Commercial Aircraft Design Characteristics
- Trends and Growth Projections

International Industry Working Group
Fifth Edition R1, 2007

COMMERCIAL AIRCRAFT DESIGN CHARACTERISTICS
- TRENDS AND GROWTH PROJECTIONS

NOTICE OF REVISION

The original document was released in March 1969 and the first revision issued in March 1970. It was again revised in Oct. 1973 at the time of the fuel embargo. A caution was noted that the impact on these trends could not be assessed at that time.

The revision issued in Jan. 1979 reflected the direction in design toward improved fuel efficiency. This trend is expected to continue in the future as noted in areas of wingspan, increased application of advanced technology in materials, high lift devises, and increased aerodynamic efficiency.

The January 1990 and November 2003 revisions show continuing trend towards improved fuel efficiency, reduced noise and emissions. The development of larger aircraft continues through derivative stretch models and an all-new double-deck aircraft as the traffic demand continues to rise.

The current revision, Fifth edition, was further revised (R1) to include new models that reached a design freeze between 2003 and 2006 and include a new page, Figure 11, Landing Gear Track vs. Fuselage Width.

This document can be accessed via http://www.boeing.com/airports , http://www.airbusworld.com , and http://www1.iata.org/Whip/Public/frmMain_Public.aspx?WgId=35

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INTRODUCTION

This document is intended to provide information on the trends in conventional takeoff and landing (CTOL) aircraft design characteristics that may influence general long-term airport planning and design. Aircraft size, weight, and other characteristics reflect the potential trends through the year 2010

Aircraft operational data, design features, and characteristics vary among manufacturers. Therefore, information regarding specific aircraft should be requested from the manufacturer. The timing for new aircraft types is based primarily on technological capabilities, airport/airway constraints, and forecasts of traffic potential.

Actual timing of new aircraft introduction is critically dependent upon further economic analysis and decision by airlines. As part of any airport improvement program, specific facility requirements will depend on the serving airline's plan which will dictate the specific aircraft type, aircraft mix, and the level of traffic.

Design innovations and new concepts will be developed as the cargo / passenger market continues to mature and grow. Therefore, the data are subject to change and will be revised as required.

This document reflects the coordinated efforts of the manufacturers with inputs from IIWG members. The international Industry Working Group (IIWG) is an industry organization sponsored by airframe and engine manufacturers (ICCAIA), International Air Transport Association (IATA), and Airports Council International (ACI) to discuss, promote, and resolve aircraft/airport compatibility issues of mutual interest.

TYPICAL FORECASTS

Figure 1A shows typical forecasts of revenue passenger kilometers/miles (RPK/RPM). Following a year of decline in 2001 and two successive years of stagnation, world airline passenger traffic is forecast to grow at an annual rate of around four percent.

Even with the decline in cargo being shipped in 2001, the typical cargo forecast (Figure 1B) indicates ICAO world revenue cargo tone miles / tonne kilometers increasing by about 50% between 2003 and 2010. This projection indicates that the freight tone miles of cargo will grow more rapidly than the RPM's through 2010.

The forecast was made early in 2002, taking into account the effect of 9/11 events.

TYPICAL FORECASTS

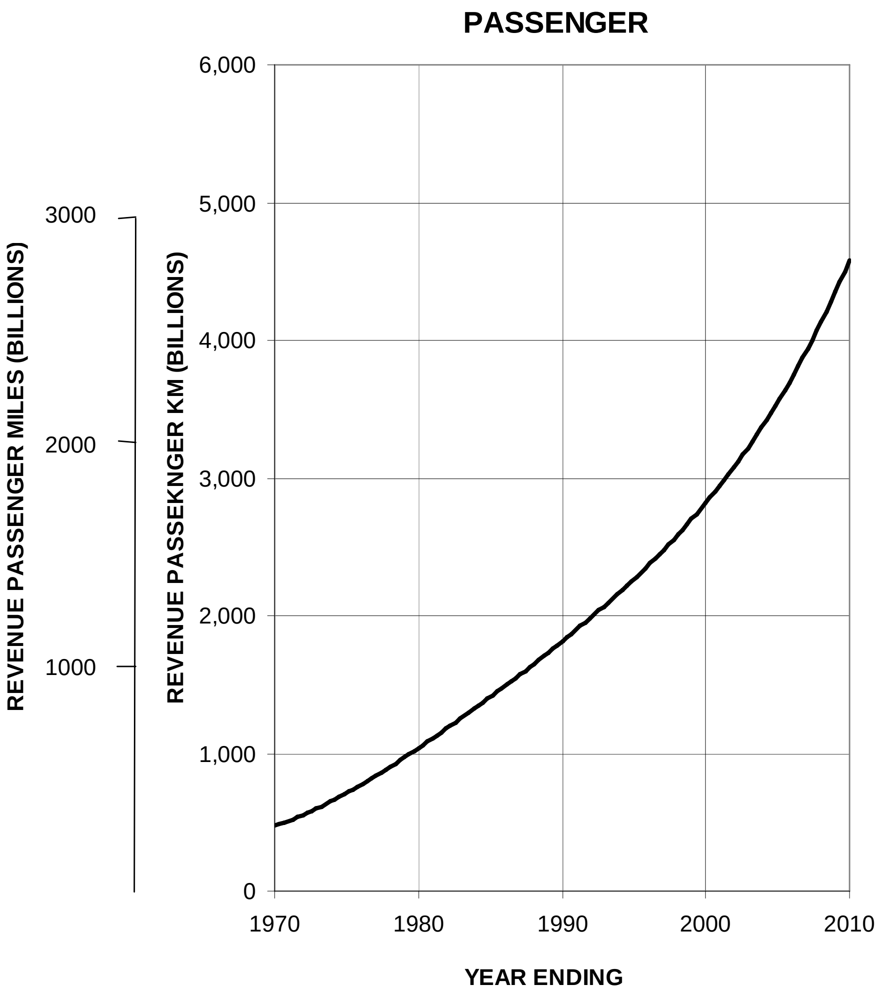


FIGURE 1A

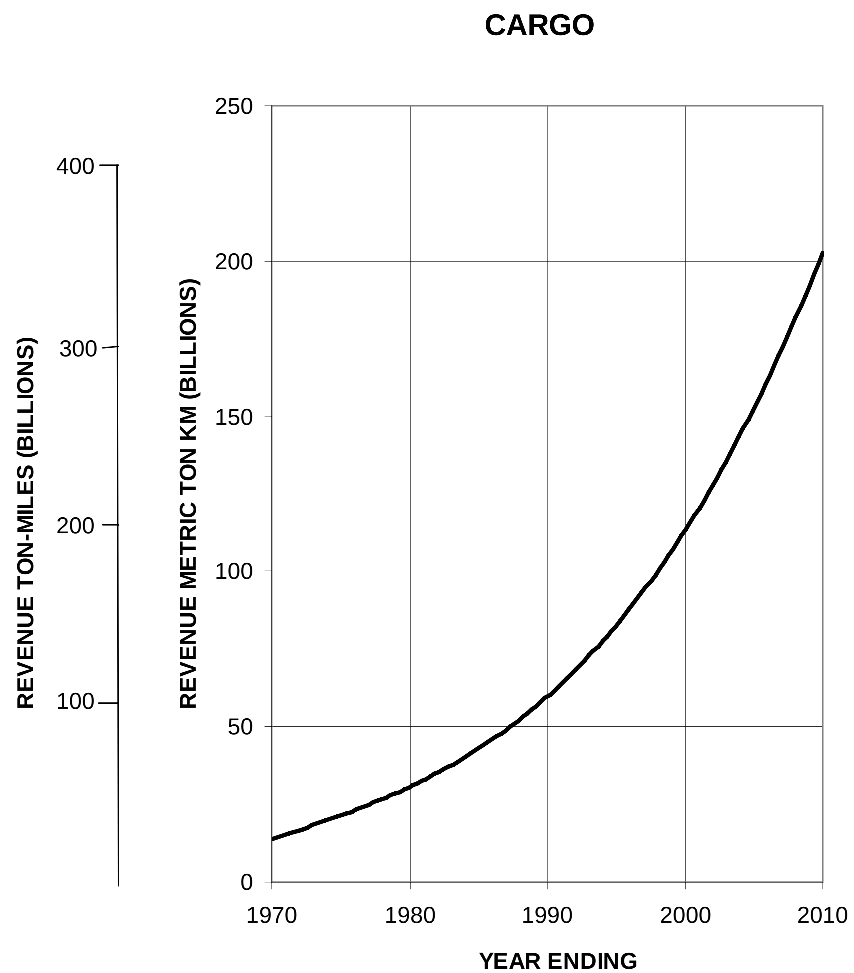


FIGURE 1B

PASSENGER AIRCRAFT CAPACITY GROWTH TREND

Figure 2 illustrates the continuing growth in passenger aircraft payload capability. The capacities in mixed class layouts reached 400+ seats in the early 70's with Boeing 747 series, and will reach 550+ seats in 2008 with Airbus A380. The A380 aircraft, in an all-economy high density arrangement, could exceed 800 seats for dedicated markets.

There are strong indications that future trends could see the coexistence of very high capacity aircraft and modules of smaller capacities for the long range/very long range operations, corresponding to hub and spoke or point to point demands from the market.

Note: All capacities shown in reference seating layout for 1, 2 or 3 class arrangement depending on aircraft typical range operations.

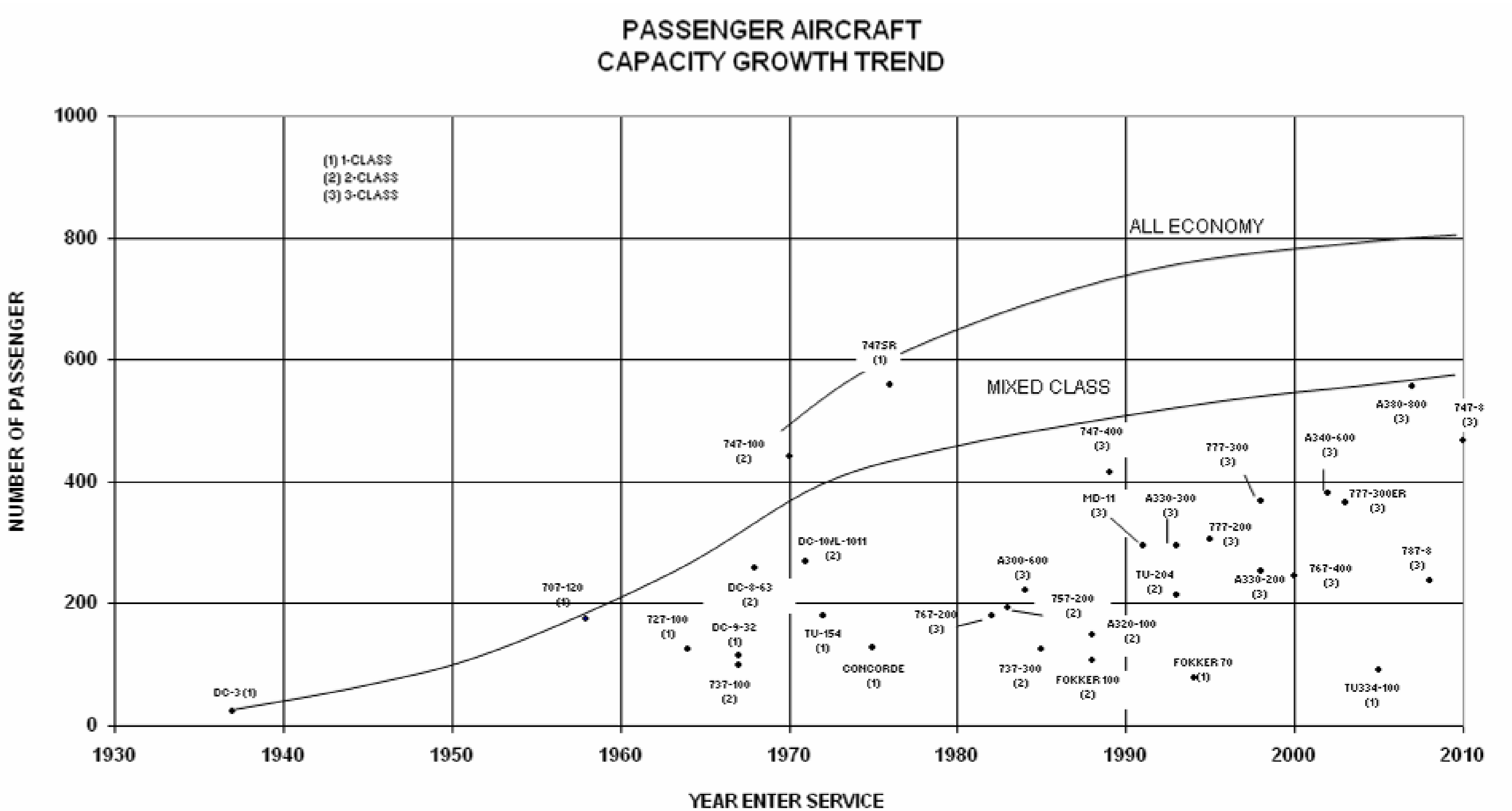

PASSENGER AIRCRAFT
CAPACITY GROWTH TREND
NUMBER OF PASSENGER
YEAR ENTER SERVICE
0
200
400
600
800
1000
1930
1940
1950
1960
1970
1980
1990
2000
2010
(1) 1-CLASS
(2) 2-CLASS
(3) 3-CLASS
ALL ECONOMY
MIXED CLASS
DC-3 (1)
707-120 (1)
727-100 (1)
DC-9-32 (1)
737-100 (2)
DC-8-63 (2)
747-100 (2)
747SR (1)
DC-10/L-1011 (2)
TU-154 (1)
CONCORDE (1)
767-200 (3)
A300-600 (3)
757-200 (2)
737-300 (2)
FOKKER 100 (2)
A320-100 (2)
747-400 (3)
MD-11 (3)
A330-300 (3)
TU-204 (2)
FOKKER 70 (1)
777-300 (3)
777-200 (3)
A330-200 (3)
A340-600 (3)
777-300ER (3)
767-400 (3)
A380-800 (3)
747-8 (3)
787-8 (3)
TU334-100 (1)

FIGURE 2

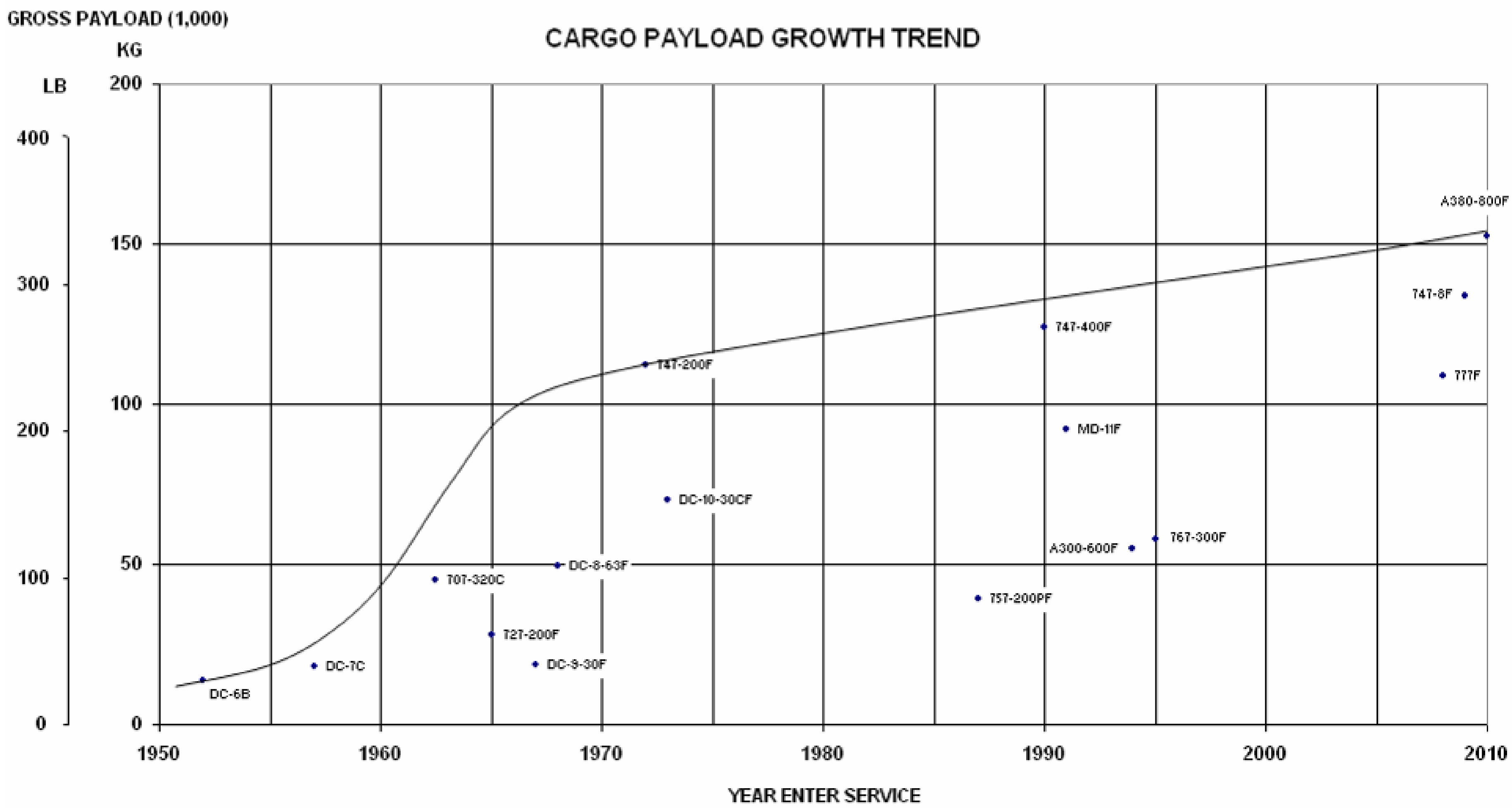
CARGO PAYLOAD GROWTH TREND

Cargo payloads, which include mail, express and freight, are increasing in size and weight as larger aircraft enter service with the airlines. Figure 3 illustrates this growth trend.

