IN-01
129297
P.89

NASA Technical Memorandum 107669

FUTURE REGIONAL TRANSPORT AIRCRAFT MARKET, CONSTRAINTS, AND TECHNOLOGY STIMULI

(NASA-TM-107669) FUTURE REGIONAL TRANSPORT AIRCRAFT MARKET, CONSTRAINTS, AND TECHNOLOGY STIMULI (NASA) 89 p

N93-13025

Unclas

G3/01 0129297

W. Don Harvey and Brent Foreman

October 1992

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

TABLE OF CONTENTS

ABSTRACT 1

INTRODUCTION 1

SYMBOLS 3

TRENDS AND FORECASTS 6

REGIONAL/COMMUTER TRANSPORT DEFINITION 6

MARKET FORECASTS AND INFLUENCES 7

WORLD ISSUES 7
U.S. ISSUES 8

AIRCRAFT TRENDS 10

FLEET SIZE 10
AIRCRAFT SIZE AND SPEED 10

OPERATING COSTS AND TECHNOLOGY INFLUENCES 11

FUTURE MARKET FORCES 12

CONSTRAINTS AND STIMULI 12
REGIONAL AIRCRAFT---NEW MARKET ISSUES 12

IMPACT OF TECHNOLOGY 14

ADVANCED TECHNOLOGY INFLUENCE ON DOC 14

TECHNOLOGY OPPORTUNITIES 14

ADVANCED WING DESIGN 16
LAMINAR FLOW TECHNOLOGY 17

HIGH-LIFT AERODYNAMICS 18
PROPULSION 19
NOISE REDUCTION 21
MATERIALS 21
AVIONICS AND CONTROL 22

FUTURE MARKET SCENERIO 23

CONCLUDING REMARKS 24

REFERENCES 26

ABSTRACT

This report provides updated information on the current market and operating environment and identifies interlinking technical possibilities for competitive future commuter-type transport aircraft. The conclusions on the market and operating environment indicate that the regional airlines are moving toward more modern and effective fleets with greater passenger capacity and comfort, reduced noise levels, increased speed, and longer range. This direction leads to a nearly "seamless" service and continued code-sharing agreements with the major carriers. Whereas the benefits from individual technologies may be small, the overall integration in existing and new aircraft designs can produce improvements in direct operating cost and competitiveness. Production costs are identified as being equally important as pure technical advances.

INTRODUCTION

In the National Aeronautics and Space Administration (NASA) authorization hearings from Fiscal Year 1979, the U.S. Senate Committee on Commerce, Science, and Transportation reported a perceived problem in commuter-type air service between smaller cities and connecting major hubs. NASA, in cooperation with the Department of Transportation and the Civil Aeronautics Board, was requested to prepare a comprehensive report on technology improvements that would most likely increase the public use of commuter aircraft and to determine whether NASA's research could help manufacturers solve these technical problems. In December 1980, an Ad Hoc Subcommittee of NASA's Aeronautics Advisory Committee reviewed the study and provided its conclusions and recommendations. A summary of these previous efforts and more recent updated information are published in SAE 1982 Transactions, Section 3, Volume 91, entitled "Advanced Technology for Future Regional Transport Aircraft" by Louis J. Williams (ref. 1).

Since these previous studies, the U.S. regional airlines have experienced phenomenal growth (ref. 2). Many have done so by sacrificing their identities in becoming part of a major airline. These partnerships have grown so fast that regionals, looking more like the majors, have been classified by the U.S. Transportation Department as airlines with less than $100 million in gross revenue. Since deregulation in 1978, the regional airline industry has tripled in size (ref. 2). This apparent upheaval began in the 1980's, when airline deregulation generated an intense climate of competition. Most of the major airlines at that time proceeded to form partnerships with regionals and turned them into feeders to gain new markets and higher load factors. In 1989, 43 of the top 50 carriers used the two-letter designator code of a larger airline to list their flights. In total, there were 54 code-sharing agreements between regional and major airlines. These relationships vary from outright ownership by a major carrier (17 airlines) to partial ownership (4 airlines) to pure marketing alliances devoid of ownership (33 airlines) (see refs. 2 through 6).

Prior to deregulation, most of the regionals were operating propeller-driven aircraft that seated fewer than 40 passengers and could reach airports that were less than 200 miles away and too small for the commercial jets of the major fleets. The industry continued to add new, more sophisticated aircraft to the fleet, retiring the older piston-powered aircraft. Thus, the total number of aircraft in scheduled regional airline service rose from 1,265 in 1979 to 1,907 in 1989 with an average aircraft seating capacity increase from 12.5 to 21.8 seats. The average trip length has correspondingly increased from 123 to 181 miles. Passenger enplanements have risen from 14 million in 1979 to 37.4 million in 1989. Revenue passenger miles increased to 6.77 billion in 1989 from 1.72 billion in 1979. One very important consequence of deregulation was that carriers began to provide seamless or end-to-end service under the same brand name (code sharing) .

Today's regional airlines in the United States, Europe, and elsewhere are identified with the entrepreneurial spirit (refs. 7 and 8). While regionals are vital for tomorrow's Europe, they have in the past been severely tested by a lack of suitable aircraft for short, thinly-traveled routes and more recently by the regulatory emissions and noise environment. Europe's aircraft manufacturers have risen to the challenge and developed aircraft that are specifically designed to meet the economic and operating needs of regional airlines. Europe's aerospace manufacturers dominate the world market for commuter aircraft, although competition comes from the United States, Canada, and Brazil (refs. 9 and 10).

The introduction of new state-of-the-art technology aircraft offering amenities similar to those found on large jet aircraft can contribute to greater public acceptance and stimulate higher growth. Procurement of new aircraft plus increased integration of service with the major airlines will lead to new opportunities for the regional/commuter industry. However, while the regional jet concept provides the most obvious way to expand into new areas of growth, it may also be where the industry is most likely to come into competition or conflict with their partners, major airframe manufacturers (ref. 11), and environmental regulators.

By all accounts, the U.S. and foreign regional/commuter airlines have experienced a growth trend (refs. 2-4). In the United States, this trend has outpaced the growth of the major U.S. airlines. Forecasters predict that larger regional aircraft will dominate the market by the turn of the century. There are about 25 different regional aircraft with between 19 to 70 seats on the market today. In such a competitive and expanding regional market, the viability of so many aircraft programs is often doubted. Break-even points in terms of profit remains notoriously elusive, even though some American manufacturers have delivered over 200 aircraft in the past. While in the late 1980's there were large regional aircraft purchases, recent social and economic problems have dimmed what had been an optimistic outlook for several production lines. U.S. manufacturers have been experiencing a turbulent time--with cost cutting, lay-offs, and production slowdowns due to market uncertainty. On the other hand, both poor traffic and expensive fuel could bring about failures among the operators of aircraft, rather than the manufacturers. Consequently, there has been a rather large negative shift in the U.S. trade balance over the past 10 years for general aviation and commuter aircraft.

With this concern in mind, the NASA Langley Research Center initiated a study in the fall to1989 to evaluate the current commuter aircraft market and operating environment and to identify interlinking technical possibilities for competitive future commuter-type transports. Summary briefings on the results of this study have been presented to industry and their comments are incorporated in the evaluations and findings herein. The purpose of this paper is to provide updated information on commuter airline trends and forecasts, airline development, and technology opportunities. While the vastness of the subject is recognized, the present paper summarizes the factors that are believed to have a major impact on future regional/commuter transport aircraft and their operations.

SYMBOLS

a	speed of sound
c	chord
C_D	section drag coefficient
cd	total drag coefficient
C_L	section lift coefficient
cl	total lift coefficient
Δg	gust load factor
M	Mach number
R	unit Reynolds number

s	wing area
t	thickness
v	velocity
s	wing area
w	wing weight
α	angle of incidence
δ_F	flap deflection
Λ	leading-edge sweep angle

<u>Subscripts</u>

c	chord
DD	drag divergence
g	gust
min	minimum value
tr	transition
$\perp$	normal to leading edge
max	maximum value
	infinity

<u>Abbreviations</u>

a/c	aircraft
AR	aspect ratio
ASM	available seat miles

ASNM	available seat nautical miles
ATC	air traffic control
CAD	computer assisted design
CAM	computer assisted manufacturing
CF	crossflow
CIM	computer integrated manufacturing
DFVLR	Deutsche Forschungsanstalt fur Luft-und Raumfahrt
dBA	decibel
DOC	direct operating cost
EPNL	effective perceived noise level
FAA	Federal Aviation Administration
GAL	gallon
GDP	gross domestic product
HPT	high pressure turbine
HSNLF	high speed natural laminar flow
LP	low pressure
LS	low speed
LTPT	Low Turbulence Pressure Tunnel
L/D	lift-to-drag-ratio
MAC	Mean aerodynamic chord
NACA	National Advisory Committee on Aeronautics
NASA	National Aeronautics and Space Administration

NLF	natural laminar flow
NM	nautical miles
PAX	passenger
RPM	revenue passenger miles or revolutions per minute
SHP	shaft horse power
SFC	specific fuel consumpton
TE	trailing edge
TS	Tollmien-Schlichting
UHBR	ultra high bypass ratio

TRENDS AND FORECASTS

Regional/Commuter Transport Definition

As traffic grows, larger aircraft can be used at the same frequency, however, it is not generally within the operator's ability to match traffic growth and aircraft size variation requirements closely without acquiring new aircraft. Figure 1 is an attempt to show the growth in aircraft seating capacity for different types of aircraft that includes developed and stretched version and in-service and proposed new aircraft. The figure also illustrates a seating capacity gap between 100 and 200 that apparently exists for in-service aircraft. The procurement of additional aircraft and increased integration of service with major carriers can lead to new growth opportunities for the regional industry. From a fleet once made up of general aviation-type aircraft, the future regional airline fleet will increasingly be made up of a larger variety of more sophisticated aircraft. Thus, for purposes of this study, it was deemed necessary to define the future commuter transport aircraft.

Historically, the concept of short-haul or long-haul transports has had a range associated with it that has increased with the passage of time and the advance of technology. Inherently, there has also been an increase in speed associated with range. In this context, there appears to be a real plateau in the near future for short-haul transports.

The short-haul aircraft is one that is designed as the most efficient vehicle for a given short-stage length, while being capable of stage lengths that are 3 to 4 the short-stage length with full passenger capacity (between 100 and 200 passengers). A strictly short-haul aircraft, would gain on the short ranges by not being penalized with the full load range requirements but would, of course, not generally find favor with the operator because of its inflexibility.

Feeder-type aircraft generally are smaller in size (between 50 and 100 passengers) but often are capable of stage lengths similar to that for short-haul aircraft. For this study, a regional/commuter transport is defined as an aircraft with flexibility that includes the capacity of performing a multi-hop operation without refueling, thus minimizing ground time and requiring a high maximum landing weight greater than 95 percent of maximum takeoff weight.

Market Forecasts and Influences

World Issues

A generally accepted forecast of the traffic for total world transports (ref. 12) is shown in figure 2. The only world areas excluded are the Peoples Republic of China and domestic operations in the USSR. The overall trend (fig. 2) in revenue passenger miles (RPM) suggests a steady decline in the average percentage growth per year although the historical and forecast annual growth continues to steadily increase out to the year 2005. This world and U.S. forecast represents a doubling of traffic between 1990 and 2005. Obviously, the projection of demand is dependent on the gross domestic product (GDP) and airline fares. The projected trends in traffic for the United States, non-United States and world in figure 2 are based on the annual GDP forecast growth rates (ref. 12) shown in figure 3.

Currently, the commuter market appears to have too many aircraft entrants, too many potential customers, and too few customer dollars. There are at least 20 manufacturers from which about 500 airlines worldwide will order a forecast 3000 aircraft by the next decade. A forecast growing commuter/feeder market worldwide (ref. 2--3) needs access to a reasonable choice of modern aircraft with a low purchase price and operating cost and with high passenger appeal. Satisfaction of this need may only be met with fewer manufacturers with sufficient resources to invest in a new development program with the potential of a reasonable return.

The goal of the European Economic Community (EEC) is to create a single internal market by the end of 1992 (ref. 13). The European Regional Airlines Association (ERA) (ref. 13) members include 42 airlines, 21 manufacturers, 20 airports, and 33 other companies and organizations. This EEC goal would serve as a growth catalyst (fig. 3) and free movement of people, goods, and capital between the already congested member states. Today, the European regional industry is in a similar position as the U.S. regionals were immediately following deregulation. Overall, European passenger traffic has experienced recent growth increases of nearly 17 percent per year (ref. 14). This trend is expected to continue with those whose regionals are entering similar code-sharing agreements as those which exist in the United States. Currently, almost 70 percent of ERA member airline operations link regional airports with the large hubs. Denial of access to Europe's hub airports would likely spell economic disaster for the continent's regional airlines and airports (ref. 13).

Through the year 2000, the Asia Pacific rim countries (refs. 15 and 16) are expected to lead the world in GDP growth, averaging more than 5 percent per year (fig. 4), according to Boeing (ref. 12) forecasts. Based on this economic growth, Boeing further predicts that by the end of the century, 12 percent of all Asians will take at least one flight a year, compared with 6 percent today. Intraorient travel will represent most of the traffic growth (increasing at about 8 percent per year). About 40 million passengers are forecast to travel within the Pacific rim in 1993, up from 17 million passengers in 1983. About 50 percent of this traffic is to be generated by northern Asian countries, primarily Japan. If this vibrant Asian market trend continues as predicted, a significant increase in aircraft orders and a larger transportation network will be required to meet demand.

U.S. Issues

The annual percentage changes in the U.S. regional and major airline traffic growth (ref. 2) are shown in figure 4. Regional carriers flew 3.266 million hours in 1989 compared to 1.390 million hours in 1979. They improved flight schedules, increased aircraft speed, and trip length for more frequent service. Figure 5 shows historical and forecast passenger enplanements and RPM's for the U.S. regional airlines (ref. 2). Enplanements are forecast to double by the year 2000 from the 37.4 million in 1989. Similarly the RPM's are expected to double.

While growth in the regional airline industry seems to be robust, it is far below that speculated by the industry following deregulation. "Hub-spoke" operations have increased competition in a majority of city-pair markets, but at hubs dominated by one carrier, competition is reduced on dense, short-haul routes (ref. 2). The apparent additional traffic generated with a maturing market will produce a diminishing percentage growth. Thus, in the absence of a pronounced economic downturn, traffic in the next several years should show growth of around 5 percent per year (figs. 2-5), beyond which a downward trend in growth rate might be expected toward an anticipated domestic growth rate of around 3 to 5 percent.

Airport congestion, is already a serious problem and could get worse with the projected traffic growth. If not remedied, this could have a depressive effect on airline growth. For example, if the market for regionals is restricted to its current role of providing feed to the major airlines hubs, then the commuter industry growth may become limited due to available slot competition. In general, code sharing with a major airline is accepted as a key to success. In 1989, the top 50 regionals in the United States carried over 96 percent of all regional traffic (ref. 2). Either directly or indirectly, the major airlines control almost 90 percent of regional traffic. It seems highly probable that more major airlines will attempt to wholly own their feeder carriers in order to increase overall efficiency such as in the use of aircraft, equipment, and terminal slots. However, opportunities for growth do exist. Routine delays in the U.S. air transportation system, due to serious air terminal and air traffic congestion, will increase public discontent with service through hub airports. Assuming that the hub and spoke system is here to stay, the regionals may be able to experience dramatic growth by offering a wide scale substructure of point-to-point routes that bypass congestion at connecting hub airports.

The increasing availability of larger, faster turboprop or jet aircraft with longer range, will give the regional airlines the flexibility to efficiently take advantage of potential overall system problems. They may, for example, extend their service area with longer spokes as feeders to hubs; accept routes that may be given up by major airlines in favor of more profitable routes; and provide additional point-to-point service in order to free up capacity at hub airports.

According to the U.S. Commerce Department's statistics, manufacturers in the United States have in the past maintained a dominance in aircraft production, and consequently, trade balance (fig. 6a and b) that has served to offset the trade deficit resulting from other industries. The total economic impact of commercial aviation (airline and airport operations, aircraft manufacturing, general aviation) in the United States has been estimated by the Partnership for Improved Air Travel (PIAT) to be about $595 Billion in 1990 or 5.6 percent of the gross national product (GNP). However, in future years this percentage for the wide-body aircraft trade surplus for the United States may gradually decrease. The highly subsidized Airbus consortium (ref. 17) has gained significant worldwide and U.S. market shares in the wide-body aircraft trade (projected to be around 30 percent of the world market). While the United States continues to hold a competitive edge in the wide-body (fig. 6b) trade (ref. 12), regional transports are produced almost exclusively outside the United States. The dramatic downturn in the U.S. trade balance since the early 1980's for general aviation and commuters (fig. 6a) is believed to be due to the combined shift in advanced commuter aircraft design and lower production costs to foreign nations and the liability insurance costs to the U.S. manufacturers of small private aircraft.

Aircraft Trends

Fleet Size

The U.S. Regional Airlines Association (ref. 2) reported a total operational fleet of 1,907 aircraft in 1989. Sixty-eight percent of the total fleet were turboprop aircraft which contributed about 85 percent of the 3.25 million total flying hours. Only 2.2 percent of the aircraft were jet powered. Figure 7 also compares the U.S. historical and forecasted regional and major air carrier fleet (ref. 18).

In the most highly developed areas in the world (United States of America and Europe), forecasters predict (refs. 12 and 17) lower traffic growth rates (about 6.5 percent) than in the rest of the world, in some cases only half as much from 1990 to 2000. However, the projected commuter aircraft unit builds alone, required to handle forecast world-wide traffic (fig. 2) by the year 2000 (ref. 2), adds up to a total of around 14,700. Airplane retirement potential is growing rapidly as the world fleet ages. Older airplanes (average age of about 15 years) are becoming more expensive to operate and maintain. Consequently, depending on retirement age assumptions, an additional number of commuter aircraft will be required as replacements. Boeing forecasts (ref. 12) over 3,500 commercial jet airplanes will be retired between 1991 and 2005.

Aircraft Size and Speed

From the fleet once made up of predominately general aviation type aircraft, the future regional airline fleet will be increasingly composed of larger, faster, and longer-range aircraft. For example, Federal Aviation Administration (FAA) market projection (fig. 8) are that the average seating capacity of such aircraft is expected to increase at an average annual rate of around 4 percent, rising from 19 in 1988 to 30 in the year 2000. The number of aircraft with under 15 seats (1/3 of the U.S. fleet in 1989) continues to decline. The FAA projects that only about 150 (7 percent of total) of the current smallest regional aircraft will be in service by 2001. Continued sales growth is expected in the medium-size aircraft (15-19 seats) over the next few years and will account for about one-third of the U.S. fleet. The greatest growth in the fleet is projected to be in the 20-40 seat commuters, that accounted for 17 percent of the total fleet compared to 8 percent for the larger aircraft. By the year 2000, these two larger class aircraft are forecast to account for about 63 percent of the total fleet. As of June 1990, the U.S. regional airlines alone had about 175 new aircraft on order and 200 options with seating capacity that ranged from 29 to 107.

Based on a recent study, there currently appears to be a growing number of 80 to 130 seat, all-new or derivative twinjet aircraft under consideration for service in the regional market around 1996 (ref. 11). Manufacturers' worldwide estimate this market to vary between 2,000 and 5,000 over the next 25 years, based on fleet replacements and growth of city-pair routes. The value of this market has been estimated by the manufacturers' to be between $60 to $150 billion.

A listing of some of the new or proposed regional aircraft being offered in the 1990's is shown in figures 9a and b. As can be seen, these aircraft have a wide range of seating capacity while increased speed and range are also of importance. However, of further significance is the foreign manufacturing dominance of these new aircraft being offered. Figure 10 summarizes the seating capacity, and figure 11 cruise speed variations with range for in-service and new or modified regional aircraft being offered. In general, the figures indicate the desire of regional airlines to purchase faster airplanes with increased passenger capacity in an effort to reduce direct operating costs (DOC). This allows a faster turnaround time, with more revenue passenger miles in a given day.

Figure 12 illustrates the block time variation with seats for several regional aircraft based on a 500 nautical mile stage length. The results show that small jet-powered turbofan aircraft have block times which are about 30 minutes less than the new generation turboprops. This reduced block time corresponds to about a 20 percent decrease in trip time. As the airlines move to increase size and speed, the average stage length will increase in order to feed their code-sharing partners. The corresponding duration of passenger discomfort will discourage the use of turboprops on the longer flights. While in the past, the turboprop engine was considered more efficient compared to turbofans for aircraft with small seating capacity, new demands have made the distinction less clear.

Operating Costs and Technology Influences

In 1979, fuel cost was reported as the major contributor to the overall direct operating costs (DOC) for regional aircraft operators as shown in figure 13, compared to ownership (insurance and maintenance, etc.) in 1989. The results shown for 1989 were taken from several different airline fleet operating data presented in the November 1989 issue of Air Transport World (ref. 19). The individual fleet size used for the calculations consisted of: 8 Dash-7's; 11 CVR-580's; 13 F-27's; 12 Dash-8's; 5 Shorts-360's; and 12 EMB-120's. While the fuel cost/gal has been significantly reduced over the10-year spread indicated, the total DOC has nearly doubled from 8.5 cents/seat-mile to 14.75 cents/seat-mile primarily influenced by increased costs due to ownership, maintenance, and crew. Assuming the cost of fuel and crew do not experience radical increases, growth of the regional aircraft fleet will be guided primarily by ownership costs.

Figure 14 compares the actual DOC against seats for the previously discussed individual regional turboprop and jet fleet data with similar 1989 results for wide-to-narrow body aircraft, taken from the March 1990 issue of Air Transport World (ref. 20). These larger aircraft fleets used in the calculations consisted of: 4 B747-400's; 32 B747-200's; 4 A320's; 33 B757-200's; 62 B727-200's; 3 MD-87's; 19 DC9-30's. Because of the combined smaller fleet and aircraft sizes, all of the new aircraft suffer from a lack of economies of scale and schedule or utilization inefficiency. This will not only affect operating costs directly but indirectly through lower average daily utilization. The results (fig. 14) clearly indicate a gradual decrease by a factor of 5 in DOC between 30-50 passenger (average DOC = 15 cents) and the 400 passenger (average DOC = 3 cents) aircraft. In terms of representing aircraft fuel efficiency, figure 15 summarizes the available seat-miles per gallon (ASM/GAL) against average stage length for a range of aircraft operational data. The values of ASM/GAL shown (fig. 15) were obtained by multiplying the seating capacity of each aircraft times the average stage length divided by the gallons of fuel burned. The larger the value of ASM/GAL, the greater the efficiency. It is clear from figure 15 that the larger jet aircraft with long stage lengths are the more fuel efficient. Thus, it seems that fuel prices still represent a large element of DOC after ownership and will, therefore, continue to be a driving factor for the introduction of new technologies.

To be competitive in the air transport market (fig. 16), it is mandatory to reduce the aircraft production costs through better and shorter design time, manufacturing, and validation (ref. 21-22). The question often asked by the aircraft manufacturers and the regional airlines industry was, "What do the aeronautical disciplines of propulsion, aerodynamics, airframe materials, avionics, and control systems have to offer those who regard them from the aircraft production cost (non-recurring cost, market acceptance, return on investment) or the airline operational cost (ownership, crew, maintenance, fuel, landing fees, navigation costs) viewpoint ?". In other words, technology innovation will be tied to the ultimate goal of providing real benefits to the operators in terms of lower costs and increased revenue potential, while ensuring safety factors (refs. 22 to 27).

When assessing the changes in direct operating costs as a result of applying new technology, the results depend not only on the changes in weight, fuel consumption, and maintenance, etc., but on the aircraft sales price. Figure 17 (ref. 22) attempts to illustrate the estimated effect of applying an arbitrary 5 percent change to several technologies on DOC. Obviously, all factors cannot be changed equally and the integrated effect will influence overall improvements. The results are based on a 100-seat aircraft with high bypass ratio engines and a 500 nautical mile range. However, the estimate (ref. 22) indicates that new technology improvements providing reductions in drag, engine SFC, and structural weight will change DOC between 2 to 3.5 percent. It is interesting to note that a change of about 3 percent in DOC can be realized from reduced flight time due to improved air traffic control (ATC). On the other hand, the production costs have been reported to represent a larger percentage (about 75 percent) of the initial price and of the cost of ownership (ref. 22) as shown in figure 18. Therefore, one of the most significant reductions in economics can result from improvements in production costs that are influenced by improved design methods, procurement, manufacturing techniques, and batch size. Because of the interrelated benefits, resulting from all aspects of advanced technology and proper application to various aircraft, it is not reasonable to establish precise values for the worth of individual technologies.

FUTURE MARKET FORCES

Constraints and Stimuli

As discussed previously, there are many factors that contribute to the market potential and direct operating costs and should be considered by the aircraft designer and operator. Various constraints that will influence growth and development are economics, fuel costs, airport congestion (fig. 19), environmental factors (figs. 20-22), and application of technology. Areas that may stimulate growth are electronic communications, advanced ground transportation systems, and trade balance.

All of the above indicated constraints and stimuli are difficult to quantify and prioritize in advance. It is clear that a major political conflict or economical downturn could lead to a war or depression, but, on the other hand, no explosive economic growth is anticipated worldwide. Therefore, it is understood that they are to be considered in the normal sense of growth and forecast.

Regional Aircraft -- New Market Issues

There are several unresolved issues facing industry as to how far can we go in improving aircraft technology in order to overcome the constraints of fuel conservation, noise and emissions, saturation of airspace and competition from surface transportation. To what extent can market requirements be met by applying technology to derivative aircraft rather than new aircraft? If market requirements cannot be met, what kinds of new aircraft should be developed or what radical changes to existing air-transport systems could be implemented? What new systems might emerge before the end of the century? Will the regional jet reshape the market? Do economics favor building a jet with fewer than 100 seats? Will new-technology high-speed turboprops provide the same seat-mile operating cost as for similar jets when applied to aircraft with twice the seating capacity? Can the regional jet be used to bypass major hubs as a "high-density feeder" and reduce air traffic congestion? Will more and more regional travel be linked to travel with the major airlines? Will the regional industry continue consolidation of carriers while the market expands?

IMPACT OF TECHNOLOGY

Advanced Technology Influence on DOC

The design of an all new aircraft certainly offers a unique opportunity to introduce the combined improvements from advanced technologies generated in the various aeronautical disciplines while at the same time it can introduce high risk to investors. A new design will require a large initial investment in non-recurring costs which can only be recovered if the market accepts the product with its beneficial influences in sufficient numbers to ensure a timely return on investment.

Technology advances anticipated in the next several decades are expected to represent a steadily improving state-of-the-art in all the major disciplines. Except for possibly laminar flow wings, no radically new technology which has not already begun in modest application is envisioned. Therefore, the aim will be to single out some of the major areas where identified advanced technology developments (fig. 23) and future applications could contribute to overcoming the constraints and reducing costs. The main technology targets include aerodynamics, structures and materials, propulsion, systems and equipment, active controls, flight deck, and noise. The inter-relationship of these technologies is very important and the beneficial gain is dependent on how the technologies are used to give the best overall result. A rough estimate of DOC can be determined based on evaluating technology trade-offs while holding the target performance requirements constant (ref. 23) as follows:

1. $\Delta DOC\ (\%) = 0.12\Delta\ \text{fuel} + 0.35\Delta\ \text{Price} + 0.15\Delta\ \text{MTOW}$

2. $\Delta \text{Price}\ (\$) = 3.8 + 4.0\ T/T_o + 2.5\ S/S_o + 5.7\ W/W_o$

where T = SLST of the engine

S = severity factor on systems and landing gear
W = airframe weight less engines
T_o, W_o, S_o = reference conditions
Δ = change

Calculations were made without finance cost included and based on the assumption that the changes in fuel cost and airframe price with maximum takeoff weight are strong functions of DOC changes. The airframe price changes (DPrice) were based on engine data, systems severity factor, and airframe weight less engines. Fuel price and maximum takeoff weight are based on current price and design weights. It should be emphasized that the DOC results calculated by this approach are rough and simplified. It is especially difficult to estimate the maintenance and airframe labor per flight hour based on weight which will tend to reduce the expected benefits.

Figure 24 is an attempt to estimate the influence of potential advanced technology applications on DOC for a market forecast new regional aircraft having propfan engines, 100 passenger seating capacity, fuel at $1/US gal, 1500 block-hours/year, and 500 nautical miles stage. The most important result is that DOC can be strongly influenced by advanced airframe technology. The most obvious contribution comes from airframe cost reduction that is price dependent, with the next being fuel and crew of nearly equal magnitude. Financial costs are not included. The following paragraphs list technology influences (See fig. 24) based on detailed discussions presented later.

Crew--safety requirements will continue to demand a minimum of two crew. Emphasis will be placed on more efficient time utilization and reduced work load by active control systems. A potential long range forecast will include an ergonomic cockpit. Computer integration and fully integrated displays will boost both ground and aircrew mobility and productivity. A maximum Influence of 20 percent is estimated.

Airframe--the production costs constitute a very large percentage of the initial cost and of the cost of ownership (depreciation, interest, etc.,). Reductions in economics can stem from improvements in integrated design, manufacturing techniques, production learning along with quality and market quantity. A maximum influence of about 40 percent is estimated.

Fuel-prices will continue to be a driving factor for the introduction of new technologies. To fully realize the potential fuel savings for next generation engines will require an integrated design approach involving aircraft systems, aerodynamics and structures. The potential gains will further be weighed against problems posed by generated noise and vibration, blade retention, and limitations on size, speed, and aircraft configuration. A maximum influence of about 20 percent is estimated.

Maintenance--savings can be generated by computer-controlled digital avionics through centralized fault detection displays, cabin intercomunication, data reporting systems that can reduce maintenance training and tracking, engine and airframe spare parts orders that reduce overall turnaround time. A maximum influence of around 11 percent is estimated.

The above estimated individual technology influences on DOC can obviously amount to millions of dollars in savings unless extra development and production costs along with engine price for a new aircraft prohibit any improvement of return on investment.

Technology Opportunities

In general, recent technology developments have been directed toward application to large transport aircraft. However, these same developments may have potential application to future larger commuter aircraft design. Technology opportunities subsequently follow.

Advanced Wing Design

Numerous referenceable papers have been published in recent years on the progress made in advanced wing design and their performance potential since the development of the supercritical wing. This progress can be summed up in terms of the drag divergence Mach number variation with thickness-to-chord ratio as shown in figure 25. Obviously, a trade must be made between increased design cruise speed due to thinner wings, and increases in thickness that permit use of higher aspect ratios with less weight penalty and increased lift-to-drag ratios. Some of this technology has been implemented in the design of advanced aircraft. In a simplified way, figure 26 is an attempt to show relative efficiency of advanced wing technology in terms of the equivalent improvement in wing thickness-to-chord ratio, lift coefficient, and Mach number normalized for the effects of wing sweep. The ultimate goal is to achieve a relative efficiency of E = 1.0 for wing design through the following well established and combined performance parameters:

(3) $E = M_{\perp} + 0.86\,(t/c)_{\perp} + 0.12\,c_{l\perp}$

where $M_{\perp}$ = Mach number normal to leading edge

$(t/c)_{\perp}$ = thickness-to-chord ratio normal to leading edge

$c_{l\perp}$ = lift coefficient normal to leading edge

The constants in equation (3) are based on fairings of a large data base generated over the years for individualized parameters (see for example ref. 22) that evolved from advanced designs. A net change of $M_{\perp} = 0.01$ being equivalent to a net change of around $t/c_{\perp} = 1$ percent is seen in figure 26 to be representative of the progress over the past several decades. Finally, improvements in overall aerodynamic efficiency (ML/D) of around 15 percent have occurred over the past 15 years (refs. 22-23).

Laminar Flow Technology

The overall aerodynamic performance of an airplane is, in general, characterized by the lift-to-drag ratio which is a strong function of the wing aspect ratio. Historically the lift-to-drag-ratio seems to be leveling out. Thus, recent and future technology efforts will continue to be directed toward achieving laminar flow (through natural or controlled means), giving the potential for large drag reductions over the wings at cruise lift conditions (ref. 28). The advent of natural laminar flow (NLF), laminar flow control (LFC) or hybrid combinations of NLF/LFC along with high lift devices have been a major factor driving new designs and should influence DOC.

In the late 1970's, NASA began weighing the benefits and costs of the laminar flow technology. Design and testing of advanced airfoil concepts in the NLF and LFC class has grown steadily since then. A summary of the experimental verification of design performance results is shown in terms of maximum lift coefficient $(C_l)_{max}$ (fig. 27) and minimum drag coefficient $(C_d)_{min}$ (fig. 28) variation with chord Reynolds number R_c, for these latest NASA developed NLF airfoils (ref. 29). The results indicate reductions in drag as high as about 60 percent are possible. This could result in increases of 15 percent in the lift-to-drag ratio. Of further importance is that essentially no loss in the lift curve slope occurs when boundary layer transition is fixed in the leading edge--only the drag increases to that of an equivalent turbulent wing as expected (fig. 29). While these results proved promising, much work remains to be done to establish practical design and fabrication solutions and operational viability of this technology.

