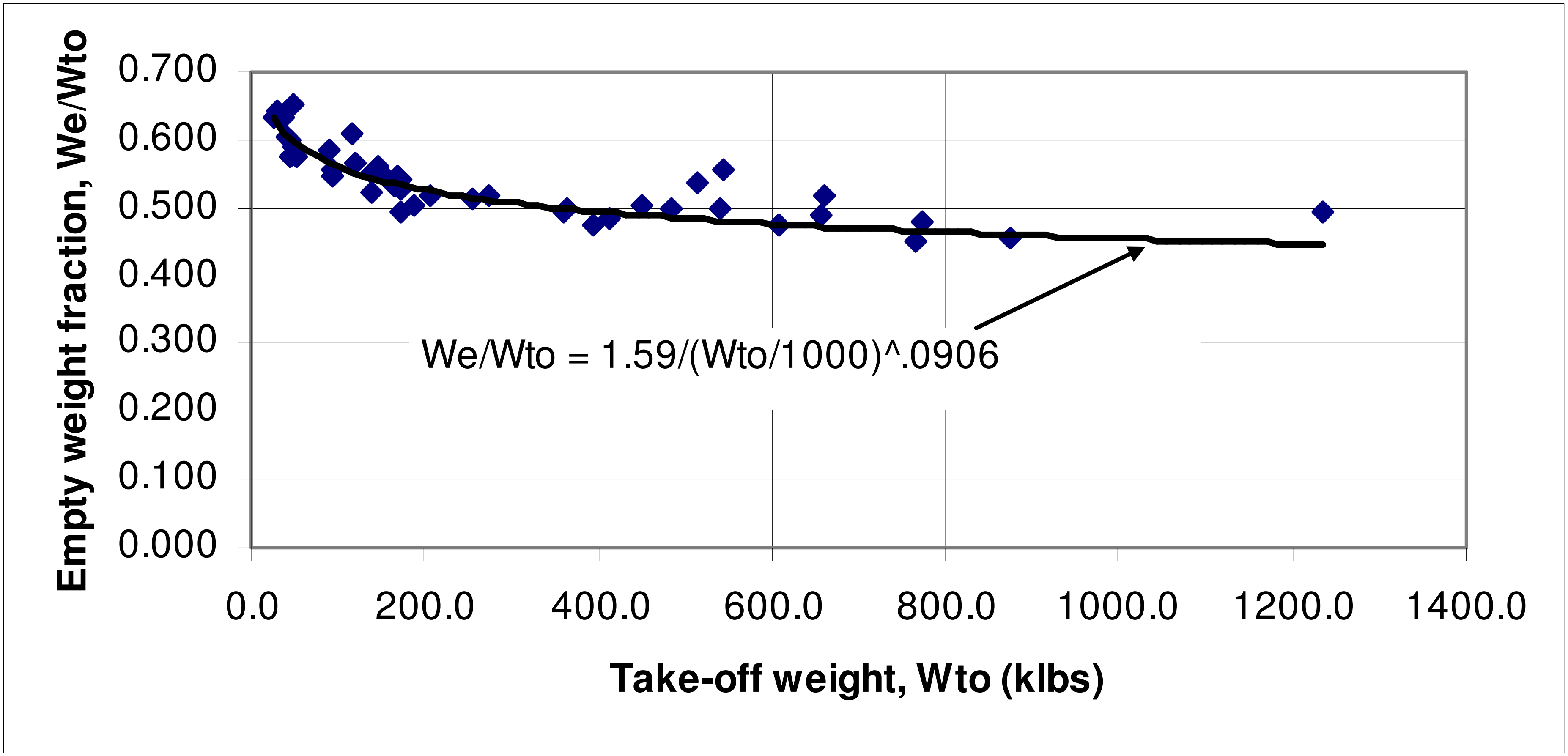



Correlation for the weight fraction of trapped fuel and oil

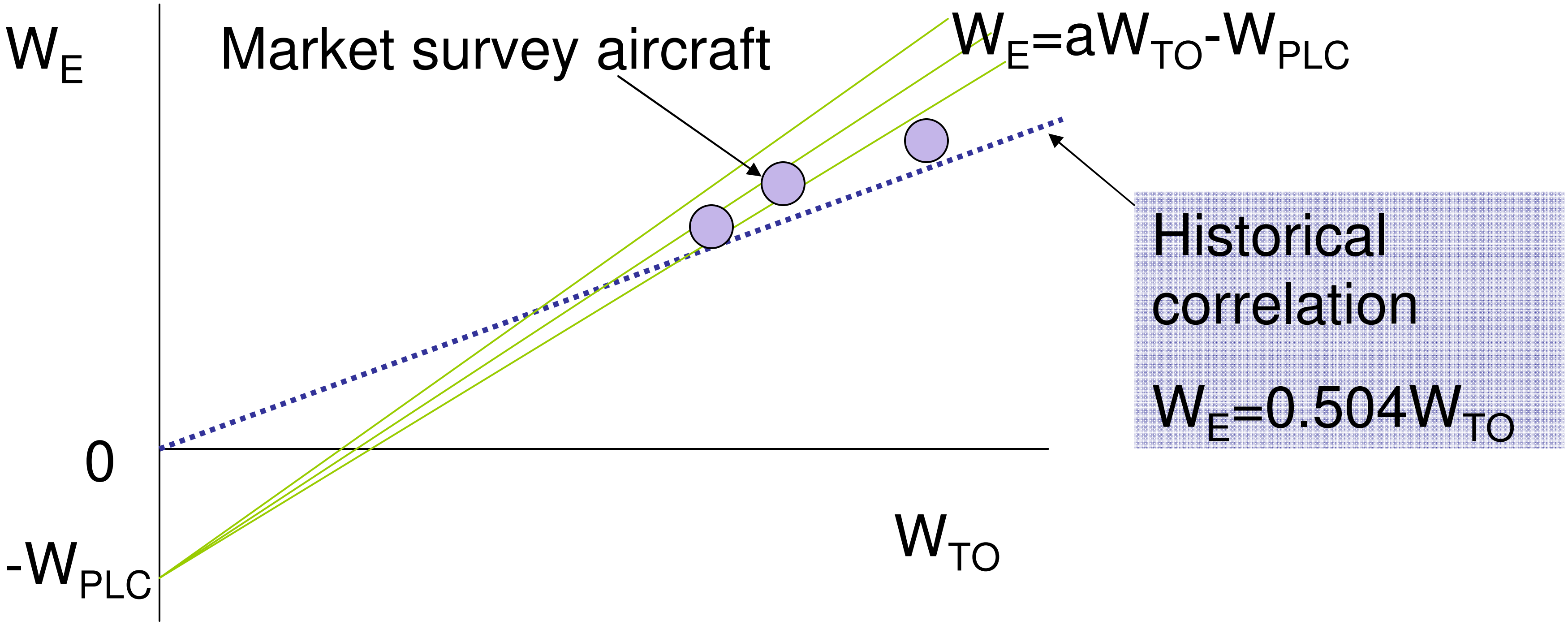
# Empty weight vs take-off weight for 45 airliners



# Empty weight vs take-off weight for 45 airliners



# Estimating aircraft empty weight



# Cruise fuel requirement

$$R = \frac{V}{C_j}\frac{L}{D}\log_e\frac{W_4}{W_5}$$

Breguet Range Equation

$$\frac{W_5}{W_4} = \exp\left[-R\left(\frac{V}{C_j}\frac{L}{D}\right)^{-1}\right]$$