In the past, most cargo was carried in aircraft that were designed primarily for passengers. The sharply increasing quantity of air cargo has driven the design of freighter versions like Boeing 747-400F or Airbus A380-800F (as opposed to convertible freighter aircraft). These freighter versions better match the specific needs of cargo transportation. The Airbus A380 Freighter, to enter into service in 2010, will offer a payload capacity exceeding 150t (Figure 3). (Note: the Antonov 225, a derivative of the cargo aircraft Antonov 124, has an extreme cargo capacity of 250t. However, only a single unit has been built so far and is hence not represented on the trend line.

Should the cargo transportation demand maintain its sharp rate of increase, dedicated very high payload freighter aircraft may be necessary. Manufacturers have envisaged specific configurations, such as blended wing bodies or flying wings, to fulfill such requirements.

To ensure continued growth in payload and the profitability of cargo operations, improvements in methods, equipment, and terminal facilities will be required in order to reduce cargo handling costs and aircraft ground time and to provide improved service for the shippers.



GROSS PAYLOAD (1,000)
KG
LB
CARGO PAYLOAD GROWTH TREND
200
150
100
50
0
400
300
200
100
0
1950
1960
1970
1980
1990
2000
2010
YEAR ENTER SERVICE
DC-6B
DC-7C
707-320C
727-200F
DC-9-30F
DC-8-63F
747-200F
DC-10-30CF
757-200PF
747-400F
MD-11F
A300-600F
767-300F
A380-800F
747-8F
777F

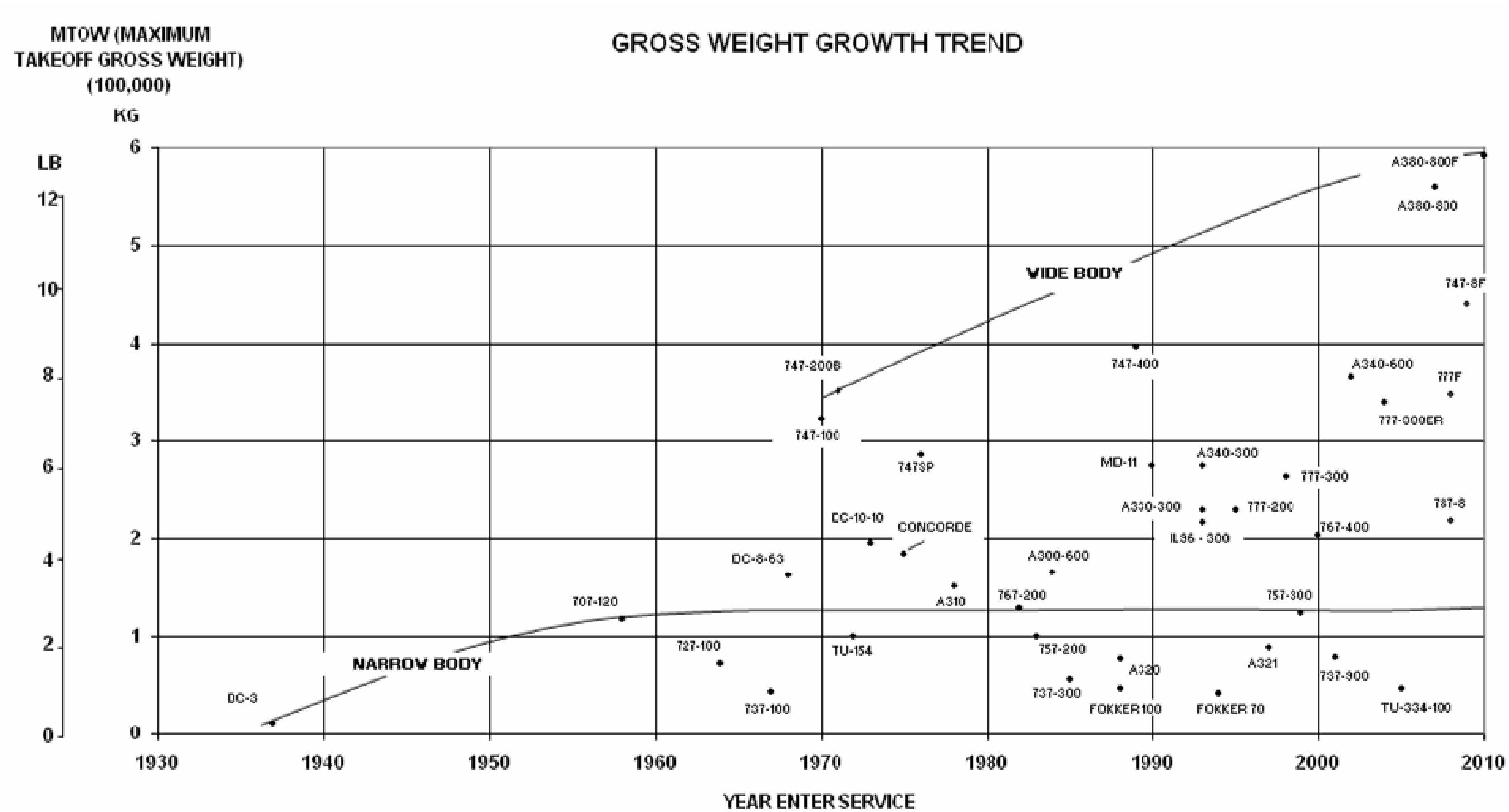
FIGURE 3

GROSS WEIGHT CAPACITY GROWTH TREND

Figure 4 indicates a continuing increase in transport airplane size and weight. Passenger airplanes with gross weights of 560t will be operational in 2008, and freighters with 590t in 2010. Since this weight is within the capability of present technology, size limitations will be influenced primarily by specific transportation requirements, operational economics, and airport/airways constraints.

These projections should be considered when planning future runway and taxiway bridges and pavement bases that must accommodate the movement and parking of high gross weight aircraft. In addition to the effects on the pavement structure itself, other facilities below the pavement level, such as road tunnels, service ducts, and drainage pipes should be considered.

This chart shows a grouping of aircraft in two categories, narrow-bodies and wide-bodies, and reflects the upper level expectations in those categories. The gross weight in narrow body category shows a leveling trend with no foreseen projects above 120t MTOW, due to the limited ranges and capacity of such aircraft. In the wide-body category, very high capacity aircraft such as Airbus A380 have significantly increased the gross weight limit. Naturally, a lot of models with intermediate gross weight will continue to enter into service into these two categories.



GROSS WEIGHT GROWTH TREND
MTOW (MAXIMUM TAKEOFF GROSS WEIGHT) (100,000)
KG
LB
YEAR ENTER SERVICE
WIDE BODY
NARROW BODY
DC-3
707-120
727-100
737-100
DC-8-63
747-200B
747-100
747SP
DC-10-10
CONCORDE
TU-154
A310
767-200
757-200
737-300
A300-600
747-400
MD-11
A320
FOKKER 100
FOKKER 70
A340-300
A330-300
IL96 - 300
777-200
777-300
A321
757-300
767-400
737-900
TU-334-100
A340-600
777-300ER
777F
787-8
747-8F
A380-800
A380-800F

FIGURE 4

WINGSPAN GROWTH TREND

Prior to the mid 1970s, 35-degree sweep and aspect ratios* of approximately 7 offered the best overall characteristics for subsonic jet transports. This meant that as the weight of the aircraft increased, the wingspan also grew because the wing area increased proportionally with the weight.

Since the energy crisis in 1973 there have been concerted efforts to conserve fuel due to its rising cost. Wing design characteristics have since changed to become more fuel efficient. The wing aspect ratio is being increased on some existing aircraft, which increases the wingspan by 6 to 7 percent. New wing design technologies combined with higher performance engines will permit significant reduction in fuel consumption. These new design trends will have a significant impact on the future design of the terminal and airfield geometry.

The need for very high capacity aircraft had raised the debate about adequate dimensions for a new aircraft and airport category. In consultation with industry organizations, ICAO established the Code F airport category with 80 m as the reasonable upper limit of the wingspan (Figure 5).

Note: the Antonov 225, a giant cargo aircraft, has an 88.4 m wingspan, well above code F limit. However, only a single unit has been built so far and is hence not represented on the trend line.

These new design trends will have a significant impact on the future design of the terminal area and airfield geometry.

*Aspect ratio = span^2 / wing area

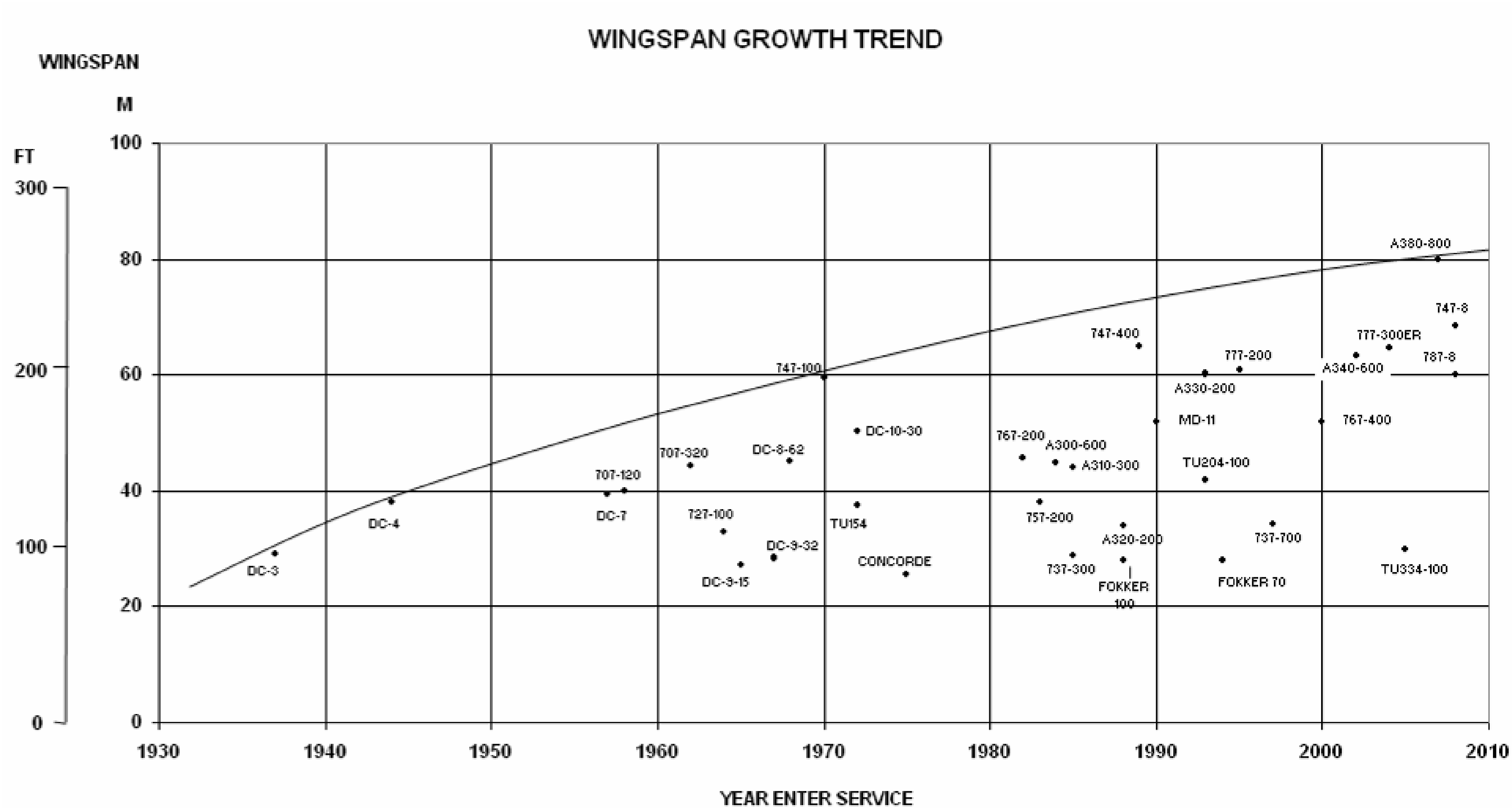
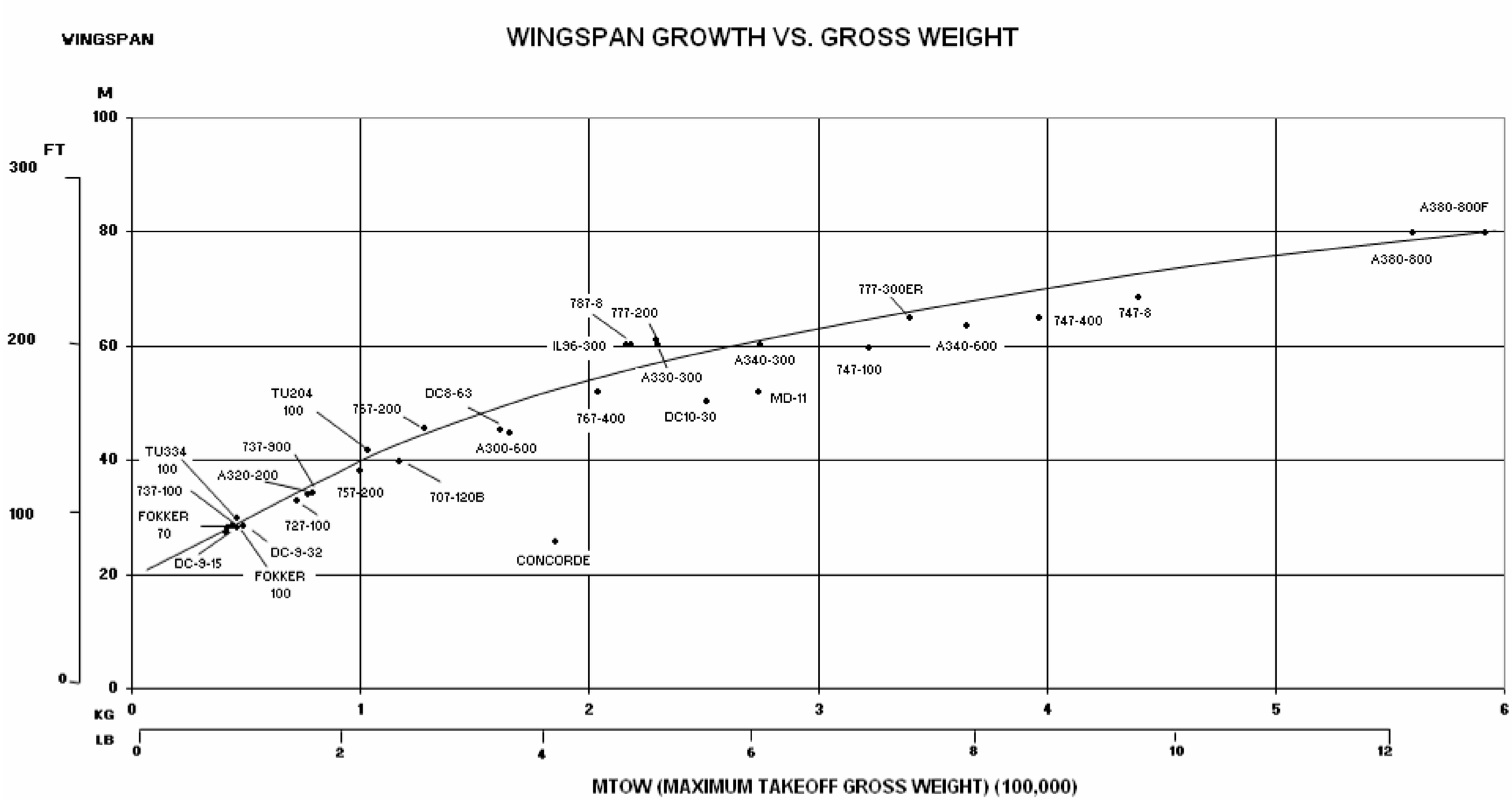

WINGSPAN GROWTH TREND
WINGSPAN
M
FT
300
200
100
0
100
80
60
40
20
0
1930
1940
1950
1960
1970
1980
1990
2000
2010
YEAR ENTER SERVICE
DC-3
DC-4
DC-7
707-120
707-320
727-100
DC-9-15
DC-9-32
DC-8-62
747-100
DC-10-30
TU154
CONCORDE
767-200
A300-600
A310-300
757-200
737-300
A320-200
FOKKER
100
747-400
MD-11
A330-200
777-200
TU204-100
FOKKER 70
737-700
A340-600
767-400
777-300ER
747-8
787-8
A380-800
TU334-100

FIGURE 5

WINGSPAN GROWTH VERSUS GROSS WEIGHT

Figure 6 shows how wingspan has grown with increased airplane gross weight in a statistically well-correlated relation. While the gross weight increased 26-fold from the DC-3 to the early 747, the wingspan only doubled. These moderate increases in span were made possible by improvements to aerodynamics and materials technologies, allowing newer airplanes to take advantage of improved wing loading and hence reduce wing area / wing span for a given weight.