Analysis using both wind-tunnel and flight natural laminar flow (NLF) experimental data as input to compressible boundary-layer stability codes (ref. 30) shows that instability (Tolmein-Schlichting waves, T-S or crossflow vortices, CF) builds up with increasing chord Reynolds number (Rc), leading-edge radius, and wing-sweep angle (ref. 31). The effect of leading-edge sweep (Λ) on experimental transition Reynolds number (Rtr) for these data is shown in figure 30 for a range of Mach number and Rc. Correspondingly, the nominal limits of NLF in terms of Rc and sweep are shown in figure 31 and are based on expeirmental flight data and infinite swept-wing computations (with a typical favorable pressure gradient) as indicated by the line fairings. Sweep-induced crossflow effects become dominant above about 15 degrees (figs. 30-31). A typical NLF wing with moderate sweep (12 degrees), high aspect ratio (9-10) and low taper ratio is shown in figure 31 for short-haul aircraft.

From figures 30 and 31, it is assumed that NLF could be maintained over 50 percent chord of the upper and lower wing surfaces. NLF was assumed to extend over 80 percent of the span. Thus, based on the experimental laminar and turbulent variations of total drag with Rc, shown in figure 32 for several high-speed airfoils of different thickness ratios ($0.12 < t/c < 0.16$) and lift coefficient of $C_l = 0.6$, friction drag reductions of the order of 50 percent are anticipated. Figure 33 shows example drag polars for a swept NLF airfoil concept with and without fixed transition. Since the wing is expected to contribute about 50 percent of the total aircraft friction and pressure drag, realization of this amount of NLF would save about 10 percent of the aircraft cruise drag. However, since the maintenance of NLF is known to vary with lift coefficient, altitude, and speed, laminar flow is expected to be lost at takeoff influencing the block fuel consumption.

It should be noted that, even with fixed transition on advanced technology NLF wing designs, good performance characteristics have been demonstrated to exist for both wind-tunnel and flight tests (figs. 29 and 33). However, NLF wings are known to exhibit earlier drag rise with Mach number than that for turbulent wings. Furthermore, the application of conventional leading-edge slat or flaps for high lift will likely trip the flow, especially at low speeds.

High Lift Aerodynamics

Equally important, are the low-speed characteristics and high-lift devices required for improving takeoff and landing performance (L/D) while maintaining weight and cost efficient systems to minimize ownership expenses. A comparison of flight data for the variation in maximum lift coefficient with flap angle is shown in figure 34 (refs. 32-33) for several aircraft wing aspect ratios and trailing-edge flap configurations. Significant gains in maximum lift have been achieved through a combination of increased wing aspect ratio (AR) and advanced single slotted flap systems relative to double slotted flaps on equal or lower aspect ratio wings. Experimental flight results and theoretical limits of maximum lift coefficient are compared in figure 35. The data and theory diverge and indicate that an upper limit of maximum lift coefficient is being reached with unpowered flap systems as aspect ratio is increased (ref. 34).

While the limited data (fig. 35) for upper surface blowing (USB) indicate large gains can be made, the added complexity for such systems on commuters does not seem warranted at this time. Increased wing sweep tends to degrade maximum lift coefficient for a given configuration complexity as shown in figure 36 (ref. 34). Therefore, current and future high-speed wing commuter designs will require careful integration of high-lift systems on swept wings.

The potential performance improvement for a mechanical high-lift system is shown in figure 37 by using results from a wing with aspect ratio AR=8, sweep angle of 35 degrees, and flap-angle settings from 0 to 60 degrees (ref. 34). The potential performance gain over the range of conditions shown is seen to be that generated by the shaded band bound by the polar envelope of the data and ideal trend. Consequently, the large gains to be made in L/D are at higher values of lift (fig. 37) through improved understanding of the effects of compressibility (fig. 38), high Reynolds number (fig. 39) (ref. 35-37), and three-dimensional flow.

Propulsion

Fuel price increases in the early 1970's inspired manufacturers to develop the first high by-pass-ratio (HBPR) engines specifically for long-range transport aircraft (ref. 38). The primary design objectives of the engines were improved fuel consumption, reduced noise, reduced component weight penalty, higher turbine-inlet temperatures, and good operational and maintenance characteristics. As indicated by efficiency in figures 40 and 41 and classified in figure 42, future ultra-high by-pass-ratio (UHBPR) engines promise large fuel and propulsive efficiency improvements through lowered SFC (refs. 38 to 42). For current turbofans, this anticipated improvement may be lost by excessive weights due to the fan shroud and thrust reversers along with associated drag effects. The open rotor (unducted fan or propfans) and advanced ducted fans promise improvements of the order of 25 to 40 percent reduced SFC depending on the comparable turbofan chosen. Based on the same core technology, counter-rotating propfans indicate fuel savings of about 25 percent. These engines offer larger fuel savings and light weight, both of which must be balanced against the constraints posed by noise, vibration, blade retention, and limits on aircraft size, speed and configuration.

There appears to be an emerging international market for 80 to 120-seat transports (ref. 11) as illustrated in figure 1. Depending on size, speed, range, and utilization requirements, a single aircraft with advanced propulsion systems may not outweigh the advantages of an aircraft family in this same market that integrates all aspects of new and proven technologies in the areas of aerodynamics, propulsion and structures if the fuel price remains nearly constant. This economic gap between small and large aircraft is illustrated in figure 43 for new technology turboprops and jets (ref. 21). Individual design studies may very well indicate that, within the present or near term economic conditions, the turbofan could offer the better solution in terms of risk, development efforts, layout, and economics of a 80 to 120-seat aircraft.

The current prevailing wisdom regarding propulsion configurations for market forecast for larger, longer range transports is that ducted ultra-high by-pass engines will be required. This is supported by the continued high-cruise ($0.82 < M < 0.85$) speeds of large airliners, trends toward similar higher speeds for commuters, where the efficiency of the unducted propfan is reduced (fig. 41). The maximum takeoff thrust requirements projected for future high-speed commuters would be between 10,000 and 20,000 pounds.

An important factor in the selection and optimization of engine installation for commercial transport aircraft has always been the engine by-pass ratio. Improved engine specific fuel consumption (SFC) or DOC can be achieved through technology advances (ref. 38 to 42) in thermal and propulsive efficiency as indicated by the example in figure 44 which is for a turboprop (ref. 41). Thermal efficiency requires increases in overall pressure ratio, turbine inlet temperatures, and component improvements. Propulsion efficiency may be improved through increased engine by-pass ratio with corresponding reductions in fan pressure ratio. Whereas a two-stage high pressure turbine (HPT) is optimum using SFC as the criterion, a one-stage HPT shows up optimum on the DOC plot due to the savings in initial cost and maintenance based on studies of advanced technology engines by General Electric, Garrett, and Allison. Their results indicated that the advanced ducted propfans would be about 25 percent more efficient than the same size current engines and around 8-16 percent better than a second generation of engines. They are expected to weigh 10-20 percent less, cost within 10 percent, and require significantly less maintenance (fig. 45). At 100 nautical mile stage lengths, these improvements lead to 10-20 percent trip fuel reductions and 6-20 percent reduction in DOC depending on engine baseline and size (fig. 46). The indicated improvements in DOC are, of course, dependent on fuel price and pressure ratio (ref. 41).

As fan pressure ratio is reduced (bypass ratio increase), the direct-driven turbofan has to accommodate a number of factors that can reduce engine efficiency (fig. 47). Because the fan-tip speed reduces as diameter increases for a given thrust, the LP-shaft speed drops. This will lead to an increase in LP-shaft torque which compromises the design. The LP turbine will require stages of increasingly larger diameter to avoid unacceptable losses in efficiency. While the geared fan can overcome these problems, the gearbox inefficiency and installation penalties have to be taken into account (fig. 47).

Whether geared propfans or gearless UDF engines are considered in the aircraft design, the open rotors with helical-tip speeds greater than Mach 1 can cause more near-field noise than shrouded fans that tend to shield noise. This constraint along with heavier and required larger diameter for the same thrust may lead to configurational repercussions (i.e., cg location) that negate fuel-flow benefits.

Engine designs for significant SFC gains and aerodynamics for higher L/D are becoming more complicated and more difficult to achieve. This is due to attendant compromises on other aspects of the technical balance sheet such as weight, cost, reliability, maintenance, etc., and also in part to the DOC, regulatory and environment issues. Recent developments to meet forecast traffic demands suggest that high-bypass-ratio engines are going to dominate well into the next century (fig. 48) from reference 35. Even if UHB engines materialize in the near future, their rate of assimilation may be slow (ref. 40). The development of advanced high-temperature and light-weight materials, cost of replacement, industry capacity, and economic and environmental (noise and emissions) conditions will tend to drive the rate of change.

Noise Reduction

While the commuters and wide-body types of the 1970's and 1980's, with low and high-bypass-ratio engines, satisfy the present noise requirements (FAR 36 STAGE 3) as indicated by the data in figure 49 from reference 43, the narrow-body types with old technology and noisy engines will be phased out of operation by the year 2000 based on recent FAA regulations. Thus, under the ever-increasing impact of public pressure, the introduction of new aircraft with advanced technology, quiet engines will become of primary importance.

Figure 50 (reference 44) is an illustration of noise source variation with bypass ratio for turbofans and propfans. While many feel that a technology "floor" has been reached for reducing noise, it is reasonable to expect that the absolute level will increase with the development of larger thrust engines required for aircraft either under development or forecasted. However, there are those who feel that a potential break-through may come from research in active noise suppression by source frequency cancellation. Figure 51 shows noise reduction progress for conventional engines by comparing the noise footprint area of an advanced turboprop, typical twin turboprop, with the 90 EPNL noise level footprint of an advanced turboprop (ref. 44).

Quiet, economic air-transport systems can be achieved only as a result of an integrated approach by the engine, aerodynamic, and the airframe designer in close liaison with the aircraft operator. Judgments will have to be made to obtain the desired balance between noise and other major design parameters such as strength, weight, performance, economics, airworthiness and reliability. Although noise has become an increasingly important factor in determining the aircraft configuration and its operation, the achievement of quieter aircraft must not be compromised for safety.

Materials

Weight reduction continues to be one of the major objectives of airframe manufacturers. Reducing aircraft weight is one of the more effective ways of reducing drag, increasing payload and consequently, reducing the DOC. Thus, the development and application of advanced metallic materials and composites with embedded high-strength fibers has been progressive over the past several decades. Figure 52 shows the anticipated materials distribution and corresponding weight savings, resulting from their application (ref. 42), for an aircraft having the same geometry. There has been an increasing application of better aluminum alloys, steels, and titanium for primary structures as also shown in the figure. The application of composites such as glass fiber, Kevlar, and carbon fiber have steadily found their way on secondary structures and furnishings, and significant weight savings are anticipated over the next decade from their use. There is considerable speculation by U.S. manufacturers as to when composites will be introduced and accepted into the primary structures of civil aircraft (ref 45-46), even though Airbus (A300-310 vertical tail and A320 empennage), Beech Starship, and several military aircraft are flying today with carbon fiber materials in their primary structure.

Materials that are combinations of aluminum alloy and layers of composites and aluminum-lithium (Al-Li) have promise for considerable weight reduction, high strength, and damage tolerance. Of major importance is that these materials may offer improvements in structural efficiency, without changes in conventional design and manufacturing techniques or maintenance. However, manufacturing costs, life cycle fatigue, and inspection of such materials requires further research.

Avionics and Controls

One of the essential features of advanced aircraft is clearly going to be the integration of computer technology that includes controllers and fully integrated displays. This technology will allow improved flight management by providing cabin intercommunications, a constant watch on systems and information on a need-to-know basis (Automatic Flight System), and Air Traffic Control (ATC) functions. Integrated digital technology through computers will be crucial to fly-by-wire operations with full authority engine control. Such systems will enhance safety by ensuring that the aircraft will remain within its flight envelope, provide continuous monitoring of required information useful for maintenance purposes, and provide centralized fault or malfunction display (fig. 53). The Heads Up Display (HUD) system for example, allows Alaska Airlines to fly in fog conditions more often. There may be associated economic benefits due to overall reduced insurance fees with the onboard backup safety systems. All of these advanced features, when applied, can significantly increase the crew productivity.

Flight-path control systems (especially for approach and landing) have been effectively applied for many years. However, such technology continues to advance from the reliability and safety standpoint. When applied, more advanced systems for takeoff monitoring, thrust management and flight optimization will ultimately result in better fuel economy for commuter aircraft.

Active controls technology may permit increases in the flight envelope, speed, buffet limits, or allow different design configurations with weight savings, but still requires extensive research before incorporation into civil aircraft. One of the major complaints by commuter passengers continues to be that of "ride roughness." It can be shown (fig. 54) that the responses to the gust load factor (Dg) for various existing fixed wing aircraft (GA, commuters, transports) varies adversely with wing loading (W/S), for constant lift coefficient and gust velocity. Application of active controls may result in optimum design with improved W/S.

Future Market Scenerio

With the 21st century just around the corner, the aviation industry finds itself in a current mode of recovery and facing some hard facts for the future. Airport congestion has joined the more traditional problems of safety, reliability, profitability, and environmental compatibility. Thus, the action of the above-mentioned constraints and stimuli will influence the forecast market traffic and sales of regional or short haul aircraft.

Against this background and given the technology level of today's transports, it seems that the next generation of regional or commuter aircraft will be the product of a gradual evolutionary process based on market needs, rather than revolutionary or totally new designs. It appears unlikely that there will be massive change in air transport technology as obvious as, for example, the jet engine. Thus, the following summary is offered.

1. The future worldwide forecast "short haul" market potential is large (figs. 2 and 3).

2. The major forecast expansion areas not currently covered by their own aircraft production are Japan, China, Latin America, Africa, and the Middle East.

3. Implementation of new technology to reduce airframe manufacturers costs and to reduce direct operating costs to operators will be the key requirement driving aircraft design.

4. Problems forecast in air traffic control (ATC) saturation and airport congestion require solutions and will greatly influence regional airlines operations and future aircraft design.

5. Forecast for larger regional aircraft to handle traffic will require designers and operators to meet more stringent environment regulations (pollution, noise, emissions) and to improve passenger ride quality.

6. While the regional airline provides the future method for the businessman's travel, new communications systems will enter the market and provide competition.

7. The integrated effect from advancements made in aerodynamics, propulsion, and structures will continue to be effective in meeting forecast challenges.

CONCLUDING REMARKS

Both the U.S. and foreign commuter airline industry continues to experience a growth trend. In the past decade, the regionals have experienced a tremendous increase in revenue passenger miles (RPM) and number of aircraft used. The FAA predicts that, by the year 2000, the number of RPMs will more than double. Thus, reasonably firm conclusions can be drawn on the way the market will develop through the end of the century, with regard to developments in air transport systems and aircraft, barring any major unpredictable international domestic or economic situations. The conclusions on the market and operating environment clearly interlink with technical possibilities and the development of future air transport systems. Code-sharing agreements between small carriers and the majors will continue to be essential for the survival of regional airlines.

The regional fleet market is clearly demanding not only a large replacement of older aircraft for more economic and environmentally efficient aircraft, but with 80 to 130 seats due to forecast traffic. In fact, the smaller capacity in-service U.S. aircraft may now be considered in the emerging higher capacity commuter class. Currently, the production of commuter type aircraft is almost exclusively outside of the United States. This has led to a trade inbalance for these type of aircraft. A reversal in this trend requires the U.S. manufactures to enter the market in an aggressive manner. The aircraft configurations under development or projected are expected to provide substantial benefits to the operator, passenger, and the community due to the incorporation of advancing technology. In general, the regional airlines are moving toward more modern and effective fleets with greater passenger capacity and comfort, reduced noise levels, increased speed and longer range.

Technology disciplines will continue to advance and be directed toward improving both the economics and performance of aircraft. Whereas the benefits from individual technologies may be small, the overall integration in existing and new aircraft designs will continue to produce improvements in direct operating costs and competitiveness. Since production costs are equally as important as pure technical advances, research and development into means of improving manufacturing methods and production efficiency is paramount. Therefore, advances on a broad front are essential to remain competitive, especially in today's market.

The problems of saturation of the airspace, the airport, and the supporting ground facilities have emerged again and are forecast to worsen. It is, therefore, felt that necessary studies and research be conducted in a timely manner so that we are prepared for the implications of the forecast explosive growth in the air traffic system.

REFERENCES

1. Williams, Louis J.: Advanced Technology for Future Regional Transport Aircraft. SAE 1982 Transactions Sect. 3-Vol. 91. pp. 2481-2497.

2. 1990 Annual Report of the Regional Airlines Association. Deborah C. McElory, Editor.

3. Lopez, Ramon: U.S. Regionals See a Healthy Future. Interavia Aerospace Review, June 1990. pp. 462-463.

4. The Battle for Regional Power, Flight International, July 3-9, 1991, pp. 34-36.

5. Fotos, Christopher P.: Regional Airlines Must Strengthen Ties to Major Partners in Next Decade. Aviation Week and Space Technology, June 17, 1991. pp. 173-174.

6. Fotos, Christopher P.: Regionals Grapple With Era of Market Consolidation, Aviation Week and Space Technology, June 25, 1990. pp. 38-42

7. No Matter Who Owns Them, Feeders Need Entrepreneurial Spirit, L'Osservatore, Professional Pilot, January 1990. pp. 62-63

8. Gilson, Charles: Regional Jet Wars, Flight International, July 3-9, 1991. pp. 32-35

9. Lyson, M. W.: Jets, Props and the Airline Customer, Commuter Air International, September 1990.

10. In Service Regional Aircraft Charts, Interavia Aerospace Review, June 1990.

11. Miller, Barry: Crowding Out the 100-Seat Market, Interavia Aerospace Review, August 1991, pp. 29-33

12. Current Market Outlook, Boeing Commercial Aircraft Group, the Boeing Company, Seattle, Washington, DC, 1991.

13. Ambrose, Mike A.: Regionals are Vital for Tomorrow's Europe, Interavia Aerospace Review, June 1990, pp. 458-460.

14. Europe: Regional Airlines Spread Their Wings, Aviation Week and Space Technology, June 25, 1991.

15. Proctor, Paul: Strong Asian Economy Boosts Outlook for Airlines Industry, Aviation Week and Space Technology, May 27, 1991, pp. 85-87.

16. Asia-Pacific: The Projected Bright Spot for Sales, Aviation Week and Space Technology, June 25, 1990, Advertiser Sponsored Market Supplement, pp. 5-18.

17. Market Prospective for Civil Jet Aircraft, Airbus Industries (AL/CM-P 3120110/90), November 1990.

18. FAA Aviation Forecasts-Fiscal Years 1989-2000, FAA-APO-89-1, March 1989.

19. Aircraft Operating Data, Air Transport World, November 1989. pp. 138.

20. Aircraft Operating Data, Air Transport World, March 1990. pp. 146.

21. Hopkins, Harry: Family Matters, Flight International, May 9-15, 1990. pp. 38-39.

22. Brown, D. G. and K. S. Lawson: The Pay-Off for Advanced Technology in Commercial Aircraft Design and Operation, Aeronautical Journal, November 1976. pp. 4612-467.

23. Fischer, B.: Configurational Repercussions of New Technologies in the Design of a Regional Airliner, AIAA 89-2022.

24. Rek, Bron: Commuter Shop Window 1990, Interavia Aerospace Review, July 1990, pp. 4451-457.

25. Pilling, Mark: The 90-120 Seat Jet Race is on, Interavia Aerospace Review, August 1990, pp. 1096-1098.

26. Moxon, Julian: High Tech Commuter, Flight International, May 29 to June 4, 1991, pp. 69-70.

27. Pilling, Mark: Where is the Profit in Building Regional Passenger Aircraft? Interavia Aerospace Review, December 1990, pp. 635-639.

28. Natural, Laminar Flow and Laminar-Flow Control. NY Hussaini and R. W. Barnwell (editors), Springer-Verlag, 1991.

29. Harvey, W. D.; and Bobbitt, P. J.: Toward Lower Drag with Laminar Flow Technology. ICAS-88-4.1.2, August 1988.

30. Malik, M. R.; and Orszag, S. A.: Efficient Computation of the Stability of Three-Dimensional Compressible Boundary Layers. AIAA Paper 81-1277, June 1981.

31. Harvey, W. D.; Harris, C. D. and Brooks, C. W.: Experimental Transition and Boundary-Layer Stability Analysis for a Slotted Swept Laminar Flow Control Airfoil, Numerical and Physical Aspects of Aerodynamic Flows IV. Springer -Verlay, Edited by Tuncer Cebeci, 1990 , pp. 373-390.

32. Obert, E.: The Aerodynamic Development of the Fokker 100. ICAS-88-1.6.2, pp. 807-826.

33. Eggleton, B.: R and D in the Evolution of the Dash 8 Fifth Canadian Symposium on Advanced Technology Light and General Aviation Aircraft. Ottawa, Canada. May 28-30, 1984.

34. Dillner, Bertil; May, Fred W.; and McMaster, John H.: Aerodynamic Issues in the Design of High-Lift Systems for Transport Aircraft. AGARD-CP-365, May 1984.

35. Morgan, H. L.; Ferris, J. C.; and McGhee, R. S.: A Study of High-Lift Airfoils at High Reynolds Numbers in the Langley Low-Turbulence Pressure Tunnel, NASA TM-89125, July 1987.

36. Mack, M. D.; and McMasters, J. H.: High Reynolds Number Testing in Support of Transport Airplane Development (Invited Paper). AIAA 92-3982.

37. Valarazo, W. O.: High Lift Testing at High Reynolds Numbers (Invited Paper). AIAA-92-3986.

38. Fischer, B. and Klug, H.: Configuration Studies for a Regional Airliner Using Open-Rotor Ultra-High-Bypass-Ratio Engines, AIAA 89-2580.

39. Zimbrick, R. A. and Colehour, J. L.: Investigation of Very High Bypass Ratio Engines for Subsonic Transports, J. Propulsion, Vol. 6, No. 4, pp. 490-496, July-August 1990.

40. Peacock, N. J. and Sadler, J. H. R.: Advanced Propulsion Systems for Large Subsonic Transports. AIAA 89-2499

41. Strack, W. C.: Propulsion Opportunities for Future Commuter Aircraft, Eighteenth Joint Propulsion Conference, Cleveland, Ohio, June 21-23, 1982.

42. Robinson, P. and Brown, D. G.: Short Haul Transport for the 1990's, Aeronautical Journal, November 1979, pp. 413-436.

43. Janes - All the World's Aircraft (1984- 1992)

44. Brown, D. G. and Blythe, A. A.: Noise of Advanced Subsonic Air Transport Systems. Journal of Sound and Vibration (1975), 43(2) pp. 219-236.

45. Sweetman, Bill: Why Composites Wait in the Wings. Interavia Aerospace Review, April 1992, pp. 48-53.

46. Flint, Perry; and Donoghue, J. A.: Hidden Cost of High Tech. Air Transport World. July 1992, pp. 22-30.

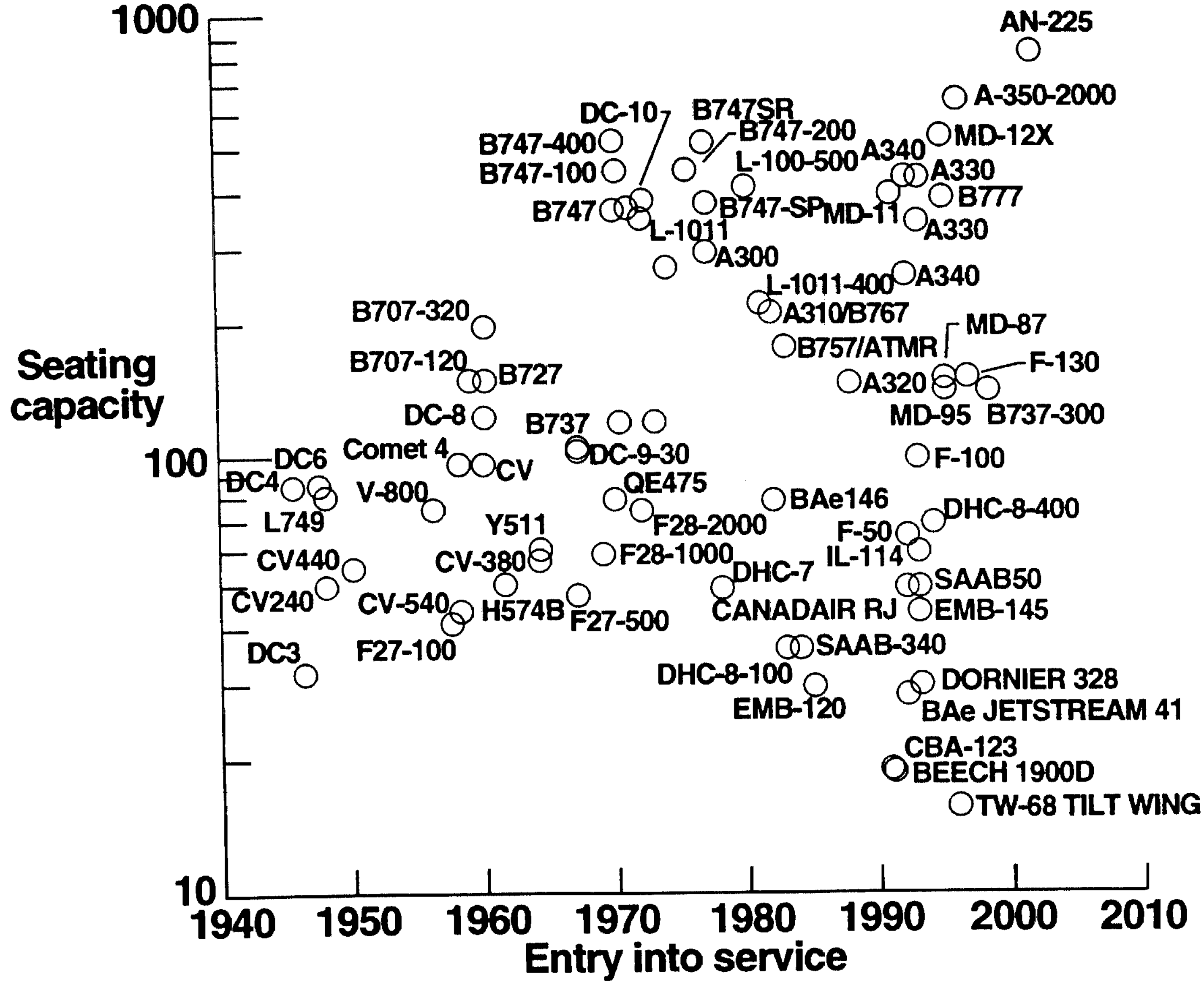


Figure 1. - Growth in aircraft seating capacity for in-service and proposed aircraft.

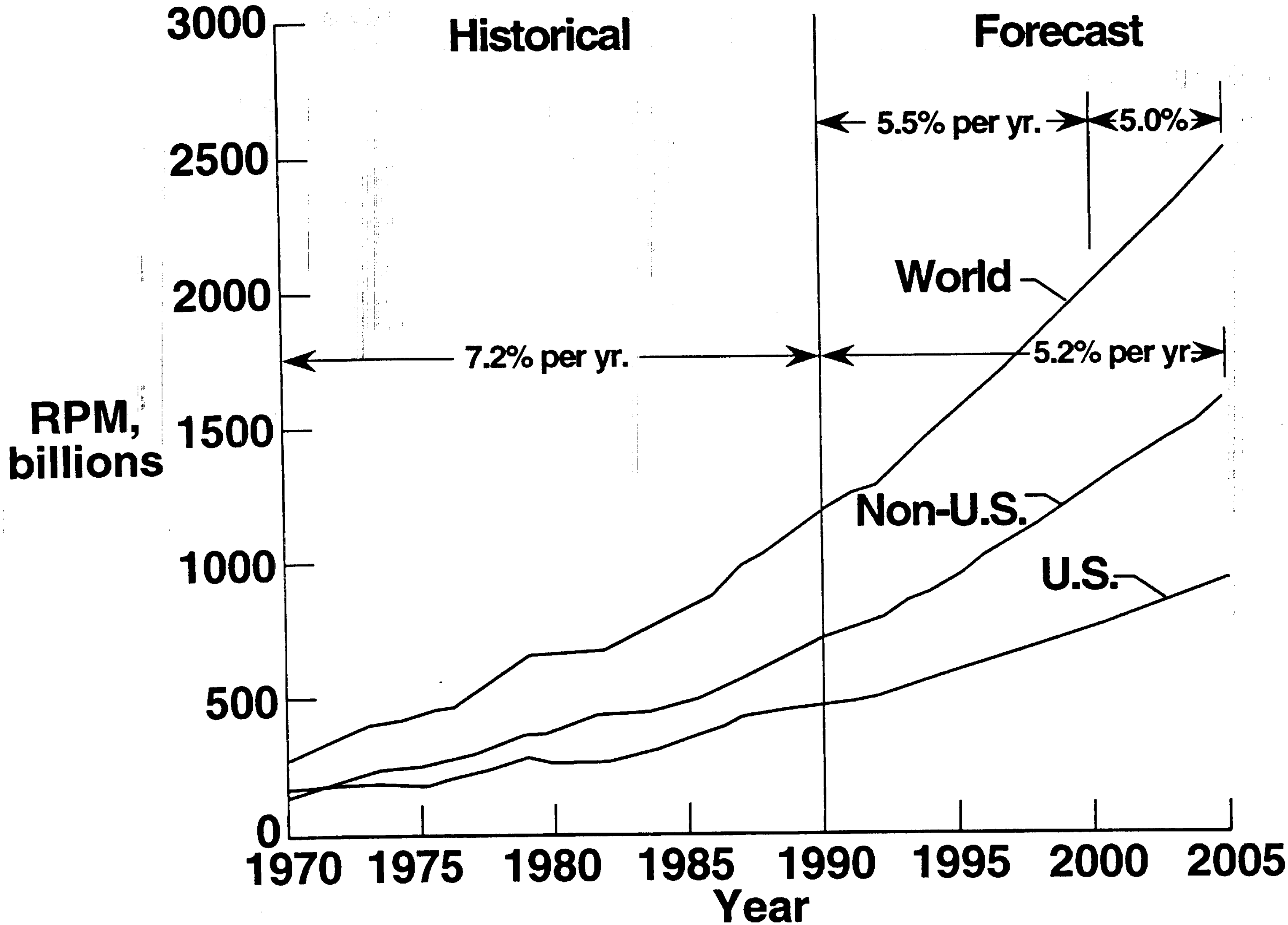


Figure 2. - World and U.S. Air Travel Forecast.

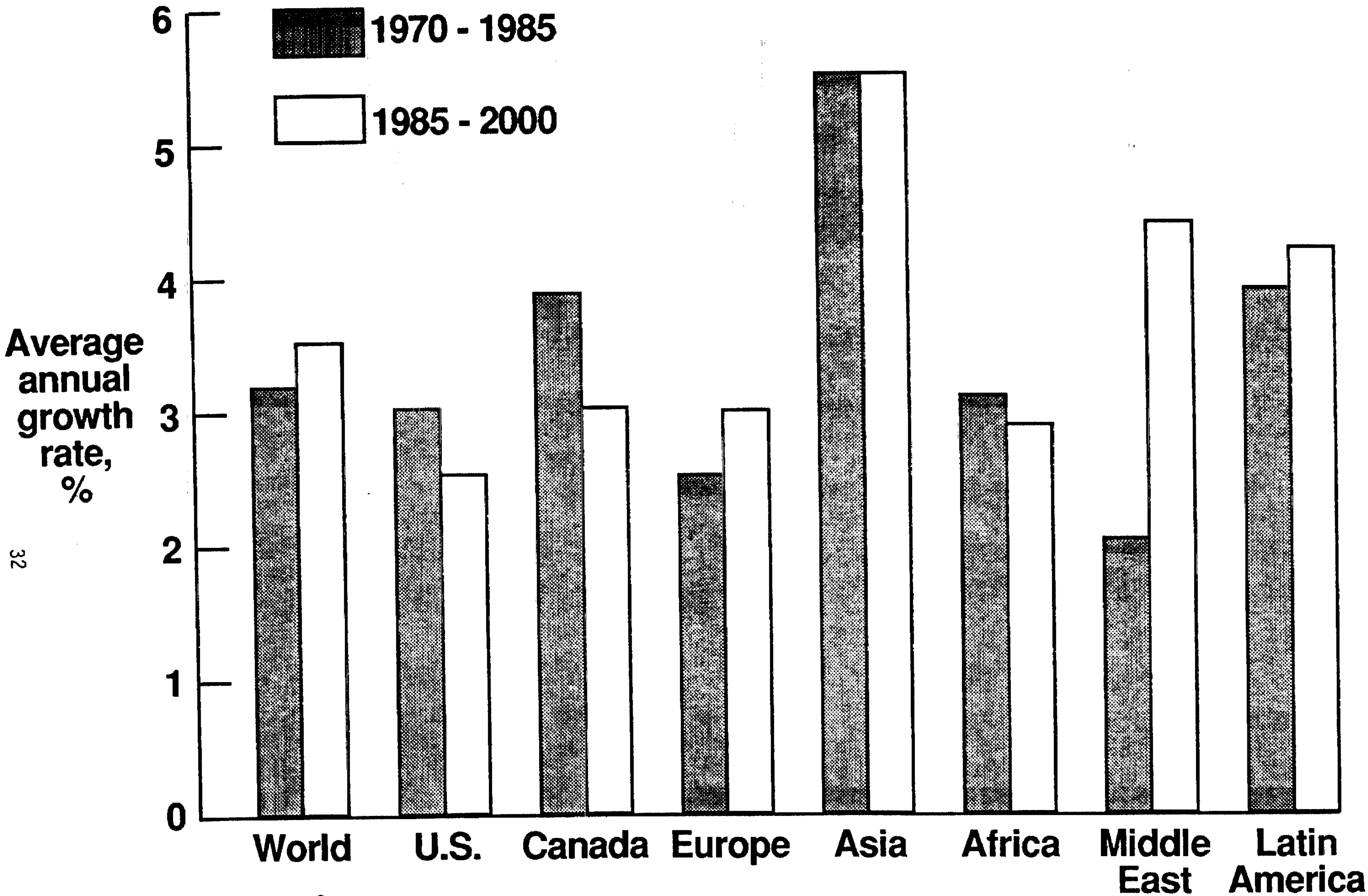


Figure 3. - Comparison of average annual gross domestic product (GDP) for several geographic areas.