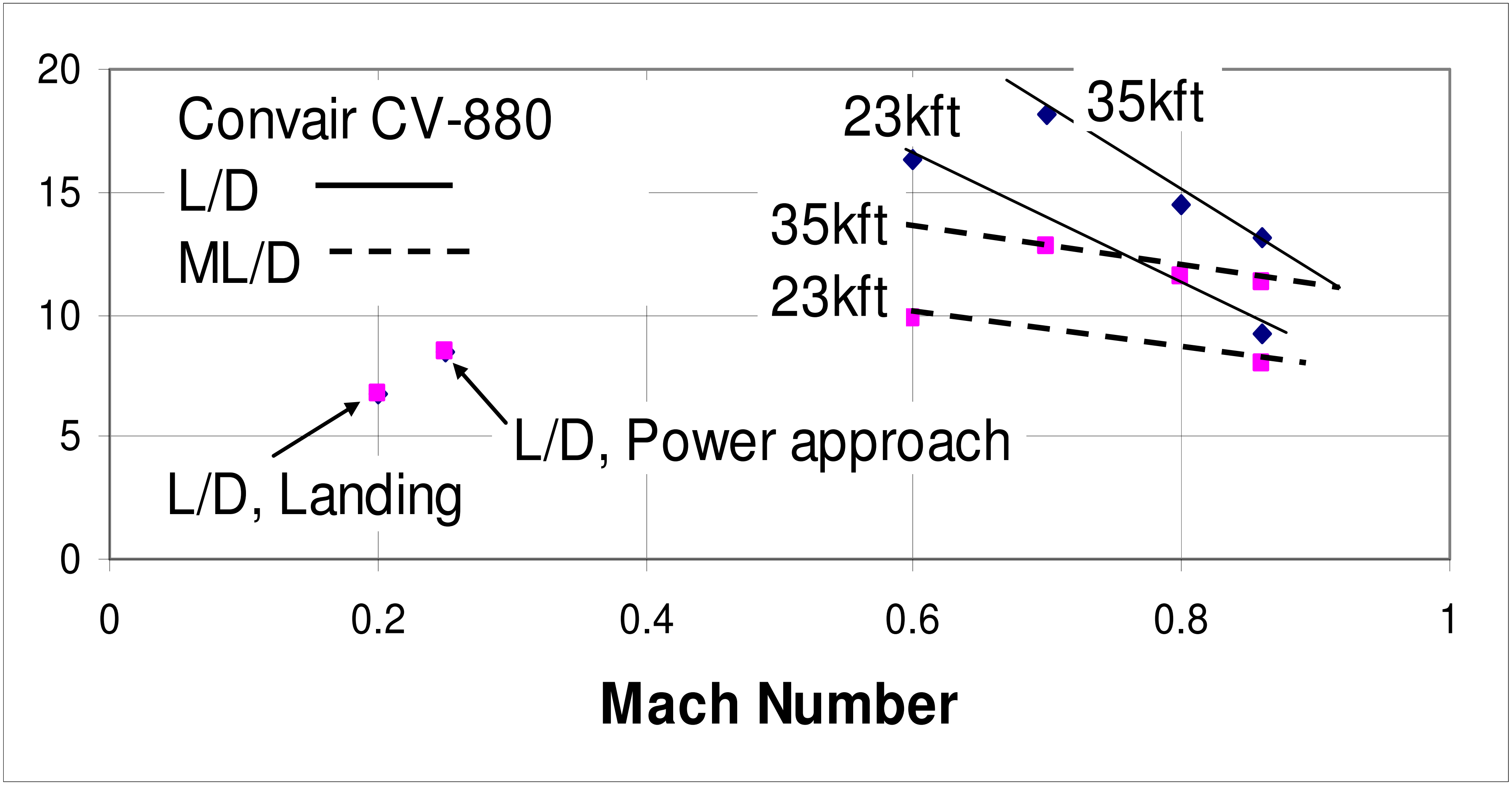
Ratio of Weight at End of Cruise to Weight at Start of Cruise