VINGSPAN
WINGSPAN GROWTH VS. GROSS WEIGHT
M
FT
KG
LB
MTOW (MAXIMUM TAKEOFF GROSS WEIGHT) (100,000)
A380-800F
A380-800
777-300ER
747-8
747-400
A340-600
747-100
A340-300
MD-11
787-8
777-200
IL96-300
A330-300
767-400
DC10-30
DC8-63
A300-600
767-200
TU204
100
707-120B
757-200
737-900
A320-200
727-100
TU334
100
737-100
FOKKER
70
DC-9-15
DC-9-32
FOKKER
100
CONCORDE

FIGURE 6

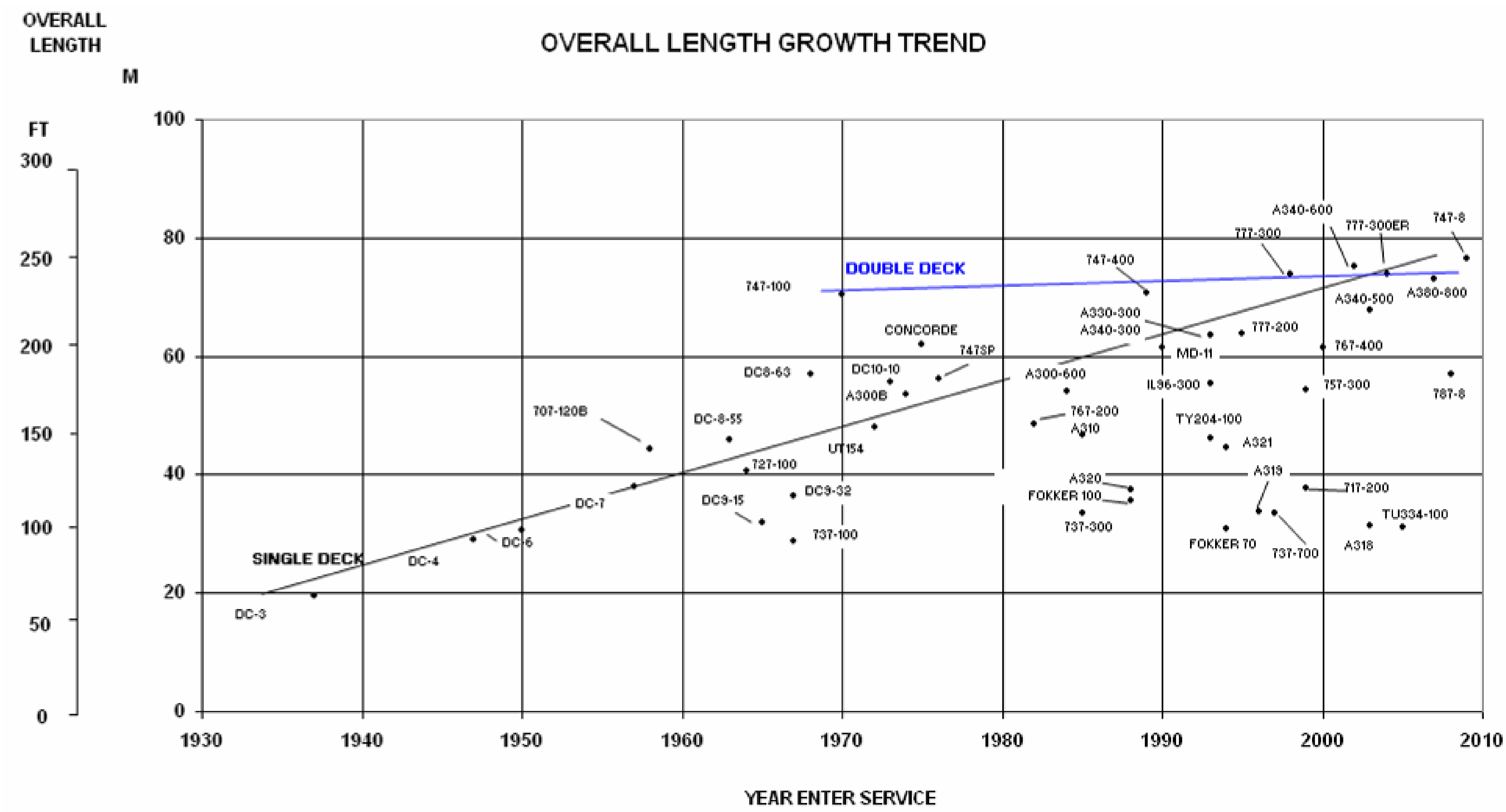
OVERALL LENGTH TREND

Figure 7 indicates overall length growth trends during the past 60-plus years.

There has been a steady increase in aircraft length to match required passenger capacities. Boeing 777-300 or Airbus A340-600 exhibit an overall length of about 75 m for capacities of slightly less than 400 passengers (mixed class). To accommodate these higher capacities without increasing the aircraft length, manufacturers have developed multiple deck configurations, like Boeing 747 ("1.5 deck") or Airbus A380 (full double deck). The latter has a capacity 40% more than B777 or A340-600, with similar overall length.

As with wingspan, the demand for very high capacity aircraft had raised debate about the overall lengths targeted to fit in existing or planned airport infrastructures. An 80 m dimension was set up as a preferred target for a new large aircraft. However, industry studies have shown that a length of more than 80 m can be accommodated but infrastructure cost will rise sharply above 85 m.

Note: the Antonov 225, a giant cargo aircraft, has an 84 m overall length. However, only a single unit has been built so far and is hence not represented on the trend line.



OVERALL LENGTH
OVERALL LENGTH GROWTH TREND
M
FT
DOUBLE DECK
SINGLE DECK
YEAR ENTER SERVICE

FIGURE 7

OVERALL LENGTH GROWTH VERSUS GROSS WEIGHT

As aircraft gross weight increases to accommodate more payload or achieve longer ranges, the increase in overall length for a given fuselage cross-section is limited by structural design and takeoff rotations requirements. Within these limits, subsonic aircraft must grow by widening the body or by multi-deck design. The introduction of multi-deck passenger aircraft could affect terminal design and passenger handling. Close coordination between airline operations, aircraft manufacturers and airport passengers, like those launched for a New Large Aircraft such as the A380, is necessary to ensure that future terminals can handle both single and multi-deck aircraft (Figure 8)

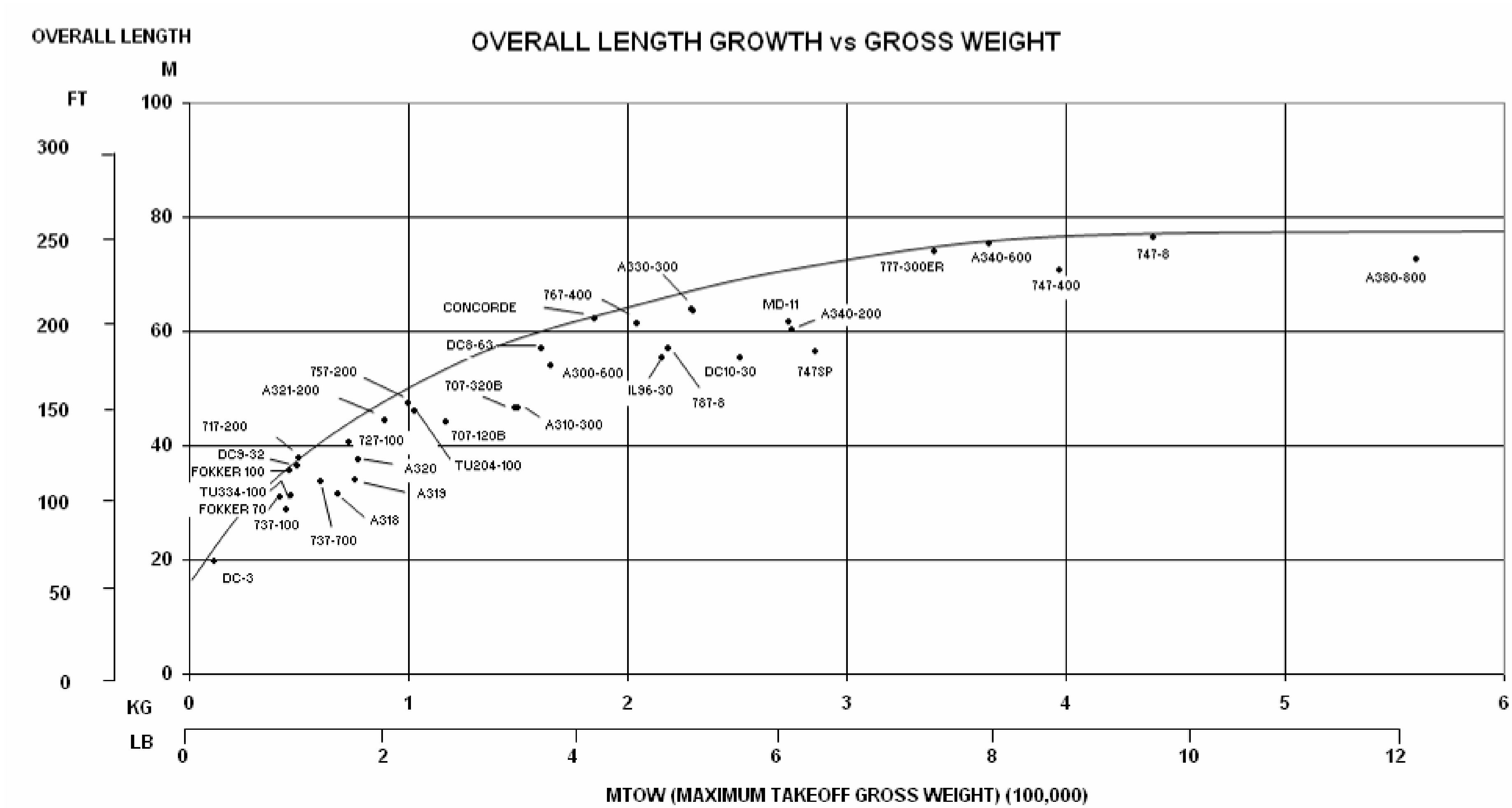
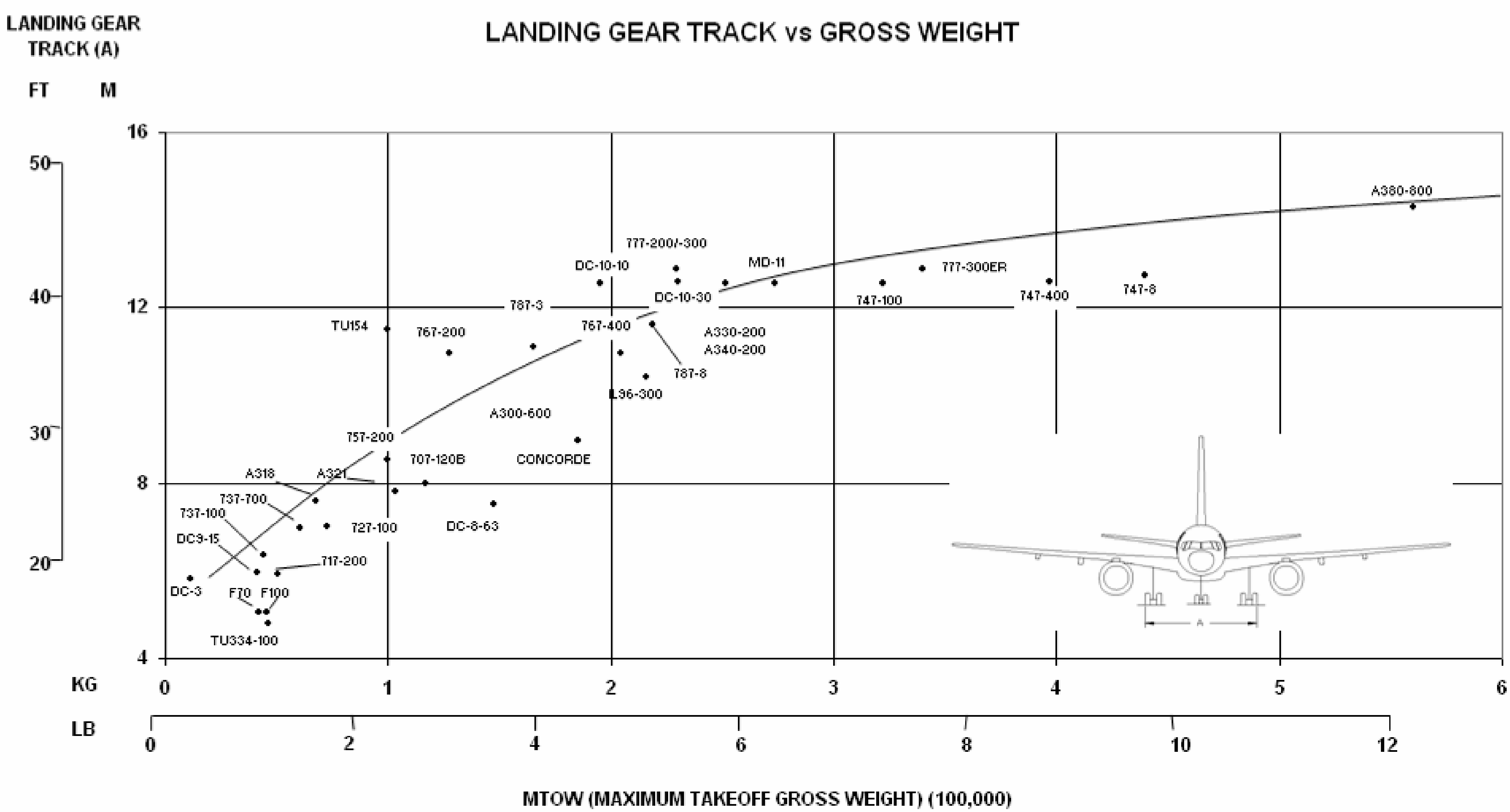

OVERALL LENGTH GROWTH vs GROSS WEIGHT
OVERALL LENGTH
M
FT
100
80
60
40
20
0
300
250
200
150
100
50
0
KG
LB
0
1
2
3
4
5
6
0
2
4
6
8
10
12
MTOW (MAXIMUM TAKEOFF GROSS WEIGHT) (100,000)
DC-3
737-100
FOKKER 70
TU334-100
FOKKER 100
DC9-32
717-200
A321-200
757-200
727-100
A320
A319
A318
737-700
TU204-100
707-120B
707-320B
A310-300
DC8-63
A300-600
CONCORDE
767-400
A330-300
IL96-30
787-8
DC10-30
MD-11
A340-200
747SP
777-300ER
A340-600
747-400
747-8
A380-800

FIGURE 8

LANDING GEAR TRACK VERSUS GROSS WEIGHT

Landing gear track, measured to the outside edge of the outer main landing gear tires (A), increased with the continuing growth in aircraft gross weight as shown on Figure 9. This increase in track may also be correlated to the heavier aircraft requirement for larger wing areas, normally requiring a resultant increase in wingspan. This increase in gear tread will affect runway and taxiway width and fillet radii requirements.

For larger airplanes such as the 747 and A380, a relatively narrow track width can be achieved with a multi-post main landing gear arrangement while maintaining the required performance capability.



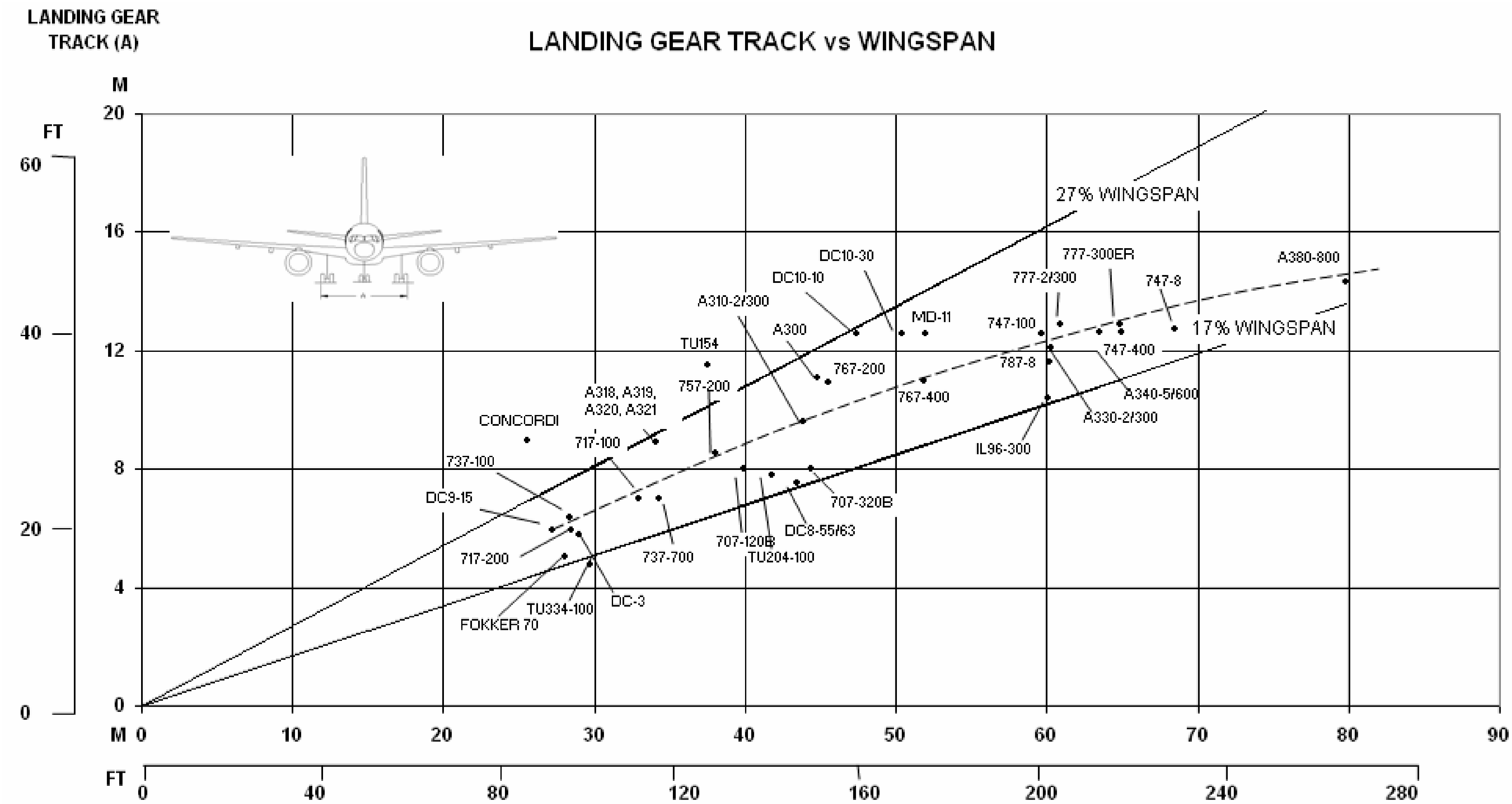
LANDING GEAR TRACK vs GROSS WEIGHT
LANDING GEAR TRACK (A)
FT
M
16
12
8
4
50
40
30
20
A380-800
777-200/-300
DC-10-10
MD-11
777-300ER
DC-10-30
747-100
747-400
747-8
787-3
TU154
767-200
767-400
A330-200
A340-200
787-8
L96-300
A300-600
757-200
CONCORDE
707-120B
A318
A321
737-700
737-100
727-100
DC-8-63
DC9-15
717-200
DC-3
F70
F100
TU334-100
A
KG
0
1
2
3
4
5
6
LB
0
2
4
6
8
10
12
MTOW (MAXIMUM TAKEOFF GROSS WEIGHT) (100,000)

FIGURE 9

LANDING GEAR TRACK VERSUS WINGSPAN

Determination of runway and taxiway widths, and of runway-taxiway and taxiway-taxiway separations are established, in part, by the aircraft landing gear arrangement and wingspan. Figure 10 shows that the outside-to-outside spread of the main landing (A) gear varies between 15 percent and 27 percent of the wingspan.