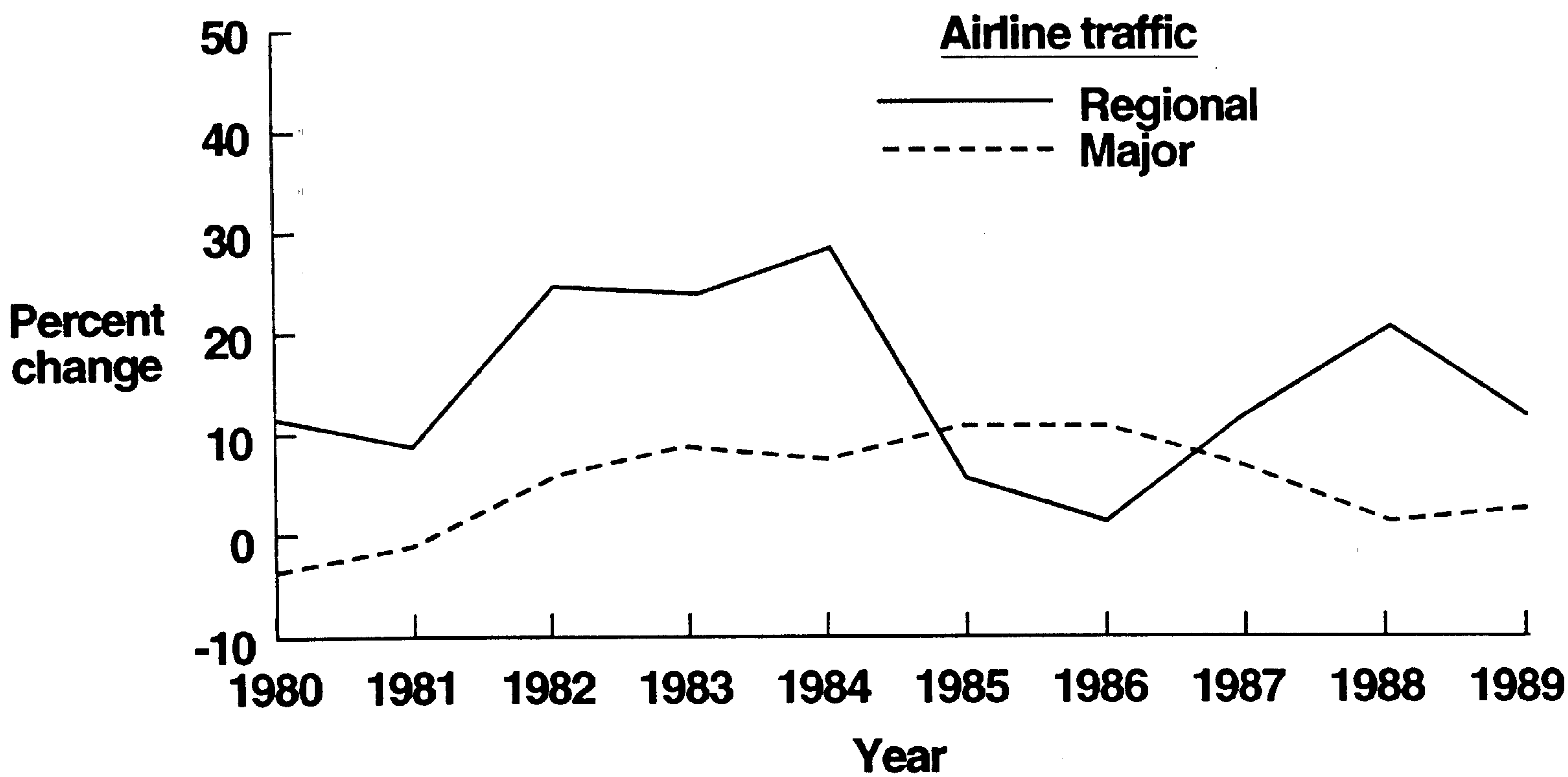


Figure 4. - Comparison of percentage change in regional and major airline traffic growth between 1980 and 1989.

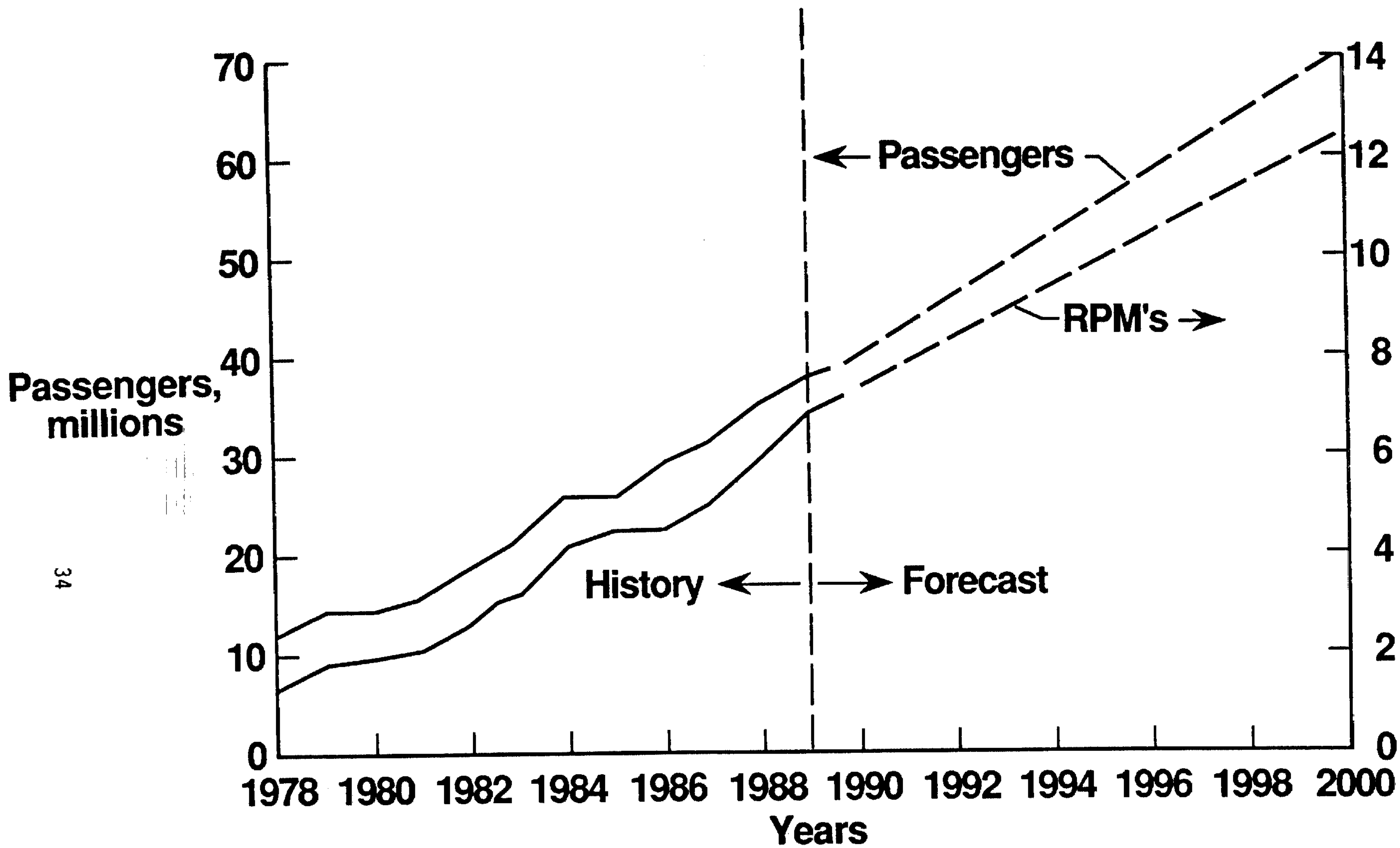
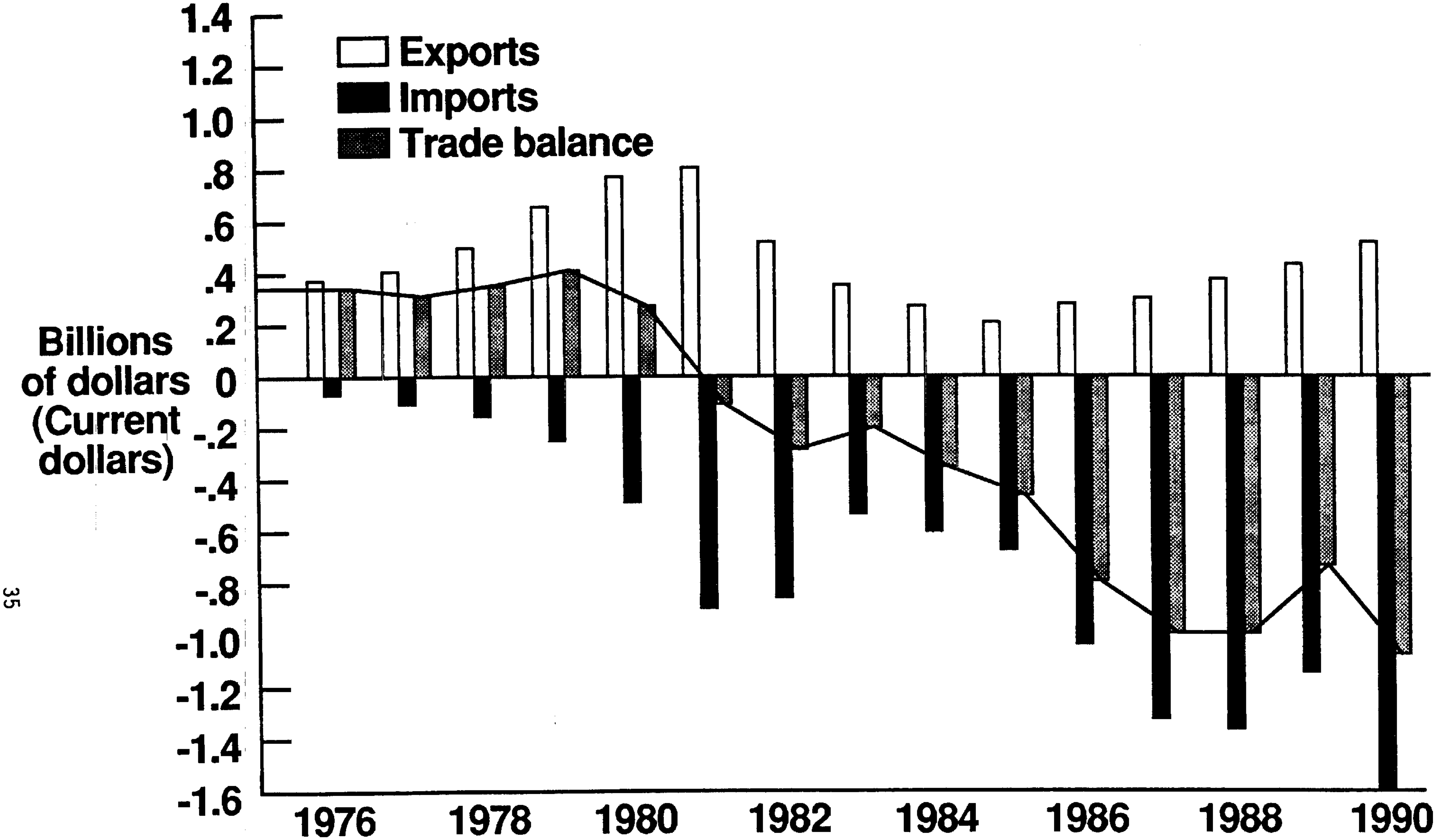
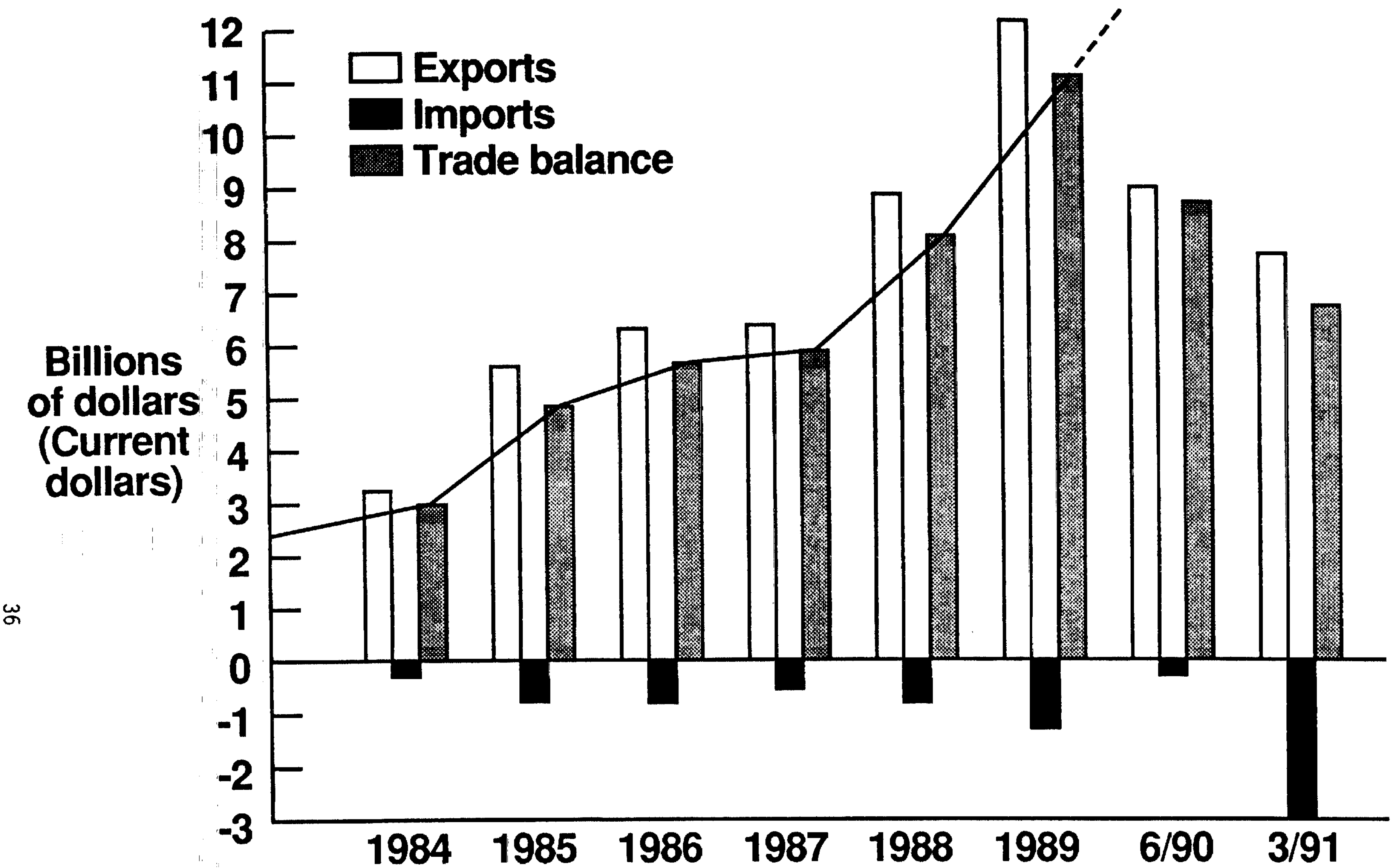


Figure 5. - U.S. regional airline passenger enplanements forecast.



(a) General Aviation and commuter aircraft.

Figure 6. - U.S. general aviation, commuter, and widebody aircraft trade balance.



(b) Widebody aircraft.

Figure 6. - U.S. general aviation, commuter, and widebody aircraft trade balance.

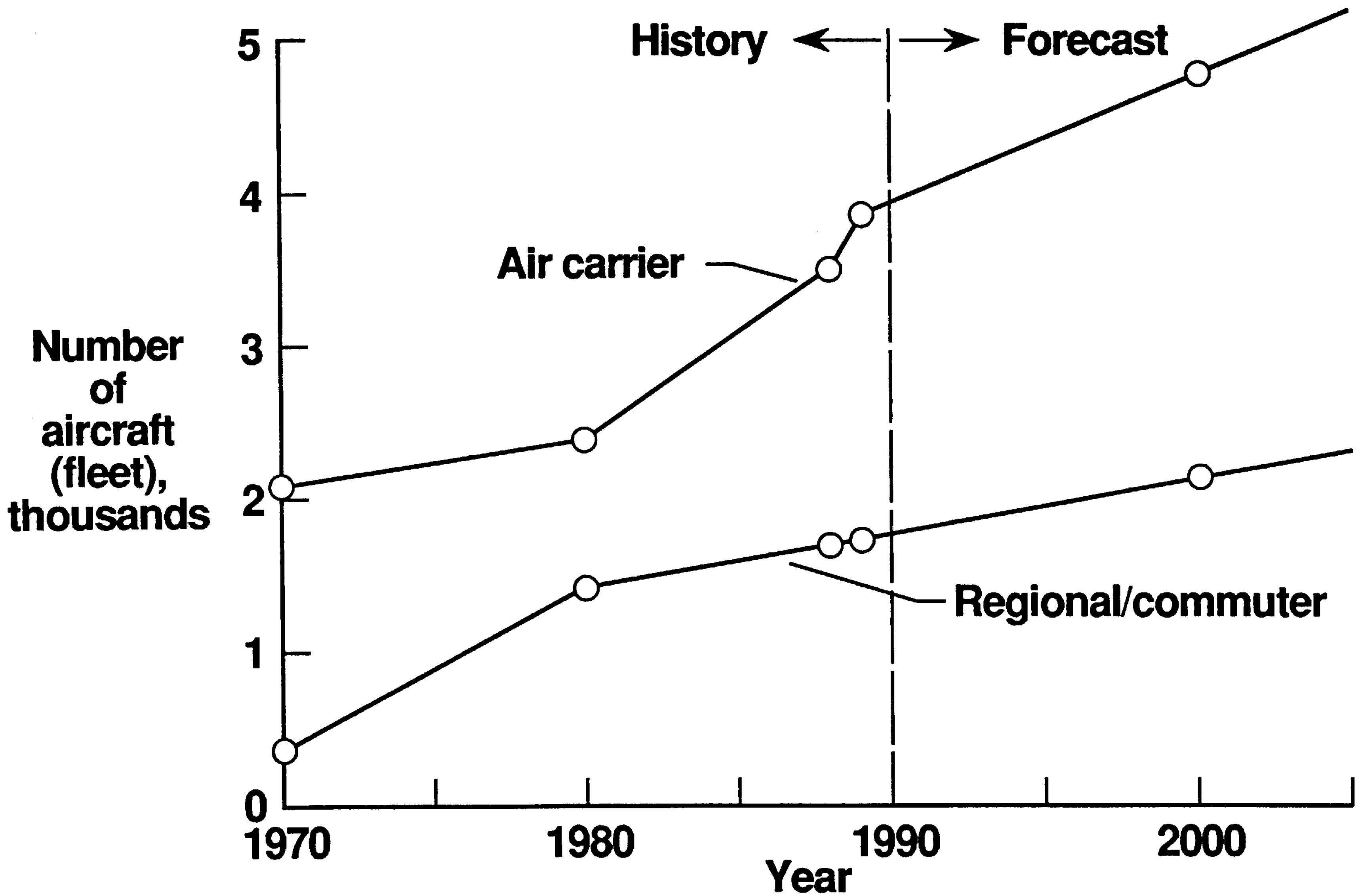


Figure 7. - U.S. airline aircraft fleet forecast.

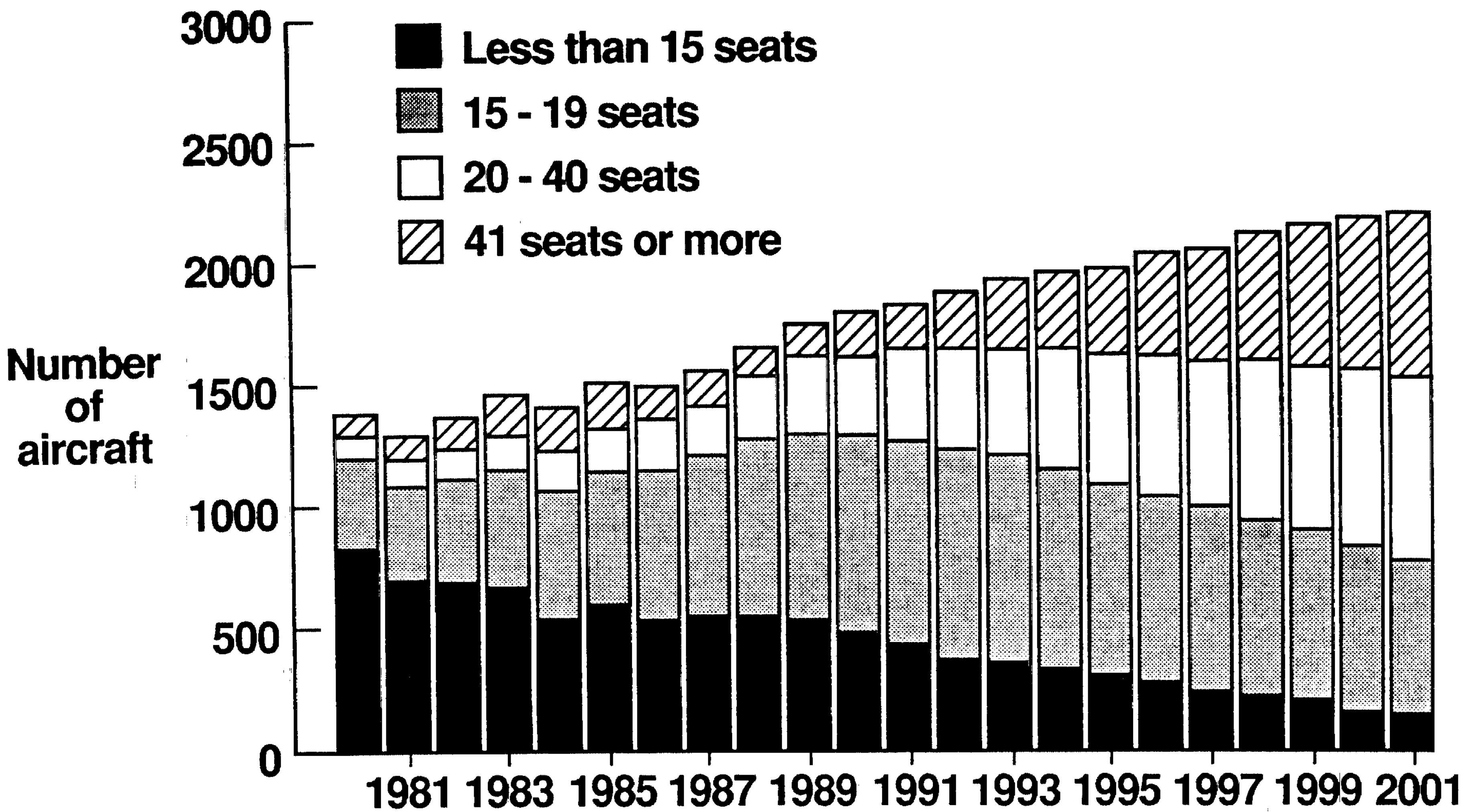


Figure 8. - Growth in average size of commuter aircraft seating capacity.

MANUFACTURER	AIRCRAFT	SEATS	SPEED (knots)	RANGE (miles)	COST ($ M)	ENGINES	ENGINE POWER	YR AVAIL.
Beech Aircraft	1900D	19	287	800	3.94	2XPT6A-67D	1280 SHP	'91
British Aerospace	JETSTREAM 41	29	295	590	5.5	2XTPE331-14HR/GR	1500 SHP	'92
Canadair	CANADAIR REGIONAL JET	50	459	781	16	2XCF34-3A	8729 lbs	'92
Boeing/DeHaviland	DASH 8 -400	70	350	1100			3500 SHP (Req'd)	'94
Deutsche Aerospace	DORNIER 328	30	345	700	7.2	2XPW119	2180 SHP	'93
Dornier Composite Aircraft	SEASTAR CD2	12	190	220	3.3	2XPT6A-135A	650 lbs	
Embraer	EMB-145	45	431	1180	11.6	2XGMA3007	6750 lbs	'93
Embraer/Fama	CBA123	19	350	780	4.85	2XTPF-351-20	1300 SHP	'91
LET	L-610	40	264	469		M602	1609 SHP	
Ilyushin	IL-114	114						'93
SAAB	2000	50	360	1340	13	2XGMA-3100	3650 SHP	'93
IPTN	N-250	50	300	800	9.5	2X ?		
CASA	CASA-3000	70	360	1000		2XGMA-2100		'96
McDonnell Douglas	MD-95	105						

(a) New aircraft.

Figure 9. - New or modified regional aircraft for the 1990's.

MANUFACTURER	AIRCRAFT	SEATS	SPEED (knots)	RANGE (miles)	COST ($ M)	ENGINES	ENGINE POWER	YR AVAIL.
British Aerospace (UK)	RJ70 (BAe 146-100 New wing)	70	425	930	18	Lycoming 4XALF502 (Derated)	6271 lbs	
T Ishida (Japan)	TW-68 Tilt wing	16						'96
Deutsche Aerospace (Germany)	Dornier 328(L) (20' stretch)	50	345	700		Pratt & Whitney 2XPW119	2180 SHP	
FOKKER (Holland)	F-50-200 (New wing + empennage)	64	410	1600		Rolls-Royce 2XTAY650	15100 lbs	
ITPN (Indonesia)	N-270 (N-250 stretch)	70						
German-Chinese	MPC-75 MPC-85	75 85						
FOKKER	F-50 (stretch)	66				Pratt & Whitney 2XPW127	2750 SHP	'92
	F-100(MTOW = 101K lbs + new fuel tank)	100		1700		Rolls-Royce 2XTAY650	15100 lbs	'93
	F-100 (stretch)	135				Rolls-Royce 2XTAY680	1800 lbs	
Aeritalia, CASA, Aerospatiale	AAC-90 AAC-120	90 120						
British Aerospace (UK)	RJ80 (BAe146-100)	80						
Canadair	RJ200(stretch)	70				GE 2XCF34		
USSR (Ilyukshin)	IL-114	60	270	540	~12	2XTV7-117		'93

(b) Modified aircraft.

Figure 9. - New or modified regional aircraft for the 1990's.

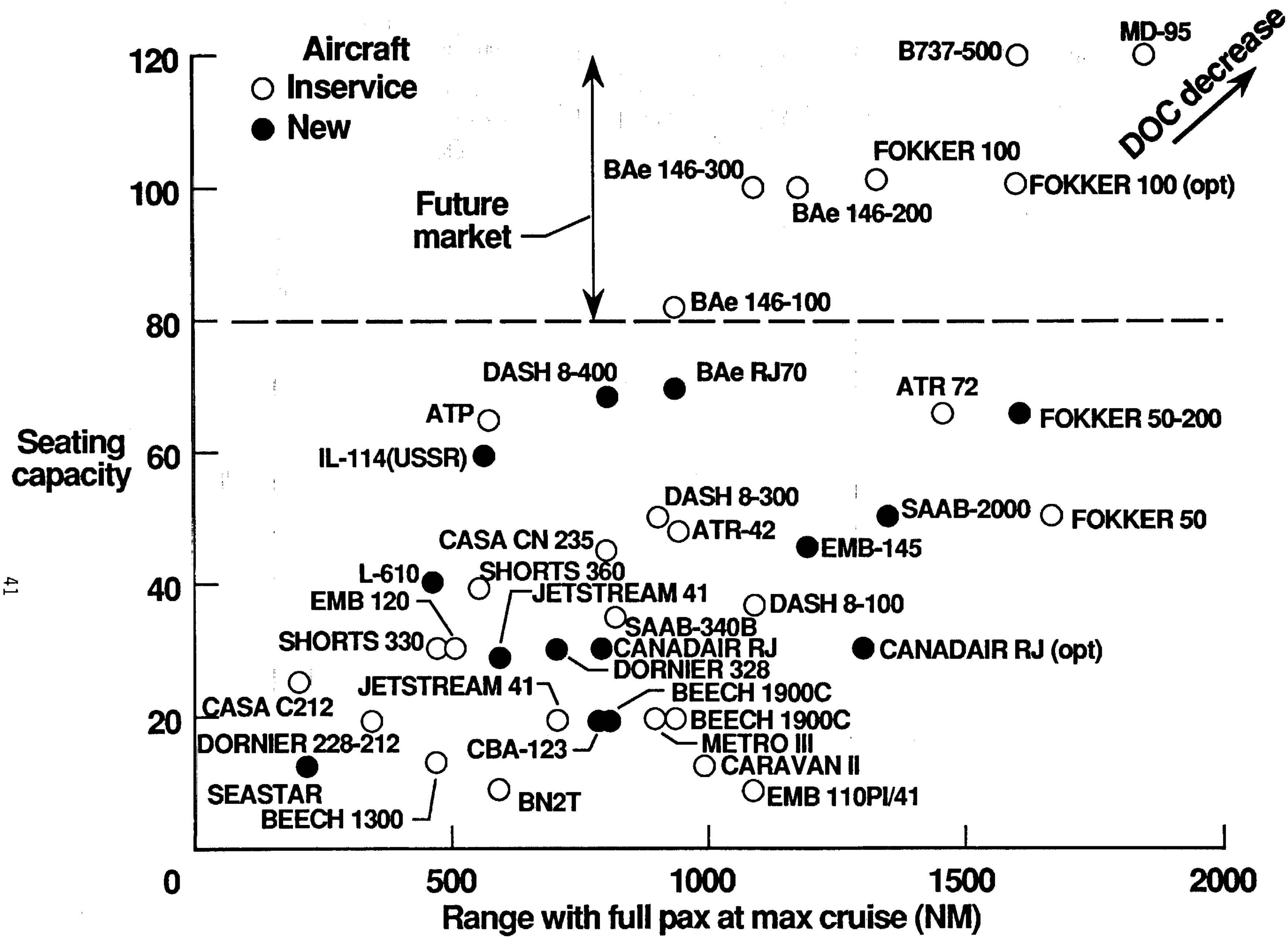


Figure 10. - Comparison of seating capacity with range for in-service and new regional aircraft.