$0.76<M<0.86$ Mach Number

$0.5<C_j<0.6$ Specific Fuel Consumption

$14<L/D<18$ Lift to Drag Ratio

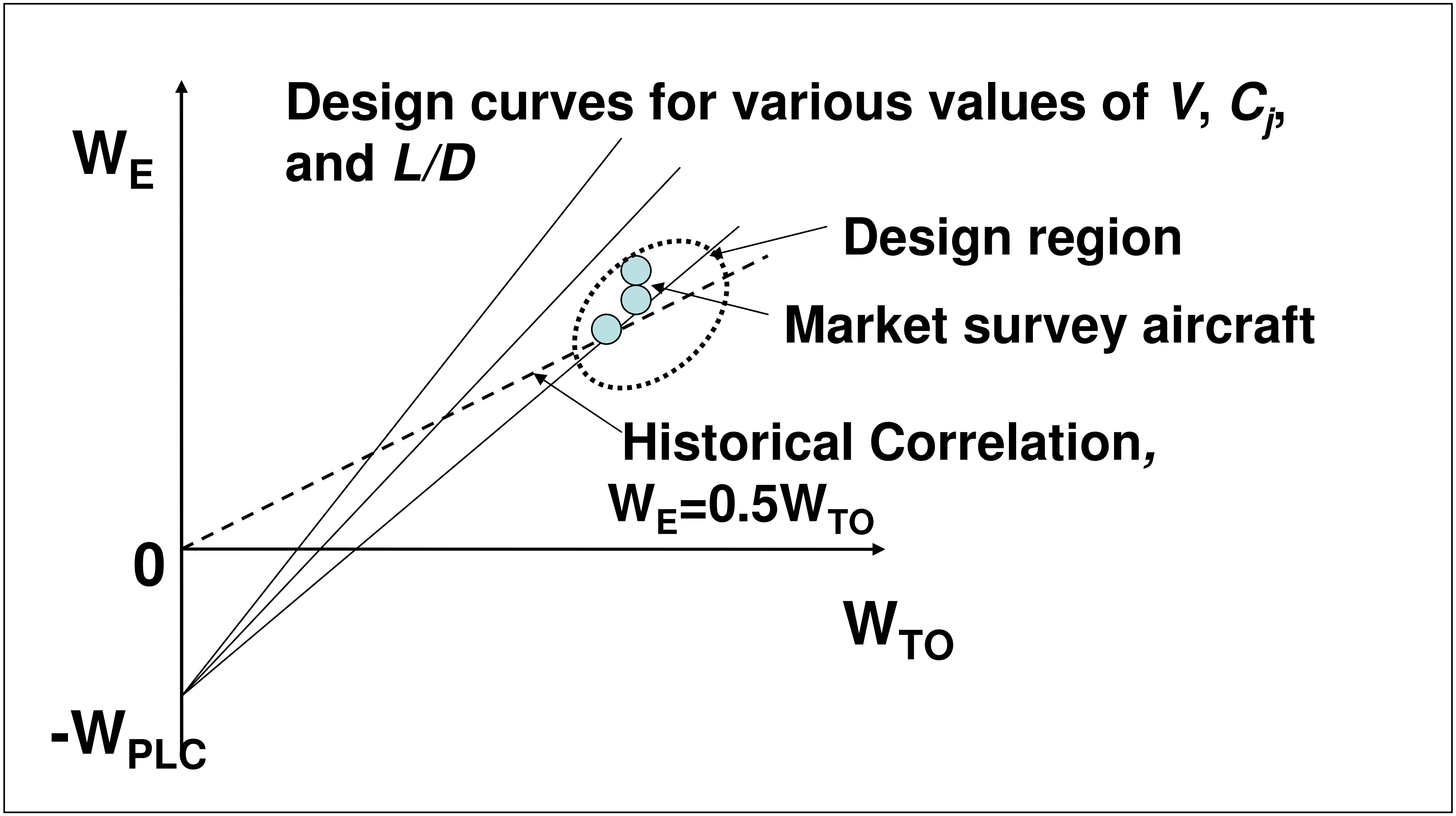
# L/D characteristics of a jet airliner



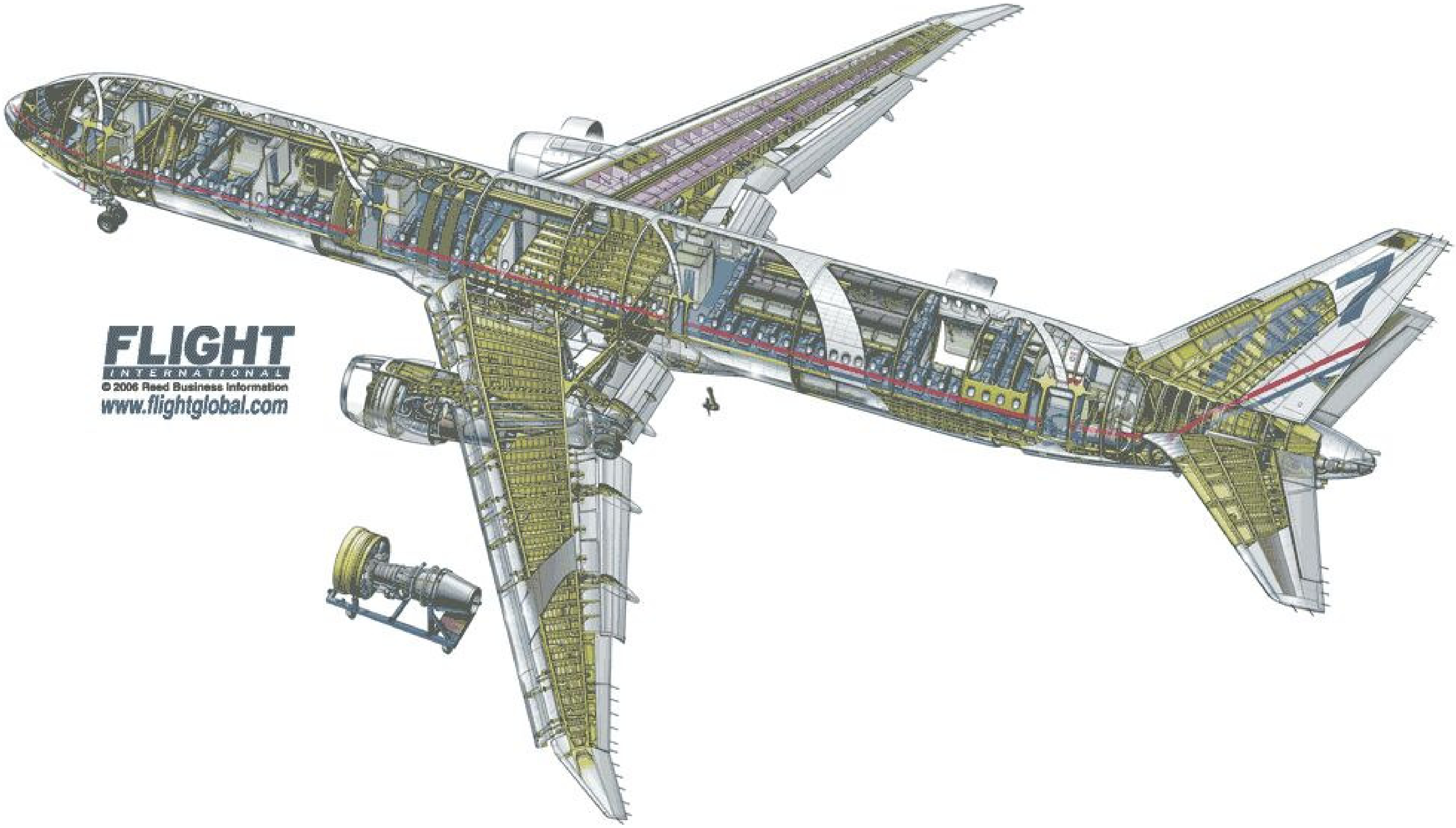
# Jet fuel characteristics

| | | | | | | |
|---|---|---|---|---|---|---|
| Wide-cut gasoline | Jet B | JP-4 | 6.36 lb/gal | -50C to -58 | 18,720 Btu/lb | 119,000 Btu/gal |
| Kerosene | Jet A | JP-8 | 6.76 lb/gal | -40C to -50C | 18,610 Btu/lb | 125,800 Btu/gal |

# Design plot for estimating empty and take-off weight of airplane



# 3. Fuselage Design



# Fuselage design factors

- Optimal aerodynamics, reducing aerodynamic drag

- Suppression of aerodynamic instability

- Comfortable and attractive seat design, placement, and storage space

- Safety features to deal with emergencies such as fires, cabin depressurization, etc.; proper placement of emergency exits, oxygen systems, etc.

- Easy handling for cargo loading and unloading, safe and robust cargo hatches and doors

- Structural support for wing and tail forces acting in flight, as well as for landing and ground operation forces

•Structurally optimized, saving weight while incorporating protection against corrosion and fatigue

•Optimized flight deck, reducing pilot workload and protecting against crew fatigue and intrusion by passengers

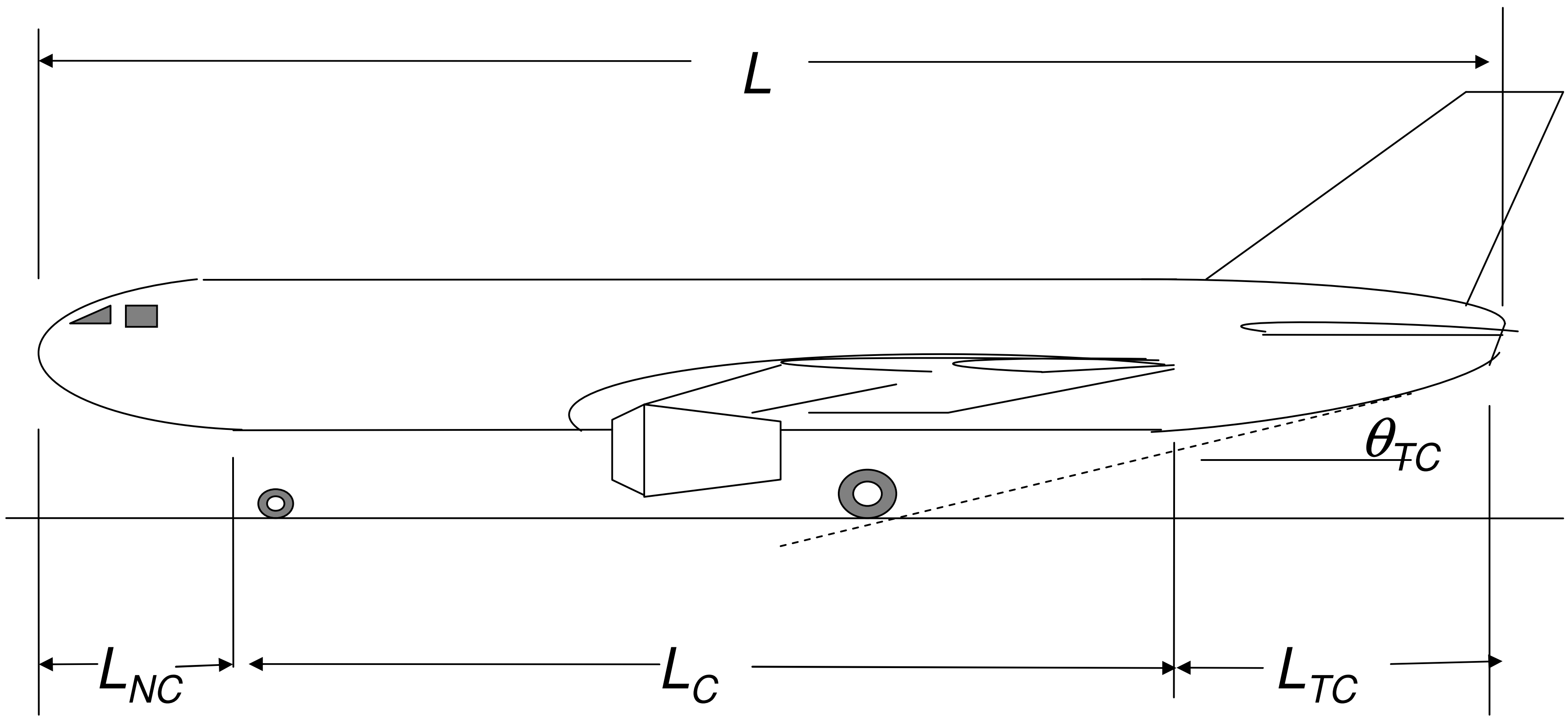
•Convenient size and placement of galleys, lavatories, and coat racks