The dashed trendline indicates that the track width, while increasing over time, is beginning to level off, particularly for multi-post main gear aircraft. The reason for this is that aircraft with four or more main landing gears can achieve a required takeoff rotation angle while maintaining a reasonable lower service door height for GSE (ground service equipment) compatibility. The lower fuselage height will have shorter landing gears and therefore narrower track.



LANDING GEAR TRACK (A)
LANDING GEAR TRACK vs WINGSPAN
M
FT
20
60
16
40
12
8
20
4
0
0
27% WINGSPAN
17% WINGSPAN
A380-800
777-300ER
777-2/300
747-8
747-100
747-400
787-8
A340-5/600
A330-2/300
IL96-300
DC10-30
DC10-10
MD-11
767-400
A310-2/300
A300
767-200
TU154
757-200
A318, A319, A320, A321
CONCORDI
717-100
737-100
DC9-15
717-200
737-700
707-320B
DC8-55/63
707-120B
TU204-100
TU334-100
DC-3
FOKKER 70
M 0 10 20 30 40 50 60 70 80 90
FT 0 40 80 120 160 200 240 280

FIGURE 10

LANDING GEAR TRACK VERSUS FUSELAGE WIDTH

A correlation exists between the landing gear track width and fuselage width since the main landing gear truck typically folds into the wheelwell which is defined by the fuselage cross-section. There are some variations from the trend line due to configuration differences and different solutions to the integration of such factors as engine ground clearance, takeoff rotation angle, service heights, etc. (Figure 11).

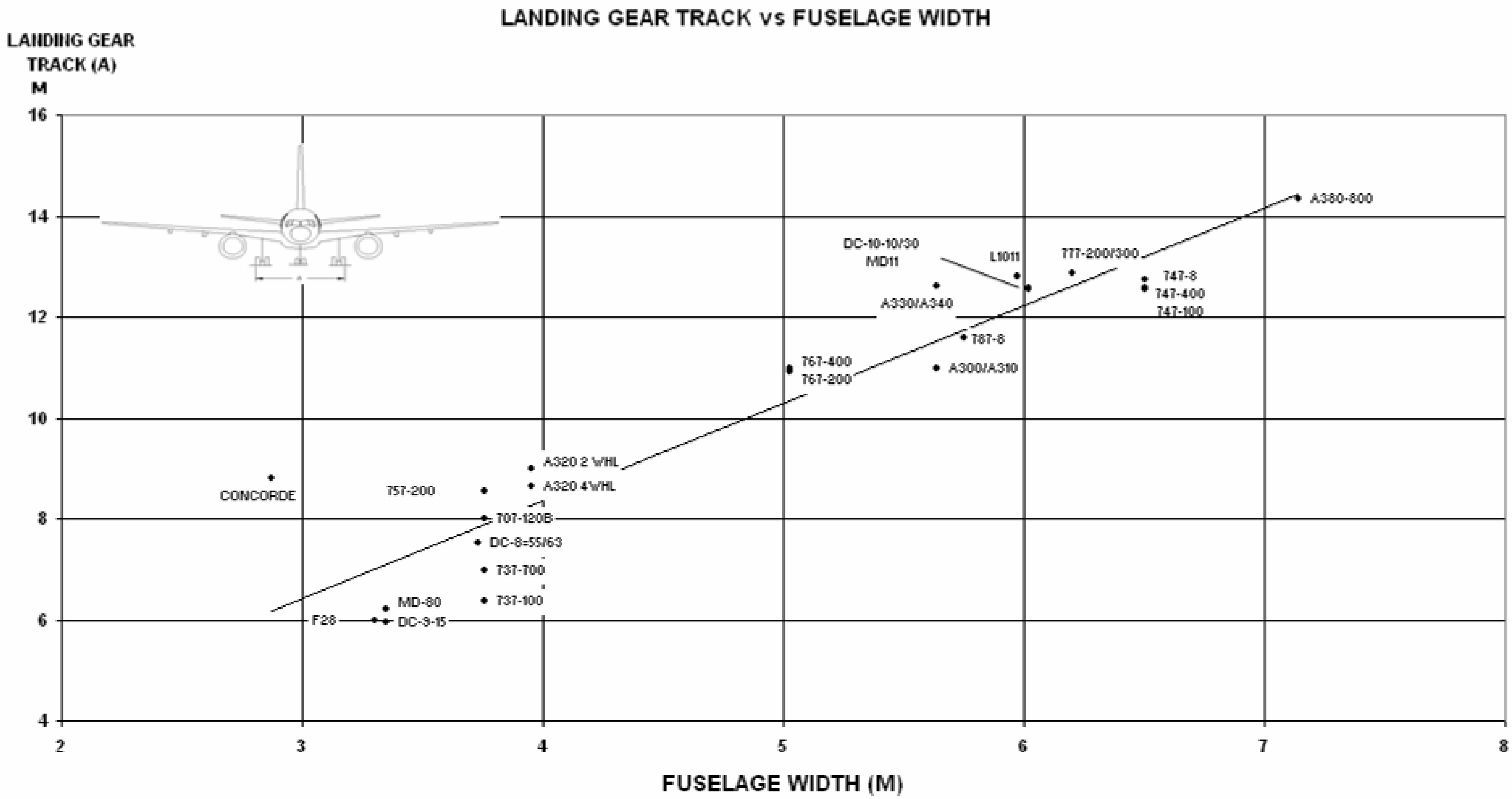

LANDING GEAR TRACK vs FUSELAGE WIDTH
LANDING GEAR TRACK (A) M
16
14
12
10
8
6
4
2
3
4
5
6
7
8
FUSELAGE WIDTH (M)
A380-800
DC-10-10/30
MD11
L1011
777-200/300
747-8
747-400
747-100
A330/A340
787-8
767-400
767-200
A300/A310
A320 2 WHL
A320 4 WHL
CONCORDE
757-200
707-120B
DC-8=55/63
737-700
737-100
MD-80
F28
DC-9-15

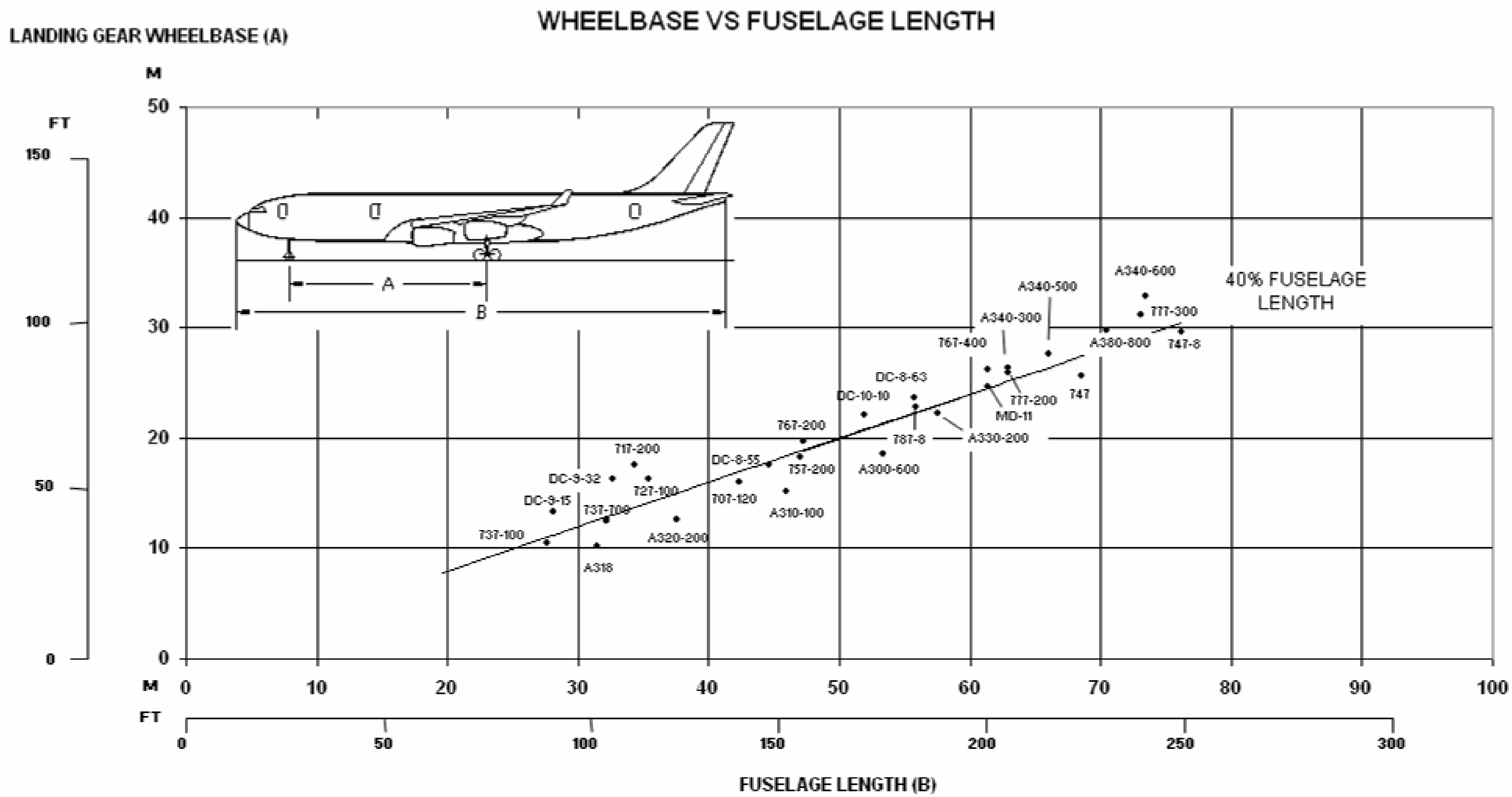
FIGURE 11

WHEELBASE VERSUS FUSELAGE LENGTH

Requirements for turn fillet areas and maneuvering areas are influenced by the aircraft landing gear arrangements and steering capability. Figure 12 shows the trend line is 40 percent of the fuselage length for the distance between the centroids of the nose and main gear (A). Fuselage length is defined as the length of the body sections of the airplane without the wing and tail empennage assemblies (B).

Recent stretched versions of existing airplanes, like Airbus A340-600 or Boeing 777-300, fit over this trend line. On-board taxiing camera systems have been developed for these aircraft to assist the pilot in safely judging the available pavement edge clearance during turning maneuvers.

As the fillet and maneuvering requirements on airfield pavements have increased over time, airports have gradually made improvements to the system to accommodate these new demands.



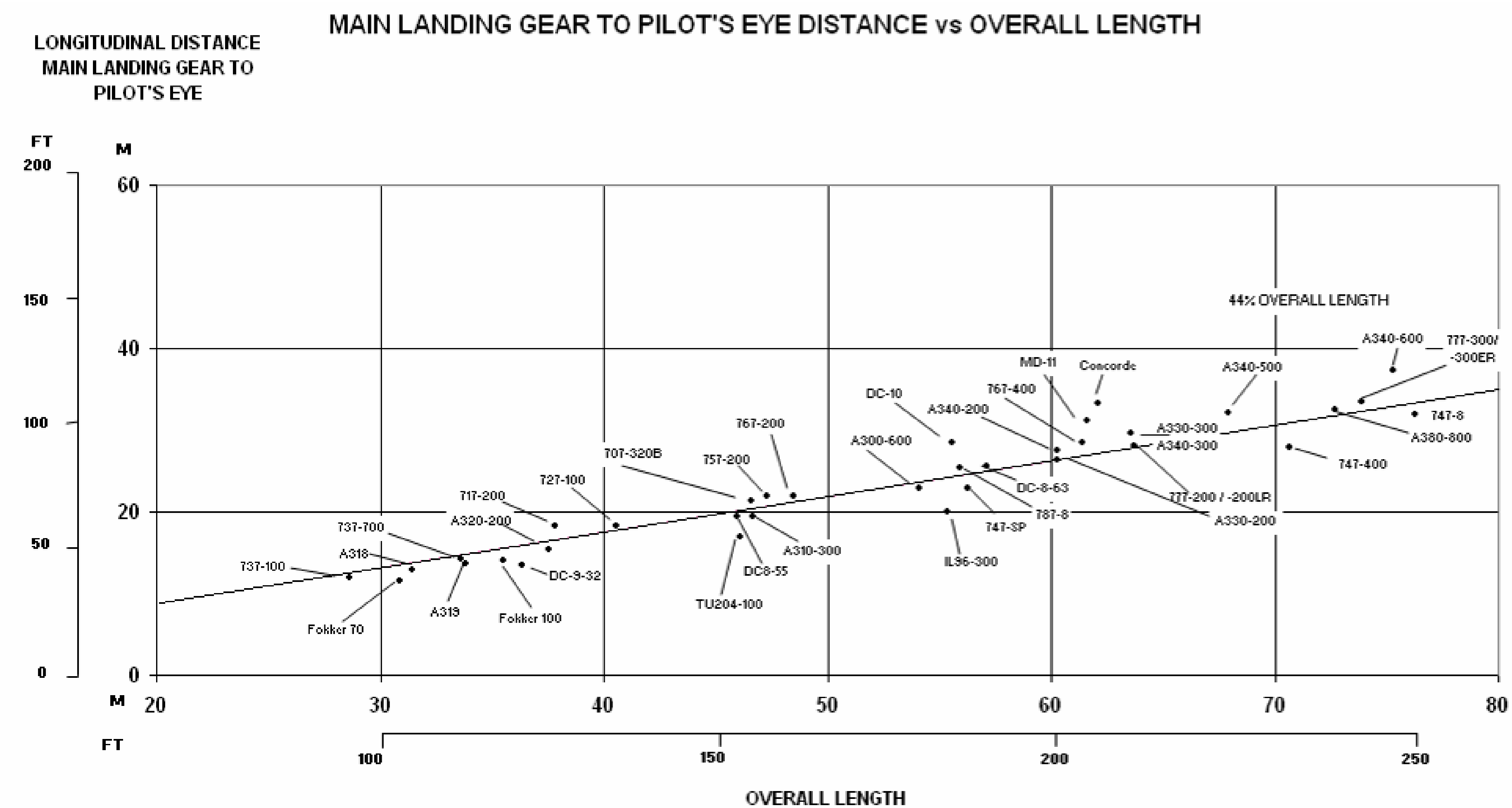
WHEELBASE VS FUSELAGE LENGTH
LANDING GEAR WHEELBASE (A)
M
FT
50
40
30
20
10
0
150
100
50
0
A
B
40% FUSELAGE LENGTH
737-100
A318
DC-9-15
737-700
DC-9-32
717-200
727-100
A320-200
DC-8-55
707-120
757-200
A310-100
767-200
DC-10-10
DC-8-63
A300-600
787-8
A330-200
767-400
MD-11
777-200
A340-300
A340-500
747
A380-800
A340-600
777-300
747-8
M 0 10 20 30 40 50 60 70 80 90 100
FT 0 50 100 150 200 250 300
FUSELAGE LENGTH (B)

FIGURE 12

MAIN LANDING GEAR TO PILOT'S EYE DISTANCE VERSUS OVERALL LENGTH

As the length of the aircraft increases, the horizontal distance between the main landing gear and the pilot's eye may also increase as shown in Figure 13. This will result in a requirement for larger turn fillets on the taxiway system. It can also affect the ability of the airplane to make a 180-degeree turn from one taxiway to another, thereby influencing the taxiway-taxiway separation.

As the fillet and maneuvering requirements on airfield pavements have increased over time, airports have gradually made improvements to the system to accommodate these new demands.