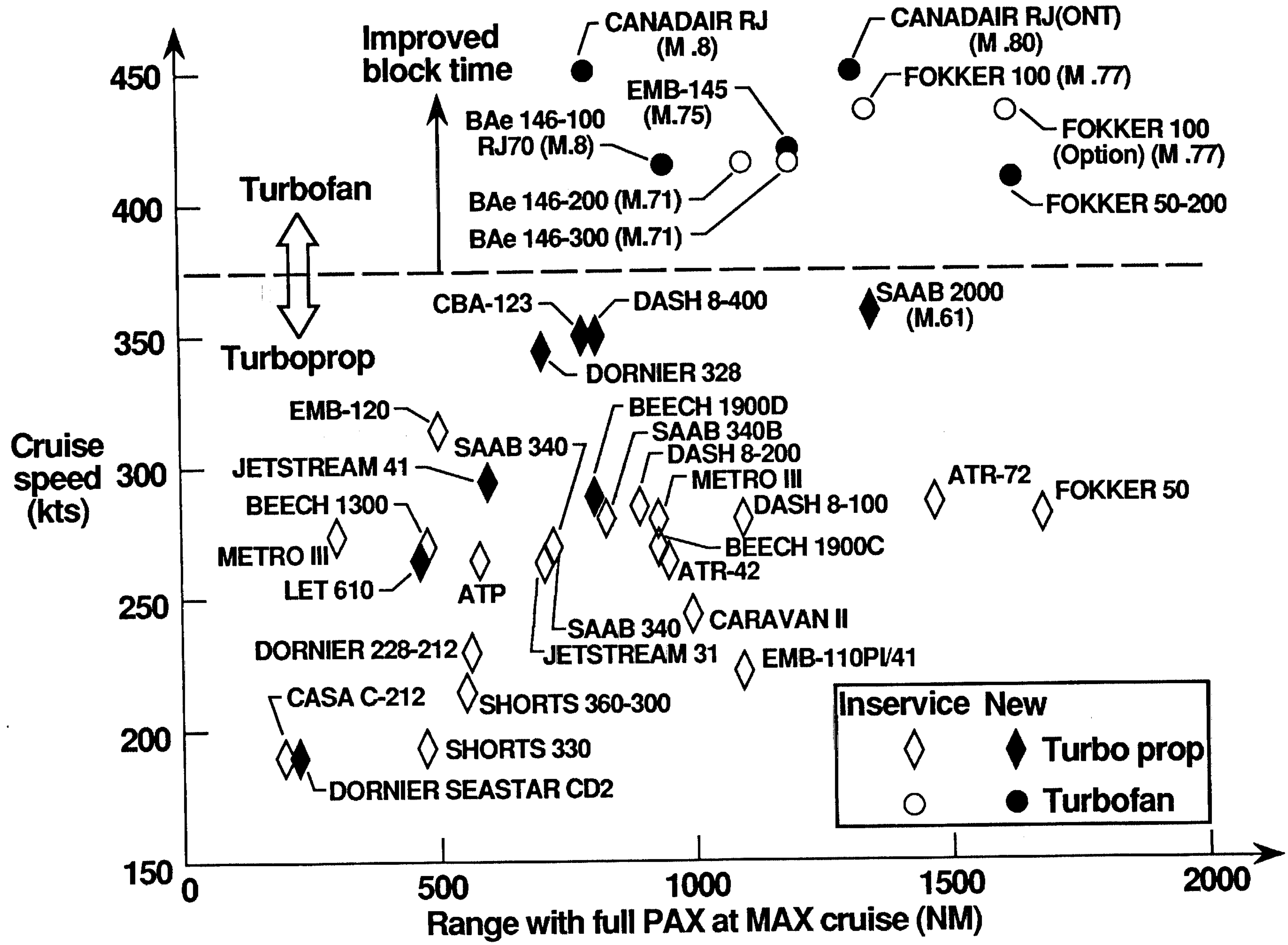


Figure 11. - Comparison of cruise speed with range for in-service and new regional aircraft.

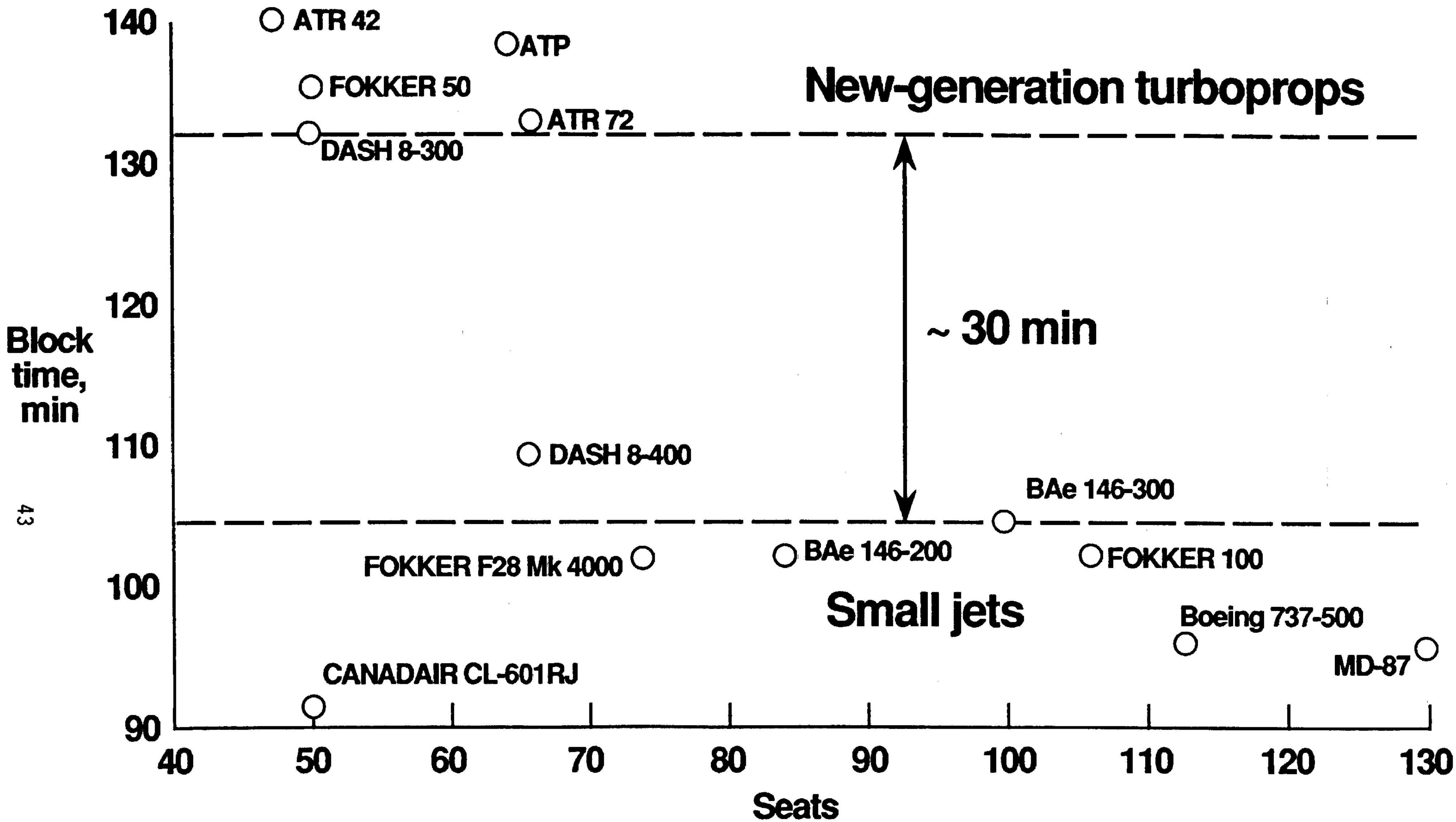


Figure 12. - Comparison of block time with seats for several regional transports.

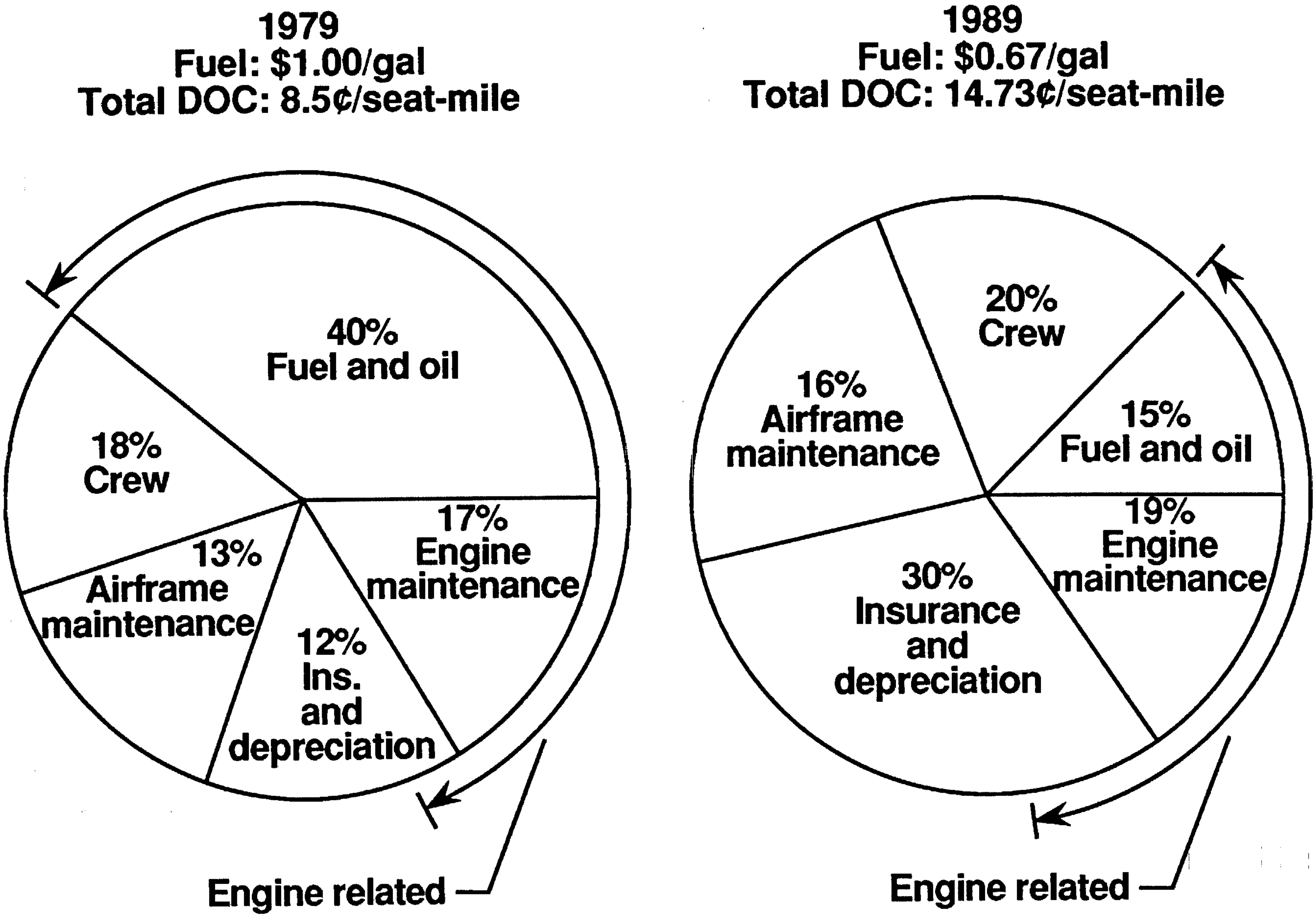


Figure 13. - Comparison of the average direct operating cost (DOC) for regional transports in 1979 and 1989.

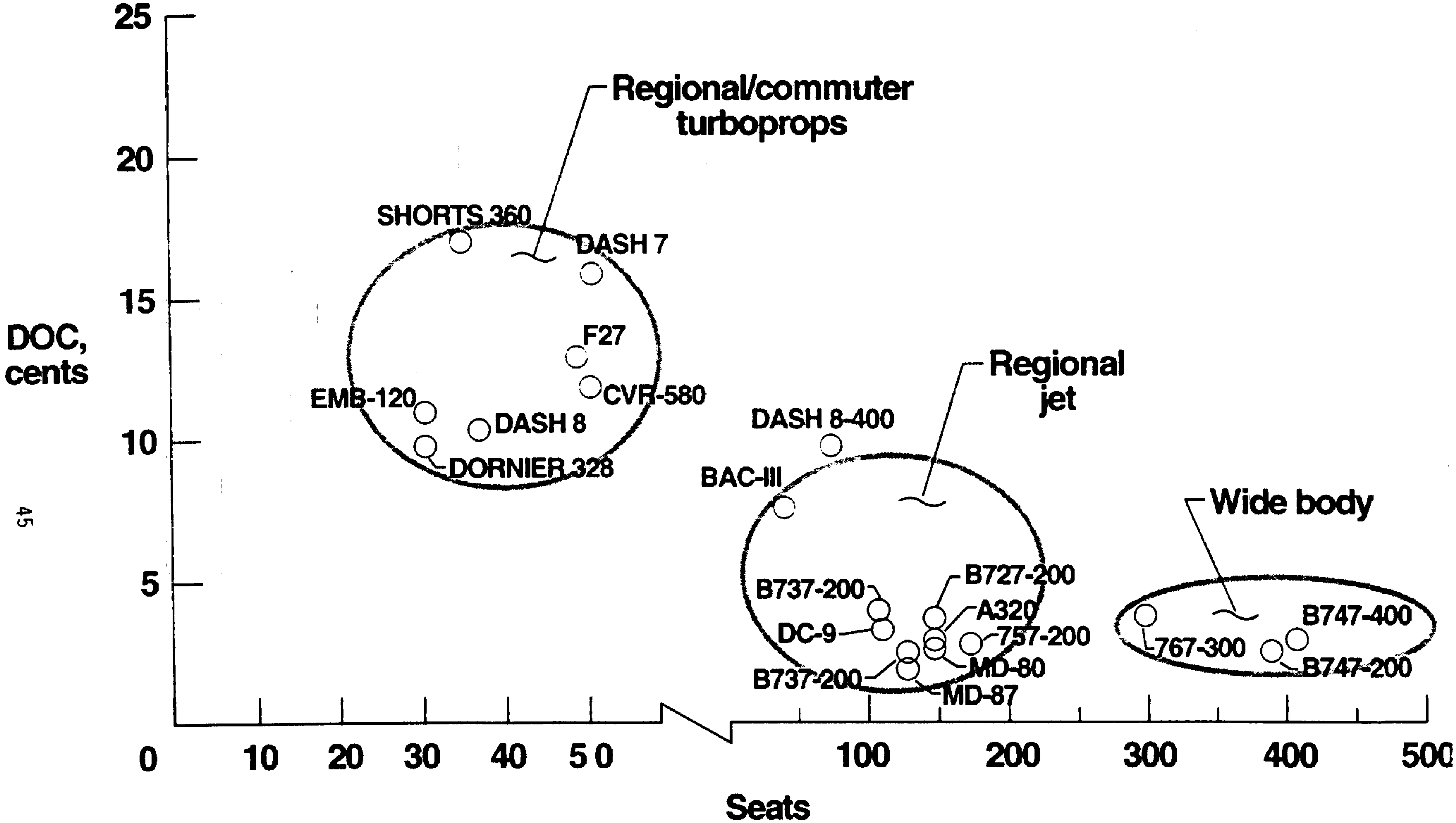


Figure 14. - Variation of direct operating cost (DOC) with seats based on fleet data for several aircraft types.

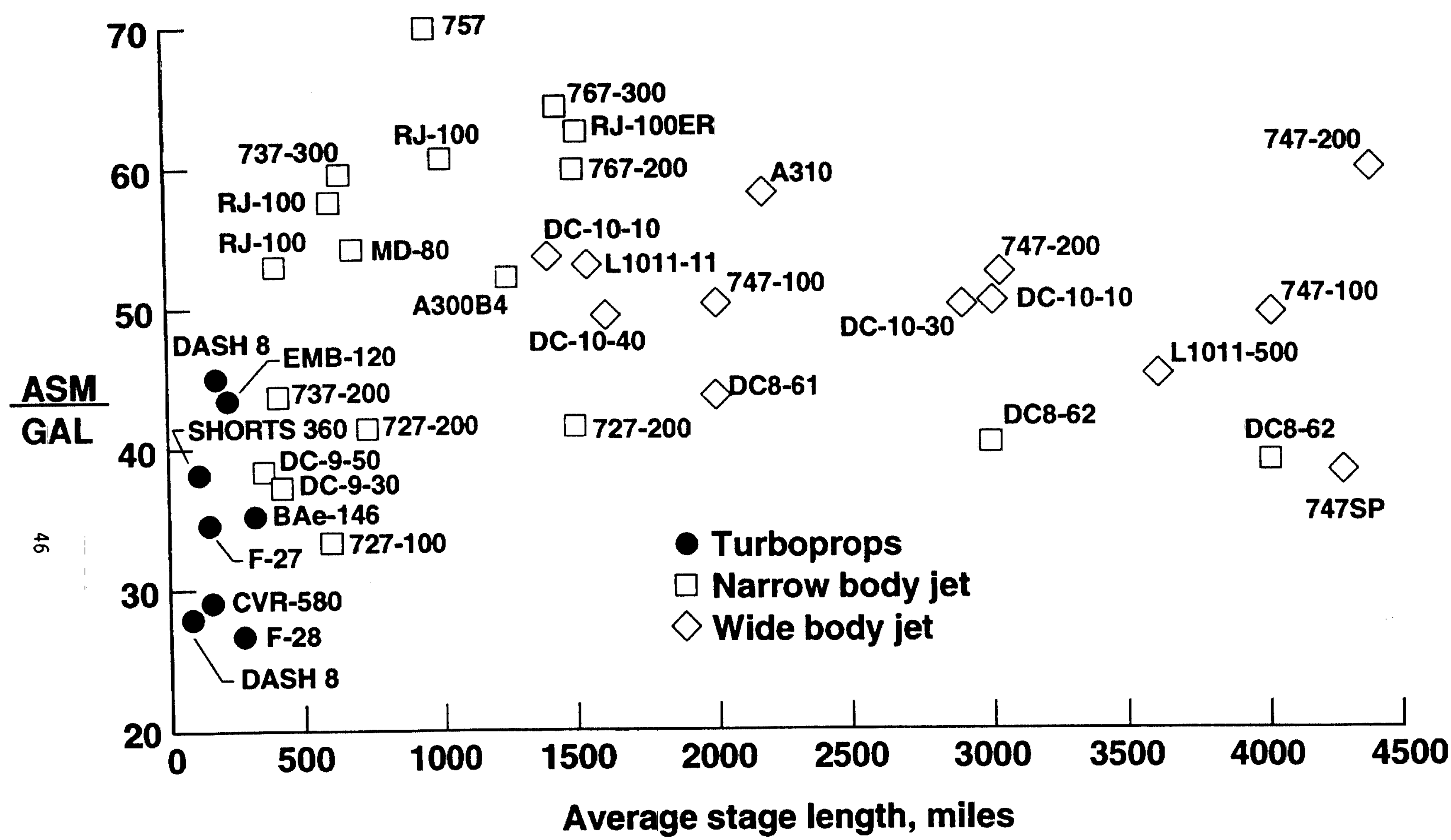


Figure 15. - Variation of fuel efficiencies with average stage length for several types of aircraft.

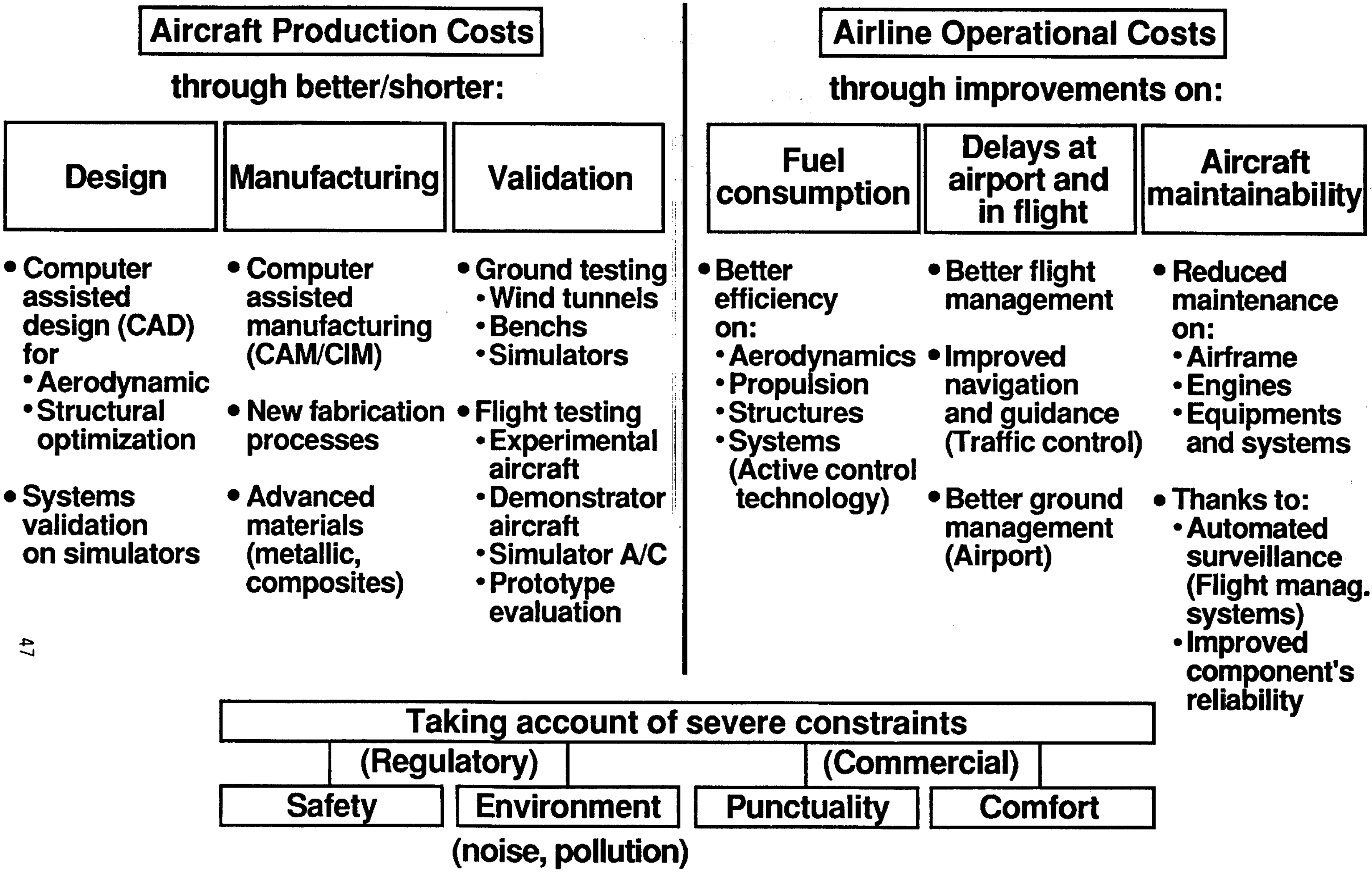


Figure 16. - Areas requiring mandatory reduction in aircraft production and operational costs to be competitive on the air transport market.

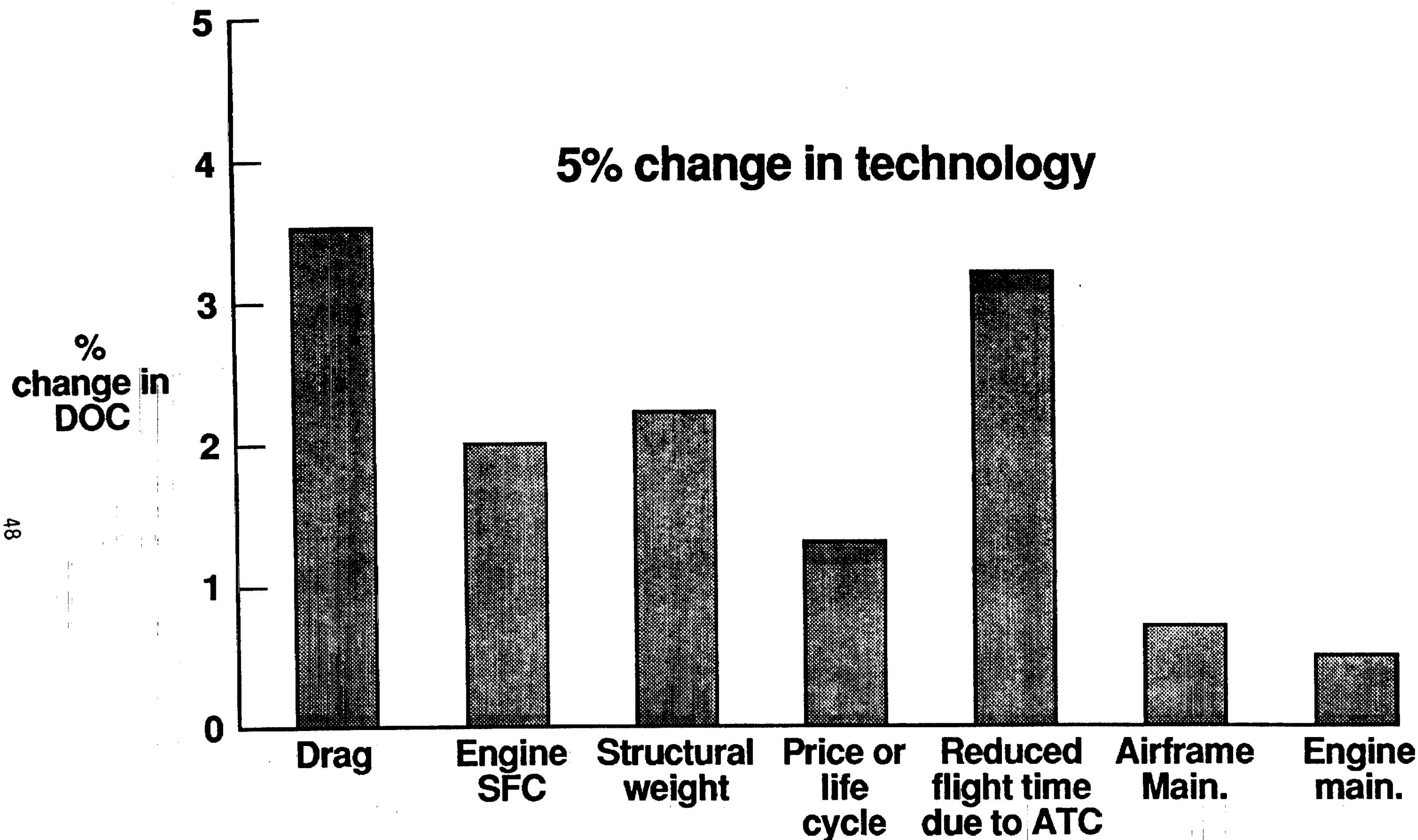


Figure 17. - Estimated effects of individual technology on direct operating costs of an aircraft.

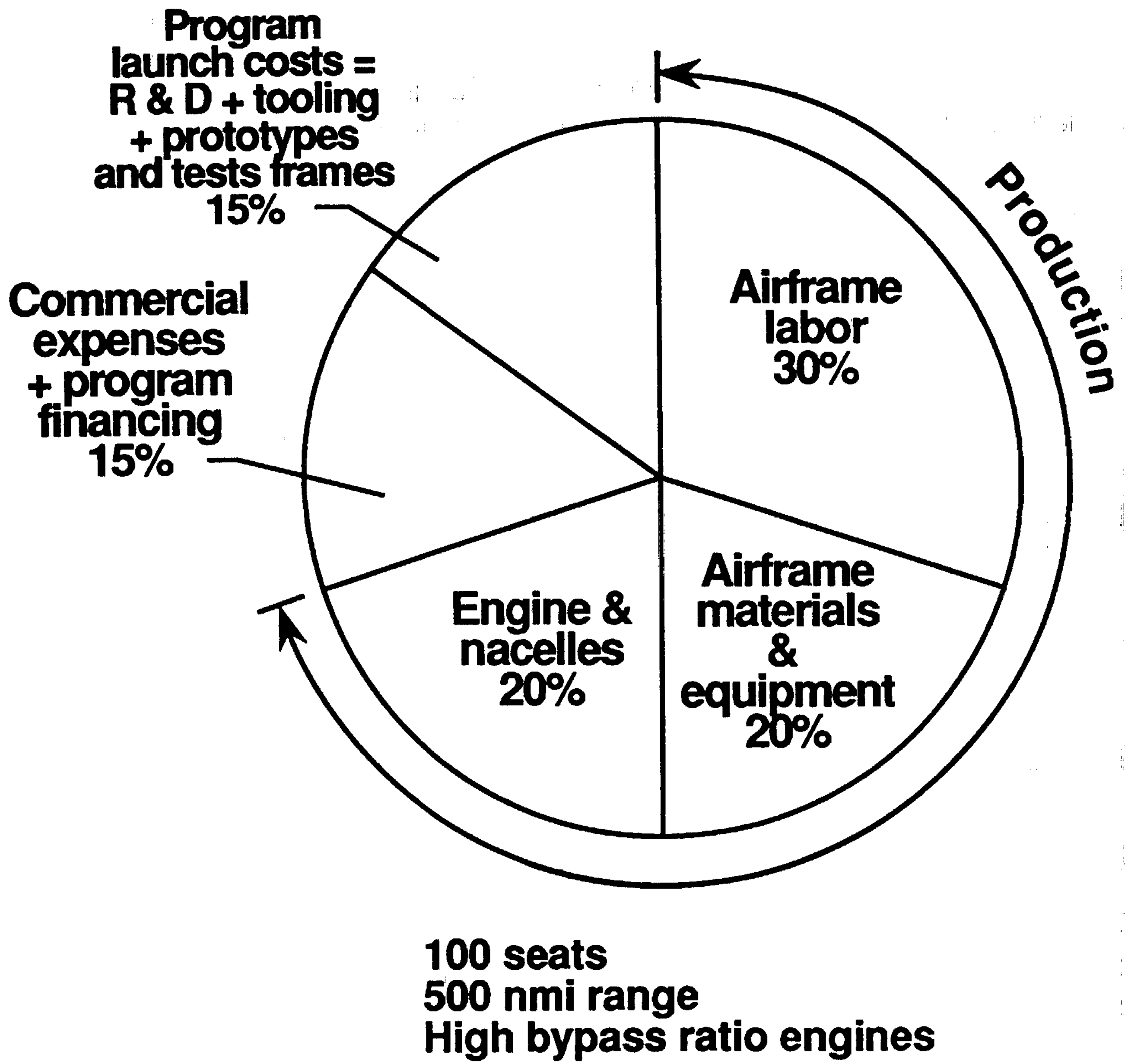


Figure 18. - Approximate breakdown of aircraft selling price.

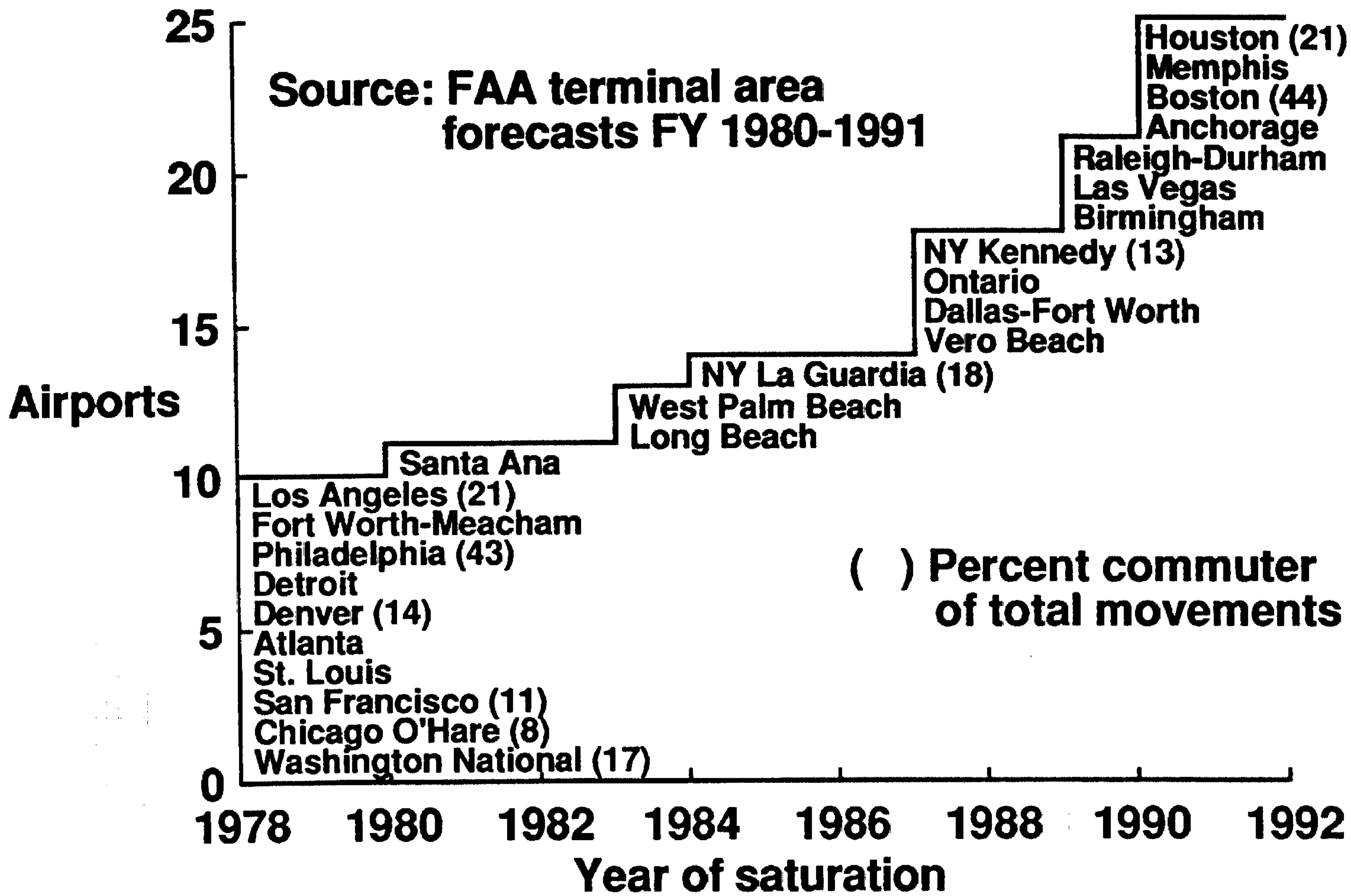


Figure 19. - Forecast year in which busy-hour operations at U.S. airports exceed practical IFR capability.