•Suppressed noise and vibration, providing a comfortable, secure environment

•Control of cabin climate including air conditioning, heating, and ventilation

•Providing housing for different sub-systems, including auxiliary power units, hydraulic system, air conditioning, etc.

# Major components of fuselage



# Circular fuselage cross-section

- A circle has the greatest cross-sectional area per unit perimeter. The drag of a typical fuselage, which has a rather large fineness ratio (*l/d*), is dominated by skin friction

- A circle is strongest under internal pressure. At stratospheric cruising altitudes the outside pressure is 0.2 to 0.3 atmospheres, while the internal pressure is maintained at that at 8,000 feet, or about 0.7 atmospheres. Pressure difference across the thin skin of the cabin ranges from 0.4 to 0.5 atmospheres, or 6 to 7 psi (40 to 50 kPa)

- A circle more easily accommodates growth in Np in terms of manufacturing since cylindrical sections, called plugs, can be reasonably easily added to so-called stretched versions of a given aircraft.

# Circular cross-section limitations

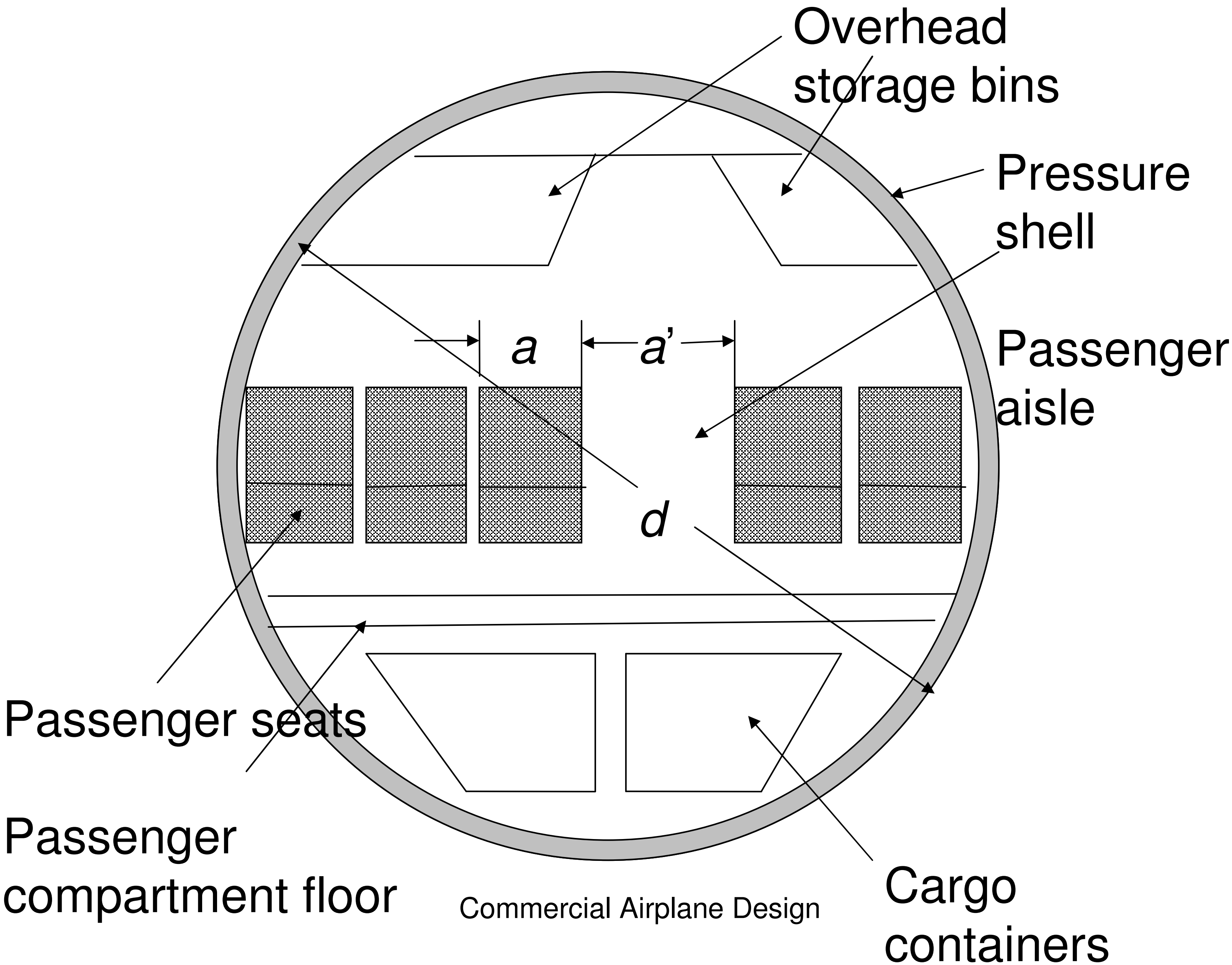
•Limited space outside the passenger compartment for auxiliary systems and cargo. The passenger compartment must be located around a diameter of the circle for the greatest width for seats and aisles.

•Awkward circular sectors above and below the passenger compartment to house other items.