MAIN LANDING GEAR TO PILOT'S EYE DISTANCE vs OVERALL LENGTH
LONGITUDINAL DISTANCE MAIN LANDING GEAR TO PILOT'S EYE
FT
M
200
150
100
50
0
60
40
20
0
44% OVERALL LENGTH
A340-600
777-300/ -300ER
MD-11
Concorde
A340-500
767-400
DC-10
A340-200
747-8
767-200
A300-600
A330-300
A340-300
A380-800
707-320B
757-200
747-400
727-100
DC-8-63
717-200
777-200 / -200LR
787-8
A320-200
737-700
747-SP
A330-200
A318
A310-300
IL96-300
737-100
DC-9-32
DC8-55
TU204-100
A319
Fokker 100
Fokker 70
M
20
30
40
50
60
70
80
FT
100
150
200
250
OVERALL LENGTH

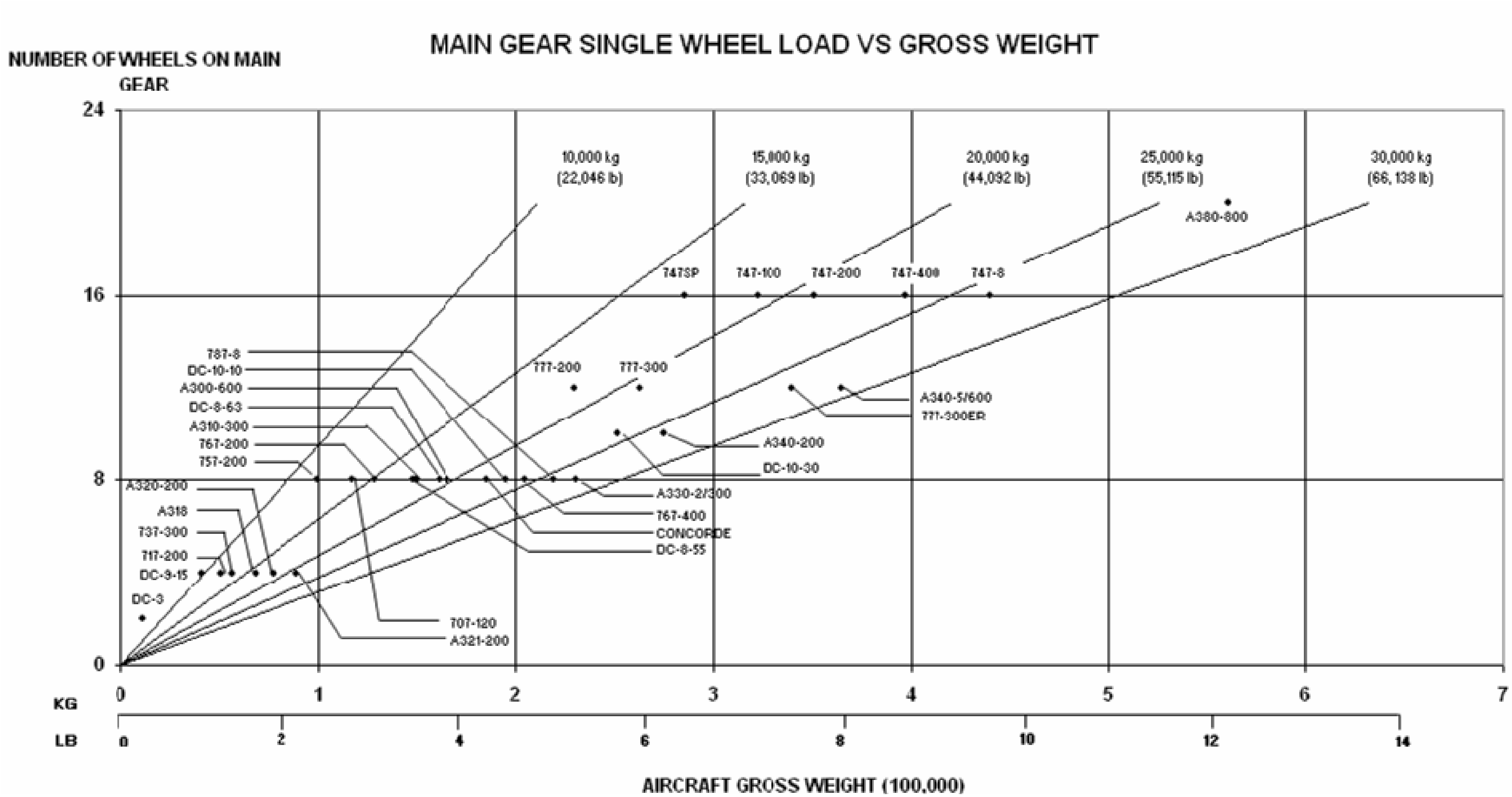
FIGURE 13

MAIN GEAR SINGLE WHEELS LOAD VERSUS GROSS WEIGHT

Wheel loads have been steadily increasing through the years, as shown in Figure 14. The "load lines" were determined by dividing 95 percent of the aircraft weight by the total number of main landing gear wheels. These increases, particularly in the last few years, have been obtained without exceeding runway strength requirements by using multiple landing gear, wider lateral and longitudinal wheel spacing, and larger tires.

A study of airport pavement strength indicates that pavements are gradually being strengthened to accommodate the increases in single wheel loads. Additionally, for aircraft with gross weights up to 690,000 kg (1,300,000 pounds), aircraft manufacturers are attempting to provide landing gear configurations consistent with present and future pavement strength and thickness requirements.

However, design of bridges and overpass structures on new airport infrastructures must take careful consideration of landing gear posts unit loads, in addition to overall aircraft gross weight, in order not to penalize operations of large capacity aircraft.



MAIN GEAR SINGLE WHEEL LOAD VS GROSS WEIGHT
NUMBER OF WHEELS ON MAIN GEAR
24
16
8
0
10,000 kg (22,046 lb)
15,000 kg (33,069 lb)
20,000 kg (44,092 lb)
25,000 kg (55,115 lb)
30,000 kg (66,138 lb)
A380-800
747SP
747-100
747-200
747-400
747-8
787-8
DC-10-10
A300-600
DC-8-63
A310-300
767-200
757-200
A320-200
A318
737-300
717-200
DC-9-15
DC-3
777-200
777-300
A340-5/600
777-300ER
A340-200
DC-10-30
A330-2/300
767-400
CONCORDE
DC-8-55
707-120
A321-200
KG
0
1
2
3
4
5
6
7
LB
0
2
4
6
8
10
12
14
AIRCRAFT GROSS WEIGHT (100,000)

FIGURE 14

TAIL HEIGHT GROWTH TREND

Over the years, the tail height has grown in proportion to the general increase in the overall length and span of the aircraft. Increasing tail heights affect runway to taxiway separation and runway to parking stand separation as it relates to the obstacle clearance zone and its related transition surfaces. Tail height must also be considered for new and existing hangar structures.

Figure 15 shows a trend for a continued increase in overall tail height.


TAIL HEIGHT
FT
M
TAIL HEIGHT GROWTH TREND
100
75
50
25
0
30
20
10
0
1930
1940
1950
1960
1970
1980
1990
2000
2010
YEAR ENTER SERVICE
DC-3
DC-4
DC-6
707-120B
707-320B
727-100
DC9-15
DC9-32
DC-9-32
DC-8-63
747-100
747SP
DC-10-10
A300-B2
A300-B4
A300-B4
767-200
757-200
A300-600
A310-300
A310-300
A300F4
757-200PF
777-300
747-400
A340-200/300
A330-300
MD-11
A300-600F
777-200
777-300
A330-200
A321-200
A321-100
A319
717-200
767-400
A318
A340-600
A340-500
787-8
747-8
A380-800

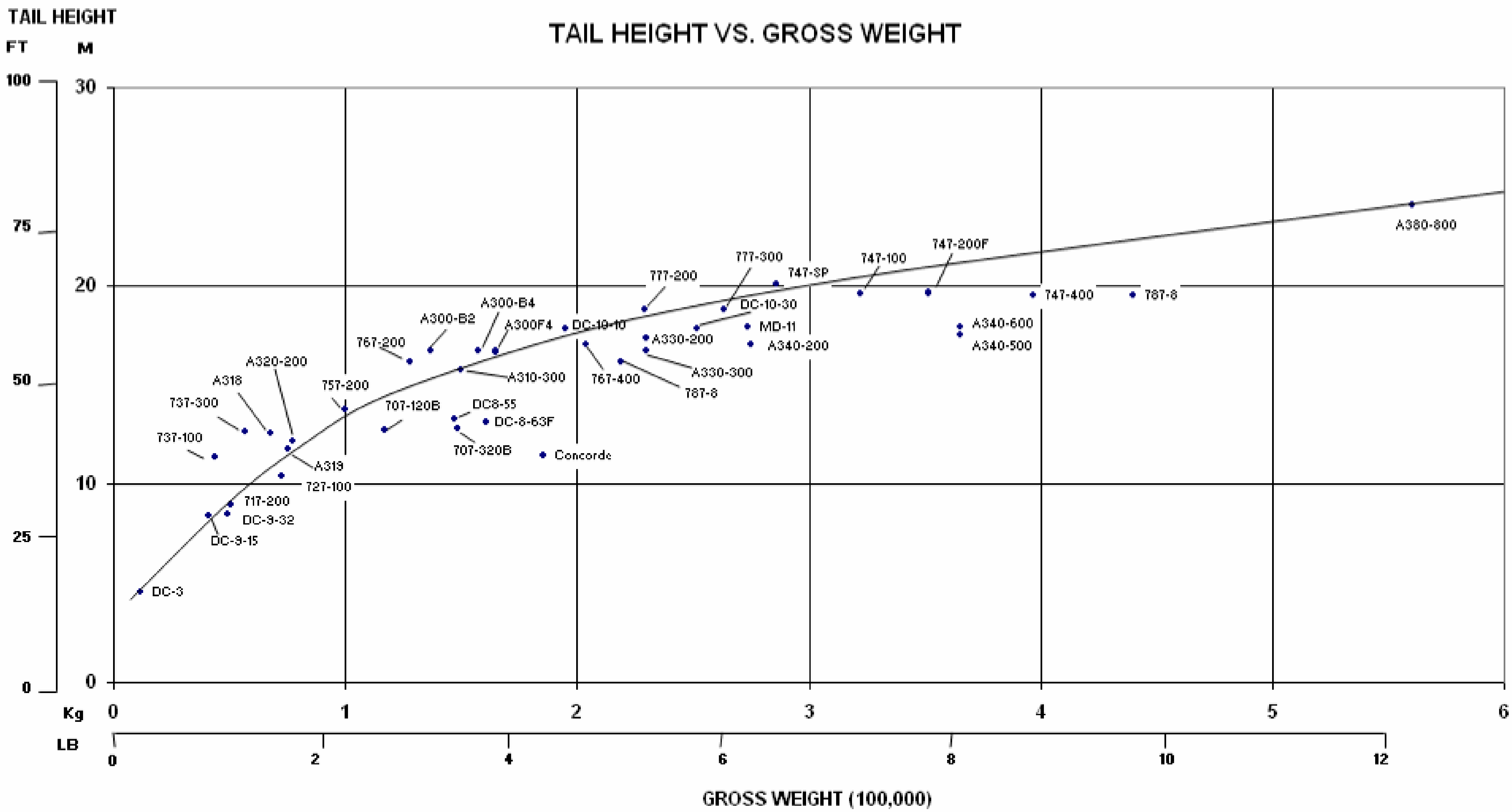
FIGURE 15

TAIL HEIGHT VERSUS GROSS WEIGHT

Because of a great variety in design options, future vertical tail dimensions cannot be closely estimated. For example, a high gross weight multi-deck aircraft with a relatively short wing-to-tail distance can have a very high tail.

Increasing tail heights affect runway to taxiway separation as it relates to the obstacle clearance zone and its related transition surfaces and runway to parking stand separation. Tail height must also be considered for new and existing hangar structures.

Figure 16 illustrates potential tail height growth that could be expected with increases in aircraft gross weight



TAIL HEIGHT VS. GROSS WEIGHT
TAIL HEIGHT
FT
M
100
75
50
25
0
30
20
10
0
Kg
0
1
2
3
4
5
6
LB
0
2
4
6
8
10
12
GROSS WEIGHT (100,000)
DC-3
DC-9-15
717-200
DC-9-32
727-100
A319
737-100
737-300
A318
A320-200
757-200
707-120B
767-200
A300-B2
A300-B4
A300F4
A310-300
DC8-55
DC-8-63F
707-320B
Concorde
DC-10-10
767-400
787-8
A330-200
A330-300
777-200
777-300
747-SP
DC-10-30
MD-11
A340-200
747-100
747-200F
A340-600
A340-500
747-400
787-8
A380-800

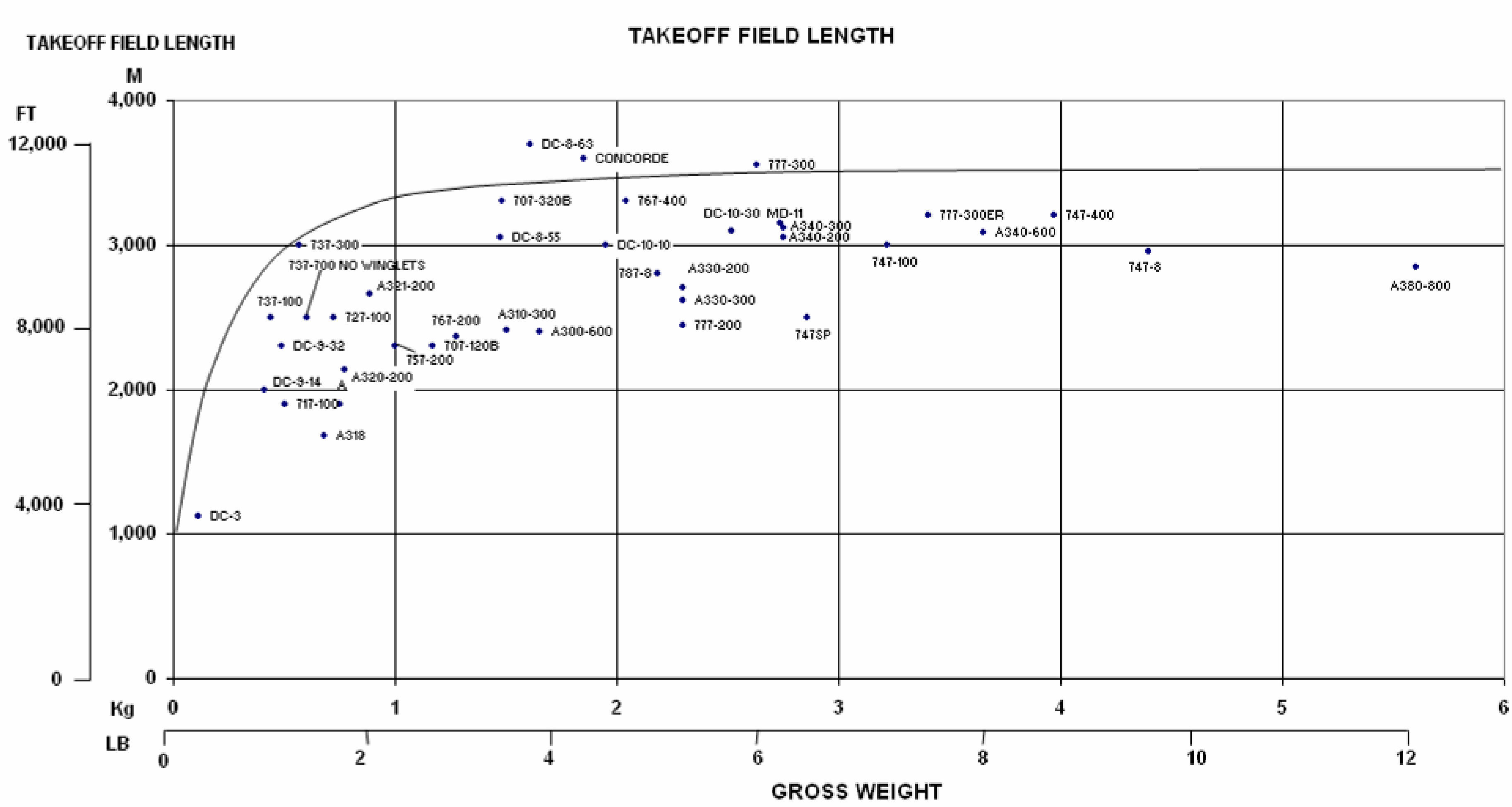
FIGURE 16

TAKEOFF FIELD LENGTH

Figure 17 shows that the trend toward longer takeoff distances* for high gross weight aircraft has leveled off. This is due, in part, to the increasingly constrained airport system and the lack of available land to increase Takeoff Field Length (TOFL) or to build new and longer runways.

This reduction or leveling off of TOFL can be attributed primarily to increased engine thrust and wing lift. Since temperature, altitude, runway slope and obstructions affect TOFL, close coordination is required between the airline operators, airport planners, and the aircraft manufacturers when planning runway length.

*Standard conditions: Sea level, ISA+15^{o} temperature, MTOW



TAKEOFF FIELD LENGTH
TAKEOFF FIELD LENGTH
M
FT
4,000
12,000
3,000
8,000
2,000
4,000
1,000
0
0
DC-8-63
CONCORDE
777-300
707-320B
767-400
DC-10-30
MD-11
A340-300
A340-200
777-300ER
747-400
A340-600
DC-8-55
DC-10-10
747-100
747-8
737-300
737-700 NO WINGLETS
787-8
A330-200
A380-800
A321-200
A330-300
737-100
727-100
767-200
A310-300
A300-600
777-200
747SP
DC-9-32
707-120B
757-200
A320-200
DC-9-14
717-100
A318
DC-3
Kg
0
1
2
3
4
5
6
LB
0
2
4
6
8
10
12
GROSS WEIGHT

FIGURE 17

LANDING FIELD LENGTH

Runway length requirements are established by aircraft takeoff capabilities. Figure 18 is included here to show the additional gains made in aircraft landing performance*. This is a result of advanced high lift systems that permit lower approach speed and shorter landing distance.