Figure 20. - Major U.S. airports with nighttime curfews.

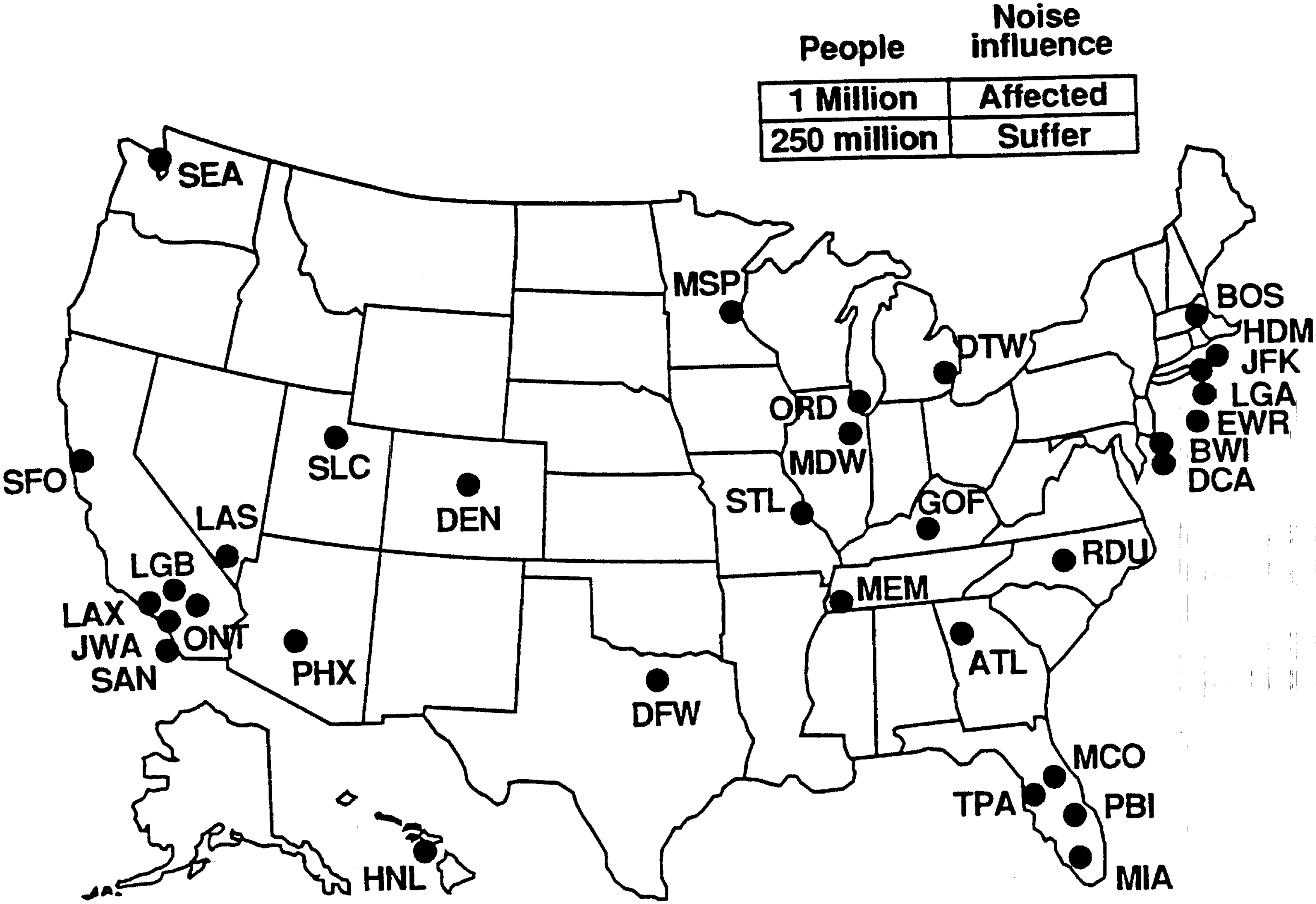


Figure 21. - Noise impacted airports of most concern in the U.S. for 1990.

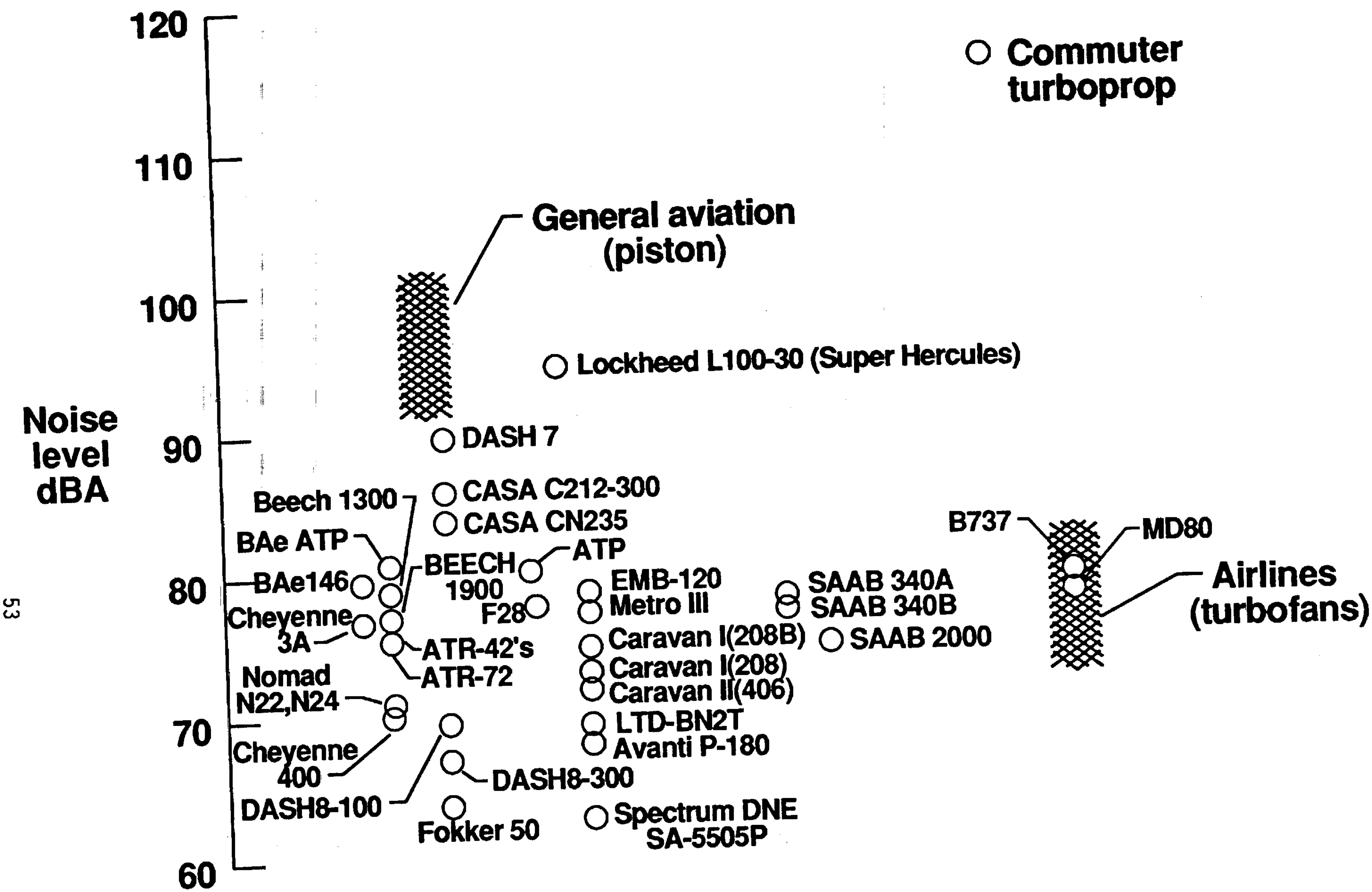


Figure 22. - Comparison of aircraft interior noise levels based on measurements at mid-fuselage and with 100 percent torque and RPM. (Ref: Janes All the World's Aircraft, 1990-1992.)

- Improved fuel efficiency → operating cost reductions
  - aerodynamic improvements → drag reductions
  - propulsion developments → reduced S.F.C.
  - structures and materials advances → reduced weight
  - systems improvements → operating economies
- Improved reliability → reduced delays, spares cost reductions
  - digital avionics applications
  - Improved systems design - electrical, hydraulic, mechanical
  - reduced spares holdings
- Improved maintainability → maintenance cost reductions
  - corrosion prevention
  - digital systems - built-in test equipment
  - improved accesssibility
- First cost reductions
  - production methods developments
  - commonality of technical advances - learning curve

Figure 23. - Advanced technology targets for improvements in aircraft production and operating costs.

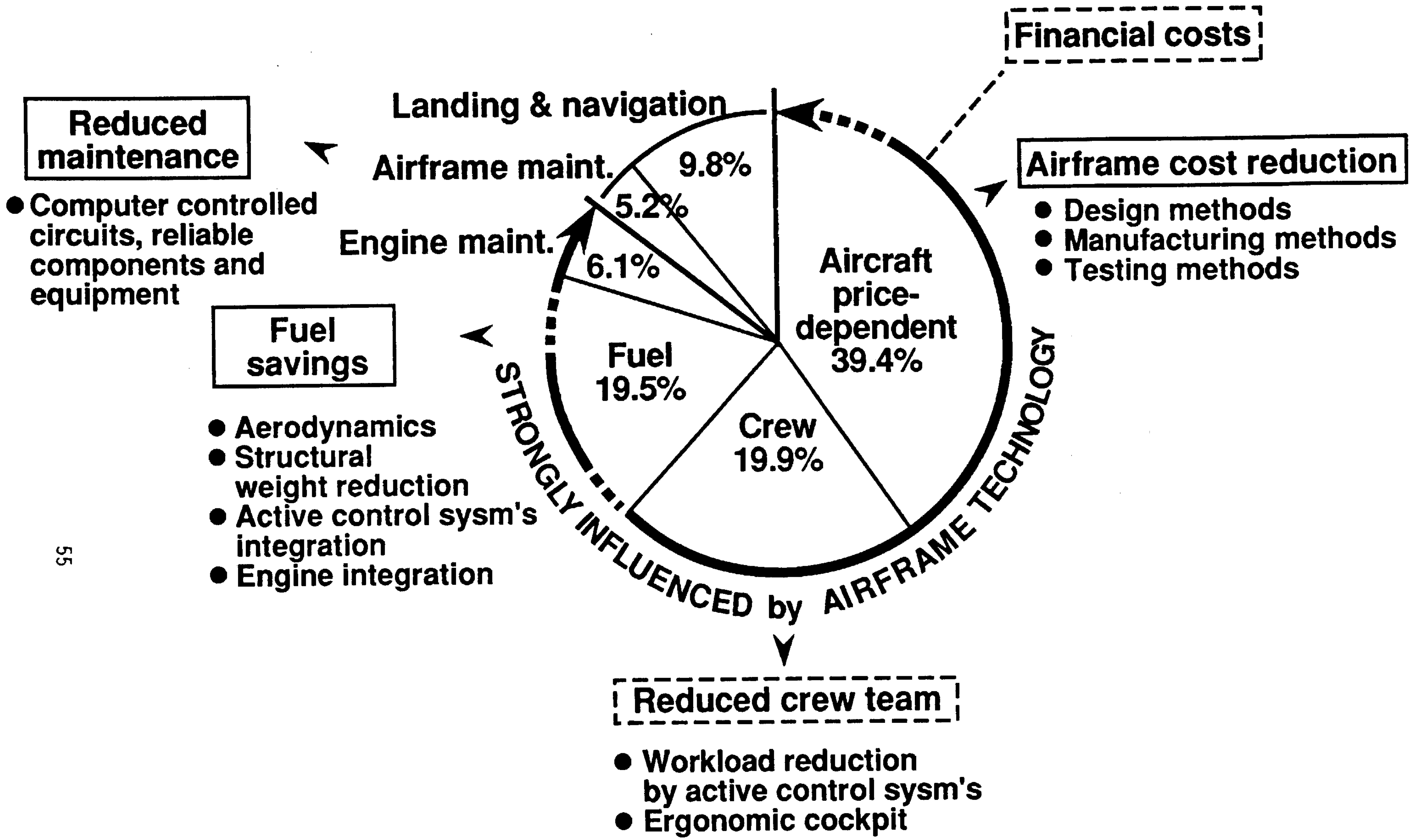


Figure 24. - Example of advanced technology influence on direct operating cost (DOC); 100 seats and 500 nautical mile range aircraft.

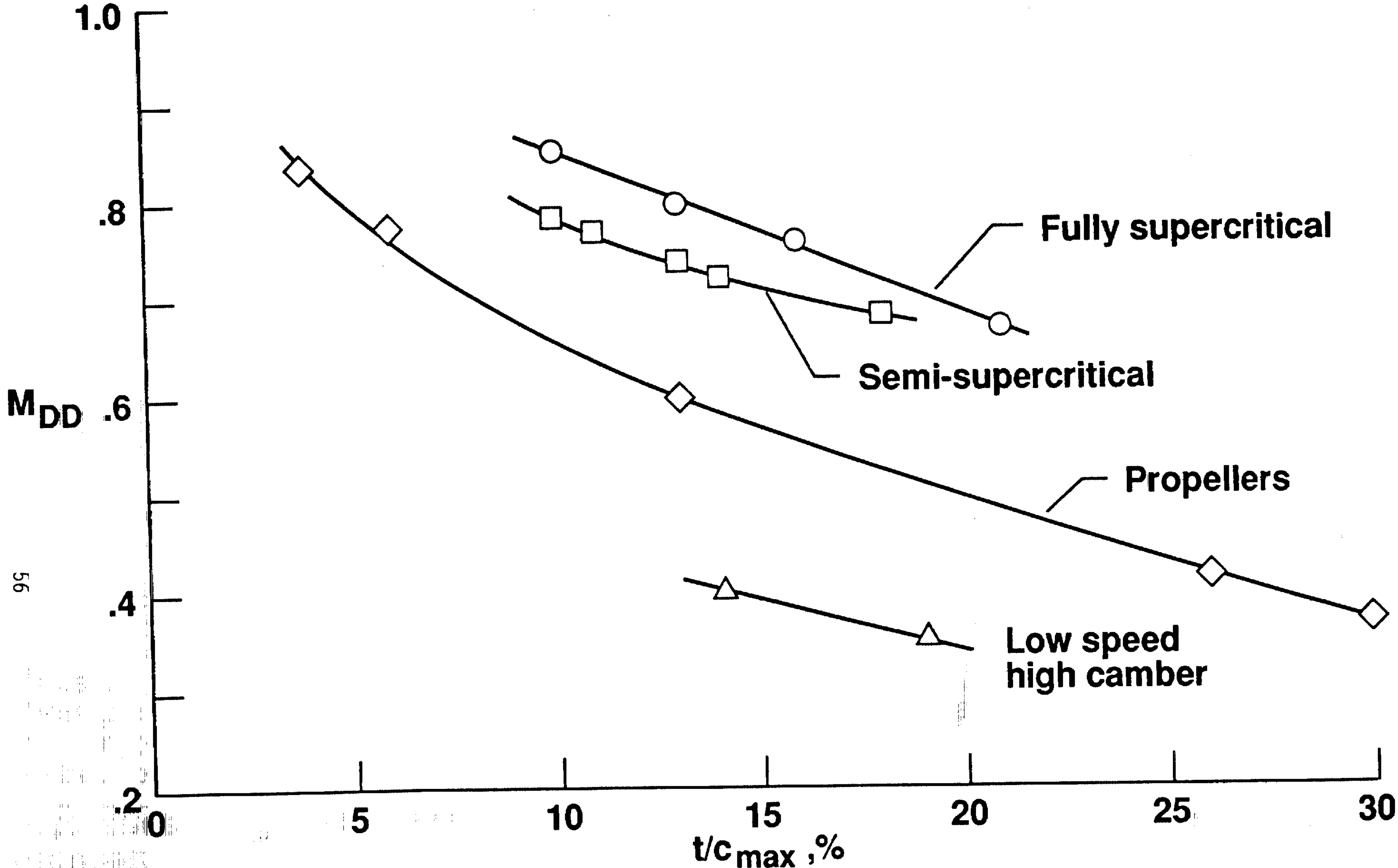


Figure 25. - Experimental variation of drag divergence Mach number with thickness-to-chord ratio for several airfoils.

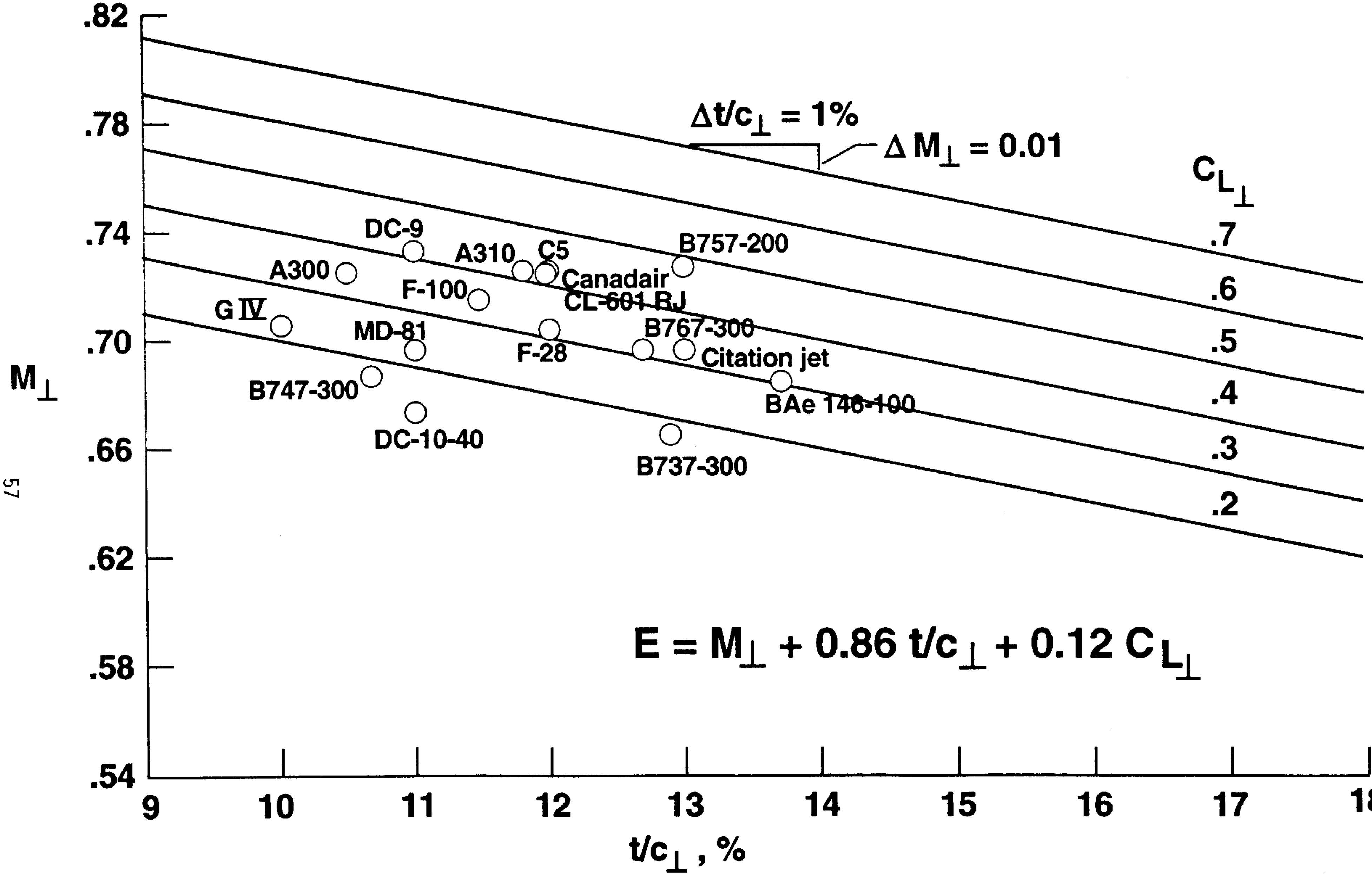


Figure 26. - Advances and relative efficiency of high speed wing technology for several design parameters.

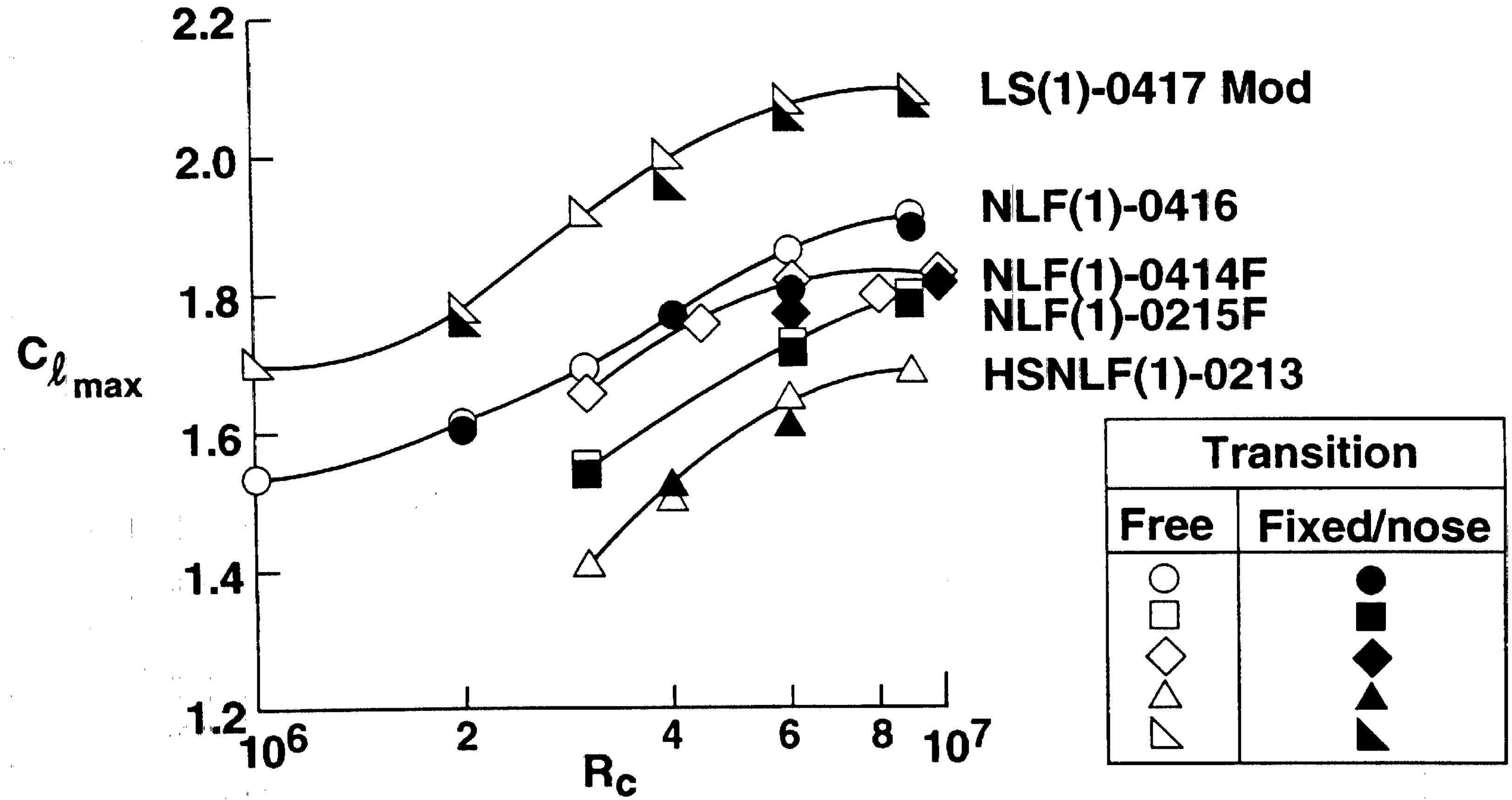


Figure 27. - Variation of maximum lift with chord Reynolds number for several advanced NASA NLF airfols.

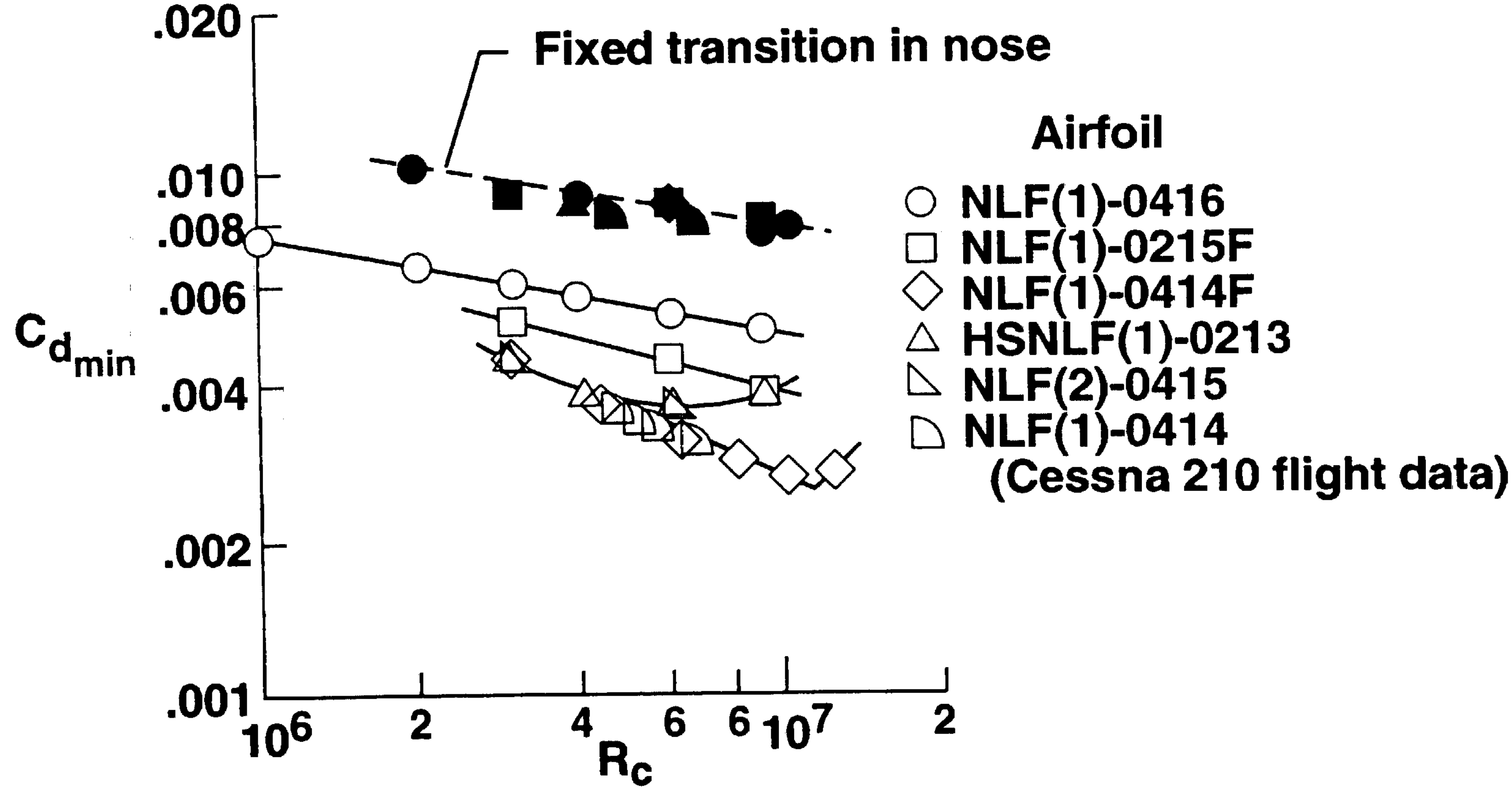


Figure 28. - Variation of minimum drag with chord Reynolds number for several advanced NASA NLF airfoils.

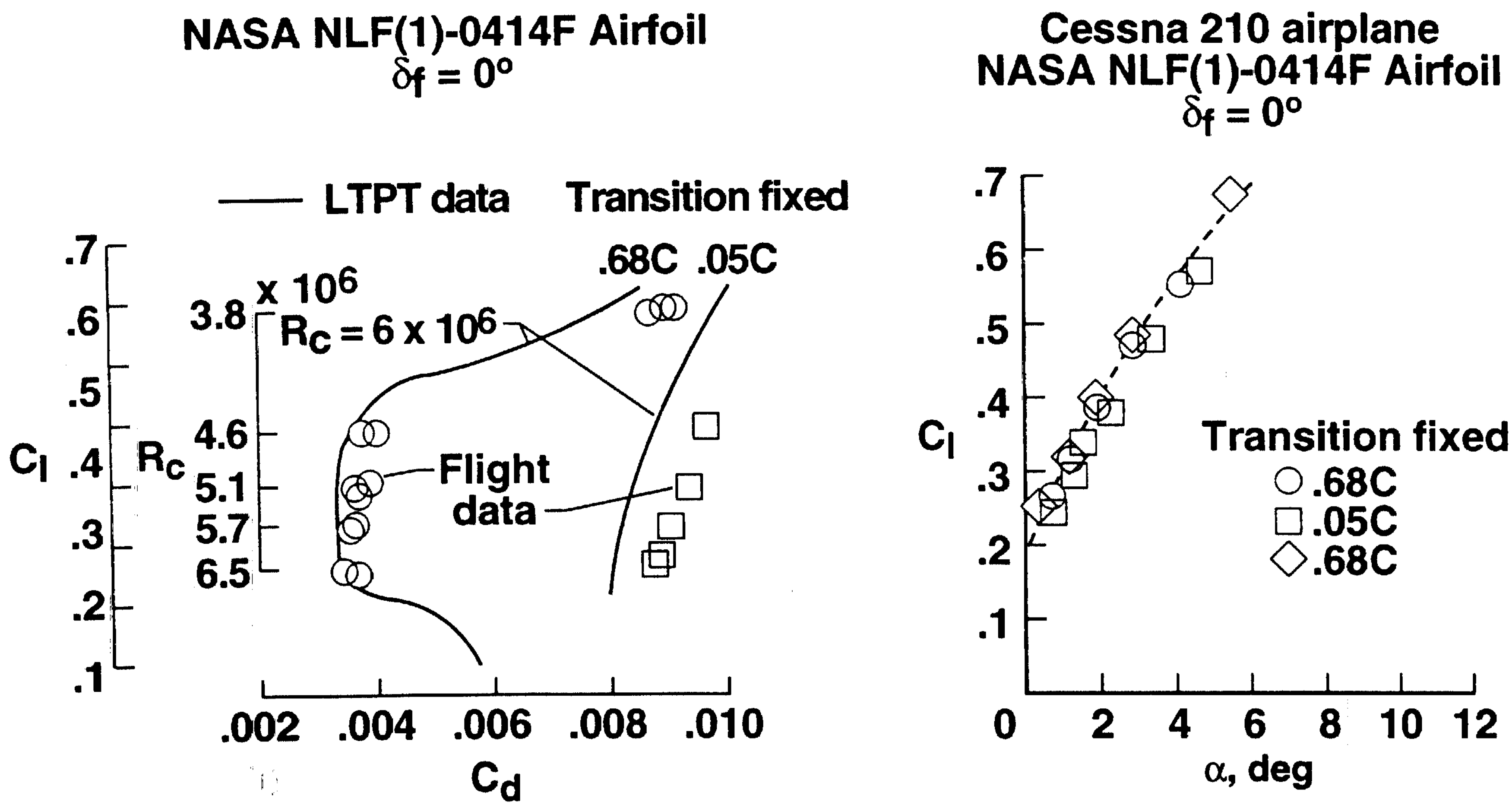


Figure 29. - Comparison of wind tunnel and flight performance data for NASA NLF(1) - 0414F airfoil.