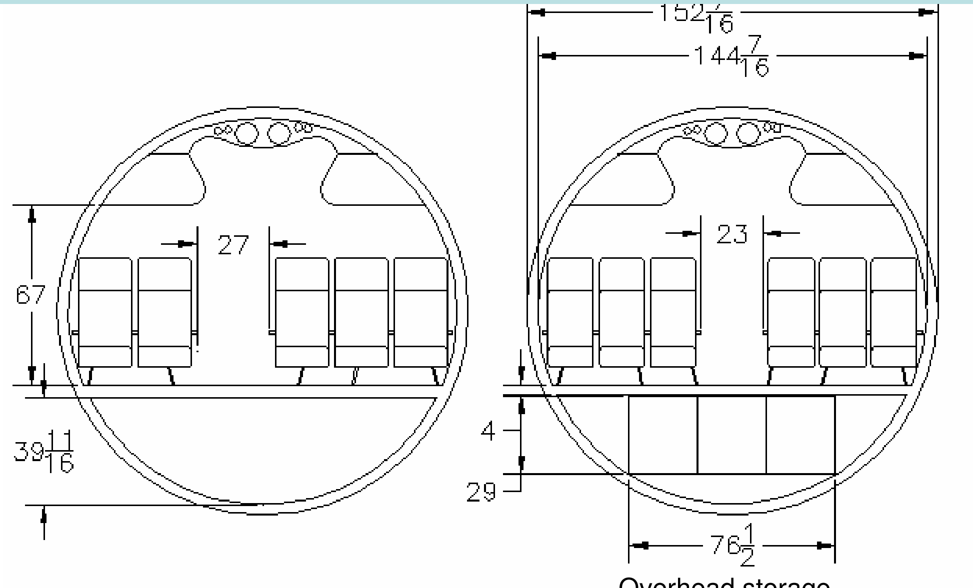
•Modern designs have expanded the lower portion of the circular cabin into a more rectangular cross-section in the vicinity of the wing root chord to accommodate more internal carriage.

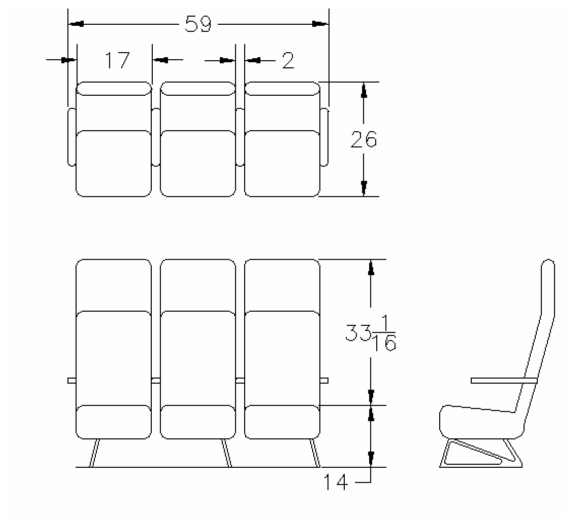
•Cabin forward and aft of the wing root is maintained as a circular cross-section, and stretching will require plugs to be added in these regions.