*Standard conditions: Sea level, ISA, dry runway, MLW

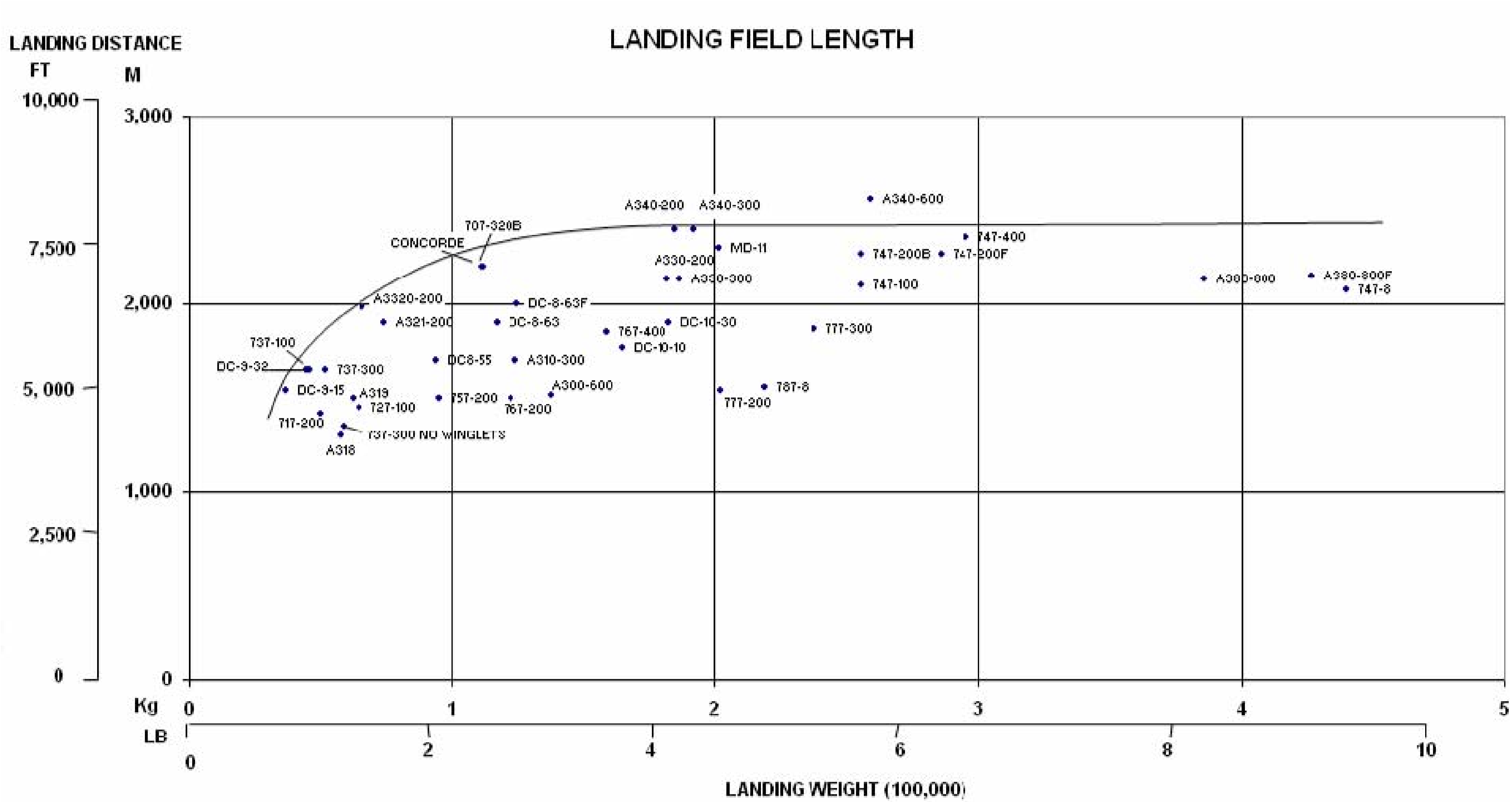

LANDING FIELD LENGTH
LANDING DISTANCE
FT
M
10,000
7,500
5, 000
2,500
0
3,000
2,000
1,000
0
A340-200
A340-300
A340-600
707-320B
CONCORDE
MD-11
747-400
A330-200
747-200B
747-200F
747-100
A3320-200
DC-8-63F
A321-200
DC-8-63
767-400
DC-10-30
777-300
DC-10-10
737-100
DC-9-32
737-300
DC8-55
A310-300
DC-9-15
A319
727-100
757-200
767-200
A300-600
777-200
787-8
717-200
737-300 NO WINGLETS
A318
A380-800F
747-8
Kg
LB
0
1
2
3
4
5
0
2
4
6
8
10
LANDING WEIGHT (100,000)

FIGURE 18

RAMP AREA

Ramp area per aircraft continues to increase, as does ramp area per passenger. Figure 19 shows that the ramp area increases linearly as the number of passengers increase. Note that growth versions of particular aircraft models follow the same trend lines as new models. Also, note that ramp area requirements for a given passenger configuration are significantly reduced by multi-deck aircraft.

Aircraft ramp area requirements are based on the rectangle formed by the wingspan plus 7.5 m (25 feet) and the aircraft overall length plus 7.5 m (25 ft).

Careful analysis of anticipated aircraft types and schedules should be made by the airport planner to determine ramp area requirements.

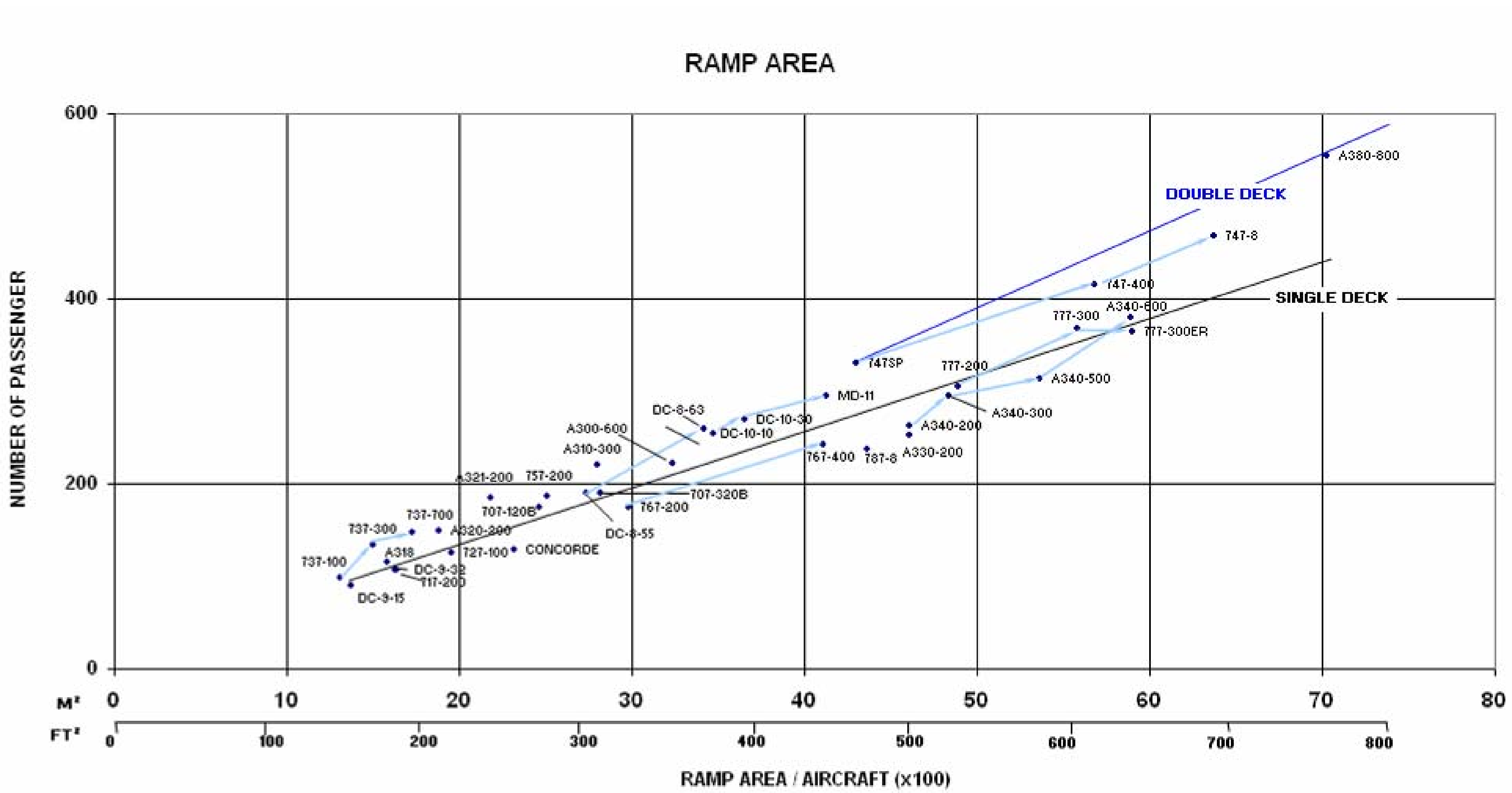
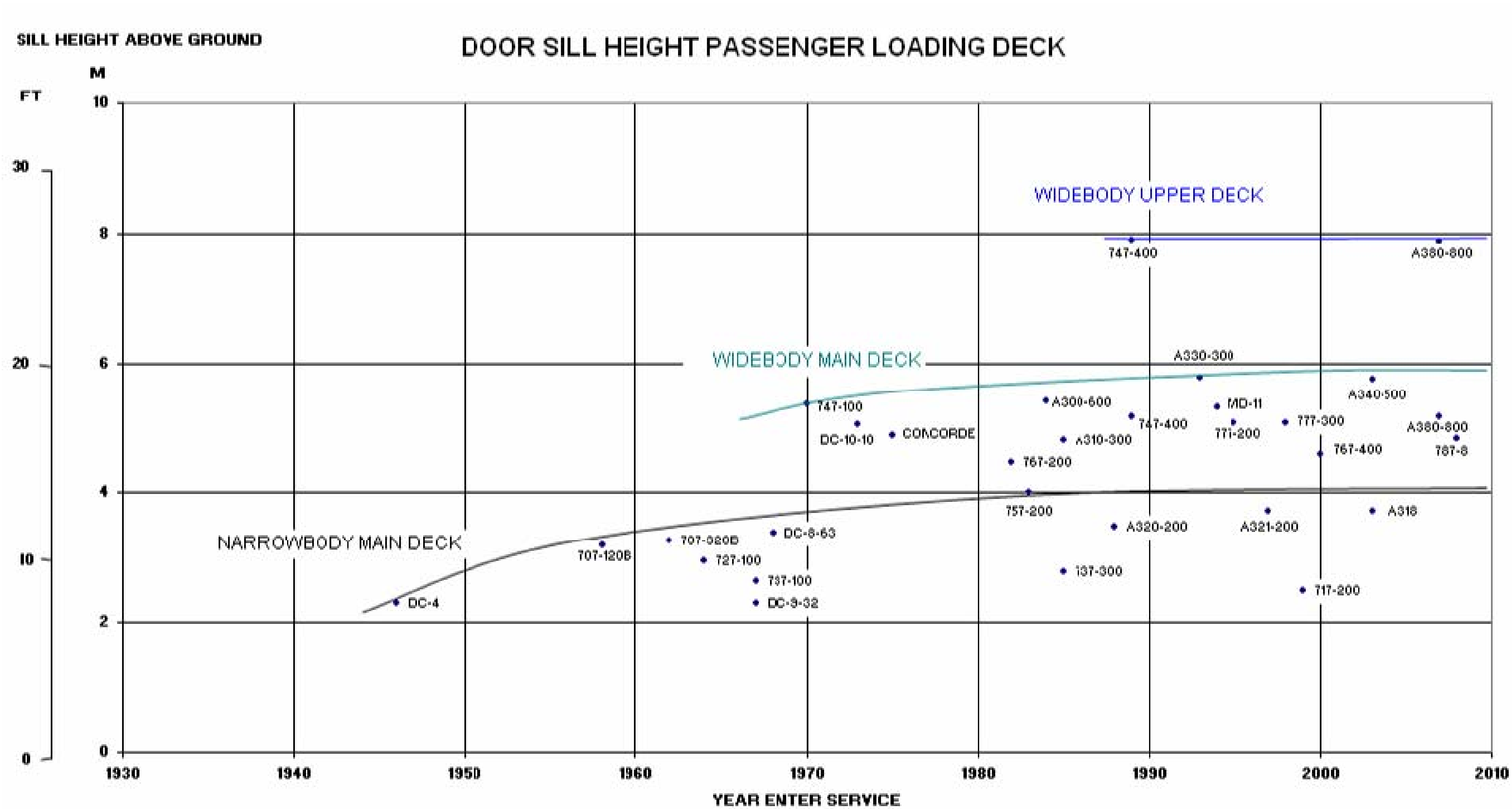

RAMP AREA
NUMBER OF PASSENGER
RAMP AREA / AIRCRAFT (x100)
M²
FT²
DOUBLE DECK
SINGLE DECK
A380-800
747-8
747-400
A340-600
777-300
777-300ER
747SP
777-200
A340-500
MD-11
A340-300
DC-8-63
DC-10-30
DC-10-10
A340-200
A300-600
A310-300
767-400
787-8
A330-200
A321-200
757-200
707-320B
707-120B
767-200
737-700
737-300
A320-200
DC-8-55
A318
727-100
CONCORDE
737-100
DC-9-32
717-200
DC-9-15

FIGURE19

DOOR SILL HEIGHT PASSENGER LOADING DECK

In figure 20, it can be seen that the main passenger deck sill heights remained fairly constant for the first generation jet transport family. The wide-bodied passenger transports show a pronounced increase in these sill heights due to the larger diameter fuselage and larger underwing engine nacelles. Historically, baggage and cargo have been carried on the lower deck with passengers occupying the main deck. Full-length, multi-passenger-deck aircraft with increased sill height will enter into service in 2008. This new upper-deck sill height requirement may require new passenger loading bridges. The freighter version of this aircraft will require a new upper deck cargo loader.



SILL HEIGHT ABOVE GROUND
DOOR SILL HEIGHT PASSENGER LOADING DECK
M
FT
10
30
8
20
6
4
10
2
0
0
WIDEBODY UPPER DECK
747-400
A380-800
WIDEBODY MAIN DECK
A330-300
747-100
DC-10-10
CONCORDE
A300-600
747-400
A310-300
767-200
MD-11
777-200
777-300
767-400
A340-500
A380-800
787-8
757-200
A320-200
A321-200
A318
NARROWBODY MAIN DECK
707-120B
707-320B
727-100
737-100
DC-9-32
DC-8-63
737-300
717-200
DC-4
1930
1940
1950
1960
1970
1980
1990
2000
2010
YEAR ENTER SERVICE

FIGURE 20

CARGO PAYLOAD GROWTH VERSUS GROSS WEIGHT

The projected growth of air cargo suggests that manufacturers will continue to design freighter versions of current or future passenger aircraft through 2010. Currently, cargo aircraft accounts for approximately 11 percent of the total fleet, and it is estimated to remain at 10-11 percent through the year 2010.

Many factors affect the ratio of payload to maximum ramp weight. A study of existing and projected cargo aircraft designs indicates that this ration varies from 25 to 35 percent. This is illustrated in Figure 21.

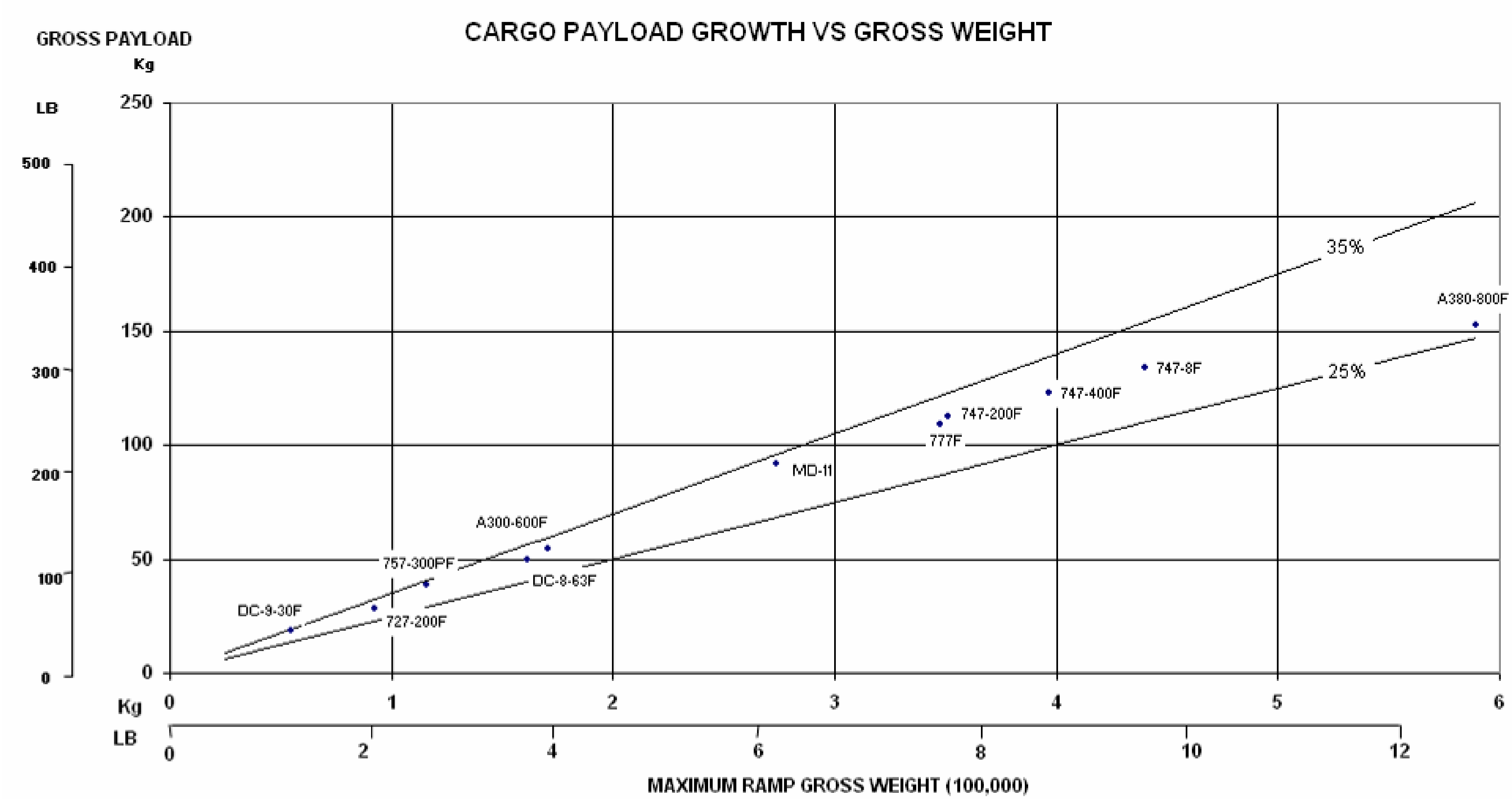

CARGO PAYLOAD GROWTH VS GROSS WEIGHT
GROSS PAYLOAD
Kg
LB
250
200
150
100
50
0
500
400
300
200
100
0
35%
25%
A380-800F
747-8F
747-400F
747-200F
777F
MD-11
A300-600F
757-300PF
DC-8-63F
DC-9-30F
727-200F
Kg
0
1
2
3
4
5
6
LB
0
2
4
6
8
10
12
MAXIMUM RAMP GROSS WEIGHT (100,000)

FIGURE 21

CARGO COMPARTMENT DOOR SILL HEIGHT TREND

Since cargo aircraft are converted or designed from passenger aircraft platforms, cargo loading door sill heights are generally determined by the height of the floors in the baggage and passenger compartments of the basic passenger transport configuration. Multi-deck cargo aircraft will require new cargo loading equipment due to the increase in upper-deck-door sill height.