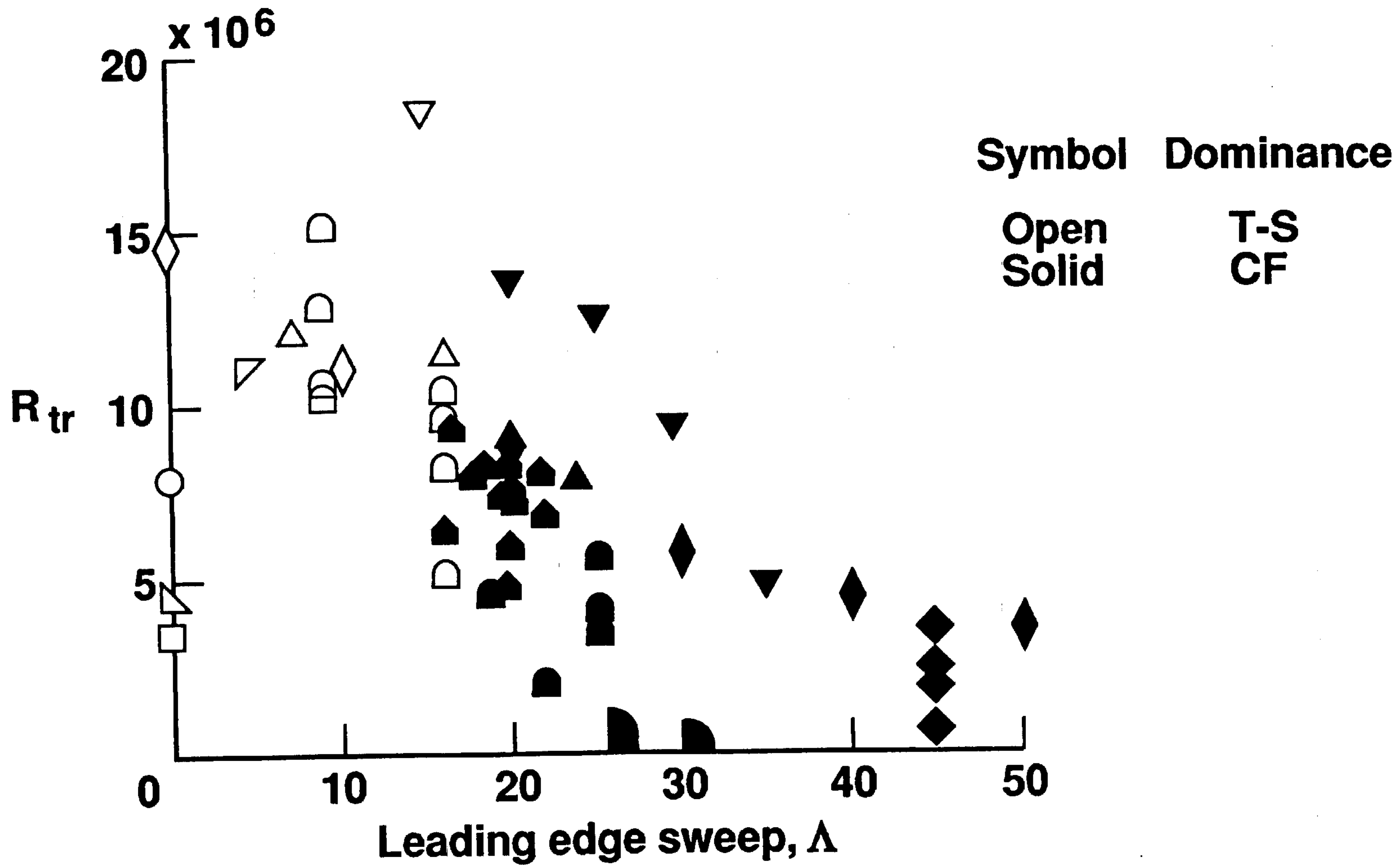


Figure 30. - Effect of leading edge sweep on experimental transition for NLF wings in wind tunnels and flight; $0.2 \leq M_{\infty} \leq 1.76$ and $0.3 \leq R_c \leq 40 \times 10^6$.

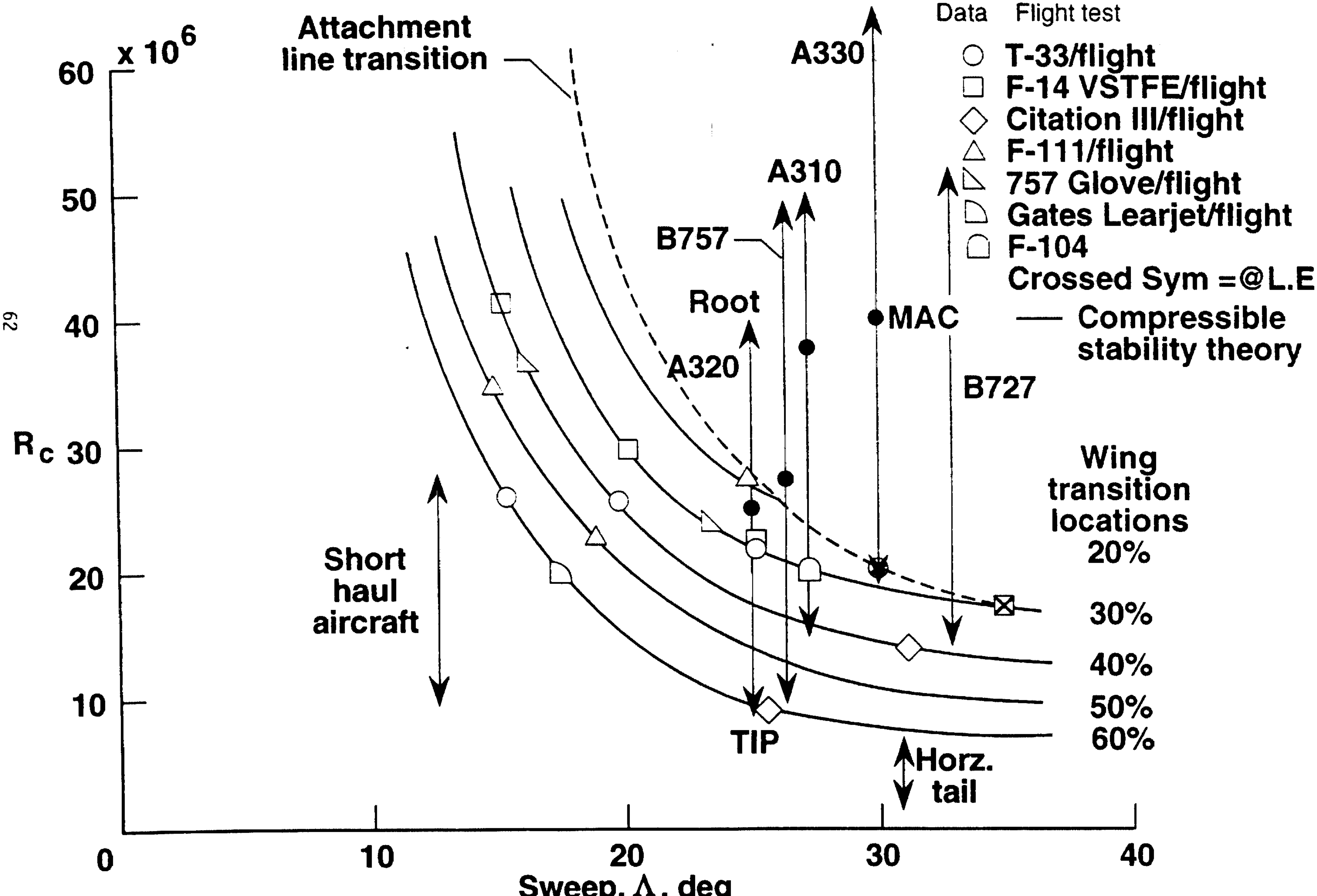


Figure 31. - Comparison of predicted and experimental flight transition results on swept NLF wings for $0.3 \leq M_{\infty} \leq 1.2$.

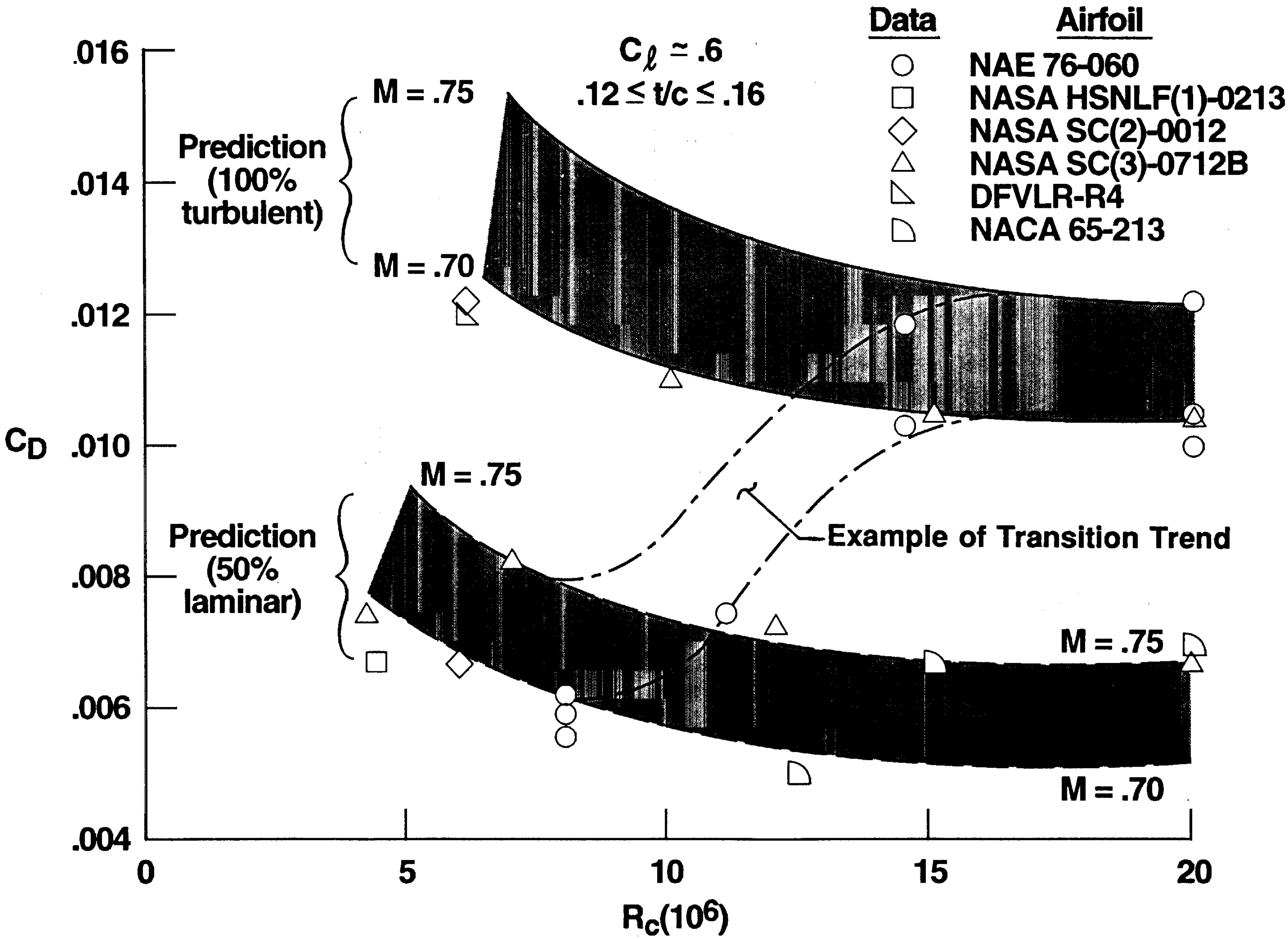


Figure 32. - Variation of section drag with Reynolds number based experimental airfoil data with either 100 percent turbulent or 50 percent laminar flow.

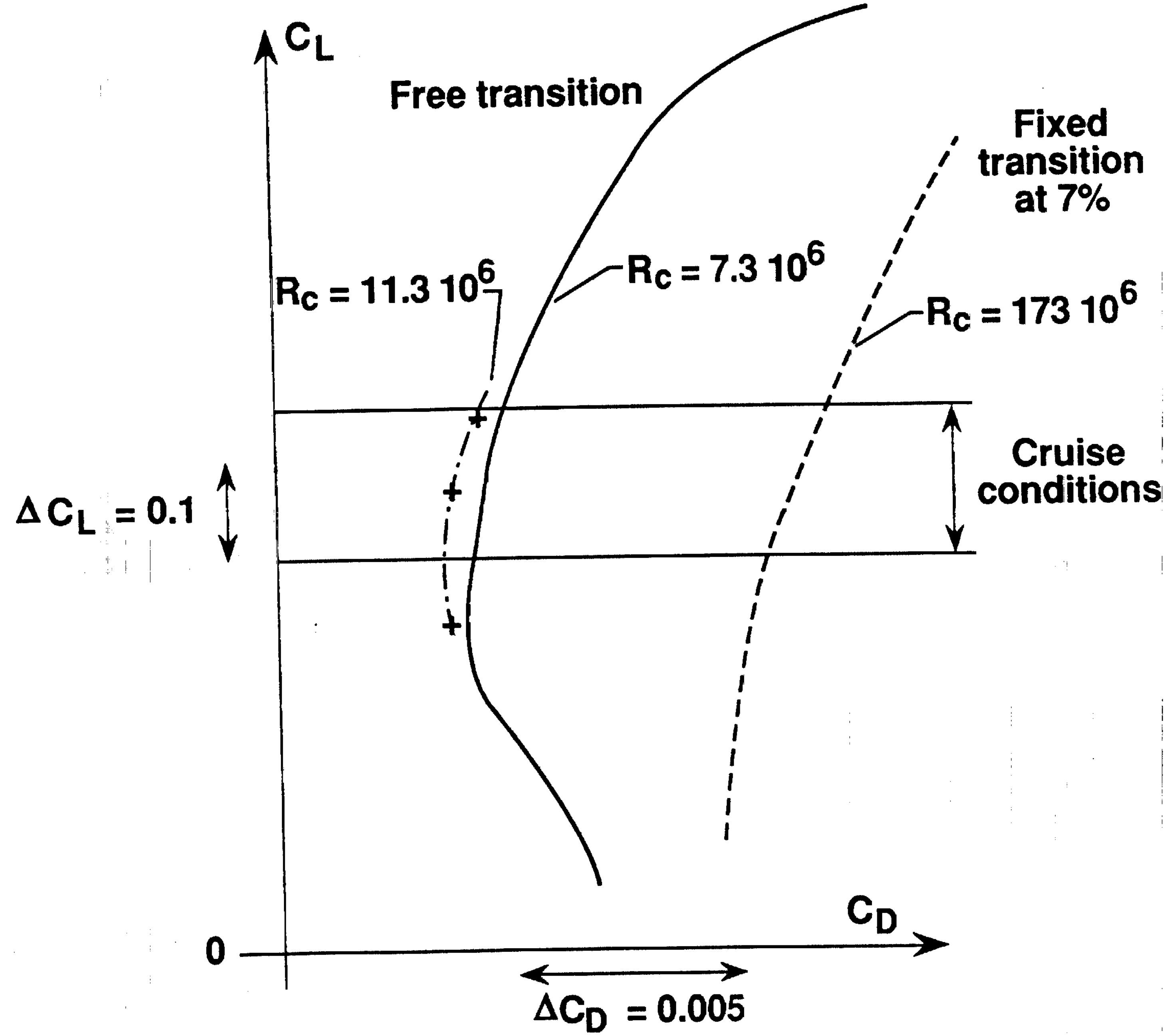


Figure 33. - Predicted drag polars for swept NLF airfoil at $M_\infty = 0.74$ and $\Lambda = 12°$, with and without fixed transition.

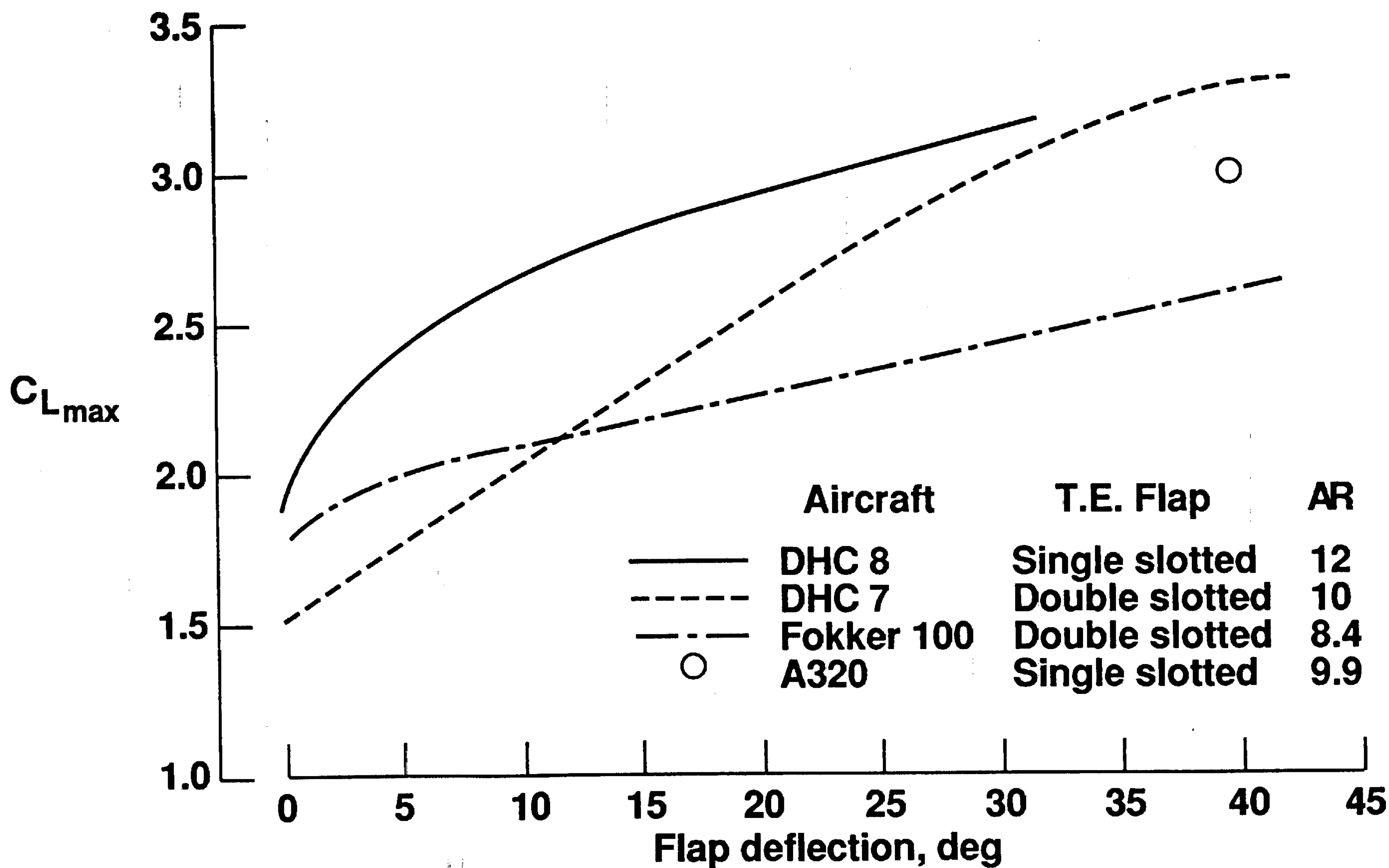


Figure 34. - Comparison of in flight maximum lift coefficient variation with flap angle for several aircraft.

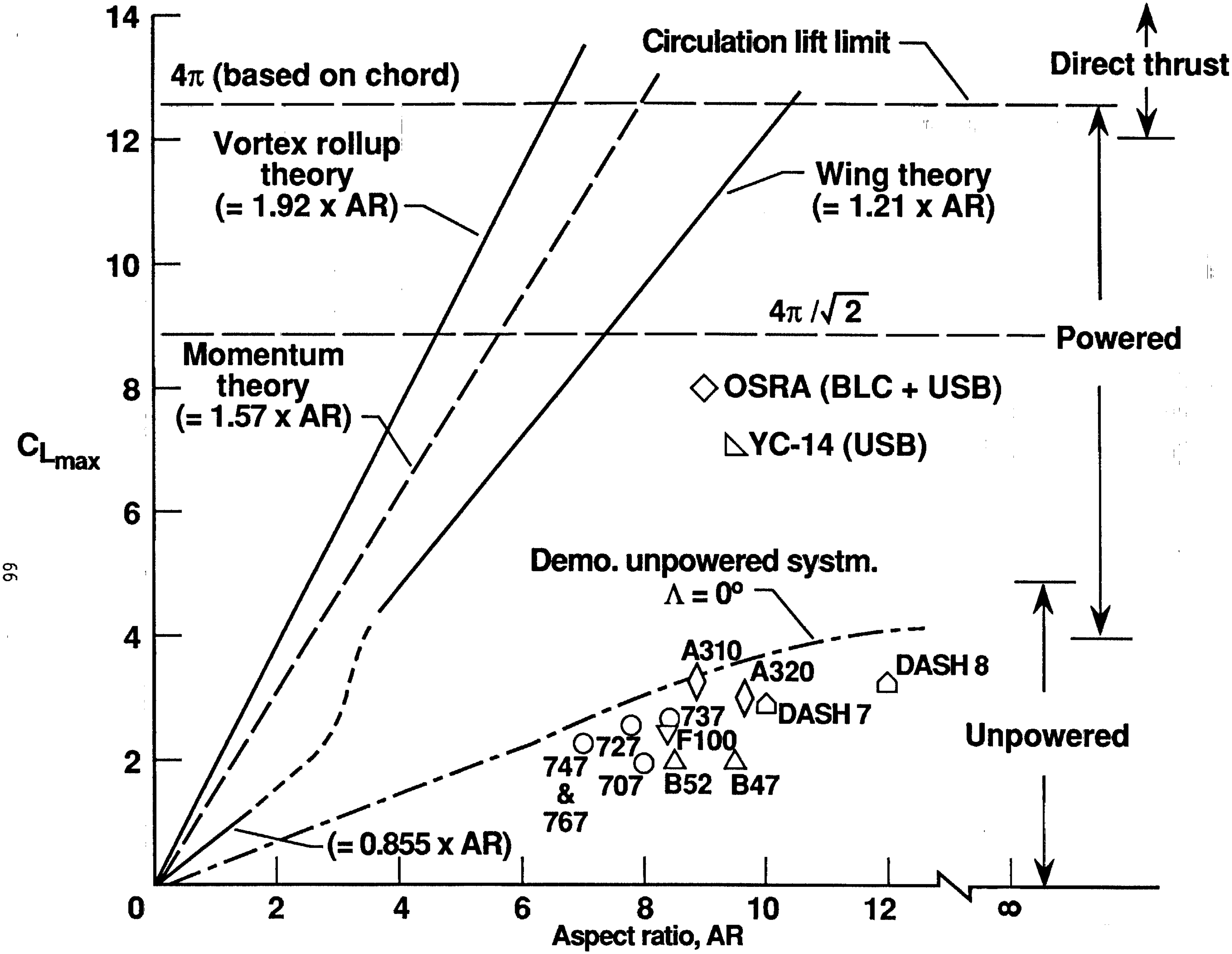


Figure 35. - Comparison of experimental and theoretical limits of maximum lift coefficient with wing aspect ratio for transport and commuter aircraft.

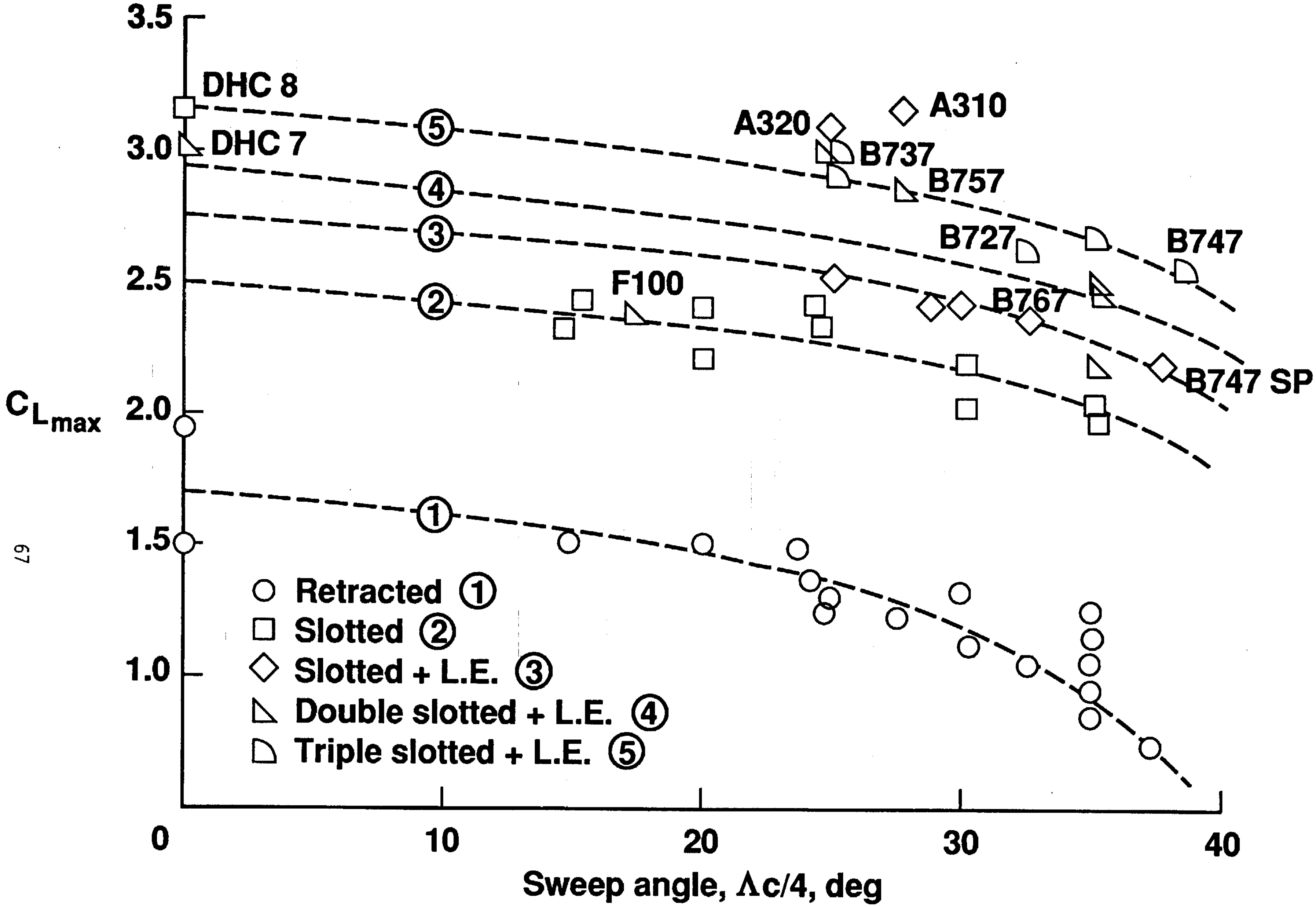


Figure 36. - Variation of maximum lift coefficient with sweep for several transport and commuter aircraft.

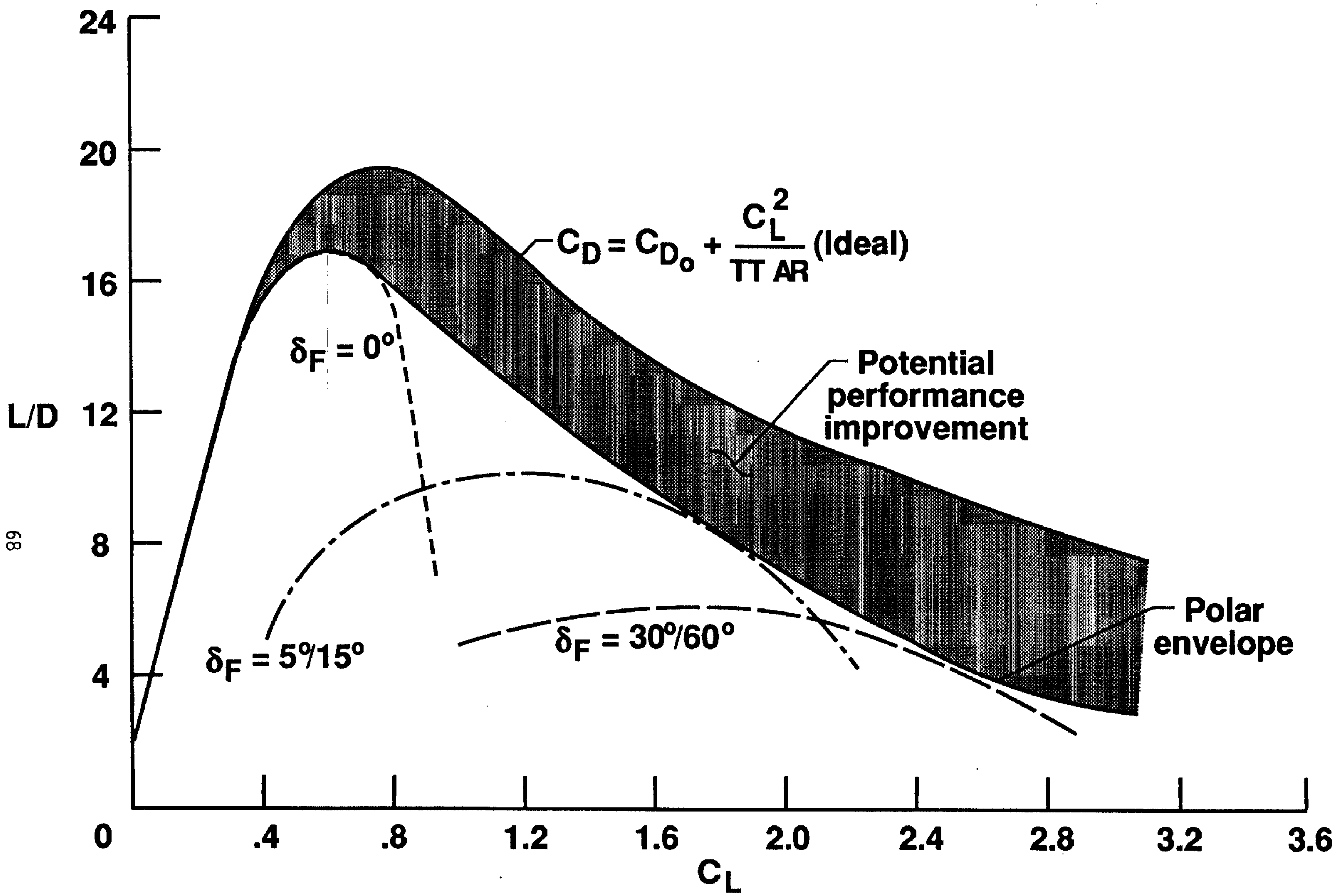


Figure 37. - Potential performance improvement for mechanical high-lift system, AR = 8 and $\Lambda = 35°$ wing.