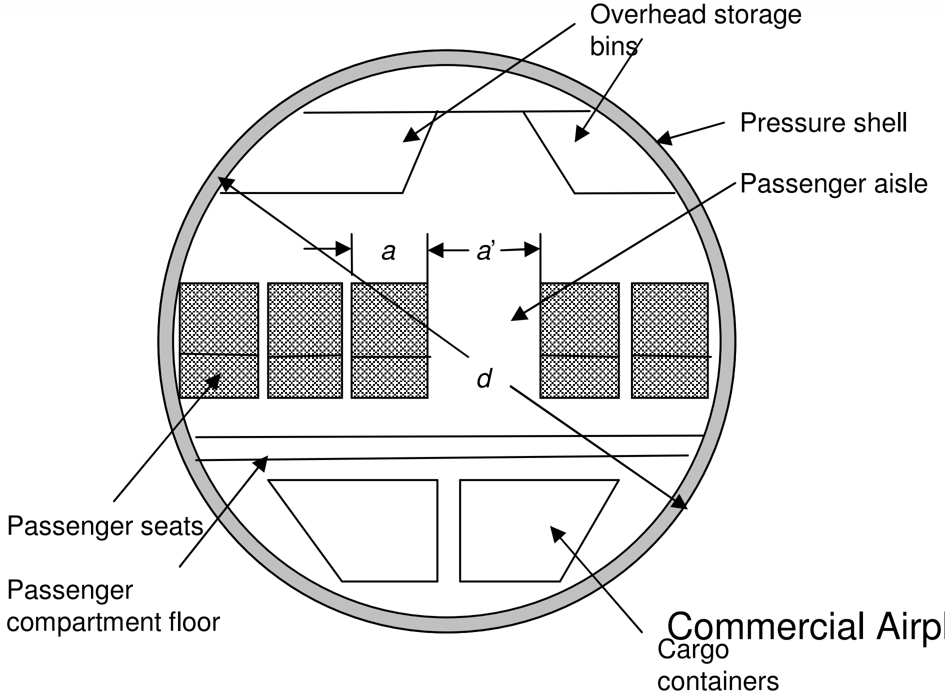
# Layout of the cabin cross-section

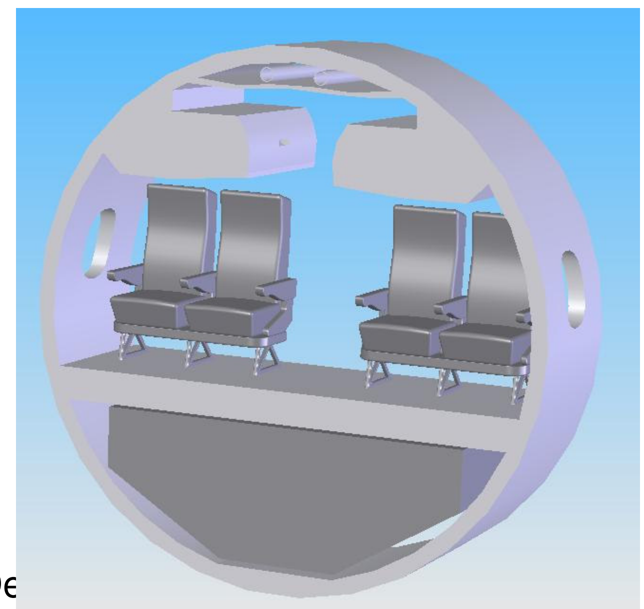


# Cabin cross-section

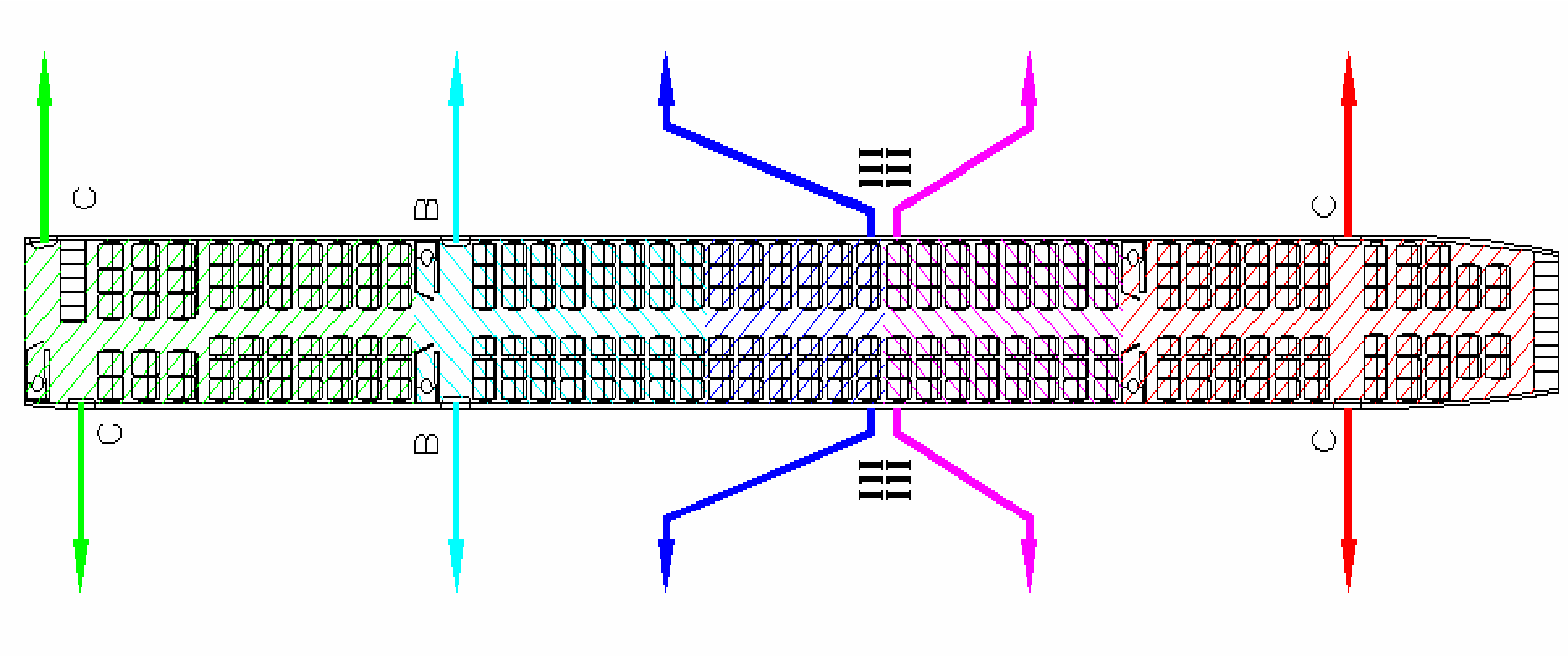