Aircraft designed specifically to meet cargo requirements may only have a single deck with a lower sill height. This type of aircraft has mainly been used by the military thus far, as shown in Figure 22. A wider use of these military freighters for civilian applications has been limited by the incompatibility with commercial container/pallet sizes. Currently, the AN124 enjoys some commercial application to haul outsized cargo. The economies realized from the operation of very large cargo transports are expected to more than compensate for the increased complexity and cost of ground based facilities and equipment, even when they must incorporate sufficient flexibility to service two or more types of aircraft with different loading sill heights.

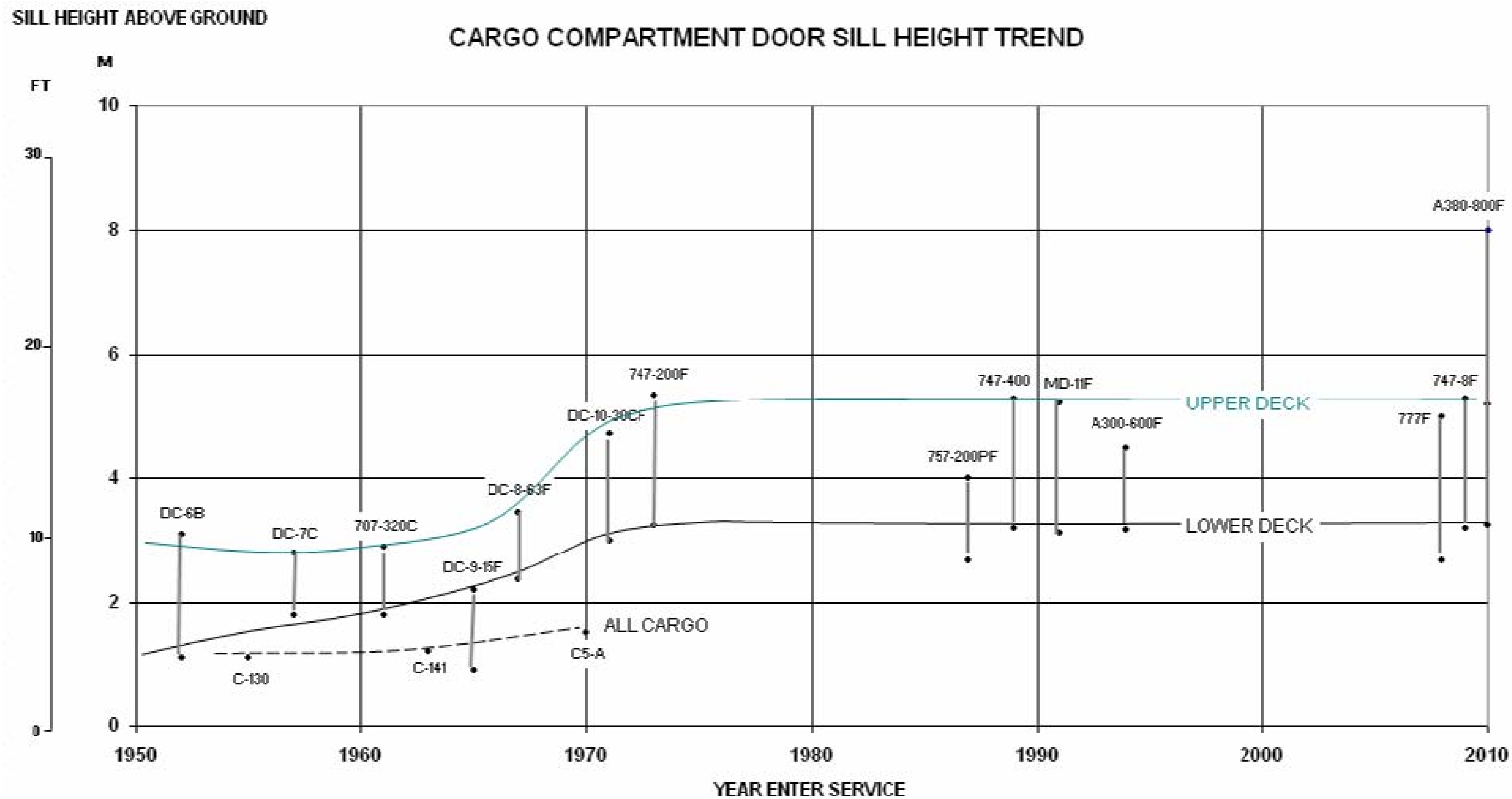
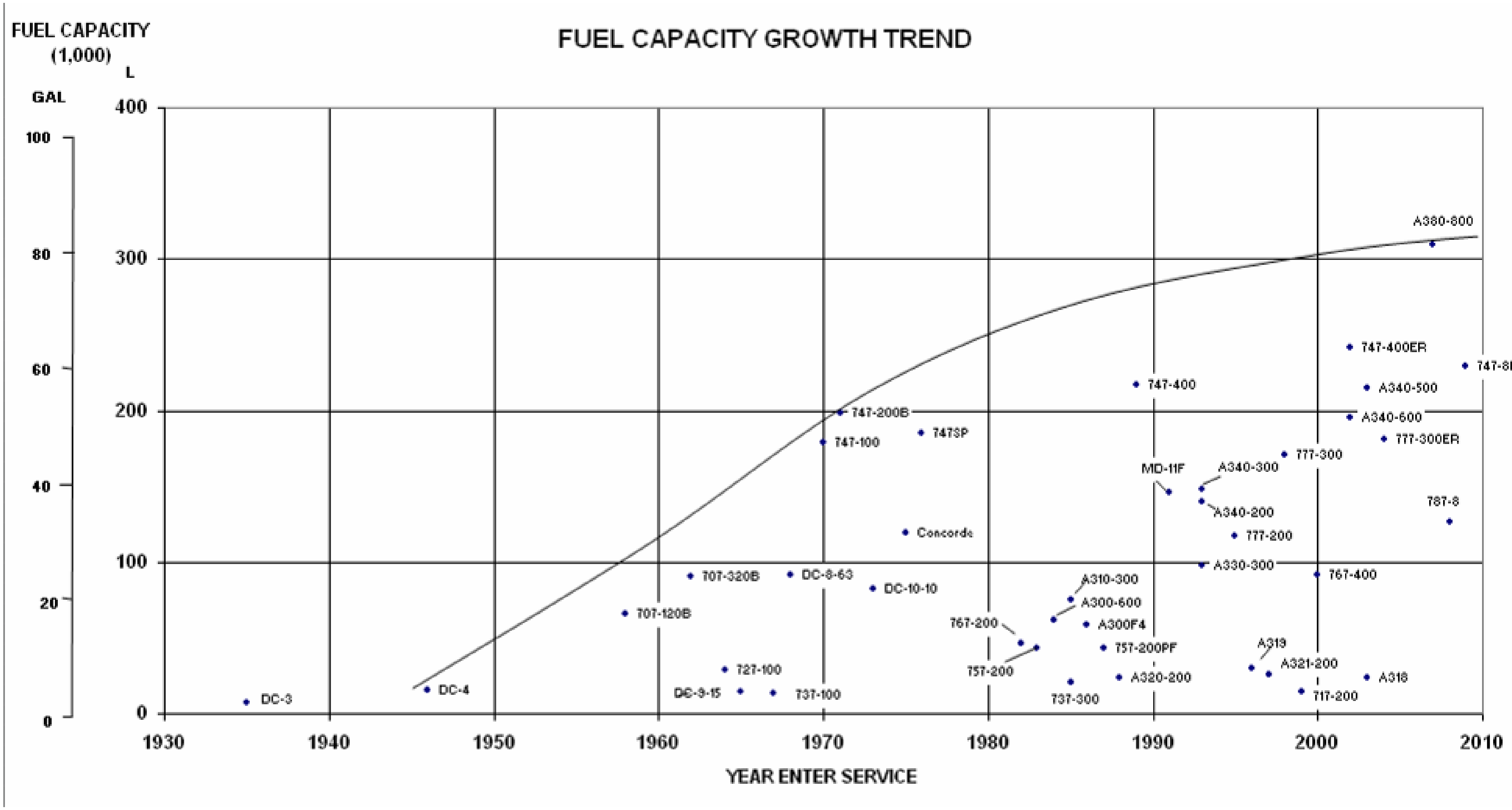

SILL HEIGHT ABOVE GROUND
CARGO COMPARTMENT DOOR SILL HEIGHT TREND
M
FT
10
8
6
4
2
0
30
20
10
0
A380-800F
747-200F
747-400
MD-11F
747-8F
UPPER DECK
DC-10-30CF
A300-600F
777F
757-200PF
DC-8-63F
DC-6B
DC-7C
707-320C
LOWER DECK
DC-9-15F
ALL CARGO
C5-A
C-141
C-130
1950
1960
1970
1980
1990
2000
2010
YEAR ENTER SERVICE

FIGURE 22

FUEL CAPACITY GROWTH TREND

As shown in Figure 23, fuel capacity requirements over the past 60-plus years have increased steadily. These requirements, coupled with the need for shorter turnaround time, have resulted in increased total flow capability of the fueling system.

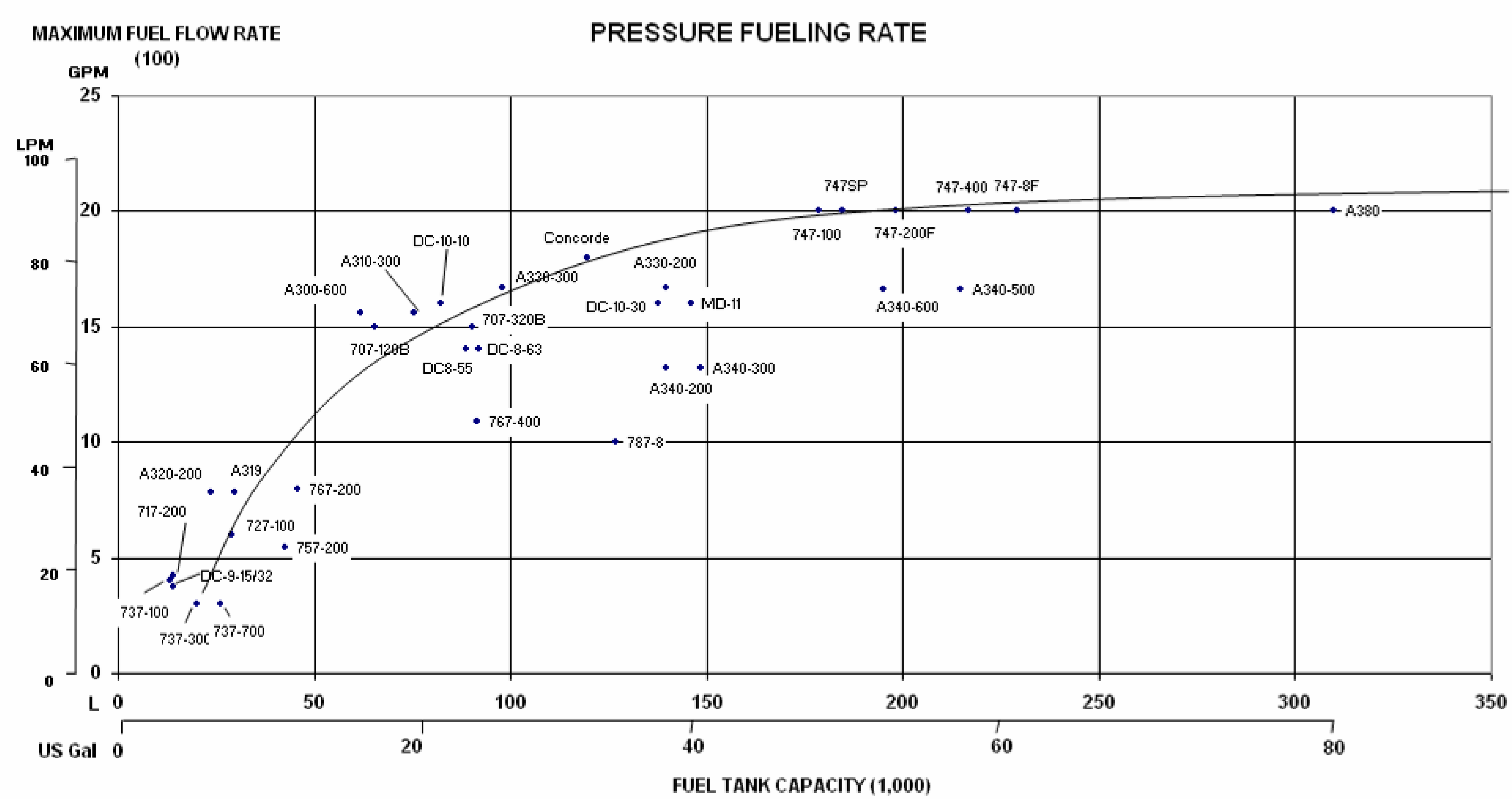


FUEL CAPACITY GROWTH TREND
FUEL CAPACITY (1,000)
L
GAL
400
300
200
100
0
100
80
60
40
20
0
1930
1940
1950
1960
1970
1980
1990
2000
2010
YEAR ENTER SERVICE
DC-3
DC-4
707-120B
707-320B
727-100
DC-9-15
737-100
DC-8-63
DC-10-10
747-100
747-200B
747SP
Concorde
767-200
757-200
737-300
A310-300
A300-600
A300F4
757-200PF
A320-200
747-400
MD-11F
A340-300
A340-200
777-200
A330-300
777-300
A313
A321-200
717-200
767-400
A318
747-400ER
A340-500
A340-600
777-300ER
787-8
747-8F
A380-800

FIGURE 23

PRESSURE FUELING RATE

The maximum total fuel flow rate is equal to the number of fueling connectors multiplied by the initial acceptance rate of the fuel tanks. This initial acceptance rate is a function of the fueling equipment design, in which tank ventilation and fuel manifold size both play an important role. Figure 24 shows maximum total fuel flow rate into the aircraft and how it varies with aircraft total tank capacity. (The maximum total flow rate is defined as the initial maximum acceptance rate of all the aircraft fueling connectors when filling all tanks simultaneously at a supply pressure of 50 pounds per square inch.) It should be noted that the rates depicted in Figure 24 are initial flow rates, and that they will decrease as the fuel tanks begin to fill. Without a major breakthrough in fueling equipment capabilities, it is reasonable to assume that more fueling connectors will be added in the future if aircraft tank capacity increases substantially. If a derivative of the 747 with a much larger wing or derivatives of A380 with higher fuel flow rates requirements are launched, these increases could become a reality.

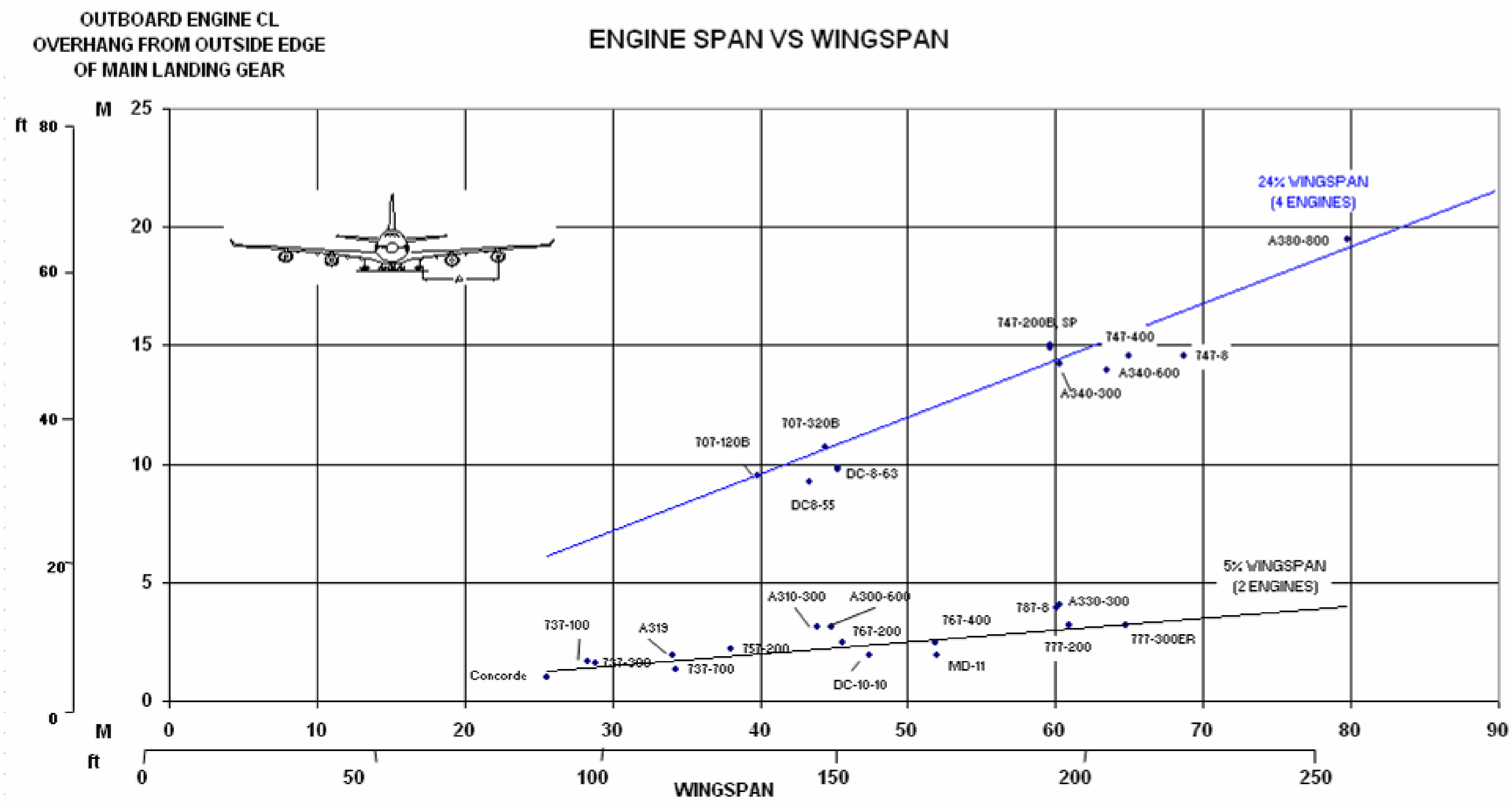


PRESSURE FUELING RATE
MAXIMUM FUEL FLOW RATE
(100)
GPM
LPM
100
25
20
15
10
5
0
80
60
40
20
0
747SP
747-400
747-8F
A380
747-100
747-200F
Concorde
DC-10-10
A310-300
A330-300
A330-200
A300-600
DC-10-30
MD-11
A340-600
A340-500
707-320B
707-120B
DC-8-63
DC8-55
A340-300
A340-200
767-400
787-8
A320-200
A319
767-200
717-200
727-100
757-200
DC-9-15/32
737-100
737-300
737-700
L
0
50
100
150
200
250
300
350
US Gal
0
20
40
60
80
FUEL TANK CAPACITY (1,000)

FIGURE 24

ENGINE SPAN VERSUS WINGSPAN

Requirements for widths of shoulder stabilization are established by the location of the outboard engines outboard of the main landing gear. Figure 25 shows the maximum engine spread of about 5 percent of the wingspan for 2-engined aircraft and 24 percent of the wingspan on 4-engined aircraft from the outside tire edge.