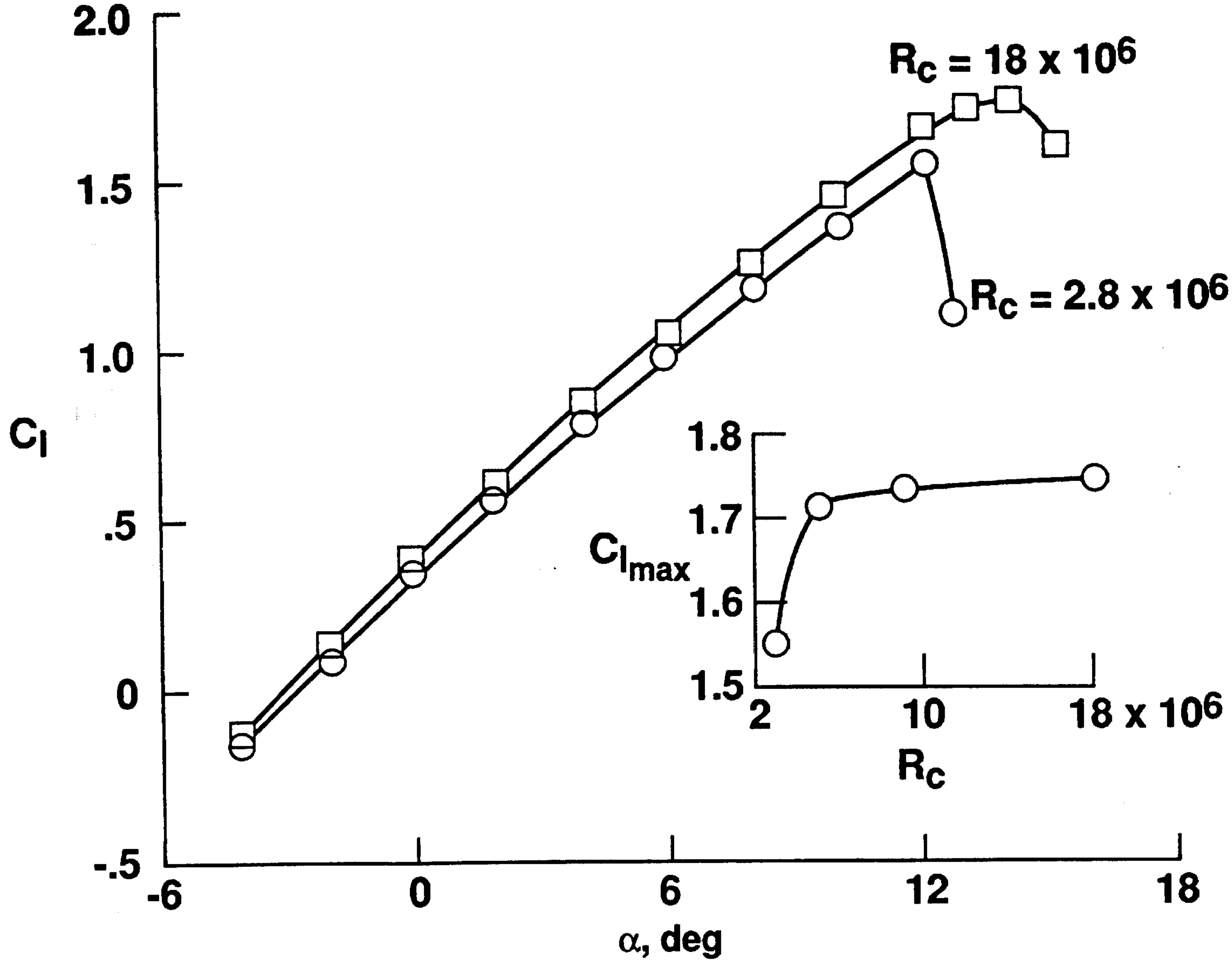


Figure 38. - Effect of Reynolds number on lift performance of an airfoil large-vane high-lift system, $M_\infty = 0.2$.

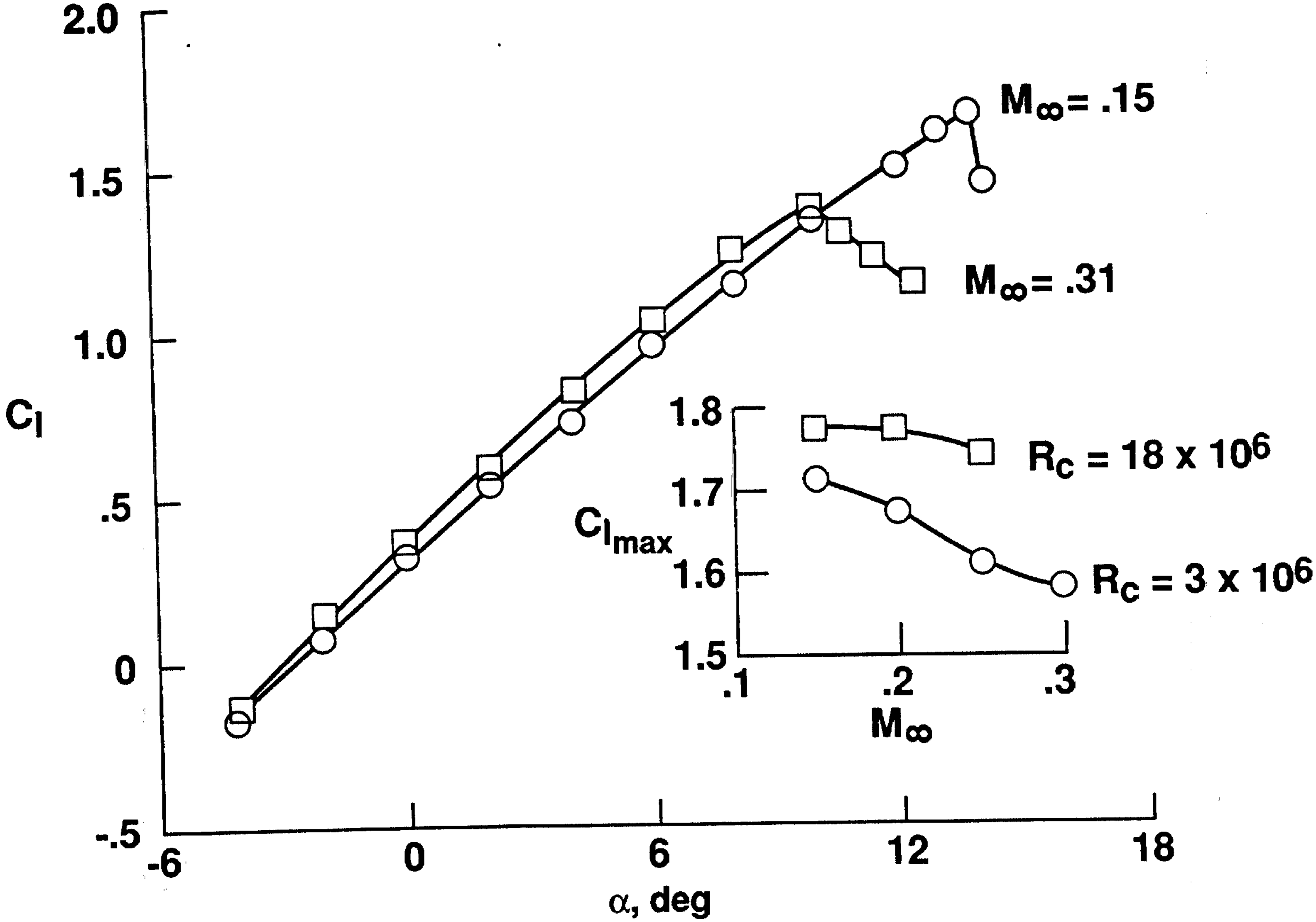


Figure 39. - Effect of Mach number on lift performance of an airfoil large-vane high-lift system at constant Reynolds number.

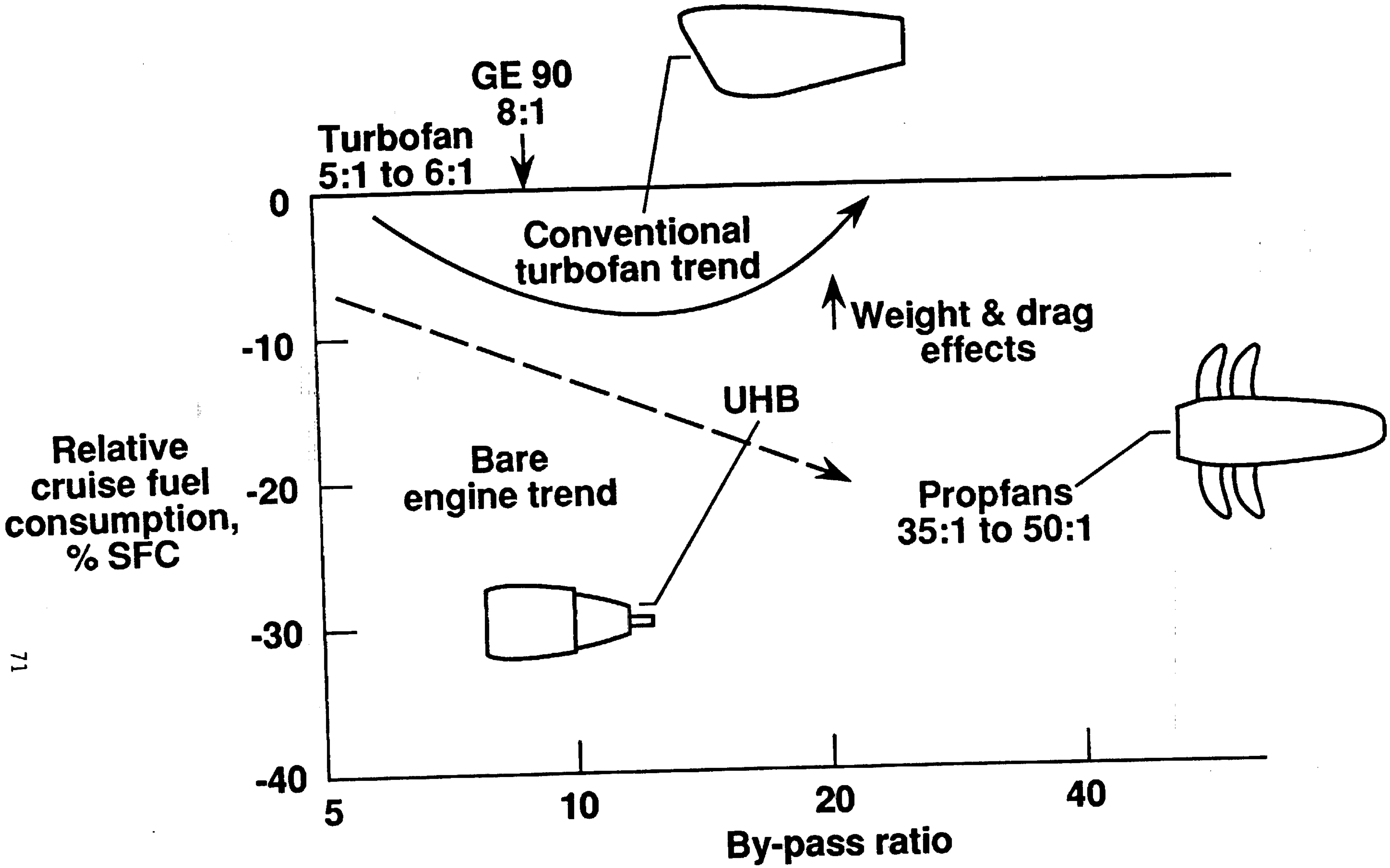


Figure 40. - Variation of relative fuel efficiency improvement with engine by-pass ratio.

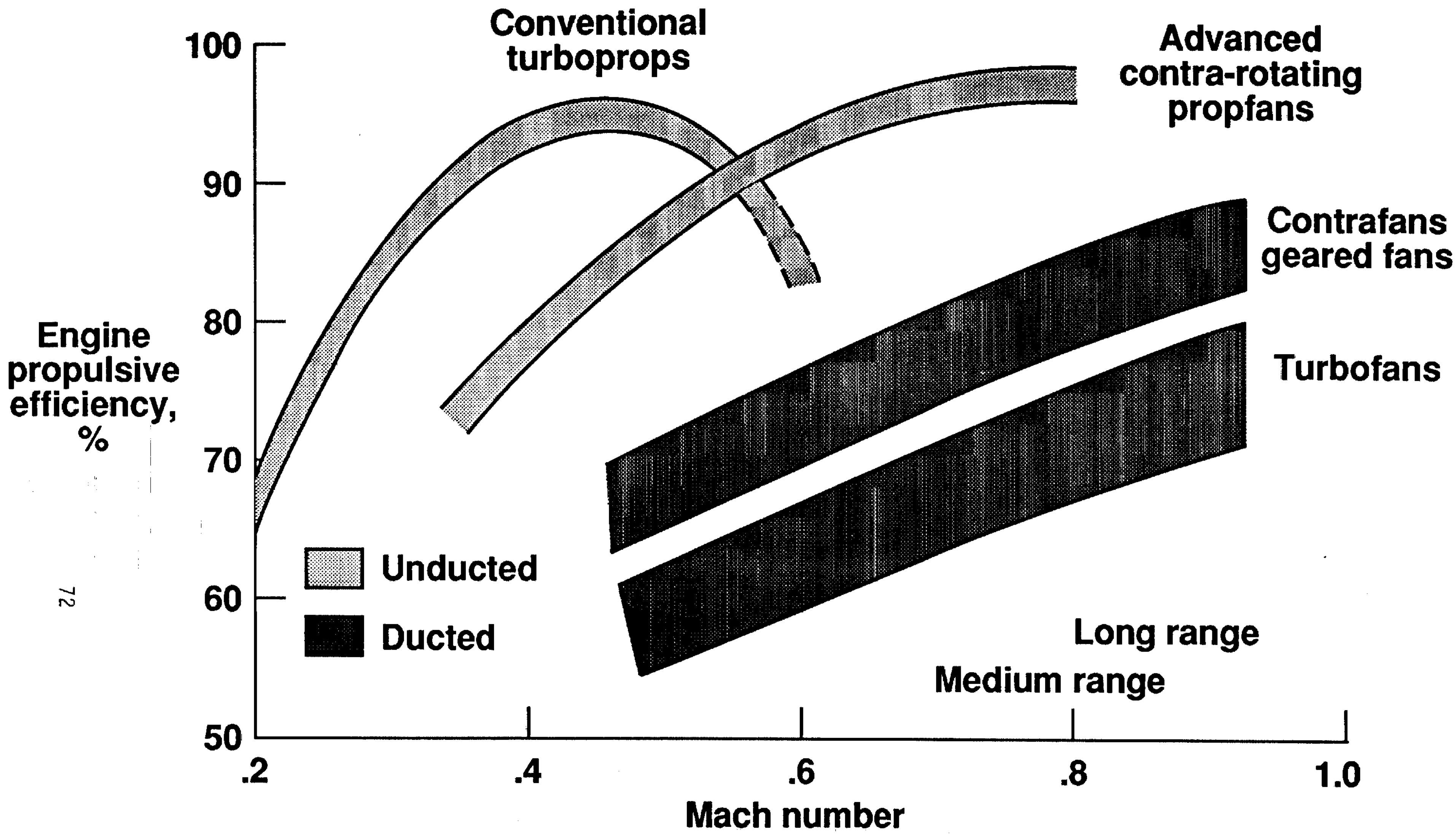


Figure 41. - Effects of cruise Mach number on engine propulsive efficiency, 3500 feet altitude.

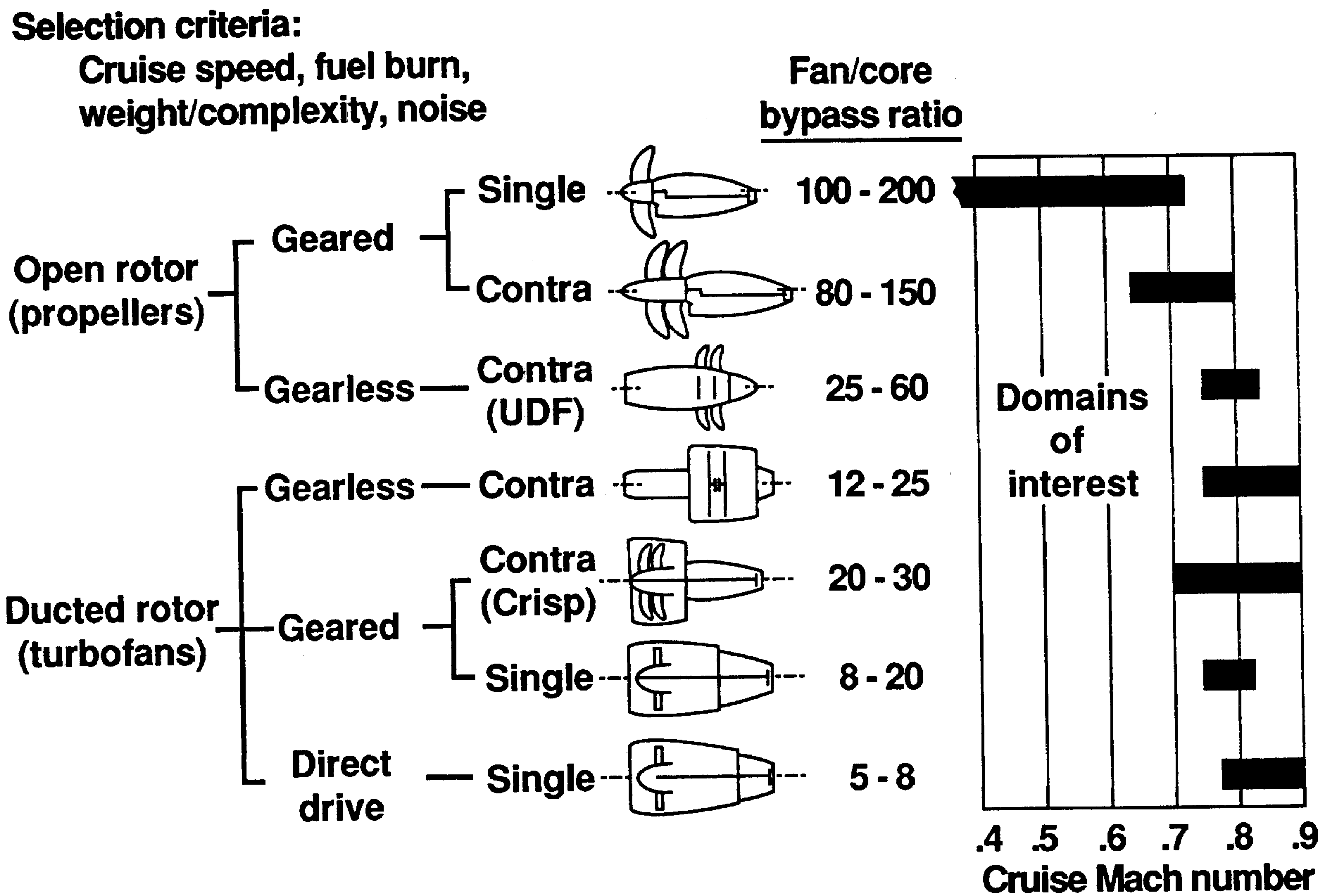


Figure 42. - Classification of engine propulsion in terms of bypass ratio and cruise Mach number.

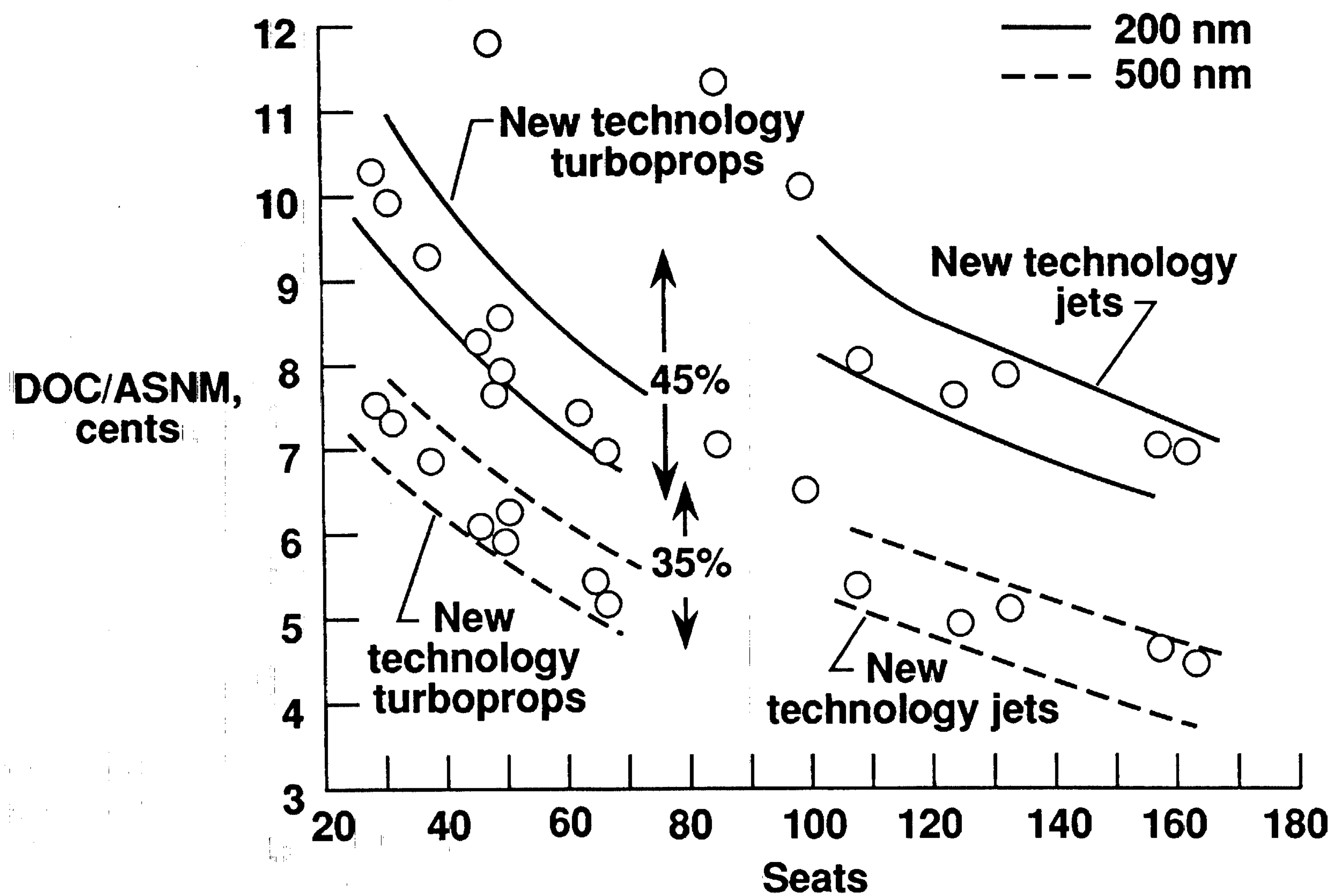


Figure 43. - Variation of direct operating cost per available seat nautical miles with seating capacity for new technology jets and turboprops.

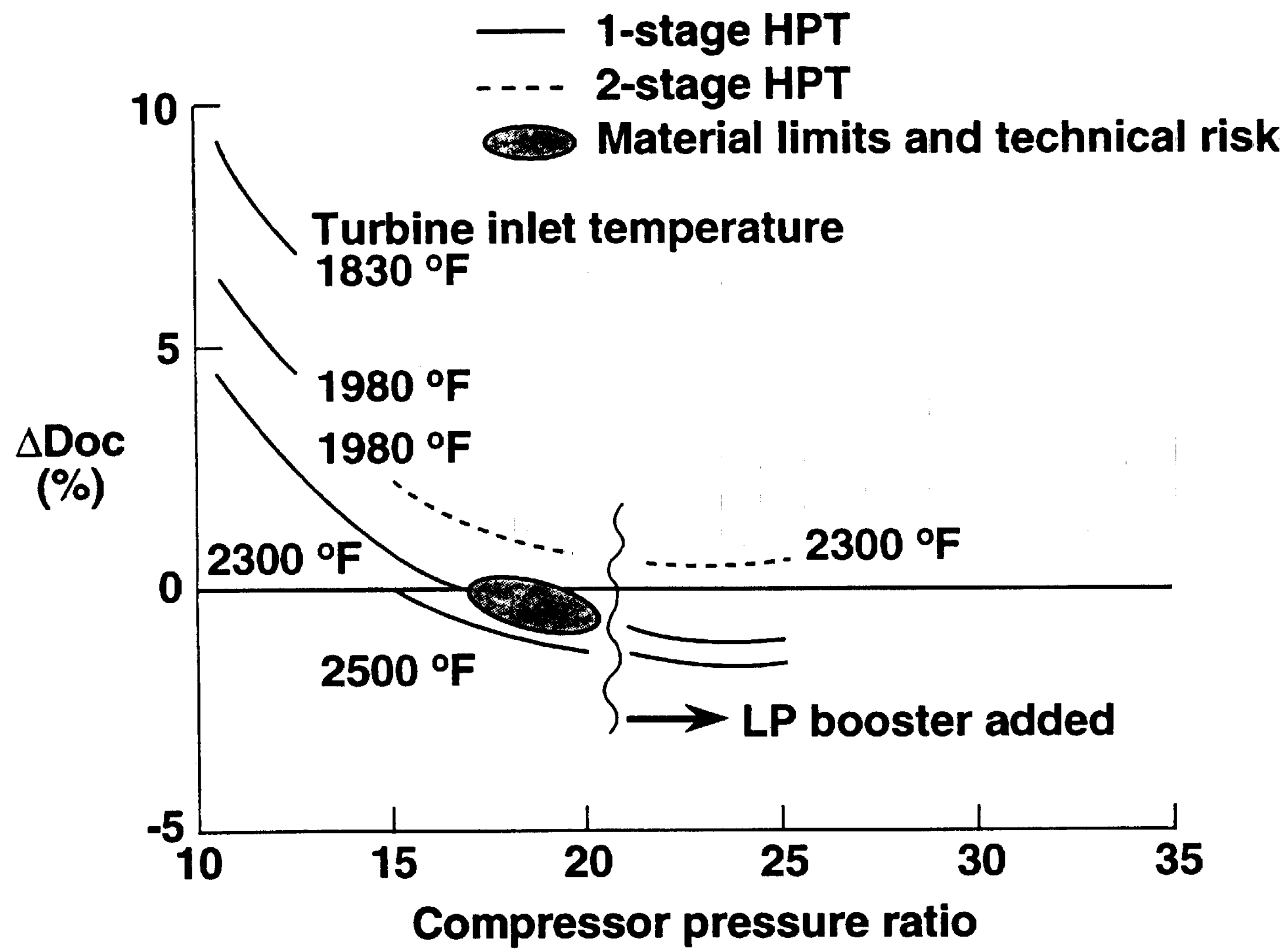


Figure 44. - Variation in relative change of aircraft direct operating cost with advanced commuter engine cycle selection. 100 NM, $1.50/gal fuel, 30 passenger, M_{∞}= 0.45, and 1500 SHP/ENGINE.

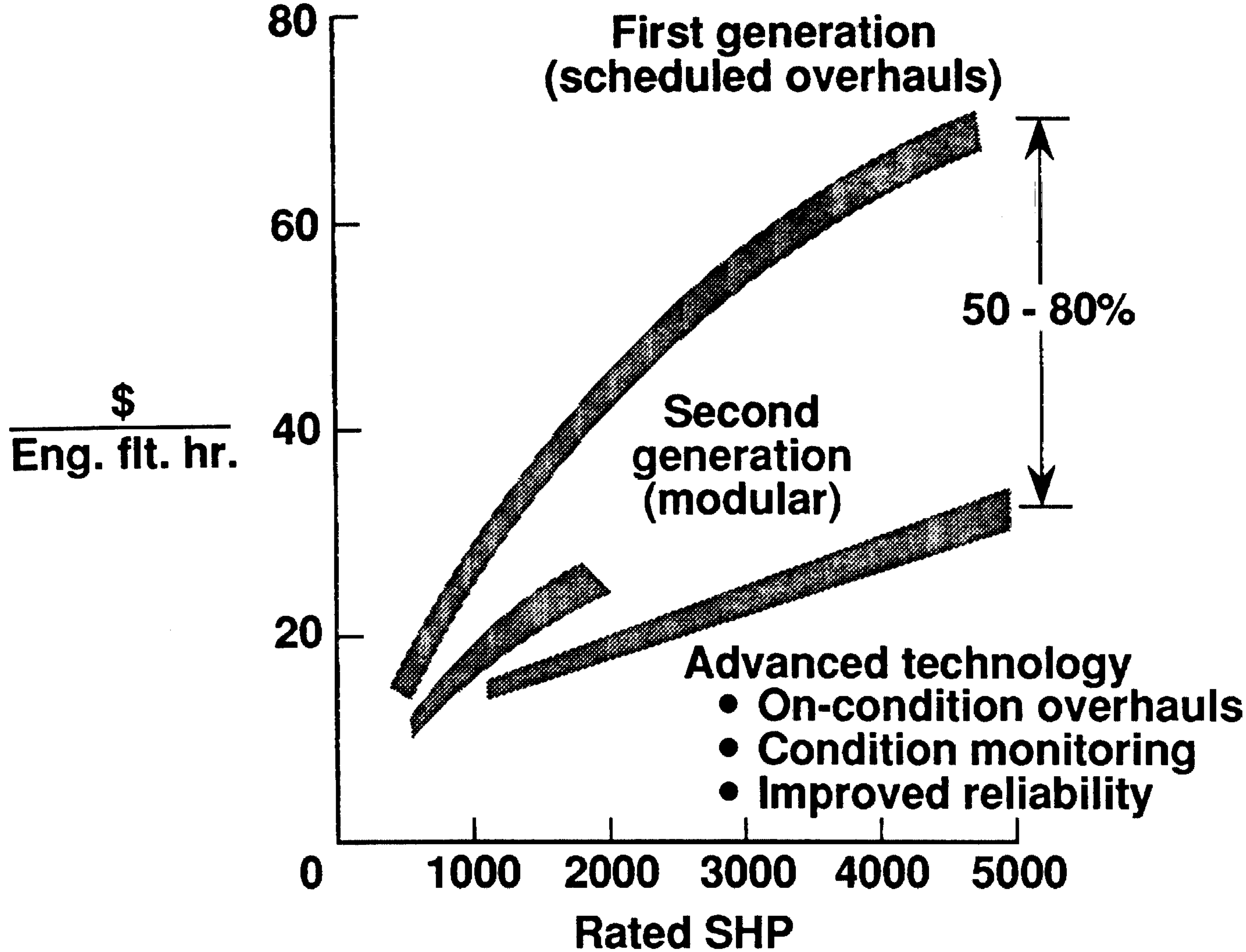


Figure 45. - Maintenance cost reduction for a second generation engine compared to an advance technology second generation engine, 100 NM stage length.

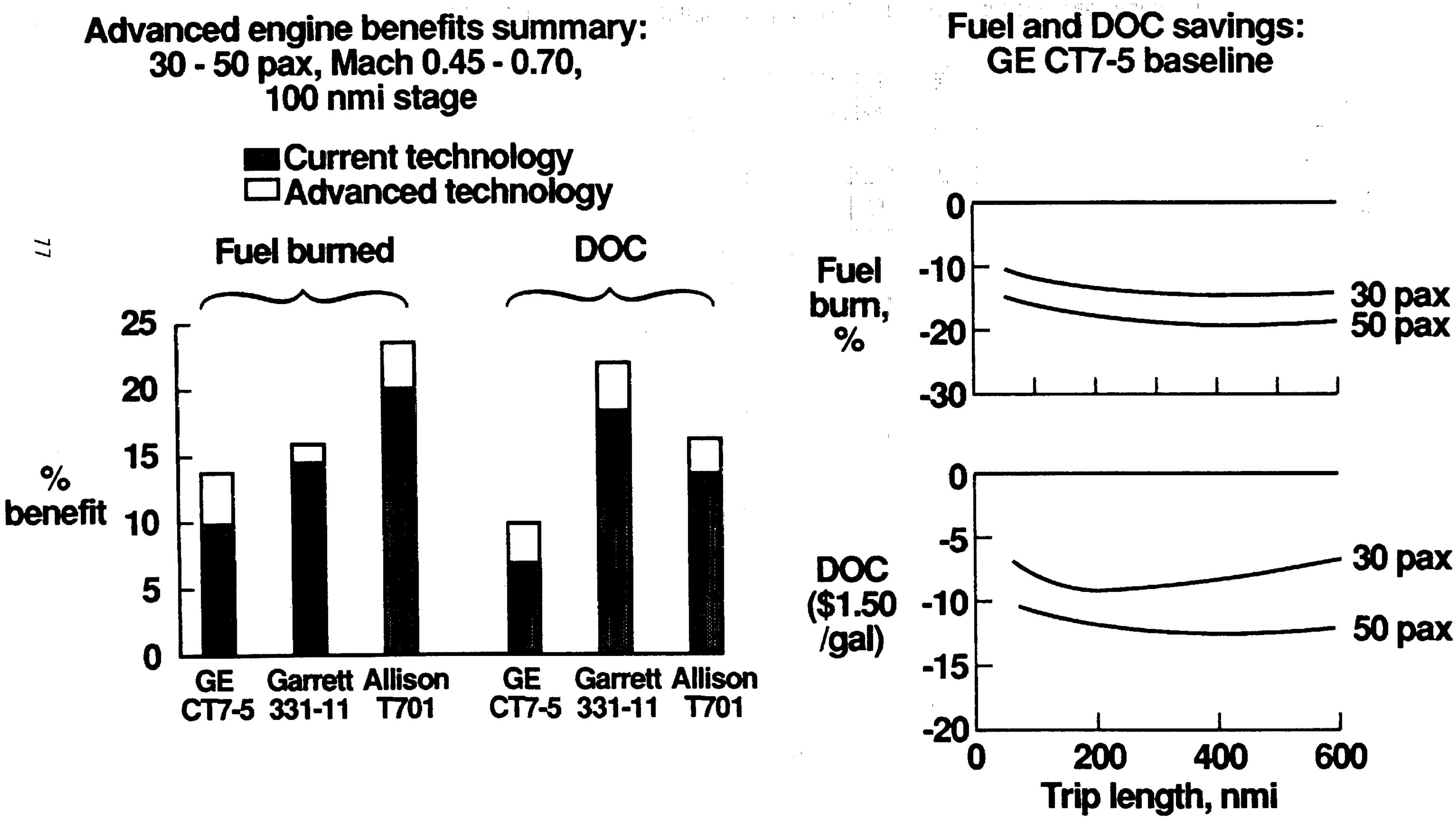


Figure 46. - Comparison of fuel burn and direct operating cost (DOC) for three current and advanced technology engines.