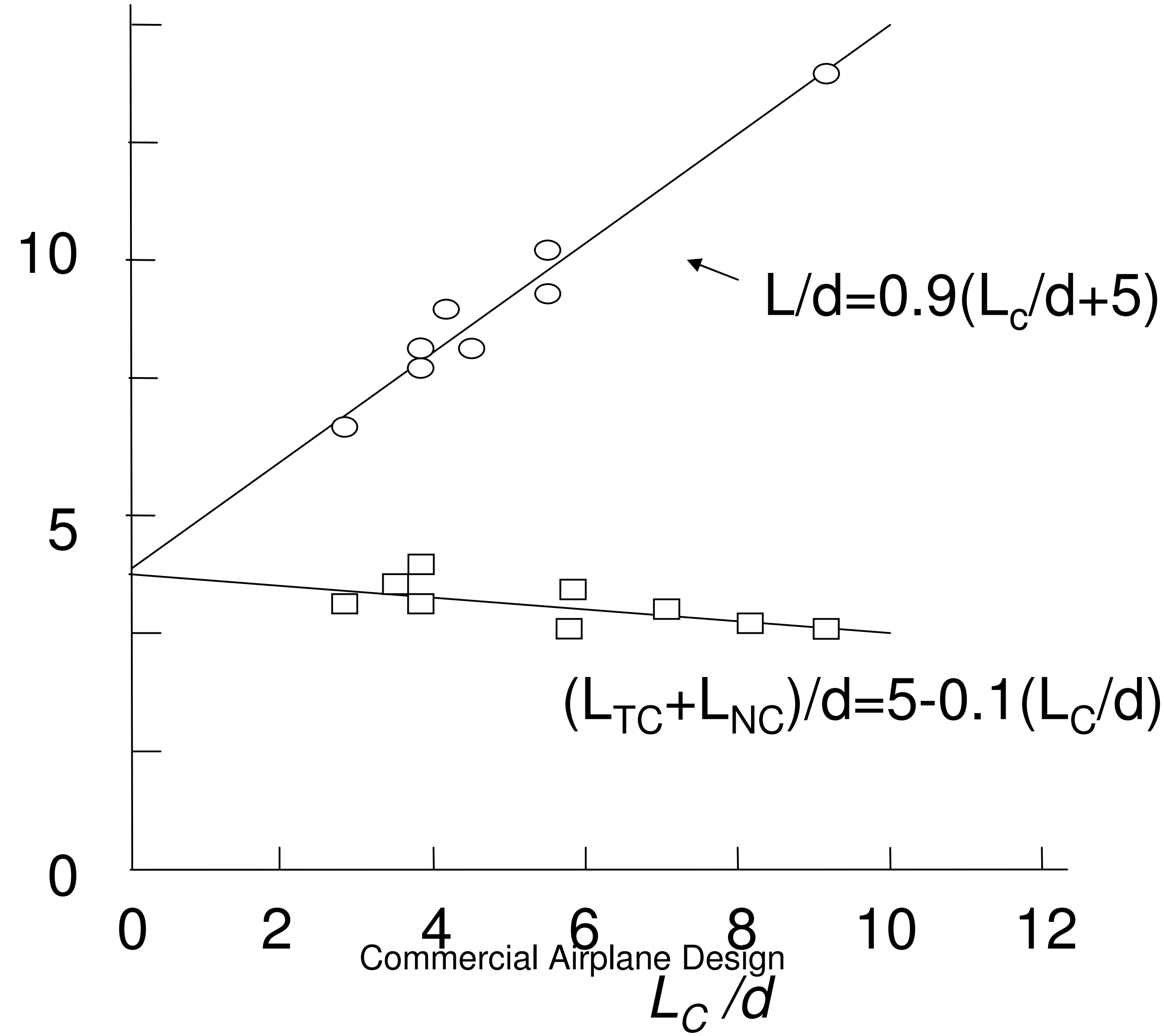



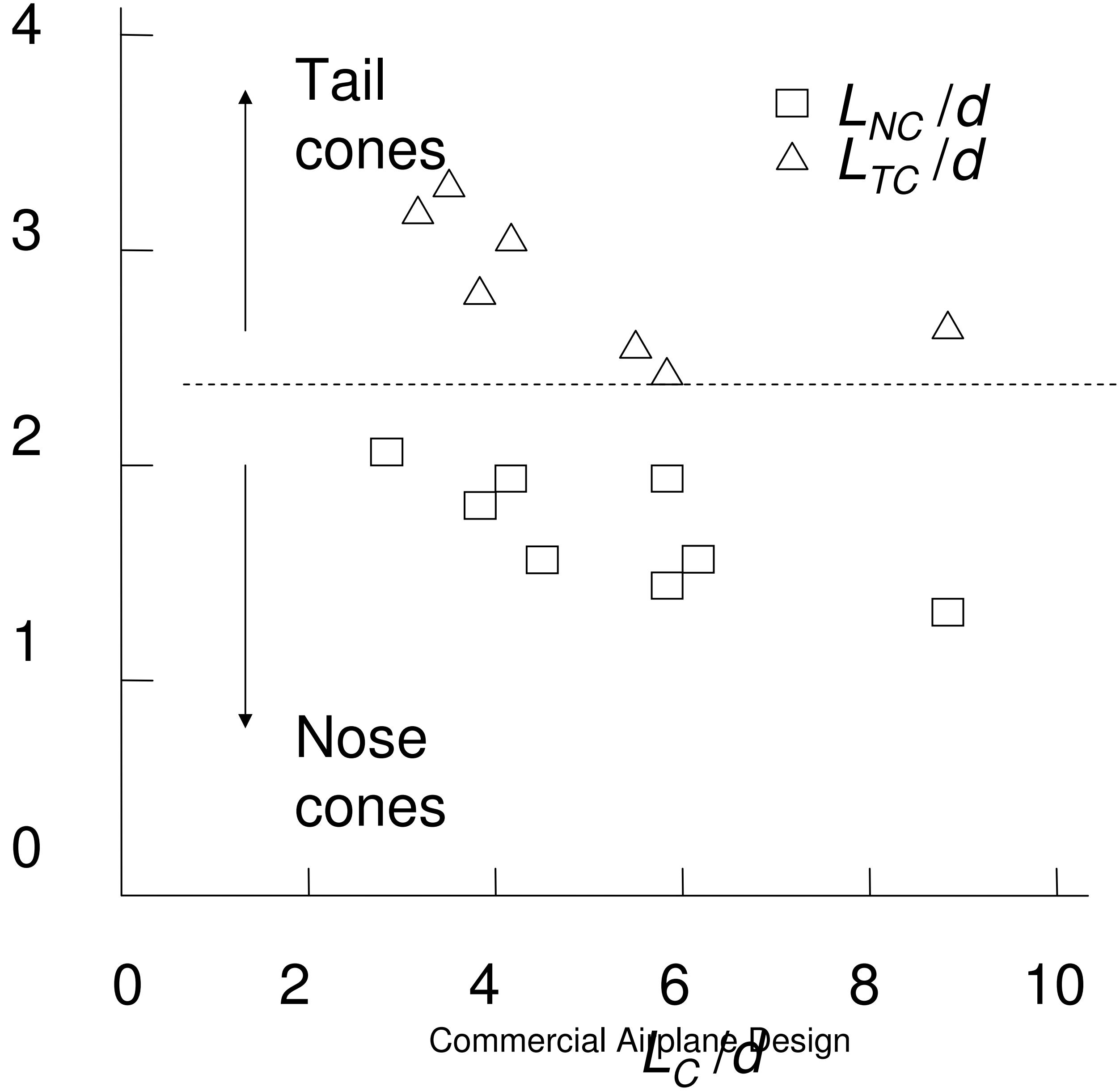
# Cabin floor plan



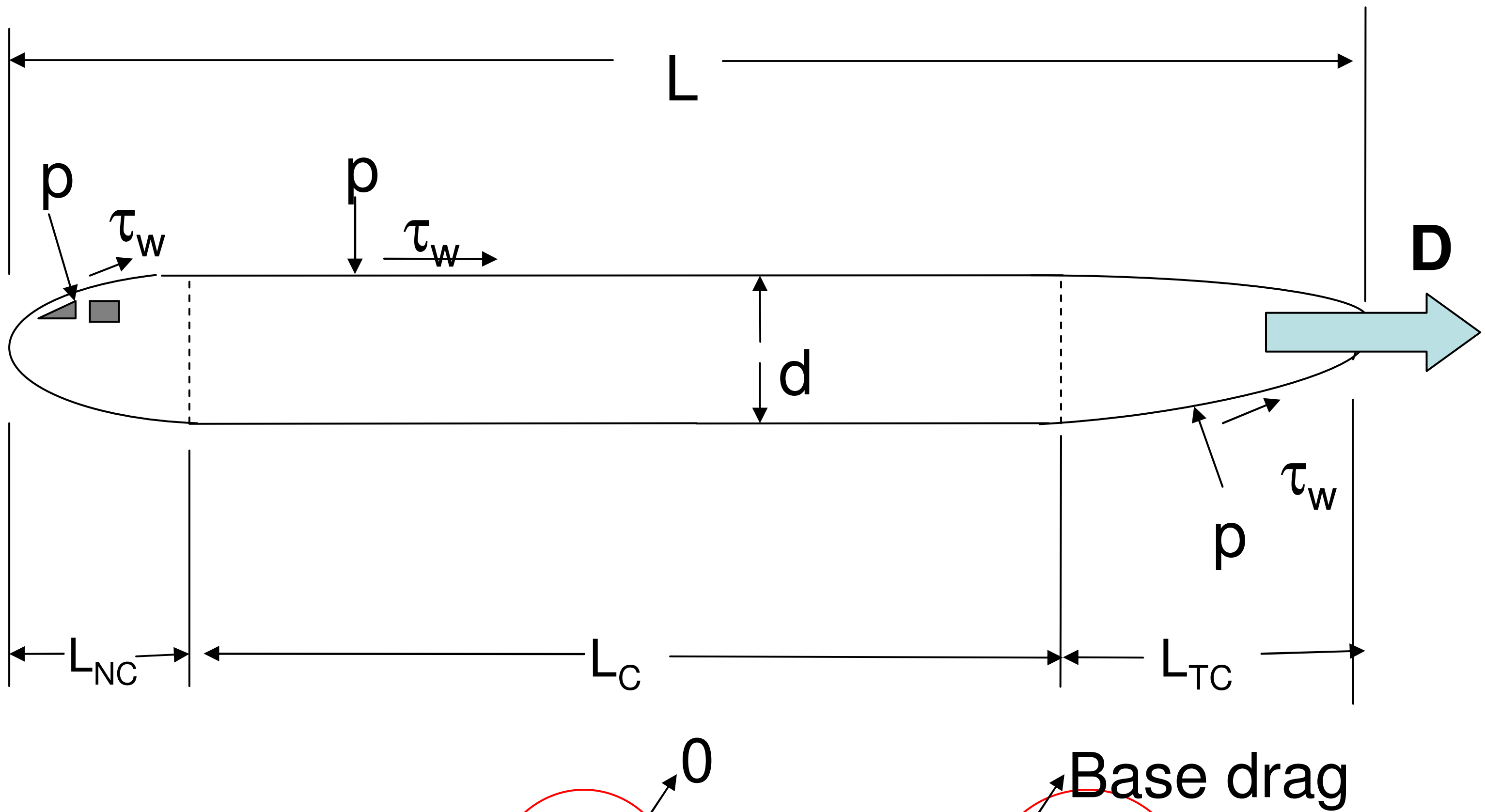
# Correlation of fineness ratio and fuselage dimensions



# Nose and tail cone correlations

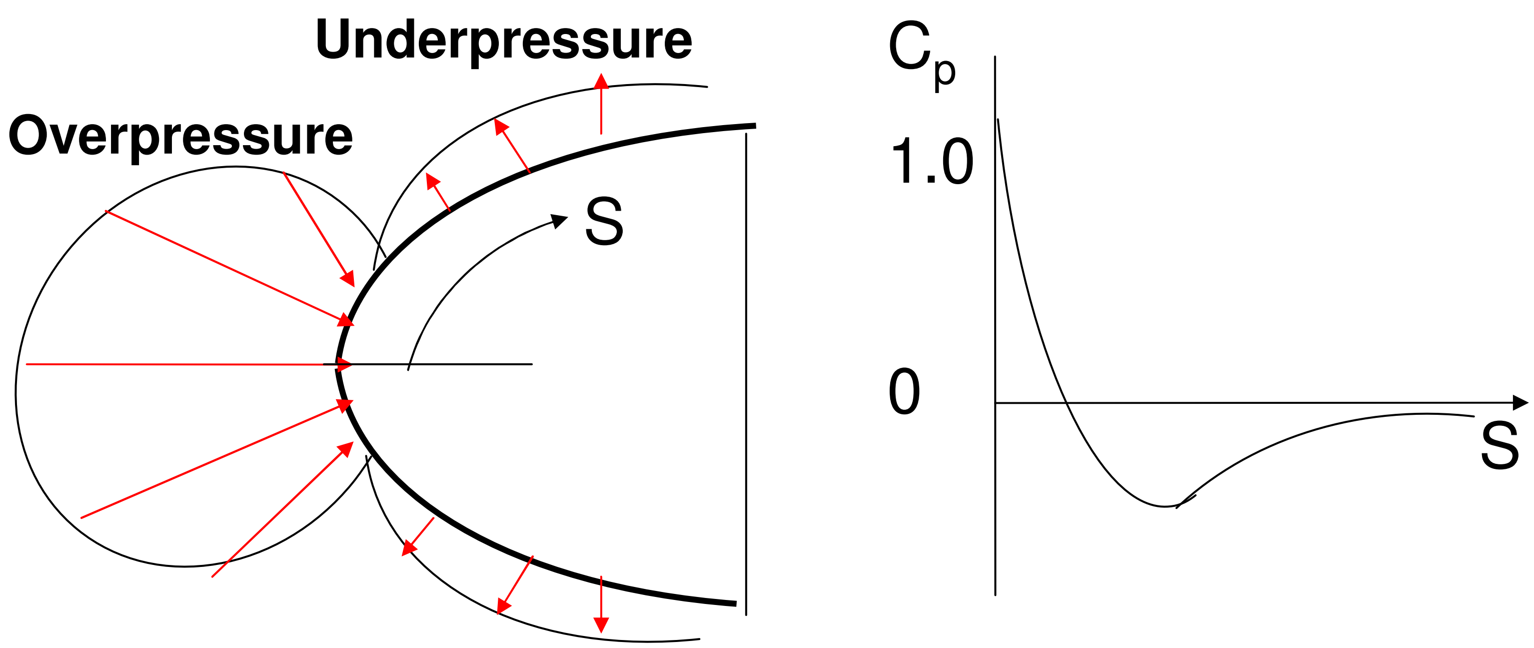


# Fuselage drag breakdown




$$D = D_{p,NC} + D_{f,NC} + D_{p,C} + D_{f,C} + D_{p,TC} + D_{f,TC}$$

# Nose cone pressure drag is approximately zero




The overpressure is just about balanced by the underpressure so that the pressure drag on the nose cone is approximately zero, $D_{p,NC}$~0

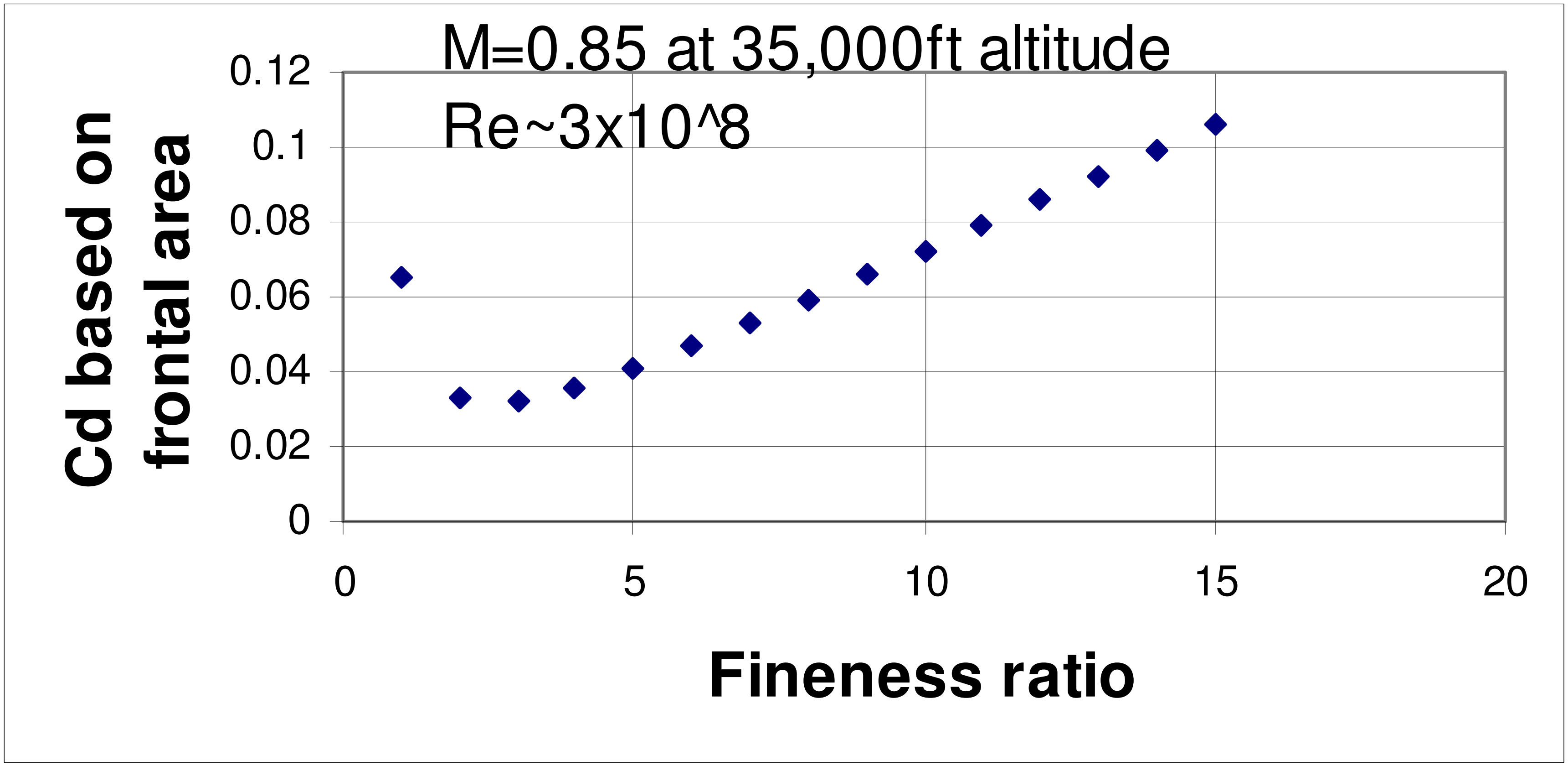
# General equation for fuselage drag

$$D = D_{f,NC} + D_{f,C} + D_{f,TC} + D_{p,BASE}$$

$$c_D = \frac{D}{qS} = c_f\left(\mathrm{Re}, M\right)\frac{S_{wetted}}{S} + \frac{D_{p.BASE}}{qS}$$

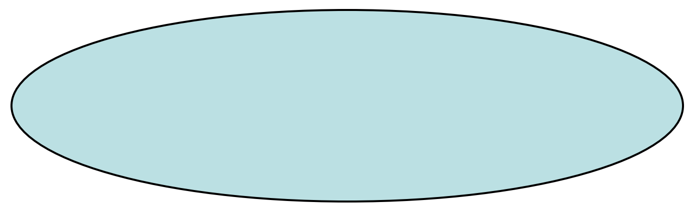
$$c_{D,fuselage} = 4kc_F\left(\mathrm{Re}, M\right)F\left(1 + \frac{1.5}{F^{3/2}} + \frac{7}{F^3}\right)$$

# Variation of fuselage drag with fineness ratio



# Optimal fineness ratio

The minimum drag coefficient occurs for F~3 but this would not be a practical fuselage design for safely and efficiently packing passengers



For compressible flows where M~1 the slimmer fuselages would have reduced wave drag due to compressibility and they have the advantage of efficient use of space