OUTBOARD ENGINE CL
OVERHANG FROM OUTSIDE EDGE
OF MAIN LANDING GEAR
ENGINE SPAN VS WINGSPAN
24% WINGSPAN
(4 ENGINES)
5% WINGSPAN
(2 ENGINES)
A380-800
747-200B, SP
747-400
747-8
A340-600
A340-300
707-320B
707-120B
DC-8-63
DC8-55
A310-300
A300-600
787-8
A330-300
767-400
767-200
777-200
777-300ER
737-100
A319
737-300
757-200
737-700
Concorde
MD-11
DC-10-10
WINGSPAN

FIGURE 25

ENGINE GROUND CLEARANCE VERSUS OVERHANG FROM MAIN GEAR

Engine heights and locations outboard of the main landing gear are shown on Figure 26. They affect obstruction heights and, when combined with blast considerations, affect the strength required for runway edge lights, and in some cases, runway and taxiway signs. Trend line shown is the envelope of the minimum clearance.

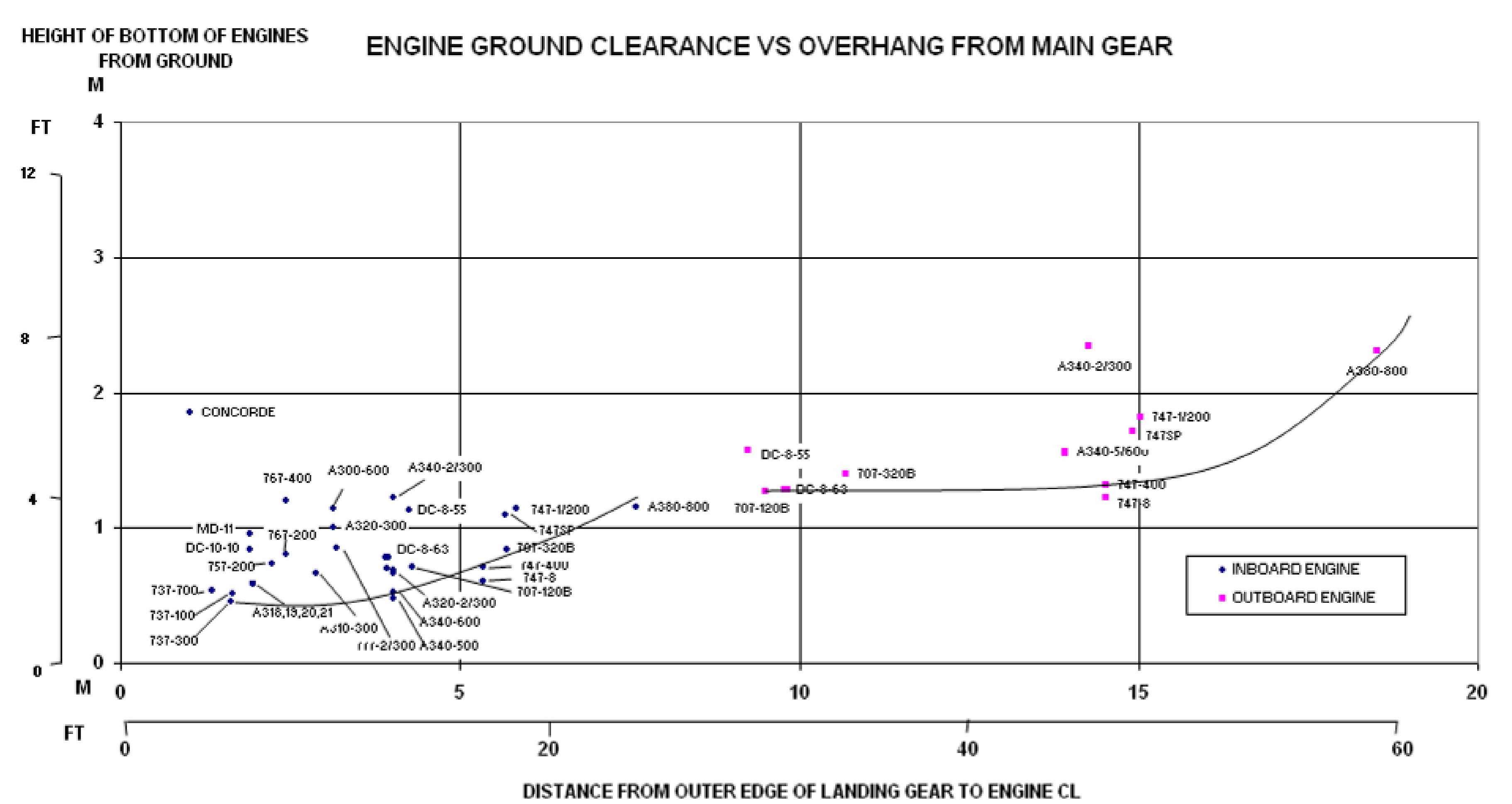

ENGINE GROUND CLEARANCE VS OVERHANG FROM MAIN GEAR
HEIGHT OF BOTTOM OF ENGINES FROM GROUND
M
FT
DISTANCE FROM OUTER EDGE OF LANDING GEAR TO ENGINE CL
INBOARD ENGINE
OUTBOARD ENGINE
CONCORDE
767-400
A300-600
A340-2/300
DC-8-55
747-1/200
747SP
A380-800
MD-11
767-200
A320-300
DC-10-10
757-200
DC-8-63
707-320B
747-8
707-120B
737-700
737-100
737-300
A318,19,20,21
A320-2/300
A340-600
A340-500
A340-5/600
747-400
0
1
2
3
4
5
8
10
12
15
20
40
60

FIGURE 26

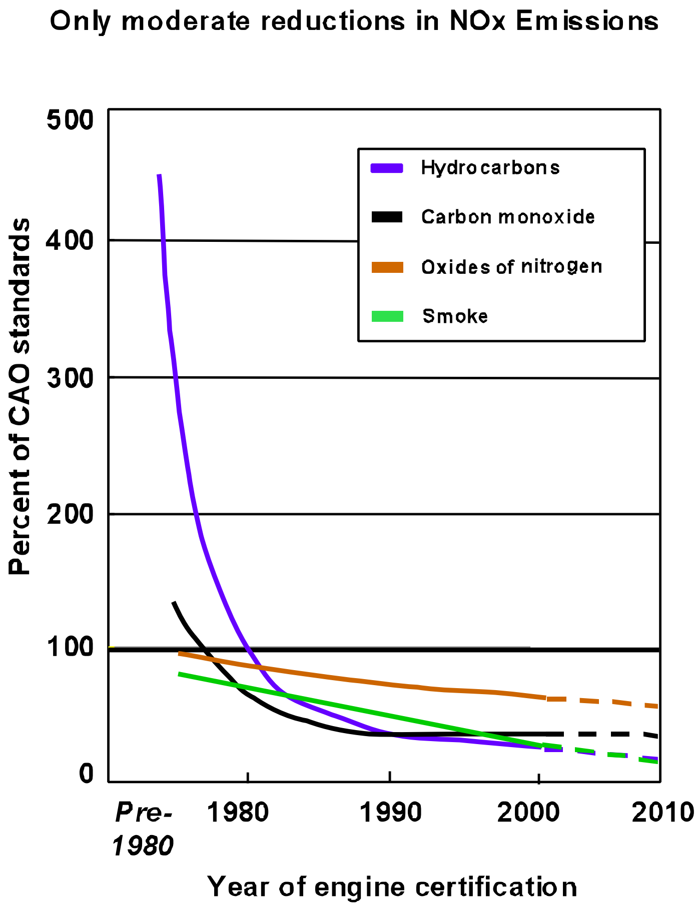
EMISSIONS REDUCTION TRENDS

Aircraft engine emissions can impact both local air quality and climate change. The primary emittants of concern from a local airquality standpoint are oxides of nitrogen (NOx) and unburned hydrocarbons (HC) which, along with carbon monoxide (CI) and smoke, are currently regulated by ICAO. The current standard for NOx was implemented in 1996 and this standard resulted in a stringency increase of more than 25% over the initial standard adopted in 1986. Standards for smoke, CO and HC have not changed since 1986.

From a global standpoint, carbon dioxide is the emittant of concern. Carbon dioxide is a byproduct of burning hydrocarbon fuels, and is reduced through engine cycle improvements to reduce fuel burn. Presently there are no standards governing CO2, although ICAO's Committee on Aviation Environmental Protection (CAEP) is looking at introducing market based options (charges, levies, voluntary programs and emissions trading) to drive the aviation industry to reduce CO2 emissions. Although it accounts for only 4.2% of the total global warming potential, the concern today is that aviation generated C02 is projected to grow to approximately 5.7% by 2050.

Aviation has done its share to reduce these emissions – today's modern airliners are 70% more efficient than they were 40 years ago, while the industry also has been able to make significant improvements to NOx, CO, HC and smoke. This has been no easy feat, since methods used to reduce fuel burn – higher pressure ratios and cycle temperatures – generally lead to higher NOx levels. These trends are illustrated in Figure 27.

Emissions Reduction Trends



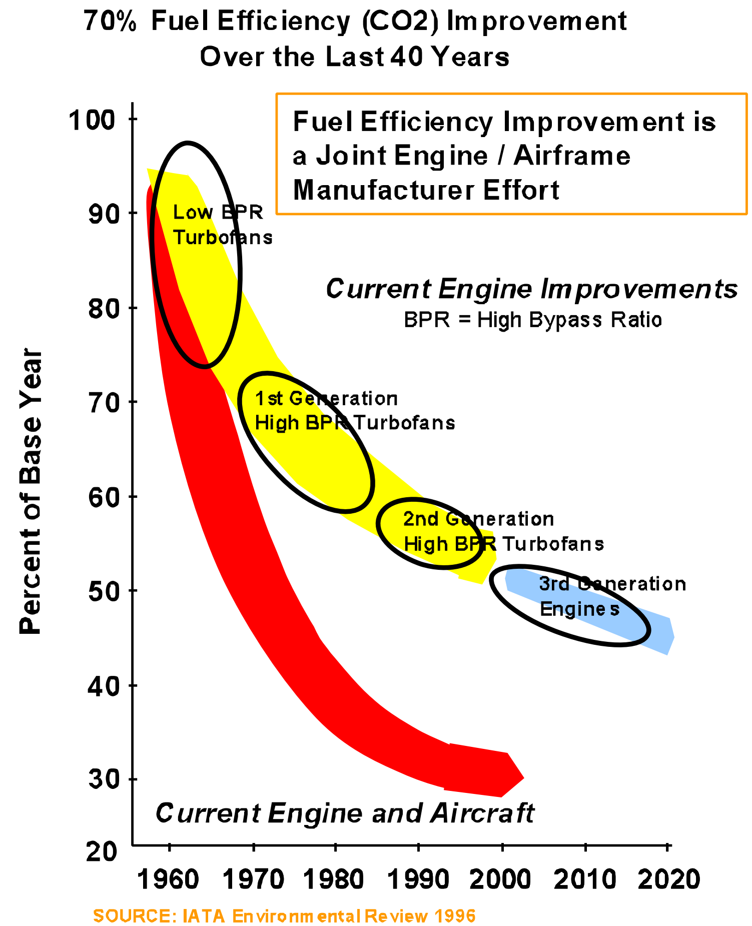


FIGURE 27

AIRCRAFT NOISE LEVEL TREND
SUBSONIC TRANSPORTS

Emphasis on noise reduction technology and the development of high bypass-ratio turbofan engines have produced significantly quieter airplanes since the introduction of the jet age in the 1960's. The noise levels of today's new technology airplanes are a total of 50 decibels quieter at the three certification points than those of the first generation jet airplanes. Technology has delivered this noise reduction through high bypass ratio engines with reduced jet velocities, advances in airframe, nacelle and engine component designs and improved airplane performance. Further progress will require advances across a wide range of noise sources. The expected benefits will not be as dramatic in the absence of ambitious noise research programs and sustained funding (Figure 28)

AIRCRAFT NOISE LEVEL TREND
SUBSONIC TRANSPORTS

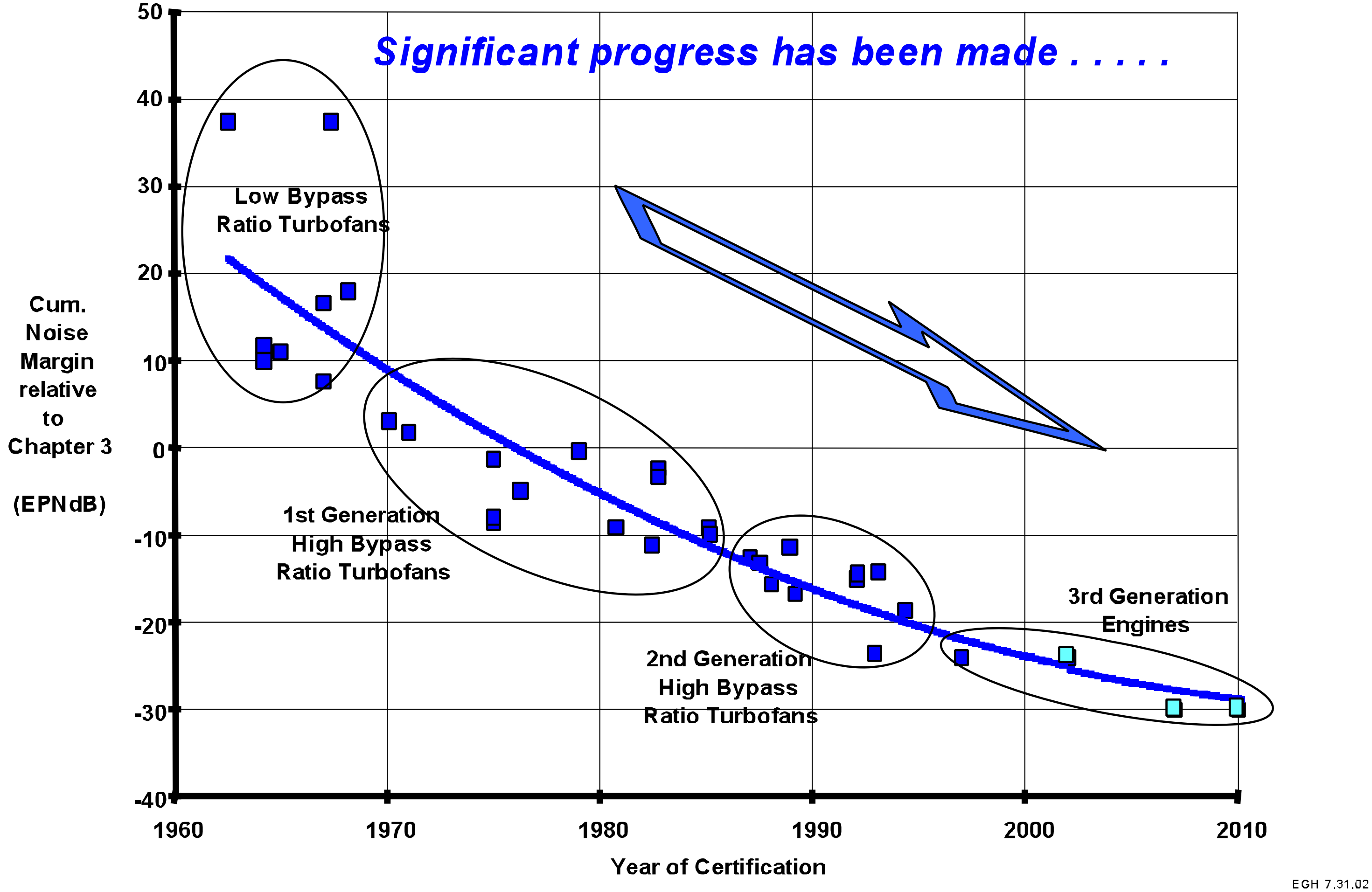


FIGURE 28