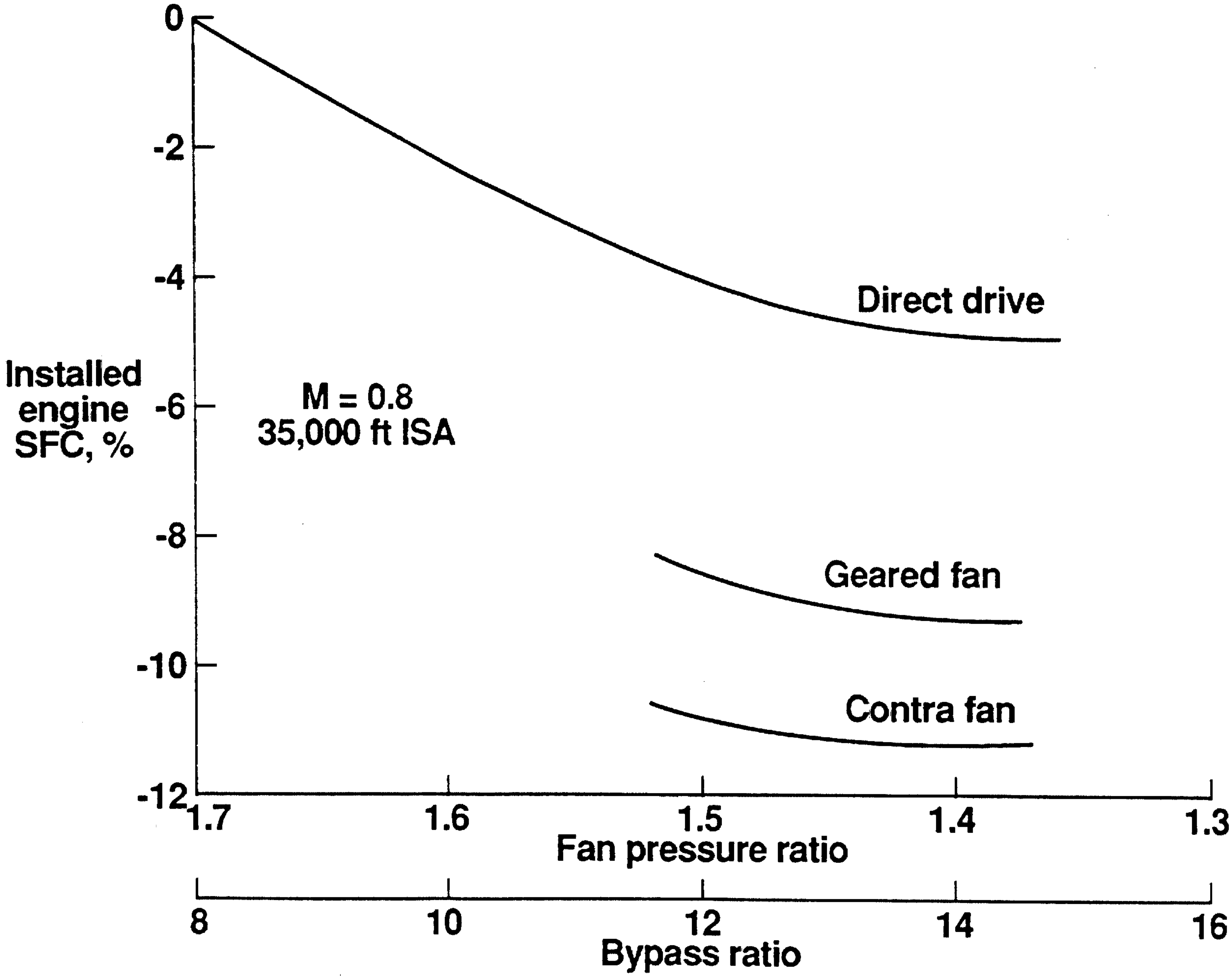


Figure 47. - Projected effect of fan pressure ratio and advanced technology engine configuration on installed SFC for year 2000.

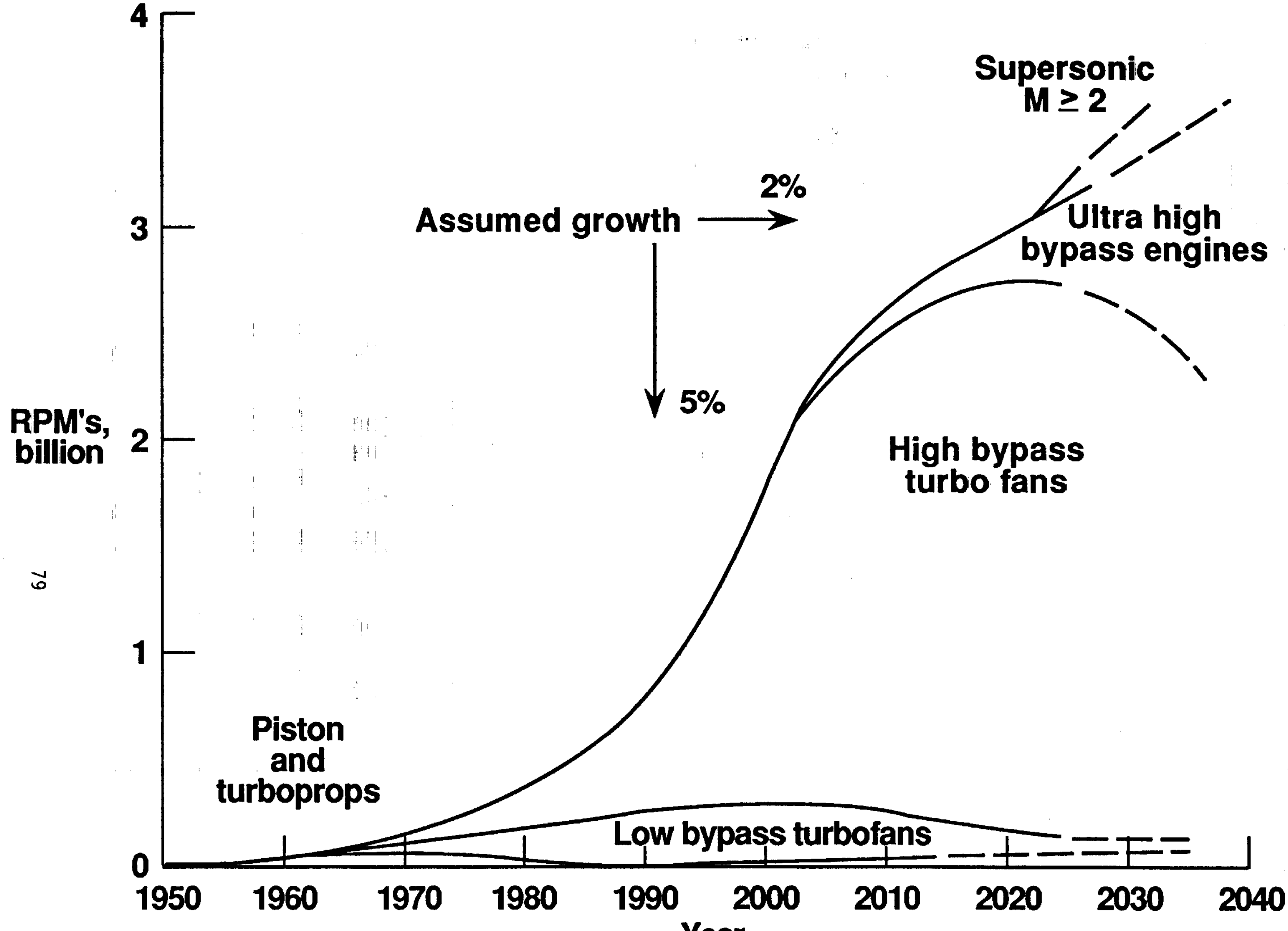


Figure 48. - Projected engine development requirements to meet forecast traffic growth.

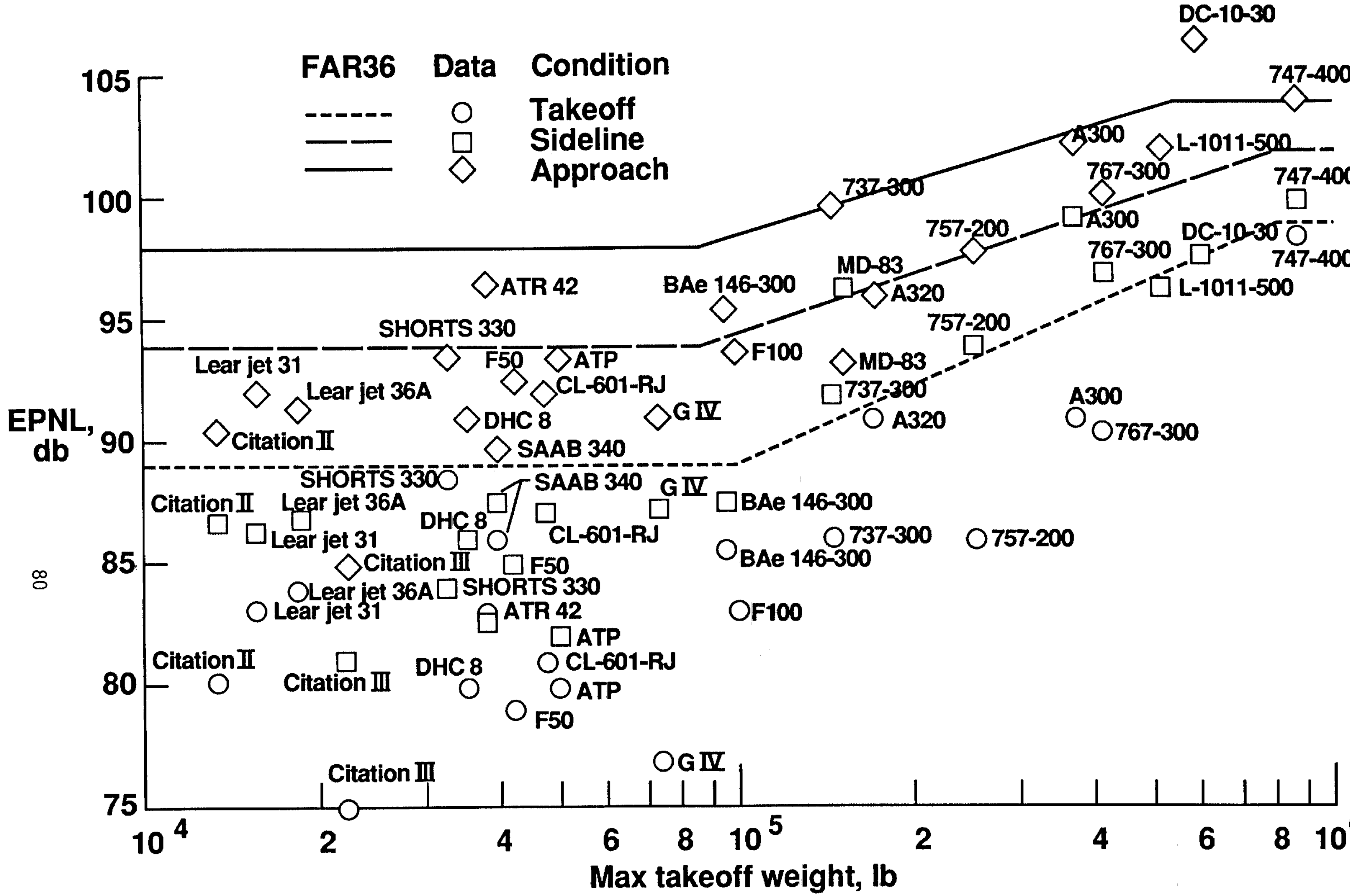


Figure 49. - Comparison of aircraft engine noise compliance with FAR 36 stage 3 regulations for takeoff, sideline, and approach.

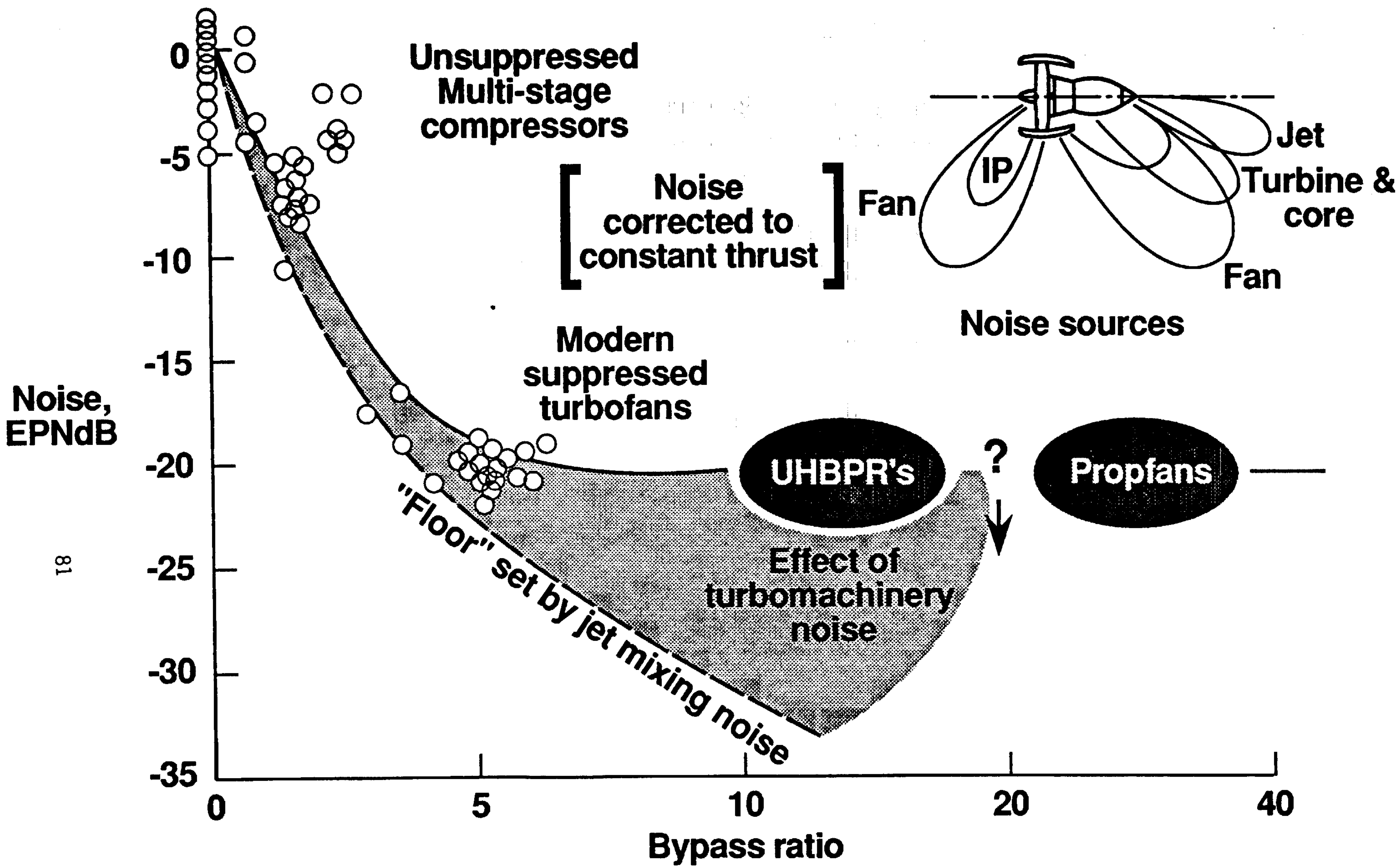


Figure 50. - Variation of engine noise source reduction with bypass ratio.

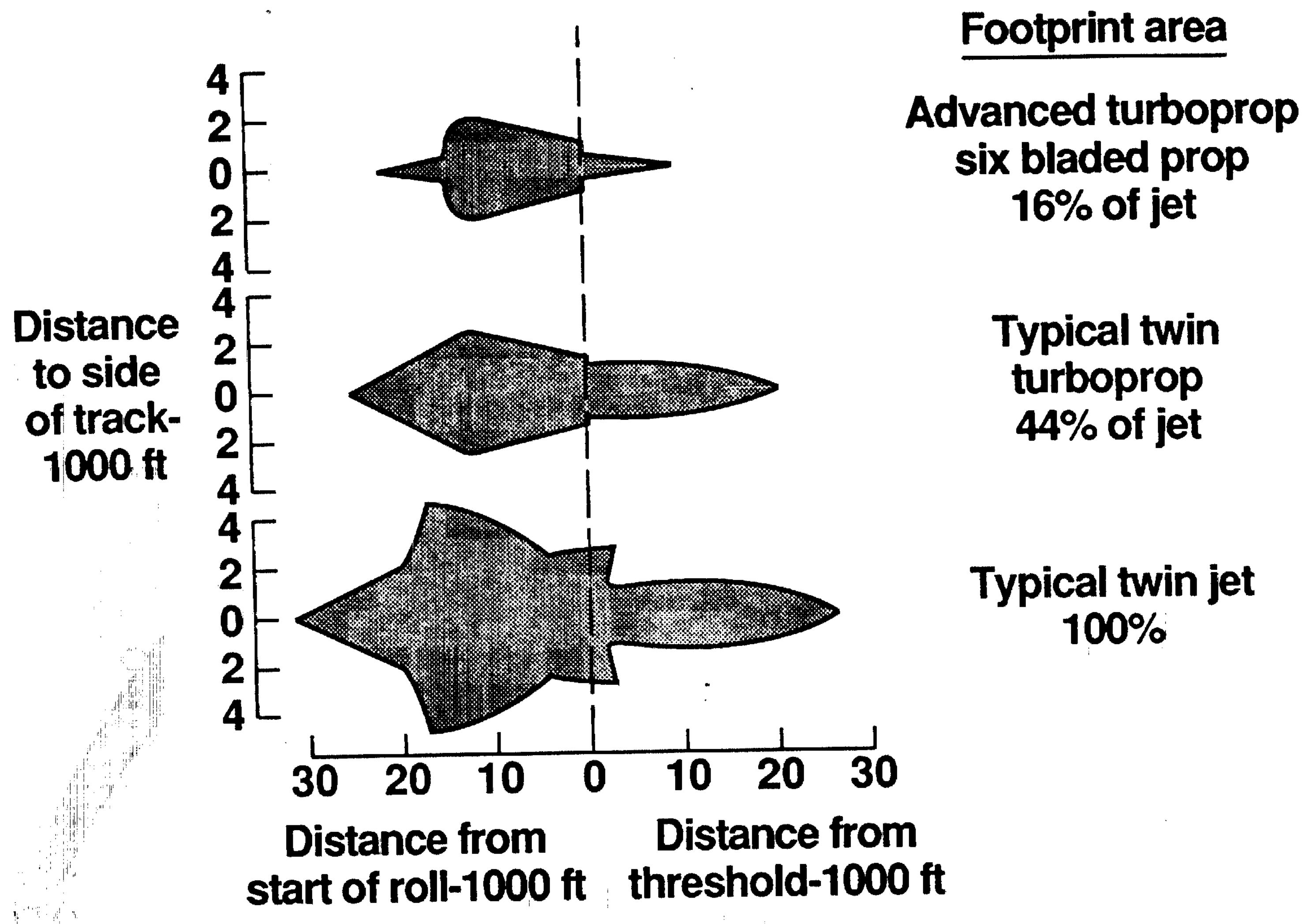


Figure 51. - Comparison of aircraft noise footprint area reduction for six bladed prop, turboprop, and twin jet based on 90 EPNL reference area.

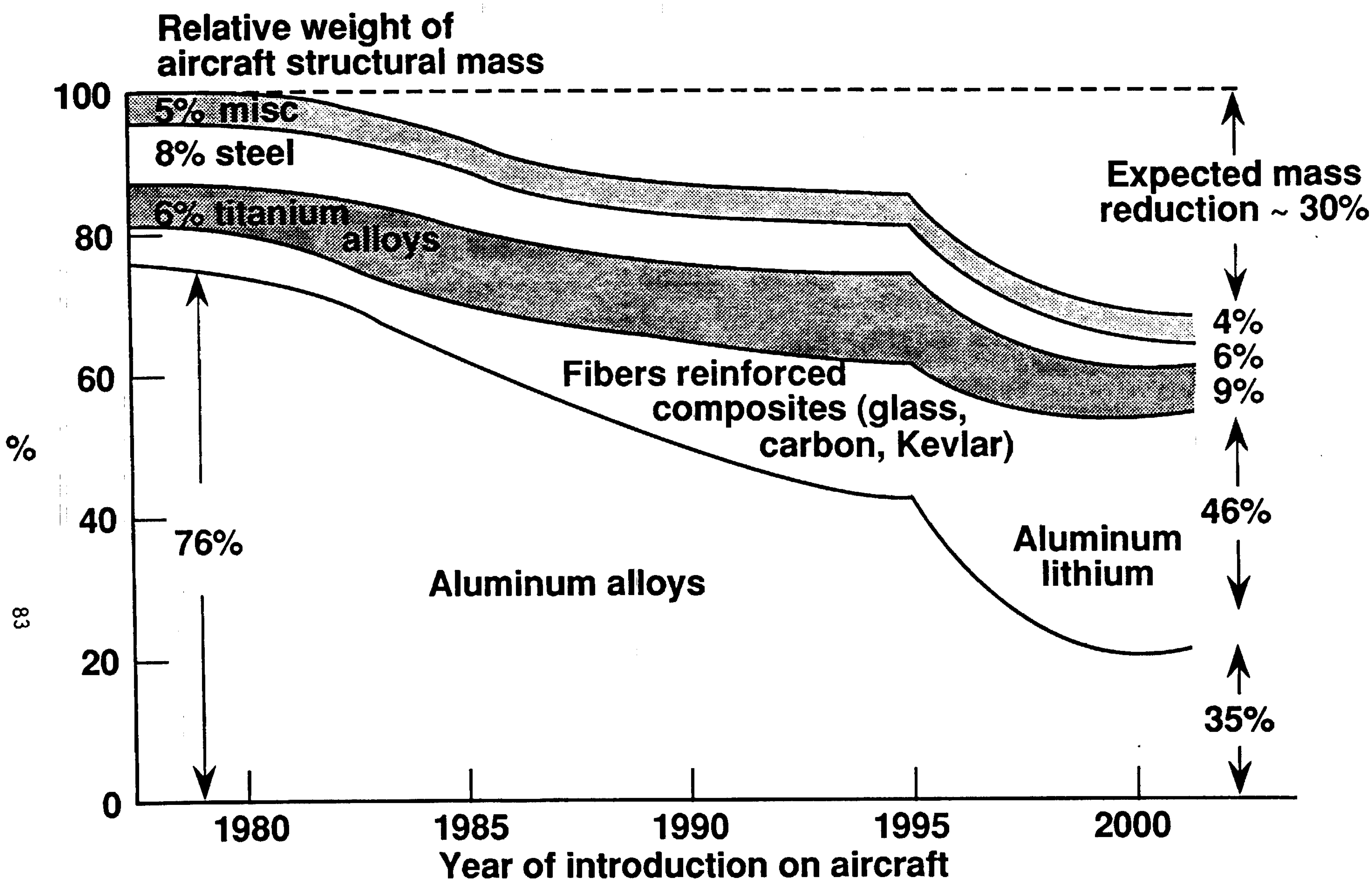


Figure 52. - Projected aircraft structural weight reduction contribution for several advanced materials.

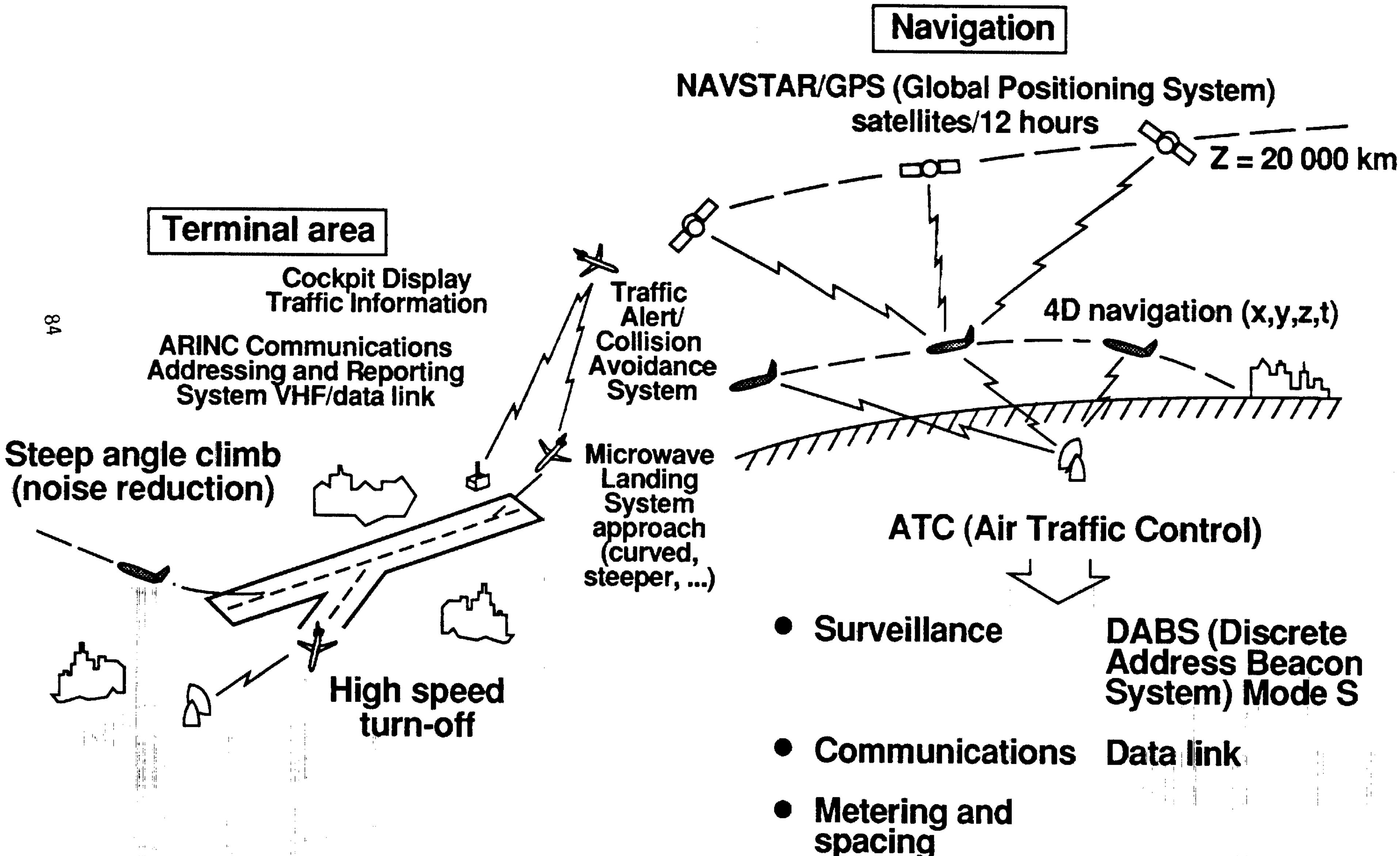


Figure 53. - Schematic illustrating advanced air traffic control (ATC) and flight management for enroute and terminal area.

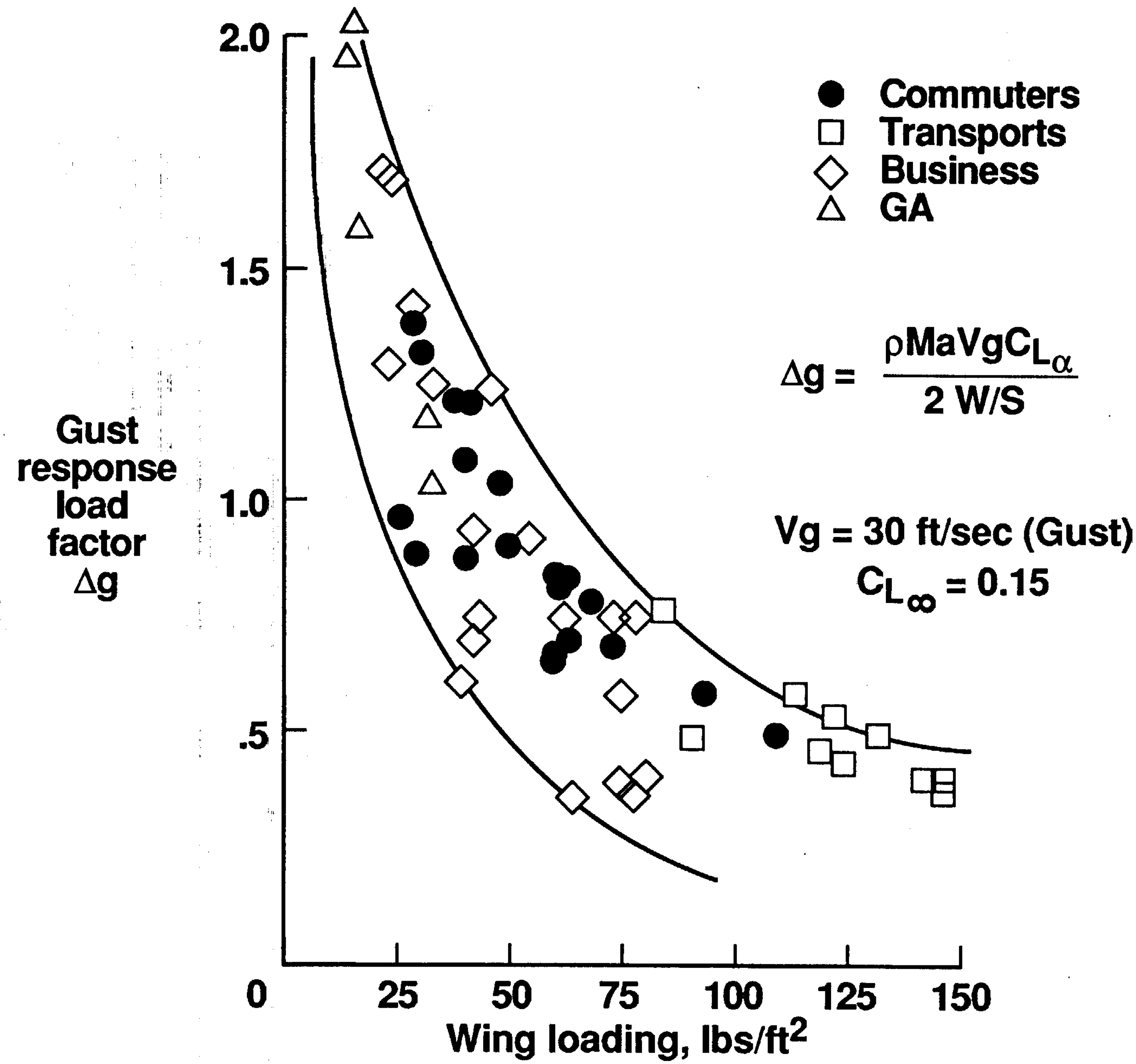


Figure 54. - Variation of calculated gust response load factor with wing loading for a range of aircraft type.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
October 1992

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Future Regional Transport Aircraft Market, Constraints, and Technology Stimuli

5. FUNDING NUMBERS
WU 505-69-20-01

6. AUTHOR(S)
W. Don Harvey and Brent Foreman

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, Virginia 23681-0001

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-107669

11. SUPPLEMENTARY NOTES
W. Don Harvey: Langley Research Center, Hampton, Virginia.
Brent Foreman: Auburn University, Auburn, Alabama.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited

Subject Category 01

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

This report provides updated information on the current market and operating environment and identifies interlinking technical possibilities for competitive future commuter-type transport aircraft. The conclusions on the market and operating environment indicate that the regional airlines are moving towards more modern and effective fleets with greater passenger capacity and comfort, reduced noise levels, increased speed and longer range. This direction leads to a nearly "seamless" service and continued code-sharing agreements with the major carriers. Whereas the benefits from individual technologies may be small, the overall integration in existing and new aircraft designs can produce improvements in direct operating cost and competitiveness. Production costs are identified as being equally important as pure technical advances.

14. SUBJECT TERMS
Commuter Aircraft
Aircraft Systems
Air Transportation

15. NUMBER OF PAGES
88

16. PRICE CODE
A05

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT